Bundle of documents for Oral hearings commencing from 19 August 2024 in relation to the Queen Elizabeth University Hospital and the Royal Hospital for Children, Glasgow

Bundle 18 – Documents referred to in the expert report of Dr J.T. Walker

Volume 2 (of 2)

SCOTTISH HOSPITALS INQUIRY

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Review

Association between healthcare water systems and *Pseudomonas aeruginosa* infections: a rapid systematic review

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SUMMARY

Background: *Pseudomonas aeruginosa* is an opportunistic pathogen with a particular propensity to cause disease in the immunocompromised. Water systems have been reported to contribute to *P. aeruginosa* transmission in healthcare settings.
Aim: To systematically assess the evidence that healthcare water systems are associated with *P. aeruginosa* infection; to review aspects of design that can increase their potential to act as a reservoir; and to compare the efficacy of strategies for eradicating contamination and preventing infection.
Methods: A rapid review methodology with a three-step search strategy was used to identify published studies. Scientific advisors were used to identify unpublished studies.
Findings: Twenty-five relevant studies were included. There was plausible evidence of transmission of *P. aeruginosa* from water systems to patients and vice versa, although no direct evidence to explain the exact mode of transfer. Two studies provided plausible evidence for effective interventions: point-of-use filters and increasing chlorine disinfection. Non-touch taps and aspects of water system design were identified as probable risk factors for *P. aeruginosa* biofilm formation and subsequent transmission to patients. Poor hand hygiene or compliance with contact precautions were identified as potential contributory factors; plausible evidence to confirm this was not available.
Conclusions: Water systems can act as a source of *P. aeruginosa* infection in healthcare settings, although the route of transmission is unclear. Contamination appears to be confined to the distal ends of a water system and can persist for prolonged periods. Further studies are required to establish effective methods of preventing transmission and eradicating *P. aeruginosa* from plumbing systems.

Introduction

Pseudomonads are aerobic, non-fermentative Gram-negative bacilli that are widespread in soil, water and other moist environments. *Pseudomonas aeruginosa* is the species most

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frequently associated with disease in humans, where it acts as an opportunistic pathogen with the potential to cause infections in almost any organ or tissue, especially in patients compromised by underlying disease, age or immune deficiency. The capacity of *P. aeruginosa* to cause disease is enhanced by both innate and acquired resistance to many antimicrobials and disinfectants, virulence factors and ability to adapt to a wide range of environments.[1,2]

Data on the incidence of healthcare-associated infections caused by pseudomonads are not readily available. Laboratory reports of bacteraemia are the most reliable indicator of severe infection. In the UK, *Pseudomonas* spp. are the seventh most frequent cause of bacteraemia, accounting for ~4% of these infections and with an incidence of 7.3 per 100,000 population. There is evidence of an increase in severe disease caused by *Pseudomonas* spp. with a recent significant increase in reports of bacteraemia in England and Wales.[3] There have also been a number of outbreaks of *P. aeruginosa* affecting intensive care units (ICUs) that have highlighted the potential for *Pseudomonas* spp. to establish microbial reservoirs in the healthcare environment.[4–10]

In contrast with other waterborne pathogens, *P. aeruginosa* thrives in the environment over a wide range of temperatures and is very adept at exploiting relatively nutrient-poor circumstances. Its polysaccharide capsule enables it to adhere to surfaces and under favourable conditions the cells multiply rapidly on surfaces in contact with water delivery systems to form a biofilm. Although most bacteria are retained within the biofilm, some will become free-floating in the water (planktonic) especially when it is static for prolonged periods.[11]

Standard water treatment removes most microbial contamination from mains water. However, in large buildings, such as hospitals, there are many locations within a plumbing installation where bacteria are able to proliferate and form biofilms. These locations include parts of the system where there is stagnation or higher levels of nutrients from accumulated organic material, such as infrequently used outlets and dead legs, non-metallic materials used for pipework, and terminal outlets where the flow depends on outlet use and hence is more variable.[12] As an aerobic bacterium that relies on oxidation to metabolize carbohydrates, *P. aeruginosa* thrives best in the distal parts of the water distribution system, such as taps and sinks where there is sufficient access to oxygen.[11] Once biofilms are established, particularly in dead-legs, biocides may not be able to penetrate them and bacteria may remain deep within the biofilm.[13]

In the past, strain typing of *P. aeruginosa* relied on phenotypic techniques such as serotyping; however, in the last decade the development of molecular typing techniques has demonstrated the limitations of these methods in characterizing the relatedness of clinical and environmental strains.[2,10] Studies using molecular typing have implicated environmental sources in the acquisition of *P. aeruginosa* colonization and infections in patients on ICU and other healthcare settings.[14] These investigations have generally been related to outbreaks of highly antibiotic-resistant strains. They have suggested that *P. aeruginosa* colonizing or infecting patients may contaminate the plumbing system, which then becomes a reservoir and contributes to transmission of infection over prolonged periods.[6–10,15] Investigations of the most recent outbreaks in Northern Ireland and Wales have added to concerns about the link between infections, tap design and biofilms in hospital water systems.[4,5,16,17]

Whereas there is a considerable body of published literature, much of it is derived from outbreak reports, it is of variable detail and quality, and has not been subjected to systematic assessment. This paper describes a rapid systematic review (RR) of evidence to determine the extent to which transmission of *P. aeruginosa* from water sources presents a risk to patients, the role of specific components of the plumbing system and the efficacy of strategies for preventing and eliminating contamination of the system.

Methods

The aim of the RR was to assess the epidemiological and technical literature with the specific objectives of identifying evidence that healthcare water systems are associated with patient colonization and/or infections in augmented care units (ACUs); to investigate aspects of design that can increase the potential for the system to act as a reservoir; and to assess the effectiveness of engineering and infection prevention interventions in eradicating or controlling *P. aeruginosa* in water systems in healthcare facilities (Box I).

A rapid review methodology was employed. The RR is characterized by the application of the systematic review process with limitations applied due to the need for prompt answers to policy or therapy questions.[18] This RR used an expedited process, as suggested by The Magenta Book (SSRC) and limited database searches to Medline, Embase (Ovid), Aqualine (Cambridge Scientific Abstracts) and the National Guidelines Clearing House; only published peer-reviewed literature in English was retrieved within the period 1998–2012. 'Grey' literature was not retrieved.[19]

For the purpose of this review, a plumbing system was taken to represent those fixtures and fittings responsible for conveying water from its entry into a building to its immediate collection after use. ACUs were defined as neonatal, paediatric and adult intensive care, burns, organ transplant, oncology, haematology, cystic fibrosis and renal units.

The review considered both experimental and epidemiological study designs including non-clinical experiments (plumbing systems), randomized controlled trials (RCTs), non-RCTs, quasi-experimental, before-and-after studies, prospective and retrospective cohort studies, case–control

Box I
Objectives of the review

1 Evidence that healthcare water systems are associated with patient colonization/infection with *Pseudomonas aeruginosa* in augmented care units.
2a Effectiveness of engineering and water safety interventions for reducing *P. aeruginosa* growth in healthcare water distribution/plumbing systems and water outlets.
2b Aspects of the water system, e.g. design and type of fixtures and fittings that can lead to systems acting as a potential reservoir for the transmission of *P. aeruginosa* in augmented care settings.
3a Effectiveness of infection prevention interventions for reducing the transmission of *P. aeruginosa* from potable water from healthcare water distribution systems to vulnerable patients.
3b Effectiveness of other infection control interventions, e.g. hand hygiene and antimicrobial stewardship.

studies and analytical cross-sectional studies for inclusion. In the absence of the aforementioned designs, it considered descriptive epidemiological studies, including case series, individual case reports and descriptive cross-sectional studies for inclusion.

Search strategy

A three-step search strategy was used to identify published studies. An initial search of Medline was undertaken to identify keywords in titles and abstracts and index terms used to describe articles. A second search, using the keywords and index terms was repeated in Medline and Embase. The following MESH heading and search words/terms were used:

- pseudomonas aeruginosa, multidrug-resistant pseudomonas aeruginosa, outbreak(s)
- infection, healthcare associated infection, nosocomial infection, waterborne infection
- infection control
- biofilm(s), colonization
- water, tap water, water quality, water temperature
- water distribution, water network, plumbing, plumbing installations, water supply, water outlet(s), water system(s), pipe(s), u-bend(s), water fittings, water source(s)
- respirators, ventilators, incubators, humidifiers
- faucets, taps, sensor taps, electronic taps, electronic faucets, showers, aerators, rosettes, thermostatic mixer valves, basins, sinks, sink traps
- point of use water filters, end-line filters, filters, silver ions, copper ions, ionization, ozone, ultraviolet, chlorine dioxide, chemical disinfection, monochloramine, free chlorine, thermal disinfection, thermal shock

For studies which focused on plumbing systems, a separate search in Aqualine (Cambridge Scientific Abstracts) was conducted using keywords. Third, the reference lists of all identified reports and articles were searched for additional studies. Finally, as this RR was limited to three databases, scientific advisers were asked to verify that no important published studies, or recent unpublished studies, had been missed. Two members of the review team independently assessed the title and abstract of the search results for relevance against the following criteria: reported primary research or epidemiological data related to an outbreak of *P. aeruginosa*; clinical studies were situated in ACUs; evaluated infection prevention, engineering, materials and plumbing factors or interventions; used genotyping to confirm associations between *P. aeruginosa* colonization or infection.

Assessment of abstracts for methodological quality and microbiological methods was carried out independently by two reviewers using the standardized appraisal tools from the Joanna Briggs Institute.[20] Data were extracted from papers using a standardized data extraction tool adapted from the Joanna Briggs Institute and used to develop a narrative summary of the data. Due to the heterogeneity of the studies, criteria for plausibility were developed to determine the extent to which studies were valid and reliable in terms of study design and outcome measurement (Table I). Twenty-five studies were assessed, of which eleven studies were deemed to provide plausible evidence. Data were then synthesized using a narrative approach.

Results

The search identified 196 potentially relevant studies (Figure 1). Following a review of title and abstracts, 116 studies were retrieved for further assessment. Of these, 43 were identified for assessment of methodological quality and data extraction, and 25 included in the RR. The majority (19) of studies addressed objective 1; these were predominantly outbreak reports based on retrospective analyses and short-term prospective follow-up in ICUs or haemo-oncology units. Only two involved case–control or comparison groups and therefore no studies were considered to be highly plausible. Eleven of these studies provided plausible evidence relevant to one or more of the objectives of the review.

Evidence that healthcare water systems are associated with patient colonization and/or infection with P. aeruginosa in ACUs (Objective 1)

Only seven studies were assessed as providing plausible evidence of a link between a plumbing system acting as reservoir for *P. aeruginosa* and colonization and/or infection in patients.[21–27] These were prospective observational or cohort studies undertaken during endemic periods which investigated the contribution of endogenous and exogenous transmission of *P. aeruginosa* to colonization/infection of patients, using molecular methods to identify temporal relationships between environmental reservoirs and the onset of colonization/infection. They used surveillance specimens taken from patients on admission and at a minimum of weekly until discharge, to identify colonization with *P. aeruginosa* and sampled multiple water system outlets, including tap water, sink siphon or overflow and/or sink U-bends at intervals ranging from every 72 h, twice weekly, to every 2 weeks.[21–27] In two studies, samples were taken from taps with aerators fitted, but the aerators were removed and decontaminated at regular intervals.[23,26]

Table II summarizes the evidence from these studies for the transmission of *P. aeruginosa* from plumbing systems to patients and vice versa based on the temporal relationship in the sequence of positive cultures with indistinguishable genotypes. Whereas the data demonstrated that plumbing reservoirs of *P. aeruginosa* were responsible for patient colonization and infection, there was also evidence of transmission of *P. aeruginosa* between patients involving clones that were not recovered in the water or plumbing systems, presumably via staff or equipment. Several authors reported poor hand hygiene as a contributory factor.[23,24,26]

There was little evidence to explain the exact mode of transfer from plumbing to patient and vice versa. Examples cited for the use of tap water, which could have acted as the vehicle of transmission in addition to contaminated staff hands, were making up enteral feeds and personal care activities such oral care and patient washing.[22,25] The disposal of wash water and ventilator traps was considered probable means by which *P. aeruginosa* was transferred from patient to plumbing.

A further 14 studies were considered to provide descriptive evidence of low plausibility for Objective 1.[6–8,28–36] They reported outbreaks of *P. aeruginosa* in a range of ACU settings but, in the absence of surveillance results, temporal relationships

Table I
Criteria for plausibility

Objective	Plausibility criteria
1	Prospective design +/− comparison group. Data collection during epidemic or endemic period. Patient sampling includes surveillance specimens at baseline (admission or intubation) and clinical specimens as appropriate. Molecular typing of ≥1 colony using robust methodology. Matched profiles of strains isolated from patients and water/plumbing systems. Methods allow temporal relationship to be identified between plumbing system being a reservoir for *Pseudomonas aeruginosa* and identification of colonization/infection in patients OR exposure to water system/specific component shown to be associated with acquisition of *P. aeruginosa*. Examination of multiple outlets of water and plumbing system. Includes repeated sampling during the observation period.
2a	*Chemical treatment of water supply/treatment of fixtures and fittings:* applied to plumbing installations at a single location (i.e. under a limited set of water quality conditions) and comparison made using before-and-after treatment measures. *Model rig systems:* demonstrate that chemical treatment reduces the amount of biofilm formation, and/or reduction in numbers of *P. aeruginosa* or bacteria generally and there is a parallel comparison of efficacy in reducing bacterial numbers. The intervention is defined and introduced at a defined point. If more than one intervention, these are introduced in a stepwise way. Robust sampling and microbiological methods used.
2b	*P. aeruginosa* consistently recovered in association with a design feature (e.g. sink traps, flow straighteners). Consistent results obtained from repeated sampling undertaken on multiple devices on more than one occasion. Robust sampling methods used.
3	Prospective design+/− comparison group. Data collection during epidemic or endemic period. Patient sampling includes surveillance specimens at baseline (admission or intubation) and clinical specimens as appropriate. Molecular typing of ≥1 colony using robust methodology. Matched profiles of strains isolated from patients and water/plumbing systems. Methods allow temporal relationship to be identified between plumbing system being a reservoir for *P. aeruginosa* and identification of colonization/infection in patients OR exposure to water system/specific component shown to be associated with acquisition of *P. aeruginosa*. Examination of multiple outlets of water and plumbing system. Includes repeated sampling during the observation period. Clearly reported intervention, introduced at a defined point in an epidemic or endemic period. If more than one intervention, these are introduced in a stepwise way. Repeated outcome measurement of interventions. Intervention associated with reduction in number of patients colonized/infected with *P. aeruginosa*.

between strains from patients and the environment were not established. In addition, sampling of water and plumbing systems was undertaken on a single occasion, infrequently or from a limited number of outlets, and inadequately reported. However, some of these studies described interventions of interest for Objectives 2 and 3, respectively.

Effectiveness of engineering and water safety interventions for reducing P. aeruginosa growth in healthcare water distribution/plumbing systems and water outlets (Objective 2a)

There were no RCTs or quasi-experimental studies that demonstrated a causal relationship between water safety interventions and reductions or control of *P. aeruginosa* in the literature. A small number of technical studies, conducted under laboratory conditions, were excluded at the retrieval stage as they did not address the review objectives. The majority of the 11 studies retrieved described interventions, often several implemented at the same time, undertaken in order to eradicate *P. aeruginosa* from the plumbing system during outbreaks and were assessed as being of low plausibility.[8,9,15,22,29,31,34–38] The poor design of studies, absence of data and lack of long-term follow-up meant that it was not possible to determine whether attempts at eradication of *P. aeruginosa* from the plumbing system were effective or to distinguish the effect of multiple interventions. Reported interventions involved: avoiding use of water; replacement of fixtures and fittings; dismantling outlets followed by cleaning and disinfection with chlorine, hydrogen peroxide; autoclaving or increasing temperature of water at the outlet; system-wide chlorination at higher than normal concentrations; installation of outlet filter devices or filtered water systems.[7–9,15,22,23,26,29,31,35,37,39] Some studies used several methods, and often repeated attempts were required to eradicate *P. aeruginosa* from the water system. The removal of fixtures and fittings, e.g. aerators, and the installation of devices such as point-of-use filters and systems for ensuring microbiologically safe water have been reported as effective but costly.[34,38,39] Chemical treatment and

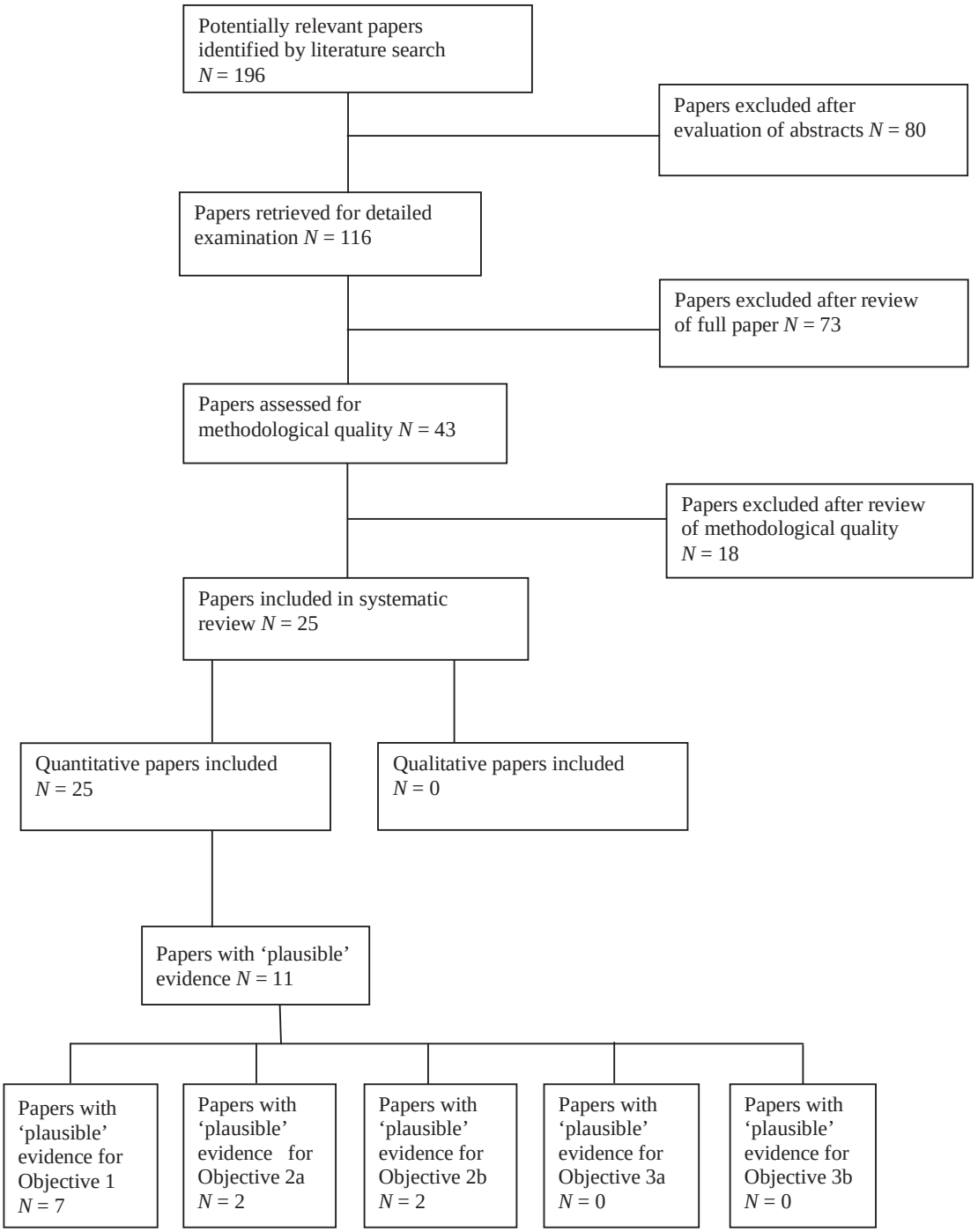

Figure 1. Selection and evaluation process for included papers.

increasing water temperature was reported as effective by some studies but not others.[7,22,36]

Only two studies undertaken in the clinical setting were assessed as providing plausible evidence for the effect of intervention. The first of these was an outbreak investigation, in which *P. aeruginosa* associated with catheter-related bloodstream infections (BSIs) in a paediatric onco-haematology unit was recovered from shower heads and hoses. The introduction of 7-day filters fitted to showers and chlorine disinfection at 0.5 mg/L was associated with a reduction in *Pseudomonas* spp. recovered from the plumbing system.[7] No further *Pseudomonas* spp. were recovered from the plumbing system when chlorination was increased to 2.7 mg/L. Concern about the effect of chlorination on plumbing materials and the cost of filters resulted in these measures being replaced by the installation of a water loop, which produced microbiologically controlled water and sustained the quality of the water beyond the outbreak period.

The second study employing point-of-use filters to reduce endemic *P. aeruginosa* infections in a surgical ICU was conducted over a 3-year period.[39] The rates of *P. aeruginosa* colonization and infections among a random sample of 50% of

Table II
Probable sources of patient-acquired *P. aeruginosa* (PA) on intensive care unit (ICU) as determined by surveillance or clinical cultures

Study	No. of patients admitted/ included	No. of patients with PA (no. with infection)	No. of endogenous[a] acquisitions (% of all patients with PA)	No. of patient-to-patient transmissions (% of all patients with PA)	No. of tap-to-patient transmissions (% of all patients with PA)	No. of patient-to-tap transmissions (% of all patients with PA)	No. of other route/not known (% of all patients with PA)
Berthelot *et al.*[21]	59	26 (10)	21 (81%)	0	5 (19%)	0	–
Reuter *et al.*[23]	53[b]	31	–	–	13 (42%)	4 (13%)	14 (45%)
Rogues *et al.*[26]	152[c]	38	6 (16%)	6 (16%)	7 (18%)	11 (29%)	5 (3[d]) (21%)
Trautmann *et al.*[22]	390	17 (17)	5 (29%)	5 (29%)	4 (24%)	–	3 (18%)
Trautmann *et al.*[24]	–	16 (9)	–	–	8 (50%)	2 (13%)	5[e] (31%)
Vallés *et al.*[25]	72	31 (4)[e]	9[f] (29%)		19 (61%)	3[g] (10%)	
Cholley *et al.*[27]	123	17	–		1 (6%)	0	13 (76%)

[a] Strain not previously isolated from the environment/other patients.[21]
[b] Admission with stay in ICU >4 days, no acute respiratory distress.
[c] Stay in ICU >72 h.
[d] Cases associated with bronchoscope.
[e] Recruited ventilated patients, included those who acquired colonization >48 h after admission; infections = ventilator-associated pneumonia.
[f] Association defined as the same genotype in tap water in same room as patient (but eight of these patients had a strain that was present in tap water of other rooms – extracted from data).
[g] Same genotype recovered from patient and water at same time.

patients admitted to the ICU >3 days (154 pre-filter vs 141 post-filter) were compared. *P. aeruginosa* colonization was reduced by 85% ($P < 0.0001$) and invasive infections by 56% ($P < 0.0003$) following the introduction of point-of-use filters. Collection of tap water samples showed no *P. aeruginosa* recovered after the introduction of the filters, and no changes in hand hygiene behaviour, as monitored by alcohol gel use, were detected.

Aspects of the water system, e.g. design and type of fixtures and fittings that act as a reservoir for the potential transmission of P. aeruginosa in ICUs (Objective 2b)

Six papers addressing this question were identified, only two of which were assessed as plausible.[8,28,34,38,40,41] The first plausible study evaluated water quality in two models of non-touch taps (NTTs) newly sited in a clinical area, one with fixed water temperature (23 taps) and the second with cold and warm temperature selection (15 taps).[40] Ten taps of conventional design adjacent to NTTs without temperature selection were also included in the assessment. Seventeen (74%) NTTs without temperature selection and one with temperature selection (7%) were contaminated with *P. aeruginosa* ($P < 0.001$) and in some NTTs the magnetic valve and outlet were highly contaminated. Adjacent conventional taps were not contaminated and some NTTs had total cell counts that were 100 times higher than in conventional taps. This study did not provide any indication as to how long it took for the NTTs to become contaminated, nor did it allow for the possibility that taps were contaminated on arrival from the manufacturer; this was a potential problem that was only identified 5 years later.[42]

In the second plausible study, an outbreak of *P. aeruginosa* in a haemo-oncology unit was attributed to a whirlpool bath used by patients.[28] A case–control study confirmed that the use of the whirlpool bath was a significant risk factor for infection. All seven of the case patients compared with nine out of 28 control patients had used the bathtub ($P < 0.003$) and case patients used the bath 4.3 times compared with 1.7 times in the control group. The design of the bath meant that the drain closed 2.54 cm below the surface of the bath and was hence contiguous with the bath water. *P. aeruginosa* was not recovered from tap water but contamination was probably derived from patients using the bath since it was used as treatment for perianal fissures or ulcers and all the case patients and 79% of control patients had diarrhoea. In the 5 years following replacement of the bath no further clusters of *P. aeruginosa* were identified.

Although the other four studies were assessed as low plausibility, they did indicate that the design of both plumbing systems and the area around patient bed spaces may pose a risk to vulnerable patients.[8,34,38,41] A number of short communications, not considered in this RR, have commented on outbreaks of *P. aeruginosa* coinciding with the introduction of NTTs and aerators/flow straighteners and ending after their subsequent removal.

Effectiveness of infection prevention interventions for reducing the transmission of P. aeruginosa from the use of potable water from healthcare water distribution systems to vulnerable patients (Objective 3a)

A number of studies suggested that colonization of patients with *P. aeruginosa* arose from the use of potable water for nursing and clinical care activities such as personal care (bathing and showering), enteral feeding and oral care.[22,25,35,37] However, studies introduced a number of interventions aimed at minimizing this route of transmission, often simultaneously with other general infection control precautions, such as isolation, using alcohol hand rub and using sterile or bottled water for drinking, suspending medications, enteral feeds, washing patients' faces and oral care.[15,26,30,31,37–39] No studies providing plausible evidence for interventions to minimize the

transmission of *P. aeruginosa* from potable water to patients were found.

Some studies suggested that contamination of handwash basins with *P. aeruginosa* could have occurred as a result of washing soiled utensils or disposal of waste water, such as from ventilator traps, cascade humidifiers or patient wash water and, in one study, use as a temporary sluice for body fluids.[15,28,34,35] However, there was little evidence that these explanations were based on structured observation of healthcare worker behaviour and they were therefore deemed to be of low plausibility.

Effectiveness of other infection control interventions, e.g. hand hygiene, antimicrobial control (Objective 3b)

Standard infection control interventions such as hand hygiene, alcohol hand disinfection, contact isolation and restriction of antimicrobial agents were reported as being implemented as a control measure during outbreaks.[15,30,31,34,36,37] No studies providing plausible evidence for the efficacy of these measures were identified. Some studies reported that healthcare workers' hands were sampled as part of the outbreak investigation; however, compliance with infection control procedures, such as hand hygiene and alcohol hand disinfection, was not measured. Contact precautions were instigated as a matter of course in outbreak periods, but again, none of the studies observed staff adherence. In the absence of data on compliance it is difficult to determine the relative contribution of patient-to-patient and handwash basin/sink-to-patient transmission. In four studies, antibiotic selective pressure was addressed by implementing changes to antimicrobial prescribing policies.[29–31,35] However, these changes were one of several interventions and outbreaks continued despite them.

Discussion

This rapid systematic review found a limited number of publications that provided plausible evidence for the role of water and plumbing systems in colonization or infection of patients with *P. aeruginosa* in ACUs. Most of the literature was descriptive and based on outbreak reports, and it was not possible to determine the route or order of transmission of *P. aeruginosa* between water fittings and patients. Evidence from prospective studies during endemic periods, using molecular typing and frequent surveillance of both the plumbing system and patients, provides plausible evidence that strains of *P. aeruginosa* found in handwash basins, showers/taps and tap water can be a source of *P. aeruginosa* in both the colonization and infection of patients in ACUs. *P. aeruginosa* contamination appears to be confined to the distal ends of a plumbing installation (tap fittings, flow straighteners, shower heads, and sink drains), rather than the entire system. A number of different strains of *P. aeruginosa* may be present in the water system without being linked to colonization/infection of patients but water systems may also remain contaminated with the same strain of *P. aeruginosa* over prolonged periods.

The studies do not provide any direct evidence for how handwash basins/sinks become contaminated. They postulate that contamination occurs through exposure to patient material, e.g. washing water and respiratory system water, with the sink then acting as a reservoir for onward transmission to other patients through contact with staff hands or use of water for patient care, e.g. washing, brushing teeth and preparation of enteral feeds. Other possibilities are that *P. aeruginosa* may be present in the incoming water or that taps are contaminated during the handwashing procedure. The association with the tap outlet indicates a physiological niche for *P. aeruginosa* to establish a reservoir, regardless of route of acquisition.

Patient-to-patient transmission is mostly assumed to be via hands of staff and studies suggest that this is a more common route than sink-to-patient or patient-to-sink transmission.[22,26] However, this assumption, while reasonable, is not based on any consistent or prolonged measurement of staff hand carriage or observation of compliance with infection control procedures, such as hand hygiene, alcohol gel use or contact precautions. It is therefore difficult to determine the relative contributions of patient-to-patient and handwash basin/sink-to-patient transmission. Staff may also transfer *P. aeruginosa* between hand basins.[23]

Whereas the studies included described methods of monitoring and testing water and plumbing fittings, the approach to sampling was often not well reported. Water temperature was often not specified, i.e. hot or cold or mixed, some studies only sampled water fittings once, whereas others took samples over several weeks. These methods are likely to vary in their ability to detect *P. aeruginosa* and in the reliability with which they identify contaminated water systems as the source of *P. aeruginosa* in patients. Additionally, if healthcare workers use a handwash basin or sink immediately prior to taking the sample from the tap, contamination with *P. aeruginosa* may be missed. Studies mostly do not describe whether the tap was preflushed or when it was last used prior to the sample being collected. Some studies reported outbreaks of *P. aeruginosa* that could not be linked to water systems, although inadequate water sampling may have obscured a relationship.[17]

Microbiological methods also have an influence on the interpretation of epidemiological data on routes of transmission of *P. aeruginosa*. Selection of single colonies from environmental cultures for typing may fail to identify contamination of water/fittings associated with multiple strains. Phenotypic characteristics such as colonial morphology do not reliably correlate with genotypes; thus, studies which have genotyped only single or morphologically distinct colonies may have resulted in incomplete characterization of the relationship between clinical and environmental isolates.[2,8,9,14] Selection of multiple colonies for genotyping of isolates is likely to provide a more reliable indication of epidemiological links.[25] Similarly, focusing only on strains with particular resistance phenotypes may have missed potential transmission by genotyping only those isolates that expressed the resistance pattern of interest. Moreover, *P. aeruginosa* in patients is generally identified through screening swabs (rectal and respiratory tract). The reliability with which these detect low-level colonization is unknown and this may affect the attribution of *P. aeruginosa* acquisition to an endogenous or exogenous route.

There is little plausible evidence for the efficacy of interventions to eradicate *P. aeruginosa* from the plumbing system, since the majority of the studies were poorly designed and unable to distinguish the effect of multiple interventions during an outbreak. The main interventions were removal and replacement of components of the plumbing system, use of

filtration devices or methods of disinfection or decontamination of water and delivery systems, including systematic treatment of the incoming water supply with chlorine, thermal disinfection of taps, autoclaving of tap aerators and increasing the temperature of water within taps to >50 °C. Dismantling and mechanical cleaning of taps and aerators was also described. The introduction of point-of-use filters was described as effective in eliminating *P. aeruginosa* from water taken from outlets and preventing colonization/infection of patients, but costly.[7,39] There is no robust evidence to support the efficacy of infection control precautions in limiting transmission from water systems in ACUs.

The ability of *P. aeruginosa* to form biofilms readily may be facilitated by some types of plumbing materials and plumbing locations, with the design of fittings having the potential to exacerbate this growth. NTTs have been found to be contaminated with *P. aeruginosa*; outbreaks have coincided with their introduction and have stopped when replaced, although none of this evidence was assessed as plausible.[40] The presence of a magnetic valve constructed from rubber plastic and a polyvinylchloride membrane, where fitted, is also likely to encourage bacterial growth and formation of biofilms.[2] Flow straighteners are prone to accumulate scale that may subsequently harbour biofilm and have been implicated in outbreaks. However, several studies have found no effect on water contamination or patient colonization if they are regularly removed, descaled and autoclaved.[23,26] Robust studies to underpin policy recommendations about the fitting of these devices in healthcare plumbing systems are not available.

In conclusion, this RR has provided a narrative synthesis of the limited literature describing outbreaks of *P. aeruginosa*, and links to plumbing systems and the use of water in ACUs. This literature suggests that strains of *P. aeruginosa* may persist in water systems over prolonged periods but are confined to the distal parts in sinks and associated fittings. Strains of *P. aeruginosa* recovered from tap water or the water system can also be found in patient surveillance and clinical specimens and, although patient-to-patient transmission remains a frequent route, there is plausible evidence that both sink-to-patient and patient-to-sink transmission occurs. Further, well-designed studies are required in order to determine effective methods of preventing or eradicating contamination of water systems, and infection control procedures that will minimize the risk of transmission from water system to patients. Where possible, such studies should be designed prospectively and include baseline and ongoing surveillance/clinical cultures, repeated cultures from multiple water outlets, molecular typing of more than one colony and methods that allow temporal relationships between plumbing system and infection/colonization in patients to be identified.

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Sink-Related Outbreaks and Mitigation Strategies in Healthcare Facilities

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HEALTHCARE ASSOCIATED INFECTIONS (G BEARMAN AND D MORGAN, SECTION EDITORS)

Sink-Related Outbreaks and Mitigation Strategies in Healthcare Facilities

Leighanne O. Parkes[1] · Susy S. Hota[2,3]

Abstract

Purpose of Review In this review, we summarize recent outbreaks attributed to hospital sinks and examine design features and behaviors that contributed to these outbreaks. The effectiveness of various risk mitigation strategies is presented. Finally, we examine investigational strategies targeted at reducing the risk of sink-related infections.

Recent Findings Outbreaks of hospital sink-related infections involve a diverse spectrum of microorganisms. They can be attributed to defects in sink design and hospital wastewater systems that promote the formation and dispersion of biofilm, as well as healthcare practitioner and patient behaviors. Risk mitigation strategies are often bundled; while they may reduce clinical cases, sink colonization may persist. Novel approaches targeting biofilms show promise but require more investigation.

Summary Emphasis should be placed on optimizing best practices in sink design and placement to prevent infections. Hospitals should consider developing a rational surveillance and prevention strategy based on the current design and state of their sinks.

Keywords Sink · Hand hygiene · Hospital-associated infections · Infection control · Biofilm · Multidrug-resistant organisms

Introduction

Since the mid-nineteenth century, when Semmelweis first proposed that simple handwashing could drastically reduce maternal mortality, hand hygiene has been a central tenet of infection prevention and control. As an important enabler of hand hygiene, hospital sinks play an important role in these efforts, and much emphasis has been placed on optimizing their accessibility in patient care settings. Ironically, hospital sinks are rich microbial breeding grounds and reservoirs for the transmission of nosocomial pathogens and resistance genes [1–3]. Accordingly, it behooves us to define effective infection control strategies to minimizing the contamination of hospital sinks and prevent microbial transmission to vulnerable patient populations.

Here, we review recent outbreaks related to contaminated hospital sinks, examining specifically design features and healthcare provider behaviors that contribute to the transmission of sink pathogens. We discuss various risk mitigation strategies that have been employed and their efficacy, with a focus on future directions.

Recent Outbreaks of Sink-Related Infections in Healthcare Facilities

The relationship between sinks and hospital-associated infection with hydrophilic organisms has long been described. Over 40 years ago, epidemiologic studies offered intriguing insights into the transmission of *Pseudomonas aeruginosa* from sinks to patients admitted to burn units, where culture-based environmental screening of sink drainage systems demonstrated high colonization rates of up to 70.2% [4, 5]. Since then, numerous outbreaks have been described, and advances in molecular techniques have strengthened the association between human infections and hospital sinks. Over the past 5 years, there has been an explosion of such outbreak reports, involving an ever-expanding patient population and pantheon of microorganisms.

This article is part of the Topical Collection on *Healthcare Associated Infections*

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While any water source within healthcare facilities may be susceptible to colonization with waterborne pathogens, contaminated hand hygiene sinks are commonly implicated as the source of outbreaks. These outbreaks most frequently occur in neonatal and adult intensive care units (ICUs) and burn units, as well as hematology-oncology and transplant wards (Table 1). Accordingly, the individuals most commonly affected by sink-related outbreaks are vulnerable patient populations, including neonates, the critically ill, and immunosuppressed.

Waterborne bacteria predominate in sink-related outbreaks, with *P. aeruginosa* being the most commonly identified organism. Other pathogens include Enterobacteriaceae, such as *Escherichia coli*, *Klebsiella pneumoniae*, *Klebsiella oxytoca*, *Serratia marcescens*, *Enterobacter* species, *Citrobacter* species, and *Pantoea agglomerans*. Non-fermenting organisms such as *Stenotrophomonas maltophilia*, *Acinetobacter baumanii*, *Elizabethkingia meningoseptica*, and *Burkholderia* species as well as *Fusarium* species and *Mycobacterium mucogenicum* have also been described (Table 1).

Multidrug-resistant (MDR) organisms are featured prominently in these reports, with carbapenemases most frequently identified. Enterobacteriaceae producing extended-spectrum beta-lactamases (ESBLs) as well as multidrug-resistant *P. aeruginosa* and *A. baumanii* are also commonly identified. The overrepresentation of MDR organisms in outbreak reports might simply reflect a failure to recognize sink-related transmission of more susceptible pathogens that are not commonly included in infection control surveillance. The true burden of sink-related infections is therefore likely underestimated as there is currently no widespread systematic surveillance strategy addressing this type of hospital-associated infection.

Design Features that Promote Sink-Related Infections

Sinks are complex items, with multiple fixtures that present a unique environment for microorganisms (Fig. 1). There are two main ways that sink design may facilitate the spread of pathogens: (1) by promoting formation of biofilm and (2) by encouraging disruption of established biofilm, resulting in aerosolization, splashing, or contamination of adjacent surfaces.

Promotion of Biofilm

Hospital water systems are rife with biofilm [1, 2, 49••]. Sinks, in particular, are susceptible to biofilm formation, as they are repositories of gray-water (wastewater without fecal contamination). Planktonic bacteria, when in the aqueous environment of a sink, form a biofilm by attaching to and colonizing solid surfaces. A multicellular and sessile bacterial community forms as the bacteria adopt a quorum-sensing phenotype. The bacterial community expands and matures, secreting extracellular polymeric substances, which encase and reinforce the growing colony, trap and concentrate nutrients, and protect against mechanical and chemical disinfection [50]. The polymicrobial constituents interact in complex cooperative and antagonistic ways, resulting in the emergence and transfer of resistance genes and virulence factors [51]. The horizontal transfer of GIM-1 [52], KPC, NDM [53], and MRSA [54] has been demonstrated in hospital sinks.

Sink biofilm formation is often enhanced by certain design features, leading to high microbial burden. These features include the use of plastic traps [36••]; faucets with aerators or other flow modulators [9, 10, 12, 13, 27, 46, 47, 55]; rimmed faucet spouts [7, 36••]; sink rubbers [56]; and overflow holes [31]. When biofilm and corrosion deposits are visibly noted on faucet aerators, *P. aeruginosa* load in water has been demonstrated to be on average 2-log higher compared to water from those faucets without aerators [13]. A number of outbreak investigations cite the presence of biofilm or "slime" coating these sink features, although the method of detection is most often visual [6, 13, 48, 57]. Other means of biofilm detection, such as biomass quantification (heterotropic plate counts, adenosine triphosphate measurement), visualization of structure (confocal laser scanning microscopy), and activity measurements, are more often employed in experimental models [58–61].

Disruption and Dispersion of Biofilm

Cells within the biofilm can actively detach, reverting back to their planktonic phenotype or, passively slough as a consequence of changes in nutrient availability, chemical disruption, or aberrations in fluid dynamics [50, 60]. These sloughed aggregates may then transfer to the hands of healthcare workers and adjacent patient care items such as medications, medical supplies, or devices or make direct contact with patients, causing infection [61]. Two key sink design features that facilitate such aerosolization, splashing, and/or surface contamination are the depth of the sink basin, and the faucet positioning relative to sink drain.

Basin Depth

Shallow basins are thought to cause cross-contamination of hands during handwashing [11] and promote splashing [32, 38, 43] with subsequent contamination of the faucet, sink collar, and adjacent surfaces. In their investigation of several clusters of IMP-4 carbapenemase-producing Enterobacteriaceae (CPE) infections in the ICU setting, Kotsanas et al. identified shallow basins in addition to deteriorating porcelain, and a tap with water flowing directly into the drain, as all contributing to significant and visible water spray [38]. De Gyeter et al. performed air sampling, culturing

such Gram-negatives as *S. maltophilia*, *S. marcescens*, and *Pseudomonas* species from bioaerosols generated when the faucets in their ICU were running. As a consequence of the short vertical distance (20 cm) between the faucet and the drain, contamination of the faucet with bioaerosol was postulated as contributing to their facility's outbreak [32].

Faucet Positioning

Water flowing directly into the drain can disrupt established biofilm in sink traps, causing pathogens to disperse via the Venturi-effect. Numerous studies have identified or postulated this mechanism as contributing to outbreaks [6, 9, 14••, 15, 19, 28, 31, 32, 36••, 44, 55, 62]. Jencson and colleagues used culture-based methods to demonstrate the dissemination of *Candida* species from the sink drain onto the basin and surrounding countertops upon coincident water flow [63]. Hota et al. injected fluorescein into sink traps demonstrating spray of drain and trap contents up to 1 m from the sink during use [64]. Similarly, Starlander et al. injected safranin into their sink drains to reveal visible contamination of the basin rim with water running [29]. Kotay et al. employed an experimental design, using green-fluorescent protein-expressing *E. coli* to elucidate the mechanisms of bacterial dispersal from sinks. They demonstrated, over the course of 7 days, the extension of biofilm from colonized P-traps up into the drain at an astonishing rate of 2.5 cm per day and subsequent dispersal of *E. coli* to the surrounding areas (< 76 cm) with faucet use. They also described retrograde colonization of the P-trap from a common pipe, suggesting that biofilm creep might extend beyond an individual contaminated sink and into horizontal piping [65••].

Factors Beyond the Sink

The observation that sinks in patient care areas might be colonized by retrograde biofilm creep has implicated the greater network of hospital wastewater systems as sources of sink-related infection [6, 13, 28]. Materials used in hospital piping should be taken into consideration, given that plastic has been shown to encourage biofilm formation more than copper or stainless steel [66]. Shaw et al. implicated plastic P-traps as one of a number of sink design features that might have contributed to a high incidence of MDR Gram-negative bacilli (GNB) infections in their ICU. Given the perceived extent of contamination through their water system, they adopted a "water-safe" program involving the complete removal of hand hygiene sinks from their ICU to terminate the spread of these organisms [36••]. Defective conditions in water systems, such as underuse, high temperatures, excessive pressure fluctuations, and alterations in flow can lead to trap seal depletion, and shearing, thereby magnifying the problem. In a root cause analysis, Yablon et al. identified substantial dead-end water piping as resulting in inadequate chlorine residuals and subsequent colonization of multiple sinks with *P. agglomerans*, precipitating an outbreak on a hematology-oncology ward [39]. Gormley et al., using a full-scale test rig, modeled the aerosolization of *Pseudomonas putida* through a building as the consequence of empty traps, a defect not uncommon in many buildings [67••]. More recently, Mair-Jenkins and colleagues attributed a sustained restaurant *Salmonella enteric ser. Typhimurium* outbreak to bioaerosol contamination of a kitchen as the consequence of ineffective traps as well as wastewater pooling and biofilm formation [68••]. Although outside of a hospital environment, this example demonstrates that ineffective trap seals may lead to sink contamination.

Healthcare Provider Behaviors that Contribute to Infection Transmission from Sinks

Healthcare providers can contribute to the colonization of hand hygiene sinks and the transmission of nosocomial pathogens through two means: (1) the misuse of sinks and (2) the placement of patient care materials proximal to sinks.

Misuse of Sinks

The disposal of patient wastewater into hand hygiene sinks may directly introduce pathogens into sink plumbing and onto sink fixtures, resulting in colonization. Moreover, antibiotic run off and the organic materials in patient wastewater promote resistance in and provide nutrients to existing biofilms. A recent study has demonstrated that the upward growth of biofilm from colonized traps into drains was accelerated by the addition of nutrient-rich items similar to those frequently disposed down sinks [65••]. Balm and colleagues performed a root cause analysis in their investigation of a protracted *E. meningoseptica* outbreak. They describe the disposal of patient secretions and the cleaning of re-useable patient care items in hand hygiene sinks as significant contributors [46]. Sinks subject to such misuse were found to be more likely contaminated with *E. meningoseptica* (odds ratio 4.38, 95% CI 1.68–11.39, $p = 0.004$). These behaviors persisted despite directed interventions due to nursing time constraints, as well as the distance between patient rooms and the unit dirty utility room, which was perceived as interfering with workflow [46].

Placement of Patient Care Materials Adjacent to Sinks

The use of surfaces adjacent to hand hygiene sinks for preparation of patient care items or the storage of clean supplies has also been identified during outbreak investigations as contributing to transmission. During their evaluation of a prolonged clonal MDR *P. aeruginosa* outbreak, Salm et al. identified that

Table 1 Relevant sink-related outbreaks and associated risk mitigation strategies since 2012

Reference	Organism	Sink source	Molecular method used	Setting	Intervention									
					Complete replacement of sink	Replacement of sink components	Installation self-cleaning trap	Disinfection with chlorine solution	Disinfection with other	Pressurized steam	Enhanced cleaning	Descaling	Point-of-use filters	Eliminate storage of clean items near sink
Breathnach et al. [6]	*P. aeruginosa* (VIM)	Drain; T-pip-e	PFGE; VNTR	W	√	√								√
Garvey et al. [7]	*P. aeruginosa*	Drain	PFGE	BICU					U		√	√		
Garvey et al. [8]	*P. aeruginosa*	Faucet	PFGE	HO									√	
Davis et al. [9]	*P. aeruginosa*	Drain	WGS	NICU	√	√		√						
Mayes et al. [10]	*P. aeruginosa*	Aerator	N/A	NICU		√					√			
Ambrogi et al. [11]	*P. aeruginosa* (VIM)	Drain	PFGE	ICU		√			U					
Knoester et al. [12]	*P. aeruginosa* (MDR)	Drain; aera-tor	AFLP	ICU		√		√						
Bedard et al. [13]	*P. aeruginosa*	Drain; aera-tor	qPCR	NICU		√							√	√
Aspelund et al. [14••]	*P. aeruginosa* (MBL)	Drain; pipes	PFGE	W	√				√	√				
Wendel et al. [15]	*P. aeruginosa* (GIM-1)	Drain	PFGE; MLST	ICU W		√								√
Salm et al. [16]	*P. aeruginosa* (MDR)	Drain	Rep-PCR	ICU		√								
Johansson et al. [17]	*P. aeruginosa*	Drain	MLVA; PFGE	TW										
Vos et al. [18]	*P. aeruginosa* (MDR)	Drain	N/A	U					U					√
Schneider et al. [19]	*P. aeruginosa*	Trap	RAPD-PCR; microarray	HO		√	√						√	
Brandt et al. [20]	*P. aeruginosa* (CRO)	Drain	N/A	HO			√							
Diederen et al. [21]	*P. aeruginosa* (VIM-2)	Drain	N/A	ICU		√			U					
Guleri et al. [22]	*P. aeruginosa* (MDR)	Pipes; trap	VNTR	ICU	√			√						
Kossow et al. [23••]	*P. aeruginosa* (MDR)	Trap	N/A	HO			√		U		√		√	
Leistner et al. [24]	*P. aeruginosa* (XDR)	Sink	Rep-PCR	ICU		√								
Liese et al. [25]		Trap	N/A	HO					U					

Table 1 (continued)

	P. aeruginosa (MBL)													
Clarivet et al. [26]	*Klebsiella pneumoniae* (OXA-48)	Trap; aerator	PFGE	ICU W		√		√	U					
Maltezou et al. [27]	Serratia marcescens	Drain	PFGE	NICU	√			√						√
Chapuis et al. [28]	*Enterobacter cloacae* (ESBL)	Drain	PFGE; MLST	HO				√				√		
Starlander et al. [29]	*Klebsiella pneumoniae* (ESBL)	Drain	PFGE	ICU	√									
Tofteland et al. [30]	*Klebsiella pneumoniae* (KPC)	Drain	PFGE; MLST	ICU	√			√						
Lowe et al. [31]	*Klebsiella oxytoca* (ESBL)	Drain; aerator	PFGE	ICU		√			√		√			
De Geyter et al. [32]	Polymicrobial CPE	Drain; trap	PFGE	ICU	√	√			√					
De Jong et al. [33]	*Klebsiella pneumoniae* (ESBL)	Drain	PFGE	ICU		√		√						√
Leitner et al. [34]	*Klebsiella oxytoca* (KPC)	Drain; overflow	Rep-PCR; MLST	HO	√									
Van Oers et al. [35]	Polymicrobial MDR-GNB	Sink	PFGE	ICU	√									
Shaw et al. [36••]	Polymicrobial MDR-GNB	Trap	N/A	ICU		√		√	U		√		√	
Seara et al. [37]	*Klebsiella pneumoniae* (NDM)	Trap	PFGE; MLST	IH		√		√	√	√				
Kotsanas et al. [38]	Polymicrobial CPE (IMP-4)	Drain	PFGE	ICU				√		√				
Yablon et al. [39]	Pantoea agglomerans	Sink	PFGE	HO					U					√
Wolf et al. [40]	Polymicrobial ESBL	Drain	AFLP	ICU			√							
Vergara-Lopez et al. [41]	*Klebsiella oxytoca* (IMP-8)	Trap; pipes	PFGE	ICU	√	√			√					
Umezawa et al. [42]	Acinetobacter baumanii	Faucet	Rep-PCR; MLST	ICU	√				U					
Hong et al. [43]	Acinetobacter baumanii	Faucet	MLST	PICU	√			√						
Landelle et al. [44]	Acinetobacter baumanii	Trap	N/A	ICU				√	√					
Guyot et al. [45]	Stenotrophomonas maltophilia	Sink	PFGE	ICU	√									
Balm et al. [46]		Aerator	Rep-PCR	ICU		√		√						

Table 1 (continued)

Ashraf et al. [47]	Elizabethkingia meningoseptica Mycobacterium mucogenicum	Aerator	Rep-PCR	HO		√						√
Litvinov et al. [48]	*Fusarium* species	Faucet; drains	Phylogenic	HO				√			√	

Reference	Intervention	Outcome						Follow-up	
	Eliminate disposal patient waste	Reduction cases	No further cases	Reduction colonization	No further colonization	Ongoing cases	Ongoing colonization	Surveillance	Environmental screening
Breathnach et al. [6]		√						√	
Garvey et al. [7]	√						√		√
Garvey et al. [8]	√			√					√
Davis et al. [9]			√					√	
Mayes et al. [10]								√	
Ambrogi et al. [11]			√		√			√	√
Knoester et al. [12]		√					√	√	√
Bedard et al. [13]			√				√	√	√
Aspelund et al. [14••]					√		√		√
Wendel et al. [15]			√					√	
Salm et al. [16]	√	√						√	
Johansson et al. [17]			√					√	
Vos et al. [18]		√						√	
Schneider et al. [19]		√						√	
Brandt et al. [20]							√	√	√
Diederen et al. [21]			√					√	
Guleri et al. [22]					√				√
Kossow et al. [23••]		√		√				√	√
Leistner et al. [24]	√	√						√	
Liese et al. [25]			√	√				√	
Clarivet et al. [26]			√		√			√	√
		√			√			√	√

Table 1 (continued)

Maltezou et al. [27]								
Chapuis et al. [28]		√					√	
Starlander et al. [29]	√	√	√	√			√	√
Tofteland et al. [30]			√		√		√	√
Lowe et al. [31]			√	√			√	√
De Geyter et al. [32]	√		√	√			√	√
De Jong et al. [33]	√	√			√			√
Leitner et al. [34]		√					√	√
Van Oers et al. [35]	√		√	√			√	√
Shaw et al. [36••]	√	√					√	
Seara et al. [37]			√	√			√	√
Kotsanas et al. [38]					√			√
Yablon et al. [39]		√					√	
Wolf et al. [40]			√				√	√
Vergara-Lopez et al. [41]			√	√			√	√
Umezawa et al. [42]			√				√	
Hong et al. [43]			√	√			√	√
Landelle et al. [44]	√				√		√	√
Guyot et al. [45]		√					√	
Balm et al. [46]					√			√
Ashraf et al. [47]			√				√	
Litvinov et al. [48]			√		√		√	√

U, unidentified; *N/A*, not available; *MLST*, multilocus sequence typing; *Rep-PCR*, repetitive element palindromic PCR; *PFGE*, pulse-field gel electrophoresis; *AFLP*, amplified fragment length polymorphism; *RAPD-PCR*, random amplification of palindromic DNA; *VNTR*, variable number tandem repeat; *MLVA*, multiple locus variable number tandem repeat; *WGS*, whole genome sequencing; *qPCR*, quantitative PCR; *XDR*, extensively drug-resistant; *HO*, hematology-oncology; *W*, ward; *TW*, transplant ward; *NICU*, neonatal ICU; *PICU*, pediatric ICU; *IH*, inter-hospital

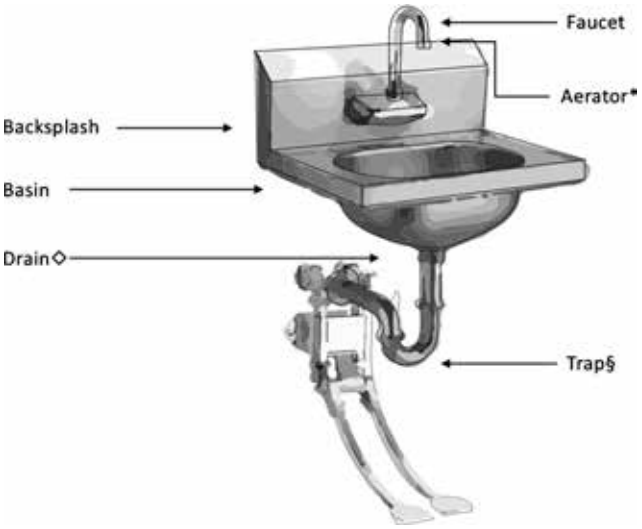

Fig. 1 Anatomy of a hospital sink and associated nomenclature. *Flow modulator; §U-bend/P-trap/S-trap/Siphon; ◊outlet/strainer; image courtesy of Bryan Graham Huck

admission to a room with a colonized sink and hemofiltration were independently associated with an elevated risk of acquiring the outbreak organism. A process audit revealed that during hemofiltration, dialysate bags were emptied in and prepared adjacent to the hand hygiene sinks. Droplet spray during sink use was thought to be contaminating the dialysate bags. After replacing sink traps, implementing single-use bags and restricting practices around sinks, the incidence of infections decreased [16]. Ashraf et al. report an outbreak of *M. mucogenicum* bloodstream infections originating from a hand hygiene sink with a colonized faucet aerator. An audit revealed that saline flushes were being prepared on the counter adjacent to the contaminated sink, using a saline bag that was hung over the sink basin, presumably leading to the contamination of the flushes [47].

Infection Control Strategies Used During Sink-Related Outbreaks

Infection control strategies are often bundled together during outbreaks, with an emphasis placed upon (1) cleaning and disinfection; (2) biofilm disruption; (3) installation of point-of-use filters; and (4) the replacement of sink plumbing and/or fixtures. It is thus difficult to determine whether a single given intervention was responsible for successfully interrupting the outbreak, or if success is predicated upon a variety of interventions.

Cleaning and Disinfection

Although many studies fail to describe what products and/or processes were employed, based upon reported outcomes, it appears that cleaning and disinfection alone is rarely effective in eliminating sink colonization. A variety of disinfectants, administered with varying frequencies, have been evaluated. Chlorine-containing solutions have been used in concentrations ranging from 250 [33] to 1000 ppm [36••, 37, 69] and administered multiple times per day [27, 43], daily [9, 28, 33, 36••, 37, 39, 55, 69, 70], and thrice weekly [12], either alone or in combination with other biocides [37]. Other chemical disinfectants have been applied with limited efficacy, including hydrogen peroxide [31], glucoprotamin [32], acetic acid [14••], amphoteric and cationic surfactants including quaternary ammonium compounds (QACs) [37, 70], sodium hydroxide [37], and polyhexamethylene biguanide hydrochloride [70]. When successful, the effect of disinfectants appears to be temporary or solely interrupts the outbreak without completely decolonizing the sinks. Garvey et al. report that "descaling and disinfection" with enhanced routine cleaning was insufficient to rid hand hygiene sinks of *P. aeruginosa* in their burn ICU, noting recolonization following 102 days [7]. Two other studies highlighted a similar pattern of clearance and subsequent re-emergence [38, 46]. Bacteria living in biofilm are able to survive in the presence of 100 to 1000 times higher concentrations of disinfectants than their planktonic counterparts. They may also limit the penetration of disinfectants, sequestering and expelling these agents [71]. The use of disinfectants in the presence of biofilm can select for resistance, and reduced susceptibility to chlorine and QACs has been reported [72]. Moreover, the presence of organic residue as well as inadequate contact time within the sink environment might contribute to the observed reduced efficacy of these agents.

Biofilm Disruption

Pressurized steam has been employed as an adjunct to chemical disinfection, capitalizing on the thermotoxic effect of high temperatures while also disrupting biofilm. Herruzo et al. achieved clearance of OXA-48 *K. pneumoniae* from their sink drains following the application of pressurized steam with a chlorine-containing solution. However, the effect of their intervention was short-lived, with 50% of sinks recolonized within 9 months [61]. A similar pattern of temporary clearance followed by re-emergence was noted in a similar study following a very brief 3 days [38].

Self-disinfecting traps have shown more promise in disrupting biofilm. These units use vibration, bundled with heat or ultraviolet radiation to remove existing biofilm, reduce microbial burden, and prevent further biofilm formation. In practice, these units may successfully reduce rates of sink-related hospital-associated infection and/or sink pathogen colonization [19, 20, 23••, 40, 72, 73••]. However, the implementation of self-disinfection traps is often bundled with other interventions, such as point-of-use filters, plumbing or fixture replacement, and chemical disinfection. When evaluated alone, Wolf et al. noted complete interruption of ESBL

transmission events as well as sustained negative environmental cultures at 20 weeks [40]. However, although Fusch et al. found a reduction in *P. aeruginosa* clinical cases and sustained lower sink aerosol contamination rates associated with the implementation of self-disinfecting traps, their sinks remained contaminated. These units were installed after replacement of the sinks alone failed to achieve a sustained reduction in aerosol contamination, raising the possibility of a deeper reservoir [72]. Although promising, self-disinfecting traps incur substantial cost, and they require further evaluation in healthcare settings.

Point-of-Use Filters

The resiliency of pathogens in established biofilms has prompted alternative risk mitigation strategies, including the installation of point-of-use filters when enhanced cleaning and disinfection have failed [13, 36••, 48, 74]. Filters are susceptible to leaking, saturation requiring frequent changes, and microbial contamination [7] and may have other disadvantages such as reduced water pressure [75]. When used, they require a rigorous maintenance program.

Replacement of Sink Plumbing and/or Fixtures

The replacement of sinks and/or sink components has been employed most successfully as an outbreak mitigation strategy [9, 11, 12, 19, 21, 22, 26, 27, 30–32, 36••, 37, 42, 43, 69]. However, replacement of individual sink components has not been universally effective, or has produced only a temporary effect, suggesting a persistent reservoir in the retained sink fittings. Despite the replacement of drainpipes, Bedard et al. noted ongoing *Pseudomonas* colonization of the drain and faucet on environmental screening [13]. Similarly, even with replacement of faucet aerators, two other studies reported ongoing microbial colonization of their sinks [12, 46].

Complete sink replacement has been reported as effective, however, like other risk mitigation strategies, may not always successfully result in decolonization. Hong et al. attempted disinfection of MDR *Acinetobacter* colonized sinks and faucets with sodium hypochlorite five times daily. In the face of ongoing environmental colonization and clinical cases, they proceeded with complete replacement of affected sinks, effectively halting the outbreak and rendering the sinks culture negative for *A. baumanii* [43]. De Geyter and colleagues eventually proceeded to replacing their sinks after targeted replacement of traps and pipes was unsuccessful, demonstrating complete clearance of CPE from their ICU sinks. However, environmental screening continued to demonstrate the presence of hydrophilic GNB, including MDR *Pseudomonas* and *Stenotrophomonas* species [32]. Similarly, Aspelund et al., who seemed to have successfully decolonized their sink drains of *P. aeruginosa* using weekly 24% acetic acid and hot water flushing, discovered that at 13 weeks following sink replacement, the drains once again cultured positive. The organism was detected in multiple wall drainpipes suggesting a deeper reservoir in the horizontal wastewater system [14••].

In a recent 6-year quasi-experimental study, the investigators explored the effect of the removal of all hand hygiene sinks from ICU patient rooms on rates of MDR-GNB. Although lacking molecular analysis, their intervention was associated with a significant decline in their baseline MDR-GNB rates [36••]. A water-free patient care environment was also explored in an ICU where hand hygiene sinks were removed from patient care areas. Following their intervention, they observed a significant reduction in GNB colonization in their patients, an effect which was most pronounced in those with long ICU-stays [76••]. Such an intervention could only be considered in a setting with high hand hygiene compliance rates using alcohol-based hand rub as well as low endemic *Clostridioides difficile* rates.

Despite attempts at disinfection, the implementation of biofilm disruption strategies, and complete replacement of affected sinks, bacterial pathogens often persist as colonizers of hospital premise plumbing and fixtures [49••, 77]. This said, a number of these interventions are successful in terminating transmission of pathogens from sinks to patients and therefore should not be dismissed as ineffective.

Investigational Strategies to Mitigate the Risk of Sink-Related Infections

A number of additional risk mitigation strategies are under investigation but have not yet been adequately tested in clinical environments. These include newer methods of biofilm disruption and prevention, and resistome modulation.

Enzymes, such as proteases, DNAses, and polysaccharide depolymerases, function by dismantling biofilm matrix; when used in conjunction with chemical disinfectants, they may enhance the biocidal effect [78]. However, enzyme efficacy is predicated upon the appropriate selection of a mixture of agents targeting the unique and heterogeneous composition of the biofilm matrix being treated. As of yet, enzymes have been used effectively only in laboratory based-experimental models and the food industry [79–81]. Similarly, bacteriophage therapy is conceptually intriguing given that phages are able to easily penetrate biofilm matrix, targeting and eradicating the constituent microorganisms [50]. Bacteriophages are species-specific, which hinders their use in multispecies biofilms like those in a hospital environment.

Quorum-sensing inhibitors or quorum quenching strategies have been suggested as effective means to prevent biofilm formation; however, this research remains very much in its infancy [82]. The use of surfaces with antimicrobial properties may prevent biofilm formation by limiting microbial burden. Metals with biocidal properties have been evaluated in healthcare settings [83]. Copper has been identified as being most effective at reducing overall bacterial burden, with studies examining sinks and sink drainage pipes [83, 84]. However, there is limited high-quality evidence to suggest the efficacy of copper alloy in reducing sink-associated infections. Moreover, the longevity of the antimicrobial effects of copper ions in the sink environment and its ability to generate resistance remains undefined. Silver and selenium nanoparticles have similarly been investigated but their efficacy in sinks has not been clearly demonstrated [85, 86].

More recently, ozone has been implemented in sink design as a biofilm prevention strategy. A recent study examined the efficacy of a stand-alone hand hygiene sink that features an ozonation cycle designed to prevent biofilm formation in the drain and trap. Following experimental inoculation of the sink with *Pseudomonas* species and *Candida auris*, complete eradication of the organisms from the trap was noted at 9 days. The study failed to demonstrate significant decolonization of either the strainer or the remainder of the sink [87]. It is unclear how this system would perform in a hospital setting where well-established multispecies biofilm might be present in the distal wastewater plumbing.

A *Bacillus*-based cleaning strategy has been used to modulate the hospital resistome by counteracting the growth of drug-resistant surface pathogens [88]. However, no research has evaluated the introduction of similar, non-pathogenic probiotic organisms in an aqueous environment. Moreover, a metagenomics study characterizing the microbiome of hospital shower hoses identified genes related to disinfectant tolerance and antimicrobial resistance amidst the largely non-pathogenic microbes identified [49••]. More research directed at understanding the complexities of biofilm communities is required before a similar risk mitigation approach is introduced.

Lessons Learned

These outbreaks have taught us that reactionary responses and mitigation strategies are woefully ineffective at eliminating sink colonization with clinically significant pathogens and, in some cases, their transmission. Furthermore, the implementation of policies restricting the use of hand hygiene sinks to handwashing is unlikely to be sufficient in isolation. With respect to hospital sink-related infections, there is a role for prevention through design. Despite the frequent identification of deficiencies in sink design as a primary driver behind sink-related infections, many of the sinks described in recent outbreak investigations do not adhere to current recommended standards. The reasons behind this are likely multifactorial and might simply reflect the age of the healthcare facilities and the relative expense of retrofitting. It may also reflect the often overlooked importance of infection prevention and control in healthcare design.

Currently, the Canadian Standards Association, in alignment with many other national facility design standards like the American Institute of Architects, stipulate that a hand hygiene sink be installed within each inpatient room and no more than 6 m distance from a given patient's bed [89, 90]. As the presence of hand hygiene sinks remains an essential component in infection prevention and control, our focus should be on optimizing sink design to prevent microbial transmission. The standards themselves have been informed by the literature and provide provisions for a design that discourages formation of biofilm, minimizes the aerosolization of water from the drain and/or trap, and dissuades high-risk behaviors. At minimum, new builds of healthcare facilities should adhere to these standards. Older facilities should take stock of their existing design and implement simple engineering controls that follow the same principles.

Beyond design-based prevention methods, infection control strategies should include "safe water practices." These should stipulate that hand hygiene sinks be dedicated to handwashing, and that the disposal of patient wastewater in sinks is prohibited. Moreover, until a safe distance is clearly defined, it is reasonable to suggest that the placement of clean supplies or clean work surfaces within 1 m of hand hygiene sinks be avoided or, alternatively, a barrier be installed to protect these vulnerable zones.

Finally, recognizing that sinks will always contain microorganisms, infection prevention and control programs should consider performing a facility-wide risk assessment to determine the hazard potential of their current sinks, based on design features. This will inform the need for enhanced surveillance and/or proactive risk mitigation to avoid sink-related outbreaks.

Conclusion

Hospital sinks provide a permissive environment for biofilm formation and microbial colonization and sink-related outbreaks are increasingly reported over time. The role of hospital sinks has become even more salient in the era of emerging antimicrobial resistance, given that CPEs and other MDR-GNBs have demonstrated an affinity for this environmental niche. Risk mitigation strategies such as cleaning and disinfection as well as sink replacement have been employed with variable success, often halting outbreaks or reducing clinical cases but failing to decolonize the sinks. It is neither reasonable nor feasible to expect sterility of hospital sinks. Emphasis should thus be placed on optimizing best practices in sink design and placement, as well as healthcare provider behaviors to prevent transmission of potentially dangerous pathogens from sinks.

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Compliance with Ethical Standards

Conflict of Interest We declare that we have no conflicts of interest relevant to this manuscript. Full disclosures available upon request.

Human and Animal Rights and Informed Consent This article does not contain any studies with human or animal subjects performed by any of the authors.

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Clinical Infectious Diseases

REVIEW ARTICLE

The Hospital Water Environment as a Reservoir for Carbapenem-Resistant Organisms Causing Hospital-Acquired Infections—A Systematic Review of the Literature

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Over the last 20 years there have been 32 reports of carbapenem-resistant organisms in the hospital water environment, with half of these occurring since 2010. The majority of these reports have described associated clinical outbreaks in the intensive care setting, affecting the critically ill and the immunocompromised. Drains, sinks, and faucets were most frequently colonized, and *Pseudomonas aeruginosa* the predominant organism. Imipenemase (IMP), *Klebsiella pneumoniae* carbapenemase (KPC), and Verona integron-encoded metallo-β-lactamase (VIM) were the most common carbapenemases found. Molecular typing was performed in almost all studies, with pulse field gel electrophoresis being most commonly used. Seventy-two percent of studies reported controlling outbreaks, of which just more than one-third eliminated the organism from the water environment. A combination of interventions seems to be most successful, including reinforcement of general infection control measures, alongside chemical disinfection. The most appropriate disinfection method remains unclear, however, and it is likely that replacement of colonized water reservoirs may be required for long-term clearance.

Keywords. carbapenem-resistant; carbapenemase; healthcare-associated infections; outbreak; water.

Over the last 10–15 years, clinically relevant carbapenem-resistant organisms (CROs), such as *Pseudomonas aeruginosa, Acinetobacter baumannii,* and the Enterobacteriaceae, have disseminated globally [1]. Genes encoding for important carbapenemases, such as *Klebsiella pneumoniae* carbapenemase (KPC), oxacillinase-48 (OXA-48), and the metallo-β-lactamases, are often transmitted between organisms by mobile genetic elements, such as plasmids, contributing to their spread. Limited treatment options and high mortality in those infected are particularly worrying. Hence, understanding reservoirs and transmission of common CROs and transmissible carbapenemases is a research priority.

Hospitals present a unique opportunity for bacteria to interact, proliferate, and infect vulnerable populations. The healthcare water environment, including potable water, faucets, sink surfaces and wastewater drainage systems (drains, sink/shower traps, toilets, drainage pipes), can be a reservoir for nosocomial pathogens, such as drug-resistant Enterobacteriaceae, *Pseudomonas* spp., and *A. baumannii* [2–4]. The prevalence of these multidrug-resistant organisms (resistant to ≥3 antimicrobial classes) is rising [5], and they will increasingly dominate the hospital environmental microbiome. Determining effective infection control (IC) measures to decontaminate environmental reservoirs and prevent cross-transmission of multidrug-resistant organisms between patients and the environment may minimize potentially lethal outbreaks. The aim of this literature review was to summarize studies identifying common CROs in the hospital water environment, the evidence for CRO transmission between this environment and patients, and successful IC interventions to terminate outbreaks and eliminate CROs from this environment.

METHODS

PubMed was searched using the following Medical Subject Headings (MeSH) and text terms: (enterobacter* OR pseudomon* OR acinetobacter) AND (drain OR sink OR shower OR faucet OR hospital water) (search date: 7–9 March, 2016). All abstracts in English, French, Spanish, and German from 1967 to the search date were screened. Articles were excluded if the full article was unavailable through PubMed or the

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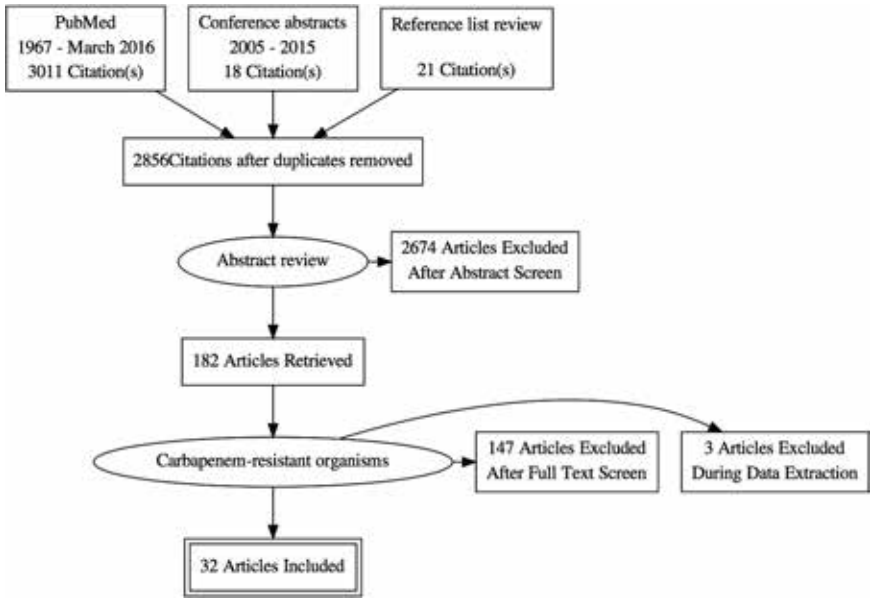

Figure 1. Flowchart of study selection process. Three studies were excluded during data extraction because the outbreak organism was not found in the water environment.

University of Oxford, if the study did not occur in the acute healthcare setting, if it involved hospital wastewater remote to patient care areas, or if the organisms of interest were not identified. Citations in the selected articles were reviewed for additional relevant reports.

Additional searches of conference abstracts were undertaken (9–10 March 2016) for the European Congress of Clinical Microbiology and Infectious Diseases (2005–2015), Interscience Conference on Antimicrobial Agents and Chemotherapy (2013–2014), Infectious Diseases Society of America ID Week (2004–2015), and the Australian Society of Infectious Diseases (ASID) meetings (2013–2015).

All studies involving CROs (organisms phenotypically nonsusceptible to ≥1 carbapenem or producing a carbapenemase) were then included. The ORION (Outbreak Reports and Intervention Studies of Nosocomial Infection) framework was used to assess outbreak reports [6]. Data were collected for the following variables: author, publication year, study design,

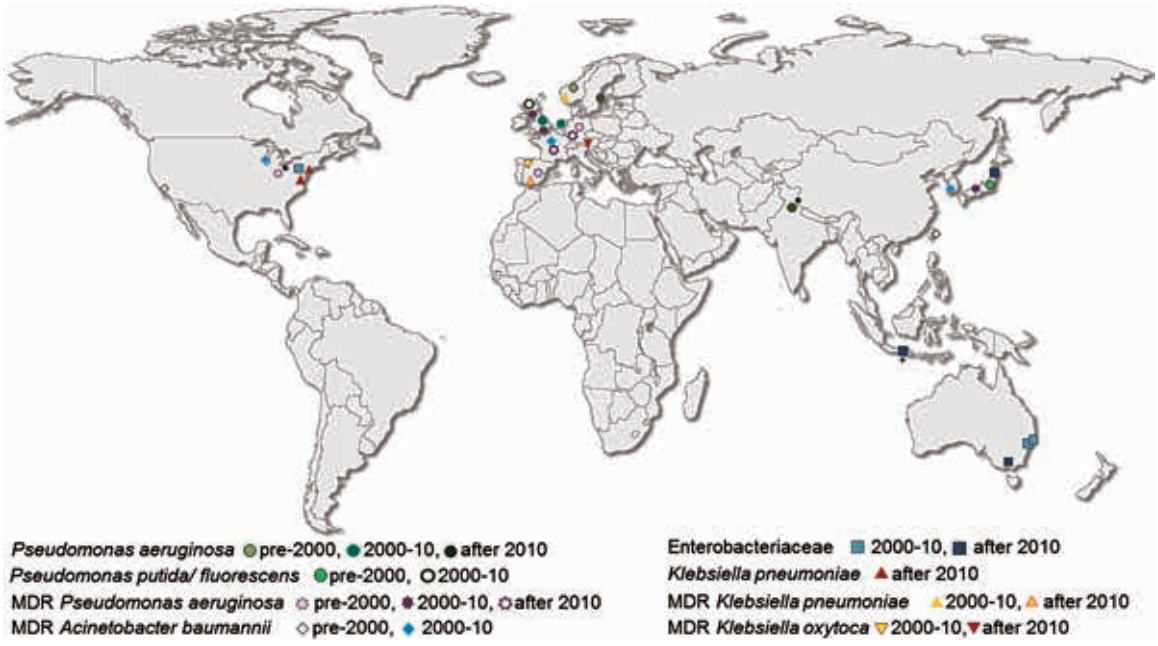

Figure 2. Geographic and temporal distribution of carbapenem-resistant organisms (CROs). The geographic and temporal distribution of the included studies based on the organism reported. MDR, multidrug-resistant (resistant to ≥3 antimicrobial classes). *Study period unknown. †Dewi et al [10] report *Acinetobacter* spp. and *Aeromonas* spp. along with Enterobacteriaceae.

Table 1. Study Settings and Populations[a]

Patient population	Studies, No. (N = 32)	Intensive Care Unit	High-risk (Hematology, Nephrology, Burns Unit)	Multiple Wards	Other[b]
Adult	25	Knoester et al [25], Kotsanas et al [26], Durojaiye et al [16], Wang et al [27], La Forgia et al [28], Wendel et al [29], Bukholm et al [31], Tofteland et al [32], Vergara-López et al [33], Leitner et al [20], Snitkin et al [22], Podnos et al [23], Odom et al [11], Peña et al [35], Pitten et al [36], Biswal et al [8], Landelle et al [37]	Wong et al [19], Leitner et al [20], Breathnach et al [21], Leung et al [24], Betteridge et al [7], Ambrogi et al [18], Odom et al [11]	Peña et al [35], Pitten et al [36], Kouda et al [38], Landelle et al [37], Seara et al [34], Yomoda et al [9], Breathnach et al [21], Biswal et al [8]	None
Pediatric/ neonatal	3	Hong et al [30], Alter et al [15]	None	None	Ito et al [14]
Not given	4	Majumdar et al [17], Kaiser et al [13]	None	Stjarne Aspelund et al [12]	Dewi et al [10]

[a]Some studies included multiple different settings, so categories are not mutually exclusive.

[b]Single non–high-risk wards or not specified.

organism, carbapenemase mechanism, reservoir(s), evidence of environment-patient transmission, and type/success of interventions (Supplementary Table 1). Authors of studies reporting terminating outbreaks were contacted (August 2016) regarding the ongoing success of any interventions.

RESULTS

Study Settings and Populations

Search and screening strategy results are shown in Figure 1. Thirty-two studies were included (Supplementary Table 1). Of these, 27 were outbreak investigations, and 5 were epidemiological surveillance studies [7–11]. Twenty-three were full articles, 6 were conference abstracts [10–15], 2 were letters [16, 17] and 1 was a short report [18]. The studies included data from Europe (n = 16), Asia (n = 7), North America (n = 6), and Australia (n = 3) (Figure 2). Thirty studies occurred between 1996 and 2015, with 50% of these since 2010. Two studies did not document the study time frame [8, 15]. Most were conducted in adult inpatients, with 7 in pediatric/neonatal populations or unspecified (Table 1). Eleven studies involved immunocompromised patients, including those with hematological malignancies [12, 19–22], solid tumors [22], primary immunodeficiencies [22], renal disease [18], burns [7, 8, 23, 24], or unspecified diagnoses [11]. Fifteen studies occurred solely in the intensive care setting [13, 15–18, 23, 25–33], and the others involved various medical/surgical wards, intensive care units, operating theaters, or the whole hospital (Table 1).

Patient Sampling Strategy and Risk Factors for CRO Infection/Colonization

In total, 926 patients from 31 studies were CRO colonized (n = 184), infected (n = 189), or unspecified (n = 553). In 22 studies, active patient screening was performed, varying in site (swab samples from the rectum, nose, throat, groin, axilla, perineum, perianal, wound, and catheter sites; samples of sputum, urine, stool, tracheal aspirate, blood, and gastric tubes) and frequency (twice weekly, weekly, or fortnightly). The prevalence of patient infection or colonization ranged from 1.6% to 26.7% (reported in 8 studies [8, 14, 19, 22, 24, 30, 31, 33]). Risk factor analysis for colonization/infection was performed in 4 studies [14, 24, 25, 31], and risks included preceding surgery, patient location, prolonged mechanical ventilation, older

Table 2. Water Reservoirs Containing Carbapenem-Resistant Organisms[a]

Water Reservoir	Studies, No. (N = 32)	References
Drains/drainage systems	17	Peña et al [35], Kotsanas et al [26], La Forgia et al [28], Betteridge et al [7], Leitner et al [20], Wendel et al [29], Breathnach et al [21], Leung et al [24], Snitkin et al [22], Tofteland et al [32], Vergara-López et al [33], Yomoda et al [9], Stjarne Aspelund et al [12], Odom et al [11], Knoester et al [25], Landelle et al [37], Seara et al [34]
Sink surfaces	14	Betteridge et al [7], Wendel et al [29], Knoester et al [25], Podnos et al [23], Wang et al [27], Biswal et al [8], Hong et al [30], Bukholm et al [31], Kouda et al [38], Landelle et al [37], Dewi et al [10], Kaiser et al [13], Ito et al [14], Leung et al [24]
Faucets	8	Odom et al [11], Knoester et al [25], Majumdar et al [17], Pitten et al [36], Hong et al [30], Bukholm et al [31], Alter et al [15], Leung et al [24]
Water	3	Knoester et al [25], Ambrogi et al [18], Bukholm et al [31]
Inflatable hair wash basin	2	Wendel et al [29], Knoester et al [25]
Sensor mixer taps	1	Durojaiye et al [16]
Water/tea dispenser	2	Wong et al [19], Ito et al [14]
Shower/shower equipment	3	Betteridge et al [7], Leung et al [24], Seara et al [34]
Toilet bowl/brush	2	Breathnach et al [21], Kouda et al [38]

[a]Some studies had multiple water reservoirs, so categories are not mutually exclusive.

Table 3. Carbapenem-Resistant Organisms and Carbapenemase Type[a]

Organism	Studies, No. (N = 32)	Reservoirs	IMP	KPC	VIM	NDM	GIM	MIC/Phenotype only
Pseudomonas aeruginosa	13	Sinks, drains, faucets, hair wash basins, water samples, sensor mixer taps, toilet bowls/brushes	None	None	Knoester et al [25], Ambrogi et al [18], Breathnach et al [21], Stjarne Aspelund et al [12]	None	Wendel et al [29]	Peña et al [35], Durojaiye et al [16], Majumdar et al [17], Pitten et al [36], Biswal et al [7], Bukholm et al [31], Kouda et al [38], Alter et al [15]
Other *Pseudomonas* spp.	2	Drinking water dispenser, water pipes	Yomoda et al [9]	None	None	None	None	Wong et al [19]
Acinetobacter baumannii	5	Sinks, drains, faucets	None	None	None	None	None	Podnos et al [23], Wang et al [27], La Forgia et al [28], Hong et al [30], Landelle et al [37]
Klebsiella pneumoniae	7	Drains, faucets, showers, sinks	Kotsanas et al [26], Leung et al [24], Ito et al [14]	Snitkin et al [22], Tofteland et al [32], Odom et al [11]	None	Seara et al [34]	None	None
Klebsiella oxytoca	3	Drains, faucets, showers, sinks	Leung et al [24], Vergara-López et al [33]	Leitner et al [20]	None	None	None	None
Enterobacter spp.	5	Drains, faucets, showers, sinks	Kotsanas et al [26], Betteridge et al [7], Leung et al [33]	Tofteland et al [32]	None	None	None	Dewi et al [10]
Escherichia coli	3	Drains, cold tea dispenser	Kotsanas et al [26], Betteridge et al [7], Ito et al [14]	None	None	None	None	None
Serratia marcescens	3	Drains, faucets, showers, sinks	Kotsanas et al [26], Betteridge et al [7] , Leung et al [24]	None	None	None	None	None
Other (*Leclercia* spp., *Pantoea* spp., *Citrobacter freundii, Raoutella planticola, Escherichia hermannii, Aeromonas hydrophilia, Proteus mirabilis* or not specified)	4	Drains, faucets, showers, sinks	Betteridge et al [7] , Leung et al [24]	Kaiser et al [13]	None	None	None	Dewi et al [10]

Abbreviations: GIM, German imipenemase; IMP, imipenemase; KPC, *Klebsiella pneumoniae* carbapenemase; MIC, minimum inhibitory concentration; NDM, New Delhi metallo-β-lactamase; VIM, Verona integron-encoded metallo-β-lactamase.

[a]Some studies included multiple different species, so categories are not mutually exclusive.

age, burns, longer hospital stay, and drinking tea from a contaminated dispenser. Length of stay before colonization/infection was documented in only 10 studies, varying from 1 to 134 days [19, 24–26, 28–30, 32–34]. Mortality was assessed in 18 studies, with a mean rate of 25.7% (range, 0%–85%) [12, 16, 19–24, 26, 28–36]. However, 2 studies did not comment on whether deaths were attributable to the study organism(s) [28, 36].

Environmental Sampling Strategies

Hospital water environment investigations included sampling from faucets (n = 18), drainage systems (n = 17), sink surfaces (n = 16), and water (n = 14). Other environmental samples were taken in 26 studies, including medical equipment, patient environment, antiseptic solutions/liquid soaps, enteral nutrition, staff areas, and air samples. Sampling methods varied but typically included moist sterile swab/water samples of varying volumes. Only 5 studies detailed sink and drainage system design [18, 20, 21, 26, 30].

All studies identified the relevant CROs in the water environment, mostly in drains/traps, sink surfaces, and faucets (Table 2). CROs were found in other sites in 15 of 32 studies. The hands of healthcare workers (HCWs) were sampled in 6 studies [8, 17, 23, 27, 33, 36]; additional pharyngeal, rectal, and nasal swab samples were obtained in 2 [8, 33], 1 [33], and 1 [8] study respectively. The study CRO was not colonizing HCWs in any studies.

CROs Investigated

Organisms studied included *P. aeruginosa*, *Pseudomonas fluorescens, Pseudomonas putida, A. baumannii*, and various Enterobacteriaceae (Table 3). Molecular carbapenemase identification was performed in 17 studies. The genes identified included bla_{IMP} (n = 6), bla_{KPC} (n = 5), bla_{VIM} (n = 4), bla_{NDM} (n = 1), and bla_{GIM} (n = 1) (Table 3). Multiple species of Enterobacteriaceae were involved in 7 studies, suggesting interspecies/intergenus resistance gene transfer [7, 10, 13, 14, 24, 26, 32], specifically demonstrated in vitro for bla_{IMP} and bla_{KPC} [7, 9, 32].

Microbiological and Typing Methods Deployed

Microbiological methods for culture and identification were clearly described for 11 studies [11, 19, 20, 22, 24–26, 29, 32, 33, 37], with no methods given in 7 [12–15, 17, 28, 35]. Methods differed in the media and biochemical tests used. Samples from patients in 2 studies [25, 34] were incubated in an enrichment broth; however, only 1 of these studies supplemented this with a carbapenem disc [34], following Centers for Disease Control and Prevention recommendations [39]. Antimicrobial susceptibility testing methods were reported in 26 studies and included disc diffusion, microbroth dilution, Etest and PCR. Seven of 32 studies did not report susceptibilities [7, 10–14, 24]. CROs were susceptible only to polymixin B/colistin in 8 of 16 studies that reported testing for colistin susceptibility [18, 21, 23, 27, 28, 30, 36, 37]. In 4 studies that did not test for colistin susceptibility, CROs remained susceptible only to amikacin [15, 16, 26, 35]. Variable susceptibility to fluoroquinolones, tigecycline, fosfomycin, other aminoglycosides, and β-lactams was found in the remaining 13 studies. One study reported that the outbreak organism (KPC–*Klebsiella pneumoniae*) became resistant to all antibiotics after initially being susceptible to gentamicin, tigecycline, and colistin [22]. Molecular typing was performed in all but 2 studies [8, 10], mostly using pulsed-field gel electrophoresis (Table 4).

CRO Transmission and IC Interventions

The organism under investigation was detected in both patients and the environment in all but 1 study where only the environment was assessed [10]. All studies found evidence of cross-transmission between patients and the environment based on epidemiological links and/or identical antimicrobial susceptibility phenotypes/molecular typing (Table 4).

Nine studies reported IC breaches that probably contributed to outbreaks. These included poor sink design [18, 20, 21, 26, 30], use of sinks for contaminated clinical waste disposal [20, 26, 37], storage of clean patient materials around sinks/sluices [21, 29], reuse of nonsterile surgical drapes and open drainage in the cystoscopy room [35], use of a single brush to clean sinks without between-site disinfection [26], blocked sewage pipes and waste pipe leaks [21], and failure to clean shower drains [21]. Nontouch sensor taps were a reservoir in 1 study [16].

Interventions to eliminate CROs were reported in 27 studies. Twenty-five studies included water environment decolonization interventions, including chemical disinfection (alcohol, chlorination, aldehydes, biguanides, sodium hypochlorite [bleach], acetic acid, hydrogen peroxide, silver nitrate, hot water, and pressurized steam), sterile water for high-risk patient care, assignment of sinks to hand hygiene only, and replacement of contaminated equipment, faucets, sinks or drainage systems (Figure 3). Two studies reported cleaning or disinfecting the water environment, but without details [17, 23]. Two studies described agents used to clean rooms but did not provide

Table 4. Bacterial Strain/Mobile Genetic Element Typing Methods[a]

Typing Method	Studies, No. (N = 32)	Reference(s)
PFGE	20	Breathnach et al [21], Snitkin et al [22], Tofteland et al [32], Seara et al [34], Wendel et al [29], Wong et al [19], Podnos et al [23], Yomoda et al [9], Stjarne Aspelund et al [12], Kotsanas et al [26], Kouda et al [38], Peña et al [35], Majumdar et al [17], Pitten et al [36], Wang et al [27], Ambrogi et al [18], Landelle et al [37], Vergara-López et al [33], Kaiser et al [13], Alter et al [15]
Resistance gene PCR	8	Knoester et al [25], Seara et al [34], Wendel et al [29], Betteridge et al [7] , Kotsanas et al [26], Kouda et al [38], Leung et al [24], Odom et al [11]
MLST	5	Tofteland et al [32], Seara et al [34], Hong et al [30], Wendel et al [29], Leitner et al [20]
Rep-PCR	4	Snitkin et al [22], Leitner et al [20], Betteridge et al [7], Stjarne Aspelund et al [12]
Plasmid/MGE profiling	3	Tofteland et al [32], Betteridge et al [7] , Yomoda et al [9]
RAPD	2	Wong et al [19], Podnos et al [23]
AFLP	2	Knoester et al [25], Bukholm et al [31]
VNTR	2	Durojaiye et al [16], Breathnach et al [21]
REA	1	La Forgia et al [28]
WGS	2	Ito et al [14], Snitkin et al [22]
Antimicrobial susceptibility profile only	1	Biswal et al [7]

Abbreviations: AFLP, amplified fragment length polymorphism; MGE, mobile genetic element; MLST, multilocus sequence typing; PCR, polymerase chain reaction; PFGE, pulsed-field gel electrophoresis; RAPD, random amplification of polymorphic DNA; REA, restriction enzyme analysis; Rep-PCR, repetitive element sequence-based PCR; VNTR, variable-number tandem repeat; WGS, whole-genome sequencing.

[a]Some studies used multiple methods, so categories are not mutually exclusive. One study did not perform any typing (Dewi et al [10]).

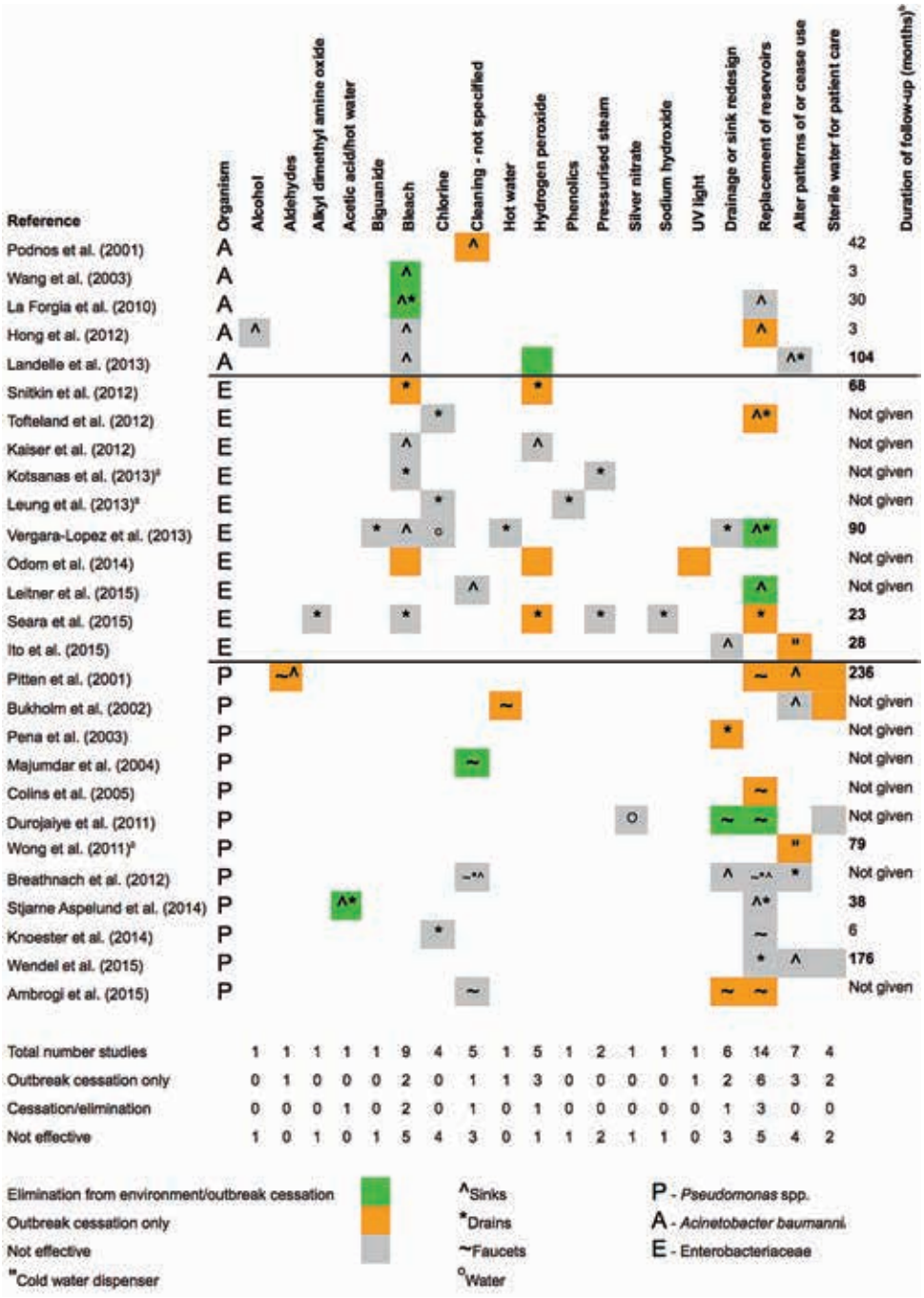

Figure 3. Infection control interventions and outcomes. Five studies did not report any interventions (Betteridge et al [7], Biswal et al [7], Kouda et al [38], Yomoda et al [9], Dewi et al [10]), and 5 reported only plumbing interventions (Wong et al [19], Wendel et al [29], Alter et al [15], Peña et al [35], and Ito et al [14]). For duration of follow-up (*right axis*), months shown in bold denote studies that responded to our communication.

specific information on disinfecting the water environment [11, 22].

Twenty-two studies reported enhancing general IC measures, including contact isolation, strict hand hygiene, active surveillance, reinforcement of cleaning and disinfection procedures, audits, and education sessions. Of the 25 studies that reported specific environmental interventions, 22 reported success in terminating the clinical outbreak, whereas just more than one-third of these managed to eliminate the organism from environmental reservoirs (Figure 3) [12, 16, 17, 20, 27, 28, 33, 37]. Interventions successful at disinfecting water reservoirs included cleaning of sinks and taps (details not given) [17], daily cleaning of sink surfaces with 0.1% sodium hypochlorite [27], weekly cleaning of sinks and plumbing with acetic acid/hot water [12], transferring all patients to a dedicated isolation unit and hydrogen peroxide vapor disinfection [37], replacing

nontouch sensor taps with conventional taps [16], and replacing sinks or drainage systems [20, 33]. Kouda et al [38] reported success without giving details of interventions.

Only 7 of 22 studies reporting success stated the duration of follow-up after the intervention [23, 27–30, 33, 34], which ranged from 2 months to 3.5 years. The authors of 10 studies responded to our communication regarding further follow-up. Seven of these reported no further cases of the outbreak organism [14, 19, 22, 33, 36, 37, 38]. Kouda et al [38] attributed their success to ceasing use of a urinal and changes to mopping practices (details not given). Snitkin et al [22] occasionally isolated CROs from drains, but not the original outbreak organism. Wendel et al [29] reported ongoing sporadic patient cases and environmental isolation despite enhanced IC measures and banning storage of patient material around sinks, however further strain typing has not been done. Seara et al [34] reported 7 additional cases in 2015, but none in 2016. They found hydrogen peroxide vapor to be the most effective disinfectant. Stjarne Aspelund et al [12] reported re-emergence of the outbreak organism after sink replacement, but no further cases or environmental isolation since July 2015, a change thought attributable to weekly flushing of sink drains and waste pipes with acetic acid/hot water.

DISCUSSION

Hospital Water Environment as a Reservoir of CROs

Drains/traps, sinks and faucets were the most common reservoirs of CROs identified. Others included portable hair washing basins, water samples, drink dispensers, toilet bowls/brushes, and shower equipment (Table 2). Initial seeding of these reservoirs was potentially due to contamination from affected patients [20, 22, 25, 32, 33, 36, 37]. Large, complex premise plumbing systems could have areas of stagnation and corrosion, variable nutrient and microbiology loads, and water temperatures ideal for promoting bacterial colonization and biofilm formation [3, 4]. Once colonized, there may be further propagation via the wastewater drainage system to distal sink drains connected to the initial reservoir, and via direct or indirect water contact to other patients [2].

P. aeruginosa was the most frequent organism (41% of studies), and distributed across all water reservoirs. *A. baumannii* was found predominantly in sink basins, and Enterobacteriaceae most commonly in drains. These findings may reflect biological differences in which *Pseudomonas* spp. and *Acinetobacter* spp. are environmental colonizers surviving in low-nutrient conditions, whereas Enterobacteriaceae are predominantly of human origin and their concentration in drains may represent a different ecosystem and inoculation directly from patient waste. However, all these organisms are capable of colonizing water system biofilms [3]. Knowing the predominant site for each organism may help guide surveillance strategies, outbreak investigations, and IC interventions.

Because they can be horizontally transferred on mobile genetic elements, carbapenemase genes represent the most concerning mechanism of carbapenem resistance and may be readily transmitted in environmental reservoirs. Tofteland et al [32] found evidence of possible environmental bla_{KPC}-plasmid transfer between *K. pneumoniae* strains, and Betteridge et al [7] concluded there was likely environmental intergenera plasmid exchange between Enterobacteriaceae. Resistance genes and associated mobile genetic elements should therefore be characterized in CRO outbreak investigations. Despite this, only 56% of studies assessed carbapenemase production. The most common enzymes identified were bla_{IMP}, bla_{KPC}, and bla_{VIM}, consistent with previous prevalence reports [1]. Phenotypic surveillance may facilitate the detection of novel carbapenemases.

CRO Transmission Between the Hospital Water Environment and Patients

There was evidence of CRO transmission between the environment and patients based on phenotypic [8] or genotypic methods in all studies assessing this, but most studies used relatively low-resolution methods. Fourteen studies used >1 genetic typing method (Table 4), potentially allowing for greater discrimination. Despite this, transmission routes were difficult to characterize, possibly due to both limited sampling and typing resolution. Whole-genome sequencing (WGS) is a highly discriminatory typing tool increasingly used in outbreak/transmission investigations. Two studies used WGS, with Snitkin et al [22] highlighting its advantages, including confirmation of a monoclonal outbreak, identification of unexpected modes of transmission, and tracking several potential resistance mutations in newly colistin-resistant isolates.

Previous studies have found that HCWs may facilitate nosocomial transmission of multidrug-resistant organisms [3]. Notably, there was no evidence of HCW colonization in the studies reviewed. However, only 19% assessed HCWs, perhaps underestimating the role of HCWs in CRO transmission. Other confounders could include inappropriate timing of sampling and observer effects if staff were aware of surveillance during sampling. Despite the absence of HCW colonization, 10 studies concluded that HCWs were probably implicated in CRO transmission [17, 18, 20, 22, 23, 25, 27, 32, 36, 37]. Colonization of a sink in a medication room attended only by HCWs was cited as evidence for this in 1 study [20]. Most studies also reported a significant reduction in transmission with enhancement of general IC measures, including reinforcement of hand hygiene and contact precautions. However, the relative contribution of HCWs to CRO transmission remains undefined.

Within the hospital there are numerous opportunities for patient exposure to water and drainage reservoirs [4]. Transmission may result from direct or indirect water contact,

or from droplets created during water activities, highlighting the importance of water delivery and wastewater design to minimize these risks. Seven studies recognized that poor design or use of sinks, drains, and sluice areas may have contributed to institutional outbreaks [18, 20, 21, 26, 29, 30, 37]. Guidelines for design of hand-wash basins generally include a large basin to contain splashes, taps that are not aligned directly over drains to minimize aerosols, no plugs or overflows, and ensuring that basins are not used for disposal of patient-related waste [40]. This guidance varies by country and application of the recommendations probably varies between institutions.

Effective IC Strategies

IC strategies used mostly included bundled approaches involving enhanced general IC measures, disinfection, and replacing reservoirs, making it difficult to ascertain the relative contribution of individual approaches. Enhancing general IC measures led to a reduction in clinical cases in most studies but often did not completely terminate outbreaks.

Chemical disinfection was most useful for environmental colonization with *A. baumannii* and *P. aeruginosa*. Faucet contamination with *P. aeruginosa* was successfully treated with aldehydes [36] or hot water [31], and Enterobacteriaceae with bleach, hydrogen peroxide vapor or UV light [11]. Eradication of sink colonization with *A. baumannii* was possible with bleach [27] or hydrogen peroxide vapor [37], however chemical disinfection was not effective for Enterobacteriaceae. In drain colonization, some success with eradicating Enterobacteriaceae and *A. baumannii* was reported using bleach [11, 22, 28] or hydrogen peroxide vapor [11, 22, 34, 37]. One study reported ongoing suppression of *P. aeruginosa* with weekly disinfection of sinks and drainage systems with acetic acid/hot water [12]. Use of hydrogen peroxide vapor was most promising, but this method is expensive and was ineffective in liquid and foam form [13, 34]. Bleach, hot water, UV light, and aldehyde-based disinfectants were effective in some studies, but other studies reported failures with these agents. Other agents were also used without success (Figure 3). Notably, the concentrations and deployment of agents varied widely; standardizing approaches would allow for more comparable outcome assessment.

Overall, the most successful intervention was replacing reservoirs (Figure 3). Replacing taps contained 67% of outbreaks associated with *P. aeruginosa* affecting faucets [15, 16, 18, 36]. Replacement of drains/drainage systems and sinks was always successful for Enterobacteriaceae colonization [20, 32–34] but failed with *P. aeruginosa* [12, 21, 29]. Other effective strategies included drainage or sink redesign, sterile water for care of high-risk patients, and prohibiting the storage of clean patient material around a sink. These findings may also be relevant for water-environment associated outbreaks with organisms that harbor other resistance mechanisms, such as extended-spectrum- β-lactamases. A list of current recommendations from international and national organizations on the prevention and control of CROs can be found in Supplementary Table 2; no organization makes recommendations regarding environmental sampling or chemical disinfectant.

Review and Study Limitations

General limitations of our study include potential publication bias and the language and literature source restrictions used in this review. Healthcare water environments are probably often neglected in outbreak assessments, which may result in an underestimation of the problem.

The heterogeneity in study methods also limits the generalizability of conclusions. Measuring the clinical impact of outbreaks was difficult; 23 studies did not give prevalence data, and 13 did not assess mortality rates. Screening of patients and the environment varied widely with regard to the methods used, frequency, and site. Rectal swab/fecal samples are recommended for patient CRO colonization screening [5], but 10 studies only sampled other body sites, and 9 did not screen patients at all. Consequently patient colonization may have been underestimated in up to 60% of studies.

Differences in environmental sampling, such as collecting water samples before or after tap flushing and use of varying water volumes, may affect sampling sensitivity. Microbiological methods differed between studies, and although the use of selective culture media may have improved detection, organisms with near-breakpoint minimum inhibitory concentrations could have been missed, underestimating the true prevalence and extent of environmental contamination. Molecular tests may increase sensitivity [29].

CONCLUSIONS

Water environment-associated CRO outbreaks have been reported increasingly in the last 5 years. Critically ill and immunocompromised patients are particularly at risk. Drains/traps, sinks and faucets were most frequently colonized, and *P. aeruginosa* was the predominant organism. Standardizing patient and environmental screening, and microbiological methods, when investigating CRO outbreaks may allow earlier detection of reservoirs. Carbapenemases should be characterized, and strains typed to confirm relatedness. WGS is a promising tool for determining transmission routes, reservoirs, and resistance mechanisms.

The incorrect design and use of hand-wash basins and other water areas may propagate outbreaks. Various IC interventions have been used with mixed results for each organism and reservoir. A combination of interventions is probably required to terminate outbreaks and eradicate CROs from the environment. Useful approaches include reinforcing general IC measures,

combined with chemical disinfection using hydrogen peroxide vapor. Further studies assessing the effectiveness of different chemical disinfection strategies are needed. Replacement and improved management of colonized water reservoirs is also probably an important component of control.

Supplementary Data

Supplementary materials are available at *Clinical Infectious Diseases* online. Consisting of data provided by the authors to benefit the reader, the posted materials are not copyedited and are the sole responsibility of the authors, so questions or comments should be addressed to the corresponding author.

Notes

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Review

A systematic review of nosocomial waterborne infections in neonates and mothers

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ABSTRACT

Background: Water is an important, overlooked, and controllable source of nosocomial infection. Hospitalized neonates and their mothers are particularly vulnerable to nosocomial waterborne infections. Our objectives through this systematic review were to: investigate water sources, reservoirs, and transmission routes that lead to nosocomial waterborne infections in neonates and their mothers; establish patient risk factors; compile measures for controlling outbreaks and recommended strategies for prevention; and identify information gaps to improve guidelines for reporting future outbreaks.

Methods: We searched PubMed, Web of Science, Embase, and clinicaltrials.gov. Peer-reviewed studies reporting contaminated water as a route of transmission to neonates and/or their mothers were included.

Results: Twenty-five studies were included. The most common contaminated water sources in healthcare facilities associated with infection transmission were tap water, sinks, and faucets. Low birthweights, preterm or premature birth, and underlying disease increased neonatal risk of infection. Effective control measures commonly included replacing or cleaning faucets and increased or alternative methods for hand disinfection, and recommendations for prevention of future infections highlighted the need for additional surveillance.

Discussion/conclusion: The implementation of control measures and recommended prevention strategies by healthcare workers and managing authorities of healthcare facilities and improved reporting of future outbreaks may contribute to a reduction in the incidence of nosocomial waterborne infections in neonates and their mothers.

1. Introduction

Nosocomial infections are a persistent challenge worldwide. In the United States, they affect up to 10% of all hospitalized patients (Anaissie et al., 2002). Nosocomial infections contribute to morbidity and mortality, and increase financial burdens and length of stay for patients in low-, middle-, and high-income countries (Anaissie et al., 2002; Ducel et al., 2002; Hassan et al., 2010). Water systems are significant and controllable sources of nosocomial infections that are often inadequately managed in healthcare facilities (HCFs) (Anaissie et al., 2002; Cunliffe et al., 2011; Exner et al., 2005). In large, urban HCFs such as hospitals, patients may be exposed to poorly designed or managed systems, leading to increased risks of disease outbreaks (Cunliffe et al., 2011). In smaller, rural facilities in low- and middle-income countries (LMICs), there may be limited access and availability of water or use of unsafe water sources and unsafe stored water (Bartram et al., 2015; Shields et al., 2015; World Health Organization and UNICEF, 2015).

Inadequate management of HCF water systems can lead to nosocomial infections in more vulnerable hospitalized populations, including those that are immune-compromised, are old, or have underlying diseases (Ducel et al., 2002). Neonates and their mothers are particularly vulnerable. Surveillance studies show 15–20% infection rates in neonatal intensive care units (NICU). Neonates with risk factors such as low birthweights are especially predisposed to infection due to poor immune defenses and intrusive life support systems (Baltimore, 1998). A point prevalence survey of 29 NICUs in the United States showed an infection rate of 11.4%, while individual NICU nosocomial infection rates ranged from 6% to 25%. Multicenter studies in Europe ranged from 8% to 10% (Sohn et al., 2001).

Postpartum sepsis is the leading cause of direct maternal death in the United Kingdom, and a growing source of morbidity and mortality

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in the United States (Bauer et al., 2013). Nulliparous women, women with multiple births, and women with chronic conditions are at a higher risk of developing infections after pregnancy (Knowles et al., 2015), though the large majority of the 6.0% observed postpartum infection rate manifest after hospital discharge (Yokoe et al., 2001). In 2013, estimates suggest 430,000 neonatal deaths were caused by sepsis or other infection (Oza et al., 2015).

Exposure to nosocomial pathogens can lead to a variety of adverse health outcomes in neonates and their mothers. Infections can occur in the bloodstream, lower respiratory tract, and urinary tract, and can increase mortality (Anaissie et al., 2002; Ducel et al., 2002; Sohn et al., 2001).

Prior systematic reviews have described studies of waterborne nosocomial infections, but there is a need for an up-to-date, comprehensive review that highlights the vulnerability of this population in particular. Experts and supporting actors call for improvements in water, sanitation, and hygiene (WaSH) in HCFs to improve maternal and neonatal health and reduce morbidity and mortality rates (Velleman et al., 2014). However, there is insufficient characterization of the impact of waterborne nosocomial infections on maternal and neonatal health.

We systematically reviewed the scientific literature to better understand the causes of and prevention strategies for waterborne nosocomial infections on neonatal and maternal health. The primary objectives were:

- What are the most common water sources, reservoirs, and transmission routes that lead to nosocomial infections in neonates and their mothers?
- What are the patient risk factors in nosocomial waterborne infections in neonates and their mothers?
- What measures and strategies are effective in controlling ongoing outbreaks or recommended for preventing future outbreaks of nosocomial waterborne infections in neonates and their mothers?
- What information gaps exist in the literature on nosocomial waterborne infections in neonates and their mothers?

In addition to addressing these topics, we propose a set of reporting guidelines for nosocomial waterborne infections to improve consistency and better inform practice and research.

2. Methods

A systematic review was conducted of studies reporting waterborne infections of neonates and their mothers in HCFs.

2.1. Eligibility

Studies were included based on the following criteria: reported symptomatic clinical disease; reported on HCFs where deliveries could occur; and contained primary data. Editorials, reviews, and studies exclusively reporting colonization of patients without infection were excluded. Studies exclusively reporting *Legionella pneumophila* species as the infectious microbe were also excluded due to recent literature review pertaining to *Legionella* (see Leiblein et al., 2016). There was no limit on the date of publication.

2.2. Definitions

Neonates are defined as children under 28 days old (World Health Organization, 2014). When age was not specified, patients referred to as “newborn” or “neonate” or treated in the neonatal or nursery unit of a hospital were characterized as neonates. Water sources, reservoirs and transmission routes included tap water, peripherals (e.g. faucets, sinks, shower heads), water baths, water used to prepare aqueous solutions, and water used in humidifiers, ventilators, and incubators. HCFs included hospitals, outpatient clinics, and nursery facilities.

2.3. Search strategy

We used the initial stages of a search strategy employed in a previous systematic review of nosocomial waterborne infections in patients of all ages (Li et al., 2016).

Peer-reviewed studies were identified through PubMed, Web of Science, Embase, and clinicaltrials.gov. The following search statements were used: (waterborne OR water) AND (health facilities OR “health care facilities, manpower, and services” OR hospitals OR hospital OR “Hospital Design and Construction” OR hospital-acquired OR nosocomial) AND (disease outbreaks OR infection control OR “Cross Infection” OR “Disease Reservoirs”).

Three independent reviewers using Cochrane’s Covidence online software screened the titles and abstracts of studies obtained from searches. Studies independently approved by two of three reviewers were included in the next stage of screening. Conflicts between the three reviewers were resolved by one of these reviewers. Full texts of selected studies were screened in two stages: initially for the reasons for exclusion as described above, and subsequently to limit the review to neonates and/or mothers as an affected population. The references lists of included studies were searched for additional eligible studies. The search was updated on March 17, 2016.

2.4. Data extraction

The following data were extracted from included studies: setting (HCF type and country information), microbial testing (including temporality and antimicrobial susceptibility); water sources, reservoirs and transmission routes tested; non-water environmental reservoirs tested; conclusion about cause of infection; length of study; number of neonates and/or mothers affected; risk factors for infected patients; other populations affected (including staff and infants older than 28 days); outcomes for neonates, mothers, and other populations; implemented control measures; recommended prevention strategies.

2.5. Synthesis of results

Extracted data were tabulated to compare and summarize findings. Due to the heterogeneity of the results, meta-analysis was not performed.

3. Results

3.1. Search results and study characteristics

The screening process and results are summarized in Fig. 1. This resulted in 16 studies satisfying the inclusion criteria for nosocomial infections of neonates. No studies were found that reported exclusively on infection of mothers. A review of the references of included articles identified nine previously unidentified articles that were included after full text review. One additional study was excluded on the basis it reported on the same outbreak as another included study (Cabrera and Davis, 1961; George et al., 1961). Metadata for the 25 included studies are listed in Table 1 and a summary of the extracted data in Table 2. Based on the synthesized findings and the identified information gaps, a list of criteria for the reporting of waterborne nosocomial infections is proposed in Table 3.

The included articles were published between 1951 and 2016, with study lengths ranging from two weeks to six years. Most studies were case series (n = 17, 68%), followed by case-control studies (n = 3, 12%). All 25 studies took place in inpatient hospital settings, specifically in the neonatal unit, nursery, or neonatal intensive care unit. The hospitals had different managing authorities, most commonly university hospitals (n = 14, 56%). The studies were from 17 countries;

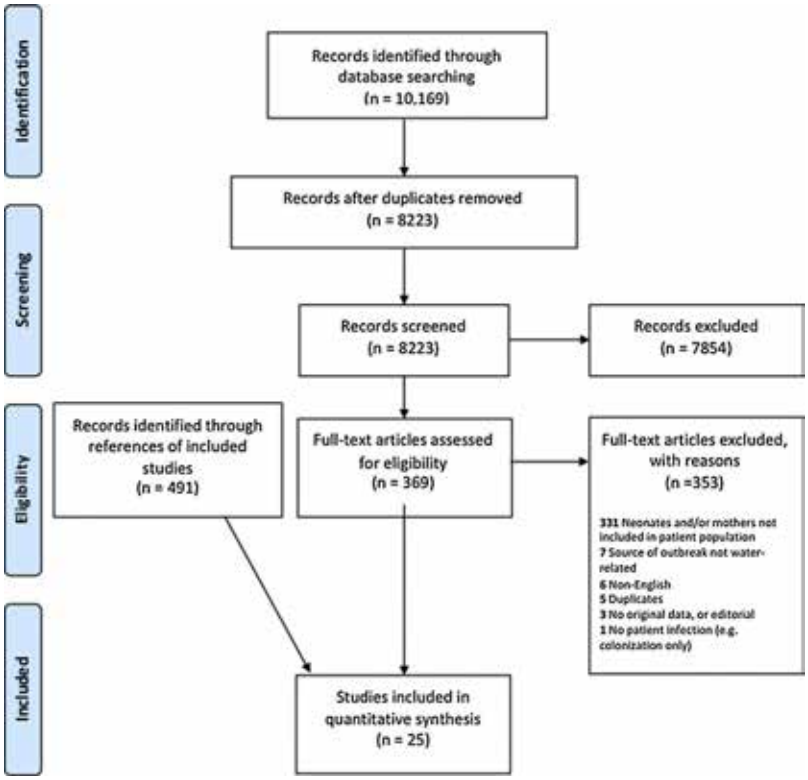

Fig. 1. Schematic of search strategy.

most studies took place in high income countries (n = 13, 52%), with fewer from upper middle income (n = 6, 24%) and lower middle income (n = 3, 12%), and one from a low income country (n = 1, 4%) according to the World Bank Income Classification (World Bank, 2016).

3.2. Patient populations

The number of neonates found to be infected or colonized by one or more waterborne pathogens ranged from one to 516.

Thirteen studies (52%) specified the age or age range of the infants affected, but all characterized patient(s) as "neonate(s)" and/or "newborn(s)" and/or took place in the neonatal or nursery unit of a hospital and thus satisfied the inclusion criteria. The majority of studies reported testing all other neonates in the unit after the initial infection was identified, and seven studies (28%) tested hospital staff or caregivers and/or postnatal mothers for colonization. Of the studies that tested hospital personnel, two found infections and/or colonization of one or more staff by the same species as the causal agent (Mendis et al., 1976; Randrianirina et al., 2009), and five noted a lack thereof (Abrahamsen et al., 1989; Antony and Prasad, 2011; Cabrera and Davis, 1961;

Table 1
Studies included in synthesis.

Study	Country	Income Classification	Managing Authority	Setting	Study design
Abrahamsen et al. (1989)	Norway	High income	Public university hospital	Urban	Case series
Antony and Prasad (2011)	India	Lower middle income	Private university hospital	Rural	Case series
Brown and Baublis (1977)	USA	High income	Public university hospital	Urban	Surveillance study
Büyükyavuz et al. (2006)	Turkey	Upper middle income	Public university hospital	Suburban	Surveillance study
Cabrera and Davis (1961)	USA	High income	Unknown	Urban	Case series
Crivaro et al. (2009)	Italy	High income	Public university hospital	Urban	Intervention study
Epstein et al. (1951)	USA	High income	Private hospital	Urban	Case series
Grundmann et al. (1993)	Germany	High income	Public university hospital	Urban	Case series
King and Murphy (1964)	USA	High income	Not-for-profit hospital	Urban	Case series
Lee (2008)	Malaysia	Upper middle income	Private hospital	Urban	Case-control
Mendis et al. (1976)	Sri Lanka	Lower middle income	Maternity hospital	Urban	Case series
Molina-Cabrillana et al. (2013)	Spain	High income	Public university hospital	Urban	Case series
Mosayebi et al. (2011)	Iran	Upper middle income	Maternity and gynecology hospital	Urban	Case series
Mutlu et al. (2011)	Turkey	Upper middle income	Public university hospital	Urban	Case-control
Muyldermans et al. (1998)	Belgium	High income	Public-private university hospital	Urban	Case-control
Naze et al. (2010)	France	High income	Unknown	Urban	Case series
Plotkin and McKitrick (1966)	USA	High income	Unknown	Rural	Cohort study
Pegues et al. (1994)	Guatemala	Lower middle income	Public teaching hospital	Urban	Case series
Randrianirina et al. (2009)	Madagascar	Low income	Public pediatric hospital, public military hospital	Urban	Case series
Thong et al. (1981)	Malaysia	Upper middle income	Private university hospital	Urban	Case series
Verweij et al. (1998)	Netherlands	High income	Public university hospital	Urban	Case series
Walker et al. (2014)	Northern Ireland	High income	Varies	Mostly rural	Cross-sectional
Wilson et al. (1961)	USA	High income	Public university hospital	Urban	Case series
Yapicioglu et al. (2012)	Turkey	Upper middle income	Public university hospital	Urban	Case series
Zheng et al. (2016)	China	Upper middle income	Public university hospital	Urban	Case series

Table 2
Condensed data extraction table.

Study	Infectious agent	Water source	Number neonates affected	Outcomes for neonates	Additional populations investigated
Abrahamsen et al. (1989)	*Flavobacterium meningosepticum*	Sinks, used rubber stoppers for the milk bottles and cleaned teats that were stored in water	8	Septicaemia (2), septicaemia and meningitis (2), colonization (4)	Septicaemia in one infant (> 28 days); colonization of two infants (> 28 days); all staff were negative
Antony and Prasad (2011)	*Enterobacter cloacae*	Water used to bathe neonates	18	Death (8), septicaemia (10)	All staff and mothers were negative
Brown and Baublis (1977)	*Pseudomonas aeruginosa*	Sink drains, nasopharyngeal catheter rinse bottles	81	Death (3, +3 unrelated), sepsis (22), pneumonia (34), bronchitis/tracheitis (13), unspecified infections (12)	None
Büyükyavuz et al. (2006)	*Klebsiella pneumoniae; coagulase negative Staphylococcus*	Formula heater water	20	Septicaemia (20)	None
Cabrera and Davis (1961)	*Flavobacterium meningosepticum*	Leaking sink trap	44	Death (9, +1 unrelated), hydrocephalus (3), clinical symptoms (1), nasal colonization (30)	All staff were negative
Crivaro et al. (2009)	*Pseudomonas aeruginosa*	Sinks	135	Death (4), sepsis (1), pneumonia (5), urinary tract infection (1), colonization (124)	None
Epstein et al. (1951)	*Salmonella oranienburg*	Waterbath for reheating milk bottles	18	Death (3), clinical symptoms	All staff and mothers were negative
Grundmann et al. (1993)	*Pseudomonas aeruginosa*	Faucets, sink traps	6	Meningitis (1), septicemia (1), bronchopneumonitis (1), unspecified infections (3)	None
King and Murphy (1964)	*Pseudomonas aeruginosa, Escherichia coli, Proteus*species, *Aerobacter cloacae*	Water baths used for formula bottles	Unknown	Diarrhea	None
Lee (2008)	*Burkholderia cepacia*	Ventilator water traps, humidifier water trap	25	Death (1), Septicaemia (24)	Death of infant (> 28 days)
Mendis et al. (1976)	*Salmonella bareilly*	Sink, taps	516	Death (12), mild pyrexia (75), colonization with or without diarrhea (429)	Colonization of 91 staff
Molina-Cabrillana et al. (2013)	*Pseudomonas aeruginosa*	Faucets	6	Pneumonia (3), conjunctivitis (3)	Pneumonia in three infants (> 28 days), conjunctivitis in three infants (> 28 days)
Mosayebi et al. (2011)	Flavobacterium sepsis	Distilled water and stills	45	Death (8), respiratory distress (27), lethargy (7), poor feeding (7), cyanosis (2), hypoglycaemia (1), tachypnoea (1)	None
Mutlu et al. (2011)	*Spingomonas paucimobilis*	Distilled water used for humidifying incubators and mechanical ventilators	13	Death (1), sepsis (12)	None
Muyldermans et al. (1998)	*Pseudomonas aeruginosa*	Water bath used to thaw fresh frozen plasma	5	Death (3 unclear if related), colonization (1)	None
Naze et al. (2010)	*Pseudomonas aeruginosa*	Commercial bottled mineral water used to prepare milk, tap water samples, faucets, sink, sink drains	42	Death (1), septicaemia (1), colonization (40)	None
Plotkin and McKitrick (1966)	*Flavobacterium meningosepticum*	Saline solution used to wash infants' eyes at birth	2	Death (1), permanent brain damage (1)	None
Pegues et al. (1994)	*Serratia marcescens*	Tap water	26	Death (23), fever/sepsis/meningitis (26)	None
Randrianirina et al. (2009)	*Klebsiella pneumonia*	Tap water used to rinse aspiration tubes	9	Death (3), fever and respiratory distress (6)	Colonization of staff member (1), fever and respiratory distress in infant (> 28 days) (1)
Thong et al. (1981)	*Flavobacterium meningosepticum*	Hand basins, babies' bath basins, stock bottles of aqueous chlorhexidine	11	Death (2), hydrocephalus (2), fever and clinical symptoms (3), colonization of throat (4)	Throat colonization of two postnatal mothers (2), all staff negative
Verweij et al. (1998)	*Stenotrophomonas maltophilia*	Tap water from three outlets used for washing infants	5	Death (1), septicaemia (1), endotracheal colonization (3)	None
Walker et al. (2014)	*Pseudomonas aeruginosa*	Neonatal unit taps	2 neonatal units	Death (4)	None
Wilson et al. (1961)	*Pseudomonas aeruginosa*	Aerators in faucets	1	Death (1)	None
Yapicioglu et al. (2012)	*Pseudomonas aeruginosa*	Water and filters of electronic faucets in patient rooms and lab	11	Death (2), ventilator-associated pneumonia (3), blood stream infection (6)	Ventilator-associated pneumonia in infant (> 28 days) (1)
Zheng et al. (2016)	*Pseudomonas aeruginosa*	Incubator water	17	Death (1), pneumonia (16)	None

Table 3
Proposed criteria for reporting of waterborne nosocomial infections.

Keyword	Description
Setting	Further description of setting, including whether the healthcare facility was located in a rural or urban area and the country income level
HCF water system	Description of the HCF's water system (i.e. source, reliability, additional treatment processes used)
HCF water safety plan	Description of building-level water safety plan, if one exists
HCF routine water surveillance	Existing or proposed guidelines for routine surveillance of water quality in HCF, if they exist
Water testing	Description of all water sources, reservoirs, and transmission routes tested, with disaggregated results, and additional description of any excluded from testing
Non-water testing	Description of all non-water environmental reservoirs tested, with disaggregated results
Hand hygiene	Existing or proposed practices for hand disinfection among healthcare workers, and whether or not healthcare workers' hands were tested as potential transmission route
Pathways	Explanation of potential pathways between water source, reservoir, or transmission route and patients
Causal evidence	Evidence of causal relationship between acquired infection and water source, reservoir, or transmission route including a discussion of temporality (i.e. Bradford Hill criteria)

Epstein et al., 1951; Thong et al., 1981). One study found colonization of two mothers (Thong et al., 1981) and two found all tested mothers to be negative for the microbe of interest (Antony and Prasad, 2011; Epstein et al., 1951). Five studies (20%) described the infection and/or colonization of infants older than 28 days, with the oldest at 146 days (Epstein et al., 1951; Lee, 2008; Molina-Cabrillana et al., 2013; Randrianirina et al., 2009; Yapicioglu et al., 2012).

Fourteen studies (56%) identified risk factors for nosocomial waterborne infection in neonates. None of the studies mentioned risk factors for mothers or caretakers. Nine studies noted most or all affected neonates were either preterm (Antony and Prasad, 2011; Crivaro et al., 2009) or premature (Cabrera and Davis, 1961; Grundmann et al., 1993; Mendis et al., 1976; Mosayebi et al., 2011; Mutlu et al., 2011; Wilson et al., 1961; Yapicioglu et al., 2012). Seven studies noted that affected neonates were debilitated, had underlying disease, required the highest level of care, or had prolonged stays in the HCF (Antony and Prasad, 2011; Brown and Baublis, 1977; Grundmann et al., 1993; Randrianirina et al., 2009; Wilson et al., 1961; Yapicioglu et al., 2012; Zheng et al., 2016). Four reported low birthweights (Antony and Prasad, 2011; Crivaro et al., 2009; Mosayebi et al., 2011; Pegues et al., 1994). One study found neither birthweight nor gestational age was significantly different between the neonates infected and the controls (Muyldermans et al., 1998), and another found no significance in prematurity between those affected and unaffected (Abrahamsen et al., 1989). Two studies found neonates subject to frequent use of antimicrobials or exposure to invasive procedures were more at risk (Pegues et al., 1994; Verweij et al., 1998).

3.3. Causes of infections

The causal agents of clinical disease included the following 12 bacteria: *Pseudomonas aeruginosa* (n = 10, 43%), *Flavobacterium meningosepticum* (n = 4, 17%), unspecified *Flavobacterium* (n = 1, 4%) *Klebsiella pneumoniae* (n = 2, 9%), *Burkholderia cepacia* (n = 1, 4%), *Enterobacter cloacae* (n = 1, 4%), *Salmonella bareilly* (n = 1, 4%), *Salmonella oranienburg* (n = 1, 4%), *Serratia marcescens* (n = 1, 4%), *Spingomonas paucimobilis* (n = 1, 4%), coagulase negative *Staphylococcus* (n = 1, 4%), and *Stenotrophomas maltophilia* (n = 1, 4%). One study did not mention the cause of infection, but noted that *Pseudomonas aeruginosa, Escherichia coli, Proteus* species, and *Aerobacter cloacae* were found in contaminated water linked to a diarrheal outbreak (King and Murphy, 1964).

In 24 of the 25 cases, the infectious agent was isolated from tap water, an aqueous solution, water reservoir (water bath, ventilator, humidifier, or incubator), sink(s), and/or faucet(s). In each, one or more of these sources were concluded to be a primary transmission route and/or environmental reservoir. The remaining study was unable to speciate the organisms found in the tap water, but noted elevated total and fecal coliform in the tap water and confirmed malfunctioning of the well-water chlorination system (Pegues et al., 1994). Thirteen of these studies (52%) used genotypic or phenotypic methods to determine whether the strain isolated from the patients was identical to that in the water source (Antony and Prasad, 2011; Brown and Baublis, 1977; Crivaro et al., 2009; Grundmann et al., 1993; Mutlu et al., 2011; Muyldermans et al., 1998; Naze et al., 2010; Plotkin and McKitrick, 1966; Thong et al., 1981; Verweij et al., 1998; Walker et al., 2014; Yapicioglu et al., 2012; Zheng et al., 2016).

The most commonly colonized water sources, reservoirs, and transmission routes were tap water, sinks, and/or faucets, which were found to be contaminated in 15 studies (60%). Water baths were contaminated in three studies (12%). Additional sources of contamination included water used to bathe neonates, rinse bottles, formula heater water, humidifier and ventilator water, distilled water, bottled mineral water, a saline solution, aqueous chlorhexidine, and incubator water. The authors of six of the studies (24%) believed healthcare workers' handwashing with contaminated water was a contributing factor in the transmission of infection to the neonates (Antony and Prasad, 2011; Brown and Baublis, 1977; Cabrera and Davis, 1961; Crivaro et al., 2009; Verweij et al., 1998; Wilson et al., 1961).

Twenty-one studies (84%) described sampling non-water-related environmental reservoirs. The most commonly tested were incubators, air, healthcare workers' hands, disinfectants, soap, floors and walls, and various equipment and instruments. Nine studies (36%) isolated the implicated species from non-water reservoirs, including soap (Yapicioglu et al., 2012), healthcare workers' hands (Brown and Baublis, 1977; Crivaro et al., 2009; Pegues et al., 1994), bronchial suction tubing (Thong et al., 1981), a formula heater (Büyükyavuz et al., 2006), the handles of a hamper (Cabrera and Davis, 1961), sponges (Wilson et al., 1961), and nasogastric tubing (Randrianirina et al., 2009).

3.4. Outcomes measured

Twenty-three studies reported isolation of the infectious agent from one or more neonates in addition to reporting clinical symptoms of infection of one or more neonates. One of the remaining studies was an investigation into taps at multiple HCFs and only reported number of deaths at these HCFs (Walker et al., 2014). The other was a short article that provided few details about the affected neonates (King and Murphy, 1964). Twenty studies (80%) reported death of one or more neonate(s), though one study noted it was unclear whether the nosocomial waterborne infection was the cause of the deaths (Muyldermans et al., 1998).

3.5. Control measures and recommendations for prevention

Twenty-one studies (84%) discussed control measures implemented to stop the spread of infection. The most frequent measures were cleaning, replacing, and/or fixing faucets and/or sinks (Abrahamsen et al., 1989; Cabrera and Davis, 1961; Grundmann et al., 1993; Thong

et al., 1981; Wilson et al., 1961; Yapicioglu et al., 2012), isolating infected neonates (Abrahamsen et al., 1989; Antony and Prasad, 2011; Crivaro et al., 2009; Epstein et al., 1951; King and Murphy, 1964), improving hand disinfection compliance or implementing use of alternative hand disinfectants among hospital staff (Antony and Prasad, 2011; Brown and Baublis, 1977; Crivaro et al., 2009; Pegues et al., 1994; Verweij et al., 1998), sterilizing or disinfecting water before use by boiling or other methods, particularly in regards to washing neonates (Antony and Prasad, 2011; Molina-Cabrillana et al., 2013; Thong et al., 1981; Verweij et al., 1998), and replacing water baths with dry incubators (King and Murphy, 1964; Muyldermans et al., 1998).

Eighteen studies (72%) discussed or recommended long-term strategies for prevention of future infection. Common themes included increased surveillance and timely identification of infection (Antony and Prasad, 2011; Büyükyavuz et al., 2006; Crivaro et al., 2009; Epstein et al., 1951; Mendis et al., 1976; Molina-Cabrillana et al., 2013; Mosayebi et al., 2011; Muyldermans et al., 1998; Thong et al., 1981; Zheng et al., 2016) and addressing problems with faucets by replacing electronic faucets or cleaning or replacing aerators (Verweij et al., 1998; Walker et al., 2014; Wilson et al., 1961; Yapicioglu et al., 2012). None of the studies recommended any organizational or systemic facility changes as a strategy for prevention.

4. Discussion

This systematic review is the first to report in-depth on waterborne nosocomial infection in neonates and mothers. The causal agent of clinical disease was most commonly isolated from sinks and faucets, which were also points of intervention. No studies were found that reported exclusively on mothers or emphasized mothers as a primary affected population.

The studies included were heterogeneous in reporting results. Several lacked information, including the age of the infants or the number of exposed neonates, which could have been used to calculate attack rates or otherwise conduct a *meta*-analysis. This demonstrates a need for more standardized reporting of nosocomial infections in the future in order to more comprehensively synthesize the information required to inform policy, practice, and research. Based on data provided and omitted from studies included in this review, we propose a list of criteria to report waterborne infections in HCFs (Table 3). Standardized reporting will help with future *meta*-analytic studies.

4.1. Cause of infection

The infectious agents identified through this review were all bacterial agents as listed in Table 2. A previous review on waterborne nosocomial outbreaks included most of these bacteria species and emphasized the large disease burden of *P. aeruginosa* in particular (Anaissie et al., 2002). The United States Centers for Disease Control and Prevention (CDC) includes *P. aeruginosa*, *Burkholderia cepacia*, *Stenotrophomonas maltophlia*, *Serratia marcescens*, *Sphingomonas* spp., and *Enterobacter* spp. on its list of prevalent waterborne organisms in healthcare settings (Sehulster and Chinn, 2003).

The most frequently identified contaminated water sources, reservoirs, or transmission routes among the studies in this review were tap water, sinks, and faucets, which is consistent with previous reviews on nosocomial waterborne infection (Anaissie et al., 2002; Exner et al., 2005). Anaisse, et al. notes the buildup of biofilms in the distribution lines or tanks as a primary cause of this, resulting from water stagnation and/or poorly designed or aging systems (Anaissie et al., 2002). Healthcare workers' handwashing with this contaminated water was hypothesized as a transmission route in six studies in this review. Crivaro, et al. and Brown, et al. found healthcare workers' hands to be contaminated with the microbes of interest in their studies (Brown and Baublis, 1977; Crivaro et al., 2009). Brown, et al. also examined the spread of the microbe through airborne water droplets from contaminated tap water and found an affected radius of 1.8 m around sinks, suggesting microbes can readily reach healthcare workers' gowns (Brown and Baublis, 1977). Additionally, the outbreak described by Randrianirina, et al. spread between two hospitals with shared staff members who were thought to be responsible for the transmission of the microbe (Randrianirina et al., 2009). Bathing patients or washing medical equipment with contaminated water were transmission routes found in several of these studies and in previous literature (Anaissie et al., 2002). The majority of the studies included in this review tested environmental sources other than water sources, such as incubators, air, and soap. However, most of these sources were not colonized and most studies concluded they were not a contributing transmission route.

Four of the 25 studies explicitly stated they were unable to conclude whether the water source, reservoir, or transmission route caused the patient infections(s) or vice versa (Brown and Baublis, 1977; Crivaro et al., 2009; Grundmann et al., 1993; Walker et al., 2014). Nine of the studies established a causal relationship through observing that the spread of infection was stopped soon after an intervention that addressed the contaminated water source, reservoir, or transmission route (Cabrera and Davis, 1961; King and Murphy, 1964; Mendis et al., 1976; Molina-Cabrillana et al., 2013; Mosayebi et al., 2011; Muyldermans et al., 1998; Naze et al., 2010; Randrianirina et al., 2009; Yapicioglu et al., 2012). Almost half (n = 12, 48%) did not discuss temporality in the observed infections or outbreaks.

4.2. Patient risk factors

Low birthweight, preterm or premature birth, underlying disease, routine antimicrobial use, and exposure to invasive procedures were reported patient risk factors for nosocomial waterborne infection in neonates in several of the studies in this review. Sohn, et al. conducted a study on nosocomial infection in NICU patients, which focused on both waterborne and non-waterborne infection, and similarly found low birthweight as a significant patient risk factor. Infants with birthweights ≤1500 g were found to be 2.69 times more likely to acquire a nosocomial infection, and over fifty percent of the acquired infections in the NICU were in infants with birthweights ≤1000 g (Sohn et al., 2001). Baltimore, et al. also noted birthweight as the strongest patient risk factor in neonatal nosocomial infection, and cited poor immune defenses and life support systems such as ventilators and catheters as additional risk factors (Baltimore, 1998). The studies by Abrahamsen, et al. and Muyldermans, et al. were in contrast to the other studies included in this review and in contrast with the literature, as they concluded birthweight and/or gestational age were not significant in determining which neonates acquired infections (Abrahamsen et al., 1989; Muyldermans et al., 1998).

4.3. Antimicrobial resistance

The problem of antimicrobial resistance complicating therapy for neonates was a common theme among the studies in this review. Eleven of the 25 studies noted that one or more strains of the infectious microbe showed resistance to two or more classes of antimicrobial agents. Two studies noted the infectious microbe was susceptible to all antibiotics tested (Molina-Cabrillana et al., 2013; Muyldermans et al., 1998). This is similar to the findings by Anaisse, et al., which found 76% of the waterborne microbes that caused nosocomial outbreaks and were tested for susceptibility to antimicrobials were resistant to two or more classes (Anaissie et al., 2002). In a review on neonatal nosocomial infection, Baltimore, et al. states the high prevalence of antibiotic use in the NICU promotes antibiotic resistance in infectious agents (Baltimore, 1998). In the outbreak studied by Randrianirina, et al. in Madagascar − the only low-income country included in this review − the infectious agent was resistant to nine classes of antimicrobials and three neonates died because their mothers could not afford treatment (Randrianirina et al., 2009).

4.4. Control and prevention

Contaminated sinks and taps were the most commonly implicated transmission route, and several studies prioritized addressing these areas in their control measures. Removing colonized aerators, cleaning taps with disinfectant, and/or fixing leaking sinks were important steps in controlling several of the outbreaks (Cabrera and Davis, 1961; Grundmann et al., 1993; Wilson et al., 1961). Removing and replacing electronic faucets was vital in another outbreak, as electronic faucets have increased likelihood of being colonized due to the low water pressure and stagnant water in the column (Exner et al., 2005; Yapicioglu et al., 2012).

A prevention emphasis among the studies was education of and proactivity among healthcare providers. This encompasses handwashing behaviors and use of sterile water for bathing neonates. Baltimore, et al. states that handwashing is the "least expensive and most effective" way to prevent the spread of infection among patients (Baltimore, 1998). From a historical perspective, Ignaz Semmelweis – a Hungarian physician and one of the first pioneers of hand disinfection – demonstrated in 1847 that effective hand disinfection could decrease maternal mortality rates from 16% to 3% within several months (Pittet and Boyce, 2001; Semmelweis, 1861). Several outbreaks included in this review were controlled by encouraging the use of alcohol rubs or alternative handwashing agents for hand disinfection or by implementing educational programs for staff on the importance of handwashing (Antony and Prasad, 2011; Brown and Baublis, 1977; Crivaro et al., 2009; Verweij et al., 1998). Using sterile water rather than tap water for washing preterm and at-risk neonates was suggested in other studies (Thong et al., 1981; Verweij et al., 1998). Overall, there was a theme of the importance of active surveillance and monitoring of sinks and taps in neonatal units (Antony and Prasad, 2011; Büyükyavuz et al., 2006; Crivaro et al., 2009; Molina-Cabrillana et al., 2013; Thong et al., 1981; Verweij et al., 1998; Zheng et al., 2016). Furthermore, it was noted that timely identification and response to infections is vital for controlling them (Crivaro et al., 2009).

4.5. Information gaps and proposed guidelines for reporting

Several information and knowledge gaps were identified through this review. There were few studies identified from LMICs – despite evidence suggesting that the maternal and neonatal disease burden is greatest in these settings (Lawn et al., 2010). Water supply infrastructure problems are different in LMICs as compared to high-income countries (World Health Organization and UNICEF, 2015). Pegues, et al. discusses contributions to the outbreak in a hospital in Guatemala City, Guatemala included limited supply of and low quality antiseptics and lack of sinks in addition to the malfunctioning of the well-water chlorination system, all concerns that may be especially applicable in other LMICs (Pegues et al., 1994). Problems may be particularly acute in small facilities in rural areas where sources may not be in the building or may be unreliable, forcing staff to collect water from distant sources and store water in the facility, which may introduce additional contamination (Bain et al., 2014; Shields et al., 2015). Improvements to HCF monitoring and surveillance systems in LMICs may help document the extent of the problem and identify areas that have high levels of exposure to water contamination (Cronk et al., 2015). Upgrades to reliable, safe, piped water in these areas would be an optimal solution (Bartram et al., 2015); use of packaged water may be an appropriate short-term solution (Williams et al., 2015). These supplies would benefit from safe management and the implementation of building-level water safety plans to prevent contamination (Cunliffe et al., 2011).

ORION (Outbreak Reports and Intervention Studies of Nosocomial Infection) is a 22-item checklist intended to raise the standard of reporting nosocomial infection by emphasizing transparency and the use of appropriate statistics (Stone et al., 2007). Based on the information synthesized from studies in this review, we created a supplemental list with items especially relevant for waterborne nosocomial infection (Table 3). Much of this information is not consistently reported in available literature. For example, only one of the 25 studies described existing or proposed guidelines for routine surveillance of the water quality in the hospital. Improvements in reporting waterborne nosocomial infection would allow for a more comprehensive understanding of the burden of disease and inform practice and research into this problem.

4.6. Limitations

A limitation of this study was that the original search strategy did not include terms for neonatal and maternal health or specific locations in health care facilities, such as intensive care units. Limitations of the studies included in this review included the heterogeneity of the studies. Additionally, in studies, it was difficult to establish causation. Because all of the studies isolated the infectious agent from the water source, reservoir, or transmission route after the infection(s) manifested, it was not possible to draw definitive conclusions about temporality.

5. Conclusion

We documented transmission routes, environmental reservoirs, and patient risk factors common in waterborne nosocomial infection of neonates, confirming these infections are preventable and can be controlled. Information gaps in the included studies were used to propose additional criteria for guidelines on reporting nosocomial outbreaks. Additional studies are necessary to determine the global burden of disease and develop strategies for prevention of further waterborne nosocomial infection in this vulnerable population. Improving safe management of water supplies in maternity settings would reduce unnecessary morbidity and mortality among neonates and their mothers.

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Cluster of non-tuberculous mycobacteraemia associated with water supply in a haemato-oncology unit

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SUMMARY

Non-tuberculous mycobacteria (NTM) are ubiquitous environmental organisms but rarely cause infections. Clinical, microbiological and epidemiological investigations and subsequent management of a cluster of NTM bacteraemia on a haemato-oncology unit are reported. From October 2007 to July 2008, five patients being managed for haematological malignancies developed pyrexia and general malaise. *Mycobacterium mucogenicum* (four patients) and *Mycobacterium neoaurum* (one patient) were identified from their blood cultures. The environment, in particular the water system, was investigated to identify the source of the infection and multiple water samples were cultured according to established criteria. NTM were also isolated from the hospital water system. Central venous catheters (CVCs) were removed and the patients were successfully treated with antibiotics. Environmental measures and changes in CVC care were introduced to prevent further episodes of NTM bacteraemia in these patients. Despite these measures, NTM continued to be present in the water system, but new clinical cases were not identified. NTM are common environmental organisms and are recognized as being difficult to remove from water systems. CVCs were presumed to be the portal of entry in this cluster of NTM bacteraemia, and the implementation of changes to CVC care protocols was successful in preventing further infections in this immunocompromised patient group.

Introduction

Central venous catheters (CVCs) are essential for the delivery of chemotherapeutic agents, administration of blood products and total parenteral nutrition (TPN), and the management of infections in patients with haematological malignancies, especially those undergoing intensive therapy such as haematopoietic stem cell transplantation. The risk of CVC-associated bacteraemia is increased in this patient population as a result of a number of factors including prolonged neutropenia, allografting and the administration of TPN. Environmental organisms have been increasingly reported as a cause of bacteraemia in this patient group.

Overall, CVC-associated mycobacterial infections are uncommon but clusters of cases of bloodstream infections caused by non-tuberculous mycobacteria (NTM) secondary to water contamination are known to occur. Species such as *Mycobacterium mucogenicum*, *Mycobacterium phocaicum* and *Mycobacterium chelonae* have been reported.[1–5] NTM are environmental organisms, commonly found in domestic water supplies, and complete eradication from hospital water supplies is difficult. Misinterpretation of the initial microbiological findings may lead to delays in diagnosis.[4] Potential clinical complications of infection include bacteraemia, septic emboli, lung colonization and soft tissue and bone infections. The prompt identification and investigation of clusters of cases is of prime importance in prevention and control by appropriate corrective measures.

In this report, a cluster of five cases of CVC-associated NTM bacteraemia over a 10-month period in a haemato-oncology unit are described. The investigations undertaken to identify clinical

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cases and sources of infection along with the prevention and control measures are discussed.

Methods

Hospital setting

The Western General Hospital in Edinburgh is a tertiary care teaching hospital in central Scotland. The haemato-oncology unit has 24 inpatient beds; 10 of these are on the transplant unit (all single room accommodation with en-suite showers and toilets) where patients undergoing intensive therapy, including haematopoietic stem cell transplants (HSCTs), are treated within protective isolation. The other 14 inpatient beds are located in an adjacent ward, which has a mixture of single-, two-, and four-bedded rooms and communal showers. The day-patient unit is housed on the same site but in a separate building. The unit performs around 10 sibling allografts and 25 autografts per year.

Description of incident

The first patient (A), who was post-autologous peripheral blood stem cell transplant for relapsed follicular non-Hodgkin lymphoma (NHL), presented with general malaise and high temperature in October 2007. A Gram-positive bacillus was cultured from blood taken from the Hickman line but was initially misidentified as a coryneform bacterium. When a repeat culture was positive, further tests identified it as an atypical mycobacterium. Subsequently, four similar cases were identified between June and July 2008.

Epidemiology

Clinical data on the patients involved were obtained from the case notes and the laboratory information management system.

A case was defined as any patient on the unit with pyrexia and with NTM bacteraemia who had been admitted to the haematology transplant unit between October 2007 and October 2008.

Microbiological methods

Culture and identification

Blood cultures were taken from each lumen of the Hickman line of patients with fever and other evidence of infection and, where possible, samples for blood culture were also obtained from a peripheral vein (BacT/Alert® 3D, bioMérieux, Hazelwood, MO, USA). On removal of colonized Hickman lines the catheter tips were sent for microbiological investigation and were processed by semiquantitative culture.[6]

Positive blood culture bottles were subcultured on to non-selective media and the NTM isolates were identified by Ziehl Neelsen (ZN) stain and cultural characteristics, in accordance with accepted protocols.[7] The NTM were confirmed by the Scottish Mycobacteria Reference Laboratory (SMRL) with a commercial kit combining polymerase chain reaction and hybridization (GenoType Mycobacterium CM kit; Hain Lifescience GmbH, Nehren, Germany). Sequencing of the 65 kDa heat shock protein gene (*hsp* 65) followed by comparison of the sequence data from the online database (GenBank) was used to identify isolates not confirmed by this method. Determination of sensitivity to co-amoxiclav, carbapenems, clarithromycin, amikacin, ciprofloxacin, cotrimoxazole, vancomycin, tetracycline, tigecycline and linezolid was performed using E-tests (AB Biodisk, Solna, Sweden).

In response to the NTM cluster, surveillance blood cultures were performed to detect mycobacterial colonization of Hickman lines from patients admitted to the haemato-oncology unit during the period of the cluster. For this purpose weekly Hickman line blood cultures were taken from all inpatients and those who had been recently discharged, over a four-week period. These were additional to the blood cultures performed for clinical indications.

Environmental samples

Water sampling was commenced in July 2008 and repeat water testing was done at regular intervals. Water was collected from all hot and cold showers, sinks, and baths on the haemato-oncology unit before and after running the water for 2 minutes. The water in the mains tank inlets and other areas thought to be a potential source of biofilm was also sampled. Water samples were tested by pour plate method using yeast extract agar to determine aerobic colony counts.[8] Counts >300 cfu/mL were determined using suitable dilutions. For detection of NTM, a 100 mL water sample was drawn through a 47 mm diameter hydrophilic membrane under negative pressure. The membrane was then placed on tryptone soy agar and blood agar with GC (gonococcal) supplement and incubated at 35 °C for 48–72 h and 30 °C for one week respectively.[9] Growth on the membrane was screened for the presence of NTM by the ZN stain, and positive samples were sent to the SMRL for identification. At SMRL, 5×20 mL aliquots of the water were centrifuged and the deposit pooled together, plated on to LJ slopes and inoculated into Bactec MGIT 960 (Becton Dickinson, Oxford, UK) bottles. Isolate identification was confirmed as outlined in the previous section.

Environmental investigations

An investigation of the water system was carried out by the Estates Department to identify potential contributing factors.

Results

Epidemiology

NTM bacteraemia was identified in five patients. The patient clinical characteristics are summarized in Table I. All five patients presented with pyrexia. They all had Hickman lines, had been inpatients on the transplant unit and had also attended the day-patient unit. Three patients were undergoing intensive treatment for acute myeloid leukaemia, one patient was <100 days from autologous HSCT for follicular lymphoma and one patient was receiving intensive therapy for transformed follicular lymphoma. The clinical outcomes for the patients are summarized in Table I. The Hickman lines were presumed to be the portal of entry of NTM and were removed or replaced when NTM were identified in blood cultures. Initial antibiotic therapy was continued in patients with resolving pyrexia; otherwise the patients' antibiotics were changed to clarithromycin and meropenem as per antibiotic sensitivities. One patient (A) died of post-transplant complications not directly related to the infection, four weeks after diagnosis of NTM bacteraemia. The other patients had no long-term consequences of the infection.

Microbiological results

Clinical samples

In total, 14 blood culture bottles were positive for NTM (all aerobic), from five clinically infected patients. All patients had multiple blood cultures taken and all had more than one blood culture bottle positive with mycobacteria. Three patients had positive peripheral blood cultures in addition to positive Hickman line

Table I
Details of patients from whom mycobacteria were isolated during the cluster period

Patient	Sex, age (years)	Diagnosis	Stage of treatment	Date of collection of first NTM-positive BC	Dates and site of collection of BC negative for mycobacteria	Positive BC Date collected	No. of bottles positive/total no. of bottles collected	Isolate recovered	Neutrophil count ($\times 10^9$/L) on day of collection (±2 days)	Antibiotic therapy	Outcome
A	F, 62	Follicular NHL	BEAM autograft D94	10 Oct 2007	10 Oct 2007 P, R, B 12 Oct 2007 W, B, R, U 13 Oct 2007 P	10 Oct 2007 W 12 Oct 2007 U	2/9	*M. mucogenicum*	0.39	Multiple, including clarithromycin	Died four weeks post detection of mycobacteraemia
B	F, 46	AML	AML 15 D19 cytarabine #4	04 Jun 2008	04 Jun 2008 R, U 09 Jun 2008 P	04 Jun 2008 W 09 Jun 2008 P	2/5	*M. mucogenicum*	0.0	Ceftazidime Gentamicin Teicoplanin	Recovered
C	M, 41	AML with MLD	AML 15 D37 ADE #2	20 Jun 2008	20 Jun 2008 R 22 Jun 2008 P 22 Jun 2008 R 23 Jun 2008 U	20 Jun 2008 P, W 22 Jun 2008 W	3/6	*M. neoaurum*	0.37	Meropenem	Recovered
D	M, 42	High grade transformation of follicular NHL	R-CODOX-M/R-IVAC D10 #2	21 Jul 2008	21 Jul 2008 R 23 Jul 2008 W	21 Jul 2008 P, W 23 Jul 2008 P, R	4/6	*M. mucogenicum*	0.02	Ciprofloxacin Clarithromycin	Recovered
E	F, 40	AML with MLD	AML 15 D57 DA#2	22 Jul 2008	22 Jul 2008 U 25 Jul 2008 P	22 Jul 2008 U, R, B	2/3	*M. mucogenicum*	1.5	Ciprofloxacin	Recovered

NTM, non-tuberculous mycobacterium; NHL, non-Hodgkin lymphoma; BEAM, busulphan–etoposide–amsacrine–melphalan; AML, acute myeloid leukaemia; DA, daunorubicin–cytarabine; ADE, cytarabine–daunorubicin–etoposide; MLD, multi-lineage dysplasia; R-CODOX-M, rituximab–cyclophosphamide–vincristine–cytarabine–methotrexate; BC, blood culture; R-IVAC, rituximab–ifosfamide–etoposide–cytarabine; R, W, B: red, white, blue lumen of the Hickman line; P, peripheral BC; U, BC unspecified site.

cultures. Due to lack of information, it could not be determined whether the other two patients' positive blood cultures had been sampled peripherally or through their Hickman lines. The time from collection to positivity by BacT/Alert® 3D ranged from two to four days with a mean and median of three days each. All isolates were sensitive to clarithromycin, amikacin and cotrimoxazole. No further cases of NTM were identified in the surveillance blood cultures.

Environmental samples

Initial sampling of water showed high total viable counts (TVCs) of bacteria and NTM from the showers. NTM were isolated from seven of the 10 showers. Of these, three were identified as *M. mucogenicum*, two as *M. chelonae* and two as *Mycobacterium* spp. However, post chlorination, repeat sampling of the same areas revealed persistent high TVCs of bacteria and NTM from five out of 10 showers. Of these five positive showers, two had previously been negative. Further repeat testing of all 10 showers revealed persistently high TVCs. TVCs from one water tank were initially high but reduced significantly after cleaning of the ballcocks and rebalancing of the tank to minimize stagnation.

Environmental investigations

The water system supplying the transplant unit was 10 years old, and no alterations had been carried out. There were no 'dead legs' or 'long runs' and the 'return legs' were as close as possible to the point of use. The showers had been replaced in April 2008 and cleaned every three months. However, several factors are likely to have contributed to the development of biofilm and relatively high levels of NTM in the transplant unit water supply. The pipes in the transplant unit were plastic with sealed tank units. The adjacent haematology ward was supplied by a separate copper-piped water system shared with the oncology wards. The water system to the transplant unit was a cold water supply from the public mains direct to the ward with a branch of this providing mains drinking water. The remainder flowed into two parallel, connected cold water tanks, which served the rest of the outlets in the building. This also supplied the hot water system kept at 60 °C. At patient point of use there were thermostatically controlled valves mixing hot and cold to result in temperatures of 43 °C. Some staff areas may have had uncontrolled water temperatures. There had been an incident involving use of the fire hydrants in April 2008 and there had been concern about interruption to the water supply during that period, which may have allowed some overgrowth of mycobacteria.

Chloramine, a weaker biocide than chlorine, had been used for disinfection of the public water supply over the four years preceding the cluster of cases. An inadequately planned preventive maintenance programme may have resulted in reduced functioning of ballcocks and pressure pump valves, and accumulation of stagnant water in one of the tanks. The implementation of changes in the water supply had taken place without discussion with the infection control team.

Control measures and outcome

Water supply

Following removal of all the patients from the ward, the cold water storage tanks supplying the transplant unit were cleaned and disinfected with chlorine dioxide. The ballcocks to the tanks and hot water pressure pumps were also removed and either cleaned or replaced. As stagnation of the tanks was thought to be a contributory factor, the tanks were rebalanced to allow the regular flow of water, and a system to maintain this was implemented. Subsequently only

one tank was available for use at a time and the other tank was emptied and shut down to ensure good flow of water.

All showerheads and hoses were replaced, shower curtains were removed, and subsequently showers were treated as wet rooms. As biofilms re-accumulate with time, a package of preventive measures and maintenance was introduced, which included regular 12-weekly cleaning and chlorination of the hose, showerheads, washbasins and drain taps. Flushing of showers for 2 min before every use was also introduced.

Changes in clinical practice

To prevent further cases, Hickman line Interlink connectors were replaced with Bionector connectors, which have fewer connections and a tighter seal. Prior to the cluster, Hickman line insertion sites and ports were covered with dressings, which were removed for showering. This practice was changed to the use of transparent semipermeable polyurethane dressings, which are maintained while showering. These ensure protection of the entry site of the Hickman line and easy visual inspection. Nursing staff and patients were re-educated in relation to these changes in practice, and the principles of good Hickman line care were reinforced.

Following the above interventions no further cases of NTM were identified in the subsequent 12-month period and none of the original cases developed recurrent NTM bacteraemia.

Discussion

This paper reports a cluster of CVC-associated NTM bacteraemia in patients with haematological malignancies. Timely and directed environmental investigation revealed the water supply as the likely source of the organism. Following the implementation of corrective measures, which included the use of new maintenance procedures for the hospital water supply and changes to Hickman line dressing practices, no further cases were identified.

From retrospective reviews, the overall incidence of mycobacterial infections in HSCT recipients appears to be low, affecting 0.5–1% of patients.[10,11] However, a small number of other haemato-oncology and HSCT units have reported similar outbreaks of CVC-associated NTM bacteraemia secondary to contamination of the water supply. In one paediatric haemato-oncology unit, five such patients were identified over a six-month period. Water cultures identified the tap water on the unit as a potential source of the infection and intermittently low chlorination levels were thought to be a contributory factor. Consequently, chlorine levels were corrected and the taps were replaced. The investigators also reviewed CVC care practices and these were changed to recommend protection of the exit site during bathing. Following these measures surveillance cultures of the water supply were negative and there were no further occurrences of CVC-associated NTM infections over the next 12 months.[2]

The investigators of another NTM outbreak involving six patients on an HSCT unit performed a case–control study to attempt to identify common risk factors in the cases. They found no statistically significant differences in the patient factors studied. Again the water supply was identified as a source of infection as bathing practices on the unit did not protect the CVC exit sites. It was also noted that showerheads had higher levels of *M. mucogenicum* compared to sink water and that flushing the showerheads for 2 min reduced the levels of bacteria.[1] In a report of a similar NTM outbreak in a military HSCT unit it was noted that the episodes of bacteraemia were not reduced by introducing sterile drinking water but were prevented by the use of sterile water for bathing.[12]

M. mucogenicum is resistant to first line anti-tuberculous agents but is generally susceptible to other antibiotics. There is little evidence in the literature on the appropriate management of patients. In these cases a combination of clinical management, removal of intravenous catheters and empiric therapy with an aminoglycoside and a macrolide and/or quinolone was considered appropriate until antimicrobial susceptibility results were available. The optimal duration of therapy is unknown.[13]

NTM are ubiquitous environmental organisms found in soil, dust and water and are relatively resistant to chlorination at the levels found in drinking water.[14] In drinking water systems, biofilms are an important source of NTM. These microbial communities attach to surfaces and produce an extracellular matrix that enhances their survival and provides protection against antimicrobial treatments.[15] A study by the Environmental Protection Agency in the USA found mycobacteria in >60% of the hospital water systems sampled, most commonly *M. mucogenicum*.[16]

Chlorine dioxide, free chlorine or chloramine are the most common compounds used for chemical disinfection of water supplies, and are commercially available. Chlorine dioxide has the disadvantage of producing large amounts of chlorite which can be toxic, and therefore, despite its fast action, its use is relatively limited. Chlorine dioxide solutions at either 600 or 30 ppm killed *Mycobacterium avium-intracellulare* within 60 s after contact but contamination by organic material significantly affected the microbicidal properties.[17] Chloramine is more stable than free chlorine, persists for longer and achieves greater residual activity with lower total chlorine exposure and chlorine residues, and is therefore becoming more commonly used. Chloramine has been used to treat the public water supply in some areas of Scotland since 2005.

In spite of the many chlorine-based disinfection mechanisms available to us, the presence of mycobacteria in a water supply may not be directly related to the level of chlorine. A study conducted in Boston compared the susceptibility of water-borne *Mycobacterium* species to concentrations of free chlorine in water supply systems and found that disinfection procedures in that region were not efficient in eliminating pathogenic mycobacterium in the supply systems and may be a potential risk factor for people with increased susceptibility.[18] In a study published in 1994, Glover *et al.* did not detect a correlation between heterotrophic bacteria or chlorine levels and the presence of NTM in their examination of Los Angeles drinking water.[19] They concluded that the occurrence of NTM was related to the architecture of plumbing at the site of sampling, and large buildings such as hospitals would be more likely to have plumbing dead ends containing biofilm which may include NTM.

In this study several factors have been identified that may have contributed to relatively high levels of NTM in the transplant unit water supply, including areas of water stagnation and inadequate chlorination. The corrective measures introduced to address these problems would reduce the levels of *Mycobacterium* species in the water supply but would be unlikely to eradicate the organisms.

Consequently the issue of exposure of the Hickman line exit and hub sites to water has also been addressed, as previous investigations suggest that this is the most likely entry site for infection. Currently recommended best practice is the use of intact, dry, adherent, transparent, semi-occlusive dressings, which are maintained in place during bathing.[20] These have the advantage of protecting the site from water exposure while also allowing continuous inspection of the site, compared with gauze dressings. The reduced number of connectors decreased the risk of contamination with environmental organisms. During the investigation of this cluster an attempt was made to analyse whether CVC-specific factors may have contributed to the risk of infection but it was very difficult to obtain comprehensive information retrospectively. In response to this, a new system has been introduced locally to record Hickman line histories, including dates of insertion, infections, access difficulties, CVC-associated thrombosis and dates and reasons for removal.

The results of the investigations of this cluster indicated that the showers and washbasins were the likely source of infection and the CVCs were the presumed portal of entry. The evidence for this conclusion is largely circumstantial based on the presence of NTM in the water supply and the absence of further infections following changes in CVC care practice and extensive cleaning of the water system. However, it is in keeping with the findings of previously published outbreaks in similar settings.[2]

The absence of further cases of mycobacterial bloodstream infection following the change in CVC care practice, despite the persistence of mycobacterial contamination of the hospital domestic water supply, suggests that infection control measures can play a major role in preventing mycobacteraemia from water sources in immunocompromised patients.

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Clinical Infectious Diseases

MAJOR ARTICLE

Two-Phase Hospital-Associated Outbreak of *Mycobacterium abscessus*: Investigation and Mitigation

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(See the Editorial Commentary by Crist and Perz on pages 912-3.)

Background. Nontuberculous mycobacteria (NTM) commonly colonize municipal water supplies and cause healthcare-associated outbreaks. We investigated a biphasic outbreak of *Mycobacterium abscessus* at a tertiary care hospital.

Methods. Case patients had recent hospital exposure and laboratory-confirmed colonization or infection with *M. abscessus* from January 2013 through December 2015. We conducted a multidisciplinary epidemiologic, field, and laboratory investigation.

Results. The incidence rate of *M. abscessus* increased from 0.7 cases per 10 000 patient-days during the baseline period (January 2013–July 2013) to 3.0 cases per 10 000 patient-days during phase 1 of the outbreak (August 2013–May 2014) (incidence rate ratio, 4.6 [95% confidence interval, 2.3–8.8]; $P < .001$). Thirty-six of 71 (51%) phase 1 cases were lung transplant patients with positive respiratory cultures. We eliminated tap water exposure to the aerodigestive tract among high-risk patients, and the incidence rate decreased to baseline. Twelve of 24 (50%) phase 2 (December 2014–June 2015) cases occurred in cardiac surgery patients with invasive infections. Phase 2 resolved after we implemented an intensified disinfection protocol and used sterile water for heater-cooler units of cardiopulmonary bypass machines. Molecular fingerprinting of clinical isolates identified 2 clonal strains of *M. abscessus*; 1 clone was isolated from water sources at a new hospital addition. We made several water engineering interventions to improve water flow and increase disinfectant levels.

Conclusions. We investigated and mitigated a 2-phase clonal outbreak of *M. abscessus* linked to hospital tap water. Healthcare facilities with endemic NTM should consider similar tap water avoidance and engineering strategies to decrease risk of NTM infection.

Keywords. hospital outbreak; nontuberculous mycobacteria; *Mycobacterium abscessus*; infection control; hospital water safety.

Nontuberculous mycobacteria (NTM) are hardy environmental microorganisms found in water, dust, and soil [1]. NTM commonly colonize municipal water [2–4], including tap water at healthcare facilities [5–9], and form biofilms in water distribution systems [10].

Outbreaks of *Mycobacterium abscessus* and other rapidly growing mycobacteria are common and have been associated with colonized plumbing systems in commercial buildings [11, 12] and healthcare facilities [13–16]. Organisms belonging to the *Mycobacterium abscessus* complex (*M. abscessus* subspecies *abscessus*, *M. abscessus* subspecies *massiliense*, and *M. abscessus* subspecies *bolletii*) are intrinsically resistant to many antibiotics and disinfectants [17]. Infections due to *M. abscessus* are difficult to diagnose and typically require months of therapy using multiple antibiotics [18, 19].

In March 2014, we identified an increase in patients with positive cultures for *M. abscessus*. Most patients had positive respiratory tract cultures, including numerous positive bronchoalveolar lavage (BAL) cultures from lung transplant recipients. We undertook a multifaceted investigation to confirm cases, identify sources, and implement mitigation strategies.

METHODS

Study Setting

Duke University Hospital (DUH) is a 957-bed tertiary care hospital located in North Carolina. A new hospital addition containing 160 intensive care unit (ICU) and intermediate beds, as well as 16 operating suites, was opened for patient care in late July 2013. The original portions of DUH continued to be used for patient care, predominantly for non-ICU medical and surgical patients after July 2013. DUH utilizes the municipal water supply.

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The Duke University Institutional Review Board approved this investigation and research.

Epidemiologic Investigation

We identified all patients with growth of *M. abscessus* from any clinical specimen obtained at the hospital from January 2013 through December 2015. All patients with a first-time positive culture were considered cases with the following exceptions: Patients with a culture obtained during the first 2 days of admission or from a DUH outpatient clinic were excluded unless they had previously been hospitalized at DUH within 30 days prior to culture collection. After retrospective case finding was completed for the period from January 2013 through February 2014, we prospectively applied the same case definition for detection of incident cases from March 2014 through December 2015. Relevant clinical data were abstracted from the electronic medical record.

Field Investigation

We investigated the environment, equipment, and practices used in the bronchoscopy suite [20, 21] and the clinical microbiology laboratory [22, 23] to exclude a pseudo-outbreak. Subsequently, based on characteristics of case patients, we investigated additional locations of the healthcare facility, including ICUs and operating rooms (ORs) in the new addition, to identify potential environmental sources of *M. abscessus* where exposure to this organism was considered possible.

We conducted a comprehensive survey of the existing and new hospital addition's water systems [24]. This survey included a water flow analysis to identify potential locations with reduced or restricted water flow, reduced disinfectant levels, or cooling within the hot water distribution system.

We performed mycobacterial cultures of biofilms [10] from water outlets and equipment in the hospital, as well as from water outlets in the community surrounding the hospital (Supplementary Table). We also performed air-sampling experiments in ORs to evaluate for aerosolized particles containing NTM [25].

Laboratory Methods

Standard mycobacterial culture methods were utilized (see page 3 of the Supplementary Data) [2, 26]. All environmental and selected patient isolates of *M. abscessus* were identified to subspecies and typed using erythromycin ribosomal methylase [*erm*(41)] [27] and region V RNA polymerase subunit beta (*rpoβ*) [28] gene sequencing. Variable number tandem repeats (VNTRs) [29] and pulsed-field gel electrophoresis (PFGE) [30] were also performed on representative environmental and patient isolates.

Statistical Analysis

Incidence rate ratios (IRRs) were estimated using maximum likelihood, assuming the number of cases followed the Poisson distribution. Wald 95% confidence intervals (CIs) were calculated, and likelihood ratio χ^2 tests were used to compare incidence rates. Calculations were performed in SAS software, version 9.4 (SAS Institute, Cary, North Carolina).

RESULTS

Outbreak Investigation, Phase 1: August 2013–May 2014

Epidemiologic Investigation

Ten cases of *M. abscessus* were detected over 150 651 patient-days during the preoutbreak baseline period from January 2013 through July 2013; 71 cases were identified over 234 956 patient-days from August 2013 through May 2014 (phase 1) (Figure 1A). Thus, the incidence rate increased from a baseline of 0.7 cases per 10 000 patient-days to 3.0 cases per 10 000 patient-days (IRR, 4.6 [95% CI, 2.3–8.8]; $P < .001$).

Lung transplant recipients represented 39 of 71 (55%) cases during phase 1 (Table 1). Other cases included patients with recent cardiac surgery (n = 9 [13%]), cancer (n = 5 [7%]), and hematopoietic stem cell transplantation (n = 5 [7%]), as well as multiple other patient types (n = 13 [18%]). Sixty-nine (97%) patients had exposure to the new hospital addition within 30 days prior to the first positive culture.

Mycobacterium abscessus was initially recovered from the respiratory tract in 56 (79%) phase 1 cases, including 36 of 39 (92%) lung transplant recipients. Thirty-five of 36 (97%) respiratory isolates from lung transplant recipients were recovered from BAL cultures. The median time from lung transplantation to first positive *M. abscessus* culture was 13 days (interquartile range [IQR], 6–47 days; range, 0–4716 days).

Thirty-six of 71 (51%) patients who met the case definition during phase 1 received antimicrobial therapy for infections, and 17 (24%) patients died within 60 days of the first positive culture.

Field Investigation

Phase 1 of the outbreak temporally correlated with the opening of the new hospital addition (Figure 1B). The predominance of respiratory isolates suggested that colonization or infection occurred via exposure through the aerodigestive tract, likely from routine care practices using tap water. Investigation of bronchoscopy equipment, the endoscope reprocessing suite, microbiology laboratory, and lung and cardiac surgery ORs revealed no source of the outbreak.

Environmental cultures obtained in April and May 2014 from biofilms of water sources were positive for NTM in 19 of 24 (79%) locations at the new hospital addition, 14 of 25 (56%) sites at the existing hospital, and 5 of 12 (42%) locations in the community surrounding the hospital (Supplementary Table). Only cultures taken from biofilms of water sources at the hospital addition were positive for *M. abscessus*, with 12 of 24 (50%) sites positive for *M. abscessus* subspecies *abscessus*. Sites testing positive for *M. abscessus* included patient room faucets, patient care ice machines, ICU hallway water faucets, a patient room

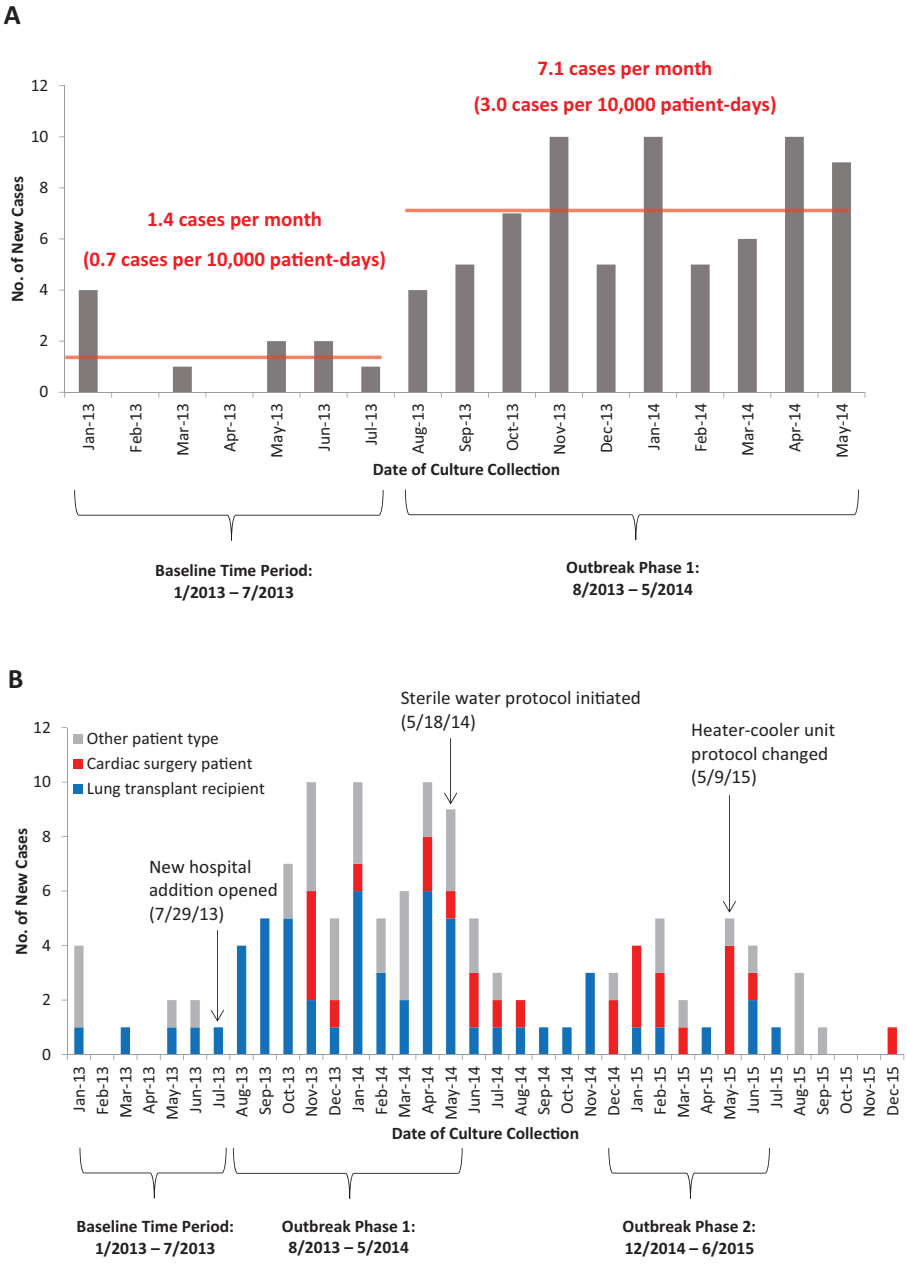

Figure 1. Epidemic curve of *Mycobacterium abscessus* colonization or infection. *A*, Initial epidemic curve including the baseline time period (January 2013–July 2013) and phase 1 of the outbreak (August 2013–May 2014). *B*, Final epidemic curve portraying key events and incident cases over the full 3-year study period, including phase 2 of the outbreak (December 2014–June 2015). Cases were stratified by patient type. The timeline of both epidemic curves was constructed from dates of culture collection, which in some cases occurred months after date of suspected patient inoculation. In particular, cardiac surgery cases that were identified after the 9 May 2015 heater-cooler unit disinfection protocol changes were either linked to cardiac surgeries performed before these protocol changes (n = 3) or were thought to be unrelated to the cardiac surgery (n = 1).

shower head, a utility room water basin, and an OR scrub sink faucet.

Interventions and Subsequent Surveillance

Based on data from the field investigation, we developed and implemented a sterile water protocol in May 2014 that ultimately included all lung and heart transplant recipients, ICU patients, and patients with disrupted gastrointestinal tracts. These patients received sterile water instead of tap water for oral care, speech therapy assessments, enteral tube flushes, respiratory therapy, consumption, and, until surgical sites were well-healed, bathing. New lung and heart transplant recipients also continued tap water avoidance after hospital discharge in the early postoperative period.

We noted an overall decrease in *M. abscessus* cases, including cases among lung transplant recipients, during the period from June 2014 through November 2014 (Figure 1B). The overall incidence rate decreased from 3.0 to 1.0 cases per 10 000

Table 1. Characteristics of Patients Who Developed Incident Colonization or Infection With *Mycobacterium abscessus* During or up to 30 Days After Hospitalization, 2013–2015

Characteristic	Overall (January 2013–December 2015) (n = 126)	Phase 1 (August 2013–May 2014) (n = 71)	Phase 2 (December 2014–June 2015) (n = 24)
Median age, y (IQR)	63 (50–68)	63 (50–67)	59 (49–68)
Male sex, No. (%)	92 (73)	52 (73)	15 (63)
Patient type, No. (%)			
Lung transplant	58 (46)	39 (55)	5 (21)
Cardiac surgery	27 (21)	9 (13)	13 (54)
VAD (no heart transplant)	9 (7)	2 (3)	6 (25)
Heart transplant	8 (6)	4 (6)	4 (17)
Valve surgery (no VAD)	6 (5)	2 (3)	2 (8)
Coronary artery bypass grafting (no valve surgery)	3 (2)	1 (1)	1 (4)
Ventricular septal defect repair	1 (1)	0 (0)	0 (0)
Malignancy (no hematopoietic stem cell transplant)	10 (8)	5 (7)	1 (4)
Chronic lung disease (no lung transplant)	8 (6)	4 (6)	2 (8)
Hematopoietic stem cell transplant	5 (4)	5 (7)	0 (0)
Esophagectomy	5 (4)	2 (3)	1 (4)
Other solid organ transplant (no lung or heart transplant)	4 (3)	2 (3)	1 (4)
Orthopedic surgery	3 (2)	2 (3)	0 (0)
Other patient type	6 (5)	3 (4)	1 (4)
Site of first positive culture, No. (%)			
Respiratory	86 (68)	56 (79)	9 (38)
Bronchoalveolar lavage	67 (53)	45 (63)	6 (25)
Blood	15 (12)	4 (6)	6 (25)
Pleural fluid	8 (6)	4 (6)	2 (8)
Sternal wound	5 (4)	0 (0)	5 (21)
Bone	3 (2)	2 (3)	0 (0)
VAD driveline site	3 (2)	0 (0)	2 (8)
Peritoneal fluid	2 (2)	2 (3)	0 (0)
Other	4 (3)	3 (4)	0 (0)
Time of diagnosis in solid organ transplant recipients			
Median days from transplant surgery to positive culture (IQR)			
All solid organ transplant recipients (n = 70)	41 (12–114)	18 (8–73)	105 (59–352)
Lung transplant (n = 58)	34 (11–94)	13 (6–47)	80 …
Heart transplant (n = 8)	43 (18–106)	18 …	95 …
Other solid organ transplant (n = 4)	169 …	483 …	144 …
Positive culture during index transplant surgery hospitalization, no./total No. (%)			
All solid organ transplant recipients	43/70 (61)	33/45 (73)	3/10 (30)
Lung transplant	36/58 (62)	29/39 (74)	1/5 (20)
Heart transplant	6/8 (75)	4/4 (100)	2/4 (50)
Other solid organ transplant	1/4 (25)	0/2 (0)	0/1 (0)

Patients with a positive culture obtained on day 1 or day 2 of admission were excluded unless they had previously been hospitalized within 30 days prior to the date of the first positive culture.
Abbreviations: IQR, interquartile range; VAD, ventricular assist device.

patient-days (IRR, 0.3 [95% CI, .2–.6]; $P < .001$), and the incidence rate among lung transplant recipients decreased from 1.7 to 0.6 cases per 10 000 patient-days (IRR, 0.3 [95% CI, .2–.7]; $P = .005$).

Outbreak Investigation, Phase 2: December 2014–June 2015

Epidemiologic Investigation

Two patients who had recently undergone cardiac surgery had cultures collected in December 2014 that returned positive for *M. abscessus*. These cases led to a second epidemiological investigation that ultimately included a cluster of 13 cases among patients who had undergone recent cardiac surgery at the hospital and had positive cultures from December 2014 through June 2015 (phase 2) (Figure 1B). One case reflected respiratory colonization, but the remaining 12 (92%) patients developed extrapulmonary invasive disease.

We analyzed the cohort of all cardiac surgery patients who met the case definition over the entire 3-year study period. Twenty-two cases of extrapulmonary invasive *M. abscessus* infection occurred after cardiac surgery. The first invasive

infection was identified in November 2013. Infections followed heart transplant (n = 8 [36%]), ventricular assist device (VAD) insertion (n = 8 [36%]), valve replacement (n = 4 [18%]), and coronary artery bypass grafting (CABG) (n = 2 [9%]) surgeries. Sites of initial positive cultures included bloodstream (n = 10 [45%]), sternal wound (n = 5 [23%]), VAD driveline site (n = 2 [9%]), pleural fluid (n = 2 [9%]), respiratory tract (n = 2 [9%]), and pelvic ascites (n = 1 [5%]). Three additional cardiac surgery patients with invasive infections did not meet the case definition because they had not been hospitalized within 30 days prior to initial culture collection.

Twenty-one of 22 (95%) patients from this cardiac surgery cohort required cardiopulmonary bypass (CPB) during surgery; the remaining patient underwent chest exploration with a CPB machine on standby in the OR. Median incubation time from possible inoculation in the OR to first positive nonrespiratory culture was 42 days (IQR, 20–94 days; range, 2–366 days). Nearly all cardiac surgeries performed after July 2013, including all cardiac surgeries performed in this cohort, occurred in ORs in the hospital addition.

All 22 cardiac surgery patients had extensive perioperative comorbidities and complicated postoperative courses in addition to *M. abscessus* infection. Nineteen (86%) patients received antimicrobial therapy, and 9 (41%) died within 60 days of the first positive culture.

Field Investigation

We reinvestigated lung and cardiac surgery OR suites and surgical practices. Mycobacterial cultures from cardiothoracic surgery OR air samples were negative. We also reviewed our maintenance and disinfection protocol for heater-cooler units (HCUs) of CPB machines. Our hospital used Stöckert 3T HCUs, and the manufacturer's instructions for use changed in 2010, recommending filtered rather than unfiltered tap water for use in these machines; however, we found that water changes were performed with unfiltered tap water and that the disinfection procedure was not performed according to the instructions for use. Cultures from biofilms of HCUs were negative for *M. abscessus*, but a culture from a biofilm of the faucet used to fill HCUs was positive for *M. abscessus*. Only a single series of cultures from biofilms of external HCU components, including tubing and overflow water canisters, was performed before we instituted a new water change and disinfection protocol for HCUs, as described below.

Our survey of the hospital water system identified several factors that may have contributed to increased concentrations of *M. abscessus* within the new addition's water distribution system. The addition utilized Leadership in Energy and Environmental Design (LEED) standards to reduce water usage [31]. The water system had low flow rates and low residual disinfectant (chloramine) levels at multiple water outlets. The hot water system was a recirculating loop, and hot water stored in reservoirs required prolonged flow times to reach outlets. Relatively small amounts of water from the municipal water supply entered the recirculating hot water loop each day, which also contributed to low chloramine levels.

Interventions and Subsequent Surveillance

We made several process, patient care, and water engineering changes to terminate the outbreak among cardiac surgery patients and prevent new clusters among other patient types (Supplementary Figure 2).

A study published in the midst of our investigation demonstrated the potential for aerosolized NTM from CPB machine HCUs to contaminate patients during cardiac surgery [25]. In early May 2015, based on the results of this study and our epidemiologic investigation, we changed our protocol for maintenance and disinfection of HCUs. The new protocol included daily water changes with sterile water and daily disinfection with hydrogen peroxide, in addition to intermittent bleach-based disinfection. We also directed HCU exhaust away from the surgical field. We replaced all existing HCUs with new HCUs by early June 2015 and used only sterile water in these machines. Also in early June, we notified at-risk patients and healthcare providers of the potential for NTM infection after cardiac surgery and described associated signs and symptoms to facilitate case detection. At the same time, we notified the US Food and Drug Administration (FDA) about the potential causal link between HCU use and NTM infection.

We implemented 3 primary water engineering–related interventions at the new addition to reduce microbial proliferation and burden: we flushed water throughout both the cold water and recirculating hot water systems; removed or adjusted water flow restrictors, aerators, and a redundant hot water tank; and decreased the percentage of recirculating hot water that bypassed heat exchangers. These changes led to higher and more consistent flow rates, increased mixing of municipal water within the hot water loop, faster delivery of hot water to distal outlets, and increased chloramine levels throughout the plumbing system. Additionally, we installed point-of-use 0.2-μm water filters [32] at OR scrub sink faucets.

A single case of *M. abscessus* infection occurred in a cardiac surgery patient who underwent CPB after implementation of HCU protocol changes and engineering interventions (Figure 1B). This patient developed *M. abscessus* infection of pelvic ascites after CABG, and we suspected that inoculation did not occur at the time of CABG.

Laboratory Investigation, Phase 1 and Phase 2

Seventy case patient and 17 environmental isolates of *M. abscessus* recovered during the study period were submitted for *erm*(41) gene sequencing, region V *rpoβ* gene sequencing, and/or VNTR. All but 2 patient isolates and all environmental

isolates analyzed belonged to 1 of 2 clones (see page 5 of the Supplementary Data).

Fifty-three of 70 (76%) patient isolates were consistent with clone A; 15 (21%) isolates were consistent with clone B; and only 2 (3%) isolates were inconsistent with either clone (Table 2). All 18 patient isolates analyzed from cardiac surgery patients with invasive infections and all 17 environmental isolates of *M. abscessus* exhibited clone A fingerprinting patterns.

We additionally performed gene sequencing and VNTR on patient isolates collected prior to the study period. Isolates with clone A and clone B fingerprinting were identified as early as 2010 and 2007, respectively.

PFGE was performed on 9 clone A patient isolates collected from 2010 through 2015 and 8 clone A environmental isolates from phase 1 of this investigation; all isolates were clonal (Figure 2A) [30]. PFGE was also performed on 10 clone B patient isolates collected from 2007 through 2015, and 9 isolates were clonal (Figure 2B).

DISCUSSION

We report a biphasic outbreak of *M. abscessus* in patients hospitalized at a tertiary care hospital.

Cases from phase 1 of the outbreak predominantly involved lung transplant recipients with colonization or infection of the respiratory tract. We hypothesized that micro-aspiration of *M. abscessus* from tap water used for patient care activities led to subsequent pulmonary colonization or infection [33, 34].

The second phase of the outbreak primarily involved cardiac surgery patients with invasive infections. Based on reports of NTM infections in cardiac surgery patients and the prevalence of wound and bloodstream infections, we hypothesized that patients in this second cluster acquired infection via aerosols generated from colonized HCUs [25].

One of the 2 distinct molecular clones of *M. abscessus* involved in this outbreak was recovered from tap water sources at the new hospital addition; however, both clones were present in clinical cases that occurred several years before the addition opened. Also, both *M. abscessus* clones were isolated from patients who had never been admitted to the hospital. Thus, isolates of *M. abscessus* obtained from this investigation were not unique to the new addition, the existing hospital, or the study time period and likely represent colonization of the local municipal water supply.

Low flow rates within the hospital addition's water circuit and a redundant hot water circulation system may have led to

Table 2. Summary of Gene Sequencing and Variable Number Tandem Repeats of Case Patients and Environmental Isolates of *Mycobacterium abscessus* Obtained From 2013 Through 2015

Characteristic or Isolate Type	*M. abscessus* Clone A[a]	*M. abscessus* Clone B[b]	Other *M. abscessus* Isolates[c]
Gene sequencing			
erm(41) gene	Subspecies *abscessus* Type VI	Subspecies *massiliense*	Miscellaneous
*rpo*β gene	Subspecies *abscessus* C→T mutation, base pair 207	Subspecies *abscessus*	Miscellaneous
VNTR			
Primer TR155	5 copies	…	…
Type of isolate			
Patient isolates[d]			
All cases analyzed (n = 70)	53 (76)	15 (21)	2 (3)
Phase 1 cases (n = 38)[e]	31 (82)	6 (16)	1 (3)
Phase 2 cases (n = 15)[e]	13 (87)	2 (13)	0 (0)
First positive culture was from respiratory tract (n = 39)	29 (74)	9 (23)	1 (3)
First positive culture was not from respiratory tract (n = 31)	24 (77)	6 (19)	1 (3)
Lung transplant cases (n = 33)	25 (76)	8 (24)	0 (0)
Invasive cardiac surgery infections (n = 18)	18 (100)	0 (0)	0 (0)
Environmental isolates (n = 17)	17 (100)	0 (0)	0 (0)

Data are presented as No. (%) unless otherwise indicated.

Abbreviation: VNTR, variable number tandem repeat.

[a]An isolate was considered consistent with clone A if it had a C→T mutation at base pair 207 of the *rpo*β gene or VNTR with 5 copies for primer TR155. All isolates from cases meeting 1 of these criteria that underwent *erm*(41) gene sequencing had the *M. abscessus* subspecies *abscessus* type VI *erm*(41) gene.

[b]An isolate was considered consistent with clone B if it had an *M. abscessus* subspecies *M. massiliense erm*(41) gene. All isolates from cases meeting this criterion that underwent *rpo*β gene sequencing had the *M. abscessus* subspecies *abscessus rpo*β gene.

[c]All isolates with gene sequencing not consistent with clone A or clone B were considered "other" *M. abscessus* isolates.

[d]Patient isolates included met the outbreak case definition and represented either *M. abscessus* colonization or infection. Only selected case patient isolates underwent molecular fingerprinting.

[e]Phase 1 of the outbreak occurred from August 2013 through May 2014. Phase 2 occurred from December 2014 through June 2015.

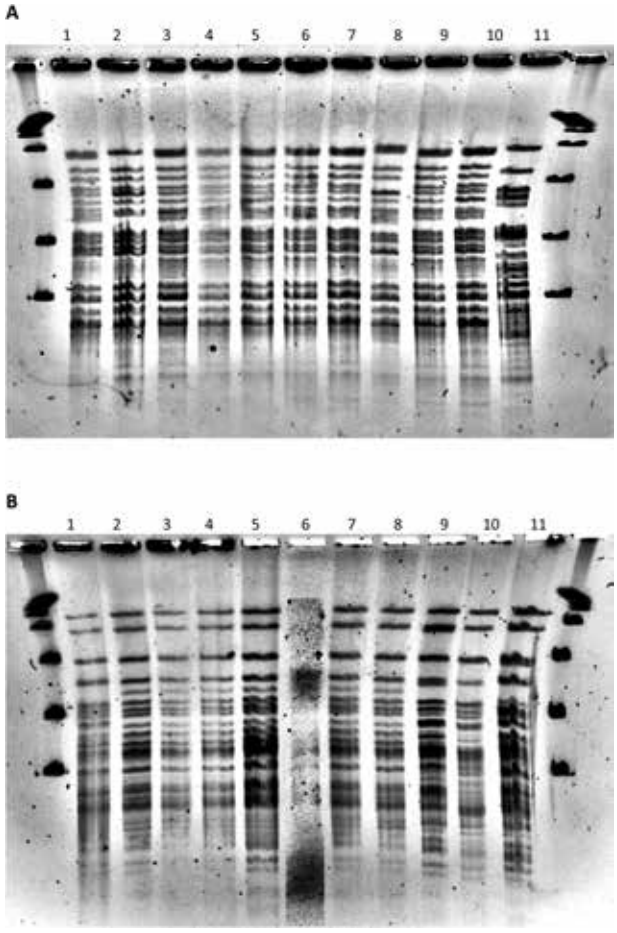

Figure 2. XbaI pulsed-field gel electrophoresis (PFGE) of patient and environmental isolates of *Mycobacterium abscessus* obtained from 2007 through 2015. *A*, Isolates selected for this panel demonstrated gene sequencing and/or variable number tandem repeats (VNTRs) consistent with outbreak clone A [*erm*(41) gene: subspecies *abscessus*, type VI; *rpo*β gene: subspecies *abscessus*, C→T mutation at base pair 207; VNTR: primer TR155, 5 copies]. The panel includes 2 preoutbreak patient isolates from 2010–2012 (lanes 1, 2), 4 case patient isolates from phase 1 of the outbreak period (lanes 3, 4, 5, 6), 2 case patient isolates from phase 2 of the outbreak period (lanes 7, 9), 1 patient isolate from the outbreak period that did not meet the case definition (lane 8), 1 environmental isolate from phase 1 (lane 10), and the *M. abscessus* subspecies *abscessus* type strain—ATCC19977^T (lane 11). The 9 patient isolates included samples from bronchoalveolar lavage (n = 5), blood (n = 1), pleural fluid (n = 1), sputum (n = 1), and sternal wound (n = 1). All clinical and environmental isolates (lanes 1–10) were clonal [30]. Isolates were indistinguishable or closely related except isolate 8 (possibly related), and all 10 isolates were unrelated to the *M. abscessus* subspecies *abscessus* type strain (lane 11). Seven additional environmental isolates from phase 1 were also indistinguishable (data not shown). *B*, Isolates selected for this panel demonstrated gene sequencing consistent with outbreak clone B [*erm*(41) gene: subspecies *massiliense*; *rpo*β gene: subspecies *abscessus*]. The panel includes 4 preoutbreak patient isolates from 2007 through 2013 (lanes 1, 2, 3, 4), 3 case patient isolates from phase 1 of the outbreak period (lanes 5, 6, 7), 1 case patient isolate from phase 2 of the outbreak period (lane 9), 2 patient isolates from the outbreak period that did not meet the case definition (lanes 8, 10), and the *M. abscessus* subspecies *massiliense* type strain—CIP108297^T (lane 11). The 10 patient isolates included samples from bronchoalveolar lavage (n = 4), blood (n = 2), pleural fluid (n = 2), soft tissue (n = 1), and sputum (n = 1). All patient isolates (lanes 1–10) except isolate 10 were clonal [30]. Patient isolates other than isolate 10 were indistinguishable or closely related except isolates 1 and 9 (possibly related). Isolate 6 had poor image resolution but appeared related. All 10 isolates were unrelated to the *M. abscessus* subspecies *massiliense* type strain (lane 11).

amplification of NTM in the addition's water supply over time. These conditions contributed to low chloramine levels and water temperatures favorable for *M. abscessus* growth.

Our initial mitigation strategy eliminated exposure to tap water for high-risk patients via a protocol that used only sterile water for clinical care practices. We observed a sustained decrease in the incidence rate of *M. abscessus* obtained from pulmonary sources after this intervention. Then, after a second cluster of cases occurred in patients after cardiac surgery, we purchased new HCUs, intensified the HCU disinfection protocol, and began using only sterile water for HCU water changes. Subsequently, the outbreak among cardiac surgery patients resolved.

We also implemented water engineering–related mitigation strategies designed to decrease the burden of *M. abscessus* in the hospital water supply (Table 3). Complete eradication of *M. abscessus* and associated biofilms from hospital tap water and plumbing infrastructure was not realistic given the environmental persistence of NTM [32]. Nonetheless, engineering interventions should decrease risk of patient colonization if tap water exposure occurs despite avoidance strategies.

Other recent outbreaks of postoperative invasive NTM infections traced to the use of CPB and Stöckert 3T HCUs have received widespread attention. Sax et al investigated an outbreak of *Mycobacterium chimaera* at a Swiss hospital among cardiac surgery patients that was molecularly linked to colonized HCUs [25, 39]. Hospitals in Europe, Pennsylvania, and Iowa have also reported *M. chimaera* infections following cardiac surgery [40–43]. Whole genome sequencing performed on *M. chimaera* isolates from 11 patients and 5 Stöckert 3T HCUs from hospitals in Pennsylvania and Iowa suggested point-source contamination [44], which may have occurred at the manufacturing site in Germany [45]. The FDA and Centers for Disease Control and Prevention released updated safety recommendations in October 2016 that advised avoidance of 3T HCU devices manufactured prior to September 2014 and notification of patients who had been exposed to these devices [36, 46].

Data from our investigation do not conclusively prove that aerosolization of *M. abscessus* from colonized HCUs caused invasive infections in cardiac surgery patients; however, we believe this mechanism provides the most likely explanation for these infections (see page 5 of the Supplementary Data). Infections in cardiac surgery patients at our hospital most likely arose from *M. abscessus* present in the hospital water supply that in turn colonized HCUs. In contrast, outbreaks of *M. chimaera* in cardiac surgery patients at multiple other hospitals worldwide likely stemmed from point-source contamination in Germany [44, 45].

This outbreak and investigation has important implications for other medical centers (Table 3). First, NTM are often present in hospital water, and factors that increase their concentration or promote aerosolization onto vulnerable patients

Table 3. Selected Interventions Made and Recommendations for Other Healthcare Facilities to Decrease Risk of Healthcare-Associated Nontuberculous Mycobacterial Infection

Intervention Made at Our Hospital	Recommendations for Other Healthcare Facilities
Clinical practice and equipment-related interventions	
Sterile water use for direct patient-care activities of patients at risk	• Healthcare facilities with infections from NTM should consider avoidance of tap water [35] and use of sterile water for patient care activities, such as oral care, enteral tube flushing, speech assessment, consumption, and bathing. • Local epidemiology should determine target patient groups, potentially including critically ill and immunosuppressed patients, those with disrupted gastrointestinal tracts, and patients with early postoperative wounds. Continuing to avoid tap water after hospital discharge may also reduce risk for recent lung or heart transplant recipients.
HCU sterile water use and disinfection protocol	• Hospitals should adhere to FDA and manufacturer recommendations for HCU use, water changes, and disinfection practices [36, 37].
Epidemiologic and clinical surveillance for NTM infection	• Hospital epidemiologists should perform retrospective and prospective surveillance for invasive NTM infections. • Clinicians should consider NTM infection when evaluating patients with infection after cardiac surgery, especially for atypical clinical manifestations and prolonged incubation periods. • Clinicians should request mycobacterial cultures, particularly for surgical specimens.
Environmental and engineering-based interventions	
Periodic flushing of both cold water and recirculating hot water; removal of flow restrictors and redundancies in plumbing system	• Facilities with high-efficiency and/or recirculating water systems should consult with water engineering experts about periodically flushing stagnant or recirculating water from the circulation, avoiding or removing flow restrictors, and minimizing redundancies in the plumbing system.
Monitoring of hot water temperatures and flow times to water outlets	• Water engineering personnel should perform surveillance of hot water temperatures throughout the hot water distribution system [38].
Monitoring of chloramine levels in hospital water supply	• Water engineering personnel should measure disinfectant (eg, chloramine or chorine) levels at entry to the facility and at point of use. If proximal disinfectant levels are low, healthcare facilities may need to contract with municipal water authorities.
Installation of point-of-use water filters in clinical locations	• Facilities with endemic NTM should consider use of 0.2-μm point-of-use water filters [32].
Mycobacterial cultures of biofilms obtained from hospital water outlets	• If facilities experience outbreaks of NTM, they should evaluate the water system and associated equipment for NTM colonization.

Abbreviations: FDA, US Food and Drug Administration; HCU, heater-cooler unit; NTM, nontuberculous mycobacteria.

can produce outbreaks. Second, long-term surveillance for NTM by healthcare facilities is critical for outbreak detection. NTM surveillance is difficult and can be complicated by preexisting endemic disease in the community with the same NTM strains, atypical clinical manifestations, and prolonged incubation periods. Third, strategies that minimize exposure of vulnerable patients to waterborne NTM can successfully mitigate outbreaks; however, multiple or unexpected types of exposures may occur. Therefore, in response to outbreaks, we recommend combining water avoidance strategies with water engineering–based interventions designed to decrease the concentration of NTM colonizing healthcare facility water or equipment. We found that redundant water systems designed to conserve water may create low-flow states and contribute to NTM proliferation within hospital plumbing systems. Indications and methods for screening healthcare facility water systems for NTM to help prevent outbreaks need to be developed.

This investigation had limitations. The case definition did not differentiate colonization from invasive infection because of the inherent difficulties in making this clinical distinction, especially in lung transplant patients. Also, our investigation did not capture infected patients with negative cultures, no cultures, or those who did not return to our hospital for follow-up. In addition, while many patients died, we cannot state that these deaths were attributable to *M. abscessus* infection, in part because many patients were critically ill with multiple comorbidities in addition to *M. abscessus* infection. Finally, to protect subsequent patients, we implemented an HCU disinfection protocol prior to confirming a microbiological link between colonized HCUs and invasive *M. abscessus* infections following cardiac surgery. The limited number of HCU cultures and low sensitivity of environmental culture techniques for NTM [2] could explain our inability to microbiologically confirm HCU colonization with *M. abscessus*.

In summary, we utilized a multidisciplinary team to investigate and mitigate a hospital-associated outbreak of clonally related *M. abscessus* that was epidemiologically linked to colonized tap water. We made multiple patient care and water engineering interventions. Primary interventions included institution of an inpatient sterile water protocol for high-risk patients, implementation of a protocol for enhanced disinfection and sterile water use for HCUs of CPB machines, and water engineering changes designed to decrease NTM burden in the plumbing system. Other healthcare facilities, particularly those with endemic NTM or newly constructed patient care facilities,

should consider similar multifaceted strategies to improve water safety and decrease risk of healthcare-associated infection from NTM.

Supplementary Data

Supplementary materials are available at *Clinical Infectious Diseases* online. Consisting of data provided by the authors to benefit the reader, the posted materials are not copyedited and are the sole responsibility of the authors, so questions or comments should be addressed to the corresponding author.

Notes

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The Biofilm Matrix

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The biofilm matrix

Hans-Curt Flemming and Jost Wingender

Abstract | The microorganisms in biofilms live in a self-produced matrix of hydrated extracellular polymeric substances (EPS) that form their immediate environment. EPS are mainly polysaccharides, proteins, nucleic acids and lipids; they provide the mechanical stability of biofilms, mediate their adhesion to surfaces and form a cohesive, three-dimensional polymer network that interconnects and transiently immobilizes biofilm cells. In addition, the biofilm matrix acts as an external digestive system by keeping extracellular enzymes close to the cells, enabling them to metabolize dissolved, colloidal and solid biopolymers. Here we describe the functions, properties and constituents of the EPS matrix that make biofilms the most successful forms of life on earth.

Biofilm
A loose definition for microbial aggregates that usually accumulate at a solid–liquid interface and are encased in a matrix of highly hydrated EPS. Included in this definition are cell aggregates such as flocs (floating biofilms) and sludge, which are not attached to an interface but which share the characteristics of biofilms. Multispecies biofilms can form stable microconsortia, develop physiochemical gradients, and undergo horizontal gene transfer and intense cell–cell communication, and these consortia therefore represent highly competitive environments.

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Microorganisms do not live as pure cultures of dispersed single cells but instead accumulate at interfaces to form polymicrobial aggregates such as films, mats, flocs, sludge or 'biofilms' (REF. 1). In most biofilms, the microorganisms account for less than 10% of the dry mass, whereas the matrix can account for over 90%. The matrix is the extracellular material, mostly produced by the organisms themselves, in which the biofilm cells are embedded. It consists of a conglomeration of different types of biopolymers — known as extracellular polymeric substances (EPS) — that forms the scaffold for the three-dimensional architecture of the biofilm and is responsible for adhesion to surfaces and for cohesion in the biofilm. The formation of a biofilm allows a lifestyle that is entirely different from the planktonic state. Although "the precise and molecular interactions of the various secreted biofilm matrix polymers … have not been defined, and the contributions of these components to matrix integrity are poorly understood at a molecular level" (REF. 2), several functions of EPS have been determined (TABLE 1), demonstrating a wide range of advantages for the biofilm mode of life.

EPS immobilize biofilm cells and keep them in close proximity, thus allowing for intense interactions, including cell–cell communication, and the formation of synergistic microconsortia. Owing to the retention of extracellular enzymes, a versatile external digestive system is generated, sequestering dissolved and particulate nutrients from the water phase and allowing them to be utilized as nutrient and energy sources. The matrix also acts as a recycling centre by keeping all of the components of lysed cells available. This includes DNA, which may represent a reservoir of genes for horizontal gene transfer. EPS can also serve as a nutrient source, although some components of EPS are only slowly biodegradable and, owing to the complexity of EPS, complete degradation of all components requires a wide range of enzymes. The matrix protects organisms against desiccation, oxidizing or charged biocides, some antibiotics and metallic cations, ultraviolet radiation, many (but not all) protozoan grazers and host immune defences. Ecologically, competition and cooperation in the confined space of the EPS matrix lead to a constant adaptation of population fitness.

It is unclear whether the matrix confers an ecological advantage on all cells in the biofilm, in particular those that are furthest from the surface. Simulations of competition in a biofilm revealed a strong evolutionary benefit for polymer producers at the expense of non-producers, possibly because polymers push the daughter cells of polymer producers closer to oxygen-rich environments[3].

EPS have been called 'the dark matter of biofilms' because of the large range of matrix biopolymers and the difficulty in analysing them[4]. EPS can vary greatly between biofilms, depending on the microorganisms present, the shear forces experienced, the temperature and the availability of nutrients. EPS were initially denoted 'extracellular polysaccharides' but were renamed, as it became clear that the matrix also contains proteins, nucleic acids, lipids and other biopolymers such as humic substances[1,5]. Extracellular bacterial structures such as flagella, pili and fimbriae can also stabilize the matrix[6]. Membrane vesicles derived from outer membranes of Gram-negative bacteria can contain a range of enzymes and DNA and can alter matrix properties[7], sometimes acting as 'killer vesicles' targeted at competing biofilm organisms.

Table 1 | **Functions of extracellular polymeric substances in bacterial biofilms**

Function	Relevance for biofilms	EPS components involved
Adhesion	Allows the initial steps in the colonization of abiotic and biotic surfaces by planktonic cells, and the long-term attachment of whole biofilms to surfaces	Polysaccharides, proteins, DNA and amphiphilic molecules
Aggregation of bacterial cells	Enables bridging between cells, the temporary immobilization of bacterial populations, the development of high cell densities and cell–cell recognition	Polysaccharides, proteins and DNA
Cohesion of biofilms	Forms a hydrated polymer network (the biofilm matrix), mediating the mechanical stability of biofilms (often in conjunction with multivalent cations) and, through the EPS structure (capsule, slime or sheath), determining biofilm architecture, as well as allowing cell–cell communication	Neutral and charged polysaccharides, proteins (such as amyloids and lectins), and DNA
Retention of water	Maintains a highly hydrated microenvironment around biofilm organisms, leading to their tolerance of dessication in water-deficient environments	Hydrophilic polysaccharides and, possibly, proteins
Protective barrier	Confers resistance to nonspecific and specific host defences during infection, and confers tolerance to various antimicrobial agents (for example, disinfectants and antibiotics), as well as protecting cyanobacterial nitrogenase from the harmful effects of oxygen and protecting against some grazing protoza	Polysaccharides and proteins
Sorption of organic compounds	Allows the accumulation of nutrients from the environment and the sorption of xenobiotics (thus contributing to environmental detoxification)	Charged or hydrophobic polysaccharides and proteins
Sorption of inorganic ions	Promotes polysaccharide gel formation, ion exchange, mineral formation and the accumulation of toxic metal ions (thus contributing to environmental detoxification)	Charged polysaccharides and proteins, including inorganic substituents such as phosphate and sulphate
Enzymatic activity	Enables the digestion of exogenous macromolecules for nutrient acquisition and the degradation of structural EPS, allowing the release of cells from biofilms	Proteins
Nutrient source	Provides a source of carbon-, nitrogen- and phosphorus-containing compounds for utilization by the biofilm community	Potentially all EPS components
Exchange of genetic information	Faciliates horizontal gene transfer between biofilm cells	DNA
Electron donor or acceptor	Permits redox activity in the biofilm matrix	Proteins (for example, those forming pili and nanowires) and, possibly, humic substances
Export of cell components	Releases cellular material as a result of metabolic turnover	Membrane vesicles containing nucleic acids, enzymes, lipopolysaccharides and phospholipids
Sink for excess energy	Stores excess carbon under unbalanced carbon to nitrogen ratios	Polysaccharides
Binding of enzymes	Results in the accumulation, retention and stabilization of enzymes through their interaction with polysaccharides	Polysaccharides and enzymes

EPS, extracellular polymeric substances.

Extracellular polymeric substances
Hydrated biopolymers (including polysaccharides, proteins, nucleic acids and lipids) that are secreted by biofilm cells to encase and immobilize microbial aggregates. These biopolymers are responsible for the macroscopic appearance of biofilms, which are frequently referred to as 'slime'.

Globally, EPS represent a dominant fraction of the reduced-carbon reservoir in soils and in sediments, and suspended aggregates in oceans and freshwater. There, they serve as nutrients and thus play an important part in microbial ecology[8–12].

In this Review, we focus on the role of these matrix components in the architecture of bacterial biofilms, discuss the challenges of isolating EPS and describe the different components of biofilms. BOX 1 provides information about EPS of other organisms.

EPS and biofilm architecture

Cells in a biofilm are surrounded by EPS, which constitute the immediate environment of these cells. Some EPS, in particular those forming capsules, are associated more closely with cell surfaces than others. The formation and maintenance of structured multicellular microbial communities crucially depend on the production and quantity of EPS[13]. The concentration, cohesion, charge, sorption capacity, specificity and nature of the individual components of EPS, as well as the three-dimensional architecture of the matrix (the dense areas, pores and channels), determine the mode of life in a given biofilm. The resulting biofilm morphology can be smooth and flat, rough, fluffy or filamentous, and the biofilm can also vary in its degree of porosity, having mushroom-like macrocolonies surrounded by water-filled voids. All of these morphologies have the same effect: to transiently immobilize biofilm cells and allow the existence of long-term mixed-species microconsortia, with their interactions and gradients; this provides very diverse habitats on a small scale, favouring biodiversity.

Box 1 | Extracellular polymeric substances from fungi, algae and archaea

Extracellular polymeric substances (EPS) are not unique to bacteria. Some of the most abundant EPS producers are microalgae (in particular, diatoms)[103]. Microalgal EPS play important parts in the stabilization of sediments[104] and the entrainment of sand[105], but they are also involved in marine fouling. The green alga *Penium margaritaceum* has been shown to produce large amounts of EPS (predominantly polysaccharides[106,107]) that, in turn, support the growth of heterotrophic bacteria which use EPS as a substrate. Fungi (yeasts and moulds) also produce EPS. Examples are certain *Candida* spp.[108] that produce EPS which are involved in the processes of flocculation, adhesion and biofilm formation[109]. The archaeon *Sulfolobus solfataricus* produces polysaccharides in response to adhesion[110]; other than this, there is surprisingly little information about the EPS matrices of archaea.

The use of microelectrodes (to monitor oxygen levels, for example) revealed spatial heterogeneity in biofilms on a micrometre scale[14] (FIG. 1). On the basis of staining with lectins and imaging with confocal laser scanning microscopy to differentiate various EPS components and biofilm organisms, it was concluded that the EPS matrix provides a physical structure that segregates microdomains[15]. These regions harbour different biochemical environments that are enzymatically modified in response to changing conditions. For further investigation of the matrix architecture, a reliable allocation of the binding sites of lectins is crucial. Chemical analyses can possibly be put into a spatial context by combining confocal laser scanning microscopy and Raman microscopy[16] (BOX 2).

The architecture of biofilms is influenced by many factors, including hydrodynamic conditions, concentration of nutrients, bacterial motility and intercellular communication as well as exopolysaccharides and proteins, as demonstrated by the altered morphology of biofilms produced by mutants lacking components of EPS. For example, exopolysaccharides of *Vibrio cholerae*[17] and colanic acid of *Escherichia coli*[18] are involved in the formation of a three-dimensional biofilm architecture. The *Bacillus subtilis* biofilm matrix consists of an exopolysaccharide and the secreted protein TasA, both of which are required for the structural integrity of the matrix and the development of biofilm architecture in the form of fruiting body-like structures[19]. During aggregation of the soil bacterium *Myxococcus xanthus*, the polysaccharide component of the extracellular matrix forms a scaffold within the fruiting-body structure[20]. One of the best studied exopolysaccharides involved in biofilm formation is alginate in the biofilms of mucoid strains of the opportunistic pathogen *Pseudomonas aeruginosa*[21,22]. Alginate is not essential for *P. aeruginosa* biofilm formation[23], but it has a notable effect on biofilm architecture when it is present. Under conditions in which alginate producers form structurally heterogeneous biofilms, non-mucoid strains develop flat and more homogeneous biofilms (FIG. 2a–c).

Acetyl groups are common substituents of exopolysaccharides, and they increase the adhesive and cohesive properties of EPS and alter biofilm architecture. The modification of alginate with acetyl groups strongly influences the aggregation of bacteria into microcolonies and determines the structurally heterogeneous architecture of mature biofilms[21,22] (FIG. 2e,f). Biofilm architecture can also be strongly influenced by the interaction of anionic EPS, containing carboxylic groups, with multivalent cations. For example, Ca^{2+} can form a bridge between polyanionic alginate molecules, stimulating the development of thick and compact biofilms with increased mechanical stability[24] (FIG. 2d).

Humic substance
A component of the natural organic matter in soil and water enviroments. Humic substances are mixtures of compounds that are formed by limited degradation and transformation of dead organic matter and that are resistant to complete biodegradation. They can be divided into three main fractions: humic acids, fulvic acids and humin. They usually include phenolic and polyaromatic compounds (containing peptide and carbohydrate moieties with carboxylic substituents), providing the acidic character.

Flagellum
A long, thin, helically shaped bacterial appendage that provides motility. A flagellum consists of several components and moves by rotation, much like a propeller. The motor is anchored in the cytoplasmic membrane and the cell wall.

Pilus
A bacterial surface structure that is similar to a fimbria but is typically a longer structure, and that is present on the cell surface in one or two copies. Pili can be receptors for bacteriophages and also facilitate genetic exchange between bacterial cells during conjugation. Type IV pili mediate twitching motility, which is a flagella-independent form of bacterial translocation over surfaces, and can be involved in biofilm development.

Isolation of EPS

The identification of EPS components depends on the isolation method used. However, efficient EPS isolation is challenging, particularly for EPS from environmental biofilms, which can contain an immense range of components that each require different extraction methods. In a mixed-species biofilm, many members of the microbial community contribute their own (and often specific) EPS that then merge into a complex mixture[11] and remain in the matrix even after their producers have died or left the biofilm. Furthermore, it is next to impossible to quantitatively isolate EPS from a given biofilm, because some of the EPS fraction remains bound to the bacteria, and because the isolation procedure damages cells, causing intracellular material to leak into the matrix.

There is no universal EPS isolation method — the extraction procedure has to be adapted to the specific type of biofilm under investigation. Centrifugation, filtration, heating, blending, sonication, and treatment with complexing agents and with ion exchanger resins have been described[25,26], and the use of sodium hydroxide has even been reported[27], although this method almost certainly leads to contamination with cytoplasmic components. One popular method uses a cation exchanger resin[28], which removes the cations that bridge the negatively charged groups of the polysaccharide and protein moieties of EPS. Alginate from *P. aeruginosa* is comprised solely of uronic acids, which are not found inside the cells and can therefore be used as EPS markers during isolation[29]. The presence of intracellular enzymes, such as glucose-6-phosphate 1-dehydrogenase (G6PD, also known as Zwf), indicates contamination with cellular components. Following extraction, a common concentration step is to precipitate solubilized EPS by adding ethanol or acetone[11]; however, this method primarily precipitates polysaccharides, leading to an underestimation of the other components of EPS.

Common EPS isolation techniques inherently select for water-soluble EPS and lose insoluble EPS, including cellulose, which is an important constituent of the matrices of many bacteria. Cellulose plays an important part in biofilm-related infections caused by *Escherichia coli*, *Klebsiella pneumoniae*, *Enterobacter* spp., *Citrobacter* spp. and *Salmonella enterica* subsp. *enterica* serovar Typhimurium[6,30–32]. Isolation of cellulose requires harsh conditions, such as treatment with acetic acid and nitric acid at 95 °C[3].

Exopolysaccharides

Polysaccharides are a major fraction of the EPS matrix[28,29]. Most are long molecules, linear or branched, with a molecular mass of 0.5×10^6 daltons to 2×10^6 daltons.

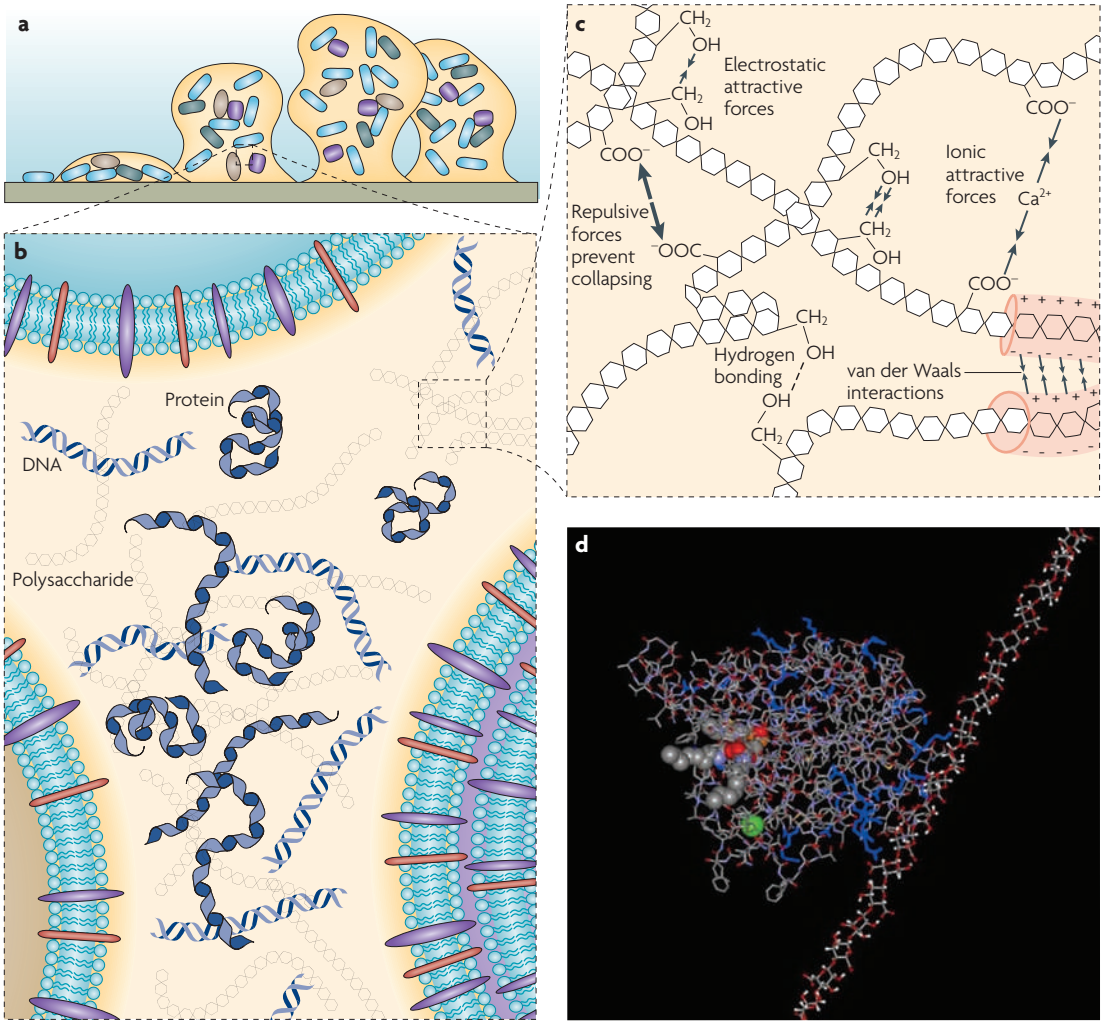


Figure 1 | **The extracellular polymeric substances matrix at different dimensions. a** | A model of a bacterial biofilm attached to a solid surface. Biofilm formation starts with the attachment of a cell to a surface. A microcolony forms through division of the bacterium, and production of the biofilm matrix is initiated. Other bacteria can then be recruited as the biofilm expands owing to cell division and the further production of matrix components. **b** | The major matrix components — polysaccharides, proteins and DNA — are distributed between the cells in a non-homogeneous pattern, setting up differences between regions of the matrix. **c** | The classes of weak physicochemical interactions and the entanglement of biopolymers that dominate the stability of the EPS matrix[47]. **d** | A molecular modelling simulation of the interaction between the exopolysaccharide alginate (right) and the extracellular enzyme lipase (left) of *Pseudomonas aeruginosa* in aqueous solution. The starting structure for the simulation of the lipase protein was obtained from the Protein Data Bank[117]. The coloured spheres represent 1,2-dioctylcarbamoyl-glycero-3-*O*-octylphosphonate in the lipase active site (which was present as part of the crystal structure), except for the green sphere, which represents a Ca^{2+} ion. The aggregate is stabilized by the interaction of the positively charged amino acids arginine and histidine (indicated in blue) with the polyanionic alginate. Water molecules are not shown. Image courtesy of H. Kuhn, CAM-D Technologies, Essen, Germany.

Several polysaccharides have been visualized by electron microscopy as fine strands that are attached to the cell surface and form complex networks. Microscopic techniques in combination with specific carbohydrate staining using fluorescently labelled lectins or antibodies (BOX 2), as well as biochemical analyses for independent verification, have demonstrated the ubiquity of matrix polysaccharides not only in biofilms from natural marine, freshwater and soil environments and from man-made water systems, but also in biofilms associated with chronic infections in humans and in pure-culture experimental biofilms. In recent years, exopolysaccharides from an extensive range of bacterial species from diverse environments have been isolated and characterized[33].

Several exopolysaccharides are homopolysaccharides, including the sucrose-derived glucans and fructans produced by the streptococci in oral biofilms, and cellulose formed by *Gluconacetobacter xylinus*, *Agrobacterium tumefaciens*, *Rhizobium* spp. and various species from the Enterobacteriaceae[6] and Pseudomonadaceae families[29]. However, most exopolysaccharides are

Fimbria
A filamentous structure composed of one or a few proteins that extends from the surface of a cell and can have diverse functions. Fimbriae are involved in attachment to both animate and inanimate surfaces and in the formation of pellicles and biofilms. They assist in the disease process of some pathogens, such as *S. enterica*, *Neisseria gonorrhoea* and *Bordetella pertussis*.

Membrane vesicle
A vesicle that is formed from the outer membrane of Gram-negative bacteria, is secreted from the cell surface and contains extracellular enzymes and nucleic acids. These vesicles may represent mobile elements in the EPS matrix.

Capsule
A discrete polysaccharide (sometimes also protein) layer that is firmly attached to the surface of a bacterial cell, closely surrounding it, in contrast to less compact, amorphous slime that is shed into the more distant extracellular environment.

Lectin
A protein or glycoprotein of plant, animal or microbial origin that binds to carbohydrates with a characteristic specificity. Fluorescently labelled lectins can be used as probes to investigate EPS composition, enabling the microscopic *in situ* detection of EPS and their distribution in biofilms.

Raman microscopy
A spectroscopic technique based on inelastic light scattering (Raman scattering) of monochromatic laser light in the near-ultraviolet range, revealing vibrational, rotational and other low-frequency modes in a system. The technique is used for the analysis of chemical bonds and is suitable for very small volumes, allowing spectra and chemical information to be obtained for the molecules present in that volume.

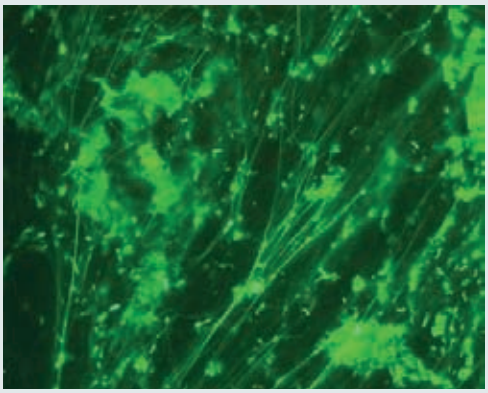
Box 2 | ***In situ* detection of extracellular polymeric substances**

The most important tool for non-destructive *in situ* detection of components of the extracellular polymeric substances (EPS) in biofilms is confocal laser scanning microscopy (CLSM) in combination with fluorescent dyes[15]. Using fluorescently labelled lectins, exopolysaccharides are visualized according to their interaction with specific target sugars. Such approaches have revealed the complex composition and arrangement of EPS in natural biofilms[15]. Fluorescently labelled antibodies against exopolysaccharides have been used in a similar way[111]; this technique is well established for use with pure cultures. In an excellent overview of the topic, Neu and Lawrence[112] reported clear-cut specific multilabelling but also nonspecific binding patterns with both lectins and antibodies.

A promising approach is the use of CLSM-based lectin-binding analysis in combination with Raman microscopy[16]. This combination gives a more in-depth insight into EPS composition. However, the allocation of spectra to individual lectin-stained clusters remains a challenge and requires substantial further development.

An approach to localizing enzymatic activity in biofilms is direct microscopic visualization by staining with fluorogenic substrates[43]. Phosphatase activity in laboratory biofilms and in activated sludge flocs was detected using the water-soluble substrate ELF-97 phosphate, which yields an insoluble fluorescent precipitate upon cleavage by the enzyme. This method allowed the spatial distribution of phosphatase activity to be studied in whole flocs and in vertical sections of biofilms. Extracellular redox activity was visualized by reduction of the tetrazolium salt 5-cyano-2,3-di-4-tolyl tetrazolium chloride (CTC) to CTC formazan crystals at the point of reaction.

Extracellular DNA can be detected with dye specific for nucleic acid. For example, a 4-day-old culture of the gammaproteobacterium strain F8 (which was isolated from the Saskatchewan river, Canada) was grown on freshwater basal-medium agar and subsequently stained with the dye SYTO9 to visualize the DNA (see the figure). Aside from the DNA, the bacteria are visible as small rods between the DNA strands. Image courtesy of U. Boeckelmann and U. Szewzyk, Technische Universität Berlin, Germany.



heteropolysaccharides that consist of a mixture of neutral and charged sugar residues. They can contain organic or inorganic substituents that greatly affect their physical and biological properties. Owing to the presence of uronic acids (and, in some cases, ketal-linked pyruvate or, rarely, sulphate), many known exopolysaccharides, including alginate, xanthan and colanic acid, are polyanionic. Polycationic exopolysaccharides also exist, such as intercellular adhesin, which is composed of β-1,6-linked *N*-acetylglucosamine with partly deacetylated residues. This adhesin was discovered in important nosocomial pathogens such as *Staphylococcus aureus* and *Staphylococcus epidermidis*, which can colonize medical implants and lead to biofilm-related infections[34], and it has since been detected in a range of other bacteria[35].

Exopolysaccharides can be diverse even between strains of a single species; for example, various *Streptococcus thermophilus* strains produce heteropolysaccharides of different monomer compositions and ratios and different molecular masses[36]. *P. aeruginosa*, one of the best studied models for biofilm formation, produces at least three distinct exopolysaccharides that contribute to biofilm development and architecture: alginate, Pel and Psl[37]. Alginate is one of the most extensively studied exopolysaccharides, but it consists of only uronic acids and so is not representative of all exopolysaccharides. Alginate is a high-molecular-mass, unbranched heteropolymer consisting of 1,4-linked uronic residues of β-D-mannuronate and α-L-guluronate. These components are arranged in homopolymeric blocks of polymannuronate and heteropolymeric sequences with a random distribution of guluronate and partially *O*-acetylated mannuronate residues. Overproduction of alginate is characteristic of mucoid strains and is usually as a result of mutations in the gene encoding the σ-factor AlgU negative regulator (MucA). Alginate is involved in the establishment of microcolonies at the beginning of biofilm formation, but it is also responsible for the mechanical stability of mature biofilms. However, in non-mucoid wild-type strains, which do not express alginate biosynthesis genes, the polysaccharides Pel and Psl are involved in the establishment of biofilms. Pel is a glucose-rich polysaccharide, whereas Psl consists of a repeating pentasaccharide containing D-mannose, D-glucose and L-rhamnose[38]. Pel is essential for the formation of biofilms (called pellicles) at air–liquid interfaces and biofilms that are attached to a surface, and Psl is involved in the adherence to abiotic and biotic surfaces and in the maintenance of biofilm architecture. During attachment, Psl is anchored to the cell surface in a helical pattern, possibly promoting cell–cell interactions[39]. It then accumulates in the periphery of microcolonies during biofilm maturation, preparing a Psl-free cavity in the microcolony centre for the subsequent dispersal stage (BOX 3), during which this matrix cavity contains swimming cells together with dead cells and extracellular DNA (eDNA)[39].

In many bacteria, exopolysaccharides are indispensable for biofilm formation, and mutants that cannot synthesize exopolysaccharides are severely compromised or unable to form mature biofilms[17,18,39] (although bacteria may still attach to surfaces and form microcolonies to a limited extent). However, in mixed-species biofilms the presence of a species that produces exopolysaccharides may lead to the integration of other species that do not synthesize matrix polymers[13]. Therefore, the proportions of different exopolysaccharides in mixed biofilms do not necessarily reflect the proportions of the cells present, nor do the different exopolysaccharides add equally to the structure and properties of the resulting biofilms[40].

Extracellular proteins

The biofilm matrix can contain considerable amounts of proteins that, together, can far exceed the polysaccharide content, on a mass basis[28,41]. This has been reported for environmental biofilms as well as for activated sludge and biofilms in sewers[42].

Enzymes. Various extracellular enzymes have been detected in biofilms, many of which are involved in the degradation of biopolymers. The substrates of these extracellular enzymes include water-soluble polymers (such as many polysaccharides, proteins and nucleic acids) and water-insoluble compounds (such as cellulose,

chitin and lipids), as well as organic particles that are trapped in biofilms[43] (TABLE 2). The presence of enzymes that degrade EPS components makes the matrix an external digestive system that breaks down biopolymers to low-molecular-mass products that can then be taken up and utilized as carbon and energy sources. In addition, some enzymes can be involved in the degradation of structural EPS to promote the detachment of bacteria from biofilms. Other enzymes act as virulence factors in medical biofilms during infectious processes.

Some extracellular enzymes from bacteria (and some from fungi) are of commercial interest and are produced on a large scale industrially. In addition, extracellular enzymes carry out self-purification processes in soils, sediments and water, and these processes have been adopted for the biological treatment of drinking water and waste water, using biofilms and flocs to degrade organic substances.

Extracellular enzymes are also used for the degradation of synthetic polymers by degrading additives such as plasticizers (for example, terephthalates) or antioxidants, or by attacking the polymer backbone[44]. Furthermore, extracellular redox enzymes play a part in microbially influenced corrosion[45].

Extracellular enzymes can be efficiently retained in the biofilm matrix by their interaction with polysaccharides[43,46]. For example, the association of extracellular lactonizing lipase (LipA; also known as Lip) with alginate produced by *P. aeruginosa* is based on weak binding forces[47]; this hypothesis is supported by molecular modelling (FIG. 1d). Such interactions result in a matrix of exopolysaccharides that are biochemically activated by the attached enzymes. This arrangement retains the enzymatic activity close to the cell and keeps the diffusion distances of enzymatic products short, thereby optimizing their uptake by bacteria. Moreover, the interactions between enzymes and structural exopolysaccharides enhance the thermostability of the enzymes and their resistance to proteolysis[40].

EPS-modifying enzymes. Various enzymes can potentially degrade EPS components during starvation, targeting EPS made by the bacterium that produces the enzyme or EPS made by other species[29,48]. Examples are the dextran, inulin and levan that are formed by oral streptococci[49] and the levan that is present in the matrix voids of *Pseudomonas syringae* biofilms[50]. Exopolysaccharides are degraded mainly by hydrolases and lyases[31,50], but degradation is generally slow. In marine stromatolites, EPS polysaccharides and proteins are secreted by the bacteria and are then rapidly fragmented and rearranged by degradation, specifically by sulphate-reducing bacteria, to a more refractory polymer[11]. Furthermore, a very important stage in biofilm development is the dispersion of sessile cells from the biofilms, which allows new biofilms to be formed[39,51]. This dispersion occurs in response to environmental changes; it can be induced by nutrient starvation[52] or sudden nutrient availability[51] and requires modification of the matrix by enzymes secreted from the bacteria[51]. An example of an enzyme that degrades exopolysaccharides to allow detachment and dispersal of biofilm cells is *N*-acetyl-β-hexosaminidase (encoded by *dspB*), which is produced by the periodontal pathogen *Actinobacillus actinomycetemcomitans*[53]. A *dspB* mutant formed biofilms that could not release cells.

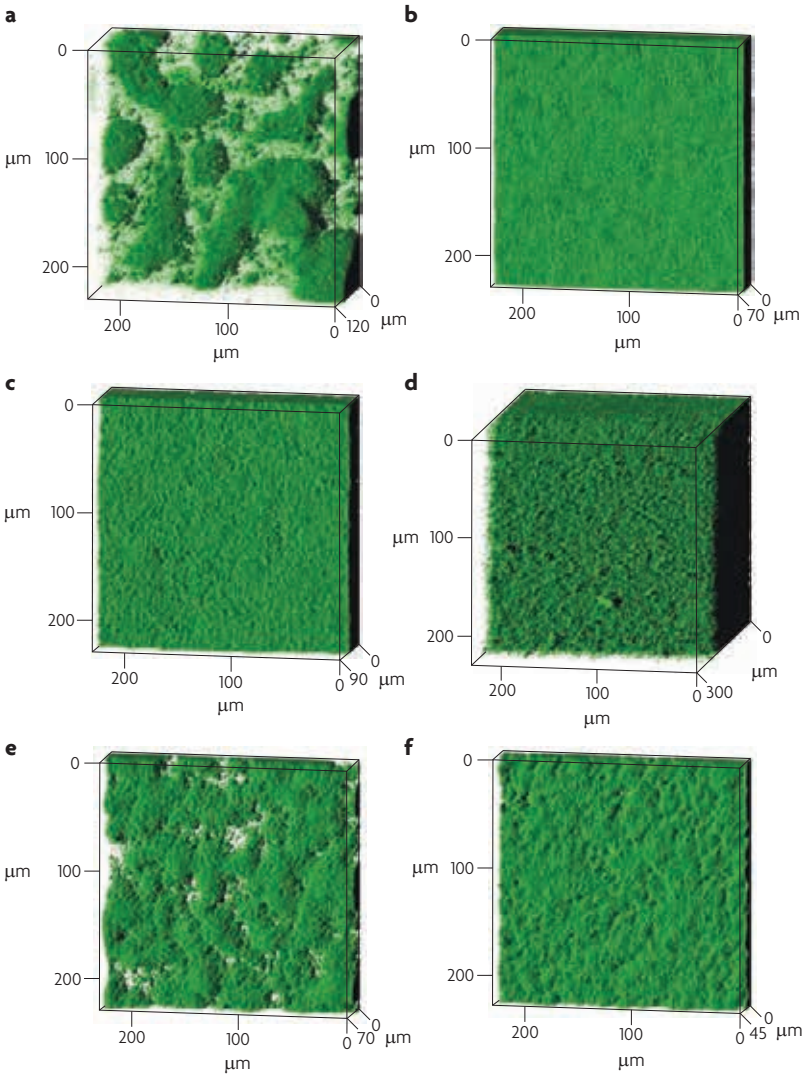


Figure 2 | **Dynamics of *Pseudomonas aeruginosa* biofilm architecture.** Confocal laser scanning microscopy images (×325 magnification) of *Pseudomonas aeruginosa* biofilms grown for 70 h on glass in a flow cell at 30 °C (with a flow rate of 20 ml per h). Biofilms were stained with DNA-binding dye SYTO9, and cells are green. **a** | A mucoid (alginate-overproducing) environmental strain, *P. aeruginosa* str. SG81 (REF. 118), which produces uneven, lumpy biofilms. **b** | A spontaneous non-mucoid revertant strain, *P. aeruginosa* str. SG81R1 (derived from *P. aeruginosa* str. SG81), which has lost the ability to produce alginate. The lack of alginate leads to the formation of smoother and flatter biofilms. **c** | The typically non-mucoid wild-type strain *P. aeruginosa* str. PAO1, which is widely used in biofilm research. This strain also produces smooth, flat biofilms. **d** | The effect of Ca^{2+} (1 mM Ca^{2+} in the growth medium) on biofilm architecture is shown for a mucoid biofilm of *P. aeruginosa* str. SG81. Ca^{2+} stabilizes the crossbridges between alginate, allowing a thicker and more stable biofilm to be formed. **e** | The dependency of mucoid biofilm architecture on the presence of *O*-acetyl groups in alginate: the clinical strain *P. aeruginosa* str. FRD1, which produces *O*-acetylated alginate, forms biofilms similar to the mucoid strain shown in part **a**. **f** | The mutant strain *P. aeruginosa* str. FRD1153 produces alginate in similar amounts to the parent strain, *P. aeruginosa* str. FRD1, but is defective in alginate acetylation and loses it mucoid phenotype. Biofilms of this strain resemble biofilms of the non-mucoid strains shown in parts **b** and **c**. Part **a**–**d** images courtesy of M. Strathmann, IWW Water Centre, Germany. Part **e** and **f** images are reproduced, with permission, from REF. 21 © (2004) Elsevier.

Box 3 | **Dispersal of biofilms**

Mixtures of enzymes for the dispersal of biofilms are described and covered by various patents, but they have poor long-term efficacy in the process of anti-fouling. Dispersion by the induction of a prophage followed by cell death and subsequent cell cluster disaggregation have been observed[100]. A substituted fatty acid, *cis*-11-methyl-2-dodecenoic acid (called 'diffusible signal factor'), was recovered from *Xanthomonas campestris* and found to be responsible for virulence as well as for inducing the release of endo-β-1,4-mannanase[113]. It has been suggested that certain species may encode stress regulons involved in biofilm dispersion. It was reported that *cis*-2-decenoic acid produced by *Pseudomonas aeruginosa* may act as a fatty acid messenger that can induce the dispersion of biofilms formed by *Escherichai coli*, *Klebsiella pneumoniae*, *Proteus mirabilis*, *Streptococcus pyogenes*, *Staphylococcus aureus*, *Bacillus subtilis* and the yeast *Candida albicans*[114]. Such a 'universal biofilm disperser' is of great interest in medical and technical systems and may be of environmental concern. Very recently, biofilm disassembly was reportedly triggered in *B. subtilis*, *P. aeruginosa* and *S. aureus* by a mixture of D-amino acids, releasing amyloid fibres that linked the cells together[115]. This process could be a strategy used by biofilm bacteria to create pores and channels locally, leading to better mass transport within the biofilm.

Bacteriophages supply a wide range of polysaccharide-degrading enzymes. However, these enzymes are very specific and rarely act on more than a few closely related polysaccharide structures. Phages and bacteria can coexist stably in biofilms, suggesting that phages would make poor tools for the control of biofilm formation. However, combinations of phage enzymes and disinfectants have been recommended as possible control strategies under certain conditions[116], and adding the phage and then the disinfectant is more effective than adding either alone.

The existence of an organism or enzyme that could disperse all biofilms would lead to a global environmental disaster, because it would find its substrates on a global scale and could compromise the self-purification function of soils and sediments as well as the functions of all biological water treatments. It is the great variability of EPS that protects biofilms and, in turn, limits the success of enzymatic anti-fouling strategies. For fast and complete biofilm removal — as is required in anti-fouling strategies, for example — existing enzymes are too slow and their activities are too limited. However, for destabilization of the matrix, they may have their virtues.

However, there is no single enzyme or simple enzyme mixture that can degrade all of the polysaccharides in a biofilm matrix.

Structural proteins. The non-enzymatic proteins in the matrix, such as the cell surface-associated and extracellular carbohydrate-binding proteins (called lectins), are involved in the formation and stabilization of the polysaccharide matrix network and constitute a link between the bacterial surface and extracellular EPS. Examples include glucan-binding proteins in biofilms of the dental pathogen *Streptococcus mutans*[54], lectin-like proteins in the matrices of activated sludge flocs[55], outer-membrane lectins of *Azospirillum brasiliense*[56] and the galactose-specific lectin LecA and fucose-specific lectin LecB[57,58] of *P. aeruginosa*, both of which have been implicated in biofilm formation. Synthetic high-affinity multivalent ligands that target LecB inhibit *P. aeruginosa* biofilm formation and induce complete dispersion of established biofilms[59], underscoring the stabilizing effect of LecB in intact biofilms of *P. aeruginosa*. The secreted protein CdrA was shown to bind directly to Psl in *P. aeruginosa* biofilms[19], leading to the suggestion that extracellular CdrA cross-links Psl molecules and thereby strengthens the matrix, whereas cell-associated CdrA anchors the cells to Psl in the matrix. The extracellular protein TasA is required for the structural integrity of *B. subtilis* biofilms, along with an exopolysaccharide[20]. Interestingly, complementation studies with *tasA* mutants and exopolysaccharide synthesis mutants revealed that TasA and the exopolysaccharide were assembled correctly outside the cells to yield a functional matrix even when each of the two EPS components was produced by different cells in the same biofilm.

Another group of extracellular proteins are biofilm-associated surface protein (Bap) from *S. aureus* and the Bap-like proteins. These are high-molecular-mass proteins on the bacterial cell surface that promote biofilm formation in several bacterial species[60]. They contain a core domain of tandem repeats that is required for the formation of a biofilm and plays a part in bacterial infectious processes. Other ubiquitous proteinaceous components of the matrix are amyloids. These compounds have been defined as orderly repeats of protein molecules arranged as fibres of indefinite length in a cross-β structure, in which the β-strands are perpendicular to the fibre axis[61]. Functional amyloids of bacterial origin have been detected in various habitats, including freshwater lakes, brackish water, drinking-water reservoirs and waste-water treatment plants[61]. Amyloids are involved in adhesion to inanimate surfaces and host cells, with subsequent invasion of the host cells, and they also function as cytotoxins for both plant cells and bacteria[61].

Lastly, proteinaceous appendages such as pili, fimbriae and flagella can also act as structural elements by interacting with other EPS components of the biofilm matrix. For example, type IV pili of *P. aeruginosa* bind DNA[62] and so possibly act as cross-linking structures. In *S.* Typhimurium and *E. coli*, the co-production of thin aggregative fimbriae and cellulose results in the formation of a rigid, hydrophobic extracellular matrix, whereas the production of either fimbriae or cellulose results in a fragile network[6], underlining the functional role of fimbriae for matrix stabilization.

Extracellular DNA

Biofilms of various origins have been found to contain eDNA, but it is reported to occur in particularly large amounts in waste-water biofilms[28], although the amount produced can vary even between closely related species. eDNA is a major structural component in the biofilm matrix of *S. aureus*, whereas it is only a minor component of biofilms formed by *S. epidermidis*[63].

Role of eDNA. Although eDNA was initially seen as residual material from lysed cells, it has become increasingly clear that it is in fact an integral part of the matrix[1] and of the biofilm mode of life[64]. The importance of nucleic acids in microbial aggregation was observed in a species from the genus *Rhodovulum*, members of which are self-flocculating bacteria; this species produces EPS consisting of carbohydrates, proteins and nucleic acids[65]. Treatment of flocculated cells with nucleolytic enzymes resulted in deflocculation, whereas polysaccharide-degrading and protein-degrading enzymes had no effect. eDNA is also a major matrix component in *P. aeruginosa* biofilms, in which it functions as an intercellular connector[66]. In addition, DNase inhibits the formation of biofilms in *P. aeruginosa*[67], and *Bacillus cereus* uses DNA as an adhesin[68].

Matrix void
A pore or channel in the biofilm matrix that contains liquid water and is not filled with hydrated EPS molecules.

Stromatolite
A laminated microbial mat that is typically built from layers of filamentous cyanobacteria and other microorganisms that become fossilized. Stromatolites are the oldest records of life on Earth, dating back 3.5 billion years.

Table 2 | **Biofilm enzymes in natural and man-made aquatic environments***

Enzyme	Type of biofilm
Protein-degrading enzymes	
Protease	River biofilms and activated sludge
Peptidase	Drinking-water biofilms, river biofilms, waste-water biofilms, sewer biofilms, marine aggregates and activated sludge
Polysaccharide or oligosaccharide-degrading enzymes	
Endocellulase	River biofilms
Chitinase	River biofilms and estuarine-sediment biofilms
α-glucosidase	River biofilms, sewer biofilms, stream sediment biofilms, lake sediment biofilms, waste-water biofilms, marine aggregates and activated sludge
β-glucosidase	River biofilms, biofilms from trickling biofilters, sewer biofilms, stream sediment biofilms, lake sediment biofilms, marine aggregates and activated sludge
β-xylosidase	River biofilms and lake sediment biofilms
N-acetyl-β-D-glucosaminidase	River biofilms, marine aggregates and activated sludge
Chitobiosidase	Marine aggregates
β-glucuronidase	Activated sludge
Lipid-degrading enzymes	
Lipase	Marine aggregates and activated sludge
Esterase	River biofilms, lake sediment biofilms, drinking-water biofilms, sewer biofilms, stream sediment biofilms and activated sludge
Phosphomonoesterases	
Phosphatase	River biofilms, sewer biofilms, stream biofilms, marine aggregates and activated sludge
Oxidoreductases	
Phenol oxidase	River biofilms
Peroxidase	River biofilms
Extracellular redox activity	Activated sludge

*Data from REF. 46.

eDNA also has antimicrobial activity, causing cell lysis by chelating cations that stabilize lipopolysaccharide and the bacterial outer membrane[69].

Localization of eDNA. The localization of eDNA can vary widely between biofilms. In *P. aeruginosa* biofilms eDNA forms a grid-like structure[70], whereas in an aquatic bacterial isolate (a gammaproteobacterium called strain F8) eDNA forms a filamentous network[71] (BOX 2). In nontypeable *Haemophilus influenzae* biofilms, eDNA is present as a dense network of fine strands as well as in individual, thicker 'ropes' that span water channels[72]. The eDNA seems to localize in a time-dependent manner in the stalks of mushroom-shaped microcolonies in biofilms. Particularly high concentrations of eDNA were found in the outer parts of the stalk, thus forming a border between stalk-forming and cap-forming *P. aeruginosa* subpopulations[70]. It was speculated that DNA in the mushroom stalks might cause the accumulation of migrating bacteria, resulting in the formation of mushroom caps.

Origin of eDNA. The origin of eDNA seems to differ between species. In gammaproteobacteria strain F8, biofilm eDNA has similarities to but also distinct differences from genomic DNA[71], indicating that this eDNA is not simply released by lysed cells. However, in *P. aeruginosa* and *Pseudomonas putida* biofilms, eDNA and genomic DNA seemed to be identical[73]. In *S. epidermidis* biofilms, eDNA is generated through the lysis of a subpopulation of the bacteria, mediated by bifunctional autolysin (AtlE). This eDNA promoted biofilm formation of the remaining population, supporting the concept of a structural function for eDNA, as suggested by Molin and Tolker-Nielsen[64]. However, lysed cells are not the only source of eDNA, and active excretion of DNA cannot be excluded.

Surfactants and lipids

Extracellular polysaccharides, proteins and DNA are highly hydrated hydrophilic molecules, but other EPS have hydrophobic properties. For example, a *Rhodococcus* sp. strain[74] that possesses a capsule but no fimbriae can adhere to Teflon and colonizes waxy leaf surfaces using EPS with hydrophobic properties. The hydrophobic character of the EPS was attributed to substituents such as polysaccharide-linked methyl and acetyl groups[75].

Lipids are also found in the matrix[41]. Lipopolysaccharides are crucial for the adherence of *Thiobacillus ferrooxidans* to pyrite surfaces[76], and *Serratia marcescens* produces extracellular lipids with surface-active properties (known as 'serrawettins')[77]. Other surface-active EPS include surfactin, viscosin and emulsan, which can disperse hydrophobic substances and make them bioavailable. They may be useful for microbially enhanced oil recovery and for bioremediation of oil spills.

Biosurfactants can have antibacterial and antifungal properties and are important for bacterial attachment and detachment from oil droplets[78]. The quest for 'green' chemicals may enhance further work on this class of molecule[79,80]. Biosurfactants generated by microorganisms at the air–water interface of surface waters obviously have an important role, influencing surface tension and, thus, the gas exchange between oceans and the atmosphere[81]. Interestingly, rhamnolipids, which can act as surfactants, have been found in the EPS matrix of *P. aeruginosa*[82]. They display surface activity and have been proposed to act in initial microcolony formation, facilitating surface-associated bacterial migration and the formation of mushroom-shaped structures, preventing colonization of channels, and playing a part in biofilm dispersion[83,84].

Water

Water is by far the largest component of the matrix, leading K. C. Marshall to call biofilms 'stiff water'. The EPS matrix provides a highly hydrated environment that dries more slowly than its surroundings and therefore buffers the biofilm cells against fluctuations in water potential. Many EPS are hygroscopic and seem to retain water entropically rather than through specific water-binding mechanisms. It has been proposed that EPS result in hydraulic decoupling during rapid wetting or drying events, protecting the biofilm-embedded bacteria

Surface-active property
The ability of a molecule to alter the interface of two different phases. Substances with surface-active properties (surfactants) are amphipatic molecules with both hydrophilic and hydrophobic (generally hydrocarbon) moieties. They partition preferentially at the interface between fluid phases with different degrees of polarity and hydrogen bonding, such as oil–water interfaces.

in unsaturated soils, for example[85]. When embedded in EPS, the cyanobacterium *Nostoc commune* maintains its photosynthetic activity during drying and rehydration, whereas EPS-depleted *N. commune* was notably impaired under these conditions[86].

Bacteria actively respond to desiccation by producing EPS[87]. Desiccation seems to be one of the environmental conditions under which EPS provides global benefits to both EPS producers and other members of the biofilm community[88]. Desiccation concentrates EPS, increasing the number of nonspecific binding sites that can react with each other (compared with the number that can react when EPS components are separated at higher water content) and reducing biofilm volume. This can be easily observed on phototrophic biofilms attached to walls, which curl up when they dry out.

The EPS matrix can act as a molecular sieve, sequestering cations, anions, apolar compounds and particles from the water phase[89]. EPS contain apolar regions, groups with hydrogen-bonding potential, anionic groups (in uronic acids and proteins) and cationic groups (for example, in amino sugars)[90]. Owing to this stickiness of the matrix, particles and nanoparticles can be trapped and accumulated. Interestingly, heavy metals such as Zn^{2+}, Cd^{2+}, and Ni^{2+} bind to cell walls of bacteria in activated sludge, whereas hydrophobic compounds such as benzene, toluene and xylene are present in the matrix[91]. The response of biofilms to absorbed substances can be complex; for example, toluene induces enhanced production of carboxylic groups in *P. putida* biofilms[92].

EPS and mechanical properties of biofilms

Although biofilms are commonly referred to as 'slime', which implies that they are not rigid structures, their mechanical stability is important. Interestingly, it seems to be mainly the exopolysaccharides in the matrix that provide this feature. The process of anti-fouling, which entails the removal of unwanted biofilms, is carried out by overcoming the cohesive and adhesive forces of the matrix. In the case of biofilms in catheters, matrix stability determines biofilm detachment and the size of the resulting embolus[93]. During the treatment of waste water, the cohesion of flocs and biofilms determines the stability of several important processes, including flocculation, settling and dewatering[94]. In natural environments, EPS play a crucial part in the stabilization of sediments[95]. Furthermore, biofilms in stagnant waters can be disrupted by the low shear forces, and extremely stable bacterial biofilms with a rubber-like appearance serve as holdfasts for members of the family Podostemaceae (the riverweeds) at waterfall impact points[96]. The mechanical properties of biofilms can be influenced by shear forces, suggesting that biofilms can undergo phenotypic adaptation[93]. Bacterial microcolonies have been observed rolling along surfaces when under steady shear forces[97].

In general, biofilms display viscoelastic properties. They undergo both reversible elastic responses and irreversible deformation, depending strongly on the forces acting on the EPS matrix. Compression experiments with *P. aeruginosa* biofilms revealed that in response to pressure the biofilms go through a phase of elastic behaviour until a break point is reached, after which the biofilm behaves like a viscous fluid[24]. This raised the concept of fluctuating binding points between EPS components that are kept together by weak physicochemical interactions such as hydrogen bonds, van der Waals forces and electrostatic interactions. Entanglement of biopolymers further contributes to matrix stability[24]. *S. aureus* biofilms show elastic-solid-like response to short-timescale stimuli and viscous-fluid-like response to long-timescale stimuli[97]. Elastic materials absorb stress energy through deformation, and transient stress events might be resisted by reversible deformation. The result is a rearrangement of the biofilm to mitigate exposure to external shear stress. It is possible that, on an intermediate timescale, a biofilm can increase the strength of its structural matrix in response to mechanical stresses by increasing EPS production[98]. The interaction of multivalent inorganic ions with EPS can greatly influence the mechanical properties of biofilms. For example, the presence of Ca^{2+} increased the mechanical stability of mucoid *P. aeruginosa* biofilms; this effect was explained by the Ca^{2+}-mediated cross-linking of polyanionic alginate molecules[24]. When the rheological properties of a biofilm were examined on a microscale level using a novel microfluidic device, finite element analysis and confocal laser scanning microscopy, increased cohesion under shear stress (known as strain hardening) was observed for biofilms of *Klebsiella pneumoniae* and *S. epidermidis*[99].

Data about the cohesive strength of biofilms vary greatly, depending on the method used to measure it. Although the magnitude of the elasticity modulus and the viscosity vary among mixed-species biofilms[94], the qualitative viscoelastic responses to shear stress are consistent[93]. Stress relaxation time (usually around 18 minutes) is similar in a wide range of environmental biofilms[98], and it was speculated that this is the shortest period over which a biofilm can mount a phenotypic response to transient mechanical stress. However, stress relaxation time can be much shorter than this in certain examples; in the case of *S. epidermidis* biofilms, it was determined to be only 13.8 seconds[99].

Conclusions

Put simply, there is no biofilm without an EPS matrix — EPS are essential for biofilm formation and make possible a lifestyle that is entirely different from the planktonic state.

However, despite much research on biofilms, basic questions remain. One of these questions concerns the extracellular enzymatic activity of the biofilm matrix and its quantitative contribution to the carbon cycle. This contribution obviously has global relevance, because these enzymes render enormous quantities of dissolved polymers and particulate substrates bioavailable for further decomposition, but this has not yet been quantified on a global scale.

How similar types of EPS influence biofilm development in different bacterial species is largely unknown. A first approach was recently reported for the staphylococcal biofilm matrix polymers poly-*N*-acetylglucosamine (PNAG; a polysaccharide) and eDNA[63], which were

Biosurfactant
A substance that is synthesized by living cells (mostly bacteria and yeasts) and that is surface active. Biosurfactants reduce surface tension, stabilize emulsions, promote foaming and are generally non-toxic and biodegradable. When grown on hydrocarbon substrates as a carbon source, microorganisms can synthesize a wide range of biosurfactants, such as glycolipids and phospholipids. These chemicals are apparently synthesized to emulsify the hydrocarbon substrate and facilitate its transport into the cells. In some bacterial species, such as *P. aeruginosa*, biosurfactants are also involved in a group movement behaviour called swarming motility.

Hydraulic decoupling
The formation of areas that have virtually no exchange of water content with their environment. An example is a desiccated EPS layer that covers an area with a high water content but has very low water transport through the layer, retaining the water underneath.

Elasticity modulus
The tendency of an object or material to reversibly develop an elastic force in response to deformation. Mathematically, the elasticity modulus is the proportionality factor between the force and the deformation, or, in other words, the slope on a plot of stress versus strain in the elastic deformation region. Stiff materials have a higher elasticity modulus, whereas soft materials have a lower one.

Stress relaxation
A deviation from the ideal elastic behaviour of a material due to an internal relief of stress under constant strain. Some materials, when put under mechanical tension, undergo internal flow processes (termed 'creep') that are at least partially irreversible and lead to a constant deformation of the test specimen.

found to have completely different structural roles in biofilms of *S. aureus* and *S. epidermidis*. PNAG made a considerable contribution to biofilm integrity in *S. epidermidis*, whereas this function was served by eDNA in *S. aureus* biofilms. Furthermore, the amount and the temporal sequence of EPS formation in response to various physical and biological conditions are largely unknown for environmental biofilms. One intriguing theory is that cell lysis and subsequent local decomposition of the EPS matrix might be advantageous for the biofilm population, creating new pores and channels that improve nutrient access[100]. The weakest point in current EPS research is the potential to predict EPS production, a prerequisite for which is the elucidation of the underlying regulatory processes. It has already become clear in several Gram-negative bacteria that cell-to-cell communication mechanisms (such as quorum sensing) and the intracellular level of the second messenger cyclic di-GMP are involved in regulating biofilm formation and the production of matrix components such as certain polysaccharides and proteins, DNA, and rhamnolipids[101,102]. A better understanding of the regulation of EPS production in mixed-species biofilms, as well as a spatial and temporal dissection of the phases in EPS production, will reveal important aspects of the oldest, most successful and widespread form of life on Earth.

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DATABASES
Entrez Gene: http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?db=gene
dspB
UniProtKB: http://www.uniprot.org
AtlE | Bap | CdrA | G6PD | LecA | LecB | LipA | MucA | TasA

FURTHER INFORMATION
Hans-Curt Flemming's and Jost Wingender's homepage: http://www.uni-due.de/biofilm-centre
Protein Data Bank: http://www.pdb.org/pdb/home/home.do

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Overview of microbial biofilms

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As the success of this two-issue special section of the Journal of Industrial Microbiology attests, the study of microbial biofilms is truly burgeoning as the uniqueness and the importance of this mode of growth is increasingly recognized. Because of its universality the biofilm concept impacts virtually all of the subdivisions of Microbiology (including Medical, Dental, Agricultural, Industrial and Environmental) and these two issues incorporate contributions from authors in all of these disciplines. Some time ago we reasoned that bacteria cannot possibly be aware (*sic*) of their precise location, in terms of this spectrum of anthrocentric subspecialties, and that their behavior must be dictated by a standard set of phenotypic responses to environmental conditions in what must seem to them (*sic*) to be a continuum of very similar aquatic ecosystems. In this overview I will, therefore, stress the common features of microbial biofilms that we should bear in mind as we use this simple universal concept to seek to understand bacterial behavior in literally hundreds of aquatic ecosystems traditionally studied by dozens of subspecies of microbiologists reared in sharply different scientific and academic conventions.

Keywords: biofilms; adhesion

Biofilm formation

Between 1936 and 1943, Zobell studied the affinity of marine bacteria for surfaces [26] and the development of a battery of new methods for the direct study of living bacteria at interfaces, coupled with many refinements of image analysis, have made it possible actually to study the behavior of bacterial cells as they adhere to these surfaces. Some bacterial cells approach a surface, adhere rapidly to that surface, initiate glycocalyx (exopolysaccharide) production and form the discrete microcolonies that are the basic organizational units of biofilms. Other cells are seen by direct microscopic methods to adhere to surfaces and then to spread out by rolling or swarming maneuvers to produce an even 'lawn' of glycocalyx-producing adherent cells before microcolony formation is initiated. These adherence behaviors are characteristic of cells of different species and are conditioned by the physiological state of the organisms concerned so that we must anticipate a very significant variety of adherence behavior as more species and more physiological states are examined.

The nature of the surface concerned certainly influences the rate of bacterial adhesion [11], and inert and living surfaces vary through a wide spectrum in the rate at which bacterial adhesion occurs [3], but decades of research have yet to yield an inert surface that is inherently resistant to bacterial colonization. In spite of the huge financial impetus that drives the search for this 'holy grail' in the medical device field, and in spite of hundreds of millions of dollars spent in proprietary corporate research, no inherently colonization-resistant material has yet been discovered. This expensive and futile search was inspired by studies using laboratory strains of bacteria whose phenotypic adaptation to growth *in vitro* had deleted all but a few of their myriad adhesion mechanisms. Hundreds of materials that resisted colonization by bacterial strains modified by thousands of transfers in the laboratory were rapidly colonized when exposed to wild strains of bacteria operating in realistic milieux. In the medical field the use of these putative colonization-resistant materials was further complicated by the extent to which organic molecules in body fluids formed conditioning films on their surfaces and by the fact that a monolayer of adherent bacteria, even if it formed very slowly, constituted a new and very welcoming surface for further bacterial accretion. It is now clear that bacterial adhesion to inert surfaces will be controlled by the incorporation of antimicrobial materials (Ahearn; Keevil, this issue) that kill incoming bacterial cells or by the eventual production of protein-coated surfaces that resemble those of living tissues [14] so closely that they accrete the same surfactants, tissue-bound antibodies, phagocytes, and endothelial cells that protect the surfaces of some living tissues from bacterial colonization.

The use of an especially elegant method of direct observation that enables us to visualize the up regulation of specific reporter genes [7] in living bacteria as they adhere to surfaces has revolutionized the study of biofilm formation. This study produced unequivocal proof that AlgC, the gene that produces the enzyme phosphomannomutase of the alginate synthesis pathway in *Pseudomonas aeruginosa*, is up regulated within 5 min of the adhesion of an individual cell to an inert surface. These direct data can now be linked to very exciting developments in the burgeoning field of biofilm genetics (Chakrabarty; Whitfield, this issue). Deretic's group [23] suggested, on the basis of very strong evidence, that AlgC is one of a large 'cassette' of genes that are up regulated by the production of a sigma factor produced by the AlgU gene and regulated by MucA and MucB [10]. This evidence, which is presented in more detail in a new review of biofilm structure [5] strongly suggests that

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biofilm cells are profoundly different from planktonic cells of the same species because of very comprehensive phenotypic changes that are regulated by a sigma factor similar to those that regulate sporulation, starvation survival, and rough–smooth phase variations. Preliminary evidence (Yu and Costerton, unpublished data) indicates that the cell envelope fractions of biofilm and planktonic cells of the same species (*P. aeruginosa*) differ profoundly in the dozens of proteins that can be resolved by modern gel chromatography and this suggests that the cassette of genes regulated by the sigma factor triggered by adhesion may include several that affect cell wall permeability. This sweeping sigma factor-regulated, adhesion-dependent, phenotypic change would be reversed when cells leave the biofilm, perhaps with the aid of the lyase enyzme [1]. This genetic concept must now be added to the consideration of observed differences in the susceptibility of planktonic and biofilm cells to antimicrobial agents (Allison and Gilbert, this issue) because adhesion-dependent phenotypic changes may be as important as diffusion barriers [15], or growth rate-dependent changes [13] in this important phenomenon. Further, these data raise the specter of a phenotypic change in the cell wall of biofilm cells of a given species of bacteria that makes these cells inherently resistant to a particular antibiotic agent, virtually all of which were developed against specific targets in planktonic cells. On a more positive note, a new and aggressive program of antibiotic development using biofilm cells as targets could quickly develop a new class of agents that specifically inhibit the unique metabolic activities of biofilm cells.

Biofilm structure

The lure of very high resolution caused many of us, including this author, to embrace electron microscopy for the examination of bacterial biofilms even though we know that we paid a high price in dehydration artifacts. While we conceded that the expolysaccharide glycocalyx of biofilm bacteria was radically condensed during dehydration, we did not imagine that this virtual collapse of the biofilm matrix profoundly altered a very elaborate biofilm structure. The recent application of the confocal scanning laser microscope (CSLM) to the study of microbial biofilms has produced a whole series of revelations. This elegant CSLM system, coupled with modern techniques for image analysis, allows us to examine living hydrated microbial biofilms [20]. Extensive CSLM studies of biofilms formed by pure cultures of Gram-negative [8] and Gram-positive (Sanford, this issue) bacteria and of natural mixed species biofilms, have allowed us to deduce certain common structural features of these adherent mcirobial populations [19] and to begin to reevaluate our conceptual models (Shea, this issue) of biofilm architecture.

The bacterial microcolony is clearly the basic structural and functional unit of the microbial biofilm (Figure 1). Microcolonies may be composed of cells of a single species or of cells of several species, but they are clearly delineated by their exopolysaccharide matrix which holds them in stable juxtaposition and regulates their effective contact with the fluid phase. Each microcolony consists of the progeny of the cells whose stimulated growth established the

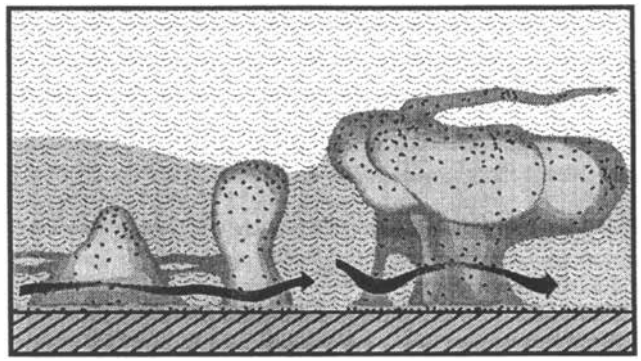

Figure 1 Diagrammatic representation of a microbial biofilm showing the organization of this adherent population, in terms of microcolonies and water channels, and the newly discovered convective flow within these channels

microcolony and therefore many must necessarily be 'sister' cells embedded in an exopolysaccharide matrix of their own creation. Simple proliferation would produce mound-like microcolonies on the colonized surface but direct CLSM observations reveal a preponderance of mushroom-shaped microcolonies in some biofilms (Figure 1) and this complex shape presupposes a measure of growth control by quorum sensing [12] or by complex cell–cell communication [16] similar to that seen in the formation of fruiting bodies by myxobacteria. It is already apparent that many factors can affect biofilm structure (Lappin-Scott, this issue) but the direct demonstration of complex microcolonial structures such as those depicted in Figure 1 demands that we attribute to these basic biofilm units the capability of growth control to produce a complex biofilm architecture. Present direct evidence allows us to conclude that biofilm bacteria live in glycocalyx-enclosed mircrocolonies whose location, size, and shape are determined by nonrandom species-specific factors. Each biofilm cell, therefore, lives in a spatially distinct microniche [4] whose characteristics govern cellular behavior.

The direct demonstration of an anastomosing network of water channels [20] that penetrate to all levels of the biofilm and bring the bulk fluid phase amongst and even behind (Figure 1) the bacterial microcolonies, was a profound revelation. This remarkable feature of microbial biofilms has now been explored in some detail [5,17] and convective fluid flow has been demonstrated within these water channels [25]. This convective flow, which maintains the same directions as the bulk fluid flow, has been quantitated within living biofilms and its discovery must revolutionize our conception of mass transfer in the adherent populations. We suggest [5] that turbulence caused by elements of the biofilm that protrude into the bulk fluid [6] may increase connective flow within these water channels, some of which are sufficiently open to permit the passage of 0.3-μm polystyrene beads [9]. The direct measurement of dissolved oxygen in living biofilms using oxygen-specific microelectrodes [21], showed that this labile nutrient penetrates through the water channels as far as the colonized surface even though the water channels are lined with respiring bacteria in microcolonies. Because the water channels of the biofilm are kept open, even near the

colonized surface (Figure 1), we must conclude that the development of bacterial microcolonies in biofilms operates under a system of elaborate controls that prevents the occlusion of these water channels. We cannot, of course, conclude that all microbial biofilms exhibit the architecture depicted in Figure 1, but our observation that mixed species biofilms at several locations in a fast flowing river display this structure [5], suggests that it is representative of biofilms in many natural ecosystems.

When we consider the elaborate architecture of microbial biofilms we are moved to suggest that this sessile mode of growth represents the highest phenotypic expression of the bacterial genome. Within biofilms bacterial replication and exopolysaccharide production are regulated so that an open system of microcolonies and water channels is produced and maintained. This property of biofilm bacteria differs profoundly from the uncontrolled replication of planktonic cells and suggests the sophistication of multicellular eukaryotic organisms whose component cells replicate under the control of lectins and hormones to produce elaborate tissues. The reward (*sic*) to the individual component cells is the same in both cases in that they gain a protected niche [4] within which they have a measure of homeostasis while keeping contact with the primitive analogue of a circulation system that delivers nutrients and removes wastes.

Another consequence of bacterial growth in structural biofilms is the opportunity for metabolic cooperation within consortia of cells of different species whose juxtaposition is stabilized within the microcolonies of the biofilm (James *et al*, this issue; [19]). Metabolic cooperation between bacteria growing in the planktonic mode of growth is difficult and must operate via the bulk fluid. However, several species may cooperate effectively in such complex activities as methane generation [22] or cellulose degradation [18] when cells of metabolically cooperative species are stimulated by each other's presence to form highly structured mixed microcolonies. Within these stable microcolonies interspecies cross-feeding is facilitated and fastidious organisms can be maintained in a microenvironment (eg complete anaerobiosis) that allows them to contribute their metabolic activity (eg methane generation) to the overall activity of the consortium (eg degradation of organic molecules). Lewandowski and his colleagues have used direct microelectrode studies of living biofilms [8] to show that completely anaerobic loci can be detected within microcolonies of a biofilm that developed in an aerobic environment and similar specific microenvironments have been detected within biofilms by the use of specific fluorescent probes [17]. These data add another dimension to the developing perception of the biofilm as the highest expression of the bacterial genome in that we see the complexity that is considered to be a distinguishing characteristic of multicellular organisms. As more direct examinations reveal more instances of complex biofilm architecture and of sophisticated cell–cell interactions within microcolonies a new perception of the phylogenetic position of bacteria in the living world begins to emerge. The planktonic cells that we have studied so assiduously during the 15 decades since the pioneering work of Koch and Pasteur may represent a simple mode of growth specialized to accomplish dispersal and the colonization of new habitats. The biofilms that have been neglected during all but the past decade may constitute a higher and much more complex mode of bacterial growth that has effective homeostasis, a primitive circulatory system, and a measure of cellular specialization. What we microbiologists have done during these 15 decades is somewhat similar to a study of plants and animals that has been confined to the examination of their spores, gametes, seeds, and other propagules.

In case this peculiar misplaced emphasis is dismissed as an obtuse philosophical matter, it is important to consider the considerable impact of this modern biofilm concept on practical areas in industry and in medicine. The biofilm bacteria that cause befouling in industry and device-related infections in medicine (Khardori, this issue) have been shown to be inherently resistant even to very high levels of antimicrobial agents (Khardori; McFeters; Allison and Gilbert, this issue). The general protection of biofilm cells from antibacterial agents extends to surfactants (Busscher, this issue), heavy metals (Ahearn, this issue), and antibiotics (Hoiby, [19]) and even to protection from phagocytic predators [5]. Early in our studies of microbial biofilms, when our working hypothesis visualized essentially planktonic bacterial cells embedded in a homogeneous intercellular matrix [3], we suggested that this matrix might impose a diffusion limitation that protected biofilm cells. Detailed studies of diffusion [24] contradicted this concept and this hypothesis was essentially replaced by an hypothesis invoking the reduced growth rate of biofilm cells [2]. Now it is apparent that biofilm bacteria are profoundly phenotypically different from the planktonic bacteria that were the targets in virtually all of the design and screening programs that produced our vast armamentarium of modern biocides and antibiotics. We can now anticipate that, when biofilm bacteria replace their planktonic counterparts as targets for these design and screening programs, new classes of antibacterial agents will be developed that will be truly effective in killing bacteria within biofilms (McFeters, this issue). Perhaps the most useful aspect of our new understanding of biofilms is the ability to use probes of biofilm architecture and of metabolic activity to monitor the actual killing of bacteria in spatial terms (McFeters, this issue). These very specific probes, including polyanionic TRITC dextran probes for cationic matrix components [5], have even been used to determine the effects of the exposurse of biofilms to the DC fields that enhance the efficacy of antibacterial agents to produce the bioelectric effect (Jass and Lappin-Scott, this issue).

It is axiomatic that sharp expansions of perception based on direct observations tend to rationalize observations of natural systems that have previously been controversial. A case in point is microbially-influenced-corrosion (Arrage and White, this issue) which can now be understood in terms of the effect on a conductive surface of colonization by a biofilm that incorporates aerobic and anaerobic loci, and regions with sharply different metal-binding capabilities, within a few hundred microns of each other. Now that biofilm architecture is more accurately understood the somewhat enigmatic process of MIC can be rationalized in terms of classic oxygen concentrations and metal concen-

tration 'cells'. Similarly, we can conceive of 'engineered' biofilms in reactor systems in which fastidious anaerobes can operate in systems that are open to air and in which changing nutrient feeds can support different bacterial populations within the same areas of the reactor surface.

Conclusion

At the outset of this seminal two-issue exploration of biofilm microbiology it is important that we clearly state the paradigm shift that is now implicit in the use of the term 'biofilm'. The examination of a wide variety of living single species and natural multispecies biofilms by direct nondestructive techniques has clearly shown an architecture in which slime-enclosed microcolonies are interspersed between relatively open cell-free water channels that penetrate all regions of these adherent populations. Convective flow, and the passage of 0.3-μm polystyrene beads, has been shown by direct measurement in the water channels of several biofilms. The detailed genetic analysis of one almost ubiquitous biofilm organism, *Pseudomonas aeruginosa*, has revealed that adhesion to a surface triggers a sigma factor-directed phenotypic change in a large number of cell envelope genes some of which regulate alginate synthesis. Direct examination of living biofilms by the use of chemical or of physical probes clearly indicates that adjacent regions of these microbial biofilms may vary sharply in the concentration of metal ions or of nutrients (eg oxygen) in adjacent areas. We can therefore conclude that many gradients exist within biofilms, perhaps especially between the microcolonies where the bacterial cells live and the ramifying water channels that carry the bulk fluid throughout the biofilm. Highly structured microcolonies have been described in natural multispecies biofilms within which metabolically cooperative organisms are juxtaposed so as to facilitate complex processes like cellulose digestion or methane formation from organic compounds. Taken together these data indicate that the highly structured biofilm mode of growth provides bacteria with a measure of homeostasis, a primitive circulatory system, a framework for the development of cooperative and specialized cell functions, and a large measure of protection from antibacterial agents. These advantages of the biofilm mode of growth, which have led to its functional predominance in most natural aquatic ecosystems, are not available to cells of the same species growing in the planktonic mode. It is, perhaps, unfortunate that we know the structure and function of planktonic cells in exquisite detail but that we are just beginning to study bacterial cells in biofilms.

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Waterborne microorganisms and biofilms related to hospital infections: strategies for prevention and control in healthcare facilities

Raquel Vannucci Capelletti and Ângela Maria Moraes

ABSTRACT

Water is the main stimulus for the development of microorganisms, and its flow has an important role in the spreading of contaminants. In hospitals, the water distribution system requires special attention since it can be a source of pathogens, including those in the form of biofilms often correlated with resistance of microorganisms to various treatments. In this paper, information relevant to cases of nosocomial infections involving water circuits as a source of contaminants is compiled, with emphasis on the importance of microbiological control strategies to prevent the installation, spreading and growth of microorganisms in hospitals. An overview of the worldwide situation is provided, with emphasis on Brazilian hospitals. Different approaches normally used to control the occurrence of nosocomial infections due to waterborne contaminants are analyzed, and the use of the polysaccharide chitosan for this specific application is briefly discussed.

Key words | antimicrobial agents, chitosan, hospital infection, microbial contamination, water contaminants

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INTRODUCTION

A hospital infection can be defined as any infection acquired after patient admission and manifested during hospitalization or after patient release, being then related to hospitalization or hospital procedures. A hospital infection can be also defined as a localized or systemic condition resulting from an adverse reaction to the presence of an infectious agent(s) or its toxin(s) that was not present on admission to the acute care facility. Commonly used synonyms of hospital infection include the terms nosocomial or healthcare-associated infection (HAI).

The transmission of microorganisms responsible for nosocomial infections is a serious and recurrent public health problem, affecting both developing and developed countries. As an example, in the USA around 2 million healthcare-associated infections occur yearly, causing approximately 90,000 deaths and costing close to $4.5 billion in excess healthcare (Ecker & Carroll 2005). While the average rate of hospital infection in the USA and Europe is 10%, in Brazil it is around 15% (ANVISA 2004).

The control of hospital infections in Brazil has been regulated since 1982 by the Ministry of Health; however, only in 1997 was a Federal law (number 9431) formally established to compel hospitals to maintain a program of preventive and corrective actions related to the spreading of pathogens. Around 45,000 deaths are recorded yearly as a result of infections acquired in hospitals in Brazil, from a total of 12 million hospitalizations. General hospital infections are, unfortunately, the leading cause of deaths in intensive care units (ICUs) in Brazil, and waterborne-related contaminations play a significant role in this scenario. As a result of general nosocomial infections, the length of stay of a patient in a hospital can be extended by 10 to 14 days on average, generating costs of around $5 billion annually in complementary treatments (APM 2006).

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Organisms related to nosocomial infections are very diverse, being detected both in suspension and bound to surfaces in contact with water, in the form of biofilms. The source of microbial dissemination depends on many environmental factors, which can be minimized by specific control programs involving critical materials (surfaces, equipments and others) to prevent the occurrence of high contamination levels. Regular programs include periodical microbiological counts, visual inspection, and regular disinfection procedures, in accordance with the regulatory practice in force.

Wet surfaces and water storage and distribution systems are major sources of potentially pathogenic microorganisms that are not easy to detect or to control. The so-called waterborne pathogens include different types of bacteria, mycobacteria, fungi, parasites, and viruses (Anaissie *et al.* 2002a). Microbial biofilms, in particular, may be responsible for more than 65% of bacterial infections in the USA (Potera 1999), and this estimation was more recently increased to 80% by the National Institutes of Health of the same country (Lebeaux *et al.* 2013).

Microorganisms can easily adhere to piping systems and regions that accumulate water, especially those in which the water flow is difficult, forming biofilms. Relevant factors in the reduction of the overall quality of water and which favor the development of biofilms include the number and position of stagnant points in the water supply system, corrosion, and aging of the distribution system itself (pipe lines, connections, and storage tanks), as well as the formation of solid deposits on their surfaces. The contaminants may not only be transported by the running water system, but they may also be spread by the aerosol formed in taps and showers, dissipating easily in the environment. Surfaces conditioned by spills of contaminated water facilitate the deposition of other molecules and pathogens, and are prominent among the areas most favorable to microbial growth in hospitals.

As a result, the exposure of a patient to waterborne pathogens in a hospital may occur in many different situations, such as during a shower or a bath, while drinking water, due to the use of medical equipment rinsed with contaminated water, or to manipulation by medical personnel whose hands were previously washed with contaminated tap water (Shareef & Mimi 2008).

Biofilm-related infections are characterized by their chronicity and high resistance to antibiotics (Hanke *et al.* 2013), which makes microbiological diagnosis difficult and generally worsens a hospitalized patient's condition. In fact, in the worst scenario, the contact of a patient with waterborne pathogens can even lead to death, particularly in patients with compromised immune systems.

When in biofilms, microorganisms are more protected from the environment. Also, cells within biofilms interact more effectively through small secreted molecules (the quorum sensing concept), which enable them to better adapt to local chemical stimuli and to control the population density themselves due to the combination of intracellular signaling with modulation of gene expression (Camilli & Bassler 2006). Typically, Gram-positive bacteria secrete peptides, while Gram-negative bacteria secrete acyl homoserine lactones. As a result of population control, nutrient usage is better regulated and local permanence of the microbial community is more assured. In addition, many pathogenic bacteria are able to migrate from the environment to the human body and vice versa, having the ability to adapt to sudden responses of the host immune system, biofilm formation being a relevant example of microbial adaptation (Jefferson 2004).

HOSPITALIZATION AND OCCURRENCE OF INFECTIONS

For centuries, people who became ill were isolated in places with no natural light and no hygienic and dietetic care. Often, patients admitted for the treatment of an external injury or degenerative disorder died due to infectious diseases such as cholera, typhoid fever or suppuration. However, the development of new diseases and the death of those in isolation were associated with beliefs and superstitions. Over time, although extensive knowledge in microbiology was not yet a fact, the association between hospitalization and infection development was realized.

Conceptual and intellectual development, especially in the eighteenth century, made it possible for hospitals to perform more effective therapeutic actions, with questions raised about the conditions that favored microbial spreading, and by changing the design of hospitals from places where people were admitted to be excluded from social

life to institutions of healing and medication (Angerami & Andrade 1999).

Ignaz Philipp Semmelweis, a Hungarian obstetrician, is considered the forerunner in the control of hospital infections. In mid-1840, Semmelweis observed a difference in the number of cases of postpartum infections acquired in two clinics in a hospital in Vienna. In the first clinic, pregnant women were examined by doctors who were constantly present in the autopsy room, while in the second clinic, where the number of infections was substantially lower, the treatments were performed by midwives. On one occasion, one of the doctors was accidentally wounded by a knife while performing a necropsy, and developed an infection similar to that of the mothers. This fact led Semmelweis to conclude that the doctor had been contaminated by the same 'matter' affecting the patients, since at that time the concept of the existence of microorganisms was not well established. As a result, in 1847, Semmelweis made it compulsory for all employees of the hospital to wash their hands with a chlorine solution, thus drastically reducing the mortality associated with this problem from 12% to 1.9% (Veiga & Padoveze 2011).

RESISTANCE OF CONTAMINANTS TO ANTIMICROBIAL TREATMENTS

The use of systemic antimicrobial drugs on a large scale began in the 1940s, allowing treatment and the reduction of the number of cases of infections in hospitalized patients. However, military hospitals were soon confronted with *Streptoccoccus pyogenes* resistance to sulfonamide, a drug widely used at that time for the treatment of wounds. Similarly, the resistance of *Mycobacterium tuberculosis* to streptomycin occurred shortly after the introduction of this drug on the market. Disturbed by the infections in hospitals, the medical community received with enthusiasm other antimicrobial agents (Santos 2006), but soon after the initial use of penicillin hospitals were confronted with the resistance of *Staphylococcus aureus* to this drug. In the mid-1950s, outbreaks of resistant Staphylococcal infections were identified around the world, demonstrating the pandemic nature of the phenomenon. Later, in the 1960s, other microorganisms, especially Gram-negative bacteria and fungi, were detected as agents of infections in hospitals (Santos 2006).

Interestingly, antimicrobial resistance was a driving force for health professionals and hospital administrators to recognize the need to establish procedures to monitor, control, and prevent the occurrence of infections developed during hospitalization. Such procedures have to take into account the main groups of occupants in a hospital, formed by patients, professionals, and visitors. These groups are different in terms of health status, exposure to infectious agents, susceptibility to developing diseases, and also regarding cross-transmission issues (Leung & Chan 2006), and all these factors demand great attention.

One of the main factors involved in the persistence of pathogens in the hospital environment is the improper use of sanitizers regarding type and concentration. This action may cause a false sense of disinfection, generating strains tolerant to different treatments performed in the water flow system, where the contaminants may then still proliferate. The same principle applies to the indiscriminate use of antibiotics, which favors subsequent microbial resistance to various treatments. Frequently, no direct relationship can be drawn between the effect of an antimicrobial agent on free cells and on cells organized in a biofilm, since besides the structural and physiological differences between both forms, the adherent cells in a given location may not be the same as those dispersed (Capelletti 2006). The concentration of an antimicrobial agent required to eliminate sessile cells (in biofilms) can be up to 1,000 times higher than that usually used on planktonic cells (in suspension) (Costerton *et al.* 1987; Capelletti 2006; Lucchesi *et al.* 2006).

COMMONLY FOUND WATERBORNE PATHOGENS

Ferranti *et al.* (2014), after compiling worldwide information from 125 scientific reports on waterborne healthcare-associated infections published in the period from 1990 to 2012, noticed that representative microorganisms of the families *Legionellaceae, Pseudomonadaceae, Burkholderiaceae, Mycobacteriaceae, Enterobacteriaceae, Moraxellaceae, Sphingomonadaceae, Xanthomonadaceae, Flavobacteriaceae, Aeromonadaceae, Campylobacteriaceae*, and Gram-

negative cells stand out as opportunistic environmental bacteria associated with this problem. A higher number of reports were determined for the families *Legionellaceae* (38.4% of the total), associated with pneumonia, *Pseudomonadaceae* (19.2%), frequently detected in respiratory tract and bloodstream infections, and *Burkholderiaceae* (12.8%), also related to bloodstream infections. The unit seen as the most commonly affected was the ICU, probably due to the frequently compromised physical and immunological condition of the patients. The primary source of Legionnaires' disease was shown to be the hot-water distribution system, while contamination of bottled water and of distilled and sterile water were mainly attributed to contamination by *Pseudomonaceae* and *Burkholderiaceae*, respectively. Most of the reports were from Europe (52.8%, of which 14 articles were from France and 11 from Germany) or from American countries (28.8%, of which 28 were from the USA). The occurrence of the problem in developing countries is certainly underreported.

ROLE OF WATER IN DISPERSION OF CONTAMINANT MICROORGANISMS BY AIR

Contact with microorganisms in normal environments is continuous but rarely noticed, unless it causes a disease or other deleterious effects. Indoors, air typically has about 1 million bacteria per cubic meter and tap water around 10 million bacteria per liter. Each microbial ecosystem has particular characteristics according to the environmental conditions of the place where it is installed (Feazel *et al.* 2009), and in hospitals, the occurrence of airborne contaminants' transmission is quite common. Assuming that the air of a given environment has a microbial concentration of around 1,000 colony-forming units (CFU) per cubic meter, and given that a person breathes normally 30 liters of air per minute, the load of inhaled microorganisms would be approximately 1,800 CFU every hour, while a conventional filter system with an average pore size of 0.5 micron processes about 90 CFU per hour (Lee *et al.* 2004). The viability of pathogens in the air is provided by water droplets or dust particles suspended in the environment for long periods. Microorganisms suspended in air may then be easily dispersed by air currents and be inhaled by a susceptible host. Fungi of the genus *Aspergillus*, as an example, can affect approximately 15% of patients with leukemia and transplant, leading to death in around half of this population.

Generally, microorganisms in sessile form have strong virulence factors due to genetic changes that allow the synthesis of new protective substances that act outside and inside the cells. As reported by Kaur & Singh (2014), antifungal resistance is related to the capability of the extracellular matrix to adsorb antimicrobial agents, preventing their free diffusion to the contaminants inside the biofilm and also to the activation of multidrug resistance pumps during biofilm development, which may export biocide molecules from within the cells to the external environment. This combination of characteristics provides favorable cell survival conditions, which make cells in biofilms less susceptible to elimination when compared to the same microorganisms in planktonic form (Morck *et al.* 2001).

Despite the implementation of prophylactic procedures for the control of airborne contaminants in a given location, the water distribution system frequently acts also as a reservoir of opportunistic microorganisms. Sections of piping where water tends to stagnate provide good growth conditions for pathogens. The concentration of microorganisms dispersed in air increases in areas with intense use of water, which strengths the transmission of pathogens to the environment (Anaissie *et al.* 2002b). The level of humidity of the surfaces near points of water use can be an important indicator in helping prevent the establishment of contaminants. Even moisture levels as low as a little above 20% may facilitate the development of microorganisms and their dissemination on absorbent structural items such as carpeting, wallboards, and wallpapers if these materials are not properly dried within 72 hours after wetting (Centers for Disease Control and Prevention 2003).

Under adequate growth conditions, a bacterium with a doubling time of around 20 minutes can generate more than two million cells in 8 hours. Given that small amounts of substrate can fulfill the nutritional needs of the contaminants and that concentrations as low as one part per billion of organic matter in 1 milliliter of water may make possible the growth of approximately 9,500 bacteria (Dreeszen 2003), it is clear that water systems have the potential

not only to disseminate contaminants but also to support their propagation.

CRITICAL AREAS IN HEALTHCARE FACILITIES REGARDING MICROBIAL DISPERSION THROUGH WATER

Nosocomial infections originating from water can be transmitted not only by aspiration, but also by contact and ingestion. Many pathogens can survive in hospital water supply systems, transferring antibiotic resistance genes and being implicated in numerous outbreaks.

Among the highest water consumption areas in a hospital are steam generators, hemodialysis equipment, laboratories, surgical materials processing sections, air conditioning systems, and laundries (Anaissie *et al.* 2002b). The main reservoirs of pathogens in clinical settings reported in the literature are drinking water, water for dialysis, water used for washing medical devices, water used in taps and showers, water lines in dental clinics, and eye washers (Centers for Disease Control and Prevention 2003).

Proper guidelines for the monitoring and prevention of hospital waterborne infections are still limited. In recent years, increases in the occurrence of pathogenic fungi and molds in hospital areas have been detected (Falvey & Streifel 2007), and studies pointing to contaminated surfaces and water supplies as possible sources for aspergillosis (Streifel *et al.* 1987; Anaissie *et al.* 2002c) thus raise the need to formulate general and specific guidelines for monitoring hospital water sources. Avoidance of drinking hospital tap water, routine and targeted surveillance cultures for water sources, and hospital staff and patients' education are major measures to control water-associated nosocomial infections.

Monitoring and detection of the transference of pathogens from water to medical instruments are not frequently performed and can lead to incorrect diagnosis of infection. Data provided by a study of nosocomial infections related to water sources (Pall Corporation 2006) showed that devices commonly involved in microbial transmission include not only taps but also nebulizers, affecting patients with respiratory problems, and burns, neonates, patients recovering from cardiac surgery and neurosurgery, as well as the elderly, who are particularly vulnerable. According to the instructions of the Centers for Disease Control and Prevention (2003), for cleaning medical materials, such as endoscopes and bronchoscopes, the water must be of high quality to avoid microbial growth and biofilm formation within these devices.

A study of disinfection in an Italian hospital contaminated with *Legionella pneumophila* was performed by circulating peracetic acid through the piping system (Ditommaso *et al.* 2005). *In vitro* tests showed that the effective concentration for contaminant inactivation in the system was 50 ppm after 5 minutes of contact. Based on these results, a four-step disinfection protocol was then established. In the first step, the disinfectant was used at this dose but for a contact time of 30 minutes. In the second step, the treatment was repeated weekly for 3 weeks, and in the third step, the disinfection was performed in the same conditions of dosage and contact time, and repeated every month for 5 months. Finally, in the last step, the dosage was raised to 1,000 ppm of peracetic acid for a 30 minute exposure period. Despite the multiple disinfection steps, the growth of the same bacteria was detected again 30 days after the procedures, in a concentration even higher than the initial one, due to remaining cells in the form of biofilms within the water pipes, which protected the microorganisms from the disinfecting agent (Ditommaso *et al.* 2005).

Shower use can provide a source of exposure to microorganisms through aerosolization, as the inside of a showerhead provides a moist, warm, and dark environment that is frequently replenished with nutrients. The heating provided by shower water systems is obviously not hot enough to overcome the transmission of microorganisms, and most of the microbiota found in these devices is composed of groups commonly found in water and soil capable of forming biofilms in favorable conditions (Feazel *et al.* 2009). A shower system may include a reservoir of bacteria such as *Legionella*. As a result of the warming of the water in showers, this microorganism may easily spread and reach the respiratory system of the patient. In addition, water drains often cause problems in hospitals if overflow occurs, spreading pathogens on the floor surface (Prade *et al.* 1995).

Showers and taps in hospitals may also be a significant source of fungi that cause infections in patients with

weakened immune systems. In 2001, a detailed study was performed focusing on the route of transmission of *Aspergillus* related to hospital showers and taps (Warris *et al.* 2001). In this study, a total of 100 samples of this fungus were collected from air, water, and patients in a hospital in Norway. Among the samples analyzed, 55 were collected from the water system (51% in taps, 44% in the main piping system. and 5% in showers), 25 were obtained from the air, and 20 originated from 13 immunocompromised patients. The samples collected from the water were genetically distinct from those obtained from the air. However, in nine of the 13 patients evaluated, *Aspergillus* strains genetically similar to those found in the water system were detected.

Although opportunistic pathogens have been cultured from showerheads, little is known about either the prevalence or the nature of the microorganisms that can be aerosolized during showering. To determine the composition of showerhead biofilms and water, in 2009 a study was carried out focusing on the ribosomal RNA gene sequences of biofilms from 45 showerheads from nine sites in the USA (Feazel *et al.* 2009). The authors found that sequences representative of non-tuberculous mycobacteria and other opportunistic pathogens were highly frequent in many showerhead biofilms.

The development of cyanobacteria (blue algae) in drinking water reservoirs, which culminated in a toxic syndrome known as toxic pneumonia, was reported in Scandinavia (Annadotter *et al.* 2005). Symptoms such as fever and signs of respiratory tract failure were usually detected in only 1.5 to 6 hours after people had bathed, and the presence of endotoxins dispersed in the aerosols generated during the bath were reported as the probable causative agent.

In Brazil, in 1996, a major outbreak of waterborne nosocomial infection occurred in the town of Caruaru, Pernambuco, affecting 131 patients with chronic renal failure undergoing hemodialysis. Of these, 46 died due to intoxication by microcystin produced by the algae present in the water circuit (FAPESP 1996).

As already mentioned, several pathogens can affect debilitated patients, such as *Escherichia coli, Klebsiella, Staphylococcus aureus, Streptococcus pneumoniae*, *Nocardia* spp., *Mycobacterium* spp., *Haemophilus influenzae*, and *Neisseria meningitidis* (Nucci & Maiolino 2000), among others. However, some microorganisms are noteworthy, both in number and type of infection, such as the bacterium *Pseudomonas aeruginosa*, which is often found in different regions of the body and the environment due to being easily adaptable to different conditions. This bacterium is ubiquitous in water and has been responsible for mortality rates around 30% among patients with pneumonia and sepsis and 60% in burned patients (Angelbeck 2004). Bacteria such as *L. pneumophila* can cause pneumonia during hospitalization, both through contaminated water and by airborne transmission, while *Serratia marcescens* may usually be associated with pneumonia and sepsis in patients undergoing chemotherapy. The last mentioned microorganism is slow growing, has invasive properties and the tendency to resist many of the antibiotics used nowadays (Koneman *et al.* 2001). Additionally, *Methylobacteria*, a group characterized by being composed of slow-growing microorganisms resistant to chlorine-based treatments, are described as important pathogens transmitted by water (Hiraishi *et al.* 1995). Also noteworthy are the *Mycobacteria*, which are capable of survival at extreme temperatures, such as in ice machines and hot water, particularly the *intracellulare* species, which can persist for more than a year in distilled water. Other bacteria commonly found in drinking water and of great importance regarding the incidence of infections include *Stenotrophomonas maltophilia, Aeromonas hydrophila, Acinetobacter* spp., *Enterobacter* spp., *Flavobacterium* spp., and *Burkholderia cepacia* (Angelbeck *et al.* 2006).

Another microorganism associated with major concern is *Acinetobacter*, due to its rapid ability to develop resistance to many antimicrobial agents, including several antibiotics and heavy metals (Akbulut *et al.* 2014). This bacteria may demonstrate hemolytic activity, and if infecting a hospitalized person, its discharge through untreated or only partially treated hospital contaminated wastewater may direct it to surface waters, where it is capable of persisting for extended periods, continuing the contamination and spreading cycle.

Fungi are responsible for approximately 8% of total hospital infections, the ones from the genus *Aspergillus* being the most important regarding infections in immunocompromised patients, particularly those from the species *flavus*, *niger*, and *fumigatus* (ANVISA 2004), which may cause death in about half of the patients affected.

Therefore, taking into account the high prevalence of contaminants in water, various contamination control alternatives complementary to the use of chemical agents are being considered in many hospitals, particularly in Europe. In Germany, since over 40% of infections by *Pseudomonas* spp. in intensive care units were associated with the use of water, a growing number of disposable filters have been installed in taps and showers for the protection of patients (Reiter 2004). The installation of these filters is considered a very cost-effective alternative if elements such as the expense of rehabilitation of the affected patients and measures to treat the contaminated area are taken into account. It was observed that the installation of only seven filters in a hospital reduced substantially the infections, with savings of approximately 82% in the total usually spent to circumvent the problem.

In severe cases, more aggressive intervention strategies are required and sometimes the only possible measure to prevent or stop the process of infection in patients with high risk is restriction of water use (Squier *et al.* 2000) and establishing very strict water quality control standards. As an example, healthcare guidelines of the Centers for Disease Control and Prevention (2003) state that for dialysis water, microbial count levels below 200 CFU per milliliter are recommended.

The severity of the problem is illustrated by a case related to the intensive care unit of a hospital in France, in which the bacterium *P. aeruginosa* was detected in approximately 10% of 657 samples of tap water collected (Rogues *et al.* 2007). The percentage of transmission of this contaminant particularly through the hands of the local health workers was 14%, with the same strain being isolated from 38 patients. This case report strengthens the concept that among the many sources responsible for nosocomial infections, hospital water is a controllable but surely overlooked one.

SYSTEMATIC MONITORING AND CONTROL OF HOSPITAL INFECTIONS: OVERVIEW IN BRAZIL

Although in Brazil the first hospital infection control committees arose in the 1960s (Padoveze & Fortaleza 2014), the Brazilian National Agency of Sanitary Surveillance (Agência Nacional de Vigilância Sanitária, ANVISA) was only officially instituted in 1999. Since then, this agency has been responsible for the national program of prevention and control of infections related to healthcare facilities. However, to our knowledge, no systematic and detailed studies on nationwide statistics of the occurrence of hospital infections exclusively related to waterborne microorganisms and biofilms are available in the literature.

An analysis of the magnitude of general nosocomial infections in Brazil was performed by the Department of Infection Control in Hospitals of the Ministry of Health, involving 99 hospitals located in different capitals of Brazilian states, totaling 8,624 patients (Prade *et al.* 1995). The average hospital stay of patients affected by nosocomial infections was 21.7 days and the infection rate was 13%. Prevalence was observed for respiratory tract (28%), followed by surgical (15%), skin (15%), and urinary-related (11%) cases. In a situation different from what is now seen, it was noticed in 1995 that 46% of the patients in surgical clinics and 24% of patients in regular clinics used antibiotics without apparent infection or diagnostic, a practice that favors the development of microbial resistance and complications of further treatment. The southeast region had at that time the highest prevalence of nosocomial infections (16.4%, 37 hospitals), followed by the northeast (13.1%, 27 hospitals), north (11.5%, eight hospitals), south (9.0%, 15 hospitals), and midwest (7.2%, 12 hospitals). The nature of the hospitals was taken into consideration, and public hospitals that had higher rates of infection (18.4%) were compared to teaching hospitals (11.8%) and to those of the private sector (10%).

In 2007, a nationwide search was performed to analyze the existence of committees for hospital infection control, as well as for microbiological laboratories in Brazilian hospitals (ANVISA 2013). According to the reported information, only 4.3% of the evaluated institutions had the support of municipal committees for the control of hospital infections. Moreover, it was detected that in approximately 40% of the hospitals, microbiology laboratories were unavailable. This hampers the adoption of policies for the rational use of antimicrobial agents and also contributes to increase the risk of treatment failure in patients with infectious diseases. It was noted that effective measures for monitoring, evaluating, and reporting of nosocomial infection indicators needed to be improved. This

study also shows that hand washing was identified as one of the most relevant items related to infection control, as also stressed by Borges *et al.* (2012); nevertheless, water itself is seldom recognized as a potential source of contaminants. Obviously, despite hand washing being a simple, inexpensive, and effective measure to prevent the spreading of pathogens in the hospital environment (El-Far & Richtmann 2001), the water used to do it must have adequate microbiological quality.

An investigation performed from 2007 to 2008 in a state hospital of Sumaré, in São Paulo State, showed that from the 862 deaths observed in that period, around 9% were associated with nosocomial infections (Guimarães *et al.* 2011). Although bacterial resistance was not the focus of that particular study, multidrug resistance rates above 30% for Gram-positive cells and over 40% for Gram-negative cells were detected.

Similarly, according to the National Agency of Sanitary Surveillance in Brazil, in 2007, 64 hospitals reported multidrug resistance of cultures of the bacterium *P. aeruginosa*, commonly found in water (ANVISA 2008). On average, only 58% of the tested cultures showed susceptibility to at least one of nine major antimicrobials used in conventional antibiotic therapy (amikacin, gentamicin, levofloxacin, ciprofloxacin, meropenem, imipenem, cefepime, ceftazidime, and tazobactam).

In 2013, a survey on the prevalence of healthcare-associated infections in Brazilian hospitals was carried out, in which 91 hospitals were evaluated (Fortaleza *et al.* 2013). The overall infection rate was 11.1%, varying from 2.5% (hospitals with less than 50 beds) to 18.3% (hospitals with more than 200 beds). The most prevalent infections were pneumonia (3.6%), bloodstream infection (3.5%), surgical site infection (1.4%), urinary tract infection (1.1%), and skin infection (0.4%). The risk factors more frequently identified were: central venous catheter (17.8%), surgery (15.5%), urinary catheter (14.0%), and mechanical ventilators (8.1%). Etiologic agents were identified only in 9.1% (43 of 473) of infections. Gram-negative organisms were more frequent (56.0%) and, among them, *Klebsiella* spp. (19.0%) and *P. aeruginosa* (16%) were predominant. Among Gram-positives (35.0%), coagulase-negative *Staphylococci* were more prevalent (16%) than *S. aureus* (9.0%) or *Enteroccoccus* spp. (6%). Yeasts were identified in 9.0% of the infections in this study, and in a former survey, molds were also found to be relevant as hospital waterborne contaminants in Brazil (Varo *et al.* 2007). The monitoring of seven points of distribution of water in a hemodialysis unit in the state of São Paulo, from April to July 2006, indicated the presence of 116 isolates of filamentous fungi, of which 41% were *Trichoderma* spp., 25% *Cladosporium* spp., 14% *Aspergillus* spp., and 10% *Fusarium*.

A recent analysis (ANVISA 2013) showed that among the elements recommended for evaluation by the World Health Organization (WHO 2011), the items that better met the international compliance standards with regard to prevention and control of nosocomial infections in Brazilian healthcare institutions are vigilance, technical guides, and environment. Monitoring, evaluation, and relation to public health, however, did not reach adequate levels.

Owing to being among the 10 largest economies in the world, Brazil's situation regarding statistics, prevention and control of infections related to healthcare facilities attributed to waterborne microorganisms and biofilms may be potentially correlated to that of other developing countries in the BRICS group (Brazil, Russia, India, China and South Africa, which represents more than 40% of the world's population) and also of other nations. Therefore, the data presented herein could well serve to instigate more thorough assessment of the problem and also of ways to more effectively deal with it.

CONTAMINATION CONTROL IN WATER SYSTEMS: TRADITIONAL METHODS AND INNOVATIONS

In natural environments, microorganisms are mostly found as biofilms, in sessile communities, consisting of microbial associations of interdependent species that can colonize and develop on various types of surfaces. The cells in biofilms are protected by an extracellular polymeric matrix (EPS) of complex and heterogeneous composition, which promotes microbial attachment, proliferation, and differentiation. Owing to displaying hydrophilic and hydrophobic regions, the EPS enables the development of biofilms on different materials (Tsuneda *et al.* 2003).

Biofilms are formed in a sequence of events, which may vary according to the microbial flora present and cell adaptation to different media (Figure 1). Initially, planktonic cells

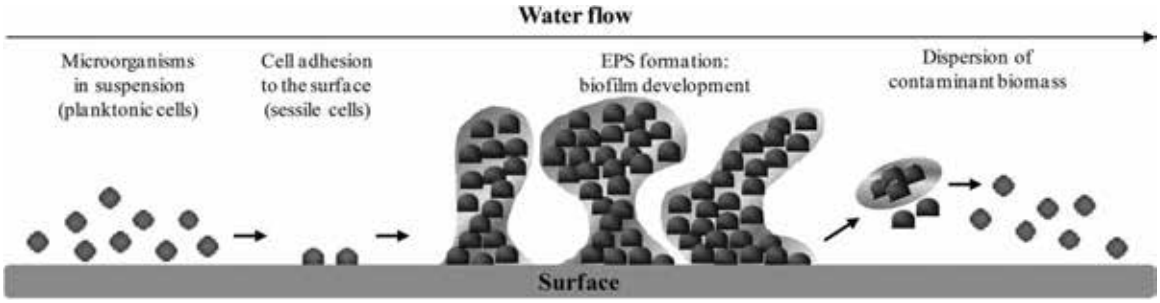

Figure 1 | Major steps involved in biofilm formation. Planktonic cells attach to the surface, forming an extracellular polymeric matrix that stabilizes the biofilm and through which the fluid is able to circulate. Extracellular and intracellular signaling activates modulation of gene expression, contributing to improved cell resistance and survival. Upon biofilm maturation, daughter cells and microcolonies may be released and dispersed in the fluid stream, thus being able to colonize other surfaces.

are transported to the surface of the liquid phase by sedimentation, diffusion, or convection. Then, cell adhesion to the surface occurs, normally through weak forces in an initially reversible step, and afterwards through less reversible forces such as ionic or covalent bonds. After adhesion, cell growth effectively takes place and the structure of the biofilm stabilizes as a whole with the formation of the EPS, through which circulates the fluid in the vicinity of the biofilm. The biofilm is then considered mature, releasing cells as a result of quorum sensing or nutrient level control, biofilm tearing due to continuous liquid flow or by shedding of daughter cells. The released cells may, in turn, colonize other surfaces, restarting the contamination cycle.

Currently, the most used methods to prevent and control microbiological contamination on surfaces can be divided basically into three categories: mechanical cleaning procedures, use of sanitizing agents, and use of antimicrobial coatings or membranes. However, there are many factors that may contribute to microbiological contamination of water and culminate in biofilm formation. The misuse of disinfection methods is among the most problematic, because in this way the elimination of the contaminant focus may not be obtained. Some of the most frequently used approaches to disinfect water are compiled in Table 1. Nonetheless, their limitations should be considered when selecting a specific treatment (Schindler 2001).

Several strategies can be employed to control the infection rates originating from water in hospitals (Curtis 2008), including simple measures such as using sterile water as drinking water and in showers. Also, cleaning of showers with detergents and phenolic compounds, heating water at temperatures above 50 °C, and immediate repair of leaks and damages resulting from water flow are rather effective. More elaborate strategies are also available, such as water treatment with UV light or ionization systems based on copper and silver. The use of chemical agents is also indicated, however most of them, even at dosages above the usual, are unable to completely and permanently eradicate biofilms already installed, which develop again and may turn resistant (Angelbeck *et al.* 2006).

In general, the concentration of chlorine necessary to eradicate most of the microorganisms present in water is approximately 0.3 milligrams per liter. However, even with the addition of free chlorine in water pipes at concentrations as high as 4.3 milligrams per liter, some coliforms can survive (LeChevallier *et al.* 1984). This can be attributed to some common factors in water circuits: the chlorine added may not reach all areas of the water distribution network in sufficient quantity for its action, and part of the chlorine added may react with traces of pre-existing organic matter or corrosion products, among other possibilities. Even portions of biofilms detached from surfaces as a result of the action of disinfectants can be problematic. Such fragments can serve as a source of easily assimilable organic carbon for the maintenance of the living microorganisms remaining in the system.

In most cases, the cost for the treatment of biofilm-related contamination is much greater than the amount that would be spent if there were actions to prevent its occurrence. As mentioned previously, a current alternative, very attractive and with proven efficacy, is the use of filters at points of final consumption, such as in taps and showers (Ortolano *et al.* 2005; Sheffer *et al.* 2005; Exner *et al.* 2005; Lin *et al.* 2011). Point-of-use water filtration is one of the particular strategies recommended by Lin *et al.* (2011) for

Table 1 | Relevant strategies of water disinfection and their characteristics (compiled from Schindler 2001; EPA 2011; Lin *et al.* 2011)

Disinfection technique	Advantages	Disadvantages
Flow of hot water	Does not require specialized equipment	Risk of burns
	Does not involve the use of chemical agents	Damage to pipes
		Difficulty in reaching the whole area in complex distribution systems
Chlorination	Good short-term efficacy	Requires periodic analysis of the chlorine level
	Well understood disinfectant capability	*Mycobacteria* and *Legionella* are potentially resistant
	Established dosing technology	Ineffective against *Cryptosporidium*
		Development of odor, allergic reactions, and carcinogenic byproducts (trihalomethanes)
		Corrosive
		Does not permeate effectively in biofilms
Ionization (copper/silver)	Good efficacy in short- and long-term use	Water must present low concentration of dissolved solids
	Easy equipment installation and maintenance	High water pH and low ion concentrations may affect the method's efficacy
	Accumulation of ions inside the biofilm considered as the basis for the prolonged bactericidal effect	Requires routine maintenance and monitoring (every week for copper and once every 2 months for silver)
		Only effective with flow of hot water
		Corrosive to steel and galvanized pipes
Exposure to UV light	Easy installation	Poor penetration in biofilms
	Pronounced action in planktonic cells	Frequent microbial recolonization
	Does not require the use of chemical agents	Water supply should not be turbid for higher treatment efficacy
	No significant by-product implications	Difficulty in reaching the whole area in complex distribution systems
	Generally highly effective for protozoa, bacteria, and most viruses and particularly for *Cryptosporidium*	Efficacy is reduced by high water flow, presence of organic materials, and high microbial levels
		High costs
		No residual effect distributed to the remainder of the system
Ozonization	Good short-term efficacy	Requires specialized equipment which is difficult to install and maintain
	Benefits of destruction of organic micropollutants (pesticides, taste and odour compounds)	High costs
	Strong oxidant and highly effective disinfectant compared with chlorine	Action limited to the injection point
		Fast decomposition of ozone
		Questionable effect on biofilms
		Residual effect insufficiently long lasting for distribution over the system under treatment
Chloramination	No significant by-product issues	Considerably less effective compared with chlorine

(*continued*)

Table 1 | continued

Disinfection technique	Advantages	Disadvantages
	Generally less taste and odour issues than chlorine	Monochloramine can cause anemia in patients undergoing hemodialysis
	Stable monochloramine residual penetrates biofilms	Increased populations of other microorganisms (*Mycobacterium* species)
	Wider working pH range than copper/silver ionization and chlorine	Presence of nitrogen by-products and increased lead leaching in drinking water
		Use of monochloramine generally limited to municipal water treatment plants

emergency disinfection methods in the case of hospital-acquired Legionnaires' disease, in addition to the use of superheat-and-flush disinfection and/or shock chlorination.

The high efficiency of the approach based on installing point-of-use water filters was recently reported by Zhou *et al.* (2014). The filters were capable of eliminating *Legionella* spp., *P. aeruginosa*, *Mycobacterium* spp., and filamentous fungi from the tap water of a liver transplant unit in a hospital in Shanghai, China, also reducing the incidence of colonization and infection with Gram-negative bacteria by 47%.

Another example of the successful use of the filtration strategy is described by Vianelli *et al.* (2006), who reported the use of disposable filters with 0.2 μm pore size at points of consumption such as taps and showers in bathrooms at hematology and oncology areas in an Italian hospital. Such an approach not only allowed a significant reduction of *P. aeruginosa* bacteremia, but also contributed to the control of infection outbreaks involving the same organism. The authors also point out that despite the increase in the annual operating costs due to changing the filters weekly, a significant contribution to the reduction of morbidity, consumption of antibiotics, and length of stay of patients in the hospital was noticed.

The filtering approach can be used as a complementary procedure to chemical disinfection treatments, with the advantage of capturing microorganisms that may have survived exposure to these agents or have not been reached in stagnant regions of the piping system.

A comparative study of different strategies to control *Legionella* spp. in a hot water supply, conducted at a university hospital in Italy for 10 years (Marchesi *et al.* 2011), showed that filters placed directly in water use points perform best with respect to the reduction of contamination, followed by the use of heating, chlorine dioxide, heat shock, and hyperchlorination. The use of chlorine dioxide, however, is the least expensive procedure followed by thermal shock, hyperchlorination, heating, and filtration.

Although cost is a relevant factor in the analysis, strategies for high efficacy in microbial control of water and based on a combination of two or more distinct principles of disinfection can be vitally important in sectors where hospital treatments are carried out on severely immunocompromised patients. Strategies also comprehending the use of devices and materials of extremely low risk to patients and to the environment, such as those based on the use of natural-origin bioactive compounds like chitosan, are being increasingly considered, mostly to coat surfaces prone to short-time contact with moisture.

ALTERNATIVE APPROACHES TO PREVENT WATERBORNE NOSOCOMIAL INFECTIONS USING THE BIOPOLYMER CHITOSAN

Chitosan, a polymer obtained by deacetylation of chitin, a polysaccharide that has a structure similar to cellulose, has attracted great interest for application in the biomedical area lately due to its antimicrobial properties (as a biocide and biostatic agent) (Chandy & Sharma 1990). Its use as a natural coagulant for the treatment of drinking water in the isolated form or together with other approaches is also well documented (Lee *et al.* 1992; Eikebrokk & Saltnes 2001; Fabris *et al.* 2010; Khaira *et al.* 2013).

Besides these attributes, chitosan is a versatile material that can be used alone or in combination with other compounds, aiming at improving its physical, mechanical, and/or biological characteristics for specific applications. It can be processed in different forms, such as solutions, gels, particles, dense and porous films and membranes, among others, and has low toxicity to humans. As a consequence of all these attractive characteristics, added to its high availability, its use in the development of biomaterials has been increasingly investigated in recent years, with great emphasis on the production of wound dressings (Jayakumar *et al.* 2011).

Chitosan has the capacity to inhibit the growth of a wide variety of bacteria, molds, and yeasts (Singla & Chawla 2001; Raafat & Sahl 2009). However, the presentation form of the final material can significantly influence its antimicrobial activity (Foster & Butt 2011). The high density of positive charges in chitosan molecules is highlighted in several studies as one of the main factors involved in its mode of action, propitiating the interaction with microbial cells and their toxins, which are typically negatively charged. The cell wall composition of many organisms commonly found in water, such as cyanobacteria, is similar to that of Gram-negative bacteria, which also have negative charges in their surface (Cossich 2000). The reproductive structures of some filamentous fungi are also negatively charged (Dunlap *et al.* 2005), as well as the surface of common yeasts (*Saccharomyces* spp. and *Candida* spp.), which in all of the situations described would favor the interaction of cells with chitosan. In this sense, chitosan is successfully used as a flocculating agent to remove impurities in chemical and biological water treatment (Strand *et al.* 2002).

Studies involving the use of chitosan as a coating for surfaces indicate that this method of antimicrobial protection provides a promising field of application in the control of nosocomial pathogens (Wang *et al.* 2012; Cobrado *et al.* 2013). However, the intrinsic bactericidal activity of chitosan seems to be more intense in preparations in the form of solutions or gels than in neutralized materials (Foster & Butt 2011). It is assumed that there is a significant contribution to the chitosan antimicrobial effect from the organic acids commonly used to solubilize this polysaccharide due to the pH reduction of its solutions or gels (Chung *et al.* 2003; Fujimoto *et al.* 2006). Consequently, the antimicrobial activity observed for chitosan and its derivatives is perceptible only when the pH is below the dissociation constant of the amino groups of the respective compounds. This mechanism is not limited to soluble forms of chitosan, but is also verified in solid chitosan samples (Kong *et al.* 2010). Thus, when the use of neutralized chitosan films at basic or neutral pH conditions is desired, the chitosan device should ideally be combined with compounds having microbicidal activity to more effectively control the development of microbial biofilms.

Styrene-acrylic coupons coated with this polymer and exposed to clinically relevant microorganisms such as *Staphylococcus epidermidis* and *Candida albicans* showed enhanced antifouling activity in comparison to coupons treated with conventional antimicrobial agents (Carlson *et al.* 2008). In the same type of application, chitosan in the form of a neutralized film in combination with the antibiotic rifampin has already been successfully used for controlling the development of *S. epidermidis* and *S. aureus* biofilms (Cao & Sun 2009).

Other prospects for application of this biopolymer in microbial control of water used in hospitals should be further explored, both directly as a potential antimicrobial agent in solution and in an indirect way as a matrix for the incorporation of other antimicrobial agents.

CONCLUSION

The number of cases of infections of nosocomial origin associated with systems of water distribution in hospitals around the world is highly significant. The development and adoption of more effective measures to prevent its progression is an assured need, as is providing qualified information on this matter to professionals working in healthcare facilities and also to patients and their companions, mostly in developing countries, where activities on prevention, monitoring, and control of waterborne contaminants tend to be more limited. It is essential that when the use of antimicrobial agents cannot be avoided to overcome waterborne pathogens' replication and spreading, these compounds should be employed in a rational way to minimize the major problem of development of microbial resistance to their presence. Despite the fact that filtration

systems are particularly cost-effective as alternative or complementary approaches to control waterborne contaminants in hospitals, the use of antimicrobial agents of natural origin, such as chitosan, should be more frequently considered for the purpose of reducing the risk of nosocomial infections together with other useful strategies.

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Pseudomonas aeruginosa routine water sampling in augmented care areas for NHSScotland

This guidance applies to the following high risk areas:

- Bone Marrow Transplant Units, Haemato-Oncology and Neonatal Units, and any other care areas where patients are severely immunosuppressed through disease or treatment.
- Critical and intensive care units (neonatal, paediatric and adult), renal units, and respiratory units (including Cystic Fibrosis patient care units). Burns units and other care areas where patients have extensive breaches in their dermal integrity.

Routine water testing in NHSScotland should be specific for *Pseudomonas aeruginosa* in augmented care areas. Water testing for *Pseudomonas* species is not advised as not all *Pseudomonas* are clinically relevant.

Note: If *Pseudomonas aeruginosa* is detected in the water supply the local Water Safety Group (WSG) must assess the risk of continuing to use the tap water in that clinical area. The Infection Control Committee should be informed.

Frequency of Water Sampling

Routine water sampling for *Pseudomonas aeruginosa* should be undertaken at least six-monthly using a pre-flush sample. This routine testing aims to support timely review of all the component parts of the water system to determine whether there is a 'niche' (area) in the system capable of supporting a *P. aeruginosa* containing biofilm; if there are 'niches' in the water system biofilm is likely to occur rapidly; (correspondence to HPS from HIS water group).

The frequency of testing should increase if any of the criteria in **Table 1** is met.

Table 1: Criteria for increased testing

1	There is an increase in clinical isolates within the care area and water borne pathogens are indicative of a source of infection/colonisation.
2	There have been changes made to the water distribution and delivery system components or water system configuration.
3	Pre-flush trend analysis demonstrates increasing cfu/100mls.

Pre- flush Classification of Results and actions

A pre-flush sample should be obtained following Appendix 2[1].

1. **Not detected:** No further action required; re-sample six-monthly (earlier if any of the criteria in Table 1 is met).
2. **Detected: Counts 1-10 cfu/100mls:** Re-test outlet using pre- and post-flush sampling until three consecutive negative samples (each subsequent sample being taken on receipt of previous sample result). Following three consecutive negative results samples should be taken weekly for four weeks; after four weeks, if the outlet remains negative commence quarterly routine sampling.
3. **Detected: Counts >10cfu/100mls:** Retest the outlet and risk assess the need to remove the outlet from service; retest using pre and post-flush sampling as explained in point 2.

Actions: Re-sampling results (pre-flush and post-flush)

Comparison of counts from pre- and post- samples can help derive the source of the *Pseudomonas aeruginosa*.

Detected: the WSG must review results and produce a risk reduction action plan considering the following thresholds for action:

1. **Result: High pre-flush >10cfu + low post-flush counts <10 cfu/100mls:** These results are indicative of a local water outlet problem; investigate cause and ensure controls are in place. The following must be considered:

[1] **Guidance for neonatal units (NNUs) (levels 1, 2 & 3), adult and paediatric intensive care units (ICUs) in Scotland to minimise the risk of *Pseudomonas aeruginosa* infection from water**

- Removing the outlet from use.
- Implement extended flushing time at the outlet.
- Remove and replace contaminated outlets and Thermostatic Mixer Valve (TMV) pipe-work back to the supply junction.
- Disinfect any new components and fittings before re-installation.
- Re-assess system component requirements to reduce risk i.e. no inserts. Where possible hard plumb all pipe-work.
- Installation of Point of Use (POU) filters (this should be considered a short-term control measure).
- Installation of outlets that are demountable and, auto-clavable, part of planned maintenance and compatible with POU filters.

2. **Result: High Pre- flush + post flush counts > 10 cfu/100mls:** These results are indicative of a wider problem within the water supply; investigate cause and ensure controls are in place. The following must be considered:

    - Removing the outlet from use.
    - Installation of Point of Use (POU) filters (this should be considered a short-term control measure). Requesting an engineering survey of the water system to review, to guide remedial actions alongside the water sampling results.
    - A review of the hospital water delivery system materials and the compatibility with water; BS 6920-1 sets out requirements for non-metallic materials that should not enhance microbial growth. The review should include:
        - Identifying substances that may be present in rubber compounds, and are also occasionally associated with non-metallic materials such as plasticised (softened) plastics, which can provide nutrients for *Pseudomonas aeruginosa* growth.
        - Identifying materials such as ethylene propylene diene monomer (EPDM) rubber may be susceptible to microbial colonisation often used in flexi hoses.

3. **Result: High pre-flush + post flush counts >100 cfu/100ml:** Single outlet contamination is indicated by high counts. If other nearby outlets have no or low counts, investigate cause and ensure controls are in place. The following must be considered:

    - Removing the outlet from clinical use and continue daily flushing.

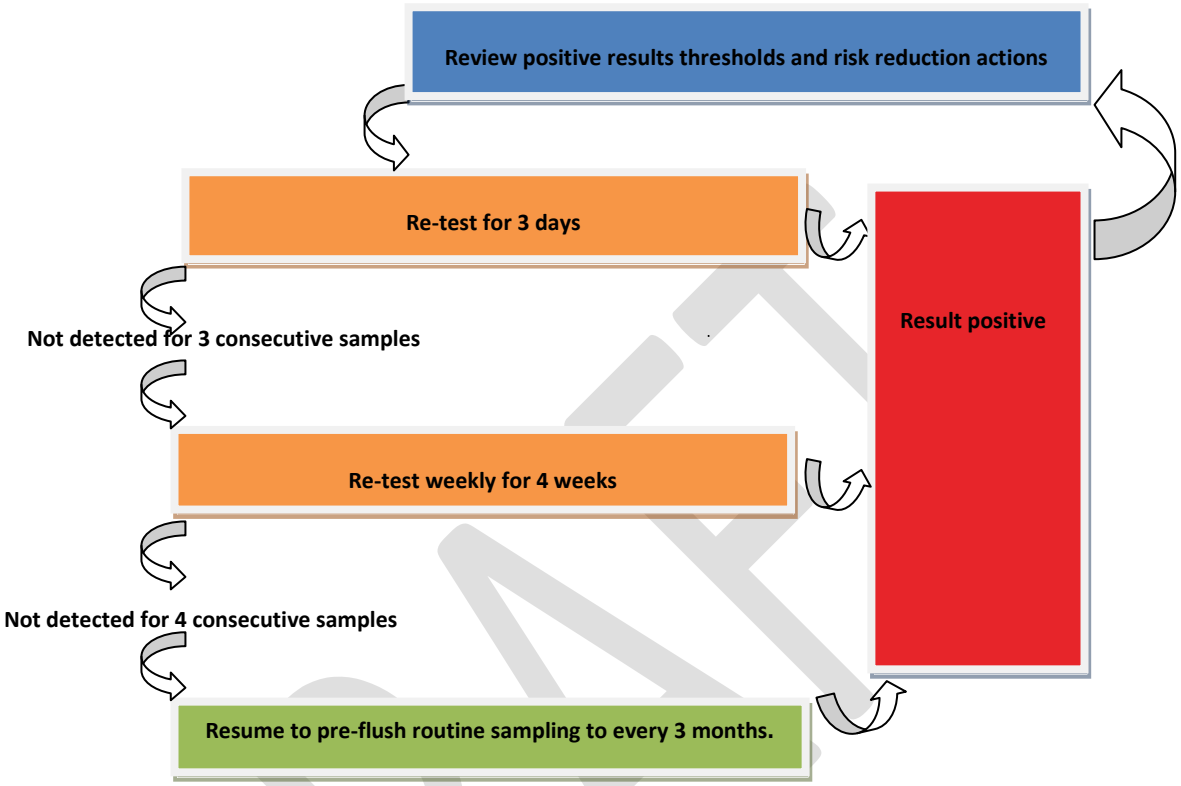
- Explore further testing dilutions (seek advice from WSG) of pre and post-flush water samples from the outlet or use an extended 5 minute flush prior to post-flush sampling.
- Alternatively, disinfect outlet and re-sample post-flush.
- Removal of flow straighteners; if not feasible clean and/or disinfect the straighteners according to the manufacturer's instructions or replace with new. Straightener replacement frequency should be confirmed via sampling results.
- Assess splash risk from the outlet; if confirmed, investigate the following:
    - Check compatibility of tap design flow profile with the clinical hand wash basin (CWHB);
    - Height compatibility between tap outlet and surface of basin;
    - Excess water pressure; and
    - Blocked or malfunctioning flow straightener(s).

4. Result: Not detected

See Figure 1 below for retesting frequencies and period of negative results required prior to re-instatement of outlets removed from use.

Figure 1

Pseudomonas aeruginosa positive result re-sampling frequencies (pre-flush and post-flush) and actions



Outlets taken out of use:

Re-samples must remain not detected for 2 weeks prior to re-instatement of outlet.

HFS, HPS and *Pseudomonas aeruginosa* and Water (Scotland) Group

Guidance for neonatal units (NNUs) (levels 1, 2 & 3), adult and paediatric intensive care units (ICUs) in Scotland to minimise the risk of *Pseudomonas aeruginosa* infection from water

This guidance:

- Is designed to minimise the risk of infection with *Pseudomonas aeruginosa* – the risk however can never be eliminated.
- Is in addition to the extant:
  - The control of Legionella bacteria in water systems. Approved Code of Practice and Guidance (L8).
  - The control of legionella bacteria in hot and cold water systems HSG274 Part 2
  - Water safety for healthcare premises Part A: Design, installation and testing. SHTM 04-01
  - Water sources and potential infection risks to patients in high risk units – revised guidance. CEL 08(2013)
- Includes the information previously issued in Scotland related to *Pseudomonas aeruginosa* (*P. aeruginosa*) and other water-related organisms specifically*: '*Additional information on Pseudomonas aeruginosa and opportunistic water borne pathogens' from Health Protection Scotland (HPS) and Health Facilities Scotland (HFS). [1-3]
- Is due for review in July 2019. In the interim, a draft addendum 'Pseudomonas aeruginosa routine water sampling in augmented care areas for NHSScotland' has been devised to be used along with this guidance.

A multi-disciplinary approach is required for this guidance to work as intended. The actions cannot be left solely to Estates staff: collaboration and participation from Infection Prevention & Control Teams, Clinical staff and domestics as well as Estates & Facilities Teams is required. This is the key to ensuring that infection control risks are highlighted, managed and mitigated.

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Definitions

Hand wash station	A wash hand basin with mixer tap, paper towels and non-antimicrobial liquid soap in a single use container designated for hand washing use only
Sink	A sink into which fluids used on patients may be discarded. After such a procedure hands should be decontaminated as per the National Infection Prevention and Control Manual Chapter 1: Standard Infection Control Precautions.

Contents

Critical Control Point		Lead Responsibility
1	The hospital water delivery system	Estates
2	Flushing taps to reduce the risk of pipework system contamination	Senior charge nurse
3	Preventing direct water usage colonising/ infecting vulnerable patients	Senior charge nurse
4	Preventing indirect water usage from colonising/infecting patients	Senior charge nurse
5	Preparedness for clinical incidents and earliest possible detection of any clinical incidents	IPCTs
6	Prompt investigation and control measure application for any clinical incidents	IPCTs

A) Introduction

Pseudomonas aeruginosa (*P. aeruginosa*) and other similar opportunistic pathogens, are micro-organisms that can cause outbreaks in any healthcare setting where patients are immunocompromised through drugs, disease, invasive device use or the presence of wounds[4]. There have been serious healthcare associated outbreaks mainly in NNUs and ICUs (adult and paediatric) attributed to *P. aeruginosa* where the source of the organism was thought to be tap water[5-9]. In such incidences *P. aeruginosa* at low levels in the water will have formed a biofilm on tap components or parts of the water circulation system. Periodic sloughing of *P. aeruginosa* biofilm will occur when the water tap is operated[10]. In other outbreaks of *P. aeruginosa* the source has been identified as one or more hand wash station drain. However, in such outbreaks the original source may still have been the tap water which subsequently colonised the drain[11]. In a number of cases, sinks have become sources of pathogenic spread after disposal of body fluids or exudates into hand-wash stations[12-14].

This guidance differs from that released in other UK[15-23] countries with respect to the clinical areas where it is directed to be followed, and with respect to some control measures. This is because the application of the control measures including flushing of all tap outlets is considered to have reduced the risk of *P. aeruginosa* infection in general. In addition, ongoing local and national surveillance since the *P. aeruginosa* incidents associated with water was recognised, has not identified any similar clinical incidents in Scotland.

Guidance Presentation

This guidance is designed to minimise the risk of patients developing a *P. aeruginosa* infection by identifying the actions that are required at 6 Critical Control Points. In addition, to support the successful implementation of this guidance at the critical control points, the Organisation Management requirements are specified in the guidance. Although written specifically for *P. aeruginosa* the actions and control measures included will also reduce the risk of HAI from other similar organisms.

B) General Information

Pseudomonas aeruginosa (P. aeruginosa)

P.aeruginosa is a Gram negative organism which is ever-present in the environment being most commonly found in soil and water[4;5]. *P.aeruginosa* can also be part of the normal gut flora and selected out by antibiotics which are not active against it. It is often termed an opportunistic pathogen. Thus there can be infection from a patient's own flora as well as from environmental sources which is the main topic discussed in this document. (An opportunistic pathogen is one which normally only causes an infection in a person with a weakened immune system).

Survival in the environment

Without effective decontamination, P. aeruginosa can survive in any moist environment site indefinitely. For example, P. aeruginosa can survive in a variety of sources such as: topped up fluid containers, hand wash station drains and any other equipment/environment sources [7;11;24;25]. Prolonged contamination of environmental sources can make outbreaks difficult to control. It is the management of the water system before and after the tap, including the correct cleaning of the tap outlet, hand wash stations and the correct discarding of fluids potentially contaminated with P.aeruginosa, that are crucial to reducing the risk to patients.

High Risk Environments

Patients in adult and paediatric intensive care units and babies receiving intensive or high dependency care are at the highest risk of infection with *P. aeruginosa* and similar organisms[4.] This guidance is applicable to NNUs providing all levels of care (1, 2 & 3) as well as adult and paediatric ICUs. In addition, a local NHS board risk assessment should be undertaken to identify any additional clinical settings where patients are extremely vulnerable to infection caused by *P. aeruginosa*. This risk assessment should take account of any previous clinical incidents in individual clinical settings. If additional units are identified as being at increased risk, then these units should be included in the local NHS Board's Water Safety Plan and the recommendations in this guidance followed in these additional clinical settings.(See:Appendix 5).

High-risk procedures

Some procedures involve the cooling of syringes containing infusates in ice-water. This has resulted in outbreaks infections when the ice-water was contaminated[26-28]. Syringes should not be cooled in ways that could contaminate the contents, or the tip of the syringe. The use of ice made from sterile water may be appropriate.

Infections Caused by *P. aeruginosa*

Different infections can arise as a consequence of *P. aeruginosa* or similar organisms. The site of infection depends on the particular patient defence mechanisms that are weakened. The key significant infections are:

- Ventilator Associated Pneumonia (VAP).
- Blood stream infections (BSI) often associated with a vascular catheter or with contamination of an infusate [prepared drug].
- Non-VAP pneumonia.
- Wound infections or surgical site infections.
- Urinary Tract Infections (including catheter associated urinary tract infections (CAUTIs)).
- Insertion site infections around any invasive device. (The presence of invasive devices predisposes immunocompromised colonised patients to *P. aeruginosa* infection).
- As well as the above, neonates are particularly vulnerable to conjunctivitis.

Routes of transmission

P. aeruginosa that does not arise from a patient's own flora can be transmitted in healthcare settings from the environment or from another patient as follows:

Environment-to-patient

The routes of transmission from the *P. aeruginosa* in taps, drains and from any other contaminated environment/equipment source to the patients prior to infection developing, includes:

- Direct contact from contaminated water, or splashes from water outlets,
- Indirect contact, e.g. routes involving contaminated hands, contaminated equipment/environments, such as reusable wash-bowls.

Patient-to-patient

Dissemination of *P. aeruginosa* from colonised patients to the environment or to other patients can occur from any clinical procedure that creates an aerosol from, for example, open suctioning or wound irrigations[5]. *P. aeruginosa* does not give rise to person-to-person cross-transmission as easily as more common HAI pathogens such as MRSA or *Clostridium difficile*.

Incubation Period

There is no defined incubation period for *P. aeruginosa* as patients can be colonised without ever becoming infected. However, if there is a significant patient exposure event, for example, a contaminated infusate, an infection (blood-stream infection (BSI)) can arise quickly usually within 12 hours of the infusion commencing.

Period of Communicability

As long as a patient remains colonised, patient-to-patient transmission within a clinical area is possible. Environment to patient cross-transmission can arise as long as any environmental sources remain contaminated[4;24;29].

C)The SIX CRITICAL CONTROL POINTS TO REDUCE *P.aeruginosa* RISK

Six critical control points have been identified where control measures and actions are required to reduce the risk of *P.aeruginosa* infection in the NNUs and ICUs (adult and paediatric).

1. Critical Control Point 1: The hospital water delivery system

1.1 Estates and Facilities managers must:

- Review site engineering and cleaning protocols to establish that they are in accordance with current guidance including SHTM 04-01*Water safety for healthcare premises*[30], *HSE guidance note L8 Approved Code of Practice*[31], HSE guidance *HSG274 Part 2: The control of legionella in hot and cold water systems*[32] and that manufacturers' instructions with regard to installation and maintenance have been followed.
- Ensure taps and thermostatic mixing valves (manual and automated) have been commissioned (including programming auto flush cycles) and routinely validated, as per the manufacturer's instructions.
- Ensure that water flowing from the taps does not flow directly into the drain holes (to prevent splash back). Waterflow must impact on the basin offset from the drain hole. Flushing (automated or manual) should not result in splashes beyond the hand wash station area.
- Liaise with the Senior Charge Nurse regarding infrequently used hand wash stations or sinks(used and/or flushed once a day) which should be subjected to a documented flushing regime, risk assessed and regularly reviewed for the need for the hand wash station or sink to be still there. (See:Appendix 1 - Number of hand wash stations required in the NNUs and ICUs).
- For automated taps, ensure records of remote flushing are available.
- Remove any redundant branches from circulating mains and provide straight couplings on distribution pipework to eliminate residual dead-legs or blind stub-ends created by plugged Tee-pieces.
- Check the length of any dead-legs and remove any non-compliant pipework. Minimise dead-leg length where possible elsewhere by taking return leg up to hand wash stations and skins.(This should be included in a water risk assessment).
- Before undertaking any modifications to pipework, perform a risk assessment.
- Keep records of risk assessments and modifications made.
- Consider whether thermostatic mixer valve, where such a valve is considered necessary, can be located closer to the outlet.

- Wherever considered necessary, new taps should have integral thermostatic control or be replaced with a thermostatically controlled tap subject to risk assessment.
- Carefully select taps to minimise the formation of aerosols. The water flow profile should be compatible with the shape of the hand wash station. Biofilm can develop on flow straighteners, rosettes and aerators. It is therefore recommended that these are removed. However, the decision to remove flow straighteners, rosettes and aerators should be based on risk assessment, as their removal can create turbulent flow at increased pressure resulting in splashing of surrounding surfaces and flooring. It will be necessary for the engineer to adapt the water distribution system using flow regulating valves to regulate the flow as required. A discharge flow rate from taps of 3 litres per minute will be sufficient to avoid splashing.
- Avoid positioning alcohol based hand rub dispensers such that any drips could fall on to the taps or into the basin of the hand wash station.

1.2 Modifications to the Hospital Water Delivery System

There is no requirement to change taps as a consequence of this guidance. The information here is for when there is a planned replacement/refurbishment, new installation or a recognised need to do so**.**

Installation of taps

It is not possible to have taps ‘pre-disinfected’. Disinfection will have to rely on normal flushing and disinfection protocols that would apply to any new installation before commissioning and putting into use. In new build or refurbishment projects this process should be undertaken as close as possible to the system being handed over to avoid pipework being left unused filled with stagnant water and in consultation seek advice from HFS. A daily flushing regime should be put in place until the system is handed over. Automated tap sensors should be positioned away from the tap. Taps should ideally be removable and easily dismantled for cleaning and disinfection. Automated taps have a greater risk of their complex internal surfaces becoming contaminated with micro-organisms and biofilms. Automated taps are therefore not recommended for low-use situations, however, remote flushing can mitigate the risk of biofilm formation.

Thermostatic mixing devices have complex internal structures that can entrap waterborne bacteria and biofilm. Risk assessments should be carried out to determine the potential to replace thermostatic mixing devices in augmented care accommodation where it is unlikely that patients will use wash hand basins.

Sampling of water for *P. aeruginosa*

Routine sampling of water to detect *P. aeruginosa* should not be carried out. This is because little reassurance can be gained from ad hoc samples which can give rise to false negative results.

A procedure for taking water samples for *P. aeruginosa* (when requested by a clinical microbiologist/ICD) is provided in Appendix 2 – Procedure for taking water samples (when requested by a clinical microbiologist/ICD).

NOTE

While the policy of 'engineering out the problem' always applies, there are situations where this may not be easily achieved, or may not be appropriate.

These would include where alterations would create disruption and danger of infection. This will particularly apply to retrospective compliance.

Similarly, where new build or refurbishment projects have already been contracted prior to the publication of updated guidance and contractual implications would inhibit making changes to the employer's requirements, then retrospective modifications to the engineered system may not be practical.

In these situations a risk-based and proportional response should be adopted by assessing risks arising from hazards, identifying the appropriate actions recommended within the guidance, and identifying operational steps to be taken in order to manage, eradicate or minimise the risks.

2. Critical Control Point 2: Flushing taps to reduce the risk of pipework system contamination

2.1 Senior Charge Nurse Responsibilities

- Ensure that **all** non-autoflushed taps in the NNU and ICU patient areas and areas where clinical procedures are prepared or performed are flushed daily, first thing in the morning, at the maximum flow rate that does not give rise to any splashing beyond the basin/sink, e.g. on the floors. The flushing should be for a period of 1 minute and recorded.
- Identify and report any problems or concerns relating to the safety, maintenance, reduced usage, any changes in use and cleanliness of all water outlets to the Infection Prevention and Control Team (IPCT) and Estates and Facilities Departments as relevant.

Splashing created by flushing taps which falls beyond the sink area can create a risk of slippage/falls.

Where outlets are flushed daily; there is no additional requirement for weekly flushing to comply with *Legionella* guidance unless risk assessment specifies a need for more frequency.

In practice this task (flushing of taps)may be assigned to the domestic services department. However, the Senior Charge Nurse should have evidence that this procedure is being performed as specified. This task could be added to the local cleaning matrix/schedule.

3. Critical Control Point 3: Preventing direct water usage colonising/infecting vulnerable patients

The advice in this section is based on the assumption that there are **no ongoing clinical incidents to suggest water system contamination**, and the guidance in Critical Control Points 1, 2, and 4 are being followed.

3.1 Neonatal Care Procedures

Neonatal Care Procedures	
Care Procedure	**Actions**
Washing babies Options include: • Face wash • Nappy change • Top and tail • Bed bath • Immersion bath	• Type and frequency of wash determined by clinical condition and individual need (points to consider include temperature and physiological stability, skin integrity, weight). • Use tap water for washing. • Use small volumes (<50mls) for face wash, nappy change, top and tail and bed bath.
Defrosting breast milk	Options include • Defrost in a designated milk fridge • Defrost outside the fridge at room temperature. Note: Once defrosted and warmed to room temperature milk cannot be returned to the fridge or refrozen. Discard any remaining milk • Defrost using a warming/thawing device designed to ensure no direct contact with the bottle/syringe with non-sterile water. Alternatively, use sterile water which has been warmed in a warming cabinet. • **DO NOT DEFROST FROZEN BREAST MILK BY PLACING THE CONTAINER IN WARM TAP WATER**.[33, 34]

Neonatal Care Procedures	
Care Procedure	**Actions**
Warming breast or formula milk	Options include: • Take milk out of fridge one hour prior to use • Warm using a warming device designed to ensure no direct contact with the bottle/syringe with non-sterile water. Alternatively, use sterile water which has been warmed in a warming cabinet • **DO NOT WARM MILK BY PLACING CONTAINER IN WARM TAP WATER**
Use of ICE	Do not use ICE for direct baby care (NNUs all levels) Ice may be directly used for rare but important clinical conditions. This would be under senior medical instruction/supervision and done when the remote risk of P.aeruginosa infection would be outweighed by the clinical benefits of using the ice.

3.2 Paediatric and Adult ICU usage of Tap Water

There is no restriction on the usage of water for washing, drinking or oral hygiene by adults or paediatrics. The guidance on the use of ice remains extant, i.e. the use of ice for consumption by severely immunocompromised patients should not be taken from automatic ice-making machines but should be made with sterile water[35].

4. Critical Control Point 4: Preventing indirect contact with *P. aeruginosa* from colonised/infected patients

This critical control point is divided into 3 sections: 1) Clinical Procedures, 2) Discarding Potentially Contaminated Fluids and 3) Environment/Equipment Decontamination Procedures. This section applies to adult and paediatric ICUs and all NNUs). For clinical procedures including hand washing procedures and the discarding of fluids (blood, body fluid or potentially contaminated fluids), follow the National Infection Prevention and Control Manual[36] including the use of Personal Protective Equipment. NHS Boards should be able to demonstrate compliance with the National Infection Prevention and Control Manual.[36]

1. Clinical Procedures	
Hand Washing/Hygiene Procedures	Use hand wash stations **only** for hand washing. If it is not possible to comply with this instruction then alert the IPCT who will assist/advise in completing a risk assessment. Follow hand washing procedure as shown in Chapter 1 SICPs of the National Infection Prevention and Control Manual[36]. Discard hand hygiene product bottles when empty – never top up.
Aseptic procedures (including IV drug preparation procedures)	Do not **prepare or perform** aseptic procedures in areas where there are concurrent procedures that are generating splashes which could contaminate a sterile surface, e.g. collecting water from a tap. Decontaminate all surfaces on which aseptic procedures are to be performed prior to commencing a procedure – use a detergent or alcohol wipe.
Aerosol generating Procedures	Follow existing guidance for aerosol generating procedures detailed in the national guidance on respiratory tract infections[37]

2. Discarding Potentially Contaminated Fluids	
Small volume fluids	Do not discard small volume fluids (e.g. ET condensate, baby washing water <50mls) into hand wash stations. Empty fluids directly into a clinical waste bag. Alternatively these small volumes may be absorbed by (e.g. cotton wool balls), before disposal into a healthcare waste bag.
Larger volume fluids	e.g. Bed bath fluids/baby bath water/large volume of ET condensate. Safely transport containers and discard in sluice or a sink, which is not a hand wash station. If it is not possible to comply with this instruction then alert the IPCT who will assist/advise in completing a risk assessment.
Suction/chest drain bottles	Seal and discard disposable lined suction containers in a healthcare waste bag or, use solidifying gel prior to discarding in a healthcare waste bag.
3. Environment/Equipment Decontamination Procedures	
(Key) Equipment Decontamination	**Incubators - Follow Manufacturer's Guidance** There is no requirement to use sterile water to clean incubators after use. Tap water and general purpose detergent may be used. Do not use disinfectants that will degrade the incubator material. The critical factor **is the thorough drying** of the mattress and all parts of the incubator. Any moisture left within or on the incubator will encourage microbial growth – including *P. aeruginosa*.
	Humidifiers attached to incubators Use only sterile or distilled water (as per manufacturer's instructions) to fill and top up
	Humidifiers **Reusable** humidifiers must be able to withstand reprocessing in a Central Decontamination Unit as per manufacturer's instructions. If they are not able to withstand reprocessing in a CDU then an alternative method of decontamination as listed in the manufacturer's guidance must be followed.

Hand wash station cleaning	Frequency: minimum daily Procedure for cleaning hand wash stations is provided as Appendix 3.
Storage of equipment	Do not store any equipment items where they may be exposed to splash contamination.
Non-clinical procedures that generate a spray, e.g. cleaning spray bottles	**Do not top up any** fluid containers, e.g. spray bottles used for cleaning. Refillable spray bottles **must not** be used for cleaning solutions. Do not use spray bottles in areas where aseptic procedures are being prepared or are ongoing. Where possible avoid using spray bottles.

5. Critical Control Point 5: Preparedness for Clinical Incidents and Earliest possible detection

5.1 Clinical Isolate Surveillance and Preparedness

IPCTs should:

- Be alert to the possibility that patients in NNUs, ICUs and immunocompromised patients in general are at increased risk of cases/outbreaks of *P. aeruginosa* (or similar type of organism).
- Include *P. aeruginosa* from a blood culture as an alert organism from an adult or paediatric patient.[38] (An alert organism is identified by the microbiology laboratory and referred to the IPCT for assessment of possible healthcare associated acquisition and to identify any possible environmental/equipment sources).
- When assessing alert organisms be mindful that *P. aeruginosa* can be selected for by prior antibiotic usage.
- In a neonatal unit include *P. aeruginosa* from any clinical specimen as an alert organism.
- Ensure they can detect in real time any possible outbreak early through effective local surveillance and monitoring of numbers of cases over time.
- Be able to facilitate early identification of possible source(s), i.e. have a testing protocol in place ready for testing of water outlets for *P. aeruginosa.*
- Have a contingency plan for NNUs and ICUs to enable safe patient care to continue without direct patient/water contact, e.g. use of patient wipes and sterile water in neonatal units.

Testing of water for *P. aeruginosa* is only required if a very specific reason has been identified, e.g. suspected or confirmed outbreak, or a series of sequential cases. Testing of water for *P. aeruginosa* in the absence of a clinical incident may provide little reassurance as a negative result refers only to the single point in time when the specimen was taken.

Further information on microbiological examination of water supplies for *P. aeruginosa* can be found in Health Technical Memorandum 04-01: Addendum. *Pseudomonas aeruginosa* - advice for augmented care units'. (See Appendix 4)

5.2 National *P. aeruginosa* Surveillance and Reporting of Clinical Incidents

The total number of bacteraemias caused by *P. aeruginosa* is published annually as part of the Scottish Antimicrobial Resistance Surveillance Programme. Real-time surveillance of specific alert organisms is a local responsibility for NHS boards. Emerging background monitoring aimed at identifying emerging threats is being reviewed.

Any local outbreak or incident should be assessed using the Hospital Infection Incident Assessment Tool (HIIAT) and reported to HPS if amber or red. In addition, if there is an active ongoing clinical incident, where the source is considered to be tap water, then HPS should also be informed regardless of the HIIAT.

6. Critical Control Point 6: Prompt investigation and control measure application for any clinical incidents

Should local alert organism surveillance identify a possible outbreak caused by *P. aeruginosa*, then the rigour of investigation and control measures must still apply regardless of the considered vulnerability of the patients in the clinical setting. In an area where there may be an immediate risk, the IPCT should work urgently with Estates/Facilities.

When investigating any individual patient's healthcare experience in time, place and person, the IPCT needs to consider:

- The patient's entire inpatient/outpatient journey (all wards where the patient stayed during their current hospitalisation).
- The history of invasive device use, including antibiotic administrations.
- How water is used in the clinical areas where the patient has been cared for and how it was used by the patient.
- How drugs, particularly IV drugs, are prepared in the clinical area.
- All possible reservoirs, e.g. water and environmental where colonisation could have arisen.
- All patient/water/environmental microbiology details.

6.1 Outbreak Control Measures

- Confirm that the existing guidance detailed in Control Points 1 – 4 is being followed.
- Consideration should be given to preventing patients coming into contact with potentially contaminated water until it is confirmed that water is not the source, i.e. water coming into direct patient contact.
- Implement the Pseudomonas Outbreak Checklist and/or HPS Generic Outbreak Checklist if there are situations with an ongoing infection risk. (If an incident arises contact HPS).
- Isolate or cohort neonates with *P. aeruginosa* colonisation or infection. Adult and paediatric ICU patients do not require isolation.

N.B. Seek advice and/or involve Consultant in Public Health Medicine (CPHM), HFS, HPS in incidents.

6.2 Point-of-use tap filters

Routine use of point-of-use filters is not recommended. Point-of-use filters are not a primary preventative measure, or a primary control measure. They may be considered if there is a recognised clinical incident and the role of water in the incident is yet to be identified. Therefore any new taps in NNUs and ICUs should be capable of including a point-of-use filter.

While the installation of point-of-use filters will maximise delivery of safe water supplies there is a danger that their inclusion will lead to a false sense of security and reduce the risk of compliance with primary prevention measures of flushing all frequently used outlets, hand hygiene and the safe discarding of potentially contaminated fluids.

Removal of point-of-use filters would be a clinical decision but the only way to be confident that elimination of potential re-seeding by incoming water supplies has been achieved would be to fit point-of-use filters permanently or to make amendments to plumbing and taps. It should be recognised that their installation will be detrimental to water flow in gravity installations with restricted pressure.

D) Organisational Management

There must be good dialogue and communication between the IPCT, Infection Control Manager Estates and Facilities departments and the NNUs and ICUs.

Chief Executive's Responsibilities

As detailed in SHTM 04-01 and CEL 08 (2013) [1;30] the CEO is ultimately responsible for ensuring:

- Clinical areas where patients at the highest risk of *P. aeruginosa* or similar infection have been identified.
- Clinical Directors and Senior Charge Nurses of these clinical areas have been informed of the risks and the actions in this guidance needed to prevent *P. aeruginosa*.
- Best practice relating to the use of hand washing facilities is consistently and fully applied.
- There is a nominated Responsible Person (Water) for their NHS board. See Section 6 of SHTM 04:01 Part B, paragraph 6.7 http://www.hfs.scot.nhs.uk/publications/1343743141-Version%201.2.pdf
- There are robust systems and documentary evidence of safe water management systems which includes having a Water Safety Group (WSG) responsible for developing and maintaining a Water Safety Plan (WSP), inclusive of risk assessments and actions to mitigate risks.
- A report is provided to the board, at least annually providing assurance that appropriate arrangements are in place and operating in accordance with the requirements of the CEL and supporting guidance, including the status of the Water Safety Plan and Action List.

Organisational Arrangements for the Water Safety Group (WSG)

- As the risks around *P. aeruginosa* infection in hospitals include the fixtures, fittings as well as the use of water in clinical settings and clinical procedures, a medical microbiologist should be on the WSG to advise and lead on these issues.
- The WSG may be led by the Responsible Person (Water) and there must be a clear line of responsibility to the CEO through the Infection Control (or other) Committee. (The Responsible Person (Water) has a duty to link with the ICD and the ICD has a duty to be involved in the risk assessments.)
- The WSG is responsible for ensuring it identifies microbiological hazards, assessing risks, identifying and monitoring control measures and developing incident protocols.
- The WSG should ensure a co-ordinated approach between IPCTs, clinical staff and Estates/Facilities department on all water issues. Involved in developing the Water Safety Plan (WSP) will be: IPCT, Senior Nurses, Estates, Medical Physics (re: incubator, humidifiers etc), Health and Safety and

Domestic Services Managers. See Appendix 5 for the Key Steps of a Water Safety Plan for a Healthcare Facility.

Risk Assessment and identification of actions that are required to reduce or negate *P. aeruginosa* risks:

- Details of the ICUs and other clinical settings that are considered to be at high-risk of *P. aeruginosa* infection based on the patients' immune status and any previous clinical *P. aeruginosa* incidents.
- Confirmation that the Clinical Directors and Senior Charge Nurses in these clinical areas have been informed of the *P. aeruginosa* risk to their patients.
- An assessment in these clinical areas of the suitability of the water distribution system including design, maintenance and configuration of pipework, provision, location and design of thermostatic control devices, design and layout of hand wash stations i.e. position of sensor, soap, gel and angle of lever on operated tap, identifying unused and under-used outlets and hand wash stations and the unnecessary use of flexible hoses and any containing inappropriate lining materials.
- Confirmation that there are sufficient easily accessible hand wash stations that are all being used or flushed at least daily in all NNUs and ICUs and other recognised clinical units. (See Appendix 2).
- An assessment of the clinical practice and ongoing care of invasive devices, cleaning of patient equipment and usage of hand wash stations that could compromise patients.
- The sampling and monitoring that needs to be put in place in the event of an outbreak or incident.
- Those NHS boards with existing robust water management policies for *Legionella* will already have in place much of the integral requirements for developing a WSP.
- The WSP will complement SHTM 04-01[30] Parts A & B.

The Water Safety Plan Action List

As a consequence of the Risk Assessment in the Water Safety Plan a series of actions will be made. The WSG must advise the Infection Control (or other) Committee of the relative importance of these actions and the order in which any remedial action should take place to optimise patient safety.

The Action List should include any training and competency issues required to ensure compliance with this guidance.

Training and competency

Where Healthcare Workers (HCWs) undertake additional actions or carry out a task in a specific way, for example the flushing of a water source, cleaning of a hand wash basin or the installation of soap dispenser, these HCWs must be provided with training and information detailing how to carry out the tasks effectively.

E) Appendices

Appendix 1 - The number of hand wash stations required in the NNUs and ICUs

Regulations on hand wash stations are contained in SHFN 30 and SHTM 04-01[30;39]. In relation to the number of hand wash stations SHFN 30 states:

"To encourage good practice and give reasonable access, it is recommended that there should be:

- *Ideally in intensive care and high dependency units (critical care areas), one hand wash basin at the front of each bed space"*

The latest information suggests that the more hand wash stations in any given clinical environment the less the amount of water pulled through from any individual water outlet (tap) and consequently the greater the risk for biofilm formation on pipework[40]. Overall safety from all HAI (*P. aeruginosa* and non- *P. aeruginosa*) risks needs to be balanced. Therefore, a precise number of hand wash stations to beds/cots are not specified in this guidance. SHTM 04-01[30]/SHFN 30[39] is currently being revised in line with the instructions in this section:

- There should be *sufficient*, *easily accessible*, hand wash stations for clinical staff to use to decontaminate their hands.
- What precisely ***sufficient hand wash stations*** means for any given clinical area needs to be determined locally through a risk assessment.
- The IPCT and the clinical team should agree for the local risk assessment whether there are sufficient numbers of hand wash stations and sinks in their NNUs and ICUs.
- Clinical staff should confirm that, given the vulnerability of their patients, the distance from all bed/cot-sides to the nearest hand wash station does not prevent, or inhibit, the HCW taking the opportunity to perform hand washing as required.
- This assessment can be confirmed by hand hygiene audit data which should demonstrate that when hand-washing is required, it is being reliably performed by all staff.
- If it is considered that major works are required as a consequence of the above statements, contact HFS prior to developing plans.

Appendix 2 - Procedure for taking water samples (when requested by a clinical microbiologist/ICD)

- Sampling will only be taken if a clinical incident has occurred.
- The method of water sampling outlined in this guidance differs from the collection of water samples for other purposes e.g. sampling for *Legionella.*
- Sampling should only be undertaken by staff trained in the appropriate technique for obtaining water samples. See SHTM 04-01 - Water Safety for healthcare premises Part C – TVC Testing Protocol http://www.hfs.scot.nhs.uk/publications/1360856813-V1.2%20SHTM%2004-01%20Part%20C.pdf
- Sampling should take place during a period of no use (at least 2 hours or preferably longer) of that outlet, if that is not possible, during a time of lowest usage. This will normally mean sampling in the early morning, through a variety of usage patterns may need to be taken into account.
- The sampling protocol is designed to ensure the best chance of isolating any organism from the tap or outlet. As such the tap should not be disinfected by heat or chemicals or cleaned before sampling. Disinfectants in the water, such as chlorine or chlorine dioxide, will have residual activity and may inactivate bacteria after taking the sample but prior to its processing. To preserve the microbial content of the sample the disinfectant should be neutralised. Neutralisers should be present in the sterile sampling containers.

How to sample

Two sterile containers of 500-1000ml volume containing a suitable neutraliser will be required.

Two separate samples must be obtained from the same outlet:

- A **pre-flush** sample should be taken from the tap/outlet when the tap or outlet has not been used for at least 2 hours.
- The tap should then be run for one minute and a second identical **post-flush** sample taken.

Sample containers should be carefully labelled such that the outlet and the water to be tested (i.e hot, cold or mixed) can be clearly identified, diagrammatic maps indicating numbered outlets to be sampled can be helpful in this respect.

Without touching the screw thread, inside of the cap or inside of the collection container hold the container under the tap and collect approximately the first 450 – 500 ml water.

Replace the cap and invert to mix the neutraliser with the collected water.

If the water feed to the outlet is provided by:

- A separate cold water supply and hot water supply; or
- Separate cold water and a pre-blended hot water supply

The container should be filled with half the sample by running the cold water into the container first. The rest of the sample should then be collected from the hot or blended outlet.

The post-flush sample should be collected in the same way.

The collected water should be processed within 2 hours or refrigerated within 2 hours at 2-8C and processed within 24 hours. Transport may be aided by the use of temperature controlled box.

Further information on microbiological examination of water supplies for *P. aeruginosa* can be found in 'Water Sources and *Pseudomonas aeruginosa* infection of taps and water systems, DH, 31 March 2012' (see Appendix 4)

Appendix 3 - Guidance on cleaning of sinks/basins and taps in ICUs and neonatal units to minimise risk of *P. aeruginosa*

Step 1: Cleaning the surrounding area

All basins, sinks and surrounding areas should be free from clutter and debris:

- Put on disposable gloves and apron.
- Using a new disposable cloth and detergent damp-clean the paper towel holder then the soap dispenser, paying particular attention to the underside of the soap dispensing unit, finishing with the nozzle.
- Then clean the splash-back area, working from top to bottom
- Then clean the underside of the sink/basin working from the higher level downwards.
- Carefully dispose of the cloth into the appropriate waste bag.
- Dry all surfaces with disposable cloth/towel as above.

Step 2: Cleaning the wash-hand basin

- Using a new disposable cloth and 1,000 ppm available chlorine, clean tap(s) first – start at the tap outlet end (**do not put cloth into the tap outlet**), finish at the base and then clean tap handles.
- Using the same cloth clean the accessible part of the overflow or waste outlet to remove visible dirt. Dispose of the cloth in the appropriate waste bag.
- Using a new disposable cloth clean round the inside of the sink/basin from top rim of bowl.
- Rinse as above.
- Carefully dispose of cloth in appropriate waste bag.
- Dry all surfaces with disposable cloth/towel as above.
- Dispose of gloves and apron in appropriate waste bag and decontaminate hands between the cleaning of each sink/basin.

Always ensure that the cleaning product being used is compatible with the surfaces on which it is being used.
N.B. Refillable spray bottles **must not** be used for cleaning solutions

Enhanced cleaning

During outbreaks/isolation nursing or terminal clean, the process is the same however the frequency may change. This will be guided by the local IPCT.

Appendix 4 - Microbiological examination of water samples for *P. aeruginosa*

[Source: Health Technical Memorandum 04-01: Addendum. *Pseudomonas aeruginosa* - advice for augmented care units, Department of Health 2013]

https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/140105/Health_Technical_Memorandum_04-01_Addendum.pdf

Appendix 5 – Key steps of a Water Safety Plan (WSP) for a Healthcare Facility[41]

- Establish an Environmental Monitoring Committee (or equivalent).
- Document and describe the entire domestic water distribution system including schematic diagrams.
- Carry out a hazard analysis and risk characterisation, assessing the likelihood and impact.
- Assess the risks pertaining to all domestic water, water systems, water uses, routes of exposure and patient risk groups.
- Assess incoming source water quality and composition.
- Identify and evaluate existing control measures.
- Identify and implement additional control measures.
- Carry out scalding risk assessments.
- Enter ongoing risks onto the facility's risk register and manage appropriately.
- Monitor and audit control measures.
- Ensure maintenance is carried out in line with current recommendations.
- Maintain an up-to-date hygiene logbook.
- Develop written policies and procedures.
- Develop a contingency plan for major disruptions to the incoming water supply.
- Establish a communication plan.
- Provide staff training and ensure competency.
- Carry out the necessary validation, verification, and audit processes.
- A WSP is a dynamic document. It is important that it is not seen as a one-off exercise. It must be kept up-to-date. Many factors in the day-to-day running of a facility can affect the risk of water system contamination such as:
    - Planned/unplanned works or maintenance of the water system;
    - Building renovation or refurbishment;
    - Closure and re-opening of the facility or parts of it (planned or unplanned)
    - Change of use of the building, or part of it;
    - Disruptions to the water supply or to the facility;

The WSP should be reviewed on an annual basis and when there are alterations, repairs, changes of use, building works, or critical incidents.

Sites where there are mixed uses such as buildings for direct healthcare provision and buildings for administration are often supplied by the same mains water supply. However, water systems use within both will be substantially different and can negatively impact in either direction. This must be addressed during the development of a WSP and there must be clear responsibility for the safety of water on the site.

The key factors that influence risk and should be incorporated in a healthcare facility's WSP and assessed as part of the risk assessment are:

- Source water quality and characteristics;
- Age, design and size of building;
- Temperatures, pressures and flow;
- Materials, fixtures and fittings;
- Unit/ward design;
- Augmented care units;
- Outlet use;
- Cleaning, maintenance and disinfection;
- Staff training; and
- Audit.

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Review

Waterborne infections in haemato-oncology units — a narrative review

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SUMMARY

Bone marrow transplant and haemato-oncology patients are at risk of healthcare-associated infections due to waterborne pathogens. We undertook a narrative review of waterborne outbreaks in haemato-oncology patients from 2000 to 2022. Databases searched included PubMed, DARE and CDSR, and were undertaken by two authors. We analysed the organisms implicated, sources identified and infection prevention and control strategies implemented. The most commonly implicated pathogens were *Pseudomonas aeruginosa*, non-tuberculous mycobacteria and *Legionella pneumophila*. Bloodstream infection was the most common clinical presentation. The majority of incidents employed multi-modal strategies to achieve control, addressing both the water source and routes of transmission. This review highlights the risk to haemato-oncology patients from waterborne pathogens and discusses future preventative strategies and the requirement for new UK guidance for haemato-oncology units.

Introduction

Water-related incidents in a new-build hospital have highlighted the vulnerability of haemato-oncology patients to waterborne infections [1,2]. By the very nature of their disease haemato-oncology patients are immunosuppressed and susceptible to infections from both endogenous and exogenous sources. Hospital admissions and treatments bring additional risk factors including chemotherapy, presence of central venous catheters and steroid use [3]. Mains drinking water is not sterile and contains a range of waterborne micro-organisms including Opportunistic Premise Plumbing Pathogens (OPPPs) [4]. Where water systems are not managed appropriately these waterborne pathogens will increase in number resulting in infections in susceptible individuals [5]. We undertook a narrative review of waterborne outbreaks/incidents in haemato-oncology patients to enable a better understanding of pathogens involved, sources and routes of transmission and relevant control measures with a view to making recommendations for implementing future preventative strategies.

Methodology

A narrative review was performed using relevant search terms: (1) water AND Gram negative bacteria AND nosocomial infection, (2) bone marrow transplant unit OR hematopoietic stem cell transplant unit OR haematology unit OR haemato-oncology unit OR allogenic transplant OR autologous transplant AND water outbreaks OR waterborne infection. The databases employed were PubMed, CDSR, DARE from 'Jan 2000

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to Oct 2022' for reviews and original articles. Relevant documents were scanned before exclusion, along with non-English papers, posters and conference reports. Pathogens involved, sources of infection, patient numbers, infection types, control measures and outcomes were noted. Published data were checked for additional references. Two authors undertook the literature reviews.

Findings

Epidemiology and Microbiology

A total of 40 papers were identified and included for analysis [6—45] (Table I). 80% of papers were from Europe, the USA and the UK. The largest number were from the USA (nine papers), UK (eight papers), France (six papers).

Of the 40 papers analysed, the most commonly implicated pathogens were; *Pseudomonas* spp. (13 papers), non-tuberculous mycobacteria (NTM) (eight papers) and *Legionella pneumophila* (five papers). Four incidents involved *Sphingomonas* spp., and three incidents involved fungi. Other incidents were due to *Enterobacter cloacae*, *Klebsiella oxytoca*, *Achromobacter* spp., *Pantoea agglomerans*, *Ochrobactrum anthropi* and *Stenotrophomonas maltophilia*. Of the 40 incidents, eight were polymicrobial, four of which involved multiple Gram-negative organisms and four NTM outbreaks involving more than one species of mycobacteria. *Mycobacterium mucogenicum* was the most common NTM implicated (six papers) followed by *M. chelonae* (three papers). Of the *Pseudomonas* spp. related incidents, the majority (11/13) involved *P. aeruginosa* (seven outbreaks were associated with multi-drug-resistant strains).

Bloodstream infections were the most common, reported in 34 papers. Other infection sites included the respiratory tract, skin, urinary tract and colonization was reported in nine papers.

Thirty-one papers utilized typing including pulsed field gel electrophoresis (PFGE), multi-locus sequence typing (MLST), PCR-based methods and whole-genome sequencing (WGS). Typing results in the majority of the 31 papers were complex with the identification of either multiple patient genotypes, diversity of environmental strains or both and only partial matching of the two. In only three papers did typing results appear straightforward in that patient isolates matched each other and environmental isolates.

Routes of transmission and sources

Several potential routes of transmission were reported, including direct patient contact with contaminated water, e.g., showering, bathing, washing hands and teeth brushing. Indirect contamination was reported via hands of healthcare workers or contaminated equipment. Aerosolization is a recognized route of transmission for Legionella and was postulated as a potential route for *Fusarium* spp. [7], this route is also implicated in transmission from drainage systems. Multiple sources of water contamination were reported with 15 incidents involving more than one source. Twenty-five incidents reported positive water samples (i.e., contaminated) from tap water or tap components, 14 involved drains (10 of these were sink drains and four were shower drains), nine involved shower water or shower heads, three involved toilets and three demonstrated the involvement of water storage tanks. Of the remaining sources the following were implicated; baths (two), ice machines (two), incoming mains water (one), water dispensers (one), humidifiers (one) decorative water features (one), bidet taps (one) and unidentifiable source (one).

Control measures

Interventions were multi-modal in most incidents (24/40) addressing both source and routes of transmission. Twenty-one incidents involved a bundled infection prevention and control (IPC) approach. For two studies no information on control measures was provided. Thirteen incidents employed the use of biocides with the most common agent being hydrogen peroxide. Eighteen incidents reported ensuring that the water from the outlets was microbiologically safer for the susceptible patient groups with the majority (14/18) using point of use filters (POUFs). Whilst drain cleaning was reported in six papers, detail was lacking on the agents used, contact time, concentration and frequency. In 13 incidents a degree of refurbishment took place ranging from outlet replacement to installation of a separate water loop or replumbing.

Discussion

This literature review identified 40 publications describing incidents linked to water or wastewater in haemato-oncology units. Given the high susceptibility to infection in this patient group due to underlying disease and combined with the presence of invasive devices, 40 publications might be regarded as surprisingly modest. Greater understanding of waterborne infections is relatively recent. Up until 2012, *Legionella* spp. was regarded as the principal waterborne infection. However, that changed with the neonatal *P. aeruginosa* outbreak in Belfast in 2012 [46]. A wide range of organisms are naturally found in water in buildings, some of which are known as OPPPs and many can cause human disease [20]. Many of these environmental micro-organisms can be difficult to identify using conventional biochemical tests and the introduction of matrix assisted laser desorption ionization — time of flight (MALDI-TOF) is likely to improve identification and recognition.

Pseudomonas spp. and non-tuberculous mycobacteria were the most commonly implicated pathogens identified in this review. The papers reporting *Legionella* spp. involved the shortest time to recognition of an incident/outbreak and length of outbreaks were relatively short (four of five outbreaks were less than 15 days). This is likely due to the awareness that a single case of *Legionella* spp. warrants simultaneous investigation and surveillance for other cases. Only in one instance was there a significant delay leading to eight cases in three months. Outbreaks due to Gram-negative micro-organisms and non-tuberculous mycobacteria were recognized due to the unusual nature of the organisms and their known associations with water sources. The average length of NTM outbreaks was eight months and that of more unusual Gram-negative OPPPS outbreaks was nine months.

Enterobacterales and *Pseudomonas* spp. outbreaks had long durations ranging from four months to three years, to one month to seven years, respectively. This likely reflects the challenges of surveillance and outbreak detection for

Table I
Summary of incidents

	Reference, first author/year	Organism(s)	Resistant organism	Prompt for investigation	Source	Number of patients	Type of infection	Outbreak measures
1.	Amoureux *et al.*, 2017	*Pseudomonas aeruginosa*	Yes	Resistant nature of organism	Sinks and shower drains	Seven	Bloodstream Urinary Colon ization	Changing of drains unsuccessful Complete refurbishment
2.	Anaissie *et al.*, 2001	Fusarium species	No	Increased incidence of Fusarium cases	Sink drains, tap aerators, showerheads, water tank	38 (of which 30 had acute leukaemia)	Disseminated Cutaneous	Avoidance of tap water Sterile water for drinking Avoid showering during periods of severe immunosuppression
3.	Aumeran *et al.*, 2007	*P. aeruginosa, Pseudomonas putida*	No	Increased incidence of Pseudomonal bacteraemia's in a three-month period and compared with the previous year	Water outlets secondary — refillable disinfectant detergent spray cleaning bottles — this led to further cases after the water system had been cleared of the organism	Eight	Bloodstream infection Exit sites and intraluminal infections	Chlorination of water network Application of point of use filters Installation of separate water loop to affected ward— this produced microbiologically controlled water Replacement of refillable detergent sprays with ready to use solutions. Increasing the size of the catheter dressing at the exit site (previously reduced to minimize discomfort dressing removal)
4.	Baird *et al.*, 2011	*Mycobacterium mucogenicum* and *neoaurum*	No	Cluster of NTM bacteraemias	Shower water	Five	Bloodstream	Removal of patients from unit Cleaning and disinfection of storage tanks Cleaning and replacement of water pressure pumps Rebalancing of tanks

								to minim ize stagnation risk Replacement of showerheads and hoses 12-weekly cleaning and chlorination of hose, showerheads, washbasins and drain traps Flushing of showers for 2 min before every use. Hickman line interlink connectors were replaced with bio nectar connectors, which have fewer connections and a tighter seal. The use of transparent semipermeable polyurethane dressings, which are maintained while showering. Nursing staff and patients were re-educated in relation to these changes in practice, and the principles of good Hickman line care were reinforced
5.	Berrouane *et al.*, 2000	MDR Pseudomonas	Yes	Cluster of three infections in a 30-day period	Whirlpool bath	Seven	Bloodstream Respiratory infection Urinary tract	Withdrawal of bath from use Replacement system installed Weekly cleaning protocol implicated
6.	Breathnach *et al.*, 2012	MDR Pseudomonas	Yes	Resistant nature of organism	Waste-water outlets	85 cases in outbreak 1	Bloodstream	Enhanced cleaning and decontamination

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Table I (*continued*)

	Reference, first author/year	Organism(s)	Resistant organism	Prompt for investigation	Source	Number of patients	Type of infection	Outbreak measures
						(hospital wide) and four cases in outbreak 2 (haemato-oncology)		Refurbishment/ replacement of taps, sinks, sluice areas Education re waste pipe blockage Switching to degradable paper towels Rimless toilet pans Avoiding storage of clean items in sluice Shower drain cleaning Weekly disposal of toilet brushes Education re safe disposal of sanitary items Replumbing of mains wastepipe Reduced shower water pressure
7.	Deliere *et al.*, 2000	*Ochrobactrum* spp.	No	Rare organism	Tap water	Three	Bloodstream Colon ization	Nil reported
8.	Erat *et al.*, 2020	*Legionella pneumophila* serogroup 2-14	No	Single case of Legionella	Tap water	One	Respiratory	Superheating Hyperchlorination Hydrogen peroxide Flushing of taps and showerheads with descaling agents
9.	Furtwangler *et al.*, 2017	*L. pneumophila* serogroup 1	No	Single case of Legionella	Outlets Existing water hose emptying devices may have exposed the patient to the pathogen while he was sitting on the bathroom floor	One	Respiratory	Point of use filters already installed
10.	Garvey *et al.*, 2018	*P. aeruginosa*	No	Three patient cases prompted additional water testing	Water outlet in ward preparation room and contaminated	Three	Bloodstream	Cleaning and thorough drying of infusion therapy procedure trays

					infusion therapy procedure trays			Application of point of use filters
11.	Gbaguidi-Haore *et al.*, 2017	*P. aeruginosa*	Yes	Resistant nature of organism	Sink P traps	Ten	Bloodstream Colon ization	Cleaning of traps Replacement of traps on patient discharge Hand hygiene measures Changes to waste disposal practices Removal of hand showers for washing toilets
12	Gillespie *et al.*, 2000	*P. aeruginosa*	Yes	Resistant nature of organism	Drains	Five	Bloodstream Respiratory	Dismantling and disinfection of drains
13	Habermann *et al.*, 2020	Non-tuberculous mycobacteria; mucogeniucm/ chelonae/ fortuitum/ undefined	No	Increased incidence of cases compared with none the year before	Contaminated tap water	Five	Bloodstream	CVC guidance and education
14	Hugon *et al.*, 2015	*Achromobacter* spp.	No	Unusual organism	Tap water Disinfectant atomizers	Seven	Bloodstream	Filters Sterile water used to prepare antiseptic solution Disinfectant dispensers without spray introduced
15	Inkster *et al.*, 2021	*Cupraividus pauculus* and multiple other Gram-negative environmental bacteria	No	Unusual organism	Taps and showers, hospital water tanks, drains	23	Bloodstream	Alternative sources of water provided Point of use filters Installation of chlorine dioxide dosing Replacement of taps, sinks and drains Drain cleaning Enhanced environmental cleaning
16	Inkster *et al.*, 2021	*Mycobacterium chelonae*	No	Unusual organism	Tap and shower water	Two	Bloodstream	Point of use filters
17	Johnson *et al.*, 2018	*Sphingomonas* spp.	No	Unusual organism	Tap water	9 of 12 were transplant patients	Bloodstream, respiratory	Chlorination Superheating
18	Jolivet *et al.*, 2020	OXA-48 CPE variety of bacteria	Yes	Resistant nature of organism	Toilets and sink drains	37	Bloodstream Urinary	Cohorting, dedicated unit, dedicated staff

(*continued on next page*)

Table I (*continued*)

	Reference, first author/year	Organism(s)	Resistant organism	Prompt for investigation	Source	Number of patients	Type of infection	Outbreak measures
							Respiratory Colon ization	Contact precautions Education of staff Toilet cleaning with descaling and bleaching Rimless toilets
19	Kilic *et al.*, 2007	*Sphingomonas* spp.	No	Unusual organism	Tap water Bath tub	Four	Bloodstream	Cleaning of sinks and changing taps
20	Kline *et al.*, 2015	*M. mucogenicum*	No	Four cases in a two-month period compared with nil the previous year	Tap water, showerheads, hospital hot water source, city water supply to hospital	Six	Bloodstream	Protection on CVCs during bathing
21	Kossow *et al.*, 2019	*P. aeruginosa*	Yes	Resistant nature of organism	Toilets Shower drains	34	Colon ization Bloodstream Respiratory	New shower drain design Pall filters on shower heads and taps Biorec disinfection syphons under wash basins Rimless toilets Disinfectant toilet flushing water system Patient screening Enhanced cleaning
22	Leitner *et al.*, 2014	KPC producing *Klebsiella oxytoca*	Yes	Resistant nature of organism	Sink drains	Ten	Bloodstream Respiratory Colon ization	Enhanced cleaning Hand hygiene measures Replacement of sinks
23	Litvinov *et al.*, 2015	Fusarium species	No	Unusual organism	Showers, tap water, drains	Ten	Disseminated Cutaneous	Point of use filters
24	Livni *et al.*, 2008	*M. mucogenicum*	No	Clustering of cases and none the previous year	Automatic faucet	Five	Bloodstream	Replacing the contaminated faucets, optimal water chlorination and proper coverage of the CVC
25	Lyytikainen *et al.*, 2001	*P. aeruginosa*	Yes	Resistant nature of organism	Shower heads	Five	Bloodstream	Removal of showerheads
26	Nucci *et al.*, 2002	*Exophiala jeanselmei*	No	Unusual organism	Deion ized water solution	Multiple patient groups — eight with	Bloodstream	Discontinued use of deionized water

						haematological malignancy		
27	Nur Askin *et al.*, 2022	*Sphingomonas paucimobilis*	No	Environmental organism	Hot tap water	51	Bloodstream	Boiling and chlorination of tank water Restriction of tap water use
28	Oren *et al.*, 2002	*L. pneumophila* serogroup 3	No	Four cases in a 16-day period	Possible humidifiers	Four	Pneumonia	Restriction of water use Disconnection of humidifiers from air conditioning system Ciprofloxacin prophylaxis Superheating and hyperchlorination Surveillance for further cases
29	Palmore *et al.*, 2009	*L. pneumophila* serogroup 1	No	Two concurrent cases	Decorative water fountain	Two	Respiratory	Fountain drained and removed
30	Perola *et al.*, 2002	*S. paucimobilis*	No	Cluster of infections with environmental organism	Shower and tap water	One	Bloodstream infection	Disinfection of aerators and showerheads
31	Sakhnini *et al.*, 2002	*Stenotrophomonas maltophilia*	No	Two concurrent cases	Tap water	Two	Disseminated with skin and soft tissue involvement	Education New ward opened
32	Shachor-Meyouhas *et al.*, 2011	*M. mucogenicum*	No	Increased incidence of infection with none in preceding period	Unidentified	Eight	Bloodstream infection	CVC care and cover during bathing
33	Schenider *et al.*, 2021	*P. aeruginosa*	No	Three cases in a one-week period and none in previous year	Errant water jet into contaminated syphons	Three	bloodstream	Replacement taps with PALL filters with change in angle Biorec syphons
34	Tagashira Y *et al.*, 2015	*M. mucogenicum* *Mycobacterium canariasense*	No	Unusual organism	Tap water	Five	Bloodstream infection	Enhancing CVC dressing prior to showering
35	Iroh Tam *et al.*, 2014	*M. chelonae* *Mycobacterium immunogenicum*	No	Increased incidence with none in preceding year	Water and ice machines	Fifteen	Respiratory infection Blood stream infection Colon izations	Introduction of bottled water for consumption Shower flushing
36	Van der Swet *et al.*, 2022	*Enterobacter cloacae* *P. putida*	Yes	Resistant nature of organism	Sinks and shower drains (EB) Toilets (PP)	24	Bloodstream and urine (EC) Colonization (PP)	Weekly treatment with liquid caustic soda of sink drains and

(*continued on next page*)

Table I (*continued*)

	Reference, first author/year	Organism(s)	Resistant organism	Prompt for investigation	Source	Number of patients	Type of infection	Outbreak measures
								toilets Patient education re. splash risk Syphons of sinks renewed HH enforcement Isolation and cohorting Change to SDD − Colistin added Cipro removed
37	Vianelli *et al.*, 2006	*P. aeruginosa*	No	Increased incidence compared with previous year	Taps, showerheads, bidet taps, shower traps	Not reported	Bloodstream infection	Application of point of use filters
38	Watkins *et al.*, 2017	*L. pneumophila* serogroup 1	No	Increased incidence of cases	Potable water	Ten	Pneumonia	Water restrictions Bottled water for drinking and hygiene Application of point of use filters Superheating, flushing and hyperchlorination of water system Programme of follow up sampling
39	Wong *et al.*, 2011	*Pseudomonas fluorescens*	Yes	Resistant strain detected on screening	Water dispensers	Nine	Colon ization − detected on routine screening	Removal of contaminated dispenser
40	Yablon *et al.*, 2017	*Pantoea agglomerans*	No	Increased incidence of environmental organism	Sinks in several rooms including pharmacy clean room and ice machine	3 of 12 had haem malignancy	Bloodstream	Inadequate residual chlorine and dead-end piping addressed Removal of infusion products from sink proximity Removal of clean room sink Avoidance of water near clean room hoods Education of staff

CVC, central venous catheter; EC, Enterobacter cloacae; HH, Hand hygiene; PP, Pseudomonas putida; SDD, selective decontamination of digestive tract

organisms that may be considered to be both endogenous and exogenous. Four outbreaks of *P. aeruginosa* were due to sensitive strains and were recognized due to the following: (1) five bloodstream infections with *P. aeruginosa* and three with *Pseudomonas putida* in three months compared with two bloodstream infections with *P. aeruginosa* in the previous year and none with *P. putida*; (2) three *P. aeruginosa* bloodstream infections in one month compared with zero in previous and following years; (3) a rise in *P. aeruginosa* bloodstream infections from 19 to 61 in the following year; (4) due to the local team investigating more than two cases of *P. aeruginosa* within a month [8,15,38,42].

The presence of antibiotic resistance was the driver for recognizing the remaining *P. aeruginosa* outbreaks. The majority of outbreaks were drain associated which have previously been described as having a protracted course with low numbers of infections [47]. Similarly, the Enterobacterales outbreaks involved drug-resistant strains, two of which were carbapenemase-producing Enterobacterales (CPE) and were associated with drains. A feature of some of these outbreaks is that the first case to be detected is often not the first transmission event. Hence, as drain-related events may be protracted, it is important to record unusual infections and to compile a list of alert micro-organisms that can be used to inform clinical teams of historical and ongoing infections [6,11,16,23].

Waterborne outbreaks can be both polymicrobial and polyclonal and as a result may be difficult to recognize by conventional interpretation. Indeed, it is not unusual for typing results not to find a match between the clinical and environmental isolates and as such cases are excluded as being part of an incident (only three papers matched clinical and environmental isolates). One example was a polymicrobial cluster of 10 bacteraemias involving several Gram-negative environmental organisms (*P. aeruginosa*, *Acinetobacter* spp., *A. xylosoxidans*, *S. paucimobilis* and *S. maltophilia*) over several months in adult haematology patients [35]. Ten patients were affected and due to the nature of these bacteria and a likely environmental reservoir, water was tested [35]. Whilst the authors focused on *S. paucimobilis*, a wide range of Gram-negative micro-organisms were detected in the hospital water, implicating the water distribution system as the source. Interventions included mechanically washing and disinfecting faucet aerators and showerheads in chlorine periodically. However, the clinical rates for Gram-negative micro-organisms returned to the level before the outbreak, indicating that the water distribution system was still contaminated and seeding the outlets and showers. With regard to *S. paucimobilis*, there was a heterogeneity of random amplified polymorphic DNA (RAPD) patterns which reflected the diversity of *S. paucimobilis* clones in the hospital water system [35]. Such data reinforces the difficulty of typing clinical and environmental strains.

Amoureux *et al.* described seven cases of IMP-19 *P. aeruginosa* infections linked to contaminated sinks [6]. The seven clinical isolates belonged to three distinct genotypes (A—C) of which six belonged to genotype A. Furthermore, they detected IMP19-producing isolates belonging to eight different species of Gram-negative bacteria including *S. maltophilia*, *Sphingomonas* spp., *Achromobacter xylosoxidans* and *Commamonas testosteroni*. The author's results and analysis led them to conclude that due to the diversity of species involved the environmental contamination likely occurred a long time ago [6]. Similarly, Annaisse *et al.* found that three patients with *Fusarium* spp. matched on typing over several years which established the persistence of the fungus in the hospital water for a prolonged period. Multiple different genotypes in patient and environmental isolates were identified, again reinforcing the difficulty of matching clinical and environmental strains [7].

While investigating an outbreak of *M. mucogenicum*, Shachor-Meyouhas *et al.* noted that the molecular patterns of seven patient isolates were diverse, suggesting infection with multiple clones [37]. Thorough investigation did not reveal the origin of the outbreak and water testing was negative. This was felt to be due to the challenges of environmental sampling or processing. The view was that different strains probably reflect the existence of various strains in the water system. Despite no positive water results or typing matches there were no further cases following the implementation of infection control measures.

At least two of the outbreaks might be described as groundbreaking. Anaissie *et al.* were the first to consider water as a source of *Fusarium* spp. following their retrospective investigation over a period of 10 years [7]. Secondly, Braethnach *et al.* recognized the role of the healthcare wastewater system as a reservoir and superhighway for strains of multidrug-resistant *P. aeruginosa* to be transmitted and dispersed around the hospital [11]. The investigation/outbreak occurred over a period of six years. Whilst this might seem long it took 45 years for microbiologists to accept that water could transmit the same organism following publications by Joachim Kohn in 1967 [48].

Over half of all studies implemented a bundled IPC approach to control. These strategies are important to ensure that the source of the waterborne outbreak is controlled. In addition, the transmission routes need to be identified and targeted with infection control strategies including hand hygiene, education around sinks and splash risk (can be up to 2 m), drains (discarding of patient waste or the washing medical devices in sinks) water sources (whole water system maybe colonized), central venous catheter (CVC) care and storage/cleaning of equipment.

The identification of central lines as a risk factor was reported in 19 papers and the importance of line care for this patient cohort was emphasized. It was postulated that lines became infected with contaminated water when showering or bathing in tap water where the sites were not adequately protected. In a multi-species outbreak (*P. aeruginosa* and *P. putida*), Aumeran *et al.* observed that nurses had reduced the size of the catheter dressing at the line exit site, with the aim of minimizing discomfort at the time of dressing removal. As a result, the catheter dressings covered an insufficient area and therefore the line was exposed to contaminated water [8].

Baird *et al.* highlighted that prior to a cluster of NTM bloodstream infections, lines and ports had been covered with dressings which were removed for showering enabling waterborne micro-organisms to access the lines and ports. Following NTM infections they applied transparent semi-permeable polyurethane dressings, which remained *in situ* while showering and ensured both protection of the entry site of the line and easy visual inspection. Hickman line connectors were also

replaced with ones that had fewer connections and tighter seals. Following these line interventions there were no further cases [9].

Habermann *et al*. identified line care as the main contributing factor to their outbreak of NTMs. In addition to the five patients involved within the hospital, they also identified that patients showered and bathed at home without adequately protecting the CVC. Sterile transparent semi-permeable dressings were provided for patient use when bathing and showering. They also focused on an education programme on CVC care for families and healthcare staff [18].

In an *M. mucogenicum* outbreak, Kline *et al*. reported that patients were allowed to take baths or shower with IV catheters connected and without connections being covered. They also determined that the time to replace CVC dressings after bathing was variable, even when wet. Time varied from immediately after bathing to hours later. A new policy with guidelines about protecting CVC sites and connections from water while bathing was implemented to be used in both hospital and home settings. After implementing the new guidelines, not only did NTM infections decrease but they also observed a reduction in bacteraemia in the BMT patients due to other unusual environmental bacteria (*P. putida, S. paucimobilis,* and *Methylobacterium* spp.) [25]. However, none of the IPC measures addressed the fundamental issues of the water system being contaminated [9,18].

As with Legionella control, education and training are important components of a bundled approach, however in many instances training requirements were insufficient. This probably reflects the belief that potable water is safe for patients and the lack of education provided to staff concerning exposure and transmission risks to susceptible patients from water/wastewater.

In 13 papers, outbreak controls included refurbishment ranging from replacement of taps, sinks, toilets and waste traps, to installation of a separate microbiologically controlled water loop and re-plumbing of a wastewater system. Amoureux *et al*. described an outbreak of bla_{IMP-19} producing *P. aeruginosa*. Changing the drains failed to eradicate biofilm necessitating a rebuild of the ward which was 16 years old [5]. Aumeran *et al*. describe the creation of a new water loop to control an outbreak of *Pseudomonas* spp. and included daily chlorination of the water supported by double prefiltration and terminal filtration. Post installation water testing was negative and conveys the amount of investment and work that has to be undertaken to protect vulnerable patients [8].

One outbreak highlighted the importance of water safety measures in the outpatient setting. Yabon *et al*. reported 12 cases of *Pantoea agglomerans* isolated from blood or catheter tips in patients attending a clinic. Investigations revealed deficiencies in the preparation and handling of parenteral medications. Seven of nine patient isolates were indistinguishable from strains isolated from the pharmacy clean room sink. They noted infusate bags were placed on counters close to the sink area and were at risk from splashing. Consideration should be given to sink placement and indeed whether a sink is required at all in such settings [45]. This outbreak demonstrates that waterborne incidents related to outpatient clinic practices may go unrecognized as patients may spend just a few hours in this environment, preventing a link being made.

Furthermore, the identification of sources such as decorative water fountains, ice machines, water dispensers, water coolers and humidifiers highlight the risk to susceptible patients from water sources encountered outside the patient bedroom/bathroom [33,34,40,45].

Whilst there is ventilation guidance pertaining to haemato-oncology units there is no current UK guidance document which provides advice to mitigate the risk from water in this vulnerable patient group. Many of the incidents in this review were identified due to the unusual nature of the organism or a resistance pattern which made outbreak detection easier. It is likely that transmission events in this patient cohort go unrecognized, particularly when due to unusual Gram-negative bacteria that may also be considered to be endogenous in origin, e.g., *P. aeruginosa* or Enterobacterales. A limitation of this paper is that we undertook a narrative review which has the potential for bias. A full systematic review may have produced more outbreak/incident papers. A further limitation is that the literature searches were performed on English databases.

Acceptance that mains drinking water is a risk to vulnerable patients in modern healthcare facilities remains a challenge. In 1998 the Bouchier report into cryptosporidium and water supplies recommended "that all water, from whatever source, that might be consumed by immunocompromised persons should be brought to the boil and allowed to cool before use" [49]. A publication six years later, investigated the provision of drinking water in 10 Trusts covering 15 immunocompromised units. In nine units, mains drinking water was supplied, in three boiled mains water, and the remaining two either sterile or carbonated water. They also reviewed the options for providing safe drinking water and concluded that POUFs provided the best option for the delivery of safe water. However, this does not control for microbially contaminated water distribution system and susceptible 'at risk' patients may also be located elsewhere in the hospital [50].

In 2003 the World Health Organization document "Heterotrophic plate counts and drinking water quality" was published [51]. The section "Infections from HPC organisms in drinking-water amongst the immunocompromised" provided detailed information in Table A and B on the quality of water required for different groups of immunocompromised patients [51]. Unfortunately, the wisdom of such information was not adopted widely in the UK. In France, Guidance from 2005 recommends the use of specific water quality for haemato-oncology patients (and all immunocompromised patients) obtained with 0.2-μm filtration [52].

The rise in antimicrobial resistance has been paralleled by the rise in reports of transmission events from wastewater systems in highly developed healthcare systems. Due to intractable outbreaks of highly resistant organisms from wastewater systems a small but increasing number of units have had to resort to water-free patient care as a means of preventing further spread. In the Netherlands, where the first water free intensive therapy unit was established, not only was the outbreak terminated but the overall incidence of acquisition of all Gram-negative organisms was reduced [53]. Such conclusive evidence supports the theory that antibiotic-resistant strains do not have any special adaptations to dispersal from wastewater systems but merely attract our attention.

A draft report by the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) on water quality for patient care has recently been published for consultation [54]. This report follows in the steps of the WHO publication from 2003, stipulating the water quality required for different patient groups [51]. For the most vulnerable, either sterile water, or water provided through a sterilizing grade filter is required. We believe that determining the water quality required for a particular patient group is essential and it would be prudent for the UK to produce guidance as provided by the WHO and ASHRAE to tackle the source of the problem.

We must design out the risks from water and wastewater systems in high-risk units such as haemato-oncology. In reviewing the case reports for this publication, it is clear that (1) there are two main sources of waterborne outbreaks in the clinical environment, the water distribution system and the drainage system, and (2) there is still an uncertainty and degree of unwillingness to accept that water or wastewater are responsible for transmission of infection to patients. Some of this we believe stems from a lack of surveillance and the ability to review historical data for comparative outbreaks over, e.g., a number of years rather than months.

In terms of water and drain systems there is the chicken and egg situation, e.g., was the organism present in the water or wastewater system first or did it originate from the patient? Regardless, there are now multiple publications demonstrating that the source of many clinical isolates are either water, or wastewater.

Primarily the focus must be on the water system as water source must in the first instance be safe. Dedicated water systems, either sterile or with fully designed continual chemical dosing should be considered. Whilst there is a role for the long-term application of POUFs, the fitting of these without controlling the microbial contamination of the water system does not address the underlying issue. However, the implementation of POUFs would provide protection to vulnerable patients from NTMs which are known to be tolerant to the chemical biocides used to treat water system [55]. Filter fittings do leak and may therefore still present a transmission risk. Care should be taken to ensure protection from all patient accessible water sources accessible not just those within the patient room. Installation of ice machines and water dispensers should be avoided on these wards and practices in preparation and treatment rooms should mitigate risk from water.

IPC strategies are important, including the provision of sterile water to immunocompromised patients to reduce infection risk. Attention to central line care with applications of CVC dressings while showering and bathing must be addressed. Education and training of all staff is an important component of any prevention strategy. Ideally this should consist of recognizing the risks from water and waste water, including hygienic plumbing, sink hygiene (not disposing of patient material down the drain) and avoidance of storage of products on sinks or within 2 m to avoid splash contamination.

Infection control surveillance is also important and is very much based around recognition of alert organisms. Waterborne organisms should be listed as alerts within the infection control software database. As waterborne outbreaks can run a protracted course, monitoring of alert organisms should cover long periods. When a suspected incident relating to water/wastewater is identified the infection control database should be interrogated simultaneously for other alert organisms, as publications demonstrate that some outbreaks are polymicrobial (if the conditions are suitable for one organism, there are likely to be more).

Due to the difficulty in eradication of biofilms from plumbing components and drains, control measures such as cleaning and disinfection may be unsuccessful and replumbing/refurbishment may be required. Success may depend on the type of refurbishment. Evidence is clear that simply replacing plumbing components and drains when the water system is contaminated where there is a lack of IPC training, will only bring temporary respite. Current guidance documents acknowledge risks from inadequate ventilation in this high-risk cohort and provide recommended parameters [56]. We request that UK guidance is written and implemented for the control of environmental risk from water and wastewater/drainage systems.

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Comments; Appendix 1 - Summary of Patient Safety Indicators by Sandra Devine

1. The paper submitted by Sandra Devine on patient safety indicators (PSI) is fundamentally flawed as the safety indicators chosen are in relation to endogenous bacteria such as Staph aureus and E coli and not exogenous bacteria acquired from an environmental source e.g. Stenotrophomonas, Aspergillus. These PSIs (SABs, E coli, CDI) cannot be used as a proxy for the safety of the hospital built environment and as such can only give false assurances. They are measuring the wrong thing.

2. In this paper it is stated that '*A significant proportion of HAI are considered avoidable and prevention of these infections provides an opportunity to improve patient outcome and reduce unnecessary costs within healthcare systems'* This is correct but this is not the approach taken by NHSGGC who suggest that hospital acquired infections are the norm and as long as they are similar to other hospitals then there is no problem. One of the aims of a new build hospital is to design out the risk of hospital acquired infection therefore one should take no comfort in having similar infection rates to older hospitals including the one they moved from e.g. Yorkhill. Zero tolerance whilst difficult to achieve is a concept aspired to by many IPCTs with each case of HAI an opportunity for learning and not one to be dismissed simply because it happens elsewhere.

3. The social deprivation highlighted is not relevant to the issue with the building, acquisition of exogenous infections and the number of incidents/outbreaks involving ward 2A. These children did not drink, smoke, or take drugs and do not have pre-existing comorbidities of the adult population. The unit is a national service taking children from all over Scotland for treatment and not just the Glasgow area. Even if social deprivation was of relevance, given that social deprivation has remained relatively constant how would this explain the dramatic reduction in infections post control measures and transfer back to the new ward 2A.

4. There is reference to the point prevalence study in 2016. The disadvantages of point prevalence studies are that they are conducted at a particular point in time so are not representative of the whole picture. If for example a PPS was undertaken in November of 2018 it would fail to capture the HAIs reported from March-Sept that year, a substantial number. The survey was undertaken in 2016 just one year after opening the new build hospital and before many of the issues with the building had declared themselves. Importantly, point prevalence studies do not tell us how an individual acquired the infection.

5. NHSGGC quote ARHAI as saying there is no one single point source. This is an accurate point made by ARHAI however NHSGGC have interpreted this comment incorrectly. As the epidemic curve for the 2018 incident shows there was a continuous intermittent source i.e. The water and drainage systems. With a point source outbreak patients are exposed over a short period of time with the number of cases rising rapidly to a peak over one incubation period, this was not a feature of the 2018 or 2019 2A IMTs.

6. Sandra Devine's view has changed dramatically since an email sent in June 2016 where she states in relation to ward *4B 'I understand their position but 'we' are right. Looking at the table there is no doubt about this - shocking really that this new unit is so far off basic standards to ensure safety. I wouldn't want any of my family in there and that's always a sense test for me.'*

Combating *Legionella* by focusing on the right species

Jimmy Walker PhD, BSc, a microbiologist with over 30 years' experience in water microbiology and decontamination, discusses the important aspects of Legionnaires' disease for those with responsibility for hospital water systems, and what we need to understand about the presence of this waterborne pathogen in such systems to safeguard patients.

Do Water Safety Groups (WSG) need to eliminate all species of *Legionella* from their water systems? The public health data indicates that focusing on *Legionella pneumophila* is the most effective way to reduce risks to patient safety. Data from Denmark demonstrate that the urinary antigen test is not a source of bias in public health figures, and that efforts to eliminate non-*pneumophila* species can be a red herring for WSGs, who should focus their efforts on managing the water system and on testing for *L. pneumophila* to minimise the risk to vulnerable patients.

Background

Reducing *Legionella* risk to prevent Legionnaires' disease is a key concern for Estates Departments and infection control specialists. WSGs must consider the risk posed by different *Legionella* species. The family Legionellaceae (commonly known as *Legionella*) comprises over 60 species, and more than 70 serogroups. Most healthcare and community-acquired Legionnaires' disease cases (>95%) are caused by *L. pneumophila*, even though laboratories have consistently recovered non-pneumophila species from water systems, including healthcare settings.[1,2]

> To address Legionnaires' disease risks, we must consider the type of species present, and the vulnerability of patients

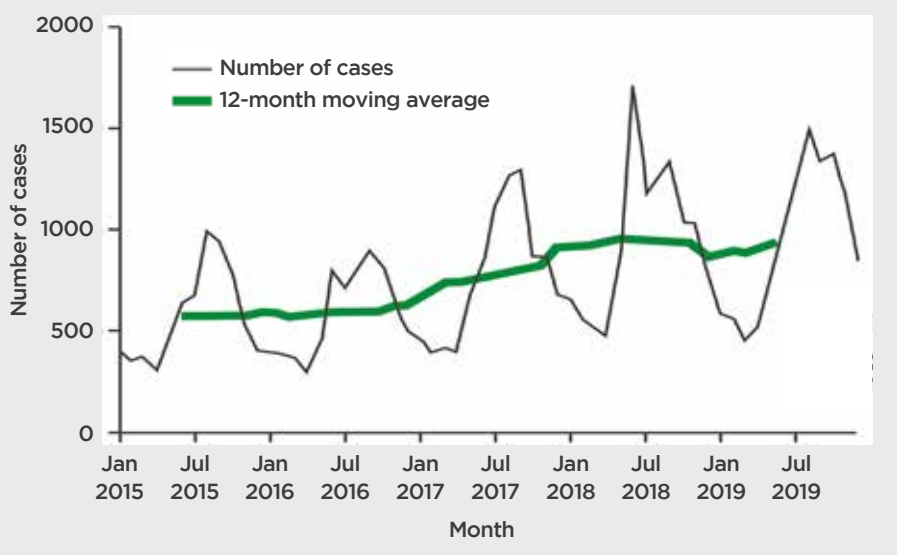
To address Legionnaires' disease risks, we must consider the type of species present, and the vulnerability of patients, and therefore Estates and Infection Control teams need to assess the public health data available on Legionnaires' disease. Guidance published by the Health and Safety Executive broadly specifies *Legionella* monitoring. However, it is not possible to recover all 60 species of *Legionella* using traditional culture-based methods, as is acknowledged in the ISO 11731 standard.[3]

Identifying the source of risk

L. pneumophila is the greatest risk concern for patient safety. In England and Wales, non-*pneumophila* strains account for less than 1% of clinical cases.[4] In France, 98% of culture-confirmed Legionnaires' disease cases are attributable to *L. pneumophila*.[5] Similar statistics are seen in travel associated-Legionnaires' disease cases,[6] in Japan,[7] and in US CDC outbreaks.[8] An analysis of 10 years of culture diagnoses from a study of more than 40,000 patients across the EU (including the UK) found that even for healthcare-acquired Legionnaires' disease, 98% of the cases were caused by *L. pneumophila*.[9] These figures are consistent with recent scientific findings which begin to explain the mechanisms that increase the virulence of *L. pneumophila* when compared with other species.[10]

Improving the control of *Legionella pneumophila*

UK and ECDC clinical data demonstrate that we need to improve the control of *Legionella pneumophila* to prevent Legionnaires' disease (Figure 1). Due to the clinical significance of *L. pneumophila*, and delays in diagnosis using culture, rapid urinary antigen tests (UAT) were developed for patient diagnosis, and detect *L. pneumophila* serogroup 1 antigen in urine samples from patients with symptoms of pneumonia.[11] The majority (90%) of the Legionnaires' disease cases reported to the ECDC are initially diagnosed by the UAT.[6] However, as the UAT only identifies cases associated with *L. pneumophila* serogroup 1, the question has been raised, 'Is the true number of Legionnaires' disease patients infected with non-*pneumophila* species under-reported, and, if so, what implications would that have for those responsible for Water Safety Plans?'



Source: European Centre for Disease Prevention and Control. Legionnaires' disease. In ECDC *Annual epidemiological report for 2019*. Stockholm: ECDC, 2021.

Figure 1. Distribution of Legionnaires' disease by month, EU/EAA, 2015-2019. The number of Legionnaires' disease cases continues to increase despite current measures to prevent it.

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Extensive clinical data from Denmark (Figure 2), which has one of the highest rates of documented Legionnaires' disease cases in Europe, can help answer that question. In Demark, the use of the UAT to diagnose patients is rare. Instead, 80-90% of Legionnaires' disease cases are initially diagnosed by polymerase chain reaction (PCR), meaning Legionnaires' disease cases caused by both *L. pneumophila* and other species of *Legionella* are detected and reported.[12] Yet the Danish data also highlights the importance of focusing on *L. pneumophila* to protect from Legionnaires' disease. Even where UAT is not used to diagnose patients, 93% of PCR-diagnosed cases in 2019 were caused by *L. pneumophila*, (including community-acquired, hospital/nursing home-acquired, and travel within Denmark cases).[13] In fact, only one case of Legionnaires' disease out of the 112 that were culture-verified could be confirmed as a non-*pneumophila* species. In 2020, the result was very similar – 93% of PCR-diagnosed cases were caused by *L. pneumophila*, and only two patients could be culture-confirmed for non-*pneumophila* species.[14]

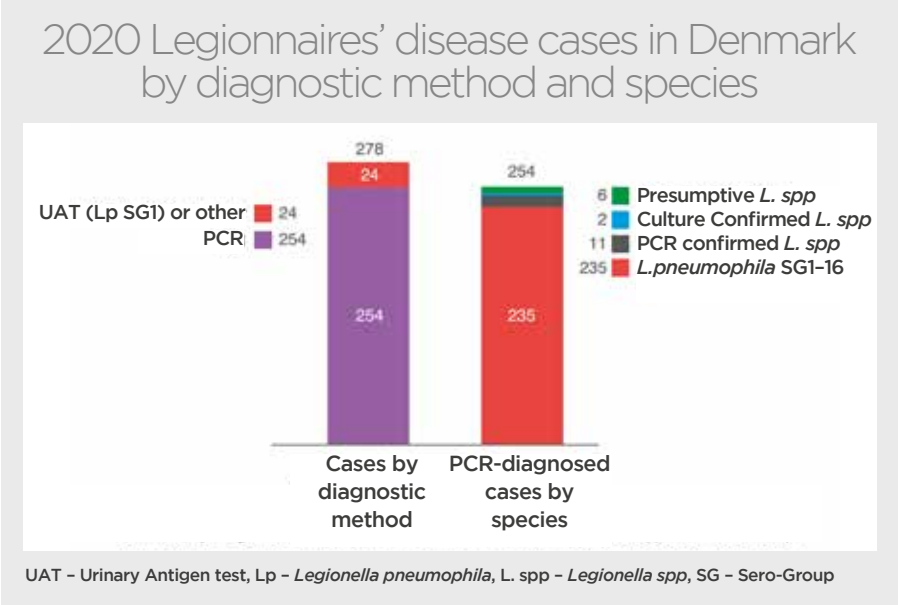

Figure 2: 2020 Legionnaires' disease cases in Denmark by Diagnostic Method and Species (adapted from SS1, 2021[14] and SSI, 2021[15]). Very few cases caused by non-*pneumophila* species were detected in Denmark, which does not rely on the UAT for initial diagnosis.

Asymptomatic patients

An additional 11 cases were confirmed as non-*pneumophila* species by PCR, but not by culture.

Notably, in 2020 Danish epidemiologists also found 18 patients that returned positive PCR results for non-*pneumophila* species, but were asymptomatic, and therefore were not considered to have Legionnaires' disease. As stated in their report: "*Legionella* non-*pneumophila* species occur in the vast majority of water systems (up to 100%), and often in higher numbers than *L. pneumophila*. The vast majority of these species have a very low or no infectiousness in humans, but the fact that they are very common produces a risk of 'false' positive PCR results, particularly in patients who undergo upper airway sampling."[14]

As the Danish data confirms, the UAT is not a significant source of bias in assessing the risk posed by different species of *Legionella*; *L. pneumophila* is the most clinically relevant species, and should be the focus of *Legionella* sampling and control in water safety programmes. The researchers also highlighted that non-*pneumophila* species are nearly ubiquitous in water systems, and generally do not cause a risk to patient safety. A management programme that aims to eliminate these pervasive red herrings could take a disproportionate amount of resources, and potentially distract from areas of high *L pneumophila* risk in facilities, while contributing little to patient safety.

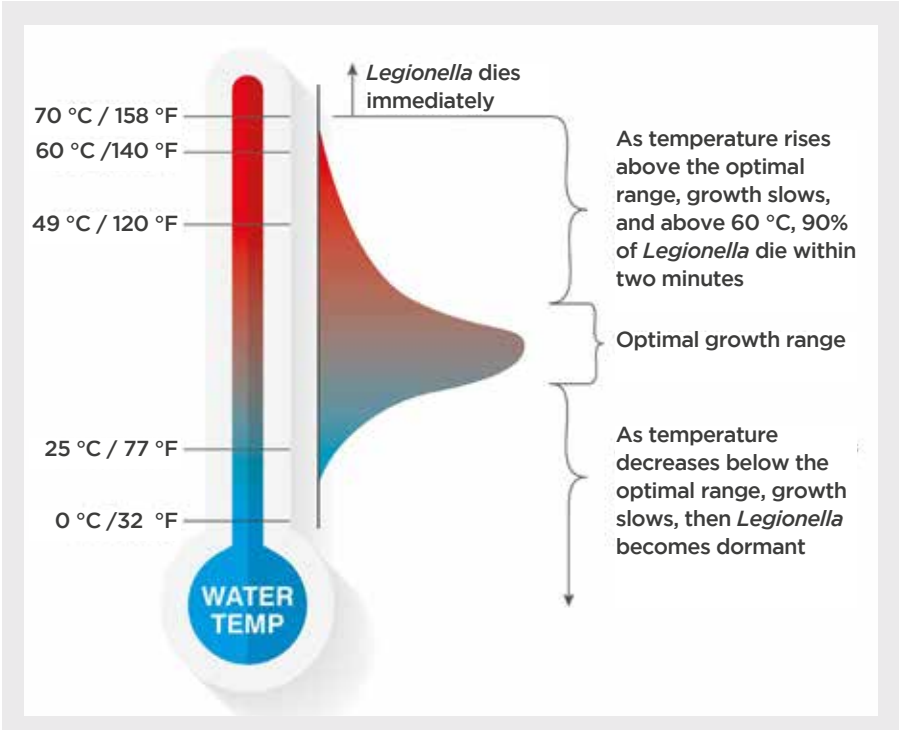

Figure 3: Temperature effects on survival and growth of *Legionella* in laboratory conditions (adapted from ASHRAE guidance[16]). Maintaining temperature can be an effective control measure for *Legionella*.

Management of *Legionella* in water systems

Microbiological testing apart, effective management of waterborne pathogens in water systems is crucial to safeguarding patients. The detection of waterborne pathogens such as *Legionella* in healthcare water systems is one aspect to the overall water safety programme. However, while a zero tolerance would be ideal, from the above clinical data, it is clear that the control of *L. pneumophila* is of primary importance for minimising disease transmission.

Fundamentally, the vast majority of Legionnaires' disease cases in healthcare buildings occur due to the failure to control microbial growth in water systems. Design and commissioning are important aspects for microbial control, yet during the build stage many parts of the water systems are left stagnant following pressure testing, which results in water contamination prior to occupation.

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A 'trained and competent' WSG

The establishment of a trained and competent Water Safety Group is crucial to the safe management of the healthcare water system, and the WSG needs to ensure that the Water Safety Plan identifies inherent risks within the building. This will involve reviewing i) the physical build – by inspecting the cold water tanks to ensure that they are clean and not oversized, that calorifiers are reaching at least 60 °C, pipes are insulated, water is moving through all the loops, and that water is being effectively drawn off at all the outlets to avoid stagnation and microbial growth, and ii), assessing the temperature of both the hot and cold water system is crucial to controlling the growth of microorganisms, i.e. keeping the cold water below 20 °C and the hot water distributed above 55 °C (Figure 3).

Measuring temperatures is normally carried out manually by someone with a thermometer, with ward staff operating outlets and recording this using paper log sheets. More recently, automated temperature recording of the cold water storage, and calorifier flow and return temperatures, has been introduced through building management systems. However, to understand whether temperature and flow regimens across the hospital and, particularly in the augmented care units, are controlling *L. pneumophila*, remote monitoring should be considered. By deploying temperature sensors on the hot and cold water supplies including water outlets, frequent temperature measurements can be recorded automatically, and analysed using algorithms, in real time, to identify microbial risks. Good preventative practice could then include automated flushing of underused outlets.

Even when these control measures are followed, verified, and documented, it is critical for Water Safety Groups to measure their effectiveness by sampling for *Legionella*. WSGs should focus their efforts and testing on *L. pneumophila*, as efforts to address non-*pneumophila* species use valuable resources, and draw focus away from the detection and remediation of *L. pneumophila* to minimise the risk to vulnerable patients. hej

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Dr Jimmy Walker

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Unusual types of pitting corrosion of copper tubes in potable water systems

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Section III
BIOCORROSION

16

Unusual Types of Pitting Corrosion of Copper Tubes in Potable Water Systems

G. G. Geesey, P. J. Bremer, W. R. Fischer, D. Wagner, C. W. Keevil, J. Walker, A. H. L. Chamberlain, and P. Angell

I. INTRODUCTION

Copper tube has long been the standard for many plumbing applications throughout the world. Of the total copper consumption in Europe and the U.S. in 1989, copper tube represents 11 and 14%, respectively.[1] This translates to approximately 250,000 tons of copper tube in each of these regions annually. The longstanding success of copper as a conduit for a wide variety of water delivery systems has been attributed to numerous features including durability, corrosion resistance, and antimicrobial activity.

Unusual pitting corrosion failures have, however, occurred in a small number of institutional buildings in different regions of the world in recent years. Incidences of an abnormal form of pitting corrosion were primarily in hot and cold water distribution systems of hospitals. While water provided from the mains to the facilities was initially potable, subsequent storage at some of the facilities may have resulted in changes in water quality before introduction to the water distribution system within the buildings. The pitting appeared to be unlike any previously reported failures. After extensive analysis, it was discovered that a film

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of microbial origin was always present in areas where pitting was observed. The occurrence of a biofilm was believed to contribute in some way to this new form of pitting corrosion of copper plumbing material used in these institutional buildings.

Most corrosion engineers and scientists are not familiar with the potential roles that microbes may have in corrosion reactions. What are the criteria that can be used to implicate microorganisms in pitting corrosion of copper or other metals? It is usually the slimy texture of the corrosion deposit that leads most investigators to suggest a microbiological role. The slimy deposit is actually the result of the biofilm mode of growth. Ironically, biofilms are ubiquitous in nature and are present to varying degrees on virtually every surface in contact with nonsterile water. Microbial biofilms are present on corroding and noncorroding surfaces.

The reason that biofilms had not been associated with pitting corrosion of copper plumbing tube prior to 1985, when it was first reported in a German hospital, may be that no one specifically looked for or suspected their involvement. Although sulfate-reducing bacteria (SRB) had been implicated in certain types of corrosion as far back as the 1930s where anaerobic conditions and high sulfate concentrations occurred,[2] microbially influenced corrosion (MIC) had not been considered to be important in the corrosion of copper tubing through which oxygen-containing water with low sulfate concentrations was circulated. Although polysaccharide-containing biofilms are present on most pipe surfaces, the detection of this and other microbial products led Fischer et al.[3] to establish a connection between the microbiological slime layer and underlying pits in the corroding copper tubing in the hospitals where the problems have occurred. Considerable research has been conducted in the past 5 years to gain a better understanding of the role that biofilm microorganisms can play in pitting corrosion of copper tube. Through this research, we have obtained some understanding of the factors such as water chemistry, temperature and system design, installation, operation, and maintenance that predisposes a system to corrosive microbial attack. This chapter summarizes what we have learned on this subject.

II. TYPES OF PITTING IN COPPER TUBE

A. Classical Types of Pitting

Several different types of pitting corrosion are known to occur in copper tubing used for water service in institutional buildings.[4] Type 1 pitting occurs in cold water lines that contain water supplied from deep bore holes.[5] This water contains low concentrations of microorganisms and organic carbon and high concentrations of dissolved inorganic ions. Pits develop in the inner wall of copper tube. The pits contain soft crystalline

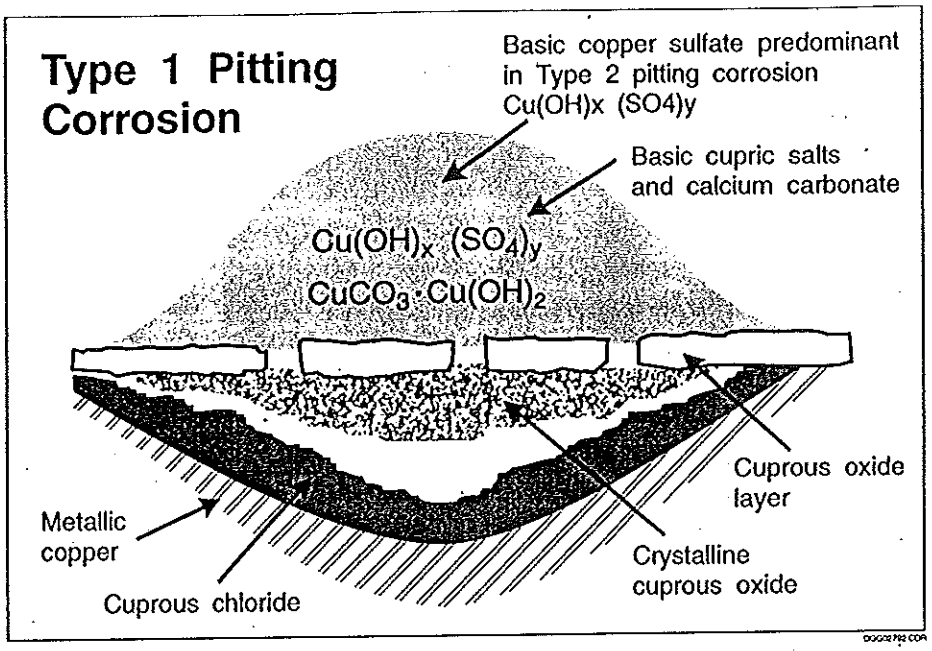

FIGURE 1. Type 1 pitting corrosion.

cuprous oxide under a membrane of cuprous oxide crystals (Figure 1). Cuprous chloride also occurs in the pits. Basic copper carbonate mounds occur over the pits. Type 1 pitting occurs in the presence of certain hard well waters. Luce[6] has shown that Type 1 pitting propensity of such waters depends on pH, dissolved oxygen, chloride, sulfate, sodium, and nitrate. There are no indications to date which suggest that microorganisms are involved in this type of pitting corrosion.

Copper tubing is fabricated to different hardness: hard, half-hard, and soft. In the past, a film derived from the drawing lubricant that becomes carbonized during the softening (bright annealing) process has been related in a rather complicated way to Type 1 pitting corrosion of annealed copper tube.[7] Abrasive cleaning or controlled oxidation of the tube bore is now carried out as a final step in the manufacturing process to remove the film. Hard-drawn tubes, not being bright annealed in the course of fabrication, are much less likely to contain carbon films. However, carbon films are sometimes found in hard-drawn tubes, presumably as a result of exposure to unusually high temperatures during the drawing process. No influence of tube hardness has been detected with respect to the unusual type of pitting corrosion.[3,8–10]

Type 2 pitting occurs in systems which circulate hot, soft water. The pits contain hard, crystalline cuprous oxide and are covered by small nodules composed of copper oxides and basic copper sulfate (Figure 1). An adherent cupric oxide-cuprous oxide layer exists over the unpitted surface. Type 2 pitting occurs primarily at temperatures above 60°C or where the water is below pH 7.4 or where the bicarbonate-sulfate ratio

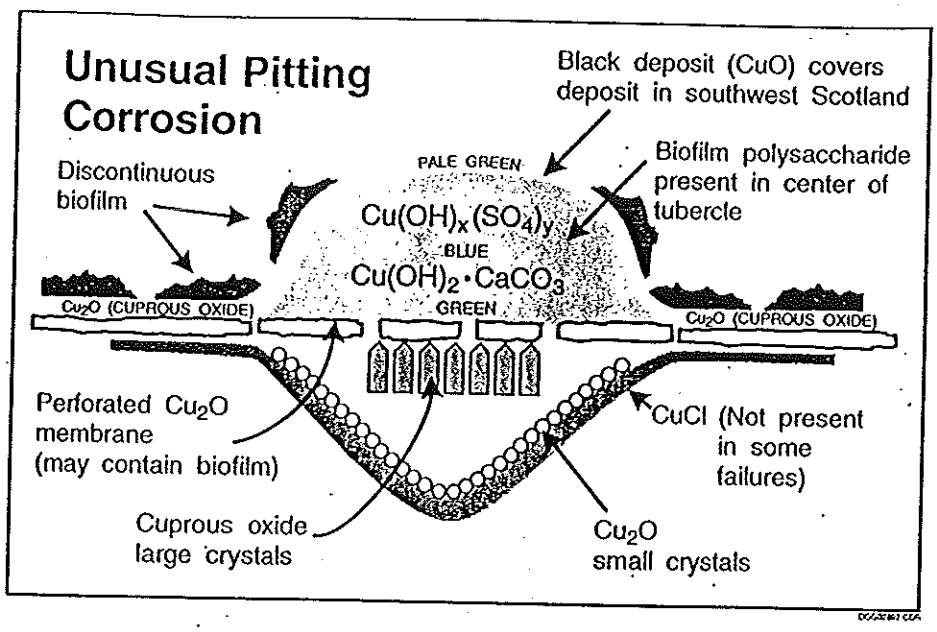

FIGURE 2. Unusual type of pitting corrosion.

in the water is less than 1. Like Type 1 pitting, no evidence currently exists that suggests microbiological involvement in this form of pitting corrosion.

Type 3 pitting is characterized by groups of small hemispherical pits under a common covering of basic copper sulfate. An oxide membrane extends across all the pits in the group with a perforation above the center of each pit. Up to 1% sulfide may be found in the pits. This type of pitting occurs in pipes carrying cold water with high pH, low hardness, and low mineral and low organic content. This type of pitting has been restricted to two areas in Sweden. No involvement of microorganisms has been demonstrated in this type of pitting corrosion.

B. Unusual Types of Pitting

Two unusual types of pitting corrosion have been observed which are thought to involve microbial biofilms.[11] One resembles Type 3 in that numerous pits occur beneath a common basic copper sulfate crust with the oxide membrane across the pits being randomly perforated. This type of pitting has been reported in certain hospitals in southwest Scotland which use surface waters that contain relatively high concentrations of dissolved organic compounds, suspended particulates including microorganisms, and low buffering capacity (pH 7.4 to 9.3). The other new type of pitting occurs in cold, warm, and hot water systems and exhibits features of both Type 1 and Type 2 pitting (Figure 2).[9] It resembles Type 1 pitting in that the pits are hemispherical and contain soft crystalline cuprous oxide with varying amounts of cuprous chloride under a

cuprous oxide membrane. It resembles Type 2 pitting in that the oxide on the surface between the pits is largely cupric. The mounds above the pits are principally basic copper sulfate, often with a deposit of powdery cupric oxide around the periphery and on parts of the deposit itself.

Immersion of the tubing in 25% nitric acid indicated the absence of a carbon film and hence the pitting was not Type 1. A dried gelatinous film was present that stained positive with periodic acid Schiffs base (PAS) reagent or Gentiana violet, indicating the presence of polysaccharide.[9,11] This unusual type of pitting has been referred to as "Type 1 ½" pitting and has been in Saudi Arabia, Germany, Scotland, and more recently in southwest England. A description of the corrosion products from copper tubing collected from the various institutional facilities has been reviewed.[9,11,12]

With one exception, cases in which these unusual types of pitting occurred were from soft water supplies. The waters in which the unusual type of pitting corrosion have been observed have total hardness of between 25 to 40 mg/l $CaCO_3$, alkalinity (carbonate hardness) between 10 and 20 mg/l $CaCO_3$, chloride between 15 and 20 mg/l, and sulfate between 10 and 30 mg/l. In most cases, the sulfate content is approximately twice the carbonate content. Since the water is so poorly buffered, pH is quite variable in water associated with this type of pitting. A more complete description of water characteristics where the unusual types of pitting corrosion have been observed is presented by Fischer et al.[9] and by Wagner et al.[13]

In addition to those cases described above, there have been other reports of pitting corrosion in copper tube exposed to soft supply waters containing chloride and sulfate ions in Kuwait.[14] Although their description of the pits resembled that of Type 1½ pitting corrosion, they did not look for or observe the presence of a biofilm. Instead, they proposed yet another mechanism that involved attack of the protective cuprous oxide film along grain boundaries by chloride ions.

III. DESCRIPTION OF PITTING CORROSION OF COPPER IN INSTITUTIONAL WATER SYSTEMS

A. Saudi Arabia Hospital Study

An unusual type of pitting corrosion of copper tubing was reported in a hospital in Saudi Arabia. There were significant differences in the occurrence of pitting in sections of the hospital piping system that received water from different sources.[14] The unusual type of pitting was most prevalent in pipe sections of the hospital that contained warm water. Although no microbiological studies were performed on failed tubing from this system, PAS-positive material was recovered from the pipe wall.[11]

B. Corrosion Characteristics of German Hospital Copper Water Lines

Pitting corrosion similar to that observed in Saudi Arabia and from a hospital in eastern Scotland was reported in a hospital in Germany shortly after it had opened in 1986.[9] Approximately one third of the water system exhibited failures. Coincident with the pitting phenomena was a temporary and locally high concentration of dissolved copper ions and solid copper corrosion products in the water. Problems occurred with highest frequency in deadleg sections of cold and warm water lines. The tubes contained a deposit of adherent cupric oxide and showed pitting under mounds of basic cupric sulfate with loose powdery cuprous oxide inside, on top of, and around the perimeter of the pit.

Chemical analysis of the corrosion products revealed copper complexes with organic compounds of microbial origin such as pyruvate, lactate, and histidine.[15] A biofilm was detected and found to contain polysaccharides, oligopeptides, and *n*-acetylated derivatives of glucose, mannose, and galactose. Extended absorption fine structure spectroscopy detected Cu^{1+} complexes with imidazole residues of histidine in the biofilm.[16]

Microbiological evaluation of the corrosion deposits recovered from a county hospital in Germany was carried out by Wagner et al.[10,13] The presence of high numbers of surface-associated bacteria was not always correlated with pitting. The range of culturable bacterial species was quite variable even among the pitted pipe samples, indicating that one species was not responsible for all the observed pitting corrosion. Nevertheless, three isolates were consistently recovered: two strains of *Pseudomonas paucimobilis*, each with different pigmentation, and *P. solanacearum*.[11] Whereas all three isolates were capable of growth as suspended cultures at temperatures as high as 40°C, one strain of *P. paucimobilis*, when grown in a mixed-population biofilm, tolerated temperatures of 50°C.[11] The isolate of *P. solanacearum* was found to be a facultative anaerobe capable of nitrate respiration to dinitrogen and capable of producing large quantities of uronic acid-containing exopolysaccharide which was enhanced at elevated temperatures. The three isolates displayed copper tolerance, particularly at elevated temperatures which coincided with enhanced exopolysaccharide production.[16] Thus, there may be a relationship between temperature, exopolysaccharide production, copper tolerance, and pitting corrosion. Additional research needs to be carried out to establish any correlation between these factors.

Water that had passed through the water distribution system of the hospital was run through test loops of copper tube.[10,13] After 2 years, the manifestations of pitting and generalized corrosion were reproduced, although at a slower rate than was observed previously in the hospital piping system. A black layer of cupric oxide developed on the surface

of the tubing, tubercles of malachite or posniakite were observed, and both uniform attack and pitting attack occurred at the same time. Unlike the tubing in the hospital water distribution system, no continuous biofilm was recovered from the tubing in the test loop. Thus, simulation of the unusual corrosion reaction has been achieved, but at a slower rate and without evidence of a biofilm.

C. Corrosion Characteristics of Facilities in Southwest England

Detailed examination of copper tubing that suffered from the unusual types of pitting corrosion in two hospitals in southwest England revealed failures with characteristics similar to those in Germany, Saudi Arabia, and Scotland. Pitting was associated almost exclusively with pipes bearing black cupric oxide films containing a microbial polymer biofilm.[11] The pitted pipes were invariably from locations where ambient temperatures were 30 to 40°C and where water flow rates were low or intermittent, or in some instances stagnant. The water sources for the two hospitals in southwest England which experienced the unusual type of pitting corrosion were obtained from different rivers. The water was soft with high humic acid content.

A study was conducted to relate bacterial densities with pitting using 14 pipe samples collected from the two hospitals that experienced the unusual pitting corrosion, as well as a third hospital in the region that did not experience the unusual type of corrosion.[11] No SRB were detected in any of the samples based on anaerobic incubation in Postgate C medium at 30°C for 3 to 5 d. Twelve isolates were identified by the API 20NE system as falling into one of the three following genera: *Methylobacterium*, *Pseudomonas*, and *Aeromonas*. All samples examined had some bacteria present. The unusual type of pitting corrosion, as determined by the presence of perforations, well-developed pits, and black cupric oxide over the majority of the surface, occurred only where bacterial densities exceeded 100-colony forming units (cfu)/ml. In some cases, pitting was observed where bacterial densities were low, but polysaccharide abundance was high, based on PAS base staining.[18]

D. Hospital Survey in Southwest Scotland

Severe pitting corrosion has been reported in several hospitals in southwest Scotland. In one hospital alone, 64 failures were reported between 1982 to 1988. Angell et al.[11] reported a pepper pot pitting on the tube surface that exhibited some of the features of the unusual type of pitting corrosion reported in the other hospitals described above. Tubes contained a film that stained PAS- and alcian-positive, suggesting the presence of substituted and unsubstituted polysaccharides. A superficial

deposit of organic material was also detected that was thought to be composed of humic substances.

Examination of the pitted areas from which the corrosion product mound had largely detached revealed a copper (I) oxide layer with a number of pepper pot holes in it.[11] The perforations in the cuprous oxide layer of these pits were larger than those associated with the pits in tubing from the hospitals in Germany, Saudi Arabia, and southwest England (Figure 2). A short distance from the pit, a deposit of cuprous oxide was observed beneath a layer containing spherical cupric oxide nodules and biofilm. McEvoy and Colbourne[19] found that more severely corroded tubes contained a more fully developed biofilm. Microbiological analysis of the black tubercles covering the perforated areas indicated the presence of SRB and a variety of aerobes, including *Pseudomonas* and *Alcaligenes* spp., pink-pigmented facultatively methylotrophic bacteria, and fungi.[20] By contrast, fewer and much smaller black nodules were observed in the tubing taken from hospitals that had not experienced pitting corrosion. No pitting was observed in tubing with thin biofilms containing fewer rod- and cocci-shaped bacteria.[20]

IV. FACTORS CONTRIBUTING TO MICROBIALLY INFLUENCED PITTING CORROSION OF COPPER TUBING

A. Temperature

Substandard water maintenance was thought to contribute to the corrosion problems. The institutional buildings experiencing pitting corrosion had a lower temperature in their hot water systems than those without corrosion. Practical experience has shown that MIC has not been a problem in water systems maintained above 60°C. Studies by Walker et al.[34] showed that the hot water in the hospitals which experienced the pitting corrosion was not maintained at a sufficiently high temperature to inhibit microbial growth. Most of the time the temperature was below 50°C, which enabled the bacteria to proliferate. A two-stage continuous culture model was used to mimic the corrosive environment of one of the hospitals.[34] Using a microbial inoculum from the corroded copper tubing, these authors showed that the biofilm could be established at temperatures up to 55°C. However, at temperatures above 55°C the biofilm was greatly reduced. That pitting corrosion and biofilm accumulation were much more pronounced at temperatures below 55°C than above that temperature suggests the involvement of a biological rather than a nonbiological reaction. It was concluded that the temperature of the hot water supply has a significant role in the control of MIC in these institutional buildings.[34]

B. Water Chemistry

Although the quality of the supply water was considered to be good, the level of assimilable organic carbon (AOC) was found to be higher than in other areas where corrosion problems were absent. The water in hospitals which did not maintain their hot water above 50°C exhibited higher AOC, presumably due to sloughing of biofilm from the walls of the tubing. In this respect, the growth of biofilm microorganisms on the walls of the piping can lead to the degradation of water quality. Besides serving as nutrients for the bacteria, some of the organic carbon (i.e., humic substances in the supply water) are strong chelators of copper and counteract the bactericidal properties of copper ions in solution. Aluminum-chelating phenolic material was recovered from the biofilm/corrosion deposits.[35]

Dissolved oxygen concentration in the water of hospitals experiencing corrosion dropped to 0.1 mg/l during the 11-h period that hospital activities were minimal (between 7 p.m. and 6 a.m.). This drop was believed to be due to the respiratory activities of the biofilm bacteria, since the planktonic bacterial densities were not high enough to account for the oxygen demand. The establishment of anaerobic conditions was thought to promote the growth of SRB which were found in the biofilm and may have contributed to the corrosion reactions.

The supply water also contained fine particulates which accumulated in the storage tanks and promoted microbial growth. A combination of the factors identified above were thought to promote the extensive biofilm growth on the inner pipe surface and contribute to the pitting of the underlying copper surface. Although a specific mechanism was not identified for the microbial role in the corrosion process, it was felt that removal of the humic substances from the water, increasing the water temperature to 55 to 60°C, and a general cleanup of the system was needed to control the corrosion problem. Unfortunately, once this type of corrosion is allowed to start, it is difficult to control.

C. Design and Installation

In addition to water characteristics and temperature, plumbing design and installation seem to play a significant role in system susceptibility to MIC.[8] Stagnation of water can occur through the existence of deadlegs built into the system. These regions are particularly vulnerable to microbial accumulation and are difficult to treat. Stagnation also occurs when water is left in the system for extended periods of time following pressure testing before the system goes into operation. Systems designed with long horizontal runs of tubing are susceptible to MIC. This feature

promotes the accumulation of sediment on the bottom of the tubing, which increases the surface area for microbial colonization and growth and promotes the development of anaerobic conditions in these areas which are conducive for the growth of SRB and other potentially corrosive anaerobic species. Inadequate filtration of source water can also lead to sediment accumulation in various parts of the system. Poor soldering practices can lead to the accumulation of a bead on the inside of the tubing at joints. This irregularity in surface contour has long been known to produce eddies in the water flow pattern and promote erosion corrosion that is free of deposits of any kind. The protruding bead also acts to entrain bacterial cells that accumulate as a biofilm in the eddies.

V. LABORATORY SIMULATIONS OF MICROBIALLY INFLUENCED CORROSION OF COPPER

A. Attempts to Reproduce Unusual Type of Pitting Corrosion Observed in the Field

Controlled laboratory studies were carried out to determine whether the three bacterial isolates recovered from the corroded tubing in the German hospital, when grown as a mixed population in a synthetic water, could reproduce the pitting corrosion of copper observed in the field.[11] Flow-through reactors containing copper rings exposed to synthetic water with a chemistry similar to that used by several of the hospitals described above that experienced the unusual type of pitting corrosion were operated in the presence and absence of bacteria and the corrosion rates compared after 5 months. The copper surfaces exposed to these conditions exhibited none of the features of the pitted copper tubes recovered from the hospitals, although there were important differences between the materials recovered from the sterile and inoculated reactors. The sterile copper surfaces exhibited slight superficial corrosion with a basic cupric carbonate deposit. The remainder of the surface contained a cuprous oxide film. On the outer edge of the copper ring a pit was observed which contained crystalline cuprous oxide.

The rings from the inoculated reactor contained a biofilm with polysaccharide. Corrosion was observed over a broad area, producing an orange layer of cuprous oxide and in some places a more coherent cuprous oxide film surrounded by deposits of basic copper carbonate and sulfate crystals. In other areas of the ring pits containing loose copper oxide were observed under basic copper carbonate deposits. A film of black cupric oxide occupied areas surrounding the pits. Although this laboratory study failed to reproduce the spherical nodules of cupric oxide characteristic of the unusual type of pitting observed in the hospitals described above, pitting was observed in the presence of polysaccharide-producing bacterial biofilms.

B. FTIR Studies

Sensitive analytical techniques have been developed to study MIC of copper in real time, in a nondestructive manner, and without disturbance to the system. Bremer and Geesey[21] demonstrated that bacteria isolated from pits in corroded copper tubing removed from a heat exchanger could be grown either as a batch culture or as a continuous culture on a germanium internal reflection element (IRE) and monitored by attenuated total reflectance Fourier transform infrared spectroscopy (ATR/FTIR) for up to 417 h (Figure 3). The spectra revealed the accumulation of microbial products over time at the surface of the IRE. These products consisted largely of protein and polysaccharide as well as other unidentified components. Operation in the double beam mode using a sterile IRE exposed to a sterile liquid bacterial culture medium allowed accurate subtraction of components from the bulk aqueous phase that had adsorbed to the surface of the inoculated IRE (Figure 4).

ATR/FTIR was adapted for MIC studies of copper by depositing ultrathin films of copper on the IRE (Figure 5).[22] Copper films of 6 to 7 nm nominal thickness, when deposited by vapor deposition, appeared to be continuous based on X-ray photoelectron spectroscopic analysis and contained a cuprous oxide layer at the surface. Atomic force microscopic evaluation of the copper thin films revealed them to be coalescing aggregates of copper atoms (Figure 6). When IREs coated with 6- to 7-nm-thick films were submerged in an aqueous medium, there was sufficient transmission of IR radiation through the Cu to obtain significant water absorbance at 1640 cm^{-1}. The intensity of the water absorption band was found to be very sensitive to changes in thickness of the copper film.[22–24] This feature can be used to study the effect of microbial biofilms and their products on the integrity of the oxidized copper surfaces in aqueous environments.

One strain of *P. paucimobilis*, recovered from the corroded copper tubing in the German hospital, when grown as a biofilm on thin films of copper on Ge IREs, promoted higher rates of copper corrosion than sterile controls subjected to otherwise similar conditions.[17] That attached bacteria and not suspended bacterial cells promoted the observed deterioration of the copper film was demonstrated by flow-through studies. After an initial inoculation to initiate biofilm development on the copper film, no additional bacteria were added to the aqueous medium flowing over the surface. Corrosion occurred only after biofilm had developed.[17] These results suggest that pure cultures of bacteria isolated from pitted copper tubing can destabilize copper under highly controlled laboratory conditions.

Several bacteria were isolated from corrosion deposits on copper tubing exposed to tap water from laboratory faucets at California State University, Long Beach, and used to study the MIC of copper. One

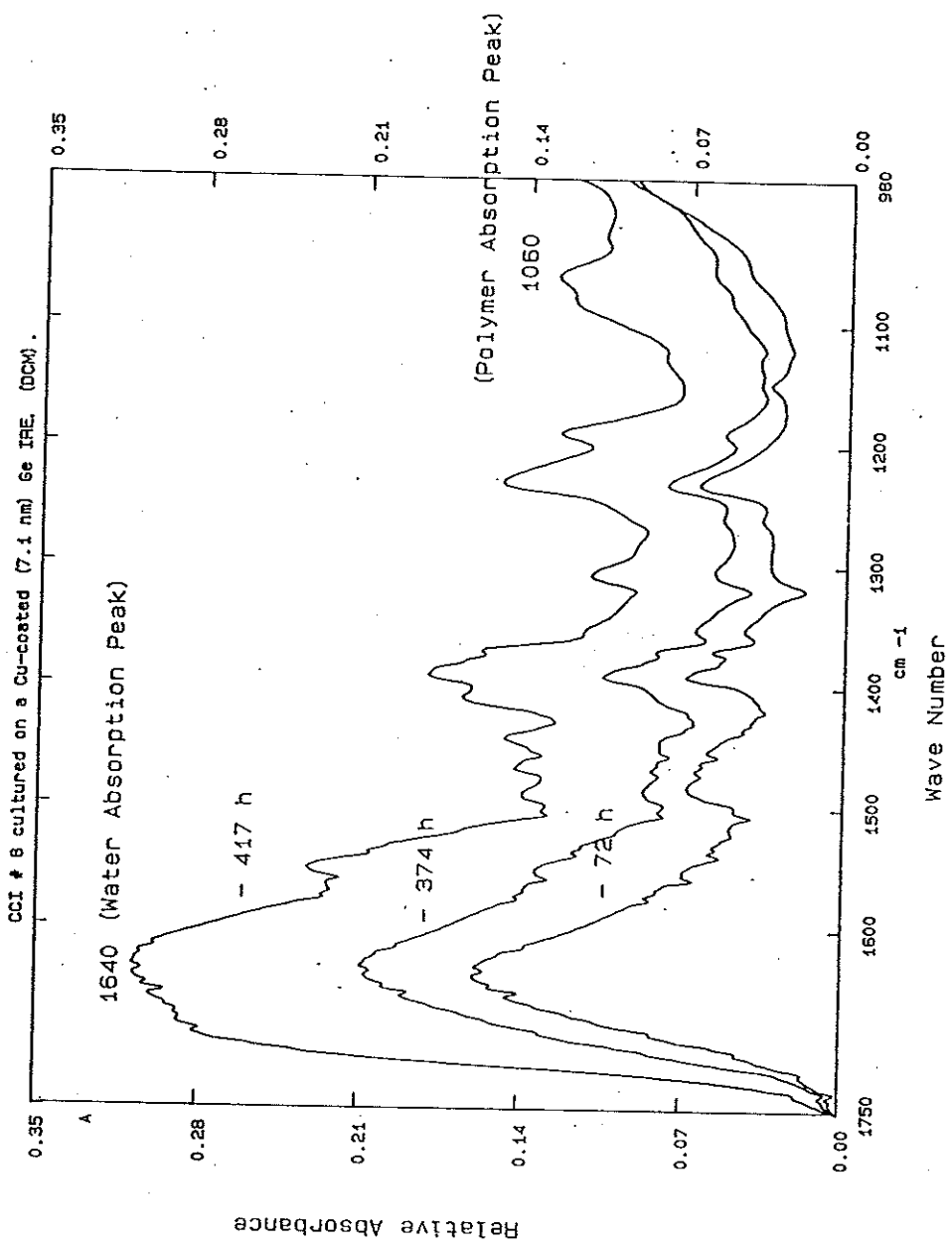

FIGURE 3. Infrared spectra collected at various times after inoculation of bacterial isolate CCI#8 in an ATR cell containing a Cu-coated germanium IRE.

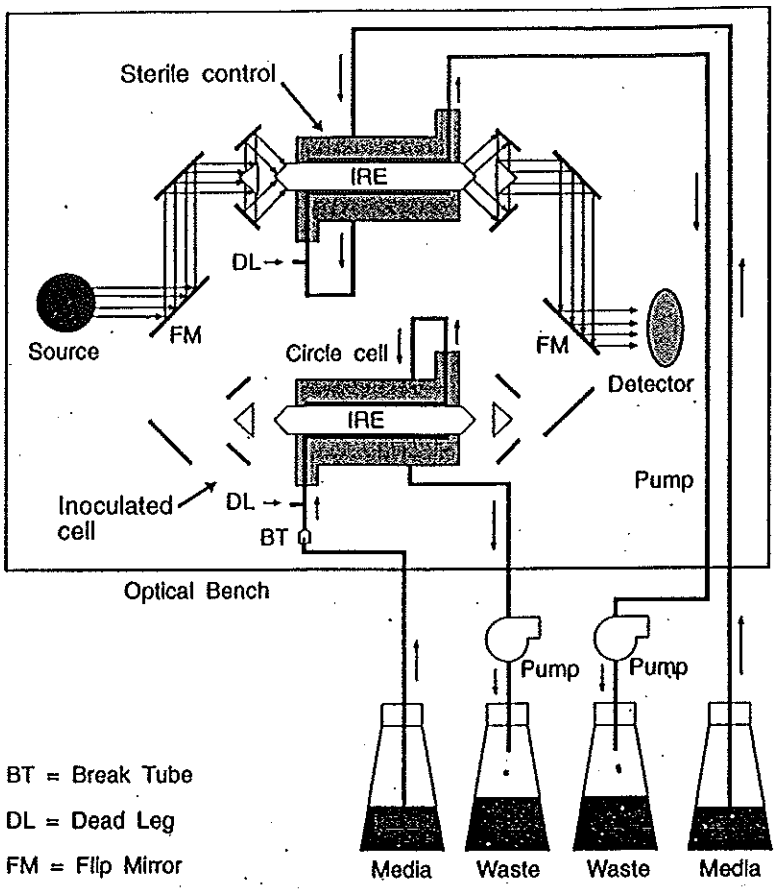

FIGURE 4. Schematic diagram of the optical bench of an FTIR spectrometer containing two cylindrical ATR cells operated in the dual beam mode.

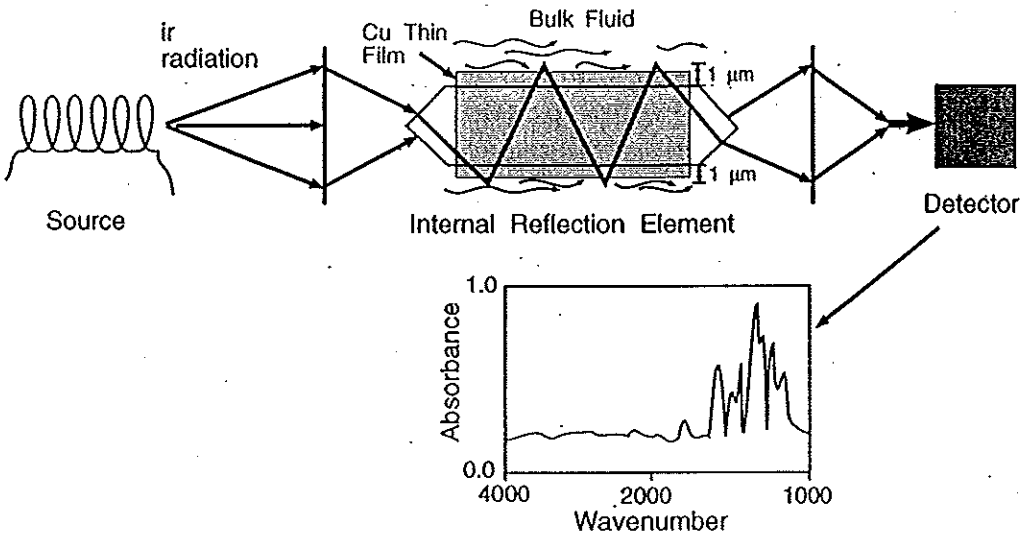

FIGURE 5. Schematic diagram of a copper-coated germanium IRE exposed to flowing medium inoculated with film-forming bacteria.

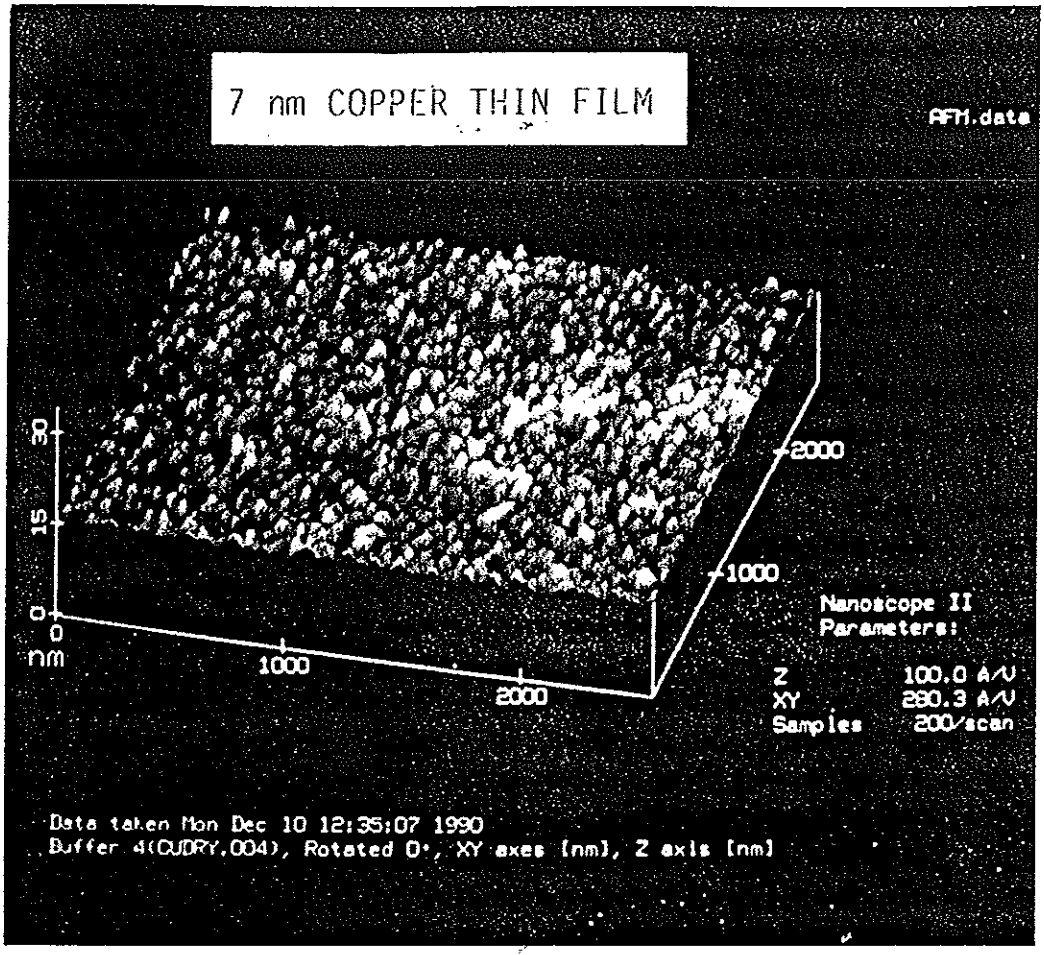

FIGURE 6. Atomic force micrograph of a 7-nm-thick copper film deposited on a germanium coupon by physical vapor deposition.

isolate, referred to as CCI#8, when exposed to a copper-coated IRE in stagnant culture media, produced an immediate decrease in the stability of the copper film based on changes in the intensity of the water absorbance band.[25] When this experiment was repeated with another bacterial isolate (CCI#11), the copper film remained stable in the presence of this bacterium over a 77-h period. These studies suggest that some, but not all, bacteria promote deterioration of copper thin films.

A similar study was performed in a flow-controlled sampling cell.[25] When CCI#8 was inoculated into the flowing medium that passed over the copper film, very little deterioration of the metal was observed over a 2.5-h period. Unlike the static culture experiment described above, no change in the stability of the copper film was observed after flow was suspended and the sampling cell was maintained as a static culture. However, when flow was resumed after 64 h as a static culture, there was an immediate loss of film stability. There was visual evidence of a biofilm on the inoculated IRE and localized deterioration of the copper

film under the biofilm. No bacterial growth or deterioration of the copper film was observed in the sampling cell that was maintained as a sterile control under the same flow regime. The results suggest that flow conditions influence biofilm-induced deterioration of the copper film and that in the absence of bacteria, flow has little or no effect over the range of flow conditions tested in these experiments. It should be noted that flow conditions have been shown to affect copper corrosion without the assistance of microorganisms.

The experiments described above were rerun over a longer time period under different flow regimes to obtain a better understanding of the relationship between flow, biofilm growth, and deterioration of the copper film.[26] Exposure of the copper thin film to CCI#8 under flowing conditions for 330 h resulted in only slight deterioration of the metal. This corresponded to a corrosion rate of 8.4×10^{-4} mpy.[27] Shortly after flow was stopped, the corrosion rate increased to 8.8×10^{-3} mpy.[27] These rates represent the average corrosion rate over the entire IRE and not where focused attack occurred under portions of the biofilm.

At the same time that the copper film deteriorated there was an increase in the amount of exopolysaccharide that accumulated on the surface.[26] No increase in accumulation of other cell components such as protein was observed during this time. The accumulation of biofilm on the copper-coated IRE was confirmed by visual examination and plating of homogenized biofilm at the termination of the experiment. Again, the area under the biofilm was discolored, verifying the copper deterioration detected by the FTIR. The data confirm earlier studies that changes in flow rate and allowing the system to become stagnant promote biofilm-induced copper corrosion.

Some bacterial biofilms protect copper from the destructive action of other bacteria. Biofilms of CCI#11, grown under flowing or quiescent conditions, caused no detectable deterioration of the copper film, even over exposure periods of up to 500 h.[26] Once established, biofilms of CCI#11 protected the copper film from attack by CCI#8 over a 300-h period under flowing or quiescent conditions. Protection was not due to exclusion of CCI#8 from the surface by the biofilm of CCI#11, since changes in the infrared spectrum of the biofilm were observed after inoculation of CCI#8 to the system and approximately equal numbers of both bacterial types were recovered after plating samples of the biofilm on solid culture medium after termination of the experiment. These results demonstrate for the first time that a particular type of bacterium can protect the surface of copper from the aggressive localized attack of another type of bacterium. Since biofilms are present on most surfaces submerged in aqueous environments and only a very small fraction of these surfaces are subject to pitting corrosion, it is not unreasonable to suggest that some bacteria play a protective role in MIC of copper tubing.

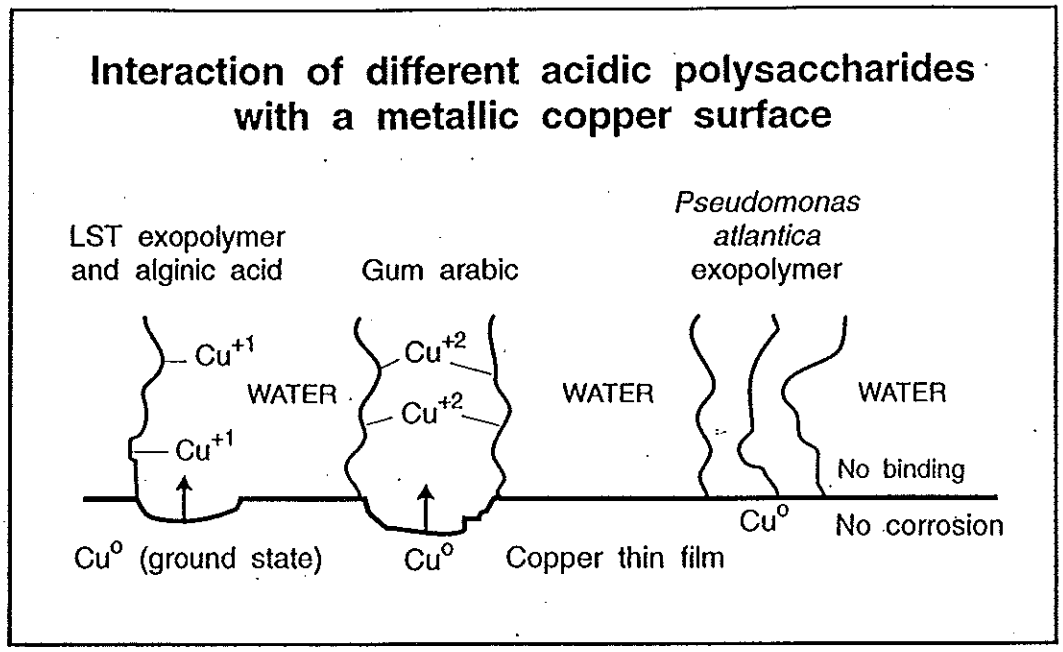

FIGURE 7. Interactions of different acidic polysaccharides with a metallic copper surface. Different polymer chemistries stabilize the copper in different valence states.

C. Role of Microbial Exopolysaccharides in Localized MIC of Copper

Studies by Fischer et al.[3] and Paradies et al.[15] indicated that polysaccharides and oligopeptides were associated with corrosive biofilms. Exopolysaccharides isolated from biofilm bacteria have been shown to destabilize copper thin films. When a copper-coated IRE was exposed to a 1% solution of a crude acidic exopolymer from a sediment bacterium (FRI), the copper film corroded immediately.[28] A similar phenomenon was observed when the copper-coated IRE was exposed to a suspension of other acidic polysaccharides such as alginic acid and gum arabic.[24] The results suggest that metallic copper is sensitive to a wide range of acidic polysaccharides, including those produced by some biofilm-forming bacteria that colonize copper tube.

Results from several studies suggest that the metallic copper is oxidized by acidic polysaccharides. X-ray photoelectron spectroscopy has shown that some of the copper deposited on the IRE after exposure to gum arabic and alginic acid was oxidized to Cu^{2+}, that which was exposed to other bacterial polysaccharides was oxidized to Cu^{1+}, and that which was exposed to yet other types of bacterial exopolysaccharides underwent little oxidation and remained as Cu^0 (Figure 7).[29-30] These results are consistent with a corrosion mechanism based on a copper concentration cell formed by the excretion of exopolysaccharides with

different affinities for copper ions by different bacterial species within a biofilm.[31–32]

Paradies et al.[8] presented evidence that the imidazole or L-histidine groups of the oligopeptide chains in biofilms participate in complex formation with Cu^{1+}. These authors also have detected a Cu^{3+} complex in corrosive biofilms which was formed through a reaction with peroxide. A corrosion mechanism involving these complexes has been proposed.

The chemistry and possibly the structure of exopolysaccharides of copper-corroding bacteria are influenced by the presence of copper in the surrounding environment. Bremer and Geesey[33] demonstrated that the copper-complexing carboxyl groups contributed by uronic acid subunits are significantly more abundant in exopolysaccharides produced by cells exposed to copper than those produced in environments with little or no copper present. The exopolymer produced in the presence of copper bound approximately 16% of its weight in copper. It is likely that some microorganisms produce large amounts of copper-complexing exopolymers to protect themselves from the toxic effects that Cu^{2+} has on essential reactions inside the cell. These polymers accumulate during biofilm growth in a heterogeneous manner over the surface. This heterogeneity may promote localized dissolution of metallic copper, which takes the form of pitting. Whether pitting propensity is simply related to the quantity of exopolymer produced or a reflection of subtle differences in exopolymer chemistry or structure remains to be determined. Further research will be required to gain a more complete understanding of the role of specific bacterial exopolymers in pitting corrosion of copper. Nevertheless, significant progress has been made in demonstrating the participation of microbial biofilms in this phenomenon.

VI. PREVENTION OF MIC OF COPPER TUBING USED IN POTABLE WATER SYSTEMS

Based on the information presented above, it appears that a combination of factors contribute to the unusual forms of pitting corrosion of copper tube in institutional buildings such as hospitals. These factors include the use of soft water with low pH, high suspended solids, and AOC content, long-term or periodic stagnation of water in the pipeworks which produces widely fluctuating oxygen concentrations, maintaining water temperatures that promote rapid growth and activity of naturally occuring bacteria that form biofilms on the pipe wall, and the lack of an adequate monitoring program to periodically evaluate water quality and pipe wall condition. Thus, it should be possible to avoid the undesirable corrosion by identifying and specifying limits for these parameters.

Nuttall and Rich[36] described the key factors for design, installation, and commissioning of copper plumbing systems in large public buildings. From a microbiological point of view, they were concerned more with control of *Legionella pneumophilla* than of corrosion-causing microorganisms, since there was little information available on MIC of copper tube at that time. More recently, Fischer et al.[9] have summarized many of the precautions that should be followed when water chemistry, temperature, and system operation predispose the system to MIC. Based on these previous reports and the studies described above, a number of recommendations can be made that reduce the likelihood of microbially induced pitting corrosion of copper tubing. The recommendations fall into three categories: system design, installation, and operation.

The system should be designed to minimize the possibility of water stagnation. Deadlegs (sections of tubing which contain stagnant water for long periods of time without being refreshed in any way) should be eliminated. In large installations, pumps should be installed that maintain water flow velocities between 0.7 to 1.5 m/s at all times. Filtration equipment may be desirable for removal of suspended particulates in the source water that could accumulate along horizontal runs of plumbing.

Although little attention has been given to monitoring programs, periodic examination of the interior pipe wall surface for deposit accumulation, tubercle formation, and biofouling permits recognition of a potential MIC problem and initiation of corrective action before control over the problem is lost. Monitoring of this nature requires installation of removable, replaceable pipe sections at different locations in the system, periodic inspections, and a plan of corrective action when MIC is observed. This alternative could be less costly than replacement of all failed tubing in a system that is particularly prone to MIC.

Installation of the plumbing system should be carried out according to copper tube manufacturers' recommended procedures. Soldered joints should be smooth and free of solder beads on the inside pipe surface. Debris introduced into the tubing during installation should be removed before pressure testing. No water should be introduced into the system for pressure testing or for other reasons until it is certain that the system can be operated under the conditions for which it was designed soon after testing has been completed. The system should never be allowed to go out of operation without draining all of the water. Only high-quality water should be used during pressure testing. If there is a delay between the time the system is pressure tested and put into commission, water should be circulated through all wetted tubing at regular intervals to prevent stagnation. Immediately prior to commissioning, the system should be sterilized to kill any harmful microorganisms that inadvertently entered the system during previous operations.

Operating conditions should be based on health-related, microbiological standards applicable to potable water systems. The use of high-quality water is strongly recommended. Water hardness should be adjusted to establish a protective oxide film on the inner surface of the plumbing material. Of all the recommendations made, maintaining proper water temperature in the lines is the most important for minimizing MIC. Water temperature should be maintained below 25°C for cold water and above 55°C for hot water at all times. Maintenance of these temperatures may require water flow through the pipes at regular intervals.

In summary, certain water chemistry, system design, and installation and operation practices predispose copper tubing to microbially induced pitting corrosion which results in through-wall perforations that are costly to repair. The phenomenon appears to be related to a combination of chemical and biological factors which act in concert to cause the observed failures in institutional buildings. By altering several of these factors at the same time, it should be possible to reduce or eliminate the problem.

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Microbiologically influenced copper corrosion in potable water with emphasis on practical relevance

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Key words: biofilm, copper, potable water, remedial measures

Abstract

The physical and chemical properties of biofilms, in combination with metabolic and degradation products of biological origin, influence the nature and local chemistry of the aqueous phase at the copper/biofilm phase boundary. The pitting susceptibility of copper is determined by this change of water composition at the copper/biofilm phase boundary and is supported by the mixture of solid corrosion products and the biofilm at the copper surface. Several factors influence the susceptibility of copper to MIC: commissioning, design and operating conditions; the chemical composition of the water and the relevant biological activity. Field experience and theory showed that a combination of methods should be used to protect existing copper installations. In summary, water chemistry seems to be a major influencing parameter for the described corrosion problems. Raising the alkalinity of the potable water whilst optimising the chloride/sulphate ratio is considered as the most promising preventative measure to overcome the described problems.

Introduction

Copper is an excellent material for plumbing purposes. Despite the widespread use only a few corrosion failures have occurred under special circumstances (Ferguson et al. 1996; Japan Copper Developm. Assoc. 1982; Winkler 1990). Pitting corrosion of copper has been extensively investigated during the last fifty years. Pitting corrosion was shown to be promoted by carbonaceous films which were formed by cracking lubricants during the bright annealing process (Campbell 1954; Lucey 1967). Later it was found that a special type of oxide layer also resulted in pitting corrosion in certain types of water (Baukloh et al. 1990). Such oxides grow when copper tubes – especially hard-drawn tubes – are jointed by brazing. The manufacturers made successful efforts to produce copper tubes free from carbonaceous films. This quality is today required by the relevant standards and specifications (DVGW GW392). Different methods based on surface treatments e.g. grit blasting and preoxidizing processes were used to achieve such a high quality (Baukloh et al. 1982; Cornwell 1973, 1976; Gilbert 1966).

Despite these measures, potable water installations in mainly institutional buildings in different regions of the world were affected by an unexpected pitting of copper pipework. No specific type of tubing (hard, halfhard, soft annealed) showed a particular susceptibility to this type of pitting. Microbiologically influenced corrosion (MIC) has been identified as causing the observed problems (Angell et al. 1990; Campbell et al. 1993; Fischer et al. 1988; Geesey et al. 1987, 1994; Nuttall 1993; Wollmann 1994). This type of corrosion of metals and alloys is now generally accepted and considered to be a major concern in terms of economic losses and pollution (Characklis et al. 1990; Dowling et al. 1990; Heitz et al. 1996; Houghton et al. 1988). However, experience and scientifically-based knowledge did not indicate a remarkable susceptibility of copper to pitting in the respective water distribution areas. Causes and mechanisms of these microbiologically influenced corrosion processes were by no means

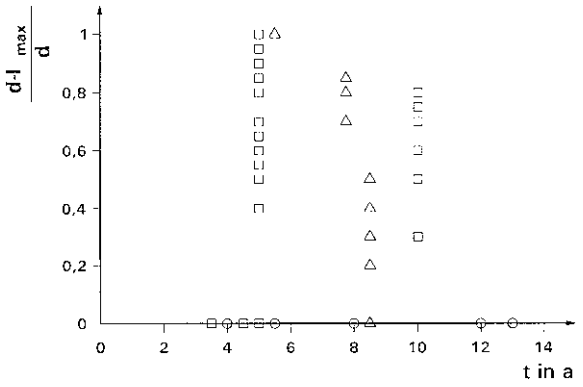

Figure 1. Evaluation of the maximum pit depth of the installed copper tubes for different public buildings in the same water distribution area as a function of operating time of the installations in years; d (in μm) is the thickness of the copper tube wall (usually 1000 μm), l_{max} the maximum pit depth observed in a copper tube removed from the installation after a certain operating time. Consequently, d – l_{max}/d = 0 means the perforation of the tube. □ Building A; △ Building B; ○ Building C

understood at their first occurrence. The scope and objective of this contribution is to provide an overview about factors that influence the susceptibility of copper to MIC and to assess the relevant influencing parameters yielding an overview about the present state of knowledge.

Case studies of copper pipe corrosion

Potable water installations

Potable water installations were affected by MIC, namely in Germany, Saudi-Arabia, Southwest-England, Scotland and Sweden in the mid eighties. A further confirmed case of MIC has been reported from Australia (Wallace 1996). Failure analyses were performed (Campbell et al. 1993; Fischer et al. 1992b, 1994, 1995; Linder et al. 1983) and test rigs were set up in affected buildings and in the laboratory to simulate and understand the corrosion process (Angell et al. 1990; Wagner et al. 1992a, 1994a, 1995b, 1996c, 1996b, 1996e, 1996f) as a basis for the evaluation of countermeasures.

From practical experience it could be assumed that in cold water installations no failure within an installation is to be expected when no failures occur in the first few years after commissioning. About three years after commissioning of the installation this likelihood usually decreases (Franqué von 1968a, 1968b, 1972; Kruse 1991). This does not hold true for this microbiologically influenced copper corrosion process as depicted in Figure 1 (Wagner et al. 1996c). In Figure 1 the corrosion progress occurring in copper installations in three large institutional buildings and situated in the same water distribution area was validated by performing inspections of copper tubes affected by MIC using the maximum pit depth as the evaluation criterion. A relative measure for the pit depth d-l_{max}/d (d: thickness of the copper tube in μm; l_{max}: maximum pit depth in μm) was plotted as a function of operating time after set-up of the installation. The zero line means a perforation, the 'one' a tube without any pitting attack. Wall thickness was usually 1 mm. The inspections were performed in installations with service lives of up to thirteen years. Figure 1 reveals the following facts:

- The likelihood of failure did not exhibit a relative maximum between the years one and three;
- perforations occurred even after a use of thirteen years, eg in building C;
- pit depths measured on different samples after a certain time of use varied between zero and perforation, that is 1 mm (see especially after 4.5 years for building A);
- a change for the worse could be observed within the installation of building A after 10 years despite the performance of countermeasures (Fischer et al. 1995). This indicates that the MIC process could be slowed down considerably, but not eliminated completely by these measures.

Since these results were evaluated for three different buildings in the same water distribution area, also taking into account the described characteristics of this corrosion process, the relevance of MIC being a special mode of corrosion could be established. The typical further characteristics for the MIC process under consideration are the occurrence of

- copper by-products in a dissolved or particulate state and
- extra-cellular polymeric substances mixed with solid corrosion products usually consisiting of black copper(II) oxide and/or posniakite/malachite.

Complex biofilms are ubiquitous at interfaces in nature (Ellwood et al. 1982). One possible cause of the pitting and consequent perforation of the copper pipes was the presence of extra-cellular polymeric material (Wagner et al. 1992a). These extra-cellular polymeric substances comprise different organic materials, i.e. polysaccharides, glycolipids and oligopeptides (Bremer et al. 1992; Ford et al. 1977; Little et al. 1986). These biofilms are possibly formed as a consequence of

the growth of copper resistant microorganisms (Cornwell et al. 1973; Cooksey et al. 1992).

The biofilm observed here on copper comprised extra-cellular polymeric material with a high water content and included bacteria, fungi and adventitious algae. The biofilm was either situated underneath or mixed with solid copper corrosion products. The chemical composition of the solid corrosion products and parts of the biofilm were investigated in more detail for a representative German case (Fischer et al. 1992). Dark-red copper(I)-oxide, black copper(II)-oxide, blue-green posniakite and malachite were identified. The structure of the extra-cellular polymeric substances was described as linear and/or cross-linked acidic or partly non-ionic polysaccharides (Fischer et al. 1988; Paradies et al. 1992). In some other cases, the copper pipes were covered with a polysilicate film which was insoluble in acids (Fischer et al. 1995). This film was not of biological origin. However, because the manifestations of corrosion were the same, this material was not differentiated from the biofilm described above. Therefore, the authors consider the physico-chemical properties of the biofilm to play an essential role in this MIC process (Siedlarek et al. 1994; Wagner et al. 1996a).

In addition to the biofilms, an exceptional level of biological activity within the failed copper tubes was observed in some cases. This was either indicated by the chemical composition of the biofilm mentioned above (Fischer et al. 1988) or by tremendous oxygen consumption during periods of stagnation (Angell 1992; Nuttall 1993). This was interpreted as indirect evidence of metabolic activities leading to the formation of biofilms. Many investigations dealing with MIC in potable water installations report on the influence of living microorganisms leading to the formation of a biofilm (Hadley 1948; Walker et al. 1990). Microorganisms live and die, and their metabolism changes as they progress along the growth curve. Consequently, the biosynthesis of extra-cellular materials as well as many biochemical processes cannot be considered as constant. No specific types of microorganisms can be confirmed as having a detrimental influence on the corrosion process because no validated, generally accepted model for the description of the relevant corrosion process is available. Nevertheless, it has been suggested that some bacteria will attack copper when they become sessile on the copper surface (Arens et al. 1995, 1996; Dutkiewicz et al. 1996; Geesey et al. 1986; Webster et al. 1996).

General attack was detected in the failed piping of all cases. Pitting attack was also detectable. The pits had a hemi-spherical shape in the majority of cases, however, in one case pinhole-shaped pits were also found. Although the copper surface was usually covered with a biofilm mixed with solid corrosion products, parts of the stained copper tubes were shiny without detectable signs of attack in some cases. This was observed when either the biofilm showed a heterogeneous structure and stabilized corrosion elements or the chemical and physical status of the corrosion products or their adherence were not uniform (Angell et al. 1990; Wagner et al. 1992b).

In all cases involving this type of MIC the distributed potable water was a soft, weakly buffered and slightly alkaline water prepared from surface water (Fischer et al. 1995). The probability of copper pitting in these types of fresh water under these conditions is negligible using the available knowledge described in the literature (Lucey 1975, 1982) or given in a DIN Standard (DIN 50930). This indicated that other factors were responsible for the corrosion damage. In three countries (Germany, Saudi-Arabia, Scotland) both the cold and warm water circuits showed the same manifestations of corrosion and failure. These manifestations could be attributed to Type I pitting corrosion (Lucey 1975, 1982). This means that no effect of water temperature could be evaluated.

Large plumbing systems

There is significant evidence that large plumbing systems are more prone to MIC. The highest failure rate occurs where a high degree of branching and long horizontal runs are present in the installation. The likelihood of MIC pitting increases when the water stagnates and is replenished infrequently, and is at a maximum under intermittent flow conditions when periods of stagnation are prolonged. Usually, domestic houses are affected to a much lesser extent by this type of corrosion.

An installation is much more susceptible to pitting with increasing contamination of the water supply, e.g. by the use of open water tanks and dirty filters. A long delay between the running of the installation and the initial commissioning and pressure testing can affect the likelihood of corrosion, especially when water remains in the copper tubes due to incomplete drain-down.

The hospital water systems under investigation were primarily aerobic but evidence of transient anaer-

obic conditions has been reported (Nuttall, 1993). A wide range of bacteria has been isolated from waters and copper tube surfaces associated with pitting corrosion. The copper (II) ion is very toxic for many organisms but those associated with the pitting showed a range of tolerance levels with some evidence (Angell & Chamberlain, 1991) that those with low tolerance may be protected by other more tolerant strains when in mixed culture.

Factors affecting copper pipe corrosion

Design, installation and operating conditions

The installation and operating conditions were evaluated as possible causes for the damage (Fischer et al. 1992, 1995; Wagner et al. 1992a, 1994a, 1994b, 1996c, 1996b). The conditions of the installation after the pressure test and operation determine the likelihood of corrosion. Other factors to consider are the pipe sizes and actual flow rates, storage vessel size, conditions of maintenance/cleanliness and temperature control.

The role of microorganisms

There are numerous ways in which organisms, particularly microorganisms can play a role in corrosion processes. The number of organisms for copper is rather larger than for many other metals as it is susceptible to such a wide range of chemical reactions (Pope et al., 1984). Thus the corrosion can be initiated by localised breakdown of the normal passivating surface coatings, primarily Cu_2O. Classes of active compounds produced by microorganisms include:

- Inorganic acids, such as dissolved CO_2; organic acids, e.g. acetic, butyric; acidic polysaccharides, e.g. alginate, xanthan; ammonia; sulphur-containing compounds like cysteine or H_2S.
- Proteins, unless exceedingly acidic or rich in sulphur amino acids are frequently protective, the amino nitrogen and copper having a high affinity and effectively acting as a corrosion inhibitor.

Typically, to exert an effect organisms need to be held in close proximity to the metallic surface and for the localised changes in chemistry to be prolonged by reduced diffusion away from the localised site. The establishment of microcolonies or a matrix-enveloped biofilm will both achieve this effect. Thus, unless planktonic bacteria can produce a very significant shift in the bathing medium, for example through pH changes or H_2S production they are unlikely to be involved in MIC. In practice, this is fairly unlikely in any flowing system, although partial or complete stagnation could allow development of significant levels to affect corrosion (Angell, 1992). Very dense populations of bacteria on a metal surface can lead to corrosion inhibition in aerobic systems due to competition for oxygen, so a patchy, heterogeneous biofilm is more likely to cause corrosion.

Bacterial copper tolerance

Extracellularly secreted materials, either copper binding proteins (Gordon et al., 1992) or acidic polysaccharides (Bremer & Geesey, 1993) can play major roles in microbiologically influenced copper corrosion processes. Those extracellular polysaccharides secreted in response to the presence of copper had a higher level of uronic acid substituents. The copper stimulus also increases the levels of polysaccharide secreted by many bacteria. In practice over 40 isolates of different organisms were obtained from pitted copper tubes but many were expected natural water flora organisms such as *Pseudomonas vesicularis, Ps. stutzeri, Sphingomonas-paucimobilis, Comamonas testosteroni, Flavobacterium breve* together with a large amount of *Moraxella lacunata* and *Moraxella sp*. (Chamberlain et al., in preparation).

Biofilms

The presence of a biofilm is a key feature in the majority of cases of microbially influenced corrosion. These films comprise microorganisms, organic and inorganic particulates and a binding matrix which is usually predominantly polysaccharide with additional proteins and other cell-derived organic compounds, such as nucleic acids. These biofilms have been the subject of considerable study in recent years (Chamberlain et al., 1988), in particular those associated with the occurrence of pitting corrosion of copper. The first indication that a biofilm matrix containing polysaccharides may be of importance in the case of copper MIC was reported by Fischer et al. (1988). This was based initially on the staining reaction with Gentian Violet, essentially a non-specific polysaccharide stain, but was subsequently supported by detailed chemical analyses. The major component was a xanthan-like material together with polymers resembling bacterial alginate, which show acetylation of the uronic acid residues, unlike the brown algal versions.

The role of polysaccharides

Most polysaccharides associated with microbial corrosion have some form of anionic group on the molecule and this has lead to several models of how such materials could produce pitting. Thus, Mittelman and Geesey (1985) showed that polymer from a river bacterium was capable of binding copper and could be effective at establishing copper concentration cells on a copper surface. This basic concept was evolved by Bremer and Geesey (1991) into a laboratory-based model of MIC of copper. Geesey and Bremer (1992) demonstrated that the *(Pseudomonas) Sphingomonas paucimobilis* isolated by Angell and Chamberlain (1991) from pitted copper tubes from a German Hospital were capable of dissolving thin, (6–7nm) vapour-deposited copper films on germanium internal reflection elements examined by ATR/FTIR. Subsequent work with isolates from copper tube from the USA confirmed that some strains of bacteria, which were stimulated to produce extracellular polysaccharides by the presence of copper, could show varied behaviour towards the thin copper films. Thus, some polymers dissolved it whilst others did not, and those which did were usually rather acidic in their reaction due to uronic acid carboxyl residues. However, the presence of a non-dissolving strain could protect the copper surface against the actions of the aggressive polymer.

On the basis of an extensive series of papers relating to copper binding by bacterial polymers (Geesey et al., 1987; Jolley et al., 1989; Geesey and Bremer, 1990) they suggested that some polysaccharides with acidic groups such as uronic acid or pyruvyl substituents were known to frequently possess high affinity binding sites for copper (Geesey et al., 1986) thereby promoting the removal of further metallic copper ions. The juxtaposition of two such polymers of differing copper binding affinity could allow the development of a differential concentration cell, resulting in the establishment of an anodic site beneath the polymer binding the most copper (Geesey and Mittelman, 1985).

These data are indicative of a capability of some bacterial polysaccharides to dissolve thin copper films, however, it is still some way from the development of pitting in the accepted corrosion sense. This has been demonstrated subsequently (Campbell et al., 1993) using a mixed culture including the *Sphingomonas paucimobilis* mentioned above, plus a strain of *Sph. yanoikuae* and an *Acidovorax sp.* which originally appeared to be closely allied to *Ps. solanacearum*, a noted plant pathogen. The organisms were inoculated into packed beds of 1cm sections of 15mm copper tube and supplied with artificial tap water initially, followed by actual tap water from the supply which was associated with the copper corrosion incidence in SW England. Two systems were operated, one inoculated and one sterile. The inoculated system showed true pitting on both internal and external surfaces of the pipe rings, whereas the sterile system had a very low number of pits on external faces alone, but only where rings had been in contact to produce 'crevices'. The process took approximately 2 years to occur and it is tempting to suggest that one or both of the two attendant bacterial strains may have acted as a partial protection system as described by Geesey et al. (1994). Final recovery of organisms at the termination of the experiment showed all three strains were still present with no other organisms as contaminants.

The role of oxygen differential cells

Other models have been put forward. Walker et al. (1994) proposed that the 'pepper-pot' pitting found in Scottish hospitals was essentially the footprint of the microcolony structure within the biofilm. It was suggested that the creation of oxygen differential cells with low oxygen levels beneath the organisms could create the required anodes. In our own research we have shown that a number of bacteria associated with MIC of copper are capable of producing polysaccharides which can interfere with the passage of chloride ions to the metal surface (Wagner et al., 1995a). The recent observations on biofilm structure described by Keevil et al. (1995) suggest that there are numerous channels which perforate the biofilm polymer mass allowing easier access to the regions close to the metal surface. Such a structure could raise serious objections to the cation selectivity mechanism if it were not for the fact that, as stated by Keevil, 'the structure can also appear confluent because of the production of copious EPS gel **within** the channels'. Recent work with other bacterial polysaccharides has shown that anion migration can be limited by quite thin layers of dilute polymers (Hart et al., in preparation). However, even those biofilms with extensive channels still possess a basal layer, albeit only 5–10 μm thick, which covers the metal surface.

Physico-chemical aspects and their role

The physico-chemical properties of biofilms play a decisive role in the MIC process (Siedlarek et al. 1994c; Wagner et al. 1996a). These physical properties depend entirely on its chemical composition.As mentioned ear-

lier, its primary composition consists of structures similar to that of xanthan, eg pyruvate residues, highly crosslinked and of high molecular weight. It also contains alginate like structures, a polysaccharide consisting of mannuronate and guluronate residues arranged in a non-regular clockwise pattern along a linear chain (Fischer et al. 1988; Paradies et al. 1992). Because of the accumulation of fixed negative charges within this biofilm due to its major components, this type of biofilm is expected to be cation selective yet permeable for components like water and oxygen.

The cation selectivity and permeability of this type of biofilm gave rise to the following arguments (Siedlarek et al. 1994c):

- Only cations and neutral components, eg water, oxygen and carbon dioxide, but no anions can pass through the coating consisting of extracellular polymeric substances with a high water content to a copper surface when in contact with potable water as observed in the failure cases. This allows the formation of copper oxides or copper hydroxides beneath the coating, but not the deposition of salt layers, e.g. copper(I)-chloride.
- The electrochemical force for the transport of copper ions through the biofilm is provided by the gradient of the electrochemical potential of ions produced through the anodic partial reaction of the corrosion reaction, i.e. copper oxidation.
- A very thin layer consisting of copper(I)-oxide is formed, when a bare copper surface comes into contact with an aqueous phase (Burke 1990; Strehblow 1984; Speckmann 1985, 1988).

A low pH can be assumed at the phase boundary copper/biofilm due to the dissociation constant of the carboxylic acid groups. Typical pK_a values of interest here are in the range of 4.2–5.6 according to titration experiments and conductivity measurements (Siedlarek et al. 1994c). The electrolyte at the phase boundary copper/biofilm becomes acidic if an adhering deposit of copper(I)-oxides or copper(I)-hydroxides is formed electrochemically through the reaction with water. Higher pH values in the range between 6.5 and 9.5 are established at the phase boundary biofilm/potable water corresponding to the pH range of potable water according to the German drinking water ordinance (Bundesgesetzblatt). These considerations infer the existence of a pH gradient across the biofilm coating (Wagner et al. 1991).

These theoretical considerations were substantiated by the performance of laboratory experiments, mainly in chloride-ion containing electrolytes using complementary electrochemical techniques (Siedlarek et al. 1994c; Wagner et al. 1996a). The biopolymers were directly situated on top of the bare copper surface. During exposure a layer of copper(I)-chloride was formed on top of the biopolymer, followed by a layer of copper(I)-oxide (Siedlarek et al. 1994a, 1994c; Wagner et al. 1996a, 1996d). The biopolymer coating stabilizes a low pH at the phase boundary copper/biopolymer due to its acidic functions leading to an enhanced copper by-product release compared to a copper electrode without biopolymer. In the pitting areas the biopolymer coating was either not present or partially disrupted during exposure. In these anodic areas the corrosion behaviour is determined by the anions and their ratios. Therefore, promising countermeasures should be based on the optimization of the anion ratios in the potable water with regard to chloride, sulphate and bicarbonate. These measures are also considered to be beneficial in terms of reducing cuprosolvency by supporting the formation of protective layers.

The mechanism of the formation of reaction layers must be well understood to describe promising countermeasures to overcome MIC problems. Anions like sulphate, chloride and bicarbonate together with protons are the main influencing parameters for the deposition of reaction layers of solid corrosion products during corrosion of copper when in contact with aerated cold water of potable quality.

The influence of chloride and sulphate ions on the corrosion reactions of copper is well understood (May 1953; Lucey 1967; Billiau 1983; Pourbaix 1976; Al-Kharafi et al. 1982; Shalaby et al. 1989; Siedlarek et al. 1993, 1994a; Fischer et al. 1992a, Edwards 1994b; Patel 1996). In sulphate-containing electrolytes, voluminous reaction layers of crystalline copper(I)-oxide are formed at potentials higher than the threshold potential. The deposited layers do not inhibit the anodic partial reaction to any observable extent. The only manifestation of corrosion is general attack. In electrolytes containing chloride, two reaction layers are formed, namely copper(I)-chloride underneath and an amorphous film of copper(I)-oxide on top of the copper(I)-chloride. This amorphous copper(I)-oxide is formed via hydrolysis of copper(I)-chloride, and inhibits the anodic metal dissolution. The observed manifestation of corrosion is therefore repassivating pitting with maximum pit depths of about 100 μm $\pm$ 30 μm. These observations for both chloride and sulphate ions are independent of pH in the range of $4 < \mathrm{pH} < 10$. In general, an increase in the sulphate concentration increases

the pitting tendency of copper, whilst an increase in the chloride or nitrate concentration decreases the pitting tendency (Lucey 1968).

The available results concerning the system $Cu/H_2O/CO_2$ do not allow conclusive statements concerning the corrosion behaviour of copper (Edwards 1994a, 1994b, 1996; Thomas 1972, 1972a; Mattsson 1980, 1988; Adeloju 1986; Ushakova 1991, 1991a, Alhajji et al. 1996). Although bicarbonate has long been considered essential in the prevention of copper corrosion problems (Cruse et al. 1985), recent work has demonstrated that bicarbonate has a dual nature that is dependent on the solution pH (Edwards 1994a, 1994b, 1995, 1996; Majerowski et al. 1996). Contrary to expectations, a higher content of bicarbonate was found to increase copper corrosion rates below about pH 8.1. Above about pH 8.1, the presence of bicarbonate tends to passivate copper surfaces and decrease corrosion rates (Edwards 1995). In nearly all of the cases where bicarbonate was reported to have beneficial effects in practice, the solution pH was greater than pH 7.7 (Milosev et al. 1992; Thomas 1972; Drogowska et al. 1992; Mattson et al. 1968; Hongve et al. 1995; Nielsen 1995).

In electrolytes with binary mixtures of anions (chloride/sulphate and bicarbonate/sulphate) the sulphate ions influence the repassivation of the copper material unfavourably (Project IVA5-20400789; Siedlarek et al. 1994b). Generally a tendency to pitting is favoured by a high sulphate/chloride ratio (Lucey 1968). For the corrosion system $Cu/CO_2/H_2O$ plus a second anion only isolated results are available (Thomas and Tiller 1972; Nishikata et al. 1990, Obrecht 1962, Wagner et al. 1996e). For example, copper pitting occurs in hard waters containing dissolved carbon dioxide and oxygen having a pH range of 7.0–7.8 and a sulphate/chloride concentration ratio of 3–4: 1 (Obrecht et al. 1969). However, it could be shown in recent work that a moderate increase of the bicarbonate level in a chloride/sulphate electrolyte leads to a considerable decrease of the manifestations of copper corrosion (Wagner et al. 1996e). A change of the chloride/sulphate ratio by increasing the chloride concentration yields a further reduction of the maximum pit depths of the copper (Wagner et al. 1996e).

Remedial and preventative measures

An MIC process as the cause for the breakdown of a copper potable water piping system must be clearly identified before discussing remedial measures. Staining procedures were developed to allow the rapid detection of biofilms that play a key role in this corrosion process (Chamberlain et al. 1988; Walker et al. 1994). Successful countermeasures were developed, substantiated and introduced into practice to protect the installations (Fischer et al. 1995; Wagner et al. 1996c, 1996b). This included the test of the suitability of alternative installation materials (Fischer 1993; Wagner 1995).

Design, installation and operating conditions

The following methods of remedial treatments should be considered when MIC is encountered (Fischer et al. 1995, Wagner et al. 1996b):

- Ensure cleanliness and minimize delays in starting operation after setting up the installation.
- Avoid pockets of air resulting in partly filled pipes.
- Clean the inner surface of the installation with citric acid and/or sulphamic acid and replace the damaged section. Without this additional treatment a simple replacement with copper is not a suitable countermeasure, as a higher likelihood of corrosion and, consequently, the occurrence of failures in a much shorter time period have to be expected (Wagner et al 1996c). Reinstallation with another material could also be a successful countermeasure.
- Insulate hot and cold water sections and maintain hot water at $T > 50\,^{\circ}C$ and cold water at $T < 25\,^{\circ}C$.
- Increase the water circulation by using pumps.
- Reduce suspended solids and total organic carbon in the source water with filters.
- Minimize dead-ends in the system as well as long, horizontal sections.
- Install monitoring loops and sampling ports.
- Maintain the flow rates to establish a continually present oxygen concentration.
- Design the system in modular form to avoid problems caused by large single water systems.
- Make changes in more than one parameter to minimize the reappearance of pitting. This is the most important point.

Water treatment

Modulation of the water alkalinity is considered a most promising approach to overcoming corrosion problems in copper installations including MIC problems. This effect should be enhanced when the chloride/sulphate ratio is changed by the addition of chloride based on

laboratory experiments (Wagner et al. 1996d). This approach is supported by experiences obtained in practice. The corrosion situation of copper tubes in contact with soft potable waters was improved satisfactorily in the Netherlands (Elzenga et al. 1981), in Sweden (Linder 1987), in the USA (Edwards et al. 1995) and in Australia (Majerowski et al. 1996) by the addition of bicarbonate. Nevertheless, microbial influences have not been reported in these cases. In a water distribution area in Germany affected by MIC and copper by-product release, bicarbonate dosing in combination with UV-treatment was shown in a test site to be a promising remedial measure (Baukloh A, personal communication). In another German case, the exchange of sulphate ions versus chloride ions resulted in a remarkable improvement of the pitting corrosion behaviour of copper (Kruse 1987).

As mentioned earlier, a moderate increase of the bicarbonate level in a chloride/sulphate electrolyte led to a considerable decrease in the manifestations of copper corrosion in laboratory experiments (Wagner et al. 1996e).

Conclusions

Several factors influence the susceptibility of copper to MIC: commissioning, design and operating conditions; the chemical composition of the water and the relevant biological activity. Field experience and theory showed that a combination of methods should be used to protect existing copper installations. In summary, water chemistry seems to be a major influencing parameter for the described corrosion problems. Modulating alkalinity of the potable water whilst optimising the chloride/sulphate ratio is considered as a most promising preventive measure to overcome the described problems.

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Influence of Plumbing Materials on Biofilm Formation and Growth of *Legionella pneumophila* in Potable Water Systems

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A two-stage chemostat model of a plumbing system was developed, with tap water as the sole nutrient source. The model system was populated with a naturally occurring inoculum derived from an outbreak of Legionnaires' disease and containing *Legionella pneumophila* along with associated bacteria and protozoa. The model system was used to develop biofilms on the surfaces of a range of eight plumbing materials under controlled, reproducible conditions. The materials varied in their abilities to support biofilm development and the growth of *L. pneumophila*. Elastomeric surfaces had the most abundant biofilms supporting the highest numbers of *L. pneumophila* CFU; this was attributed to the leaching of nutrients for bacterial growth from the materials. No direct relationship existed between total biofouling and the numbers of *L. pneumophila* CFU.

The colonization of plumbing systems by *Legionella pneumophila* is well documented (6, 10, 11, 31), and the growth of the organism in potable water supplies may lead to human infection (2, 4, 16, 26, 30). The bacterium is incapable of growth in sterile water because it requires nutrients to be supplied by other microorganisms, including bacteria (35), amoebae (25), and cyanobacteria (29). In several investigations, *L. pneumophila* was detected in biofilms on the surface of the plumbing fixtures, including shower heads, spouts, and valve seats (4, 37). The persistence of the pathogen in treated water systems has been attributed to the survival of the organism within biofilms on rubber materials in taps and showers (7).

Before plumbing materials are permitted for use in the United Kingdom, their influence on water quality is examined according British Standard BS 6920 (1). This ensures that the material does not contribute to poor water quality by producing unacceptable taste or odors, by releasing chemicals, or by encouraging microbial growth. The procedure uses a natural river water inoculum and a water sample of known chemistry. Bacterial growth is determined indirectly by measuring oxygen consumption. The test is simple and rapid and has undoubtedly contributed to improving water quality. However, the method does not provide information on the rate of biofilm formation on different plumbing materials or indicate which organisms are present within the biofilm. Of particular interest are the proportions of pathogens that occur in biofilms developing on surfaces. Natural latex is no longer used in plumbing systems because it provides nutrients for the growth of microorganisms. Therefore, this material was used as a positive control surface for biofouling; however, it was not known whether the surface would encourage the growth of pathogens, including *L. pneumophila*.

There are a number of examples of how different materials affect the biofilm growth of different microorganisms. The hydrophobic-hydrophilic nature of the surfaces is known to affect the attachment of aquatic bacterial species to surfaces (17). Biofilm may be encouraged to develop on the surface of a plumbing material if that material is able to supply nutrient for bacterial growth, as is the case for latex (5). Plastic surfaces are known to leach metal ions at a sufficiently low level to prevent a toxic effect but could possibly contribute cations essential for enzyme function. Bacterial cells directly in contact with the materials are more likely to take up the ions. The plasticizers and other components of the pipe material may also be directly utilizable by some of the community of microorganisms in the biofilm and so contribute to the consortium as a whole. It is not understood how these materials (including latex) affect the growth of *L. pneumophila* in biofilms.

Previous work has suggested that surfaces of copper were poorly colonized by cultures of *L. pneumophila* in a recirculating model with tap water as the nutrient source but that rubber components were heavily colonized, forming a dense biofilm with large numbers of *L. pneumophila* CFU (27). The model system recirculated the water for 4 months prior to observation of the *L. pneumophila* in the biofilm by fluorescein-labelled monoclonal antibodies. Other work has indicated that there is little difference in the degrees of colonization of plumbing materials (39); however, the study evaluated the colonization of materials by using pure cultures of *L. pneumophila* in a 10% algal extract solution which was recirculated for 14 days. Use of a more realistic model and enumeration of the total bacterial flora and *L. pneumophila* by culture showed that copper was inhibitory to the colonization and growth of *L. pneumophila* (38).

A two-stage biofilm model system was developed from that used previously (38), to study in greater detail the possible influences of eight different plumbing materials on biofilm development and the growth of *L. pneumophila*. The system was designed to study growth under conditions realistically simulating those encountered within potable water systems.

MATERIALS AND METHODS

Two-stage biofilm model. The growth medium for the model system was from one domestic potable cold water supply and

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was filter sterilized by using a 0.2-μm-nominal-pore-size nylon filter. Water sterilized in this way was shown to remain chemically unchanged (8). The inoculum was sludge from the bottom of a calorifier implicated in an outbreak of Legionnaires' disease and contained an indigenous population of *L. pneumophila* along with a diverse range of bacteria, amoebae, and protozoa. To avoid artificial selection of microorganisms for inoculation, microorganisms were not subcultured prior to inclusion in the model. The model system was inoculated at the onset of the work and operated continuously until all experiments had been completed.

The model, which was briefly described previously (23), consisted of two glass vessels linked in series. The first vessel simulated a storage or holding tank, and the second vessel (which was constantly fed by the first) modelled the distribution system. In order to maintain the reproducibility of the model system, the inoculum and conditions within the first vessel remained unaltered throughout the experiment and no plumbing materials were introduced into this vessel. This vessel was used to supply a constant inoculum of microorganisms for the colonization of the various materials. Biofilms were generated in the second vessel by inserting 1-cm^2 coupons of sterile plumbing materials into the culture suspended on titanium wire. The only materials used in the construction of the model were glass, silicon, and titanium to prevent leaching of iron, manganese, and chromium, etc., from metals into the system.

The first vessel had a retention volume of 500 ml, and the flow rate of sterile water into the vessel resulted in a dilution rate of 0.05 h^{-1}. When the retention volume was exceeded, the effluent was pumped via a weir system into the second vessel. This second vessel was also supplied with additional sterile water to maintain a total dilution rate of 0.2 h^{-1}. The effluent from the second vessel was pumped into a waste collection bottle.

The environmental parameters of the chemostats were controlled and monitored with Anglicon microprocessor control units (Brighton Systems, Hove, United Kingdom) linked to a personal computer. The temperature of the vessels was maintained at 30 ± 0.1°C by using proportional integral derivative controllers and warmed by an external heater mat. The temperature was measured with a glass temperature probe inserted into the aqueous phase of the vessel. The glass galvanic oxygen electrode was temperature compensated, and the dissolved oxygen tension was maintained at 20% ± 0.5% via proportional control of the stirrer speed (this maintained a fluid velocity of 1 to 2 m s^{-1}). The pH and E_h of the vessels were monitored throughout the experiments.

Generation of biofilms. Sections of each of the plumbing material tubes were cut open to make coupons. The tube was cut into sections with an inside area of 1 cm^2, and a 1-mm-diameter hole was drilled so that the coupons could be suspended from titanium wires. Materials that are commonly used in the construction of water systems were selected. The materials were all commercially available and were obtained from a local plumbing stockist. These included sections of the elastomeric materials, natural latex and ethylene-propylene copolymer. The plastic tubing that was used was polypropylene, polyethylene, chlorinated polyvinyl chloride (PVCc), and unplasticized polyvinyl chloride (PVCu). The test materials were cleaned with acetone to remove any oil or dirt and were then suspended on the wire beside a control glass surface. The tile assemblies were placed in bottles of water and heat sterilized by autoclaving.

The model system was run continuously for the duration of the work, and the colonization of each material was tested in series in the second vessel of the model system. Each chemostat experiment had plumbing materials of only one type. For each of the experiments, the material to be colonized and the control glass surface were aseptically immersed into the aqueous phase of the chemostat culture at day 0. The tiles were removed after 1, 4, 7, 14, 21, and 28 days from the onset of the experiment. Biofilms were aseptically removed from the curved, inside surface of the pipe or glass tile with a dental probe. The biofilm was resuspended in 1.0 ml of sterile water and vortexed for 30 s to disperse the microorganisms.

Microbiological assessment of biofilm and planktonic samples. The resuspended biofilm or planktonic sample was serially diluted into sterile water, and then 0.1-ml amounts were inoculated onto various selective and nonselective agar media. Heterotrophic non-legionella species populations were enumerated by using a nonselective, low-nutrient R2A medium (21) to avoid substrate shock. Buffered charcoal yeast extract (BCYE) agar (20) was used to culture more fastidious bacteria, including legionellae. BCYE medium was supplemented with glycine, vancomycin, polymixin, and cycloheximide to produce GVPC agar, a selective medium for legionellae (9). All plates were incubated at 30°C for 7 days prior to counting of the CFU on the agar. Those colonies on BCYE and GVPC agars that showed the characteristic ground-glass appearance of *L. pneumophila* were subcultured onto BCYE and BCYE lacking cysteine. Organisms were presumptively identified as *L. pneumophila* if they were unable to grow in the absence of cysteine but capable of growth on BCYE.

One plate of each medium which contained 30 to 100 colonies in which colony morphology could be distinguished was selected for evaluation of population profiles for each biofilm at each age. Each colony type was subcultured onto double-strength R2A (R3A) (21) or BCYE three successive times before inoculation into the appropriate API (bioMerieux, Basingstoke, United Kingdom) and Biolog (Hayward, Calif.) bacterial identification systems.

Statistical analysis of data. The colonization levels of materials were compared by using the Wilcoxon matched-pair, signed-rank test for this type of correlated, nonparametric data. The power efficiency of this test relative to the *t* test for correlated means is reported to be 95.5% (18). Calculations were performed with "Statistics," a computer package by K. B. Smith (27a). Each plotted datum point was the mean value of the number of CFU occurring on two biofilms, each plated in duplicate onto each medium.

Microscopy of samples. For scanning electron microscopy (SEM), the tiles of plumbing materials were removed from the chemostat and gently rinsed in sterile water to remove planktonic bacteria. The biofilm was fixed and stained with 1% (wt/vol) osmium tetroxide in 0.1 mM phosphate buffer at pH 6.9 for 2 h and then dehydrated through an alcohol series. Tiles were mounted on 0.5-in. (~1.3-cm) SEM specimen stubs by using a high-conductivity silver paint (Acheson Colloid Company, Prince Rock, Plymouth, United Kingdom). Specimens were coated with a 20-nm layer of gold in an Edwards 12E6 vacuum coating unit and then examined in a Cambridge Stereoscan S2A SEM operated at 10 kV accelerating voltage.

Biofilms were also examined by light microscopy and differential interference microscopy to determine the structure and depth of biofilms as described previously (24).

Leaching of nutrients from materials. The extent of nutrient release from the materials was assessed by total organic carbon (TOC) analysis of the water. Sections (3 cm^2 in surface area) of the sterile plastic material were inserted into 10 ml of sterile distilled water and shaken for 3 days to allow nutrients to be released into the water. The negative control was a sterile glass

TABLE 1. Comparison of the numbers of microorganisms occurring in the biofilm and planktonic phases of the model system

Organism(s)	Material	No. of microorganisms (mean)[a] in:		
		Biofilm (CFU cm^{-2})	Planktonic phase (CFU ml^{-1})	Biofilm/planktonic ratio
Total flora	Stainless steel	2.13×10^5	2.23×10^5	0.96
	Polypropylene	4.54×10^5	4.48×10^5	1.01
	PVCc	5.14×10^5	6.20×10^5	0.83
	PVCu	6.23×10^5	3.22×10^4	10.35
	Mild steel	1.69×10^6	2.23×10^5	7.58
	Polyethylene	2.75×10^6	1.62×10^6	1.70
	Ethylene-propylene	1.08×10^7	7.45×10^5	14.47
	Latex	5.50×10^7	1.87×10^6	29.4
Legionellae	Stainless steel	1.03×10^4	5.30×10^3	1.94
	Polypropylene	2.10×10^4	3.42×10^3	6.14
	PVCc	2.24×10^4	1.23×10^3	18.21
	PVCu	7.75×10^3	1.06×10^3	7.31
	Mild steel	2.06×10^4	5.30×10^3	3.89
	Polyethylene	6.76×10^3	6.68×10^3	1.01
	Ethylene-propylene	1.44×10^5	1.80×10^3	80
	Latex	2.20×10^5	1.38×10^4	12.2

[a] Means were calculated from all values determined over 1 to 28 days.

coupon which was treated as described previously for the test materials. TOC analysis was determined with a Beckman model 915B Tocamaster TOC computational system. For the determination of total carbon (TC) the syringe-injected liquid sample entered a combustion tube containing oxidizing catalyst maintained at 950°C. The sample carbon was completely oxidized to CO_2, and any water vapor was condensed and removed at the ambient dew point. The resultant sample cloud was conveyed by a continuous flow of dry, carbon-free carrier gas to the integral infrared analyzer for the detection of CO_2.

For the detection of inorganic carbon (IC), the sample was injected into the reaction tube containing a quartz chip wetted with phosphoric acid maintained at 155°C. IC reacted with the acid to liberate CO_2, which was carried via the carrier gas to the infrared analyzer. The TOC was determined by the difference of the TC and the IC. The standards for the calibration of the TC were 100, 50, and 0 mg of sodium bicarbonate per liter. For IC, the standards were 100, 50, and 0 mg of potassium biphthalate per liter. The injection volumes for both TC and IC were 50 μl. The standards and samples were injected in triplicate, and mean values were calculated.

RESULTS AND DISCUSSION

Planktonic microorganisms. The planktonic flora in the model system contained a total microbial flora of 10^4 to 10^6 CFU ml^{-1}, with numbers of *L. pneumophila* CFU between 10^3 and 10^4 ml^{-1} (Table 1) in most experiments. One exception to this was observed following the inclusion of latex and ethylene-propylene in the culture. A slight increase in the total numbers of microorganisms was observed on both occasions, with concomitant reductions in the numbers of *L. pneumophila* CFU. The diversity of microorganisms in the planktonic phase was maintained during the experiments, with all of the organisms that were present initially being maintained in culture (data not shown).

Biofouling of plumbing materials. All of the materials were rapidly colonized by microorganisms following insertion into the aquatic model system; the lowest concentration of flora was 5.24×10^4 CFU cm^{-2} on the stainless steel surface after only 24 h (Fig. 1). Elastomeric surfaces (latex and ethylene-propylene) were the most rapidly biofouled and supported a population of $>1.0 \times 10^7$ CFU cm^{-2} after an equivalent period. Stainless steel and the plastic materials supported biofilms which contained 10^5 to 10^6 CFU cm^{-2} after 24 h.

Latex and ethylene-propylene remained the most heavily colonized materials for the duration of the experiment, with maximum numbers of 8.9×10^7 and 2.9×10^7 CFU cm^{-2}, respectively (Table 2). These were found to be significantly more colonized than the other materials tested (with a confidence limit of 95%). Stainless steel supported the smallest numbers of microorganisms in biofilms compared with the other materials, with a maximum recoverable microflora of 6.45×10^5 CFU cm^{-2}. In contrast, mild steel (which was observed to rust) supported a biofilm which contained up to 4.95×10^6 CFU cm^{-2}.

Of the plastic materials, polyethylene appeared to be most heavily colonized, with a recoverable microflora of 1.3×10^7 CFU cm^{-2} after 4 days in the model system. The total numbers of microorganisms on the surface of the other plastics remained between 10^5 and 10^6 CFU cm^{-2} for the duration of the experiment, with polypropylene, PVCc, and PVCu more heavily colonized in ascending order.

For the duration of the experiments, the elastomeric surfaces supported higher numbers of microorganisms than the control glass surfaces. The glass surface supported less than 1.4% of the microorganisms occurring on the latex surface and less than 7.1% of the microorganisms occurring on the ethylene-propylene surface. Polypropylene and PVCc surfaces supported higher numbers of microorganisms than the glass control surfaces throughout colonization. Although the initial colonization of polyethylene and PVCu was more rapid than colonization of the control glass surface, this was not maintained and there was no significant difference in the colonization levels of the materials and the control glass surfaces over the remaining 27 days.

All of the material surfaces (with the exception of polyethylene and PVCu) supported significantly higher total floras than the control glass surfaces (with a 95% confidence limit). The polyethylene surface had a two-tailed probability of equalling or exceeding the sample statistic of the *t* distribution of 6%, and the PVCu had a two-tailed probability of equalling or exceeding a *t* distribution statistic of 9%.

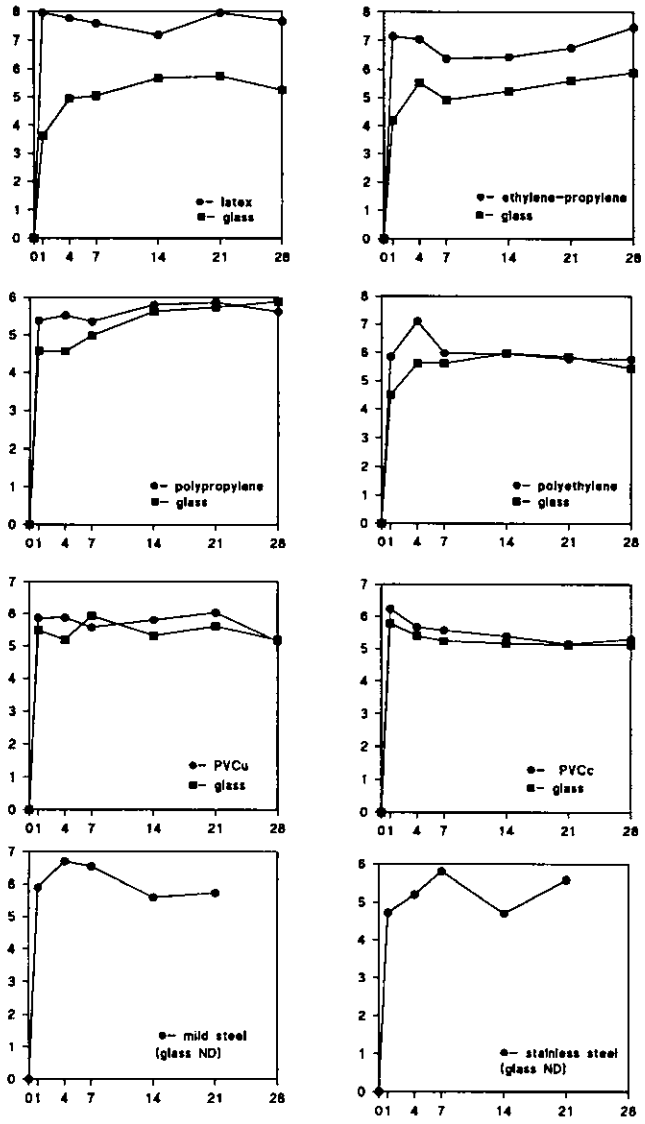


FIG. 1. Colonization by nonlegionella species of plumbing materials and control glass surfaces at 30°C in tap water containing a mixed population of microorganisms. *x* axis, age of biofilm (in days); *y* axis, nonlegionella species $\log_{10}$ CFU cm $^{-2}$. In all cases, the standard deviation is less than $\log_{10}$ 0.15 of the plotted mean datum points. ND, not done.

Inclusion of *L. pneumophila* into biofilms. *L. pneumophila* was found in the biofilms on all of the surfaces of all of the materials after only 24 h of exposure to the water containing the pathogen (Fig. 2). The numbers of *L. pneumophila* CFU which became included in the biofilms on the surface of the materials were unrelated to the total number of microorganisms present (Table 1). The biofilms on the elastomeric materials were found to contain the largest numbers of *L. pneumophila* for the duration of the experiment, with over 2×10^6 CFU cm $^{-2}$. However, *L. pneumophila* accounted for a maximum of only 3.5% of the total bacterial community on the elastomeric surfaces. In contrast, several materials had a higher proportion of *L. pneumophila* within the biofilm, and most notably large numbers of the pathogen occurred in the biofilm on PVCc after 7 days.

TABLE 2. Comparison of materials for their ability to support biofilm development and colonization by *L. pneumophila*

Material	Colonization (mean CFU cm $^{-2}$)		Colonization ratio[a]	
	Total flora	*L. pneumophila*	Total flora	*L. pneumophila*
Glass	1.90×10^5	1.70×10^3	1	1
Stainless steel	2.13×10^5	1.03×10^4	1.1	6.1
Polypropylene	4.54×10^5	2.10×10^4	2.4	12.4
PVCc	5.14×10^5	2.24×10^4	2.7	13.1
PVCu	6.23×10^5	7.75×10^3	3.3	4.6
Mild steel	1.69×10^6	2.06×10^4	8.9	12.1
Polyethylene	2.75×10^6	6.76×10^3	14.5	4.0
Ethylene-propylene	1.08×10^7	1.44×10^5	56.8	84.7
Latex	5.50×10^7	2.20×10^5	289	129

[a] The colonization ratio is the number of CFU cm $^{-2}$ of the total flora or legionellae recovered from each material compared with that on glass.

The numbers of *L. pneumophila* CFU varied in the biofilms which developed on the plastic surfaces. Polypropylene supported a biofilm containing up to 6.6×10^4 CFU of *L. pneumophila* cm $^{-2}$, which accounted for 10.3% of the total biofilm flora. Polyethylene contained fewer *L. pneumophila* CFU, with a maximum of 2.3×10^4 CFU cm $^{-2}$, and these accounted for 4% of the total biofilm flora. The PVCu material supported a biofilm with a maximum of 1.0×10^4 CFU of *L. pneumophila* cm $^{-2}$ in the biofilm, which represented only 1% of the microorganisms. In contrast, the PVCc material supported a biofilm which contained 7.8×10^4 CFU of *L. pneumophila* cm $^{-2}$ and accounted for as much as 15% of the total biofilm flora. The metal surfaces contained a high proportion of *L. pneumophila* within biofilms on their surfaces, with as much as 11% of the population on stainless steel and 31% of the population on mild steel being *L. pneumophila*.

The biofilms which formed on the plumbing materials were consistently found to contain more *L. pneumophila* than those on the control glass surfaces. Without exception, the materials tested had significantly larger numbers of *L. pneumophila* CFU in their biofilms than the glass surfaces, with a 95% confidence limit. The glass surfaces were found to contain less than half of the number of *L. pneumophila* CFU occurring on the plumbing material surfaces.

Comparison of colonization levels of different plumbing materials with levels on glass. When mean values were compared, all of the plumbing materials were found to have higher total colonization levels and larger numbers of *L. pneumophila* CFU than glass (immersed into the model system with no other materials) (Table 2). The elastomeric materials supported the largest numbers of total flora and *L. pneumophila* CFU, but the increase in the total biofouling was greater than the increase in numbers of *L. pneumophila* CFU. The plastics supported increases in biofilm floras from 2.4 to 14.5 times that occurring on the glass surfaces. Similarly to the previous planktonic data, the numbers of *L. pneumophila* CFU in the biofilms on the plastic surface were not directly related to the increases in total flora; for example, PVCc had a threefold increase in total flora compared with glass but a disproportionate increase in the *L. pneumophila*, which was 13 times greater. Stainless steel was the least colonized of the plumbing materials, but increased the numbers of *L. pneumophila* CFU within the biofilm above those of the PVCu and polyethylene despite the fact that they supported greater total floras.

The numbers of *L. pneumophila* CFU on the surface of the mild steel coupons were greater than those on stainless steel.

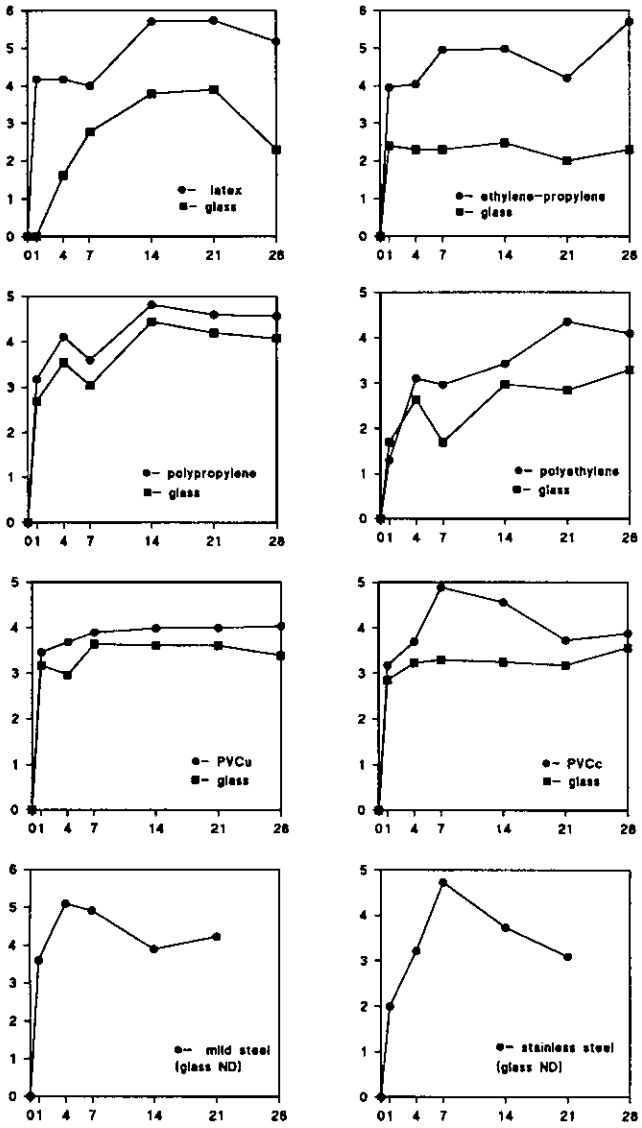


FIG. 2. Colonization by *L. pneumophila* of plumbing materials and control glass surfaces at 30°C in tap water containing a mixed population of microorganisms. *x* axis, age of biofilms (in days); *y* axis, *L. pneumophila* $\log_{10}$ CFU cm^{-2}. In all cases, the standard deviation is less than $\log_{10}$ 0.15 of the plotted mean datum points. ND, not done.

This could possibly be due to the increased availability of iron due to the corroding of the mild steel. Iron is an essential growth nutrient and is usually of limited availability in aquatic systems (22).

Composition of biofilm and planktonic floras. The mean total biofilm floras and mean numbers of *L. pneumophila* CFU in the planktonic phases were compared (Table 1). In most cases, the biofilm was found to contain greater numbers per unit of area than occurred in the planktonic phase per unit of volume. The greatest ratios of biofilm to planktonic microflora occurred in the presence of PVCu, mild steel, ethylene-propylene, and latex. By contrast, the greatest ratios of biofilm-associated to planktonic *L. pneumophila* occurred in the presence of polypropylene, PVCc, PVCu, ethylene-propylene, and latex.

The data suggest that *L. pneumophila* can often be detected in greater numbers in the biofilm than in the planktonic phase, although this varies with time and the material sampled. The determination of water quality in aquatic systems often involves only sampling of water, partially because of the ease of access and processing. However, more accurate determination would be possible if biofilms were also sampled, particularly in those systems with large surface area-to-volume ratios (e.g., cooling towers).

Microorganisms present on material surfaces after 24 h. The microorganisms that colonized the surfaces of the material surfaces varied in species composition (Table 3). After 24 h, the community on the mild steel was dominated by pseudomonads which accounted for 52% of the flora; the principal species were *Pseudomonas testosteroni* and *Pseudomonas paucimobilis*. Other organisms that occurred in large numbers on this material included *Methylobacterium*, *Acinetobacter*, and *Klebsiella* spp. The pseudomonads accounted for 61% of the species present after 24 h on the stainless steel surface, with *P. paucimobilis*, *P. testosteroni*, *Pseudomonas stutzeri* and *Pseudomonas vesicularis* being present. The single most abundant microorganism was an *Acinetobacter* sp. (2.6×10^4 CFU cm^{-2}).

A diverse range of pseudomonads was present on the PVCc surface after 24 h, including *Pseudomonas acidovorans*, *Pseudomonas mendocina*, *P. paucimobilis*, *P. stutzeri*, and *Pseudomonas xylesoxidans*. Actinomycetes were also present. Initial colonization of the polyethylene was also predominantly by pseudomonads. The principal species were *Pseudomonas fluorescens*, *P. acidovorans*, and an *Acinetobacter* sp. In contrast, pseudomonads and the other gram-negative microorganisms occurred in approximately equal proportions in the biofilm forming on the polypropylene. The most abundant organisms were *Pseudomonas diminuta* and an *Acinetobacter* sp., with *P. fluorescens*, *P. mendocina*, an *Alcaligenes* sp., a *Flavobacterium* sp., a *Methylobacterium* sp., and actinomycetes representing a small proportion of the biofilm flora. Biofilms developing on the PVCu surface were composed of a mixture of gram-negative microorganisms (principally *P. acidovorans* and *P. vesicularis*) and of actinomycetes.

The latex surface was initially colonized by a mixed flora, including *P. xylesoxidans*, an *Acinetobacter* sp., and actinomycetes. The community of microorganisms on ethylene-propylene was initially dominated by *Acinetobacter*, *Aeromonas*, *Flavobacterium*, and *Alcaligenes* spp. Approximately 15% of the biofilm was composed of pseudomonads, with *P. diminuta* and *Pseudomonas maltophilia* occurring in equal numbers.

Communities of microorganisms present after 21 days on material surfaces. Pseudomonads continued to dominate in the community developed on the mild steel surfaces, representing 62% of the total flora. However, *Pseudomonas aeruginosa* and *P. vesicularis* replaced *P. mendocina*, *P. testosteroni*, and *Klebsiella* spp. that had previously been on the surface (Table 4). A similar proportion of pseudomonads was present on the surface of stainless steel, where an *Aspergillus* sp. and an *Alcaligenes* sp. replaced a *Flavobacterium* sp. and *P. mendocina* within the community.

The diversity of microorganisms within the biofilm on latex was increased by the addition of *P. paucimobilis* and *P. stutzeri* to the surface; however, pseudomonads accounted for only 11% of the flora. A similarly low proportion of the flora on ethylene-propylene was composed of pseudomonads, and the mature biofilm community included large numbers of *Aspergillus* sp. cells and actinomycetes. In contrast, pseudomonads composed between 37 and 49% of the biofilm communities on the plastic surfaces.

TABLE 3. Microorganisms on the surface of various plumbing materials after 24 h

Organism	Microorganism population[a] (CFU cm^{-2}) on:							
	Mild steel	Stainless steel	Latex	Ethylene-propylene	Polypropylene	Polyethylene	PVCu	PVCc
L. pneumophila	3.95	0.1	15	9	1.5	0.5	2.9	1.5
P. aeruginosa					1.9	260		
P. acidovorans							37	880
P. diminuta				1,000	22			
P. fluorescens					26	380	1	
P. maltophilia	80	10	8,000	100		20	3	
P. mendocina	60	25	4,000	3	3		4.7	210
P. paucimobilis	100	10		1,000		0.2	1.2	300
P. stutzeri	90	1						
P. testosteroni	410	12	9,000		1	80	2	150
P. vesicularis						6.2	59	
P. xylosoxidans			36,000					310
Actinomycetes sp.	10	6	34,000		1		19	200
Aeromonas sp.				8,000				
Alcaligenes sp.	70			2,000	4	0.2		
Flavobacterium sp.	40	7	800	1,000	3	0.3	0.2	290
Methylobacterium sp.	110	4			3		5	
Klebsiella sp.	130							
Acinetobacter sp.	300	26	40,000	10,000	17	440	0.6	

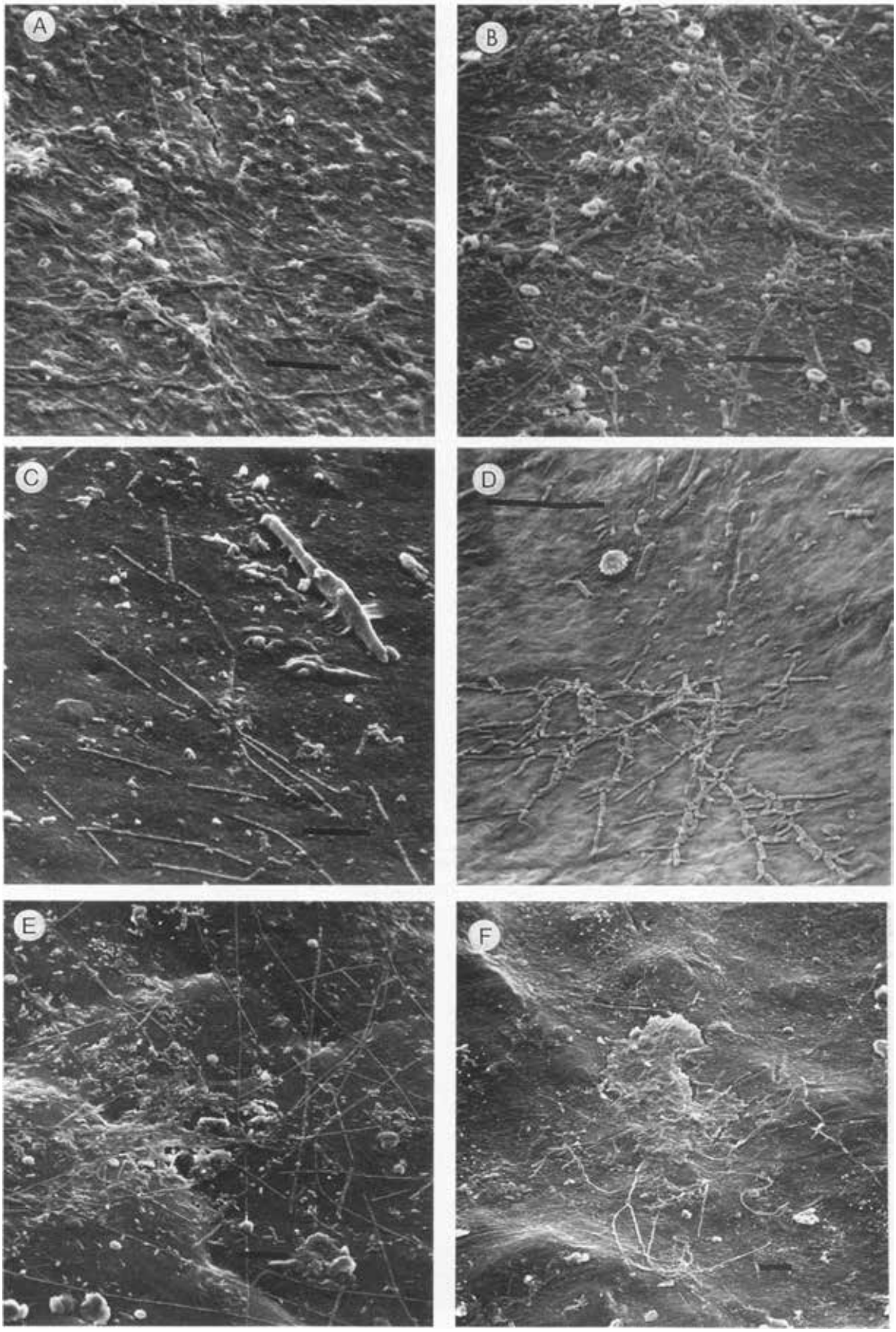
[a] Numbers of non-*Legionella* populations are represented as a sum of the CFU cm^{-2} occurring on R2A, BCYE, and GVPC media. *L. pneumophila* populations are represented as the mean of those CFU cm^{-2} occurring on BCYE and GVPC media.

Microscopy of biofilms. Latex and ethylene-propylene were completely covered with a thick layer of biofilm after only 24 h of immersion in the chemostat culture (Fig. 3A and B). The biofilm could be observed without magnification and varied in depth across the surface but was at least 200 μm deep. The biofilm was composed of a range of microorganisms including bacteria of diverse morphologies and amoebae, which were embedded in an extracellular matrix. Cracks in the biofilm were evident following preparation, and the substratum could be observed beneath the biofilm in some regions. In results similar to those for recovery of microorganisms, biofilms on the plastic surfaces appeared to form less rapidly than those on the elastomeric materials. Microorganisms on the plastics initially occurred in small microcolonies on the surface, and these developed into denser areas of biofilm, particularly in crevices on the material surfaces (Fig. 3E and F). As biofilms matured, the space between the microcolonies was reduced and by day 28 most plastic surfaces were covered in a biofilm; however, channels (where water and nutrients could flow) were still evident by the SEM procedure used here or the light microscopy procedure described by Rogers and Keevil (24). Grazing amoebae and other protozoa could be observed in some samples (Fig. 3C and D). Mild steel was heavily corroded after 24 h of immersion in the culture, and few microorganisms could be observed among the corrosion products (Fig. 3G). The accumulation of debris on the surface of stainless steel

TABLE 4. Composition of communities of microorganisms on the surface of various plumbing materials after 21 days

Organism	Microorganism population[a] (CFU cm^{-2}) on:							
	Mild steel	Stainless steel	Latex	Ethylene-propylene	Polypropylene	Polyethylene	PVCu	PVCc
L. pneumophila	17	13	150	500	37	13	11	7.9
P. aeruginosa	30							
P. acidovorans						40		11
P. diminuta						2		
P. fluorescens				1,000				3
P. maltophilia	10	11	3,000			10	10	
P. mendocina			13			40	0.01	
P. paucimobilis	30	36	5,000	1,600	790	170	140	36
P. stutzeri	140	70	2,000					0.1
P. testosteroni		180				20		8
P. vesicularis	250							3
P. xylosoxidans						7		40
Actinomycetes sp.	130	2	7,000	8,000		9	0.01	2.8
Aeromonas sp.			6,000					
Alcaligenes sp.	10	10			320	80		30
Flavobacterium sp.	41		15,000	2,400		0.2	90	50
Methylobacterium sp.	20	150			140	30	60	23
Klebsiella sp.			31,000					
Acinetobacter sp.	70	39	22,000	3,100	400	180	40	60
Aspergillus sp.		0.2		4,400				

[a] Numbers of non-*Legionella* populations are represented as a sum of the CFU cm^{-2} occurring on R2A, BCYE, and GVPC media. *L. pneumophila* populations are represented as the mean of those CFU cm^{-2} occurring on BCYE and GVPC media.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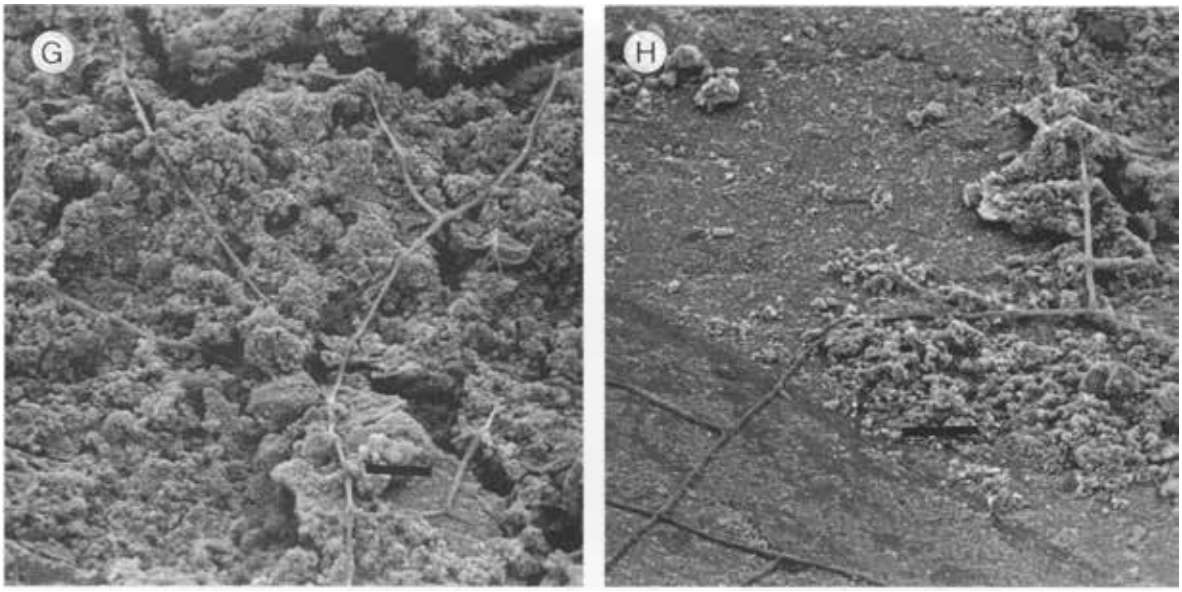

FIG. 3. SEM of biofilms forming on plumbing material surfaces showed that latex (A) and ethylene-propylene (B) were very heavily colonized with thick biofilms which covered the whole material surfaces. The plastic materials were less heavily colonized, but some areas of the polypropylene (E) and polyethylene (F) surfaces were found to have regions where thicker biofilms formed. Amoebae could be observed on the surface of PVCu (D), and other predatory microorganisms were evident on PVCc (C). Some microorganisms were observed on stainless steel (H) and mild steel (G) surfaces despite the accumulation of corrosion products. Bar, 10 μm.

also made observation difficult, but attached growth could be discerned (Fig. 3H).

Amoebae and other protozoa on biofilms. Both resting and motile rotifers which were present were identified as *Rotari neptunia*. Other protozoa included predatory *Lacrymaria* spp., which are known to ingest amoebae. Amoebae isolated from the culture included *Hartmannella vermiformis*, *Hartmannella cantabrigiensis*, and *Verillifera bacillipedes*, which were kindly identified by T. J. Rowbotham (Public Health Laboratory Service, Leeds).

Leaching of nutrients from material surfaces. Incubation of the materials in water produced elevated levels of TOC with all of the materials (Table 5). The latex, ethylene-propylene, and polyethylene surfaces increased the concentration of organic carbon in excess of 150 mg of C liter^{-1}. Copper and the other plastic materials only slightly increased the amount of TOC in the water.

The plumbing materials examined in this investigation were all found to support biofilms, and all of these biofilms contained *L. pneumophila*. Each of the substrata was colonized by different pioneering species, despite the presence of the same planktonic bacterial community, and the biofilm which developed varied in diversity, abundance, and morphology. Materials colonized under the same environmental conditions are therefore influenced by the supporting material. The most extensive biofilms occurred on the surface of the elastomeric materials, and this was attributed to the leaching of nutrient from the material, which increased the total available nutrient in the system. The greatest numbers of *L. pneumophila* CFU were also detectable in the biofilms developing on the elastomeric materials; however, the biofilms were so extensive that the pathogen formed only a minor component of the biofilm flora. It is evident, however, that the materials could indirectly cause an increase in the numbers of the pathogen to proliferate in the aquatic environment by encouraging biofilm growth on the surface.

TABLE 5. TC leached from materials exposed to water for 3 days

Material in water	TOC (mg liter^{-1})[a]
Glass (control)	2.78 ± 0.4
Copper	4.15 ± 0.17
Polybutylene	4.46 ± 0.15
PVCc	6.02 ± 0.11
PVCu	5.42 ± 0.11
Polypropylene	5.98 ± 1.56
Polyethylene	179 ± 0.82
Ethylene-propylene	157 ± 0.84
Latex	320 ± 19.4
Stainless steel	Not done
Mild steel	Not done

[a] Values are the means of three determinations ± standard deviations.

The plastic surfaces were also capable of supplying some additional nutrient to the bacterial flora, but this was not the major cause of enhanced colonization of the plastic surfaces compared to copper. The plastic materials had crevices and hollows on the surface as a result of their manufacture. These hollows were rapidly colonized, and areas of dense biofilm which eventually extended outwards were formed there. The initial colonization of these areas could be due to the protection from shear forces they gave to the colonizing bacteria.

Growth of *L. pneumophila* can be examined in situ in operating cooling or plumbing systems, but since *L. pneumophila* CFU occur in small, fluctuating numbers and since the conditions within any water system vary widely, comparison of results is difficult (12). Previous work modelling the ecology of *L. pneumophila* has principally been concerned with batch culture in the planktonic phase. This work was important in the use of naturally occurring, mixed populations for the simulation of water environments for the determination of factors influencing growth of *L. pneumophila* (34, 40). However,

problems may be encountered when using batch culture; for example, in studies of *L. pneumophila* in coculture with cyanobacteria, the accumulation of algal products resulted in the elevation of pH and consequently prevented the growth of *L. pneumophila*. The use of a continuous culture model system has overcome some of the drawbacks associated with either sampling naturally occurring communities or batch culture experiments.

The biofilm serves as a focal point where bacterial and protozoal populations interact. The pioneering bacterial population will modify the surface conditions to enable bacterial succession to take place. The resultant biofilm may aid colonization by *L. pneumophila* by supporting bacterial floras that provide essential nutrients (24, 28, 29, 32, 36); by removing high inhibitory concentrations of oxygen by respiration (19) or by encouraging protozoal populations which can act as hosts for the pathogen (13, 14, 25). However, the biofilm (or regions of it) may be inhibitory to *L. pneumophila* if bacterial flora produce extracellular products that inhibit growth directly (3, 15, 32) or encourage a protozoal population that uses *L. pneumophila* as a preferential food source (33). This process of modification of the biofilm flora would be continuing and dynamic until a stable climax community was achieved. The material used in the plumbing system would affect this community by influencing the primary colonizing species and subsequent populations.

The data presented here demonstrate that numbers of *L. pneumophila* CFU cannot be predicted from the total numbers of bacteria present in the biofilms. Since the current British standard (BS 6920) only determines the potential for total microbial growth of a material, it is unsuitable for indicating the potential of a plumbing material to encourage growth of this pathogen. It would be preferable to use water system materials that did not encourage the growth of *L. pneumophila* by supporting bacterial populations in the biofilm which aid the growth of the pathogen. This is particularly so in hospitals, where large numbers of susceptible patients are exposed to water which may be at the optimum temperature for the growth of the pathogen.

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Integration of *Pseudomonas aeruginosa* and *Legionella pneumophila* in drinking water biofilms grown on domestic plumbing materials

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ABSTRACT

Drinking water biofilms were grown on coupons of plumbing materials, including ethylene-propylene-diene-monomer (EPDM) rubber, silane cross-linked polyethylene (PE-X b), electron-ray cross-linked PE (PE-X c) and copper under constant flow-through of cold tap water. After 14 days, the biofilms were spiked with *Pseudomonas aeruginosa*, *Legionella pneumophila* and *Enterobacter nimipressuralis* (10^6 cells/mL each). The test bacteria were environmental isolates from contamination events in drinking water systems. After static incubation for 24 h, water flow was resumed and continued for 4 weeks. Total cell count and heterotrophic plate count (HPC) of biofilms were monitored, and *P. aeruginosa*, *L. pneumophila* and *E. nimipressuralis* were quantified, using standard culture-based methods or culture-independent fluorescence in situ hybridization (FISH). After 14 days total cell counts and HPC values were highest on EPDM followed by the plastic materials and copper. *P. aeruginosa* and *L. pneumophila* became incorporated into drinking water biofilms and were capable to persist in biofilms on EPDM and PE-X materials for several weeks, while copper biofilms were colonized only by *L. pneumophila* in low culturable numbers. *E. nimipressuralis* was not detected in any of the biofilms. Application of the FISH method often yielded orders of magnitude higher levels of *P. aeruginosa* and *L. pneumophila* than culture methods. These observations indicate that drinking water biofilms grown under cold water conditions on domestic plumbing materials, especially EPDM and PE-X in the present study, can be a reservoir for *P. aeruginosa* and *L. pneumophila* that persist in these habitats mostly in a viable but non-culturable state.

Introduction

In drinking water distribution systems, all surfaces in contact with water can be colonized by microorganisms (Kilb et al., 2003; Servais et al., 1995; Wingender and Flemming, 2004). Certain types of plastic and elastomeric materials can promote biofilm formation due to the release of biodegradable compounds providing favourable nutrient conditions for microorganisms (Keevil, 2002; Kilb et al., 2003; Rogers et al., 1994b). It has been estimated that about 95% of all microbial cells present in drinking water distribution systems exist as biofilms on pipe surfaces and only 5% occur in the water phase (Flemming et al., 2002); similarly, in a domestic hot water system, most of the culturable bacteria (72%) were found to be surface-associated (Bagh et al., 2004). Drinking water biofilms are formed predominantly by microorganisms of the autochthonous aquatic microflora without any relevance to human health. However, drinking water biofilms have the potential to harbor opportunistic pathogens which can harm human health, especially in immunocompromised people (Flemming et al., 2002; Keevil, 2002). Once integrated in a drinking water biofilm, these organisms are protected from external stresses such as the action of disinfectants and can thus persist and possibly multiply inside the biofilm. Contamination of drinking water occurs when opportunistic pathogens are released from a biofilm as a consequence of physical disturbance or active detachment of infectious cells, which then pose a potential threat to human health (Flemming et al., 2002; Szewzyk et al., 2000).

Important opportunistic pathogens which can be involved in biofilm-associated contamination of domestic plumbing systems are *Pseudomonas aeruginosa* and *Legionella pneumophila* (Eboigbodin et al., 2008; Keevil, 2002). *P. aeruginosa* appears sporadically in drinking water distribution systems, for example as a consequence of contamination during construction works (Clark et al., 1982; Hambsch et al., 2004), but these bacteria seem to occur at a higher frequency in domestic plumbing systems compared to water mains (Wingender et al., 2009). In drinking water biofilms, *P. aeruginosa* has been observed to be occasionally present (Emtiazi et al., 2004; Kilb et al., 2003; Lee and Kim, 2003). The occurrence of *L. pneumophila* has been associated with biofilms in warm water plumbing systems, where the bacteria persist and can replicate in association with free-living protozoa (Lau and Ashbolt, 2009). Growth of *L. pneumophila* occurs between 25 °C and 45 °C. How-

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ever, there are indications that *L. pneumophila* can also survive at lower temperatures in drinking water environments. Thus, the persistence of *L. pneumophila* in drinking water biofilms cultivated at 15 °C or 20 °C has been reported (Gião et al., 2009; Lehtola et al., 2007; Rogers et al., 1994a). Coliform bacteria, which also include opportunistic pathogens such as certain *Citrobacter*, *Enterobacter* and *Klebsiella* species, are occasional contaminants of drinking water distribution systems and have been found in the biofilms on pipe walls and rubber-coated valves in these systems (Kilb et al., 2003; LeChevallier et al., 1987; Wingender and Flemming, 2004; Feuerpfeil et al., 2009). However, their distribution and hygienic relevance in domestic plumbing systems is largely unknown.

The detection of opportunistic bacteria in drinking water biofilms has usually been performed by methods based on the culturability of the organisms. However, bacteria may enter a viable but non-culturable (VBNC) state as a response to some form of environmental stress (Oliver, 2005). In the VBNC state the bacteria fail to grow on routine bacteriological media, but they are still alive and typically demonstrate low levels of metabolic activity. Viability markers of VBNC cells may be respiratory activity, cytoplasmic membrane integrity or the presence of ribosomes detected by fluorescence in situ hybridization (FISH) using oligonucleotide probes targeted at specific sequences of 16S rRNA molecules. Oliver (2005) listed more than 60 bacterial species which have been described to be capable of entering the VBNC state, including *P. aeruginosa*, *L. pneumophila* and coliform species. Investigations of the VBNC state are usually performed using planktonic cells, so it is largely unknown if the VBNC state can also be induced in biofilm environments.

The effect of pipe materials on biofilm formation as well as on the persistence of pathogens in biofilms has mainly been studied on materials which make up drinking water distribution systems, while domestic plumbing materials that usually differ from those of distribution systems have been considered less frequently (Eboigbodin et al., 2008; Rogers et al., 1994a, 1994b). Common plumbing materials are copper and plastics, but other material types such as elastomers can also be found as components of plumbing systems (WHO, 2006).

The aim of the present study was to investigate the possibility that the integration and persistence of *P. aeruginosa*, *L. pneumophila* and the coliform species *Enterobacter nimipressuralis* in pre-established drinking water biofilms is influenced by the type of plumbing material. The focus was on copper, plastic and elastomeric materials that occur as relevant components of plumbing systems in Germany. The fate of the bacteria introduced into the biofilms was traced by both cultural methods and the culture-independent FISH technique in order to recognize a possible VBNC state of the target organisms on the different plumbing materials.

Materials and methods

Bacterial strains

P. aeruginosa AdS was a water isolate from an automatic shut-off valve of a shower in a plumbing system of a school building. Identification was performed, using the API 20 NE system (bioMérieux) and GN Microplates (Biolog) according to the manufacturer's instructions. *L. pneumophila* AdS (serogroup 1) was a biofilm isolate from the same automatic shut-off valve. Species and serogroup determination of *L. pneumophila* was performed, using a commercially available latex agglutination test kit (Oxoid). Species identity of both *P. aeruginosa* AdS and *L. pneumophila* AdS was confirmed by 16S rDNA sequencing. *E. nimipressuralis* 9827 clone A was isolated from an elevated tank of a drinking water supply system; the isolate was kindly supplied by Prof. Exner, University of Bonn, Germany.

Plumbing materials

Four different materials were employed: copper, silane cross-linked polyethylene (PE-X b), electron-ray cross-linked polyethylene (PE-X c) and ethylene-propylene-diene-monomer (EPDM) rubber. The PE-X b, PE-X c and EPDM fulfilled the physical and chemical specifications of German recommendations for plastic or rubber materials (Anonymous, 1977, 1985) as well as the microbiological specifications of the German Gas and Water Association (Anonymous, 2007) as a prerequisite for their use in contact with drinking water. The materials were employed in the form of coupons (26 mm × 76 mm), which were treated with 70% (v/v) ethanol for 10 min, washed in deionized water and air-dried for 24 h before use.

Preparation of bacteria

For cultivation of *P. aeruginosa* AdS or *E. nimipressuralis* 9827 clone A, 20 mL of Lenox broth (per L: 10 g tryptone, 5 g NaCl, 5 g yeast extract, pH 7.0) in a 100-mL Erlenmeyer flask were inoculated with a single colony pre-grown on nutrient agar (Merck) at 36 °C for 24 h, and the culture was incubated at room temperature (approximately 23 °C) with shaking at 180 rpm for 24 h. For cultivation of *L. pneumophila* AdS, 20 mL of yeast extract broth (Ristroph et al., 1980) were inoculated with a single colony pre-grown on BCYEα agar (Oxoid) at 36 °C for 72 h, and the culture was incubated at 36 °C with shaking at 180 rpm for 24 h. Bacteria from the liquid cultures were harvested by centrifugation (15 min, 1912 × *g*, 10 °C), washed twice in 20 mL of filter-sterilized tap water and suspended in 200 mL of filter-sterilized tap water to a concentration of approximately 3×10^6 cells/mL. The bacterial suspensions were incubated statically at 20 °C (*P. aeruginosa* and *E. nimipressuralis*) or 30 °C (*L. pneumophila*) for 24 h and subsequently combined.

Cultivation and inoculation of drinking water biofilms

Drinking water biofilms were grown in a 200-L stainless steel tank connected to a cold water laboratory tap and perfused with drinking water at a flow rate of 20 L/h. The concentration of assimilable organic carbon in the drinking water was approximately 6 μg C/L (G. Schaule, personal communication). Up to 32 coupons of the plumbing materials were introduced vertically into the tank and fixed with stainless steel clamps to a stainless steel bar. After 14 days of perfusion with drinking water, coupons were transferred to 100-mL stainless steel flow-through reactors. Six coupons of each material were vertically placed in a reactor with a distance of 3 mm between the coupons. The reactors were filled with a suspension of *P. aeruginosa*, *L. pneumophila* and *E. nimipressuralis* (10^6 cells/mL of each organism) by injecting 100 mL of the bacterial suspension into the tubing at the reactor inlet. After static incubation at room temperature for 24 h, the reactors were connected to a cold water laboratory tap and continuously perfused with drinking water for 4 weeks.

Microbiological analysis

Samples for microbiological analysis were biofilm suspensions and effluent from the biofilm reactors. For biofilm analysis, the biomass from both sides of two coupons was scraped off, using a sterile rubber scraper and suspended into 20 mL deionized water. For biofilm dispersion, the suspensions were vortexed for 2 min. Serial dilutions of the suspensions were prepared in deionized water. The water phase was sampled by collecting reactor effluent in sterile 250-mL glass flasks.

Determination of the total cell count in biofilm supensions was performed by staining the cells with the fluorochrome 4′,6-

diamidino-2-phenylindole (final concentration: 5 μg/mL in 0.4% (v/v) formaldehyde) and enumeration of the cells under an epifluorescence microscope. The heterotrophic plate count (HPC) was determined on R2A medium by the spread plate method (Reasoner and Geldreich, 1985). Colonies were enumerated after incubation of the plates at 20 °C for 7 days. *P. aeruginosa* was quantified according to the standard DIN EN ISO 16266 (2008). Serial dilutions of biofilm suspensions were spread-plated on CN agar (Oxoid). Plates were incubated at 36 °C for 2 days. In reactor effluent, *P. aeruginosa* was detected by filtering up to 100 mL through 47 mm mixed cellulose ester membrane filters with a pore size of 0.45 μm. Filters were transferred to CN agar and the plates were incubated at 36 °C for 2 days. Quantification of *L. pneumophila* was performed according to the standard ISO 11731 (1998). Biofilm suspensions were spread-plated on GVPC agar (Oxoid) after acid treatment. Plates were incubated at 36 °C for 10 days. Up to 100 mL of the reactor effluent were filtered through black 47 mm mixed cellulose ester membrane filters with a pore size of 0.45 μm and acid treated. Filters were placed onto GVPC agar and the plates were incubated for 10 days at 36 °C. All determinations of HPC, *P. aeruginosa* and *L. pneumophila* were performed in triplicate and results were expressed as colony-forming units (cfu). Detection of *E. nimipressuralis* was performed, using the Colilert-18/QuantiTray2000 system (IDEXX) according to the manufacturer's instructions.

FISH analysis

FISH of biofilm cells was performed, using probe Psae16S-182 (Wellinghausen et al., 2005) and probe LEGPNE1 (Grimm et al., 1998) for the detection of *P. aeruginosa* and *L. pneumophila*, respectively. The probes were labeled with Cy3. The cells were fixed with 4% paraformaldehyde in phosphate-buffered saline, pH 7.2 (PBS), at 4 °C for 1 h, washed in PBS and resuspended in a mixture of equal volumes of PBS and absolute ethanol. 10 μL of fixed biofilm suspension were pipetted onto epoxy-coated 8-well diagnostic slides (Thermo Scientifc). After dehydration in 50%, 80% and 96% ethanol (3 min for each step) the samples were hybridized in 10 μL of hybridization buffer (0.9 M NaCl, 20 mM Tris [pH 8.0], 0.01% SDS, 40% (v/v) formamide and 5 ng/μL oligonucleotide probe Psae16S-182 or 0.9 M NaCl, 20 mM Tris [pH 7.6], 0.01% SDS, 25% (v/v) formamide and 5 ng/μL oligonucleotide probe LEGPNE1) in a humid chamber at 46 °C for 90 min. Unbound probe was removed by washing in 25 mL washing buffer (56 mM NaCl, 20 mM Tris [pH 8.0], 0.01% SDS and 5 mM EDTA for probe Psae16S-182 or 160 mM NaCl, 20 mM Tris [pH 7.6], 0.01% SDS and 5 mM EDTA for probe LEGPNE1) at 46 °C for 15 min. Bacterial cells were counterstained with DAPI (1 μg/mL) for 20 min, washed in deionized water and stored at 4 °C until enumeration. Cells were counted using an epifluorescence microscope at 1000-fold magnification. 40 randomly selected fields of view or at least 200 cells were enumerated for each filter with the help of a counting grid (100 μm × 100 μm).

Characterization of Pseudomonas and Legionella biofilm isolates

For confirmation of *P. aeruginosa* isolates from biofilms, representative colonies from primary cultures on CN agar were subcultured on nutrient agar (36 °C, 24 h) and identified by typical pigment production, positive cytochrome oxidase reaction (Bactident-Oxidase, Merck) and the biochemical profiles in the API 20 NE system (bioMérieux) according to the manufacturer's instruction. Genotyping of *P. aeruginosa* isolates was performed by pulsed-field gel electrophoresis (PFGE) essentially as described by Head and Yu (2004), using the endonuclease SpeI and DNA digestion at 37 °C overnight. For confirmation of *L. pneumophila* (serogroup 1), representative colonies from GVPC agar were subcultured on nutrient agar and BCYEα agar at 36 °C for at least 3 days.

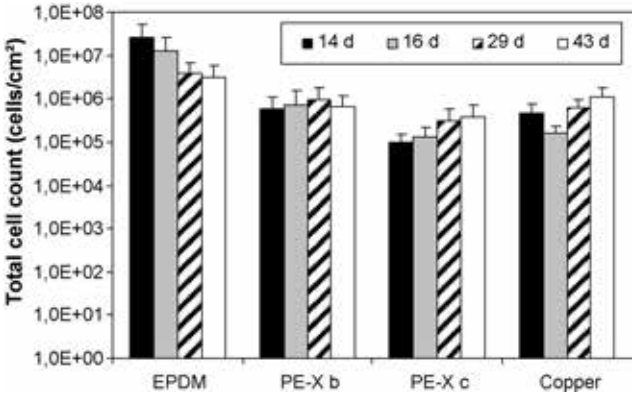

Fig. 1. Total cell counts of drinking water biofilms grown on EPDM, PE-X b, PE-X c and copper under constant flow conditions. Total cell counts after 14 days were determined in four independent experiments and total cell counts after 16, 29 and 43 days were determined in three independent experiments.

Those colonies which were able to grow on BCYEα agar, but failed to grow on nutrient agar, were regarded as *Legionella*. For the confirmation of *L. pneumophila* serogroup 1, a commercially available latex agglutination test kit (Oxoid) was used according to the manufacturer's instruction. Genotyping of *L. pneumophila* isolates by PFGE was performed essentially as described by Chang et al. (2009). DNA digestion was carried out with 20 units of the endonuclease SfiI per agarose plug at 50 °C for 18 h.

Results

Formation of drinking water biofilms on plumbing materials

The aim of the present study was to investigate the incorporation of the hygienically relevant bacterial species *P. aeruginosa*, *L. pneumophila* and *E. nimipressuralis* into established drinking water biofilms on plumbing materials under laboratory conditions. For this purpose, biofilms were grown on coupons of elastomeric (EPDM) and plastic (PE-X b, PE-X c) materials as well as on copper in a stainless steel tank under continuous flow-through with drinking water for 14 days. The mean temperature of the water inside the tank was 20.3 °C (range 16.6–21.9 °C; $n = 8$). The mean pH of the influent water was 7.86 (range 7.67–8.19; $n = 35$). After 14 days, coupons with attached biofilms were transferred to 100-mL stainless steel flow-through reactors for spiking of the biofilms with the test bacteria and subsequent monitoring of the microbiological composition of the biofilms for another 4 weeks. The mean water temperature inside the reactors was 18.8 °C (range 10.1 °C–24.6 °C; $n = 122$).

The number of total cells and culturable HPC bacteria of the biofilms on the four plumbing materials was determined over the period of 14 days (biofilm spiking) to 43 days (end of experiments) (Figs. 1 and 2). After 14 days, total cell counts were higher in biofilms on EPDM (2.6×10^7 cells/cm^2), followed by total cell counts on PE-X b (5.2×10^5 cells/cm^2), copper (4.6×10^5 cells/cm^2) and PE-X c (1.0×10^5 cells/cm^2). Thus, total cell counts on PE-X b, copper and PE-X c were 50, 57 and 260 times lower, respectively, than on EPDM. At the end of the experiments after 43 days, only a minor difference in the total cell counts between the materials was observed, with 3.2×10^6 cells/cm^2 on EPDM, followed by 1.1×10^6 cells/cm^2 on copper, 6.9×10^5 cells/cm^2 on PE-X b and 3.7×10^5 cells/cm^2 on PE-X c, corresponding to 2.9, 4.6 and 8.6 times lower values on copper, PE-X b and PE-X c, respectively, than on EPDM.

The concentrations of the culturable HPC bacteria (Fig. 2) were always about 1 log unit lower than the total cell counts in biofilms grown on EPDM, PE-X b and PE-X c (2.2×10^6,

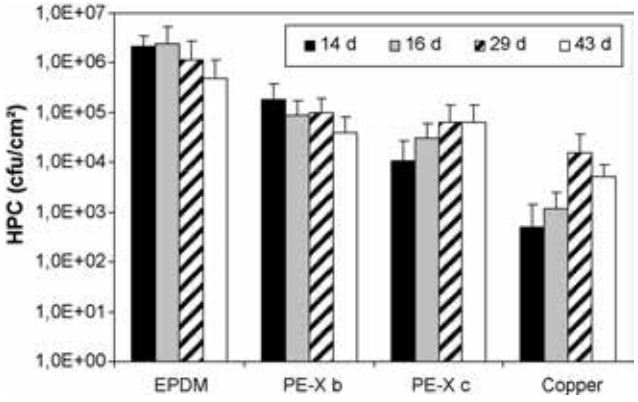

Fig. 2. Heterotrophic plate counts of drinking water biofilms grown on EPDM, PE-X b, PE-X c and copper under constant flow conditions. Heterotrophic plate counts after 14 days were determined in four independent experiments and heterotrophic plate counts after 16, 29 and 43 days were determined in three independent experiments.

1.9×10^5 and 1.1×10^4 cells/cm^2, respectively, after 14 days, and 4.9×10^5, 3.9×10^4 and 6.3×10^4 cfu/cm^2, respectively, after 43 days). Biofilms on copper revealed significantly lower concentrations of culturable bacteria (5.1×10^2 and 5.2×10^3 cfu/cm^2 after 14 and 43 days, respectively) compared with the biofilms on the other materials, and the HPC values were 2 to 3 log units lower than the total cell counts. In the period between 14 and 43 days the variation in total cell counts and HPC was never more than 1 log unit on the single materials, indicating that after 14 days of drinking water flow-through the biofilms had already reached relatively high and stable cell densities. An exception were biofilms on copper which showed an increase in HPC of more than 1 log unit between 14 and 29 days, indicating a delayed growth of heterotrophic biofilm bacteria on this material. The average fraction of culturable bacteria on total cells was 18.1% in biofilms grown on EPDM, 18.0% on PE-X c, 15.3% on PE-X b and only 0.9% in biofilms grown on copper.

Incorporation of P. aeruginosa, L. pneumophila and E. nimipressuralis into established drinking water biofilms

To investigate the fate of *P. aeruginosa*, *L. pneumophila* and *E. nimipressuralis* in drinking water biofilms, 14-day-old biofilms grown on EPDM, PE-X b, PE-X c and copper coupons were spiked with a mixture of *E. nimipressuralis*, *P. aeruginosa* and *L. pneumophila* cells which had been starved in drinking water for 24 h. After inoculation, the presence of the bacteria was monitored with standard cultural methods as well as with culture-independent FISH (for *P. aeruginosa* and *L. pneumophila*) over a period of 4 weeks under continuous flow-through with drinking water in two independent experiments performed successively. Prior to inoculation, *P. aeruginosa*, *L. pneumophila* serogroup 1 and coliform bacteria were not detected culturally in 14-day-old biofilms and in 100-mL volumes of influent drinking water.

P. aeruginosa was observed in the biofilms grown on EPDM, PE-X b and PE-X c (Fig. 3). Concentrations of culturable *P. aeruginosa* were relatively low (50% of samples: <1 cfu/cm^2, 70% of samples: <10 cfu/cm^2) and varied between the single experiments and the four materials. Application of the culture-independent FISH method showed up to 4 log units higher concentrations of *P. aeruginosa* than the cultivation method (Fig. 3). Taken together the data for bacterial concentration determined by culture and by FISH in the two independent experiments showed that *P. aeruginosa* persisted on EPDM and PE-X c for up to 28 days, and on PE-X b for only up to 14 days. In biofilms grown on copper, *P. aeruginosa* could be detected neither by cultivation nor by FISH.

L. pneumophila was detected in biofilms on any of the four materials and persisted there for up to 28 days (Fig. 4). On EPDM, PE-Xb and copper, the number of culturable cells tended to decrease over the observed time; this effect was most pronounced on copper. In most cases, the concentration of FISH-positive *L. pneumophila* cells was significantly, sometimes several orders of magnitude, higher than the number of culturable bacteria.

PFGE analysis of *P. aeruginosa* and *L. pneumophila* re-isolated from biofilms over the 4-week period after inoculation always

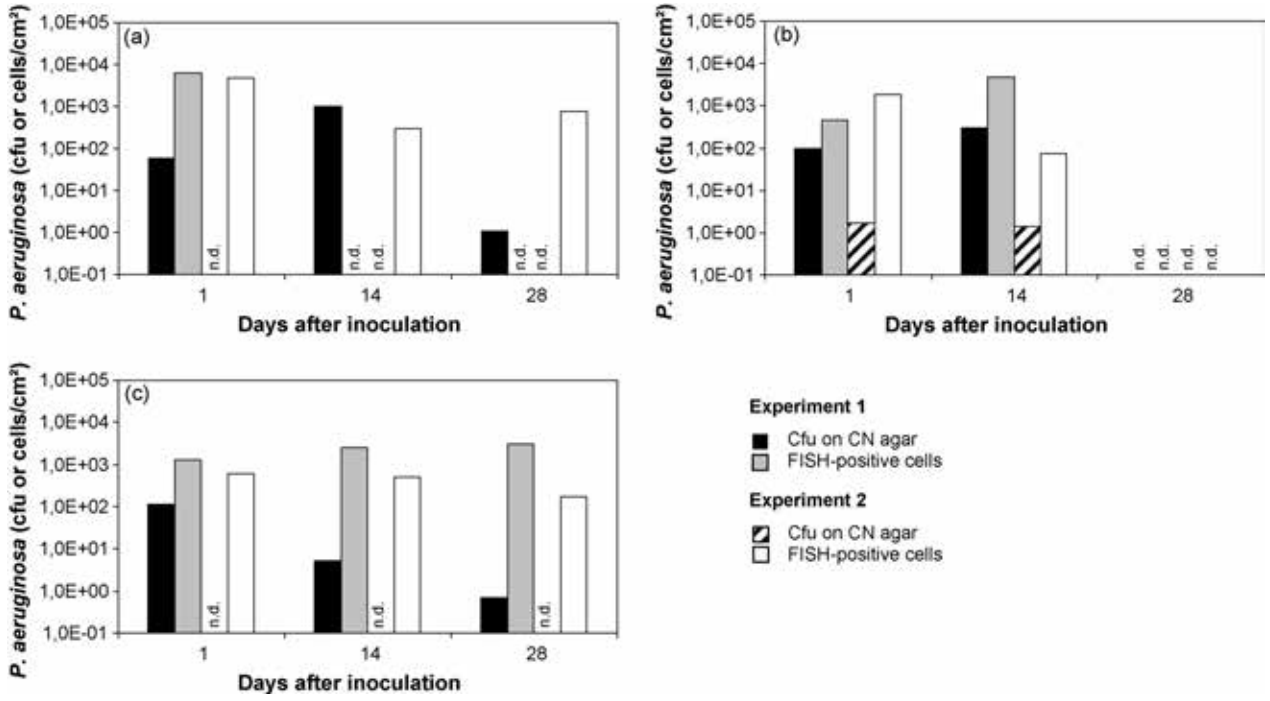

Fig. 3. Persistence of *P. aeruginosa* in drinking water biofilms on (a) EPDM, (b) PE-X b and (c) PE-X c under constant flow conditions. *P. aeruginosa* in the biofilms was quantified by cultivation on CN agar and by FISH. n.d., not detected.

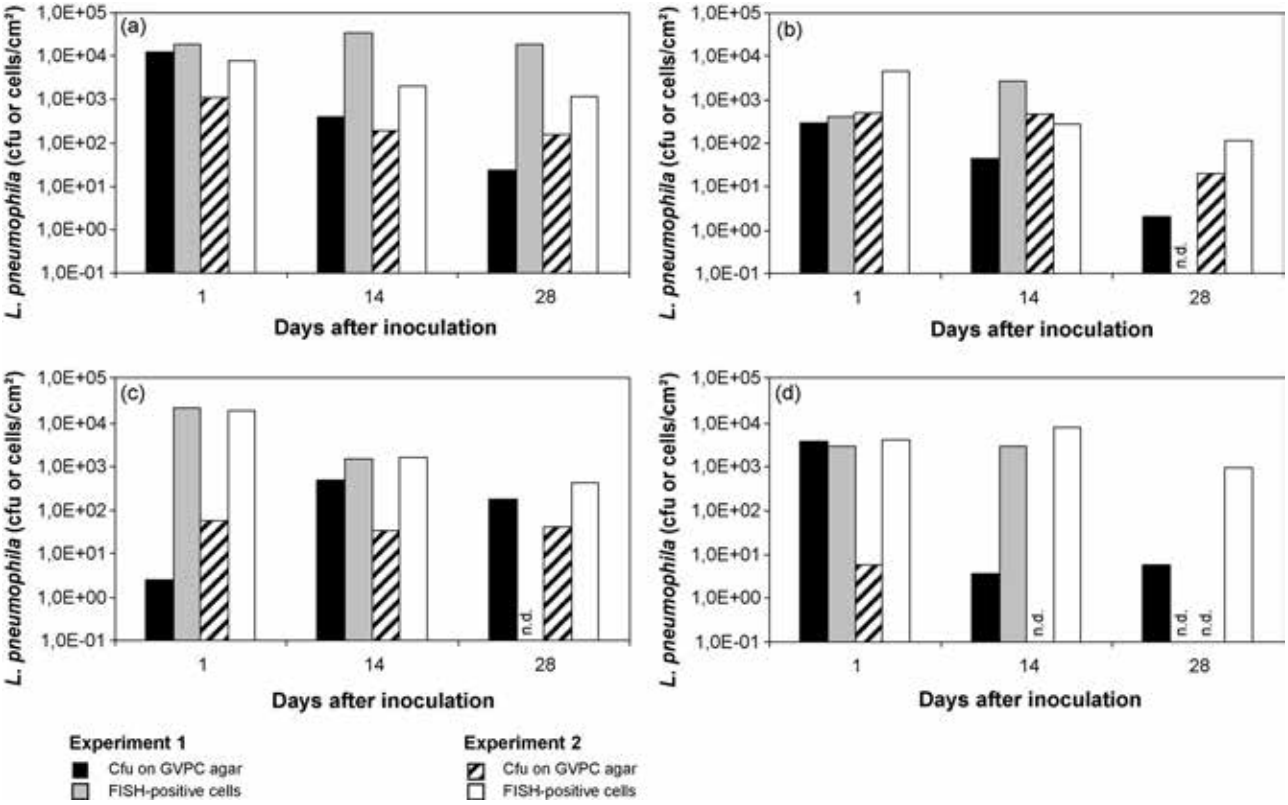

Fig. 4. Persistence of *L. pneumophila* in drinking water biofilms (a) EPDM, (b) PE-X b, (c) PE-X c and (d) copper under constant flow conditions. *L. pneumophila* in the biofilms was quantified by cultivation on GVPC agar and by FISH. n.d., not detected.

showed the same macrorestriction patterns compared with those of the bacteria used for inoculation of the biofilms (data not shown), confirming that the original strains had persisted in the biofilms and no secondary contamination with other *P. aeruginosa* or *L. pneumophila* clones from the influent water had occurred.

In 100-mL volumes of the reactor effluents, *P. aeruginosa* and *L. pneumophila* were detected at least as long as the organisms were found in the corresponding biofilms.

The coliform bacterium *E. nimipressuralis* was not detected culturally in any of the biofilms of all materials. Since no oligonucleotide probe specific for this bacterial species was available, FISH could not be performed to detect possibly unculturable organisms in the biofilms.

Discussion

Development of drinking water biofilms depending on plumbing materials

It has been known for many years that type and characteristics of pipe materials can influence the formation of microbial biofilms in drinking water systems (Colbourne, 1985; Schoenen, 1989). Most studies have focused on materials relevant to drinking water distribution systems, while materials used to construct domestic plumbing systems have less often been considered (Eboigbodin et al., 2008). Since drinking water in Europe should meet the necessary quality requirements at the point of consumption, it is important to understand the development of biofilms and their role as reservoirs for opportunistic pathogens both in water distribution mains and in consumers' plumbing systems. The plumbing materials including copper, two types of polyethylene (PE-X b and PE-X c) and the elastomer EPDM rubber were chosen for the present study, based on their occurrence in domestic plumbing systems in Germany. The plastic and rubber materials met specific physical and chemical requirements (Anonymous, 1977, 1985), but also the microbiological specifications relating to their biofilm formation potentials (Anonymous, 2007), that are the basis for the recommendation of their use in drinking water systems in Germany. Biofilm development was followed over a period of 43 days under flow-through of cold tap water. Biofilm formation based on the determination of total cell counts and colony counts of HPC bacteria was more pronounced on EPDM compared to PE-X b, PE-X c and copper. A direct comparison of the four materials with respect to biofilm formation has not been published before. However, enhanced microbial colonization of EPDM and other elastomeric materials has been observed in field and laboratory studies (Kilb et al., 2003; Rogers et al., 1994b). Using a chemostat model of a plumbing system inoculated with sludge from a calorifier, Rogers et al. (1994b) found higher colony counts of heterotrophic bacteria in drinking water biofilms grown on ethylene-propylene material (1.08×10^7 cfu/cm^2) compared to PE (2.75×10^6 cfu/cm^2) and other plastic and steel materials over an exposure period of 28 days. Bressler et al. (2009) reported total cell counts and HPC values of 1.2×10^9 and 1.0×10^8 cfu/cm^2, respectively, for 14-day-old drinking water biofilms on a type of EPDM which complied with the physical and chemical requirements, but, in contrast to the EPDM of the present study, did not meet the microbiological requirements of German recommendations for rubber materials in contact with drinking water. A lower degree of leaching of biodegradable compounds as nutrients for microbial growth from EPDM (Rogers et al., 1994b) may be an explanation for the lower values of total cell counts and HPC in the biofilms of our study compared to those of the other studies mentioned, indicating that significant variations in biofilm formation have to be expected dependent on the chemical composition of EPDM materials.

In the present study, total cell counts of biofilms grown on copper were as high as those of biofilms on PE-X b and PE-X c

already after 14 days, whereas the HPC of copper biofilms was 2 log units and 3 log units lower than those of biofilms grown on PE-X c and PE-X b, respectively. These results suggest that drinking water biofilms of cell densities comparable to those on plastic materials can develop on copper surfaces, but the fraction of culturable bacteria in copper-associated biofilms can be drastically reduced. In only a few other studies, copper and PE-X or PE, sometimes in combination with other materials, were directly compared with respect to biofilm formation. Copper exposed in a drinking water distribution system for 12–15 days revealed biofilms with lower total cell counts and colony counts (HPC) than biofilms on hardened PE (PE-HD) coupons (Schwartz et al., 1998). The HPC values of biofilms grown on PE-HD were about one order of magnitude less than the corresponding total cell counts, whereas the fraction of the HPC in copper biofilms was significantly lower similar to the results of our study. Based on total cell count, Lehtola et al. (2004) observed a slower formation of drinking water biofilms in copper pipes compared to PE pipes, but after 200 days there was no difference in the cell numbers between the pipe materials; however, HPC of biofilms on copper and PE was not different over the whole experimental period. Wingender and Flemming (2004) found the same or even slightly higher levels of biofilm formation (as total cell counts) on copper compared to PE exposed for 18 months in a drinking water distribution system. Van der Kooij et al. (2005) reported that levels of HPC and adenosine triphosphate (ATP) of biofilms on PE-X were higher than those of biofilms grown on copper in a model warm water system over a 2-year period. In static (batch) experiments, biofilm formation based on ATP analysis was lowest on copper compared to PE-X or PE and other plastic and steel materials after an incubation at 30 °C for 112 days (Tsvetanova and Hoekstra, 2009) or at 25 °C for 90 days (Yu et al., 2010). Taken together, when total cell counts were used as a parameter to monitor biofilm formation, biofilms of cell densities comparable to those on plastic materials can develop after longer periods of weeks or months. However, biofilm formation on copper analyzed by colony counts or ATP content has often been observed to be limited or delayed compared to other materials. A possible explanation for the low fraction of culturable or metabolically active bacteria in relation to the total number of cells may be the inhibitory effect of dissolved copper ions which can affect metabolic functions, cause cell injury or induce a VBNC state of the biofilm organisms. In addition, as copper does not leach any nutrients, limitation of growth substrates is expected to exist at copper surfaces compared to elastomeric and plastic materials where enhanced biofilm formation has been attributed to the leaching of biodegradable organic compounds (plasticizers, antioxidants, lubricants, heat stabilizers) supplying additional nutrients to the biofilm organisms (Keevil, 2002; Kilb et al., 2003; Rogers et al., 1994b; Van der Kooij et al., 2005). Favourable nutrient conditions may be an explanation for the relatively high fraction of culturable bacteria in biofilms grown on EPDM, PE-X b and PE-X c compared to copper in the present study.

Integration of P. aeruginosa and L. pneumophila in drinking water biofilms on plumbing materials

In the laboratory-reactor system used in the present study, spiking of 14-day-old drinking water biofilms grown on EPDM, PE-X b and PE-X c materials with *P. aeruginosa* and *L. pneumophila* resulted in the incorporation and persistence of these organisms in the biofilms for up to 29 days (end of experiments). The detection of the organisms in the biofilms paralleled their presence in 100-mL volumes of reactor effluents, indicating that biofilms represented the source of contamination for the water phase. In the biofilms, the concentration of culturable *L. pneumophila* was generally higher compared to that of *P. aeruginosa*. However, when quantified by FISH, the cell numbers of both organisms in the biofilms were observed to be in similar orders of magnitude. An exception was the observation that *P. aeruginosa* was not detectable neither by culture nor by FISH on copper, although part of the biofilms consisted of culturable HPC bacteria, indicating that there was no complete inhibition of heterotrophic biofilm organisms on the copper surface. In contrast, *L. pneumophila* was detected in biofilms on copper both by culture and by FISH. These results indicate that copper ions may be inhibitory to the colonization of drinking water biofilms by *P. aeruginosa*, while *L. pneumophila* became incorporated into the copper-associated biofilms. However, the fraction of culturable *L. pneumophila* tended to decrease over the observation period of 28 days, suggesting that copper ions affected culturabilty of *L. pneumophila* in our experimental system.

The numbers of *P. aeruginosa* and *L. pneumophila* determined by FISH were often several orders of magnitude higher than the concentrations determined culturally. On some occasions, *P. aeruginosa* could not be detected using the culture method, but was only detected by FISH as observed on EPDM and PE-X c (Fig. 3, experiment no. 2); a similar observation was made for *L. pneumophila* on copper (Fig. 4, experiment no. 2). It is not known if all bacteria detected by FISH using oligonucleotide probes which are targeted at intact rRNA are still viable. But based on the assumption that detection of rRNA with fluorescent oligonucleotide probes indicated viability, the low ratio of culturable cells to FISH-positive cells suggests that *P. aeruginosa* and *L. pneumophila* may occur here in a VBNC state.

The seeding experiments of the present study were performed on young biofilms over a time of about 4 weeks similar to the observation periods of several weeks reported in comparable studies (Armon et al., 1997; Bressler et al., 2009; Långmark et al., 2005; Lehtola et al., 2007). This experimental period was suitable for monitoring the fate of *P. aeruginosa* and *L. pneumophila* in drinking water biofilms (Figs. 3 and 4). However, considering dynamics of biofilm composition during biofilm ageing under conditions of real drinking water systems, experiments over extended time periods of months or years will be necessary for evaluating the long-term persistence of these opportunistic pathogens in drinking water biofilms.

In the literature, relatively little information exists regarding the occurrence of *P. aeruginosa* in biofilms on materials which are relevant to plumbing systems and which have been considered in the present study. In municipal drinking water systems, *P. aeruginosa* was only sporadically found in biofilms such as on galvanized iron surfaces (Lee and Kim, 2003), on steel coupons (Emtiazi et al., 2004), and in one (concentration of *P. aeruginosa* 0.4 cfu/cm^2) of 13 biofilms from EPDM-coated valves in German drinking water distribution systems (Kilb et al., 2003). In testing microbial performance of materials, ethylene propylene polymer was among the elastomers which were found to support growth of *P. aeruginosa* (Colbourne, 1985). In a chemostat model of a plumbing system, *P. aeruginosa* was identified in naturally occurring mixed-population biofilms cultivated at 20 °C, 40 °C or 50 °C on polybutylene (Rogers et al., 1994a). In the same experimental system, biofilms grown at 30 °C were shown to include *P. aeruginosa* already after 24 h on polypropylene and PE at concentrations of 1.9 and 260 cfu/cm^2, respectively (Rogers et al., 1994b); after 21 days, the bacteria were also detected in biofilms on mild steel (30 cfu/cm^2). Seeding experiments in a flow-through reactor demonstrated the integration and persistence of *P. aeruginosa* at densities of approximately 1×10^2 to 3×10^2 cfu/cm^2 in established drinking water biofilms on EPDM coupons for 28 days (Bressler et al., 2009). These observations and the results from the present study indicate that *P. aeruginosa* may occur in a culturable state in drinking water biofilms, mostly at relatively low concentrations compared to the general biofilm microflora, on materials which are employed in plumbing systems. However, quantification of *P. aeruginosa* using FISH gave orders

of magnitude higher concentrations of the organisms on EPDM, PE-X b and PE-X c, suggesting that culture-based methods may significantly underestimate the actual occurrence of *P. aeruginosa* in drinking water biofilms.

P. aeruginosa could not be detected on copper. Recently, it has been demonstrated that pure cultures of *P. aeruginosa* were rapidly killed upon adhesion to different copper cast alloys (Elguindi et al., 2009). Thus, a possible explanation for the absence of *P. aeruginosa* in the copper-associated biofilms of our study may be the release of copper ions which were toxic to *P. aeruginosa* and prevented the colonization of the copper surface. In contrast to these observations, *P. aeruginosa* has been identified among the microorganisms identified in biofilms of corroded copper pipes of a hospital (Wagner et al., 1992) and a nuclear power plant (Wallace et al., 1994). These observations indicate that *P. aeruginosa* nevertheless has the potential to survive in mixed-population biofilms on copper under conditions, which have yet to be defined.

A number of studies have considered the fate of *L. pneumophila* either as a component of naturally occurring mixed-population biofilms or following artificial spiking of drinking water biofilms, however, under experimental conditions that differed from those of our study. The inclusion and persistence of naturally occurring *L. pneumophila* at cold water temperatures and multiplication of these bacteria at warm water temperatures in biofilms of autochthonous water bacteria have been observed on various plumbing materials including ethylene-propylene, PE-X, unplasticized PVC and copper (Keevil, 2002; Rogers et al., 1994a, 1994b; Van der Kooij et al., 2002, 2005; Gião et al., 2009). Seeding experiments reported in the literature indicated that *L. pneumophila* could become integrated in preexisting biofilms and survive or even multiply in these biofilms, depending on the environmental conditions (Armon et al., 1997; Långmark et al., 2005; Lehtola et al., 2007). Increased concentrations of *L. pneumophila* are preferentially found in warm water systems where temperatures are favourable for growth of these bacteria (25–45 °C). The results of the seeding experiments of the present study that were conducted at water temperatures below 25 °C demonstrate that integration and persistence of *L. pneumophila* in biofilms can also occur under cold water conditions. This is in accord with observations of other studies. Armon et al. (1997) found that culturable *L. pneumophila* survived in biofilms of heterotrophic drinking water bacteria on glass and PVC at 24 °C for more than 40 days. *L. pneumophila* inoculated into 1-month-old drinking water biofilms grown on PVC coupons in a Propella reactor was shown to persist in the biofilms under high-shear turbulent flow at an average temperature of 15 °C for at least 4 weeks and was also found in the water during this period (Lehtola et al., 2007). At lower water temperatures of 5.0–8.5 °C, addition of *L. pneumophila* to 8-week-old drinking water biofilms on glass surfaces in a pilot-scale water distribution system provided with chlorinated and UV-treated water also resulted in an accumulation and persistence of these bacteria over the experimental period of 38 days (Långmark et al., 2005). Replication of *L. pneumophila* was not observed in our experiments and other studies mentioned above which were all conducted at temperatures of ≤20 °C. A possible reason may be low water temperatures, where growth of *L. pneumophila* is not expected to occur. These observations suggest that, under cold water conditions, drinking water biofilms can represent a reservoir of *L. pneumophila* in a culturable or VBNC state. In case of a shift to higher temperatures multiplication of the bacteria can be expected; possibly, also the transition between the culturable and VBNC state may be influenced by water temperature. Future experiments have to be done in order to investigate these aspects of multiplication and the role of the VBNC state of *L. pneumophila* under warm water conditions on the relevant plumbing materials considered in the present study.

A significant drop in *L. pneumophila* culturability was observed on copper in contrast to the PE-X and EPDM materials. Sensitivity of *L. pneumophila* in copper-associated biofilms has also been found in other experimental systems. Copper temporarily limited the growth of *L. pneumophila* in biofilms of a model warm water system compared to PE-X during 250 days of exposure to warm water, but the levels of the bacteria were the same on both materials after 2 years (Van der Kooij et al., 2002). Keevil (2002) found *L. pneumophila* to colonize mature biofilms on aged copper surfaces only in low culturable numbers. However, despite low culturability high numbers of FISH-positive cells of *L. pneumophila* were still observed in our study, again indicating that the bacteria may persist in a VBNC state in biofilms on copper surfaces.

The prerequisite for *Legionella* colonization of water systems seems to be the presence of other heterotrophic organisms, which establish the biofilms and thus provide the habitat for *Legionella* colonization and facilitate interactions between bacteria and protozoa (Lau and Ashbolt, 2009). A major mechanism of *L. pneumophila* growth in aquatic biofilms is supposed to be the replication within protozoan hosts which supply nutrients for legionellae. Intracellular occurrence of *Legionella* in amoebae within biofilms on PE has been demonstrated in situ in domestic cold water plumbing systems (Kalmbach et al., 1997). In a number of studies, replication of *L. pneumophila* within biofilms of heterotrophic bacteria grown under static conditions or in flow-through systems was only observed in the presence of amoebae such as *Hartmannella vermiformis* (Murga et al., 2001; Kuiper et al., 2004). In preliminary observations, the presence of amoebae in our biofilms on EPDM coupons was detected by phase-contrast microscopy and FISH using the oligonucleotide probe EUK516 for *Eukarya*; using amoeba-specific probes, amoebae of the genus *Hartmannella* were identified, while amoebae of the genus *Acanthamoeba* were not detected (unpublished results). Thus, amoebae may be involved in the persistence of *L. pneumophila* in the biofilms of the present study. Further research is under way to establish the role of amoebae in our biofilms, in particular in terms of entering and leaving the VBNC state.

In conclusion, our study demonstrates that *P. aeruginosa* and *L. pneumophila* represent opportunistic pathogens that can integrate in drinking water biofilms on materials which are relevant for domestic plumbing systems. They can persist at least for several weeks in these biofilms which then represent a reservoir for the pathogens and a source of drinking water contamination. In mature biofilms, culturable *P. aeruginosa* and *L. pneumophia* usually seem to be only a minor fraction of the microbial biofilm communities. However, part of the population seems to be able to persist in a VBNC state at high numbers. It is unknown which mechanisms are responsible for the induction of the VBNC state of *P. aeruginosa* and *L. pneumophila* in drinking water biofilms and the hygienic relevance of the VBNC state of these organisms is still unclear. Transition into and resuscitation from the VBNC state into a culturable state and proliferation to hygienically relevant levels may occur under certain environmental conditions such as water stagnation, changes in water temperature, presence of disinfectants or toxic metal ions such as copper, interactions with protozoa and nutrient leaching from materials resulting in favourable growth conditions. Studies are under way to define the mechanisms which are responsible for the persistence of *P. aeruginosa* and *L. pneumophila* in the VBNC state in biofilms on plumbing materials.

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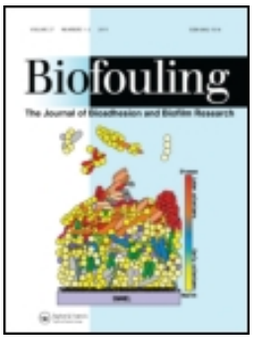

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The effect of material choice on biofilm formation in a model warm water distribution system

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Water distribution systems (WDS) are composed of a variety of materials and may harbour potential pathogens within surface-attached microbial biofilms. Biofilm formation on four plumbing materials, viz. copper, stainless steel 316 (SS316), ethylene propylene diene monomer (EPDM) and cross-linked polyethylene (PEX), was investigated using scanning electron microscope (SEM)/confocal microscopy, ATP-/culture-based analysis, and molecular analysis. Material 'inserts' were incorporated into a mains water fed, model WDS. All materials supported biofilm growth to various degrees. After 84 days, copper and SS316 showed no significant overall differences in terms of the level of biofilm formation observed, whilst PEX supported a significantly higher level of biofilm. EPDM exhibited gross contamination by a complex, multispecies biofilm, at a level significantly higher than was observed on the other materials, regardless of the analytical method used. PCR-DGGE analysis showed clear differences in the composition of the biofilm community on all materials after 84 days. The primary conclusion of this study has been to identify EPDM as a potentially unsuitable material for use as a major component in WDS.

Keywords: biofilm formation; water distribution system; EPDM; PEX; copper; stainless steel

Introduction

Large scale water distribution systems (WDS), including those found in healthcare facilities such as hospitals, may be composed of a variety of different materials, with material choice being governed by factors such as cost and durability (Percival 1999). Throughout WDS, a wide variety of factors, such as design, age of installation, temperature, and flow type, exert effects on the biofilms within, and it is difficult to relate colonization to a single determining factor (Kielemoes et al. 2000). Materials commonly used in modern plumbing systems include metals such as copper and stainless steel (SS), rubber-based materials such as ethylene propylene diene monomer (M-class) rubber (EPDM) and plastics such as cross-linked polyethylene (PEX). Various studies have been carried out on these and many other materials, and have shown that type and degree of formation of biofilm on these surfaces may vary significantly, although local environmental conditions also play a significant role (Kielemoes et al. 2000; Zacheus et al. 2000; Momba 2004; Lehtola et al. 2005; Traczewska and Sitarska 2009).

Most biofilm formation in WDS occurs on the pipes, because they constitute the greatest surface area available for contamination, and no single material has been developed for use in plumbing systems which is resistant to biofilm formation (Rogers et al. 1994; Camper 2000), even in the presence of high disinfectant concentrations (Momba 2004). Indeed, pipe material characteristics have been shown to have a direct and profound influence on the amount, rate and type of biofilm formation, the subsequent prevalence of potential pathogens in the water, and the effectiveness of disinfection regimes such as UV treatment, ozonation and chlorination in their control (Zacheus et al. 2000; Lehtola et al. 2005). Consequently, there is a pressing need to continually improve understanding of bacteria–surface material interactions if the negative effects of biofilm formation in large scale WDS are to be avoided, such as release of potential pathogens (eg *Legionella pneumophila* and *Pseudomonas aeruginosa*) into the water and the accelerated corrosion of metal surfaces which is attributed to multispecies biofilms (Rittman 2004).

The influence that pipe materials exert on bacterial adhesion and biofilm formation is rooted in characteristics such as surface structure and chemical composition. For example, surface roughness has been shown to greatly influence bacterial attachment on SS (Arnold

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and Bailey 2000), and may vary greatly not only between material types, but also between different grades of the same material.

Copper is the most popular modern plumbing material (Zhang et al. 2008; Moritz et al. 2010) because of its low cost and the ease with which it can be machined into a wide variety of pipes and fittings. It is also deemed highly suitable by the plumbing industry due to its perceived antimicrobial properties. However, studies have shown that whilst the antimicrobial properties of copper are employed to good effect in, for example, copper–silver ionization biofilm control systems (Stout and Yu 2003), they are over time negated at the pipe surface by the formation of biofilms largely through the chelation of metal ions within the extracellular polymeric substance (EPS) matrix (Starkey et al. 2004), and the oxidation and subsequent passivation of the surface. Certain biofilm-bound microorganisms may also exhibit some copper-resistance (Kielemoes and Verstraete 2001). The formation of biofilms on copper pipes has also been shown to induce characteristic pitting corrosion known as 'cuprosolvency' which may cause problems such as pipe failure, as well as adversely affecting public health (Walker et al. 1991; Wagner and Chamberlain 1997; Critchley et al. 2001; Pavissich et al. 2010). SS is an alloy metal of which there are many types and grades (Percival 1999) that is viewed as a possible alternative to copper. In addition to iron, it may contain molybdenum, nickel and chromium, which facilitates the effective resistance to corrosion over long periods, due to the formation of a thin layer of chromium or potentially antimicrobial molybdenum-based oxides at the material surface (Percival 1999). Numerous studies have been carried out on its biofilm-supporting capabilities (Percival et al. 1998a, 1998b; Arnold and Bailey 2000; Kielemoes et al. 2000; Zacheus et al. 2000).

PEX and EPDM are primarily used in flexible plumbing hoses, with the latter also used in fittings such as sealing gaskets. Studies have shown that the tendency of PEX and related materials to leach microbial nutrients such as phosphates into the water leads to the promotion of biofilm formation, particularly in the weeks immediately following installation (Lehtola et al. 2004), and therefore debate continues as to the merits of using such materials in plumbing situations.

The aim of this study was to compare the biofilm formation capabilities of virgin copper, stainless steel (SS316), PEX and EPDM over an 84 day period, from a microbiological viewpoint and with consideration of the potential public health implications.

Materials and methods

Description of model warm WDS

The model WDS (or 'test rig'), used during this study was manufactured by research and development staff at Dart Valley Systems (DVS) Ltd, Paignton, UK. The test rig was mounted on a bench in a temperature-controlled laboratory, where the ambient temperature was maintained at 16°C ± 2°C (Figure 1). A mains water supply-fed polypropylene 20 l unheated water storage/pump assembly (Northern pump supplies Ltd, Bradford, UK), running at a pressure of 2.4 bar, supplied water to the test rig, and services supplying hot and cold water separately to the test rig were housed directly underneath the bench. A standard 15 l unvented under-sink heater (Model: EP 15 UR 3kW, Ariston, UK) supplied hot water at 75°C. The test rig consisted of eight vertical pipes or 'systems', plus associated 15 mm outer diameter (OD) fixed copper plumbing. A 'system' constituted the primary area from which samples were taken for biofilm analysis and was comprised of the following vertically-arranged elements: thermostatic mixing valve ('TMV', Reliance Water Controls Ltd, UK), thermal purging solenoid (ASCO Ltd, UK), pressure dumping lever, sample inserts interspersed with seven chrome ball valves, and purging solenoid (ASCO Ltd, UK).

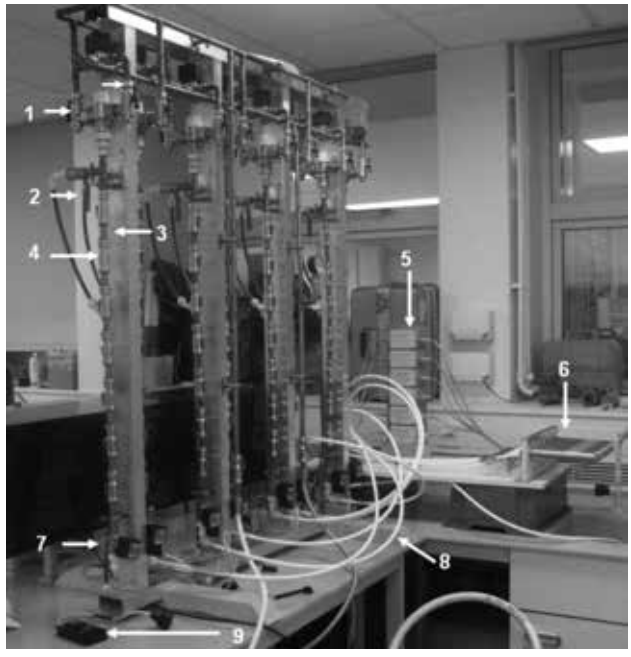

Figure 1. Test rig used in current study 1 = thermostatic mixing valve (TMV); 2 = pressure dumping lever; 3 = copper insert; 4 = chrome ball valve; 5 = auto-flush control box; 6 = infra-red operated 'no-touch' tap; 7 = purging solenoid; 8 = LLDPE tubing connecting test rig systems to taps; 9 = 'key switch' for manual flushing.

The experimental portion of each system was divided into six removable pipe sections, or 'inserts'. Each consisted of 15 mm OD copper pipe. Inserts were 79 mm in length, and separated by SS/chrome ball valves, which facilitated insert isolation and removal, whilst leaving the rest of the system undisturbed. A TMV at the top of each system ensured that water was supplied at a temperature of 41°C, and all systems were flushed twice daily at a temperature of 41°C for 30 s. This temperature is representative of that which would be used in a typical commercial installation (Mr Colin Richards, DVS Ltd, personal communication). Manual flushing was performed using a key switch. The flow rate from each system was set during manufacture to be 6 l min^{-1}, and is typical of a commercial installation.

Each system was connected to an infra-red operated Aquarius Surgeon's Scrub-Up ('no-touch') tap (DVS Ltd, Paignton, UK). Connection was *via* standard polypropylene fittings and identical lengths (1800 mm) of 12 mm OD linear low density polyethylene (LLDPE) tubing with an inner diameter (ID) of 6 mm.

This study was carried out as two 3-month trials, in order that the materials under investigation could be accommodated on the test rig in such a way as to satisfy the need for sound statistical analysis.

Description of materials

Four Water Regulations Advisory Scheme (WRAS)-approved materials, viz. copper, SS316, PEX and EPDM, were analyzed for their ability to support biofilm formation. The copper and SS316 inserts used were 79 mm in length with an inner diameter of 13 mm. Previously unused lengths of EPDM and PEX (ID 10 mm), were removed from lengths of braided SS flexible hose, cut into identical 79 mm sections using scissors which had been flame-sterilized using 70% industrial methylated spirits (IMS) and inserted into six virgin 79 mm copper pipe inserts, which were cut in such a way as to minimize contact with the copper surface after the insertion of EPDM/PEX sections. These copper-EPDM/PEX assemblies were then fitted into the test rig systems.

Removal of inserts

Sampling was undertaken every 28 days, for 84 days. On each sampling day, inserts were removed from the test rig in a way which helped to maintain reproducibility and personal safety. Sampling of inserts was carried out sequentially, ie beginning with system one and working along the test rig, with inserts being removed from the bottom of each system. At all times, care was taken to avoid environmental contamination and to retain water within the inserts, thus avoiding unnecessary biofilm disturbance.

Inserts were handled individually and secured in a vertical position using a bench-top vice, before cleaning of the exterior with 70% industrial methylated spirits (IMS). A rotating pipe cutter, was cleaned using 70% IMS and used to cut portions of copper/SS316 insert for downstream processing, whilst a sterile razor blade was used to cut portions of EPDM and PEX.

Collection of water samples from test rig

Water samples were collected in pre-autoclaved 1 l conical flasks. Contamination by airborne contaminants was minimized by covering the individual flasks with aluminium foil prior to autoclaving. Water samples were collected from each system in sequence. Each system was then separated from the LLDPE piping, no-touch tap assembly and a 30 mm length of new, pre-autoclaved, LLDPE piping connected in its place. This was done in order to facilitate effluent collection in a manner which prevented unnecessary contamination of effluent samples. The key switch was then used to manually flush the system, and effluent was collected in an appropriately labelled conical flask for a period of 10 s. Water samples were also collected from the hot feed, cold feed and mains water supply, after allowing water to run to waste for 30 s before collection in order to eliminate standing water in the pipes.

Culture-based analysis

An insert portion of known length (approximately 20 mm) was cut as previously described. A pre-sterilized cotton collection swab (ThermoFisher Scientific Ltd, UK), pre-moistened in sterile bacteriological (0.85%) saline, was used to swab the entire inner surface of this portion for a minimum of 20 s. Each swab was stored at 4°C after use until all swab samples had been collected. Each swab head was removed using scissors which were flame-sterilized using 70% IMS immediately prior to use, and placed into 1 ml of sterile bacteriological (0.85%) saline. The sample was mixed continuously for 1 min using a vortex mixer, before removal and disposal of the swab head using pre-sterilized metal forceps. Serial tenfold dilutions of each sample were prepared in 1.5 ml microcentrifuge tubes using sterile bacteriological saline as the diluent, to a final volume of 1 ml. Triplicate spread plates were prepared of three appropriate dilutions, using 100 μl of sample and R2A agar (Oxoid, Basingstoke, UK). The exact dilutions used were dependent on the materials under investigation, and expected bacterial numbers.

Incubation of plates was carried out in the dark for two weeks at 20°C.

In order to enumerate culturable *Pseudomonas* spp. associated with insert-bound biofilms, 100 μl of the appropriate dilutions were spread plated onto triplicate CFC agar (Oxoid, Basingstoke, UK) plates. *Pseudomonas aeruginosa* NCIMB 8126 (NCIMB Ltd, Aberdeen, UK) was streaked onto a single CFC agar plate as a positive control, and plates were incubated in the dark at 20°C for 5 to 7 days. Culture-based analysis of 100 μl water sample aliquots was carried out according to the same protocol. Where lower counts were expected, water samples were filtered onto 0.45 μm cellulose nitrate filters (Whatman, UK) using a filtration manifold/vacuum pump assembly.

Scanning electron microscope (SEM) analysis of inserts and materials

Sections of each material approximately 10 mm in length were cut as previously described and fixed in 5 ml of 2.5% glutaraldehyde in 0.1 M sodium cacodylate buffer, pH 7.2. After fixing, inserts were gently rinsed in 10 ml of 0.1 M sodium cacodylate buffer for 15 min. Samples measuring approximately 5 mm × 10 mm were cut, either using metal shears or a razor blade (depending on the material), labelled on the reverse side using a diamond pen, and serially dehydrated in 5 ml of 30%, 50%, 70%, 90% and 100% ethanol (15 min in each). Samples were then critical point dried with ethanol as the intermediate fluid and CO_2 as the transition fluid (Emitech K850; Kent, UK). All samples were gold coated using an Emitech K550 sputter coater (Emitech) and then screened using a Jeol JSM 5600 LV electron microscope (Jeol, Tokyo, Japan).

Confocal laser scanning microscopy (CLSM) analysis

Live/Dead® staining of biofilm

Live/Dead® BacLight stain (Invitrogen, UK) was employed to qualitatively assess bacterial cell viability. The two staining solutions, comprising Syto9 and propidium iodide, were prepared and combined according to the manufacturer's instructions, and 30 μl of the mixture were applied to the inner surface and the sample incubated at room temperature in a 25 mm foil-wrapped Petri dish for 30 min. The sample was then removed using forceps and gently placed in a 25 mm plastic Petri dish containing 3 ml of sterile bacteriological (0.85%) saline, which acted both as a rinsing agent and support medium during observation. In order to prevent sample movement during observation, each sample was immobilized by using two flat pieces of copper pipe, of approximately equal size to the samples being analyzed. Observation of all fluorescently-labelled samples, was carried out using an LSM 510 confocal laser scanning microscope (Carl Zeiss Ltd, Germany), equipped with a ×40 water dipping objective.

ATP analysis

Samples for analysis of surface-associated adenosine triphosphate (ATP) were collected in the same way as for culture-based analysis. Samples were placed in a bench-top microcentrifuge and pulse-spun in order to loosely pellet any suspended copper which may have interfered with the activity of the luciferase enzyme used in the measurement of ATP. The supernatant was then aspirated using a 200 μl micropipette and placed into a fresh, sterile, labelled 1.5 ml microcentrifuge tube. A further spin was carried out in order to pellet the suspended biofilm material (10,000*g*, 10 min), and the supernatant carefully aspirated and discarded. The pelleted cells were resuspended in 100 μl of bacteriological (0.85%) saline and stored at −20°C for 24 h. After this period, they were transferred to −80°C until processing.

The effluent from each experimental system was also analyzed for ATP at each monthly sampling session. Sample water (50 ml) was pipetted into two 50 ml polypropylene Falcon tubes (total volume 100 ml), and centrifuged in a bench top centrifuge (3000*g*, 15 min) to pellet the cells. After centrifugation, 49 ml of supernatant were pipetted from each tube, and the cells resuspended in the remaining 1 ml. The two 1 ml aliquots were then combined in a single sterile 2 ml microcentrifuge tube and spun in a bench-top microcentrifuge (10,000*g*, 10 min). After centrifugation, the supernatant was carefully aspirated from each tube and discarded. The pelleted cells were resuspended in 100 μl of bacteriological (0.85%) saline and frozen at −20°C for 24 h. After this period, they were transferred to −80°C until processing. ATP was quantified using the ATP biomass kit HS (Biothema AB, Sweden), in conjunction with a Pi-102 tube luminometer (Hygiena International Ltd, Watford, UK).

Bacterial community (PCR-DGGE) analysis

Biofilm samples for DNA extraction from test rig inserts were collected as previously described. Swabs were retained and separate extractions carried out on both the swabs and the vortexed samples, after which these samples were recombined in a single volume of Tris-EDTA (TE) buffer for downstream processing. Lysozyme solution (50 μl of 50 mg ml^{-1} in TE buffer) was added to each sample, before incubation for

30 min at 37°C, followed by addition of 35 μl of lysis solution (50 mM Tris-chloride, 25 mM EDTA pH 8.0, 3% SDS, 1.2% PVP) and 200 μl of extraction solution (10 mM Tris-chloride, 1 mM EDTA pH 8.0, 0.3 M sodium acetate, 1.2% PVP; pre-warmed to 60°C). An equal volume of TE-equilibrated, ice-cold phenol solution was then added, before addition of 1 ml chloroform and centrifugation for 15 min at 3000*g*. The upper aqueous layer was transferred to a sterile 1.5 ml microcentrifuge tube, and the DNA precipitated using 0.5 volumes of ice-cold isopropanol, before centrifugation at 10,000*g* for 20 min at 4°C. The DNA pellet was washed twice using 1 ml 70% molecular biology-grade ethanol, before gentle drying using a drying chamber/vacuum pump assembly, and resuspension overnight at 4°C in 20 μl of sterile molecular biology-grade water. The DNA concentration was determined at 260 nm using a NanoDrop™ 1000 spectrophotometer (Thermo Scientific Ltd, DE, USA). PCR amplification of the variable V3 region of 16S rRNA genes was carried out using 3 μl of DNA template, 25 μl of RedTaq™ PCR Reaction Mix (Sigma Aldrich, UK), 20 μl of molecular biology-grade water, 1 μl of the reverse primer P2 (5′-ATT ACC GCG GCT GCT GG-3′) and 1 μl of the forward primer P3 (5′-CC TAC GGG AGG CAG CAG-3′), which had a GC clamp attached at the 5′ end (5′-CGC CCG CCG CGC GCG GCG GGC GGG GCG GGG GCA CGG GGG G-3′). Primers were synthesized by Eurofins MWG Biotech Ltd, Germany. A touchdown PCR was carried out as described by Muyzer et al. (1993), using a Techne TC312 thermal cycler (MIDSCI, MO, USA) and PCR products were run on 1.5% agarose gels to assess PCR success. Denaturing gradient gel electrophoresis (DGGE) was performed using a DGGE-2001 system (CBS scientific, CA, USA). PCR products were run on 8% polyacrylamide gels (160 mm × 160 mm × 1 mm) containing a denaturing gradient of 40%–60% (where 100% denaturant is 7 M urea and 40% formamide). All gels were run at 65 V for 17 h at 60°C in 1 × Tris-acetate-EDTA (TAE) buffer. All samples relating to the same study were loaded in triplicate on the same gel, and DGGE gels were stained for 20 min in 100 ml 1 × TAE buffer containing 10 μl of a 10000 × stock solution of SYBR Gold nucleic acid gel stain (Molecular Probes, UK). Visualization was carried out in a BioRad 1387 universal hood II (BioRad laboratories, Italy).

Statistical analysis

Data analysis (pair-wise T-tests, Kruskal–Wallis/one-way ANOVA and *post hoc* LSD tests as appropriate) was carried out using Microsoft Excel and SPSS V17.0 (SPSS Ltd, Chicago, USA). A p-value of <0.05 was used to indicate a significant difference. Analysis of DGGE fingerprints was carried out using the community ecology analysis software Primer 6.0 (Plymouth Marine Laboratory, UK). For each gel, two-dimensional non-metric multidimensional scaling (nMDS) analysis was used to represent the relative similarities between the different conditions represented on each gel. Cluster analysis was used to check the observed groupings, and an analysis of similarity (ANOSIM) analysis was also performed as a measure of the similarity of replicates both within and between groups.

Results

Culture-based analysis

Figure 2 shows the results of culture-based analysis of all materials. After 28 days all materials supported high counts of culturable aerobic bacteria (CAB), indicating rapid initial colonization in all cases. EPDM was shown to support significantly higher numbers than the other three materials (7×10^6 cfu cm^{-2}, $p < 0.05$), with numbers of EPDM-associated CAB continuing to increase at a steady rate post-28 days, to a level of 9.4×10^7 cfu cm^{-2} after 84 days ($p < 0.05$). No statistically significant increases were observed on the other three materials post-28 days. Indeed, copper and SS316 showed a marginal drop in CAB numbers after 84 days, to a value of 3.13×10^4 cfu cm^{-2}. After 84 days, CAB levels associated with PEX were significantly higher than was observed on both copper and SS316 ($p < 0.05$). However, PEX counts were not significantly higher in comparison to numbers seen at day 28 ($p > 0.05$).

Counts of culturable *Pseudomonas* spp. indicated a higher level of colonization on EPDM and PEX than was observed on copper and SS316. Indeed, none were isolated from the two metals. In contrast, culturable

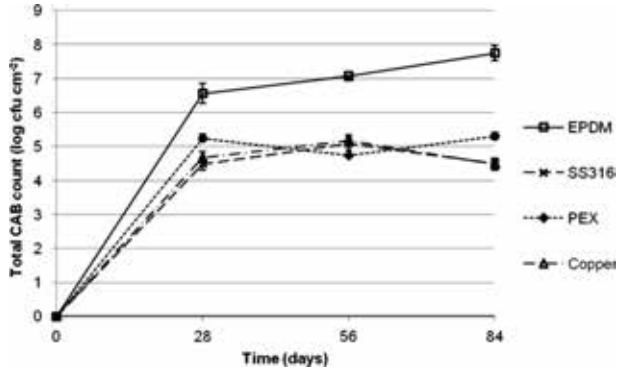

Figure 2. Total culturable aerobic bacteria counts on EPDM, stainless steel 316 (SS316), PEX and copper test rig inserts over 84 days. Error bars = SD.

Pseudomonas spp. levels on EPDM were 1.08×10^5 cfu cm^{-2} after 28 days, increasing to 2.56×10^5 cfu cm^{-2} after 84 days. This indicated that in the case of EPDM, culturable *Pseudomonas* spp. were present in greater numbers than the total CAB populations of both copper and SS 316. PEX was also shown to support culturable *Pseudomonas* spp. at a level which increased over time to a maximum of 8.36×10^3 cfu cm^{-2} after 84 days.

Figure 3 shows the results of culture-based analysis of the effluent associated with the test rig. After 28 days, total CAB numbers associated with effluent samples collected from systems containing EPDM were significantly higher than were observed from systems associated with other materials, reaching a peak level of 3.97×10^5 cfu ml^{-1}. After 84 days, total CAB numbers associated with EPDM system effluent had dropped (3.38×10^5 cfu ml^{-1}), but remained significantly higher than was observed at the start of the experiment ($p < 0.05$). Comparison with effluent from systems containing copper, SS316 and PEX after 84 days indicated significantly higher levels of CAB ($p < 0.05$). In the case of effluent associated with systems containing PEX, numbers of CAB increased until 56 days, after which time a drop to approximately day zero levels was observed. CAB numbers associated with both copper and SS316 effluent did not differ significantly from each other. Culturable *Pseudomonas* spp. were cultured from the effluent associated with all materials throughout the experiment. Colony counts were low relative to the total CAB, with mean values for all effluent samples ranging from 3.87×10^1 cfu ml^{-1}, to 1.34×10^2 cfu ml^{-1} during the experiment, following an initial mean peak value of 8.54×10^2 cfu ml^{-1} at day zero.

No statistically significant changes in effluent-associated culturable *Pseudomonas* spp. numbers were observed during the study and no relationship was identified between effluent-associated culturable *Pseudomonas* spp. numbers and material.

ATP analysis

Figure 4 shows the results of ATP analysis of materials associated with the test rig systems. ATP levels associated with EPDM were significantly higher than those from other materials at all times post-day zero. A peak mean level of 0.93 pmol cm^{-2} was recorded at 28 days, followed by a statistically significant drop to a mean value of 0.47 pmol cm^{-2} ($p < 0.05$) at day 84. Similarly, PEX exhibited a peak in detected ATP at 28 days, and a subsequent gradual drop by the end of the experiment, although the values observed in this case were significantly less than in the case of EPDM.

SS316 showed a gradual, low-level increase in ATP levels throughout the experiment. At day 84, ATP levels on this material were significantly greater than was observed on both PEX and copper ($p < 0.05$), whilst copper was shown to support low ATP levels relative to all other materials, with no significant net increase in ATP levels post-day 28, although a marginal steady increase in ATP concentration was observed until day 56.

Figure 5 shows the results of ATP analysis of effluent associated with the test rig systems. ATP levels associated with EPDM system effluent were significantly higher than were observed on other materials at all times post-day zero, with a peak mean concentration of 0.64 pmol ml^{-1} recorded after 28 days, followed by a gradual drop in concentration to 0.56 pmol ml^{-1} at day 84 ($p < 0.05$). In contrast, mean

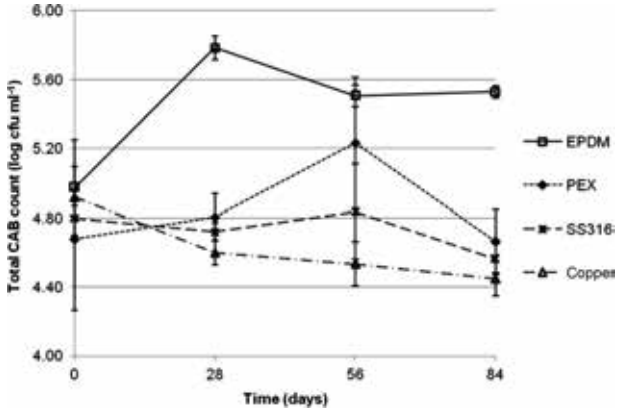

Figure 3. Total culturable aerobic bacteria (CAB) counts in test rig system effluent associated with EPDM, PEX, stainless steel 316 (SS316) and copper inserts, over 84 days. Error bars = SD.

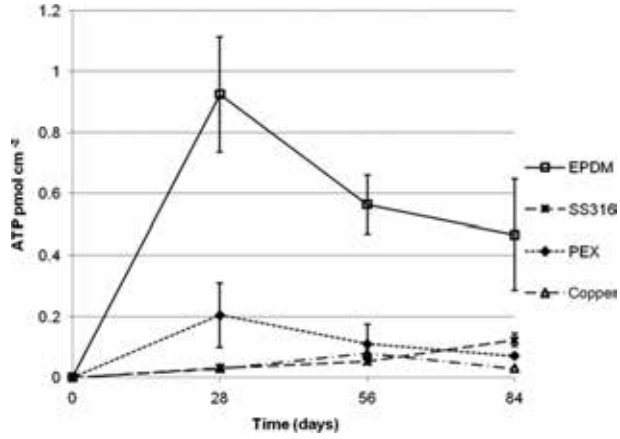

Figure 4. ATP concentrations associated with EPDM, stainless steel 316 (SS316), PEX and copper test rig inserts over 84 days. Error bars = SD.

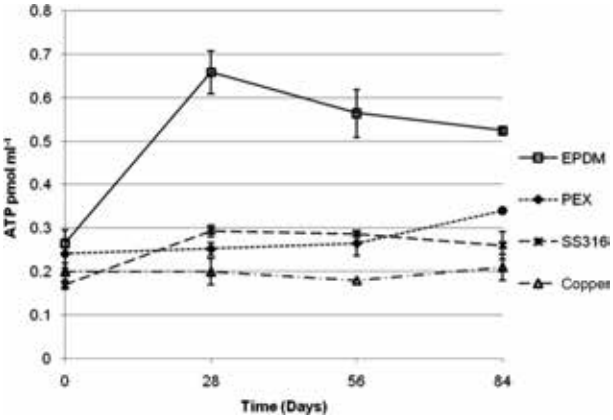

Figure 5. ATP concentrations associated with test rig system effluent associated with EPDM, PEX, copper and stainless steel 316 (SS316) inserts, over 84 days. Error bars = SD.

ATP concentrations associated with PEX system effluent exhibited a marginal but statistically insignificant increase over time ($p = 0.11$). A marginal net increase was also observed in the case of SS316, with ATP concentrations at 28 and 56 days marginally exceeding those observed in PEX system effluent, before dropping to a concentration which was significantly lower than the final value recorded from PEX system effluent. In contrast, copper system effluent ATP concentrations remained consistently low. Indeed, in this case the ATP concentration recorded after 84 days was not significantly different from the mean value recorded at the start of the experiment.

SEM analysis

Qualitative assessment of scanning electron microscope (SEM) samples of uncontaminated pipe material samples showed clear differences between them, primarily in terms of apparent surface roughness (data not shown). Copper and SS316 appeared to present a highly irregular, cracked surface. In the case of copper, an amount of seemingly loose material, or 'flaking', was observed. EPDM also demonstrated a high degree of surface roughness and was punctuated at irregular intervals by holes of unknown depth and of irregular size (not shown). In contrast, PEX was relatively smooth. There were clear differences between the biofilms which formed on each material, in terms of coverage, overall community diversity, and structure (Figure 6).

Discrete microcolony formation was observed on copper throughout the experiment. These microcolonies appeared to be primarily composed of small coccoidal cells, which were arranged in a highly

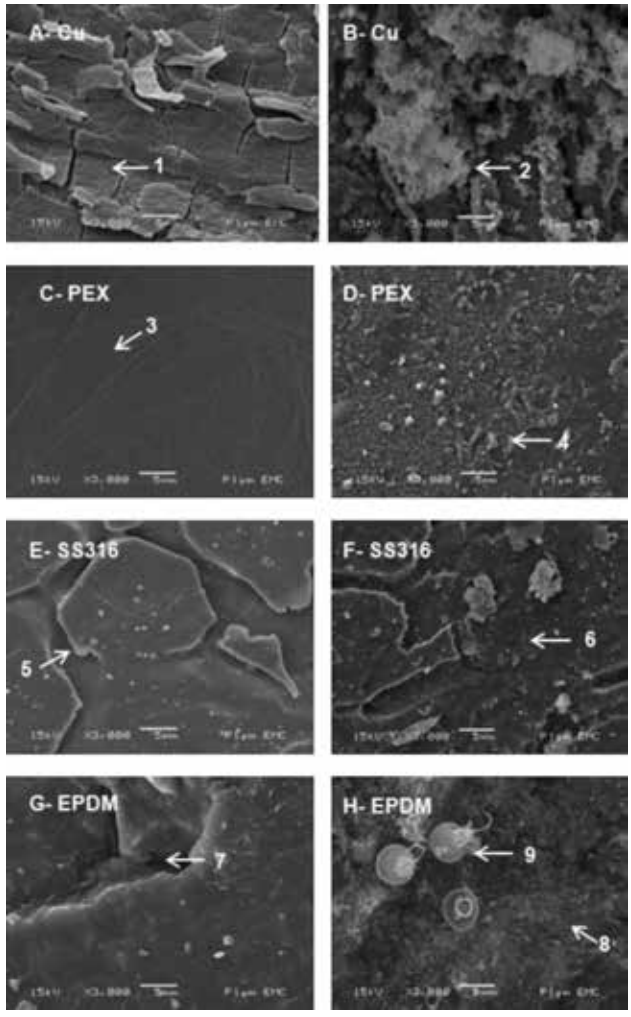

Figure 6. SEM images of copper (Cu), PEX, stainless steel 316 (SS316), and EPDM, before (images A, C, E and G) and after (images B, D, F and H) 84 days exposure to test rig conditions. Numbered white arrows highlight key features: 1 = fragmentation of copper surface; 2 = discrete, raised microcolony formation; 3 = PEX surface appearing smooth in comparison to other materials; 4 = thin biofilm formation and numerous diverse bacterial morphologies; 5 = SS316 surface showing irregular fissures; 6 = microcolonies and bacteria morphologically distinct from those observed on copper; 7 = EPDM surface characterized by highly uneven surface topography and irregular pitting; 8 = copious, microbiologically diverse biofilm, including flagellated protozoa (9).

structured manner, with a number of pores and channels permeating the microcolony structure. SS316 was also shown to support microcolony formation. However, whilst copper microcolonies were at times complex and well-developed structures, on SS316 this was less so, with a greater variety of cell morphologies present and many more individual cells observed on this SS316 than was observed on copper. There was no obvious association between

microcolony formation and material surface features on either copper or SS316.

PEX biofilms were markedly different from the copper/SS316 biofilms in that there was no apparent formation of structured microcolonies at any point during the study. Instead, the formation of a thin biofilm layer closely associated with the substratum was observed. After 84 days, large amounts of EPS had been deposited at the surface, as well as a variety of primarily rod-shaped bacteria, the sizes and shapes of which was suggestive of a diverse bacterial community. The nature of the EPS also appeared to be diverse, although it was difficult to attribute this to the presence of particular microorganisms. After 84 days, this EPS layer had developed to such an extent so as to obscure many of the microorganisms present.

SEM analysis of EPDM indicated the rapid formation of copious amounts of diverse biofilm. After 28 days, there was complete coverage of the substratum and this was the case for the duration of the study, with a diverse community of microorganisms being observed throughout. At 28 days, testate protozoa were seen in close association with the biofilm and these persisted throughout the remainder of the study.

Confocal microscopy

Surface coverage estimation

Figure 7 shows the results of surface coverage assessment, using the nucleic acid stain Syto9. After 28 days, all materials showed evidence of increasing biofilm coverage, and continued to do so for the duration of the experiment. EPDM demonstrated almost complete surface coverage from 28 days onwards, indicating particularly rapid and profuse biofilm formation, whilst biofilm coverage of PEX was shown to be significantly greater after 84 days than was observed on either copper or SS316 throughout ($p < 0.05$). However, the degree of coverage after 84 days was significantly less than was observed on EPDM ($p < 0.05$). Copper and SS316 showed similar levels of coverage. However, statistically significant differences were observed at day 28 and day 84, when copper demonstrated marginally greater coverage than SS316 ($p < 0.05$).

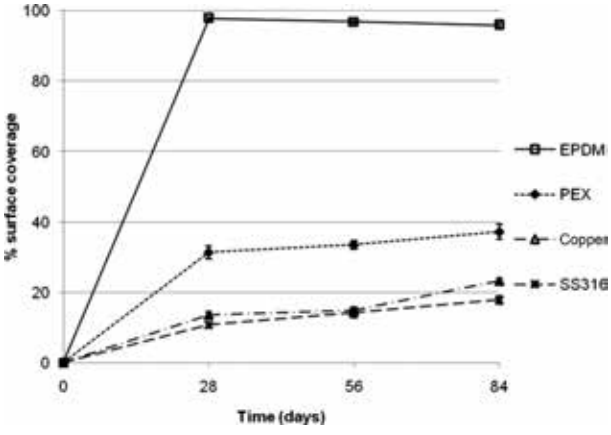

Figure 7. Surface coverage of EPDM, PEX, copper and stainless steel 316 (SS316) test rig inserts over 84 days, assessed using nucleic acid staining and confocal microscopy. Error bars = SD.

Qualitative assessment of bacterial viability

Qualitative assessment of bacterial viability revealed clear differences between materials stained after 84 days, and example images are shown in Figure 8. Live/Dead® staining of copper biofilm appeared to stain both the cells and the EPS, demonstrating the co-aggregation of groups of live (green) cells, as well

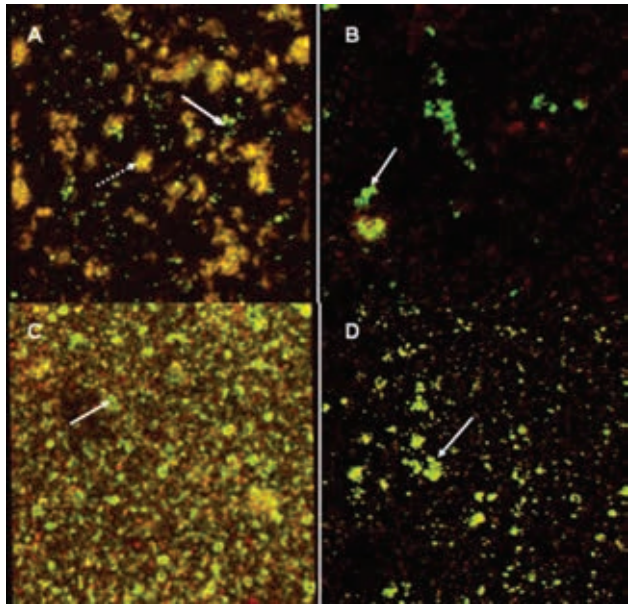

Figure 8. Confocal microscopy images of (A) copper, (B) PEX, (C) EPDM and (D) stainless steel 316 (SS316) biofilms stained after 84 days with Live/Dead® BacLight bacterial cell viability stain. Viable cells are green, non-viable cells are red. Microcolonies are indicated by solid white arrows in all images. In the case of the copper biofilm shown in (A), the EPS appears to have picked up a substantial amount of the stain (example indicated by dashed white arrow). In both PEX and EPDM biofilms, the majority of viable bacteria appear to be clearly microcolony-associated, with biofilm formation particularly profuse on EPDM. On SS316, small microcolonies are ubiquitously spread over the surface, with non-viable (red) individuals clearly visible.

as the existence of large numbers of both viable (green) and non-viable (red) individuals over much of the surface. In contrast, Live/Dead® staining of EPDM appeared to confirm previous SEM/coverage observations in that the surface was completely covered with biofilm material. Microcolonies consisting of viable cells were visible as highly fluorescent greenish-yellow patches. Whilst a large number of non-viable cells were clearly visible, these were not as obviously microcolony-associated. However, the numbers of bacteria present were so great, it was difficult to make accurate judgements as to the spatial arrangement of viable/non-viable cells. Microcolonies consisting primarily of viable cells were observed in biofilms formed on PEX after 84 days. Investigation of these microcolonies through manipulation of the projected (3D) image suggested that these were closely adhered to the substratum and lacking the structure observed in microcolonies observed on other materials, thus supporting SEM observations. The majority of cells existing as individuals on PEX appeared to be non-viable. In the case of SS316, the majority of viable bacteria were once again shown to be contained within microcolonies, with non-viable bacteria mainly distributed as individuals over the surface (Figure 8D). Many of these microcolonies were small, generally consisting of fewer cells than was observed on copper. The occasional single viable individual cell was observed. This distribution of small microcolonies supports the SEM analysis, where the similar observations were made.

DGGE analysis of bacterial communities

Both non-metric multidimensional scaling (nMDS) analysis and cluster analysis of DGGE fingerprints clearly indicate the existence of distinct bacterial communities associated with each of the four materials (Figures 9 and 10). Average similarities between replicates of each material were high in all cases, ranging from 77.8% to 88.92%. The average similarities of DGGE fingerprints between material types were lower, eg 53.10% between copper and PEX, and 38.38% between SS and all other materials (Table 1). Species richness, indicated by the mean number of bands present (Table 1), was highest on EPDM, and lowest on SS and PEX. The similarity half matrix of the DGGE fingerprints is shown in Table 1. The highest similarity was observed between copper and PEX (mean 53.10%, SD = 3.82%) whilst copper and SS exhibited the lowest similarity (mean 30.03%, SD = 2.76%). An ANOSIM R statistic of 1 was calculated, suggesting that replicates within groups were more similar than those from other groups.

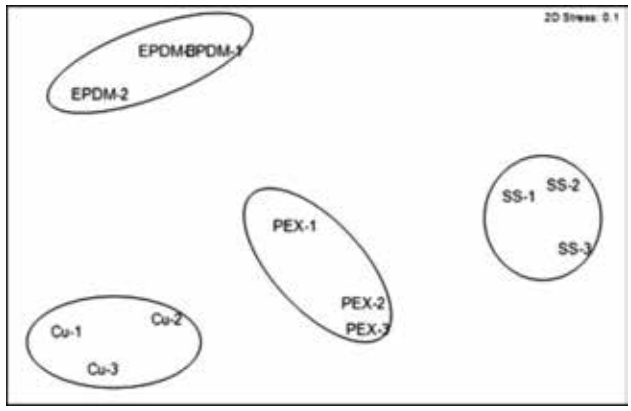

Figure 9. Non-metric multidimensional scaling analysis plot of DGGE fingerprints showing relative similarities between copper (Cu), stainless steel 316 (SS), EPDM and PEX biofilm communities after 84 days. 1–3 denote replicate number in each case.

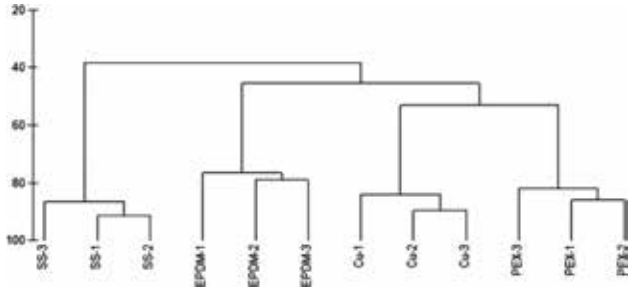

Figure 10. Cluster analysis of DGGE fingerprint indicating levels of similarity between copper (Cu), stainless steel 316 (SS), EPDM and PEX biofilm communities after 84 days. 1–3 denote replicate number in each case.

Discussion

Material choice in the context of a WDS has a major influence on the type and extent of biofilm formation therein, and therefore also on the potential for pathogen dissemination into the immediate environment. This, coupled with the fact that progress toward the development of commercially-viable, biofilm-proof materials appears to be slow, is a testament to the adaptive abilities of the vast majority of microorganisms to form biofilms. The results presented would appear to support this summation in that the materials used during this study all supported biofilm growth to some degree, yet these biofilms exhibited some clear differences.

There have been many studies conducted on the effect of material choice on biofilm formation, investigating a wide range of commonly-used materials. The approaches employed in these studies are varied, from *in situ* studies in a clinical setting

Table 1. Similarity half matrix between presence/absence of DGGE bands of EPDM, PEX, stainless steel 316 (SS316) and copper (Cu) biofilm communities after 84 days 12 hourly, 30 second flushing at 41°C.

	Replicate	Sp. r/ness	EPDM			PEX			SS316			Cu		
			1	2	3	1	2	3	1	2	3	1	2	3
EPDM	**1**	18	100.00											
	2		74.98	100.00										
	3		78.16	79.02	100.00									
PEX	**1**	15	55.00	49.63	49.25	100.00								
	2		49.10	42.39	42.65	85.94	100.00							
	3		51.67	44.87	48.03	78.78	84.93	100.00						
SS316	**1**	15	40.45	32.57	35.89	49.77	51.75	52.68	100.00					
	2		40.45	32.06	37.62	49.05	49.37	50.67	91.32	100.00				
	3		36.22	29.26	31.59	47.80	50.97	47.73	86.79	86.25	100.00			
Cu	**1**	16	46.69	45.32	49.91	53.61	47.09	48.06	27.41	27.28	25.64	100.00		
	2		43.29	38.89	44.29	58.72	55.78	55.25	33.35	33.66	31.51	83.46	100.00	
	3		39.47	37.16	41.10	55.50	53.25	50.61	30.97	30.40	30.04	84.55	89.55	100.00

Note: **Sp. r/ness** = species richness expressed as mean number of bands observed in three replicates.

(Percival 1999), to laboratory studies using reactors (Bressler et al. 2009; Moritz et al. 2010) and model distribution systems (Zacheus et al. 2000; Lehtola et al. 2005). The WDS employed here is unique in its design and whilst it is important to keep in mind that biofilm formation may differ significantly between water systems, due to differing conditions therein, the results obtained are generally reflective of previous studies involving these materials and allow several conclusions to be drawn.

The observation that EPDM supported biofilm formation at a consistently higher level than the other materials studied is in agreement with studies by Bressler et al. (2009) and Moritz et al. (2010), with the former reporting CAB counts of 10^8 cfu cm^{-2} after 14 days, whilst the latter reported $\sim 10^7$ cfu cm^{-2} over the same period, with a marginal net drop in numbers of CAB over the remaining 29 days of the study. *Pseudomonas* spp. were cultured at levels higher than the numbers of total CAB seen on any other material, and the inclusion of *P. aeruginosa* into WDS biofilms has previously been reported (Rogers et al. 1994; Lee and Kim 2003; Bressler et al. 2009; Moritz et al. 2010). Given that culture-based analysis severely underestimates bacterial numbers in a sample, this observation gives cause for concern, given the high profile occupied by members of this genus as nosocomial pathogens, in particular *P. aeruginosa* (Anaissie et al. 2002; Ortolano et al. 2005; Bressler et al. 2009). The presence of other potential pathogens such as *Legionella* and *Mycobacterium avium* at any point during the study cannot be discounted, and investigations into their presence and physiological status may form the basis of future work.

In recent years, the suitability of EPDM for use as a plumbing material has been subject to some debate, with the non-WRAS approved equivalent having previously raised some safety concerns from a microbiological viewpoint (Anon 2006). The tendency for elastomeric materials such as EPDM, and plastics such as PEX, to leach potential microbial nutrients such as phosphorus-based compounds into the water is believed to be a major contributory factor towards the formation of biofilm thereupon, and EPDM has previously been shown to support high numbers of autochthonous drinking water bacteria, as well as *P. aeruginosa* and *L. pneumophila*, in comparison to commonly employed metals and plastics (Rogers et al. 1994; Kilb et al. 2003; Lehtola et al. 2004; Bressler et al. 2009). Careful flushing, after manufacture and before installation, may be a way of alleviating rapid and profuse biofilm growth such as was apparent in this study. However, other factors also affect biofilm formation, and it is unlikely that removal of leachable biodegradable material would provide the sole solution. Based upon the evidence presented in this study, coupled with that of other EPDM-based studies, the suitability of EPDM for use as a major component in plumbing systems is questionable.

The duration of any study of this kind will have a major bearing on the results obtained, given the effect of time on dynamic aspects of biofilm formation, such as biomass development and community changes. It may be argued that gathering data over a period longer than the 84 days of this study would be of greater practical benefit, given that most systems are intended for long-term use post-installation, and the slow growth of bacteria often associated with such a challenging environment. Over extended periods (> 200 days) it has been shown that copper and PEX support similar levels of biofilm, even if plastic materials such as PEX initially form biofilms more rapidly (Zacheus et al. 2000; van der Kooij et al. 2005). This is thought to be due to the initial leaching of biodegradable substances from PEX (Lehtola et al.

2004), although copper may also be exerting an initial antimicrobial effect in this case. These effects are eventually negated and hence the two materials begin to show similar levels of biofilm.

CLSM analysis of Live/Dead®-stained biofilms after 84 days yielded insights into how their physiological state differed according to the material on which they were grown. In all cases, it was observed that microcolony formation was linked to the presence of a far greater number of viable microorganisms, with individual (ie non-microcolony associated) cells predominantly exhibiting non-viability. The inclusion of CLSM analysis where possible may be considered fundamental to modern biofilm study as it provides insights which are not possible using other microscopical techniques such as SEM. Less versatile than CLSM, SEM involves highly destructive preparation processes. However, this study shows that the two techniques employed in tandem are highly complementary. Microscopical analysis of EPDM biofilm indicated the presence of microcolonies of viable cells under CLSM, a detail which is not observable under SEM. Conversely, SEM revealed a wide variety of microorganism morphologies, including protozoa, providing a qualitative, if crude, evaluation of community diversity.

The association of protozoa with mature WDS biofilms has been well documented, particularly with reference to the exploitation of species such as *Acanthamoeba* and *Hartmanella* by *Legionella* spp. (Thomas et al. 2004; Garcia et al. 2007), and has also been reported on both SS and PVC (Pedersen 1990). The fact that no protozoa were observed on any surface apart from EPDM during this study may be due to the comparative short term nature of this study, and the consequent relative immaturity of non-EPDM biofilms. Further work in establishing their relationship with EPDM biofilm-associated bacteria, in particular *Legionella* spp., would enhance understanding of biofilm ecology and pathogen dissemination associated with this material.

The heavy staining of the EPS component using CLSM may be due to the presence of high levels of extracellular DNA, given that the Live/Dead® staining kit is composed of two nucleic acid stains, although this was not definitively confirmed. It is possible that preferential binding of the stain to extracellular DNA in the EPS may have occurred, thus reducing the efficiency with which the stain bound to the target bacteria, particularly those exhibiting low levels of RNA, a possible indicator of low metabolic activity and a target molecule for the nucleic acid stains used. ATP analysis suggested that overall metabolic activity of copper biofilms was indeed lower at 84 days than on any other material, thus partially supporting this theory. Extracellular DNA has been described as a key structural component in many biofilms under certain environmental conditions, such as those formed by *P. aeruginosa* (Allesen-Holm et al. 2006) and *Neisseria meningitidis* (Lappann et al. 2010). However, its employment as a structural component in mixed environmental biofilms has not been widely studied. Copper was the only material on which possible profuse extracellular DNA production and its subsequent Live/Dead® detection was observed. It would have been prudent to definitively confirm its presence/absence by other means, in order to rule out the possibility of non-specific binding to other EPS components, for example by employing the fluorescence/microplate-based method of quantification used by Lappan et al. (2010). This is an area worthy of further investigation. A more in-depth analysis of the biofilm EPS on each material would also have been of value, given that this component forms a considerable proportion of many biofilms and plays a crucial role in biofilm form and function, playing a variety of constructive, protective and even nutritive roles (Flemming et al. 2007). On this basis, it would be desirable to factor EPS analysis into any future biofilm study.

Microscopic investigation of SS316 and PEX provided useful insights into what were revealed to be structurally very different biofilms. SS316 biofilms were characterized by microcolonies in which viable bacteria predominated, whilst PEX was unique in that a large number of individual (ie non-aggregated), surface-associated cells were observed in comparison with other materials. That PEX failed to support the obvious development of microcolonies extending away from the pipe surface and into the bulk fluid may be explained by examining the hydraulic forces which are likely to be at work within the inserts composed of this material. Because PEX had a smaller inner diameter in comparison to the two metals, it is assumed that the shear stresses acting on the attached bacteria would have been greater than those observed on, for example, copper, therefore favouring the formation of thinner biofilms, a phenomenon described by Melo and Vieira (1999). Whilst EPDM piping had the same dimensions as PEX, it is possible that other factors, such as greater surface roughness, which increases the available colonisable surface area whilst influencing microbial cell transport and attachment (Percival 1999), and available micronutrients, may have negated such hydraulic effects in this case.

Analysis of surface coverage using nucleic acid staining and CLSM clearly supported observations using other techniques, in that rapid and complete coverage of the EPDM surface was seen after 28 days whereas, in the case of the other materials, coverage

was seen to increase gradually over time following an initial rapid development of a non-confluent biofilm. CLSM provided perhaps the clearest indication that the non-metallic materials were promoting greater initial biofilm formation, and that SS316 and copper demonstrated similar coverage levels over time. It is important to recognize the possible limitations in analyzing the material surface in this way. Firstly, application of a nucleic acid stain means that the majority of what was analyzed was likely to be cellular in nature, although as mentioned the possibility of binding to structural (and non-structural), EPS-bound extracellular DNA is a possibility. Therefore, the EPS component is largely ignored. Secondly, analyzing a two-dimensional or a 'plan' view of a curved pipe surface largely ignores the fact that biofilm growth may not only be occurring over the pipe surface but also approximately perpendicular to the surface, depending on the overriding local flow conditions. Therefore, a potentially significant proportion of the total biomass may be overlooked, particularly in situations when laminar flow or stagnation predominate, as this has been shown to promote the growth of thicker, less cell-dense biofilms (Melo and Vieira 1999). These limitations are recognized. However, adopting this approach was deemed acceptable, and it is believed that the results are in the main reflective of the overall biofilm development process, in that copper and SS316 biofilm coverage was similar throughout the study, with PEX biofilm coverage levels slightly greater, and EPDM exhibiting gross contamination.

The mode of operation of the test rig played a significant role in determining the way in which biofilms developed therein. The selected flushing regime, whilst not necessarily reflective of normal WDS use, enabled this study to be carried out in a controlled manner, whilst ensuring regular delivery of water to each system and measurable biofilm formation. As it was, a lengthy stagnation period was enforced on the forming biofilms for the majority of the time, and this can lead to increased detachment both during the stagnation period and at the point of reintroduction of turbulent flow (Lehtola et al. 2006). This may go some way in accounting for the high numbers of CAB (and ATP) observed in the EPDM system effluent at day 28, after which time the biofilm stabilised as it reached stationary state and adapted to the flow regime employed, a situation which manifested itself as a reduction in both CAB and ATP levels. However, the limitations of these techniques should be borne in mind in that there exists the possibility of the presence in the effluent of bacteria in the VBNC state (and exhibiting low activity).

Bacterial attachment on SS has been extensively researched due to its use in a wide range of industrial processes which expose it to microbial contamination, with the two main focal points of such research being the effects of surface finish (Arnold and Bailey 2000) and SS grade (Percival et al. 1998b; Percival 1999) on microbial colonization. Several authors have reported a tendency for bacteria to preferentially colonize grain boundaries, scratches and surface imperfections, with highly polished surfaces showing a lesser degree of colonization (Kielemoes et al. 2000; Medilanski et al. 2002). However, during this study no evidence of this was observed, with surface distribution of bacteria (as either individuals and in microcolonies) apparently quite homogenous.

Other studies involving SS have also included other materials, in various combinations, such as copper, PVC, and polyethylene (PE) (Niquette et al. 2000; Zacheus et al. 2000; van der Kooij et al. 2002). These studies have shown that there is little difference over extended periods of time (up to 2 years) between these materials, as effects both conducive and inhibitive to biofilm formation are gradually negated. Therefore, if a new WDS is to be installed, budgetary considerations and resistance to microbially induced corrosion, a phenomenon to which copper is particularly susceptible (Walker et al. 1991; Percival et al. 1997; Critchley et al. 2001), may be factors which ultimately govern material choice.

PCR-DGGE analysis of bacterial communities associated with different materials after 84 days showed that, while species richness did not vary greatly between the four materials, the communities were clearly very different. EPDM demonstrated the greatest species richness. Whilst this is perhaps unsurprising given the large amount of biofilm associated with this material, the number of bands observed was lower than has been previously observed. For example, Bressler et al. (2009) reported up to 68 DGGE bands derived from drinking water biofilms which had been grown on EPDM coupons immersed in a laboratory flow-through reactor system for 14 days. However, any direct comparisons would be unwise, given the differing experimental procedures employed. It is presumed that the growth of copious biofilm would offer greater opportunities for recruitment of new bacterial species into the existing biofilm, resulting in the increased species richness (in comparison to other materials) which was indeed observed, albeit at what is possibly a lower-than-expected level. Few studies have specifically employed DGGE to investigate bacterial communities on plumbing materials (for examples, see Bressler et al. (2009) and Yu et al. (2010)), preferring instead to employ techniques such as fluorescence *in situ* hybridization (FISH) and culturing to target specific microorganisms (eg Moritz et al. 2010).

In conclusion, copper and SS316 showed few significant overall differences in terms of biofilm formation. ATP and culture-based analysis of inserts showed that PEX may also be performing at a very similar level. These observations are generally in agreement with the results of other, longer-term studies (Zacheus et al. 2000; van der Kooij et al. 2002). It may be concluded that the main benefit of this study has been to identify EPDM as a potentially unsuitable material for use as a major component in WDS.

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Determinants of *Legionella pneumophila* Contamination of Water Distribution Systems: 15-Hospital Prospective Study

Richard M. Vickers, BS; Victor L. Yu, MD; S. Sue Hanna, MPH, RN; Paul Muraca, MS; Warren Diven, PhD; Neil Carmen, BS, MER; Floyd B. Taylor, DSc

ABSTRACT

We conducted a prospective environmental study for *Legionella pneumophila* in 15 hospitals in Pennsylvania. Hot water tanks, cold water sites, faucets, and showerheads were surveyed four times over a one-year period. Sixty percent (9/15) of hospitals surveyed were contaminated with *L pneumophila*. Although contamination could not be linked to a specific municipal water supplier, most of the contaminated supplies came from rivers. Parameters found to be significantly associated with contamination included elevated hot water temperature, vertical configuration of the hot water tank, older tanks, and elevated calcium and magnesium concentrations of the water ($P < 0.05$). This study suggests that *L pneumophila* contamination could be predicted based on design of the distribution system, as well as physicochemical characteristics of the water. [Infect Control 1987; 8(9):357-363.]

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INTRODUCTION

Legionnaires' disease is now recognized as a major nosocomial problem.[1-3] Its presence has been linked to the degree of *L pneumophila* contamination within the hospital water distribution system. We have found *Legionella* contamination of the water supply linked to the presence of Legionnaires' disease within these same hospitals.[4-8] Currently, notable gaps exist in our knowledge of the prevalence of *L pneumophila* contamination of water distribution systems and those environmental factors that predispose to such contamination. Specifically, is the source of incoming water a predisposing factor for *L pneumophila* contamination? Are there physicochemical characteristics of water that might predispose to contamination of water distribution systems by *L pneumophila*? And, do certain types of plumbing and water distribution systems have a predilection for *L pneumophila* colonization?

We, therefore, conducted a 15-hospital prospective study over one year in order to determine the extent of *Legionella* contamination in these hospitals and to elucidate those factors that might predict contamination of these water distribution systems.

METHODS

Hospitals

The 15 study hospitals were all members of the Hospital Council of Western Pennsylvania, an association of hospitals and health care facilities in western Pennsylvania. The Council is a nonprofit, voluntary organization offering programs in administration, professional services, and education for member hospitals. One of the notable programs is the group purchasing program in which hospital goods are purchased collectively at a cost savings. The 15 hospitals enrolled in the study had volunteered their participation in response to a solicitation sent to 45 hospitals by the Hospital Council. None of the hospitals enrolled were known to have cases of legionellosis.

The 15 hospitals were geographically located as follows:

TABLE 1
SURVEY OF WATER DISTRIBUTION SYSTEMS FOR 15 HOSPITALS FOR *L PNEUMOPHILA* CONTAMINATION

Hospital No.	% HWT Samples *Lp*	% Distal Sites *Lp*	Serogroups Represented	Age* Years	HWT (Horizontal [H] Vertical [V])	Water Source
51	0	0	NA	2	H	River
81	0	0	NA	4	H	Lake
63	0	0	NA	4	H	River
31	0	0	NA	4	H	Well
18	0	0	NA	17	H,V	Lake
58	0	0	NA	19	H	Lake
99	0	10	4	15	H	River
38	17	5	1,4	34	H,V	River
78	17	17	4,5	29	H	River
94	41	0	3,6	25	H,V	River
56	50	10	1,3	23	H	River
33	36	38	1	25	H,V	River
41	71	5	1,4,6	15	H,V	Well
90	77	95	1,2,5,6	5	V	River
96	83	25	1	18	V	River

NA = Not applicable.
HWT = Hot water tank.
Lp = L pneumophila.
** If multiple hot water tanks in one hospital, mean age is given.*

three hospitals in the immediate Pittsburgh area; eight hospitals within a radius of 10 to 30 miles; and four hospitals within a radius of 50 to 80 miles. The bed capacities of the hospitals ranged from 150 to 800, with a mean of 400. In most instances, these hospitals served both metropolitan and urban populations and have teaching programs. The Pittsburgh hospitals are serviced by the City of Pittsburgh Water Authority whose source is the Allegheny River. Of the 12 hospitals outside the city (10- to 80-mile radius), 8 are serviced by independent water authorities and 4 are supplied by the Western Pennsylvania Water Company using the Monongahela River. Also, two of the independent water authorities use the Youghiogheny River as a source of water.

Water Distribution Systems

Of the 15 hospitals surveyed, 7 (47%) had a preventive maintenance program that consisted of cleaning or flushing the tanks on a weekly to annual basis. Two of fifteen (13%) had periodic checks for leaks and 6 of 15 (40%) had no preventive maintenance program.

Two designs were observed for hot water recirculation: total system volume recirculation (15/15, 100%) and recirculation within individual tanks (7/15, 47%). Recirculation of water throughout the system is accomplished by low volume pumps. The circulation is slow and functions to keep the water warm throughout the system such that the system can deliver hot water on demand to distal sites. Recirculation of hot water within a tank minimizes scale/sediment accumulation. The water is usually mixed by a pipe that leaves the top of the tank, loops outside, and reenters at the bottom.

The capacity of individual hot water tanks ranged from 264 to 6016 gallons (mean = 1500 gallons). The configuration of the tanks is given in Table 1. Tanks were designated as "vertical" if the vertical dimension (height) exceeded the horizontal dimension (width), while tanks were designated as "horizontal" if the horizontal dimension exceeded the vertical dimension.

Specimen Collection and Processing for *Legionella*

Hot water tank specimens were collected from the 15 hospitals in four sampling periods (October 1982, January 1983, April 1983, October 1983) over one year by the same team of investigators. Water was generally collected from tank bottoms in screw-cap bottles in the amount of 20 to 500 mL. Water temperatures (both set-point and actual tank sample) were recorded at time of sampling. Ten distal site (faucet or showerhead) samples from each hospital were collected on swabs in two of the four sampling periods. The same sites and tanks were sampled throughout the study period. One cold water site, usually the cold water tank, was also sampled from each hospital in the first sampling. Water and swabs were plated directly onto selective media containing dyes, glycine, and antibiotics and processed as previously described.[4,5] (This medium is commercially available from Gibco, Madison, WI, and Remel, Lenexa, KS.) Ten to forty milliliters of direct culture-negative water samples were concentrated by centrifugation at 1000 g for 20 minutes, the sediment resuspended at 1.0 mL volume, and then recultured using 0.1 mL per plate. A modified acid-wash treatment was used on water samples overgrown with non-*Legionella* organisms.[9] Ten milliliters of water was centrifuged at 1000 g for 20 minutes, the sediment resuspended at 1.0 mL, 2.0 mL acid-buffer added for 3 minutes, and 0.1 mL

of the mixture plated onto buffered charcoal yeast extract and selective media.

Metal Ion Analysis

Hot water tank samples were analyzed for metallic ions. Concentrations of calcium,[10] magnesium,[10] zinc,[11] iron,[12] and lead[13] were determined by atomic absorption spectroscopy. Samples were stored at 2° to 6°C until tested. Analyses were performed on coded samples without knowledge of culture results.

Suspended Solids Analysis

As previously published,[14] hot water tank samples were analyzed for nonfilterable solids. One hundred milliliters of the suspended water sample was passed through a 0.45 micron pore-sized filter in a Gooch crucible. The crucible was placed in a drying oven at 100°C for one hour and then cooled in a dessicator. The solid analysis was calculated from the weight of the nonfilterable residue.

STATISTICAL ANALYSIS

The study was analyzed in two ways. The first analysis was directed at individual hot water tanks (N = 47, two instantaneous heating systems excluded). It was assumed that hot water tanks constitute a unique environment in which parameters specific to an individual tank may be operational in the determination of *L pneumophila* positivity. Outcome measures were presence and quantity of *L pneumophila* isolated for each individual hot water tank. Observations for each tank included chemical content of the water within the tank, temperature of the tank water, age, capacity, and configuration of each tank.

The second analysis was directed at the individual hospital (N = 15). This analysis was based on the assumption that there would be ecological parallels or similarities within each hospital that would be operative for *all* tanks within the same hospital. Outcome measures were presence of *L pneumophila* within the water distribution system at any time. Observations for each hospital were those parameters that would be constant for all tanks within that hospital, including source of incoming water, thermostat set-point, presence of a maintenance program, and geographic location in the state.

All parameters were stored in a data bank housed on the Prophet System (Division of Research Resources, National Institutes of Health). To assess association between outcome measures and individual observations, the Fisher's exact test was used. The Mann-Whitney rank sum test was applied in those instances where normality assumptions could not be met.

Multivariate Analysis

To examine the association of *Legionella* positivity and other factors in more detail, the following strategy was used: those factors found significantly associated with *Legionella* positivity using two-way contingency table analysis were all entered as a group into a stepwise logistic regression model in which *Legionella* positivity was the dependent binary variable (BMDP, University of California). The analysis entailed adding variables singly to the model, comparing the best model with the additional variable to the existing model, and retaining the new model if it provided a significantly better description of the data than the preceding model. The probabilities to enter and remove variables were set respectively at 0.10 and 0.15. To further explore the relationship of *Legionella* positivity and the variables selected by the logistic regression, the methods of generalized linear models were used.[15] Both hierarchical and nonhierarchical models were considered. The values for sensitivity, specificity, and predictive value were computed as previously described.[16]

TABLE 2
WATER TANK CONFIGURATION SIGNIFICANTLY ASSOCIATED WITH *L PNEUMOPHILA* CONTAMINATION

Configuration	*Lp* Present	*Lp* Absent	Fisher's Exact Test, *P* Value
Horizontal	8	20	
Vertical	15	4	< 0.05

Data shown is for 47 hot water tanks in 15 hospitals (2 instantaneous steam heating systems not included).
Lp = L pneumophila.

RESULTS

Environmental Survey for *L pneumophila*

Of the 15 hospitals sampled, 9 of 15 (60%) yielded *L pneumophila* during the one-year sampling period (Table 1). Of the 9 positive hospitals, the percent of hot water tanks in a given hospital yielding *L pneumophila* over the four sampling periods ranged from 17% (1/6) to 100% (4/4). Forty-nine percent (23/47, two instantaneous systems excluded) of all hot water tanks yielded *L pneumophila* with 91% (21/23) positive on more than one sampling. Hot water tanks from one hospital failed to yield any *L pneumophila* over the one-year period, but 10% of distal sites including faucets and showerheads yielded the organism. *L pneumophila* was isolated from cold water sites of only two hospitals (#38 and #41 in Table 1).

Serogroup 1 was seen in 67% (6/9) of the positive hospitals, but all serogroups tested (1 through 6) were found in at least one hospital (Table 1). Multiple serogroups were isolated from four tanks in three hospitals.

The concentration of *L pneumophila* recovered from positive samples ranged from 10 to 3000 colony-forming units (CFU) per milliliter. No significant association could be established for concentration of *L pneumophila* versus type of water distribution system and physicochemical characteristics of water.

Water Source

The 15 hospitals received their water via ten different water companies and no single source could be implicated as significantly more contaminated. Table 1 shows that most of the water suppliers of contaminated hospitals received their water from rivers—the Youghiogheny, Monongahela, and Allegheny ($P < 0.09$, Fisher's exact test).

Plumbing System Characteristics

Configuration of the hot water tanks was found predictive of *L pneumophila* contamination (Table 2). Vertical tanks were significantly more likely to be contaminated than horizontal tanks ($P < 0.05$, Fisher's exact test). No association was found for tanks with recirculation versus those without for the presence of *Legionella* contamination. Two hospitals used an instantaneous steam heating system (Figure) in addition to conventional hot water tanks, and no evidence of *L pneumophila* contamination was found in these hospitals.

Table 3 shows the thermostat set-point temperature of the hot water tanks was significantly associated with the presence of *L pneumophila*; tanks with set-point temperatures exceeding 60°C were more likely to be free of *Legionella*. We also observed that thermostat set-point only roughly correlated with the actual temperature of the water when sampled. More detailed analysis of 102 samplings taken from 47 tank samples in which the *actual* temperature was entered for statistical analysis (as opposed to thermostat set-point) confirmed that higher temperatures were significantly associated with the negative cultures ($P < 0.05$, Fisher's exact test, data not shown).

The age of the individual tank was significantly associated with the presence of *L pneumophila* (Table 4). Newer tanks were more likely to be free of *L pneumophila* contamination ($P < 0.05$, Mann-Whitney rank sum test). Tanks less than five years old were generally free of *L pneumophila* ($P < 0.05$, Fisher's exact test).

Application of a periodic preventive maintenance (as described in the Methods section) by the hospital had no apparent effect on the presence of *L pneumophila* in the water distribution system. We also point out that appearance, cleanliness, and overall upkeep of the system was not associated with the presence or absence of *L pneumophila* contamination.

TABLE 3
WATER TANK TEMPERATURE SIGNIFICANTLY ASSOCIATED WITH *L PNEUMOPHILA* CONTAMINATION OF HOT WATER TANKS

Thermostat Set-Point	*Lp* Present	*Lp* Absent	Fisher's Exact Test, *P* Value
< 60°C (140°F)	9	3	< 0.05
≥ 60°C (140°F)	0	3	

Data shown is for L pneumophila *positivity in 15 hospitals. Mann-Whitney rank analysis for 47 individual hot water tanks is also significant,* P < 0.05.

Fisher's exact test analysis for actual recorded temperature *of 102 water tank samples is also significant,* P < 0.05.

Lp = L pneumophila.

Water Quality

Higher concentrations of calcium and magnesium in tank water were significantly associated with *L pneumophila* positivity of that water ($P < 0.05$, Mann-Whitney rank sum test). No association was found for copper, zinc, iron, and suspended solid concentrations (Table 4).

Multivariate Analysis

Those factors found to have significant association with *Legionella* positivity ($P < 0.05$) when each was considered separately through the use of two-way contigency table methods were as mentioned above: age of tank, tank configuration, tank water temperature, calcium concentration, magnesium concentration, and source of the water. When these factors were used in the logistic regression model, the factors that remained significantly associated with positivity were source of water and calcium concentration. The water tanks are classified accordingly in Table 5-A. The results of further investigation using hierarchical and nonhierarchical models in the generalized linear models program and using Table 5-A as input indicated that the best model was the one that included only the interaction terms of water source and calcium concentration. The statistic from generalized lin-

TABLE 4
FACTORS ASSOCIATED WITH PRESENCE OF *L PNEUMOPHILA* IN 47 HOT WATER TANKS IN 15 HOSPITALS

	Median (range) Values in Hot Water Tanks				Mann-Whitney
	Lp Present		*Lp* Absent		*P* Value Rank Sum
Age	16 years	(5-37)	11 years	(1-42)	< 0.05
Calcium	30 mg/L	(3-48)	21 mg/L	(1-31)	< 0.05
Magnesium	10.2 mg/L	(1.1-20.4)	5.5 mg/L	(1.1-288)	< 0.05
Copper	1.0 mg/L	(0.07-20.2)	0.85 mg/L	(0.11-345)	NS
Zinc	2.85 mg/L	(0.11-18.6)	.49 mg/L	(0.08-15.2)	NS
Iron	0.16 mg/L	(0.09-25.9)	0.22 mg/L	(0.13-8.68)	NS
Suspended solids	206 mg/L	(13-761)	102 mg/L	(51-300)	NS
Capacity	850 gallons	(480-6020)	846 gallons	(110-3450)	NS

Lp = L pneumophila.
NS = Not significant, P > 0.05.

ear models program for testing the interaction model was the lack of fit chi-square = 3.404 with 2 degrees of freedom, $P = 0.182$, indicating no lack of fit. Of the four combinations of water source and calcium concentration, the combination of river source of water and high calcium concentration differed from the other three combinations, which did not differ from each other. These latter three were collapsed into a single class and used as a reference against which to compare the observations from the river source of water and high calcium concentration in order to obtain the odds ratio given in Table 5-B. The combination of river source and high calcium concentration also gave the highest sensitivity and predictive value when compared with individual parameters, which were significant via univariate analysis (Table 6).

DISCUSSION

This survey is the most comprehensive and detailed for *L pneumophila* contamination of hospital water distribution systems yet reported. Because *L pneumophila* contamination can be seasonal, culturing at only one or two points in time will not provide an accurate measure of contamination. This study examined hot water tanks and distal sites (showerheads and faucets) in 15 hospitals four times over the one-year study period. Thus, not only was the major source of the organism being cultured (hot water tanks), but the sites relevant to the individual patient were also surveyed. The high frequency of culturing provided an index of consistency. The same investigators were involved in obtaining samples from each hospital and the collection methods were standardized. State-of-the-art culture methodology was employed, including the use of selective dye-containing media (superior and more efficient than guinea pig inoculation),[17-19] large volume centrifugation, and acid treatment for specimens contaminated with resistant water bacteria.[9] As a result, we were able to obtain a detailed overview of water contamination.

We found that a surprisingly high percentage (60%) of the 15 hospitals surveyed were contaminated with *L pneumophila* with most of the hospitals showing consistent contamination throughout the study. This same culture protocol had previously revealed environmental contamination in four other Pittsburgh hospitals.[5-8] In three of these hospitals, nosocomial legionellosis had never been documented prior to environmental culturing. When specialized laboratory tests for *Legionella* were subsequently introduced into these hospitals, these three hospitals were discovered to have a significant incidence of nosocomial legionellosis.[6-8] Although no attempt was made to link water contamination to disease in the 15 hospitals in this study, these findings have obvious implications for the detection of occult nosocomial legionellosis, given our previous experience. Because the percentage of contaminated hospitals was fairly high in this study, we wonder if surveys elsewhere might show similar frequencies. If so, the possibility arises that underdiagnosed nosocomial legionellosis may become more apparent as clinician awareness increases and as specialized laboratory testing for *Legionella* becomes more readily available.

TABLE 5
A. DISTRIBUTION OF OBSERVATIONS BY WATER SOURCE, CALCIUM CONCENTRATION AND *LEGIONELLA* POSITIVITY FOR INDIVIDUAL HOT WATER TANKS*

	Calcium	*Lp* Present	*Lp* Absent
Nonriver source	High	0	4
	Low	2	5
River source	High	18	7
	Low	0	4

B. COLLAPSED FORM OF PART A (above)

	Lp Present	*Lp* Absent
River source plus high calcium	18	7
Other conditions	2	13

Odds Ratio = 16.71.
95% Confidence Interval (2.97, 93.78).

**N = 40; in 7 tanks, calcium concentrations were not available.*

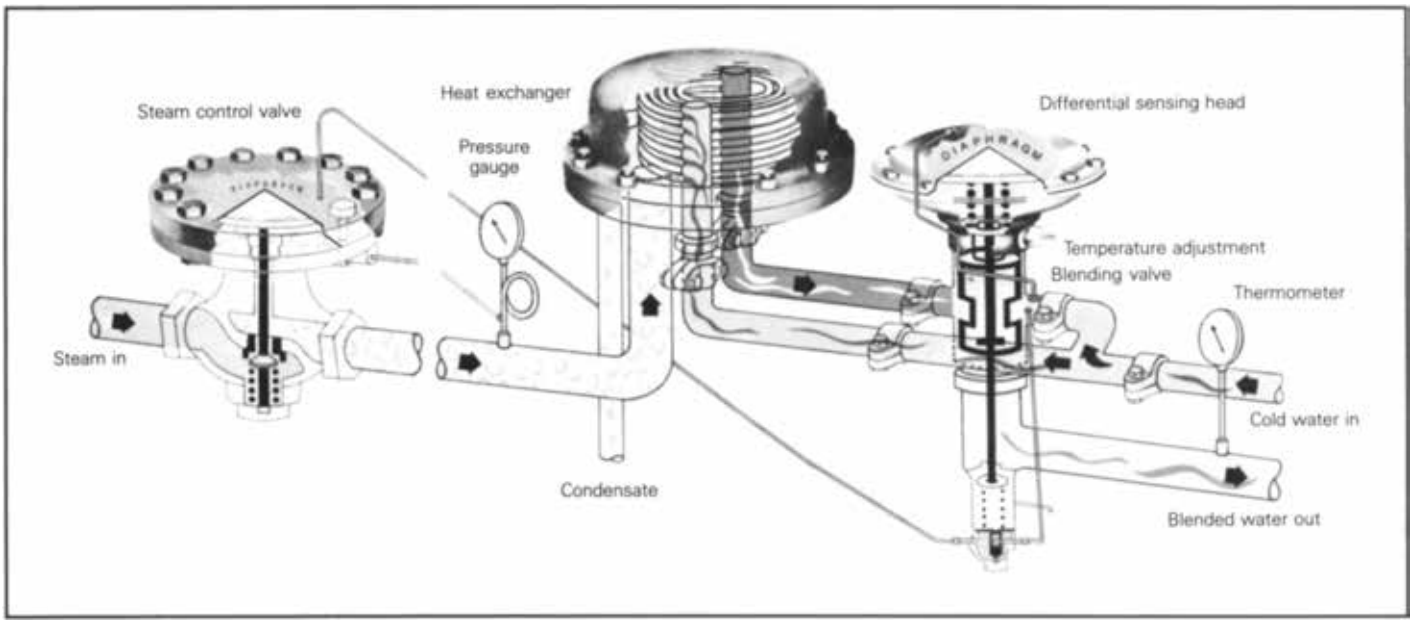
High calcium = calcium ≥ 15 mg/L.
Low calcium = < 15 mg/L.

Lp = L pneumophila.

TABLE 6
SENSITIVITY, SPECIFICITY, AND PREDICTIVE VALUE FOR HOT WATER TANK PARAMETERS APPLIED TO 47 HOT WATER TANKS IN 15 HOSPITALS

	Sensitivity	Specificity	+ Predictive Value*	− Predictive Value†
River source + calcium	90	65	72	87
Calcium > 15 mg/L	90	45	65	82
River source	87	31	56	77
Temperature > 60°C	65	83	53	73
Vertical configuration	65	83	79	71

**Predictive value of a positive result.*
†*Predictive value of a negative result.*



Schematic of an instantaneous steam heating system. This system has no hot water tank (the breeding ground for *L pneumophila*) and heats water under high steam pressure to 88°C (which is bactericidal for *L pneumophila*).

The design of the water distribution system appears important in predisposing to *L pneumophila* colonization. For example, water tanks whose vertical dimension exceeded their horizontal dimension were significantly associated with *L pneumophila* colonization. The reason for this condition remains to be determined, but vertical water tanks have more diverse strata of heating within the tank and sediment accumulation at the bottom of the tank may be thicker.

The temperature of the hot water tanks was a critical factor for *L pneumophila* contamination. The thermostat set-point of the hot water tanks correlated with the presence of *L pneumophila*; lower temperatures were significantly associated with *L pneumophila* contamination. We caution that the set-point temperature may be an imprecise indicator of the temperature at the bottom of the tank (the site of maximal organism accumulation); the actual temperature was usually lower. When the *actual* temperature was used as the dependent variable in a sample of 102 water tank samples, statistical analysis confirmed that water samples at a higher temperature range were significantly less likely to be contaminated by *L pneumophila*. The optimal temperature for survival and propagation of *L pneumophila* in tap water ranges from 32° to 42°C; higher temperatures tend to be inhibitory for *L pneumophila*.[20-23]

Older tanks were significantly associated with contamination by *L pneumophila* (Table 4). The reason for this association is uncertain, but it should be noted that accumulation of scale and sediment would be minimal in a new system. In addition, the amount of deposition and replenishment of *L pneumophila* from incoming potable water would be related to the number of years the water tank was in service.

Two hospitals used an instantaneous steam-heating system in their water distribution systems, and neither had *L pneumophila* cultured from its water supply. Such a system would theoretically be nonconducive to *L pneumophila* colonization because these systems heat water to 88°C which is bactericidal for *L pneumophila*,[22] and because they have no hot water storage tank, a breeding ground for *L pneumophila* (Figure).[4]

We found that concentration of calcium and magnesium correlated significantly with *L pneumophila* contamination of hot water tanks. Calcium and magnesium are the principal divalent metallic cations involved in formation of scale deposits and are primary determinants of water hardness. Scale and sediment formation are dependent on a number of environmental variables including water pressure, temperature, flow rate, and water hardness. We have previously shown that *L pneumophila* localizes and concentrates in areas within the water distribution system laden with scale and sediment. The sediment contributes nutrients utilized by commensal microorganisms that foster the growth of *L pneumophila* as well as providing a physical shelter for the organism.[23]

We emphasize that *L pneumophila* contamination should not be construed as evidence that the water distribution system is being poorly managed. Hospitals with preventive maintenance programs were as likely to be contaminated with *L pneumophila* as hospitals without such programs. It should also be noted that chlorination was maintained in these water distribution systems at a standard level of one to two parts per million; however, this concentration is known to be inadequate in killing *L pneumophila*, a relatively chlorine-resistant microorganism.

The major weakness of this study is that it is confined to a relatively small number of hospitals in one geographic area. Thus, caution should be exercised in any extrapolation to individual hospitals. The predictive value of parameters found significant in this study may be less

useful in other geographic areas with lower prevalence of contamination. On the other hand, this study provides a framework for future large-scale studies over a wider geographic area. Parameters found significant in this study should be reassessed prospectively to confirm their validity.

We also emphasize that parameters found significant in this study should not be considered absolute; exceptions can easily be found. For example, one VA Medical Center did not encounter a problem with nosocomial legionellosis until they moved into their *new* hospital building. And, the once highly contaminated hot water tanks in the Pittsburgh VA Medical Center[4] have a horizontal rather than vertical configuration.

It is noteworthy that trends were easily discernible by statistical analysis. Furthermore, the parameters found statistically significant were supported by a plausible biological hypothesis that could explain the observed association. Thus, there seems to be rational and predictable ecology of this organism within water distribution systems. Knowledge of the design of the distribution system as well as physicochemical characteristics of the water can be useful in assessing the risk of *L pneumophila* contamination.

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A field study of the survival of *Legionella pneumophila* in a hospital hot-water system

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SUMMARY

The colonization, survival and control of *Legionella pneumophila* in a hospital hot-water system was examined. The organism was consistently isolated from calorifier drain-water samples at temperatures of 50 °C or below, despite previous chlorination of the system. When the temperature of one of two linked calorifiers was raised to 60 °C, by closing off the cold-water feed, the legionella count decreased from *c.* 10^4 c.f.u./l to an undetectable level. However, 10 min after turning on the cold-water feed which produced a fall in calorifier temperature, the count in the calorifier drain water returned to its original level. Investigations revealed that the cold-water supply was continually feeding the calorifiers with *L. pneumophila*. Simple modifications in the design of the system were made so that the cold-water feed no longer exceeds 20 °C; these measures have considerably reduced the number of *L. pneumophila* reaching the calorifiers.

INTRODUCTION

Legionella pneumophila is often found in the piped water of large buildings where it may serve as a source of human infection. Indeed, there have been a number of reports implicating hospital hot- and cold-water systems with outbreaks of Legionnaires' disease [1–3] in addition to those associated with cooling towers [4, 5]. For this reason, most hospitals follow Department of Health advice [6] which recommends circulating hot water should be delivered at the taps not below 50 °C to reduce the risk of infection.

Nevertheless, despite the fact that in many hospitals hot water is distributed to wards above 50 °C, *L. pneumophila* is frequently isolated from taps and showers in little used or remote parts ('dead-legs') of the plumbing system ([7] and Barker and Farrell, unpublished data). A previous report [8] showed that flushing intermittently the entire hot-water supply system of a hospital unit, with water at 77 °C, reduced the number of contaminating legionellae but did not necessarily eradicate them.

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We found that, in spite of careful maintenance on the calorifiers in a hospital unit using cleaning and flushing, and temporary chlorination of the water to 10 p.p.m. for 10 h, *L. pneumophila* was consistently isolated from the system. Thus the control of this organism in plumbing systems of large buildings continues to pose a problem for those responsible for their maintenance.

This investigation was initiated in 1986 to examine in detail the source of contamination, the dynamics of colonization and the survival of *L. pneumophila* in a hospital hot-water system. Samples were taken from the point at which the Severn Trent Water Authority (STWA) mains enters the establishment, from selected sites in the distribution network, and from the hot and cold outlets in the wards. The efficacy of raising calorifier temperatures as a means of controlling legionellae colonization was also examined.

METHODS

Water sampling protocol

Cold-water samples were taken at specific points in a segregated distribution system supplying two horizontal calorifiers (A and B), operated in parallel to provide domestic hot water for two hospital wards and the pathology department (Fig. 1). Samples were taken, as shown in Fig. 1 from: (1) the inlet of the STWA supply, (2) the hospital cold-water 'break-tank' (which reduces the mains water pressure in this system), (3) the water softener, (4, 5) the cold-water storage tank which feeds the calorifiers.

Calorifier study

After cleaning, flushing and disinfecting the system by drawing chlorinated water from the water storage tank, through the calorifiers and then out of the drain taps at the bottom of the vessels, preliminary samples were taken from each calorifier drain over a 6-month period to establish the level of contamination by legionellae. Thereafter, disinfection was done once more before survival studies were carried out by raising the temperature of the water throughout one calorifier to ascertain the temperature and time required to kill any contaminating legionellae.

The experiments were conducted in the morning (Test 1), when there was a high demand on the system for hot water and repeated when the demand for hot water was at its minimum during the afternoon (Test 2).

Test 1. The calorifier temperature was raised by closing the cold water feed to one of them (Fig. 1, A), whilst the feed to the second calorifier (B) remained open, so that it could be monitored as a control. Water samples were taken from the drains (Fig. 1, 6 and 7) of both calorifiers at the start of the experiment and then at regular intervals until the drain temperature of the test calorifier (A) reached approximately 60 °C. Then the cold feed valve was opened and 10 min later a further sample was collected.

Test 2. When the first calorifier had been tested as above, the test procedure was reversed, so that the temperature in calorifier (B) was increased to 60 °C.

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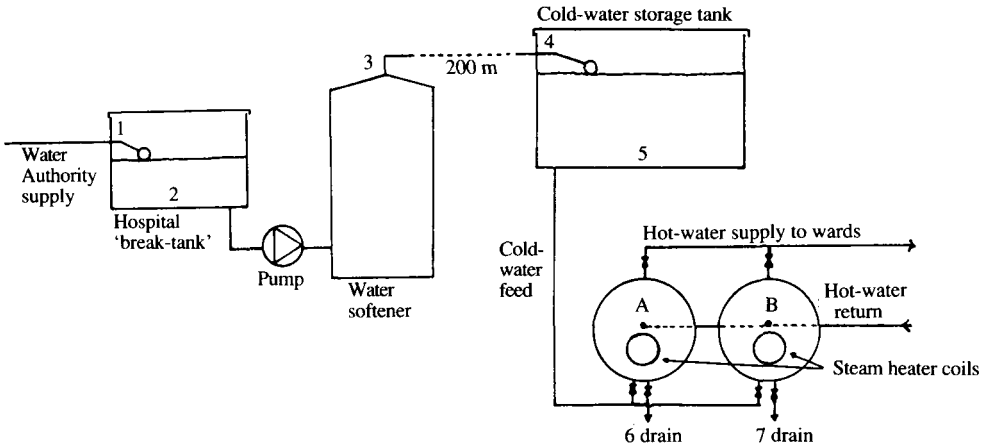

Fig. 1. A diagram (not to scale) of the water-distribution system supplying a hospital unit. Hot water is heated in two horizontal calorifiers A and B. Sample points 1, Water Authority inlet; 2, hospital 'break-tank'; 3, water softener; 4, inlet to the cold-water storage tank; 5, tank water; 6, 7, calorifier drains.

Laboratory methods

The bacterial flora of 1 l water samples was filtered out with a 0·2 μm, 142 mm diameter, nylon membrane under positive pressure. The membranes were then cut into segments and retained debris resuspended in 50 ml of sterile distilled water by vigorous shaking. Before culturing, a 10 ml volume of each suspension was heated to 50 °C for 30 min to reduce the number of bacterial contaminants.

The number of colony forming units per litre (c.f.u./l) of *L. pneumophila* in the concentrated samples were determined on buffered charcoal yeast extract agar (BCYE [9]) with and without the addition of glycine (0·3% w/v), polymyxin (80000 IU/l), vancomycin (3 mg/l), and cycloheximide (80 mg/l).

The inoculated plates were incubated at 37 °C in a moist atmosphere and examined daily for up to 10 days before discarding. Presumptive strains of legionella were tested for cysteine dependence before positive identification by immunofluorescence, using rabbit antisera, prepared against *L. pneumophila* serogroups 1–6 (supplied by the Division of Microbiological Reagents and Quality Control, Colindale, London).

RESULTS

Preliminary samples

Preliminary experiments showed that *L. pneumophila* serogroup 4 was present in 23 of 30 samples taken from calorifiers A and B drainage outlets during a 6-month period. These numbered from 10^2–10^5 c.f.u. of legionella per litre of water. Serogroups other than serogroup 4 were not found when up to six separate colonies from the isolation plates were examined by immunofluorescence for serogroups 1–6.

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Table 1. *The effects of time and temperature on the survival of* L. pneumophila *in drain waters of Calorifier A (Test 1, high hot-water demand)*

Time of water sample collection (min)	Calorifier A (cold-water feed closed)			Calorifier B (cold-water feed open)		
	Calorifier temperature (°C)		Viable count c.f.u./l (drain water)	Calorifier temperature (°C)		Viable count c.f.u./l (drain water)
	Top	Drain		Top	Drain	
Start	76·5	33	4×10^3	73	31	5×10^3
5	76	34	$3·5 \times 10^3$	72	28	$6·5 \times 10^3$
15	76	40·5	$3·0 \times 10^3$	71	28	5×10^3
30	75	49	1×10^4	70	27	$1·25 \times 10^4$
60	74·5	65	Legionella not isolated	66·5	27·5	$2·5 \times 10^4$
10 min after cold supply to calorifier A opened	74	35	$1·5 \times 10^4$	67	29	$1·5 \times 10^4$

Table 2. *The effects of time and temperature on the survival of* L. pneumophila *in drain waters of Calorifier B (Test 2, low hot-water demand)*

Time of water sample collection (min)	Calorifier A (cold-water feed open)			Calorifier B (cold-water feed closed)		
	Calorifier temperature (°C)		Viable count c.f.u./l (drain water)	Calorifier temperature (°C)		Viable count c.f.u./l (drain water)
	Top	Drain		Top	Drain	
Start	55	32	$1·2 \times 10^4$	60	32	$1·8 \times 10^4$
15	—	—	NT	60	34·5	$3·5 \times 10^4$
35	45	40·5	$1·4 \times 10^4$	59	37	1×10^3
47	—	—	NT	63	40	2×10^3
80	—	—	NT	71	50·5	2×10^3
100	50	32	4×10^3	65	60·5	Legionella not isolated
15 min after opening cold supply to calorifier B	68	40	2×10^3	61	39	6×10^3

NT, not tested.

Survival studies

As preliminary samples taken from the calorifiers had shown them to be consistently contaminated with *L. pneumophila*, the effect on the organisms survival of raising the temperature in one of them (calorifier A) was studied. Table 1 shows that before the cold water supply had been shut off (in order to increase the temperature in the vessel), 4×10^3 c.f.u./l of *L. pneumophila* serogroup 4 were found in the drain water, the temperature of which was 33 °C. When, 30 min after closing off the cold-water supply, the drain temperature had reached 49 °C, 1×10^4 c.f.u./l of *L. pneumophila* were found – this difference in bacterial count is thought to be within experimental error.

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However, 30 min later when the drain temperature had increased to 65 °C, legionellae were no longer detected in the sample. At this stage the cold-water feed to calorifier A was reopened; after only 10 min the drain water temperature had fallen to 35 °C and contained $1{\cdot}5 \times 10^4$ c.f.u./l *L. pneumophila* serogroup 4. The temperature at the top of the calorifier remained fairly constant throughout the experiment at about 75 °C. The count of *L. pneumophila* in the control calorifier (B), where the cold feed was left open, varied between 5×10^3 and $2{\cdot}5 \times 10^4$ c.f.u./l and the highest temperature recorded at the drain was 31 °C.

Table 2 shows the results obtained after closing the cold water supply to calorifier B (Test 2). Five samples of the drain water taken over an 80-min period, contained *L. pneumophila*, ranging in number from $1{\cdot}0 \times 10^3$–$3{\cdot}5 \times 10^4$ c.f.u./l. The temperature of the drain water at the start of the experiment was 32 °C and after 80 min it had reached 50·5 °C. Twenty minutes later the temperature had increased to 60·5 °C and legionellae were no longer detected. At this point the cold-water feed to calorifier B was turned on again and within 15 min the temperature had fallen to 39 °C and the legionella count had increased to 6×10^3 c.f.u./l.

High or low demand for hot water on the wards had no significant effect on the results of the survival studies. For Test 2, a more gradual increase in the drain temperature of calorifier (B) was achieved by regulating the amount of steam passing through the heating coil, to try and ascertain more precisely the temperature required to kill *L. pneumophila* under these conditions (Table 2).

Although these experiments revealed that the drain waters (below 50 °C) of calorifier A and B consistently contained legionella, it was reassuring to find that from samples of the hot water, at 52 °C from taps in the wards, *L. pneumophila* serogroup 4 was not isolated. It was also found that a temperature of about 60 °C killed legionella in the calorifier, because the organism was not isolated from drain water samples. However, as the organism reappeared in the drain water within 10 min of turning on the cold-water feed, it seemed likely that this feed to the calorifier was the source and therefore a detailed examination of the cold-water supply was made.

Legionellae were not isolated from cold-water samples, 1, 2 and 3, taken from the STWA inlet, the hospital 'break-tank' and the water softener (Fig. 1). There was 200 m of pipe between the water softener and the water-storage tank feeding the calorifiers and the only convenient sampling point for this length of pipe was at the ball valve inlet to the tank itself (Fig. 1, sample point 4). Three samples of this water were negative, but a fourth sample contained a small number of *L. pneumophila* serogroup 4; the count was 5×10^2 c.f.u./l of water. Four of four samples of the cold-tank water (Fig. 1, sample point 5), yielded *L. pneumophila* serogroup 4, with counts ranging from 6×10^2–$4{\cdot}4 \times 10^4$ c.f.u./l.

DISCUSSION

Our findings suggest, as has been shown by others [10] that *L. pneumophila* gets into plumbing systems in very low numbers from mains water, but it cannot be detected by the usual laboratory methods until multiplication has taken place in warm conditions of 20–45 °C.

In the present system there was a long length of ducted pipework, creating a

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raised ambient water temperature, between the water softener and the calorifier water storage tank, so it was not surprising that the first positive sample was found at end of this pipework (sample point 4). The temperature of the water at the ball valve inlet was *c.* 12 °C and contained only 500 c.f.u./l of *L. pneumophila* serogroup 4, i.e. the lower limit of detection by our method. However, higher legionellae counts (up to $4{\cdot}5 \times 10^4$ c.f.u./l) were found in the tank water itself, multiplication being stimulated by a water temperature of 25 °C, and probably also by stagnation at the warm bottom of the tank. This cold tank was sited about 6 m above the calorifiers and was not adequately insulated, consequently heat gain was considerable. Moreover, the cold water feed to calorifiers was complex, with a 'dead-leg' containing water at about 25 °C; suitable conditions for multiplication of legionellae.

As the cold-water storage tank and interconnecting pipework was a reservoir of legionellae, and these in turn continually fed the calorifiers, a critical problem could arise in the event of a steam shut down. If the temperature at the top of the calorifiers fell, where water is drawn off, then legionellae would not be killed and consequently they would contaminate the hot-water distribution system and no doubt colonize some areas if the shutdown was for a long period.

In order to rectify some of the above defects, simple modifications in the design of the plant have been made to ensure that the cold-water feed to the calorifiers does not exceed 20 °C: a 'dead-leg' between the water-storage tank and the calorifiers has been removed; the cold-water storage tank has been insulated and the calorifier room below provided with a false ceiling to reduce bottom heating. These measures have considerably reduced the number of *L. pneumophila* reaching the calorifiers from the cold-water feed because, in the 2 years since they were introduced, the counts in repeat samples of calorifier drain water have been consistently in the order of 500 c.f.u./l.

Heating water to 60 °C and above is an effective way of killing *L. pneumophila* both *in vitro* [11] and, as this investigation has shown, also under environmental conditions. It was difficult to maintain an even temperature throughout the calorifiers because the steam heater coils were positioned towards the centre of the vessels, thus creating temperature stratification ranging from *c.* 30 °C at the bottom to > 60 °C at the top. It proved impossible in this system to achieve a temperature of > 60 °C at the drains without closing off the cold water supply. However, in practice this will usually not matter during normal operational conditions, as the draw-off point is taken from the top of the calorifiers. The temperature there was sufficiently high (*c.* 65 °C) to destroy legionellae and to ensure that ward tap temperatures were > 50 °C; these outlets were clear of the organisms.

Monitoring water systems for *L. pneumophila* has limitations because of the uncertainties inherent in laboratory concentration methods which may result in wide variations in the apparent number of organisms in the same sample. For example, we found as much as a 10^3 difference in c.f.u./l of *L. pneumophila* in sequential water samples taken every 10 min from the same calorifier drain. The question is whether this is a true reflection of the level of contamination, as influenced by the demand for hot water by the wards, turbulence in the calorifier, or merely a reflection of laboratory inaccuracy. The recovery of *L. pneumophila*

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from seeded water samples can vary by up to 50%, presumably because of problems of eluting bacteria from the surface of membrane filters (J. E. Barker, unpublished data). For this reason the estimation of legionella numbers using this method should be regarded as an approximation only.

Regular monitoring of water systems for *L. pneumophila* has little value other than to establish a rough numerical baseline. Moreover, routine bacteriological surveillance could justifiably be questioned because, as this study has shown, effective maintenance and temperature controls are simple methods of controlling colonization by this organism, except where danger of scalding has to be considered. There is a case for fitting calorifiers with alarm systems, to alert engineers to significant changes in temperature (be they high or low), which may be unsafe.

Nevertheless, temperature control alone may not be sufficient to eradicate legionellae from plumbing systems. Cold-water feed to the calorifiers must be protected against heat gain to keep the number of legionellae entering calorifiers to a minimum. The calorifier temperature should never fall below 60 °C, at the draw-off point, which should in great measure protect the peripheral plumbing network from contamination once the system has been cleared.

Many of the recommendations made in this report have now been incorporated into various Codes of Practice [12–14] which if followed in detail, should minimize the risk of legionella infection from domestic water systems.

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The Regulation and Quality Improvement Authority

The Regulation and Quality Improvement Authority

Independent Review of Incidents of *Pseudomonas aeruginosa* Infection in Neonatal Units in Northern Ireland

Interim Report

31 March 2012

informing and improving health and social care
www.rqia.org.uk

The Regulation and Quality Improvement Authority

The Regulation and Quality Improvement Authority (RQIA) is the independent body responsible for regulating and inspecting the quality and availability of health and social care services in Northern Ireland.

RQIA was established in 2005 as a non-departmental public body under The Health and Personal Social Services (Quality, Improvement and Regulation) (Northern Ireland) Order 2003 to drive continuous improvements in the quality of services, through a programme of inspections and reviews.

The vision of RQIA is to be a driving force for positive change in health and social care services in Northern Ireland.

This is accomplished by focusing on the delivery of a robust quality and regulatory framework which is fit for purpose. This ensures that RQIA provides independent assurance about the safety, quality and availability of health and social care services in Northern Ireland; encourages continuous improvements in those services; and safeguards the rights of service users. This is undertaken through four outcomes:

- **Improving care:** we encourage and promote improvements in the safety and quality of services through the regulation and review of health and social care
- **Informing the population:** we publicly report on the safety, quality and availability of health and social care
- **Safeguarding rights:** we act to protect the rights of all people using health and social care services
- **Influencing policy:** we influence policy and standards in health and social care

RQIA encourages continuous improvement in the quality of services, through a planned programme of inspections and reviews.

The RQIA Review Programme takes into consideration relevant standards and guidelines, the views of the public, health care experts and current research.

During these reviews we examine the service provided, highlight areas of good practice and make recommendations for improvements to the service provider. We report our findings and share any lessons learned across the wider health and social care sector.

In addition, when required, we carry out reviews and investigations in response to specific issues of concern or failures in service provision.

The outbreaks and incidents of *Pseudomonas aeruginosa* which occurred across Northern Ireland during December 2011 and January 2012 have resulted in this review, facilitated by RQIA, which was undertaken in response to a request by the Minister for Health and Social Services and Public Safety.

Foreword by Professor Pat Troop

Independent Review of Incidents of *Pseudomonas aeruginosa* Infection in Neonatal Units in Northern Ireland

On 30 January 2012, Edwin Poots, MLA, Minister for Health, Social Services and Public Safety, asked RQIA to undertake a review into the incidents of pseudomonas in neonatal care settings in Northern Ireland, with an interim report to be produced by the end of March 2012.

The review team was established comprising leading experts in the fields of neonatology, microbiology, and medical engineering from across the United Kingdom. I am particularly grateful for the contribution of the representatives of Bliss and Sands, two national voluntary organisations with specific expertise in this area.

This interim report presents our findings relating to the first two terms of reference: to examine the cause of the infection; and to consider the responses of the organisations involved.

We met with the families of a number of the infants colonised and infected with pseudomonas, including some of those who tragically lost a baby. I sincerely thank these families for their openness, honesty and their willingness to contribute at such a difficult time. We will continue our engagement with families during the second phase of this review and we extend an invitation to any other families who have been affected, if they wish to meet with the review team.

I am very grateful for the co-operation of staff in all of the health and social care organisations under review: the five health and social care trusts; the Health and Social Care Board; the Public Health Agency; and the Department of Health, Social Services and Public Safety.

We have found that everyone we have spoken to has been deeply affected by the tragic loss of life. Staff have asked us to make sure that all possible steps are taken to protect infants from harm.

This interim report makes 15 recommendations for immediate consideration by the Minister. The final report of the review will be presented to the Minister in late May 2012 and will include a particular emphasis on the experiences of the families.

Professor Pat Troop CBE FRCP FFPH DSc
Review Chair

Table of Contents

Foreword by Professor Pat Troop

1. Introduction and Background to the Review

On 12 December 2011 the Western Health and Social Care Trust (Western Trust) declared an outbreak of *Pseudomonas aeruginosa* at the neonatal unit at Altnagelvin Hospital, Londonderry, after three babies were confirmed to be infected. One baby had tragically died and a second baby had been transferred to the neonatal unit in the Royal Jubilee Maternity Service (RJMS), Belfast, for surgery for an unrelated condition.

On 17 January 2012 the Belfast Health and Social Care Trust (Belfast Trust) declared an outbreak of *Pseudomonas aeruginosa* infection in the neonatal unit of the Royal Jubilee Maternity Service. At that time, two babies who had been confirmed as having the infection had tragically died and another baby was known to have been infected in December. A third baby also died after the outbreak was declared.

During the period from 17 to 31 January 2012, screening of babies in units across Northern Ireland confirmed that there were babies in other units who had been colonised with pseudomonas on their skin.

On 30 January 2012 the Minister for Health, Social Services and Public Safety, Mr Edwin Poots, asked RQIA to facilitate the establishment of an independent review into the circumstances leading to the incidents and the effectiveness of the response. The review should also examine the experience of the families of the babies who had died and of others who had been affected by the incidents. An interim report was requested by the Minister by 31 March 2012 to ensure that lessons learned were acted on as soon as possible. A final report is to be submitted to the Minister by 31 May 2012. Terms of reference were agreed and RQIA established the review team under the chairmanship of Professor Pat Troop.

The death of their newborn babies was devastating for families. The period of the outbreaks was also extremely stressful for those families whose babies were either infected or colonised with pseudomonas. The terms of reference outlined that the review team would engage directly with the parents of babies who had been affected by the outbreak. The review team considered that it was important to meet with families at an early stage to find out if they had questions that they felt could be answered through the review. They also wished to allow them to share information in order to inform the review findings. The interim report outlines some themes that were identified during discussions with those parents who the review team has already met. These will be considered in detail in the final report.

During this phase of the review, team members spoke with staff from organisations across Northern Ireland. The review team was impressed with the professionalism of all staff and it was evident that the incidents in the neonatal units had a significant impact on them. Staff expressed their commitment to following any recommendations that would improve the neonatal service in Northern Ireland.

The interim report provides a high level timeline of events. It sets out the interim findings of the review team as to the circumstances leading to the pseudomonas incidents and how they were responded to.

It provides an initial set of recommendations for consideration by the Minister based on the findings and conclusions of this stage of the review.

We would like to thank all parents who shared their experiences with us at this very difficult time. We are also grateful to the staff in all organisations who facilitated the review team during this phase of the review.

2. Terms of Reference

The terms of reference for the review were agreed with the Minister for Health, Social Services and Public Safety and the Chair of the RQIA Independent Review Team.

It was agreed that the review would focus on the occurrences of *Pseudomonas aeruginosa* which led to the tragic deaths of a baby in Altnagelvin Hospital and three babies in the Royal Jubilee Maternity Hospital"s neonatal intensive care unit.

The Review would also examine the actions and responses of eight organisations to relevant circulars and advices issued in respect of water sources and potential infection risk to patients, disseminated since 15 September 2010. The organisations reviewed were:

- Department of Health and Social Services and Public Safety (DHSSPS)
- Health and Social Care Board (HSCB)
- Public Health Agency (PHA)
- Belfast Health and Social Care Trust (Belfast Trust)
- Northern Health and Social Care Trust (Northern Trust)
- South Eastern Health and Social Care Trust (South Eastern Trust)
- Southern Health and Social Care Trust (Southern Trust)
- Western Health and Social Care Trust (Western Trust)

The review was commissioned under Article 35(1)(b) of the Health and Personal Social Services (Quality, Improvement and Regulation) (Northern Ireland) Order 2003 and would cover the period 1 November 2011 to 31 January 2012.

The review would be conducted in two phases.

Phase One Terms of Reference

1. To investigate the circumstances contributing to the occurrences of pseudomonas infection in neonatal units from 1 November 2011.

2. To review the effectiveness of the trusts" management of the occurrences of pseudomonas infection and colonisation within neonatal units, to include:

    a. The management of the occurrence of pseudomonas infection and colonisation in the neonatal unit in the Western Trust.
    b. The management of the declared outbreak of pseudomonas infection and colonisation in the neonatal unit in the Belfast Trust in January 2012.
    c. The management of any colonised babies in the other neonatal units across Northern Ireland.

3. To review the effectiveness of the governance arrangements across all five health and social care trusts with regard to the arrangements for the prevention and control of infection and all other relevant issues in their respective neonatal units.

4. To review the effectiveness of the communication between the DHSSPS, the HSCB, the PHA, and the five health and social care trusts in respect of all relevant information and communications on the pseudomonas bacterium.

5. To examine any other relevant matters which emerge during the course of the review.

6. To identify any learning from the circumstances and make recommendations for all agencies involved.

Phase Two Terms of Reference

In recognition of the tragic impact of pseudomonas infection for the families of those babies who have been directly affected by the bacterium, RQIA during the course of this review will engage directly with the parents of those babies affected. Phase two of the review will deal directly with these issues. Early into the review, it was agreed that families may wish to come forward as soon as possible and thus the opportunity was afforded to those families to meet with the review team prior to phase one being concluded. RQIA believes that this is a vital part of the review to ensure the stories of families are told and therefore this invitation will be extended to the beginning of May 2012.

1. To consider the experience of families of babies affected by the pseudomonas infection and colonisation within neonatal units since 1 November 2011.

2. To examine any other relevant matters which emerge during the course of phase two of the review.

3. To identify any learning from the experiences of parents and make recommendations for all organisations involved.

Arrangements for Reporting

The Minister for Health requested two reports:

An interim report completed by the end of March 2012 which would highlight the key findings and provide recommendations arising from phase one which should be implemented immediately to assure the safety of the neonatal service; and

A final report completed by the end of May 2012 which would provide more detail and further recommendations for the service and include findings from phase two.

This report comprises the interim report, which was submitted to the Minister on 30 March 2012.

3. Methodology

3.1 The Independent Review Team

The review was conducted by an independent review team established at the beginning of February 2012. Its membership included:

- Professor Pat Troop, CBE, former Chief Executive of the Health Protection Agency as well as former Deputy Chief Medical Officer at the Department of Health (Chair of the RQIA Independent Review Team)

- Mr Andy Cole, Chief Executive from the charity, Bliss (Babies born too soon, too small, too sick)
- Dr Michael Kelsey, Consultant Microbiologist, Whittington Hospital NHS Trust, London
- Dr Ian Laing, former Consultant Neonatologist and Clinical Lead for the Neonatal Managed Clinical Network of the South and East of Scotland
- Ms Ann McMurray, lay reviewer from the charity, Sands (Stillbirth and Neonatal Death)
- Mr Graham Marsh, former NHS Acute Foundation Trust Director of Property and Medical Engineering
- Ms Mae Nugent, Practice Development Nurse, Neonatal Unit, University College London Hospital NHS Foundation Trust, London
- Dr Tyrone Pitt, former Deputy Director of the Laboratory of HealthCare Associated Infections (LHCAI), Health Protection Agency, London and Bacteriology Consultant to the National Health Service Blood and Transplant Service
- Ms Farrah Pradhan, lay reviewer from the charity, Bliss (Babies born too soon, too small, too sick)
- Dr David Stewart, RQIA Director of Reviews and Medical Director, Belfast

The independent review team was supported by RQIA staff:

- Ms Janine Campbell, Project Administrator
- Mrs Elizabeth Colgan, Senior Inspector, Infection Prevention/ Hygiene
- Mr Hall Graham, Head of Primary Care and Reviews
- Mrs Jacqueline Murphy, Senior Project Manager

3.2 Information Requests

RQIA wrote to those organisations subject to the review to request their co-operation in informing the review. Detailed information was requested from them, including:

A chronology of the events relating to the organisation which was relevant to the review's terms of reference. This chronology covered the period from 15 September 2010 (date of issue of DHSSPS Circular HSS (MD)34/2010 entitled Water Sources and Potential Cross Infection Risks from Taps and Basins – Interim Advice) until 31 January 2012 (date of Minister"s statement to the NI Assembly, announcing the commencement of the review).

Details of all actions taken following the DHSSPS letters:

1. DHSSPS Letter: HSS(MD)34/2010 from Chief Medical Officer and Deputy Secretary/Chief Estates Officer, dated 15 September 2010 : Water Sources and Potential Cross Infection Risks from Taps and Basins – Interim Advice
2. DHSSPS Letter: PEL (11) 13 from Deputy Secretary/Chief Estates Officer, dated 1 July 2011: Water Systems and Potential Infection Risks
3. DHSSPS Letter HSS(MD)31/2011 from Chief Medical Officer and Deputy Secretary/Chief Estates Officer, dated 22 December 2011: Water Sources and Potential Infection Risk to Patients
4. DHSSPS Letter HSS(MD)4/2012 from Chief Medical Officer and Deputy Secretary/Chief Estates Officer, dated 28 January 2012: Interim Guidance on Pseudomonas and Neonatal Units

Description of organisational structures, to include:

- senior management structure
- lead responsibility and groups relevant to the planning or provision of neonatology services
- lead responsibility and groups relevant to infection control
- lead responsibility and groups relevant to estates services

Copies of all **relevant policies and procedures**.

Copies of all **relevant documentation** (to include minutes of meetings and correspondence) with regard to the chronology of events.

Copies of all **relevant governance documentation** (eg: incidents reporting, risk registers, etc) with regard to the chronology of events.

Details of **any other relevant information surrounding the pseudomonas outbreaks** from 1 November 2011 until 31 January 2012.

Each HSC trust was also requested to complete a questionnaire outlining the **profile of the neonatal units (NICUs) and special care baby units (SCBUs)** and to submit copies of **results of microbiological investigations of water or clinical samples for pseudomonas linked to each neonatology unit/special care baby unit.**

Further requests for information have been made as the review has progressed.

3.3 Interviews and Meetings

Visits to the five Neonatal Intensive Care Units (NICUs) in Northern Ireland were undertaken by members of the independent review team who met with various levels of staff, including medical and nursing staff.

Also during a four week period, meetings and interviews were held with managerial and clinical staff across the health and social care sector, to include:

- DHSSPS staff
- PHA staff
- HSC Board staff
- Chief Executives
- Medical Directors
- Trust estates personnel
- Trust facilities personnel
- Trust infection control personnel
- Trust medical staff
- Trust nursing staff
- Trust microbiologists
- Belfast Trust Root Cause Analysis Investigation Team

Various meetings were also held with parents and grandparents of eight families who have been affected directly by the *Pseudomonas aeruginosa* infection. Families whose babies had been affected by the outbreaks were invited to meet with the review team. Phase two of the review will continue to provide opportunities for other families to come forward to share their experience with the review team.

During phase one, liaison with national organisations, including the Health Protection Agency, has also taken place to ensure a comprehensive understanding of what is happening across the United Kingdom.

4. Background and Context to the Provision of Neonatal Care in Northern Ireland

4.1 Health and Social Care in Northern Ireland

Health and social care in Northern Ireland is provided as an integrated service. There are a number of organisations who work together to plan, deliver and monitor health and social care across Northern Ireland.

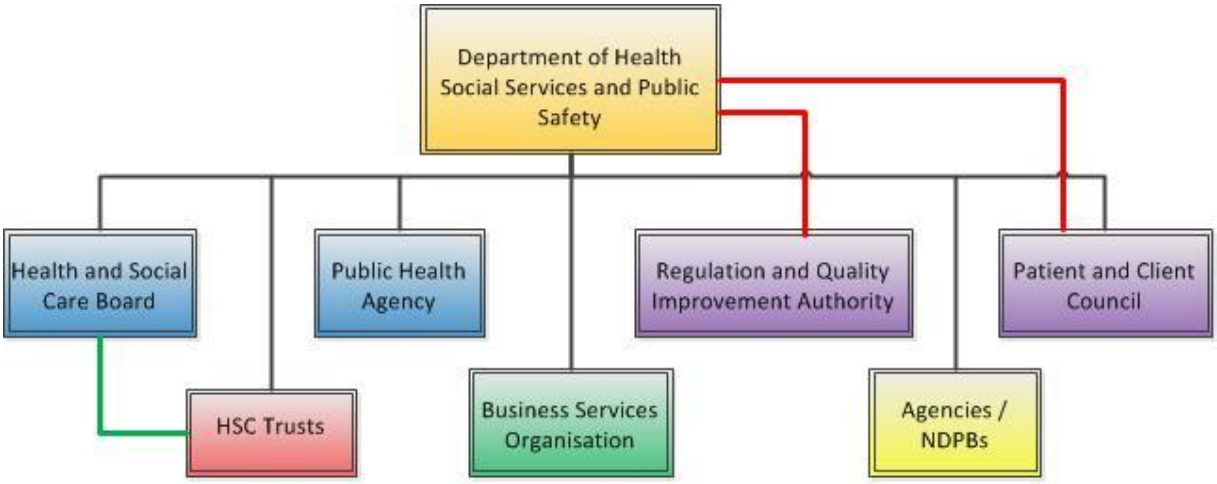

Figure 4(a): Health and Social Care Structure in Northern Ireland

Department of Health, Social Services and Public Safety (DHSSPS)
The DHSSPS has three main business responsibilities:

- **Health and Social Care (HSC)**, which includes policy and legislation for hospitals, family practitioner services and community health and personal social services
- **Public Health**, which covers policy, legislation and administrative action to promote and protect the health and well-being of the population
- **Public Safety,** which covers policy and legislation for fire and rescue services.

Within the DHSSPS, the key business groups are the Resource and Performance Management Group, the Healthcare Policy Group, the Social Policy Group, the Health Estates Investment Group (HEIG), the Chief Medical Officer Group (encompassing the Population Health Directorate) and the Office of Social Services. The DHSSPS also has a Modernisation Directorate and a Human Resources Directorate.

Health and Social Care Board (HSCB)
The HSCB is responsible for commissioning services, resource management and performance management and service improvement. It works to identify and meet the needs of the Northern Ireland population through its five local commissioning groups which cover the same geographical areas as the HSC trusts.

Public Health Agency (PHA)
The PHA has the key functions of improving health and wellbeing and health protection. It also provides professional input to the commissioning process. The PHA is jointly responsible (with the HSCB) for the development of a fully integrated commissioning plan for health and social care in Northern Ireland. The organisation works in partnership with local government, key organisations and other sectors to improve health and wellbeing and reduce health inequalities.

Health and Social Care Trusts
There are a total of six health and social care (HSC) trusts in Northern Ireland. Five HSC trusts provide integrated health and social care services across Northern Ireland:

- Belfast HSC Trust (Belfast Trust)
- Northern HSC Trust (Northern Trust)
- South Eastern HSC Trust (South Eastern Trust)
- Southern HSC Trust (Southern Trust)
- Western HSC Trust, (Western Trust)

The HSC trusts manage and administer hospitals, health centres, residential homes, day centres and other health and social care facilities and they provide a wide range of health and social care services to the community.

The sixth trust is the Northern Ireland Ambulance Service Trust (NIAS), which operates a single Northern Ireland-wide service and aims to improve the health and well-being of the community through the delivery of high quality ambulance services.

The DHSSPS, HSCB, PHA and the HSC trusts are the organisations which are subject to this review.

4.2 Admissions of Babies to Neonatal Care

In 2010 there were 25,300 live births registered in Northern Ireland, a small increase (2%) on the number of births registered in 2009.[1] Each year approximately 2,000 newborn babies in Northern Ireland will need extra care and will be admitted to a neonatal unit. Most of these will need intensive or high dependency care.[2]

Babies who are most likely to require admission to a neonatal unit are:

- premature babies (a baby who is born before a gestational age of 37 completed weeks is considered to be premature)
- low birth weight babies (a baby that weighs less than 2,500 grams at birth is considered to be of low birth weight)
- babies with congenital abnormalities or other medical problems
- babies requiring assessment and/or management for acquired surgical problems
- babies born to mothers who have had problems during pregnancy
- multiple births

[1] Births in Northern Ireland 2010: Northern Ireland Statistics and Research Agency (NISRA) - http://www.nisra.gov.uk/archive/demography/publications/births_deaths/births_2010.pdf
[2] Neonatal Intensive Care Outcomes Research and Evaluation (NICORE) - http://www.publichealth.hscni.net/directorate-public-health/service-development-and-screening/nicore

Neonatal units in hospitals specialise in the care of those babies born early with low weight or who have a medical condition that requires specialised treatment.

One in nine babies born in the United Kingdom will spend at least a few days in a neonatal unit. Some babies may need breathing support or monitoring, some may have an infection and need antibiotics, and some may be suffering from other medical conditions. The length of a baby's stay may vary from days, to weeks or months, depending on their needs.

A premature baby can face many problems such as hypothermia, respiratory conditions and jaundice and they will be susceptible to infections.

In the unit, a baby may be attached to monitors and may have intravenous lines inserted. It may not be possible to hold the baby, or it may not be possible to do so for long.

High staff / patient ratios, specialised equipment and treatment make neonatal services a high cost, relatively low volume specialty. Daily, or even hourly fluctuations, in relatively small numbers of babies result in peaks and troughs of activity, which are much more marked than in higher volume services.

4.3 Provision of Neonatal Services in Northern Ireland

4.3.1 Levels of Care

There are three levels of care in Northern Ireland, namely:

Level 1: Neonatal Intensive Care (NIC)
This care is provided for babies with the most complex problems who require constant supervision and monitoring and, usually, mechanical ventilation. Due to the possibility of acute deterioration, a trained doctor must always be available. Extremely immature infants all require intensive care and monitoring over the first weeks.

Level 2: High Dependency Care (HDU)
This care takes place in a neonatal unit and involves care for babies who need continuous monitoring, for example those who weigh less than 1,000 grams, or are receiving help with their breathing via continuous positive airway pressure (CPAP) or intravenous feeding, but who do not fulfil any of the requirements for intensive care. A trained doctor should be available.

Level 3: Special Care
This care is provided for all other babies who could not reasonably be looked after at home by their mother. Babies receiving special care may need to have their breathing and heart rate monitored, be fed through a tube, supplied with extra oxygen or treated for jaundice. This category also includes babies who are recovering from more specialist treatment before they can be discharged. Special care which occurs alongside the mother is often called "transitional care„ but takes place outside a neonatal unit, in a ward setting.

4.3.2 Policy

In June 2005 the Chief Medical Officer commissioned a paper in response to concerns that the existing neonatal service in Northern Ireland was unable to meet rising demand. A small project group was established to provide a robust baseline position for specialist neonatal services activity in Northern Ireland, and to inform future service planning, provision and development. The resulting paper was published in May 2006.[3]

The conclusions of the paper included:

- regarding nursing staff, Northern Ireland has a skilled and committed neonatal workforce but capacity to train an increased number of neonatal nurses was a priority to meet future service requirements;
- regarding medical staff, out of hours consultant medical cover for area neonatal units includes neonatologists, acute paediatricians and community paediatricians. This was concerning if very premature or extremely low birthweight babies were unable to access the regional unit for their initial care. Future cot configuration should take into account 24 hour medical staffing;
- babies born before 28 weeks gestation and weighing less than 1,000 grams should receive their initial care in the regional unit with 24 hour neonatal cover;
- once care in the regional unit is no longer required, transfer or repatriation of these babies should be considered to free up cots for other newborns requiring regional care;
- very low birthweight babies, (<1500gms) comprise around 1% of total births, account for almost a quarter (24%) of admissions and over half (54%) of total level 1 and 2 days. The impact of a few additional babies in this category would therefore have a disproportionately large effect on number of cot days, particularly in the regional unit;
- highest occupancy levels were in level 2 cots;
- a regional transfer system was considered to be essential for units to fully function as a network;
- an effective managed clinical network for neonatal services would require full commitment from obstetricians, paediatricians and trust management; and
- patients and the public would require information and education about the purpose and functions of a managed clinical network and the implications this may have for the location of their care.

[3] Position Paper on Specialist Neonatal Services in Northern Ireland (May 2006): http://www.dhsspsni.gov.uk/neonatalservicesinni.pdf

4.3.3 Neonatal Care Settings in Northern Ireland

Whilst there is an informal neonatal network in Northern Ireland, units are independent and autonomous. Neonatal services are provided by:

One regional unit
The Royal Jubilee Combined Neonatal Intensive Care and Special Care Baby Unit based at the Royal Jubilee Maternity Hospital in Belfast (Belfast Trust).

Four area Neonatal Units which provide neonatal intensive care, high dependency care and special care. They are:

1. Antrim Area Hospital in Antrim (Northern Trust)
2. The Ulster Hospital in Belfast (South Eastern Trust)
3. Craigavon Area Hospital in Craigavon (Southern Trust)
4. Altnagelvin Hospital in Londonderry (Western Trust)

There are also **two Neonatal Units providing special care (Level 3) (SCBUs)** at:

1. Daisy Hill Hospital in Newry (Southern Trust)
2. Erne Hospital in Enniskillen (Western Trust)

Causeway Hospital in Coleraine (Northern Trust) has paediatric services on site and can stabilise babies prior to transfer to another unit.

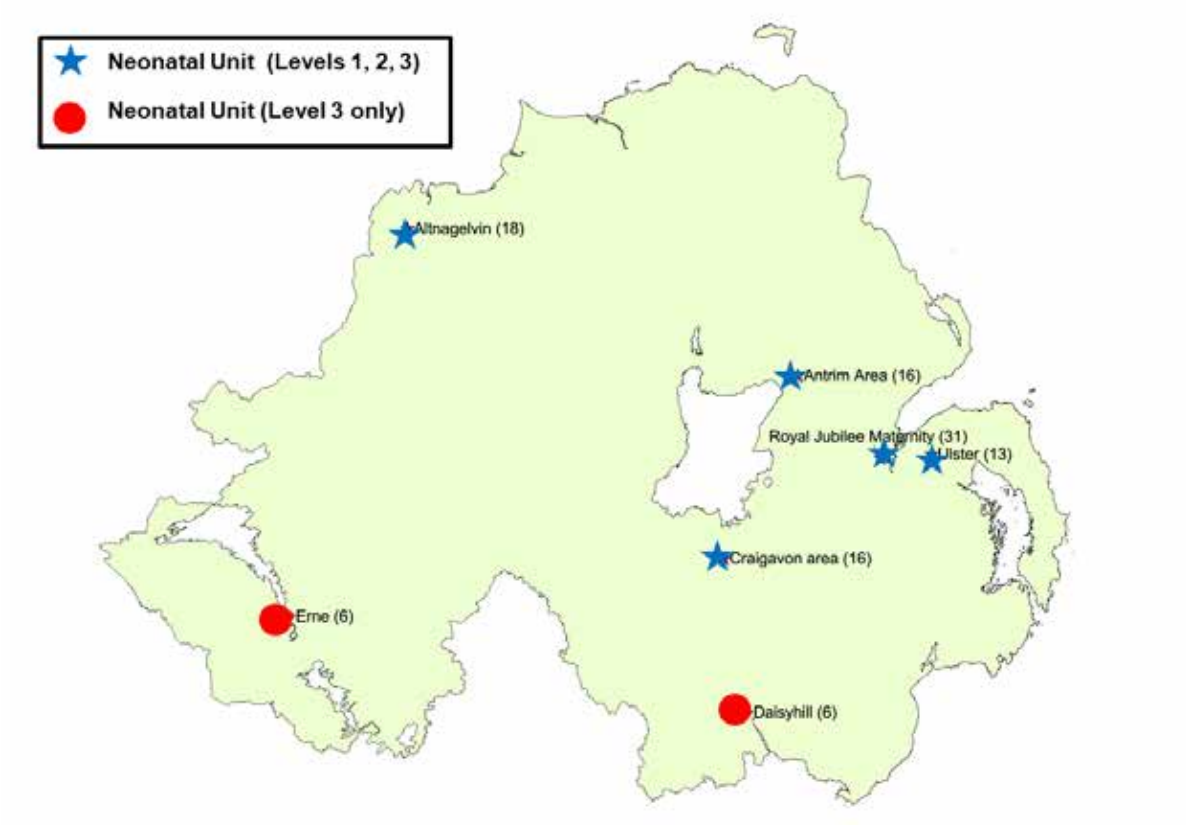

Figure 4(b): Map of Neonatal Units in Northern Ireland (Number of Cots in Brackets)

Belfast Trust: The Regional Unit (Royal Jubilee Maternity Service (RJMS))
This is a combined neonatal and special care baby unit. It is based in the Royal Jubilee Maternity Hospital and is located on the Royal Group of Hospitals site in Belfast. It was constructed in 1934, with two major extensions added (circa 1960/1970) and provides the entire range of pre and post-natal maternity services. The neonatal unit incorporating NICU is located within the main block.

The NICU was opened in December 1993 with a large intensive care room (ICU) and three rooms with four cots. This unit is funded for 9 level 1 cots, 7 level 2 and 15 level 3.
In February 2000, the Royal Jubilee NICU amalgamated with Royal Maternity neonatal unit, and cots increased to 31 with an additional two rooms in the new special care area, Rooms 1 and 2. In 2006, due to an infection, the unit was repainted, vaporised and clinical units built beside each incubator space in ICU.

Some refurbishment has taken place since August 2011:

- 19 August – 12 September 2011 the floor in ICU was replaced, central units were replaced, and wash hand basins with sensor taps were installed.
- 20 September - 4 October 2011: the floors in the main corridor and rooms 5a, 5b and 5c were replaced, as well as wash hand basins and sensor taps installed.
- 20 January 2012 – 6 February 2012 the ICU was again refurbished, with central panel"s new sinks and sensor taps with ultra violet (UV) point of use (POU) devices.
- 8 February 2012 – present: rooms 5a, 5b and 5c are having new panels, new sinks and sensor taps with UV POU devices installed.

Northern Trust: Antrim Hospital Neonatal Unit
Antrim Area Hospital which included a Neonatal Unit was opened in 1994.

The unit consists of 16 cots, six of which are intensive care cots, two sets of four nursery cots and two single isolation cots.

South Eastern Trust: Ulster Hospital Neonatal Unit
This NICU opened in 2007 as part of the new maternity building. It consists of two clinical areas:

- ICU/HDU area with five cots, and
- SCBU area with 10 cots

In addition, there is a side room where a baby may be stabilised prior to transfer to another unit when no other space is available or for a baby requiring palliative care.

The trust is currently only funded to have 13 cots (two Level 1, two Level 2, and nine Level 3). However, the physical space allows for 15 cots and this provides the flexibility to respond to regional demands. This has staffing and equipment resource consequences.

There are two ensuite parent bedrooms, a kitchenette, administrative space, two store rooms, two utility rooms, a test room, a staff toilet and staff room. There have been no extensions or refurbishments since the unit opened.

Southern Trust: Craigavon Hospital Neonatal Unit
This unit opened in 1972, with facilities for 28 special care cots.

Following a refurbishment programme in the early 1980s the piped air and oxygen supply to the unit was upgraded to facilitate an increasing number of admitted neonates who required more intensive respiratory support. Over the next decade there was a gradual reduction in the number of cots as instrumental deliveries and all caesarean section infants were no longer routinely admitted to the neonatal unit.

In 1987, the unit was formally upgraded to an intensive care unit with the introduction of an infant ventilator. In 2005 cot capacity was 14 (two intensive care level 1, four high dependency level 2 and eight special care level 3 cots). In 2006, in response to an increasing number of infants requiring intensive care, the intensive care nursery was refurbished and an additional level 1 intensive care cot was provided. Cot capacity was now 15 (three intensive care level 1, four high dependency level 2 and eight special care level 3 cots).

A further review of service took place in 2009 driven by increased demand from the southern area population and an increased birth rate at the hospital, creating pressures on maternity services. Alongside this came the introduction of a new service model for neonatology which would provide measures to alleviate pressures on cots in relation to level 3 care. An additional level 3 cot was introduced and plans put in place to provide two additional transitional care cots. The additional level 3 cot was opened in March 2011. Cot capacity increased to 16 (three level 1 intensive care cots, four high dependency level 2 cots and nine special care level 3 cots.) Health care assistants are currently completing a training programme to gain QCF level 3 accreditation and, on completion, transitional care cots on both the Craigavon and Daisy Hill sites will open.

In 2011, the reorganisation of facilities within the unit resulted in the creation of a dedicated isolation facility which could accommodate a level 1, 2 or 3 infant. An existing nursery was also upgraded. The new service model for neonatology within the Southern Trust, supporting the introduction of the concept of transitional care, created two family rooms to allow infants who were within 24-48 hours of discharge to be nursed in these rooms with their parents under the supervision of neonatal staff.

Current capacity remains at 16 cots (three intensive care level 1, four high dependency level 2 and nine special care level 3 cots). When transitional care is introduced April 2012 onwards, cot capacity will be 18 (three intensive care, four high dependency and 11 special care cots, two of which will be utilised as transitional care cots).

Southern Trust: Daisy Hill Neonatal Unit providing Level 3 Care
This Neonatal Unit has been operational since the hospital was opened in 1981. The cot capacity is for six special care infants. The unit will admit and stabilise level 1 and level 2 infants prior to transfer.

The unit underwent a refurbishment in 2010, resulting in a change in the designation of one of the level 3 cots to be used flexibly as a level 2 cot approximately 25% of the time and provision of one additional transitional care cot. In addition, a separate isolation room was created along with enhanced facilities for parents.

Health care assistants are currently completing a training programme to gain QCF level 3 accreditation and, upon completion, the transitional care cot will open.

Western Trust: Altnagelvin Neonatal Unit
At present, the Neonatal Unit at Altnagelvin is an 18 cot unit. This unit has been in existence since the 1960"s since the hospital was built.

The unit has been refurbished on several occasions during this time and moved to new premises in February 2009, where it is now situated in the south wing, Altnagelvin Hospital. There are 5 areas:

- ICU
- High dependency
- Special care
- Two single isolation rooms

Western Trust: Erne Neonatal Unit providing Level 3 Care
The Neonatal Unit at the Erne Hospital in Enniskillen was established in October 1994 and has always had a capacity of six cots.

This unit will be moving to South West Acute Hospital, Enniskillen, in June 2012.

4.4 Activity Levels

Numbers of Cots
There are 106 cots across Northern Ireland. Figure 4(c) outlines the number of cots by level in each Neonatal Unit across the five trust areas.

TRUST	BELFAST	NORTHERN	SOUTH EASTERN	SOUTHERN		WESTERN		NORTHERN IRELAND
UNIT	**Royal Jubilee**	**Antrim**	**Ulster**	**Craigavon**	**Daisy Hill**	**Altnagelvin**	**Erne**	**TOTAL**
Level 1	9	4	2	3	0	3	0	**21**
Level 2	7	2	2	4	0	6	0	**21**
Level 3	15	10	9	9	6	9	6	**64**
TOTAL	**31**	**16**	**13**	**16**	**6**	**18**	**6**	**106**

Figure 4(c): Number of Cots by Level across Northern Ireland. Source: Information provided by HSC Trusts (February 2012)

In Altnagelvin, 0.5 cots at Level 1 are funded by HSE, Republic of Ireland for transfers from Letterkenny General Hospital, County Donegal.

Numbers of Admissions

Figure 4(d) shows the numbers of admissions by level of cots across Northern Ireland between September 2010 and January 2012 inclusive.

TRUST	BELFAST	NORTHERN	SOUTH EASTERN	SOUTHERN		WESTERN		NORTHERN IRELAND	
UNIT	Royal Jubilee	Antrim	Ulster	Craigavon	Daisy Hill	Altnagelvin	Erne	TOTAL	AVERAGE PER MONTH
Level 1	422	191	139	250	28	137	39	1206	70.94
Level 2	242	74	215	59	10	129	12	741	43.59
Level 3	111	127	132	169	163	165	129	996	58.59
TOTAL	775	392	486	478	201	431	180	2943	**173.12**
AVERAGE PER MONTH	45.59	23.06	28.59	28.12	11.82	25.35	10.59	**173.12**	

Figure 4(d): Numbers of Admissions by Level of Cots across Northern Ireland between September 2010 and January 2012 inclusive. Source: Information provided by HSC Trusts (February 2012)

In Craigavon and Daisy Hill, admissions are based on new admissions (including transfers in from other sites) within the month and excludes babies already occupying a cot as at the last day of the previous month end. The level is based on the level on admission date.

Occupancy Rates

Figure 4(e) shows the occupancy rates (as a percentage) by level of cot across Northern Ireland between September 2010 and January 2012.

TRUST	BELFAST	NORTHERN	SOUTH EASTERN	SOUTHERN		WESTERN		NORTHERN IRELAND
UNIT	Royal Jubilee	Antrim	Ulster	Craigavon	Daisy Hill	Altnagelvin	Erne	AVERAGE
Level 1	78.86	47.18	39.24	61.24	0.00	62.06	0.00	**57.71**
Level 2	101.13	96.35	116.12	54.59	0.00	48.94	0.00	**83.43**
Level 3	68.72	101.74	93.53	89.65	63.06	72.88	60.35	**78.56**

Figure 4(e): Occupancy Percentage Rates by Level of Cots across Northern Ireland between September 2010 and January 2012 inclusive. Source: Information provided by HSC Trusts (February 2012)

In Erne the Unit cares for babies at Level 3. Babies at Levels 1 and 2 are stabilised and transferred out unless they only require that level for 28-48 hours.

Occupancy Rates

Figures 4(f), 4(g) and 4 (h) show the occupancy rates (as a percentage) for Levels 1, 2 and 3 cots across Northern Ireland between September 2010 and January 2012.

Units can use cots flexibly, particularly between Levels 1 and 2.

MONTH	LEVEL 1				
	Belfast Royal Jubilee	Northern Antrim	South Eastern Ulster	Southern Craigavon	Western Altnagelvin
Sep-10	70.00%	50.80%	35.00%	40.00%	45.00%
Oct-10	139.70%	54.00%	13.00%	52.00%	66.00%
Nov-10	81.40%	32.50%	30.00%	54.00%	31.00%
Dec-10	95.60%	58.00%	37.00%	57.00%	68.00%
Jan-11	96.70%	46.70%	11.00%	38.00%	49.00%
Feb-11	72.20%	28.60%	16.00%	44.00%	56.00%
Mar-11	61.20%	29.80%	18.00%	84.00%	65.00%
Apr-11	54.85%	54.00%	53.00%	49.00%	53.00%
May-11	66.60%	49.20%	45.00%	24.00%	32.00%
Jun-11	46.20%	23.30%	35.00%	50.00%	54.00%
Jul-11	67.30%	69.30%	37.00%	63.00%	34.00%
Aug-11	76.70%	27.40%	39.00%	92.00%	12.00%
Sep-11	65.90%	50.80%	55.00%	91.00%	81.00%
Oct-11	100.00%	79.80%	61.00%	29.00%	80.00%
Nov-11	82.20%	55.00%	37.00%	73.00%	127.00%
Dec-11	77.40%	31.50%	61.00%	73.00%	96.00%
Jan-12	86.70%	61.30%	84.00%	128.00%	106.00%

Figure 4(f): Occupancy Rates (%) by Level 1 Cot across Northern Ireland in 2011. Source: Information provided by HSC Trusts (February 2012)

	< 70%
	70%-94%
	> 94%

BELFAST TRUST: Notes. This information is an indicator and should be used indicatively only. When patients have not been discharged on the system i.e. a cot is apparently occupied by two patients at the one time. In specific regard to NICU there could also be issues in relation to the transfer between categories of levels of care i.e. there is quite a bit of transfer of babies between cots of differing levels of care which would exacerbate the issue.

SOUTHERN TRUST: CRAIGAVON Notes: % Occupancy Rate = Occupied Cots for each day in Month \ Available Cots by each day in Month. % Occupancy is a snapshot daily position as per completion of Neo-natal proforma (9am)

MONTH	LEVEL 2				
	Belfast Royal Jubilee	Northern Antrim	South Eastern Ulster	Southern Craigavon	Western Altnagelvin
Sep-10	130.90%	103.30%	162%	53%	55%
Oct-10	147.60%	66.10%	187%	58%	73%
Nov-10	130.90%	126.60%	112%	52%	49%
Dec-10	121.60%	88.70%	103%	81%	55%
Jan-11	121.10%	154.80%	126%	62%	54%
Feb-11	95.90%	114.30%	104%	85%	40%
Mar-11	89.40%	87%	76%	48%	43%
Apr-11	90%	108.30%	123%	66%	78%
May-11	104.60%	106.40%	74%	44%	48%
Jun-11	65.70%	38.30%	143%	56%	32%
Jul-11	82%	61.30%	74%	21%	61%
Aug-11	93%	74.20%	123%	48%	26%
Sep-11	74.70%	65%	72%	61%	47%
Oct-11	83.40%	96.80%	76%	27%	51%
Nov-11	117.60%	156.60%	140%	55%	25%
Dec-11	77.80%	91.90%	92%	33%	46%
Jan-12	93%	98.40%	187%	78%	49%

Figure 4(g): Occupancy Rates (%) by Level 2 Cot across Northern Ireland in 2011. Source: Information provided by HSC Trusts (February 2012)

	< 70%
	70%-94%
	> 94%

BELFAST TRUST: Notes. This information is an indicator and should be used indicatively only. When patients have not been discharged on the system i.e. a cot is apparently occupied by two patients at the one time. In specific regard to NICU there could also be issues in relation to the transfer between categories of levels of care i.e. there is quite a bit of transfer of babies between cots of differing levels of care which would exacerbate the issue.

SOUTHERN TRUST: CRAIGAVON Notes: % Occupancy Rate = Occupied Cots for each day in Month \ Available Cots by each day in Month. % Occupancy is a snapshot daily position as per completion of Neo-natal proforma (9am)

MONTH	LEVEL 3						
	Belfast Royal Jubilee	Northern Antrim	South Eastern Ulster	Southern Craigavon	Southern Daisy Hill	Western Altnagelvin	Western Erne
Sep-10	65.10%	104.60%	101%	98%	69%	77%	58%
Oct-10	27%	117.40%	98%	98%	44%	81%	77%
Nov-10	56.40%	98.30%	109%	105%	47%	68%	43%
Dec-10	50.10%	87.40%	116%	90%	49%	79%	83%
Jan-11	71.80%	79.70%	107%	124%	77%	85%	65%
Feb-11	88.50%	105.70%	95%	115%	71%	65%	68%
Mar-11	88.30%	114.80%	105%	124%	90%	70%	75%
Apr-11	78.40%	106.30%	79%	106%	67%	70%	43%
May-11	50.10%	103.50%	102%	71%	85%	86%	26%
Jun-11	67.10%	83.30%	70%	85%	75%	100%	23%
Jul-11	74.40%	83.50%	84%	84%	53%	49%	86%
Aug-11	65.80%	115.20%	96%	52%	78%	97%	41%
Sep-11	63.30%	113%	74%	81%	49%	84%	79%
Oct-11	72.20%	92.60%	61%	80%	56%	67%	37%
Nov-11	81.10%	92.30%	92%	71%	49%	49%	78%
Dec-11	96.10%	122.60%	103%	88%	72%	63%	71%
Jan-12	72.60%	109.40%	98%	52%	41%	49%	73%

Figure 4(h): Occupancy Rates (%) by Level 3 Cot across Northern Ireland in 2011. Source: Information provided by HSC Trusts (February 2012)

	< 70%
	70%-94%
	> 94%

BELFAST TRUST: Notes. This information is an indicator and should be used indicatively only. When patients have not been discharged on the system i.e. a cot is apparently occupied by two patients at the one time. In specific regard to NICU there could also be issues in relation to the transfer between categories of levels of care i.e. there is quite a bit of transfer of babies between cots of differing levels of care which would exacerbate the issue.

SOUTHERN TRUST: CRAIGAVON Notes: % Occupancy Rate = Occupied Cots for each day in Month \ Available Cots by each day in Month. % Occupancy is a snapshot daily position as per completion of Neo-natal proforma (9am)

SOUTHERN - DAISY HILL: % Occupancy is a snapshot daily position as per completion of Neo-natal pro-forma (9am). Total % Occupancy is different to Level 3 % Occupancy. The Total % includes cots occupied by Level 1 \ 2 babies, but there is no formal allocation of Level 1 \ 2cots.

4.5 Transfer Service

The neonatal transfer service is known as CONNECT and was established in October 2010. It operates from 09:00 until 18:00 hours Monday to Friday. After 18:00 hours, the sending hospital will contact the Northern Ireland Ambulance Service (NIAS) and the sending hospital will send their own staff to accompany the baby.

The CONNECT service also operates on Saturday and Sunday mornings (five hours) when it is nurse led. It is funded for 60 hours per week, for nursing and 40 hours per week registrar time. A 0.5 WTE Medical Consultant directs the service,

A medical consultant directs the service which is a joint neonatal and paediatric service.

CONNECT has its own dedicated ambulance and is part of the Northern Ireland Ambulance Service (NIAS) capital replacement programme. The service has its own incubator which the nursing staff are responsible for cleaning and there is a cleaning policy in place. According to IPCN staff in the Belfast Trust and the Southern Trust this was in place but needed to be updated. There is also a private ambulance service Aeromedics, which is used primarily by the Western Trust.

The CONNECT team has medical consultant and registrar input, as well as nursing input. The Co-ordinator is a nurse.

Approximately 560 babies have been transferred up until December 2011 (approx 40 transfers per month). The transfers include both planned and unplanned with back transfers (transfer back to originating hospital) of babies usually scheduled for Saturdays and Sundays. Many transfers (perhaps up to 200) are on site transfers from RJMS to other RVH sites such as the imaging centre or RBHSC.

The service provides training and study days for the region.

5. *Pseudomonas aeruginosa*

5.1 Introduction

Pseudomonas aeruginosa is a type of bacterium which is widely found in the natural environment. It is commonly found in soil and water and is particularly associated with wet and humid environments. It can survive in conditions that other bacteria are unable to. It can produce a biofilm which creates a protective layer when it grows in a water system. It requires a source of carbon in order to grow.

Pseudomonas aeruginosa rarely infects healthy individuals but can cause severe infection in patients who have underlying health problems such as cystic fibrosis, or burns. Pseudomonas can cause infections in different body systems including the skin, urinary tract, gut, respiratory system and blood. *Pseudomonas aeruginosa* can be found on the skin without necessarily causing infection, a situation known as colonisation.

Premature babies are very susceptible to infection with *Pseudomonas aeruginosa.* They have not yet developed their full immune system and have much less protection than full term babies from antibodies passed across the placenta from their mother. Very premature babies have delicate skin which can be damaged and infected very easily. Consequently, pseudomonas infection can have a devastating effect on the baby. These babies are also particularly at risk from colonisation of their respiratory system which can lead to severe infection. A premature baby is also frequently cared for in a humidified incubator, and *Pseudomonas aeruginosa* thrives in a humid environment.

5.2 Typing of Pseudomonas Bacteria

There are a very large number of different strains of *Pseudomonas aeruginosa.* New strains are continually occurring through genetic changes as the bacteria adapt to the environment. These strains can have different characteristics in relation to where and how they grow.

To identify related clusters of cases and outbreaks, it is important to be able to distinguish between the different strains. Linking strains from human and environmental sources can help to establish the source of an outbreak and possible methods of transmission.

There are differences in the genetic makeup of these different strains. Genetic testing (typing) can be carried out to identify strains to see if there is a relationship between cases of infection or between cases and environmental sources.

One method of testing is Variable Number Tandem Repeat typing (VNTR). The advantage of using this method is that there is a faster turnaround time compared to other methods of typing. Results are usually available within a day.

Every strain of *Pseudomonas aeruginosa* has a VNTR code which is a sequence of nine numbers. Number sequences for pseudomonas isolated from different sources can be compared when considering if cases or environmental sources are related.

5.3 Reporting of Pseudomonas

In Northern Ireland information on pseudomonas is based on voluntary reporting by hospital clinical microbiology laboratories to the Public Health Agency (PHA). At present only blood infections (bacteraemia) are reported.

In Northern Ireland, the number of reported cases of bacteraemia caused by pseudomonas has been gradually increasing over the past decade from 81 reports in 2001 to 113 reports in 2011. For babies under the age of one year, around one or two cases have been reported each year in Northern Ireland.

In the United Kingdom, from 2006 to 2008, there was an 8% increase in the number of *Pseudomonas* infections reported to the Health Protection Agency (HPA) (3,679 reports in 2006 compared with 3,957 reports in 2008), followed by a 4% reduction to 3,807 reports in 2010. Ninety-three per cent of these were *Pseudomonas aeruginosa*.

5.4 Pseudomonas and Water Systems

Domestic and hospital water systems are frequently colonised with pseudomonas with biofilms developing in pipework, taps and U-bends when there is a source of carbon to support growth.

Water distribution systems in hospitals and other large buildings are frequently complex networks and can be of considerable length. Dead ends, pipework subject to biofilm build-up, slow throughput, insufficient temperatures (below 55°C in the hot water pipes and above 20°C in the cold pipes) and infrequently used outlets all contribute to bacterial growth and making complete eradication of bacteria almost impossible. Pseudomonas is particularly likely to grow where there is stagnant water in the system which may occur if taps are not flushed regularly.

Several methods are used to reduce the possibility of pseudomonas infection in the water distribution system and also to prevent transmission to vulnerable patients. These include:

- ensuring that there are no areas of water stagnation resulting from low or limited use as this creates ideal conditions for growth of pseudomonas
- flushing all taps regularly in wards that contain vulnerable patients
- maintaining hot and cold water at the correct temperatures – cold water below 20°C and hot water above 55°C
- ensuring best practice in relation to infection control

There has been considerable debate regarding which design of tap is most likely to protect the water system from bacterial contamination. In many healthcare settings, sensor taps have been introduced as the no-touch operation reduces the risk of spread of infection through touching tap surfaces.

However, sensor taps have internal components which may support pseudomonas growth if they contain carbon. Also, there has been concern that low flow rates increase the risk of the growth of pseudomonas.

Following blending of hot and cold water supplies by a thermostatic mixer valve, water will be supplied for use at 41°C providing an environment in which pseudomonas bacteria can multiply. The position of such thermostatic mixer valves will vary, some will be integral with the mixer tap and others sited upstream of the tap.

5.5 Outbreaks of *Pseudomonas aeruginosa* Linked to Neonatal Units

Pseudomonas aeruginosa has been a known risk cause of outbreaks in neonatal care settings for over 50 years[4]. Investigations of outbreaks have linked causes to different factors including contaminated equipment[5], staff fingernails [6], use of water baths to thaw frozen plasma [7], hand hygiene[8], contaminated feeding bottles[9] the use of expressed breast milk for feeding[10] and contamination of a dextrose multidose vial[11].

There have been a number of reports about electronic sensor taps becoming colonised by *Pseudomonas aeruginosa.* In November 2011, a report was published from Turkey that an outbreak affecting 12 babies in a neonatal intensive care unit was probably due to contamination of electronic sensor taps.[12]

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[11] Archibald LK et al. *Enterobacter cloacae* and *Pseudomonas aeruginosa* polymicrobial bloodstream infections traced to extrinsic contamination of a dextrose multidose vial. *J. Pediatr.1998 Nov;133(5):640-4.*
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6. Chronology Overview

6.1 Introduction

In order to understand the complex sequence of events in the period leading up to and during the pseudomonas incidents, each organisation was asked to prepare a timeline of relevant events for the period from 15 September 2010 to 31 January 2012.

The timelines and supporting evidence have been considered by the Review Team and an outline of the key events is set out below.

This overview has been divided into six sections to facilitate understanding:

- Issue of relevant circulars and advices by DHSSPS
- Outbreak at Altnagelvin Neonatal Unit
- Outbreak at Royal Jubilee Maternity Service (RJMS) NICU
- Cluster of cases associated with Craigavon Hospital Neonatal Unit
- Cases linked to Antrim Hospital Neonatal Unit
- Regional response following the declaration of RJMS outbreak

6.2 Issue of Relevant Circulars and Advices by DHSSPS

DATE	CIRCULAR / ADVICE ISSUED BY DHSSPS
15 September 2010	Circular **HSS (MD) 34/2010,** was issued to HSC Trusts for action. The circular contained interim advice which had been provided to NHS Trusts in England in a letter issued by the Department of Health on 27 August 2010. Further investigation was taking place in England. **HSS (MD) 34/2010** advised trusts that DHSSPS had become aware of reports from England and Wales of outbreaks of infection caused by pseudomonads. The incidents had occurred in in augmented care wards, (such as adult or neonatal intensive care, renal and burns units) and hand hygiene stations had been identified as the source. There had been evidence of persistent colonisation of the faucets (taps). The circular required trusts to assess the risk to their patient population and, where appropriate, establish if the water used in hand washing had an unacceptable bacterial count. The circular provided advice on the use and cleaning of hand hygiene stations and actions to be taken if contamination of faucets was found. Trusts were asked to review their engineering protocols and to ensure that manufacturer"s instructions in regard to installation and maintenance had been followed.

1 July 2011	A Professional Estates Letter, **PEL(11)13,** was issued to HSC organisations for action. The letter provided a summary of the key outcomes of a workshop held in 2010 to share lessons from the Belfast Trust from a case study of control of legionella in a healthcare facility. **PEL(11)13** set out a number of actions to reinforce good practice, for the management of water delivery systems in healthcare facilities, to minimise and manage the risk of contamination by organisms such as legionella and pseudomonas. Actions required included a review of written schemes for the control of exposure from legionella bacteria in water. Reviews were to be carried out using a team approach involving Infection Control Teams and Estates Management Teams to identify potential risk areas. Water sample testing was to be undertaken, if not already in place, for areas where patients may be more vulnerable to the risk of infection from legionella. Water systems were to be reviewed to identify and remove water outlets that were not in use and dead legs within the hot and cold water systems as part of ongoing system maintenance. Chief Executives were to provide a statement of assurance, by 31 August 2011, that written schemes had been reviewed.
23 August 2011	An alert notice, **NIA-2011-002,** was issued by the Northern Ireland Incident Centre (NIAIC) relating to flexible water supply hoses. This followed alerts issued in England and Wales. The alert drew attention to the risk that some flexible hoses in potable water supply systems may have an enhanced risk of harbouring legionella and other organisms. Organisations were asked to identify flexible hoses and carry out a risk assessment for possible contamination with harmful microorganisms. Action was to be completed by 1 January 2012.
22 December 2011	A circular **HSS(MD)31/2011** was issued for action by HSC organisations. The purpose was to remind organisations of the potential risks posed by water in healthcare facilities and to reinforce the messages contained in **HSS (MD) 34/2010** and **PEL(11)13.** Organisations were advised that similar events had now been reported in Northern Ireland to those which had led to the issue of **HSS (MD) 34/2010**. The circular set out actions to be followed where there was contamination of faucets in an augmented care ward to protect patients. The circular advised that research, commissioned by the Department of Health in England into the potential risks associated with pseudomonas contamination in wash hand basin water taps, had been largely completed. Actions required included ensuring that the contents of both **HSS (MD) 34/2010** and **PEL(11)13** were brought to the attention of all relevant staff. Organisations should ensure that they were fully compliant with the good practice outlined in relation to both the management of water systems and infection control practice.

22 December 2011	Systems and processes should be in place to provide robust assurance, and documentary evidence, of compliance with best practice for the management of water systems and infection control practice (particularly in relation to hand hygiene and/or aseptic non-touch technique).
28 January 2012	A circular, **HSS (MD) 4/2012,** was issued to HSC Trusts, the Public Health Agency and the HSC Board providing interim guidance on pseudomonas and neonatal units. This guidance had been developed in consultation with the Health Protection Agency in England. **HSS (MD) 4/2012** stated that as a precautionary measure for immediate action, all water from hand washing stations should be assumed to be potentially contaminated until proven otherwise. "For this reason there should be no direct or indirect contact between this tap water and the babies themselves. Sterile water should be used for all contact with babes including cleaning incubators or other equipment." **HSS (MD) 4/2012** set out advice on water testing and taps, correct use of hand hygiene stations and cleaning of taps and sinks. It advised that the PHA was undertaking environmental risk assessments of each unit to determine what specific action needed to be taken. The circular included a Northern Ireland interim protocol for testing of water from clinical hand wash stations *for Pseudomonas aeruginosa* to be put in place until further notice.

The Review team has received evidence on the actions taken by HSC organisations in relation to the circulars and advices outlined above. This will be considered in the final report of the review.

6.3 Outbreak at Altnagelvin Hospital Neonatal Unit

DATE	ACTION
26 November 2011	A baby being cared for in the ICU room of Altnagelvin Neonatal Unit had a urine specimen sent for testing. Two days later this was reported to be positive for *Pseudomonas aeruginosa.* The baby developed pseudomonas infection of the skin and blood cultures were sent for testing. On 2 December 2011, the baby was transferred from Altnagelvin to RJMS NICU in Belfast for treatment of another condition. The blood cultures were reported to be positive for pseudomonas on 4 December 2011 and this information was passed by phone from Altnagelvin laboratory to RJMS NICU on that day.

6 December 2011	The condition deteriorated of a second baby in the ICU room, who had been very unwell since birth. Blood cultures were taken and, on 8 December 2011, were reported by the laboratory to be positive for *Pseudomonas aeruginosa.* The baby did not respond to treatment and died on 10 December 2011.
10 December 2011	A third baby being cared for in the ICU room developed signs of infection and a decision was taken to treat the baby for a presumed diagnosis of pseudomonas infection. Preliminary blood culture results on 11 December 2011 indicated that the baby had a bacterial infection of the blood and this was confirmed as *Pseudomonas aeruginosa* on 12 December 2011.
12 December 2011	The Altnagelvin Infection and Prevention Control (IPC) team informed the Western Trust Medical Director about the cases of infection with pseudomonas. The Medical Director convened an Incident Control Team (ICT) meeting that day to review the facts, confirm appropriate infection control measures were in place and co-ordinate on-going investigations. A series of actions was agreed including environmental sampling, observation of practice, checking the ventilation system, a terminal clean of the ICU room and arrangements for talking to parents. Following the meeting, the PHA was informed of the outbreak through contact with the on-call Specialist Registrar who subsequently informed the on-call Health Protection Consultant and Director of Public Health that three babies had pseudomonas infection and that one had died.
13 December 2011	The Western Trust Medical Director briefed the Trust Chief Executive and the Deputy Chief Medical Officer (CMO) at DHSSPS. The Deputy CMO referred the Western Trust Medical Director to the guidance issued in September 2010 in **HSS (MD) 34/2010.** The Deputy CMO subsequently informed the CMO that day and a submission was prepared to brief the Minister about the pseudomonas incident. The CMO asked colleagues for advice as to whether to re-issue **HSS (MD) 34/2010**. The Deputy CMO advised Health Estates Investment Group (HEIG) who made contact with the WHSCT head of infection control and a member of estates staff. The PHA nominated three members of staff to join the Incident Control Team in WHSCT. These staff attended the ICT meeting to offer support and advice on control measures and investigation. The ICT met again and was attended by representatives from the PHA. The ICT was advised that the ICU room, in which the three babies had been located, had been used intermittently and babies were normally placed in two cots at the front of the room.

13 December 2011	During this period, babies had also been looked after at the back of the room. The sink at the back of the room was not frequently used and swabs from this sink had shown heavy growths of pseudomonas. Tap water was being used during nappy changes hitherto a common practice in the UK. A paediatric consultant informed the ICT that she had been advised that there was a second baby with pseudomonas in RJMS NICU as well as the baby who had transferred from Altnagelvin. Actions agreed by the ICT included; contact with RJMS by the PHA and the Western Trust Head of Infection Control; contact with the transfer service who had brought the baby from Altnagelvin to RJMS; flushing of taps in all augmented care wards[13]; sterile water to be used at all times for all babies in ICU and High Dependency Unit (HDU); no water to be used from the taps in ICU.
14 December 2011	A Serious Adverse Incident form was submitted to the HSCB by WHSCT. At the daily ICT meeting, the Health Protection Consultant from PHA presented advice from the HPA that screening of babies in NICU for both pseudomonas and MRSA should be carried out on a weekly basis. The Western Trust agreed to start this on Monday 19 December. Samples were sent from Altnagelvin to the HPA reference laboratory for analysis of the strains of *Pseudomonas aeruginosa.* HEIG e-mailed WHSCT head of Operations and Maintenance re-iterating the practice contained within HSS(MD) 2010. The CMO decided that a further circular should be issued to HSC organisations to highlight estates and infection control aspects. This was discussed at a teleconference between the DHSSPS and a Consultant in Health Protection at PHA.
15 December 2011	The ICU room which had the tap positive for pseudomonas had the infected tap and associated thermostatic mixer valve (TMV) replaced. The water system was chlorinated, retested and found to be clear. A terminal clean was carried out for the ICU room. The Western Trust ICT was informed that preliminary results of the strain typing of the two babies in RJMS ICU indicated they had different strains. The Western Trust shared this information with a Senior Medical Officer at DHSSPS during a briefing on the outbreak on the following day.

[13] The operational definition of augmented care at that time (in the absence of regional guidance) was: Adult intensive care/high dependency; Neonatal units; Oncology.

21 December 2011	A temporary relocation of the Neonatal Unit took place to enable a completed disinfection of the water system to proceed. Antimicrobial paint was applied to the walls during this period. The Western Trust responded to a press enquiry in relation to the death of a baby. The trust did not confirm any details to protect confidentiality but did issue a statement which included the information that: "The Trust can confirm that there was an uncommon infection caused by Pseudomonas in early December 2011 at Altnagelvin Hospital"s Neonatal Intensive Care Unit. All the necessary infection prevention and control measures were put in place and the infection has now been eradicated." This story was reported in a local paper.
22 December 2011	**HSS(MD) 31/2011** was issued by DHSSPS – received by WHSCT by e-mail and circulated to relevant officers within the trust on the following day. A preliminary verbal report was received from the HPA Reference Laboratory which suggested that two of the three babies infected in Altnagelvin NICU had the same strain of pseudomonas as the contaminated tap in the ICU room. One baby appeared to have a different strain. These results were confirmed in writing on 30 December 2011. The strain leading to infection in one baby was subsequently found from a swab taken from a sink at the front of the ICU room on 12 January 2012.
5 January 2012	The outbreak of pseudomonas in Altnagelvin NICU was discussed at a meeting of the PHA Regional Protection Advisory Forum attended by representatives from some trusts.
12 January 2012	The results of the fourth weekly screen of babies for pseudomonas showed that two babies had colonisation with pseudomonas. The previous screens had all been negative. Environmental swabs were repeated.
16 January 2012	The results of the environmental swabs were reviewed and two taps were positive for pseudomonas. Neither of these taps had been positive when tested three times previously.
20 January 2012	A Western Trust Incident Review Team met to review the management of the incident and the results of the screening of babies and the environment. The team then became aware of the Belfast Trust outbreak.
Period following 20 January 2012	The Western trust participated in the regional processes following the declaration of the outbreak at RJMS ICU and took forward agreed actions at local level. There were no further infections or colonisations with pseudomonas of babies reported from Altnagelvin Neonatal Unit in the period up to 31 January 2012.

In summary, an outbreak of infection caused by *Pseudomonas aeruginosa* occurred in Altnagelvin Neonatal Unit between 26 November 2011 and 10 December 2011. This caused infection of three very pre-term babies of whom one died. All three babies had been nursed in the ICU room of the NICU.

Two babies had the same strain of *Pseudomonas aeruginosa* as was found in a contaminated tap at the back of the ICU room. The other baby had a different strain which was subsequently found from a swab of a sink at the front of the ICU room on 12 January 2012. This sink had previously been negative. Following a programme of actions to control the outbreak, there were no further cases of infection in the unit after 10 December 2011. In January 2012, two babies were found to have colonisation with *Pseudomonas aeruginosa*, through a weekly screening programme established following the outbreak.

6.4 Outbreak at Royal Jubilee Maternity Service Neonatal Unit

DATE	ACTION
2 December 2011	A baby, known to have *Pseudomonas aeruginosa* of the skin, was transferred from Altnagelvin NICU to RJMS NICU for treatment of another condition (Section 6.3). Blood cultures, taken in Altnagelvin, were reported to be positive for *Pseudomonas aeruginosa* on 4 December 2011 and this information was passed by phone from Altnagelvin Hospital to RJMS NICU on that day.
6 December 2011	A baby in RJMS NICU, who had been born in RJMS, had respiratory secretions sent to the laboratory. These were confirmed to be positive for *Pseudomonas aeruginosa* on 8 December 2011.
8 December 2011	A medical microbiologist informed an Infection Prevention Control (IPC) Nurse at Belfast Trust that there were two babies in NICU with pseudomonas in the unit. Two IPC nurses visited NICU and recommended that the two babies should be co-located (nursed together to minimise risk of spread to other patients). The IPC nurses provided advice on cleaning and bed spaces were cleaned to facilitate the co-location of the two babies. The nurses noted that the roof of the unit was leaking and a sample of water was obtained. On advice from microbiology this was not processed. The IPC nurse was advised on 9 December by the Estates Department that the required repairs were being dealt with.
9 December 2011	The *Pseudomonas aeruginosa* isolates from the two babies were sent to the HPA Reference laboratory in England for typing due to concern that there had been two cases of pseudomonas within one week in the unit.

13 December 2011	An IPC nurse visited NICU to ensure that the contact precautions for the two babies were in place. A consultant neonatologist and the NICU Manager at RJMS were advised of an outbreak of pseudomonas at Altnagelvin Hospital through a phone call from a paediatrician there.
14 December 2011	An IPC nurse from Altnagelvin contacted the IPC team in Belfast Trust by email to advise of the outbreak there. The Altnagelvin IPC nurse advised that a sink was the possible source of the infection. A consultant at PHA contacted the Belfast Trust IPC doctor about the baby from Altnagelvin who had transferred with pseudomonas. The IPC doctor advised the PHA consultant that respiratory secretions from another baby in RJMS had tested positive for pseudomonas.
15 December 2011	Preliminary typing results from the HPA Reference Laboratory indicated that the strains of pseudomonas for the two babies in RJMS were different. As there was no evidence for spread of infection between the babies, the infection in the baby born in RJMS was considered to have been sporadic. The Belfast Trust advised the PHA of the preliminary typing results and an SAI form was not submitted.
16 December 2011	PHA advised Belfast Trust directors at the Belfast Trust performance meeting with PHA and HSCB of the outbreak of pseudomonas at Altnagelvin NICU. The cases in RJMS NICU were also discussed. A Senior Medical Officer in DHSSPS advised the CMO and colleagues in DHSSPS by email that, following typing, the two cases in RJMS were unrelated as they had different strains.
22 December 2011	**HSS(MD) 31/2011** was received by email in the Belfast Trust and circulated to relevant officers within the trust on the following day.
29 December 2011	The Belfast Trust Director of Nursing received advice from the Trust IPC Doctor that **HSS(MD) 31/2011** would be considered at the next meeting of the trust Water Safety Group on 24 January 2012.
5 January 2012	A baby in RJMS NICU developed respiratory symptoms and a specimen was sent for testing. This was reported as possible *Pseudomonas aeruginosa* on 6 January 2012. The baby"s condition deteriorated rapidly and the baby died later that evening. Blood cultures taken on 6 January 2012 subsequently grew *Pseudomonas aeruginosa* which was reported on 8 January.
9 January 2012	The Medical Microbiology Team requested that the isolate from the baby should be prepared to be sent for typing in view of concern about a possible outbreak. A decision was made to expedite typing rather than escalate and call an outbreak. NICU was visited by a medical microbiologist and an infection Control Nurse who provided advice on de-cluttering and cleaning.

10 January 2012	The medical microbiologist was informed by the clinical team in RJMS NICU that they had heard there was a baby in Craigavon Area Hospital (CAH) NICU who had bacteraemia caused by *Pseudomonas aeruginosa.* The medical microbiologist contacted the laboratory at CAH and was provided with information about the investigation results for the baby.
11 January 2012	The RJMS medical microbiologist discussed the information about the baby in CAH with the RJMS Trust IPC Doctor and considered it was probable that the infection had been acquired in CAH.
13 January 2012	Belfast Trust contacted the HPA Reference Laboratory to emphasise urgency and expedite typing for the sample which had been sent. A baby in RJMS was diagnosed with ventilator acquired pneumonia. This baby had been born in Daisy Hill Hospital and transferred to RJMS via Craigavon Hospital. Respiratory secretions were sent for analysis. The baby"s condition did not respond to treatment and the baby died on 14 January 2012. On 15 January 2012, the respiratory secretions and blood cultures taken on 14 January 2012 were both reported as positive for *Pseudomonas aeruginosa.*
16 January 2012	Blood cultures were obtained from a baby in RJMS NICU who required to be ventilated that day. On 18 January 2012 *Pseudomonas aeruginosa* was isolated. The baby"s health continued to deteriorate despite treatment and the baby died on 19 January 2012. The HPA Reference Laboratory phoned Belfast Trust at 18:15 to advise that the strain of pseudomonas from the baby who died on 6 January 2012 was identical to the strain found in the baby from whom samples had been taken on 6 December 2012 in RJMS NICU. An incident meeting was arranged for the following day.
17 January 2012	An incident meeting was held at which the outbreak was confirmed. Initial control measures were established which included: restricting admissions to NICU; co-locating affected infants; environmental sampling to include potential habitats of pseudomonas especially taps and water; alcohol rubs immediately after hand washing; sterile water for nappy changes; screening all other infants; expediting typing for babies who had been infected on which this had not yet been carried out. Following the incident meeting, PHA was informed by the Belfast Trust of the outbreak. The trust sent an Early Alert notification to the DHSSPS about the incident and reported it as an SAI on the following day. The Chief Executive was briefed on the situation by the Director of Specialist Hospitals and Women and Child Health.

18 January 2012	An isolate was cultured from the sputum of a baby in the unit which was subsequently confirmed as *Pseudomonas aeruginosa.*
19 January 2012	A meeting of the Belfast Trust Outbreak Control Team was held. The OCT was advised that further information on strain typing was now available and the strain of *Pseudomonas aeruginosa* cultured from samples from the baby who died on 14 January 2012 was different to the other strains which had been identified. 4 babies had been found to be colonised with *Pseudomonas aeruginosa* through the screening exercise carried out on 16 January 2012. Environmental sampling had detected pseudomonas in swabs from two taps in NICU and another tap was likely to be confirmed positive. The OCT agreed further control measures including taking action to move babies out of the unit so that it could be subjected to intensive cleaning. The OCT agreed to issue a press release that day in relation to the outbreak. A helpline was established by Belfast Trust that evening.
20 January 2012	A press conference was held in the Belfast Trust in which the Minister and CMO and PHA participated in relation to the outbreak. NICU was closed and babies moved to other rooms in the Regional Neonatal Unit. Following replacement of wash hand basins and sensor taps, the unit was reopened on 6 February 2012. Following the declaration of the outbreak the OCT continued to meet to manage the outbreak and trust staff participated in regional teleconferences and meetings. Helpline established by Belfast Trust and announced at a press conference.
24 January 2012	Typing results from the HPA Reference Laboratory confirmed that the baby who had been diagnosed within CAH with pseudomonas from a positive blood culture taken on 29 December 2011 had the same strain as had caused the outbreak in Belfast. The results also confirmed that the baby who had died in RJMS on 19 January 2012 had the same strain. A meeting was held for parents of babies in the unit to provide them with information about the outbreak.

Following the establishment of a review of the epidemiology of the NICU outbreaks by PHA, important additional information has emerged as to the distribution of infections and colonisations with *Pseudomonas aeruginosa.* This will be considered further in the final report of the review. The Review Team has been provided with an interim analysis which has reported the following preliminary findings in relation to the outbreak at RJMS NICU:

- In total there were five cases of infection and 10 colonisations associated with the strain of pseudomonas linked to the Belfast outbreak. Three of the babies died. For one baby pseudomonas was not the reported cause of death.

- The baby who died in RJMS on 14 January 2012 had a different strain which was subsequently found in three babies who were colonised and were in Craigavon Area Hospital.

- Two babies who were initially screened negative in RJMS were found to be positive with the strain associated with Belfast when they were rescreened on transfer to Antrim and Craigavon Hospitals
- *Pseudomonas aeruginosa* of the same strain as the babies in the Belfast outbreak was detected in water samples taken from hand washing taps in RJMS in both NICU (4 taps out of 6) and SCBU (1 tap out of 6).
- The earliest sample of *Pseudomonas aeruginosa* which has been epidemiologically linked to the Belfast strain was taken on 15 November 2011 in a baby who was transferred from RJMS to Craigavon Area Hospital and who subsequently was found to have the strain linked to Belfast when a subsequent sample was taken on 26 January 2012. A further colonisation was detected in a baby in RJMS on 21 November 2011 and was subsequently found when screened on 20 January 2012 in Daisy Hill Hospital to have the strain associated with Belfast.

Following a programme of actions to control the outbreak there were no further incidents of infection or colonisation with *Pseudomonas aeruginosa* found in RJMS after 25 January 2012 and up to 31 January 2012, in the period subject to this review.

6.5 Cluster of Cases Associated with Craigavon Hospital Neonatal Unit

DATE	ACTION
22 December 2011	**HSS (MD) 31/2011** was received by Southern Trust and circulated to relevant directors and staff.
29 December 2011	A baby in Craigavon Neonatal Unit had blood cultures taken which subsequently were found to be positive for *Pseudomonas aeruginosa.* The baby had been born in RJMS and initially cared for in RJMS NICU before transfer to Craigavon on 23 December 2011. The baby died in January 2012. Pseudomonas was not the reported cause of death. This baby was later found to have had the strain of pseudomonas linked to RJMS NICU in Belfast.
14 January 2012	In keeping with routine practice, RJMS NICU contacted Craigavon NICU and advised of the death of a baby that day who had been previously in Craigavon Neonatal Unit.
16 January 2012	A microbiologist at Craigavon was contacted by a microbiologist from Belfast Trust regarding 2 babies from Craigavon who had been transferred to RJMS. She asked if Craigavon had had any problems with pseudomonas bacteraemia or colonisation in the past year. The Craigavon microbiologist contacted the Trust Clinical Director of Infection Prevention and Control.

17 January 2012	The Southern Trust Lead Infection Control Nurse contacted the Belfast Senior Infection and Prevention Control Nurse to seek information and clarity with regard to pseudomonas in RJMS. The Lead ICN informed the Clinical Director and IPC Team and the Medical Director was subsequently informed.
18 January 2012	The Clinical Director and Lead ICN visited Craigavon Neonatal Unit. It was agreed to include pseudomonas in routine screening of babies from other units. The isolation of transferred babies until screening results were available was standard practice in the unit. Enhanced monitoring and IPC precautions were reinforced.
20 January 2012	All babies in Craigavon Neonatal Unit and Daisy Hill SCBU were screened for pseudomonas. A baby was transferred to Craigavon Neonatal Unit from RJMS NICU who was screened for pseudomonas and was reported to be positive on 22 January 2012. Subsequently this was found to be the strain associated with Belfast.
21 January 2012	Provisional results of swabs for screening indicated probable positive results for 2 babies in Craigavon Neonatal Unit and one in Daisy Hill SCBU. Additional nurse staffing was provided to establish 1:1 cohort nursing and isolation for all colonised infants. Sterile water for washing of babies was implemented in both the neonatal unit and SCBU following a conversation between the Lead ICN and a colleague in Belfast Trust.
22 January 2012	The provisional results from the previous day were confirmed. The baby in SCBU had been transferred from the Royal Belfast Hospital for Sick Children, having been earlier in RJMS and was subsequently found to have the strain associated with Belfast.
23 January 2012	A Control Team Meeting was held and a programme of further actions particularly relating to risk management of sinks/water and enhanced cleaning was agreed for immediate implementation.
24 January 2012	A third infant in Craigavon Neonatal Unit was confirmed positive for pseudomonas colonisation from the screening of babies which had taken place on 20 January 2012.
26 January 2012	At 19:30 the Clinical Director for Infection Prevention and Control was telephoned by the Belfast IPC Doctor. The IPC Doctor advised that a baby who had been transferred from Craigavon to RJMS NICU in early January, and who had subsequently died, had a strain of *Pseudomonas aeruginosa* which was not the strain linked to Belfast and was possibly a Craigavon strain.
27 January 2012	Given the strain information, PHA held a teleconference with HPA, spoke to the Southern Trust that evening and produced and issued guidance on further actions to be taken. The trust Chief Executive confirmed to the DPH that an Incident Control Team would meet the following morning, the Chief Executive would chair that team and that all additional actions required by the PHA would be taken.
28 January 2012	A Pseudomonas Incident Team was convened, attended by PHA representatives. All recommended actions were reviewed and considered to be in place.

The interim findings of the epidemiology study being carried out by the PHA indicate that one baby was infected and three babies were colonised with the same strain of *Pseudomonas aeruginosa* which has been linked to Craigavon Neonatal Unit. The baby who was infected with the strain spent several hours in the unit awaiting transfer to RJMS from Daisy Hill. The baby later died in RJMS NICU. A further baby developed bacteraemia while being cared for in Craigavon Neonatal Unit, having being transferred from RJMS. This baby had the strain of pseudomonas which has been linked to Belfast. A number of different strains of pseudomonas have been found in swabs taken from taps and sinks in the Neonatal Unit in Craigavon but no direct link has been established between the strains found in the environmental screening/water testing and the infection and colonisations.

6.6 Cases Linked to Antrim Hospital Neonatal Unit

Two babies were found to be colonised at Antrim Neonatal Unit through screening.

DATE	ACTION
20 January 2012	A baby screened on admission to the unit was found to be positive for *Pseudomonas aeruginosa.* This baby had been transferred from RJMS Neonatal Unit and was subsequently found to have the strain linked to Belfast. The baby had screened negative in Belfast on 17 January 2012.
24 January 2012	A baby screened in Antrim Neonatal Unit was found to be positive who had only been cared for in Antrim. This strain has, to date, been found to be unique and has not been linked to any of the human or environmental strains associated with these incidents.

Environmental sampling from two sinks and water samples from taps in Antrim neonatal unit were found to be positive for *Pseudomonas aeruginosa.*

6.7 Regional Response following the Declaration of RJMS Outbreak

DATE	ACTION
17 January 2012	PHA was informed by Belfast Trust that babies in the neonatal unit had pseudomonas, of whom two had died. PHA offered support and advice to the Belfast Trust on control measures to be put in place and on the need to draw on learning from Western Trust. DHSSPS received Early Alert from Belfast Trust that two babies were confirmed with same strain of pseudomonas infection, of whom one baby had died. Trust awaiting results on two other babies of whom one had died. Admissions to the unit were to be restricted.

18 January 2012	DHSSPS prepared a submission for the Minister advising of outbreak at RJMS. SAI notification form was submitted by Belfast Trust to HSCB concerning outbreak at RJMS.
19 January 2012	PHA representatives attended the Belfast Trust Outbreak Control Team (OCT) meeting. DHSSPS briefed by PHA on the incident. Minister issues press release offering sympathy to the families of the two young babies who had died at RJMS. A third baby died in RJMS neonatal unit during the night who had pseudomonas.
20 January 2012	PHA held a teleconference with Belfast Trust at 09:30. HSCB chaired a later teleconference with all trusts, the Minister, DHSSPS, and PHA to discuss how to manage the capacity of neonatal cots across Northern Ireland. PHA contacted the regional neonatal transfer service and Northern Ireland Ambulance Service. Guidance on health protection advice when transferring babies between units was discussed with trust clinical staff and issued to trusts by PHA. Press conference held with Minister and CMO joining Belfast Trust and PHA representative. Minister issued a press release following death of the third baby at RJMS and CMO and Minister provided interviews for media.
21 January 2012	PHA representatives attended the Belfast OCT meeting PHA held a teleconference with HPA to seek advice as to whether to start weekly screening of babies. HPA advised a risk based approach based on pattern of cases and colonisations. Regional teleconference was held with all trusts and guidance given on transfer of minimising neonatal transfers, transferring in utero when possible and screening babies before and after transfer between units. Decision taken during teleconference that sterile water should be used for all washing of babies during nappy changes.
22 January 2012	PHA and HSCB agreed that PHA should lead the joint response as issues were primarily related to public health rather than service delivery. The DPH was nominated as Incident Lead Director. PHA/HSCB/BSO activated their Joint Response Plan in relation to incidents. They agreed to establish an Emergency Operations Centre. Plans were developed for a regional epidemiological investigation to be carried out.

22 January 2012	A teleconference was held between with HPA, Belfast Trust and PHA to discuss issues relating to water and taps. The daily regional conferences were now formally regarded as meetings of the Regional Health Response Group (RHRG), CMO and Senior Medical Officer from DHSSPS participated.
23 January 2012	Joint Emergency Operations Centre was established. PHA recommended that Belfast Trust OCT set up a sub-group to provide assurance that all control measures were implemented. PHA issued guidance to trusts on management of colonised babies, screening and infection control measures. At RHRG, Belfast Trust advised that samples of 4 out of 6 sinks in NICU were presumptive positive results. DHSSPS advised Belfast Trust that tap replacements should be with manual lever operated taps without thermostatic mixer valves. DHSSPS informed UK estates organisations of the outbreak with request for advice if available. Minister issues press release to advise that 6 babies in RJMS were confirmed to have pseudomonas infection and one more potentially infected. Minister provides update at Oral Questions in NI Assembly.
24 January 2012	Minister gave detailed statement to the NI Assembly on the outbreaks. Minister and CMO facilitated media interviews. A press release was issued that the case of infection from previous day was now confirmed. PHA and DHSSPS initial teleconference was held to consider the need to test water and replace taps based on the balance of risk. PHA teleconference was held with trusts to go through guidance issued on 23 January.
25 January 2012	PHA visited RJMS to explore the potential to increase capacity in the neonatal unit. Liaison took place between PHA and HPA Board with regard to management of the incident. CMO wrote to CMO (England) to ask that specific areas in national report on potential risks from pseudomonas were prioritised for action to protect vulnerable patients. CMO convened a conference call with PHA to discuss Point of Use Filters and taps.

26 January 2012	Joint Response Incident Control meetings were established given the potential that the incident could impact on other neonatal units. A teleconference took place between PHA, DHSSPS, and Belfast Trust to discuss use of Point of Use filters. Further DHSSPS/PHA teleconference on water testing and replacement of taps in other units. It was determined that further guidance should be issued by the DHSSPS. PHA issued further guidance to trusts with updated guidance on case definitions, reporting requirements and screening.
27 January 2012	CMO formally requested expert advice and support from the HPA. PHA held teleconference with trusts re environmental risk assessment guidance. During daily RHRG teleconference the decision to use sterile water for bathing or toileting infants was confirmed. PHA issued guidance for GPs and paediatric doctors as to why discharged babies do not need to be followed up. PHA held a teleconference with HPA to discuss emerging strain typing results. Advice was issued to Southern and Northern Trusts in view of the results. CMO held a teleconference with Trust Medical Directors and requested information on response to DHSSPS guidance letters.
28 January 2012	DHSSPS and PHA met to agree final guidance on water sampling and tap replacement programme. CMO convened a teleconference with trusts, the PHA and HSCB to review the situation. CMO convened a teleconference with HPA and PHA to agree interim protocol for water testing. PHA and South Eastern Trust held a teleconference to discuss presumptive positive results from taps in neonatal unit. PHA advised that babies should remain in the unit with control measures and regular screening of babies and water sampling. Minister issued a statement about situation in South Eastern Trust CMO provided updates to Minister, Permanent Secretary, Chair and Deputy Chair of Health Committee.

28 January 2012	DHSSPS guidance HSS (MD) 4/2012 issued to trust Chief Executives. Site visit by PHA to NHSCT to discuss and seek assurances in respect of advice issued on evening of 27 January.
29 January 2012	PHA issued guidance to trusts on the process for reporting tap replacements and water sample results to PHA. PHA provided information for trusts to use for parents which would explain the need for water sampling. DHSSPS and HPA agreed to hold a teleconference to discuss the protocol for scientific testing of taps at Porton Down. CMO gave live interview on the current situation.
30 January 2012	DHSSPS shared interim guidance with other UK CMOs. Health Estates agreed to establish a Regional Water Group to oversee tap replacement programme. Arrangements put in place for a daily teleconference between HEIG, trusts and PHA on tap replacement programme. PHA agreed on-site visits to neonatal units to collect information for epidemiology investigation. Minister asked RQIA to facilitate an independent review.
31 January 2012	Minister gave a second statement to the NI Assembly on pseudomonas in neonatal units followed by press interviews. CMO held a teleconference with other UK CMOs to discuss pseudomonas in neonatal units in Northern Ireland. This meeting included Chair of Advisory Committee on Antimicrobial Resistance and Healthcare Associated Infection (ARHAI). ARHAI was asked by CMO to provide advice on pseudomonas in all augmented care settings. HPA initiated a teleconference with PHA and Health Estates to discuss scientific examination of taps to inform the national evidence base. PHA issued further guidance recommending twice weekly screening of babies in neonatal units and screening when babies are transferred from other units. RHRG conference call. Altnagelvin reported presumptive positive water tests. Belfast Trust reported a Pseudomonas colonised baby in their paediatric ICU who had been in RJMS neonatal unit. PHA carried out a risk assessment and advised that screening of others in the unit was not required. HPA/PHA teleconference was held to review information related to Craigavon neonatal unit.

7. The Family Perspective

In recognition of the tragic impact of pseudomonas infection for the families of those babies who have been affected, it was decided that during the course of the review the parents of those babies affected should be engaged with directly.

A letter was sent, through the trusts, to parents of babies that had been affected by pseudomonas offering to meet with them. It was felt that it was extremely important to hear the views of families as they might have information that was relevant to the review and also they may have questions that they felt should be answered.

The review team has met with eight families so far. For the purposes of this interim report the following is a combined short account of the experiences they shared with review team members during the meetings. A more detailed account of the issues arising will be included in the final report.

Families stated that their decision to share their experiences with the review team was influenced by their understanding that lessons would be learned and recommendations would be made to try to prevent such an outbreak happening again. The review team recognises that this was a very difficult subject to discuss and wishes to thank all those involved for their participation, openness and willingness to share their experiences.

Generally families were initially positive regarding how they were treated by medical and nursing staff. They were very positive about the clinical care their babies had received, however after some discussion some issues regarding communication and passing on of information began to emerge.

In most cases it was felt that nursing staff were good at passing on information regarding babies" care and they provided useful help with regard to feeding and caring for babies. In one case it was felt that the transfer team had looked after a baby as if it was their own and in another, the family felt that their baby had been looked after by the “A team.”

However there were some reservations regarding the passing on of information from some medical staff as they tended to use language that was too technical.

The families were asked about what effect they felt the outbreaks had on staff and they realised that there had been a big impact on staff who had been noticeably upset and stressed. They also realised that in many cases nursing staff were upset and hurt by the fact that babies in their care were sick.

When asked about when and what they were told about pseudomonas some of the families felt that they had not been sufficiently informed about the seriousness of their babies" condition.

When asked about infection control procedures in neonatal units all families noted that they felt that infection control procedures had been good. They also had been given instructions on washing hands and being bare below the elbows.

There is still an opportunity for families to engage with the review team if they wish in advance of the final report.

8. Interim Findings and Conclusions

8.1 Introduction

The Terms of Reference for this review requested an interim report to be submitted to the Minister by 31 March 2012 to enable any immediate actions identified to be taken forward as soon as possible.

The review team has been made aware during phase one of this review of a number of important exercises that are underway at national and regional levels and will be relevant to the final report of this review. These include:

- Water Sources and potential *Pseudomonas aeruginosa* Infection of Taps and Water Systems: Advice for augmented care units: Department of Health which was published on the Department of Health (England) website on 30 March 2012.
- The UK Advisory Committee on Antimicrobial Resistance and Healthcare Associated Infection (ARHAI) has established a sub-group to advise on the management of infections in neonatal units.
- Taps which were removed from neonatal units across Northern Ireland have been sent for analysis by the Health Protection Agency laboratory at Porton Down.
- Collection of further information about pseudomonas incidents in augmented care settings across England by the Health Protection Agency.
- The Public Health Agency is completing an epidemiological investigation of the pseudomonas incidents in Northern Ireland.
- Belfast Trust is completing a root cause analysis of the circumstances leading to the pseudomonas outbreak in the neonatal unit at Royal Jubilee Maternity Service.

The review team has met with the PHA team carrying out the epidemiological investigation. The information provided has been helpful in understanding the complex pattern of the events which have occurred.

The review team has received a briefing on the emerging findings from the Belfast Trust root cause analysis, which closely mirrors the interim conclusions reached independently by RQIA"s review team.

The findings and conclusions set out in this interim report focus on the first two terms of reference for the review:

1. To investigate the circumstances contributing to the occurrences of pseudomonas infection in neonatal units from 1 November 2011.

2. To review the effectiveness of the trusts" management of the occurrences of pseudomonas infection and colonisation within neonatal units, to include:

    a. The management of the occurrence of pseudomonas infection and colonisation in the neonatal unit in the Western Trust.
    b. The management of the declared outbreak of pseudomonas infection and colonisation in the neonatal unit in the Belfast Trust in January 2012.

c. The management of any colonised babies in the other neonatal units across Northern Ireland.

The final report, to be presented to the Minister by 31 May 2012, will set out findings and conclusions in relation to the following terms of reference:

3. To review the effectiveness of the governance arrangements across all five health and social care trusts with regard to the arrangements for the prevention and control of infection and all other relevant issues in their respective neonatal units.

4. To review the effectiveness of the communication between the DHSSPS, the HSCB, the PHA, and the five health and social care trusts in respect of all relevant information and communications on the pseudomonas bacterium.

The review team considered that it was essential that families of those babies affected by the pseudomonas incidents should be provided with an early opportunity to meet with the team and meetings with eight families have taken place.

8.2 First Term of Reference

To investigate the circumstances contributing to the occurrences of pseudomonas infection in neonatal units from 1 November 2011

In the period from 1 November 2011 to 31 January 2012, outbreaks of *Pseudomonas aeruginosa* occurred in the intensive care rooms of two neonatal units in Northern Ireland, at Altnagelvin Hospital and Royal Jubilee Maternity Service (RJMS). A cluster of cases was linked to Craigavon Area Hospital Neonatal Unit. A baby was colonised who was born and cared for in Antrim Area Hospital Neonatal Unit. No cases of colonisation or infection were found linked to the Ulster Hospital Neonatal Unit.

8.2.1 Analysis of strains found in babies

Analysis of typing of strains of *Pseudomonas aeruginosa* linked to the outbreak has been complex as several different strains have been linked to the outbreak. This work is ongoing. The findings to date indicate that the infection or colonisation of babies in each of the four neonatal units was associated with different strains of *Pseudomonas aeruginosa*.

In Altnagelvin three babies became infected in early December 2012. Two had a single strain and one had a different strain.

In RJMS four babies became infected and 11 were colonised with a single strain of *Pseudomonas aeruginosa.* One of the colonised infants subsequently became infected following transfer to another neonatal unit. The earliest identified sample linked to this strain was on 15 November 2011 and the latest on 23 January 2012.

In Craigavon, three babies were found to be colonised with a single strain of *Pseudomonas aeruginosa* from samples taken on 20 and 24 January 2012. A baby who

had been transferred from Craigavon to RJMS on 9 January and who became infected and died in RJMS also had this strain.

In Antrim, a baby who was colonised had a separate, unrelated strain.

The Review Team has concluded that incidents relating to *Pseudomonas aeruginosa* infection and/or colonisation of babies in four neonatal units in Northern Ireland were each caused by different strains of the organism, which means they were separate outbreaks/clusters.

8.2.2 Links to strains found in water, taps and sinks

During the period when the incidents linked to *Pseudomonas aeruginosa* occurred, a large number of environmental and water samples were taken. Samples were collected in different ways in the early stages until standardised techniques were put in place. Analysis of samples for strain typing is still ongoing and a detailed analysis of taps is taking place. Nevertheless, the review team considers that the information available to date points to emerging findings and conclusions.

All five neonatal units in Northern Ireland had evidence of *Pseudomonas aeruginosa* contamination in some of the water, sink or tap samples which were tested.

In Altnagelvin Hospital, each of the two strains which led to the infection of babies was found in one of the taps or sinks in the ICU room. One of these strains was found at the time the babies were infected. The other strain was found on a swab taken on 12 January 2011 from a tap which had been previously negative. One infrequently used tap in a part of the room which was rarely used to care for babies was found to be contaminated with pseudomonas.

In RJMS, the strain which has been associated with five cases of infections and 10 colonised babies was detected in samples from four out of six taps in the main NICU room and also from a tap in SCBU.

In Craigavon Area Hospital, a direct link has not been established between the strain linked to babies and strains tested through water sampling.

In Antrim Area Hospital, the strain in a colonised baby was different to those found in water samples.

These findings indicate strong links between the cases of infection and colonisation at Altnagelvin and RJMS and the tap water in the units. In Craigavon and Antrim, links have not been established, but cannot be ruled out at this stage.

The review team has been advised that the taps and sinks in RJMS and Craigavon neonatal units had been recently replaced, prior to the incidents. The taps and sinks in Altnagelvin neonatal unit had been in used since the unit opened in February 2009. A refurbishment of RJMS had taken place in August and September 2011 during which new taps and sinks had been installed. Craigavon Neonatal Unit had a significant refurbishment, which was completed in March 2011. This included the fitting of new sensor taps and sinks in the refurbished areas.

Sensor taps, which do not require the operator to touch the tap, had been installed in all three units. Concerns about links between sensor taps and pseudomonas infection have previously been raised as set out in Section 5. The taps removed following the incidents have been sent for analysis and the review team will consider the findings when preparing the final report of the review.

During the Altnagelvin outbreak, the initial samples from taps were taken using swabs. Following the declaration of the outbreak in RJMS, regional guidance was issued on instituting water sampling and as to how water samples should be taken in a standardised manner. Trusts have advised that the presentation of test results can be different depending on the laboratory used. Some laboratories provide greater degrees of detail in relation to the level of any pseudomonas bacteria found which is helpful to assess levels of contamination.

Prior to the incidents, routine sampling of water was not carried out in relation to pseudomonas in augmented care settings across Northern Ireland. This has been introduced for neonatal care units following introduction of interim guidance issued by DHSSPS on 9 February 2012 in HSS (MD) 6/2012.

Further guidance was published on 30 March 2012 by the Department of Health (DoH) in England. The review team recommends that the current arrangements in Northern Ireland are continued pending early consideration of the DoH guidance. This will be relevant to all augmented care settings.

The review team has concluded that the outbreaks of infection of *Pseudomonas aeruginosa*, which occurred in the neonatal units at Altnagelvin and Royal Jubilee Maternity Hospitals, were linked to contaminated tap water in the intensive care rooms of the units. There is no definitive evidence to link a cluster of cases in Craigavon Neonatal Unit, and a single case of a colonised baby in Antrim Neonatal Unit to water sources in those units. Installation of sensor taps in Altnagelvin, Royal Jubilee Maternity and Craigavon hospitals prior to the outbreaks may have contributed to creating an environment for pseudomonas to become established.

8.2.3 Methods of spread of infection

The review team has sought evidence as to potential routes of transmission, through which babies could have been colonised or infected with pseudomonas from contaminated taps or sinks in the units.

The review team found that in the five neonatal units in Northern Ireland it was normal practice to use tap water for nappy changes. This has also been common practice in other parts of the United Kingdom. In units using tap water, a small container of tap water was taken from hand washing stations. The review team consider that this was a likely route for transmission of pseudomonas from taps to babies.

The review team has been advised that in the RJMS Neonatal Unit, a further potential route of transmission was through the method by which expressed breast milk was defrosted. Fresh breast milk can be frozen for up to three months. It can be defrosted in a refrigerator over several hours or more rapidly under a flow of tepid water from a tap or by standing in a container of tepid water in line with extant guidance. Tap water in neonatal units was being used for this purpose and this may have led to transmission.

Contamination of the skin of a baby may lead to subsequent colonisation but not necessarily to infection. The review team has found that the babies who developed infection in the neonatal units required many invasive procedures such as putting in intravenous lines and intubation for ventilation. There is a high risk that such procedures can lead to invasive infection when a baby has been colonised or the skin contaminated with pseudomonas.

The review team has concluded that the most likely method of spread of *Pseudomonas aeruginosa* from contaminated taps to babies in Altnagelvin and Royal Jubilee Neonatal Units was through the use of tap water for washing during nappy changes. The use of tap water to defrost breast milk previously frozen for storage may also have contributed in Royal Jubilee Maternity Service. Device related invasive procedures are likely to have contributed to the development of infection when babies had been colonised with the organism on their skin.

8.2.4 Other Factors Which May Have Contributed to the Pattern of Cases:

8.2.4.1 Fabric and design of units

Members of the review team have undertaken a series of visits to each neonatal unit. All have reported that they observed a marked difference in the fabric of the estate between the RJMS Neonatal Unit and the other units.

Neonatal Units at Altnagelvin and Ulster hospitals are located in new purpose-built facilities, opened within the last five years. They are spacious, well designed and have appropriate rooms to enable segregation of infected babies. Craigavon Neonatal Unit, although located in an older building, underwent a very significant refurbishment recently, which created a spacious and bright ICU environment with facilities for segregating infants.

Antrim Neonatal Unit is about 20 years old with separate rooms. The review team considered that the unit was generally well designed, but would benefit from the creation of additional space for the ICU room to facilitate staff movement and the use of equipment. Plans are currently in place to increase the footprint of the ICU room during 2012/2013.

The Neonatal Unit at RJMS is located in a building which opened in 1933. A planned move to a new unit is to take place in around four years" time. The main room in which the Regional Neonatal Intensive Care Unit is located is a single room with 12 cots. The unit does not have appropriate facilities for isolation, and limited space for staff to clean equipment and incubators. There is limited space for circulation within the ICU room. The distance between cots and the sluice room is likely to have contributed to the use of hand washing sinks to dispose of water after cleaning babies, and thus potentially to the spread of contamination between taps. The roof of the building leaks and the water pipework to the building is old.

The Review Team has concluded that the design of the Royal Jubilee Maternity Unit does not facilitate staff in carrying out good principles of infection prevention and control. It is recommended that the move to a new unit is expedited as quickly as possible. In the interim, steps should be taken to improve space around cots, and to create better facilities for segregation of babies with infections and for cleaning equipment and incubators.

8.2.4.2 Cleaning practices

Specific standards on cleaning methods, or on the risk assessment of functional areas and elements to determine the frequencies at which areas should be cleaned and audited, are implemented in each trust using the DHSSPS *Cleanliness Matters Toolkit* and the NPSA *National Specifications for Cleanliness in the NHS*. The review team noted that there were slight variations in cleaning practices and the frequency of cleaning between units.

All units used the above guidance and the British Institute of Cleaning Sciences BICS (Revised September 2011) method for sink cleaning or an adaption of this procedure. This procedure instructs staff to clean sinks from bottom, cleaning the taps last.

The new guidance issued from the CMO on 28 January 2012 stated that taps in neonatal units should be cleaned first starting at the base upwards from back to front working up to the nozzle and water outlet. The review team recommends that the interim guidance is reviewed to ensure that there is consistency of practice across all clinical areas.

Variations were also observed in the cleaning of incubators and where they were cleaned. In four of the units cleaning of incubators was undertaken by nursing staff. In RJMS the incubators were cleaned by staff from Patient Client Support Services (PCSS). A neonatal technician was responsible for cleaning the humidifier tray and medical attachments and signing off prior to reuse. The neonatal unit in the Southern Trust is the only unit to have a separate room for the decontamination of incubators. In the RJMS incubators are cleaned in the corridor and in other units the dirty utility room is used.

The Review Team has concluded that staff were carrying out cleaning procedures in line with recognised guidelines. It is recommended that the interim guidance dated 28 January 2012 on cleaning sinks be reviewed to provide further clarity in this matter.

The Review Team also concluded that there should be a regional approach and guidance on the cleaning of incubators and other specialist equipment for neonatal care.

8.2.4.3 Hand hygiene and use of personnel protective equipment

All units carried out self-validation hand hygiene audits and were able to produce a record of hand hygiene audit results and frequency. All units advised the review team that Independent Hand Hygiene Audits were carried out. However the review team has noted that there was variation in the methods and frequency of approach and in relation to action planning to address non-compliance issues.

The review team has been advised by two trusts (Belfast and South Eastern) that alcohol gel was routinely used after hand washing in neonatal units prior to the pseudomonas incidents. The CMO interim guidance issued on 28 January 2012 in **Circular HSS (MD) 4/2012** stated that the HPA had advised that a hand rub conforming to BS EN 1500 (*Chemical disinfectants and antiseptics. Hygienic hand rub. Test method and requirements)* should be used after washing and this would be sufficient to eliminate the risk of infection.

The review team noted that disposable plastic aprons were not worn on all occasions to protect uniforms and clothes from water splashes when undertaking wet work such as in RJMS when cleaning the incubators. They were also not always worn when undertaking invasive procedures where there is direct contact or a risk of contamination from blood or body fluids.

The Review Team concluded that independent validation of hand hygiene audits should be carried out on a regular and ongoing basis, supported by robust action plans where issues of non-compliance are identified. The team also recommends the appropriate use of PPE.

8.2.4.4 Occupancy rates

The review team has been provided by trusts with information about occupancy rates in neonatal units across Northern Ireland for the period from September 2010 to January 2012 (Section 4.4). These figures indicate that there were high levels of occupancy for Intensive Care (Level 1) across Northern Ireland for the period from November 2011 to January 2012 when the pseudomonas incidents occurred. In Altnagelvin Hospital this led to cot spaces in the ICU room being used which were not usually opened.

The Review Team concluded that during the period of the outbreaks the occupancy rates for intensive neonatal care were high which increased the pressures on the neonatal care system at that time.

8.2.4.5 The vulnerability of the babies who became infected

Nine babies became infected with *Pseudomonas aeruginosa* during the period from 1 November 2011 to 31 January 2012, five of whom died. Information provided to the review team has indicated how vulnerable these babies were to the risk of infection. Five of the babies were born at less than 26 weeks gestation and two others between 27 and 29 weeks. Babies of this age have very fragile skin and their immune systems are not fully developed. They have limited immunity transferred from their mother across the placenta.

All the babies had significant other problems and they received many invasive procedures including insertion of peripheral and central lines and intubation. All the babies had required Level 1 Neonatal Care which is the highest category of provision required.

The review team has concluded that the vulnerability of the babies predisposed them to a very high risk of infection. They consider that, in developing guidance to reduce risk of infection from pseudomonas in augmented care settings, additional safeguards should be considered for intensive and high dependency neonatal care including sterile water only to be used for washing.

8.2.5 Summary of Conclusions in Relation to the First Term of Reference

The RQIA review team has concluded that incidents relating to infection or colonisation with *Pseudomonas aeruginosa* which occurred between November 2011 and January 2012 in four of the five neonatal units in Northern Ireland were caused by different strains of the organism. When babies were transferred from one unit to another there was no spread of that particular strain of pseudomonas to other babies in the second unit. This was a good indication of the quality of infection control.

The outbreaks of infection of *Pseudomonas aeruginosa*, which occurred in the neonatal units at Altnagelvin and Royal Jubilee Maternity Hospitals, were linked to contaminated tap water in the intensive care rooms of the units. There is no definitive evidence to link a cluster of cases in Craigavon Neonatal Unit, and a single case of a colonised baby in Antrim Neonatal Unit to water sources in those units. Installation of sensor taps in Altnagelvin Royal Jubilee Maternity and Craigavon hospitals prior to the incidents may have contributed to creating an environment for pseudomonas to become established.

The most likely method of spread of *Pseudomonas aeruginosa* from contaminated taps to babies in Altnagelvin and Royal Jubilee neonatal units was through the use of tap water for washing during nappy changes. The use of tap water in RJMS to defrost breast milk may also have contributed. Invasive procedures are likely to have contributed to the development of infection when babies had been colonised with the organism on their skin.

The review team found that the current design and lack of appropriate accommodation for isolation or cleaning equipment in the Regional Neonatal Intensive Care Unit at RJMS does not facilitate good infection and prevention control practices. It is recommended that the move to a new unit is expedited as quickly as possible. In the interim, steps should be taken to create improved facilities for segregation of babies with infections and for cleaning equipment and incubators.

Cleaning practices for taps and sinks were in line with recommended practice before the outbreaks. However, the previously recommended practice is significantly different from the practice recommended in interim guidance for neonatal units issued after the outbreaks were declared. The review team recommends that guidance on cleaning sinks should be standardised across all clinical areas.

Two trusts advised that it was routine practice to use alcohol gels after hand washing in neonatal units before the incidents. This was introduced to all trusts when regional guidance was issued after the outbreaks were declared. The review team recommends that all trusts review their arrangements for independent audits of hand hygiene.

The vulnerability of the babies predisposed them to a very high risk of infection. Following guidance in Northern Ireland sterile water is now being used for washing during nappy changes in all neonatal units. The review team recommends that this is continued until there is an opportunity for Northern Ireland to fully consider the new guidance issued on 30 March 2012 by the Department of Health (England).[14]

[14] Water Sources and potential *Pseudomonas aeruginosa* Infection of Taps and Water Systems: Advice for augmented care units: Department of Health (March 2012).

8.3 Second Term of Reference

To review the effectiveness of the trusts" management of the occurrences of pseudomonas infection and colonisation within neonatal units

The review team has been provided with extensive documentation about the management of the occurrences of pseudomonas infection and colonisation. There is clear evidence that staff in all trusts acted to reduce risks of spread of infection and to investigate why the incidents had occurred. The review team has identified a number of key issues for further consideration, which may have impacted on the speed with which measures to control the outbreaks were put in place.

8.3.1 Collation and sharing of information about cases

Critical decisions about the identification and management of incidents related to infectious diseases require relevant information to be available at the appropriate time. The review team has found that this was not always the case during the management of the incidents of pseudomonas.

Case finding carried out by the PHA has identified earlier cases of colonisation, which were not known about at the time when decisions on whether to call an outbreak in RJMS were being taken. Subsequently, these were linked to the outbreak strain there. Information on positive results was not routinely fed back to previous units in which babies were cared for, which could trigger important action if there was a possible link between cases. Information was sometimes provided on an ad hoc basis about events in different units.

Information on bacterial infections of the blood is collected centrally by PHA through the Communicable Disease Surveillance System (CoSURV). However, there is not a routine surveillance system for pseudomonas. Systems are in place for MRSA and *Clostridium difficile.* The review team recommends that appropriate surveillance arrangements should be established for *Pseudomonas aeruginosa* for augmented care settings including neonatal care.

One baby was transferred between Altnagelvin and RJMS who had a known pseudomonas infection at the time of transfer. In this case, there was evidence of good transfer of clinical information and, when a blood culture was found positive at Altnagelvin after the baby had left, this information was promptly passed on to RJMS.

The review team has concluded that the lack of an agreed system for the surveillance of pseudomonas colonisation and infection led to delays in sharing of information between trusts in some cases which may have impacted on subsequent decision making.

8.3.2 Response to a case of *Pseudomonas aeruginosa* in a neonatal unit

The review team found that a single case of colonisation or infection by *Pseudomonas aeruginosa* in a baby was responded to clinically for the baby, but did not result in an investigation as to a possible source of infection. This is in keeping with normal practice for infection control for most organisms, where a source will not be sought unless at least two cases are involved. For particular high-risk organisms such as meningitis in a child, a single case would trigger immediate action.

The findings of the review team in these incidents suggest that identification of a case of pseudomonas in a neonatal unit indicates that the baby may have been exposed to an environmental water source of infection. This could have occurred while in that unit or in another unit where the baby was previously cared for since birth. Early pre-term babies are extremely vulnerable to infection with pseudomonas infection.

The findings of the review team also indicate that if water testing of taps and sinks close to the baby had taken place in units when a first baby was found to have been colonised or infected, taps contaminated with *Pseudomonas aeruginosa* might have been identified earlier in both Altnagelvin and RJMS neonatal units.

The review team has concluded that the response to the identification of the initial case of *Pseudomonas aeruginosa* in each unit was in keeping with normal practice. In the light of the findings of this review, it is recommended that *Pseudomonas aeruginosa* is identified as an alert organism for neonatal intensive care and high dependency units. When identified from a sample from a baby, taps and sinks should be tested in rooms which had been occupied by that baby since birth.

8.3.3 Process for declaring an outbreak

The review team has considered the processes with which outbreaks of *Pseudomonas aeruginosa* were declared at Altnagelvin and RJMS neonatal units.

At Altnagelvin, an outbreak was declared at a meeting of an incident team on 12 December 2011 when there had been three confirmed cases of *Pseudomonas aeruginosa* in the previous 14 days. Positive sample results were confirmed on 28 November, 8 December and 12 December 2011. No information on strain typing was available at that time. In Altnagelvin, enhanced infection control measures were put in place on the day the outbreak was declared. This included environmental sampling, including swabbing of taps, but not testing of water. As part of the enhanced infection control measures, the infection control team recognised the potential risk associated with water sources and introduced the use of sterile water instead of tap water which was being used during nappy changes.
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At RJMS there were two known cases of *Pseudomonas aeruginosa* in the unit in December 2011 with the possibility that spread had occurred between the babies. Infection control arrangements were enhanced including co-locating the two babies to reduce the risk of spread of infection to others. A decision was taken to seek typing as quickly as possible, rather than declare an outbreak. Typing results confirmed these were different strains. Subsequently, when another case was confirmed positive on 7 January 2012, infection control arrangements were put in place and typing was requested to determine whether there was a link to one of the earlier cases.

On 15 January 2012, results were confirmed positive for *Pseudomonas aeruginosa* from a baby who had died the previous day.

On 16 January 2012, the typing results were provided and confirmed that two babies had had the same strain. An incident team meeting was held on the following day. Environmental sampling was then carried out and a programme of control measures was put in place.

The findings indicate differences in approach to the declaration of outbreaks across the units. Altnagelvin declared an outbreak following three cases without typing results. Belfast Trust requested typing after two cases to determine whether they were related and put enhanced infection control measures in place. It later declared an outbreak following consideration that three cases were potentially related, of which two had been found to have the same strain.

The review team has concluded that there was no agreed approach across neonatal units in place for the declaration of outbreaks. Environmental sampling including testing of water for pseudomonas was not carried out prior to the confirmation of the outbreaks in Altnagelvin or RJMS.

8.3.4 Arrangements to carry out typing of *Pseudomonas aeruginosa*

At present, typing of *Pseudomonas aeruginosa* is carried out in the HPA Reference Laboratory in England for samples from Northern Ireland. The Reference Laboratory has analysed a large number of samples from babies and the environment in relation to the incidents subject to this review. These results have been fundamental in understanding the events which occurred.

The process of sending samples to England does take time and may have led to delays in recognising the pattern of the incidents which occurred. The review team has concluded that the establishment of arrangements for typing *Pseudomonas aeruginosa* in Northern Ireland would facilitate the earlier investigation of cases of infection and the earlier identification of related cases.

The review team has concluded that the establishment of arrangements for typing of *Pseudomonas aeruginosa* in Northern Ireland would reduce the risk of delays in identification of related incidents of infection.

8.3.5 Neonatal network arrangements in Northern Ireland

The review team has found that there is no formal neonatal network across the five neonatal intensive care units and two special care baby units. An informal network exists, but clinical staff informed the team that there are no common protocols in place across the neonatal units. Arrangements to ensure that babies are cared for in the units most appropriate to their needs are not fully developed.

A position paper on Specialist Neonatal Services in Northern Ireland in May 2006 stated that babies born before 28 weeks gestation and weighing less than 1,000 grams should receive their initial care in the regional unit (see Section 4.3.2). The review team has been advised that this is increasingly not being achieved. The three infected babies being cared for in Altnagelvin Neonatal Unit during the outbreak were all under 26 weeks.

The Neonatal Transfer Service does not operate on a 24 hour basis and alternative arrangements are put in place out-of-hours. The review team considers that this should be reviewed and plans established to expand the service with a goal to move to a 24 hour service.

The review team considers that arrangements for the provision of neonatal care would be greatly strengthened by the establishment of a formal neonatal network.

The network should ensure that the neonatal resources across the region are utilised to best effect and that units are working to common policies and procedures.

8.3.6 Summary of Conclusions in Relation to the Second Term of Reference

The review team found that staff in all trusts acted to reduce risks of spread of infection and to investigate why the incidents had occurred. The review team has identified a number of key issues for further consideration which may have impacted on the speed with which measures to control the outbreaks were put in place.

Information about cases which had occurred in other trusts was not always readily available to inform critical decisions. There is no agreed system for the surveillance of pseudomonas colonisation and infection and this led to delays in sharing of information between trusts. It is recommended that a surveillance system is established as soon as possible.

Pseudomonas aeruginosa should be identified as an alert organism for neonatal intensive care and high dependency units and when identified from a sample from a baby, taps and sinks should be tested in rooms which had been occupied by that baby since birth.

Trusts had different approaches to the declaration of outbreaks. This may have led to a delay in putting control measures in place when cases of infection occurred. It is recommended that an agreed approach is established across all trusts.

At present, typing of strains of *Pseudomonas aeruginosa* is carried out in England. It is recommended that arrangements for typing of *Pseudomonas aeruginosa* should be established in Northern Ireland to reduce the risk of delays in identification of related incidents of infection.

The current Neonatal Network in Northern Ireland operates on an informal basis. It is recommended that a formal network is established with agreements put in place to ensure that neonatal resources across the region are utilised to best effect and that neonatal units are working to common policies and procedures. Plans should be established to expand the hours of operation of the regional neonatal transfer service for neonates with the goal of establishing this as a 24 hour service.

9. Recommendations

1 The current interim guidance that sterile water should be used when washing all babies in neonatal care (Levels 1, 2 and 3) should be continued pending early consideration of the Department of Health (England) guidance issued on 30 March 2012.[15]

2 Tap water should not be used in maternity and neonatal units during the process of defrosting frozen breast milk.

3 The current arrangements for testing water in neonatal units in Northern Ireland for pseudomonas should be continued pending early consideration of the Department of Health (England) guidance issued on 30 March 2012. This guidance sets out recommendations for water testing for all augmented care units including neonatal care.

4 The presentation of test results of water samples should be standardised across the laboratories which undertake this for HSC organisations.

5 The review team recommends that guidance on cleaning sinks should be reviewed so that practice is standardised across all clinical areas.

6 Regional guidance on the cleaning of incubators and other specialist equipment for neonatal care should be produced.

7 Independent validation of hand hygiene audits should be carried out on a regular basis, supported by robust action plans where issues of non-compliance are identified.

8 The intensive care accommodation in the neonatal unit at Antrim Area Hospital should be expanded to allow more circulation space around cots.

9 *Pseudomonas aeruginosa* should be identified as an alert organism for neonatal intensive and high dependency care. When identified from a sample from a baby, taps and sinks should be tested in rooms which had been occupied by that baby since birth.

10 Surveillance arrangements should be established for *Pseudomonas aeruginosa* for augmented care settings including neonatal care.

11 All relevant organisations should work to an agreed regional protocol for the declaration of outbreaks.

12 Arrangements for the typing of strains of *Pseudomonas aeruginosa* should be established in Northern Ireland.

13 A regional neonatal network should be formally established in Northern Ireland.

[15] Water Sources and potential *Pseudomonas aeruginosa* Infection of Taps and Water Systems: Advice for augmented care units: Department of Health (March 2012).

14 The hours of availability for the regional transfer service for neonates should be expanded with plans put in place to move to a 24 hour service.

15 The development of the new Regional Neonatal Intensive Care Unit at Royal Jubilee Maternity Service should be expedited as soon as possible. In the interim period, improved accommodation for the purposes of isolation and for the cleaning of equipment should be made available for the current unit. Steps to improve the space around each cot should be considered.

10. Next Steps

This report presents the interim findings and conclusions of the independent review of the incidents of pseudomonas infection and colonisation in neonatal units in Northern Ireland.

The purpose of the report is to identify any immediate actions which should be taken forward prior to the completion of the final report of the review. This report makes 15 recommendations on the basis of the evidence which has been considered to date.

It is important to emphasise that since 30 January 2012 there have been no further incidents or outbreaks in neonatal units across Northern Ireland, which strongly indicates that the control measures put in place were successful.

During the second phase of the review, the review team will examine governance arrangements and the effectiveness of communication in relation to the pseudomonas incidents. The actions taken in response to relevant circulars and advices from DHSSPS will also be reviewed. Further consideration will be given to how organisations responded to the incidents as they unfolded. Staffing of units will also be considered. A number of other issues have emerged during phase one which require further clarification and these will be considered during phase two of the review.

In parallel with the work of the independent review team, a number of significant pieces of work are being taken forward at national and regional level. During the second phase of this review, the review team will engage further with the groups carrying out this work to ensure that emerging findings inform the final review report.

During the second phase of the review, a major focus will be on the experience of families. The review team are very grateful to those families who have met with the team during the first phase. The information they have provided has been invaluable. During the next phase the team would welcome the opportunity to talk to other families affected by the incidents should they wish to avail of this request.

11. Glossary of Terms and Abbreviations

ARHAI	Antimicrobial Resistance and Healthcare Associated Infection
Belfast Trust	Belfast Health and Social Care Trust
CAH	Craigavon Area Hospital
DH	Department of Health (England)
DHSSPS	Department of Health and Social Services and Public Safety
HP	Health Protection
HPA	Health Protection Agency
HSCB	Health and Social Care Board
NIC	Neonatal Intensive Care
NICU	Neonatal Intensive Care Unit
NNU	Neonatal Unit
Northern Trust	Northern Health and Social Care Trust
PCSS	Patient Client Support Services
PHA	Public Health Agency
PICU	Paediatric Intensive Care Unit
PPE	Personal Protective Equipment
RQIA	Regulation and Quality Improvement Authority
RBHSC	Royal Belfast Hospital for Sick Children
RJMS	Royal Jubilee Maternity Service
SCBU	Special Care Baby Unit
South Eastern Trust	South Eastern Health and Social Care Trust
Southern Trust	Southern Health and Social Care Trust
Western Trust	Western Health and Social Care Trust

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Pseudomonas aeruginosa and *Pseudomonas putida* outbreak associated with contaminated water outlets in an oncohaematology paediatric unit

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Pseudomonas; Water; Nosocomial infection

Summary This paper describes an outbreak of *Pseudomonas aeruginosa* and *Pseudomonas putida* that occurred in an oncohaematology paediatric unit between January and April 2005. Eight children had nosocomial infections due to *P. aeruginosa* ($N = 5$) or *P. putida* ($N = 3$), which were recovered from central venous catheter blood cultures ($N = 4$), the catheter exit site alone ($N = 2$), or the catheter exit site and the catheter tip ($N = 2$). Subsequent investigation showed that contaminated water outlets represented the possible source of spread. Studies of nursing and environmental cleaning practices revealed two modes of catheter contamination. A reduction in the size of the catheter dressing at the exit site gave less protective cover during showers, and a detergent-disinfectant diluted with tap water had contaminated perfusion bottles. Repetitive intergenic consensus polymerase chain reaction indicated two discrete patterns for *P. aeruginosa* and one for *P. putida*. The water network was chlorinated,

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and disposable seven-day filters were fitted on all taps and showers. Due to the deleterious effects of chlorination on the water network and the cost of the weekly filter change, a water loop producing microbiologically controlled water was installed. In addition, the concentration of the detergent–disinfectant was increased and refillable sprayers were replaced with ready-to-use detergent–disinfectant solution for high-risk areas. Following these measures, no *Pseudomonas* spp. have since been isolated in clinical or environmental samples from the ward.

Introduction

Nosocomial outbreaks caused by *Pseudomonas aeruginosa* have been reported in various settings such as adult intensive care units (ICUs), neonatal ICUs, medical wards, haematology units and burns units.[1–5] The strains involved may be spread via the hands of healthcare workers or by an environmental source such as contaminated water.[5,6]

Pseudomonas putida are aerobic Gram-negative bacteria that grow optimally at room temperature. Due to their ability to metabolize a wide range of compounds, members of this species are able to colonize soil, freshwater and the surfaces of living organisms. *P. putida* is generally considered to be of low virulence. Its isolation from clinical specimens is an unusual event and is of uncertain pathogenic significance.[7] There have been few published reports of infections due to *P. putida*, mostly in immunocompromised patients and newborns.[8,9]

This paper reports an outbreak of catheter infections caused by *P. aeruginosa* and *P. putida* in the oncohaematology paediatric unit of a teaching hospital in Clermont-Ferrand, France. Repetitive intergenic consensus (ERIC2) polymerase chain reaction (PCR) was used to investigate the possible clonal origins of the isolates.

Materials and methods

Patients

Between 18 January and 17 April 2005, eight children in the oncohaematology paediatric unit had nosocomial infections due to *P. aeruginosa* ($N = 5$) or *P. putida* ($N = 3$). All children had a central venous catheter (CVC). Isolates were recovered from CVC blood cultures ($N = 4$), from the catheter exit site alone ($N = 2$), and from the catheter exit site and the catheter tip ($N = 2$).

Bacterial isolates and antibiotic susceptibility testing

The isolates were identified by VITEK 2 and confirmed by API 32 GN system (BioMérieux, Marcy L'Etoile, Lyon, France). Antimicrobial susceptibility testing was performed on VITEK 2 using ticarcillin, ticarcillin–clavulanic acid, piperacillin, piperacillin–tazobactam, ceftazidime, cefepime, aztreonam, imipenem, tobramycin, amikacin, gentamicin, pefloxacin and ciprofloxacin.

Investigation and environmental survey

The oncohaematology paediatric unit has 11 single rooms and three protective isolation rooms with laminar flow. The hospital infection control team performed several investigations between March and May 2005, observing nursing and medical practice and environmental sampling.

There are two washbasins in seven of the patients' rooms and in the sterilization room; one washbasin in one other room, the nurses' office, the communal bathroom and toilets, the decontamination room, office and games rooms; a bath in the communal bathroom, and a shower in seven of the patients' rooms. Water is supplied to all the taps by the same main pipe via a basement distributor.

Cold water was sampled from the taps of each washbasin and shower on the ward. Samples (100 mL) were filtered through sterile filters and cultured on cetrimide agar plates that were incubated for 48 h at 37 °C. Samples for culture were also taken from a detergent–disinfectant (DD) solution used for spraying laminar flow hood and environmental surfaces. The composition of the DD solution was quaternary ammonium (<10%), glutaraldehyde (<3%) and alcohol (<5%).

Molecular typing by ERIC2-PCR

The isolates were genotyped by ERIC2-PCR in the hospital's medical microbiology department, as

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Table I Clinical description of the outbreak

Patient	Birth date	Admission date	Underlying disease	Infection diagnosis date	Symptoms	CVC insertion date	CVC removal date	Sites and dates of isolation	Isolates	DNA pattern clinical isolate	Room	Environmental site of isolation	DNA pattern environmental isolate
1	06/11/87	15/12/04	ALL Graft 10/2004	18/01/05	18/01/05: pus + inflammation 30/01/05: pus	29/06/04	04/02/05	18/01/05: CVC exit site 04/02/05 CVC tip	*P. aeruginosa*	Pattern 2	4	Shower	Pattern 2
2	22/02/94	24/02/05	IMA Graft 07/2004	25/01/05	22/01/05: pus + swelling 25/01/05: inflammation 16/02/05: fever	30/04/04	24/02/05	17/02/05: CVC exit site 24/02/05 CVC tip	*P. aeruginosa*	Pattern 3	10	Shower	Pattern 4
3	19/07/91	15/01/05	AML Graft 12/2004	28/01/05	28/01/05: inflammation 19/02/05: fever	01/12/04	–	19/02/05: CVC blood culture	*P. aeruginosa*	Pattern 2	9	–	–
5	19/02/98	25/01/05	ALL	23/02/05	12/02/05: pus 23/02/05: inflammation	28/01/05	–	24/02/05: CVC exit site	*P. aeruginosa*	Pattern 1	2	Shower	Pattern 1
7	23/09/03	20/02/05	Nephroblastoma	19/03/05	19/03/05: inflammation 27/03/05: pus + swelling	22/02/05	–	27/03/05: CVC exit site	*P. aeruginosa*	–	2	–	–
4	18/02/04	31/01/05	Retinoblastoma	01/02/05	01/02/05: fever 02/02/05: pus	–	–	04/02/05: CVC blood culture	*P. putida*	Pattern 7	6	–	–
6	02/09/03	10/03/05	Hepatoblastoma	12/03/05	12/03/05: fever	–	–	12/03/05: CVC blood culture	*P. putida*	Pattern 6	6	–	–
8	08/10/03	31/03/05	AML Graft 04/2005	17/04/05	17/04/2005: fever	–	–	17/04/05: CVC blood culture	*P. putida*	Pattern 5	6	DD Spray	Pattern 5

ALL, acute lymphoblastic leukaemia; AML, acute myeloblastic leukaemia; IMA, idiopathic medullary aplasia; *P. aeruginosa*, *Pseudomonas aeruginosa*; *P. putida*, *Pseudomonas putida*.

described previously, to study their clonal diversity.[10]

Results and discussion

Characteristics and identification of the patients

Between 18 January and 17 April 2005, five cases of CVC infection with *P. aeruginosa* and three cases with *P. putida* were identified. An outbreak was suspected because eight children had pseudomonas CVC infections, compared with two CVC infections caused by *P. aeruginosa* and none with *P. putida* during the previous year.

The patients (four girls and four boys) had a mean age of 6.5 years (range 1—17 years). Their underlying diseases were acute lymphoblastic leukaemia ($N = 2$), one grafted in October 2004; acute myeloblastic leukaemia ($N = 2$), grafted in December 2004 and April 2005; idiopathic medullary aplasia ($N = 1$), grafted in July 2004; nephroblastoma ($N = 1$), retinoblastoma ($N = 1$) and hepatoblastoma ($N = 1$) (Table I). The mean length of stay in the oncohaematology paediatric unit was 16 days.

Infection was suspected if the patient developed fever and/or CVC exit site inflammation, and was confirmed by positive culture of the CVC exit site, the catheter tip or blood culture. The mean duration between the onset of symptoms and the first positive culture was 7.5 days (range 1—23 days). *P. aeruginosa* was isolated from CVC blood culture (Patient 3), the catheter exit site (Patients 5 and 7), and the catheter exit site and the catheter tip (Patients 1 and 2), and *P. putida* strains were isolated from CVC blood culture (Patients 4, 6 and 8) (Table I).

It is noteworthy that Patient 8 had been in a protective (bubble) isolation room for 12 days when CVC infection occurred. CVCs were only removed in Patients 1 and 2. Patients 3, 4, 5 and 6 were treated with a combination of amikacin and a β-lactam agent (ticarcillin, ceftazidime or imipenem). None of the patients died.

Susceptibility results and molecular typing results (Table I)

The antimicrobial susceptibility patterns of the five *P. aeruginosa* clinical isolates suggested the possibility of different strains. Variability was observed for ticarcillin, ticarcillin—clavulanic acid, piperacillin, piperacilllin—tazobactam, tobramycin, gentamicin and pefloxacin. All of the strains were susceptible to ceftazidime, cefepime, imipenem, amikacin and ciprofloxacin. The antibiograms of *P. aeruginosa* isolates were not superimposed on ERIC2-PCR patterns since there were six susceptibility patterns and four molecular patterns. Isolates from Patient 1 (CVC tip) and from Room 4 had the same antibiogram and the same molecular type (pattern 2). Isolates from Patient 3 (CVC blood culture) and Patient 1 (CVC tip) had different antibiograms but the same molecular types (pattern 2), as did Patient 5 (CVC exit site) and Room 2 (pattern 1) (Figure 1). These findings are consistent with previous reports that susceptibility testing is unreliable in the identification of *P. aeruginosa* strains as unpredictable changes may occur during outbreaks.[11]

This also applies to *P. putida*, which had four susceptibility patterns and three molecular patterns in the outbreak studied. The same molecular pattern was found in isolates from Patient 8 (CVC blood culture) and the DD spray (Pattern 5).

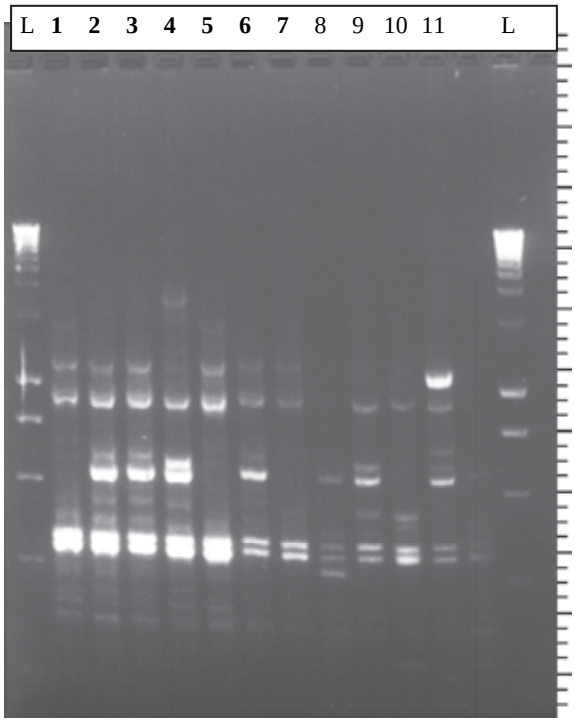

Figure 1 Enterobacterial repetitive intergenic consensus polymerase chain reaction molecular typing for *Pseudomonas aeruginosa*. 1, Patient 5, Pattern 1; 2, Patient 1, Pattern 2; 3, Patient 3, Pattern 2; 4, Patient 2, Pattern 3; 5, Room 2 (shower), Pattern 1; 6, Room 4 (shower), Pattern 2; 7, Room 10 (shower), Pattern 4; 8, *P. aeruginosa* PY2129; 9, *P. aeruginosa* MN 2015; 10, *P. aeruginosa* CF 947; 11, *P. aeruginosa* ATCC 27853; L, ladder. Strains 8, 9 and 10 were bacteria from the authors' microbiological laboratory collection.

Molecular typing is useful in confirming an outbreak and any possible environmental sources. ERIC2-PCR is a reliable epidemiological tool for *Pseudomonas* spp., including *P. aeruginosa* and *P. putida*.[10,12]

Environmental survey and control measures (Table II)

Pseudomonas spp. can survive and replicate in moist environmental reservoirs. Thus, the recognition of an outbreak leads to the epidemiological investigation of water sources.[3,5]

The infection control team was informed during the last week of February 2005 that four CVC infections with *P. aeruginosa* had been confirmed. Water samples from the showers of Rooms 2 (Patient 5), 4 (Patient 1), 9 (Patient 3) and 10 (Patient 2) were analysed as the children used them regularly. The results showed a high concentration of *P. aeruginosa* in shower water from Rooms 2, 4 and 10.

The first set of measures, introduced at the beginning of March 2005, was to replace the shower heads and hoses and to disinfect the taps. Despite these measures, however, water sampling of all the showers and washbasins in March 2005 showed that most water outlets in the ward were contaminated with several *Pseudomonas* spp. isolates. Furthermore, three new CVC infections were identified; one caused by

Table II Results of environmental microbiological samples and control measures

09/03/05: shower heads and hoses replaced; taps cleaned and disinfected

Filters (0.22 μm)

Date		28/02	22/03—30/03	1/04—13/04	15/04—30/04	1/05—13/05	18/05—31/05	1/06—08/06
Chlorination		No	No	0.5 ppm	2.7 ppm	2.7 ppm	0.5 ppm	No
Room 1	S	—	—	—	N	—	—	—
	NW	—	N	—	N	N	N	N
	PW	—	P. put 10	N	N	N	N	N
Room 2	S	P. aer >150	—	N	N	—	—	—
	NW	—	N	—	—	—	—	—
	PW	—	P. put 10	N	N	—	—	—
Room 3	S	—	—	N	N	—	—	—
	NW	—	P. aer >150	—	N	—	—	—
	PW	—	N	P. aer >150	N	—	—	—
Room 4	S	P. aer >150	P. aer >150	P. aer >150	P. aer 35	N	—	N
	NW	—	P. aer >150	—	N	N	N	N
	PW	—	N	—	N	N	N	N
Room 5	S	—	—	—	P. aer >150	—	N	—
	NW	—	P. aer >150	P. aer >150	N	N	N	N
	PW	—	P. flu	—	N	N	N	N
Room 6	PW	—	P. aer > 150	N	N	—	—	—
Room 9	S	—	—	—	—	—	—	—
	NW	—	P. stu	—	—	N	—	—
	PW	—	—	—	—	N	—	—
Room 10	S	P. aer >150	—	N	—	—	—	—
	NW	—	P. aer >150	—	P. aer >150	N	—	—
	PW	—	N	N	—	N	—	—
Treatment room	NW	—	—	P. aer >150	P. aer 3	N	N	N

Results are expressed as colony-forming units per 100 mL.
ppm, Parts per million; P. aer, *Pseudomonas aeruginosa*; P. flu, *Pseudomonas fluorescens*; P. stu, *Pseudomonas stutzeri*; P. put, *Pseudomonas putida*; N, negative result on non-filtered tap; S, shower; PW, patient washbasin; NW, nursing washbasin.

P. aeruginosa (Patient 7) and two by *P. putida* (Patients 4 and 6).

The water network was chlorinated from 30 March 2005, and chlorination was increased on 14 April 2005 because the level was low (Table II). In addition, disposable seven-day filters (0.22 μm) were fitted on all taps and showers in the unit. After the implementation of these measures, no further contamination with *Pseudomonas* spp. was observed. Water samples taken from the main distribution pipes yielded negative microbiological results throughout the outbreak period.

Due to the deleterious effects of prolonged chlorination of the water network and the cost of changing the disposable filters every week, it was decided in June 2005, to install a water loop producing microbiologically controlled water (Sogoba, Aubagne, France). The system provides water treated by daily chlorination, comprising double prefiltration (5 μm and 1 μm) and terminal filtration (0.22 μm). All the microbiological water analyses performed in the ward after installation of the water loop yielded negative results.

Molecular typing revealed that some clinical strains were indistinguishable from environmental isolates (pattern 2 = Patient 1, Patient 3 and Room 4; pattern 1 = Patient 5 and Room 2) (Figure 1). During the outbreak, several observational studies of nursing and environmental cleaning practices were performed. It was noticed that the nurses reduced the size of the catheter dressing at the exit site by cutting the edges, in order to minimize discomfort at dressing removal. Consequently, the catheter dressings covered an insufficient surface and provided less protection during showers. Contamination with *Pseudomonas* spp. may have occurred as a result; the nursing staff have since abandoned this practice.

In April 2005, a third *P. putida* CVC infection was identified in a patient (Patient 8); this patient had not taken showers because he was in strict isolation in a bubble. Investigation of nursing practices showed that before the preparation of parenteral perfusions under a laminar flow hood, the perfusion bottles and hood surfaces were sprayed with a DD solution that was diluted with tap water and stored in a plastic spray bottle. The DD solution was sampled and culture produced heavy growth of *P. putida*. Proliferation of the strain in the disinfectant was probably made possible by the development of a biofilm within the spray. Molecular typing of this strain and the strain isolated from Patient 8 revealed indistinguishable patterns. This prompted recommendations for use of DD in all hospital departments. The concentration was increased from 0.25% to 0.5% (one to two sachets in 8 L of water), and refillable sprayers were replaced with a ready-to-use DD solution for the disinfection of infusate bottles and laminar flow hoods. Since the implementation of these measures, no *Pseudomonas* spp. have been isolated from clinical or environmental samples in the ward.

In conclusion, several potential environmental reservoirs of *P. aeruginosa* and *P. putida* were clearly implicated in the outbreak. The relative importance of the potential sources of catheter contamination is difficult to establish. The analysis of nursing practices detected two unexpected but likely modes of contamination, and led to the implementation of appropriate measures to stop the outbreak.

Acknowledgements

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Generation of Pseudomonas aeruginosa Aerosols During Handwashing from Contaminated Sink Drains, Transmission to Hands of Hospital Personnel, and its Prevention by Use of a New Heating Device

Pseudomonas aeruginosa Aerosolbildung während des Händewaschens aus kontaminierten Abflüßen, Übertragung auf Hände des Krankenhauspersonals, und ihre Verhinderung durch den Gebrauch einer neuen Heizvorrichtung

GERD DÖRING, MARTINA ULRICH, WOLFGANG MÜLLER,[2] JOCHEN BITZER, LUISA SCHMIDT-KOENIG, LUISE MÜNST, HEIKE GRUPP, CHRISTIANE WOLZ, MARTIN STERN[1], and KONRAD BOTZENHART

With 5 Figures

Abstract

Pseudomonas aeruginosa was isolated from sinks of washing basins, showers, toilets and bathtubs, from the personnel and patients of a mixed infectious disease ward in a German children's hospital during a prospective 4-week epidemiological study. 81% of all sinks were contaminated with *P. aeruginosa* strains. Upon entering the hospital, all personnel hand cultures were *P. aeruginosa*-negative. However, during duty, 42.5% of the personnel members carried different *P. aeruginosa* strains on their hands. Detection of *P. aeruginosa* strains in sinks preceding the isolation of identical genotypes from personnel hands suggested a transmission route from sinks to hands. Opening of water taps generated aerosols containing *P. aeruginosa* sink organisms which contaminated hands during hand washing. Survival times of various *P. aeruginosa* strains in aerosols was dependent on strain characteristics, light and humidity, and $t_{1/2}$ differed between 3–76 min. Heating of washing basin sinks to 70 °C with a new, safe and inexpensive device inhibited bacterial growth in sinks, generation of *P. aeruginosa* aerosols, and resulted in hand cultures negative for *P. aeruginosa* after washing.

Zusammenfassung

Pseudomonas aeruginosa wurde aus Abflüßen von Waschbecken, Duschen, Toiletten und Badewannen, vom Personal und von Patienten einer Infektionsstation eines deutschen Kinderkrankenhauses während einer 4-wöchigen prospektiven epidemiologischen Studie isoliert. 81% aller Abflüße waren mit *P. aeruginosa*-Stämmen kontaminiert. Vor dem Betreten des Krankenhauses waren alle Personalhände *P. aeruginosa*-negativ. Während des Dienstes jedoch trugen 42.5% der Personalmitglieder verschiedene *P. aeruginosa*-Stämme auf ihren Händen. *P. aeruginosa*-Genotypen auf Personalhänden, die zuvor aus Abflüßen isoliert worden waren, ließen auf einen Übertragungsweg vom Abfluß auf die Hände schließen. Das Öffnen von Waschbecken-Wasserhähnen erzeugte Aerosole, die *P. aeruginosa*-Abflußstämme enthielten und die Hände während des Händewaschens kontaminierten. Die Überlebenszeiten verschiedener *P. aeruginosa*-Stämme in Aerosolen waren abhängig von Stamm-Charakteristika, Licht und Feuchtigkeit und $t_{1/2}$ differierte zwischen 3–76 min. Das Erhitzen der Waschbeckenabflüße auf 70 °C mit einer neuen, sicheren und billigen Vorrichtung verhinderte bakterielles Wachstum in den Abflüßen, die *P. aeruginosa* Aerosolbildung und ergab *P. aeruginosa*-negative Handkulturen nach dem Waschen.

Introduction

Pseudomonas aeruginosa, one of the most common nosocomial pathogens for several patient populations including cystic fibrosis, paraplegia, immunocompromised and burn patients, is predominantly found in moist areas (2, 9). Sink drains of washing basins, toilets and showers therefore have been addressed as major environmental reservoirs and sources for infections with *P. aeruginosa* in hospitals (2, 4, 9, 12, 14, 17, 21, 24). However, the transmission of sink drain organisms to patients remains currently controversal. In favour of such a route, microbial aerosols have been demonstrated after flushing toilets (6) and patients were found to be colonized with *P. aeruginosa* strains which were identical by pyocin typing or genotyping with isolates from hospital sinks (3, 4, 21, 24). Based on these results, some investigators developed devices to decontaminate sink waste-traps (11, 13, 21). Clearly, the hypothesis of a sink-to-patient transmission of *P. aeruginosa* or other microorganisms needs further substantiation. An improved typing method for *P. aeruginosa* based on a highly strain-variable DNA sequence (18, 23) seems to be a good tool for these epidemiological investigations. Previously (5, 10, 19, 24, 25), we used this probe to compare *P. aeruginosa* patient isolates with environmental isolates in different hospital settings. In the present study, we compare *P. aeruginosa* isolates from patients, personnel and sink drains of a children's hospital ward. We demonstrate that *P. aeruginosa* sink isolates may contaminate hands of the personnel during hand washing, and show that the organisms survive considerable periods of time in aerosols and on hands. These results prompted us to develop a new heating device which inhibits bacterial growth in sink drains, and consequently results in *P. aeruginosa*-negative hand cultures after washing.

Material and Methods

Patients. The 145 bed children's hospital of the university in Tübingen, Germany, has a 11 bed mixed infectious disease unit. During the 4-week prospective epidemiological study from June to July 1989, 25 patients with various diseases were hospitalized on this ward, including one patient with cystic fibrosis, one patient who was mechanically ventilated and one immunocompromised patient. 40 members of the personnel enter the ward for three shifts per day. The personnel wears freshly laundered uniforms for each shift. Disposable gloves are not generally worn when handling a patient. Disinfection and hand washing is usually carried out after handling a patient.

P. aeruginosa isolation. Nose swabs and stool specimens from all 25 patients and the 40 members of the personnel working in the infectious disease ward were obtained once weekly. Additionally, hand cultures were obtained from the personnel once weekly, and once from 37 members of personnel before entering the hospital. Samples from all sink drains of the ward (19 washing basins, 13 toilets, 1 shower and 1 bathtube) were obtained once weekly. Nose samples were collected using sterile cotton swabs which were plated on cetrimide agar plates immediately after collection. Stool samples were collected in sterile plastic tubes, and aliquots suspended in 4 ml sterile 0.9% sodium chloride solution. 100 µl of the suspensions were distributed on cetrimide agar. Hand samples were obtained by washing one hand for 1 min in a sterile plastic bag (National Lab, Hamburg, Germany) containing 100 ml of sterile physiological saline. The saline was filtered through a membrane (Nalgene, Rochester, USA, no. 130–4045), the membrane placed on a cetrimide agar plate and incubated for 24 h at 37 °C. *P. aeruginosa* was identified using routine methods including growth on cetrimide agar, biochemical fermentation, and genotyping. 131 *P. aeruginosa* isolates from patients, personnel, and environmental sources were genotyped.

Genotyping of P. aeruginosa. Genotyping of *P. aeruginosa* with the exotoxin A (ExoA) DNA probe was carried out as described previously with some modifications (5, 18, 25). Briefly, purified *P. aeruginosa* DNA was digested with the restriction endonucleases *Bgl*II, *Sal*I and *Xho*I, electrophoresed through a 0.6% agarose gel and transferred to a nylon membrane (Pall, Dreieich, Federal Republic of Germany) using the Southern method (20). The *Escherichia coli* plasmid pCMtox (23) was labeled with digoxigenin-11-dUTP (Boehringer Mannheim, Germany) by oligolabelling, and used for hybridization of prehybridized nylon membranes. Isolates were compared visually for differences in probe-reactive fragments. Fragment size was determined by comparison with labelled lambda *Hind*III fragments. Typically there are two (*Bgl*II, *Xho*I) or three (*Sal*I) labelled fragments for each strain, revealing the variable region upstream of the ExoA gene, and the constant region downstream of the ExoA gene. Two isolates were considered different, if one or more of the three strain-specific, probe-reactive fragments differed in size. In cases of doubt, when strains were run of different gels and the size of respective fragments showed differences of less than 0.5 kb, the strains were reexamined on one gel.

P. aeruginosa aerosol generation from washing basin sinks. A washing basin sink was contaminated with 30 ml of a suspension of *P. aeruginosa* PAO1 (10^{10} organisms/ml). After 5 min the tap was opened for 30 sec. Thereafter an impactor (Reuter centrifugal sampler, Biotest, Germany) equipped with Standard I agar (Merck, Darmstadt, Germany) was held for 4–8 min at a 15 cm distance from the opening of the sink drain. The agar was incubated for 24 h at 37 °C, and bacterial colonies typed and quantified. These experiments were repeated twice. Thereafter, the sink drain was equipped with a heating device (see below) and the above described experiments were repeated. Thereafter, the sink drain was contaminated again with the *P. aeruginosa* PAO1 suspension and the experiments were repeated. In other experiments the faucet of the contaminated washing basin was opened and hands which had been disinfected before with alcohol, were washed with and without soap for 1 min. The hands were dried with a towel and thereafter immersed into a plastic bag containing 100 ml of physiological saline. *P. aeruginosa* was cultured as described before.

Installation of a heating device covering the washing basin sink drain. A 70 cm self regulating heat trace with cold lead and end seal (Raychem, Offenbach, Germany; type 20 XTV2-CT) was tighly bound to a U-shaped sink drain (diameter: 4 cm, material: steel plated with chromium) in order to cover 20 cm of the sink. The heat trace was covered with dam material (1 cm dam material per 1 cm of sink diameter) (Missel, Stuttgart, Germany; type Misselfix-Garant) in order to avoid temperature loss, and the device connected to a wall-socket. The heat trace consumes 30 Watt and reaches 70 °C after 180 min. No significant water loss in the sink drain was seen when the heating device was used over 24 h without opening the faucet.

Determination of P. aeruginosa survival times in aerosols. For the determination of the survival times of airborne *P. aeruginosa*, a rotating aerosol drum (16) was used (Fig. 1),

constructed with modifications according to *Goldberg* et al. (7). The *P. aeruginosa* nonmucoid strain PAO1, the nonmucoid strain WT20 and its mucoid isogenic variant MUC20 were grown on Standard I agar plates (Merck, Darmstadt, Germany) for 16 h at 37 °C, suspended in distilled water, and homogenized by shaking with glass beads for 1 h. Aerosols were generated with a nebulizer into the rotating drum for 70 sec at 10 l/min. The particle concentration was measured with a light scattering photometer and samples of CFU recovered at different times (5–120 min) using the Andersen sampler (1). The value of the particle concentration and the detected viable CFU provides the possibility to calculate β_{biol} and from this value the half life time $t_{1/2}$ (16). Experiments were carried out with and without light a 25 °C (± 2 °C) and at a relative humidity (rh) of 36% (± 5%) and 80% rh (± 5%).

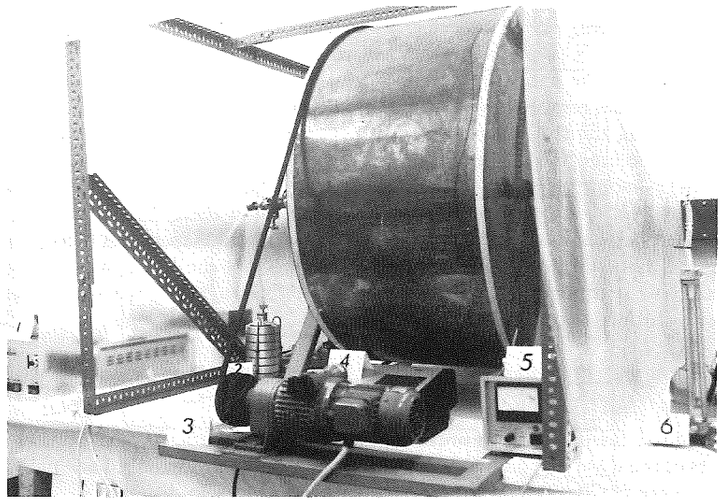

Fig. 1. The rotating aerosol chamber. The drum (4) rotates at 3 rpm by use of an electric motor (3). It has a volume of 0.38 m^3, a radius of 0.495 m, and allows sampling during rotation: air is sucked out of the drum through a plastic tube into the Andersen sampler (2) and the light scattering photometer (1). The chamber was equipped at the axis with a lamp (380–780 nm). The aerosol is generated by a vacuum pump equipped with a rotameter (6). It is passed through a a plastic tube near the axis into the chamber. Temperature and relative humidity are measured (5).

Abb. 1. Rotierende Aerosolkammer. Die Trommel (4) rotiert mit 3 Umdrehungen pro Minute mittels eines elektrischen Motors (3). Sie hat ein Volumen von 0.38 m^3, einen Radius von 0.495 m, und erlaubt die Probeentnahme während der Rotation. Dabei wird die Luft aus der Kammer durch einen Plastikschlauch in den Andersen-Sammler (2) und das Streulichtphotometer (1) gesaugt. Die Kammer ist an der Achse mit einer Lampe (380–780 nm) ausgestattet. Das Aerosol wird durch eine Vakuumpumpe, die mit einem Rotameter (6) ausgestattet ist, erzeugt. Es wird durch einen Plastikschlauch in der Nähe der Achse in die Kammer geleitet. Temperatur und die relative Feuchte werden gemessen (5).

Results

P. aeruginosa isolates from the environment

Samples from all sinks in the infectious disease ward of the hospital were collected once weekly. *P. aeruginosa* was cultured from 17 of the 19 washing basin sinks (89.5%), from the shower sink and the bathtube sink as well as from 6 of the 13 toilet sinks (46.2%) during the 4-weeks period. In 15 contaminated washing basin sinks, single *P. aeruginosa* genotypes persisted between 2–4 weeks. These results show that the sinks in this ward are highly contaminated with persisting *P. aeruginosa* strains. Four different genotypes (P1–P4), isolated from contaminated washing basin sinks were also detected on hands of the personnel and in the stool of one patient.

P. aeruginosa isolates from patients and hospital personnel

5 of the 25 patients (20%) admitted to the infectious disease ward were *P. aeruginosa*-positive in stools (4 patients) or nose swabs (2 patients). Both the patient with cystic fibrosis and the patient with mechanical ventilation were infected or colonized with *P. aeruginosa*, respectively. 4 of these patients were present on the ward only for one week during the study period. None of the patient strains revealed genotypical identity with isolates from the environment of the ward or from personnel specimens.

27 of 161 personnel hand cultures (17%) yielded *P. aeruginosa*. 17 of the 40 personnel members (42.5%) were positive for this organism at least once during the study period. When hand cultures were collected from 37 personnel members before entering the hospital, none yielded *P. aeruginosa*, suggesting that the bacteria were hospital-acquired. Nose swab samples were all negative for *P. aeruginosa*, whereas 3 members had positive stool samples.

Transmission of P. aeruginosa genotypes from sink drains to personnel hands and patients

Fig. 2 shows the distribution of the genotypes P1, P2, P3 and P4 in environmental reservoirs of the ward and on hands of the personnel and in the stool of one patient. All four genotypes persisted from the first to the fourth week in different washing basin sink drains. Clearly, detection of these strains subsequently in specimens of the personnel or a patient is indicative for a sink-to-person transmission: P1 which revealed the largest distribution, was detected on the hand of a charwoman in the third week; P2 and P3 were detected on hands of nurses in the third and fourth week, respectively; Genotype P4 which persisted in two washing basin sinks was also isolated from the stool of one patient in the second week of the study. The patient entered the ward in this week. Thus, these results demonstrate hospital-acquired *P. aeruginosa* colonization of personnel and a patient from washing basin sinks.

In order to investigate the mechanism of transmission of the strains from the sink drains to hands in more detail, one washing basin sink was contaminated with 10^{10} viable *P. aeruginosa* organisms of PAO1. After opening the water tap for 30 sec, a mean of 75 CFU of various gram positive, gram negative bacteria and fungi were detectable on the impactor agar. A mean of 28 CFU of PAO1 (based on genotyping) was recovered on the agar. Heating of the sink drain overnight to 70 °C resulted in negative cultivation of *P. aeruginosa* and other microorganisms on the impactor agar. Repeated artificial contamination of the sink with *P. aeruginosa* and sampling with the impactor after opening of the water tap yielded a mean of 35 CFU of *P. aeruginosa*

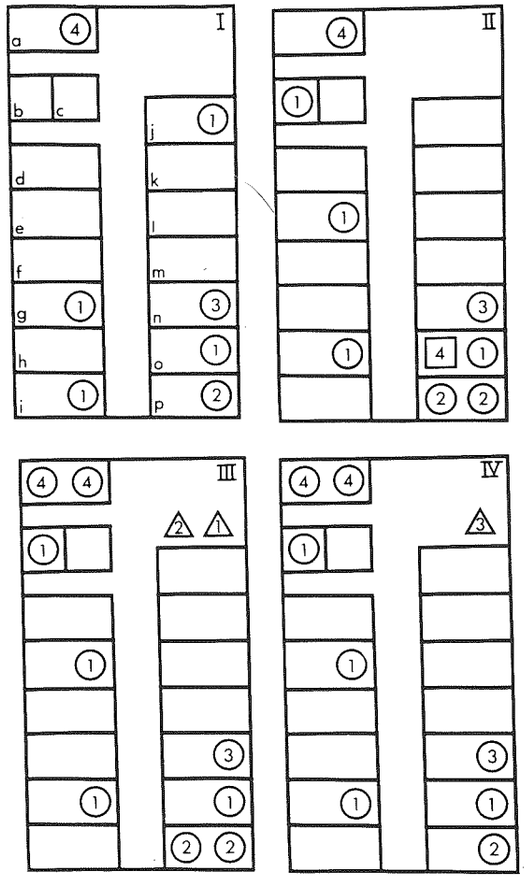

Fig. 2. Distribution of *Pseudomonas aeruginosa* genotypes P1–P4 in environmental water reservoirs (○), and occurrence on hands of the personnel (△) and in the stool of one patient (□) in the mixed infectious disease ward of a children's hospital. *P. aeruginosa* was sampled for four weeks and the distribution of the genotypes on the schematic ground-plan of the ward is given for each week I–IV: a: toilet with washing basin; b: kitchen; c: bath; d: personnel room; e–i and n–p: patient rooms; j: endoscopy room; k: waste room; l: toilet; m: doctor's room.

Abb. 2. Verteilung der *Pseudomonas aeruginosa* Genotypen P1–P4 in Wasserreservoiren der Umgebung (○), das Vorkommen auf Personalhänden (△) und im Stuhl eines Patienten (□) in der gemischten Infektionsstation eines Kinderkrankenhauses. *P. aeruginosa* wurde 4 Wochen lang gesammelt und die Verteilung der Genotypen ist für jede Woche I–IV auf dem schematischen Grundriß dargestellt: a: Toilette mit Waschbecken; b: Küche; c: Bad; d: Personalraum; e–i und n–p: Patientenzimmer; j: Endoskopie-Raum; k: Abfallraum; l: Toilette; m: Arztzimmer.

PAO1 but no other microorganisms. Without opening the faucet, no PAO1 organisms were detectable on the impinger agar.

When hand washing was performed in the *P. aeruginosa* contaminated washing basin without soap, 2,400 CFU of PAO1 were grown on the filter membrane after the hands were dried and immersed in the sterile plastic bag containing 100 ml of physiological saline. Hand washing with soap yielded 1,200 PAO1 CFU per 100 ml saline.

Transmission of a P. aeruginosa genotype between the hospital personnel

The *P. aeruginosa* genotype P5 was isolated from stools of one member of the personnel in the first and third week of the study period and on the hand of another member of the personnel in the first week. P5 was never isolated from patients or environmental sources in the ward and thus had no clinical significance.

P. aeruginosa survival times in aerosols

As shown by the distribution of particles in the 6-step Andersen sampler, 80% of *P. aeruginosa* WT20 and MUC20 were 0.67–1.05 µm in diameter. As shown in Figs. 3, 4 and 5, survival of *P. aeruginosa* in aerosols correlated with rh, absence of light and a nonmucoid strain characteristic. $t_{1/2}$ survival of PAO1 was 76.4 min at 80% rh and 29.6 min at 36% rh (Fig. 3). At 36% rh, light reduced $t_{1/2}$ of the nonmucoid strain

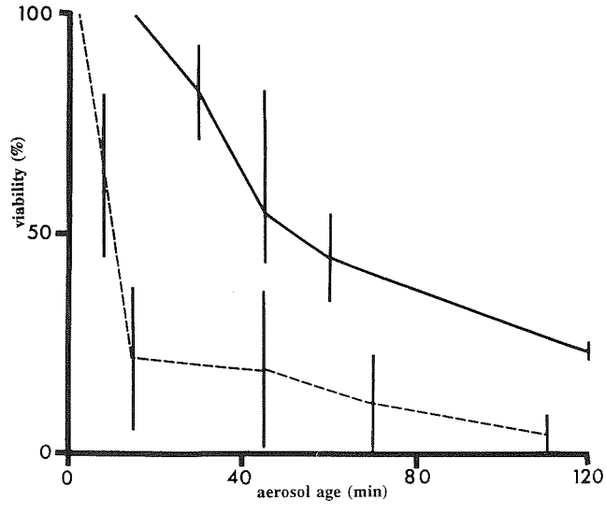

Fig. 3. Survival of aerosolized *Pseudomonas aeruginosa* PAO1 in a rotating aerosol chamber at 80% relative humidity (rh) (——), and 36% rh (– – – –) without light. Means of three independent determinations ± SD are given.

Abb. 3. Überlebenszeiten von aerosolisiertem *Pseudomonas aeruginosa* PAO1 in einer rotierenden Aerosolkammer bei 80% relativer Feuchte (rF) (——), und 36% rF (– – – –) ohne Licht. Die Mittelwerte dreier unabhängiger Bestimmungen ± Standardabweichung sind dargestellt.

WT20 from 25.5 min to 13.3 min (Fig. 4). The mucoid strain MUC20 revealed a $t_{1/2}$ of 10.9 min and 3.5 min without and with light, respectively (Fig. 5). Survival of *P. aeruginosa* PAO1 on hands was comparable to aerosol survival and $t_{1/2}$ was about 15 min at 25 °C and 36% rh (data not shown). These results indicate that *P. aeruginosa* may survive considerable time in aerosols and on hands, so that exposed susceptible humans such as patients with cystic fibrosis might readily inhale airborne *P. aeruginosa* or may be contaminated by contact with healthy carriers.

Discussion

In the present study, genotyping of *P. aeruginosa* isolates from patients, the hospital personnel and the environment were used to get more insight into the routes of infection and strain transmission in an infectious disease ward of a children's hospital. As in previous studies (3, 4, 5, 12, 17, 21, 24), sink drains of water basins and toilets represent major environmental reservoirs for *P. aeruginosa*. These reservoirs may be contaminated with *P. aeruginosa* by patient strains via the personnel as shown previously (22). The high percentage of *P. aeruginosa*-positive hand cultures (42.5% of the personnel members) is in accordance with other studies (21). Further evidence for the important role of hospital personnel as vehicles for *P. aeruginosa* strain transmission

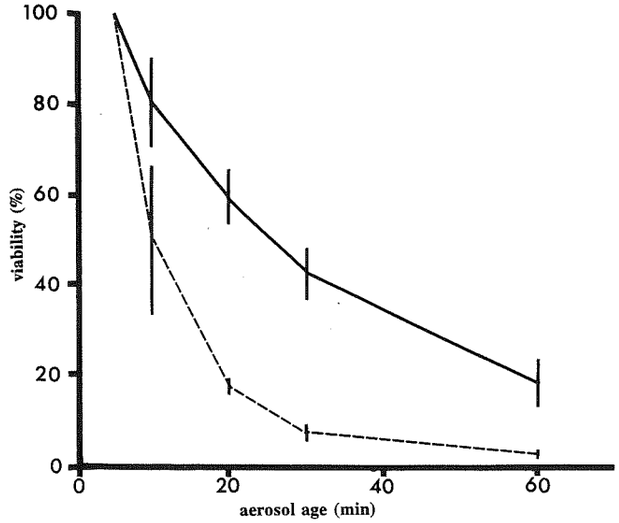

Fig. 4. Survival of aerosolized nonmucoid *Pseudomonas aeruginosa* WT20 in a rotating aerosol chamber at 36% relative humidity without (——) or with (– – – –) light (380–780 nm). Means of three independent determinations ± SD are given.

Abb. 4. Überlebenszeiten von aerosolisierten nichtmukoiden *Pseudomonas aeruginosa* WT20 in einer rotierenden Aerosolkammer bei 36% relativer Feuchte ohne (——) und mit (– – – –) Licht (380–780 nm). Die Mittelwerte dreier unabhängiger Bestimmungen ± Standardabweichung sind dargestellt.

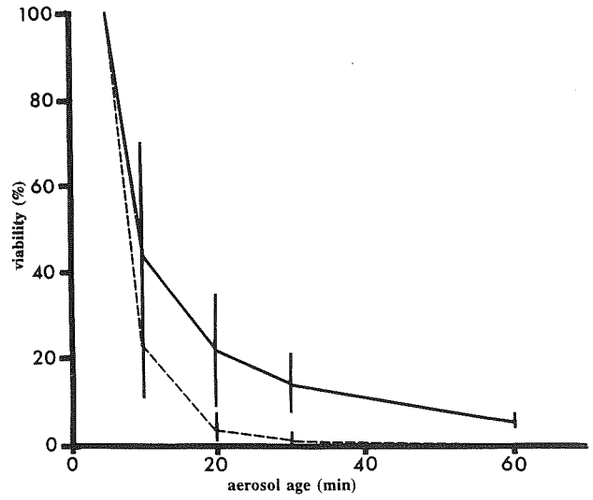

Fig. 5. Survival of aerosolized mucoid *Pseudomonas aeruginosa* MUC20 in a rotating aerosol chamber at 36% relative humidity without (——) or with (– – – –) light (380–780 nm). Means of three independent determinations ± SD are given.

Abb. 5. Überlebenszeiten von aerosolisiertem mukoiden *Pseudomonas aeruginosa* MUC20 in einer rotierenden Aererosolkammer bei 36% relativer Feuchte ohne (——) und mit (– – – –) Licht (380–780 nm). Die Mittelwerte dreier unabhängiger Bestimmungen ± Standardabweichung sind dargestellt.

was provided in the present study by longitudinal comparison of *P. aeruginosa* genotypes present in sink drains and on personnel hands. In three cases, single *P. aeruginosa* genotypes were isolated from sink drains before isolation on personnel hands, strongly suggesting a transmission route from the sinks to the hands. In all other cases where *P. aeruginosa* organisms on personnel hands have not been found in sinks of the ward, it has to be assumed that other reservoirs in the hospital including nebulizers, inhalation devices or respirators exist which lead to such a contamination, since hands were free of *P. aeruginosa* when the personnel entered the hospital. Of particular interest is the finding of a fecal-hand transmission route in one case which was, however, not clinically relevant.

Although the environmental reservoirs of the ward were highly contaminated with *P. aeruginosa* strains, and a high percentage of the personnel carried this organism on their hands, we were unable to isolate identical *P. aeruginosa* genotypes also from patient specimens. The limited study period, the small number of patients, and their diseases which did not represent typical risk groups for *P. aeruginosa* infection, may account for this finding. In a previous study (*Döring, G.* et al, unpublished) 60% of intensive therapy unit patients shared their colonizing *P. aeruginosa* strain with strains either found in specimens from other patients or from sink drains of the unit. Since the patients were virtually immobile, and since genotypically identical strains were found widely distributed in the unit, other transmission routes than via the personnel were

not probable. A sink-to-patient-transmission route was suggested, when in three cases distinct *P. aeruginosa* genotypes have been detected in sinks prior to their isolation from patient specimens.

Similar results were obtained from hospitalized paraplegic patients with *P. aeruginosa* urinary tract infections (24), where 48% of the patients harboured strains identical to those found in the environmental water reservoirs of the specialized wards. The wide distribution of single *P. aeruginosa* genotypes in the ward, the isolation of strains from rooms unaccessable for the patients, and the outbreak of urinary tract infections by single *P. aeruginosa* strains in groups of patients within short time periods, suggested also that the strains were distributed by the personnel rather than by the mostly immobilized patients (24).

Although these and other epidemiological studies strongly suggest measures to inhibit bacterial growth in hospital sink drains, little has been done in this respect in the past. Thus, heating devices proposed by several authors (11, 13, 21) have not found general acceptance and currently are mostly unknown. Device costs, the increasing use of plastic sink drains in hospitals which do not allow heating, and the general lack of knowledge about the mechanism by which *P. aeruginosa* or other pathogenic bacteria in the sink drain may contaminate hands during handwashing, may explain this situation. Backsplash and aerosol production has been shown to occur during handwashing and toilet flushing (3, 6, 11) and *P. aeruginosa* was detected on agar plates up to a ten-foot distance around a washing basin while the faucet was activated for three ten-second intervals (3). When a toilet was contaminated with *Escherichia coli* and agar plates were exposed throughout the room, flushing of the toilet resulted in detectable bacteria in a limited area around the toilet within the first 2 h and up to 6 h in a more random distribution of *E. coli* in the room (6).

That such a mechanism may also occur during the opening of a water tap was demonstrated in the present study. Thus, normal handwashing without appropriate disinfection measures after handwashing may lead to contamination with bacterial or viral organisms persisting in the sink drains rather than to decontamination. If patients with high risk to acquire *P. aeruginosa* or other bacteria (i. e. patients with cystic fibrosis) wash their hands or brush their teeth in such contaminated washing basins, colonization and infection from such sources may consequently occur. A close contact to such contaminated reservoirs seems to be important for the contraction of pathogens via aerosols, since survival of *P. aeruginosa* in aerosols is relatively short and comparable to survival times of other gram negative rods (8, 15). Therefore, hygienic measures to decontaminate washing basins and toilets are recommended as well as improved hygienic measures for hand disinfection.

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Practice Points

The sink splash zone

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Pseudomonas aeruginosa is an important nosocomial pathogen that commonly colonizes hospital water supplies, including taps and sinks [1]. It has been reported previously that water outlets are the most likely source of *P. aeruginosa* nosocomial infections in an adult intensive care unit (ICU) [2], and it has been described how widespread introduction of control measures, both human factors and engineering solutions, can reduce infections [3,4]. Joung *et al.* demonstrated how water droplets can release aerosols [5]. Similarly, Estrada-Perez *et al.* showed the extent of dispersal of water droplets when showering [6]. Stevens *et al.* demonstrated that a wide range of waterborne pathogens can result in infections [7]. Hence, there is a theoretical risk of water droplets harbouring waterborne pathogens contaminating surrounding areas, leading to transmission. This study examined splashing from water outlets on an ICU, and undertook an unannounced audit to determine which items were located within 2 m of a sink ('splash zone').

University Hospitals Birmingham NHS Foundation Trust (UHB) is the largest UK hospital trust, with the biggest co-located ICU globally (100 beds) [3]. The ICU has 231 water outlets, of which 130 are nominated for hand hygiene [3]. It consists of four units: ICU Area A (29 beds) specializes in liver, renal surgery/transplant; Area B (23 beds) specializes in trauma, vascular and burns surgery; Area C (24 beds) specializes in neurosurgery; and Area D (24 beds) specializes in cardiac and lung surgery/transplant. This study found that substantial splashing does occur from sinks during the use of taps, including during handwashing (Figure 1A,B). Absorbent paper sheeting was laid out on the floor and a tap was run; the sheeting was subsequently examined for visible moisture marks (Figure 1A,B). A snapshot audit was undertaken for each area, and equipment/care within 2 m was recorded. Sixty bed spaces were audited, with 15 beds selected per unit to obtain a representative picture of activity around sinks on the units. Some bed spaces were excluded if they were unoccupied or unavailable for privacy/dignity/care reasons. Equipment/care was classified into 16 categories.

Category A included invasive access equipment (e.g. intravenous ANTT™ trays and phlebotomy equipment), and this was found within the splash zone of 65% of sinks (Figure 1C), with visible water splashes present on occasion. Category B was split into 'Bi: ventilators' and 'Bii: respiratory equipment' (e.g. O_2 masks, humidification devices and Yankauer suckers). Ventilator equipment was found within the splash zone of 18% of sinks, and respiratory equipment was found in the splash zone of 27% of sinks. Category C consisted of haemofiltration and dialysis equipment/products, and these were found in the splash zone of 12% of sinks. Category D included personal care items (e.g. mouth care items, toiletries and washbowls), and

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Figure 1. (A) Water from a running tap can splash some distance away from the sink, highlighted by circles on the paper towels on the floor. (B) Water can splash from undertaking hand hygiene, again highlighted by wet paper towels on the floor. (C) A typical intensive care unit patient bed space with equipment situated around a handwash basin.

these were found within the splash zone of 68% of sinks. Category E consisted of nutrition/enteral items (e.g. food/drinks, enteral pumps and oral medication syringes), and these were found within the splash zone of 33% of sinks. Category F included alcohol hand rub and personal protective equipment dispensers, and these were found within the splash zone of 57% of sinks. Category G consisted of housekeeping and cleaning equipment (e.g. environmental service worker trollies, mops and disposable cloths), and this was found within the splash zone of 5% of sinks. Category H comprised care devices that

contact with patients' skin (e.g. patient moving/handling and temperature regulation equipment), and these were found within the splash zone of 43% of sinks. Category I consisted of medications and medicine administration equipment (e.g. infusion pumps), and these were found within the splash zone of 32% of sinks. Category J included patients with negative pressure wound therapy equipment, and they were found within the splash zone of 5% of sinks. Category K consisted of patients with invasive line devices *in situ*, and parts of these devices were found within the splash zone of 12% of sinks. Category L included patients with urinary catheters *in situ*, and they were found within the splash zone of 18% of sinks. Category M comprised invasive monitoring equipment (e.g. intracranial pressure monitoring equipment, left ventricular assist devices, external pacing wires and oesophagogastroduodenoscopy equipment), and this was found within the splash zone of 5% of sinks. Category N consisted of patient admission packs which included MRSA swabs and vacutainer collection tubes, and these were found within the splash zone of 5% of sinks. Category O consisted of computers on wheels, and these were found within the splash zone of 48% of sinks.

Quick *et al*. demonstrated that *P. aeruginosa* can be found in the patient environment of UHB's burns unit, with environmental isolates being indistinguishable from patient isolates [8]. Splashing from a tap/sink contaminated with *P. aeruginosa* is a potential route for introduction of this organism into the patients' environment. This study found that a wide variety of patient equipment resides within 2 m of taps and sinks on an ICU, some of which are colonized with *P. aeruginosa* [2—4]. These items are at risk of contamination with a range of waterborne pathogens, presenting a transmission risk to patients [7]. This study also found that a faster water velocity of water exiting the tap resulted in a larger splash zone (data not shown); as such, equipment >2 m from the sink could also be at risk of contamination. This study did not investigate the angle of impact of water on the basin/sink, and whether this affected the radius of the splash zone. In addition, this study did not consider different water angles from different tap configurations, and whether this affected the splash zone. There is a theoretical risk that different taps and different water impact angles could affect the splash zone, and further work is warranted to investigate this.

It is suggested that healthcare settings should consider splash zones within augmented care and possibly other care settings, and should avoid housing patient equipment or undertaking/preparing for invasive interventions within these zones. Alternative considerations could be removal of sinks from preparation areas where alcohol hand rub may be used to decontaminate hands, installation of sinks specifically designed to reduce splashing, engineering solutions to tackle water velocity, or provision of water-free patient care whilst retaining handwash stations for essential hand hygiene. Continued education on water microbiology safety is also a key intervention for healthcare practitioners to prevent transmission of waterborne infections such as *P. aeruginosa*.

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Contaminated sinks in intensive care units: an underestimated source of extended-spectrum beta-lactamase-producing Enterobacteriaceae in the patient environment

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SUMMARY

Background: Extended-spectrum beta-lactamase-producing Enterobacteriaceae (ESBLE) outbreaks in intensive care units (ICUs) associated with contaminated handwashing sinks have been reported.

Aim: To conduct a regional study to assess whether handwashing sinks in 135 ICU patient rooms are a potential source of contamination, and to identify factors associated with an increased risk of sink contamination.

Methods: A multicentre study was conducted in 13 ICUs, including microbiological testing for ESBLE contamination at 185 sinks. The micro-organisms isolated were analysed using randomly amplified polymorphic DNA analysis to assess clonal spread in ICUs. Data were collected to document the use of each sink, factors that may contribute to contamination of clinical areas near to the sinks, and routine cleansing procedures for the sinks.

Findings: Fifty-seven sinks were contaminated (31%) with ESBLE, mostly *Klebsiella* ($N = 33$) and *Enterobacter* ($N = 18$). In two ICUs, a high contamination rate was associated with clonal spread of an epidemic isolate. Risk factors for contamination of and by handwashing sinks were frequent: 81 sinks (44%) were used for handwashing as well as the disposal of body fluids; splash risk was identified for 67 sinks (36%), among which 23 were contaminated by ESBLE. Routine sink disinfection was frequent (85%), mostly daily (75%), and involved quaternary ammonium compounds (41%) or bleach (21%). A lower sink contamination rate was significantly associated with use of the sink being restricted to handwashing and to daily sink disinfection using bleach.

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Conclusions: In ICUs, contaminated sinks are a potential source of ESBLE in the environment of the patient, a problem that may be underestimated by ICU teams. Relatively simple measures may result in a rapid improvement of the situation, and a significant decrease of the risk of exposure of ICU patients to multiresistant Enterobacteriaceae.

Introduction

In acute-care settings, Enterobacteriaceae are frequently involved in nosocomial infections leading to increased morbidity, mortality and hospital costs.[1] The reservoir for these pathogens is the gastrointestinal tract of patients, and cross-transmission is believed to occur via the contaminated hands of healthcare workers and via environmental contamination.[2–4] These Gram-negative bacteria are increasingly resistant to available antibiotics, and nosocomial outbreaks of extended-spectrum beta-lactamase-producing Enterobacteriaceae (EBSLE) and carbapenemase-producing Enterobacteriaceae (CPE) have been reported, particularly in intensive care units (ICUs).[5,6]

Contaminated handwashing sinks have been reported as responsible for outbreaks of infections in ICUs.[7–9] The use of sinks for disposal of body fluids has been suggested as resulting in their contamination with ESBLE. These organisms are able to survive in biofilms and multiply in moist conditions, such that once contaminated, the sink becomes a reservoir for ESBLE.[9,10] Studies involving fluorescent marker testing have documented the probable mechanism of transfer of pathogens present in a contaminated sink to patients.[7] Inadequate sink design (water flowing directly into the sink drain, combined with high water pressure and a shallow sink bowl) can favour the disruption of bacterial biofilms inside the drains. This facilitates transfer of the viable organisms to surrounding surfaces in close proximity to the sink, including the patient bed, and the area where aseptic procedures are performed, if there is no splash barrier between the sink and these areas. In addition, the hands of healthcare workers may paradoxically be contaminated during handwashing in a contaminated sink.

Prevention of nosocomial infections in ICUs is a major issue. Epidemiological trends of invasive infections associated with ESBLE and CPE illustrate the urgent need to focus the attention of ICU teams on the increasing risk of infections and outbreaks associated with these multiresistant bacteria.[11] In particular, efforts are needed to prevent the avoidable infections associated with ESBLE and CPE.

We conducted a multicentre study to assess whether the measures to prevent infections and outbreaks associated with contaminated handwashing sinks in ICU patient rooms were implemented in our region. In a non-outbreak context (*a priori*), 13 French ICUs were involved. Microbiological tests for ESBLE and CPE were conducted for each sink in all patient rooms. For each sink studied, data were collected to document the use of the sink, the factors possibly contributing to contamination of clinical areas near to the sink, and the routine cleaning procedure used.

Methods

Setting

The region has 174 ICU patient rooms in the 16 ICUs of nine healthcare institutions. The study was carried out over a one-month period (January 2013) and involved 13 of these 16 ICUs (81.2%) in seven hospitals and one surgical clinic, including 134 of the 174 patient rooms in the region (77.0%). Of the 134 patient rooms, 133 (99%) were studied; the sample size (number of sinks) was 185, as 81 rooms (61.2%) had one sink and 52 rooms (38.8%) had two sinks. The study was managed jointly with the heads of all participating institutions, the physicians responsible for the ICUs, the local hygiene practitioners and the regional infection control practitioner. This study was run in accordance with the French Healthcare recommendations for prevention of infection, and as such did not require ethical approval.

Microbiological study

In each patient room, all sink drains were sampled by rotating sterile, cotton-tipped swabs inserted to a depth of 5–7 cm through the sink drain. Swabs were rapidly plated on ChromID ESBL selective agar plates (bioMérieux, Marcy l'Etoile, France), which were then incubated at 37 °C for 48 h. Enterobacteriaceae were identified using Vitek® 2 Gram-negative Identification Cards (bioMérieux). Susceptibility to antimicrobial agents was tested by the disc diffusion method on Mueller–Hinton agar and interpreted according to the French guidelines.[12] The double-disc synergy test was used to detect ESBLE. Bacteria showing a diminished susceptibility to ertapenem and/or imipenem were tested for carbapenemase production using the Hodge test and the carbaNP test.[13] To assess clonal spread in each ICU, ESBLE isolates were typed by randomly amplified polymorphic DNA analysis using primers selected according to the species (Table I).[14] The interpretation of random amplification of polymorphic DNA (RAPD) findings was based on differences in banding patterns.

Data collection

Data were collected by the local hygiene practitioners in a standardized questionnaire to assess how the sinks studied were routinely used (handwashing only, or handwashing and waste disposal), and to search for risk factors that may contribute to contamination of clinical areas near to the sink (sink design, distance between the sink and the patient bed, presence of an anti-splash barrier). The routine disinfection

Table I
Oligonucleotides used as primers for random amplification of polymorphic DNA typing

Oligo names	Sequence
p208	ACGGCCGACC
p272	AGCGGGCCAA
opam7	AACCGCGGCA
p270	TGCGCGCGGG

procedures implemented for the sinks in each participating ICU were recorded (product used, volume of product used, frequency of sink disinfection).

Statistical analysis

All variables were examined by univariate analysis using the chi-square test or Fisher's exact test, as appropriate. All statistical tests were two-tailed. $P < 0.05$ was considered statistically significant. Epi Info software, version 6, was used for statistical analysis.

Results

Microbiological study

Of the 185 sink drain swabs, none yielded CPE, but 57 (30.8%) yielded ESBLE (Table II). The contamination rate of sink drains varied between ICUs, from 0 to 81.8% of the samples. Two different ESBLE isolates were obtained from each of three swabs such that a total of 60 ESBLE were isolated.

Among the 60 ESBLE isolates, *Klebsiella* was the most numerous (33/60, 55.0%) with 29 *K. pneumoniae* and four *K. oxytoca* (Table III). The *Enterobacter* genus was the second most numerous genus (18/60, 30.0%) with 16 *E. cloacae*, one *E. aerogenes* and one *E. asburiae*. In the seven ICUs where contaminated sinks were identified, there was a complex pattern of sink–drain contamination, with more than one species contaminating the sinks from the ICU. However, species diversity in contaminated sinks varied greatly between ICUs: it was largest in ICU 120-1, with four different species found in the four contaminated sinks of the unit, whereas by contrast, contamination of most sinks in two ICUs involved the same species: *E. cloacae* in ICU 122-1 (in seven of 10 sinks) and *K. pneumoniae* in ICU 145-1 (seven of eight). To assess clonal spread in ICUs, the ESBLE isolates were subjected to RAPD typing and isolates of the same species and from the same ICU were compared. This indicated that different isolates from the same ICU had similar RAPD patterns in five cases: ICU 122-1 with six sinks contaminated with similar *E. cloacae* isolates, ICUs 145-1 and 152-4 with sinks contaminated with similar *K. pneumoniae* isolates (six and two pairs of isolates, respectively), ICU 127-1 with two sinks contaminated with similar *C. freundii* isolates, and ICU 152-1 with two sinks contaminated with similar *K. oxytoca* isolates. The combination of a high rate of sink contamination and a contamination of several sinks with genetically similar isolates was observed for ICUs 122-1 and 145-1. No isolates were found with similar RAPD patterns contaminating sinks in different ICUs.

Table II
Extended-spectrum beta-lactamase-producing Enterobacteriaceae (ESBLE) contamination of the 185 sinks sampled in the nine participating healthcare institutions (HCIs)

HCI	ICU	No. of patient rooms	No. of sinks per room	No. of sinks studied	No. of ESBLE-positive sinks	Sink contamination rate
1	120-1	12	1	12	4	33.3%
2	122-1	11	1	11	9[a]	81.8%
3	127-1	10	2	20	9[a]	45.0%
4	134-1	10	1	10	0	0
5	136-1	14	1	14	8[a]	57.1%
5	136-2	10	1	10	0	0
5	136-3	10	1	9	0	0
6	145-1	11	2	22	8	36.4%
7	152-1	4	1	4	3	75.0%
8	155-1	12	1[b]	13	0	0
9	152-2	4	2	8	0	0
9	152-3	8	2	16	0	0
9	152-4	18	2	36	16	44.4%
All		134		185	57	31.0%

[a] Two different ESBLE were isolated at one sink.
[b] One of the 12 patient rooms contains two sinks.

Sink use, risk factors that may contribute to contamination of clinical areas near to the sink, and routine sink disinfection

In conformity with current French guidelines, each patient room contains at least one handwashing sink. In 51 of the 52 rooms (98.1%) with two sinks, one sink was dedicated to handwashing by healthcare workers, and the second was used for disposal of body fluids (waste water from the patient toilet). The remaining 81 patient rooms each had only one sink, used for both handwashing and patient toilet. No sink was used for disposal of patient urine (0/185). Sink design was generally poor. Thirty-four of the 185 sinks had aerators (18.4%). Water from the tap was directed straight into the outlet, allowing splash-back from the sink drain trap, in 103 cases (76.3%); and visible splashing out of and close around the sink when the tap was turned on was recorded in 34 cases (25.2%). The distance between the sink and the patient bed was rarely less than 1 m (2/135, 1.5%) but very often between 1 and 2 m (56/135, 41.5%). Barriers to reduce contamination of the areas around the sink by splashes from the drain were installed in only 12 cases (12/135, 8.9%). Thus, there was evidence of splash-back risk for 67 of the 185 sinks (36.2%), including 23 of those contaminated by ESBLE. The participating ICUs can be classified into three groups: the first group of six ICUs without any contaminated sinks, the second of two ICUs with contaminated sinks but without epidemic spread, and the third group of five ICUs with both contaminated sinks and epidemic spread. Splash-back risk was significantly associated with the third group of ICUs: splash-back risk was identified for 23 of the 67 sinks in the first group, in 0/16 in the second group and in 45/103 sinks of the third group ($P = 0.003$).

Routine sink disinfection was reported for 158 of the 185 sinks (85.4%): disinfection was daily (116/185, 74.8%), weekly (20/185, 10.8%) or at the time of patient discharge (22/185, 11.9%). The time of exposure and the volume of disinfecting product varied substantially between ICUs, from 25 mL of pure product to several litres of variously diluted solutions. The most frequent disinfectant products used were quaternary ammonium compounds (76/185, 41.1%) and bleach (39/185, 21.1%). Routine disinfection was not associated with a low rate of sink contamination (Table III).

Three conditions were found to be significantly associated with a lower ESBLE sink contamination rate (Table IV): first, the use of the sink restricted to handwashing as compared with the use of the sink for both handwashing and disposal of body fluids

Table III
Species distribution of the 60 extended-spectrum beta-lactamase-producing Enterobacteriaceae (ESBLE) recovered from the 185 sink swabs

ICU	No. of ESBLE	*Klebsiella*		*Enterobacter*			*Citrobacter*	Others
		pneumoniae	*oxytoca*	*cloacae*	*aerogenes*	*asburiae*		
120-1	4	1		1		1	1	
122-1	10	1	1	7				1[a]
127-1	10	4		2	1		2	1[b]
136-1	9	6		2			1	
145-1	8	7	1					
152-1	3		2				1	
152-4	16	10		4			1	1[c]
All	60	29	4	16	1	1	7	3

ICU, intensive care unit.
[a] *Escherichia coli*.
[b] *Pantoae* sp.
[c] *Serratia marcescens*.

(7/52 for handwashing use only vs 24/72 for multiple uses, $P = 0.034$); second, sink disinfection with bleach as compared to that with quaternary ammonium compounds (0/19 for bleach vs 20/56 for quaternary ammonium compounds, $P = 0.002$); and third, daily sink disinfection using bleach as compared to weekly disinfection with bleach (0/19 for daily vs 9/20 for weekly, $P < 0.001$).

Table IV
Risk factors for contamination of sinks and clinical areas near to the sink for extended-spectrum beta-lactamase-producing Enterobacteriaceae (ESBLE)-contaminated and ESBLE-free sinks

Risk factors	Sinks			
	All	ESBLE-contaminated ($N = 57$)	ESBLE-free ($N = 128$)	*P*
Sink use				
Handwashing only	51	7	44	$P < 0.001$
Patient toilet	84	50	34	
Splash risk factor	67	23	44	
Aerator	34	9	25	
Water directed straight into the drain	103	39	64	
Visible splash when tap turned on	34	17	17	
Distance between the sink and patient bed				
<1 m	2	1	1	
1–2 m	56	22	34	
Splash barrier	12	1	11	
Routine sink disinfection	158	54	104	
Daily	116	37	79	
Weekly	20	9	11	
Bleach	39	9	30	
Daily	19	0	19	$P < 0.001$
Weekly	20	9	11	
Quaternary ammonium compounds daily	56	20	36	

Discussion

This extensive multicentre regional study is the first to document handwashing sink contamination with ESBLE and CPE in a non-outbreak context (*a priori*). An encouraging finding was that there was no evidence of contamination of sinks with CPE. But by contrast, the rate of contamination with ESBLE was high, more than 30%. Concordant with previous reports, sink contamination in several ICUs was varied, reflecting the diversity of ESBLE carried by their patients.[15] However, *Klebsiella* and *Enterobacter* were the groups most frequently contaminating the sinks, whereas *E. coli* was rare. Although *E. coli* is the species most frequently involved in human ESBLE carriage, it may not be able to survive in biofilms as successfully as *Klebsiella* and *Enterobacter*.

The high overall rate of sink contamination was the result of two divergent situations: for one group of six ICUs there was no sink contamination, whereas for the other seven ICUs the rates of sink contamination by ESBLE were very high, similar to or higher than those reported during handwashing-sink-associated outbreaks in ICUs.[16] In two ICUS, numerous sinks contaminated with a single ESBLE strain were found, suggesting epidemic spread. In the case of ICU 122-1, an investigation of a recent cluster of *E. cloacae* infections was conducted by the local infection control team simultaneously with this study, but until this screening of sinks, they had not been considered as a potential reservoir. In this case, RAPD typing of clinical isolates and those recovered from the sinks showed similar patterns, strongly suggesting an epidemiological link between the environmental and the clinical isolates. Our findings argue for the need to consider sink contamination whenever a cluster of infections associated with Enterobacteriaceae is identified in an ICU.

This study showed that factors that may contribute to contamination of clinical areas near to the sink occur frequently among the ICUs in our region. Note that in ICU 122-1, where a cluster of infections was associated with the spread of the same strain into numerous sinks, water from all the taps was directed straight into the outlet; visible splashing out of and around the

sink when the tap was turned on was recorded, and the distance between the sink and the patient ranged between 1 and 2 m. To prevent avoidable nosocomial infections in ICUs, especially those involving ESBLE and CPE, we believe that there is an urgent need to improve the present situation. Various measures should be taken.

First, the paradoxical contamination of hands during handwashing, via splash-back of micro-organisms present in contaminated sink drains, should be totally eliminated.[17] Efforts are required to reduce the risk of handwashing sink contamination by the multiresistant micro-organisms that colonize ICU patients. In the present study the lowest ESBLE contamination rate of sinks was in patient rooms with two sinks, with clear delineation between handwashing sinks and sinks for other purposes. Note that there was only one sink per patient room in the two ICUs in which there were putative epidemics.

Indeed, if the dirty utility room is too far away, and because of the risk associated with transporting body fluids from ICU patients (especially for patient isolation), one sink in the patient's room may be used by healthcare workers for the disposal of body fluids. Thus, two different sinks in the patient room allows one to be rigorously restricted to handwashing, thereby preventing its contamination by multiresistant organisms in body fluids from colonized patients. We recommend reserving one sink in ICU rooms solely for handwashing, and suggest that sinks used for waste disposal should be systematically considered to be potentially contaminated. Sinks that are not clearly reserved for handwashing should not be used for handwashing by healthcare workers. If there is only one sink per patient room and it is used for the disposal of body fluids, alcohol hand rub should be used prior to aseptic procedures; and if handwashing is necessary, handwashing should be followed by hand-rubbing.

Second, the risk of splash-back should be minimized in all ICU rooms. A reduction in the microbial load in the environment may help decrease the transmission of micro-organisms within healthcare institutions, particularly if combined with other infection prevention measures, including appropriate hand hygiene.[18] Hota *et al.* injected a fluorescent marker into the plughole of a sink and turned the tap on for several seconds: fluorescent residues were found all over the sink, and at least 1 m from the sink.[7] They also suggested that smaller, undetected, particles travelled far further than 1 m. Therefore, if the distance between sink and the patient bed, patient care equipment or medical aid supplied is less than 2 m, the water pressure should be reduced, and anti-splash barriers installed around the sink. The two ICUs in which there were putative epidemics were those with the highest splash-back risks, and splash-back risk was significantly associated with the group of ICUs with contaminated sinks and epidemic spread. In ICI 122-1, splashing was seen when the tap was turned on at all sinks, and the distance between the sinks and the patient beds was between 1 and 2 m; the combination of sink contamination and splash-back risk at sinks may have contributed to the development of the outbreak in this centre.

Third, we suggest that all handwashing sinks in ICUs should be decontaminated daily with bleach. As a consequence of antibiotic selection pressure, hospital sinks are increasingly at risk of being contaminated by resistant Enterobacteriaceae. Outbreak management has demonstrated that eradication of ESBLE from sinks is difficult, or even impossible, especially when *Klebsiella* spp. or *Enterobacter* spp. are involved, probably because it is difficult to act on the biofilm in distal parts of the plumbing system and because micro-organisms in biofilms survive successfully in sink drains despite frequent exposure to disinfectants.[9,16] Sinks are permanent components of the hospital environment and the management of contaminated handwashing sinks is complex. The aim of control measures in practice, therefore, is to reduce contamination of sinks, rather than to eliminate these contaminations. In this study it was shown that preventive disinfection gave divergent results. Routine disinfection in general made no significant contribution to preventing sink contamination. However, daily use of bleach appeared to be the most effective approach to limiting ESBLE contamination of sink drains, and may therefore minimize the risk to ICU patients of acquiring nosocomial infections from their environment. Our study has some limitations and further investigations of these issues are required. In particular, it would be useful to assess the long-term effects of using bleach for decontaminating sinks, and to determine the optimal amounts and exposure times for limiting ESBLE contamination of sinks.

This study shows that sinks in ICUs are frequently contaminated by multiresistant micro-organisms, and that they may be a potential source of ESBLE in the environment of the patient as a consequence of splash-back effects. These findings underline the need to continue to educate ICU staff regarding this underestimated risk. Relatively simple measures may result in a rapid improvement of the situation, and a significant decrease of the risk of exposure of ICU patients to multiresistant Enterobacteriaceae.

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None declared.

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Aerosols Containing *Legionella pneumophila* Generated by Shower Heads and Hot-Water Faucets

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Shower heads and hot-water faucets containing *Legionella pneumophila* were evaluated for aerosolization of the organism with a multistage cascade impaction air sampler. Air was collected above two shower doors and from the same rooms approximately 3 ft (91 cm) from the shower doors while the hot water was running. Low numbers (3 to 5 CFU/15 ft^3 [0.43 m^3] of air) of *L. pneumophila* were recovered above both shower doors, but none was recovered from the air in either room outside the shower door. Approximately 90% (7 of 8 CFU) of the *L. pneumophila* recovered were trapped in aerosol particles between 1 and 5 μm in diameter. Air was collected 1 to 3 ft (30 to 91 cm) from 14 sinks while the hot water was running. Low numbers (1 to 5 CFU/15 ft^3 of air) were recovered from 6 of 19 air samples obtained. Approximately 50% (6 of 13 CFU) of the organisms recovered were trapped in aerosol particles between 1 and 8 μm in diameter. Shower heads and hot-water taps containing *L. pneumophila* can aerosolize low numbers of the organism during routine use. The aerosol particle size is small enough to penetrate to the lower human respiratory system. Thus, these sites may be implicated as a means of transmission of *L. pneumophila* from potable water to the patient.

The acquisition of nosocomial Legionnaires disease has been linked to inhalation of aerosols containing *Legionella pneumophila*, originating from cooling towers (9), humidifiers (24), soil excavation sites (21), and respiratory therapy equipment (2). Outbreaks have also been reported in hospitals, where *L. pneumophila* was recovered from shower heads and potable water (8, 12, 19, 20, 22). Inhalation of aerosols generated by showers or taps is assumed to be the mode of transmission (3, 15) in these outbreaks. An experimental form of pneumonic Legionnaires disease has been produced in guinea pigs by exposing them to aerosols of concentrated potable water from a hospital where nosocomial Legionnaires disease had occurred (14). Previous investigations, however, have failed to demonstrate *L. pneumophila* in aerosols generated by contaminated shower heads from hospitals where nosocomial Legionnaires disease has been observed (11; A. H. Woo, V. L. Yu, and A. Goetz, Abstr. Annu. Meet. Am. Soc. Microbiol. 1985, L22, p. 382).

Plouffe et al. (17) described nosocomial Legionnaires disease associated with recovery of *L. pneumophila* from potable water. To define better the mode of transmission from these sites to the patient, we tested shower heads and hot-water faucets in patient rooms for aerosolization of *L. pneumophila*.

MATERIALS AND METHODS

Environmental sampling sites. Cultures of potable water from taps and shower heads were performed as described by Plouffe et al. (17). Hot-water taps and shower heads were turned on, and the initial 10 ml of water was collected. The faucet was turned off, and the inside of the shower head or tap was swabbed with a sterile, cotton-tipped swab before an additional 40 ml was collected. The swab was rinsed in the collection tube and removed. All water culture data in this report represent a combination of the organisms in the water and those rinsed off the swab. The sample was centrifuged at 1,000 × *g* for 30 min, the supernatant was poured off, and the sediment (0.5 ml) was suspended in 4.5 ml of 0.2 N HCl-KCl solution (pH 2.5) for 10 min (6). Portions of 0.1 ml of the acid-treated sample were plated onto buffered charcoal-yeast extract (BCYE) agar (Remel, Lenexa, Kans.).

Voss et al. (23) had previously reported that most of the organisms recovered from potable water came from the initial volume sampled, which represented the stagnant water in the pipe between the valve and the tap or shower head. We did not want to alter the typical situation by removing the water that held most of the organisms before sampling the air, so water cultures were obtained 1 week before air sampling, but not on the day of sampling.

Air sampling devices. An Andersen 1 AFCM viable (microbial) particle sizing sampler (Andersen Samplers, Inc., Atlanta, Ga.) was used during the initial phase of the investigation. This apparatus consisted of six round aluminum stages clamped together to form a sealed cylinder, with an air inlet above the top stage and a vacuum connection below the bottom stage. Each stage held a removable glass petri dish holding BCYE agar without antibiotics (made in our laboratory by the method of Edelstein [10]) and had air vents above the agar surface, which became progressively smaller as stages progressed from top (1.81 mm, stage 1) to bottom (0.25 mm, stage 6). These vents functioned as air jets when air was drawn through the sampler and forced suspended particles of progressively smaller size (≥7 μm at the top; 0.65 to 1.1 μm at the bottom) onto the agar at each stage. This arrangement approximated penetration of the particles into progressively lower levels of the human respiratory system, with stages 4, 5, and 6 representing penetration to secondary bronchi (2.1 to 3.3 μm), terminal bronchioles (1.1 to 2.1 μm), and alveoli (0.65 to 1.1 μm), respectively (1). The accuracy of the sampling process was dependent on a constant airflow of 1 ft^3/min (28,315 cm^3/min) through the system, provided by a continuous-duty vacuum pump attached to the bottom stage. Flow was calibrated by a dry gas meter (1).

An Andersen 1 AFCM two-stage viable particle sampler

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(Andersen Samplers, Inc.) was used in later phases of the investigation. This sampler only had two aluminum stages with different sizes of air vents, which enabled differentiation of nonrespirable (≥8 μm, stage 1) from respirable (0.8 to 8 μm, stage 2) particles and allowed use of commercially prepared BCYE agar in disposable plastic plates.

Air sampling in showers. The six-stage sampler was used to evaluate two shower rooms as follows. The sampler was placed on a ledge above the shower door, out of reach of the spray from the shower head. The hot water and air sampler were turned on simultaneously and allowed to run for 15 min; then both were turned off. The procedure was repeated for a second 15-min period after removing the culture plates and replacing them with fresh plates. The hot water was turned on normal force for the shower sampling periods and for tap sampling periods described below to simulate conditions of patient exposure.

The two-stage sampler was used at a later date and in a different fashion. The sampler was placed on a platform in the room 3 ft (91 cm) from the shower door and 2 ft (61 cm) above the floor to avoid splashing. The air was sampled for 10 min before the hot water was turned on. The culture plates were removed and replaced with fresh plates, and then the hot water and sampler were turned on simultaneously and allowed to run for 10 min. The water and sampler were turned off, the culture plates were again replaced, and the air was sampled for 10 min after the water was turned off.

Air sampling in sink areas. Air samples were obtained from 14 rooms. A total of three rooms were tested with the six-stage sampler. The sampler was placed 2 ft from the tap and turned on simultaneously with the hot water. Air was sampled continuously for 15 min; then both the sampler and the hot water were turned off.

The remaining 11 rooms were tested with the two-stage device. Of these rooms, three were tested twice, on different dates. One room was tested three times. The sampler was placed 1 to 3 ft from the tap. Air was sampled for 5 to 15 (usually 15) min before the water was turned on, and then the culture plates were replaced. The hot water and sampler were turned on simultaneously and allowed to run for 5 to 15 min. The culture plates were replaced, and the air was sampled for an additional 5 to 15 min after the water was turned off. The sampling periods before and during the time when the water was turned on and after it was turned off were the same for a given sink.

Handling of cultures. Culture plates were incubated in room air at 35°C and initially examined at 72 h after removal from the sampler. Plates were further incubated for up to 7 days to look for slow-growing organisms. Suspicious colonies were subcultured onto BCYE agar and sheep blood agar (GIBCO Diagnostics, Madison, Wis.). Colonies growing on BCYE agar but not on sheep blood agar were tentatively identified as *L. pneumophila*. Identification was confirmed by direct fluorescent antibody stain (7) with *L. pneumophila* group 1 fluorescein isothiocyanate-labeled rabbit globulin (Biological Products Division, Centers for Disease Control, Atlanta, Ga.). Subtyping of isolates was performed by microagglutination with hybridoma media containing monoclonal antibody LP-I-81 (16).

RESULTS

Air sampling in showers. A total of two paired water and air samples were obtained from each of the two shower rooms. All four water cultures grew *L. pneumophila*. Low numbers of aerosolized *L. pneumophila* (3 to 5 CFU/15 ft^3 [0.43 m^3] of air) were recovered when the air was sampled above the shower doors with the six-stage sampler (Table 1). Equal numbers of organisms were recovered in the first and second 15-min sampling periods. Of the 8 CFU recovered, 7 grew on plates from stage 3 or lower. No *L. pneumophila* was recovered when the two-stage sampler was placed outside the shower door and closer to the floor.

TABLE 1. Rooms with positive air cultures[a]

Room	Water culture[b] (CFU/ml)	Air culture			Sampler penetration	
		CFU	ft^3 sampled	CFU/ft^3	CFU	Stage
3E[c]	>200	5	30	0.17	1	1
					1	3
					2	4
					1	6
5W[c]	>200	3	30	0.10	1	3
					2	5
Sinks:						
188[c]	>200	2	15	0.13	1	1
					1	3
514[d]	3	3	15	0.20	3	2
518[d]	200	5	15	0.33	5	1
557[d]	187	1	15	0.07	1	2
948[d]	23	1	5	0.20	1	1
1158[d]	0	1	10	0.10	1	2

[a] Data are shown only for rooms with positive aerosol cultures. Rooms from which no *L. pneumophila* were recovered by air sampling were omitted.
[b] Water culture results reflect organisms recovered from both water and swabs obtained 1 week before air sampling.
[c] Six-stage sampler used.
[d] Two-stage sampler used.

Air sampling in sink areas. A total of 19 paired water and air samples were obtained from 14 hot-water faucets. A total of 17 of the water cultures grew *L. pneumophila*. Two colonies of *L. pneumophila* (one on stage 1, one on stage 3) were recovered from air around one of the three taps tested with the six-stage unit (Table 1). A total of 11 colonies were recovered (6 on stage 1, 5 on stage 2) from 5 of the remaining 13 taps tested with the two-stage unit (Table 1). All positive air cultures from the two-stage unit were obtained during the period when the tap water was running. None were ever obtained before the tap water was turned on or after it was turned off. No air cultures were positive more than once among the rooms that were tested two and three times. Organisms recovered from the water cultures and air samples from a given tap always gave the same microagglutination with LP-I-81.

DISCUSSION

Previous investigations have failed to demonstrate aerosolization of *L. pneumophila* from contaminated shower heads. A multicenter study of nosocomial Legionnaires disease associated with isolation of *L. pneumophila* from hospital shower heads was unable to prove the hypothesis that the aerosol generated by a shower head was the mode of transmission (8). Hanrahan et al. (11) reported that patients with nosocomial Legionnaires disease were significantly closer than controls to showers contaminated with *L. pneumophila* but were unable to isolate it from aerosols around the showers by using air monitoring equipment. Woo et al. recovered *L. pneumophila* from aerosols produced by a contaminated humidifier but could not detect the organism by settle plates or with an air aspirator when contaminated

showers were tested (Woo et al., Abstr. Annu. Meet. Am. Soc. Microbiol. 1985).

We recovered *L. pneumophila* when our sampler was placed in the path through which the steam exited from the shower stall, but not when it was placed in the room only a short distance (3 ft) from the shower. Most (approximately 90%) of the aerosolized *L. pneumophila* was trapped in particles small enough to reach the lower respiratory system as determined by penetration into the lower levels of the sampling chamber (stages 3 to 6 in the six-stage sampler and stage 2 in the two-stage sampler).

Our observations may explain why showering is a risk factor in some cases of nosocomial Legionnaires disease. The data cannot be extrapolated to explain nosocomial Legionnaires disease in patients who were in rooms closer to shower areas than were controls (11) because our cultures were negative a short distance from the showers. Our study was not designed specifically to address the epidemiologic link between showering and acquisition of nosocomial Legionnaires disease. We only wished to determine if shower heads and taps could generate aerosols containing viable *L. pneumophila*.

Little or no data exist regarding aerosol production from hot-water taps. Our investigations show that hot-water taps can produce aerosols containing *L. pneumophila*. Taps may be less efficient aerosolizers than shower heads since we recovered *L. pneumophila* from only 6 of 19 taps as compared with two of four shower heads, although the number of samples is too small for statistical analysis. The organisms recovered from the air around taps were equally distributed between the plates containing the respirable particles ($\leq$8 μm) and those containing the nonrespirable particles. Most of the *L. pneumophila* recovered from the air around shower heads, however, were deposited on plates from stage 3 ($\leq$5 μm) or lower. This difference suggests larger particle generation by the taps. On two occasions, air sample cultures were positive when water cultures from the previous week grew zero and three colonies of *L. pneumophila*, suggesting that heavy contamination at the tap may not be required to produce contaminated aerosols. The recovery of organisms from the aerosols when prior water cultures were negative, however, can more likely be explained by fluctuation in tap water contamination. We have observed weekly fluctuations from 0 to >200 CFU of organisms recovered from the water. We did not attempt to correlate the number of organisms in the water with the number in aerosols, for the reasons given in Materials and Methods.

Experimentally administered aerosols containing <129 CFU of *L. pneumophila* have produced nonlethal infection in guinea pigs (5). Although no one knows the minimum infectious dose for humans, the low numbers of organisms recovered from the aerosols in our study seem small relative to the expected organism load required to produce human disease. It is possible that low relative humidity at the time of the sampling decreased the number of viable organisms recovered, as had been reported previously (4). Another possible reason for low bacterial counts is the mechanical trauma and dehydration the organisms sustain during the sampling procedure, caused by forcing them through small orifices and onto the agar surface at high speed (13). It is also possible that the numbers of organisms present in shower or tap water were too low to generate large numbers of aerosolized organisms.

Our data show that shower heads and sinks can produce fine particle aerosols containing low numbers of *L. pneumophila* during routine use. The aerosol size is small enough to penetrate to the lower respiratory system. Organisms in larger particles recovered from stage 1 of both samplers, although too large to penetrate to the lower respiratory tract, may be capable of colonizing the oropharynx (18). This study lends supportive evidence to the widely held presumption that aerosols from shower heads and hot-water taps can be implicated as a means of transmission of *L. pneumophila* from potable water to the patient. The acquisition of Legionnaires disease by patients a distance from the site of aerosol generation, however, cannot be explained by our data.

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Back to Basics: CLABSI Reduction Through Implementation of an Oral Care and Hygiene Bundle

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Abstract

Children with cancer often undergo treatments that render them severely immunocompromised. Side effects of treatment place them at risk for developing oral mucositis (OM), which can potentially lead to infection and bacteremia. Staff nurses on an inpatient pediatric oncology unit noted inconsistent daily oral hygiene practices despite assessing OM consistently. Basic oral hygiene can reduce the severity of OM, and evidence-based bundled care has shown to increase consistency of practice. Based on findings and recommendations from the literature, an oral care and hygiene bundle was developed. The oral care bundle included a soft bristled toothbrush, fluoride toothpaste, twice-daily brushing and sodium bicarbonate rinses, lip balm, and oral moisturizer. The hygiene component consisted of a daily bath or shower and daily linen changes. Education on the rationale and purpose for the use of an oral care and hygiene bundle was provided to the inpatient direct care staff prior to implementation on two inpatient oncology units. Audits were performed to measure the adherence of the oral care and hygiene bundle. Central line–associated bloodstream infections were measured in collaboration with the quality and infection prevention departments. Since the oral care and hygiene bundle was implemented, laboratory-confirmed bloodstream infection rates decreased from 1.05 to 0.54 per 1,000 catheter days, while mucosal barrier injury rates decreased from 2.98 to 1.27 per 1,000 catheter days.

Keywords

pediatric oncology, central line–associated bloodstream infection, oral care, hygiene

Introduction

Children with cancer often undergo high doses of chemotherapy and various types of immunosuppressive medication regimens. These patients may be severely immunocompromised due to their treatment regimens and are at great risk for developing oral mucositis (OM) as a result of their treatment (Gandhi, Datta, Ahuja, Saxena, & Datta, 2017). Severity of OM can range from mild, painless tissue changes to bleeding ulcerations, carrying an increased risk for infection and bacteremia. Bacteremia caused by an introduction of oral or gastrointestinal flora into the bloodstream (secondary to OM) is known as a mucosal barrier injury laboratory-confirmed bloodstream infection (MBI-LCBI). While not actually associated with central lines, they are considered a subcategory of central line–associated bloodstream infections (CLABSI) by the Centers for Disease Control and Prevention (2018). Basic oral care is an essential piece of comprehensive oncology treatment, and oral care protocols are recommended to prevent mucositis in all oncology patients, regardless of age, diagnosis, or treatment modalities (McGuire et al., 2013).

Background

CLABSI are a major source of morbidity and mortality for hospitalized pediatric oncology patients, increasing length of stay (Metzger et al., 2015) and costing up to $70,000 per patient in this population (Wilson, Rafferty, Deeter, Comito, & Hollenbeak, 2014). Intensive chemotherapy regimens and radiation are significant causative factors of OM, putting pediatric patients at particularly increased risk (Duffy, Rodgers, Shever, & Hockenberry, 2015). Children with cancer are at nearly three times the risk for oral complications compared to adults with cancer (Niehaus, Meiller, Peterson, & Overholser, 1987).When combined with severe and prolonged immunosuppression and impaired integrity of mucous membranes, these patients are at high risk for translocation of organisms from the oral mucosa into the bloodstream (Linder, Gerdy,

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Abouzelof, & Wilson, 2017; Simon et al., 2016). Adherence to an oral care protocol decreases the bacterial burden in the mouth, potentially contributing to the decrease of MBI-LCBI (Linder et al., 2017).

Maintaining high-quality oral hygiene is one of the most important interventions for mucositis and mucositis-related infection prevention (Soga et al., 2011). Consistent use of an oral care protocol is beneficial in preventing or reducing the severity of OM (Hogan, 2009; Lalla et al., 2014), and bundled care has shown to increase consistency of use for many different care areas (Choi et al., 2013). Essential components of an oral care protocol include toothbrushing, rinsing, and mouth or lip moisturizer (Linder et al., 2017). Pediatric dentists recommend twice-daily toothbrushing with a soft-bristled toothbrush for all patients unless actively bleeding from gums or ulcerations (American Academy of Pediatric Dentistry [AAPD], 2018). Various oral rinses including chlorhexidine, sodium bicarbonate, and saline have been used in different protocols, though no evidence supports a reduction in OM from any one specific rinse (McGuire et al., 2013). It was reported that chlorhexidine does not prevent or reduce the severity of OM as compared to other rinses and may dry out oral mucosa and lead to further breakdown (Choi & Kim, 2012). While no rinse proves to be solely effective in preventing OM, the act of rinsing with a bland substance demonstrates to be most beneficial for removal of debris and decreasing risk for fungal growth (Harris, Eilers, Harriman, Cashavelly, & Maxwell, 2008).

Literature Review

Literature was reviewed to determine what standards to employ for consistent oral care for patients undergoing cancer treatment. A thorough literature search was performed using CINAHL Complete, EBSCO, Cochrane Database of Systematic Reviews, and PubMED. The literature review included peer-reviewed journals and published protocols regarding oral care practices for oncology patients. Evidence focusing on current best practices for oral and dental care in the general pediatric population and for immunosuppressed patients undergoing cancer treatment was synthesized. Additionally, current best practices at other nationally recognized children's hospitals were examined.

Based on the evidence, a standardized oral care and hygiene bundle was developed. The main goal of the bundle was to decrease hospital-acquired LCBI-CLABSI and MBI-LCBI. Each patient had previously received a typical toothbrush and toothpaste upon admission. It was determined that a soft-bristled toothbrush should be provided due to the fragile nature of the oral mucosa and frequent thrombocytopenia in this population. The AAPD (2018) recommends the use of fluoride toothpaste, which was in use for inpatient stays. Identifying a proper oral rinse was challenging, as evidence varied regarding a superior type of rinse. A systematic review of basic oral care for pediatric cancer patients determined that no particular rinse reduced instances of or severity of OM. In the review, both sodium bicarbonate and saline were considered to be harmless, bland, effective for oral hygiene, and favorable for patient comfort (McGuire et al., 2013). Furthermore, chlorhexidine, a commonly used product, was not recommended for patients with head and neck tumors receiving radiation (McGuire et al., 2013). Additional evidence supports the use of a sodium bicarbonate rinse over saline (Choi & Kim, 2012). In addition to oral commensals, common skin organisms are a contributing factor to CLABSI. Bathing can control the amount of skin organisms present that may cause bacteremia, contributes to CLABSI prevention, and should be completed on a daily basis (Linder et al., 2017).

Method

Staff nurses on an inpatient pediatric oncology unit noted a lack of consistent daily oral care and hygiene practices. Historically, chlorhexidine had been inconsistently prescribed at this institution and largely based on physician preference. As part of the registered nursing residency evidence-based practice project requirement, a project team was established to determine a standard of practice.

Despite the common use of chlorhexidine, its use was felt to be counterproductive to the goal of reducing OM as it is known to cause mucosal dryness. Therefore, chlorhexidine was not chosen for the oral care bundle unless otherwise medically indicated in cases such as severe oral mucosa bleeding and inability to brush the teeth. Sodium bicarbonate was selected for the oral care bundle due to the supportive evidence in the literature. Additionally, oral moisturizing gel and petroleum-free lip balm were chosen to maintain oral mucosa integrity in between brushings and rinses. Recommended oral care bundle components were presented to the hospital's central venous catheter, pharmacy, infection prevention, and quality improvement committees for consultation and interprofessional collaboration. Final recommendations were approved by the value analysis committee prior to purchasing and implementation.

The hospital's purchasing/contract specialist requested approved vendors to submit sample bundles for review. The final oral care bundle chosen included a clear plastic zipper pouch, a pediatric-sized soft-bristled toothbrush, fluoride toothpaste, sodium bicarbonate–treated oral swabs, petroleum-free lip balm, applicator cotton swabs, and small packets of a water-based oral moisturizing gel. For patients who were able, the swabs were placed in water to create a solution for mechanical rinse. For those

patients unable to rinse, the swabs were dipped in water and used to wipe the teeth and oral mucosa. The oral care bundle was given to each patient upon admission to brush teeth and rinse twice a day. Lip balm and oral moisturizer could be used as needed. Additional swabs and moisturizer would be given to the patients each day during their stay, and the toothbrushes would be replaced as needed for patients with extended length of stay.

Education on the oral care and hygiene bundle was provided to all direct care staff on two inpatient hematology oncology units with a total of 48 beds. The education methods included review at daily shift huddles, visual educational materials posted on unit education boards, and e-mail reinforcements. Additionally, hospital informatics analysts were consulted to create automatic prompts in the electronic medical record to remind direct care staff to complete and document oral care and hygiene bundle tasks. Oral care and hygiene bundle education was included in new hire orientation as well as annual skills updates for direct care staff. Throughout the project implementation, provision of consistent bundle care compliance fluctuated. To facilitate consistent compliance, the use of a charge nurse daily oral care and hygiene checklist was initiated. The charge nurse received updates from staff throughout the shift on completed oral care and hygiene. For any patient family refusal or resistance to the bundle care, the bedside nurse and charge nurse reinforced its importance in helping to prevent infection and particularly CLABSI. To further encourage patient and family compliance, new diagnosis education highlighted the oral care and hygiene bundle elements and its importance throughout the course of treatment. Furthermore, families were educated that toothbrushing is both safe and recommended for patients regardless of their platelet count (Hogan, 2009).

Laminated posters were created and placed in each patient room to visually remind staff, patients, and families of the oral care and hygiene bundle elements. The poster included the tasks in both English and Spanish as well as pictorial icons to represent each task.

Results

Project implementation began in January 2015. CLABSI rates for both units involved in the pilot were closely monitored, with each CLABSI identified by hospital infection preventionists. LCBI-CLABSI and MBI-LCBI were monitored separately, as per Centers for Disease Control and Prevention definitions. Figure 1 displays a comparison between preintervention CLABSI rates and current CLABSI rates. To compare similar time periods, the rates of the first 6 months of 2014 were compared to the most current rates, which were derived from the first 6 months of 2018.

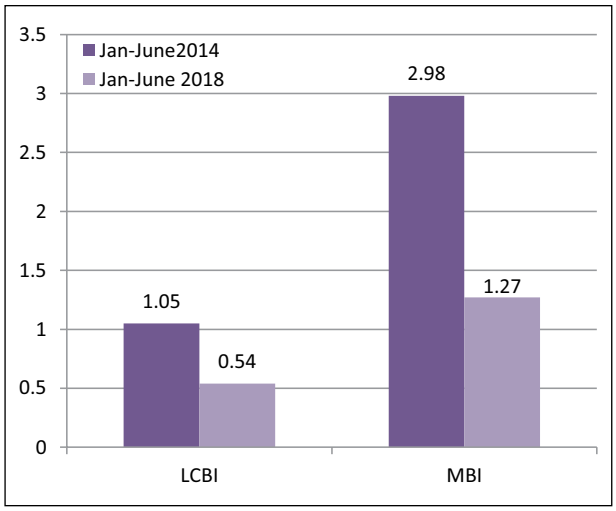

Figure 1. Pre- and postintervention CLABSI rates per 1,000 catheter days.
Note. CLABSI = central line–associated bloodstream infection; LCBI = laboratory-confirmed bloodstream infection; MBI = mucosal barrier injury.

Additionally, an exact Poisson test was used to test for a significant difference in rates between the two observation periods for each CLABSI type. A significance level of $\alpha = .05$ was used for all hypothesis tests. CLABSI rates were also compared by unit. In Table 1, the combined units' LCBI-CLABSI and MBI-LCBI rates were compared during the two observation periods. Both LCBI-CLABSI and MBI-LCBI rates of infection decreased from the 2014 observation period to the 2018 observation period. However, this change was not found to be statistically significant.

In Table 2, CLABSI rates were compared between the two (four East and four West) inpatient units. Both CLABSI types decreased between the 2014 and 2018 observation periods, with the exception of the four West MBI-LCBI rates, which increased. The decreased rate of MBI-LCBI on four East was found to be statistically significant ($p = .01$). No other changes in rate were found to be statistically significant in this analysis. Though implementation of a hygiene bundle cannot completely eliminate all CLABSI, there was a notable decrease in both LCBI-CLABSI and MBI-LCBI, with a 30.5% and 51.3% decrease, respectively. Despite minimal statistical significance found, the clinical significance of this reduction contributed to overall patient safety.

Discussion

Implications for Practice

CLABSI are a major source of morbidity and mortality for hospitalized children with cancer, and targeting to

Table 1. Comparison of CLABSI Rates by Type.

CLABSI – type	Period	CLABSI count	Line days	Rate of CLABSI per 1,000 line days	*p*
LCBI	January-June 2014	6	5,706	1.05	.51
	January-June 2018	3	5,512	0.54	
MBI	January-June 2014	16	5,706	2.80	.09
	January-June 2018	7	5,512	1.27	

Note. CLABSI = central line–associated bloodstream infections; LCBI = laboratory-confirmed bloodstream infection; MBI = mucosal barrier injury.

Table 2. Comparison of CLABSI Rates by Unit.

Unit	CLABSI – type	Period	CLABSI count	Line days	Rate of CLABSI per 1,000 line days	*p*
4 East	LCBI	January-June 2014	4	3,639	1.10	.73
		January-June 2018	3	3,646	0.82	
	MBI	January-June 2014	15	3,639	4.12	.01
		January-June 2018	4	3,646	1.10	
4 West	LCBI	January-June 2014	2	2,067	0.97	.50
		January-June 2018	0	1,866	0.00	
	MBI	January-June 2014	1	2,067	0.48	.35
		January-June 2018	3	1,866	1.61	

Note. CLABSI = central line–associated bloodstream infections; LCBI = laboratory-confirmed bloodstream infection; MBI = mucosal barrier injury.

zero nosocomial infections continues to be a substantial health care initiative (Metzger et al., 2015). The project team identified the need for standardization of evidence-based oral care and hygiene practices in hopes of reducing CLABSI rates. Though hygiene is a basic element of patient care, it is critical to comply with hygiene best practices in order to effectively prevent CLABSI (Linder et al., 2017). Implementation of a standardized oral care and hygiene bundle in the inpatient pediatric oncology population was found to decrease overall CLABSI rates. While our findings did not show the decrease in CLABSI to be statistically significant in most areas, the results are clinically significant. A decrease in CLABSI rates results in less overall infections, shorter inpatient lengths of stay, and overall cost savings (Metzger et al., 2015; Wilson et al., 2014).

Determining the best products to include in the oral care bundle was complex, as evidence provided somewhat conflicting findings (McGuire et al., 2013). The project team felt that the evidence was strong enough to implement the standardized bundle with continuous monitoring of outcomes. However, there is a paucity of research published that specifically addresses children with cancer. There is opportunity to expand the breadth of evidence and conduct further research that examines the most effective oral care and hygiene interventions for CLABSI reduction. Following evidence synthesis, the project team determined the components for a standardized oral care bundle that would lead to an effective infection prevention strategy, including a fluoride toothpaste, a soft-bristled toothbrush, sodium bicarbonate–treated oral swabs, oral moisturizer gel, and lip balm (AAPD, 2018; S. E. Choi & Kim, 2012; Harris et al., 2008; McGuire et al., 2013). The plastic zipper pouch containing the elements for oral care created a physical prompt for direct care staff to discuss the importance of oral hygiene with the patient and family upon each admission.

Patient/family resistance was a noted barrier to achieving compliance. To address these barriers, patient/family education materials were modified to enhance understanding of the importance of hygiene. Oral care and daily hygiene are fundamental patient care tasks that can be overlooked but play an important role in reducing the risk for infection (Linder et al., 2017). The poster placed in each of the patient rooms served as a visual reminder for patients and families to take part in their daily hygiene. The task prompts in the electronic medical record helped ensure that these important aspects of patient care were completed and documented by staff. Various forms of education for direct care staff helped engage them in understanding the importance of implementing the new oral care and hygiene bundle as a standard of care. Daily auditing by the unit charge nurses created an opportunity for face-to-face interaction with direct care staff in order to encourage task completion and accountability. Staff education was periodically reinforced in staff update courses and during daily unit shift huddles.

While overall infection rates did not show statistical significance, transient increases in CLABSI rates may be attributed to higher risk patients, such as an increase in

patients who had a hematopoietic stem cell transplant. Children who have had a hematopoietic stem cell transplant are at high risk for developing bloodstream infections and often require the use of significant health care resources (Dandoy et al., 2016), which affects workload and staffing ratios. The increased workload may be a contributing factor for the provision of consistent oral care and hygiene tasks.

Limitations

Consistent compliance was a limitation of this project. As ongoing audits were reviewed by unit leadership and the performance improvement committee, root cause analyses were completed to identify barriers of following through with the protocol. These barriers included patient or parent refusal, lack of staff engagement in the project, workload of direct care staff, and incongruence of charting and completion of tasks. It was observed that a lack of compliance would occur simultaneously with an increase in CLABSI. In order to increase transparency of project results and staff awareness, monthly compliance percentages were shared with staff. Staff accolades were given for high percentage results, and/or reminders of opportunities for improvement were provided.

Nurse–patient ratios and increased workload may have impeded consistency in bundle compliance, as other patient care tasks may supersede hygiene with an acutely ill patient. To address heavy workload, it is necessary to collaborate with nurse leaders to ensure adequate staffing in relation to patient acuity. Additionally, upon each admission, empowering and engaging parents and patients in their hygiene when they are able to participate independently without staff assistance may alleviate staff workload. Direct care staff were reminded to set daily goals with families that specifically addressed hygiene to further increase their engagement in this process.

Conclusion

The establishment of the oral care and hygiene bundle created a physical, visual, and task-oriented approach to helping staff promote the well-being of patients. While there continues to be barriers regarding oral care and hygiene compliance, it is evident that implementation of a standardized oral care and hygiene bundle can significantly reduce hospital-acquired CLABSI. Focusing on CLABSI reduction is imperative, as this can greatly reduce morbidity and mortality, eliminate unnecessary hospital stays, and decrease health care costs. Though more research needs to be done to further examine interventions, this project demonstrated how a nurse-led standardization of practice can have a positive impact on patient outcomes.

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The fight against SARS: a backfilling connection for the prevention of drying out of floor drains' U-traps

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Abstract

Severe acute respiratory syndrome (SARS) was first reported in China in November 2002 and had spread to Hong Kong by late February 2003. Initially hospitals were the main sites of the infection which was thought to be due to an airborne virus. However the spread of the virus to large residential tower blocks led authorities to suspect that the evaporation of toilet floor drain U-traps may be a possible way of spreading the virus. The paper reports a full scale rig testing of methods to prevent the evaporation of the U-trap water seals and concludes with recommendations for further research.

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Introduction

Severe acute respiratory syndrome (SARS) was first reported in November 2002 and had appeared in Hong Kong in late February 2003. At the beginning, hospitals were the main sites of infections, with health care workers and their patients succumbing to SARS. Doctors at the time said the virus could only be spread by coughing and sneezing. In late March, a cluster of SARS cases broke out among residents living in Block E of Amoy Garden which is a large residential estate, typical of many such large estates in Hong Kong, housing about 20,000 residents in 19 33-storey towers. The incidence has rendered the Hong Kong Department of Health to commit a detailed environmental study for Amoy Garden. It has reported that the SARS may transmit through the drainage system to the environment (HKSAR, 2003a). This has further been supported by the World Health Organisation's (WHO) environmental investigation team in May 2003 (WHO, 2003a).

Since the outbreak of SARS, the WHO has organised laboratories and research institutions to investigate the causative agent of the disease (WHO, 2003b). It has discovered (Peiris *et al.*, 2003) and was later confirmed by WHO in April 2003 (WHO, 2003b) that a novel coronavirus, termed as the SARS-CoV, is the causative agent. Later, more laboratory works have been performed to examine the characteristics of the virus. Initial findings have indicated that the SARS-CoV is more stable (up to four days) in stools from diarrhea patients (which have higher pH than normal stools) (WHO, 2003c). This indicates the importance of sealing off the sewage system from the environment.

Possible SARS transmission through drains

Researchers have recently found that many patients with SARS excrete the SARS virus in

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their stools, where it could survive for longer periods than on ordinary surfaces (HKSAR, 2003a). If water droplets carrying the virus are driven back to the living environment from the main stack(s) of the sewage system, it will endanger the users of the building. In Amoy Garden, it was believed that water droplets appearing in the main soil stack had been driven back to the residents' toilets through the floor drains with dried U-traps. Figure 1 shows a possible way of spreading virus through the floor drain with dried trap.

Common trap arrangement

Many people may not refill the traps of floor drains and cause the traps to be dried out. Moreover, it is a common practice that extraction fans are installed to extract the bad odours in the toilets. The fans' operation may create the negative pressure causing the contaminated air/mist in the vertical soil stack to flow into the toilets. Studies on how to prevent the drying out of the floor drains' U-traps have then been carried out by various bodies (HKSAR, 2003b). Initially, a suggestion was made to provide a "common trap" for basin and the floor drain so that water discharging from the basin will prevent the drying out of the trap. Figure 2 shows the initial proposed arrangement.

Initial experimental results

In order to examine the flow pattern in the proposed arrangement, a full-scale three-storey (two testing levels) steel rig has been erected. The drainage system installed is in compliance with the Building (Standards of Sanitary Fitments, Plumbing, Drainage Works and Latrines) Regulations (HKSAR, 1997). However, a full-scale experiment has demonstrated that soap water may backflow, through the floor drain, to the floor of the toilet in some situations. Other studies (Campbell and Macleod, 2001) have also indicated that the effect of detergent in drainage systems may be critical. Figure 3 shows the experimental setup and results which may be due to the forward pressure created by the flow of the soap bubbles.

Back-filling arrangement

In view of the backflow of soap bubbles, a "back-fill" arrangement is proposed. Figures 4 and 5 show the schematic details.

Experiments have been performed with the basin discharge pipe connected to approximately 150-300mm downstream (Figure 5) at the discharge side of the floor drain U-trap. The basin discharge pipe is 32mm dia. and floor drain discharge pipe and U-trap is 50mm dia. The gradient fall of the discharge pipes are 1:40. It has been observed that water will flow to fill up the floor drain U-trap when water is discharged from the

Figure 1 A simplified schematic diagram showing the possible way of extracting contaminated air into a toilet

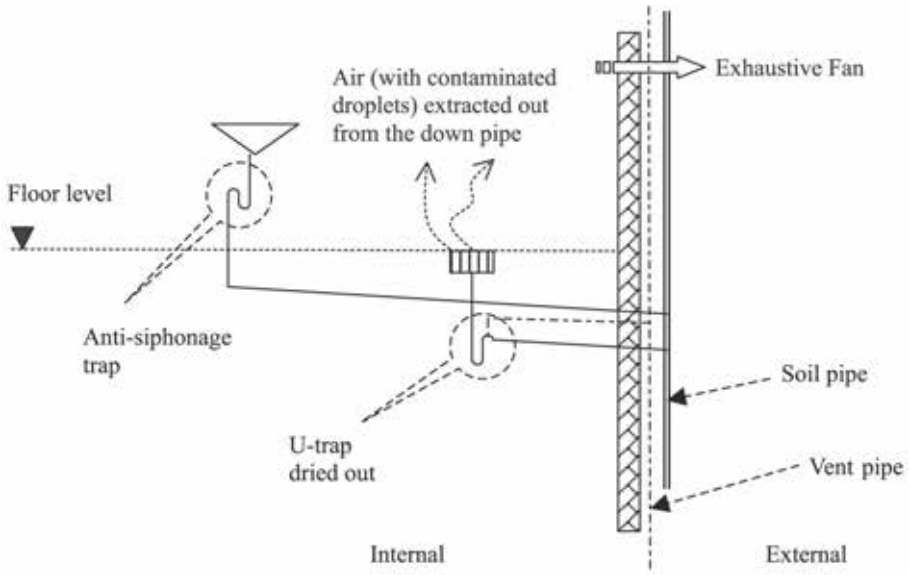


Figure 2 A simplified schematic diagram showing the common trap arrangement

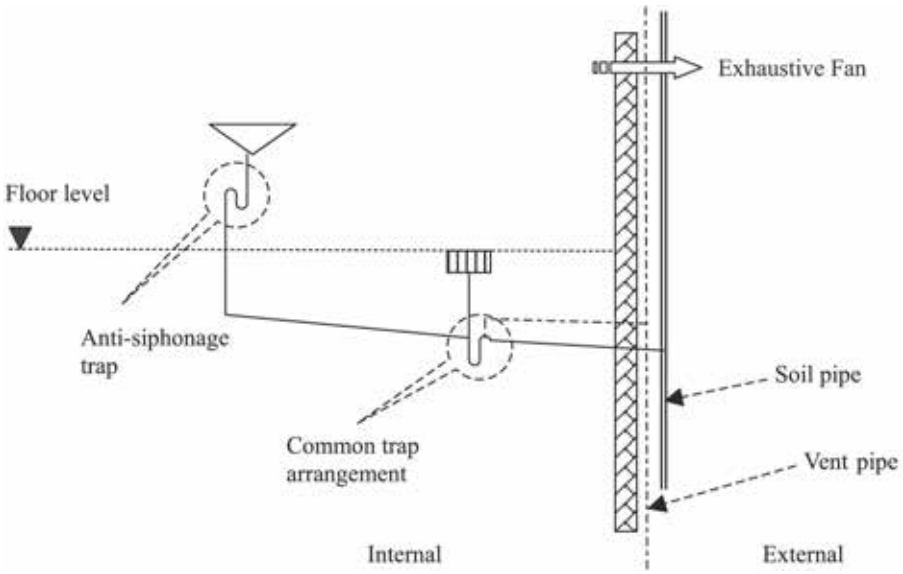


Figure 3 Full-scale experimental set-up

(a) 3-storey steel rig

(b) Backflow of soap

wash basin. The key observations are as follows:

- The floor drain U-trap has been successfully filled up at all times (rate of filling up dependent on rate of discharge of wash basin, position of the connection point, fall of the downstream discharge pipe, etc). Pictures in Figure 6 indicate clearly that a stream of water flows towards the floor drain U-trap.
- No foam (soap bubble) could possibly emerge from the floor drain inlet due to the separation of the wash basin discharge from floor drain inlet by the water seal in the U-trap.
- The rate of backfilling may be affected by the separation between the U-trap of the floor drain and the connection point of the basin's discharge pipe (i.e. D shown in Figure 5). If $D < 150$mm, there may have a possibility that the forward flow from the basin will force the water seal in the U-trap to flow out the floor drain. If $D > 300$mm, the rate of backfilling the U-trap may be so slow that the water in the U-trap can hardly be replaced.
- Particles discharging from the basin may have higher possibility of precipitating in the floor drain's U-trap.

Concluding remarks

On the basis of the full-scale tests carried out in the Laboratory of the Department of Building and Construction, City University of Hong Kong, a back-fill arrangement for the U-trap of floor drains may prevent the loss of water seal due to drying provided that the basin is frequently used. The proposed arrangement is simple and can be made by simply altering the existing waste pipe connections. This will minimise the alteration

Figure 4 The schematic diagram showing the back-fill connection

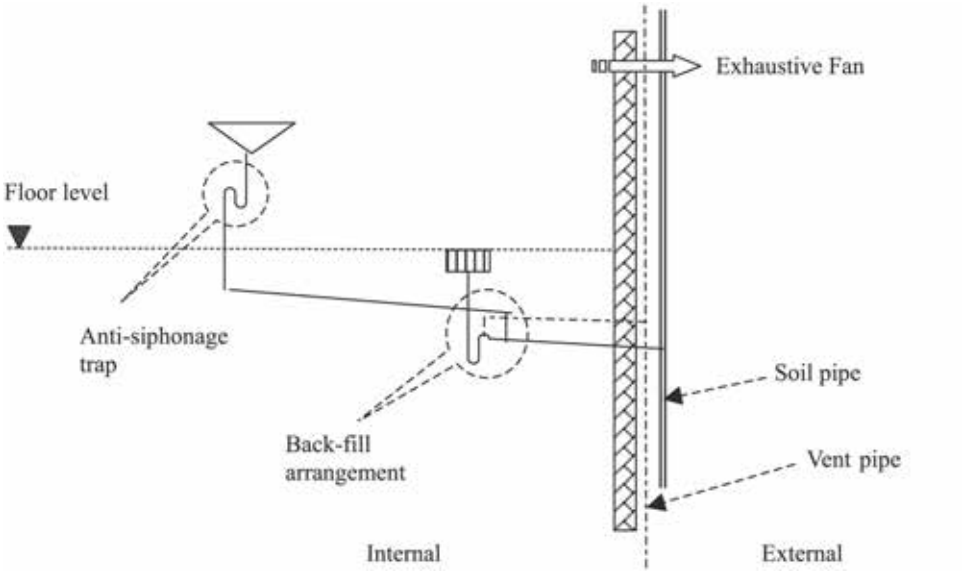


Figure 5 The back-fill connection details

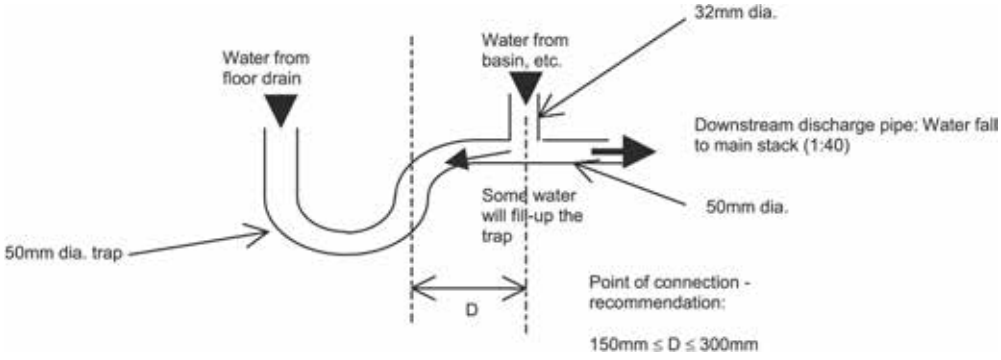
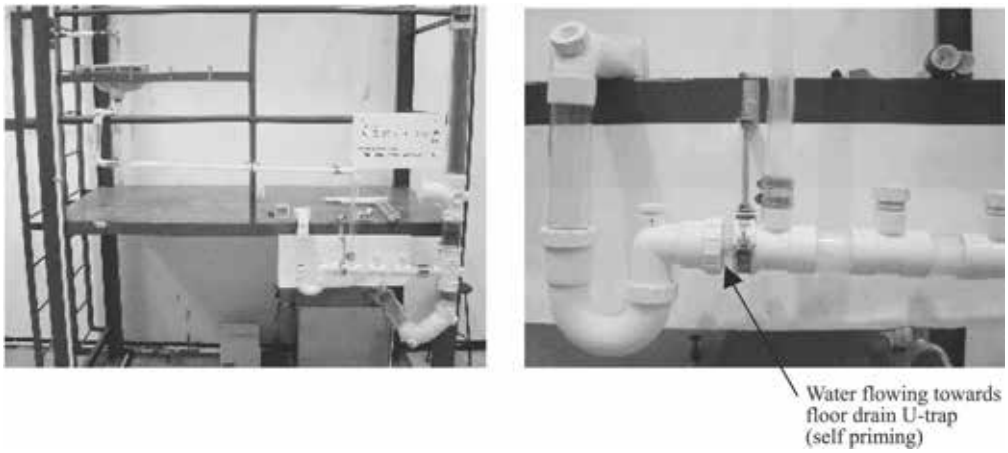


Figure 6 Pictures showing the experimental results



cost for existing systems. In addition, it has been noted that the water in the floor drain's U-trap can be replaced by the back-filling process at a reasonable rate.

In order to quantify various design parameters to enable the establishment of a set of engineering and technical guidelines, further detailed tests are proposed. Careful measurements of flow quantities using the combinations of distances of connection to the downstream discharge side to find out the critical distance beyond which such self-

priming action may not be working, are required. In addition, the limitations of using such a connection arrangement should also be studied such as the rate of water replacement in the U-trap, the possibility of blockage by precipitating particles, etc. The experiments are ongoing and will be reported in subsequent papers.

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Sink drains as reservoirs of VIM-2 metallo-β-lactamase-producing *Pseudomonas aeruginosa* in a Belgian intensive care unit: relation to patients investigated by whole-genome sequencing

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SUMMARY

Background: Hospital-acquired infections caused by VIM-encoded metallo-β-lactamase-positive *Pseudomonas aeruginosa* are a major problem in intensive care units (ICUs) worldwide. A previous study conducted in the UZ Brussel hospital revealed that sink drains of the ICU were a possible source of various multidrug-resistant pathogenic bacteria.

Aim: To investigate the presence and persistence of VIM *P. aeruginosa* in the sink drains of the four adult ICUs and their role in nosocomial infections, emphasizing sink-to-patient transmission.

Methods: Thirty-six sinks located in the ICUs of the UZ Brussel were sampled and screened for the presence of VIM *P. aeruginosa* in August and October 2019. Whole-genome sequencing (WGS) was performed on all positive sink drain isolates together with 61 isolates from patients who were retrospectively selected (ICU patients 2019–2020, $N = 46$; non-ICU patients 2019, $N = 6$).

Findings: Twenty sinks were found positive for *P. aeruginosa* at both sampling time-points. WGS revealed that the predominating environmental cluster belonged to sequence type ST111. Ten additional STs were identified. VIM-2 was detected among all ST17 ($N = 2$) and ST111 ($N = 14$) sink drain isolates. Based on whole-genome multi-locus sequence typing analysis of all genomes, 15 clusters of highly related isolates were identified, of which seven included both sink drain and clinical isolates.

Conclusion: Our findings confirm that sink drains are a possible source of VIM-2 *P. aeruginosa*, probably after being contaminated with clinical waste from patients.

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Patients could be exposed to VIM-2 *P. aeruginosa* dispersed in their environment because of colonized sink drains.

Introduction

Pseudomonas aeruginosa infections are not very common in the general population, but infections and colonization can occur in high-risk individuals such as people with cystic fibrosis, chronic lung obstructive disease, or an immunodeficiency. Hospitalized patients often have wounds, indwelling catheters, or are ventilated and could therefore be a potential host for *P. aeruginosa*. [1]. In addition, *P. aeruginosa* has been considered as an important causative agent of nosocomial infections worldwide, and, since this bacterium is intrinsically resistant or less susceptible to several antimicrobial agents, infections caused by *P. aeruginosa* are challenging to eradicate. Moreover, *P. aeruginosa* clones resistant to almost every antibiotic tested, including carbapenems, are widely disseminated. Carbapenem resistance among *P. aeruginosa* may be caused by the acquisition of carbapenemases, mainly Ambler class B metallo-β-lactamases (MBLs) [2]. Oliver *et al*. described the worldwide existence of antibiotic-resistant high-risk clones such as ST235, ST111, and ST175 [3].

A large number of *P. aeruginosa* outbreaks have been linked to sources in the environment, especially water systems [4—6]. Wash hand basin drains in hospitals may contain enormous numbers of bacteria such as *P. aeruginosa*, which may then be transmitted to patients. When water runs into the sink drain, aerosols may contaminate the environment and the hands of healthcare workers. The sink is thus an open, actively emitting pathogen reservoir [4—6]. As early as 1991, Döring *et al*. suggested that sinks could play a role in the transmission of *P. aeruginosa* [5]. Upon entering the hospital, hand cultures of all studied personnel were *P. aeruginosa* negative. However, during duty, 42.5% of personnel members acquired different *P. aeruginosa* strains on their hands. They identified identical genotypes of *P. aeruginosa* on the hands of the personnel and in the sink, suggesting a transmission route from sink to hands [5]. We also previously reported that sinks were involved in the transmission of multi-resistant carbapenemase-producing Enterobacterales in the intensive care unit (ICU) [7].

In 2019, we noticed an increasing prevalence of multi-resistant *P. aeruginosa*, such as Verona integron-encoded MBL (VIM)-positive strains, in clinical or screening isolates of patients in our adult ICU. The goal of the present study was to verify whether patients could be colonized or infected by micro-organisms present in the sink drains and to investigate whether high-risk clones of *P. aeruginosa* are present in our ICU. To achieve this goal, whole-genome sequencing (WGS) was employed.

Methods

Setting

The University Hospital Brussels is a teaching hospital with more than 700 beds. There are four ICUs for adults, each containing six beds. Every unit has nine sinks: one for every patient, one in the anteroom, one in the utility room, and one placed centrally. In total, 36 sinks are available in the ICUs.

Infection control measures and environmental cleaning policy

Patients at the ICU are screened rectally for the presence of resistant Gram-negative bacteria on admission, every week, and at discharge. Respiratory, blood, urine, and other clinical samples are taken when there is a suspicion of infection. Patients colonized or infected with multi-resistant *P. aeruginosa* are placed in contact isolation precautions in a single room with use of gloves and a disposable overcoat. The room is cleaned daily with Incidin® Plus (0.5% glucoprotamin) (Microtek, Zutphen, The Netherlands). At discharge, the room is cleaned intensively and unused consumables, such as gloves and hand alcohol, are discarded. Periodic checks of the quality of terminal cleaning are performed with the Glowcheck® (Hartmann, Heidenheim, Germany). The sinks are flushed once a week with Incidin Plus. The water supply to the ICU is unfiltered and is tested quarterly for the presence of *P. aeruginosa*.

Sink sampling and microbiological methods

Pseudomonas aeruginosa isolates were recovered by taking swabs in 36 sink drains (10—15 cm depth) (eSwab; Copan, Brescia, Italy). The sinks were sampled twice at a 1.5-month interval (August 2019 and October 2019). After sampling, 1 mL of Fastidious Organisms Broth (FB, own preparation) was added to the eSwab, and the tubes were incubated aerobically for 48 h at 37°C. Presumptive *P. aeruginosa* isolates were recovered on MacConkey agar (bioMérieux, Marcy l'Etoile, France) (48 h, aerobic incubation at 37°C) and identified by matrix-assisted laser desorption—ionization time-of-flight mass spectrometry (MALDI-TOF MS) using a Microflex LT mass spectrometer with MALDI Biotyper 3.0 software and Reference Library 3.2.1.0 (Bruker Daltonik GmbH, Bremen, Germany). The presence of the VIM β-lactamase enzyme was investigated with the RESIST-4 O.K.N.V. immunochromatographic lateral flow assay (Coris BioConcept, Gembloux, Belgium). Confirmed *P. aeruginosa* strains were further selected for WGS.

Clinical isolates

The *P. aeruginosa* isolates collected as described in 'Infection control measures and environmental cleaning policy' were stored at −80°C. From this collection, *P. aeruginosa* isolates were retrospectively selected to perform WGS. The study consisted of different subgroups (Appendix A):

- 59 clinical or rectal screening isolates from 44 randomly selected patients without cystic fibrosis, residing at least once at the ICU (January to December 2019);

- six isolates from six randomly selected patients, not residing at the ICU (May to August 2019);
- two VIM-positive isolates from clinical samples of two COVID-19 patients residing at the ICU (October to December 2020).

If, within the same short hospitalization period, multiple isolates with the same antibiotic resistance profile were obtained from a patient, only a single one was included for WGS.

Identification of strains was performed as described in 'Sink sampling and microbiological methods'. Antibiotic susceptibility testing was investigated both by the disc diffusion method and by MIC susceptibility testing using the interpretative criteria of The European Committee on Antimicrobial Susceptibility Testing (EUCAST) combined with recommendations of the National Reference Center (NRC) and BAPCOC (Belgian Commission for the Coordination of the Antibiotic Policy). The presence of the VIM β-lactamase enzyme was determined as described in 'Sink sampling and microbiological methods'.

Whole-genome sequencing

Genomic DNA was extracted using the Maxwell RSC Cell DNA purification kit (Promega Corporation, Madison, USA). Fragmentation of genomic DNA was carried out using the NEBNext® Ultra™ II FS module. Sequencing libraries, with an insert size of on average 550 bp, were prepared using the KAPA Hyper Plus kit (Kapa Biosystems, Wilmington, USA) and a Pippin Prep size selection. In order to avoid PCR bias, the PCR amplification step was excluded and a 500 ng input of genomic DNA was used. After equimolar pooling, libraries were sequenced on a Novaseq 6000 instrument (Illumina, San Diego, CA, USA) using an SP-type flow cell with 500 cycles. A 1% PhiX control library was included in each sequencing run. Sequence quality was assessed with FastQC (version 0.11.4) software (https://www.bioinformatics.babraham.ac.uk/projects/fastqc/). De-novo assembly was performed using SPAdes genome assembler (http://bioinf.spbau.ru/spades).

In-silico identification of serotypes, resistance genes, and virulence factor-related genes

Identification of serotypes and acquired antibiotic resistance genes was performed using tools available from the Center for Genomic Epidemiology (https://cge.cbs.dtu.dk/) (ResFinder 3.2, PAst 1.0) [8]. The presence of resistance genes was determined with a percentage identity (ID) threshold of 90% over the length of the reference sequence whereas β-lactamase variants were determined with a percentage ID threshold of 100%. In addition, potential virulence factor-related genes, from which a selection was made based on previous studies, were identified by the virulence factor database (VFDB, http://www.mgc.ac.cn/VFs/) [9–12].

Whole-genome multi-locus sequence typing (wgMLST) analysis

The sequencing data was analysed using the wgMLST scheme for *P. aeruginosa* available in BioNumerics v.7.6.3. (Applied Maths, Sint-Martens-Latem, Belgium). This scheme consists of 15,143 loci, including the seven classic MLST loci [13]. Both assembly algorithms were used for allele calling, i.e. the assembly-free k-mer-based approach using the raw reads and the assembly-based BLAST approach. The default settings were used for both the assembly-free and assembly-based algorithms. The quality of the sequence read sets, the de-novo assemblies, the assembly-free and the assembly-based allele calls were verified using the quality statistics window in BioNumerics. The MLST profile of each isolate was determined using the PubMLST allele mapping experiment incorporated in BioNumerics. Minimal spanning trees (MSTs) were generated using the wgMLST allelic profiles as input data in BioNumerics. Branch lengths reflect the number of allele differences between the isolates in the connected nodes. For clustering, the maximum distance between nodes was set at <14 [14].

Results

P. aeruginosa from sink drains

Pseudomonas aeruginosa was recovered from 20 out of the 36 sink drains at both sampling time-points. These positive sink drains were spread over all four ICUs. *P. aeruginosa* was absent from the sink drains of the utility rooms in all four ICUs. One isolate, Env. ICUC_PAUZB105, was excluded from the wgMLST analysis due to impurity of the DNA extract.

P. aeruginosa STs and serogroups among sink drain and clinical isolates

In total, 11 distinct STs were identified among the sink drain isolates (ST17, ST27, ST111, ST164, ST244, ST253, ST348, ST395, ST446, ST1058, and ST1074) (Figure 1). Seven of these STs were also identified in the clinical isolates (ST17, ST27, ST111, ST244, ST253, ST446, and ST1058) (Figure 1). ST111 was the predominating ST, accounting for 36% of the sink isolates ($N = 14/39$), followed by ST395 and ST446, each accounting for 13% of the sink isolates ($N = 5/39$) (Figure 1). Sink drain ST111 isolates were retrieved in all four ICUs whereas ST395 and ST446 isolates were found in three ICUs (Figure 2).

Twenty-eight different STs were observed among the 59 clinical isolates from 44 ICU patients and the six clinical isolates from six non-ICU patients from 2019, suggesting different chains of transmission (Figure 1). The most frequently identified STs, sorted by ascending order of ST number, were ST17 (five isolates from five ICU patients; one isolate from a non-ICU patient), ST27 (four isolates from four ICU patients), ST111 (nine isolates from eight ICU patients), ST175 (three isolates from two ICU patients; one isolate from a non-ICU patient), ST 235 (six isolates from three ICU patients), ST244 (eight isolates from four ICU patients), ST253 (one isolate from an ICU patient; two isolates from two non-ICU patients) and ST446 (four isolates from three ICU patients) (Appendix A). Isolates with ST175 and ST235 were found among clinical isolates only. Interestingly, the two clinical isolates from 2020 were ST17 and ST111 (Figure 1).

All ST111 isolates were associated with serogroup O12 (Appendix A). Isolates with ST175 and ST235 were linked to serogroups O4 and O11, respectively (Appendix A).

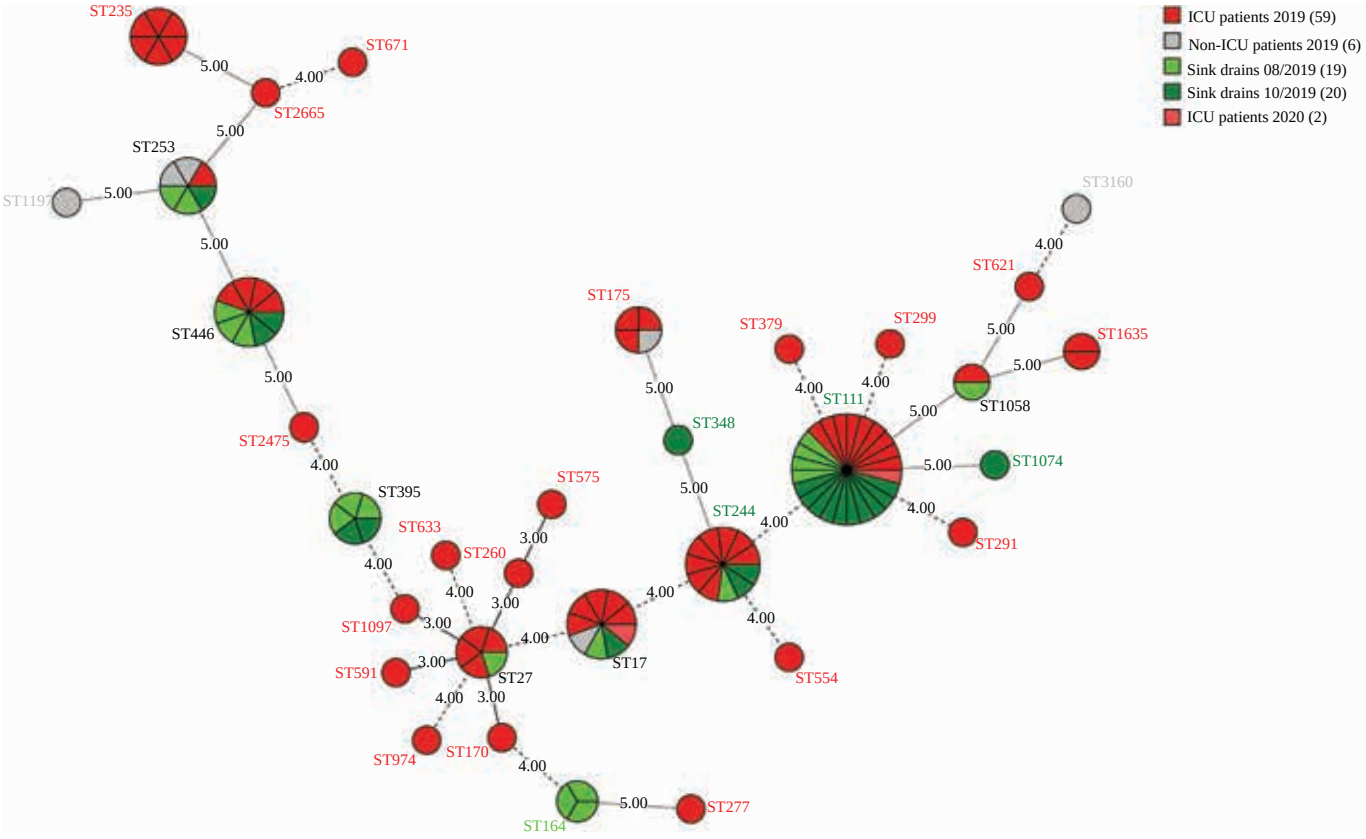

Figure 1. Minimum spanning tree based on PubMLST allelic profiles of 106 *P. aeruginosa* genomes built from PubMLST analysis, with indication of the year of isolation. The analysis was carried out in BioNumerics, using the *P. aeruginosa* wgMLST scheme. Thirty-two distinct MLST STs were identified among all isolates, i.e. 39 sink isolates, 61 clinical isolates from 46 ICU patients and six clinical isolates from six non-ICU patients. Nodes are colour-coded per type of isolate and their respective numbers as labelled. Numbers of allelic differences are indicated on the lines connecting various STs.

wgMLST analysis

Eight clusters were identified based on the wgMLST analysis of the 39 sink drain isolates (Figure 2). The isolates within the predominant environmental cluster, cluster 1 ($N = 11$), belonged to ST111. These isolates were retrieved from three out of the four ICUs (B, C, and D; Appendix A and Figure 2). The three remaining ST111 isolates clustered together (cluster 2: range: 0–6) and were all retrieved from ICU A (Figure 2). Consequently, the wgMLST analysis showed that ST111 sink drain isolates were subdivided into two clusters of closely related isolates. Also the ST17 (cluster 6: no allelic differences), ST164 (cluster 5: no allelic differences), and ST395 isolates (cluster 4: range: 0–1) were closely related within their respective clusters (Figure 2). The latter belong to the second predominant environmental cluster, cluster 4 ($N = 5$), and were retrieved from three ICUs (B, C, and D; Appendix A and Figure 2). ST446 isolates, however, were more diverse (range: 0–119). Still, three ST466 isolates, retrieved from different ICUs (A and C; Figure 2), were highly similar (cluster 7: no allelic differences). The same was seen for ST244 and ST253 isolates (range: 1–35 and 0–31, respectively) (Figure 2). For each ST, however, two isolates were closely related and belonged to clusters 3 and 8, respectively (Figure 2).

After performing wgMLST analysis on all 106 *P. aeruginosa* genomes (39 sink drain and 67 clinical isolates) seven additional clusters of highly related isolates were identified, accounting for a total of 15 clusters (Appendix B). Clusters 16* and 17* cannot be considered as clusters because the isolates were retrieved from the same patients (patients 13 and 29, respectively). Seven out of the 15 clusters included genomes of both sink drain isolates and clinical isolates (clusters 1 (ST111), 2 (ST111), 3 (ST244), 6 (ST17), 10 (ST446), 11 (ST446) and 12 (ST1058)), suggesting human-to-environment-to-human transmission. The patients within each cluster generally stayed at the ICUs from which corresponding sink drain isolates were detected. The clinical isolates within cluster 1 were retrieved from patients staying at ICU B, C or D, for example (Appendix A). Yet, within cluster 3, one isolate was retrieved from a patient that remained at ICU C during the hospital stay (patient 40), while the two sink isolates were retrieved at ICU B (Env. ICUB_PAUZB011 and Env. ICUB_PAUZB017). Interestingly, a lag of several months was observed between the collection date of some clinical samples and the environmental sampling date. Cluster 10, for example, includes one sink drain isolate (Env. ICUB_ PAUZB013) and three clinical isolates from two patients (patients 07 and 33) staying at ICU B, that showed no allelic differences although the isolates were retrieved approximately

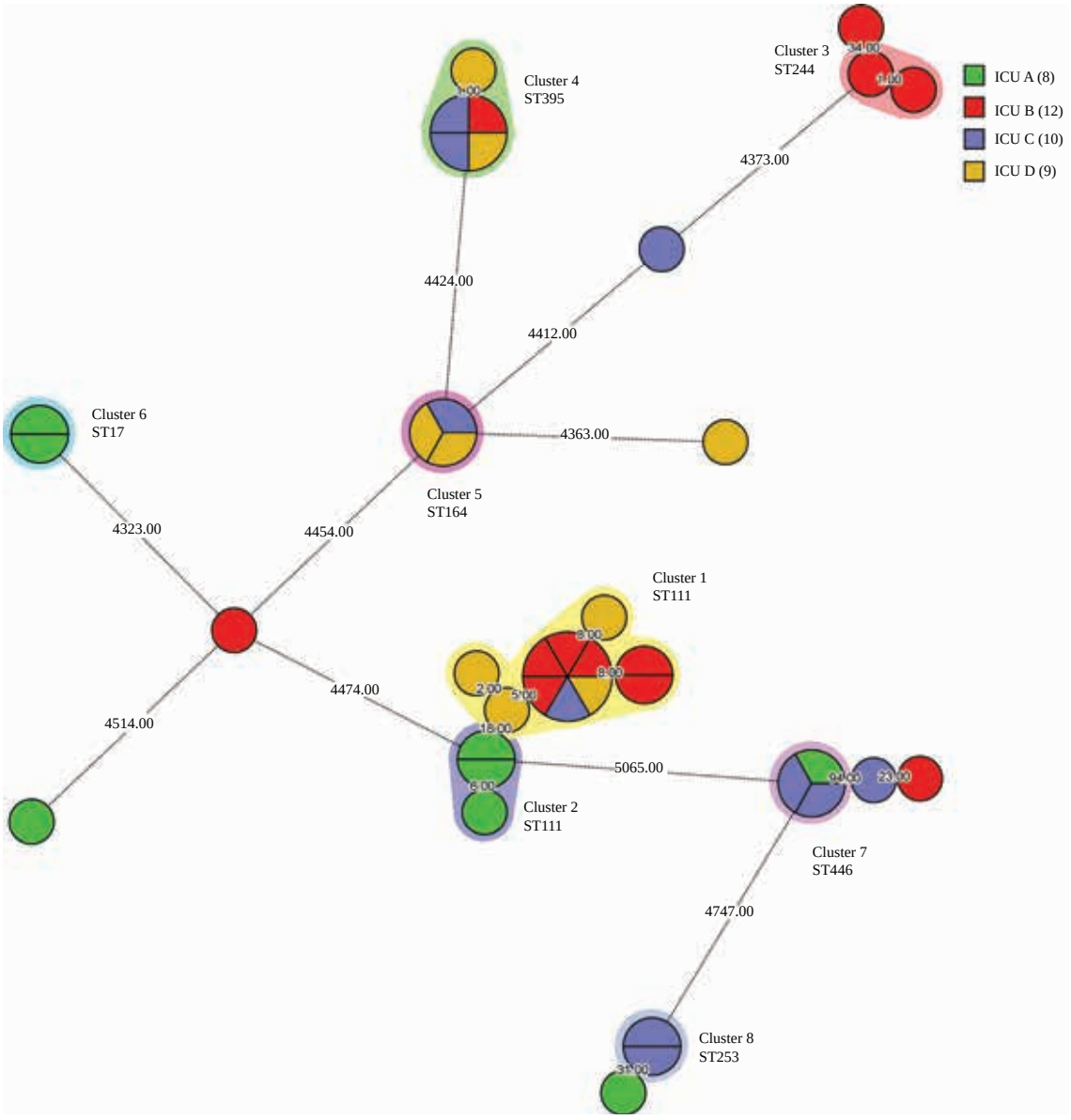

Figure 2. Minimum spanning tree based on wgMLST allelic profiles of 39 *P. aeruginosa* genomes built from wgMLST analysis. The analysis was carried out in BioNumerics, using the *P. aeruginosa* wgMLST scheme. Eleven distinct STs were identified among all sink isolates. A fixed threshold of <14 allelic differences was used for clustering of isolates. Nodes are colour-coded per originating intensive care unit and their respective numbers as labelled. Numbers of allelic differences are indicated on the lines connecting the various STs.

six months apart (Appendices A and B). The same was observed for cluster 11, where the sink drain isolate (Env. ICUC_PAUZB024) was retrieved six months after the clinical isolate from ICU C, while the clinical isolate was retrieved from a patient staying at ICU D (patient 31). These two isolates showed eight allelic differences. Also, two patients (patients 16 and 17) were admitted with a negative rectal screening and became positive for VIM *P. aeruginosa* during their hospital stay, which was after the second sink sampling time-point in October 2019. In line with this, one year later, two COVID-19 patients (patients 51 and 52) became positive for VIM *P. aeruginosa* during their hospital stay. The isolates from both patients belonged to clusters 6 (ST17) and 2 (ST111), respectively. The presence of biofilms in the drainage pipes connecting the sinks might be an explanation for the obtained results.

Within four clusters composed of sink drain isolates, no links to clinical isolates were identified (clusters 4 (ST395), 5 (ST164), 7 (ST446), and 8 (ST253)). The sink drain isolates within each cluster were closely related with 0–1 allelic differences. Four clusters comprised clinical isolates only and showed no link to the environment (clusters 9 (ST27), 13 (ST175), 14 (ST253), and 15 (ST235)). Two of these clusters comprised clinical isolates from patients staying at the ICU and non-ICU patients (clusters 13 and 14) (Appendix B). The ICU patient from cluster 13 (patient 28) had previously been hospitalized in 2018 already, staying in non-ICU wards also, where the patient might have acquired the isolate. However, the ICU

patient from cluster 14 (patient 02) did not leave the ICU during the hospital stay.

All isolates recovered from a single patient (patients 01, 10, 13, 15, 28, 29, and 33) were highly similar and belonged to the same ST, with only 0–5 allelic differences. Yet, isolates with different STs were also retrieved from some ICU patients (patients 02, 25, and 29), showing the ease with which *P. aeruginosa* infects fragile patients (Appendix A).

Phenotypic resistance profiles of clinical P. aeruginosa isolates

The phenotypic resistance profiles were investigated for the clinical samples only (Appendix C).

Antibiotic resistance and virulence gene profiles of P. aeruginosa isolates

The presence or absence of antibiotic resistance and virulence genes found in the 39 sink isolates and the 67 clinical isolates are presented in Appendices D and E, respectively.

Sixteen out of the 39 sink drain isolates (clusters 1 (ST111), 2 (ST111), and 6 (ST17)) carried the acquired β-lactamase gene bla_{VIM-2} together with the intrinsic resistance genes *aph(3′)-Iib* (chromosomal aminoglycoside phosphotransferase), bla_{PAO} (β-lactamase resistance), and catB7 (chloramphenicol resistance) (Appendix D). The intrinsic resistant genes $bla_{OXA-395}$ (β-lactamase resistance; ST111) or bla_{OXA-50} (β-lactamase resistance; ST17) were also detected in these sink drain isolates as well as the *crpP* (ciprofloxacin-modifying enzyme), *fosA* (fosfomycin resistance), and *sul1* (sulfonamide resistance) genes. All but one of these sink drain isolates carried the acquired aminoglycoside-resistance genes *aac(6′)-29a* and *aac(6′)-29b*, which are flanking the bla_{VIM-2} gene on a class 1, In59-like integron. Exactly the same genes, depending on the clusters, were found in the clinical isolates carrying bla_{VIM-2} (13 isolates from 12 patients) (Appendix D).

Interestingly, one of the clinical isolates in cluster 13 carried the bla_{VIM-4} gene (patient 28_PAUZB078; ST175). Another clinical isolate, outside a cluster, had a bla_{IMP-13} gene (patient 11_PAUZB056; ST621). Also these genes are present on class 1 integrons (Appendix D).

A wide variety of putative virulence genes involved in survival and persistence were identified among the *P. aeruginosa* genomes as expected (Appendix E). The presence of type III secretion system (TTSS) exotoxin *exoS* gene was observed in all isolates except those from ST235, ST253, ST446, ST671, ST1197, and ST2665. These isolates were the only isolates containing *exoU*, which is known to be mutually exclusive with *exoS*. The *exoY* gene was present in all isolates, except for one ST17 isolate (patient 45_PAUZB099).

The quorum sensing genes *lasI* and *lasR* were present within all but one *P. aeruginosa* genome (patient 48_PAUZB102) (Appendix E). Similarly, all except three ST17 isolates possessed the quorum sensing genes *rhlI* and *rhlR* (patient 28_PAUZB077, patient 28_PAUZB078, and patient 50_PAUZB104). Both regulatory systems are known to regulate the production of many virulence factors and the formation of biofilms.

Discussion

The prevalence of infections with multidrug-resistant Gram-negative bacteria is increasing worldwide. In 2017 the World Health Organization classified the carbapenem-resistant *P. aeruginosa* as a 'priority 1 pathogen', which means that the bacterium may pose a particular public health threat. As studies show, VIM *P. aeruginosa* occurs in a wide range of environmental reservoirs and objects in the hospital, such as floors and walls, the beds of patients, door handles and various other objects [15,16]. However, it appears that the sink drain is probably the most important reservoir with a huge number of colony-forming units. A previous study conducted in our hospital revealed that sink drains of the ICU were a possible source of various multidrug-resistant pathogenic bacteria and suggested that transmission from these drains could indeed play a role in nosocomial infections [7].

The results of the current study confirm that sink drains are a possible source of VIM *P. aeruginosa* and that patients could become colonized or infected from sinks. Indeed, taking both sampling moments together, 55% of the sampled sink drains ($N = 36$) tested positive for *P. aeruginosa*. Of these positive samples, 41% ($N = 16/39$) carried the bla_{VIM-2} gene. Fifteen clusters were distinguished among all the analysed isolates. In seven of these, a genetic link was found between clinical and environmental isolates. At least 25 of the 61 (41%) clinical samples of patients from the ICUs can be linked to isolates found in the sink drains. All patients included in this study who carried a VIM-2 *P. aeruginosa* ($N = 12$) were linked to environmental samples of ST111 (clusters 1 and 2) or ST17 (cluster 6). Seven of the 12 (58%) patients died. No single link was seen between environmental isolates and non-ICU clinical samples ($N = 6$). However, as seen in clusters 13 and 14, a link was seen between ICU and non-ICU patients. This can probably be explained by the fact that patients and staff can move between the wards leading to the spread of resistant micro-organisms. It was not always clear in our study whether the sink drains were contaminated by the patients or the other way around. We noticed that two patients with negative rectal screening on admission became VIM-2 positive during their hospital stay, after the second sink sampling time-point. One year later, the same was observed for two COVID-19 patients. This suggests transmission from sinks to patients. Actually, the latest audit performed in the ICUs, in the summer of 2020, showed that clinical waste from patients had been flushed through the sinks instead of being evacuated via waste containers meant for that purpose. This practice had already started before 2020 but continued due to the COVID-19 outbreak as the personnel wanted to keep the clinical waste of the patients as much as possible in the isolation rooms. Consequently, the ideal situation would be rooms without sinks, which will be kept in mind when the new ICUs is built. In the meantime, siphons with a separate drain for clinical waste will be installed. Consistently disinfecting the sink drains with agents active against bacterial biofilms, such as acetic acid, could be a cheap additional measure [17].

Focusing on the STs, we can conclude that ST111 is present throughout the year in patients. Moreover, we found a great diversity of STs in the sink drains, meaning that there is a broad community of *P. aeruginosa* harboured in the ICUs and that

they can circulate for months at least. Indeed, it is reported that nosocomial *P. aeruginosa* infections or colonizations are generally characterized by polyclonality [18]. ST175 and ST235, known to be MDR international high-risk clones, were found among clinical isolates only [3]. ST111, however, was isolated from both patient and sink samples.

In this study, there are some missing parts and unexplainable links. For example, multiple very closely related strains were found in different sink drains among different ICUs, without one single link to a patient (clusters 4, 5, 7, and 8). A possible hypothesis is that *P. aeruginosa* can traffic between hospital U-bend sinks via biofilms in the wastewater network as shown in a study by Moloney *et al.* [19]. It is also possible that healthcare workers are carriers of resistant strains and can transmit them between patients without a link with the environment. It is notable that the water supply to the ICU is monitored four times a year to evaluate the presence of *P. aeruginosa*. During the study, levels remained less than one colony-forming unit per 100 mL, indicating that the presence of *P. aeruginosa* is coming from the ICU itself, and not being delivered via the water supply.

Besides the identification of the STs and serogroups, additional information about virulence factors and resistance genes was provided by WGS. The acquired aminoglycoside-resistance genes *aac(6′)-29a* and *aac(6′)-29b*, the intrinsic aminoglycoside-resistance gene *aph(3′)-Iib*, the β-lactamase-resistance genes bla_{PAO}, $bla_{OXA-395}$, and bla_{VIM-2}, the chloramphenicol-resistance gene *catB7*, and ciprofloxacin-resistance gene *crpP* were frequently identified in the isolates. All but two VIM-2 isolates carried the bla_{VIM-2} gene in between two aminoglycoside-resistance gene cassettes in an In59-like integron structure, which is the same organization as described by Van der Bij *et al.* [20]. They pointed out that this integron structure is the most frequently found in outbreaks with VIM *P. aeruginosa* in the Netherlands.

Considering the virulence factors, Newman *et al.* described the negative association between the $exoU^+$ genotype and XDR phenotypes [11]. As seen in our results as well, the isolates of the international high-risk clones ST175 and ST111 were all $exoU^-/exoS^+$. However, a third international high-risk clone, ST235, which has caused numerous outbreaks worldwide and is associated with a particularly poor outcome, has an $exoU^+/exoS^-$ genotype [21,22]. Our clinical isolates also include isolates of this ST.

One limitation of this study is that it is possible that the real proportion of sink drains positive for *P. aeruginosa* is higher than we found, because we did not use selective or enrichment media. Another limitation of the study is that some sinks may have been sampled shortly after cleaning, which could explain why sometimes no bacterial growth at all was obtained. In addition, we acknowledge that no phenotypic testing of the environmental isolates was performed, i.e. the presence of genes does not necessarily reflect gene expression. Moreover, we only investigated acquired antibiotic resistance genes. The mutational resistome, affecting cell wall permeability, antibiotic efflux systems and point mutations, was not investigated [23,24].

In conclusion, this study confirms that sink drains are an important reservoir of VIM-2 *P. aeruginosa* strains, probably after being contaminated with clinical waste from patients. These bacteria can be transmitted to patients directly and indirectly via healthcare workers. Moreover, VIM-2 *P. aeruginosa* is known to lead to increased mortality. Since patients on the ICU are already vulnerable to infections, this can pose huge problems. WGS has been of great value in our outbreak investigation. It could help in the rapid recognition of an outbreak with accurate mapping of the spread and identification of potential sources, facilitating the implementation of infection control measures.

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Conflict of interest statement
None declared.

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None.

Appendices A—E. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jhin.2021.05.010.

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A pseudo-outbreak of *Pseudomonas* on a special care baby unit

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Summary: Following isolation of a multi-antibiotic-resistant pseudomonad from a newborn infant on admission to the Special Care Baby Unit and further isolation of apparently the same organism from two additional infants, a full investigation was instigated in an attempt to discover the source of the organism. This revealed a further 13 infants apparently colonized with the same organism. Repeated screening of the infants with a commercial sterile swab/transport medium failed to isolate the organism. Examination of bottles of the in-house transport medium, which had been stored under a sink, produced further isolates of the same organism. Water splashed from the sink was suspected as the ultimate source of contamination. Biochemical characterization showed that *P. pickettii* and at least one other *Pseudomonas* species were involved. The epidemiological, clinical and economic implications of the 'outbreak' are discussed together with the ultimate financial implications for investigation of such incidents.

Keywords: Pseudo-outbreak; *Pseudomonas*; special care baby unit.

Introduction

Outbreaks of pseudo-bacteraemia have been well documented over the last 10 years (Whale, 1983; McNeil *et al.*, 1985a). Contamination, prior to inoculation with blood taken for culture, of ESR bottles containing sodium citrate (Wilson *et al.*, 1981; Isphahani *et al.*, 1985), by contaminated antiseptic agents used for skin disinfection (Kaslow *et al.*, 1976; Godsen & Norman, 1985) and by use of a contaminated blood gas analyser (Henderson *et al.*, 1988) have been reported. Whilst contamination of blood cultures causes significant problems with regard to clinical relevance and to repeated and often unnecessary laboratory investigations, contamination of other clinical specimens is less well documented (Maki, 1980; Goldstein & Abrutyn, 1985; Siegman-Igra *et al.*, 1985). We report here a pseudo-outbreak on a Special Care Baby Unit (SCBU) caused by aminoglycoside-resistant pseudomonads isolated following surface swabbing of neonates.

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The 'outbreak'

An aminoglycoside resistant pseudomonad was grown from a groin swab obtained, for screening purposes, from a twin born after 35 weeks gestation. The swab had been taken shortly after the infant's birth, on admission to the SCBU. On recovery of this isolate, the baby, her twin, and their mother were barrier nursed to prevent spread of the organism. A repeat set of screening swabs from the infant and her twin was sent to the laboratory.

The following day, two further neonates appeared to be colonized with the same organism, one from an umbilical swab and the other from a nasal swab. Swabs from one of these infants had been sent from the SCBU but the other infant's swabs, although emanating from the Delivery Suite and taken within 3 h of birth, may nevertheless have used transport medium from the SCBU stock. Initially, it was unknown whether the SCBU or the Delivery Suite was the source of the organism. Consequently, all infants delivered over the next five days (66 deliveries) had surface swabs (groin/rectum, umbilical, ear, nose) sent for culture immediately on delivery. Maternal high vaginal swabs from these pregnancies were also received. In addition, the 19 infants resident on the SCBU and the three infants from whom the organism was recovered, were reswabbed (initial screen). All infants shown to be carriers were isolated and nursed as a cohort on one of the post-natal wards following discharge from the SCBU.

After initial screening results were known, repeat swabs from all 19 infants on the SCBU were obtained. On this occasion (second screen) two sets of swabs were taken from each infant at the four screening sites. The first set from each infant was taken using dry sterile swabs which were then place in bijou bottles of Amies transport medium from the ward stock, according to standard practice. The second set were taken using a commercial pre-packed sterilized swab/transport system (Vipack). A third and final screen of 13 apparently colonized infants on the SCBU was performed 24 h later using the commercial system.

Investigations

Environmental

Extensive environmental sampling on both the Delivery Suite and the SCBU was undertaken using dry swabs (Medical Wire & Equipment Co. Ltd.) which were directly plated onto blood agar. A total of 69 environmental samples from ventilation equipment, incubators, obstetric creams, wash bowls and surfaces were obtained. One hundred and fifteen bijou bottles containing Amies transport medium and obtained from the SCBU ward stock were also cultured.

In the laboratory an extensive search was undertaken for a potential source of the organism. The media sterilizer, dry media, and the preparation methodology for the Amies medium were examined in detail. Enquiries to the manufacturer supplying the sterilized plastic bijou bottles

(LIP Equipment and Service Ltd.) were made to exclude these as a possible source of contamination. One hundred and ninety-seven of these empty bottles were investigated by culture.

Microbiological

Surface swabs were taken from groin/rectum, umbilicus, ear and nose of infants by nursing staff using dry sterile swabs which were sent to the microbiology laboratory in Amies transport medium (Oxoid CM425). The latter was prepared under sterile conditions and then poured into sterile, gamma-irradiated plastic bijou bottles which had been obtained commercially. Swabs were initially cultured on quarter segments of blood agar plates, potential pathogens were identified and disc sensitivity testing was performed. Pseudomonas selective medium (Oxoid CM559) with cetrimide, fusidic acid, cephaloridine supplement (Oxoid SRW3) plus 10 μg gentamicin discs were used for the second and third screens. The isolates obtained were sent to the Identification Services Laboratory of the National Collection of Type Cultures at the Central Public Health Laboratory, Colindale for further identification and characterization.

Organism identification

Attempts were made to determine the identity of 19 isolates from 16 infants and of 13 isolates from bottles of Amies medium, by a range of up to 72 conventional biochemical tests and processing the results through the probability matrix of Holmes *et al.* (1986). This matrix includes detailed biochemical test data on 20 species of *Pseudomonas* isolated from clinical material (these entries were based on an examination of 1901 strains, in up to 83 tests each).

Results

Environmental

The organism was not isolated from any of the 69 environmental specimens examined from the Delivery Suite or from the SCBU. Of the laboratory specimens examined, the organism could not be cultured from any of the media preparation material or from any of the 197 plastic bijou bottles used for Amies transport medium (173 with bottle batch number 3776 from SCBU and 24 with batch number 4126 from the Delivery Suite). In addition, the organism could not be grown from any of the 150 swabs taken at the time of this 'outbreak' from patients elsewhere in the hospital.

Approximately 16% of the 115 bijou bottles containing transport medium (18/115), which had been obtained from the SCBU stock, grew the resistant organism. These bottles were all noted to be of a particular bottle batch number (Table I), but enquiries to the company failed to reveal a problem at source. Indeed, these bottles had a wide distribution locally in the hospital, but only the bottles obtained from the in-use SCBU stock contained the 'outbreak' organism.

Table I. *Investigation of Amies transport medium bijou bottles*

Description	Bottle batch number	Source	Total cultured	Number from which pseudomonad grown
Sterile empty bottles	3776 (*SCBU No.)	Laboratory	173	0
Sterile empty bottles	4126 (†D/S No.)	Laboratory	24	0
Amies filled bottles	3776 (SCBU No.)	Laboratory	150	0
Amies filled bottles	3776 (SCBU No.)	SCBU in-use stock	115	18

*Special Care Baby Unit; †Delivery Suite.

Microbiological

From the initial screen, none of the 66 infant/mother pairs from the Delivery Suite were found to carry the organism. Swabs from 13/19 infants on the SCBU yielded the outbreak organism from a variety of surface sites.

On the second screen, the 'outbreak' organism(s) was grown from 4/19 infants using the dry swab/Amies medium, but no isolation of the organism was obtained from any of the second set of swabs using the commercial system. On screening the SCBU infants for the third and final time using only the commercial system, the organism was not isolated from any infant (Table II).

Characterization of the outbreak organisms

On the probability matrix of Holmes *et al.* (1986) only two isolates could be identified, as *P. pickettii*, with identification scores $>0{\cdot}999$. The remaining 30 isolates failed to reach identification level and although no significance can therefore be attached to the identification scores, the most likely taxa suggested were *Pseudomonas* species, principally *P. acidovorans*, *P. pickettii*, *P. stutzeri* and *P. testosteroni*. There were, however, characters which

Table II. *Surface swabs from infants on SCBU*

	Number of isolates grown from	
	Dry swab and laboratory-derived Amies transport medium	Commercial system
Initial screen	13/19*	NT
Second screen	4/19	0/19
Final screen	NT	0/19

*Neonates 'colonized'/neonates sampled.
NT, Not tested.

excluded the 30 isolates from each of these species. Although different species were suggested as possible identifications for the various isolates, given the low identification scores it requires little heterogeneity in biochemical characters to change the species achieving the highest identification score. Thus the variety of *Pseudomonas* species suggested did not necessarily indicate that the remaining isolates belonged to different species. Indeed, examination of the biochemical data revealed relatively low heterogeneity, principally in the following characters: Hugh and Leifson O-F test, KCN tolerance, malonate utilization and production of acid from ethanol.

Discussion

This pseudo-outbreak of multi-resistant pseudomonads apparently colonizing neonates on the SCBU appears to have been caused by contamination of media used for transport of swabs. The organisms were grown from 16% of bijou bottles containing Amies transport medium which were stored on the SCBU in a stack of drawers under a sink. Although there was no evidence of leakage into the drawer, it is possible that splash into the drawer from the sink and draining area above occurred, allowing contamination of the outside of the bottles with subsequent random contamination of the Amies medium. A number of bijou bottles in the drawer were found without tops and to contain old, dry medium. The outbreak organisms were only grown from the SCBU infants when the locally prepared swab/transport system was used. When this supply of transport bottles was removed and replaced with commercial, pre-packed sterile swab/transport medium, the organisms could no longer be grown from surface swabs even from apparently previously colonized infants on the SCBU.

Although the 'outbreak' organisms were not looked for in the water supply this was clearly the most likely source of the contamination as almost all other possible sources were excluded. Indeed, organisms such as *P. pickettii* and the closely related *P. thomasii* (King *et al.*, 1979) are well recognized inhabitants of water (Hernandez & Rosenberg, 1987; Baird *et al.*, 1976). Whilst the 'outbreak' isolates were somewhat heterogeneous and belonged to at least two species this nevertheless correlates with water as the source of contamination where a mixed and continually changing population of microorganisms is present. Despite the biochemical heterogeneity, all the isolates shared the same pattern of antimicrobial susceptibility including resistance to aminoglycosides and this is why the 'outbreak' was originally thought due to a single organism. Strain heterogeneity appears to be a good marker for pseudo-outbreaks since other such outbreaks have been characterized not only by different species (Wilson *et al.*, 1981) but where typing of the organisms has been performed, different strains of the same species have been found (Cookson *et al.*, 1982).

Both the multiplicity of strains and the antibiotic resistance of the pseudomonads (Hernandez Duquino & Rosenberg, 1987) are consistent with water as the origin of this outbreak.

Water associated outbreaks of infection due to *P. pickettii* (McNeil *et al.*, 1985b; Verschraegen *et al.*, 1985) and *P. thomasii* (Dowsett, 1972; Phillips *et al.*, 1972) have been reported, sometimes with potentially serious consequences, including bacteraemia, urinary tract and wound infections, and colonization of the respiratory tract. Whilst the outcome of this investigation was satisfactory in that none of the infants became infected with the organisms, the cost of investigating such a pseudo-outbreak is considerable. In terms of patient care, it required a change in Unit antibiotic policy and the use of second-line, more expensive antibiotic agents until the source of the organisms had been ascertained. The Unit was closed temporarily to potential admissions and additional nursing time and effort were required.

In an already busy, over-extended laboratory, 1094 additional samples were examined and processed over a 5-day period. The laboratory cost of investigating this outbreak was high, estimated at £3000. Technical staff were called upon to work after hours, with no additional compensation. The costs of the Consultant Microbiologist, acting as the Infection Control Officer and the Infection Control Nurse have not been included in calculating the total cost of this 'outbreak' since under current practices it is clearly part of their responsibilities to deal with such problems (Barnass *et al.*, 1989). In the future, however, it is unclear who will take on the financial responsibility for such an investigation, including the *pro rata* input of the Infection Control Team who will, presumably have to be paid for their services once clinical budgeting is introduced.

This financial problem is cogently raised by this 'outbreak' as when clinical outbreaks occur, 'blame' may be difficult to ascribe. Here, however, it was a failure of simple housekeeping on the SCBU which was responsible for this pseudo-outbreak and its subsequent investigation. Whilst hospital administrations may in the future have to accept the bill for clinical outbreaks as part of the general costs of running a hospital, pseudo-outbreaks of this kind may, perhaps, be billed in full to the unit involved. They will certainly have to be investigated and clarified since pseudo-outbreaks often can only be deemed as such after the event. Ultimately, the need for constant vigilance both in the preparation and storage of clinical products has been shown to be of paramount importance in the avoidance of such pseudo-outbreaks.

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Comparison of the Microbiological Quality of Water Coolers and That of Municipal Water Systems

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The microbiological quality of tap water and that of water from 50 water coolers located in residences and workplaces were comparatively studied. In addition, different factors that might influence the bacteriological contamination of water dispensers were examined. Aerobic and facultative anaerobic heterotrophic bacteria, total coliforms, and two indicators for fecal contamination (fecal coliforms and fecal streptococci) as well as three types of pathogenic bacteria (*Staphylococcus aureus*, *Pseudomonas aeruginosa*, and *Aeromonas* spp.) were enumerated. It was found that 36 and 28% of the water dispenser samples from the residences and the workplaces, respectively, were contaminated by at least one coliform or indicator bacterium and/or at least one pathogenic bacterium. The respective proportions of tap water samples contaminated in a similar fashion were 18 and 22%, much less than those observed for water coolers ($\chi_1^2 = 3.71$, $P = 0.05$). We were unable to discern the dominant factors responsible for the contamination of water coolers, but cleaning the water dispenser every 2 months seemed to limit the extent of contamination.

In North America, the market for bottled water is in full expansion. Its annual growth rate is estimated to be 25% (27). The consumption of spring water (mineral salts, <500 mg/liter) accounts for most of this increase. In the Canadian province of Québec, 900,000 persons out of a population of 6,800,000 now drink bottled water (18).

Spring water contains a natural microflora composed mainly of species of the genera *Achromobacter*, *Flavobacterium*, *Alcaligenes*, *Acinetobacter*, *Cytophaga*, *Moraxella*, and *Pseudomonas* (12, 24). Initial populations are small but can evolve rapidly during bottling and storage (26). In the absence of treatment (i.e., chlorination and ozonation), bacterial multiplication may occur for 1 to 3 weeks after bottling, and the bacterial count can reach 10^3 to 10^4 bacteria per ml at 37°C (10).

In addition to natural contamination, the product can also be altered before it reaches the consumer. Contamination can occur at any time during processing. In Wales, Hunter and Burge (11) found *Staphylococcus epidermidis* and *Staphylococcus humanis* in 6 of 52 bottles of water, which was attributed to poor hygiene.

In Canada, Warburton et al. (27) reviewed the results of tests of all bottled water samples collected by Health and Welfare Canada between 1981 and 1989 and concluded that 2 to 3% of the samples contained coliform bacteria. Furthermore, Sekla et al. (25) analyzed 60 bottles of water from retail stores and processing plants and found coagulase-positive *Staphylococcus aureus* in two samples, coliforms in four samples, and *Enterococcus* spp. in one sample.

The aim of these studies was to determine if contamination had occurred in the time between collection of the water at the spring and its processing for commercial use. Such studies, however, do not account for consumer behavior regarding the preservation of the product.

In the province of Québec, 30 to 50% of all complaints about bottled water received by the Ministry of Environment were related to water coolers (18). There are some 50,000 dispensers in public places and in workplaces all over the province (18), and there are possibly as many more in private residences. To our knowledge, almost no data on the bacteriological quality of the water in these dispensers exist. Moreover, the lack of hygiene standards adds to the uncertainty surrounding health risks that could be related to the use of water coolers.

The purposes of our study were to evaluate the microbiological quality of spring water dispensed by water coolers in residences and workplaces in the Québec City region; compare the microbiological quality of this water with that of municipal tap water; and evaluate the importance of handling factors, such as cleanliness and storage time, to the microbiological quality of water coolers.

MATERIALS AND METHODS

Between 1 June and 1 August 1992, we selected and visited residences and workplaces located in two municipalities of the Québec City region chosen on the basis of their similar sizes, i.e., they had populations of around 60,000 inhabitants, and the fact that they are served by different municipal water systems. City 1 uses raw water of low quality which undergoes treatment, whereas city 2 obtains its water from a less contaminated source, and the water is only filtered and disinfected. Residences and workplaces were randomly selected from the phone book and from the list of enterprises of the Commission on Health and Security at the Work Place of the Province of Québec. A phone call was made to verify that a water cooler was in use. To be included in the study, owners of water dispensers had to have water supplied by a recognized company. We then selected 50 residences and 50 workplaces divided equally between the two municipalities.

Each site was inspected, and the results were documented. A questionnaire regarding the age of the water dispenser, the amount of water consumed, the frequency and method of cleaning, and related matters was filled out. Samples were taken from the water cooler and from the most-often-used

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faucet. To make sure that the samples were representative of the water consumed, we did not flush before sampling, and there was no attempt to sterilize the outer surfaces of the faucets. In conjunction, water samples were collected for bacterial analysis from 20 18-liter bottles of spring water (representing the five most important bottling companies in the region) before installation of the bottles on water dispensers.

The samples were collected in sterile 1-liter plastic bottles containing 5 ml of a sterile sodium thiosulfate solution (1%). They were kept at 4°C and analyzed within 24 h in a laboratory accredited by the Québec Ministry of Environment. Since infectious diseases could be spread through drinking water mainly by contamination with material of fecal origin (26), we quantified three indicators of fecal contamination (total coliforms [TC], fecal coliforms [FC], and fecal streptococci [FS]). We also assayed the water for aerobic and facultative anaerobic heterotrophic bacteria, an indicator frequently used to verify the microbiological quality of bottled water (26, 27). Finally, we quantified microorganisms known to be opportunistic human pathogens (*Pseudomonas aeruginosa*, *S. aureus*, and *Aeromonas* spp.), recognizing the concern of the World Health Organization about *P. aeruginosa* in bottled water (20) and the ubiquitous presence of *S. aureus* (3, 14) and *Aeromonas* spp. (19) in the water environment.

The heterotrophic plate count (HPC) was determined by the pour plate method at 35°C for 48 h in accordance with the technique described by the American Public Health Association (1). TC, FC, FS, *S. aureus*, and *P. aeruginosa* were quantified by membrane filtration (1). *Aeromonas* spp. were filtered (0.45-μm pore size) from 1- and 100-ml water dispenser samples and 100-ml tap water samples. Each membrane with filtered cells was placed directly on phenol red agar supplemented with 1% soluble starch and 10 μg of ampicillin per ml as suggested by Palumbo et al. (21).

The results were divided into two classes according to their degrees of contamination. A sample of 100 ml was put in class A if it was contaminated by either one of the pathogens or one of the following indicators: TC, FC, or FS. Class B was similar to class A except that the number of TC had to be 10 or more, the level considered unacceptable by the Québec Ministry of Environment for drinking water derived from a municipal water system (17).

The data were sorted according to their origin (residence or workplace). Tap water and the water dispensers were compared by using the proportions of contaminated samples in classes A and B. The various factors that could influence the quality of the water dispensed by water coolers were also examined. Finally, residences and workplaces were compared for each contamination class. To verify the statistical significance of all these comparisons, we used the chi-square test except when the conditions for that test were not met. In that case, we used Fisher's bilateral test (4).

RESULTS

The participation rates were 92% for the residences and 90% for the workplaces. The results of microbiological analyses performed on samples from the water coolers and tap water of each of the residences and workplaces appear in Table 1. Water dispensers and faucets are compared for each class of contamination in Table 2. The results of the HPCs for the water coolers, tap water, and the 20 bottle samples are presented in Table 3. It should be noted that none of these bottles was contaminated by either TC, FC, FS, or pathogenic bacteria.

TABLE 1. Proportions of contaminated water coolers and faucets in residences and workplaces

Indicator bacterium or pathogen and class of contamination	% Contaminated water coolers in:		% Contaminated faucets in:	
	Residences	Workplaces	Residences	Workplaces
TC	30	14	18	4
FC	8	0	4	8
FS	2	0	2	0
S. aureus	8	6	0	10
P. aeruginosa	0	0	0	0
Aeromonas spp.	8	14	4	8
A[a]	36	28	18	22
B[b]	30	22	8	22
B1[c]	62	62	2	12
B2[d]	44	16	0	2

[a] ≥1 FC and/or ≥1 FS and/or ≥1 TC and/or ≥1 pathogenic bacterium per 100 ml.
[b] ≥1 FC and/or ≥1 FS and/or ≥10 TC and/or ≥1 pathogenic bacterium per 100 ml.
[c] ≥1,000 aerobic and anaerobic heterotrophic bacteria per ml.
[d] ≥10,000 aerobic and anaerobic heterotrophic bacteria per ml.

We also compared the proportions of contaminated water dispensers in the workplaces and in the residences. For our two classes of contamination, there was no statistical difference in the proportion of water coolers contaminated (class A, $\chi_1^2 = 0.74$, $P = 0.39$; class B, $\chi_1^2 = 0.83$, $P = 0.36$). As for tap water, the proportion of class B samples was higher for the workplaces than for the residences ($\chi_1^2 = 3.84$, $P = 0.05$), while the proportions of class A samples were similar for the two locations ($\chi_1^2 = 0.25$, $P = 0.62$).

A second sampling of the contaminated faucets of residences and workplaces following a tap water flushing of 5 min showed only one of the tap water samples (41 TC per 100 ml) to be contaminated.

Various factors, such as socioeconomic status and the presence of very young children in the case of residences and type of enterprise (service or industrial) as well as number of employees in the case of workplaces, were considered in order to determine if they were related to the water coolers contaminated at the class A or the class B level. Moreover, we documented the maximum storage time of bottles, the duration of use of a bottle after installation on the dispenser, the frequency of cleaning of the water cooler, the interval between the last cleaning and sampling, and the type of cleaning. Statistically, for the two classes of contamination, no factors

TABLE 2. Comparison of the proportions of contaminated water coolers and faucets

Class of contamination	Contamination in residences			Contamination in workplaces			Total		
	% of C[a]	% of F[b]	P[c]	% of C	% of F	P	% of C	% of F	P
A[d]	36	18	0.04	28	22	0.49	32	20	0.05
B[e]	30	8	0.005	22	22	1.00	26	15	0.05

[a] % of C, percentage of water coolers that were contaminated.
[b] % of F, percentage of faucets that were contaminated.
[c] Significance level (χ_1^2 test).
[d] ≥1 FC and/or ≥1 FS and/or ≥1 TC and/or ≥1 pathogenic bacterium per 100 ml.
[e] ≥1 FC and/or ≥1 FS and/or ≥10 TC and/or ≥1 pathogenic bacterium per 100 ml.

TABLE 3. Distribution of the HPCs for the samples

HPC (no. of bacteria/ml)	% of water coolers in:		% of faucets in:		% of new bottles
	Residences	Workplaces	Residences	Workplaces	
0–10	10	8	50	64	45
11–100	8	2	30	18	15
101–1,000	20	28	18	12	35
1,001–10,000	20	46	2	4	5
10,001–100,000	32	12	0	2	0
>100,000	10	4	0	0	0
Range[a]	0–270,000	0–260,000	0–2,400	0–12,000	0–6,000
Median[a]	7,000	1,990	12	1.5	14

[a] Number of bacteria per ml.

stood out at a significance level of 0.05 (residences, $P \geq 0.25$ for all the factors; workplaces, $P \geq 0.16$ for all the factors). This may be due in part to the small sample size.

The quality and frequency of the cleanings were judged against the recommendations made by the Québec Bottlers Association and the Québec Ministry of Environment, which stipulate that the reservoir should be scrubbed with a commercial solution of sodium hypochlorite (6%) and rinsed every 2 months. Unfortunately, at the expense of the sample size, we had to stratify our data further to look for the influence of the frequency of cleanings when cleaning was done as recommended. In the residences, only one water dispenser of the six which were cleaned in the manner and at the interval recommended was contaminated at the class A level, and none were contaminated at the class B level. In contrast, 7 of the 12 water dispensers which were cleaned in the manner recommended, but not frequently enough, were contaminated at both levels. A comparison of these two sets of conditions for the cleaning of coolers using a Fisher test yielded probabilities of 0.15 for class A and 0.04 for class B, indicating that despite the very small sample size a benefit was derived from regular cleaning. On the other hand, there was no difference between the dispensers that were not cleaned in the manner recommended regardless of the frequency of cleaning (class A, $P = 1.0$; class B, $P = 0.61$).

In the workplaces, when cleaning was in agreement with the recommendations, 2 of 12 water dispensers were contaminated at the class A level in contrast with 1 of 12 at the class B level. When cleaning was not done in the manner recommended, the proportions were 6 of 19 and 5 of 19, respectively (class A, $P = 0.43$; class B, $P = 0.36$). Cleaning the water coolers as recommended seemed to influence the contamination, but the difference was not statistically significant. On the other hand, even when the cleaning was done in the manner recommended, the contamination of water dispensers was not affected by the cleaning frequency. Three water coolers of nine cleaned at the interval recommended were contaminated at the class A level, and two of nine were contaminated at the class B level. Similarly, two and three of the nine water coolers cleaned in the manner recommended, but not frequently enough, were contaminated at the A and B levels, respectively. A comparison of these two proportions using a Fisher test yielded a probability of 1.0. It is possible that the higher level of water consumption in the workplaces limited the risk of contamination and the importance of regularly cleaning the dispenser. The average consumption of bottles was 3.92 bottles per month in the residences as opposed to 10.43 bottles per month in the workplaces.

DISCUSSION

As expected, none of the 20 unopened bottles of spring water were contaminated by pathogenic or indicator bacteria, although small quantities of heterotrophs were recovered (Table 3). These small quantities of heterotrophs are in sharp contrast to the higher quantities reported in the literature, mainly from Europe (10, 26), and can be attributed to disinfecting processes (ozonation or UV irradiation) used by the manufacturers in Canada, which reduce bacterial numbers to low levels.

Interestingly, we found that the HPC in water coolers were much higher than those in the faucets (Table 3). Moreover, the distribution of HPC in the 20 new bottles was very similar to the result obtained with the faucet samples, indicating that the use of water coolers can promote the multiplication of heterotrophic bacteria.

In the residences, the water extracted from water coolers was markedly more contaminated than the first streams of tap water (Table 2). In the workplaces, however, the two sources were equally contaminated. The fact that in workplaces faucets are not often used and are not kept clean may be an explanation. The follow-up on the 11 contaminated faucets revealed that only 1 of them still showed signs of contamination after 5 min of flushing, thus pointing to the plumbing of the buildings rather than the municipal water system as the source of contamination.

To our knowledge, only one other study of the bacteriological quality of the water dispensed by water coolers has been done in North America. On the campus of Northeastern University, Kozlowski et al. (13) sampled 10 water coolers once a week over a period of 2 months to obtain HPCs. They found concentrations ranging from 2×10^3 to 10^6 CFU/ml. On the basis of these results, the authors insisted on the necessity of cleaning water dispensers regularly.

As was the case in the above-mentioned study, we also obtained an HPC of at least 10^3 CFU/ml for 62% of the water dispensers we sampled. Generally, this indicator is used to establish the effectiveness of the treatment methods used in municipalities. The United States Environmental Protection Agency estimates that 5×10^2 CFU/ml is the upper acceptable limit on the basis of the potential of high HPCs to interfere with detection of coliform bacteria (9).

Caution is needed when interpreting the public health significance of HPCs for bottled water. As mentioned previously, bottled water is already contaminated with a natural microflora essentially nonpathogenic for humans (7, 15). These bacteria may be potentially pathogenic to more vulnerable

individuals, however, such as infants and immunosuppressed patients (26). A recent study found a relationship between HPCs in water treated with reverse-osmosis filtration units and the incidence of gastrointestinal problems (22).

The Québec Ministry of Environment stipulates that spring water should be bacteriologically pure and free of contaminants (23). Obviously, this regulation, like all qualitative norms, is not precise. Health and Welfare Canada, however, in its Food and Drug Act, specifies that mineral and spring water must not contain coliforms (16). The World Health Organization states that bottled water must be totally free of coliforms and *P. aeruginosa*; the latter requirement was included because of the vulnerability of children and the elderly to this organism (20). In Europe, the Council of the European Community states that natural mineral water (including spring waters low in minerals) must not contain any parasite, pathogenic microorganism, *Escherichia coli* or other coliform, fecal streptococcus, sulfate-reducing anaerobic bacterium, or *P. aeruginosa*, and it stipulates that at 12 h after bottling the total number of bacteria must not exceed 100 CFU/ml (6). In the United States, only one 100-ml portion in the sampling procedure is permitted to contain four coliforms or more, but the arithmetic mean of the analytical units must not exceed one coliform per 100 ml (5). Whereas microbiological standards exist for bottled water, the same product once installed on a dispenser is generally not regulated and is rarely controlled.

Concerning our study, the proportion of water dispensers contaminated at the A and B levels is disturbing. This contamination is not related to the product itself but rather to the use of a water cooler as the dispenser. Unfortunately, we were unable to discern the dominant factors responsible for this contamination, and this constitutes a great limitation in the interpretation of the data. We must, however, look beyond the statistics. Even if certain relationships were not statistically significant, it is still revealing to look at the influence of cleaning on contamination. Regular cleanings as recommended should probably limit contamination.

As for the participants in our study, only 44% of those possessing water coolers in residences and 36% of those possessing water coolers in workplaces had been informed of the necessity of cleaning the equipment, let alone how to do it. Thus, a variety of products had been used, from baking soda to vinegar and dishwashing liquid, instead of sodium hypochlorite as recommended.

On the basis of results obtained with a sampling of initial streams of water, the bacteriological quality of municipal tap water is superior to the quality of the water dispensed by water coolers in residential sites. In part because of more instances of contaminated tap water in the survey of workplaces, there was no statistical difference in contamination between the two sources of water (Table 2). However, we demonstrated in a follow-up sampling of the contaminated faucets that tap water contamination may be derived from the plumbing of the buildings. As with lead contamination (2), it is probable that the longer the water has been standing in the tap, the greater the potential there is for bacteria to accumulate if, of course, there is a source of bacteria in the building's plumbing system. It has been proposed that tap water should be permitted to flow until it is at a constant cold temperature before use (2).

Our results indicate that we should be cognizant of the quality of the water dispensed from water coolers. Although it is possible to manufacture water dispensers which are less likely to become contaminated (8), vendors and suppliers of water dispensers should impress on their clients the need for regular maintenance of the equipment.

In addition, studies determining the health impact of drinking water from dispensers should be undertaken, and public health authorities should be made aware of water dispensers as a possible source of contamination when investigating food- or water-related epidemics.

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A Case of Legionnaires' Disease Caused by Aspiration of Ice Water

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ABSTRACT. The authors discuss the case of a 79-year-old patient who suffered from a swallowing disorder and developed Legionnaires' disease 2 days after her dismissal from an orthopedics ward, where she had recovered from hip surgery. To determine the source of the Legionnaires' disease, the authors performed an environmental investigation, which included a national, standardized questionnaire and a microbiological investigation of suspected sources. The investigation revealed ice from an ice-making machine in the hospital as the most probable source of the infection through aspiration, even though the hospital had rigorously adhered to strict assessment and decontamination schedules. The infectious serogroup was one that was not common to the area. From the data available, the authors inferred that a dose of 1–2000 colony-forming units might have caused Legionnaires' disease in this patient.

KEY WORDS: aspiration, disease-causing dose, ice cubes, ice-making machine, Legionnaires' disease

The modes of transmission accountable for *Legionella pneumophila* infections can be divided into the inhalation of aerosols originating from an environmental source or the aspiration of potable water contaminated with *Legionella*, and both forms of transmission occur in hospital-associated Legionnaires' disease. Several authors[1–5] have described the transmission of *Legionella* by aerosol-producing respiratory devices and equipment filled with tap water. Aerosolization that resulted from having an air-conditioning cooling tower close to the air-intake vent for the patient rooms was reported as the route of transmission for a hospital outbreak in Memphis, TN.[6] Microaspiration in the presence of nasogastric tubes has been implicated in nosocomial infection,[7] and aspiration of contaminated water, especially in patients who have undergone oral surgery resulting in swallowing disorders, is also a possible mode of infection in the hospital.[8] Furthermore, contamination of the potable water in hospitals is frequently found.[9] If this water is used for ice-making machines, then the ice cubes may function as a reservoir of *L. pneumophila*.[10] The microbiology of ice-making machines and their possible implication in nosocomial infection have been studied before.[11] However, nosocomial Legionnaires' disease that could be traced to the use of ice cubes from an ice-making machine has been reported, to our knowledge, only twice.[12,13] Neither of these reports were supported by genotyping results.

In this study, we present a case of Legionnaires' disease, followed by an environmental investigation using a standardized questionnaire. We investigated all the possible sources of infection found through this questionnaire for the presence of *Legionella*. On the basis of the results of the environmental investigation for this solitary case of Legionnaires' disease, we estimated the minimal infectious dose that could lead to a case of full-blown *Legionella* pneumonia.

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Case

In February of 2002, a 79-year-old woman was admitted to a hospital in The Netherlands to undergo elective surgery for a total hip prosthesis. In 1987, she had been diagnosed with a carcinoma of the larynx that was treated with resection and radiotherapy. After the reconstructive surgery later that year, she suffered from a dry mouth, resulting from a lack of sputum production, and a swallowing problem. She used a nebulizer that was continuously refilled with cold tap water to compensate for the salivation problem. The patient recovered without complications from the total hip prosthesis in 2002 and was dismissed after 12 days of hospital stay. However, 36 hours after her dismissal, she developed high fever with a temperature of 40°C, progressive dyspnea, nausea, vomiting, headaches, and a productive cough with purulent sputum. She was readmitted to the hospital intensive care unit in poor condition 3 days after her initial dismissal. A urinary antigen test for *Legionella* (Binax NOW, Portland, ME) was positive; appropriate antibiotic therapy was started. After 3 days the sputum culture became positive for *L. pneumophila* serogroup 1. Despite maximal supportive therapy, the patient did not recover and eventually died 37 days after admission to the intensive care unit from a pulmonary superinfection with *Staphylococcus aureus*. Postmortem *Legionella* could not be cultured.

METHODS

Source Investigation

Immediately after the diagnosis became clear, we started an investigation to locate possible sources that could have exposed the patient to *Legionella* spp by using a national standardized questionnaire as supplied by the National Coordinator for Infectious Disease Control in Utrecht, The Netherlands. We presumed an incubation period of 2–10 days. After compiling an inventory of all possible sources, we subsequently sampled and cultured these sources.

Source Sampling

From tap water supplies, we collected separate hot- and cold-water samples up to 500 ml, and we measured the temperature of each sample. We used swabs to collect biofilm. We resuspended these swabs in 1 ml of sterile water before transporting them to the laboratory. We collected ice cubes and transported them to the laboratory in frozen condition. From other possible sources, we collected stagnant water. If biofilm was present, we took additional swabs.

Sample Processing

We concentrated water samples by filtering them through 0.20-µm membranes, and we resuspended the filtered residues in 1 ml of sterile water. We weighed and thawed ice cubes before we filtered and resuspended them. We made a 10- and 100-fold dilution from the concentrated water samples and the resuspended swab samples. We cultured a total of 100 µl of the concentrated and diluted water samples and swab suspensions. In the case of bacterial overgrowth, we repeated the procedure after heating the samples for 30 minutes at 50°C. If inhibition by other bacteria was still suspected, then we examined the diluted samples. We also used the dilutions to quantify the positive samples. We performed cultures on buffered charcoal yeast extract agar with α-ketoglutarate (BCYE-α) with dyes and with and without the antibiotics polymyxin B, anisomysin, and vancomycin (*Legionella* MWY Selective Supplement SR 110, 111, and 118, Oxoid Ltd., Hampshire, England). We incubated plates for a maximum of 10 days at 35°C with increased humidity. We examined cultures microscopically on a daily basis. We performed the determination and confirmation of suspected colonies by using biochemical tests (oxidase, catalase, and ß-lactamase). We performed serotyping by using latex agglutination for *L. pneumophila* serogroups 1 and 2–14 (Oxoid Ltd.) and specific antibodies for serogroups 2 to 6 (Denka Seiken Co. Ltd., Tokyo, Japan).

Fingerprinting

Amplified fragment length polymorphism fingerprinting of *Legionella* isolates was performed by the National Institute of Public Health and the Environment in Bilthoven, The Netherlands, according to the protocol of the European Working Group for *Legionella* Infections.[14]

RESULTS

Source Investigation

The investigative questionnaires revealed two locations where the patient had stayed during the incubation period: the orthopedic ward in the hospital where the patient had recovered from her total hip surgery, and her home, where she had been for 3 days before being readmitted to the hospital. On the orthopedic ward, the questionnaire identified several faucets and a shower that either were used for the patient or were located in her vicinity. The patient's nebulizer, which she had used during her stay on the ward, was also considered as a possible source. The patient had the habit of drinking a glass of ice water every morning. The ice cubes were supplied by a central ice-making machine. In addition, the questionnaires revealed a faucet in the kitchen and the bathroom of the patient's home as possible sources.

Sample Processing

All samples collected from the potable water sources on the orthopedic ward and the nebulizer were negative for *Legionella* spp, as were the samples from the water sources at the patient's home. However, all water samples, swabs, and ice cubes taken from the ice-making machine were positive for *L. pneumophila* serogroup 1. We counted colony-forming units (CFUs) as between 1 and 250 per ice cube. We found an average CFU count of 6626/l (range = 2967/l–15,191/l).

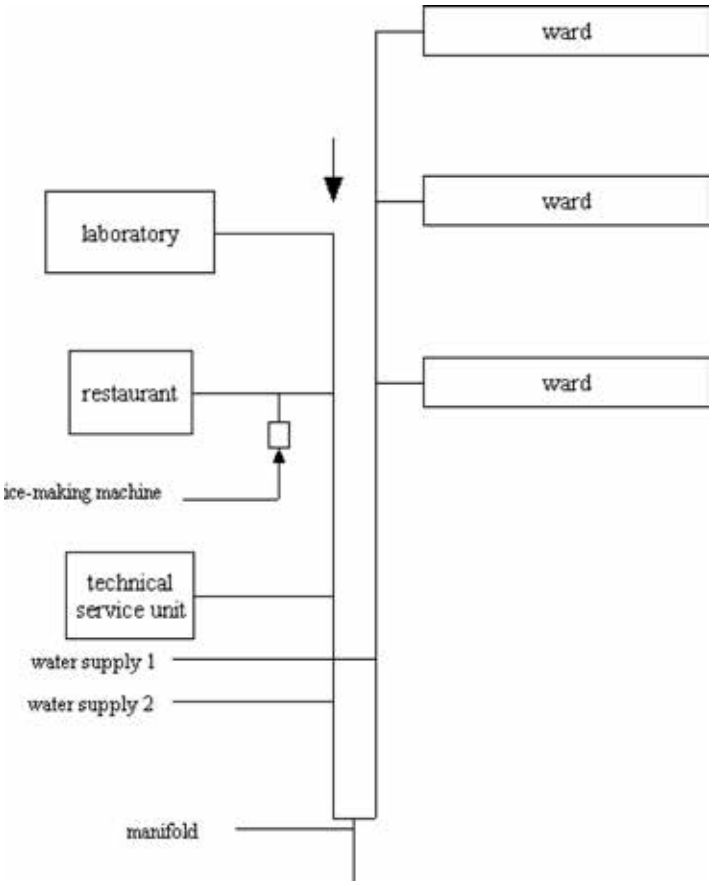

Fig. 1. Drawing of the hospital water distribution system. Water supply 1 supplies the wards. Water supply 2 supplies the laboratory, restaurant, technical service unit, and the ice-making machine. Arrows indicate areas of pipeline colonized by *Legionella pneumophila*.

A more extensive examination of the ice-making machine revealed an air temperature as high as 35°C behind the machine, causing the connection between the cold-water supply and the machine to become warm. We performed an additional investigation of the pipeline supplying the ice-making machine. We isolated *L. pneumophila* serogroup 1 from various locations in this pipeline. We counted CFUs up to 104,000/l. Besides the ice-making machine, this pipeline supplied a laboratory, a technical service unit, and the hospital restaurant (Figure 1). We called this pipeline *water supply 2*. *Water supply 1* supplied the orthopedics ward. The pipeline of *water supply 2* seemed to be colonized even at its origin because two manifolds in the boiler room distributing water to this and other water pipelines were positive for *L. pneumophila* serogroup 1 with counts of up to 1000 CFU/l.

Exposure Dose Extrapolation

We were interested in attempting to extrapolate the probable exposure dose of the patient to *L. pneumophila*. Because we did not know the exact number of ice cubes and volume of the glass of ice water the patient consumed every morning, we based our calculation of the disease-causing dose on an average glass containing a volume of 200 ml of water and including 2 to 4 thawed ice cubes, with each ice cube bearing 1 to 250 CFUs of *L. pneumophila*. These assumptions led to a count of 2 to 1000 CFUs of *Legionella* bacteria present in the glass of ice water. Therefore, the patient must have consumed water containing between 0.01 CFU/ml (meaning a chance of 1 in 100 that 1 ml of water contained 1 CFU) to 5 CFU/ml. Because the patient drank a glass of ice water every morning, the cumulative dose she was exposed to during her 12-day stay at the hospital was 0.12–60 CFUs/ml. The volume of contaminated water that actually entered her lungs when she was aspirating can be expected to be more in the range of one to several microliters instead of milliliter amounts for each aspiration event.

Fingerprinting

Amplified fragment length polymorphism fingerprinting performed on DNA extracted from the *L. pneumophila*

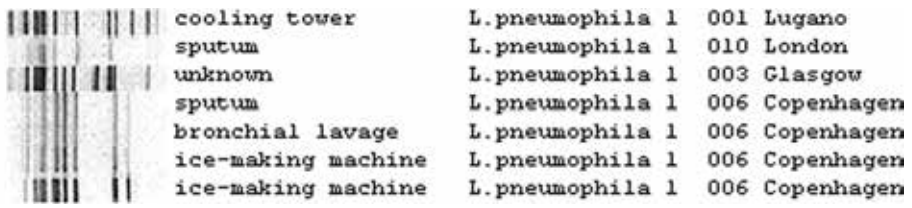

Fig. 2. Amplified fragment length polymorphism fingerprints of 7 *Legionella pneumophila* serogroup 1 isolates. Fingerprints 1–3 are of unrelated *L. pneumophila* serogroup 1 isolates from a cooling tower, sputum, and an unknown source for comparison. Fingerprints 4 and 5 are from *L. pneumophila* serogroup 1 isolates of the case patient. Fingerprints 6 and 7 are from *L. pneumophila* serogroup 1 isolates from the ice-making machine. Fingerprints 4–7 have been identified as 006 Copenhagen according to the European Working Group for *Legionella* Infections.

serogroup 1 strains of the ice-making machine and from the patient's sputum showed that the isolates were indistinguishable (Figure 2). The strains were both identified as 006 Copenhagen, according to the database supplied by the European Working Group for *Legionella* Infections.

Note that the source investigation found that regular *Legionella* control measures were maintained in the hospital for all patient-related water circuits and for a cooling tower. Results of these control measures were registered in a log. In the time period during which the patient was admitted to the hospital, no problems with control of *Legionella* were reported; the case reported here was the sole incidence of infection. The investigation also revealed that no *Legionella* control measures existed for the ice-making machine because it belonged to a pipeline circuit that did not supply any patient-related water sources or departments. The ice from the ice-making machine was originally not intended for consumption, but for tasks such as the cooling of fractured limbs of patients.

COMMENT

An important finding is that the DNA fingerprint 006 Copenhagen of *L. pneumophila* serogroup 1 was found neither in the hospital water supply nor in any water sample originating from environmental sources in the region in the period from 2000 to 2005. In addition, the patient, who had the only case of Legionnaires' disease to occur even though other patients were exposed, had a swallowing problem and a tendency to aspirate fluids. We also want to emphasize that potable water in hospitals in The Netherlands is checked regularly for *Legionella* and that rigorous decontamination schedules to eradicate *Legionella* colonization are performed; the hospital in this study kept to these rigorous schedules. Our final finding of importance is the potentially low CFU dose that may have resulted in the infection.

Graman et al[13] described a case of nosocomial legionellosis in an intensive care unit and also traced the source to an ice-making machine. The patient had a poor gag reflex and was known to aspirate, similar to the patient in the current report. Molecular typing of involved strains, however, was not mentioned in that report. What our patient had in common with this patient was the swallowing disorder that she developed after her larynx operation. Our case is the first case, to our knowledge, in which the aspiration of water contaminated with *Legionella* by ice cubes is linked to the source of the infection by molecular fingerprinting. Aspiration itself is widely acknowledged as a route of transmission for Legionnaires' disease.[7,8]

Graman et al[13] also mentioned the heating of cold-water lines in the ice-making machine interior by the compressor and condenser, which might aid the *Legionella* bacteria in multiplying. Researchers in two other studies with ice-making machines reached similar conclusions.[10,11] Although we did not look at the internal heating of the water, it may well be that the same situation existed in our ice-making machine. Furthermore, detectable amounts of *L. pneumophila* serogroup 1 were found in the pipeline supplying the machine. This colonization obviously aggravated the *Legionella* contamination. We conclude that stagnation in the water supply line, heating of the supplying water by the ventilator of the ice-making machine, internal heating of the water in the machine, and a supplying pipeline colonized with *Legionella* can be involved in producing ice cubes with viable *Legionella* bacteria incorporated in the ice. Regulations for the construction, installation, and maintenance of ice-making machines and the control of the hospital's potable water supply are mandatory. A focus on this is especially important in light of the fact that the hospital in this study, like all hospitals in The Netherlands, rigorously adhered to regular checks for *Legionella* and to strict decontamination schedules; in this case, the ice machine was missed because it was not initially intended as a source of potable water products.

The bacterial inoculum to cause Legionnaires' disease is unknown, whether transmitted through the aspiration of water or the inhalation of aerosols.[15] The estimates of the infectious dose from animal studies suggest that a high inoculum is necessary to cause disease, although the very low presence of *Legionella* in the air contrasts with this finding.[16] We attempted to infer the disease-causing dose in the presented case by

calculating the number of viable *Legionella* bacteria in the ice cubes. This evidence suggests that the patient must have developed Legionnaires' disease from an inoculation as low as 1 to several CFUs. This calculation is based on the assumption that there was perfect recovery efficiency and that sample diversity was between 1 and maximally 250 CFUs. Even if the disease-causing ice cubes contained many times that number of CFUs, the dose is still very low.

Such a low disease-causing dose could explain the infectious dose paradox described by O'Brien and Bhopal.[16] They mention that even heavily colonized water sources emit limited amounts of *Legionella* bacteria, so the chance of inhalation of an aerosolized bacterium even in the direct vicinity of a source is small. However, the chance of developing disease after inhalation seems substantial. This could explain the low attack rate seen in *Legionella* epidemics, such as the one in The Netherlands in 1999, which was caused by two whirlpool spas, with an attack rate of only 0.23%.[17] In an epidemic of *L. pneumophila* in Murcia in Spain caused by a cooling tower of a city hospital, 360,000 inhabitants of the city were potentially exposed. Only between 636 and 696 inhabitants acquired the disease, giving an attack rate of 0.2%.[18] We suggest that the substantial chance of developing the disease after inhalation may also explain the fact that, even though other patients were exposed to ice from this contaminated source, the only person to become infected was this patient with a history of swallowing problems and aspiration of fluids.

Thus, here we have identified an interesting confluence of a patient with a tendency for aspiration, a hidden source of *Legionella* contamination, an unusual strain of *L. pneumophila*, and an apparently low exposure dose. We strongly suggest that hospitals review their assessment and decontamination schedules to ensure that all sources of potable water are included, including sources that may originally not have been intended for human ingestion.

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Short report

Nosocomial outbreak of *Pseudomonas aeruginosa* associated with a drinking water fountain

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SUMMARY

Over a four-month period, ten patients were suspected of having acquired nosocomial infection to *P. aeruginosa* in the ear, nose, and throat department. Environmental and clinical isolates were compared. Only water from a drinking water fountain was contaminated by *P. aeruginosa*. This isolate and those of three patients had indistinguishable random amplified polymorphic DNA profiles. These patients had serious oncology diseases. The drinking water fountain was used for their alimentation by percutaneous endoscopic gastrostomy and was the origin of the outbreak. Another type of drinking fountain with a terminal ultraviolet treatment was installed, following which no new infections linked to drinking water were identified.

Introduction

Pseudomonas aeruginosa is a nosocomial pathogen that is particularly associated with moist environments.[1,2] In addition, *P. aeruginosa* is intrinsically resistant to many widely used antibiotics, and acquired multidrug resistance is also becoming widespread. Among a range of infections caused by this opportunistic pathogen, respiratory tract infections are the most frequent; pseudomonas pneumonia has been associated with mortality rates of up to 14%.[3]

Pseudomonas aeruginosa forms biofilms that allow persistence of micro-organisms in water systems for long periods, and helps to explain why colonization rates of hospital water systems of up to 82% have been reported.[4] Outbreaks of infection with multidrug-resistant *P. aeruginosa* may be associated with contaminated hospital waste-water systems.[5] Outbreaks caused by *P. aeruginosa* from potable water systems have already been described.[6] However, this article reports for the first time, to our knowledge, an outbreak of *P. aeruginosa* nosocomial infections due to contamination of a drinking water fountain.

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Methods

Investigation

From January to April 2013, a cluster of cases made us suspect a nosocomial outbreak of *P. aeruginosa* infections in the ear, nose, and throat (ENT) department in our hospital. Consequently, investigations were carried out on patients from whom *P. aeruginosa* had been isolated in clinical samples during this time period. We evaluated whether these patients had nosocomial infections due to *P. aeruginosa* and whether there was an epidemiological link. A nosocomial infection was defined as an infection that occurred during the care of a patient that had not been present at the admission of the patient to the ENT department. No active surveillance in the form of admission screening was undertaken. Surgical site infections were included. Water samples were collected to check whether the hospital network was contaminated by the bacterium; points of exposure to patients as showers, patients' room sinks, treatment room sinks, and a drinking water fountain were investigated. Molecular typing was performed to evaluate the genetic relatedness of different *P. aeruginosa* isolates.

Water sampling

Water sampling was undertaken after each new suspected case in the ENT department. In each case, 1 L of post-flush water was aseptically sampled in a sterile bottle with 20 mg of sodium thiosulphate (Dutscher, Brumath, France). One sample of 100 mL and two samples of 250 mL were aseptically filtered on 0.45 μm threshold cellulose acetate membranes (Millipore, Molsheim, France). These membranes were deposited on plate count agar without glucose (bioMérieux, Craponne, France) and incubated aerobically at 36°C for 48 h before reading. If *P. aeruginosa* was isolated on agar, the strain was subcultured to perform an antibiogram and all the strains were kept for molecular typing.

Molecular typing

Bacterial isolates from environmental and clinical samples with indistinguishable antibiograms were compared using a random amplified polymorphism DNA (RAPD) technique with three primers: BK4, AP12H, and VL1.[7,8] Nine isolates (six from patients, one from the fountain and two clinical control strains of *P. aeruginosa*) were tested. Polymerase Chain Reaction Master Mix was used (Promega, Charbonnieres, France) and migration was performed by electrophoresis on agarose gel.

Results

Ten patients presented with infection with *P. aeruginosa*. Six developed surgical site infections during their inpatient stay, all of whom had head and neck cancers. Four patients were found to have *P. aeruginosa* on readmission, with isolates obtained from the ear (one case), gastrointestinal tract (one case), cochlear implant site (one case) and a corneal abscess (ophthalmologic diseases are managed in the same department).

Thirty-one water samples were obtained to investigate the presence of *P. aeruginosa* in the hospital network. *P. aeruginosa* was only isolated in the drinking water fountain at high concentration (>100 cfu/100 mL). *P. aeruginosa* was not isolated from swabs of water pitchers. Antibiogram profiles of the environmental isolate and three clinical isolates were identical. The RAPD analysis showed that these isolates were genetically linked with indistinguishable fingerprints (Figure 1).

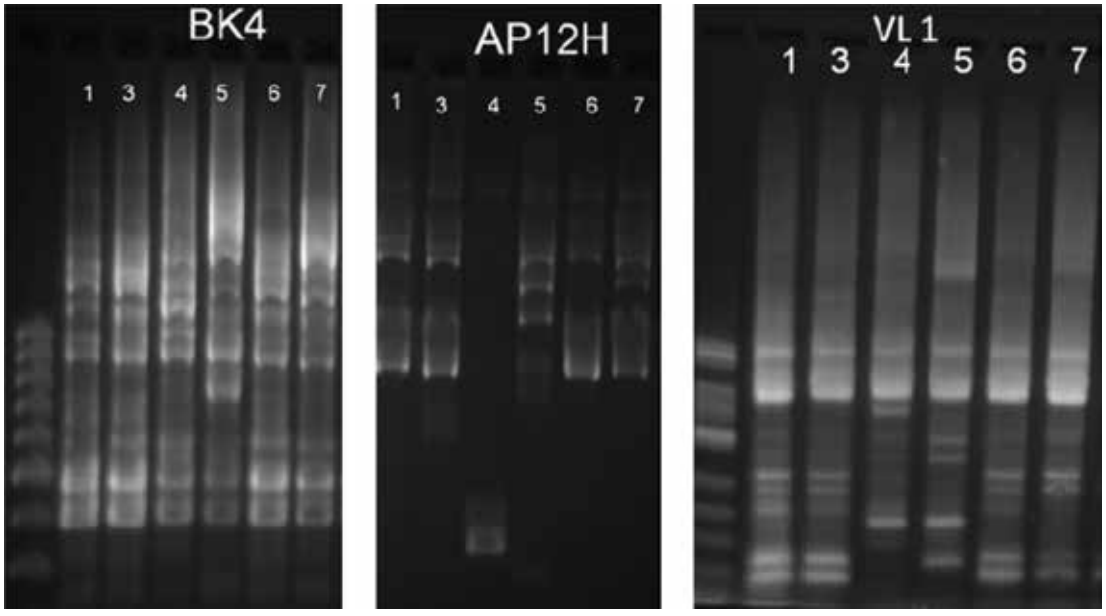

Figure 1. Molecular typing of *Pseudomonas aeruginosa* isolates. Electrophoresis gels obtained after random amplified polymorphism DNA (RAPD) with three different primers: BK4, AP12H, and VL1. To facilitate reading, only six of the nine isolates tested by RAPD are presented here. (1) Drinking water fountain; (3) ear, nose and throat (ENT) department patient 1; (4) control patient 1; (5) control patient 2; (6) ENT department patient 2; (7) ENT department, patient 3.

The corresponding three patients were treated for a head and neck carcinoma with a McCabe index 1 (fatal disease in five years) and were fed by nasogastric tube or by percutaneous endoscopic gastrostomy. The drinking water fountain was used for their alimentation and treatments by their tubes. It was concluded that the drinking water fountain was responsible for an outbreak of at least three nosocomial infections to *P. aeruginosa* in the ENT department; two of these three patients died due to their underlying pathology.

The drinking water fountain in the ENT department was taken out of service, and disinfected. However, it proved impossible to eliminate *P. aeruginosa* from the fountain. Bottled water was provided for patients until a new drinking water fountain with a terminal UV treatment was installed. In the subsequent two years no new infections with *P. aeruginosa* have been detected and microbiological sampling of the water fountain (performed quarterly) has been satisfactory.

Discussion

The drinking water fountain of the ENT department was a fountain plumbed into the mains equipped with a carbon filter, a 0.45 μm cartridge filter and a cooling system. The device was serviced in line with the manufacturer's recommendations and a protocol explaining cleaning and routine maintenance procedures (including daily disinfection of surfaces, measures to avoid stagnation of water, and six-monthly filter changes) was available in the department. Furthermore, an annual deep clean was performed by plumbers, which included descaling and additional disinfection if necessary.

The last microbiological quality control performed on the outlet water from the fountain (six months before the onset of the cases of infection) was satisfactory. However, sampling at the time of the cluster of cases revealed high concentrations of *P. aeruginosa* from the outlet water of the fountain, although the inlet water was free of *P. aeruginosa*. Even after three descaling and high-level disinfection procedures the outlet water remained heavily colonized with *P. aeruginosa*. RAPD typing provided strong evidence that at least three of the clinical cases in this outbreak were directly linked to the fountain. In French health facilities, assurance of water quality is the responsibility of the manager of the institution. Water from drinking fountains must satisfy microbiological standards for potability; in this regard *P. aeruginosa* is considered only as an additional indicator of water quality.[9] Water quality of drinking fountains is investigated routinely in the hospital of Poitiers, and before this cluster of cases each fountain had been sampled at least annually. This is more than is required by recommendations produced by the French Department of Health, which bases its recommended testing frequency on the number of hospital beds, rather than specifying that every fountain should be tested. It is recommended that one test per year be conducted per 100 beds (i.e. an institution of 1700 beds should perform 17 potability controls in a year).[9]

Although it is well known that *P. aeruginosa* is often found in hospital water systems, which can be a source of outbreaks of infection, to our knowledge no such outbreaks linked to drinking water fountains have previously been described.[4—6] Since *P. aeruginosa* was not detected in the inlet water, but was repeatedly isolated from the outlet water, even after some disinfection procedures, presence of a biofilm in the drinking fountain was the likely source of the bacterium; *P. aeruginosa* is well-known to its ability to develop biofilms.[10] Another key factor in the occurrence of this outbreak was the condition of the exposed patients. All of the patients who developed nosocomial infections with *P. aeruginosa* were tube-fed following surgical treatment of head and neck cancers; immunocompromise and anatomical abnormalities are likely to have been contributory factors to the development of infection.

In conclusion, our report demonstrates that exposure to contaminated drinking water may cause nosocomial infections with *P. aeruginosa*. This highlights the importance of including *P. aeruginosa* in the potability assessment of water outlets, at least in hospital departments admitting populations at risk. We now undertake quarterly testing of drinking water fountains in the ENT and gastroenterology departments, or avoid their use altogether. In our opinion the national recommended testing frequency in France (annual, or even less frequently) is insufficient. The use of drinking water fountains with a UV terminal treatment may be an additional control, but does not obviate the need for microbiological testing.

Conflict of interest statement
None declared.

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Nosocomial *Mycobacterium fortuitum* Colonization from a Contaminated Ice Machine[1,2]

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SUMMARY Between October 15 and November 18, 1985, 5 patients on a medical ward of the Albany VA Medical Center (Ward 8A) became colonized with *Mycobacterium fortuitum*. Because other patients in Ward 8A were at risk of developing disease with *M. fortuitum*, microbiologic surveillance to identify colonization in sputum was begun. By February 15, 1986, 30 colonized patients had been identified in this ward but none in another ward with a comparable patient population, which suggests a source unique to Ward 8A. Because water has been recognized as a source of opportunistic mycobacterial pathogens, we conducted a retrospective case-control study using a telephone survey questionnaire to examine a number of water exposures in 10 patients and 20 control subjects. Exposure to ice from the Ward 8A ice machine, but not to potable water, was associated with colonization with *M. fortuitum*. Large-volume water samples from a variety of sources were cultured for acid-fast bacilli. *M. fortuitum* was isolated only from the ice machine in Ward 8A. The ice machine was disconnected, and no additional patients became colonized. Although ice machines are infrequently implicated in nosocomial outbreaks, they represent a potential source for pathogens that survive or replicate in water.

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Introduction

Mycobacterium fortuitum is a rapidly growing organism that has been found in water, soil, and dust (1-3). Although it can colonize healthy persons without causing adverse sequelae, it can also cause skin and soft tissue infections, a slowly progressive granulomatous disease similar to pulmonary tuberculosis, and, rarely, disseminated disease in immunocompromised patients (4). Several nosocomial outbreaks and pseudo-outbreaks caused by *M. fortuitum* have been described (5-7), but in only one instance was the reservoir and mechanism of transmission identified.

Between October 15 and November 18, 1985, *M. fortuitum* was isolated from sputum specimens of five patients in one medical ward, Ward 8A, of the Albany VA Medical Center (Albany, NY). Because many of the patients in the ward had underlying lung disease, and five had acquired immunodeficiency syndrome (AIDS) and were at potential increased risk of disease, a combined epidemiologic and laboratory investigation was begun. This report describes the investigation that implicated consumption of ice from a contaminated ice machine in the ward as the source of the organism.

Methods

Case Definition

We defined a case as isolation of *M. fortuitum* from one or more clinical specimens in a patient in Ward 8A. To find cases, we reviewed all clinical microbiology records for the hospital from 1983 to 1985. In addition, we instituted active surveillance by obtaining admission and discharge sputum specimens from all patients admitted to this medical ward and to another medical ward with a comparable patient population. Surveillance sputum or oral secretions were also obtained from all employees working in Ward 8A. Specimens were obtained spontaneously without rinsing the mouth prior to collection; none were induced. Samples were considered to be sputum when Gram stain screening showed less than 10 epithelial cells per low power field. Oral secretions were collected from those patients and staff members with no cough.

Bacteriologic Investigation

Sputum specimens obtained for culture of acid-fast bacilli were routinely stained for acid-fast organisms and inoculated onto Lowenstein-Jensen slants. All cultures were held for 8 wk before being reported negative. All acid-fast organisms isolated were identified by the Laboratory Service, Albany VA Medical Center, and sent to the Special Reference Laboratory for Tuberculosis and Other Mycobacterial Diseases, West Haven VA Medical Center (West Haven, CT) for confirmation and identification of the biovariant (8). Organisms were tested for susceptibility to antimicrobial agents by using a Mueller-Hinton broth-dilution method at the Centers for Disease Control (CDC) (9).

Environmental Investigation

At the time that the first cases were identified, small-volume specimens were obtained from a variety of water sources: hot and cold water taps, drains, shower heads, and the ice machine. Also included in this initial environmental culturing were laboratory stock solutions, sludge from pipes and a hot water tank, and dust from floor and ceiling tiles. These cultures did not reveal a source of *M. fortuitum*; however, new cases of colonization were identified by surveillance cultures. Because the epidemiologic evidence pointed to patient colonization associated with water and ice exposure, we reexamined the water system and ice machine supplying Ward 8A using large-volume sampling. Thirty-five water samples and several swabs from all areas of the hospital, including the water mains, ice machines, and taps in patients' rooms and the central bathroom were collected in 1-L samples for culture of acid-fast bacilli. Water and ice were selectively cultured from a number of sites in the ice machine: the cold water supply as it enters the machine, water from the reservoir assembly, and ice from the evaporator and collecting bin. These were collected in sterile plastic bottles, refrigerated, and assayed for microbial contamination within 24 h of collection. All samples were examined using a membrane-filter technique described by Smithwick and Stratigos (10); 50 ml of each sample were used to prepare inocula for cul-

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ture, and an additional 50 ml were used for preparation of smears. After incubation for 2 to 3 wk at 37° C, colonies on inoculated plates were counted, and each colony type was stained with the acid-fast procedure. Representative acid-fast organisms were subsequently characterized as described above.

Case-Control Study

The occurrence of colonization only in Ward 8A suggested a source unique to that ward. Because water has been recognized as a potential source of opportunistic mycobacterial pathogens, we conducted a detailed chart review on the first 27 cases, looking particularly at probable water exposures. Because some patients became colonized within 24 h of hospitalization, we sought probable exposures that might have occurred within the first 24 h. Therefore, we undertook a retrospective case-control study using a telephone survey questionnaire to identify risk factors for colonization with *M. fortuitum*: consumption of tapwater, melted ice, and ice chips; showering and bathing activities; denture and mouth-care practices; smoking and alcohol consumption. The 10 most recently colonized patients in whom a diagnosis was made between December 31, 1985 and January 31, 1986, were enrolled as case-patients. The next two patients with negative surveillance cultures who had been admitted after a case were matched to control for length of hospitalization before culture. Data from the case-control study were analyzed statistically in a matched fashion using the Mantel-Haenszel estimate of the odds ratio and approximate tests of significance (11).

Results

Epidemiologic and Clinical Investigation

Between September 24, 1985 and February 13, 1986, 40 cultures from 30 patients and one employee were positive for *M. fortuitum* (figure 1). Thirty-nine of the 40 isolates were from sputum specimens; one was from bronchial washings. Acid-fast stains of sputum smears from these patients were uniformly negative, and between one and 15 colonies were isolated on Lowenstein-Jensen medium. Thirty-four cases were identified by the prospective surveillance program and six by the retrospective review of laboratory records. Twenty-two, four, one, and one patient had *M. fortuitum* isolated from one, two, three, and four separate specimens, respectively. The median age of patients was 62 yr (range, 32 to 80 yr). The underlying diseases were AIDS in five, AIDS-related complex in one, cancer in two, and chronic obstructive lung disease in nine. The organism isolated from all case-patients was identified as *M. fortuitum* biovar *peregrinum*. Surveillance specimens from a comparable patient population in another ward did not demonstrate *M. fortuitum*.

The case-finding methods described above revealed no evidence of clinical illness attributable to *M. fortuitum*. Admission and discharge sputum specimens were collected from all patients admitted after January 1, 1986 to Ward 8A and to another comparable ward. Because some

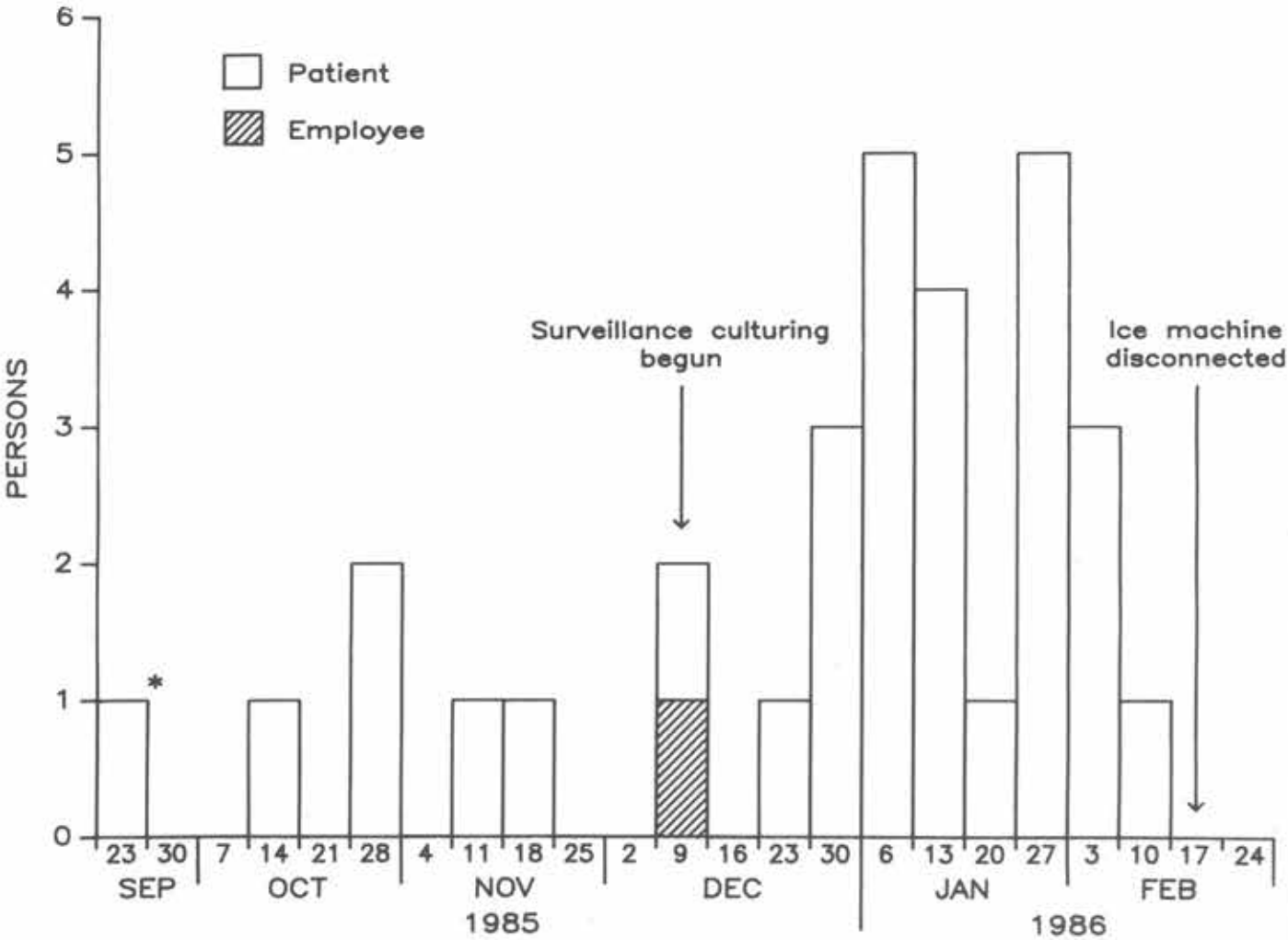

Fig. 1. Persons colonized with *Mycobacterium fortuitum* by week of culture, Veterans Administration Medical Center, September 1985 to February 1986. Asterisk indicates detection on microbiology record review.

of *M. fortuitum* biovar *peregrinum*. Antimicrobial susceptibility of environmental and clinical isolates of *M. fortuitum* biovar *peregrinum* was similar. *M. fortuitum* biovar *peregrinum* was not isolated from other potable water sources. However, *M. fortuitum* biovar *fortuitum* was isolated from the evaporator auger and from one specimen of ice from the Ward 8A machine. In addition, water from room faucets and water fountains in Wards 8A and 8B as well as all water and ice from Wards 8B and 8C ice machines were positive for *M. gordonae*.

The one ice machine serving the ward is located in the nourishment kitchen. Nurses distribute ice pitchers once a day and upon patient request, either filling the pitcher with water from the ice-machine tap or from the kitchen-sink tap. Ambulatory patients and their families have free access to the ice machine. Medications are distributed with a choice of water or juice served over ice. The machine is supplied cold water from the city water supply (figure 2). A float valve and reservoir assembly can hold as much as several hundred milliliters of water. The water freezes to the inside walls of the evaporator. A rotating auger scrapes the ice from the evaporator walls and compresses it in the top of the evaporator. The compacted ice is forced through the outlet port and through the transport tube to the storage compartment. When the storage compartment is full, the ice level detector arm actuates a switch that shuts down the ice maker. The machine is turned off for a 1-h period once or twice a day during each nursing shift. Prior to the investigation, the ice machine was cleaned on an arbitrary schedule.

The ice machine was removed from use on February 18, 1986, when it was implicated as the source of *M. fortuitum*. Surveillance cultures of patients and staff from Ward 8A and a comparable medical ward continued until March 15, 1986. No new cases of colonization were identified after removal of the ice machine. Follow-up cultures of colonized patients have been negative, and no one has developed disease with *M. fortuitum*.

Discussion

We epidemiologically and bacteriologically identified the ice machine serving the patients in one medical ward as the source of colonization with *M. fortuitum* biovar *peregrinum* in these patients. This is a unique biovariant that is rarely seen in clinical isolates; none of 24 pulmonary isolates and only three of the other isolates identified were *M. fortuitum* biovar *peregrinum* (4). In addition, only eight of 258 isolates of rapidly growing mycobacteria submitted for identification or antimicrobial susceptibility testing were identified as *M. fortuitum* biovar *peregrinum* (12).

Certain features of the ice machine and its pattern of use may have led to the high concentration of organisms found. The reservoir assembly can hold several hundred milliliters of water at a temperature suitable for replication of *M. fortuitum*. When the machine is turned off, a large amount of water can accumulate and facilitate bacterial replication. It is possible that small numbers of *M. fortuitum* are present intermittently in the city water supply and colonize the reservoir assembly and, through that site, the ice. The CDC recommends formal guidelines for reducing contamination of ice machines; these guidelines include hygienic practices and the establishment of a regular schedule for disassembly and cleaning of the machine's interior (13). Panwalker and Fuhse (14) investigated a similar outbreak where the ice machine was contaminated with *M. gordonae*. Application of the CDC recommendations successfully controlled the outbreak.

Nosocomial outbreaks of *M. fortuitum* from contaminated ice have been described previously. Kuritsky and coworkers (6) investigated an outbreak of sternal wound infection, endocarditis, and saphenous vein graft-site infection where *M. fortuitum* was found in nonsterile ice used for cooling the cardioplegia solution. Hoy and coworkers (Abstract Annual Meeting of the American Society of Microbiology, 1986; C381:391) examined a pseudo-outbreak of *M. fortuitum* in bone marrow transplant patients where bone marrow cultures were placed on contaminated ice. Our investigation was unique in providing both cultural and epidemiologic support for ice contamination as the source of the organism. Colonization with *M. fortuitum* was associated with consumption of ice water from bedside pitcher, melted ice, and ice with medications, but not from potable water sources such as water from the hall fountain or the showers or from tap water. Results of large-volume culturing and similar results of antimicrobial susceptibility tests of clinical and environmental isolates supported these findings.

Data suggests that organisms of the *M. fortuitum* complex are found in water samples from a number of geographic regions (2). Although ice machines have been infrequently implicated in nosocomial outbreaks, they represent a potential source of opportunistic pathogens that survive or replicate in water and, under appropriate circumstances, infect susceptible hosts.

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An outbreak of wound infection in cardiac surgery patients caused by *Enterobacter cloacae* arising from cardioplegia ice

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Summary This paper describes an outbreak of postoperative sternal wound infections. A cardiac surgeon noted a cluster of serious infections leading to wound dehiscence, despite the fact that none of his colleagues had noticed a rise in infection rates. The infections were predominantly with *Enterobacter cloacae*, and molecular typing and serotyping showed these isolates to be indistinguishable. Observation of the surgeon's practice revealed nothing untoward, and there were no infections among his patients operated on in another hospital. There appeared to be no significant difference between the modes of operation of the different surgeons. The operating theatres were screened to exclude an environmental source, with samples cultured on CHROMagar Orientation, a selective/differential medium designed for urine samples. Further questioning revealed one difference between the practices of the different surgeons; this surgeon used semi-frozen Hartmann's solution to achieve cardioplegia. The freezer used for this was swabbed and yielded *E. cloacae*, indistinguishable from the clinical isolates. It is hypothesized that this organism contaminated the freezer, and that the contamination was passed on to the ice/slush solution, thus infecting the patients. There have been no more cases since the freezer was

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replaced, a rigorous cleaning schedule instituted, and steps taken to reduce the possibility of any further contamination.

Introduction

Cardiac surgery generally has a low rate of postoperative infection. The consequences of infection can be catastrophic, however, due to the fact that the sternum may be poorly vascularized, either because of underlying vascular disease or because one of the internal mammary arteries is removed to use as a graft. The most common source of infection is the patient's own flora.[1] More rarely, infections are acquired from scrub nurses or other staff.[2–4] In many cases, the source is not identified with certainty. This paper describes an outbreak of deep sternal wound infections in which an unusual environmental source was identified.

Materials and methods

The outbreak

Five patients who had coronary artery bypass grafting in late April/early May 2004 developed sternal wound infection and dehiscence after surgery. The infections began between two and seven days postoperatively. Four patients had *Enterobacter cloacae* isolated from sternal samples, and one patient had negative swabs but had *E. cloacae* isolated from blood cultures.

Four of these patients were under the care of one surgeon (Surgeon B) who naturally became concerned that he might be the source of infection. There was no significant increase in infections with other organisms or among patients of other surgeons.

Epidemiological investigations

A series of incident meetings were called involving the cardiac surgery, anaesthetic, the hospital estates department and infection control/microbiology departments. The cases were reviewed in detail in order to look for common factors and to suggest hypotheses for further investigation. Infection control nurses carried out observations of hygiene standards during cardiac surgery.

Environmental screening

Extensive swabs were taken in all of the theatre areas from pieces of equipment, surfaces, floors, mops, buckets, taps and plugholes. In total, 111 swabs were taken from the four cardiac theatres and the changing rooms. These were plated directly on to chromogenic agar half-plates (CHROMagar Orientation, Becton Dickinson, Franklin Lakes, NJ, USA).[5] *Enterobacter* and *Klebsiella* spp. yield blue colonies on this medium. Possible enterobacter colonies were identified to species level by standard biochemical methods (API 20E, bioMérieux SA, Marcy l'Etoile, France).

Molecular typing of the organisms

All the clinical and environmental isolates of *E. cloacae* were serotyped, biotyped and compared by pulsed-field gel electrophoresis (PFGE) of *Xba*I chromosomal DNA digests.[6–8] Other clinical isolates of *E. cloacae* identified in the same unit in recent months were also typed, as was an isolate of *Enterobacter aerogenes* isolated from a cardiac surgery patient at the time of the outbreak. This latter isolate was submitted for typing in case the initial biochemical identification as *E. aerogenes* had been erroneous.

Results

Results of epidemiological investigations

The most obvious common factor was that four of the five cases were under the care of one surgical team. The typing results on the isolates (see below) reinforced this point as the four isolates from Surgeon B's patients were indistinguishable. Initial questioning did not reveal any significant difference in practice between Surgeon B and his colleagues. Observations carried out in theatres by the infection control team revealed several general areas where practice could be improved, but did not point to a possible source of these infections or highlight any significant difference between the various surgeons.

When the typing results described below became available and when no link other than the surgeon could be found between the cases, the possibility of carriage of the organism was raised. It was suggested that the surgeon, and possibly other staff, should be screened for enterobacter. There were serious concerns about the possible

consequences of screening staff, but fortunately it proved to be unnecessary as, at this stage, a member of the surgical team pointed out a previously overlooked difference between the practices of the surgeons. Surgeon B regularly used an 'ice slush' of frozen Hartmann's solution which was poured into the chest cavity to assist cardioplegia. The ice slush was made by freezing 1-L infusion bags of fluid in a large chest freezer for several hours, the outer bag was taken to the patient and torn open, and the inner (sterile) bag was dropped into the sterile field where it was cut open with sterile scissors and decanted into a jug for pouring. Despite using a no-touch technique, organisms on the surface of the outer bag, especially if it was wet, might contaminate the inner bag during opening. Thus, this procedure carried a risk of contamination and prompted further investigations as described below.

Results of microbiological investigations

E. cloacae was isolated from a sink in a changing room and from a mop and bucket; all other initial swabs were negative for any *Enterobacter* spp. Later, after the investigating team was made aware of the practice of using ice for cardioplegia, the freezer was inspected and tested. It was a large top-opening chest freezer that was heavily frosted. During the inspection, ice on the inside of the lid was seen to melt and drip on to the bags of Hartmann's solution below. Swabs of the freezer and the outer surfaces of the bags were taken, as well as samples of ice from the base of the freezer. All these samples yielded *E. cloacae*.

The macrorestriction length polymorphisms generated by PFGE were analysed by Dice correlation coefficient with the aid of Bionumerics software, and a dendrogram of percentage relatedness was produced using unweighted pair group matching by arithmetic averages (Figure 1). The typing results of all the isolates are summarized in Table I. The isolates from the four infected patients under the care of Surgeon B and all the isolates from the freezer were indistinguishable from each other, and were different from all but one of the other isolates tested. This one isolate was from the bypass water of one of the four cardiac bypass machines. Although this was considered as a possible source of infection, it was regarded as unlikely because the bypass circuit was completely closed and the fluid did not come into contact with the patient. Furthermore, not all the cases had been exposed to this machine, and patients from other surgical teams who were not experiencing infections were exposed to this machine. It was felt that the hypothesis that the freezer was the source of contamination was much more likely, as it fitted both the typing results and the observed differences in surgical practice. The isolates of *E. cloacae* from other patients who were also on the cardiothoracic unit in the few months before the outbreak were all different from the outbreak strain; this supported the conclusion that they were not part of the outbreak and did not acquire their infection from the freezer.

Control measures: interventions and outcome

As the outbreak was investigated and information became available, steps were taken to control the risk of infection. It was decided that all the surgeons should continue to operate, but patients being consented for surgery were informed that the risk of infection had increased and that this

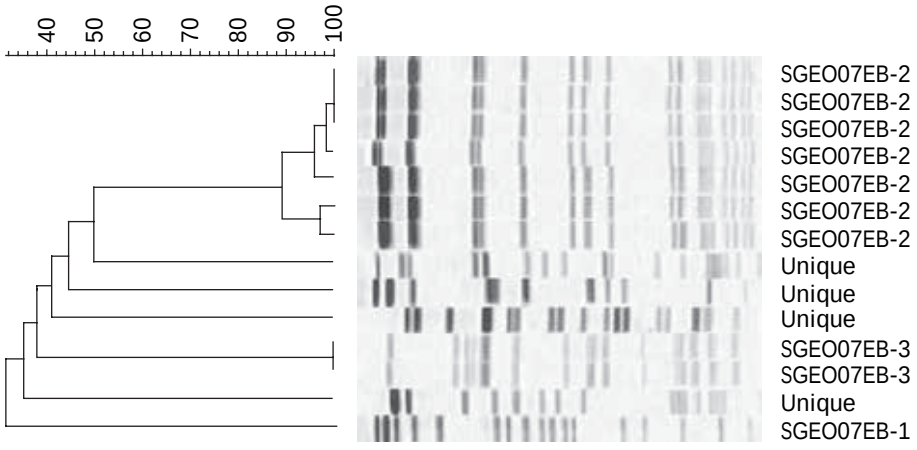

Figure 1 *Enterobacter cloacae* isolates: dendrogram showing percentage relatedness and gel image of restriction digests. Outbreak strain was SGEO07EB-2.

Table I Typing results of clinical and environmental enterobacter isolates. Outbreak isolates are shaded

Source	Surgeon	Species	Biotype	Serotype	PFGE genotype
Patient 1	A	*E. aerogenes*	–	–	SGEO07EB-1
Patient 2	B	*E. cloacae*	37	O1	SGEO07EB-2
Patient 3	B	*E. cloacae*	37	O1	SGEO07EB-2
Patient 4	B	*E. cloacae*	37	O1	SGEO07EB-2
Patient 5	C	*E. cloacae*	22	O3	Unique
Patient 6	A	*E. cloacae*	26	O3	Unique
Patient 7	B	*E. cloacae*	37	O1	SGEO07EB-2
Patient 8	C	*E. cloacae*	–	–	Unique
Mop	n/a	*E. cloacae*	66	O19	SGEO07EB-3
Sink	n/a	*E. cloacae*	22	O17/O19	Unique
Bucket	n/a	*E. cloacae*	66	O19	SGEO07EB-3
Bypass water – Theatre 4	n/a	*E. cloacae*	37	O1	SGEO07EB-2
Freezer	n/a	*E. cloacae*	37	O1	SGEO07EB-2
Bag of Hartmann's solution	n/a	*E. cloacae*	37	O1	SGEO07EB-2

E. aerogenes, *Enterobacter aerogenes*; *E. cloacae*, *Enterobacter cloacae*; n/a, not applicable.

was under investigation. They were asked if they wished to defer surgery but none did so.

Surgeons, anaesthetists and nursing staff were reminded of the need to observe scrupulous hygiene before, during and after surgery.

The antibiotic prophylaxis protocol was reviewed, and it was decided to add a single dose of gentamicin 120 mg to the existing regimen of cefradine 1 g, as the enterobacter isolates were resistant to the latter agent.

After the risk from the freezer was recognized, it was defrosted and cleaned, and a replacement upright freezer, which was easier to keep clean, was ordered. Cleaning procedures were tightened and staff were instructed to dry off any condensation on the outer bags before use to reduce the chance of droplet contamination of the fluid.

There have been no new cases in patients operated on since the interventions to control the risk from the freezer as described above. The old freezer was re-swabbed before it was replaced, with no isolation of *Enterobacter* spp.

Discussion

Deep sternal wound infection is a rare but feared complication of cardiac surgery, with a high associated morbidity and mortality. Infections when they do occur are often due to meticillin-susceptible or -resistant *Staphylococcus aureus*, and the organism frequently arises from the patient's own microbial flora.[1] Gram-negative sternal infections are also recognized, and some have been associated with the use of leg veins for cardiac artery bypass grafting. It is postulated that the vein is contaminated during harvesting and organisms are implanted into the wound cavity.[9] Dramatic outbreaks such as described here are rare and prompt a search for a specific source or cause.

Enterobacter spp. are well-recognized nosocomial pathogens implicated in a variety of infections, including bacteraemia, urinary sepsis, ventilator-associated pneumonia, and meningitis/brain abscess in neonates. Most human infections are due to *E. cloacae* and *E. aerogenes*. They are found in soil, freshwater, sewage, human and animal intestines, and (occasionally) the hospital environment.[10] Human infections may result from external contamination or intrinsic carriage, carriage can occur in up to one-quarter of patients admitted for surgery, and the proportion of carriers increases with prolonged hospital stay and antibiotic exposure.[11] Outbreaks of nosocomial infection have been linked with a variety of contaminated environmental sources, including propofol and other intravenous infusions, contaminated cotton wool swabs and blood pressure transducers.[10]

To the authors' knowledge, ice for cardioplegia has not been described previously as a risk for infection. However, in retrospect, the risk of organisms being transferred from the outer to the inner bag is obvious. If it is decided that the use of ice in this fashion is appropriate, it is important that the freezer is kept scrupulously clean and that measures such as those described above are taken to prevent contamination.

General issues in the investigation of the outbreak: consent procedure and dilemmas in investigating staff

An outbreak such as that described here places a surgical unit under considerable pressure, as doctors and managers balance the risks of continuing to operate against the harm that may result from withdrawing the service. The decision to continue to operate was not taken lightly, and it was felt ethically imperative to inform patients of the outbreak and of the possible increased risk of infection, and offer them delayed surgery or referral elsewhere. Patients appreciated being told but none of them chose to delay surgery or transfer to another unit. The issue of whether to screen staff for carriage of *Enterobacter* spp. was also debated and was decided against for several reasons. Many people carry *Enterobacter* spp. in any case, and detecting carriage would not necessarily imply that the carrier was the source of the outbreak; in fact, they could have acquired the organism from a patient rather than vice versa. Nonetheless, if carriage was detected, there would be a pressure to prevent that person from working, even though the risk they posed was unquantifiable and possibly zero. Furthermore, to be fair and thorough, any screening exercise should involve all cardiac surgical staff and not just one surgical team; however, then the dilemma of how to deal with carriers who had not had contact with cases of enterobacter infection would arise. Finally, it was felt that carriage by a staff member in itself could not explain the infections; there would have to be some lapse in asepsis to allow the wounds to become infected, and it was the lapse that was the fault, not the carriage.

Use of CHROMagar for environmental screening

Specific media such as eosin methylene blue agar are designed to select and distinguish *Enterobacter* spp. and other *Enterobacteriaceae*, but these are not readily available in clinical laboratories.[12] The authors demonstrated that CHROMagar, which is designed for diagnostic urinary samples rather than environmental screening, offers a quick, relatively inexpensive, available and effective alternative.

Conclusion

This outbreak highlights various issues, namely the possibility that ice used for cardioplegia in cardiac surgery may be a vehicle for infection, the difficult decisions and ethical dilemmas that face a surgical unit undergoing an outbreak of serious wound infections, and the potential to use available differential media, designed for diagnostic use, for environmental screening for specific pathogens.

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Public Health

HOSPITAL INFECTION FROM CONTAMINATED ICE

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Summary An outbreak of infection with *Enterobacter cloacæ*, followed by a mixed infection with *E. cloacæ* and *Pseudomonas aeruginosa* in a cardiothoracic surgery unit was traced to the use of contaminated ice from a badly plumbed ice-machine. The patients, who all had antibiotic therapy and were infected, contrasted with the staff, who also had ice from the same machine but were unaffected by it. Repeated reinfection of patients from the ice explained the failure of adequate chemotherapy and the cessation of the outbreak when the machine was disconnected. Attention is drawn to the correct installation, maintenance, and use of ice-machines. It is suggested that ice destined for patients with tracheostomies, on antibiotics, or on immunosuppressive therapy should be put into chlorinated water as a means of maintaining sterility during dispensing.

Introduction

TRACHEOSTOMY and its subsequent management render a patient highly susceptible to tracheal colonisation by bacteria. This usually happens within 48 hours (Gotsman and Whitby 1964), and the use of prophylactic antibiotics may result in colonisation with resistant organisms such as *Pseudomonas aeruginosa* or members of the *Klebsiella-Enterobacter-Serratia* group. The habitat of *Pseudomonas* within the hospital has been intensively studied; epidemics in respiratory units have been traced to contaminated airways (Phillips and Spencer 1965, Tinne et al. 1967) and to faulty techniques used for tracheal suction (Sutter et al. 1966). Sources of Enterobacteriaceæ remain obscure however, and as first step to the study of this problem a biochemical typing scheme (Cowan and Steel 1961) was introduced into this laboratory.

Initially *Klebsiella aerogenes* was the commonest organism I found in the respiratory tracts of patients in the cardiothoracic unit at this hospital. Some months later *Enterobacter cloacæ* was isolated from the sputum of seven patients from two different wards. Inquiry revealed that they had all been in the intensive-care ward. Later six patients were infected by the same strain of *Ps. aeruginosa* as defined by pyocine, serological, and bacteriophage typing methods; in three of them there was simultaneous infection with *E. cloacæ*. This paper describes the clinical features and laboratory investigation of the latter part of the outbreak, the source of which was discovered in the hospital ice-machine.

Initial Outbreak

Case 1.—This girl, aged 18, required tracheostomy and artificial ventilation after thymectomy for myasthenia gravis. 3 days later the *Pseudomonas-Enterobacter* mixture was isolated from the trachea and right pleural cavity and it later spread to the wound. Intensive local and systemic therapy with colistin and carbenicillin failed to eradicate the organisms from the throat and trachea, although the numbers of organisms present fluctuated daily and the other sites were cleared. She died 6 weeks after operation with hæmorrhage from an eroded innominate artery.

Case 2.—This lady, aged 52, had a tracheostomy and artificial ventilation, 24 hours after case 1, following an operation to remove ' Lucite ' falls from a Semb space infected with *Mycobacterium tuberculosis* and with *Staphylococcus aureus*. One ball had eroded the innominate artery, which had to be resutured at a later operation. *Ps. aeruginosa* was isolated from the space drain and trachea 5 days after the first operation. The infection apparently cleared after 8 weeks' therapy, but her respiratory function was marginal, and she died another 8 weeks later with respiratory failure.

Case 3.—This man, aged 66, had a bronchopleural fistula after a right pneumonectomy for carcinoma of the bronchus, and required tracheostomy and artificial ventilation. His throat and right pleural cavity became infected with the *Pseudomonas-Enterobacter* mixture on his 23rd postoperative day—5 days after case 2 became infected. Infection persisted in both sites despite intensive therapy and he died from respiratory failure.

Because of these infections the ward was closed to new admissions and the remaining patients were discharged as soon as they were well enough. The affected patients were nursed in isolation in separate rooms.

METHODS OF INVESTIGATION

(*a*) The clinical histories of the three patients were reviewed.

(*b*) The remaining patients in the ward were carefully monitored both clinically and bacteriologically.

(*c*) A bacteriological survey of the unit was made. Staff were questioned to detect lesions such as otitis externa or cut fingers, and finger and throat swabs from them were examined.

Ps. aeruginosa was grown either on MacConkey agar or using a medium containing nalidixic acid (5 μg. per ml.) and cetrimide (0·03%) in peptone water or nutrient agar (Tinne et al. 1967). The organism's identity was confirmed by its ability to grow and to produce pigment on this medium and by its oxidative metabolism of glucose (Hugh and Leifson 1955). Pyocine typing (Gillies and Govan 1966) was carried out and selected strains were typed with antisera and bacteriophages at the Central Public Health Laboratories, Colindale, through the courtesy of Dr. B. T. Thom. *E. cloacæ* was isolated on MacConkey agar and identified biochemically (Cowan and Steel 1961).

Samples of ice and water were taken aseptically and passed through a 47 mm. 0·2μ Millipore filter which was placed on the surface of an agar plate containing one of the media.

Results

The affected patients all required a tracheostomy and artificial ventilation. Two of them had been nursed by the same staff, but in different rooms. None of the other patients were having artificial ventilation, and so it seemed that the probable source of infection was in the ventilators or ancillary equipment. All three patients had received broad-spectrum-antibiotic therapy.

Several hundred samples from the cardiothoracic unit were examined bacteriologically. No *Pseudomonas* or *Enterobacter* organisms were found in the throats or on the hands of the staff. The environment was surprisingly free from them. *Ps. aeruginosa* was isolated from the waste-traps of sinks in the patients' rooms, the ward service rooms, and two sinks in the theatre suite. This organism was also present in dust taken from the floor of a room 3 weeks after an infected patient had left it, and in dust from the ward vacuum-cleaner. The nalidixic-acid/cetrimide medium selected *Pseudomonas* from large amounts of contaminated material such as dust, but many strains of *Proteus* were able to grow on it. *E. cloacæ* was found on a table-top, the surface of a ventilator, and in two sinks, all in the rooms of infected patients. The Blease ventilators and the suction-pumps were repeatedly stripped down and examined, but no contamination was

RESULTS OF PSEUDOMONAS TYPING

Source	Pyocine type	Bacteriophage type	Serological type
Cases 1–3	1	(68)	11
Case 4	10	(68)	11
Case 5–6	1	(68)	11
Ward sluice sink ..	1	..	4
Ward duty-room sink	1	44/1214/Colindale 11	11
Theatre sink (1) ..	10	(68)	11
Theatre sink (2) ..	10	44/M6/Colindale 21	11
Room dust (case 3) ..	10	(68)	11
Ice-machine	Not typable	F7	..

found, except in the tubing directly connected to the patients.

The "epidemic" *Ps. aeruginosa* found in all the patients and many of the sinks was pyocine, type 1. Since this is the commonest type, selected strains were sent for typing by bacteriophage and serological methods. The results (see accompanying table) confirmed that there was a single type of organism causing the outbreak. Some of the pyocine, type 10, strains turned out to be the same type as the type-1 strains. This is not surprising, because the two types differ by only a single factor. Conversely several of the type-1 strains seemed to be of differing bacteriophage and serological types.

Progress of the Epidemic

The remaining patients were gradually discharged. One man had transient colonisation of a gangrenous toe with a type-2 *Ps. aeruginosa*, which disappeared without therapy. The last patient remaining in the unit was infected 1 month after the previous cases.

Case 4.—This man, aged 67, had a Monaldi drainage of a large emphysematous cyst of the right lung. He did not require tracheostomy and his wound healed normally, though his post-operative period was complicated by renal failure. He had repeated bronchial infections with *K. aerogenes*, and 6 weeks after operation he developed superinfection with the *Pseudomonas-Enterobacter* mixture. He died 2 weeks later with respiratory failure and myocardial infarction.

Case 5.—This man, aged 45, was admitted as an emergency while the cardiothoracic unit was closed. He had a traumatic rupture of the aorta, which was repaired with a 'Teflon' graft. He required tracheostomy and artificial ventilation and was nursed by the same team, but in a different ward. The room and the equipment used had already been bacteriologically monitored, and daily swabs were taken from several sites on the patient. A throat swab taken on the 8th postoperative day grew the epidemic type of *Ps. aeruginosa*. The previous day a new suction-pump had been used, and the patient had been well enough to start having iced drinks. The suction-pump, which had already been checked, proved to be bacteriologically satisfactory, but the ice which came from an ice-machine was heavily contaminated. The use of ice was immediately stopped, and the patient was treated with local and systemic carbenicillin and colistin with a dramatic clearing of his organisms within 3 days. He made a good recovery.

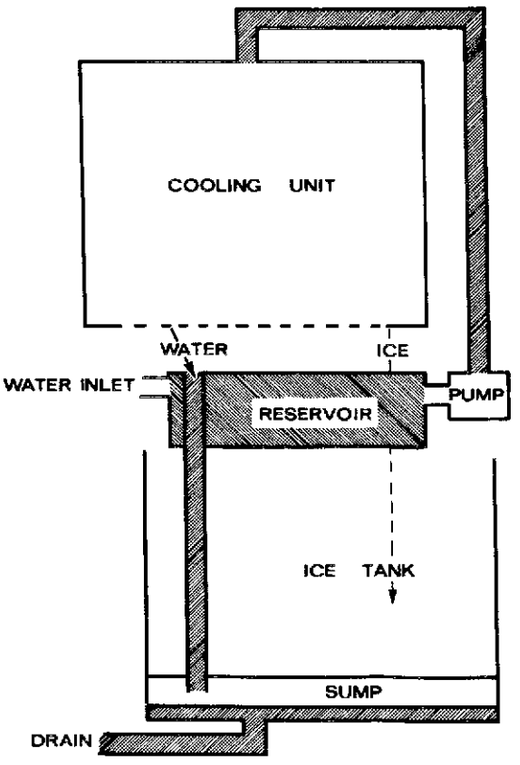
Case 6.—This man, aged 48, had an aortic-valve replacement and was of necessity nursed in the same room as case 5, though only after the latter was clear from infection and the room apparently so. He developed colonisation with the epidemic type of *Ps. aeruginosa*.

No more cases of the type-1 *Ps. aeruginosa* or of *E. cloacæ* infection occurred in the cardiothoracic unit when it returned to full working. Two later cases of *Ps. aeruginosa* urinary-tract infection were of differing types, and a surgeon had colonisation of a cut finger with a type-6 strain. *K. aerogenes* was again the commonest coloniser of tracheostomies.

The Ice-machine

The ice-machine (see accompanying figure) was in the operating-theatre suite. Ice was used for hypothermic operations and the cooling of drinks for the theatre staff and the patients on the surgical and intensive-care wards. The cooling unit at the top of the machine was fed with water from the reservoir beneath it by a pump. Excess water returned to the reservoir and was either recirculated or passed down the overflow. The ice dropped beneath the reservoir into a storage tank. The overflow from the reservoir passed along a plastic pipe to a sump beneath the ice tank, which was separated from it by a perforated metal tray. The sump was drained by a small pipe which ran horizontally to join the drain from a washbasin. The ice was removed through a door at the front of the machine with a metal shovel, which was kept on a nearby window ledge.

A Millipore filter through which 150 ml. of melted ice had been passed was covered by a confluent growth of mucoid coliform organisms after overnight incubation



Plan of the ice-machine.

on MacConkey's medium. The principal organism present was *E. cloacæ*. The machine was immediately switched off, and was examined several days later with the help of the serving engineer. Although two different strains of *Ps. aeruginosa* were isolated, neither was the epidemic type. The sump contained a mass of scale, and the water in it contained no less than five different species of protozoa.

The machine was replumbed so that waste water went into an open-ended pipe with no direct communication with the drains. The ice was raised higher above the sump by moving the metal tray, and the overflow water was diverted to prevent it splashing back on to the ice. Regular cleaning was instituted and the use of ice restricted to the theatre. Repeated samples of 150 ml. of ice were examined and produced no more than a single colony of *Escherichia coli*.

A newer model of machine was also examined. This machine had no permanent drain, and, though the cooling system was recirculating, it was enclosed. The machine was cleaned weekly. 150 ml. of melted ice grew a single colony of *Ps. aeruginosa* and three colonies of *Serratia marcescens*.

Discussion

The use of prophylactic antibiotics, the bypass of normal body defences by tracheostomy (Gotsman and Whitby 1964), and the use of immunosuppressive drugs all contribute to the increase of hospital infection with gram-negative bacilli. The value of detailed knowledge about the techniques in use in the unit was shown here in that, when case 5 became infected, items such as ventilators, sinks, and suction-pumps, and the method of tracheal suction, could immediately be eliminated as sources of infection. The practice of maintaining humidifiers at 60°C and boiling the patient's ventilator tubing daily protected the ventilators against contamination even during the outbreak. Repeated examination of the ventilators never showed contamination even when the patient's end of the tubing was heavily contaminated.

The contamination of the ice fits in well with the clinical data. Patients with tracheostomies had ice to suck, and case 4 had iced drinks. The outbreak ceased when the ice supply was cut off. Failure of intensive chemotherapy to eliminate the microbes from the throats of the first three patients can be ascribed to repeated reinfection. Identical chemotherapy worked rapidly on case 5 after he was stopped from having more ice. The possibility that the β-lactamase produced by *E. cloacæ* (Fleming et al. 1963) was inactivating carbenicillin was excluded by a simple biological test which showed no destruction of the antibiotic after exposure to a heavy log-phase inoculum of the *Enterobacter* for 1 hour.

The protective effect of a normal throat flora and respiratory tract can be inferred from the observation that neither of the epidemic organisms were present in the throats of the operating-theatre personnel, who nevertheless had regularly partaken of the contaminated ice.

Epidemics of typhoid fever have been traced to impure ice cut from river water and stored in an ice house. An epidemic of hospital infection of this type was recorded among the staff of the St. Lawrence State Hospital in 1903 (Hutchings and Wheeler 1903). The contamination of ice may still be witnessed in tropical countries when blocks are dragged along the road, and it is not surprising that cultures of bazaar ice have grown enteropathogenic *E. coli* (Iyer et al. 1965). The purity of ice from a modern machine is, however, seldom queried. Contamination of our machine could have occurred from handling the ice or from the use of a contaminated shovel; but it seems likely to have arisen owing to backflow along the drain. Presumably the protozoa present in the sump must have come by this route. The water in the sump must have been a continuous culture of microbes. Failure to recover the epidemic type of *Ps. aeruginosa* from the machine was disappointing. The prompt disconnection of the machine after the first sample had been taken may have prejudiced our chances in this respect, and the organisms may have literally gone down the drain.

Ice may also become contaminated by the practice of using the ice tank as a sort of extra refrigerator to store drugs. The use of plastic novelties such as pink elephants for cooling drinks has been shown to carry the danger of contamination from the water contained within them (Alabama Department of Public Health 1966).

An investigation into the use of ice in drinking water at Harvard revealed that it was contaminated with coliform organisms during the dispensing process from a crushing machine to individual glasses; this contamination was prevented by holding the ice in a solution of hypochlorite containing two parts per million of free chlorine before dispensing it into glasses of water (Moore et al. 1953). It seems rational to treat ice destined for patients with tracheostomies, or on antibiotics or immunosuppressive drugs, in this way.

Initially pure water may be contaminated in several other ways before reaching the patient. Bacteria have been found in the aerator of a mixer tap (Wilson et al. 1961), ion-exchange water softeners (Eisman et al. 1949), and drinking-glasses (Shooter et al. 1966). *Pseudomonas* species can multiply at low temperatures and get carbon for growth from traces of diverse and unlikely compounds. They are the commonest microbes associated with natural water-supplies.

The sink waste-traps which were found to be contaminated with *Pseudomonas* species contained an average of 7·5 million viable bacteria. These organisms were also present on the sides of the sink, and it was shown that they could readily be transferred to immersed hands. That this contamination was presumably a reflection of the epidemic is borne out by the finding of the epidemic organism in two theatre sinks, one of which was used to wash the glasses used by the staff for drinking. Meningitis caused by *Flavobacterium meningosepticum* has been traced to a contaminated drain-trap which leaked over the bottles containing the ward disinfectants (Cabrera and Davis 1961). The transfer of specific *Pseudomonas* species from a sink to a burn has been demonstrated (Kohn 1967), and sinks must be regarded as a potential hazard.

The isolation of *Ps. aeruginosa* from the floor of a room 3 weeks after an infected patient had left is a reminder that it can survive when dry (Lowbury and Fox 1953); thus the practice of screening vacuum-cleaner dust (Kohn 1966) may be useful as an indication of the presence of the organism.

I am grateful to Mr. B. B. Milstein and Mr. C. Parish for details of their cases and helpful discussions, and to Dr. M. T. Parker and Dr. B. T. Thom of the Central Public Health Laboratories, Colindale, for the further typing of the *Pseudomonas* strains.

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Brief Report

A cold hard menace: A contaminated ice machine as a potential source for transmission of carbapenem-resistant *Acinetobacter baumannii*

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Key Words:
Nosocomial
Water-borne infection
Water-related device
Multidrug-resistant gram-negative bacilli

During an investigation of potential sources of transmission of multidrug-resistant gram-negative bacilli on a spinal cord injury unit, we recovered genetically related carbapenem-resistant *Acinetobacter baumannii* isolates from the stool of 3 patients, the hands of a nurse, and an ice machine water outlet spout and drain. Our findings suggest that contaminated ice machines could serve as a potential reservoir for dissemination of multidrug-resistant gram-negative bacilli.

Hospital water and water-related devices are an important reservoir for transmission of waterborne pathogens such as *Legionella* spp, other gram-negative bacteria, and nontuberculous mycobacteria.[1] Ice machines are among devices that serve as a source of potable water and ice for patients, hospital staff, and visitors. Ice machines have previously been linked to transmission of *Legionella pneumophila*,[2] *Mycobacterium chelonae*,[3] and *Enterobacter cloacae*.[1] Here, we report on a contaminated ice machine as a potential reservoir for transmission of carbapenem-resistant *Acinetobacter baumannii.*

METHODS

A case of carbapenem-resistant *Klebsiella pneumoniae* urinary tract infection in the spinal cord unit during September 2015 prompted an investigation by the infection control department at the Louis Stokes Veterans Affairs Medical Center. A point-prevalence culture survey of stool samples from other patients on the ward was conducted. Cultures were also collected from the hands of nurses on the ward and environmental sites, including high-touch surfaces in 10 patient rooms, sinks, and 2 ice machines. Parts of the ice machine swabbed included ice, water, ice machine drain, ice machine water outlet spout, and ice outlet spout. Rayon swabs (BBL Culture Swabs; Becton Dickinson, Franklin Lakes, NJ) premoistened with phosphate-buffered saline were used to collect cultures. The swabs were incubated in 5 mL trypticase soy broth with a 10 μg meropenem disc overnight at 35°C and cultures were processed for carbapenem-resistant gram-negative bacilli using standard methods.[4]

Isolates were subjected to identification and susceptibility testing using the Vitek 2 system (BioMérieux, Durham, NC). Phenotypic determination of carbapenemase production was done using the modified Hodge test.[5] Carbapenem-resistant *A baumannii* isolates were further characterized by polymerase chain reaction (PCR) for detection of carbapenemase genes, multilocus sequence typing, and

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repetitive-sequence-based PCR for determination of genetic relatedness as previously described.[6]

RESULTS

Table 1 shows the frequency of recovery of carbapenem-resistant gram-negative bacilli from stool, nurses' hands, and environmental sites. Of 20 patients cultured, 5 (25%) had carbapenem-resistant gram-negative bacilli recovered from stool. *A baumannii* was the most common organism recovered from stool, followed by *K pneumoniae*; however, *K pneumoniae* was not recovered from nurses' hands or from the environment. *Stenotrophomonas maltophilia* was recovered from 1 sink and from the drain of 1 ice machine, but not from other sites. *A baumannii* was isolated from the stool of 3 patients, from the hands of 1 nurse, and from the inside lumen of the water outlet spout and the drain of 1 of the ice machines. No carbapenem-resistant gram-negative bacilli were recovered from the water and ice obtained from the ice machines.

By multilocus sequence typing typing, all 6 *A baumannii* isolates were sequence type based on the Pasteur scheme. Repetitive-sequence-based PCR of the isolates demonstrated a similarity index ranging from 94.2%-99.8%, suggesting genetic relatedness (Fig 1). On virulence gene analysis, all 6 *A baumannii* isolates were found to have $bla_{\text{OXA-69-like}}$ genes. In addition, the isolates from the hands of the nurses and the ice machine water outlet carried $bla_{\text{OXA-23-like}}$ genes.

With the exception of the index case, none of the patients on the ward had clinical isolates of carbapenem-resistant gram-negative bacilli. After disinfection with bleach, cultures of the ice machine were negative. The nursing staff was informed of the culture results and the importance of hand hygiene was reinforced.

DISCUSSION

During an investigation of potential sources of transmission of multidrug-resistant gram-negative bacilli on a spinal cord injury unit, we recovered genetically related carbapenem-resistant *A baumannii* isolates from the stool of 3 patients, the hands of a nurse, and an ice machine water outlet spout and drain. Our findings suggest that contaminated ice machines could serve as a potential reservoir for dissemination of multidrug-resistant gram-negative bacilli.

The directionality of spread of *A baumannii* in our study is not clear. One possible scenario is that the ice machine became contaminated by the hands of personnel that were contaminated due to contact with a colonized patient. Once contaminated, the *A baumannii* could persistently colonize the inside lumen of the ice machine outlet spout and drain due to biofilm formation.[7] It is possible that the contaminated ice machine was a source for subsequent dissemination of *A baumannii* to patients due to contamination of water exiting the contaminated water outlet spout or through contamination of the hands of personnel.

Our study has several limitations. First, although our results are suggestive, they do not prove that the contaminated ice machine was a source of spread of the carbapenem-resistant *A baumannii*. Second, we did not recover *A baumannii* from ice or ice water.

Table 1
Frequency of recovery of carbapenem-resistant gram-negative bacilli from rectal swabs, nurses' hands, and environmental sites

Organism recovered	Stool (n = 20)	Nurses' hands (n = 15)	Sinks (n = 10)	High-touch surfaces* (n = 40)	Ice machine drain (n = 2)	Ice machine water outlet† (n = 2)	Ice machine ice outlet†	Ice N = 2	Water N = 2
Acinetobacter baumannii	3 (15)	1 (7)	0 (0)	0 (0)	1 (50)	1 (50)	0 (0)	0 (0)	0 (0)
Stenotrophomonas maltophilia	0 (0)	0 (0)	1 (10)	0 (0)	1 (50)	0 (0)	0 (0)	0 (0)	0 (0)
Klebsiella pneumoniae	2 (10)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)

NOTE. Values are presented as n (%).
*High-touch surfaces included bed rails, bedside table, and call button.
†Ice machine water outlet and ice outlet refer to the spout.

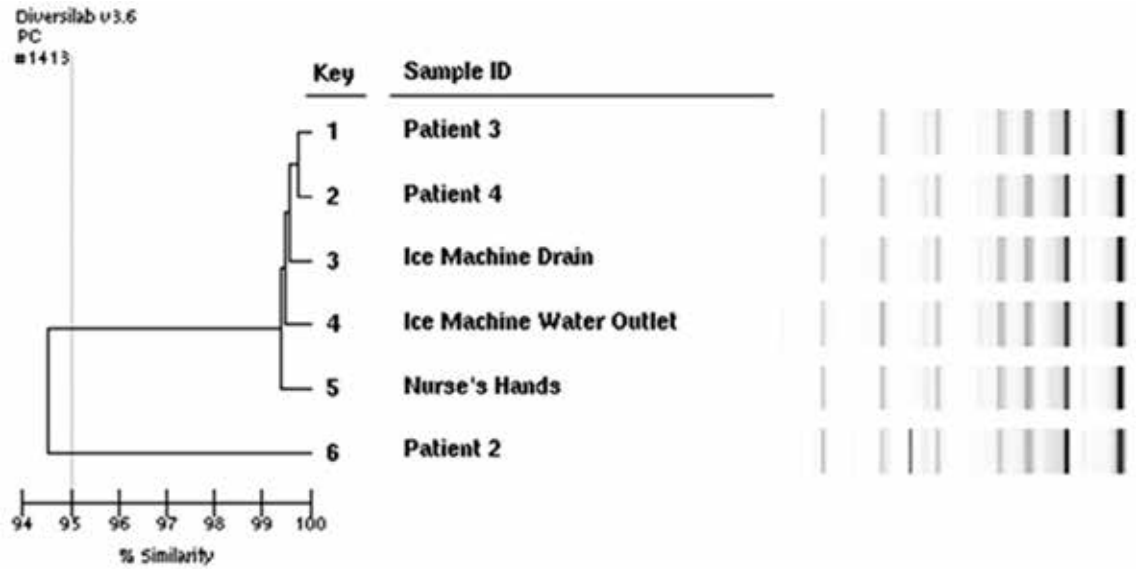

Fig 1. Results of molecular typing with repetitive-sequence-based polymerase chain reaction for 6 *Acinetobacter baumannii* isolates recovered from the stool of 3 patients, from the hands of 1 nurse, and from the inside lumen of the water outlet spout, and the drain of an ice machine. The similarity index ranged from 94.2%-99.8%, suggesting genetic relatedness.

However, recovery of *A baumannii* from the inside lumen of the water outlet spout clearly could lead to contamination of water exiting the spout. Third, we also did not demonstrate a route by which organisms in the ice machine drain could contribute to transmission. Finally, all of the *A baumannii* isolates carried the chromosomally encoded oxacillinase $bla_{\text{OXA-69}}$ gene, but only 2 carried $bla_{\text{OXA-23-like}}$ genes. However, as $bla_{\text{OXA-23-like}}$ genes are plasmid-mediated, this difference does not alter the conclusions regarding relatedness of the isolates.

CONCLUSIONS

Our findings support the recommendations of Kanamori et al[1] for prevention of the spread of pathogens from ice machines. These recommendations include use of automatic dispensers, not handling ice by hand, and providing a regular disinfection program for ice machines.

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Nosocomial outbreak of cryptosporidiosis in AIDS patients

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Abstract

***Objective*—To describe a nosocomial outbreak of cryptosporidiosis during four months after June 1989.**

***Setting*—A department of infectious diseases in Copenhagen, seeing about half the patients with AIDS in Denmark.**

***Subjects*—73 HIV antibody negative subjects and 60 antibody positive subjects admitted as inpatients during the transmission period of the outbreak (20 June-14 August), of whom 18 (17 with AIDS, one with AIDS related complex), developed cryptosporidiosis. Two further HIV negative subjects (one departmental secretary, one visiting relative) developed cryptosporidiosis.**

***Main outcome measures*—Cryptosporidia in stool samples, clinical symptoms, CD4 cell count, HIV antigen concentration, chemotherapeutic treatment.**

***Results*—The source of the outbreak was identified as ice from an ice machine in the ward, contaminated by an incontinent, psychotic patient with cryptosporidiosis picking out ice for cold drinks. The mean incubation time was at least 13 days—that is, twice that in HIV-negative patients. Of the 18 patients with AIDS who developed cryptosporidiosis, five recovered, two were symptomless carriers, three died of unrelated causes, and eight died after prolonged diarrhoea. Among the 57 exposed HIV antibody positive inpatients (excluding two patients and the index case with cryptosporidiosis diagnosed elsewhere), significantly more of those who developed symptomatic cryptosporidiosis received oral sulphonamides than those who did not (91%, 10/11 *v* 48%, 21/44, $p<0{\cdot}05$).**

***Conclusions*—The clinical and epidemiological findings indicate that infection was the consequence of very small inocula. Increased sensitivity to cryptosporidiosis may be an unrecognised side effect of oral sulphonamide treatment in patients with AIDS.**

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Introduction

Infection with cryptosporidium species is a cause of shortlived diarrhoea in immunocompetent subjects[1,2] whereas in patients with AIDS it causes prolonged, often fatal, diarrhoea, for which no effective antiparasitic treatment exists.[3] In Denmark cryptosporidiosis of more than one month's duration was seen in seven (3%) of the first 231 Danish AIDS patients.[5]

We report the epidemiological data and some clinical observations from a nosocomial outbreak of cryptosporidiosis in AIDS patients.

Setting

The department of infectious diseases provides health care services to about 100 patients with AIDS and about 500 HIV antibody positive subjects without AIDS. The ward has 32 beds in one bedded and two bedded rooms, about half of which are occupied by patients with HIV related diseases. Cryptosporidiosis was diagnosed in one patient in the department in 1987, in three in 1988, and in one during the first five months of 1989.

Outbreak

On 19 June 1989 a 29 year old, psychotic homosexual man was admitted from a closed psychiatric ward. He was HIV antibody positive, and AIDS was diagnosed on the basis of progressive multifocal leucoencephalopathy. He had watery diarrhoea and faecal incontinence, and cryptosporidia were found in a stool sample taken on 20 June. He was grossly negligent about basic hygiene, including washing his hands, and was confined to his room, but as no physical restraint could be used he was repeatedly observed in the ward; on at least two occasions he was seen picking ice for soft drinks with his hands from an ice machine situated in a storeroom in the ward.

During the subsequent 10 weeks 17 cases of cryptosporidiosis were diagnosed, with a peak incidence about seven weeks after the arrival of the index case. Cryptosporidiosis was diagnosed in another two patients 14 and 17 weeks after the arrival of the index case. The cases had one common exposure. During the hot summer of 1989 ice cooled soft drinks, with ice from the ice machine in the ward, were served to patients, staff, and visiting relatives both in the ward and in the outpatient department.

Measures taken

The ice machine was closed down on 14 August and cleaned, and the ice was subsequently used only for cooling blood samples. Isolation procedures for patients with cryptosporidiosis (wearing gloves and gowns for close contact) were not changed, and no other supplies of food and beverage were changed. Regional and national health authorities were notified of the outbreak. The new cases seen thereafter could all be traced to exposure during admission or visits to the outpatient department from 20 June to 14 August (the transmission period).

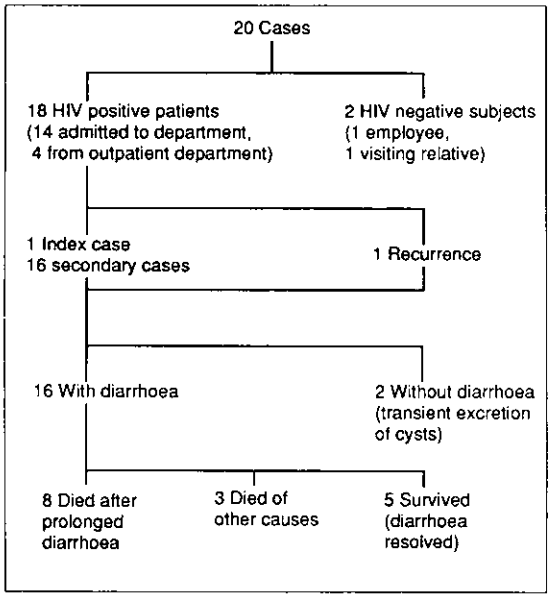
The HIV antibody positive patients who had been admitted as inpatients during the transmission period were asked to deliver a faecal sample for examination for cryptosporidium oocysts, irrespective of their symptoms. Of 60 such inpatients, 38 (63%) delivered a sample. Outpatients, HIV antibody negative inpatients, and staff members with symptoms of cryptosporidiosis were also offered a stool examination.

All stool samples were examined for cryptosporidia with a modified Ziehl-Neelsen staining technique of faecal smears.[6]

Patients

During the transmission period 73 HIV antibody negative and 60 antibody positive subjects were admitted as inpatients. Among the 60 HIV antibody positive inpatients, 14 developed symptomatic cryptosporidiosis and two asymptomatic cyst excretion; six patients with symptoms and 16 without had negative results on stool examination, and 22 HIV antibody positive patients did not deliver a faecal sample for examination. Four cases of cryptosporidiosis were diagnosed in HIV antibody positive patients, whose only contact with the department in the transmission period was visits to the outpatient department (figure).

The 20 cases of cryptosporidiosis were identified. They included HIV antibody negative subjects with diarrhoea: a secretary employed in the department and a visiting relative. The 18 HIV antibody positive patients with cryptosporidiosis comprised 17 patients with AIDS and one with AIDS related complex. One of the patients with AIDS had recovered from an episode of cryptosporidiosis six months before this epidemic.



Summary of cases involved in the outbreak of cryptosporidiosis, June 1989 to October 1989

TABLE I—*Risk factors for acquiring cryptosporidium diarrhoea in exposed HIV antibody positive patients*

	Inpatients with diarrhoea (n=11)	Inpatients without diarrhoea* (n=44)	p Value*†
Mean (SD) age (years)	40 (8·8)	38 (10·4)	NS
No (%) with AIDS	11 (100)	32 (73)	≤0·1
Mean (SD) CD4 cells (×10⁶/l)	43 (40·8)	168 (227)	0·08
No (%) positive for HIV antigen‡	8 (73)	24 (57)§	NS
Mean (SD) exposure (days)	17 (12)	15 (9)	NS
No (%) taking oral zidovudine	7 (64)	24 (55)	NS
No (%) taking oral sulphonamides‖	10 (91)	21 (48)	<0·05
No (%) taking oral corticosteroids	4 (36)	9 (20)	NS

*Excluding two symptomless carriers. ‡p24 HIV antigenaemia.
†According to *t* test or Fisher's exact test. §42 Patients tested.
‖Sulphamethoxazole-trimethoprim treatment or prophylaxis against *Pneumocystis carinii* pneumonia given to nine patients with diarrhoea and 20 without; one patient in each group received sulphadiazine-pyrimethamine for cerebral toxoplasmosis.

TABLE II—*Selected characteristics of 18 HIV antibody positive patients with cryptosporidiosis. Values are medians (ranges)*

	With no diarrhoea (n=2)	Recovering from diarrhoea (n=5)	Dying from other causes (n=3)	Dying mainly from diarrhoea (n=8)
CD4 cells (×10⁶/l)	248 (48-448)	91 (7-304)	5 (5-96)	40 (0-112)
HIV antigen (U/l)	331 (325-336)	622 (77->1000)	Negative	382 (75-1000)
Duration of diarrhoea (days)		9 (2-90)	6 (6-20)	110 (34-189)

Of the 60 HIV positive patients, only 57 were exposed to cryptosporidium infection as two patients in addition to the index case had cryptosporidiosis diagnosed elsewhere before any contact with the department. The attack rate—that is, cases of symptomatic cryptosporidiosis per number of patients exposed—among HIV antibody positive inpatients was thus 19% (11/57); among HIV antibody negative inpatients 0% (0/73); and among HIV antibody positive outpatients almost 0·5% (4 cases in about 700 visits).

Determinants of infection

The records of all HIV antibody positive patients exposed to cryptosporidium transmission as inpatients were reviewed for risk factors for acquiring symptomatic cryptosporidiosis (table I). The symptomless carriers were excluded from the analysis as other carriers may have been missed among the 22 HIV antibody positive inpatients who did not deliver a stool sample. We found insignificant trends towards higher CD4 counts, less frequent HIV antigenaemia, and fewer AIDS cases among the 44 patients without symptomatic cryptosporidiosis. Ten patients (91%) with cryptosporidiosis compared with only 21 patients (48%) without cryptosporidium diarrhoea ($p<0·05$) received oral sulphamethoxazole-trimethoprim treatment or prophylaxis for *Pneumocystis carinii* pneumonia, or both, or sulphadiazine-pyrimethamine treatment for cerebral toxoplasmosis at some time during the transmission period.

Clinical course

Among the 16 HIV antibody positive patients with diarrhoea the outcomes were as follows: in five (31%, 95% confidence interval 11% to 59%) the diarrhoea resolved, three (19%, 4% to 46%) had diarrhoea but died of other causes, and eight (50%, 25% to 75%) died after prolonged diarrhoea. The remaining two HIV antibody positive patients with cryptosporidiosis, who did not have diarrhoea, were without cryptosporidium oocysts on faecal re-examination. In the two HIV antibody negative patients the diarrhoea resolved after two and 10 days respectively.

Determinants of outcome of infection

Table II shows selected clinical and paraclinical data on the 18 HIV antibody positive patients in the outbreak. Of the five patients whose diarrhoea resolved, three recovered spontaneously after diarrhoea lasting two, three, and nine days respectively. Two patients with prolonged diarrhoea recovered after treatment with hyperimmune bovine colostrum or zidovudine for 46 and 90 days respectively.

The HIV antigen concentration and CD4 counts did not differ significantly between the five patients who recovered and the eight who died of cryptosporidiosis; most of the patients had a content of <100 million CD4 cells/l.

Attempts at treatment

The following treatments were tried, with negligible or no effect: sodium antimony glyconate (Pentostam) 5 mg/kg intravenously plus 5 mg/kg orally per day (three patients), roxithromycin (three), spiramycin (five), clindamycin plus quinine (one), and intravenous interleukin 2 (one). Hyperimmune bovine colostrum and placebo were given to eight patients as part of a placebo controlled, blinded, crossover clinical trial (N Højlyng, personal communication). Table III summarises the treatment with zidovudine, which had no consistent beneficial effect.

TABLE III—*Zidovudine treatment of 18 HIV antibody positive patients with cryptosporidiosis*

	With no diarrhoea (n=2)	Recovering from diarrhoea (n=5)	Dying from other causes (n=3)	Dying mainly from diarrhoea (n=8)
No treatment	2	2	3	1
Pre-existing and continuing treatment		2		6
Treatment started during diarrhoea		1		1

Incubation time

In six patients (ignoring the two late cases of patients with minimum incubation times of 55 and 77 days) the mean interval between their last contact with the department and the onset of diarrhoea was 13 days (range 2-31 days), implying that if they were infected in the department the incubation time must have been on average at least 13 days; as it is a minimum estimate the incubation time was most likely longer.

Discussion

Among the 19 secondary cases of patients in this outbreak, 17 had diarrhoea or asymptomatic carriage of cryptosporidia diagnosed within two weeks after the interruption of the hypothetical route of transmission. Two cases of cryptosporidiosis occurred 8 and 11 weeks after closure and disinfection of the ice machine, and it is impossible to tell whether they resulted from nosocomial spread with a long incubation or latency period or represented non-epidemic cases. Another of the 17 cases could be either a nosocomial reinfection or a recurrence of cryptosporidiosis. Recognising these uncertainties, we report the details of all 19 cases of infection possibly acquired in the department, plus the index case.

Direct evidence incriminating the ice machine in the ward is lacking, as it was closed and disinfected before it was realised that cryptosporidia might have been detected after filtration of the water it contained.[7,8] Our contention that ice from the machine transmitted cryptosporidia around in this outbreak, however, is supported by strong circumstantial evidence. Firstly, the patient who was the index case was observed picking ice with his hands, which on other occasions were observed by other staff members to be soiled with faeces. Secondly, the outbreak included a visiting relative and an employee who shared soft drinks but not food with the patients. As the employee was a secretary infection through direct patient contact was ruled out; the visiting relative was the wife of a patient with fever of unknown origin, unrelated to HIV infection. Thirdly, the outbreak included four patients whose only contact with the department during the transmission period were visits to the outpatient department. Ice from the ice machine was used in soft drinks for those attending the outpatient department during the transmission period. Fourthly, transmission was stopped after strict confinement of the index case to his room and closure of the ice machine despite the continued presence in the ward, for several months, of patients infected with cryptosporidia during the outbreak. No other departmental routines were changed.

During the course of this outbreak several important clinical observations were made. The minimum mean incubation time of 13 days is about twice as long as the two to five days and 7·2 days previously reported.[3,9] Our incubation times may represent a biased selection of the minimum incubation times observed. As the bias consists of exclusion of two patients with very long minimum incubation times a less biased estimate would yield an even longer incubation time.

In a study of cryptosporidiosis in Finns going to Leningrad[9] no case of asymptomatic carriage was detected, and the authors suggested that such cases are rare. We found two cases of asymptomatic carriage among 18 symptomless patients examined for cryptosporidia, and together with other studies in AIDS patients[10-12] this indicates that asymptomatic carriage of cryptosporidia is a frequent occurrence in exposed AIDS patients, just as it is in non-immune children in locations where cryptosporidiosis is hyperendemic.[13] This might explain the longer incubation time in our AIDS patients with cryptosporidiosis, as diarrhoea could result from aggravation of the immune deficiency in a symptomless HIV antibody positive carrier, giving the appearance of a long incubation time. Alternatively, however, a long incubation time may result, at least in part, from infection with relatively small inocula, too small to establish infection in immunocompetent subjects. This is consistent with three of our clinical observations. Firstly, we saw no cases of symptomatic cryptosporidiosis among HIV antibody negative patients despite similar exposure of a similar number of patients; in contrast, the attack rate among our HIV antibody positive inpatients was 19%. Secondly, our analysis of risk factors showed consistent trends, though individually not significant, towards more advanced HIV disease among patients developing symptomatic cryptosporidiosis, indicating a relation between immunity and infectious dose. Thirdly, the analysis strongly points to treatment with oral sulphonamides as an important risk factor. In experimental studies the inoculum required for establishing clinical infection with enteric organisms may be reduced dramatically when the host is pretreated with oral antibiotics.[14] Whether oral sulphonamides independently increase the risk of acquiring cryptosporidiosis will require further studies.

Recovery from diarrhoea was seen in 31% of the patients, which corresponds to reported figures.[3,12] We did not see an unequivocal positive effect of any of the treatments tried. The recovery rates in uncontrolled treatment trials[10,15,16] are of the same magnitude as the rate of spontaneous recovery, underscoring the unreliability of such studies.

Only a few reports of nosocomial spread of cryptosporidiosis exist. In one case five of six patients in a bone marrow transplant unit contracted cryptosporidiosis; all ultimately recovered,[8] but the mode of spread was not discovered. In another report spread of cryptosporidiosis from an AIDS patient to staff members was described.[17]

The present outbreak of hospital acquired cryptosporidiosis is thus the most serious to date, both as regards number of cases and number of deaths attributable to diarrhoea. Routine precautions against transmission of enteric organisms were in use throughout the outbreak, and we found no case for using more restrictive guidelines. Continent, cooperative patients need not be isolated in their rooms. The painful lesson from this outbreak is not that the guidelines were insufficient, but that their non-observance may have serious consequences.

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For Debate

What will the medical director do?

Ian H Johnston

Among the wide range of new arrangements and roles either implied or introduced by the new organisation of the NHS there is one which has received little attention, yet is potentially very significant—that is, the role of the medical director, one of the required (in most cases) executive directors of boards of NHS trusts.[1] It is curious that this development should have received such little attention. Most potential trusts are hospitals whose aim will be to deliver and develop good quality medical services, and ensuring this must be the prime focus of the boards of directors. Without such a focus a board would be equivalent to a manufacturer not being concerned with the quality of a product. The medical director will have the key responsibility both for ensuring that the focus is maintained and for informing the board of what is requisite. However, before attempting to clarify further the role of a medical director we should be reminded of some features of the post that may be deduced from the NHS and Community Care Act and the working papers which supplemented the white paper *Working for Patients*.

Firstly, the medical director is appointed by the chairman, the non-executive directors, and the general manager.[2] Though it would be preferable that the person appointed had the confidence of the medical staff, the post of medical director is not a representative appointment but an executive one, in which corporate responsibility is shared as a member of the board and responsibility is to the general manager. Indeed, no member of a trust board is a representative member, which is one reason why chairmen of medical advisory committees should not become medical directors. Doctors will continue to require independent representative machinery but it would be a confusion of role and interests if one doctor were to attempt to have both an executive and a representative role. (This is, of course, one of the problems that has had to be faced repeatedly by unit medical representatives over the years.)

Secondly, the original working paper says that it might be possible to combine the medical directorship with some clinical work.[2] There clearly exists an expectation that the position requires more than regular attendance at board meetings to represent the views of doctors. In fact, the most powerful reason why this position cannot be combined with a representative—that is, elected—position is that it actually requires a full time executive contribution to developing a trust's services. This assertion is based on an analysis of the work that will be required within the new arrangements for the NHS—in particular, on that required in a large teaching hospital with a wider range of specialties than most hospitals in the United Kingdom. The following is based on the needs of the General Infirmary at Leeds, but is applicable to any large hospital considering NHS trust status.

The major general areas for which a hospital of this size requires appointment of a senior doctor with responsibility for development are as follows.

- Medical services
- Clinical research
- Medical education
- Medical input into contracts for services.

In these areas development can be led only by a doctor, and the position is referred to in the white paper as medical director. This does not imply any line management authority over consultant medical staff, nor does what follows here. What, then, will the medical director do?

Medical services

The medical director's responsibility is to develop the comprehensive provision of medical services and to advise how they contribute to the aims and priorities of the trust. Currently, unless the director of public health attempts this, no individual has this responsibility. The specific responsibilities that would flow from this include the following:

- To overview and advise on arrangements for ensuring that the general performance of medical services in all specialties is efficient and in line with current medical practice and to satisfy the general manager and the board that the arrangements are adequate. An important way of achieving this is through facilitating and supporting the implementation and development of medical audit
- To review existing medical services, identifying any shortfalls in the range of services provided and to proposing means for dealing with them
- To enhance the relation of medical specialties with one another, ensuring that they dovetail as appropriate, including undertaking any arbitration between specialties, as necessary
- To help the general manager in handling consultant contracts
- To develop and facilitate the participation of consultants in management, in particular, in giving direction to the trust
- To establish arrangements for obtaining medical opinions on priorities for development (or retrenchment) and ensure that these priorities are consistent with financial and other considerations
- The role of the board of directors should not be confused here with that of management boards, whose

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CLINICAL STUDIES

Nosocomial Legionnaires' Disease: Aspiration as a Primary Mode of Disease Acquisition

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PURPOSE: Nosocomial Legionnaires' disease remains a significant problem with many unresolved questions regarding transmission of legionella organisms to patients. We performed a case-control and environmental study to identify risk factors and modes of transmission of *Legionella* infection during an outbreak of nosocomial Legionnaires' disease in a military medical center.

PATIENTS AND METHODS: During the calendar year 1989, 14 cases of nosocomial Legionnaires' disease were identified by active surveillance following the discovery of 2 culture-proven cases among organ transplant recipients. Four control patients were matched to each case by age, sex, and date of admission. Cases and controls were compared with respect to past medical history and hospital exposure variables. Odds ratios (ORs) and 95% confidence intervals (CIs) were calculated for matched variables. Environmental culturing of air and water supplies in and around the medical center was also performed.

RESULTS: The case-control study revealed the following significant risk factors for the acquisition of nosocomial Legionnaires' disease: immunosuppressive therapy (OR = 32.7, CI = 4.5 to 302.6), nasogastric tube use (OR = 18.4, CI = 2.6 to 166.2), bedbathing (OR = 10.7, CI = 2.2 to 59.0), and antibiotic therapy (OR = 14.6, CI = 2.9 to 84.4). Shower use (OR = 0.1, CI = 0 to 0.4) appeared to be a negative risk factor. Water cultures revealed *Legionella pneumophila* serogroup 1, monoclonal antibody subtype Philadelphia (identical to all patient isolates) in the ground-water supply to the hospital, 1 hot-water tank, and 15% of 85 potable water sites tested. Air sampling of cooling towers, hospital air intakes, and medical air and oxygen supplies were negative for *Legionella* organisms.

CONCLUSIONS: This study confirms the importance of potable water in transmitting nosocomial Legionnaires' disease and suggests that the organism gains access to the hospital via external water supplies. The risk factors identified in this case-control study provide evidence that Legionnaires' disease may act as a superinfection in a nosocomial setting and is likely acquired by aspiration, similar to other nosocomial pneumonias.

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Since the original description of Legionnaires' disease in Philadelphia in 1976, and the subsequent characterization of the etiologic agent, *Legionella pneumophila*, significant progress has been made in defining the epidemiology and clinical significance of infection with this agent [1,2]. Nevertheless, many questions remain regarding the role of *Legionella* in acute infection of the lower respiratory tract [3]. In particular, the mode of transmission of *Legionella* organisms from environmental sites into humans continues to be controversial [4]. Environmental sources implicated in previous outbreaks of Legionnaires' disease have included potable water, cooling systems, respiratory therapy devices, industrial coolants, and whirlpool spas [5]. Of these sources, potable water has been identified most frequently as the culprit in nosocomial outbreaks of legionellosis [6–20]. Two potential mechanisms by which *Legionella* organisms gain access to the respiratory tract include aerosolization directly from potable water sources and colonization of the oropharynx with subsequent aspiration. A recent study has shown, for the first time, an epidemiologic link between shower use and acquisition of Legionnaires' disease, suggesting aerosolization as the likely mode of acquisition in that study [15]. Circumstantial evidence from other studies, however, suggests that colonization with aspiration may also be a likely mode of organism transfer [4,6,11,18,20].

Investigation of a nosocomial outbreak of legionellosis associated with our hospital potable water supply provided an opportunity to address this issue with a 1-year case-control study.

PATIENTS AND METHODS

Hospital

Wilford Hall USAF Medical Center is a 1,000-bed multi-specialty hospital that delivers primary and tertiary care to the military population of San Antonio, Texas, and maintains active programs in solid organ and bone marrow transplantation. The hospital is composed of a single building built in 1958 with a clinic attachment added in 1981. Water for the hospital system originates from ground-water wells located on the hospital grounds. Water is chlorinated at the well head and then pumped to an energy plant where it is instantaneously heated then delivered to the hospital, where it is stored in the basement in two hot-water tanks. The hot water from these tanks is then mixed and distributed throughout the hospital potable water system.

The entire hospital is supplied by central air conditioning; windows are locked in the closed position. Cooling towers for the hospital are located 200 yards to the north of the hospital and prevailing winds blow to the northeast, away from the hospital.

Case Definition

A case of Legionnaires' disease was defined as a radiographically documented pneumonia in association with one or more of the following test results: a fourfold or greater increase in titer (specimens separated in time by at least 14 days) of indirect immunofluorescent antibodies (IFA) to a titer of greater than or equal to 1:128 using a polyvalent antigen battery consisting of *L. pneumophila* serogroups 1 to 4 (Zeus Scientific Inc., Raritan, NJ); a positive result of a direct immunofluorescent antibody (DFA) test of respiratory secretions or tissue using a monoclonal antibody directed against all known serogroups of *L. pneumophila* (Genetic Systems, Seattle, WA); or isolation of *L. pneumophila* from respiratory secretions or tissue. A case was defined as nosocomial if infection occurred 2 or more days after admission or within 10 days of hospital discharge.

Disease Surveillance and Case Finding

In April 1989, two culture-proven cases of *Legionella* pneumonia were identified in transplant patients on different units. After these cases, active surveillance for the disease was initiated by education of house staff and nurses as to the appropriate diagnostic tests to order. In addition, preprinted order forms for these tests were distributed to patient wards to be used for cases of nosocomial pneumonia. A retrospective review for positive *Legionella* IFA and DFA results for the calendar year 1989 was also performed. Cases of pneumonia were identified in a prospective fashion by the ongoing twice-weekly surveillance of all inpatients performed by the Infection Control Service. When a case was identified, the Infectious Disease consult service was notified and appropriate diagnostic studies were obtained.

Environmental Sampling and Microbiologic Methods

Clinical samples were placed on buffered charcoal yeast extract (BCYE) and two selective media as previously described (Remel, Lenexa, KS) [21]. Sputum samples were pretreated with an acid wash procedure during the final 2 months of the study [21]. Samples of tissue and bronchoscopy specimens were plated directly. Environmental samples were obtained by swabbing faucets and shower heads with sterile rayon swabs and inoculating these directly onto BCYE media supplemented with dyes, glycine, vancomycin, and polymyxin B (DGVP media) [21]. Water samples from the hot-water tanks were collected in two 1.0-L aliquots and filtered through nitrocellulose filters. Scrapings from these filters were then placed onto DGVP media. In addition, quantitative analysis of *Legionella* colonization was performed by inoculating 0.1-mL samples of potable water directly onto DGVP media as well as filtering 100-mL samples through nitrocellulose filters and plating these on DGVP media. Air samples were obtained using a two-stage microbial air sampler (Anderson Samplers, Atlanta, GA) from sites around the base of the cooling tower, at air intakes of the hospital, and from the hospital medical air and oxygen systems. The sampler was connected to a portable vacuum pump and flow meter. The two-stage sampler separates particles into nonrespirable (greater than 8.0 μm) and respirable droplet sizes [22]. Petri dishes containing BCYE media were placed on each stage and sampling was performed for 15 minutes at each site.

Clinical and environmental cultures were examined daily for 14 days. All colonies compatible with *Legionella* organisms were studied by a monoclonal antibody directed against all known serogroups of *L. pneumophila* (Genetic Systems). Serogrouping of *L. pneumophila* isolates was performed by the Special Pathogens Laboratory at the Pittsburgh Veterans Administration Hospital (Richard M. Vickers). Monoclonal antibody subtyping of *L. pneumophila* serogroup 1 isolates was performed by Dr. Jean R. Joly [23].

Case-Control Study

Control patients without pneumonia were select-

TABLE I

Legionella Diagnostic Studies in Case Patients

Test	No. Positive/No. With Test Performed (%)
DFA	12/14 (86)
IFA	3/9 (33)
Culture	3/12 (25)
DFA + culture	2/12 (17)
DFA + IFA	1/9 (11)
DFA + IFA + culture	1/9 (11)

DFA = direct fluorescent antibody test; IFA = fourfold rise in indirect fluorescent antibody titer of specimens separated by at least 14 days.

TABLE II

Univariate Analysis of Past Medical History Variables Evaluated in the Case-Control Study

Risk	No. of Cases (%)	No. of Controls (%)	Odds Ratio	95% Confidence Intervals
Immunosuppression*	8 (57)	2 (4)	32.7	4.5–302.6
Steroid use	8 (57)	4 (8)	15.7	2.9–93.1
Chronic renal failure	4 (29)	1 (2)	20.0	1.7–534.8
H_2-blocker use	8 (57)	10 (20)	5.3	1.3–23.3
Diabetes	1 (7)	1 (2)	3.8	0–156.2
Cancer	4 (29)	11 (22)	1.5	0.3–6.6
Dialysis	1 (7)	None	Undefined	Undefined
Cardiovascular disease	5 (36)	16 (31)	1.2	0.3–4.9
Chronic obstructive pulmonary disease	1 (7)	7 (14)	0.5	0–4.7

*$p < 0.05$ by sequential bivariate analysis of variables found to be significant in the univariate analysis.

ed and matched by age (± 5 years), sex, and date of admission to each case patient in a ratio of 4:1. Thorough medical record reviews, including review of nursing notes and respiratory therapy records, were conducted to determine potential risk factors for acquisition of *Legionella* infection. Past medical history variables present prior to and during hospitalization included: history of cancer, cardiovascular disease, chronic obstructive pulmonary disease, asthma, chronic renal failure, use of steroids, immunosuppressive therapy or antacids/antihistamines (H_2 blockers), smoking, and alcohol use. Hospital exposure variables studied for the 10 days prior to onset of pneumonia were oxygen therapy, intravenous antibiotics, nebulizer use, showering, bedbathing, radiology procedures, endoscopy, presence of a nasogastric tube, physical therapy, bronchoscopy, surgery, general anesthesia, emergency room admission, endotracheal intubation, pulmonary function testing, and ambulation.

Odds ratios (ORs) and Cornfield 95% confidence intervals (95% CIs) for matched variables were calculated using EPI INFO 5 computer software (USD Inc., Stone Mountain, GA). In order to identify confounding among variables, a series of stratified 2 × 2 tables were performed in which each significant variable from the univariate analysis was stratified against each other significant variable in a sequential bivariate analysis (Mantel-Haenszel stratified analysis) [24].

RESULTS

From January 1 through December 31, 1989, 14 cases of nosocomial pneumonia were identified that met the case definition for Legionnaires' disease. The mean age of these cases was 46.7 (standard deviation [SD] ± 19.7) years; the sex distribution was equal. Thirteen of the 14 patients (93%) were white. The mean duration of hospitalization prior to onset of pneumonia was 20.5 (SD ± 15.5) days. The case-fatality rate was 43%. During this time period, there was no increase noted in the overall nosocomial pneumonia rate in our hospital compared with historical norms. Major underlying conditions for case patients included allogeneic bone marrow transplantation in three (21%), renal transplantation in two (14%), neurologic disease in two (14%), coronary artery disease in two (14%), and one case each of acute leukemia, solid tumor, ulcerative colitis, diabetes mellitis with renal failure, and surgery for a thyroidectomy.

The diagnostic studies used to confirm the diagnosis of *Legionella* pneumonia are shown in **Table I.** Culture-negative cases were significantly more likely to have been treated with third-generation cephalosporins, doxycycline, or erythromycin in the 10 days prior to disease onset compared with culture-positive cases ($p = 0.03$, Fisher exact test). All patient isolates were shown to be *L. pneumophila* serogroup 1, subtype Philadelphia, by monoclonal antibody subtyping [23]. All 14 of the nosocomial cases had at least 1 DFA test performed (mean: 2.5 per patient), and 12 patients (86%) had at least 1 positive test result. In addition, of the 35 specimens submitted for DFA testing on our 14 cases, 20 (57%) were positive, or 1.7 per case.

Case-Control Study

Fifty-one control patients (mean of 3.6 per case) were matched to the 14 case patients as described above. The mean age of controls was 46.7 years (identical to cases) and the mean duration of hospitalization for controls was 5.9 days (SD ± 6.5 days). **Table II** shows the results of a univariate analysis of the past medical history variables evaluated in this study. When adjustment was made for variables found to be statistically significant in the univariate analysis, only immunosuppressive therapy remained a statistically significant ($p < 0.05$ by sequential bivariate analysis) medical history risk factor for the acquisition of *Legionella* infection.

Table III shows a univariate analysis of the hos-

pital exposure variables studied in this outbreak as potential risk factors for the acquisition of Legionnaires' disease. Of these variables, only the presence of a nasogastric tube, antibiotic use, and bedbathing remained statistically significant ($p < 0.05$) after controlling for significant hospital exposure variables from the univariate analysis.

Because of the difference in duration of hospitalization prior to the onset of *Legionella* infection for cases versus controls, we performed a subset analysis on 10 cases and 25 controls that were additionally matched on length of stay (± 7 days, case median = 10 days [range: 2 to 36 days], control median = 7 days [range: 1 to 32 days]). The only difference between this subset analysis and the full cohort analysis was that exposure to H_2 blockers did not remain a statistically significant past medical history risk factor ($p = 0.11$, Fisher exact test). All other medical history and hospital exposure risk factors were unchanged.

Analysis of hospital ward as a risk factor for *Legionella* infection was hampered by an inadequate number of suitable controls in the bone marrow transplant and intensive care units. Of note, however, is the observation that all case patients were hospitalized on the bone marrow transplant, renal transplant, or intensive care units at some time during the 10 days prior to disease onset.

TABLE III

Univariate Analysis of Hospital Exposure Variables Present in the 10 Days Prior to Legionnaires' Disease Onset

Exposure	No. of Cases (%)	No. of Controls (%)	Odds Ratio	95% Confidence Intervals
Nasogastric tube*	6 (43)	2 (4)	18.4	2.6–166.2
Bedbathing*	11 (78)	13 (25)	10.7	2.2–59.0
Antibiotic use*	11 (78)	10 (20)	14.6	2.9–84.4
Nebulizer use	4 (29)	1 (2)	20.0	1.7–534.8
Oxygen use	6 (43)	6 (12)	5.6	1.2–27.7
Radiology	8 (57)	14 (27)	3.5	0.8–14.5
Endoscopy	1 (7)	2 (4)	1.8	0–30.7
Bronchoscopy	1 (7)	None	Undefined	Undefined
Pulmonary function tests	1 (7)	1 (2)	3.8	0–156.2
Endotracheal tube	6 (43)	13 (25)	2.2	0.5–8.9
Surgery	5 (36)	24 (47)	0.6	0.1–2.5
Emergency room admission	1 (7)	6 (12)	0.6	0–5.8
Ambulation	5 (36)	44 (86)	0.1	0–0.4
Showering	5 (36)	27 (53)	0.1	0–0.4

*$p < 0.05$ by sequential bivariate analysis of variables found to be significant in the univariate analysis.

Environmental Culturing

Despite the initial recognition of *Legionella* cases in April 1989, testing of environmental sites did not begin until December 1989. A number of factors led to this decision, including concerns about the specificity of diagnosis in the cases identified by DFA alone, as well as the possibility of finding *Legionella* in the environment without adequately documenting a sustained outbreak in our patient population. However, after documenting a third culture-proven case of *Legionella* pneumonia in November 1989, it became clear that we were experiencing a persistent problem and environmental testing for *Legionella* was initiated.

Air sampling was performed from 4 sites around the cooling towers, 18 air intakes for the hospital, and the hospital medical air and oxygen systems. In addition, water mist samples were obtained from patient bathrooms with a settle plate technique while the shower was running in an attempt to isolate aerosolized organisms. We were unable to isolate any *Legionella* species from these air and water mist samples.

Water sampling outside the hospital was performed from the ground-water well on the hospital grounds, from the chlorinator at the well head, and from the energy plant. Within the hospital, water samples and swabs were obtained from both hot-water tanks in the basement, and swab cultures were performed on 85 sites from patient care areas, including faucets and shower heads in patient rooms, intensive care units, and operating rooms, as well as from fountains located on the first floor of the hospital. In addition, the water traps from 17 ventilators were cultured for *Legionella*. *L. pneumophila* was isolated from the ground water at the well head, from both hot-water tanks in the hospital, from 1 of the 2 fountains, and from 24 (28%) of the patient care areas on high-risk wards where *Legionella* cases had been housed. None of the ventilators tested were found to harbor *Legionella*.

Serogrouping and monoclonal antibody subtyping revealed that the organisms isolated from the ground-water well, 1 of the hot-water tanks, and 13 patient care areas were *L. pneumophila* serogroup 1, subtype Philadelphia, identical to our patient isolates. The other hot-water tank and 11 patient care sites contained *L. pneumophila* serogroup 3. The fountain isolate was an *L. pneumophila* serogroup other than 1 through 6. Quantitative analysis for the number of organisms present in potable water demonstrated 3 to 80 colonies of *Legionella* organisms per plate, by direct plating of 0.1 mL of tap water, and greater than 100 colonies per plate when filtering a 100-mL aliquot of water. These results suggest that our patients were exposed to an organism burden on the order of 10^4 to 10^6 colony-forming units per liter (cfu/L) in the potable water supply.

Reviews of maintenance records for the hospital over the course of the year revealed that the potable water chlorine levels, although inadequate for controlling *Legionella* colonization, had been maintained in the acceptable range (0.3 to 0.5 ppm). In

addition, the water temperature in the hot-water tanks had not dropped below 50°C during this time period. Of potential significance, however, was the observation that major renovations were taking place in the water supply to the hospital during 1989. During the time of this outbreak, pipes carrying water from the ground-water wells to the energy plant were being excavated and replaced.

COMMENTS

This report, describing a 1-year case-control and environmental investigation of 14 cases of nosocomial legionellosis, again implicates the potable water supply as the likely source of infection. This outbreak was first recognized, as in other outbreaks, by the sudden appearance of cases among a transplant population [13,14,25]. These sentinel cases prompted us to increase our surveillance for the disease using multiple diagnostic modalities in other patients with hospital-acquired pneumonia. As other authors have noted, many of these cases may have been missed had we not employed aggressive specialized techniques to confirm the diagnosis [7,11,12].

The relatively low yield from cultures in this series (25%) may be due to several factors. First, we did not routinely use selective BCYE media or acid pretreatment of specimens, both of which have been shown to increase *Legionella* recovery rates [26–28]. In addition, once this outbreak was recognized in our hospital, the physicians caring for immunocompromised patients began the early empiric use of erythromycin or doxycycline for patients with nosocomial pneumonia, frequently prior to obtainment of sputum or bronchoscopic cultures. Furthermore, many of our patients were already receiving broad-spectrum antibiotics at the time they developed their *Legionella* infection, and we occasionally noted overgrowth of the *Legionella* plates with yeast despite acid pretreatment of samples. An antibiotic pretreatment effect in reducing *Legionella* culture rates is supported by our finding that culture-negative cases were significantly more likely to have been treated with broad-spectrum antibiotics or antibiotics effective against *Legionella* compared with culture-positive cases. Other recent nosocomial legionellosis series have shown *Legionella* culture recovery rates of 14% to 35%, similar to our experience [12,15,17]. In addition, the seroconversion rate of 33% noted among our cases compares favorably with other recent series of nosocomial legionellosis in which seroconversion rates of 33% to 47% have been reported [12,14]. The inclusion of bone marrow transplant patients in our series may have also decreased the yield from serologic testing, since these patients have impaired humoral responses to new antigenic challenge [29].

The case-control portion of our investigation found immunosuppressive, corticosteroid, and H_2-blocker therapy as well as chronic renal failure to be significant univariate medical history risk factors for the acquisition of Legionnaires' disease in our hospital. After an analysis for confounding variables, however, only the use of immunosuppressive therapy remained significant. Corticosteroid and immunosuppressive therapies have previously been shown to be significant risk factors for developing nosocomial *Legionella* infection in a number of other studies [14,15,30]. Antihistamine (H_2-blocker) therapy, however, has not previously been associated with the development of Legionnaires' disease. Antihistamine therapy has, however, been shown to predispose to the acquisition of nosocomial pneumonia in general [31,32], presumably by allowing bacteria to colonize the gastrointestinal tract with the subsequent aspiration of these organisms [33]. Although demonstrated only in the univariate analysis, the increased risk for *Legionella* infection in our patients treated with H_2-blocker therapy suggests that *Legionella* organisms may be acquired in a manner similar to other nosocomial pneumonias.

In the univariate analysis of hospital exposures associated with *Legionella* in this study, the presence of a nasogastric tube, bedbathing, antibiotic treatment, nebulizer use, and oxygen use appeared to be significant variables. After adjustment for confounding, however, only nasogastric tube use, bedbathing, and antibiotic use remained significant. This association between *Legionella* infection and the presence of a nasogastric tube among our cases strongly supports the role of aspiration as a mode of disease acquisition. Marrie *et al* [20] have also recently described nasogastric tubes as a risk factor for nosocomial Legionnaires' disease. They suggest that microaspiration of contaminated potable water used to flush these tubes may be an important mode of disease acquisition. Our study supports this concept and suggests that nasogastric tube use may be a major risk factor for *Legionella* infection in hospitals that have potable water contaminated by *Legionella* organisms.

Previous studies have suggested that patients may acquire *Legionella* infection in the hospital by inhaling aerosolized organisms while showering [15,18]. In the present study, however, showering appeared to be a negative risk factor for the development of legionellosis (Table III). Conversely, patients taking only bed baths were at increased risk of developing the disease in our hospital. This finding also supports the role of aspiration in the acqui-

sition of disease in this study. Patients confined to bed, too ill to take showers, would be expected to have an increased risk for aspiration. Other nosocomial *Legionella* studies have also noted a negative association between cases and showering (or duration of time spent showering) [7,9,19], suggesting that mechanisms other than aerosolization from showers are important in transmitting the organism in a nosocomial setting.

Antibiotic therapy, in a number of previous studies, has been shown to be a significant risk factor for the development of superinfection, in general, and nosocomial pneumonia, in particular [34–36]. Antibiotic therapy has not previously been associated with the development of *Legionella* infection, however. Our finding of antibiotic therapy as a significant risk factor for the development of legionellosis suggests that antibiotics may alter the usual commensal flora, allowing for colonization by *Legionella* organisms.

Although this study reveals an epidemiologic link between our cases and known risk factors for colonization by opportunistic pathogens, we did not demonstrate oropharyngeal colonization by *Legionella* organisms. Two previous studies have suggested, however, that colonization by *Legionella* organisms may occur [37,38]. Further studies in this area are necessary with more sensitive diagnostic methods, such as polymerase chain reaction, in order to document the presence of *Legionella* colonization.

The use of medication nebulizers has recently been shown to be associated with an outbreak of nosocomial Legionnaires' disease [39]. In that outbreak, it was noted that 57% of respiratory therapy personnel rinsed nebulizers in tap water. In the current study, use of nebulizer therapy appeared to be a significant risk factor in the univariate analysis, although only four case patients (28%) were exposed to this variable. In a blind survey of our own respiratory therapy personnel, 66% admitted to rinsing nebulizers in tap water. On the basis of these observations, we would agree with Mastro *et al* [39] that rinsing nebulizers with tap water may be a common practice among respiratory therapy personnel. Although nebulizer therapy did not appear to be the major mode of *Legionella* transmission in this study, it may have been an important risk factor for those case patients exposed to this variable. We concur with the recommendations of Mastro *et al* [39] that nebulizers should not be rinsed or filled with tap water.

Our environmental investigation indicates that the reservoir of *Legionella* in our hospital is the potable water supply. *L. pneumophila* serogroup 1 isolates of the same monoclonal antibody subtype were isolated from cases and environmental sites, including a hot-water tank supplying patient care areas and multiple sinks and showers on patient wards where cases occurred. We were unable to isolate *Legionella* organisms from air sampling around the hospital cooling towers, from air intakes to the hospital, or from the hospital medical air and oxygen supplies, demonstrating the absence of *Legionella* organisms in aerosols from other potential sources. Also of significance is the finding of an identical subtype of *L. pneumophila* serogroup 1 from the ground water that supplies the hospital system. Previous authors have theorized that *Legionella* organisms gain access to the hospital water system from municipal or reservoir water supplies [40], but this is the first study in which the outbreak-associated strain has been cultured from the ground-water supply to a hospital. The temporal relationship between the excavation and replacement of pipes carrying water from the ground-water wells to the energy plant, and the onset of this outbreak, is intriguing. We speculate that this disturbance of the water supply may have triggered or exacerbated colonization of the hospital potable water system leading to the onset of cases among our patients. Because of this observation, we would recommend increased surveillance for nosocomial Legionnaires' disease, among susceptible patients, during periods of construction or maintenance of hospital water supplies.

In summary, this 1-year case-control and environmental study of nosocomial legionellosis has demonstrated *Legionella* infection in association with known risk factors for colonization by nosocomial pathogens. In addition, we have shown that *Legionella* infection is associated with risk factors for aspiration, suggesting that aspiration may be an important mode of disease acquisition. We have also confirmed that the outbreak-related strain of *Legionella* likely gains access to the hospital via the external water supply. Future studies should focus on quantitating the threshold of *Legionella* colonization that puts patients at risk of acquiring disease, as well as determining optimal methods for decreasing *Legionella* colonization of potable water systems.

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Antimicrobial Resistance and Infection Control

RESEARCH Open Access

Reduced rate of intensive care unit acquired gram-negative bacilli after removal of sinks and introduction of 'water-free' patient care

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Abstract

Background: Sinks in patient rooms are associated with hospital-acquired infections. The aim of this study was to evaluate the effect of removal of sinks from the Intensive Care Unit (ICU) patient rooms and the introduction of 'water-free' patient care on gram-negative bacilli colonization rates.

Methods: We conducted a 2-year pre/post quasi-experimental study that compared monthly gram-negative bacilli colonization rates pre- and post-intervention using segmented regression analysis of interrupted time series data. Five ICUs of a tertiary care medical center were included. Participants were all patients of 18 years and older admitted to our ICUs for at least 48 h who also received selective digestive tract decontamination during the twelve month pre-intervention or the twelve month post-intervention period. The effect of sink removal and the introduction of 'water-free' patient care on colonization rates with gram-negative bacilli was evaluated. The main outcome of this study was the monthly colonization rate with gram-negative bacilli (GNB). Yeast colonization rates were used as a 'negative control'. In addition, colonization rates were calculated for first positive culture results from cultures taken ≥3, ≥5, ≥7, ≥10 and ≥14 days after ICU-admission, rate ratios (RR) were calculated and differences tested with chi-squared tests.

Results: In the pre-intervention period, 1496 patients (9153 admission days) and in the post-intervention period 1444 patients (9044 admission days) were included. Segmented regression analysis showed that the intervention was followed by a statistically significant immediate reduction in GNB colonization in absence of a pre or post intervention trend in GNB colonization. The overall GNB colonization rate dropped from 26.3 to 21.6 GNB/1000 ICU admission days (colonization rate ratio 0.82; 95%CI 0.67–0.99; $P = 0.02$). The reduction in GNB colonization rate became more pronounced in patients with a longer ICU-Length of Stay (LOS): from a 1.22-fold reduction (≥2 days), to a 1.6-fold (≥5 days; $P = 0.002$), 2.5-fold (for ≥10 days; $P < 0.001$) to a 3.6-fold (≥14 days; $P < 0.001$) reduction.

Conclusions: Removal of sinks from patient rooms and introduction of a method of 'water-free' patient care is associated with a significant reduction of patient colonization with GNB, especially in patients with a longer ICU length of stay.

Keywords: Intensive care unit, Sinks, Gram-negative bacilli, Multidrug resistance, 'Water-free' patient care, Length of stay, Colonization

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Background

Hospital acquired infections in the Intensive Care Unit (ICU) result in patient morbidity and mortality [1]. Environmental contamination in hospitals wards and ICUs is a recognized problem for infection prevention and control [2–7], as the environment may facilitate transmission of several important health care-associated pathogens, including gram-negative bacilli (GNB) [8]. As part of the traditional hospital hand hygiene strategy and patient care, sinks are present in virtually all hospital wards and patient rooms. While sinks in the proximity of patients are advocated as a best practice of ICU design [9], involvement of these sinks in hospital-associated infections have been reported as early as the 1970s [10–14]. Recent publications have highlighted the role of sinks as a source of outbreaks and transmission of multidrug-resistant gram-negative bacilli (MDR-GNB) in intensive care units, including paediatric and neonatal ICUs [15–28]. Interventions to reduce transmission of MDR-GNB from sinks in outbreak settings have been explored [29–31], while the effect of sinks on overall infection and colonization rates has not been studied.

As multi-drug resistance (MDR) in GNB is an increasing problem in the management of hospitalized patients [32–34], we investigated the effect of the removal of sinks from the ICU patient rooms combined with 'water-free' patient care on ICU-acquired GNB colonization rates in patients admitted to the ICU.

Methods

Background and study design

In early 2014 an outbreak with extended-spectrum β-lactamase (ESBL)-producing *Enterobacter cloacae* was identified in our ICU that could be related to contaminated sinks. When the decision to remove the sinks and to implement the 'water-free' patient care method was taken, it was prospectively decided to evaluate its effect after 12 months. We conducted a pre/post quasi-experimental study to evaluate the effect of sink removal and introduction of 'water-free' patient care on colonization with GNB in patients admitted to the ICU for at least 48 h during a 12-month pre-intervention (May 2013–April 2014), the months of intervention (May 2014–August 2014) and a 12-month post-intervention period (September 2014–August 2015).

Study setting

This study was conducted in a large tertiary care medical center in the Netherlands with 953 beds. The ICU consists of five subunits, with a total 34 operational single patient rooms. Patients admitted to the ICU that need mechanical ventilation and are anticipated to stay >24 h receive selective digestive tract decontamination (SDD), which consists of 4 days of intravenous cefotaxime and topical application of tobramycin, colistin, and amphotericin B in the oropharynx and stomach [35]. No alterations were made to the SDD protocol during the study period. An essential part of SDD strategy is twice a week routine screening for colonization with gram-negative bacilli and yeasts from rectal, sputum and throat swabs.

The intervention

Between May and August 2014, all sinks were removed from all ICU patient rooms and a 'water-free' method of patient care was introduced, meaning that all patient care related activities that take place in the patient room and that would normally involve the use of tap water were adapted to a 'water-free' alternative, see Table 1.

Patient selection and medical ethical aspects

All patients of 18 years and older who were admitted to the ICU for at least 48 h were included in this study. The study was reviewed and approved (File number CMO: 2015–1764) by the ethics committee of the Radboud university medical centre and was carried out in accordance with the applicable rules concerning biomedical research using patient information. Patient data were collected and analyzed anonymously.

Data collection

Data were collected in a standardized manner according to standard definitions and were subject to data quality checks [36]. Demographic information including sex and age, referring specialty and location before ICU admission, type of admission, comorbidity, Acute Physiology and Chronic Health Evaluation (APACHE) score, days on mechanical ventilation, and ICU length of stay, were

Table 1 'Water-free' patient care activities

Patient care-related action	New method with 'water-free' working
Gloves and gowns	Universal gloving and gowning (pre- and post-intervention period)
Hand washing after visual contamination	'Quick & Clean', (Alpheios B.V., Heerlen, The Netherlands) wipes to remove extensive contamination from hands. Followed by disinfection with alcohol-based hand rub
Medication preparation	Dissolving of medication in bottled water (SPA reine, Spa, Belgium)
Drinks	Bottled water (SPA reine, Spa, Belgium)
Canula care	Disposable materials
Hair washing	Rinse-free shampoo cap (Comfort Personal cleansing products, USA)
Washing	Moistened disposable wash gloves, (D-care,Houten, The Netherlands)
Dental care	Bottled (SPA reine, Spa, Belgium)
Shaving	Electric shaving, or with warm bottled water (SPA reine, Spa, Belgium)

collected. We collected culture results (from routine SDD screenings) from the medical microbiology laboratory database. Culture results from cultures taken <48 h of admission, including all repeat findings, were excluded from further analyses. When a patient was readmitted to the ICU during the study period, culture results identical to the first ICU admission were excluded.

Outcomes and definitions

The primary outcome of this study was the GNB colonization rate, calculated as the number of primary positive microbiological results per 1000 ICU admission days, during the pre- and post-intervention periods. The colonization rates of patients with yeasts were used as a 'negative control', as yeasts do not thrive in sinks and the ICU sinks at all times had been free of yeast colonization.

Statistical analysis

'To compare the patient characteristics between pre-intervention and post-intervention period, we described continuous data as mean ± standard deviation and groups were compared using a Student-t-test, or as median (25th and 75th percentile) and compared using a Mann-Whitney U test, depending on the distribution. Dichotomous or categorical data were described as number with percentage and subgroups were compared using a Chi-squared test. The pre- and post-intervention GNB and yeast colonization rates were calculated per 1000 admission days. The colonization rate ratios were (with 95% confidence interval (CI)) calculated to quantify the effect of the intervention on these rates. For calculating the subsequent colonization rates related to ICU- length of stay (LOS), only admissions of ≥3, ≥5, ≥7, ≥10 or ≥14 days were used for the denominator (number of admission days).

Segmented regression analysis of interrupted time series data was conducted to estimate the effect of the intervention on the monthly GNB and yeast colonization rates, both immediately and over time and to identify whether there was a baseline or a post-intervention monthly trend in colonization rate [37]. An autoregressive integrated moving average (ARIMA) model was used. The model was adjusted for negative first order autocorrelation by including an autocorrelation parameter in the segmented regression model [37]. To determine if colonization was likely to be ICU-acquired and to relate it to exposure duration, time-dependent (ICU-LOS) effects were investigated. In this ARIMA model, β_0 estimates the baseline level of the monthly colonization rate at time zero; β_1 estimates the pre-intervention or baseline linear trend of the monthly colonization rate; β_2 estimates the level change in the monthly colonization rate immediately after the intervention (i.e. step change or change in level: immediate effect of the intervention); and β_3 estimates the post-intervention change in linear trend of the monthly colonization rate. Predicted rates are calculated based on model parameters. The rates during the intervention months (May 2014 – August 2014) were excluded from this analysis.

First, the full regression model was specified for the GNB and the yeast colonization, meaning that the following estimates were given: β_0, β_1, β_2, and β_3. After stepwise elimination of non-significant terms, the most parsimonious model contained only the intercept (β_0) and the significant level change (β_2) in the monthly colonization rate. This segmented regression analysis was performed on all GNB identified ≥2 days after ICU admission, and subsequently repeated for GNB first identified ≥3, ≥5, ≥7, ≥10 or ≥14 days after ICU admission, respectively.

If the segmented regression analysis would show that there was no monthly trend in GNB colonization either before or after the intervention, overall GNB colonization rates were calculated and compared between pre- and post-intervention and were defined as the number of GNB (or MDR-GNB) per 1000 ICU admission days. The rates during the intervention months (May 2014 – August 2014) were excluded from this analysis. Colonization rate ratios (and 95% confidence intervals) were calculated to quantify the effect of the intervention on the outcome and rates were compared using a Chi-squared test. This analysis was repeated for GNB identified ≥3, ≥5, ≥7, ≥10 or ≥14 days after ICU admission, respectively.

Statistical analysis was performed using IBM SPSS Statistics version 22 and STATA/SE version 11.0. A two-sided p-value <0.05 was considered to indicate statistical significance.

Results

An increased number of *Enterobacter cloacae* ESBL positive isolates was detected and communicated to the ICU in May 2014. In total 11 isolates pre and one isolate post-intervention were identified. By molecular typing we were able to show that 5 isolates were related pre-intervention. Sinks in the ICU were tested positive for *Enterobacter cloacae* ESBL prior to removal. The outbreak developed despite routine use of extensive infection prevention measures including the use of protective clothing and gloves with all patient contacts. It was decided to remove the sinks from all ICU patient rooms in order to eradicate the source of MDR-GNB in the direct patient environment.

1644 patients were admitted to the ICU in the 12 months prior to the removal of sinks from the ICU patient rooms, of which 1496 patients had a ICU-LOS ≥2 days (total 9153 admission days). In the 12 months after the removal of sinks, 1618 patients were admitted to the ICU, of which 1444 were in the ICU for ≥2 days

(total 9044 admission days). 145 (9.7%) in the pre-intervention period and 137 (9.5%) post-intervention were re-admissions (P = 0.85). See Fig. 1.

The baseline demographic characteristics of the patients at ICU admission are described in Table 2. Apart from a statistically significant difference between pre- and post-intervention patients for chronic respiratory insufficiency as a comorbidity, no other relevant differences in demographics were observed. The median ICU-length of stay was 3 days (IQR 2–6 days) pre-intervention, and 3 days (IQR 2–6 days) post-intervention (p = 0.90). In the pre- and post-intervention periods, 31.2% and 30.5% (P = 0.66) had an ICU-LOS ≥5 days, and 15.6% and 16.1% (P = 0.71) had an ICU-LOS ≥ 10 days, respectively. Over a third of the ICU admissions (38.3% pre-intervention; 34.9% post-intervention; P = 0.06) had a type of registered comorbidity at admission. A statistically significant difference between pre- and post-intervention patients (7.8% vs 4.9%, respectively; P = 0.002) was observed for chronic respiratory insufficiency.

Interrupted time series analysis

The results of the segmented regression analysis are shown in Additional file 1: Table S1. There was a statistically significant immediate effect of the removal of sinks on the monthly colonization rate of GNB, but not on the colonization rate of yeasts, with statistically significant β2 level changes for all GNB colonization outcomes for the different ICU LOS (P = 0.037 for ICU LOS ≥48 h, P = 0.005 for ICU LOS ≥3 days; P = 0.001 for ICU LOS ≥5 days; P < 0.001 for ICU LOS ≥7 days; P = 0.005 for ICU LOS ≥10 days; P = 0.011 for ICU LOS ≥14 days) . There was no pre-intervention drift in monthly GNB rates and this was also the case in the ICU-LOS-dependent analyses. Graphs with the observed and predicted colonization rates are shown in Fig. 2. The data for the interrupted time series analysis for yeast colonization are shown in Additional file 2: Figure S4.

In the most parsimonious model, the pre-intervention trend (β_1) and post-intervention trend-change (β_3) were omitted, resulting in a statistically significant immediate effect of the intervention on the GNB colonization rates.

Overall GNB colonization rates

The overall GNB colonization rates were 26.3 and 21.6 GNB/1000 ICU admission days (rate ratio 0.82; 95%CI 0.67–0.99; P = 0.02) for pre- and post-intervention groups, respectively. The difference between the groups became more pronounced over time: GNB colonization rates that were first identified in cultures taken ≥3 days (22.5 vs. 15.2; RR 0.68; 95%CI 0.53–0.86; P < 0.001), cultures taken ≥5 days (15.0 vs. 9.4; RR 0.63; 95%CI 0.45–0.87;

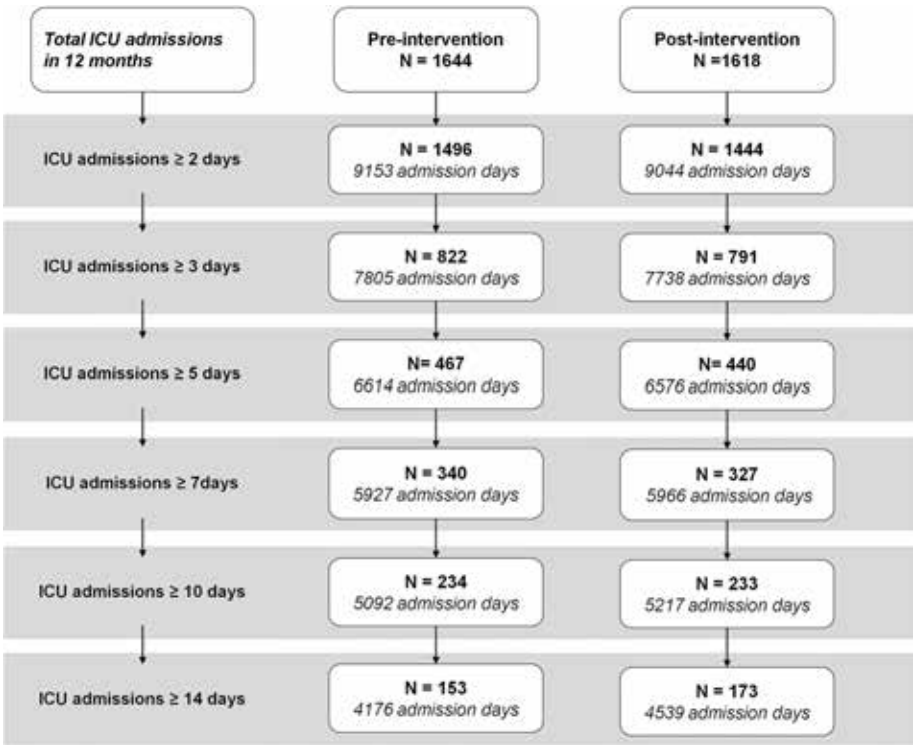

Fig. 1 Flow chart ICU admissions. Legend: Flowchart of the number of patients with an ICU-length of stay of ≥2 days, ≥3 days, ≥5 days, ≥7 days, ≥10 days and ≥14 days, and the subsequent number of admission days

Table 2 Characteristics of ICU admissions of ≥2 days before and after sink removal

	Pre intervention		Post intervention		
	n	%	*n*	%	*P*-value
ICU admissions with LOS of ≥48 h	*N* = 1496		*N* = 1444		
First or re-admission					
Primary admissions	1351	90.3%	1307	90.5%	0.85
Re-admissions	145	9.7%	137	9.5%	
Age, median (IQR)	62	[50–70]	63	[52–71]	0.07
Male sex, *n* (%)	890	59.5%	856	59.4%	0.94
BMI, mean (SD)	26.1	5.3	26.3	5.2	0.31
ICU mortality, *n* (%)	174	11.6%	146	10.1%	0.19
Hospital mortality, *n* (%)	225	15.0%	207	14.3%	0.59
ICU Lenght of stay (LOS), median days (IQR)	3	[2–6]	3	[2–6]	0.90
ICU LOS, *n* (%)					
2 days	674	45.1%	653	45.2%	0.38
3–4 days	355	23.7%	351	24.3%	
5–6 days	127	8.5%	113	7.8%	
7–9 days	106	7.1%	94	6.5%	
10–13 days	81	5.4%	60	4.2%	
≥ 14 days	153	10.2%	173	12.0%	
Apache score, mean (SD)	18.7	7.2	18.2	7.2	0.27
Days on respirator, median (IQR)	2	[0–4]	1	[0–4]	0.38
Comorbidity at ICU admission, *n* 'yes' (%)					
Any comorbidity	573	38.3%	504	34.9%	0.06
Cardiovascular insufficiency	93	6.2%	70	4.8%	0.11
Respiratory insufficiency	116	7.8%	71	4.9%	0.002
Diabetes	180	12.0%	168	11.6%	0.74
Chronic renal insufficiency	97	6.5%	83	5.7%	0.41
Neoplasm	130	8.7%	112	7.8%	0.36
Immune-insufficiency	166	11.1%	166	11.5%	0.93
Medical specialty, *n* (%)					
Surgery	330	22.1%	361	25.0%	0.04
Neurosurgery	239	16.0%	200	13.9%	
Thoracic surgery	234	15.6%	245	17.0%	
Pulmonary disease	125	8.4%	139	9.6%	
Internal medicine	64	4.3%	72	5.0%	
Other	504	33.7%	427	29.6%	
Admission type, *n* (%)					
Medical	732	48.9%	712	49.3%	0.06
Elective	528	35.3%	464	32.1%	
Emergency	236	15.8%	268	18.6%	
Admission source, *n* (%)					
Emergency	372	24.9%	344	23.8%	0.27
Clinical department	292	19.5%	302	20.9%	
Other IC unit	93	6.2%	69	4.8%	
Other	739	49.4%	729	50.5%	

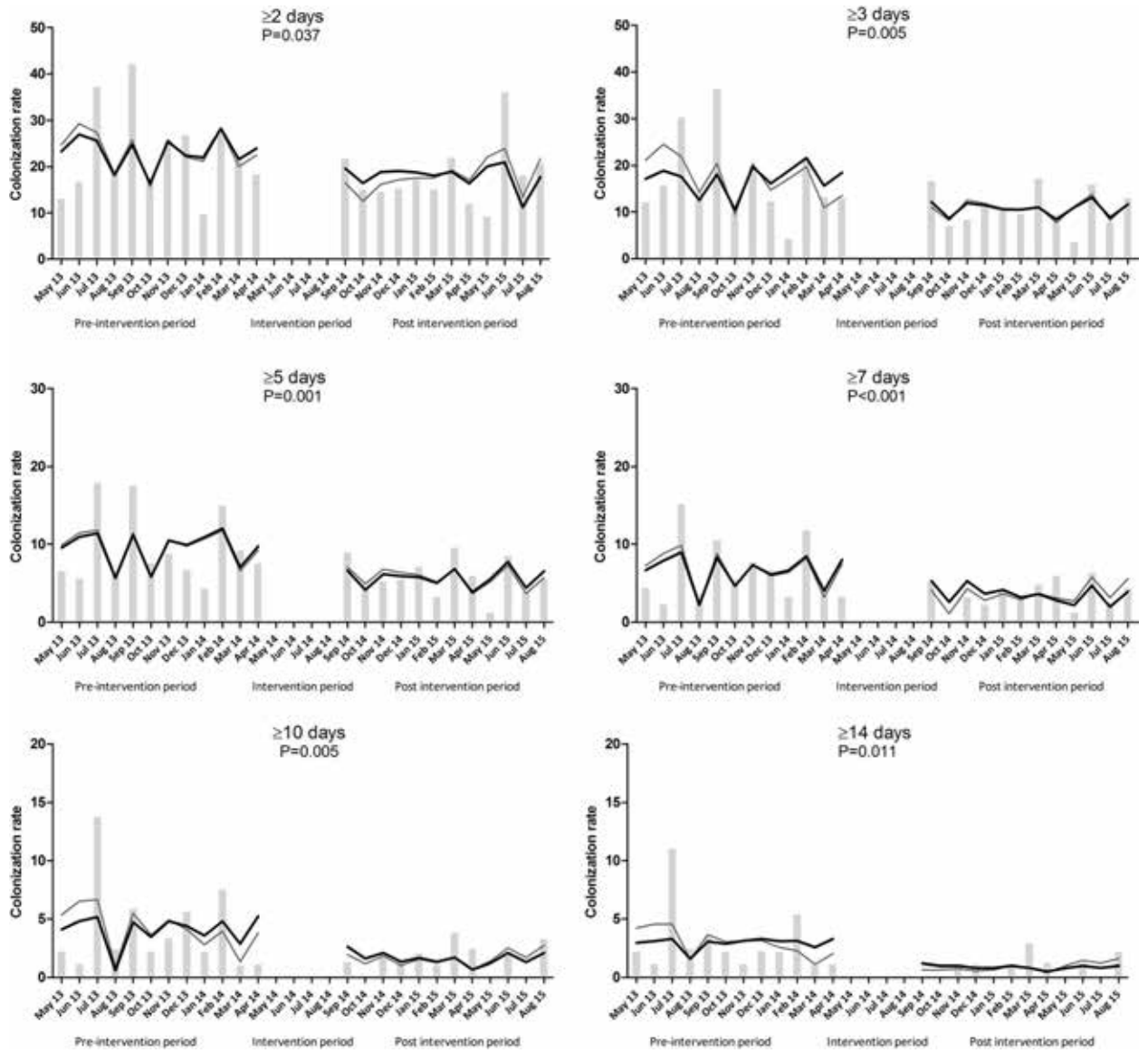

Fig. 2 Monthly gram-negative bacilli (GNB) colonization rates. Legend: Monthly GNB colonization rates (bars), the predicated rate based on the full model (*grey line*) and the predicted rate based on the parsimonious model (*black line*). β2 level change *p*-values are shown in 2A to 2F, where β2 stands for the level change in the monthly colonization rate immediately after the intervention. Section A to F refer to GNB identified in ICU patients with a length of stay of ≥2, ≥3, ≥5, ≥7, ≥10 or ≥14 days after ICU admission

P = 0.002), cultures taken ≥7 days (11.5 vs. 6.4; RR 0.56; 95%CI 0.36–0.84; *P* = 0.002), cultures taken ≥10 days (8.1 vs. 3.3; RR 0.40; 95%CI 0.22–0.73; *P* < 0.001) and cultures taken ≥14 days after ICU admission (7.2 vs. 2.0; RR 0.28; 95%CI 0.12–0.60; *P* < 0.001). As also illustrated by Fig. 3, the effect of the intervention in the GNB colonization rate increases with increasing LOS on patients at the ICU.

The (MDR-)GNB that were found on all time points are summarized in Additional file 3: Table S2.

Discussion

We have shown that the removal of sinks in patient rooms and implementation of water-free patient care is associated with a significant reduction of patient colonization with GNB and this effect was most pronounced in patients with a longer ICU length of stay.

The effect of the intervention on GNB colonization rates became even more apparent when pathogens that were first identified after longer durations of ICU stay were compared between the pre-intervention and post-

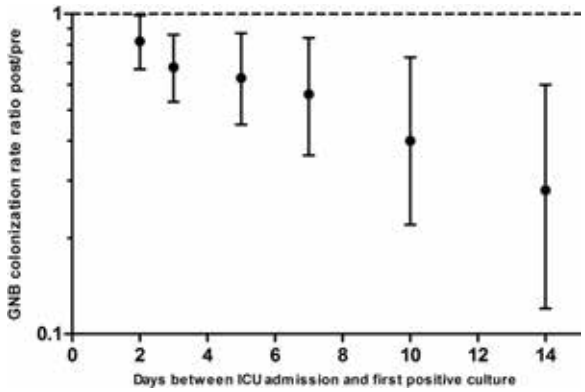

Fig. 3 Colonization rate ratios related to ICU-LOS. Legend: Colonization rate ratios (with 95%CI) were calculated to investigate the effect of ICU-LOS on the effect of the intervention. GNB identified in ICU patients with a length of stay of ≥2, ≥3, ≥5, ≥7, ≥10 or ≥14 days after ICU admission were analyzed

intervention period. Apart from the fact that with increased ICU-LOS the likelihood increases that these pathogens were acquired at the ICU, it appears plausible that a longer stay in an ICU increases the exposure to potential pathogens in the direct patient surroundings including those originated from the sinks.

The lower number GNB in the post-intervention period cannot be explained by an overall decrease in observed pathogens, as there was no effect of the intervention on yeast colonization rates. Yeast do not thrive in sinks or siphons and therefore we used them as a negative control. Furthermore, the overall number of cultures processed in the pre- and post-intervention study period were similar meaning that there was no reduction in the total number of screening cultures taken that could explain our findings.

In this study, we focused on colonization rates, and not infections. Even though infections caused by GNB would have been a more relevant clinical outcome than colonization, demonstrating the effect of an intervention on clinical infection rate would require a sample size that is not feasible. Previous work on the effects of SDD on infections with gram-negative bacilli showed that the cumulative incidence of ICU-acquired bacteremia in the SDD study group was 0.9%. To demonstrate a 30% reduction related to this intervention, approximately 26,000 patients would need to be included. Nevertheless, as colonization precedes infection, it is plausible that the intervention will have an impact on bloodstream infections with GNB.

Limitations of the study

Several limitations of this study need to be addressed. First and most importantly, this is an open label, non-randomized single-centre study. Naturally, the implementation procedures importantly limited the feasibility of using other study designs. Despite of the design limitations, in the absence of alternative explanations, we believe that it is conceivable that the removal of sinks and implementation of water-free patient care resulted in a significant reduction of GNB colonization. There was no pre-existing downward drift in colonization rate, no changes were made during the study period in the hand hygiene protocol, protocol of standard or transmission-based precautions and the protocols of cleaning and disinfection. No chlorhexidine gluconate bathing is performed in our ICU. The quality of cleaning and disinfection remained constant and antibiotic guidelines did not alter during the study. The only difference between the pre- and post-intervention periods were the differences in some of the baseline demographic characteristics, e.g., patients in the pre-intervention period more often suffered chronic respiratory insufficiency compared to post-intervention admissions. However, as the vast majority (87%) of GNB colonization was identified in patients without chronic respiratory insufficiency, it appears unlikely that this difference could account for the observed effects. Importantly, no relevant changes in procedures, staffing levels, technical infrastructure, or other major changes that could influence patient management took place during the conduct of the study. No alternative confounders could be identified that could have influenced the outcome of the study. Second, our intervention was performed in a relatively "low GNB endemic setting" due to the use of SDD [35]. It is difficult to predict how the findings of this study can be generalized to a broader setting including non-SDD hospitals. On ICU's with a higher GNB colonization rate compared to our setting, it appears plausible that the effects could be more pronounced. Removing sinks from patient rooms could be a very effective intervention with a high impact for ICUs in low-resource settings, where nosocomial infections with GNB are very common [38]. Some may argue that the removal of the sinks could interfere with the prevention of nosocomial transmission of *Clostridium difficile,* as spores are resistant to alcohol-based handrub. In our hospital the incidence of *Clostridium difficile* infections is very low. Over the last 2.5 years 4 patients were diagnosed with *Clostridium difficile* in the ICU. Centers for Disease Control and Prevention advises to wear gloves when caring for patients with *C. difficile*-associated diarrhea. After gloves are removed, hands should be washed with a non-antimicrobial or an antimicrobial soap and water or disinfected with an alcohol-based handrub [39]. Our ICU setting with use of gloves in all patient contacts is in line with these recommendations. In our ICU, we have purchased a mobile hand washing sink that can be used as a back-up in case of a serious *Clostridium* infection outbreak.

In view of our results we should reconsider the necessity of sinks and other 'wet' areas in the patient rooms. Under time constraints, healthcare workers compliance with infection prevention and control measures is often reduced, specifically in the case of hand hygiene, infection prevention protocols and waste management protocols. Reconstructing the hospital infrastructure in a way that behavior of healthcare workers is more directed towards good clinical practice is a step in the direction of sustainable infection control.

Conclusions

This study shows that removal of the sinks from all patient rooms and the introduction of 'water-free' patient care is associated with a statistically significant lower number of ICU patients that become colonized with GNB, including MDR-GNB, especially among patients with a longer length of stay at the ICU. To our knowledge, this is the first study that indicates that sinks in patient rooms not only play a role in outbreak situations, but also in sporadic transmission of GNB from sinks to patients.

Additional files

Additional file 1: Segmented regression models predicting GNB (A) and yeast (B) colonization rates. (DOCX 28 kb)

Additional file 2: (JPEG 5541 kb)

Additional file 3: Colonization with Gram-negative bacilli. (DOCX 28 kb)

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Availability of data and materials

The datasets during and/or analysed during the current study are available from the corresponding author on reasonable request.

Authors' contributions

JH and AT had full access to all the data in the study and takes responsibility for the integrity of the data and the accuracy of the data analysis. Study concept and design: JH AT, PS, HvdH. Acquisition, analysis, or interpretation of data: JH, AT, PS, HvdH. Drafting of the manuscript: JH, AT, PS. Critical revision of the manuscript for important intellectual content: JH, AT, HW, AV, EK, PS, PPs, HvdH. Statistical analysis: AT, RA. Administrative, technical, or material support: MB. Study supervision: JH, AT, HvdH. All authors read and approved the final manuscript.

Competing interests

The authors declare that they have no competing interests.

Consent for publication

Not applicable.

Ethics approval and consent to participate

The study was reviewed and approved (File number CMO: 2015–1764) by the ethics committee of the Radboud university medical centre and was carried out in accordance with the applicable rules concerning biomedical research using patient information.

Publisher's Note

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Water quality – Risk assessments for *Legionella* control – Code of practice

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Date	Text affected

Contents

Summary of pages
This document comprises a front cover, and inside front cover, pages i to ii, pages 1 to 48, an inside back cover and a back cover.

Foreword

Publishing information

This British Standard is published by BSI Standards Limited, under licence from The British Standards Institution, and came into effect on 31 January 2019. It was prepared by Subcommittee EH/3/4, *Microbiological methods*, under the authority of Technical Committee EH/3, *Water quality*. A list of organizations represented on these committees can be obtained on request to their secretary.

Supersession

This British Standard supersedes BS 8580:2010, which is withdrawn.

Use of this document

As a code of practice, this British Standard takes the form of guidance and recommendations. It should not be quoted as if it were a specification and particular care should be taken to ensure that claims of compliance are not misleading.

Any user claiming compliance with this British Standard is expected to be able to justify any course of action that deviates from its recommendations.

Presentational conventions

The provisions in this standard are presented in roman (i.e. upright) type. Its recommendations are expressed in sentences in which the principal auxiliary verb is "should".

Commentary, explanation and general informative material is presented in smaller italic type, and does not constitute a normative element.

Where words have alternative spellings, the preferred spelling of the Shorter Oxford English Dictionary is used (e.g. "organization" rather than "organisation").

The word "should" is used to express recommendations of this standard. The word "may" is used in the text to express permissibility, e.g. as an alternative to the primary recommendation of the clause. The word "can" is used to express possibility, e.g. a consequence of an action or an event.

Contractual and legal considerations

This publication does not purport to include all the necessary provisions of a contract. Users are responsible for its correct application.

Compliance with a British Standard cannot confer immunity from legal obligations.

Introduction

Legionellosis refers to illness caused by bacteria of the genus *Legionella* including Legionnaires' disease and Pontiac fever. The most serious form of disease caused by *Legionella* is Legionnaires' disease, a severe pneumonia with a relatively high fatality rate, which was first recognized in 1976. Outbreaks and sporadic infections occur throughout the world. At least 61 species of *Legionella* have been described and over 28 have been associated with disease in humans, but the predominant cause of Legionnaires' disease is *L. pneumophila. Legionella* are opportunistic pathogens of humans and normally inhabit warm, moist or aquatic environments where they grow in association with other organisms. In particular, they are known to grow in a range of protozoa. Their predilection for warm water means that they are capable of colonizing artificial water systems and equipment containing water. Legionnaires' disease is not contagious from person to person but is of environmental origin and usually contracted by inhaling the organism in an aerosol produced from water contaminated with the organism. Aspiration of water (water going down the wrong way) containing *Legionella* can also cause infection, particularly in hospitalized individuals.

There is a chain of events leading to an individual contracting Legionnaires' disease:

- the water system needs to become contaminated (inoculated) with the bacteria;
- hazardous conditions have to exist within the system for the amplification of the bacteria to sufficient concentrations to cause infection;
- the contaminated water usually needs to be dispersed into droplets fine enough to form an aerosol for transmission to the individual;
- inhalation of contaminated aerosols or, in rare cases, aspiration of contaminated drinking water; and
- the exposed individual has to be susceptible to succumb to infection.

The ubiquitous occurrence of *Legionella*, combined with their association with protozoa, means that all building water systems are susceptible to contamination with *Legionella* via the water supply or dust entering the system. It is therefore normal practice to assume that a system can become contaminated. Whether the amplification of *Legionella* is likely within the equipment or system can be inferred from the conditions of the water; the design, construction and operating conditions of the equipment or system at the time of assessment; and records of treatment and monitoring of the equipment or system in the past. It is not recommended to test for the presence of *Legionella* prior to the implementation of a water management programme.

The generation of aerosols can be observed in the operation of systems such as cooling towers, evaporative condensers, industrial processes, spa pools/hot tubs, showers and taps. Many of these can produce substantial aerosols. Some systems, such as cooling towers, evaporative condensers and some industrial processes, can transmit the aerosol widely, exposing a large population over an area up to several kilometres. Spa pools and hot tubs can expose many users and anyone in the immediate vicinity, while showers and taps are most likely to lead only to the exposure of individual users.

Finally, for an individual to become infected following exposure they have to be susceptible, usually having predisposing conditions. Only a very small proportion of those exposed develop disease, but increasing age, particularly 50 years and over, smoking, being male and being immunosuppressed through disease or treatment can increase susceptibility. Host susceptibility is therefore an important factor influencing risk and needs to be considered in the assessment.

A site-specific analysis of hazardous conditions allows appropriate control measures to be identified and put in place to protect the health and safety of employees and members of the public who could be affected by work activities. *Legionella* risk assessment is no different and is a legal requirement

under the Health and Safety at Work etc. Act 1974 [1]. The Management of Health and Safety at Work Regulations [2], [3] and the Control of Substances Hazardous to Health Regulations [4], [5] make specific requirements for risk assessment. These regulations apply to the control of *Legionella* and are embodied in the Approved Code of Practice and guidance document, "*Legionnaires' disease: The control of Legionella bacteria in water systems*" [6], otherwise known as ACoP L8, and the associated Technical Guidance HSG274 Parts 1 to 3 [7] and HSG282, *The control of legionella and other infectious agents in spa-pool systems* [8].

Risk assessment is an ongoing process and the report of the risk assessment's findings is a live document. The risk assessment report needs to be reviewed regularly in anticipation of, rather than in response to, changes. For example, the risk assessment for a new construction ought to be performed before commissioning, but then reviewed when the system has been operating normally for several weeks or months. It is recommended that a risk assessor is involved from the design stage onwards.

It is the responsibility of the duty holder to ensure that an assessment is carried out to identify and assess the risk of exposure to *Legionella* from work activities and water systems and to put in place any necessary precautions. The duty holder appoints a person to take day-to-day responsibility for controlling any identified risk from *Legionella*. The appointed competent person(s) (also known as responsible person) needs to have:

a) sufficient standing and authority within the organization (e.g. a manager or director) and competence and knowledge of the system to ensure that all operational procedures are carried out in a timely and effective manner; and

b) a clear understanding of their duties and the overall health and safety management structure and policy in the organization.

If the duty holder is competent, they may appoint themselves as the competent person. Further guidance for duty holders on how to put in place suitable arrangements for managing health and safety risk is provided in HSG65: *Managing for Health and Safety* [9].

A person is identified to carry out the risk assessment. This person can be an employee of the duty holder or an external contractor. This British Standard gives recommendations for how such a person conducts a risk assessment for *Legionella*, though the duty holder remains accountable for implementing the recommendations.

1 Scope

This British Standard gives recommendations and guidance on *Legionella* risk assessment relevant to water systems. It is applicable to any undertaking involving a work activity or premises controlled in connection with a trade, business or other undertaking where there is potential for exposure to water or when water is used or stored in circumstances that could cause a reasonably foreseeable risk of infection by *Legionella* and contracting legionellosis.

This British Standard is applicable to risk assessments being undertaken on premises, plant and systems for the first time. It also covers reviews and reassessments where a previous assessment has been undertaken and where control measures might have been implemented.

While the principles of risk assessment presented in this British Standard can be applied to natural waters, including rivers, lakes, ponds, waterfalls, caves, dew ponds or natural recreational facilities, such as boating lakes, this British Standard does not give specific recommendations for these water sources. This British Standard does not give recommendations for the preparation of the scheme of control for the risk systems identified.

Annex A gives general guidance on the assessment of systems, while Annex B to Annex E give guidance on the assessment of specific types of system. A list of equipment that might be used by a risk assessor is given in Annex F, and Annex G gives guidance on the production of schematic diagrams.

NOTE The guidance in the annexes is not intended to be exhaustive but merely to highlight some of the more common issues associated with particular systems to be considered as part of a Legionella risk assessment. Where appropriate, these annexes contain references to publications that give more detailed information about these systems.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes provisions of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

BS 7592, *Sampling for Legionella bacteria in water systems — Code of practice*

3 Terms and definitions

For the purposes of this British Standard, the following terms and definitions apply.

3.1 aerosol

suspension in a gaseous medium of solid particles, liquid particles or solid and liquid particles having negligible falling velocity

NOTE In the context of this document, it is a suspension of particles which might contain Legionella with a typical droplet diameter size of <5 µm that can be inhaled deep into the lungs.

3.2 aspiration

liquid accidentally passing into the lungs when swallowing

NOTE This is commonly referred to as water "going down the wrong way".

3.3 asset register

list of all items relevant to the risk and control of legionellosis and pertinent information to allow them to be effectively used in the written scheme of control and in the risk assessment

NOTE Ideally, this will be made available to the risk assessor by the duty holder. This includes the physical components of the system and might also include other standalone items that could present a legionellosis risk. It also includes the schematic diagram, scheme of control and risk assessment.

3.4 biofilm

community of bacteria and other microorganisms and entrained debris, embedded in a protective layer at interfaces in water systems

3.5 calorifier

apparatus used for the transfer of heat to water in a vessel by indirect means and incorporating a source of heat

3.6 dead end

blind end

capped pipe

length of pipe closed at one end through which no water passes

[SOURCE: HSG274, Part 2, 2014 [7]]

3.7 dead leg

length of water system pipework leading to a fitting through which water only passes infrequently when there is draw off from the fitting, providing the potential for stagnation

[SOURCE: HSG274, Part 2, 2014 [7]]

3.8 doubling time

time taken for a population of an organism to double in number

3.9 guidance for control

findings from the risk assessment that can be used in producing a scheme of control

3.10 hazard

biological, chemical or physical agents or water conditions with potential to cause adverse health or safety-related effects

3.11 key roles

3.11.1 duty holder

individual(s) with the legal responsibility to ensure that health and safety is managed effectively

NOTE 1 The duty holder is the employer where the risk is from their undertaking to their staff or others, the self-employed person where the risk is from their undertaking to themselves or others, or the person in control of the premises where the risk is from systems in the building (e.g. a landlord who remains responsible for the maintenance of the systems). See ACoP L8, para. 28.

*NOTE 2 In most cases there will only be one duty holder, but in cases of shared accommodation there could be a shared duty. There might be some cases where the duty holder is a group such as a corporate body, Trust, etc. The duty holder cannot delegate this duty, but can delegate managerial responsibility to the competent person, also known as the nominated responsible person (see **3.11.2**).*

3.11.2 competent person

individual appointed with, and who has accepted, responsibility under the authority of the duty holder for ensuring that the organization's responsibilities for the control of *Legionella* are met and that all individuals and organizations assigned to carry out tasks in the scheme of *Legionella* control are competent to do so

NOTE 1 Also referred to as the "nominated responsible person". This role can be taken by more than one individual, for example, in a water safety group.

NOTE 2 In a large undertaking there may be more than one competent person, each responsible for a part of the undertaking, e.g. each block of a large teaching hospital.

3.12 *Legionella*

genus of bacteria first described as a result of the outbreak of Legionnaires' disease in Philadelphia at the Bellevue-Stratford Hotel in 1976

NOTE It contains at least 61 species, according to www.bacterio.net. [Last viewed 12 December 2018.]

3.13 logbook

a) system activity logbook

b) operator activity logbook

record book (one or more) or its electronic equivalent where all relevant details of the system, the operation, its performance, its monitoring and its maintenance can be entered in a secure manner for subsequent retrieval

[SOURCE: BS EN ISO 16484-2:2004, **3.111** – order of bullets modified and monitoring added]

3.14 open evaporative cooling system

system in which a small proportion of a circulating body of water is caused to evaporate into the atmosphere, taking the latent heat of vaporization from the remainder of water and cooling it

3.15 risk

3.15.1 inherent risk

risk associated with the system before any action has been taken to control it

NOTE In the context of a Legionella risk assessment there is an assumption that the system is or will be inoculated at some point with Legionella.

3.15.2 risk (general)

likelihood of a hazardous event occurring and its consequences

NOTE In the context of this standard, amplification and dissemination of Legionella, and exposure to an aerosol of such, are hazards and legionellosis is the hazardous event.

3.15.3 residual risk

risk remaining after the application of control measures

[SOURCE: BS EN ISO 27000:2017, **2.64**, Notes removed]

3.16 risk assessments

3.16.1 risk assessment (general)

overall process of risk identification, risk analysis and risk evaluation

NOTE Includes hazard identification.

[SOURCE: BS 31100:2011, **2.24**, Note added]

3.16.2 *Legionella* risk assessment

process of identifying and assessing the risk of exposure to *Legionella* from work activities and from water systems or equipment

3.16.3 risk assessment review

process of determining if the current risk assessment and scheme of control are still valid and effective

NOTE This is completed by the competent person if systems are simple and/or they have an appropriate level of competence. Often the services of third party competent help is utilized for complex or high-risk systems such as evaporative cooling or hospital hot and cold water systems.

3.16.4 reassessment

process of reassessing a system after the need is determined by review

NOTE This entails all the steps needed in an initial risk assessment.

3.17 schematic diagram

simple but accurate illustration of the configuration of the water system, including parts that are out of use, to be effectively used in the written scheme of control and in the risk assessment

NOTE An example of a computer-drawn and a hand-drawn schematic diagram are given in Annex G. These figures are monochrome, but colour might be useful for schematics of more complex systems.

3.18 scheme of control

procedures and checks intended to control the risk of *Legionella*, including an up-to-date schematic diagram

NOTE The scheme can be in either hard copy or electronic format.

3.19 water safety group (WSG)

multi-disciplinary group formed to undertake the commissioning and development and ongoing management of the risk assessment and the scheme of control

NOTE It also advises on the remedial action required when water systems for outlets are found to be contaminated.

3.20 WRAS

Water Regulations Advisory Scheme

4 Factors to be considered in the risk assessment

There is a chain of events leading to the infection of a human by *Legionella* which should be considered in any risk assessment process:

a) contamination;

b) amplification;

c) transmission;

d) exposure; and

e) susceptibility of individuals exposed.

NOTE Further information on each of these is given in Annex A.

5 Preparations for risk assessment

5.1 Competence of the risk assessor

NOTE 1 The person appointed to carry out the risk assessment may be the duty holder or an employee of the duty holder, but in many cases it is an external contractor.

The competence of the assessor is of paramount importance and should be matched to the complexity of the system and the risk being assessed. If the assessor is not competent then the assessment might not be suitable or sufficient. In each case, they should be able to demonstrate that they have sufficient experience, specialist knowledge and understanding of:

- the factors affecting the colonization by and growth of *Legionella*;

- the evaluation and assessment of risk from *Legionella* and the controls in place;
- the procedures necessary to complete surveys, measurements and sampling (see Clause 7);
- the corrective actions that can be applied to reduce or eliminate the risk;
- the relevant control measures that can be applied, e.g. water treatment, inspections, monitoring, etc.; and
- the type of water system(s) and associated equipment to be assessed.

Risk assessors should provide evidence that they have undertaken the necessary training appropriate to the type and complexity of the system and the risk assessment required and gained practical experience with a competent assessor. Individuals commissioning risk assessments should establish the relevant competence of an assessor prior to appointment.

Assessors should have their competence formally assessed and there are organizations that require employees of service providers to do this, such as LCA's A Code of Conduct for Service Providers and UKAS accreditation for *Legionella* risk assessment. These records should be easily available for inspection.

NOTE 2 There are increasing opportunities for individuals to engage in independently recognized Continuing Professional Development (CPD) activities. This may be, for example, a record of certificates of attendance at relevant training courses, seminars and conferences, or participation in online training courses for related activities from recognized training providers.

Proportional management of *Legionella* risk is founded on effective risk assessment and any shortcoming in this process is likely to have an impact throughout risk management. Complex systems or those with unfamiliar equipment require assessors with the highest levels of competence. Assessors should obtain competent help, which might be from designers, manufacturers, specialist suppliers or technical operatives, in order to attain the collective competence to assess the risk in these systems.

NOTE 3 Hot and cold water systems can be simple in domestic and small commercial premises, more complex in larger commercial and residential premises and highly complex in healthcare and other speciality premises, each requiring a greater skill, experience, and/or training which contribute to the overall competence of the assessor. Non-domestic water systems including cooling tower systems, spa pools, hydrotherapy pools and some industrial systems depend on water treatment to control the legionellosis risk and therefore require an understanding of the principles of water treatment to complete the risk assessment. Other water systems can also range from simple to highly complex and might require the risk assessor to apply first principles rather than use a prepared format, in which case, assessors need greater knowledge and understanding of these principles and the judgement to apply them in unfamiliar situations.

NOTE 4 There is an increasing requirement, particularly in healthcare premises, to undertake risk assessments for other waterborne pathogens such as Pseudomonas aeruginosa and non-tuberculous Mycobacterium species. As a consequence, there might be pressure to include these other organisms in a Legionella risk assessment or to carry out the risk assessments together. The risk factors and controls for other organisms are not necessarily the same as for Legionella. An individual who is competent to perform a Legionella risk assessment requires a different set of skills and competence to perform these other risk assessments. Competence may be demonstrated by, for example, a CV indicating the assessor's experience or a documented assessment of competence.

5.2 Agreeing the terms of reference

The risk assessor should, before conducting the risk assessment, agree the following with the competent person and/or duty holder.

a) The scope of the risk assessment, including identifying the systems that are to be assessed and those that are not to be assessed, taking into account the asset register, any schematic diagrams (3.17) and documentation on operation and maintenance. This is important as certain aspects

of the risk assessment could require specialist knowledge or equipment [including personal protective equipment (PPE)] to which the assessor would require access. The risk assessment should take into account all parts of the system, for example, a cooling tower should not be risk assessed in isolation from the rest of the cooling system, e.g. intermediate tanks, heat exchangers, pipework, pumps, etc.

b) Whether and how the risk assessment addresses additional hazards, including biological, chemical or physical.

NOTE 1 This British Standard only applies to Legionella risk assessments.

c) Whether the asset register and/or schematic diagrams have to be prepared or redrawn as part of the assessment and, if so, their form and their coverage.

d) The person to whom the risk assessment is communicated and reported and to whom the recommendations are addressed.

e) Time frames for key milestones and the completion of the risk assessment report.

f) The necessary access to the site to be surveyed and the need for a competent escort, as necessary, who is familiar with the system(s) to be assessed and who will be responsible for the assessor's health and safety (see Clause 7).

NOTE 2 The assessor has a duty to not put themselves or others at risk during the visit.

g) That the assessor will be made aware of any factors which could compromise the validity of the risk assessment process, such as planned treatment or maintenance.

h) Any "permit to work" or access clearance necessary for access to the site of the assessment.

i) The provision of unrestricted and safe access to all relevant parts of the system(s) to be assessed; how to record any unavoidable omissions; the effect any such omissions might have on the assessment; whether the required information can be obtained by other means and; what provisions should be made to provide access on a subsequent occasion. Wherever it is practicable to do so safely, all parts of the system(s) should be visited. Whenever reported information, such as records of previous inspections, is included, this should be recorded.

j) Where a large number of essentially identical units/premises are to be assessed and it would be impractical or unrealistic to assess each individual unit/premises straight away, what proportion of these would constitute a representative sample (see 7.2). For example, where there are a significant number of similar units under the control of the landlord, such as housing associations or councils, a representative proportion of the premises for which they have responsibility should initially be assessed on a priority basis, taking into account the susceptibility of occupants, similar design, size, age and water supply, with the entire estate eventually assessed on a rolling programme of work.

While there will inevitably be common factors associated with the many and varied types of premises being assessed such that a proportion of these may be treated as a representative sample (see 7.2), the individual nature of each site should be taken into account.

5.3 Independence

The risk assessor should be able to demonstrate impartiality and independence when carrying out *Legionella* risk assessments. The risk assessor or assessing organization should not allow commercial, financial or other pressures to compromise impartiality and should be able to

demonstrate valid reasons for any proposed course of action. It should be clear, for example, why a recommendation has been made to clean cold water storage tanks.

NOTE 1 This could be achieved by including photographic evidence and, if required, supplementary testing to support the recommendation within the risk assessment report.

Where an organization provides risk assessment services as well as other services, for example, water treatment or cleaning and disinfection, it should have safeguards in place to ensure adequate segregation of responsibilities and accountabilities through appropriate reporting structures.

NOTE 2 It is important that a risk assessment is unbiased and the judgement of the risk assessor is not compromised by the assessor or a colleague responsible for designing, providing or implementing the risk control measures.

In circumstances where risk assessments are conducted internally, for example, by health and safety professionals working within the organization for which the assessment is undertaken, the assessment and any resulting recommendations should not be influenced by factors such as the cost of remediation.

6 Desktop appraisal of documentation

6.1 Preparation

If an existing risk assessment report is available, it should be appraised by the risk assessor to determine if it is still valid and to identify any changes since the last assessment.

NOTE 1 Appraising the current risk assessment can give the assessor valuable information about the water systems being assessed and the attitude of the management on site as demonstrated by their responsiveness to previous risk control recommendations made.

NOTE 2 The appraisal of the validity of the existing risk assessment cannot be performed adequately without a site survey (see Clause 7).

An appraisal should be carried out to determine whether the system is under control and the risk is continuing to be adequately managed. If the current controls, etc., are found to be insufficient or not to have been fully implemented where there have been adverse monitoring results, or if there has been a change in process or management, then the risk assessor should request/obtain and appraise the following:

a) current risk assessment;

b) current logbooks, asset register and schematic diagram(s) of the water system(s). This will allow the assessor to determine inherent risk arising from design and construction;

NOTE 3 In the absence of an up-to-date asset register or schematic diagram, the risk assessor has to make a value judgement as to whether they have sufficient information to complete and issue a risk assessment report.

c) any recent *Legionella* control audits;

d) the current written scheme of control, including:

1) the maintenance history of the water system(s) to be assessed;

2) training records of, and records of competence checks on, site personnel and contractors;

3) monitoring and inspection records;

4) the scheme for the safe operation of the systems;

5) timely and appropriate reactions to lapses of control;

6) any substantive changes in the at-risk population; and

7) any substantive changes to relevant personnel.

6.2 Appraisal of the current scheme of control

6.2.1 General

Where a scheme of control is in place, the risk assessor should undertake a detailed appraisal and audit of the scheme and report on its adequacy. If there is no scheme of control in place, a high priority in the risk assessment recommendations should be that one needs to be produced, unless the risk assessor considers that there is no reasonably foreseeable risk, in which case they should document that this is their assessment.

6.2.2 Appraisal of the maintenance and testing records within the scheme of control

The risk assessor should appraise any records showing implementation of the written scheme of control, ensuring that there is a dated signature or electronic identification against each record, depending on whether the records are stored in hard copy or electronically.

NOTE 1 Study of the maintenance records can help the assessor derive information about the continued success of any control measures that are already in place.

The risk assessor should note the relevance and success of the scheme which has been implemented. Evidence should be sought to confirm that work was completed competently and within a reasonable time, and the identity of those who carried out the work; certificates raised by others after the event should be supported by signed contemporaneous worksheets or their electronic equivalent.

The following should be considered for actions taken after adverse results have been found in the past.

a) Were the correct actions taken and the correct communication chain invoked?

b) Were the actions taken within a reasonable time?

c) Were the results rechecked (after the action) to confirm conditions were back under control?

d) If the actions did not result in better control, was an escalation procedure invoked to ensure conditions were eventually controlled? If not, is there an escalation procedure in place?

e) Were there lessons learned or a new procedure put in place to prevent recurrence?

NOTE 2 The answers to all these questions, and the review in general, might also help the assessor gain some insight into the overall management of the site.

The scope of tests can vary according to the plant on each site, but a check should be made to ensure that all the control items or tests outlined within the recognized national guidance documents for each type of system are being considered.

If these records are not being kept, or cannot be found, the assessor should recommend that a system is put in place as a matter of priority in the final assessment report.

6.2.3 Appraisal of management responsibilities

The risk assessor should check that:

a) the duty holder, the competent person and any deputies are clearly identified in the written scheme of control and that the appointment of the competent person(s) is confirmed in writing by the duty holder;

b) where applicable, there is an appropriately comprised multi-disciplinary water safety group;

c) the roles of all competent persons and parties (e.g. consultants, facilities management companies and water treatment companies) are clearly defined and contact details for these persons and parties are readily available;

d) lines of communication and the reporting structure are clearly stated in the scheme of control; and

e) the responsibility for tasks to be undertaken by each individual or party are outlined clearly with the necessary frequency of the tasks.

6.2.4 Appraisal of training records and competence checks of site and service provider personnel

The assessor should review the training records of those personnel with an involvement in the scheme of control and make comments as to their relevance and validity. In addition to the formal training records, the assessor should derive an indication of the level of competence of the staff by studying the site records.

NOTE 1 For example, the assessor can look at actions taken after adverse results have been found in the past to ensure that suitable corrective actions were taken in a timely manner. Records can also be checked to verify, as far as reasonably practicable, that staff are competent to take measurements (see 7.3).

Similarly, the assessor might be concerned that the checks on competence are inadequate, in which case they should make recommendations to improve the procedure for confirming competence.

If the assessor considers the training and/or competence of one or more of the parties to be inadequate, they should state this as part of the report and include the need for training or refresher training as a priority in the recommendations of the final assessment report.

NOTE 2 Common faults or shortfalls might include the following:

a) no records or checks of competence in place;

b) records are in place, but there is no indication of how competence was assessed;

c) records in place, but refer to training rather than employees' ability to work safely and effectively;

d) no checks on contractor, subcontractor or service provider competence;

e) no review to confirm continued and up-to-date competence.

6.2.5 Appraisal of the safe operation of the systems

The risk assessor should check that there is a scheme for the safe operation and maintenance of all risk systems within the scope of the assessment which:

a) includes a description of the correct operation of the plant and any precautions to be taken;

b) details any start-up and shutdown procedures, and plant rotation and flushing requirements for little-used outlets;

c) includes details of any plant or equipment brought onto site by third parties;

d) includes, where appropriate, method statements, e.g. for major tasks such as cleaning operations;

e) outlines any tests that are to be completed on the systems, along with the required frequency of the tests and the acceptable control parameters;

f) details defects or out-of-parameter results; and

g) logs appropriate corrective actions.

6.2.6 Appraisal of the monitoring and inspection records

The assessor should appraise the records of monitoring and inspections for the systems being assessed.

NOTE 1 These might be found within the written scheme of control or separate documents, such as logbooks (hardcopy or electronic) or maintenance reports. It is reasonable to expect these records to be easily available for inspection.

The assessor should identify the control parameters that have been set within the written scheme of control (chemical and/or physical) and check whether these have been set correctly before deciding if the existing control measures are adequate.

NOTE 2 The assessor will not necessarily have sufficient knowledge of specialized chemical formulations or control equipment or experience to determine whether any specified control parameters are appropriate. It might be necessary for the assessor to seek verification from the service provider or product manufacturer for products used and elements of the control programme.

The assessor should note the relevance and success of the monitoring and inspection work, including any microbiological tests, that has been carried out as these will indicate whether the correct actions have been taken based on the results obtained.

The results of inspections should be checked to see whether these indicate if the scheme of control is sufficient.

To obtain an indication of what to expect during the survey, the assessor should consider the following.

a) Has the work been completed competently and in a timely manner?

b) Has the work been completed at the correct frequency?

c) Do the records indicate who carried out the work and when?

If these records are not being kept, or cannot be found, the assessor should recommend in the final assessment report that such a system be put in place as a matter of priority.

NOTE 3 Common faults found include:

a) no records in place;

b) records in place, but incomplete due to actions going unrecorded;

c) actions not completed, for example, due to continued lack of access without escalation;

d) inadequate or no escalation procedures;

e) records are kept, but corrective actions have not been performed (or recorded as having being performed) following results which are out of specification;

f) no preventative maintenance in place;

g) no, or inadequate, records of maintenance in place;

h) records not kept for appropriate periods, such as the five years required by COSHH [4], [5];

i) work not completed in a timely manner.

7 Site survey

7.1 General

As part of the risk assessment, the assessor should conduct a site survey, with reference to the asset register, schematic diagrams and logbooks [see **6.1**b)]. The assessor should use the survey to check that the schematic diagrams are still valid and up-to-date. They should also familiarize themselves

with the processes taking place on site, including how these could place limitations upon measures to control *Legionella* risks, for example, deliveries of food ingredients causing organic dust to be sucked into a cooling tower and reacting with the biocides.

If the assessor identifies an imminent danger of exposure to *Legionella*, e.g. failure of a biocide dosing system, cold or hot water supplies to aerosol-generating outlets, such as showers which are significantly too warm or too cool respectively, they should report this immediately to the competent person or their site representative, and not keep this for the final written report.

NOTE Attention is drawn to Section 7 of the Health and Safety at Work etc. Act 1974 [1] regarding responsibilities of employees.

At the outset, the assessor should decide whether they have sufficient available information to assess the risk successfully. If they conclude that it is insufficient, for example because of the absence of schematic diagrams, or any other critical information, they should decline to issue the assessment, or decide to issue it in draft or otherwise qualified format, identifying any omissions and the effect they might have on the assessment.

Whether carrying out an assessment on a familiar site, or one previously unknown, the assessor should ensure their own personal safety from any health risks associated with the site. This includes operational hazards, for example, if plant is operating, history of positive *Legionella* testing results and associated hazards, such as those arising from working at height or in confined spaces [10], [11], [12], [13]. All hazards, their assessment and the precautions planned and taken, should be recorded.

The assessor should ensure that all necessary PPE is available, and prepare their own equipment list (see Annex F).

As part of the site survey the assessor should speak to management and staff to judge the effects of management culture and work practices of the organization in adding to (or reducing) the risk.

Where there is a current scheme of control, any sentinel/sampling points identified within it should be reviewed for their suitability.

7.2 Visual inspection of utilities/location for possible sources of contamination

The assessor should inspect the water system to confirm that the configuration is as illustrated in the schematic diagram (see Annex G for examples) and to determine the operation and condition of each system and its components to the extent that they could affect the proliferation and dissemination of *Legionella*. Details of each system should be examined, including any discrete plant or component and existence/location of sentinel points.

Where the system being assessed consists of several repeated units, such as multiple storeys or pods in a commercial building, the assessor should decide on representative examples to be inspected. A rolling programme should be employed to ensure that the same units are not assessed in successive cycles (see **5.2**).

NOTE 1 Where there are many individual self-contained units, such as flats or houses, the Legionella risk assessment may be scheduled to coincide with mandatory visits, such as those for gas safety checks. This type of approach may be appropriate in situations where access to housing units for Legionella risk assessment is problematic for whatever reason.

Where practicable, the assessor should check that the materials of construction of the water system have been tested for their tendency to support microbial growth as indicated, for example their compliance with BS 6920 (all parts).

NOTE 2 Attention is drawn to the Water Supply (Water Fittings) Regulations [14], [15].

7.3 Measurements

Measurements routinely taken on site, for example, temperature, should be checked for accuracy and reliability, and validated. Measurements of various types (e.g. temperature, biocide, pH) therefore should usually be undertaken and evidenced by the assessor as part of the risk assessment. Where such measurements are undertaken, test meters should be regularly calibrated to ensure accuracy. Similarly, microbiological tests may be utilized, in which case the risk assessor should consider whether the test is suitable to provide the results required for the purposes of the assessment.

7.4 Testing for *Legionella*

It is not normally necessary to take samples for *Legionella* analysis as part of a risk assessment. However, if the assessor decides it will assist in determining risk, sampling should be carried out in accordance with BS 7592.

NOTE HSG274, Parts 1, 2 and 3 [7] give further information on when sampling might need to be performed.

Testing for *Legionella* should be considered if any of the following occur.

a) The risk assessor encounters a novel situation and/or piece of equipment perceived to be a potential risk to health.

b) There is a failure of, or concerns about, control measures.

c) It is necessary to verify the operation of a control regime, particularly if it has recently been changed or implemented and the system is known to have previously been colonized.

d) The assessor has reason to doubt the validity of the results of routine tests or has identified areas of concern during the survey.

Recommendations for any further sampling should be included in the final assessment report.

8 Evaluation of the risk

8.1 General

Each risk should be analysed appropriately, considering its consequences and the likelihood of those consequences arising, to derive a measure of the severity and to set priorities for action.

Where there are common factors within the premises being assessed, while a proportion of these may be treated as a representative sample (see **5.2**), the individual nature of each site should still be taken into account.

Where the risk assessor identifies a hazardous situation from the site survey, processes, visual inspection, measurements, records or sample analysis results, they should record each situation and assess the risk arising from it.

The resulting risk assessment should take into account the inherent risk, the controls in place and how well these mitigate the risk. This combination should be evaluated to determine if the residual risk is as low as reasonably practicable (ALARP) and, if not, what additional control measures are needed to achieve this. As control measures are introduced, residual risks can fall so low that additional measures to reduce them further are likely to be grossly disproportionate to the risk reduction achieved, and are therefore unjustified. However, measures should still be monitored in case the risks change over time.

NOTE 1 Resources in an organization are finite, so an understanding of inherent risk might help to ensure that the response is proportionate to the risk. It might also help the organization to understand what its full exposure could be if controls fail, and therefore recognize the contribution of certain controls to overall risk mitigation.

NOTE 2 See Annex A for factors that increase the level of risk.

NOTE 3 Although Legionella actively grows between 20 °C and 45 °C, if the system contains water at a temperature greater than 20 °C and less than 50 °C, and an aerosol can be generated under any foreseeable circumstance (operation or maintenance), then it is a system at risk of causing legionellosis. The risk of proliferation is highest between 32 °C and 42 °C.

8.2 Risk rating systems

Legionella risk assessments should contain a risk rating system.

When assigning a risk rating, individual water systems and individual levels of relative risk should be appropriately reflected within the final report. Where risks are common it is acceptable to summarize that within the risk rating.

Risks should not simply be defined by the highest element of risk or multiple risk factors added together to find an average. For example, different buildings within a single site might have a common water source that could be collectively described under a contamination risk but one building might have showers where another does not, and this should be reflected separately within a description of the transmission risk.

NOTE "Risk scoring systems" or "risk algorithms" have been used as an aid to understanding the relative risk of the systems assessed, but they require care in use as they can mask important issues.

Any rating system used by the risk assessor should be explained to the intended reader and cover the following.

a) *Contamination*. An assessment of the risk at source, including assessment of the quality, temperature and integrity of the water supply.

b) *Amplification*. An assessment of the conditions and whether they are likely to support *Legionella* growth, including temperature, water change rate, nutrients, materials of construction and areas where water is not replaced with fresh.

c) *Transmission*. An assessment of whether droplets or aerosols are likely to form and spread.

d) *Exposure*. An assessment of the risk that droplets or aerosols will be inhaled (or contaminated water aspirated).

e) *Susceptibility of individuals exposed*. An assessment of the nature of the exposed population, taking account of their vulnerability to *Legionella* infection.

For the implementation of a risk rating system to be of value, the repeatability of the system should be assured by clear guidance on the application of such a system to all risk assessors undertaking such evaluations.

9 Risk assessment reporting

9.1 General

The findings of the risk assessment, prioritized recommended remedial works and ongoing actions should be presented as a formal document, in hard copy or electronic form as agreed in the scope. To achieve a concise report it may be appropriate to provide in an appendix any test documentation, photographs, measurements, and survey checks rather than including them directly in the main report.

The report should avoid the use of jargon or abbreviations that are not explained clearly, so that it can be readily understood by the people for whom it is intended. Most importantly, it should

be clear and unambiguous in its findings and recommendations; the inclusion of these in an executive summary section in the report can help in this respect.

NOTE 1 Where a project includes risk assessments on a number of individual systems or buildings, e.g. on an industrial, academic or hospital site, it is useful to have an overall summary report detailing the overall findings, recommendations and priorities.

The report should be concise and unnecessary repetition and/or the inclusion of superfluous information should be avoided; examples of such inappropriate content include that which relates to risk systems other than those that are the subject of the assessment, risks other than those associated with *Legionella* (these may be identified, but detailed discussion should be elsewhere) and large extracts from guidance such as ACoP L8 [6]and HSG274 [7].

It should be remembered that the principal purpose of the report is to convey to the reader the findings of the assessment in an efficient and effective manner. It should be sufficiently detailed to allow owners of the risk an appropriate understanding of the key issues and actions required to control risks from exposure to *Legionella*.

The report should be issued to a nominated person, be dated and include verification that it has been checked and by whom.

The report should explain clearly the scope of the assessment and identify those water systems that have been assessed. Whilst there will inevitably be common factors associated with the many and varied types of premises being assessed (see 7.2 on representative samples) the individual nature of each site should be briefly described with particular attention to the evaluation of susceptibility of the persons likely to be present.

The report should include details of the training, experience and skill of the assessor(s) relevant to the water systems within the scope of the assessment so as to demonstrate their competence to the reader who might be different to the person who commissioned the assessment.

The report should record the key people responsible for, and conducting, tasks relating to *Legionella* risk management.

NOTE 2 These can include the duty holder, the competent person(s), or appointed responsible person(s), members of the water safety group, service providers, site operatives, competent help and deputies.

Where the appropriate roles are not being fulfilled, remedial action should be recommended as a high priority.

9.2 Identified risks

The report should clearly highlight the status of any key risks identified (e.g. low, medium, high risk, or ALARP risk, slight risk, moderate risk, serious risk, imminent danger to health) and indicate:

- the underlying cause/source of risk(s), e.g. a particular activity or process, or source of water;
- whether the risk can be eliminated, e.g. “Removal of the little-used shower and associated pipework and fittings in Room XX”;
- if the risk cannot be eliminated, whether the risks are being managed effectively; and
- evaluation of the various risk factors (e.g. mechanical, operational or chemical) and the prioritization of corrective/remedial actions.

9.3 Control measures

Where there are shortcomings in the written scheme of control, the assessor should make practical prioritized recommendations for improvement to control any identified risk to ALARP. This should include items for urgent action and implications if no action is taken.

NOTE 1 For example, if the assessor concludes that the system being assessed has significant risk, they may recommend that the risk(s) be eliminated/minimized or substituted with a lower risk(s). For site- and system-specific control measures (monitoring, inspection and treatment), including the identification of sentinel outlets or other relevant sample and inspection points, the assessor might also recommend:

a) short-term control measures to be applied until completion of corrective actions; and

b) long-term control measures to be applied following completion of corrective actions.

The report should identify:

- the inherent risk and the residual risk (see **3.15.3**) after the written scheme of control measures are applied;
- the system-specific checks and inspections identified as required; and
- any limitations of the assessment.

The assessor should also recommend that a written scheme of control is put in place/amended to ensure that all the necessary controls are maintained, monitored and remain effective.

The risk assessment should not involve the preparation of the written scheme of control, but rather provide information that is critical to its preparation, improvement and review.

NOTE 2 Ensuring that there is a written scheme of control is a legal requirement of the duty holder, though they might instruct the risk assessor to advise or prepare the scheme of control on their behalf as a separate commission. It is important that operation and maintenance individuals are consulted.

Photographs can provide an effective means of illustrating issues that are relevant to the assessor's findings, and when used, they should be cross-referenced clearly to those findings. It should be remembered that excessive use of photographs can confuse the reader and distract from important findings of the assessment.

NOTE 3 Survey results, including tests, measurements and visual observations can be extensive on large sites and these might be best presented as an appendix or supplementary report.

NOTE 4 In some cases where third parties undertake the assessment, it might be helpful to send the draft risk assessment report to the competent person in sufficient time to allow recipients to adequately review its content and comment as to whether specific details are accurate and the assessment is appropriate.

In the event that the assessment process identifies a significant risk that requires immediate attention, the assessor should urgently communicate to the competent person any areas of evident concern prior to receipt of the written assessment report.

Whilst a risk assessment report does not have a strict lifespan or expiry date, it should include a recommendation to indicate under what circumstances a review is required (see Clause **10** for further details).

10 Risk review and reassessment

10.1 Risk assessment is an ongoing process which should be continually reviewed and updated as and when there are changes.

NOTE 1 For simple assessments of inherently low risk water systems, the risk review could be performed by the competent person providing they have the appropriate level of competence to do so. However, for complex

water systems with inherently higher risks, such as cooling towers and for water systems in healthcare, or where additional expertise is required, it is helpful to have a periodic review process involving competent help, for example, regular formal review of the performance of the risk control measures with an appropriate specialist independent consultant or with a hospital authorizing engineer being present at water safety group (WSG) meetings. This would typically range from monthly to annually dependent upon the perceived risk. The output of this review process is a determination of the need for formal reassessment of the risk.

The original risk assessment should be formally reassessed when there are significant changes to ensure that it remains valid, for example, when there are:

a) changes to the water system or its use;

b) changes to the use of the building or part of the building in which the system is installed;

c) changes to the availability of information about risks or control measures;

d) indications that control measures are no longer effective;

e) any of the factors in Clause **4**;

f) new construction works or system modifications planned; or

g) changes to the key personnel, contractors and service providers.

Where a reassessment has not been triggered by the above, there should be a policy of planned reassessment.

NOTE 2 Water systems with higher inherent risk or complex water services where changes are poorly documented may need to be reassessed frequently, e.g. annually, whereas for water systems with a lower inherent risk, or those where all changes are recorded and where systems are well managed, it may be sufficient for a formal reassessment to be performed every 2 to 5 years.

NOTE 3 It is unlikely that circumstances will be so stable that a risk assessment will not need reassessing within this period, in particular, due to staff and management changes. In reality, so many changes occur with time that it is difficult to keep track of them all, for example, general ageing and deterioration of the system and its equipment.

Any new risk assessment report should recommend a reassessment frequency based on the current and expected future risk.

10.2 When reviewing a current risk assessment report to determine whether it remains valid, the competent person(s) or the water safety group should consider:

a) the key risks identified and how these are changing over time;

b) the monitoring data for the controls in place;

c) whether key risks are being managed so far as is reasonably practicable (see HSG65 [9]);

NOTE 4 See also COSHH [4], [5] and ACoP L8 [6].

d) resources and how they are prioritized; and

e) escalation of risk management issues.

In particular, the assessor should consider:

1) the training and experience of the duty holder and competent person and those with any input into management and control, e.g. samplers, temperature monitors;

2) any known changes to supplier, owner and equipment, e.g. a change management process;

3) schematic diagrams to see if they show any known changes;

4) whether the audit trail of documents in the written scheme of control has been maintained;

5) the monitoring records for the cleanliness and condition of the system, including materials;

6) appropriate actions have been taken in a timely manner in response to monitoring;

7) the risk assessment and current scheme of control to ensure these can be read and that they make sense as standalone documents and are not just lists of cross-references; and

8) control measures and independently measure, for example, temperature and/or biocide concentration.

10.3 The reassessment should reflect the risk assessment process given in Clause **5** to Clause **8**.

The reassessed risk assessment should be issued as a new report.

Annex A (informative)
Factors to be considered during a risk assessment

A.1 General

This annex gives guidance to enable an assessment to be made of the potential for a system or piece of equipment to support the growth of *Legionella* and create a risk of legionellosis. Conditions supporting the growth of *Legionella* could occur frequently under normal operation or infrequently during exceptional but predictable circumstances, for example, during maintenance, breakdown, component failure or following a period of non-use. It might be perceived that there is a potential risk but that it is normally controlled by some feature of the design or operation of the equipment. However, if, for example, the design or application is new or novel, any control measures need to be validated.

A.2 Contamination

The chances of *Legionella* being introduced into the water or moist environment of the equipment/system are higher if the water entering is derived from a natural source, such as a river, lake or spring, or a private water supply, rather than a treated and disinfected mains water supply. Water from natural warm springs commonly contains high concentrations of *Legionella*. It may be assumed that the public mains could contain *Legionella* in low concentrations. It is not practicable to prevent *Legionella* from entering a building water system at some times and in cold mains water it is particularly difficult to detect their presence. They can be introduced from:

- the water supplied to the system;
- contaminated new components;
- dust or dirt from the air or surroundings entering during equipment failure, maintenance or normal operation;
- flooding; or
- process contamination.

The exception might be a completely closed system that is supplied with sterile water, but even then there is the possibility of contamination during temporary opening for maintenance or possibly back-colonization from an outlet. Drains can become colonized by micro-organisms, including *Legionella*. Splashes from colonized drains can contaminate outlets which could subsequently become colonized. Thus, any system/piece of equipment ought to be considered a potential source of infection by *Legionella* species if it contains or uses water and assessed for the potential for *Legionella* to grow within it, either during normal operation, maintenance or some other predictable but less common circumstances, such as temporary shutdown.

The potential for nutrients to enter the system, for example by airborne contamination, can be influenced by the location and/or operating characteristics of the equipment.

Apparently clean systems can be rapidly re-contaminated by microbial growth (biofilms) within dead legs or dead ends.

NOTE The detection of any Legionella species in a water system is considered to indicate that the system can also support the growth of L. pneumophila. Failure to detect L. pneumophila by culture when other Legionella species

are present could mean they are too small a proportion of the Legionella population to be readily detected or too few isolates have been selected for confirmation.

A.3 Amplification

A.3.1 General

When *Legionella* multiply they require appropriate physico-chemical conditions and sufficient nutrients for them and their supporting organisms to grow. *Legionella* can grow in biofilms in association with water. The system might be apparently visibly clean but still contain these organisms.

NOTE Legionella are unable to grow without the support of other organisms, and can grow inside protozoa which normally utilize other bacteria as food. Protozoa, particularly their cysts, are often relatively resistant to chlorine, heat and UV. Since the nutrients for protozoa are primarily bacteria and microscopic organic debris they can be indirectly controlled by removing their nutrient sources, i.e. keeping the system clean, free of bacteria and excluding light to prevent the growth of photosynthetic microorganisms (algae and Cyanobacteria).

In rare instances a piece of equipment is a potential source of infection without amplification of *Legionella* occurring within it. For example, a nebulizer or other misting device filled with water that already contains high concentrations of *Legionella*. In this case the temperature of the water in the equipment needs only to be conducive to survival rather than growth. *Legionella* can survive below 20 °C and die slowly at 50 °C and are not affected by pressures likely in most water systems.

Legionella can also grow in biofilms in association with more semi-solid matrices, such as the sediments, moist soil and sludges in some effluent treatment systems. These more solid materials can be broken up, homogenized in the water and aerosolized in some manner, but they would also release *Legionella* into any water surrounding them, which could in turn become aerosolized.

A.3.2 Physico-chemical conditions

The physico-chemical conditions in the equipment/system have to be considered. Temperature is particularly important. *Legionella* are generally considered to be capable of growth between 20 °C and 45 °C, but most rapid growth occurs between 32 °C and 42 °C, so this is the temperature range associated with the highest risk. The pH appears to be less important as *Legionella* can grow or survive in the range of pH likely to be found in most equipment and systems. Highly saline and similar environments are unlikely to support *Legionella*, but there is insufficient evidence published to define a safe concentration.

There are few estimates of the rate of growth of *Legionella* under natural conditions.

When grown under natural conditions in the laboratory (tap water with low nutrients, supportive complex microbial biofilm and no disinfectant), doubling times of 8 h to 14 h at 30 °C to 40 °C have been recorded. Within protozoa and human cells doubling times in the laboratory can be as fast as 2 h.

A.3.3 Nutrient sources

Nutrients for the growth of *Legionella* and their supporting flora can be derived from the incoming water. There is a spectrum of nutrient levels in the incoming water, ranging from mains water derived from groundwater (lowest) through to untreated lowland river water, hypertrophic (nutrient rich) lake water or sewage contamination (highest). Nutrients can also be derived from dirt entering the system during construction, normal operation or maintenance. Some sites, such as food processing plants, can constitute a higher risk environment due to airborne powdered ingredients (e.g. flour, chocolate powder) in the atmosphere, both within and without the plant, which can be of an

intermittent nature. The potential for system contamination with respect to the siting of factory exhausts and protection of the system(s) from airborne contamination have to be considered.

It is also important to consider the ability of the materials used to construct the equipment to supply nutrients and support microbial growth. Where components of equipment (e.g. piping, washers, seals and couplings) or systems are made of synthetic materials that could leach nutrients, e.g. plastics, the materials used in potable water systems have to be tested for their ability to support microbial growth and conformity with BS 6920-2.4, and be WRAS-approved. In other artificial aquatic systems where the minimization of microbial growth is required, i.e. *Legionella* risk systems, materials used ought not to enhance microbial growth and conformity to BS 6920-2.4 and WRAS-approval are therefore appropriate in the absence of any other relevant standards.

A.3.4 Design

The design of the system or equipment is important. Stagnant or slow-flowing water increases the risk of sedimentation of particulates out of the water, which can act as a focus for growth. Biofilms formed on surfaces at low flow rates are less firmly attached and prone to detaching. The presence of intermediate tanks and lengths of pipe with limited, intermittent or no flow could also be factors increasing risk. Similarly, irregularities on the insides of piping and particularly at joints can provide areas for colonization. Recycling of water could lead to the concentration of dirt and nutrients. Inevitably, sediments, other deposits such as scale and corrosion products, dirt and possibly biological material can accumulate in the equipment or system over time and these could offer sites for growth and inhibit the effect of some control measures. The assessor therefore has to ascertain whether the equipment or system is readily and safely accessible and can be dismantled for thorough cleaning and maintenance.

A.3.5 Water treatment and maintenance

Any water treatment or other processes already in place to control or minimize the accumulation of deposits and growth need to be reviewed to evaluate their likely effectiveness. All biocidal treatments need to be of known effectiveness including against *Legionella* (see **A.3.1** and **A.3.2**) and need to have been validated to be effective in the system/equipment and situation being assessed.

A.4 Transmission

Water containing *Legionella* has to be transmitted to humans before it can be inhaled or aspirated. For inhalation to occur, the water has to be aerosolized, producing droplets small enough to be inhaled. The survival of *Legionella* in an aerosol is dependent upon a variety of factors including humidity, temperature, light and certain toxic factors in the air. In general, survival indoors is better than outdoors. Dissemination outdoors could be up to many hundreds of metres or several kilometres. Under experimental conditions similar to common indoor conditions, 30% of a population of *Legionella pneumophila* remains viable after 30 min indoors [16].

Aspiration occurs when water is drunk but, instead of going down the throat into the stomach, goes down the wrong way into the lungs; this can also happen when ice cubes are sucked.

Systems and equipment ought to be examined for any mechanisms which can generate and release aerosols into the surrounding environment. Any process that breaks the surface of the water, even if there is little evident splashing, can produce droplets and thereby form aerosols. Dense sprays and large numbers of bubbles obviously generate aerosols, but running a tap, flushing a toilet, water striking a hard surface or the surface of a body of water (such as in a tank) can all generate aerosols, albeit to a lesser degree. While high density aerosols, such as those generated from a cooling tower or high-pressure spray cleaner, have the potential to infect large numbers of people over a large area, smaller amounts of less dense aerosol might still present a significant risk to a susceptible individual in the immediate vicinity of the source.

The rate of the aerosol generation and the distance the aerosol has to travel before inhalation also needs to be considered. Forcing water containing *Legionella* through a small orifice under high pressure might well be an efficient mechanism for aerosolizing the water, but the shearing forces could kill or injure a proportion of the bacteria. In contrast, dropping water onto a spinning disc, such as the cutting bit on a machine tool, could generate a less dense aerosol but only cause minimal injury to the bacteria, meaning of those bacteria that survive aerosolization a higher proportion are infective. Once in the air the water in small droplets rapidly evaporates, leaving a small particle or droplet nucleus containing any salts and particulate matter, including bacteria that were in the original droplet. The *Legionella* have to survive this drying process and subsequent transmission through the air before inhalation.

A.5 Exposure

The closer a person is to the source, the more likely they are to inhale the aerosol before it has become dispersed and the bacteria in it have died. One of the reasons spa pools (see Annex D) have a high inherent risk is that dense aerosols are generated relatively gently by bubbling at the surface, close to the bather's nose and mouth. Similarly, the aerosol from metal working fluid (emulsion of small proportion of oil in water) which is used to lubricate the spinning cutting bit of a machine tool is generated very close to the operator.

It is important to consider the risk generated under all modes of operation and maintenance. For example, during normal operation some systems could be entirely enclosed so that no risk is generated, but this might not be true when the equipment is opened for cleaning and maintenance.

The danger of aerosols can be eliminated by a physical barrier between people and the source, or reduced by other means, such as ducting away the contaminated air or capturing a significant portion by a mechanism such as high efficiency drift eliminators in a cooling tower.

The nature and proximity of the population exposed to the system or equipment also needs to be considered. For example, if the equipment/system is sited in a hospital ward housing immunocompromised individuals, any chance of emission of an aerosol containing *Legionella* might be considered unacceptable. Consequently, more stringent precautions or complete replacement of the equipment/system by an alternative without an associated risk of aerosol generation might be required.

A.6 Susceptibility of individuals exposed

Some individuals are much more likely to become infected than others. Susceptibility increases with age, and males are more likely to become infected than females (ratio of 3:1). Smoking is a significant risk factor. Disease or therapy that reduces immunity, such as organ transplantation, cancer, blood disease and diabetes, also significantly increases the risk of infection.

Annex B (informative)
Hot and cold water systems

B.1 Requirements of the assessor

There is extensive information on the control of *Legionella* in hot and cold water systems in ACoP L8 [6] and HSG274 Part 2 [7]. It is necessary that the assessor understands the guidance and how all the control measures work and are administered. The assessor also needs to have an understanding of the design aspects of these systems and how these affect the risk.

B.2 Domestic water systems

Wholesome hot and cold water systems (often referred to as "domestic") are the most common, usually the simplest and therefore most straightforward to understand for the less experienced assessor. Whilst small systems are generally similar and relatively simple, systems in larger buildings can include much more complex layouts and uses.

When compared to evaporative cooling systems, one major difference is that significant proportions of the pipework might be concealed and difficult, dangerous or impractical to inspect. Also, older buildings might have some components made from materials now considered unsuitable; they might be wrongly sized for present-day usage or have been modified in ways which make understanding the configuration or function more difficult.

B.3 Water supply

Where water is fed directly to the outlets from a public mains supply and is in regular use, the risk would be expected to be minimal. However, this risk could be increased if, for example, a pipe passes through a warm environment to a rarely or infrequently used outlet. Mains supply pipes that run close to the surface or above ground could be subject to significant heat gain, potentially raising the temperature above 20 °C. For this reason, almost all water systems require risk assessment.

Different water sources which might have poorer quality control than mains water supply, such as private boreholes, require additional data gathering to establish greater detail about them at the outset of the assessment so that any additional risk factors can be taken into account.

B.4 Storage of water

In the majority of systems there is some storage of cold water. This might be subject to changes in temperature, the potential for contamination and possible stagnation, all of which can increase the likelihood of *Legionella* growth. Hot and cold water systems have been identified as the cause of many sporadic cases of Legionnaires' disease. Cold water systems can become contaminated via supply water, by dirt entering uncovered or poorly covered tanks during maintenance and through back-contamination at the outlet or by splashback from taps.

For hot water, the inherent risk of water heaters incorporating storage is greater due to the potential for temperature stratification than that where there is no storage, such as plate heat exchangers or well-designed electrical instantaneous shower heaters.

There are other systems which might use heated water storage tanks within the growth range for *Legionella*, such as solar systems, heat recovery systems, ground/air source heat generation. Such

systems require built-in designed control measures such as ensuring they are heated to 60 °C for at least one hour a day. For further information, see for example, **E.9.4**.

In a combination water heater where the integral cold water tank is directly over the hot water storage vessel there is a high probability of the cold water reaching temperatures permitting the growth of *Legionella*.

B.5 Control of *Legionella* growth in hot and cold water systems

The commonly accepted method to control *Legionella* in hot and cold water systems is by temperature, ensuring:

a) hot water is maintained at 60 °C at the outlet from calorifiers and at 50 °C or above throughout any circulating hot water system. Localized failure in circulation can increase risk and can often be identified by slow or delayed temperature increase when turning on a tap. Non-circulating systems are targeted to reach a minimum of 50 °C within one minute of turning on; and

b) cold water is stored in tanks at temperatures close to the supply and ideally below 20 °C. The whole distribution system will ideally achieve less than 20 °C within two minutes of turning on a tap.

NOTE In healthcare premises, hot water temperatures at outlets or the feed to mixer units are required to be at least 55 °C, at which there is a risk of scalding. HSG274 Part 2 [7] provides guidance on when to install thermostatic mixer valves to prevent scalding.

Spikes of higher temperatures during the initial two minutes after turning on a cold tap can provide useful indications of poor design. For example, cold pipes might be gaining temperature from close co-location with hot water or other sources of heat.

HSG274 Part 2 [7] gives guidance on developing programmes of regular routine checks to confirm that the above temperatures are being achieved. Records of these results will help assess any risk arising from inconsistency in control. In some cases, methods other than temperature, or in addition to temperature, are used, for example, biocides or other chemical or physical controls.

B.6 Testing for *Legionella* and other bacteria

Usually it is only necessary to test for *Legionella* in hot and cold water systems where validating a control regime other than temperature or where there is some question over the performance of any biocide or other chemical or physical control in use, or when controls (temperature or other) fail. In some circumstances, as determined by a risk assessment, monitoring might be appropriate, for example, in premises where there are people especially vulnerable to *Legionella* infection or in the event of one or more cases or suspected cases of *Legionella* infection. Many commercial premises are also tested as a matter of routine, even though they do not fall into any of these risk categories. The results of any such monitoring need to be considered in the risk assessment.

Systems are sometimes monitored for general background bacteria (heterotroph) levels, commonly termed “total viable count” (TVC). Whilst frequent, well-conducted monitoring of this type, together with trend analysis, can yield information on the water condition, there is little or no correlation between heterotroph levels and the incidence of *Legionella*, so appropriate caution needs to be exercised in considering the results in a *Legionella* risk assessment.

Risk assessors will also need to consider the upkeep of competency in the utilization of sampling techniques (see BS 7592) and data relative to other bacteria where this is used for routine monitoring and evaluation of risk. Competency relative to techniques set out in BS EN ISO 19458 will need to be evaluated.

B.7 Monitoring through visual inspection

Contamination might yield nutrients or provide a focus for bacterial colonization in *Legionella* control. Visual checks for evidence of contamination are therefore important and HSG274 Part 2 [7] advocates their use. It is recommended that the assessor conducts a visual inspection of the hot and cold water system as part of the risk assessment, as well as examining records of previous visual checks to see the history of findings and actions taken.

Examination of tanks is an essential part of the assessment, including their configuration and water flow pattern; their size in comparison to water consumption; materials from which they are constructed, insulation, their general condition; temperatures achieved; cleanliness or contamination and means of protection against contamination. Photographic records provide useful additional information, demonstrating both satisfactory and unsatisfactory conditions.

Examination of the interior condition of calorifiers and other hot water storage vessels can provide useful information for the risk assessment. However, the size, design and mode of action of some calorifiers can make internal inspections problematic and difficult to preform if an initial survey of the system is undertaken when it is in its normal working mode. Consequently an additional visit during system downtime, e.g. during maintenance, might be required to carry out the inspection. Records of recent previous assessments of the internal condition of the vessel can be used together with an assessment of the condition of the vessel drain water. Borescopes can also be used to undertake internal examination of vessels.

Borescopes can be a source of contamination to clean tanks and therefore need to be disinfected before use. See Annex F item 6) for details of a suitable chemical disinfection.

B.8 Elements of inspection

Surveys undertaken by the assessor involve practical inspection of the whole system, not just the tanks and calorifiers. During the inspection the assessor is looking for any elements of the design, construction or operation which could lead to conditions under which *Legionella* would be expected to multiply as well as for any potential sources of aerosol. This includes the following:

a) any points in the system where there can be no flow, e.g. dead ends (capped pipes), dead legs and little-used outlets;

b) any parts of the system with low water throughput, including little-used outlets such as in unoccupied areas or where oversized tanks are installed;

c) any parts of the system which are configured in parallel with others which could lead to an imbalance in water flow;

d) routes by which contamination can enter, including poorly fitting lids on tanks, unscreened overflow pipes, inappropriate cross connections, inadequate backflow prevention and emergency water supplies;

e) cool zones at the base of storage calorifiers;

f) installations where either the hot water is able to flow into the cold water system, or vice versa. This is mainly through faults occurring during local installation and failures in backflow prevention, including hot water flowing into the cold feed to a calorifier. This can rise by convection to the tank and might only happen when the shunt pump operates, which is typically at night and therefore not evident at the time when the system is being inspected. If this problem is found it needs to be pointed out to the system maintenance operator for rectification as soon as possible;

g) any parts of the system where incubating temperatures might prevail, including dead legs, little-used outlets, showers and thermostatic mixing valves (TMVs);

h) sources of heat transfer, including heating, hot and cold pipes running together such that cold water is heated or warm water is cooled, sharing a common duct, shared lagging materials and insufficient lagging;

i) materials of construction which could yield nutrient or otherwise support microbiological growth;

j) scale, sediment, corrosion or biofilm, including at the outlets; and

k) any changes to a system which might create stagnant areas, alter flow, or create dead legs, dead ends, etc.

B.9 Training and competence of maintenance and service provider staff

Service provider staff and site personnel are required to be competent to carry out their duties, therefore this is part of the assessor's report. For example, training is necessary to ensure people involved in temperature monitoring understand how to use their equipment correctly and why the work is important. In systems where methods of control other than temperature are used, service providers and staff need to be competent in the appropriate checks, chemical handling, dosing, sampling, testing and adjusting of dosage rates to allow the required parameters to be met. They also need to be aware of the communication channels to indicate when monitored parameters are out of specification.

Where relevant maintenance has been carried out on systems, the assessor needs to inspect any records. If any of the expected records are not available, this might indicate poor management control which would need to be recorded as an additional risk factor.

Annex C (informative) Open evaporative cooling systems

C.1 General

These systems can be complex and extensive, they almost all operate at incubating temperatures and *Legionella* growth is usually controlled by a chemical treatment regime. They also generate large volumes of dense aerosols which are expelled into the surrounding area by air streams usually mechanically generated. They require assessment by specialist assessors with the relevant competence.

These systems use water to remove heat and reject it to the atmosphere. In the process, water will typically get to a temperature suitable for *Legionella* growth. The range of designs for these types of devices is continually increasing and evolving. Many systems use evaporative cooling continuously but others, for example, adiabatic cooler/condensers normally operate in a dry mode but can sometimes operate in evaporative cooling mode as well. It is the responsibility of the assessor to determine the risk presented by any particular installation and although information from the manufacturer might prove useful, risks need to be independently assessed. Examples of common systems can be found in Part 1 of HSG274 [7].

Only when sufficient controls are in place, and the system is maintained in a clean condition and a good state of repair, would such a system be classed as operating at ALARP risk.

Depending on the particular nature of the cooling system, factors that might need to be taken into account include the following:

a) non-potable make-up water;

b) aerosol generation, dissemination and its control;

c) seasonality and intermittent use;

d) proximity of susceptible populations, air intakes, etc.;

e) local sources of aerial contamination and process contamination;

f) accessibility for operation, cleaning, maintenance and inspection;

g) materials of construction;

h) physical condition;

i) dead legs, balance pipes, bypasses and cross connections;

j) intermediate collection chambers, "hot wells", "cold wells";

k) adequacy of water treatment;

l) adequacy of scheme of control, including monitoring activities; and

m) records of inspection, cleanliness and disinfection.

C.2 Open evaporative cooling systems

Open evaporative cooling systems are classed as very high inherent risk. The risk assessment of a cooling system will therefore concentrate on the controls to evaluate the residual risk.

It is essential to consider the whole cooling system, not just the cooling tower.

Annex D (informative) Spa pools

As spa pools are inherently high risk and potentially complex, the assessor needs to be competent in these types of system and understand spa pool treatment strategies, together with system design features which increase the risk of *Legionella* growth. See HSG282 [8].

Spa pools and hot tubs are warm water leisure pools designed for sitting or lying in up to the neck and not for swimming or total immersion. They are aerated by water jets and often also by air jets which create a stream of bubbles that break at the surface, releasing aerosols near the users' faces. They are not cleaned or drained after each use as opposed to a whirlpool bath.

The choice of design is dependent upon the likely bather load, whether it is to be used intermittently by a small discrete number of the bathers as in a privately owned home or a business setting, such as a rented chalet, or whether it is to be used by a large number of bathers but possibly irregularly, for example, in a spa serving a number of apartments, or continuously, for example, in a busy commercial leisure centre.

Hot tubs are a type of spa pool designed for essentially private domestic use by a small number of bathers (see BS EN 17125). They are commonly self-contained factory-built units with a free board

and skimmer system where the water level is below the top of the system to accommodate bather immersion and there is no balance tank (see Figure D.1). Hot tubs can be used in business situations where they require risk assessment, for example individual holiday chalets or hotel rooms might have their own hot tubs and hot tubs might be hired out for parties.

Those spa pools having a relatively high bather load, such as those in commercial leisure centres or a spa pool serving a hotel or block of apartments, as opposed to a single apartment are recommended to be of the deck level overflow design with a balance tank and continuous disinfection and filtration (see Figure D.2). In very large spa pools, balance tanks can be of similar construction and design to swimming pool systems with underground balance tanks. Smaller spa pools have balance tanks usually made of glass-reinforced plastic or polythene, with a firmly fitting lid, and are accessible for regular cleaning.

NOTE Safe access requirements for some balance tanks for cleaning purposes might be covered by the Confined Spaces Regulations [12], [13].

Depending on the particular nature of the spa pool, factors that might need to be taken into account include the following:

a) design appropriate for bather load and use;

b) materials of construction;

c) water supply, e.g. directly connected or via hose;

d) seasonality and intermittent use;

e) operation and maintenance;

f) spa pools on display (when chemical treatment might be less carefully applied or even not applied);

g) management and training;

h) susceptibility of users;

i) sources of environmental and user contamination;

j) frequency of cleaning and disinfection;

k) accessibility for operation, cleaning, maintenance and inspection, including air channels and all wetted parts (air channels are often not readily accessible for cleaning and balance tanks are often in locations which are difficult to access and where there is inadequate clearance for inspection and cleaning);

l) physical condition;

m) dead legs, bypasses and cross connections;

n) filters, including cleaning and backwashing;

o) balance tank, where fitted;

p) adequacy of water treatment and replacement of water;

q) adequacy of scheme of control, including microbiological monitoring activities; and

r) records of bather load, inspection, cleanliness and disinfection.

Figure D.1 — *Diagram of a typical hot tub*

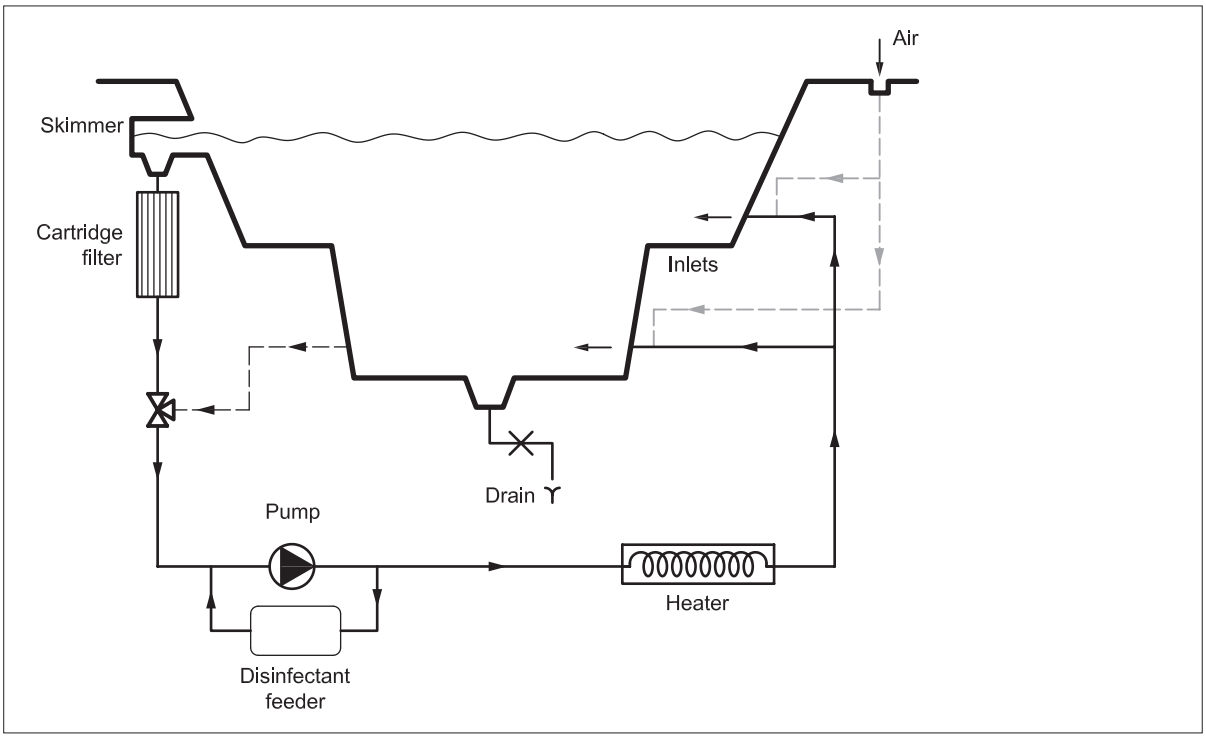
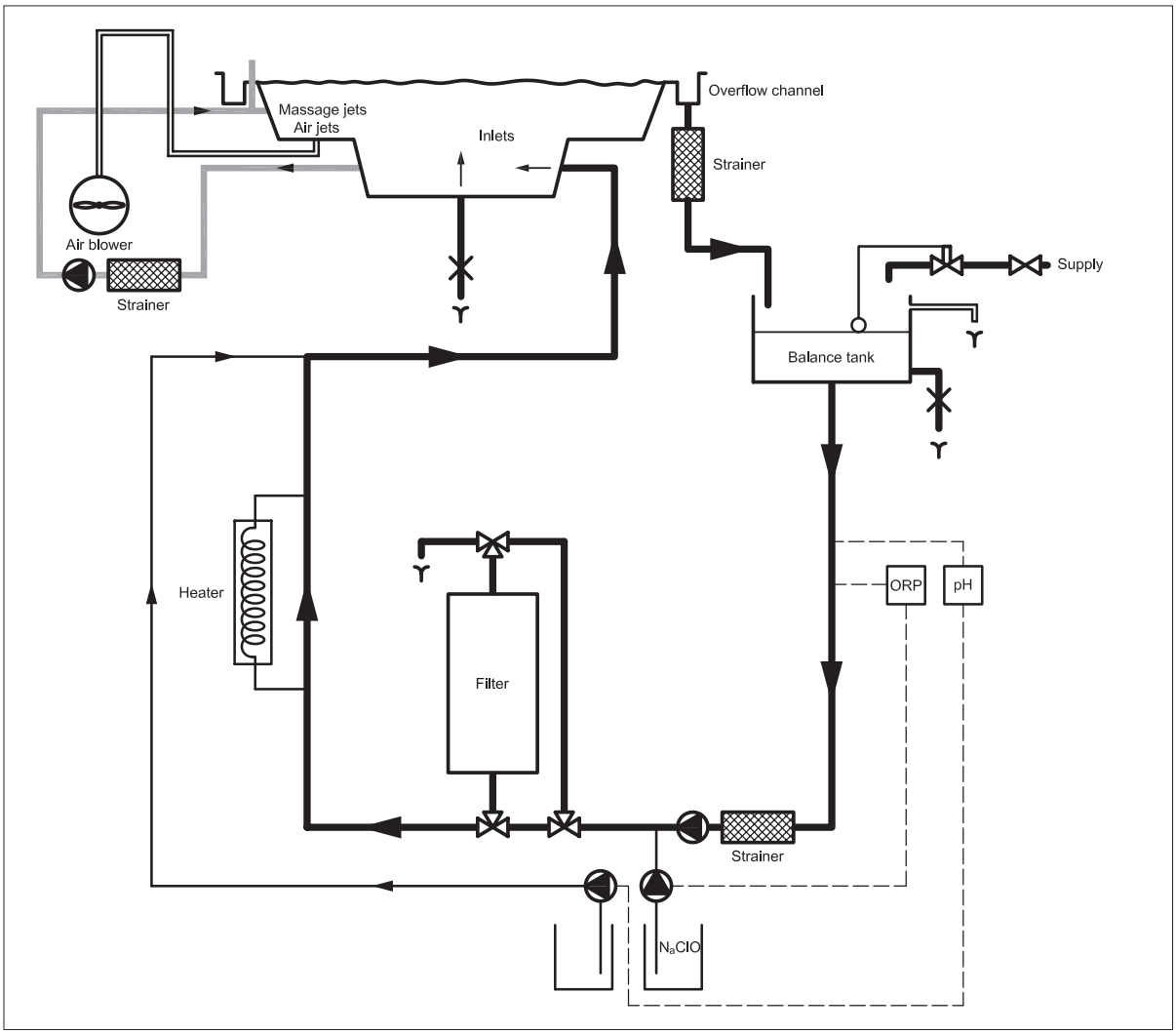


Figure D.2 — *Diagram of a typical commercial spa pool*



Annex E (informative) Other systems

E.1 Introduction

There are many other types of water systems that have been shown to be the cause of outbreaks of Legionnaires' disease, and others which are potential sources that have not yet been identified as a source in an outbreak. Many cases of Legionnaires' disease remain unexplained and in time, it is likely other potential sources will be confirmed and other pieces of new equipment identified as potential hazards. This annex discusses risk assessment issues with some of the more commonly encountered systems and some potential problems with novel technologies.

E.2 Fire suppression systems

The most common types of fire suppression system are sprinkler and drench systems. Fire hose reel systems are used less frequently. Dry riser systems are inherently safer with regards to the risk of *Legionella* growth.

When assessing these systems, the following have to be considered.

- The water might be from a source which is contaminated, e.g. a river or canal.
- Backflow prevention might be needed to protect the mains supply and other water systems.
- A large volume of water could be stored in a fire tank for very long periods without significant turnover.
- The lines from the tank to the fire hose reels could be filled with this water.
- The fire tank could have been constructed using unapproved materials, contain contamination or be in poor condition due to lack of maintenance.
- The temperature of the water in the system could be above 20 °C due to thermal gain from the building.
- When the system operates, large amounts of aerosol could be produced.

Ultimately, however, these systems are used to fight fires and the risk from fire outweighs the risk from Legionnaires' disease.

These systems are likely to be stagnant, might contain debris and be corroded to some extent. This is not of concern unless it threatens the operation of the system. The risk assessor needs to give consideration to the implications of emptying, cleaning or disinfecting fire suppression systems and what alternative fire control measures are in place.

The assessor needs to make clear that the systems are needed for safety reasons and highlight that, when testing this equipment, the work has to be completed with minimum exposure to aerosols, perhaps at times when there is a minimum number of people on site to be exposed to any aerosol produced.

E.3 Fountains and water features

Water fountains and water features, including interactive water features and zero-depth pools, release aerosol into the surrounding atmosphere. If conditions are favourable, *Legionella* can grow in them. The risk can be eliminated completely by removing the equipment. If fountains and interactive water features are to be retained, it is important that they are carefully designed and managed to control the risk.

NOTE More information can be found in the Swimming Pool Water Book by PWTAG [17].

Water features inside buildings have a greater inherent risk because they release aerosols into the building itself and have been responsible for outbreaks of legionellosis. Particularly where there is a small volume of water, the circulation pump and any decorative lighting can increase the temperature of the water to within the growth range of *Legionella* and supporting micro-organisms. There are many potential sources of nutrients in these systems, especially those which are open to the public, as debris can enter and be captured by the water.

The risk assessor needs to inspect all parts of such a system during the survey, checking the temperature of the water in the system on the day of the survey and inspecting any records of temperature that have been taken in the past.

Common faults found with such features include:

- insufficient water treatment and testing in place;
- no preventative maintenance in place;
- no, or inadequate, records in place;

- no temperature monitoring; and
- records not kept for at least five years.

E.4 Humidifiers

E.4.1 General

There are many different types of humidifiers found in industry, commerce and catering. Humidifiers are typically described by the industry as adiabatic or isothermal.

- Steam humidifiers where water is boiled to produce steam (isothermal), typically either by electrode boiler, by gas fired heaters and other heat exchange methods. Steam is injected at low pressure often into an air handling unit.
- Cold water humidifiers (adiabatic) are cold water systems that increase moisture content by evaporating water either directly into a room, or into an air handling unit. Traditionally, direct room systems are spray type and in-duct systems are either spray or evaporative types.

Spray humidifiers atomize water directly into the air which then vaporizes. The systems sometimes use compressed air at low pressure, [less than 10 bar (1 000 kPa)] to atomize the water, or high pressure typically [from 16 bar to >70 bar (1 600 kPa to >70 000 kPa)].

Evaporative humidifiers are designed in order that the air passes through an evaporative media which is saturated with water and evaporated from the surface. These by design are not intended to create aerosols.

There are a number of other cold water systems including:

- ultrasonic humidifiers, which create a very fine mist;
- atomizing water directly by spraying it onto spinning discs; and
- older designs that simply circulate excess water from a pond to spray nozzles.

NOTE Humidifiers often have or require ancillary equipment including air compressors, water treatment devices, softeners and/or reverse osmosis (RO) systems (high pressure spraying systems or larger ultrasonic systems are normally operated on RO water).

The different units operate in fundamentally different ways and the level of risk needs to be judged individually. Very few recorded outbreaks of Legionnaires' disease have been associated with humidifiers, however humidifier systems are often seasonal and during periods of low use, bacteria can potentially accumulate in stagnant water and, without proper design and maintenance regimes such as cleaning and disinfection, might present a risk. Small ultrasonic humidifying units associated with food displays have caused outbreaks of Legionnaires' disease when incorrectly installed and maintained.

E.4.2 Steam humidifiers

Steam humidifiers are likely to present minimal risk due to the high temperatures involved in the production of steam.

E.4.3 Spray humidifiers

Spray humidifiers in which the water is recirculated are intrinsically more likely to present a risk of microbial growth and are now uncommon.

With spray humidifiers, the released aerosols could contain micro-organisms if control is not achieved, including *Legionella*, which could be inhaled by people. Because people are likely to

breathe the humidified air, systems are rarely treated with chemicals to prevent the normal problems associated with using and evaporating water.

To prevent microbial growth, the systems concentrate on delivering good quality water to the humidifier, including careful attention to avoid stagnation by incorporating regularly induced operation and flushing processes.

E.4.4 Evaporative humidifiers

Evaporative humidifiers operate by applying relatively small amounts of water to a wetted media through which the air passes. They are often described as not producing aerosols, however, more accurately they can be described as having very low aerosol generation. Since evaporation occurs, the design is likely to include mechanisms for controlling increasingly dissolved solid concentrations within the water. Without careful control of water conditions and cleaning it is possible to scale (or foul) the evaporative media resulting in unintentional flow patterns and product failure.

E.4.5 Risk assessment

Humidifiers using water without recirculation, e.g. spinning disc types and some spray humidifiers, normally present a low risk provided there is continued use and the water source is largely free from bacteria, such as towns mains supply. The risk assessment will concentrate on ascertaining if there is any way that bacteria could grow within the feed system.

Humidifiers are often used seasonally or intermittently, potentially resulting in water being left stagnant in the system and allowing growth that could result in a contaminated aerosol being disseminated when the system is put into use. It is recommended that humidifiers are therefore drained down when not in use.

Risk assessment ought to involve careful visual examination of the system, including the feed water supply, to ensure it is clean, and constructed and operated appropriately. Sumps and drip trays in the humidifier and other equipment in ventilation systems, such as heater and chiller batteries, ought to be self-draining with air gaps to prevent back-siphonage from the drains.

Where humidifiers are associated with air handling units in air conditioning systems, the assessor needs to be aware of the possibility of condensation in the ductwork, as this can result in a microbial growth and a theoretical increase in risk.

Common faults found include the following.

a) Feed water supply is not satisfactory – i.e. not clean, fresh wholesome water, at less than 20 °C.

b) The feed water supply pipework is not of approved materials or creates long dead legs from the flowing main.

c) Tank fed supplies are not closely monitored for water hygiene.

d) No water test points are installed.

e) System designed does not incorporate features to prevent water stagnation, such as:

   1) automatic flushing and purging cycles, in particular, confirm the system operates automatically during periods of low use;

   2) self-draining, with air gaps to prevent back siphonage from drains;

   3) automatic water drainage if the system stops operating.

f) Within air handling systems, limited air filtration is in place or badly maintained.

g) Condensation or water carry over is causing damp conditions.

h) No evidence of commissioning and preventative maintenance activities, including:

   1) limited access to the equipment;

   2) evidence of scaling or biofilms;

   3) build-up of dirt or debris, infestation;

   4) signs of damp, mouldy conditions, caused by condensation, water carry over or leaks;

   5) no replacement of consumables, such as water filters;

   6) limited water hygiene records.

i) Any ancillary equipment, such as air compressors or water treatment devices, are not maintained as part of the system.

j) Relative humidity conditions are incorrect and set points and air changes are not at desired levels in order not to over-humidify and create damp conditions.

E.5 Vehicle wash systems

E.5.1 General

Vehicle wash systems include car washes, lorry washes (often found at distribution depots and at manufacturing plants), bus washes and train wash systems.

There are two categories with regard to water usage:

a) those that collect and recycle the wash water; and

b) those that use once-through water and discharge it to drain.

Vehicle washes can be manually operated or have automatic spray systems. They are often in the open and, when enclosed, this only reduces the nuisance of noise or spray. The degree of enclosure often has little effect on the reduction of aerosol released into the environment.

E.5.2 Types of vehicle wash systems

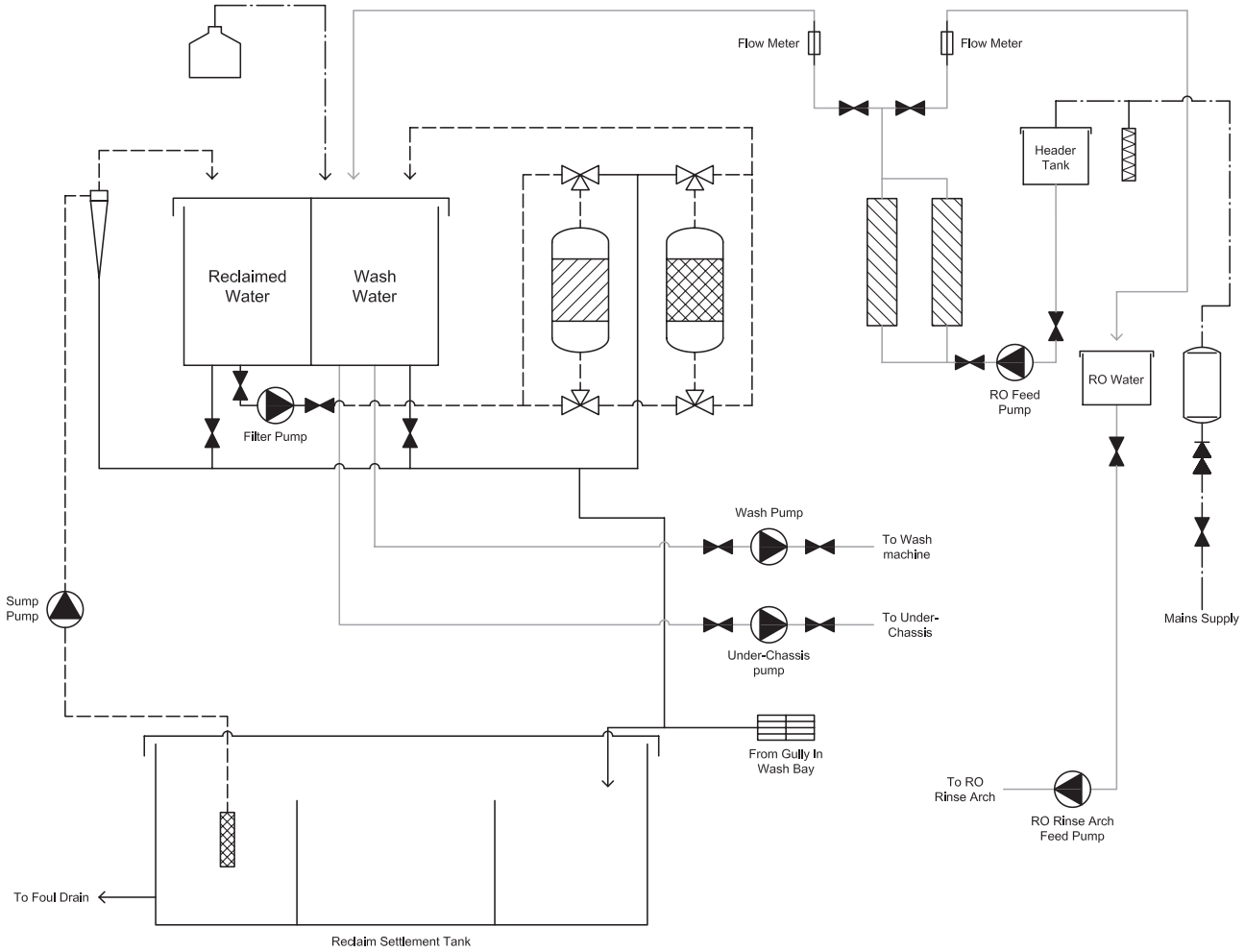
A car or lorry wash can be a manual jet wash, in which the jets or brushes are operated manually, or the automatic type, in which the washing is done by jets and brushes mounted on a moving frame that passes over the length of the car. In a train or bus washing system, the train is driven through the jets and spinning brushes.

The wash process consists of an initial wash cycle with detergents, a rinse cycle and a warm air drying cycle. It is common for the system water to be recycled through an interceptor tank (usually below ground) which separates floating debris and allows silt and grit to settle. Oil pads and filters remove small quantities of oil before the water is returned to a collection tank, filtered and returned to the initial wash cycle water.

The rinse cycle water flows into an intermediate tank where fresh water is added and cycled through carbon filters which remove detergents, remaining solids and chlorine to produce rinse quality water.

Wash systems using once-through water from a mains supply still require a full assessment, with a survey of jet operation and design and the quality and temperature of the water. On industrial sites, a process water could be used, in which case the source and possible pre-treatment need to be taken into consideration. An example of a car wash schematic diagram is given in Figure E.1.

Figure E.1 — *Example of a car wash schematic diagram*



Key

Mains water supply		Strainer	
Tank-supplied washing water		Sand filter	
Reclaimed water system		Carbon filter	
Drain/backwash line		Softener	
Water storage tank		Biocide dosing unit	
3-way valve		Hydrocyclone	
Flow meter		Isolation valve	
Cartridge filter		Double check valve	
Reverse osmosis (RO) unit			

E.5.3 Factors affecting *Legionella* risk assessments

It is important that a full understanding of the design and operation of each wash system is known to the assessor. There will always be some exposure of the user and the public to aerosols, but the degree of exposure depends on the design of the unit.

It is important to assess the temperature of the system water and to consider seasonal variations, including exposure of storage and distribution systems to thermal gain by exposure to sunlight or extended periods of stagnation due to holidays, such as in factory lorry wash installations. During periods of drought, wash systems are often the first to be shut down and there is the risk of increased proliferation of *Legionella* as a result. It is important to establish the system conditions on shutdown and the procedures in place to restart the system.

In systems in which the wash water is recycled, the presence of soaps, oils, dirt and sediments provide nutrients for microbial growth, so assessment of water temperatures and cleanliness of water after filtration/separation is important.

The significant sources of contamination to be considered in the risk assessment are:

a) the suitability and efficiency of filtration and separation system used;

b) management of filters, including carbon filters;

c) the suitability of any chemicals and associated dosing equipment;

d) the maintenance and servicing schedule of the equipment; and

e) the frequency of dirt/silt removal from the system, e.g. by gully sucker.

E.6 Thermal processing — Food industry (pasteurizers)

Food and drink products, including milk, juice, canned food, beers and others, are susceptible to spoilage by the growth of microbes. To reduce microbial activity, which is mainly bacterial but can be fungal in origin, a process called pasteurization is employed, where the food or drink product is subjected to elevated temperature which destroys the contaminant organisms without adversely affecting the taste and quality of the product.

There are several designs of pasteurizers available. Commonly, a pasteurizer consists of several zones (baths or tanks in which the product might be immersed or from which water might be pumped and sprayed over the product) which contain increasingly hotter water until pasteurization temperatures are achieved, followed by zones which reduce the temperature of the product. Such pasteurizers are called tunnel pasteurizers and typically contain a total of eight or more pre-heat and pre-cool zones. The actual number of pre-heat and pre-cool zones depends on the temperature profile the manufacturer needs for pasteurizing their product. Maximum temperatures in the hot zones can range from 60 °C up to >90 °C in certain food applications.

When considering the temperature profile in such pasteurizers, typically one pre-heat zone operates at a similar temperature as a pre-cool zone and so the zones are linked and "share" the water between those respective zones. Only the zones with water at the highest temperature are independent to allow pasteurization of the product. In certain pasteurizers the regenerative zones are linked to a cooling tower and so it is common to encounter pasteurizers that are dosed with water treatment products to maintain water quality similar to that required in a cooling system.

With water at varying temperatures, if hygiene procedures are not maintained, package failures and cross-contamination from package failures will likely provide a nutrient source to the warm water

and encourage any microbiological contamination present in the water to grow. This increased microbiological contamination present in the water, including *Legionella*, will:

a) impact pasteurizer operation due to the disturbance of the thermal balance (fouled pump strainers upsetting the balance of the flows between the regenerating zones, fouled spraying nozzles or distribution decks causing reduced flows and hence interfering with the pasteurizing process); and

b) cause health and safety risks (e.g. contaminated aerosols increasing health risks for the people working in the vicinity of the pasteurizer (*Legionella*) plus microbiological slime causing floors to become slippery).

Since a pasteurizer uses or stores water which can create an aerosol, these systems require a *Legionella* risk assessment and control programme to be implemented. It is recommended that the assessor reviews all mechanical, operational and chemical aspects of control to include inspections, cleaning procedures, water quality (corrosion, scaling and biocide efficacy), periods of extended stagnation (typically at weekends or shutdown), results from monitoring, aerosol production and employee exposure.

E.7 Tunnel washers

Plants manufacturing large metal components, particularly in the motor industry, frequently have systems for degreasing and cleansing the components prior to painting them. Other similar devices are used to cool or quench the coating after its application. This might involve passing the components on a conveyor through a tunnel, with successive spray washes of hot caustic or other solutions followed by one or more spray rinses with hot or cold water. There is dense production of sprays and considerable amounts of aerosol can be produced which might be released into the workspace. Often, the water is recycled and there is much opportunity for contamination of the water stored in collection tanks prior to reuse. In some of these tanks, the conditions could be ideal for microbial and *Legionella* growth. Tunnel washers have some similarities to vehicle washers and have been identified as the source of an outbreak on at least one occasion in a plant producing heavy machinery.

The risk assessor has to consider each step in the process as not all stages will necessarily produce a *Legionella* risk. The use of biocides might not be appropriate, so alternative means of minimizing the potential for growth have to be considered. Sampling for *Legionella* can assist risk assessment and might be required for monitoring of control.

E.8 Air scrubbers

There are many kinds of air scrubber and risk assessors are unlikely to be familiar with them all. Risk assessment will therefore require the input of the system designers. Some scrubbers incorporate the use of water which might be recycled, and this can present a risk of growing *Legionella* and causing Legionnaires' disease. A large outbreak of Legionnaires' disease was caused by an air scrubber in Norway in 2005 [18]. In design and operation, air scrubbers using water might have several characteristics in common with cooling towers. In particular, the air to be scrubbed passes through a matrix like a cooling tower pack which is kept wet by water falling through it. Scrubbers can be multiple-stage, but ultimately the air is exhausted to the atmosphere possibly after passage through other devices to reduce the release of droplets to the atmosphere. The water could then be recycled after the materials captured from the air have been removed. The removal process depends upon the nature of the materials being scrubbed from the air. It might simply be a physical process to remove particulates or one or more chemical treatments to remove or render safe soluble substances.

The risk of *Legionella* growth depends upon the nature of the materials being removed from the air and the temperature attained in the water and pack. Organic particles such as wood dust or flours and some soluble organic compounds can provide nutrients for microbial growth and will therefore potentially support the growth of *Legionella*. As always, the temperature achieved is a critical factor and some systems achieve temperatures in the high-risk range. There could be a risk of growth of *Legionella* within the pack and/or the recycled water circuit itself.

Some air scrubbers incorporate biological treatment stages to break down captured organics. These can operate at temperatures that permit the growth of *Legionella* depending upon the ecology of the system. The relative novelty of these systems incorporating biological treatment means that there is insufficient data to determine whether a particular system is likely to pose a risk. They will therefore require monitoring for *Legionella*.

As with any other system the risk assessor will have to consider the likelihood of *Legionella* growing in the system, how this can be controlled, the likelihood of droplets being released into the exhaust air and the means of reducing the droplet release. In view of the variability in design of the systems and the processes they are applied to, some monitoring for *Legionella* might be needed to assist the risk assessment process and might need to be incorporated into the ongoing monitoring of control.

E.9 “Green” technologies

E.9.1 General

Many technologies are being introduced into buildings, particularly to reduce energy demands and water usage. These include rainwater harvesting, greywater reuse, sewage reuse, solar heating, air water and ground source heating using heat pumps and geothermal heating. There are many different designs of systems coming to the market and although the risks from faecal contamination might be considered, the risks of microbial growth and the associated potential risk to public health are often overlooked. These need to be considered at the design stage so that the design requires the input of microbiologists as well as engineers, plumbers and chemists. Often, a *Legionella* risk assessment identifies factors that would be considered as creating a risk. However, as the technologies are relatively new, the risk assessor might have no prior experience of the equipment. There is also a lack of data from the microbiological sampling of such equipment. This is an instance where sampling for *Legionella* could inform the risk assessment process and might be needed to confirm control is being achieved consistently.

Commonly these systems fall out of use due to lack of understanding or commitment and this will impact the risk.

E.9.2 Rainwater collection

Rainwater harvesting systems are installed on a wide range of buildings and therefore can vary greatly in size. Rain itself contains dust and micro-organisms, but potentially the greatest source of contamination and nutrients is deposits of dirt and bird or other animal droppings from the roof or other surface from which the rain is captured. An important aspect of design, therefore, is to have mechanisms in place for trapping this or diverting the first rainfall washing off the roof after a dry period. Another key factor to be considered in the design is access to the holding tank for inspection and ease of cleaning. Sometimes, greywater recycling and rainwater capture are combined into one system and this can create difficulties for *Legionella* control as greywater is often warm and always more contaminated by micro-organisms and nutrients. Protection from thermal gain and the temperature during storage are important as large volumes could be stored for considerable times. The final use of the water and whether it is subjected to any filtration and/or biocide addition are also important factors.

E.9.3 Greywater reuse

Greywater is water generated from domestic activities, such as laundry, dishwashing and bathing, or from other sources such as air handling unit condensate or RO reject streams. It might be used for irrigation, toilet flushing or other non-potable purposes. Depending on the source, it frequently contains much higher levels of micro-organisms or has chemical characteristics different from the mains water supplies. It is also often warm and therefore a potential medium for the growth of *Legionella*. Depending upon what the greywater is used for, it might undergo different levels of treatment, often including chlorine treatment or other disinfection. The *Legionella* risk assessment has to include a careful consideration of how the water is used, the likelihood of biofilm formation and *Legionella* growth in the associated plumbing system, and the means of controlling this. If used for irrigation, the risk is related to the method of delivering the water. Sprinklers or sprays can produce significant amounts of aerosol, whereas drip irrigation produces very little, and soaking into the soil via water-permeable hoses produces little or no aerosol. This is an example of where sampling for *Legionella* might help the assessment.

E.9.4 Solar heating

In solar heating the sun's radiant energy is captured in a solar collector (solar panel), usually situated on a roof. There are two main methods of delivering the energy of the sun to generate hot water for either bathing or heating purposes. In the first, the "direct" heating method, water is passed through the solar panel to heat it and is then fed directly back into the hot water distribution system for end-use. Secondly, there is the "indirect" method, which takes water, usually containing antifreeze, from the solar panels and passes this through a heat exchanger coil located inside the hot water storage cylinder. The area where this heat exchange coil is situated forms the pre-heat store, which is the principal location where energy is delivered from the primary system. In single-cylinder systems, the heat exchange coil is in the bottom of the water tank with a second heating coil in the upper half of the tank to provide supplementary heating. The supplementary heating can ensure the water is distributed into the hot water system at the appropriate temperature when there is insufficient solar energy. There are also multi-cylinder systems in which the pre-heat store is in a separate cylinder.

There are thermal store systems where solar energy heats the body of the store and heat is extracted by a mains cold water coil passing through the vessel or by an external heat exchanger. The volume of water in the pre-heat store, called the dedicated solar volume, is usually a minimum of 25 L/m^2 of solar collector, and is additional to the normal volume of water stored in an equivalent conventional system.

On sunny days the water in the solar collector can get very hot, possibly reaching boiling point, whereas on dull winter days there might be insufficient solar energy to heat the household's water to a usable temperature. For the solar water heating system to run safely and efficiently, a range of valves and sensors are installed to switch the system on or off according to the solar energy available.

Both direct and indirect systems can present risks, depending upon their design and operation. The risk factors and control measures for solar-heated systems are the same as other hot water systems. The main difference is that in many designs of solar-heated domestic hot water systems the volume of warm or hot water stored is greater than in normal domestic hot water systems. Depending on the amount of solar energy available and the design of the system, a significant portion of this water can be at temperatures conducive to the rapid growth of *Legionella*. With many of these systems there is a conflict between maximizing energy conservation and minimizing the risk of *Legionella* growing. Energy conservation is maximized by distributing the hot water at 50 °C or less, but this increases the risk of *Legionella* growing. A common recommendation is to ensure that the stored hot water is heated to 60 °C for at least one continuous hour once a day. Currently, there is insufficient microbiological evidence available to confirm which designs and modes of operation are safe.

Consequently, sampling for *Legionella* is likely to be an essential part of the monitoring of these systems until sufficient experience has been gained to validate the controls.

More detailed information on solar heating systems is given in BS 5918.

E.9.5 Ground, air and water source heating

Other renewable energy heating systems or energy recovering systems incorporating heat pumps and extracting heat from air, the ground or water (air/ground/water source heating) are becoming more widely available. They also often use heat stores. The heat extracted is most commonly used to provide space heating, often via underfloor heating. When used for space heating the *Legionella* risk is likely to be minimal as the system remains closed in normal operation. However, sometimes the systems might also be used to heat the domestic hot water, in which case again, there might be a conflict between energy conservation and the risk of *Legionella* growth.

Annex F (informative) List of equipment

The assessor's equipment list could include:

a) calibrated immersion and contact thermometers (immersion and surface probes);

b) mobile phone (with timer and calculator), if allowed on site;

c) torch and mirror;

d) sterile sample containers for microbiological sampling;

e) paper towels;

f) digital camera if allowed on site, or portable borescope camera;

g) recording device (clipboard, voice recorder, personal digital assistant or other);

h) respiratory protective device, overalls, eye protection, safety footwear, disposable powder-free gloves, hard hat and other suitable PPE; and

i) sampling and test equipment.

The following apparatus and materials have been found useful and might also be required for the collection of samples.

1) Sample bottles, usually 200 ml, 500 ml or 1 000 ml, but 5 l or 10 l bottles might also be required.

2) Appropriate biocide-neutralizing agents.

3) Sterile absorbent cotton wool swabs, and sterile tubes (typically 30 ml capacity) containing Pages' saline or dilute (1:40) Ringer's solution.

   NOTE 1 BS EN ISO 11731 describes how to make both these diluents.

4) Wide-necked, screw-capped sterile containers (typically 50 ml capacity) for scrapings of biofilms and other materials.

5) Sterile spatulas or similar implements for scraping off or lifting out biofilm or other material samples.

6) Means for disinfection of sample points.

   NOTE 2 Disinfectant: 70% v/v (700 ml/l) ethanol and water, 70% v/v (700 ml/l) propan-2-ol and water, or a 1 in 100 dilution of a commercial grade sodium hypochlorite solution containing in the range 12% to 14%

available chlorine [0.1% available chlorine is equivalent to 1 000 mg of chlorine per litre of solution (1 000 ppm)]. Alternative disinfection methods, such as heating using a portable gas blowtorch, might also be used where safe to do so and where fittings are suitable (subject to site rules).

7) Commercially available alcohol-based wipes.

NOTE 3 These are only suitable for disinfecting external surfaces, such as immersion probes.

NOTE 4 Attention is drawn to the COSHH Regulations [4], [5].

NOTE 5 On some sites, use of certain disinfectant processes might be prohibited, for example use of ethanol on sites where there are fire or explosion risks, or hot work/blowtorches. It is essential that the specific site health and safety rules are followed.

8) Permanent marking or writing implements.

9) Recording forms, survey forms, labels. These might need to be waterproof or protected from water.

10) Sterile food grade silicone rubber tubing with appropriate clamps. The tubing ought to be in 2 m to 3 m lengths, of various internal diameters (15 mm to 30 mm) and packed in a manner that ensures it remains sterile prior to use.

11) New food grade plastic bags not containing any antimicrobial agents, elastic bands and sterile scissors.

12) Hand-held vacuum pump and sterile 1 l flasks.

13) Sterile disposable or sterilized re-usable dip samplers.

14) Containers and/or packaging materials for transportation of sample bottles, as applicable.

15) Bags for waste disposal.

Annex G (informative) Schematic diagrams

Schematic diagrams are accurate but simplified illustrations of the configuration of water systems, which include all key components and relevant components and omit everything which is not relevant. They are not formal technical drawings and are intended to be easy to read without specialized training or experience. Like maps of underground railways in many cities, they allow the person unfamiliar with the layout of a system to understand quickly the relative positions and connections of the relevant components, whilst providing only an indication of the scale. It is common for schematic diagrams to be computer-generated (see Figure G.1), which has the advantage of clarity and ease of editing, but hand-drawn diagrams are acceptable for simple systems (see Figure G.2).

Key components of a schematic diagram are the parts of a system which constitute the system itself and could be considered its principal characteristics. Relevant components are those which could have some bearing on the *Legionella* risk, but are not essential to the routine operation of the system. Details which are not relevant are those which have no bearing on the *Legionella* risk and either have no function or whose presence and function could be reasonably assumed.

For parts of the system which are inaccessible for safety and practical reasons, it is recommended that these are indicated on the schematic diagram [see **5.2** i)].

Simple systems, such as those providing drinking, washing and sanitary water in small buildings might require only very simple diagrams, but these ought to distinguish parts which are connected

directly to the supply from those supplied via tanks and calorifiers (or other water heaters). More complex buildings could require more than one diagram, for example, one showing the overall layout, one showing the configuration of the plant (tanks, pumps, softeners, etc.) and one showing the details of the fittings at the point of use. For very complex systems, a balance might need to be struck between completeness and ease of reading, in which case omissions and approximations ought to be recorded on the diagram using statements such as "General configuration only. For detail refer to as-built technical drawings or confirm by inspection".

Where control of the *Legionella* infection risk is by active devices, for example, the dosing and control equipment used on cooling tower systems, these ought to be included in the schematic diagram, showing the routes of signals from sensors (e.g. electrical conductivity) through any control units to actuators (e.g. bleed valve).

Water systems which are self-contained and separated from their supply, either for operational reasons or to protect the supply against back-contamination (e.g. cooling tower systems), ought to be illustrated showing the make-up water configuration, including the origin of the water, any pre-treatment (such as softening), and all break tanks (cisterns), pressure booster pumps, etc. These systems are likely to incorporate operational control and contingency components, such as circulation pumps, three-way valves and multiple components on standby, alternating, or in lead and lag operation, and to have multiple drain points. They might also incorporate specialized devices for particle removal heat recovery and operation in "free cooling" mode, etc., and these ought to be included in the diagram.

It is important that all schematic diagrams identify the date when they were last reviewed and updated. The name (initials) of the individual and their organization ought also to be recorded. Where required, a legend detailing any symbols or abbreviations ought to be included on the schematic diagram.

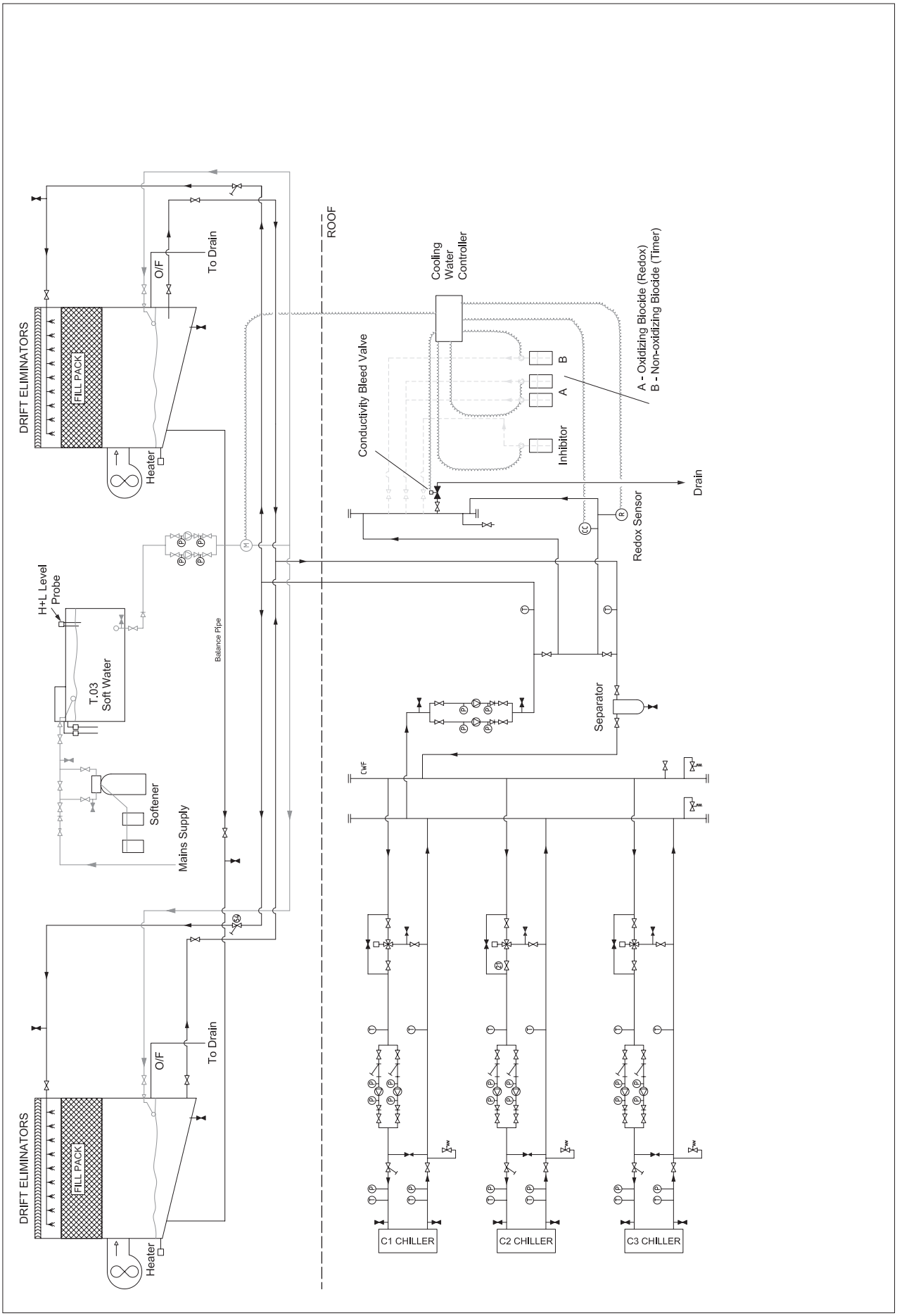
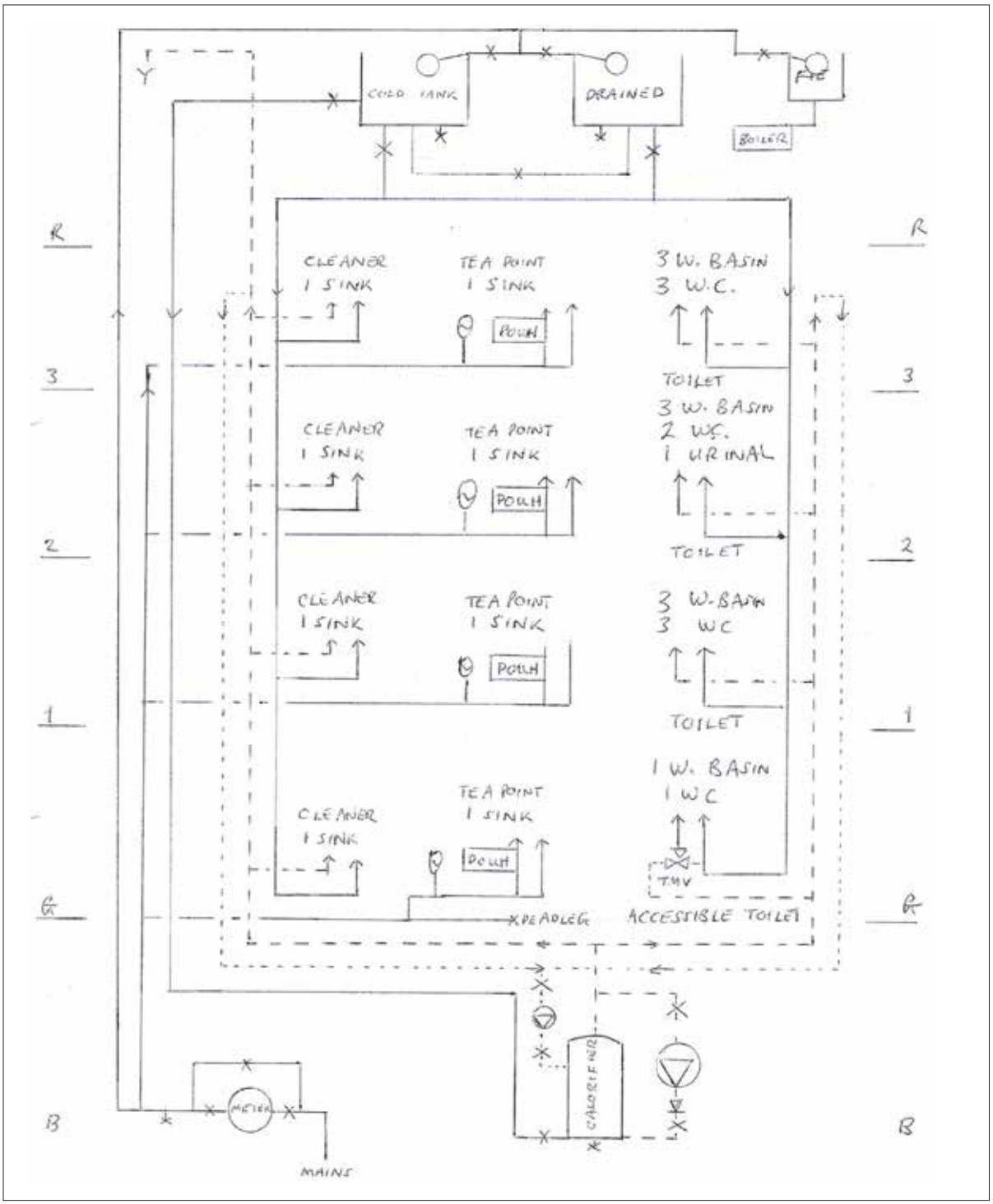


Figure G.1 — *Example of a computer-drawn schematic diagram of an evaporative cooling system*

Figure G.2 — *Example of a hand-drawn elevation of a hot and cold water system in a commercial building*



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Standard Operating Procedure:

WQS – 017

Procedures in the event of out of specification sample for Legionella and other monitored bacteria, moulds etc.

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Sampling and monitoring

NHS QEUH utilises external service providers to carry out sampling and monitoring of the water systems

1. DMA (NHS Specialist Water Service Provider) carry out sampling within the QEUH Estate of outlets on a rotational basis as follows :-

Adults and Childrens

Area	Frequency	Notes	Analysis
Ward 1D PICU	Weekly	Submitted to GRI ¼ of outlets sampled weekly on rotational basis *Approximately 12 Samples*	Potable, Pseudomonas, GNB AMS on ¼ of samples each month (rotating) Water Temperature & CLO2 level.
Critical Care Areas (Adults 4th Floor, 6C, HDU, CCW, 2A, NICU)	Monthly	Submitted to GRI *Approximately 68 Samples*	Legionella, Potable & Pseudomonas Water Temperature & CLO2 level.
A&C CWSTs & Filter Units	Monthly	Samples taken from Dips & Drains from 4 off raw tanks, 3 Filtration units x 3 sample points and 4 off bulk filtrate tank Dips and Drains *Approximately 38 Samples*	Legionella, Potable Pseudomonas GNB SAB, Temperature, CL02

Sentinel Outlets (Basement, Adult Ground Floor A&E, OPD, Acute 1st Floor Critical Care, Theatres, Consulting Rooms, 2nd Floor Medical Physics, Endoscopy, Theatres, 5th Floor Ward A,B,C,D, 8th Floor A,B,C,D, 9th Floor Ward C, 11th Floor A,B,C,D. RHC Ground Floor Concourse, OBW, 1C,2C,3B.)	Monthly	Submitted to Intertek *Approximately 142 Samples*	Legionella, Potable, Pseudomonas, SAB Water Temperature (for CL02) & CLO2 level.
Clinic 1 & 2 RHC	Monthly	Submitted to GRI *Approximately 50 Samples*	Legionella, Potable, Pseudomonas, GNB, SAB, AMS Water Temperature (for CL02) & CLO2 level.
Childrens Ward 2A & 2B	Weekly	Submitted to GRI ¼ of outlets sampled weekly on rotational basis *Approximately 140 Samples*	Potable, Pseudomonas, GNB AMS on ¼ of samples each month (rotating) Water Temperature & CLO2 level.

Retained Estate

Neurosurgery	Quarterly	Submitted to GRI *Approximately 40 Legionella & 10 Potable Samples*	Legionella, Potable Water temperature, CLO2 level.
Neurology	Quarterly	Submitted to GRI *Approximately 20 Legionella & 6 Potable Samples*	Legionella, Potable Water temperature, CLO2 level.
Maternity	Quarterly	Submitted to GRI *Approximately 40 Legionella & 10 Potable Samples*	Legionella, Potable Water temperature (CL02), CLO2 level.
Neo-Natal (New Maternity)	Quarterly	Submitted to GRI *Approximately 20 Legionella & 8 Potable Samples*	Legionella, Potable, Water temperature
PDRU	Quarterly	Submitted to GRI *Approximately 12 Legionella & 6 Potable Samples*	Legionella, Potable, Water temperature
Spinal	Quarterly	Submitted to GRI *Approximately 20 Legionella & 8 Potable Samples*	Legionella, Potable, Water temperature

Westmarc	Quarterly	Submitted to GRI *Approximately 12 Legionella & 6 Potable Samples*	Legionella, Potable, Water temperature
Podiatry	Quarterly	Submitted to GRI *Approximately 10 Legionella & 6 Potable Samples*	Legionella, Potable, Water temperature
ICE Building	Quarterly	Submitted to GRI *Approximately 79 Legionella & 7 Potable Samples*	Legionella, Potable, Water temperature
Office Block	Quarterly	Submitted to GRI *Approximately 15 Legionella & 7 Potable Samples*	Legionella, Potable, Water temperature
Teaching and Learning	Quarterly	Submitted to GRI *Approximately 19 Legionella & 6 Potable Samples*	Legionella, Potable, Water temperature
CMB	Quarterly	Submitted to GRI *Approximately 10 Legionella & 2 Potable Samples*	Legionella, Potable, Water temperature
MIU	Quarterly	Submitted to GRI *Approximately 6 Legionella & 2 Potable Samples*	Legionella, Potable, Water temperature

2. The following are sampled from the water :-

- **a.** TVC @ 37°C cfu/ml
- **b.** TVC @ 22°C cfu/ml
- **c.** Coliform cfu/100ml
- **d.** E.coli cfu/100ml
- **e.** Legionella cfu/L

3. Additionally on a monthly basis further sampling is carried out within the Adults and Childrens Hospitals testing additionally for the following :-
    a. Pseudomonas Species.
    b. SAB @ 30C & Mould @ 25oC.
    c. SAB @ 22C & Yeast @ 25oC.
    d. Cupriavidus.
    e. AMS cfu/ 100ml.
    f. Other e.g. Gram Negative bacteria.
4. These are sent to NHS Laboratory at Glasgow Royal Infirmary (GRI) for analysis and results are sent to DMA. The only exception to this is the A&C Sentinel Outlets which are submitted to Intertek Laboratories for analysis and results are sent to DMA.
5. DMA extrapolate the results for the respective buildings into specific spreadsheet for buildings. This is forwarded to Estates Management and Microbiology in the form of a Sampling Matrix.

Legionella out of spec

1. This spreadsheet sent to the NHS highlights all of the results and any out of spec results. This will be sent as soon as practicable on discovery of out of spec results. In the event of any serious issues DMA would make contact with the Lead Authorised Person (LAP) immediately.
2. If any Legionella results are found to be out of spec an Incident Report is completed and recorded on the Incident Log by the LAP. The incident report lists the issue (work request number) and on completion is signed off by the allocated resource and LAP.
3. The LAP will then extract the information to the out of spec summary which list the same information from the analysis from DMA however also lists all actions taken and history of that specific outlet.
4. The person allocated the work request will carry out the works and complete the job on their PDA. The LAP will then update the L8 out of spec summary sheet with any actions and date that the work request was completed.
5. In specific circumstances the LAP may discuss with Infection Control, ` regarding operating protocols and including but not limited to the cleaning and flushing regime or adding to the Wards little used outlet and flushing regime
6. Additionally in some cases the LAP may request DMA to add additional flushing.

Other out of spec results

1. For other out of spec results on the spreadsheet submitted by DMA e.g out of spec :-
    a. TVC @37c & 22c
    b. Coliforms
    c. Pseudomonas Species.
    d. SAB @ 30C & Mould @ 25oC.
    e. SAB @ 22C & Yeast @ 25oC.
    f. Cupriavidus.
    g. AMS
    h. Other e.g. Gram Negative bacteria.
2. In the event of any serious issues DMA would make contact with the Lead Authorised Person (LAP) immediately.
3. An Incident Report is completed and recorded on the Incident Log by the LAP. The incident report lists the issue (work request number) and on completion is signed off by the allocated resource and LAP.
4. The person allocated the work request will carry out the works and complete the job on their PDA. The LAP will then update the L8 out of spec summary sheet with any actions and date that the work request was completed.
5. The LAP will continue to monitor the results and take any further actions (which will also be recorded as a new Incident and the process above followed again).
6. In specific circumstances the LAP may discuss with Infection Control, Wards and Facilities Management regarding operating protocols and including but not limited to the cleaning and flushing regime or adding to the Wards little used outlet and flushing regime.
7. Additionally in some cases the LAP may request DMA to add additional flushing.

Resampling

1. When out of spec results are identified, DMA will carry out sampling of that outlet until a minimum of **3** clear results are obtained.
2. After further re-sampling additional information will be added to the out of spec summary and on receiving a 'not detected' or 'within parameters' result the record will be moved to the second tab on the spreadsheet which lists all previous 'not detected/within parameters' results.
3. If however further results are found to be out of spec the record is extracted and placed in the 'out of spec' tab.
4. The spreadsheet is then sent regularly to Estates Management, Infection Control and Microbiology by email also summarising any new, recurring and 'not detected' results.
5. Results are presented in a form of report to the Water Safety Group and through appropriate governance (see attached, South Sector Facilities/Infection Control Group Meetings.

Out of Specification on Point of use filters

I. When out of spec results are identified on Point of use filters, DMA will automatically change the filters and re-sample as above.

Water Sampling Out of specification definition

Microbiology and Estates agreed the following definitions for water monitoring at the QEUH and this is reflected on the sample results to highlight out of specs.

1. **E.coli & Coliforms:** *Zero CFU/100ml*

2. **TVC's 22 & 37:** *Acceptable levels out with high risk areas are < 100 CFU/ml:*

If levels are >100 CFU/ml, lab should identify the bacteria.

In the event of patient infections with suspected links to water ICD may request identification at levels <100 CFU/ml.

3. **TVC's 22 & 37:** *In high risk areas as defined by NHSGGC Pseudomonas risk assessment TVCs should be <10 CFU/ml*

If >10 CFU/ml Lab should identify the bacteria.

In the event of patient infections with suspected links to water ICD may request identification at levels <10 CFU/ml.

4. **Pseudomonas aeruginosa:** *< 10 CFU/100ml in general areas and 0 CFU/100ml in Augmented care.*

5. **Fungi:** *< 10 CFU/100ml.*

6. **Legionella Pneumophila:** *<50 CFU/litre (**Note :** Since the original definition QEUH treat any legionella positives as an out of spec from all serogroups (1 – Pneumophila) and (2-14 – Other) regardless of CFU.)*

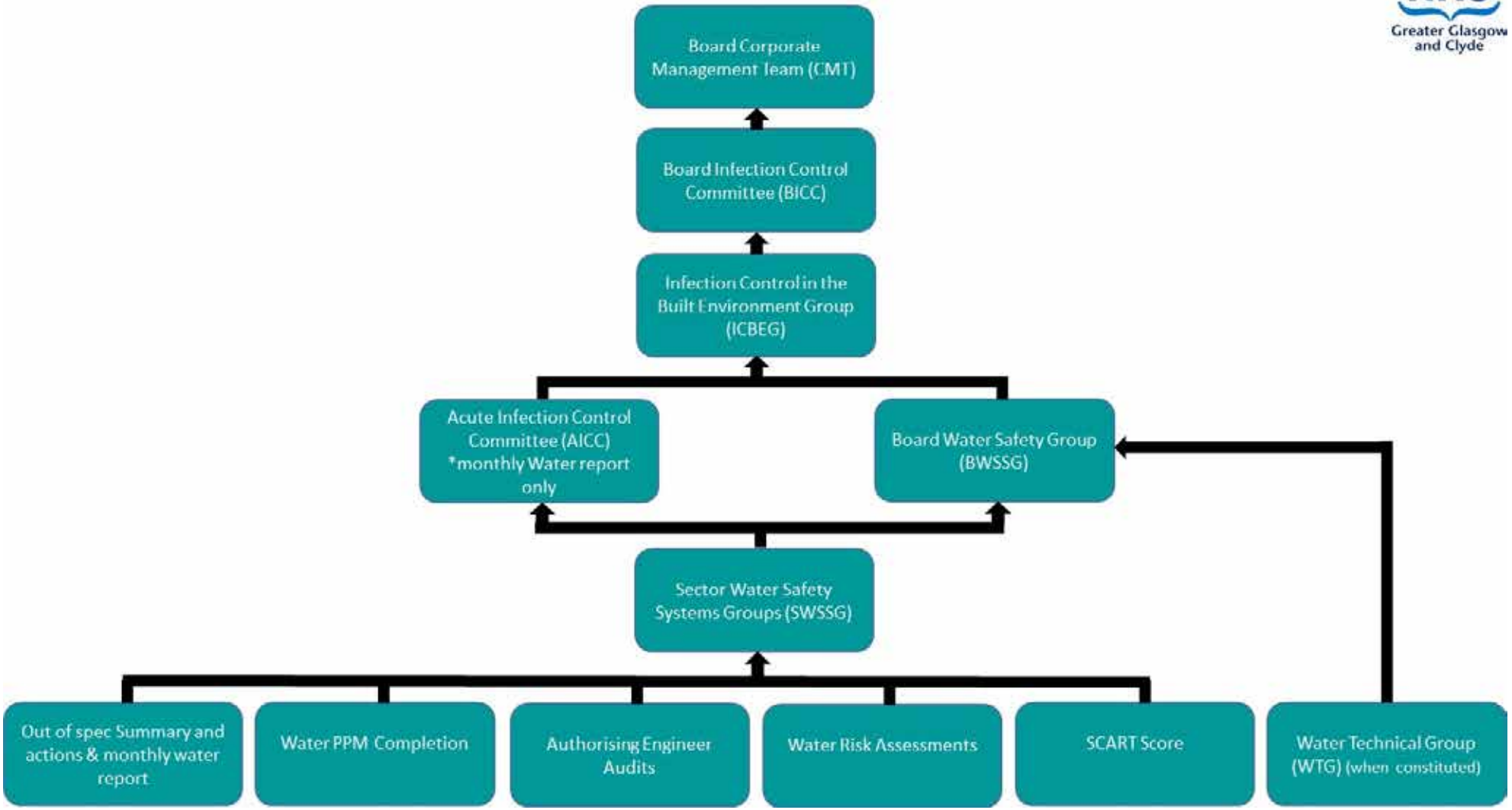
Gram negatives: *any found in any area are treated as an out of spec in the absence of any National guidance.*

Cuprivadis: *<10 CFU/100ml.*

Table 1 : Designated High risk areas :

Hospital	Ward
Adult Hospital	IT,HDU & 4b
INS	IT/HDU
Maternity Building	NICU
Maternity Building	SCBU
RHC	PICU/HDU
RHC	NICU
Transplant and haematology units	Ward 4B/4B2 and 4C haem beds Ward 2A/B (Schiehallion RHC)
Cystic Fibrosis	QEUH 7A 7D, RHC 2C,3A/B/C

Governance Water Management – QEUH Campus



The physico-chemistry of biofilm-mediated pitting corrosion of copper pipe supplying potable water

Article *in* Water Science & Technology · February 2004

DOI: 10.2166/wst.2004.0096 · Source: PubMed

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University of Southampton
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The physico-chemistry of biofilm-mediated pitting corrosion of copper pipe supplying potable water

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Abstract Copper is a generally robust material that has beneficial properties to reduce biofilm formation and pathogen colonisation of pipes supplying potable water. However, a rare pitting corrosion can occur in soft, poorly buffered waters that can lead to pipe failure. This has been shown to be mediated by a copper-tolerant biofilm whose physical and chemical heterogeneity can establish microenvironments for corrosion potentials, causing micro pits that eventually coalesce into large perforations through the pipe wall. Control of the biofilm, for example through reduced cold water or elevated hot water temperatures, can suppress this corrosion phenomenon.

Keywords Biofilm; copper; corrosion

Water Science and Technology **Vol 49 No 2 pp 91–98** © IWA Publishing 2004

Introduction

Copper is a generally robust material that has beneficial properties to reduce biofilm formation and pathogen colonisation of pipes supplying potable water (Keevil and Walker, 1992). However, a rare pitting corrosion can occur in soft, poorly buffered waters that can lead to pipe failure. Most corrosion failures of pipes have previously been attributed to one of three types (Geesey *et al*., 1994). Type 1 pitting is associated typically with hard waters from deep bore holes and temperatures of less than 25°C, causing well defined hemispherical pits. The pits contain soft crystalline cuprous oxide under a membrane of cuprous oxide crystals. The rate of pitting depends on the pH and dissolved oxygen, chloride, sulphate, sodium and nitrate. Type 2 pitting is associated with soft waters with a pH of less than 7.4 and temperatures greater than 60°C, causing deep corrosion pits of small cross section. The pits contain hard, crystalline cuprous oxide and are covered by small nodules composed of copper oxides and basic copper sulphate. Type 3 pitting is associated with high pH, low hardness and low mineral and organic content waters. It has only been observed in two areas of Sweden. The pitting is characterised by groups of small hemispherical pits under a common covering of basic copper sulphate. An oxide membrane covers all of the pits in the group with a perforation above the centre of each pit. Sulphide may be found at concentrations up to 1%.

However, another type of pitting has now become recognised. This is associated with soft, peaty waters characterised as containing a total hardness of 25 to 40 mg l^{-1} $CaCO_3$, alkalinity (carbonate hardness) between 10 to 20 mg l^{-1}, sulphate between 10 to 30 mg l^{-1} and chloride between 15 to 20 mg l^{-1}. The poor buffering results in a pH range of 7.4–9.3 and corrosion occurs at temperatures of less than 60°C or in poorly lagged cold systems (i.e. becoming warm). The result is a characteristic "pepper pot" pitting (Figure 1a) which some have called Type 1½ pitting because of some of the features it shares with Type 1 and Type 2 pitting. It resembles Type 1 pitting in that the pits are hemispherical and contain soft crystalline cuprous oxide with varying amounts of cuprous chloride under a cuprous oxide membrane. It also resembles Type 2 pitting because the oxide on the surface between the pits is largely cupric. The mounds or nodules above the pits (Figure 1b) are principally

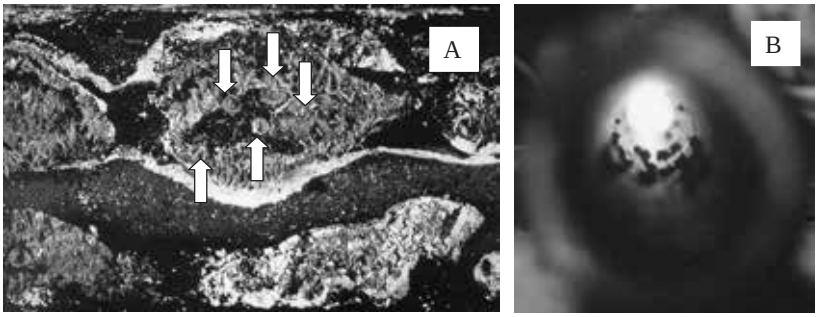

Figure 1 Longitudinal (A) and transverse (B) sections of corroding copper tube showing characteristic pepper pot pits (arrows; A) and corrosion nodules (B)

basic copper sulphate, often with a deposit of powdery cupric oxide around the periphery and on the parts of the deposit. Type 1½ pitting was first realised to cause corrosion failures in the late 1980s, usually in large runs of pipe in large institutional buildings such as hospitals in such diverse geographical locations as Scotland, South West England, Germany, Saudi Arabia and the USA. In Scotland, the extensive corrosion of hospital pipework was estimated to cost over £100 million to replace the defective pipes.

Accordingly, survey work was undertaken to ascertain the cause (Keevil *et al*., 1989). Electronic recorders were installed into some sites to monitor potentially key parameters during water usage such as temperature, pH, E_h and dissolved oxygen concentration (DOC). The data obtained showed clearly that when patients went to bed and the water usage decreased, then the hot water temperature decreased from the approximately 60°C during the day to as low as 35°C (Figure 2). Concomitantly, a complete depletion of the dissolved oxygen concentration was observed. These values returned to normal the following day when the water use recommenced.

The temperature profile of the monitoring was suggestive of a biologically mediated process, especially when also considering the associated reduction of the dissolved oxygen concentration that might have been due to respiratory activity by microbial heterotrophic species (MHS). Analysis of the water, but particularly the corroding pipe surface, showed a significant recovery of a range of sulphate reducing bacteria (SRB), fungi and MHS growing as a biofilm, including *Alcaligenes, Achromobacter, Flavobacterium, Methylobacterium, Pseudomonas* and *Sphingomonas* spp. Similar MHS were recovered from biofilms associated with corrosion pits in German pipes, including *Sphingomonas paucimobilis* and *Pseudomonas solanacearum* which were more thermotolerant when growing as a consortium and also more copper tolerant at elevated temperatures

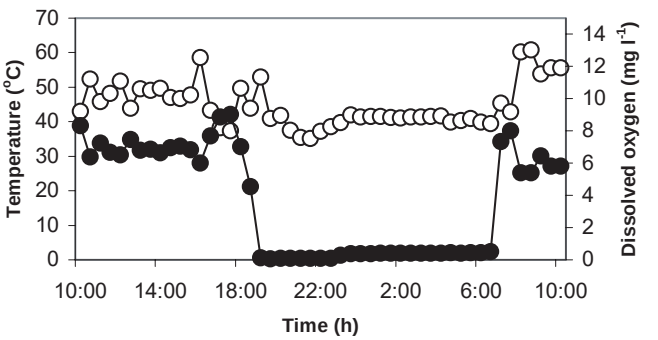

Figure 2 Changes in the temperature (open circle) and dissolved oxygen concentration (closed circle) of a hospital hot water supply during normal usage over 24 hours

(Chamberlain and Angell, 1990). This coincided with the enhanced production of exopolymeric substances (EPS) such as polysaccharides, at the higher temperatures, which in the case of *P. solacearum* produced large quantities of uronic acid-containing polysaccharide. The biofilm mode of growth at corroding sites was confirmed by using direct microscopy techniques, including stereo microscopy and episcopic differential interference contrast (EDIC) microscopy coupled with epifluorescence (Keevil and Walker, 1992; Walker *et al*., 1994). Normal biofilms in low nutrient, potable waters appear as a mosaic of stacks or fronds of microcolonies rising several hundred microns above a thin basal layer of cells on the substratum. The structure is typified, on glass surfaces for example, by many different cell types with little EPS (Figure 3a). On copper surfaces, by contrast, there are usually fewer cells but these are covered by a copious EPS (Figure 3b). Such images were previously almost impossible to obtain due to the routine use of scanning electron microscopy which requires a dehydration protocol before sputter coating and obtaining high contrast images. Invariably, only thin strings of dehydrated EPS were observed which did not convey the true scale or heterogeneity of the biofilm.

Using an MRC 600 scanning laser confocal microscope (SCLM; Biorad Ltd) equipped with a Plan Apo 60 oil objective lens, Walker *et al*. (1998) were able to observe biofilm formation on the surface of corroding copper coupons recovered from a laboratory continuous culture model system fed with Scottish upland peaty water. Light microscopy had previously been used to visualise the biofilms and their vitality. However, these biofilms had to be removed in order to examine the surface below. The SCLM technique overcame this problem by visualising biofilm cells stained with rhodamine isothiocyanate (RITC) while the copper surface was flooded with fluorescein to discern corrosion pits below the surface (Figure 4). The digitised image of the *x–y* dimension shows biofilm bacteria at the surface of the copper while pools of fluorescein below the surface are clearly visible. Transposing a series of digitised optical sections into the sagittal section *x–z* dimension clearly reveals a corrosion pit > 30 μm in depth with stained biofilm cells at the bottom. The association with biofilm metabolic activity was shown by staining corrosion pits with 5-(and -6-)-carboxy-2′,7′-dichlorofluorescein. The excitation and emission of this fluorophore decrease in acidifying conditions, thus dark zones in the digitised fluorescence image correspond to areas of low pH. These are clearly seen adjacent to individual cells and microcolonies, as a halo, in the corroding pit (Figure 5). It was concluded that these halos corresponded to zones of H^+ production or acidic EPS that would initiate a corrosion cell on the copper surface. Of note, little corrosion of copper was observed if the potable water providing the medium for biofilm growth in continuous culture was filter sterilised through a 0.2 μm nylon membrane filter before use. This procedure removed the majority of the high molecular weight humic substances from the water, suggesting that they are important for initiation of a corrosive biofilm.

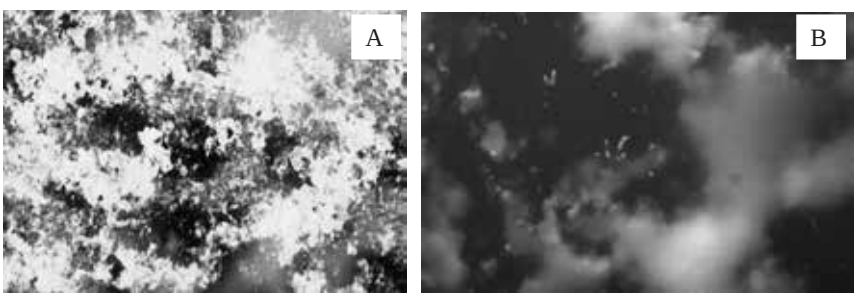

Figure 3 Heterogeneous biofilm with low EPS formed on glass (stereomicroscopic image; A) and high EPS formed on copper (epifluorescence image, B) surfaces immersed in potable water after 14 days at 20°C

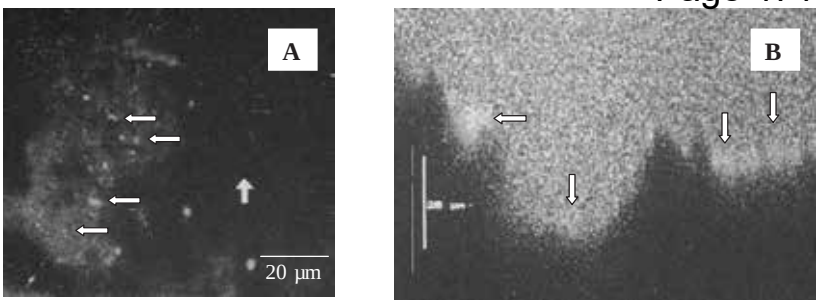

Figure 4 SCLM composite images of a copper corrosion pit described in the *x–y* dimension (A) and the sagittal section *x–z* dimension (B). Biofilm cells were stained with RITC and the whole surface is flooded with fluorescein to reveal pits below the copper surface (true surface is shown with the solid arrow, bacteria with shaded arrows)

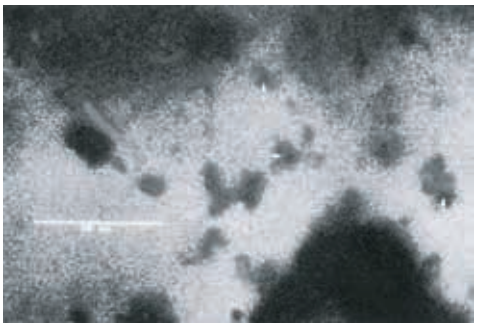

Figure 5 SCLM composite image of biofilm microorganisms stained with RITC attached to a corroding copper surface. Zones of acidification, due to reduced fluorescence of carboxyfluorescein, are shown in black and indicated by arrows. Marker bar denotes 20 μm

Discussion

Spatial heterogeneity

The studies reported have demonstrated the close relationship between the presence of copper and temperature tolerant biofilms, typically of high species diversity, and pitting corrosion. Key attributes of the corrosive biofilm are the physical heterogeneity, forming a mosaic or patchwork of cells and EPS on the copper surface, and the requirement for humic substances. The humic substances serve as important nutrients for bacteria, and a food chain is established in which pink-pigmented *Methylobacter* spp. feed off the C_1 and C_2 by-products arising from metabolism of cinnamic, ferulic and other humic-derived acids. Humic substances can also be strong chelators of copper to counteract the toxic effects of copper ions coming into solution, thereby encouraging microbial colonisation and biofilm formation. The spatial heterogeneity of the biofilm may subsequently contribute to the establishment of corrosion cells.

Metabolism and acidification

An important clue to the chemistry of Type 1½ pitting is that it only occurs in soft, poorly buffered waters. This might indicate that acidic processes may play a key role, even on the microscale. Analysis of corrosion pits in German hospital pipework identified copper complexes with pyruvate and lactate (Paradies *et al*., 1992). Cu^{3+} was also detected and this was believed to be due to an interaction with peroxide, a possible by-product of aerobic metabolism by microorganisms. An important function of biofilm MHS is to metabolise organic molecules to carbon dioxide and acids such as lactate, and respire with oxygen as a terminal

electron acceptor. This metabolism produces zones of acidification around the cells, as described, and also zones of low oxygen concentration and E_h. The latter was elegantly demonstrated by use of an *E. coli* strain containing a *nirB* nitrite reductase, oxygen-repressible, promoter fused to the β-galactosidase gene. This bioreporter construct mainly colonised the dense areas of biofilm where microaerophiles such as legionellae are found and only expressed β-galactosidase activity at these sites, indicating low oxygen zones (Robinson *et al*., 1995). These low oxygen zones probably explain how microaerophiles or strict anaerobes such as SRB can be found in biofilms growing in even fully aerated milieu; they thrive in the low oxygen niches of biofilms provided by actively respiring heterotrophic species. This may help explain why, with careful recovery techniques, oxygen-sensitive sulphides can be recovered from some sites experiencing pitting corrosion.

EPS chemical heterogeneity

The role of EPS appears important in the pitting process. Copper is known to have strong biostatic or biocidal effects on a variety of microorganisms, including pathogens. As such its use as a work surface or pipe material reduces biofouling and has a corresponding public health benefit. However, the biofilms on copper generally have a high EPS to cell ratio, suggesting that EPS production may provide an important defence strategy, perhaps through sequestration of toxic copper ions. The synthesis, chemistry and even the structure of the exopolysaccharides of copper corroding bacteria are influenced by the presence of copper in the adjacent environment. For example, uronic acid subunits bind copper through their carboxylic groups and these are much more abundant in exopolysaccharides produced by cells in a copper environment (Geesey *et al*., 1994). Significantly, the exopolysaccharide produced was able to bind 16% of its weight in copper. Indeed, polysaccharides and oligopeptides have been recovered from corroding biofilms and these have been shown to chelate copper and corrode the surface. The results of several studies using x-ray photoelectron spectroscopy suggest that copper can be oxidised by polysaccharides. With the acidic polysaccharides, alginic acid or gum arabic, copper is oxidised to Cu^{2+}; with other polysaccharides it is oxidised to Cu^{+} or remains as Cu^{o}. Imidazole or L-histidine groups of oligopeptide chains in biofilms may also complex with Cu^{+} (Paradies *et al*., 1990). As such, these results are consistent with a corrosion mechanism based on a copper concentration cell formed by the excretion of EPS with different affinities for copper ions by different species within a biofilm (Geesey *et al*., 1994).

Unified model

A unified model for the spatial and chemical heterogeneity of high species diversity biofilms on corroding copper surfaces can now be described (Figure 6). Using the evidence available the initial events of the physico-chemistry of biofilm formation probably involve the attachment of high molecular weight humic and fulvic substances, derived from the peat of the upland catchment water, to the copper surface. This provides a conditioning layer or pellicle to complex slowly leaching copper from the surface (I). It also provides an essential source of nutrients for microorganisms in a generally low carbon environment. Consequently, pioneer species are able to safely adhere to the pellicle, either non-specifically and/or through specific lectin interactions. A basal layer of cells begins to form and microcolony formation begins (II). Copper tolerant fungi might join at this stage to provide a physical mesh for consolidating further biofilm development. The second stage of colonisation then proceeds whereby secondary colonisers are able to interact with the pioneer species, possibly through specific receptors as has already been described for biofilm species in non-corroding systems (II/III) (Buswell *et al*., 1997; Rickard *et al*., 2003). As the biofilm consolidates, spatial heterogeneity and metabolism begins to

establish, including the production of protective EPS (III). The original concept of a thick, somewhat diffusion-limited, film with inherent gradients of oxygen in and metabolic products out (IV) can now be disregarded for low nutrient aquatic biofilms. It is clear that as the biofilm forms and matures there are many water channels between the stacks or fronds of microcolonies to enable sufficient supply of essential nutrients (V). Nevertheless the concerted metabolic activity of the stacks of microcolonies creates a mosaic of microenvironments, including low oxygen zones which encourages microaerophilic and anaerobic species to colonise. The detection of oxygen-sensitive SRB in copper corrosion zones not only reinforces the premise of low redox environments therein but also might indicate the localised formation of sulphides which can be highly corrosive to copper tube (Jacobs *et al*., 1998, 2000). The complex physico-chemical hetereogeneity of the biofilm establishes a physical and chemical footprint above the copper surface, with pitting corrosion inititiating underneath. Eventually, the micro-pits coalesce, leaving large pits to drive through to the outer surface.

The footprint of the spatial heterogeneity is more easily seen in chemical terms in Figure 6. This schematic describes the establishment of the microenvironments for essential factors such as high and low concentrations of oxygen, carbon dioxide, acids and acidic or neutral EPS. This results in the formation of copper concentration cells and corrosion potentials. Hence, reminiscent of the characteristic pepper pot Type 1½ pitting already described.

The pitting process can puncture holes in pipes in a matter of a few months and, once initiated, is difficult to control because corrosion cells have already been initiated and further biological activity may not be required. However, if the hot waters are kept above 55°C and cold waters below 20°C, then microbial colonisation and/or activity can be significantly reduced and Type 1½ pitting does not readily occur (Keevil *et al*., 1989; Walker *et al*., 1991).

Of note, this unified model may also be applicable to a range of other corrosion-sensitive substrata. Indeed, low redox niches on corroding iron surfaces could help explain why microaerophilic pathogens with a high iron requirement, such as *Legionella pneumophila*, grow so well in these environments (Rogers *et al*., 1994; James and Keevil, 1997). *L. pneumophila* prefers to assimilate iron as Fe^{2+}. It also needs to respire (i.e pass electrons to a terminal electron acceptor) but is sensitive to excessive oxygen concentrations and might prefer to grow with only a little oxygen but have access to alternative electron acceptors. Therefore, the unified model could provide an important link between redox-driven

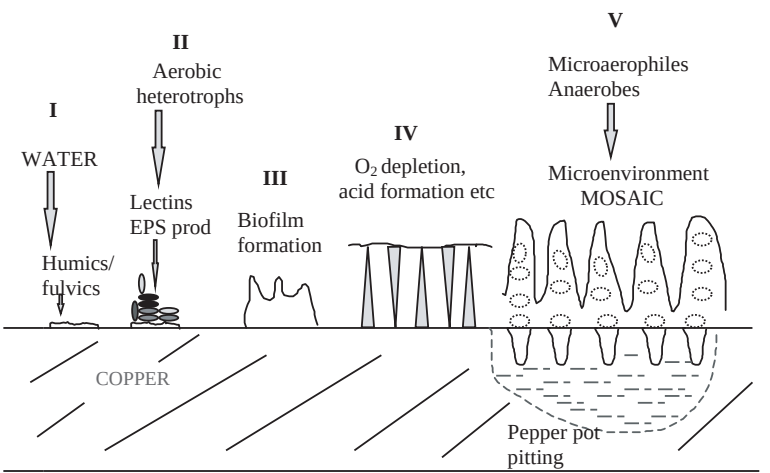

Figure 6 Sagittal z section model for biofilm accumulation on copper surface, generating a mosaic of heterogeneous microenvironments to initiate pepper pot pitting

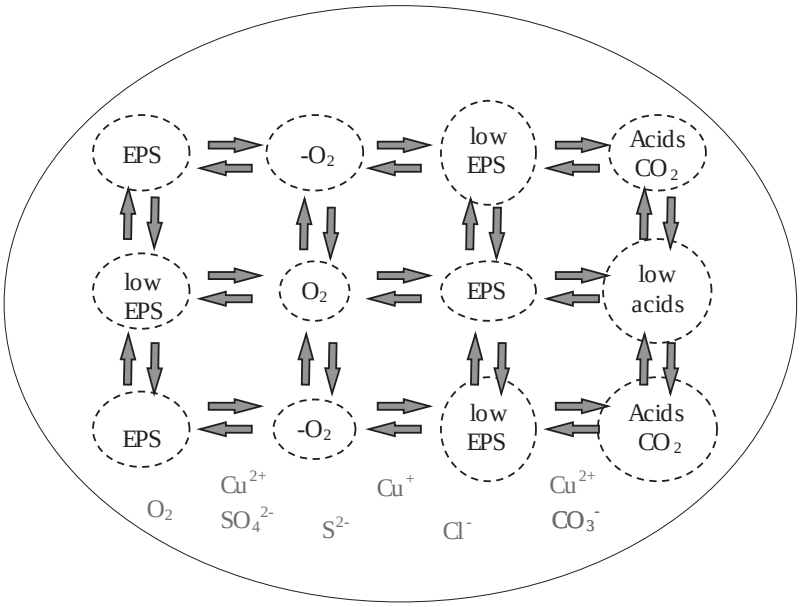

Figure 7 Planar *x–y* schematic of differential cells leading to microenvironmental pepper pot pits

corrosion processes and successful colonisation by pathogens and other microorganisms that can interface their electron transfer chains at corroding sites within the biofilm mosaic structure.

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INVESTIGATION OF BIOFILMS IN COPPER TUBE CORROSION AND THE SURVIVAL OF *LEGIONELLA PNEUMOPHILA* ON ALTERNATIVE PLUMBING MATERIALS

[redacted]
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requirements of the Open University

for the degree of Doctor of Philosophy

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DEDICATION

To my mother and father and Gill

ABSTRACT

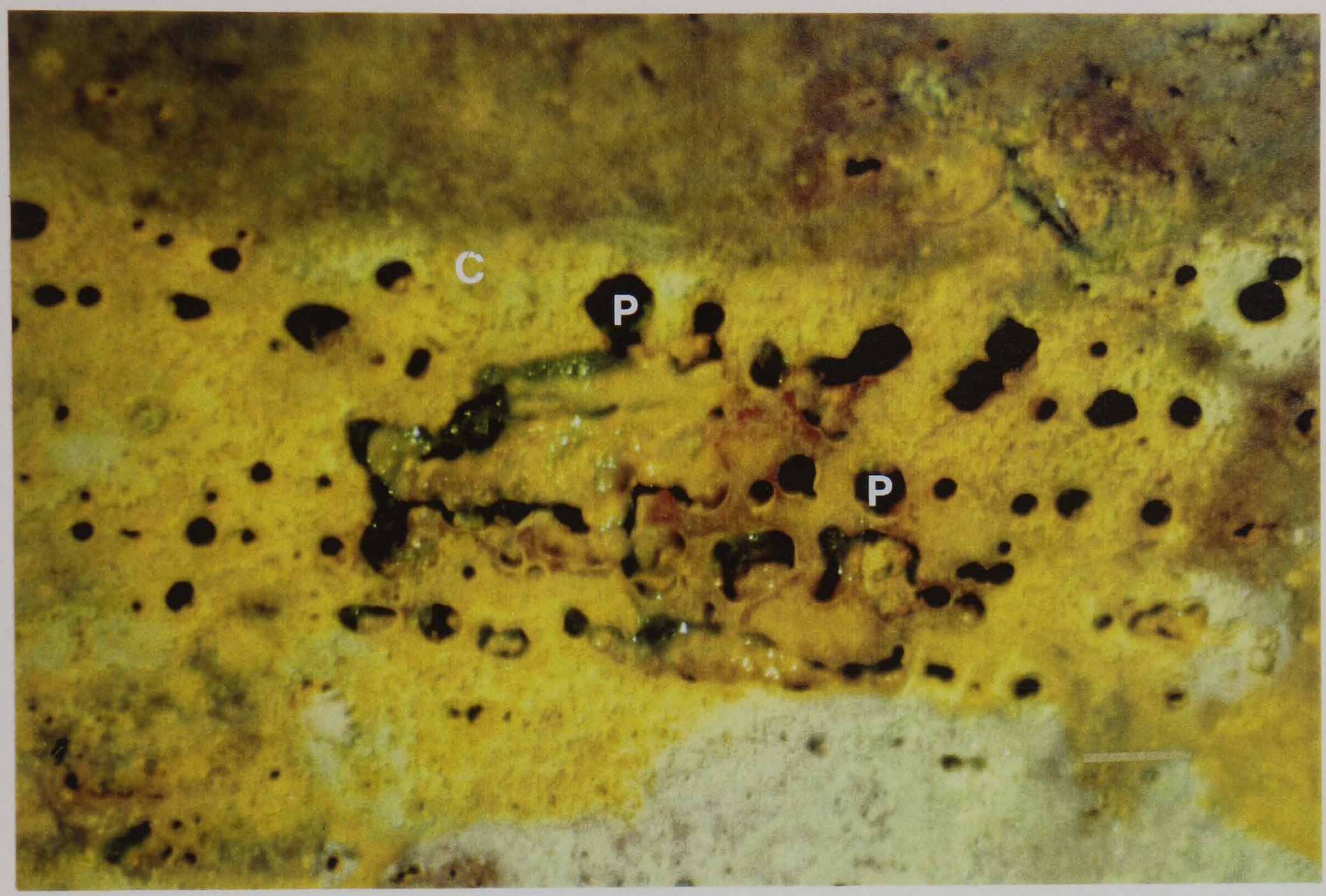
An unusual form of copper tube corrosion, occurring in two hospitals, was investigated during two site surveys and due to the presence of characteristic perforations became known as pepper-pot pitting corrosion. The corrosion was found to occur predominantly in soft water areas but mainly in hot water systems maintained below 50°C. When monitoring the hot water system at a particular site the water temperature was found to decrease overnight with a corresponding decrease in the dissolved oxygen concentration and assimilable organic carbon. Copious amounts of biofilm were recovered from the pipe surfaces thus it was hypothesised that metabolically active and respiring biofilm bacteria contributed to the creation of aggressive corrosive conditions at the copper tube surface. At control sites where this type of corrosion was not reported, the water temperature was found to be maintained above 50°C with reduced biofouling.

A laboratory model, using filter-sterilised potable water as the sole carbon source, was developed to investigate the conditions under which corrosion and biofouling was occurring. Biofilm development was demonstrated up to 55°C. At 60°C biofouling was very much reduced; however, a decrease in the number of bacteria recovered from the planktonic phase was only observed at 65°C. Planktonic bacteria were found to be dominated by pseudomonads while the biofilm was dominated by other Gram negative bacteria. Control measures that would slow down or prevent corrosion were studied. Pasteurisation (60°C) was found to prevent biofouling as well as controlling re-established biofilms but was less effective against consortia that had been previously exposed to this temperature. For the removal and control of biofilm, sulphamic acid was more effective than citric acid which allowed re-growth to occur within 14 days.

This unusual copper tube corrosion has resulted in increased use of alternative plumbing tube materials and therefore colonisation of copper and competitive plastic materials were investigated in the model system. Plastic materials were shown to encourage growth of *Legionella pneumophila* at 40°C whereas copper suppressed the growth of this water-borne pathogen. Results obtained in this investigation suggest that plastic plumbing systems pose a potential health risk by providing a means for transmission of pathogens such as *L. pneumophila*.

The association of biofilms with pepper pot pitting led to new ideas about mechanisms of microbially induced corrosion of copper tubing. A number of techniques including SEM, SCLM and light microscopy were used to demonstrate the heterogeneity and metabolic activity of biofilms produced in the laboratory model and on pipe surfaces. Mosaic microcolonies themselves are responsible for the initiation of differential concentration sites that are aggravated by exo-polysaccharides, metabolic activity and particulate matter in the aquatic environment. It is the localised distribution of initiated sites that could be responsible for the formation of multi-loci corrosion cells that are driven by an electrochemical potential forming the type of corrosion described as pepper-pot pitting.

Pepper Pot Pitting Corrosion on the Inner Surface of a Copper Pipe



Exposed view of etched copper surface illustrating characteristic pepper pot-pitting corrosion (Marker bar denotes 1 mm; C denotes the copper surface and P denotes the position of the pits).

Glossary of Terms

AOC	Assimilable organic carbon
AO	Acridine orange
CNS	Coagulase negative staphylococcus
cPVC	Chlorinated polyvinyl chloride
Cu	Copper
D	Dilution rate
DO	Dissolved oxygen
DVLO	Derjaquin, Verwey, Landau and Overbeek Theory
DIC	Differential interference contrast
EPS	Extracellular polysaccharide
ESEM	Environmental scanning electron microscope
ETS	Electron transport system
FITC	Fluorescein isothiocyanate
IFA	Immuno fluorescent assay
INT	Iodo nitro phenyl tetrazolium chloride
k_s	a constant, numerically equal to the substrate concentration
OGN	Other Gram negatives
Pe	Polyethylene
Pbu	Polybutylene
RITC	Rhodamine isothiocyanate
SCLM	Scanning confocal laser microscope
SEM	Scanning electron microscope
SPC	Standard plate count
SRB	Sulphate reducing bacteria
s	Limiting substrate
μ	Specific growth rate

V_A	Attractive forces
V_R	Repulsive forces
x	biomass

"MICROBES CAN AND WILL DO ANYTHING;

MICROBES ARE SMARTER, WISER AND MORE ENERGETIC THAN

MICROBIOLOGISTS, CHEMISTS, ENGINEERS AND OTHERS"

D. Perlmon. 1980. Dev. Indust. Microbiol. **31**.

CONTENTS

CHAPTER 1

INTRODUCTION

1.0 BACKGROUND

Since the late 1980's several large institutional buildings, such as hospitals, in very diverse areas (including Scotland, England, West Germany and Saudi Arabia) have experienced problems of copper tube failure. This has occurred in either the hot or cold water circuits, or in some cases both. After a series of site surveys in central Scotland to investigate the physico-chemical properties of sites experiencing copper tube corrosion it was tentatively proposed that bacteria could be involved in the corrosion process. Bacteria were discovered adhering to the inner surface of copper tubing in the hot water circuit where corrosion was occurring. Overnight, parameters such as temperature, assimilable organic carbon (AOC) and oxygen concentration fell markedly. These results suggested a hypothesis that, with a decrease in temperature, bacteria adhering to copper surfaces would become metabolically active, respire oxygen and consume AOC present in the water. Exo-polysaccharide produced by bacteria would chelate copper ions resulting in copper concentration cells. The heterogeneous mosaic structure of biofilm may serve to form local anodic and cathodic sites of corrosion as well as producing metabolic acids to aggravate the corrosion process. Hence biofilms have the potential to increase any physico-chemical corrosion which would have been taking place.

In order to investigate this hypothesis a laboratory model was established to simulate environmental parameters under which corrosion of copper tubing was occurring. Fouling of copper tubing, similar to that which had failed, was investigated within a continuous culture laboratory model where the media and sole carbon source was filtered sterilised water from the site of corrosion. The inoculum was composed of microorganisms scraped from the surface of a corroded copper tube. Environmental conditions in the laboratory model were then altered to investigate fouling of copper surfaces under parameters as close to those occurring in the environment. As this

system was simulating fouling within a hot water circuit of a large industrial building it was important to consider the survival of pathogenic microorganisms, in particular *Legionella pneumophila* in biofilms. *Legionellaceae* are responsible for causing legionellosis and water systems have been identified as an environmental reservoir for this bacterium (Stout *et al.* 1992). Colonisation of various typical plumbing materials e.g. copper, cPVC and polybutylene as found in water circuits were investigated to compare survival of these pathogens on different substrata.

Conditions and procedures for the growth of bacterial cultures in laboratories are many and varied. However, culture conditions provided in the laboratory do not necessarily reflect the variable environment of natural aquatic systems. The conditions to which bacteria are exposed depends very much on the particular environment, but generally will include fluctuations in light intensity, substrate concentration, temperature, oxygen concentration and water velocity (Stevenson, 1978). Nevertheless, bacteria are ubiquitous in the natural environment and are capable of adapting to changing parameters on a continual basis. Obviously where favourable conditions exist then growth will result, whereas if conditions are unfavourable then growth could be reduced or prevented. Continuous culture methodology has been extremely useful in the elucidation of substrate utilisation and competition between different species for one or more substrates in the dynamic conditions of the aquatic environment (Meyer *et al.* 1985).

Where growth conditions are favourable, but a substrate is not available, then bacterial growth will be limited. In aquatic environments the commonest type of bacteria are heterotrophs and reduced organic compounds may act as the limiting substrate for growth (Geesey, 1987; Geesey *et al.* 1987). Stevenson (1978) suggested that there are three major traits which determine growth in the environment. Primarily, metal ions, secondly substrate utilisation and finally attachment. For bacteria suspended in the aquatic phase Stevenson (1978) also considered dormancy to be an extremely

important physiological adaptation to ensure survival. Substrate availability for microbial growth in aquatic environments is generally very low, with between 1-15 mg l^{-1} of carbon available (Roszack, 1987). The term oligotrophic has been used to describe bacteria that grow in a medium containing < 1 mg l^{-1} of organic carbon supplied as a complex mixture of compounds, e.g. *Pseudomonas aeruginosa* and *Aeromonas hydrophila* have been shown to grow in the presence of only 25 and 10 μg l^{-1} (Roszack, 1987).

1.1.1 Bacterial Survival

So, what is the physiological state of bacteria in the environment? The rich complex media and specific conditions for isolation and growth of *Legionella* spp. in the laboratory are not present in the environment. Yet this pathogen is found surviving in a habitat very far from conditions that are supplied in a laboratory. It has been suggested that many environmental bacteria exist in a dormant form of which two phases are recognised to account for bacterial survival (Novitsky and Morita, 1976). Constitutive dormancy is the most widely recognised form where certain environmental triggers are associated with sporulation, such as the depleted concentration of available nutrients in triggering the formation of endospores in *Bacillus* spp. Secondly, there is exogenous dormancy, a condition in which development is delayed because of unfavourable chemical or physical conditions in the environment and is an innate property of cells under genetic regulation. The most obvious recognisable feature of this exogenous dormancy appears to be development of small cells, first reported by Novitsky and Morita (1976). These authors (Novitsky and Morita, 1977) also postulated the reductive strategy of survival i.e. an increase in cells numbers without an otherwise expected increase in cell biomass. Indeed there was an increase of up to 8-fold in cell numbers when a marine isolate was placed under starvation conditions. Such growth resulted in the production of a greater number of progeny, which were

smaller in size than the parent cells, with a corresponding increase in cell numbers enhancing the probability of survival. The ultrastructure of starved cells of *Arthrobacter* spp. was similar to non-starved parent cells; however, in starved marine vibrios a large periplasmic space was found to be present; the function of the periplasmic space is unknown. When introduced into fresh growth medium, the starved cells readily exhibited an increase in size and within 8 generations were indistinguishable from the parent cells. Laboratory cultures of bacteria exhibit standard growth phases of lag, log, stationary and death phases when inoculated into batches of suitable media (Veldkamp, 1970). However, observations by Novitsky and Morita (1976; 1977) indicated mechanisms by which the transition into death could be avoided by bacterial cells in natural environments so they could recover when favourable physical-chemical conditions were recurred.

1.1.2 Waterborne Microorganisms

Potable domestic water systems have been an important environment for study to scientists concerned with public health. From 1911-37, 16 out of 20 waterborne outbreaks in the United Kingdom resulted in enteric fever, with two being due to dysentery and gastro-enteritis. In 1937 a public enquiry implicated a water supply in a large outbreak of typhoid fever in Croydon, Surrey. It was this outbreak that led to routine chlorination at source of public water supplies. Since 1937 there have been 21 outbreaks associated with public water supplies, only one of which was identified as being due to paratyphoid (George *et al.* 1972). In 1944 Shannon and Wallace identified the importance of bacteria to water quality. Of 495 colonies on agar identified from the water phase, 448 were Gram negative bacteria such as coliforms, *Alcaligenes* spp. and *Pseudomonas* spp. Many microorganisms, such as *Pseudomonas*, *Flavobacterium*, *Achromobacter*, *Klebsiella*, *Bacillus*, *Corynebacterium*, *Mycobacterium*, *Spirillium*, *Clostridium*, *Arthrobacter*, *Gallionella*

and *Leptothrix* spp. are present in potable drinking water (Geldreich *et al.* 1972). Generally, these bacteria are not considered to be pathogenic. However, *Flavobacterium* and *Pseudomonas* spp. have been known to act as opportunistic pathogens and *Pseudomonas aeruginosa* has been identified as a major causative agent of hospital acquired infections (Favero *et al.* 1971). In the United Kingdom a total of 15 outbreaks of disease were identified between 1977-86 (Galbraith *et al.* 1987) with *Campylobacter enteritis* and viral gastro-enteritis accounting for 66% of outbreaks. From 1987-90 there was 11 water-borne outbreaks with a shift from bacterial or viral enteritis to Cryptosporidiosis which accounted for 64 % of outbreaks (Stanwell-Smith, 1991).

Between 1971-78, 224 outbreaks of waterborne disease affecting 48,193 individuals were reported by 43 states in the United States of America (Craun, 1981). Reported outbreaks increased between 1971 and 1978 (as occurred in the UK between 1977 and 1986) which was attributed to more active surveillance; however, more outbreaks probably occur than are officially reported. In a report published in 1973, Craun and McCabe, estimated that only 50% of waterborne outbreaks in municipal water systems were reported. Indeed at least two epidemiologically linked cases of disease must be reported before an outbreak is declared and a common source noted and investigated. In only 45% of cases was the aetiological agent identified, predominantly *Salmonella* and *Shigella* as these bacteria were actively sought. The most commonly identified pathogen was *Giardia lamblia*, a flagellated protozoan responsible for giardiasis. Not all outbreaks were as a result of microbial contamination of the water supply. Chemical poisonings accounted for 10% of outbreaks, four of which involved acute copper poisoning involving concentrations of 4, 12.5, 38.5, and 80 mg l^{-1} (Craun *et al.* 1976). The leaching of copper from water distribution systems was due to a number of factors such as a naturally aggressive water with a low pH, interruption of pH adjustment of a naturally aggressive water and a defective check valve on a drinks machine released CO_2 thus causing the water to become aggressive and leading to

dissolution of the copper. Acute gastro-enteritis due to chemical poisoning has also been reported in the UK. Metallic poisoning due to copper and zinc leachate has been reported (Anon, 1986). Phenol (Jarvis *et al.* 1985) and aluminium sulphate (Stanwell-Smith, 1991) have been implicated in separate outbreaks and were due to chemical spillage events.

During a comprehensive study of two water filtration plants, Payment *et al.* (1988) identified opportunistic pathogens such as *Aeromonas*, *Acinetobacter*, *Bacillus cereus*, *Flavobacterium*, *Moraxella* and *Pseudomonas spp.* (non-aeruginosa) in the untreated section of a water system. Primary pathogens identified included *Vibrio fulvis*. The treated water did not contain coliforms; however, *Aeromonas* spp. and *P. aeruginosa* were cultured from sampling sites in the distribution system downstream of the filtration plant. Such results typify the importance of regrowth in distribution systems where indicator organisms cannot initially be cultured. Actual numbers of indicator organisms may in fact be underestimated due to a variety of factors including excessive numbers of heterotrophic bacteria (e.g. with Legionella) and a process known as sublethal injury. This latter phenomenon was noted when coliform numbers from water containing chlorine were consistently higher by the multiple tube fermentation-most-probable-number (MPN) method than by a membrane filtration procedure. Bissonnette *et al.* (1975) suggested that more than 90% of indicator bacteria present in water systems may become injured in less than 1 week' exposure to chlorine. McFeters *et al.* (1982) suggested that injury sustained due to chlorine resulted in an inability to culture *Escherichia coli* from water samples and varying the diluent composition, temperature, time of exposure and growth media assisted in the recovery of injured bacteria. A major location of cell damage in water-injured coliforms is the cell envelope (Zaske *et al.* 1980) which may result in coliforms becoming sensitive to bacteriostatic or bactericidal compounds in the media. Sixteen different media normally used to culture bacteria from water suppressed growth with eleven that suppressed injured cells containing deoxycholate or bile salts (McFeters *et al.* 1982).

Where a problem of water contamination with coliforms or pathogens exists, the source has to be identified and dealt with such that no more cases occur. However dead end pipe sections and air chambers may be difficult to treat and as such would act as a foci of growth to reinoculate a water system if they were not found and remedied. Generally microorganisms in water systems can be controlled by approximately 0.3 mg l^{-1} residual chlorine, but even with remedial actions using 4.3 mg l^{-1} of free chlorine residual, coliforms may persist (LeChevallier *et al.* 1980). Ridgeway and Olson (1982) reported that free residual chlorine is an extremely potent bactericidal agent at concentrations of less than 0.1 mg l^{-1} but found that Gram-positive spore formers were able to survive 2 min exposure to 10 mg l^{-1} of free chlorine. Such resistance is an advantageous survival mechanism to particular bacteria.

Microorganisms are often associated with water/fluid systems. Bacteria can indirectly influence the consumption of potable water if their presence results in a deleterious effect upon materials used in the construction of water conduits resulting in odour or taste problems with water. Mains water has been documented to have discolouration and reduced flow through pipes due to microorganisms such as *Leptothrix* and *Gallionella* (Ridgeway *et al.* 1981). These chemolithotrophs use CO_2 in the oxidation of ferrous and manganese ions, resulting in precipitation of ferric salts around the stalked cells of *Gallionella.* Accumulation of ferric salts leads to discolouration and impairment of flow, and ultimately destruction of the support material infrastructure. Pipelines in a marine environment are normally made of mild steel and problems due to corrosion of those in use in the North Sea have been well documented (Hamilton, 1985; Edyvean, 1991). Costs of microbial induced corrosion to this particular industry have been very high.

1.1.3 Significance of pathogens in man made water systems

L. pneumophila sero group 1 Pontiac is the aetiological agent responsible for legionellosis. Legionellae have been recovered from many environmental samples including potting mix soil (Steele *et al.* 1990) and are thought to be ubiquitous in environmental water samples (Flierman *et al.* 1979 and 1981). Man made water systems such as potable water circuits, water circuit fixtures and fittings, storage tanks and cooling towers have all contained this family of bacteria (Dondero *et al.* 1980; Colbourne *et al.* 1984; Stout *et al.* 1985; Bhopal and Barr 1991). Legionellae are Gram-negative bacilli of approximately 0.3 - 0.5 μm by 2 - 3 μm. Amino acids in general play a major role in the growth metabolism of *L. pneumophila,* with no organic substrates except amino acids supporting growth (George *et al.* 1980).

Legionellosis is contracted through breathing in small water droplets. The majority of water droplets are large and will adhere to the nasal cavity lining but those which are 5 μm or less are able to enter lung alveoli (Baskerville *et al.* 1981). It is possible for aerosolised water droplets to contain bacteria and hence the aerosol will act as a means of transport for pathogenic bacteria such as legionellae. Once inside the lungs the bacteria are attacked by the primary host immune response involving macrophages. In situations where the host immune response is diminished, such as in herpes HHV6 infection there would be a suppression of lymphocytes which are the natural killer cells required in defence of a legionellae infection (Russler *et al.* 1991)

The disease, legionellosis, manifests as two forms. Firstly, there is pneumonia which is the more serious form and can be fatal, and occurs in persons who have an underlying predisposition e.g. the elderly, smokers, users of immuno-suppressive drugs or people with pulmonary conditions. With this form of Legionnaire's disease there is a 2 - 10

day incubation period and clinical features such as headaches, fever, cough, chest pain, diarrhoea and delirium and a mortality rate of 5-30%. Secondly, legionellosis also manifests as general flu symptoms known as Pontiac Fever. This is a self limiting, non-fatal influenza-like disease with a short incubation of approximately 3 days. Although, Pontiac Fever has a high attack rate the type of people affected have no underlying medical condition.

Many cases of legionellosis occur in hospitals, with hot water systems being implicated as the reservoir for *L. pneumophila* (Bartlett *et al.* 1983). Over the last decade a change in the maintenance of hospital hot water systems occurred which resulted in a reduction of the temperature from 60°C to between 40°C and 45°C. Although this change was initially introduced to conserve energy, it was later (in the USA) made a mandatory regulation such that, temperatures should not exceed 43°C to prevent scalding of patients in hospital wards (Joint Commission of Accreditation on Hospitals, 1981) - and a similar policy was followed in the United Kingdom. However, in 1983 the Joint Commission of Accreditation permitted each hospital to determine its own maximal hot water temperature.

Wadowsky (1982) grew *L. pneumophila* from waters between 25-37°C and found that at temperatures greater than 42°C the number of viable bacteria decreased dramatically. However, *L. pneumophila* has been recovered from hot water circuits in hospitals and hotels with temperatures greater than 42°C (Bartlett *et al.* 1983). Plouffe *et al.* (1983) recovered *L. pneumophila* sero group 1 from water storage tanks at 43°C to 45°C but not from systems between 58°C and 60°C. Also, in the last decade there have been a number of situations where the copper tubes in hot water circuits in hospitals have failed due to a previously unrecognised form of corrosion. In those hospitals, the hot water system was found to be maintained at less than 50°C and legionellae were recovered.

A number of factors within aquatic environments can influence *Legionellaceae* survival, such as cool spots in hot water circuits (Ezzedine *et al.* 1989), sediment in stagnant water e.g. the base of calorifiers where the temperature has decreased (Ciesielski *et al.*1984), the presence of free-living amoebae which may protect the legionellae (Anand *et al.* 1983) and low chlorine concentrations in cold water systems (Kuchta *et al.* 1983).

Results from various investigators (Timbury *et al.* 1986: Colbourne and Dennis 1988) have established that *L. pneumophila* grows in biofilms on the surfaces of different materials in water systems. In order to eradicate this bacterium from water systems control mechanisms such as biocides have been utilised. Wright *et al.* (1991) demonstrated the efficacy of biocides to eliminate planktonic bacteria but more importantly that the biocides were unable to achieve a complete kill of attached bacteria. Thus resistance of attached bacteria to biocide treatment have suggested protective mechanisms. The presence of exopolysaccharides (Costerton, 1984) or slow growth rates (Brown, 1988) have been implicated as methods by which attached bacteria could maintain a resistance to antibacterial agents.

1.2 BIOFILM

Biofilm is a term used to define discrete aggregations of organisms, generally micro-organisms and their metabolic products at an air-liquid or liquid-solid interface (Ellwood *et al.* 1982). This usually involves bacterial contact with a solid surface within an aqueous phase resulting in microcolony formation (Marshall, 1976; Hamilton, 1983; 1985; Costerton *et al.* 1987). Aquatic environments can be thought of as a reservoir for bacteria which, given the opportunity, will form a biofilm. Bacteria have been found associated with surfaces immersed in both sea and fresh-water (Cooke, 1956; Wood, 1950), sand grains (Meadows, 1965 and 1971) soil

particles (Burns, 1980) and appear to be indigenous in all but the most nutrient-depleted environments (Costerton *et al.* 1987; Costerton and Geesey, 1979).

1.2.1 Mechanism of Attachment

Attachment of bacteria to surfaces is a very complex association involving many parameters including cell size, shape, physiological state, cell surface charge, conditioning pellicle of substratum, electrolyte concentration and flow of the aqueous solution. There are a number of stages involved in adhesion of micro-organisms to surfaces (Marshall, 1976): (i) Transportation of the bacteria to surfaces (ii) Deposition of organisms to surfaces, known as the reversible step which is essentially an instantaneous attraction (iii) Permanent attachment to surfaces is an irreversible sorption involving firm adhesion of bacteria with polymers acting as bridges between bacterium and solid substrata (iv) Colonisation of surfaces by growth of micro-organisms resulting in biofilm formation (Caldwell, 1983).

(i) Initial Attachment

When the attachment of a bacterium to a surface occurs then one has to consider that there will have been a preconditioning of that surface by organic and inorganic molecules in the aqueous environment. Therefore, a bacterium will probably not come into contact with a naked surface but the environmental conditioning layer or acquired pellicle (Fazio *et al.* 1982) derived from the aqueous phase.

The movement of a liquid is variable, depending on the distance from the substratum surface and may have an influential role in biofilm formation. When considering piped waters the velocity of a liquid in a tube will have a bearing on whether or not bacteria are able to come into contact with a surface, as the velocity differs according to the distance from the tube surface. Liquid moving near a surface moves slower than liquid

in the macro-environment due to drag caused by viscosity, resulting in a laminar layer. The laminar flow velocity at a surface was measured by determining the velocity of 0.2 μm latex spheres (Lawrence *et al.* 1987) and it was demonstrated that laminar flow velocity was more than two orders of magnitude less than the macro-environment. Terms used to describe the slow drag area include mass transfer resistance layer, hydrogen bonding layer and the viscous sublayer.

The relatively still or viscous sublayer next to a surface when an aqueous solution is under turbulent flow is thought to encompass a 40 μm zone (Characklis, 1981). It is in this viscous sublayer that inertial forces become relatively unimportant in comparison to viscous forces. As such, in order to become attached to a surface, bacteria must have the ability to penetrate this layer. Adsorption of soluble materials such as low molecular weight hydrophobic molecules (lipids and fatty acids) onto substrata may affect surface charge, surface free energy and adhesion as well as attachment of bacteria (Neihof and Loeb, 1974; Fletcher and Marshall, 1982). However, the presence of macromolecules in the aqueous phase may enhance, inhibit or have no effect on bacterial attachment (Meadows, 1971; Fletcher, 1976; van Loosdrecht *et al* 1990). Fletcher and Loeb (1979) were able to demonstrate increased bacterial attachment to hydrophobic plastics with little or no surface charge e.g. polyethylene. Fewer bacteria attached to hydrophilic metals with a positive charge e.g. platinum and less to hydrophilic negatively charged surfaces e.g. glass. Considering that most bacteria appear to be polyanionic i.e. negatively-charged, then this latter negatively-charged, hydrophilic glass surface would have presented a most unfavourable substrata for them to attach to (Paul and Jeffrey, 1985).

In conjunction with the physical nature of the substratum, bacterial cell wall composition also has to be considered. Bacterial species can generally be divided into two main groups as to whether they stain Gram-positive or Gram-negative (Fig. 1.0). Both types of bacteria possess a cell wall and in Gram-positive cells this is relatively

thick (15-30 nm), rigid and composed predominantly of peptidoglycan. Covalently associated with peptidoglycan are other carbohydrate-type polymers, for example, teichoic acids and teichuronic acids (determined by growth in the presence or depletion of phosphate, respectively), polysaccharides and to a lesser degree, proteins. Protruding from the cell wall are amphiphiles, such as lipoteichoic acids which possess both hydrophobic and hydrophilic regions in their structure. Lipoteichoic acids have been shown to play a role in the adhesion of *Streptococcus pyogenes* to eukaryotic cells (Christensen *et al.* 1985). However, in Gram-negative cells the outer membrane is a complex multilayered structure of lipopolysaccharide proteins, phospholipids and lipoprotein. It is the lipoprotein which provides covalent linkage to the underlying peptidoglycan layer of the cell wall in Gram-negative bacteria. Gram-negative cells also possess polymeric amphiphiles, lipopolysaccharides, molecules which consist of three distinct regions covalently linked together: a hydrophobic lipid area (lipid A), a core polysaccharide and *O*-antigen-specific polysaccharide side chains. The lipopolysaccharide covers 30-40% of the outer cell membrane and is thought to be highly hydrophilic, thus rendering cells resistant to detergents and hydrophobic dyes. Bacterial cells like most eukaryotic cells are generally recognised as having a net negative charge (Richmond and Fischer, 1973; Rosenberg, 1981).

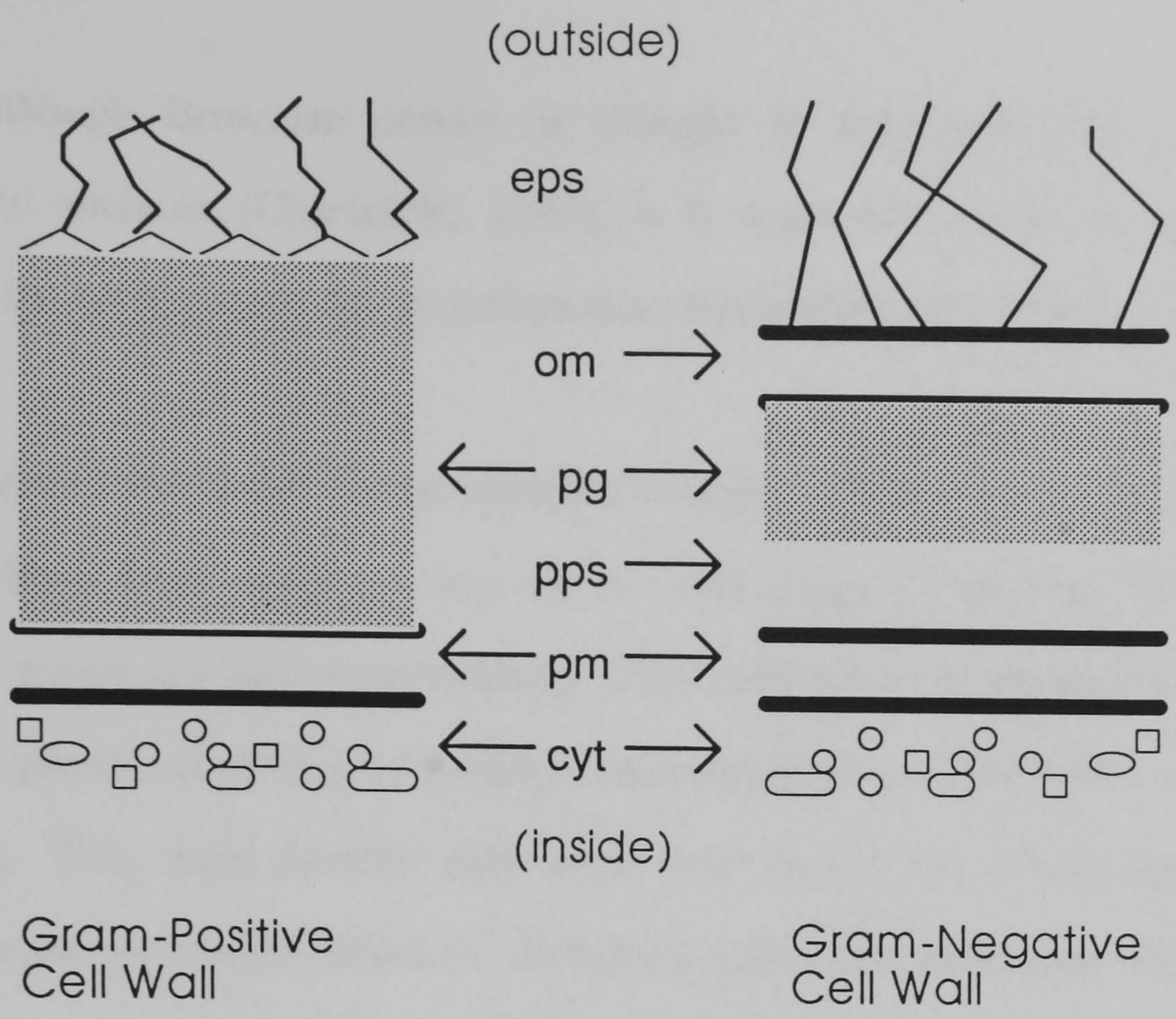


Figure. 1.0 Schematic diagram of Gram-positive and Gram-negative cell wall structures. eps denotes extracellular polysaccharides; om, outer membrane; pg, peptidoglycan; pps, periplasmic space; pm plasma membrane; cyt, cytoplasm.

A bacterium has to come into contact with a surface for attachment to occur, which implies some mechanism of transport. Under quiescent conditions transport of bacteria to surfaces is either by gravitational forces, Brownian motion or by motility, whereas if laminar flow is present then movement to a surface is by diffusion (Characklis, 1989). In a turbulent flow system, bacteria are primarily transported by fluid dynamic forces (Characklis, 1981) with gravitational effects being reduced as the density of a bacterial cell is only slightly greater than water (Marshall, 1985). Characklis (1981) suggested that sedimentation may not play a role in deposition of a single bacteria under the influence of turbulent flow. This was confirmed by Leech and Hefford (1980) who observed sedimentation of aggregates but not single cells of bacteria at the bottom of a capillary tube. Flagella provide bacteria with an active mechanism of transportation to a surface (Marshall *et al.* 1971) possibly displaying a positive chemotactic response to nutrient sources e.g. organic acids deposited as a pellicle on the surface (Fazio *et al.*

1982). Although Brownian motion is thought to contribute little to bacterial movement to surfaces (Characklis, 1981), it is considered to be of assistance in transport to the surface once the bacterium has entered the viscous sublayer.

Once a bacterium enters the viscous sublayer a number of basic forces and interactions occur and have been classified into three main groups: Van der Waals forces, electrostatic forces and hydrogen bonding. Initial adsorption of bacteria to surfaces is a reversible process involving long-range non-specific forces (Busscher and van der Mei, 1992). Two main theories have been used to describe interactions of small particles at close separation distances. Primarily, initial attachment has been described by a double layer phenomenon developed independently by Derjaquin and Landau (1941) and Verwey and Overbeek (1948) using lyophilic colloids to model living cells and known as the DVLO (Derjaquin, Landau, Verwey and Overbeek) theory. Basically all surfaces possess a charge and if the charges are similar then repulsion will occur. The DVLO theory states that the distance of separation between cell and surface in an electrolyte is the distance at which the repulsive (V_R) and attractive (V_A) forces are balanced (Fig. 1.1). An electrostatic double layer which forms around bacteria in an electrolyte consists of positive ions on the outside and negatively charged organic compounds on the inside i.e. extracellular polysaccharide. The difference in electrical potential across the electrostatic double layer is called the surface potential. Surface potential and electrostatic double layer thickness decreases with increasing electrolyte concentration. Therefore in high electrolyte concentrations the thickness of the electrolytic double layer and the surface potential are small, under which conditions, reversible bacterial adsorption readily occurs (Marshall *et al.* 1971). In the presence of sufficient electrostatic repulsion, a so called secondary interaction minimum occurs between approximately 10 and 20 nm. This theory considers long range forces such as London-Van der Waals attractive energies and electrical repulsion energies in the overlapping layers surrounding bacteria and substrata. London-Van der Waals attractive energies will tend to hold bacteria in the secondary minimum for a

short time. The mathematical expression of the DVLO theory of particle interaction includes the radius of particles. As the radius decreases the repulsive energy barrier decreases and attachment processes will be aided further by penetration of the primary minimum by cellular appendages. Examples of such appendages are fimbriae and lateral flagella that provide the intermediate structure between reversible and irreversible adhesion.

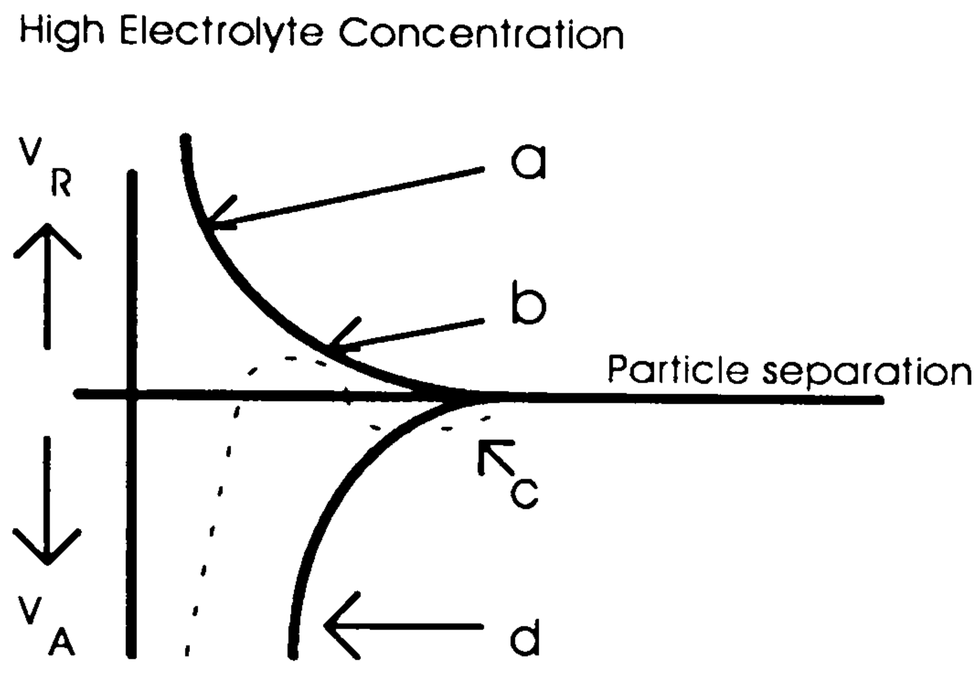


Figure 1.1 The interaction energy between a particle and substrate in a high and low electrolyte solution demonstrating the interactions at different separating distances. **a** denotes electrostatic interaction; **b**, secondary minimum; **c**, primary minimum; **d**, Van der Walls interactions ; $\mathbf{V_R}$, repulsive forces; $\mathbf{V_A}$, attractive forces (Dexter, 1975).

(ii) Irreversible Attachment

Irreversible attachment was found to be stimulated by extremely low concentrations of available carbon (Fig. 1.1). High concentrations inhibited this process which suggests

that low carbon concentrations, i.e. starvation, which produces cells of smaller radius, may in fact favour firm adhesion of micro-organisms to surfaces (Marshall *et al.* 1971). These specific short range bonds may occur over a relatively long time in respect to reversible bonding due to the necessary rearrangement of stereochemical and molecular groups by a cell in response to a surface. Ellwood *et al.* (1982) used Mitchell's chemiosmotic hypothesis of energy conservation (Jones, 1982) to suggest that microbial attachment could be energetically favourable to survival in low nutrient conditions. The translocation of protons out of the cell would generate a membrane potential (inside negative) which could be used to generate adenosine triphosphate (ATP), via an ATP'ase, as protons re-enter the cell. It is possible that contact at the surface enables cells to trap protons from an electrochemically active surface and/or surrounding cells, which it can use as an energy source hence stimulating growth and division. The former is a mechanism for enhancing a corrosion potential, while the latter is an example of inter-species hydrogen transfer. These are mechanisms by which a monolayer of dispersed cells have the potential to develop into a biofilm and may help to explain the ubiquitous nature of biofilms.

The presence of surfaces has been shown to result in a 25% increase in the growth rate of *Nitrobacter* cells attached to glass in comparison to those not attached to glass (Keen and Prosser, 1987). Increased growth was explained by the creation of a micro-environment low in nitrite (which is toxic at high concentrations) due to an extracellular slime layer formed by attached cells, rather than an accumulation of nutrients at surfaces. It is through the formation of polysaccharide adhesives that permanent attachment is mediated and has been described by Busscher and van der Mei (1992) as being a specific interaction. Christensen *et al.* (1985) identified two extracellular polysaccharides produced by a marine *Pseudomonas* spp. Busscher and van der Mei (1992) and Christensen *et al.* (1985) reported that polysaccharide B, only produced in the stationary phase of growth, was present as a capsule that was involved in initial adhesion by bacteria binding to surfaces (also indicated by Fletcher, 1988).

Polysaccharide A, in contrast was produced only by growing cells and may be produced after attachment irreversibly binds cells to the surface. Direct evidence for involvement of polymer bridging between bacteria and solid surfaces was obtained by sectioning at the adhesion surface (Fletcher and Floodgate, 1973). A number of studies of the effects that surfaces have had on bacterial activity are listed in Table 1.

Table. 1. Influence of solid surfaces on bacterial activity

Mechanism	Effect on attachment	References
Substrate uptake	stimulatory	Fletcher and Loeb (1979)
Number of cells attached	stimulatory	Hattori (1972/1981)
Change in cell size(starvation)	stimulatory	Kjellberg (1982)
Acid Production	variable	Ellwood (1982)
Respiration rate	variable	Bright (1983)
Heat production	diminished	Gordon (1983)

1.3 BIOMEDICAL ADHESION

1.3.1 Medical Implants

One of the areas where adhesion of bacteria can be a real problem is in polymeric materials used as medical prostheses for therapeutic purposes, such as catheters and implants (Jansen and Peters, 1991; Peters *et al.* 1982). Many materials used as medical implants are high molecular weight synthetic polymers such as polyethylene, polypropylene, polyurethane, polymethylmethacylate, polyesters, teflon or even silicone rubber. Foreign body infections involving strains of coagulase-negative

staphylococcus (CNS) have been identified as the main source of infections of catheters and prosthetic heart valves (Amoury *et al.* 1966). Other bacteria identified as major causative organisms of polymer associated infections are *Staphylococcus aureus*, *Enterobacteriaceae* and *Pseudomonas* spp.

Staphylococcus epidermidis is a ubiquitous commensal of human skin and mucous membranes, and although not normally causing disease in man it is an opportunistic pathogen. There are three main factors involved in determining whether it will cause disease i) strains which are encapsulated are more virulent ii) hosts who are immuno-compromised are more susceptible (as they are to other bacterial infections e.g. Legionellosis) iii) there is an increased incidence of infection in transiently implanted devices. Poisson *et al.* (1991) described microbial colonisation of endotracheal tubes in neonates who had been intubated at birth. A total of 14 tubes were examined and in half, the pharynx was found to have become colonised after three to four days of life and by a week in other cases. Significantly a slimey accretion designated to be of host origin predisposed to bacterial attachment of *S. epidermidis* and *Streptococcus agalactiae*. Although *Candida albicans* was isolated it was only found to colonise after 15 days.

S. epidermidis produces an extracellular slime layer of up to 120 μm thick on polyethylene catheters and also on an endocardial pacemaker (Peters and Pulverer, 1984). The slime layer, a glycoconjugate complex, was found to be loosely adherent to the organism and was easily removed when rinsed. This loosely adhered slime material interfered with the host immune response as the lymphoproliferative response of the human mononuclear cells (mostly T-lymphocytes) to polyclonal stimulators like streptococcal blastogen A was inhibited. Indeed, the slime layer was thought to present a mechanical barrier to antibiotic actions thus offering protection to encased bacteria, although Nichols *et al.* (1989) have shown that this is not always the case. It was suggested that slime layers may also prevent recovery of embedded bacteria during

culture thus resulting in false positives and hence lack of proper treatment for infected patients (Peters and Pulverer, 1984).

Despite host defence mechanisms and aggressive antibiotic therapy, bacterial biofilms on surfaces of plastic or metal prostheses are extremely persistent (Amoury *et al.* 1966). A number of strategies have been utilised to combat and or reduce bacterial infection of implanted polymers including the introduction of surface functional groups that exhibit anti-adhesive properties and the incorporation or coating of polymers by antimicrobial substances (antibiotics). The former method, involving modification of polymers with chemical radiation, was utilised to modify polyurethane (normally a hydrophobic surface) with the hydrophilic substance 2 hydrocymethylmethacrylate (Jansen *et al.* 1988). Thus, treated materials presented a hydrophilic surface to bacteria, resulting in reduced adhesion. In the absence of serum proteins, microbial adhesion is governed by hydrophobic forces and therefore less adhesion appears to result due to a weakening of hydrophobic interactions between the polymer and bacterium.

Infection of urinary catheters may result in growth of more than one species in the biofilm from the exterior towards the bladder (Marrie *et al.* 1983), while other intravenous or deepline feeding catheters (Hickman catheter) provide a conduit for growth of a single species biofilm of *S. epidermidis* from skin to the heart (Costerton *et al.* 1985). In many cases where aggressive antibiotic therapy has been utilised, bacteremia has been controlled but treatment has failed to kill the bacteria. Therefore, the bacteremia recurred when antibiotic treatment was discontinued (Marrie and Costerton, 1983; Peters and Pulverer, 1984). Due to such resistance, the only way to successfully treat biofouled prostheses is removal of the colonised device followed by parenteral administration of effective antibiotics.

The presence of biofilms does not necessarily result in a problem, as many intrauterine

contraceptive devices have been found to be coated with a thick multispecies biofilm yet patients from whom they were removed were not symptomatic (Costerton *et al.* 1985). However, in other instances where there are no clinical symptoms, biofilms are capable of profound effects such as decalcification of bone adjacent to colonised orthopaedic prostheses (Brause, 1989).

1.3.2 Dental Plaque

Another example of biofilms in the human body is that of dental plaque - the provoking agent of dental disease when the normal flora associated with health is perturbed. Plaque formation involves accumulation of bacteria in crevices between the tooth and gum (subgingival or supragingival plaque) and over the tooth enamel (coronal plaque). Formation of a biofilm results in i) the localisation of bacterial metabolites and toxic products resulting in dental demineralisation due to lowered pH (caries) and ii) toxic product formation causing mucosal inflammation (gingivitis and periodontitis). These diseases are among the most common of all infections in humans, with cost of treatment exceeding that of any other infectious disease (Gibbons and van Houte, 1992). Bacteria principally involved in causing disease due to dental plaque are the Gram-positive filamentous organisms streptococci (*Streptococcus mutans*), actinomycetes (*Actinomycetes viscosus*) and Lactobacilli, Gram negative organisms such as *Bacteroides* species and *Hemophilus* species. As found with endotracheal tubes in neonates, a slime layer or accretion appeared to be a prerequisite for bacterial attachment (Poisson *et al.* 1991) in the oral cavity. An acquired pellicle of proteins adsorbs from saliva onto the tooth surface enamel, and ensures within seconds that the first contact between bacteria and tooth surface, over several minutes, is always via the pellicle (Belcourt, 1976). Although the initial adsorption layer (occurring within 10 s) was shown to be homogenous, by 2 h an uneven, knotted and heterogeneous structure characterised by small projections of organic material with a thickness of up to 600 nm was present (Busscher *et al.* 1989). It is the adsorbed pellicle components that

function as receptors for bacteria but bacteria also adhere to themselves creating a multiplicity of interactions. Many specific interactions of attachment have been catalogued in the formation of dental plaque including: lectins which are carbohydrate e.g. *S. mutans* glucosyltransferase; receptor proteins, fibrillae and salivary agglutinin (Christensen *et al.* 1985). Indeed formation of dental plaque provides the best example in human microbiology of bacteria employing intermediary bacteria to link themselves to tissue surfaces involving bridging ligands derived from the host (London *et al.* 1989).

Interestingly, it is evident that the degree to which a bacterium may attach to a surface influences the extent to which it may colonise. The mouth is only one of several environments in humans that are subjected to fluid flow and others include the intestinal canal, surface of the eyes and bladder. For a thriving bacterial community to survive in such situations bacteria must multiply at a rate exceeding the dilution of flowing secretions or alternatively bacteria must attach to survive. With swallowing of saliva occurring every few minutes, then attachment to the teeth enamel or epithelial cells must occur for bacterial growth to occur. Swallowing can be considered to have numerous functions, one of which is to wash bacteria from the surface of the teeth and so away from the mouth area. Turnover of epithelial cells has been found to be slower in germ-free rodents than in conventionally infected rodent mouths (Abrams *et al.* 1963). The highest turnover of cells in the mouth has been found to occur in the gingival epithelium which is closest to the bacterial mass or dental plaque, indicating that a plaque infested mouth encourages the turnover of epithelial cells (Gibbons and van Houte, 1992).

In summary, bacterial adhesion to surgical implants and prostheses are just a few of the areas where biofilms are a major complication in the treatment of chronic or critically ill patients. Catheter-related septicaemia represents the most frequent life threatening complication of vascular catheters (Raad and Bodey, 1992). Dental plaque formation

is also a detrimental process leading to the destruction of enamel and caries in periodontal disease resulting from a biofilm.

1.4 CORROSION

Biofilms can be beneficial or advantageous to man such as in the treatment of domestic and industrial effluent, biotechnological reactors (e.g. the use of immobilised cells for the production of microbial enzymes; Stanbury and Whittaker, 1984). However, the detrimental effect of biofilms can also be of industrial significance, including the loss of heat transfer and fluid flow, corrosion and general deterioration of equipment. Bacteria that have been mainly implicated in corrosion processes are the obligately anaerobic, sulphate-reducing bacteria (SRB). Problems in the offshore oil and gas industry due to these bacteria include (a) corrosion, either externally on pipe work and steel jackets or internally in water injection systems, (b) souring, of oil or gas due to production of hydrogen-sulphide, (c) plugging of reservoirs due to biofouling (Hamilton, 1983).

1.4.1 Chemical Corrosion

Metalic corrosion is an electrochemical process which is initiated by the presence of an impurity on surfaces such that a corrosion system is really a short-circuited electrochemical cell where pure and impure areas have come into contact with an electrolyte. Potential differences developing between pure and impure areas will cause an electric current resulting in corrosion. Sites at which oxidation of the metal atoms occurs is termed the anode. The cathode, where reduction takes place, is where the electrons are taken up. The tendency for a metal to corrode is determined by the electromotive force (emf) between the anodic and cathodic sites on the surface of the metal.

The following anodic reactions of metals (M) in the presence of aqueous electrolyte will occur in an environment free of biofilms with complexing or precipitating ions.

$$M \rightarrow M^{x+}(aq.) + xe^-$$

$$M + xH_2O \rightarrow M(OH)_x\,(solid) + xe^- + xH^+$$

$$M + xOH^- \rightarrow M(OH)_x\,(solid) + xe^-$$

$$M + xH_2O \rightarrow M_x^{x-}(aq.) + 2xH^+ + xe^-$$

$$M + xOH^- \rightarrow MO_x^{x-}(aq.) + xH^+ + xe^-$$

If corrosion product accumulates at the anode, the emf of the reaction decreases until corrosion ceases. This is known as anodic polarisation.

Where neutral aerobic electrolytes are present at the cathode (cathodic polarisation) the product is continuously removed from the cathode allowing the reaction to proceed.

$$O_2 + 2e^- + H_2O \rightarrow 2OH^-$$

In the above case, oxygen is the depolariser and this reaction will be the rate controlling step. Cathodic reduction of dissolved oxygen may result in an increase in pH of the solution at the metal surface. At the anodic site the metal will form cations which can be hydrolysed by water to form H^+ ions.

$$M \rightarrow M^{2+} + 2e^-$$

$$M^{2+} + 2H_2O \rightarrow M(OH)_2 + 2H^+$$

Crevice corrosion, pitting, and erosion-corrosion are typical forms of localised

corrosion where the cathode/anode area, differential aeration and pH changes at anodic and cathodic sites are all important factors. For localised corrosion to occur there must be a continuous supply of electron acceptor species at the cathode such that the anodic reaction is not suppressed.

1.4.2 Microbial Corrosion

In general, a metal surface is able to corrode through having local anodic and cathodic sites. These can occur through heterogeneity in the metal surface; for example, if the surface is bathed in a solution which alters nutrient concentration (e.g. oxygen) from one area to another or the presence of films such as carbon. The area with the lowest oxygen concentration will release electrons, forming the anode, and the area of high oxygen concentration will consume electrons, becoming the cathode. This type of concentration cell is known as a differential aeration cell and can indirectly occur through the presence of a microbial microcolony on a surface.

Fouling is generally recognised as a layer of slime and deposits on a surface, as observed in cooling water storage tanks or barnacles and molluscs on piers stantions or on the hulls of ships. Macro-deposition is unsightly and in the case of ships can create a drag effect resulting in increased fuel consumption to maintain the same speed (Copenhagen, 1966). Eukaryotes such as fungi have also been identified to be involved in corrosion of fuel tanks as they are capable of utilising diesel and jet aircraft fuel (Smith, 1991). In the 1960's, *Hormoconis resinae* was found to survive in fuel tanks of jet aircraft due to the presence of water as a product of condensation and growth resulting in structural damage (Miller, 1981). Fouling and damage was subsequently controlled by biocides and preventing the influx of water. Historic and artistic monuments in Spain have recently been monitored for attack and numerous fungi such as *C. cladosporoides* and *Penicillium chrysogenum* have been found to be

present (Flores *et al.* 1992)

Sulphur bacteria utilise sulphides and sulphur in the presence of oxygen to produce sulphuric acid. Although they have been a major problem in polluting surface waters in mining areas their ability to acidify toxic metals by dissolution of metal ores has been used to increase copper production from low grade ores. Such acid producing bacteria are especially active against carbonate rocks such as limestone and marble. Nitrifying bacteria are also able to attack carbonate rocks by the oxidation of ammonia to nitrites and the second stage nitrifactors to oxidise nitrous acid to nitric. (Petushkova and Lyalikova, 1992). Such bacteria are chemolithoautotrophs that obtain energy from oxidation of reduced sulphur and nitrogen compounds and use carbon dioxide as a single source of carbon.

(i) Sulphate-Reducing Bacteria (SRB)

Where acidic or anaerobic conditions prevail then protons take over the role of oxygen by accepting electrons resulting in the formation of first atomic then molecular hydrogen.

$$2H^+ + 2e \rightarrow 2H + H_2$$

Under anaerobic conditions, bacteria such as *Desulfovibrio* spp. are able to utilise H_2 as an electron donor to reduce sulphate and achieve cathodic depolarisation by being directly involved in the corrosion process.

A classical mechanism of anaerobic corrosion was proposed by von Wolzogen Kuhr and van der Vlugt (1934). Cathodic depolarisation occurs through metabolic oxidation of hydrogen by anaerobic bacteria such as SRB. The mechanism of cathodic depolarisation is explained below in terms of chemical equations.

(1) Anodic reaction	$4Fe$	$\rightarrow$	$4Fe^{2+}$	$+ 8e^-$		
(2) Dissociation of water	$8H_20$	$\rightarrow$	$8H^+$	$+$	$8OH^-$	
(3) Cathodic reaction	$8e^-$	$+$	$8H^+$	$\rightarrow$	$8(H)$	
(4) Cathodic depolarisation by bacteria	$SO_4^{2-}+$		$8(H)^+$	$\rightarrow$	$S^{2-}+H_2O$	
(5) Corrosion products	Fe_2	$+$	S^{2-}	$\rightarrow$	FeS	
(6) Corrosion products	$3Fe_2$	$+$	$6OH$	$\rightarrow$	$3Fe(OH)2$	

Overall reaction $4Fe + SO_4^{2-} + 6OH^- + 4H2O \rightarrow 3Fe(OH)2 + FeS+2OH^-$

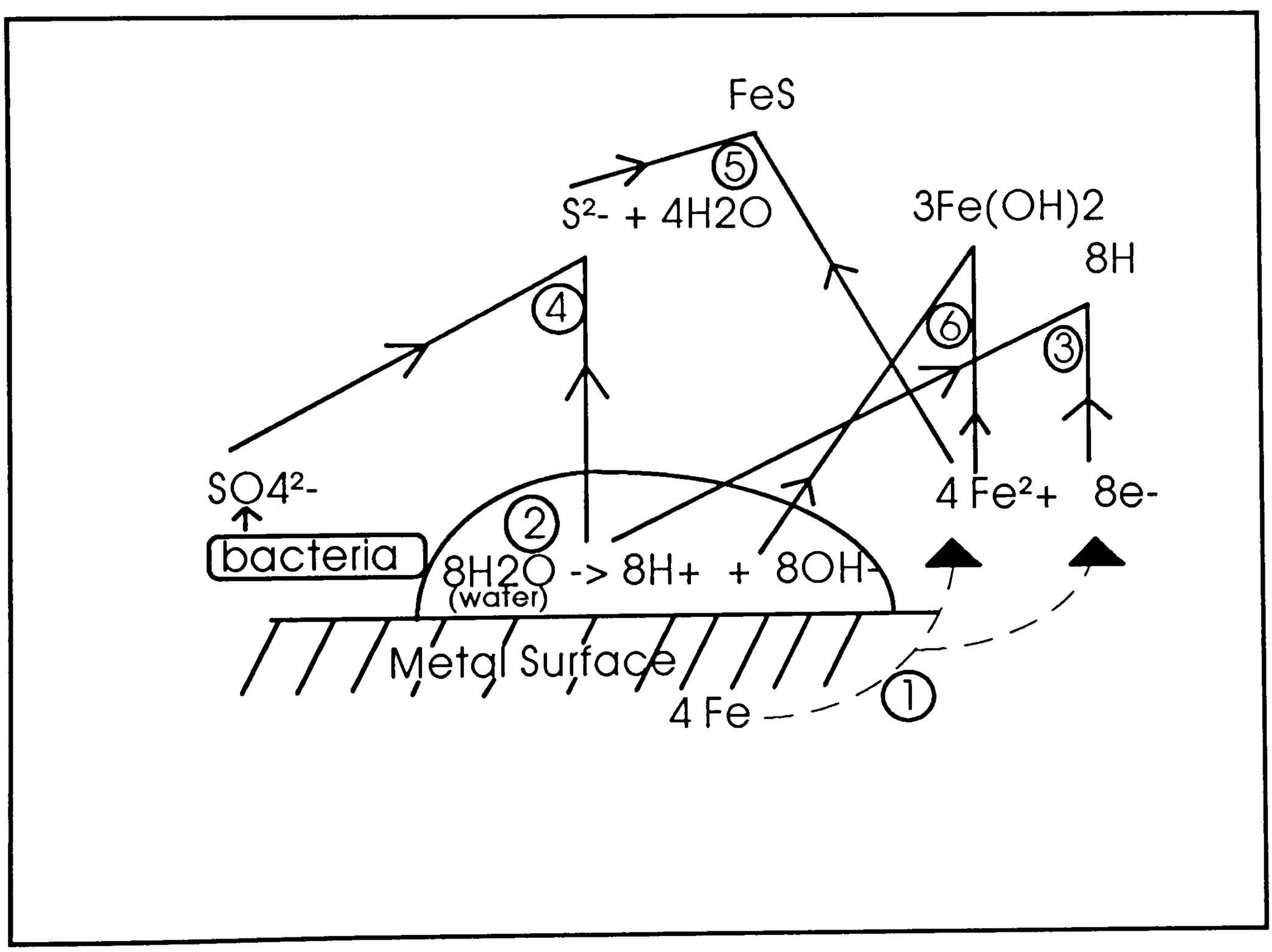


Figure 1.2 Schematic diagram of reactions (1) to (6) involved in the mechanism of cathodic depolarisation described above.

King and Miller (1971) later proposed that corrosion is under cathodic control with the critical electrochemical reaction being the adsorption of atomic hydrogen by ferrous sulphide corrosion products. Ferrous sulphide, not being a permanent cathode, is dependant upon the removal of hydrogen carried out by the action of bacterial hydrogenase located in the periplasmic space (Odom and Peck, 1984).

Other mechanisms may involve aerobic/anaerobic interfaces where sulphide could react with oxygen to produce highly corrosive elemental sulphur or polysulphides (Hardy and Bowen, 1984) - indeed these authors were able to produce a 90-fold increase in corrosion of mild steel when sparging an anaerobic culture of *Desulfovibrio* spp. with oxygen. Such varying conditions of aerobiosis would be more representative of conditions in environmental water systems where the concentration of oxygen at the aerobic/anaerobic interface is constantly or intermittently being altered.

SRB are also known to cause corrosion by production of highly corrosive and volatile phosphorous compounds believed to enhance dissolution of metal under anaerobic conditions (Iverson and Olson, 1983). Therefore, as well as the major corrosive product of FeS, SRB also produce highly corrosive iron phosphides (Fe_2P).

Therefore, SRB either play an important role in the overall corrosion processes by depolarisation of the cathode due to their ability to oxidise cathodic H_2 or by producing sulphide as an end product of their metabolism i.e.

$$SO_4^{2-} + 4H_2 \rightarrow S^{2-} + 4H_2O$$

It is the possession of hydrogenase enzymes that enable oxidisation of cathodic hydrogen. Several other species belonging to the families *Bacillaceae*, *Enterobacteriaceae*, *Pseudomonadaceae* and *Rhizobacteriaceae* also possess hydrogenase enzymes and are able to oxidise the cathodic hydrogen whilst

hydrogenase-negative strains can not. Direct evidence for oxidation of cathodic hydrogen by *D. vulgaris* was provided by using a sensitive radio-respirometric assay (Hardy and Syrett, 1983) to measure production of ^{35}S-sulphide from ^{35}S-sulphate in the presence of an X-65 steel electrode. Growth on acetate and CO_2 as carbon sources only occurred if H_2 was provided as the sole terminal electron donor (Pankhania *et al.* 1986).

Many experimental studies using SRB in pure culture and in rich media do not necessarily represent *in situ* conditions. Indeed the dynamics of biofouling are such that one investigation of a coastal power plant demonstrated a total of 46 taxa from 6 phyla biofouling the surfaces (Edyvean and Videla, 1992).

Micro-organisms are known to cause corrosion by the following processes. (1) Absorption of oxygen and other nutrients by microbial growth adhering to damp or wet surfaces establishing concentration cells. (2) Degradation of lubricating oils that may act as a carbon source to support growth, causing a reduction of its protective effect against corrosion and wear (Smith, 1991). (3) Production of metabolic products (Prince and Morton, 1989): i) Sulphuric acid by *Thiobacillus*. ii) Carboxylic acids, which are corrosive to non-metals, but not known to be aggressive to copper. iii) Sulphide ions, produced by SRB. (4) In an anaerobic environment microorganisms such as SRB may remove hydrogen or form iron sulphides which further accelerate the cathodic process. (5) Production of extracellular polysaccharides.

It is thought that all micro-organisms colonising a surface will produce extracellular polysaccharides (EPS) (Christensen *et al.* 1985) which collectively have been termed the glycocalyx (Costerton *et al.* 1985) largely composed of mannose, glucose and uronic acids joined by glycosidic linkages (Costerton and Geesey, 1979). The glycocalyx gel is able to immobilise water at the biofilm substratum interface and entrap metal species (e.g. copper, manganese, chromium and iron) and corrosion

products at surfaces. It has also been suggested to decrease diffusion rates towards and away from surfaces, as well as immobilise corrosion inhibitors and/or biocides (Hardy, 1989). However, pure metals themselves do in fact possess bactericidal properties which might reduce microbially induced corrosion (Bundy *et al.* 1980). Out of 16 pure metals, copper and cobalt were consistently observed to inhibit bacterial growth (Bundy *et al.* 1980).

In an aerated water supply containing chloride a clean copper surface will produce copper ions by anodic dissolution to combine with chloride to form cuprous chloride (Cornwall *et al.* 1973)

$$Cu \rightarrow Cu^{2+} + 2e$$

$$Cu^{+} + Cl^{-} \rightarrow CuCl$$

As cuprous chloride is unstable at near-neutral pH it hydrolyses to form cuprous oxide which precipitates at metal surfaces.

$$2CuCl + H_2O \rightarrow Cu_2O + 2HCl$$

The cathodic reaction supporting the anodic dissolution process is that of oxygen reduction.

$$O_2 + 2H_2O + 4e \rightarrow 4OH^{-}$$

Removal of hydroxyl ions allows corrosion to occur which proceeds more readily in acid water supplies or in water containing bicarbonate ions.

$$OH^{-} + HCO_3 \rightarrow CO_3^{2} + H_2$$

This latter reaction results in the precipitation of a mixed calcium carbonate and basic copper carbonate scale. Precipitation of cuprous oxide at copper surfaces acts as an organic corrosion inhibitor having two main effects: Firstly there is formation of a protective layer that is protective at locally active anodic sites and therefore stifles attack, and secondly polarisation of the cathodic reaction. Corrosion of copper tubing has been classified into two types that are distinct in their characteristics.

Type 1 Corrosion (Campbell, 1950; Lucey, 1967), occurs in hard water on annealed or half hard tubes. Corrosion pits are hemispherical and chloride ions are to be found inside the pits with basic copper carbonates (malachite) as the corrosion product. This type of corrosion occurs only at temperatures less than 25°C.

Type 2 Corrosion (Mattson and Fredrikson, 1966) is recognised to occur in soft (pH less than 7.4, low bicarbonate to sulphate ratio), hot water (greater than 60°C) in hard-drawn copper tubes. Corrosion pits are deep and narrow with a copper sulphate (bronchantite) corrosion product.

Type 3 Corrosion (Shalaby *et al.* 1989) pitting is uncommon and occurs in pipes carrying cold water with a high pH, low hardness, low mineral and low organic content where the pits are characterised by small hemispherical pits under a common covering of basic copper sulphate.

Therefore corrosion Types 1 and 2 should not be confused, as they are distinct types of corrosion occurring in water of different chemistry and at different temperatures and none of the three types have been shown to be induced by microbial action.

Characteristically the type and rate of corrosion in hospitals in central Scotland could not be explained by what would be considered normal physico-chemical corrosion. Indeed water temperature (35-50°C), pH (7.5-9.0) and metallurgical condition of the

pipe indicated type 1 pitting, whereas water composition (soft water) and pit morphology (deep pits exhibiting pepper pot phenomenon) favoured type 2 pitting attack. A more detailed account of the corrosion found in the hospital water systems in central Scotland can be found in Chapter 3.0 (page 73).

1.5 CONTINUOUS CULTURE IN ECOLOGY

Bacteria present in the planktonic phase of a water system constitute a microbial ecosystem (microcosm) of which bacterial attachment to surfaces is a necessary extension. Ideally, a laboratory system should attempt to simulate as far as possible the conditions in the prevailing environment or part of the environment under consideration. However, in trying to accomplish this the natural microcosm will undoubtedly suffer as a result of being simulated in the laboratory. Whereas, microcosms allow a systematic examination of responses in natural communities to environmental manipulation, a model never actually aims to reproduce the entire system. A model seeks to examine properties of a part of the system, ignoring or holding all remaining factors constant.

In proposing to model environmental systems, the objective was to make the model as close to the natural ecosystem as is possible, such that the model is the system. To completely understand a particular ecosystem is probably less important than to discern rules of behaviour which only apply at a fundamental level to many different ecosystems. Two main views apply to the approach of studying systems. First of all there is the fundamentalist approach where each stage in the microcosm is studied, then pieced together and extrapolated to explain the whole system. Alternatively, an approach studying the whole system rather than the sum of the components could be termed the "holistic" approach. The reality, of course, is that both approaches are valid as at some point the holistic and the reductionist must interact to present a unified

explanation of the microcosm.

Aquatic systems actually have very few freely suspended individual bacteria. The microorganisms are usually associated with particulate matter, resulting in formation of bacterial rafts (Cohen, 1989). Most lakes behave like large fermenter systems where the annual cycling of thermal stratification is the only method by which mixing occurs (Wimpenny, 1982). It is at the interface of the warm less dense upper layers and the lower colder layer that activity of the bacterial population is greatest. Water temperature changes due to convective turnover as the seasons rotate, such that there is a shift in the stratification of water chemistry and bacterial population between the two layers.

In natural environments, many microorganisms are involved in cycling various elements. An understanding of individual components in the cycling process has been achieved by isolation of pure cultures and studying microorganisms under pure culture in the laboratory. Continuous culture has been used as it allows the study of microbial growth under conditions which can be similar to those in nature from where the inoculum was extracted.

Micro-organisms can be grown in open or closed culture conditions. Batch culture is an example of a closed loop system where growth continues until a limited amount of nutrient is used up and growth stops or adverse pH changes inhibit growth. This type of system is not generally representative of the environments found in nature except in the short term. Indeed, initially batch culture environments are substrate sufficient and have been successfully utilised to demonstrate growth in the presence of more than one substrate. This work has resulted in a detailed investigation of a number of cellular control mechanisms (Harder and Dijkuizen, 1982). Where two carbon sources, particular if carbohydrate in nature, are present, bacteria will utilise substrates that will result in the greatest increase in growth rate while enzymes for other carbon source

will be repressed (catabolite repression). Sequential use of two carbon substrates and diauxic growth is the most pronounced response; however, both sequential use with no lag phase and simultaneous use have been observed using batch culture apparatus (Harder and Dijkhuizen, 1976).

Continuous culture systems involve the use of a culture vessel in which the culture is mixed and is continuously supplied with fresh nutrients at a constant volume. Spent culture and cells are continuously displaced with fresh medium such that growth can continue indefinitely. Such systems allow concentrations of one desired growth limiting substrate to be manipulated while all other factors remain constant. Other advantages of continuous culture systems are that they establish a reproducible steady state of growth, allow for the study of microbial responses to chemical and physical changes and contain a well analysed population of cells growing at submaximal growth rates typical of those which usually occur *in vivo* and *in vitro*. Other benefits are that nutrient concentrations can be as low as those found in natural environments. One caveat is that microorganisms rarely grow under true steady state conditions so such models need to be pulsed to mimic substrate fluctuations. A multi-stage system illustrating a two-stage continuous culture similar to that used in this study is shown in Fig. 1.3. An advantage of this type of system is that different conditions can prevail in different stages. In terms of this project, the laboratory model was operated to simulate an open continuous system such as that found in domestic plumbing. This type of vessel enabled coupons to be immersed into the culture such that attachment of bacteria to materials, as would happen on the inner walls of pipes in plumbing systems, could be monitored. Flow, as described by the Reynolds number (Characklis, 1981), within the vessel could also be manipulated to simulate the conditions within plumbing systems.

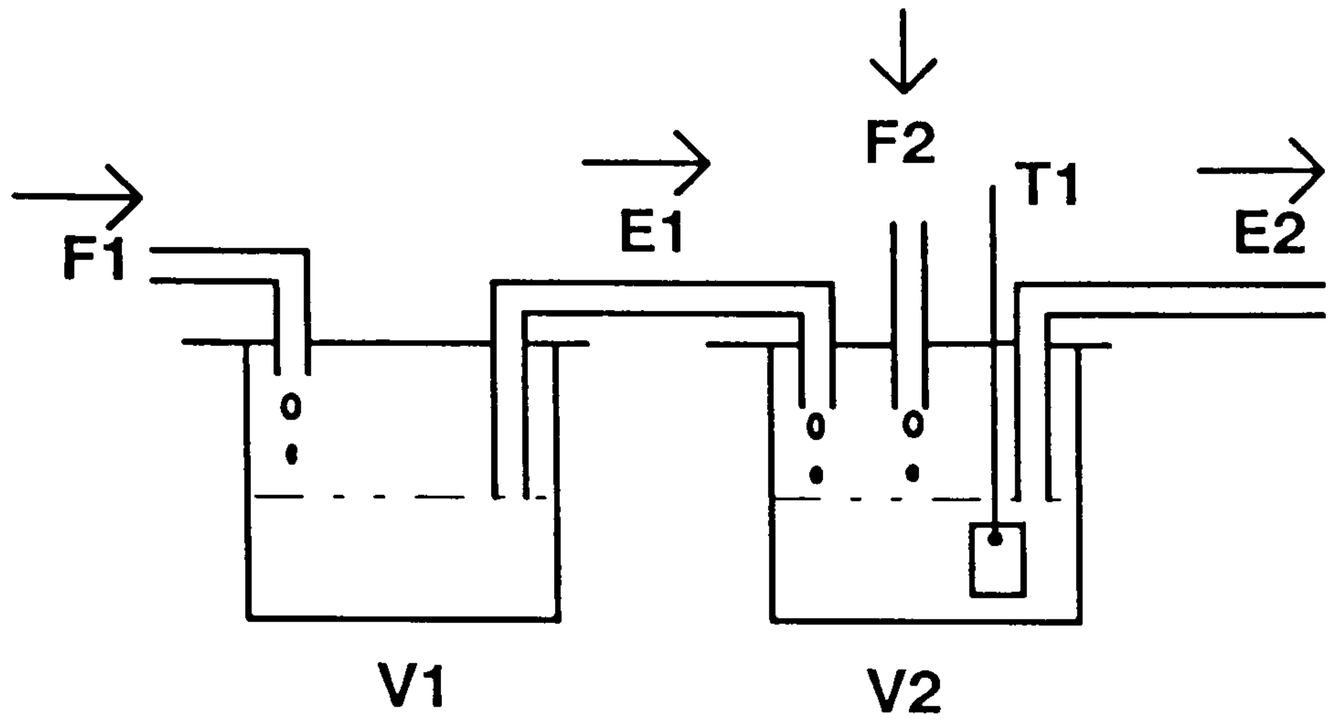


Figure 1.3 A multi-stage continuous culture laboratory model for biofilm formation.

V1, Vessel one; F1, Flow of sterile nutrients into vessel one; E1, Effluent of spent cells and media from vessel one which flows directly into vessel two V2 (F2); T1, Tile assembly on which to monitor biofilm formation; E2, Effluent from vessel two; F2, Flow of sterile nutrients into vessel V2.

In the chemostat, bacterial growth will be determined by substrate concentration, described by Monod as:

$$\mu = \mu max/(s/k_s + s)$$

Where μ is the specific growth rate per hour and s is the limiting substrate. This equation is based upon the assumption that the specific growth rate of a strain is related to its theoretical maximum (μ_{max}) and is described by a Michaelis saturation equation involving substrate concentration; k_s is a constant, numerically equal to the substrate concentration at which

$$\mu = 1/2\ \mu_{max}.$$

In continuous flow, fresh medium is supplied continuously with the dilution rate D

(units of h^{-1}), being determined by flow rate divided by the culture volume. The combination of growth with dilution governs the change in the concentration of microorganisms in the vessel with time.

Change in biomass with time = growth - output

$$dx/dt = \mu x - Dx = (\mu - D)x$$

Bacterial numbers present in the culture will remain constant where μ = D i.e. dx/dt = 0 and a steady state exists. Where μ>D there will be a decrease in residual substrate concentration for the culture leading to a decrease in growth rate till μ=D. Where μ<d an increase in substrate concentration will increase the growth rate resulting in a steady state culture unless D exceeds the critical dilution rate.

Although the term chemostat implies complete chemical control of the cellular environment, this is of course not possible. Difficulties of precision are compounded by inherent problems making it difficult to meet the assumptions used in deriving chemostat kinetics (Caldwell *et al.* 1992). Problems encountered include wall growth, back growth, plugging of tubing and also in obtaining complete mixing of the culture. Bryers (1984), used models to simulate biofilm formation which could also be modified to model mixed culture interactions, different suspended growth dependencies and various biofilm processes. He suggests that to neglect the presence of biofilms in reactor vessels can produce inaccurate estimates of kinetic/stoichiometric parameters and can lead to erroneous conclusions about the microbial culture under study, as part of the substrate would be used in biofilm growth. Model predictions suggest the metabolic activity of biofilms was greater than that of the freely suspended cells, indicating the importance of sessile bacteria in fermenters used to model suspended cultures. A number of different continuous culture chemostat systems have been devised, some of which are described below.

1.5.1 Laboratory model systems

A number of chemostat model systems have been devised to simulate environmental growth conditions of bacteria (Veldkamp, 1976). Single stage chemostats offer ecologically relevant information; however, they have the drawback that they are homogenous whilst most environments are actually heterogeneous. To simulate heterogeneous transient situations, models such as the multistage chemostat have been utilised which consist of a continuous flow culture system incorporating a number of linked vessels. Such systems have been used to model anaerobic ecosystems which are widespread e.g. aquatic sediments, waterlogged soils and sewage digesters. For example, anaerobic decomposition in a landfill includes anaerobic sulphate reduction, anaerobic nitrate reduction and methanogenesis, involving the sequential action of different bacterial types. Parkes and Senior (1988) therefore used a multi-stage chemostat to simulate an anoxic landfill dominated by methanogens with hydrogen as an important intermediate and acetogenic bacteria playing an important role in carbon mineralisation. Defined media were used. Heterogeneity within the model was increased by the addition of glass beads to increase surface area. However, in the progression towards simulation of environmental situations the increase in heterogeneity resulted in the system being less amenable to steady state kinetics. The system lends itself to modelling different environmental situations as required. The dilution rate of each vessel is dictated by the flow rate that will prevent washout or alternatively the volume of each vessel can be altered to control the dilution rate of individual vessels to accommodate for slow growing organisms.

To simulate temporal and spatial heterogeneity the bi-directionally linked continuous culture chemostat or the gradostat has been utilised (Wimpenny, 1988). The tubing-coupled gradostat consists of a series of five bidirectionally linked fermentation vessels with the culture transferred between neighbouring vessels in two directions at the same

time. Lovitt and Wimpenny (1981a and b) developed a diffusion-coupled gradostat in which vessels were linked by diffusion or mechanically assisted diffusion. Such a diffusion-coupled system has been used for the growth of *Methylophilus methyltrophus* with the highest cell yield occurring in the vessel nearest the methanol source. *Rhodopseudomonas marina* and *Rhodobacter capsulata* were also grown in varying concentrations of salinity. The diffusion-coupled system is an invaluable tool for the enrichment of different bacterial species where microbial consortia can interact even though some of the constituent species require mutually exclusive habitats.

Another system known as the compound bi-directional diffusion system has been developed by Lovitt (1981a). This is a three chambered system, each separated by a membrane to prevent physical interaction of bacteria but allows a diffusional interchange of substrates and metabolic products between the chambers. Herbert, (1992) utilised a 0.2 μm membrane with a reciprocating shaker to follow sequential flow of carbon through the microbial processes of a saccharolytic bacterium *Clostridium butyricum*, an SRB, *D. desulfuricans* and a purple sulphur bacterium, *Chromatium vinosum*. Glucose provided in the growth medium was metabolised by *C. butyricum* into lower fatty acids (primarily butyrate and acetate) and ethanol, resulting in a commensal relationship between this species and *D. desulfuricans* which utilised the primary fatty acids. The SRB was also able to enter into a mutual relationship with *C. vinosum* through cyclic reduction and oxidation of sulphate and sulphide (electron acceptor and donor respectively). Crump and Richardson (1985) using *E. coli* studied the growth of a sucrose nonfermenter and a strain that fermented glucose. Interestingly the two strains of *E. coli* were able to penetrate membranes with a pore size of greater than 0.1 μm within 24-48 h. Even with membranes with a pore-size of 0.1 μm the integrity of the membranes to bacterial cells was not maintained if the system was shaken continuously, perhaps illustrating the formation of ultramicrobacteria that penetrated the membrane or in severe cases, membrane rupture.

The above laboratory models have all been used to study bacterial growth in dynamic systems, and bacterial interactions in the planktonic phase, but they were not used to investigate bacterial attachment to surfaces. One of the main criteria that Caldwell *et al.* (1992) wished to satisfy was the definition of hydrodynamic conditions which require laminar flow velocity to be controlled. In order to do this he devised continuous flow slide culture cells which he considered gave greater precise growth conditions than chemostats. The flow cell consists of two cover slips over the top of two microscope slides resulting in a thin defined measured chamber through which the synthetic minimal media and cells flow. Subsequent review of that flow cell has suggested that due to its design that particular model may not actually provide controlled laminar flow velocity as previously suggested (Fowler, 1993). Automated computer microscopy analysis aided measurement of growth in continuous culture in terms of cell area. *P. fluorescens* has been shown to grow exponentially at a constant rate even within a single cell cycle while microbial growth during the formation of surface microcolonies was unbalanced. Colonisation manoeuvres associated with positioning, attachment and growth of this microorganism have also been observed (Lawrence and Caldwell, 1987).

Wimpenny (1982) was instrumental in developing another model for investigating bacteria in biofilms. In the constant depth fermenter, biofilm was developed within a recess of a predetermined depth with excess biofilm being mechanically swept away. Physically, the fermenter consists of (poly) tetrafluoroethylene PTFE with multiple recessed removable biofilm pans and a spring loaded PTFE scraper. Biofilm at a depth of 300 μm were generated using a dilute defined medium containing 50 mg l^{-1} of carbon. This particular model has been criticised for a number of reasons. The culture consisted of a pure culture of bacteria, a constant 300μm deep biofilm and a physical scraper impacting the biofilm have resulted in a system that is rarely found in the natural environment, perhaps resulting in an artefactual biofilm. However, the development of micro-electrodes in this work has been of immense value in the

understanding of parameter profiles within different layers of the biofilm (Wimpenny, 1988). For example, the use of oxygen electrodes with tips less than 10 μm thick showed how only the top 100 μm remains viable.

To study the influence of growth rate on the susceptibility of bacteria to antimicrobial agents, Gilbert *et al.* (1990) developed synchronous cultures of *Escherichia coli.* This was carried out by passing a pure culture of the bacterium through a filter, reversing the filter and collecting baby or daughter cells, as media was pumped through the filter to produce the synchronous culture. The effect of antibiotics on the mono-layer or biofilm-associated bacteria was then determined at different growth rates. Used as a method for separating and controlling growth rate, this model has demonstrated that the resistance of biofilm-associated cells relates to their slow growth rate rather than to any innate properties of the biofilm. However, further studies may have to be carried out to ascertain whether cells that have been impacted onto a filter i.e. biofilm-associated cells, behave and grow the same as bacteria which have formed a biofilm due to their own activities. Other investigators have described the growth of biofilms, in medical implants and laboratory models using clinically isolated bacteria, as a patchy layer of bacteria on the surface with flocculation's or fronds projecting from the surface (Marrie *et al.* 1982; Brooks and Keevil, 1993). If this is the case, then the biofilm-associated bacteria, impacted onto the filter as a mono-layer, may not represent what is happening in the environment, however, in controlling growth rate as a factor in antibiotic control of these biofilms then it does appears to very efficient. As in all laboratory models the investigator has to be very careful in extrapolating results to a real environmental situation.

The systems discussed above are only a selection of the models and simulators which have been developed to suit the needs of the various investigators in their specific wish to investigate a particular environment. Each of the systems are defined by their operators to answer particular questions about the physiology of growth in the

planktonic phase, attachment or even interaction within formed biofilms.

When presented with the task of finding a system to model a water system the one selected was that used previously by Keevil *et al.* (1987). Although that particular model was used to simulate dental plaque it was modified from a single stage homogenous chemostat to represent a flowing system as found in domestic water systems.

CHAPTER 2

MATERIALS AND METHODS

2.0 IDENTIFICATION OF BACTERIA

Identification of the aquatic, non-fastidious bacteria was performed using colony morphology, pigmentation, Gram staining (Bacteria were heat fixed, stained with methyl violet for 1 minute, rinsed in sterile distilled water, stained with iodine for 1 minute and decolourised with acetone. The bacteria were then counter stained for 30 s with carbolfuschin before being dried and viewed using a light microscope), oxidase and catalase tests (Bergeys, 19). Further identification was also carried out on strains using API 20E, API 20NE identification kits and the Vitek identification system in conjunction with the API database of biochemical determinants (API Biomerieux, Basingstoke).

2.1 IDENTIFICATION OF *LEGIONELLA PNEUMOPHILA*

Colonies of suspected *Legionella* spp., characterised by a morphology of spherical colonies with a dark grey, almost blue with a glassy appearance, were subcultured onto BCYE and non-cysteine media for primary identification of *Legionella* spp. and incubated at 30°C overnight. Those cultures which grew on BCYE (and had a characteristic smell) but not on non-cysteine media were classified as *Legionella* spp. and bacterial suspensions were prepared in sterile distilled water (1 ml). 10 μl of the bacterial suspension was placed onto the wells of a multispot microscope slide (Flow Laboratories, UK). The slide was then dried at 37°C before being fixed in acetone. Each well was then coated with 10 μl of polyclonal antibody 1-14 (Thames Water, Plc.) and the well incubated in a moist atmosphere for 1 hour at 37°C. Following three washes in phosphate buffered saline (PBS) and drying at 37°C, each well was coated with 10 μl of anti-rabbit IgG FITC conjugate, and incubated for 30 minutes at 37°C.

The microscope slides were then washed three times in PBS and dried at 37°C before viewing with an immunofluorescent microscope (Nikon, UK Ltd). For further sub-typing of the *Legionella* spp. colonies, subsequent wells were coated with type-specific monoclonal antibodies followed by anti-mouse IgG FITC.

2.2 MICROBIOLOGICAL ANALYSIS OF SITE SURVEY SAMPLES

Swabs of various taps, cold water holding tank and calorifier outlets were suspended in 10 ml sterile distilled water. All samples were serially diluted 10-fold in sterile distilled water with standard plate counts carried out in duplicate using a 0.1 ml inoculum. Total aerobic bacterial numbers were enumerated on minimal R2A (Reasoner and Geldriech 1985, Table 2, page 46) and BCYE (Pasculle *et al.* 1980; Table 4, page 48), whilst legionellae were also recovered on BCYE (Pasculle *et al.* 1980; Table 4, page 48) and GVPC (Wadowsky and Yee, 1981; Dennis *et al.* 1984a, Table 5, page 49). Sulphate-reducing bacteria were recovered on Modified Barr's medium (Pankhurst; 1971, Table 3, page 47) (pipe samples only). All agar plates were incubated at 30°C for 7 days with bacterial counts reported as colony forming units (cfu) ml^{-1} (± 100 cfu ml^{-1}). *Legionella* spp. were initially detected on BCYE and typed using immunofluorescent labelling (Section 2.1). Bacterial identification was established by colonial morphology, Gram staining, oxidase reaction, catalase reaction and API identification kits (2.1, page 44). Sections of copper tubing were cut from the tube samples and prepared for SEM analysis (section 2.12.2, page 67). Glutinous slime from the surface of the copper tubes was aseptically scraped onto a glass slide for Gram staining.

2.3 CULTURE MEDIA

Minimal R2A medium agar (Reasoner and Geldreich, 1985; Table 2) was used to isolate microorganisms aerobically by incubating at 30°C for 7 days. Modified Barr's medium agar (Pankhurst 1971, Table 3), was selected for the isolation of sulphate-reducing bacteria (SRB), which were incubated anaerobically at 30°C and 40°C for 7 days. BCYE agar (Pasculle *et al.* 1980; Table 4) and GVPC agar (Wadowsky and Yee, 1981; Dennis *et al.* 1984a; Table 5) were used for the detection of legionellae and incubated aerobically at 35°C for 7 days. When the vessel temperature was at 60°C, 0.1 ml aliquots were plated on to modified Ramaley and Hixson (1970) medium agar (Table 6) and incubated aerobically for 7 days at 6O°C for the recovery of thermophillic bacterial species. Methylobacterium medium was used for the recovery of C1 utilising methylotrophs (Table 7).

Table 2. Reasoner's Media

Ingredient	R2A g l^{-1}	R3A g l^{-1}
Yeast extract (Oxoid)	0.5	1.0
Difco proteose peptone 3	0.5	1.0
Casamino acids	0.5	1.0
Glucose	0.5	1.0
Soluble starch	0.51	1.0
Sodium pyruvate	0.50.3	1.0
K_2HPO		0.5
$MgSO_4.7H_2O$	0.5	0.6
Agar (Oxoid)	15.0	15.0

pH 7.7 and sterilise 121°C for 15 min.

Table 3: Modified Barr's Medium

Ingredient	g l^{-1}	ml^{-1}
K_2HPO_4 anhydrous	0.5	
NH_4Cl	1.0	
$CaSO_4.2H_2O$	1.0	
$MgSO_4.7H_2O$	2.0	
70% Sodium lactate solution	5.0	
Ascorbic acid*	1.0	
Thioglycolic acid Na salt	1.0	
Oxoid yeast extract	1.0	
Tap water		1000.0
Oxoid purified agar	15.0	
Resazurin (1mg ml^{-1})*	1.0	
Na_2SO_4	1.0	

* denotes modifications to the standard Barr's medium. Cool to 50°C, add 50 ml l^{-1}, 1% ferrous ammonium sulphate solution, pH 7.7 and sterilise 121°C for 15 min.

Table 4: Buffered charcoal yeast extract medium (BCYE)

Ingredients	g l^{-1} distilled water
Yeast extract (Oxoid)	10.0
Agar (Oxoid no. 3)	12.0
Activated charcoal (Norit SG)	1.5
α-ketoglutarate, monopotassium	1.0
ACES buffer (Sigma)	10.0
Potassium hydroxide (BDH)	2.8
L-cysteine	0.4
Ferric pyrophosphate	0.25

pH 6.9 and sterilise 121°C for 15 min.

Table 4.1: Non-Cysteine Medium (NCM)

Ingredients	g l^{-1} distilled water
Yeast extract (Oxoid)	10.0
Agar (Oxoid no. 3)	12.0
Activated charcoal (Norit SG)	1.5
α-ketoglutarate, monopotassium	1.0
ACES buffer (Sigma)	10.0
Potassium hydroxide (BDH)	2.8
Ferric pyrophosphate	0.25

pH 6.9 and sterilise 121°C for 15 min.

Table 5: GVPC (BCYE: minus KOH, plus the addition of the following)

Ingredient	g l^{-1}	mg l^{-1}
Glycine	3.0	
Vancomycin		5.0
Polymixin		11.0
Cycloheximide		80.0

pH 6.9 and sterilise 121°C for 15 min.

Table 6: Modified Ramaley and Hixson Medium (Thermus Media)

Solution A (Castennoitz based salts)

Ingredient	g l^{-1}	ml^{-1}
Nitrilo acetic acid	1.0	
$CaSO_4.2H_2O$	0.6	
$MgSO_4.7H_2O$	1.0	
NaCl	0.08	
KNO_3	1.03	
$NaNO_3$	6.89	
Na_2HPO_4	1.11	
Deionised water		1000

Solution B

$FeCl_3.6H_2O$	28.0	
Deionised water		1000

Solution C (Nitchs Trace Element Solution)

H_2SO_4	0.5	
$MnSO_4.H_2O$	220.0	
$ZnSO_4.7H_2O$	50.0	
$CuSO_4$	1.6	
$Na_2MoO_4.2H_2O$	2.5	
$CoCl_2.6H_2O$	4.6	
Deionised water		1000

To 100 ml of solution A, add 1.0 g yeast extract (Difco) and 1.0 g of Bactotryptone (Difco). Add 10 ml of solution B and 10 ml of solution C and make up to 1000 ml with deionised water. Adjust the pH to 8.2 with 10 M NaOH and autoclave.

Table 7 Methylobacterium medium

Ingredients	$g\ l^{-1}$	ml^{-1}
$CuSO_4.\ 5H_2O$	0.005	
$MnSO_4.4H_2O$	0.01	
Sodium Molybdate	0.01	
Boric Acid	0.01	
$ZnSO_4.7H_2O$	0.07	
Cobalt Chloride $6H_2O$	0.005	
Millipore Water		1000

2.4 INOCULUM FOR LABORATORY MODEL

The inoculum for the laboratory model was obtained from a corroded copper tube extracted from the Victoria Infirmary during the site survey in 1987 (page 73). A section of tube was identified for removal in the laboratory block where corrosion was

found to be severe. The water to this section was turned off and drained into a sterile jerrican before the section of copper tube was cut out using a hacksaw. Upon removal, one end was covered with a sterile endcap (sterilised using a portable autoclave, Prestige, UK Ltd.), before filling the tube with source water from the sterile jerrican and sealing the open end with another sterile endcap. The copper tube was transported back to the laboratory within 48 h and placed in the entry port of an anaerobic cabinet. A vacuum pump (Grant, UK) was used to evacuate the airlock to -25 in Hg. The airlock was gassed with oxygen free nitrogen (BOC) to -15 in Hg and the procedure repeated. The airlock was then evacuated to -25 in Hg before being gassed to zero in Hg with an anaerobic mixture of 80%Hydrogen:10% CO_2:10% N_2. Once inside the cabinet in the atmosphere of the anaerobic gas mix the copper tube was opened at one end and the contents placed in a sterile container. Using a sterile dental probe, scrapings of the inner surface of the copper tube were placed in Pages' amoebal saline (Pages, 1967) in sterile bijou bottles before being stored at -70°C. Recovery of microorganisms appeared satisfactory when the stored inoculum was thawed and grown in the continuous culture vessel.

2.5 LABORATORY MODEL

The design of the laboratory model was adapted from a system described by Keevil *et al.* (1987). A glass desiccater vessel (Jencons Ltd, Leighton Buzzard) was used as the base that contained a 25 mm magnetic flea (BDH) to provide a propeller for vortex mixing. The base was filled with 500 ml of distilled water in 100 ml amounts and the side of the base marked at these volumes. A titanium fermenter top plate (CAMR Engineering Services) with 9 large ports (22 mm diameter) into which were placed silicone rubber bungs (Esco Rubber/Sterlin Ltd, Middlesex) which held oxygen (Type G2, 10 mm diameter, Uniprobe, Cardiff), redox and pH electrodes (Russell pH Ltd, Auchtermuchty, Scotland). The pH electrode was calibrated against standards of pH 4

and pH 7, before and after autoclaving before being placed into the vessel top plate. The Eh electrode was calibrated against quinhydrone (BDH, UK) at pH 7 (+290 mV) and pH 9 (+176 mV). A cork borer nearest the diameter of each electrode was chosen to bore a hole in the silicone rubber bung using glycerol as a lubricant and the bung then worked over the glass section of the pH and redox electrodes. For the oxygen electrode the silicone bung had to be forced down from the top of the electrode to prevent damage to electrode sensor. The electrodes and silicone bungs were then washed in distilled water to remove excess glycerol. Four smaller ports (10 mm diameter) held glass tubing (internal diameter of 4 mm) externally covered with a few centimetres of silicone tubing to ensure sealing before being placed into the ports to be used as media inlet, outlet, air outlet and glass RT-temperature sensor (Anglicon Systems) (Fig. 2.1). The media inlet was made of glass and contained a bulbous section surrounding the media dropper to prevent grow back of organisms back up the media line. In the bulbous section was another inlet tube through which air was passed. This inlet was preceded by a 0.2 μ air filter (Sartorious) to prevent ingress of bacteria through the air pump. An air filter was also placed on the air outlet. One of the large ports was also used to hold a glass tube which was used as a sample port. Silicone tubing was connected from the glass port to a titanium sample port, into which was inserted a universal container, which had an air filter (Sartorious), onto which a syringe could be fitted to draw through a sample of the culture. All ports had brass screw caps which were screwed down to give an air tight seal. A silicone rubber O-ring greased with silicone sealant was placed between the base and lid, before using two titanium outer rings which clamped the top plate and glass base together by tightening 6 oppositely facing screws (Fig. 2.2). All components were made of glass and titanium or silicone rubber to prevent leaching of nutrients or metals, from unsuitable components, that would otherwise alter the water chemistry.

When assembled, all but one inlet to the vessel was clamped off and the vessel was completely immersed in water in a sink unit to test the integrity of the seals by

pressurising the vessels to 10 lb. pressure. Before sterilisation the rubber seals covering the ports in the electrodes, which allow the electrolyte to be filled, were opened to prevent pressure build-up rupturing the membrane seals during autoclaving. All media inlet and outlet ports were clamped off and air filters taped up to maintain a vertical position, for if these filters bend towards a horizontal position there is the possibility that they will fill with moisture and block up. The resulting pressure build-up may damage the vessel and electrodes. Once the vessel was air tight it was placed in a metal container for protection, then sterilised by autoclaving at 121°C for 30 min and allowed to equilibrate overnight before removal from the autoclave.

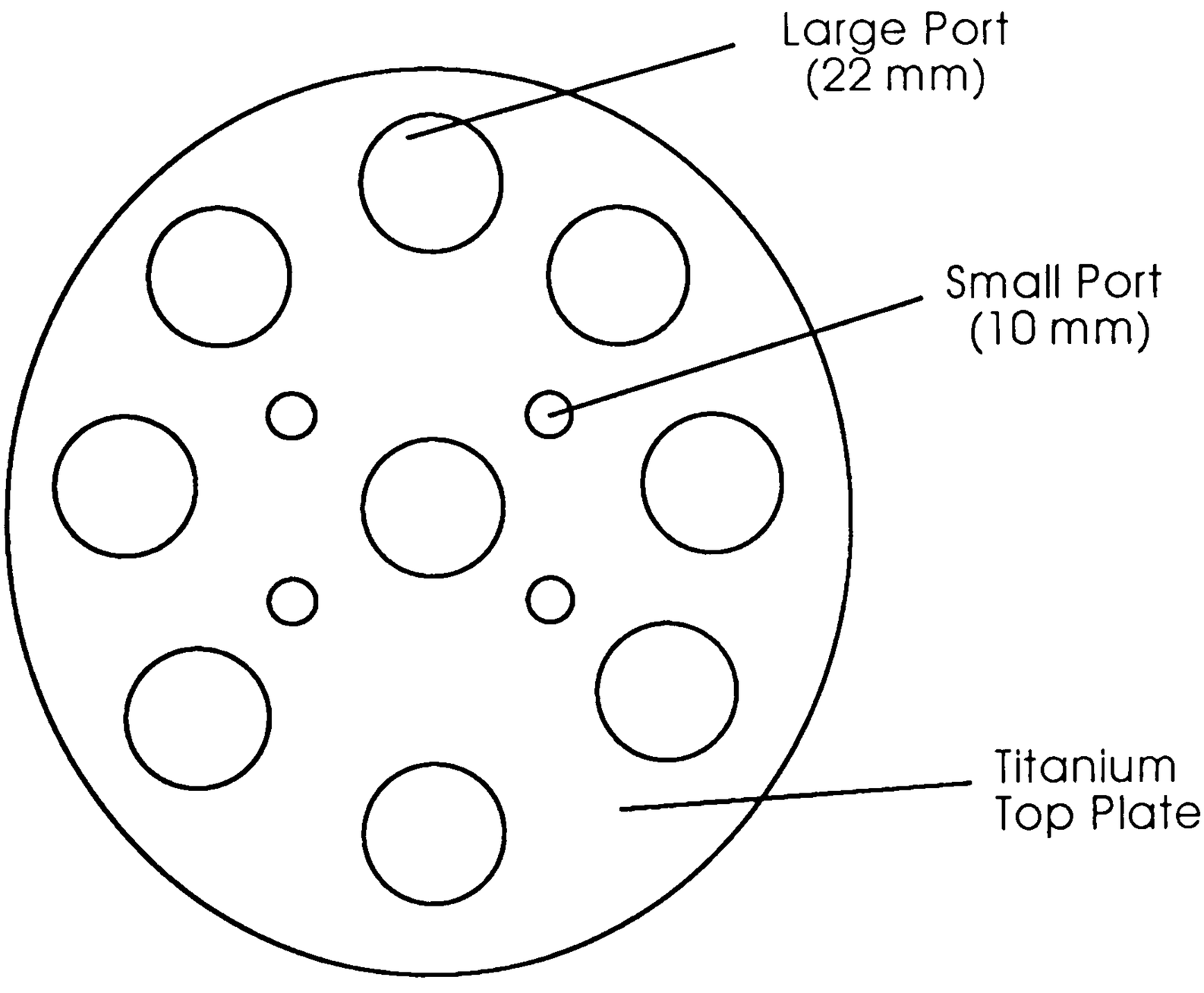


Figure. 2.1 Top plate of chemostat vessel.

After removal from the autoclave the vessel was again submerged in water to test the integrity of the seals and if this was satisfactory the vessel was set up as a chemostat. The electrodes in the vessel were connected to the microprocessor fermenter controller and the oxygen electrode calibrated to zero as the oxygen concentration would be low due to the recent autoclaving. This was carried out by making sure that the air inlet

and outlet filters were not blocked and passing oxygen free nitrogen into the vessel. With the oxygen meter set to polarographic the gain on the microprocessor fermenter controller was adjusted to read zero (approximately 30 min). Having set the zero scale, air was then blown into the vessel from the air pump in the controller and the slope adjusted to register 100%, (approximately 30 min). The pH and Eh electrodes were previously calibrated, as above, before being placed into the vessel to be autoclaved again.

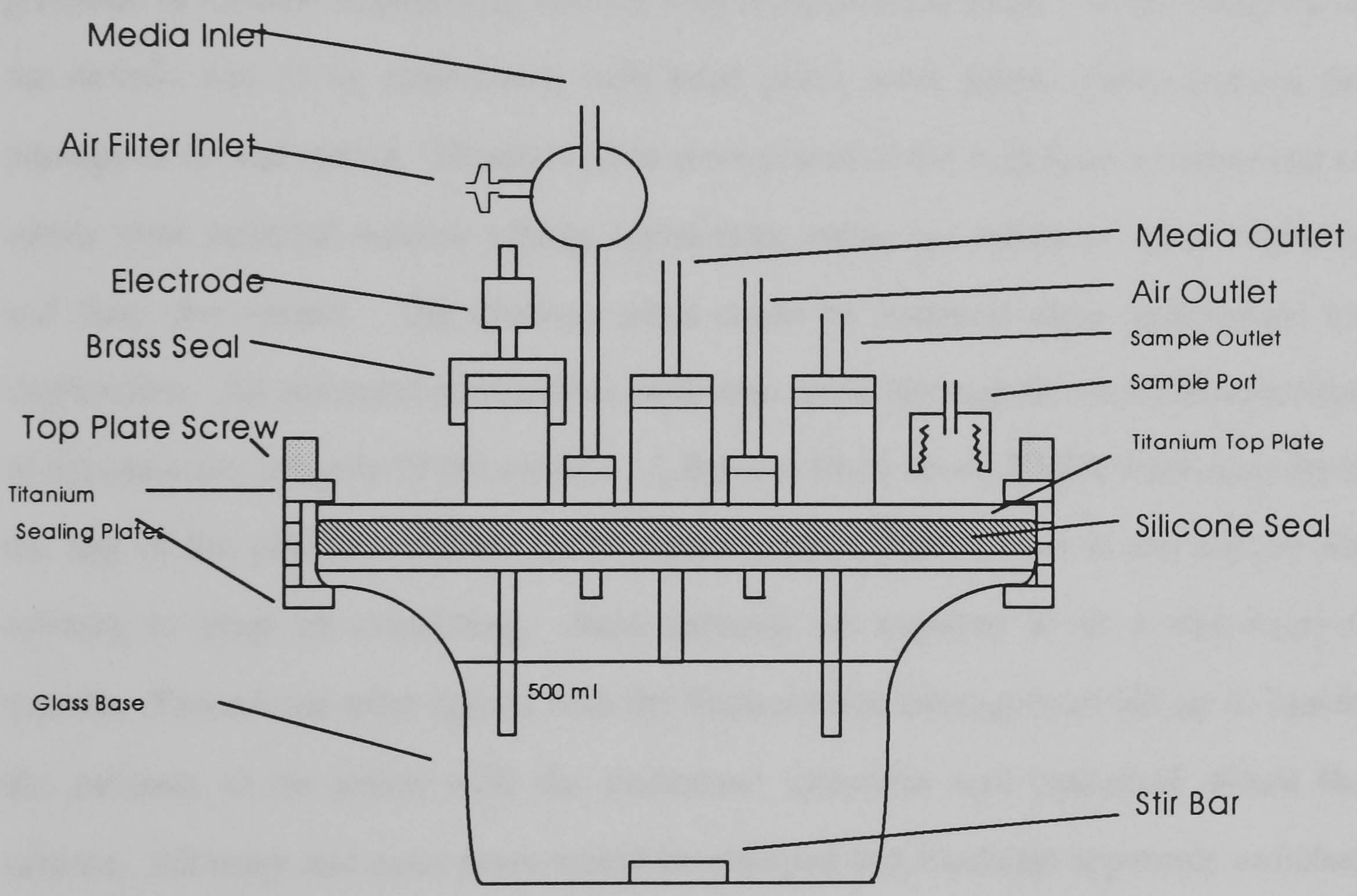


Figure 2.2 Schematic drawing of chemostat vessel

Two vessels were prepared as above with the media outlet of the first vessel connected to the media inlet of the second vessel to produce two continuous culture vessels in series. Each vessel was controlled by a microprocessor controller which was an integral unit containing temperature controller, air pump, Eh, pH, oxygen meters,

media pump and effluent pump. Air was continually pumped into each vessel. (0.5 l h^{-1}) and the oxygen concentration was controlled by the speed of the magnetic stirrer (LH Fermentation), positioned below each vessel. Otherwise the stir speed was set at 160 rpm. An asbestos mat (1.5 cm thick) was placed between the heating element (Anglicon) and the stirrer to protect the stirrer from heat.

The vessels were housed within a class III safety cabinet with a view to incorporating pathogenic microorganisms into the culture at a later date and therefore to provide operator protection (Fig. 2.3). These cabinets were designed with the assistance and guidance of CAMR Engineering section who manufactured them. As the integrity of the cabinet had to be maintained, bulk head plates were fitted, which enabled the passage of air and media. Titanium tubes were placed in the bulk head to either end of which were attached silicone tubing, transferring either air, media or spent media to and from the vessels. The titanium tubes could be removed when appropriate for sterilisation. All electrical connections were also made through an electrical bulk head to maintain the integrity of the cabinet. A fan was fitted above HEPA filters present in the top of the cabinet, to draw air in across another HEPA filter in the side of the cabinet, to keep air circulating. Such cabinets are required to be tested every 6 months. Procedures were agreed with the Fermentation Management Group to enable the cabinets to be tested with the chemostat apparatus still contained within the cabinet. All entry and exist ports would be clamped and electrical apparatus switched off before swabbing down equipment with 70 % isopropanol. Such procedures ensured that the equipment was out of use for a minimum period of time.

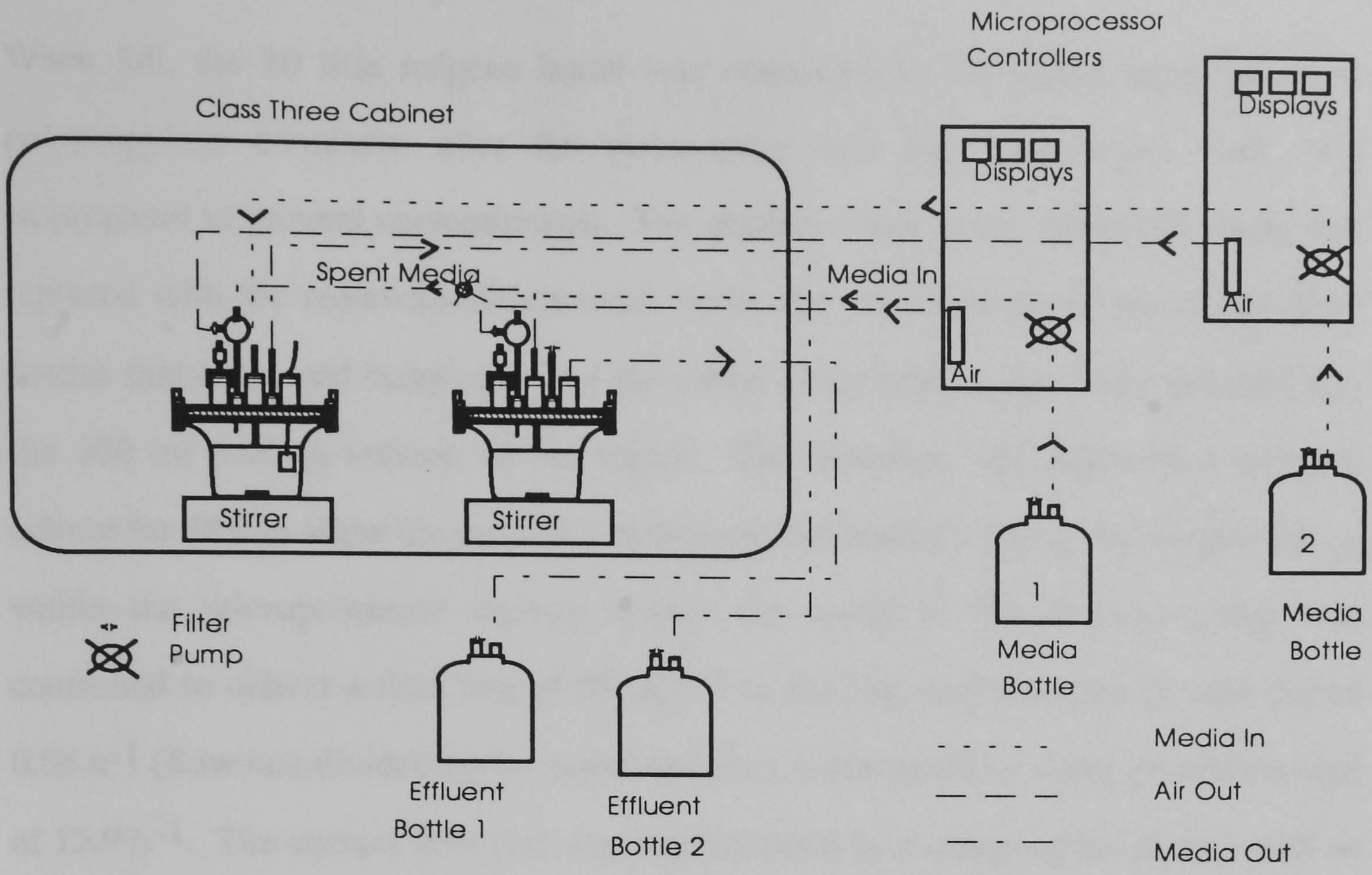


Figure 2.3 Layout of controller, chemostat vessels and cabinet

Growth medium for the continuous culture laboratory model was water obtained from the hydrant at the Victoria Infirmary. Four empty 20 litre jerricans were transported to Glasgow and returned full of soft water from the hospital. The water was placed at 5°C until required for use. After assembling the chemostat vessels in the class III cabinet, a 10 litre (high density polyethylene, Nalgene, UK) bottle was filled with soft water that was sterilised using membrane filtration (Colbourne *et al*, 1988b). A 147 mm filter housing of stainless steel (Sartorious, UK) was loaded with a 142 mm, 0.2 μm nylon membrane filters (Pall, Portsmouth) and sterilised at 121°C for 15 min. The housing was then connected to a sterile Nalgene bottle via a titanium sample port. The top of each Nalgene bottle was modified with three polyethylene connectors (media inlet, outlet and air filter) screwed through the top, such that an aseptic seal could be maintained. Soft water was sterilised by pumping (R600 pump, Watson Marlow, UK) through the filter housing, sample port and into the 10 litre bottle, using a relatively slow speed, otherwise pressure on the tubing often resulted in the tubing perishing.

When full, the 10 litre nalgene bottle was connected to the media input line by a polypropylene connector after the surrounding area had been wiped with 70% isopropanol to prevent contamination. The distilled water in the chemostat vessel was replaced with the membrane-filtered soft water and the contents of one of the bijou bottles that contained scrapings from the inside of the copper pipe were emptied into the 500 ml holding volume of the vessel. The inoculum was maintained in batch culture for 48 h to allow the inoculum to become established. Using the integral set-up within the microprocessor control system the speed of the nutrient pump was controlled to deliver a flow rate of 25 ml h^{-1} to the first vessel, a dilution rate (D) of 0.05 h^{-1} (flow rate divided by the vessel volume), equivalent to a mean generation time of 13.9 h^{-1}. The correct flow rate was accomplished by placing a glass pipette with an air filter at the top in the media in-line before the pump. Media could then be drawn into the glass pipette using a syringe and the pump set by measuring how long it takes to deliver a known volume. An auxiliary pump (Type R101, Watson Marlow) was used to pump spent media and cells from the first vessel into the second. The second vessel was also supplied with sterile media, as above, but at a rate of 75 ml h^{-1} resulting in a total flow rate of 100 ml h^{-1}, a dilution rate of 0.2 h^{-1} and equivalent to a mean generation time of 3.5 h^{-1}. Using another auxiliary pump spent media was pumped from the second vessel to an effluent container (10 litre nalgene bottle). When the 10 litre container was 80% full it was replaced by another sterile effluent bottle. Contents of the partially full effluent bottle were then sterilised by the addition of chloros resulting in a 10 % (v/v) final solution. After a contact time of 24 hours the contents were washed down a designated sink with copious amounts of water.

2.6 QUANTITATION OF MICROORGANISMS IN THE PLANKTONIC PHASE

Bacterial populations within the water phase were quantified by removing an aliquot from the water phase of the vessel using the sample port. Planktonic phase samples were extracted from the vessel at weekly intervals. From each aliquot, serial dilutions were prepared with sterile distilled water and 0.1 ml was used to inoculate R2A (section 2.9), BCYE and GVPC agar plates in duplicate. The agar plates were then incubated at 30°C for 7 days.

2.7 DEVELOPMENT AND QUANTITATION OF BIOFILMS

To obtain copper coupons on which to establish biofilms a copper tube (15 mm, thin walled, not blasted, IMI Yorkshire Copper Tube Ltd.) was machined into coupons of 1.0 cm x 1.0 cm, with a 1 mm hole at one end. Copper coupons were suspended from silicone bungs using copper wire (99%) . Glass coupons (Optiglass, UK) 1.0 x1.0 cm with a 1mm hole at one end, to be used as a control were suspended from silicone rubber bungs using titanium wire. Both sets of coupons were then rinsed in acetone to degrease the coupons and air dried by placing in medical flat bottles. The tops were covered with aluminium foil before autoclaving (Prestige laboratory autoclave). Each port hole area where the tile assembly was to be placed into the top plate was swabbed with 70% isopropanol before the sterile bung assembly was placed into the port hole on top of the fermenter head, such that coupons were suspended into the media in the vessel. The culture was established at 40°C and maintained at this temperature to allow coupons to be immersed in the vessel for 21 days. At intervals of 1, 4, 7, 14 and 21 days a glass and copper tile assembly was extracted and replaced by a sterile bung. The tile assembly was placed in a medical flat and transported to the microbiology

bench where each tile was removed from the wire, using sterile forceps, and gently rinsed in 10 ml sterile distilled water to remove unattached bacteria. Subsequently coupons were placed in 1.0 ml sterile distilled water and aseptically scraped and vortexed to remove adherent biofilm. Serial dilutions, in sterile distilled water, were prepared and a 0.1 ml aliquot of each dilution was then spread in duplicate onto R2A, BCYE and GVPC agar plates using plastic spreaders. Inoculated agar plates were then incubated for 7 days at 30°C.

2.7.1 Temperature Profile

When the last set of coupons was removed from the vessel the temperature was raised by 5°C and the culture allowed to equilibrate for 5 days before the immersion of another set of coupons. Increasing the temperature took approximately 20 min. Temperature of the cultrue in the vessel was increased after each investigation of biofouling at a particular temperature. Biofilms were generated from 40°C to 60°C and were monitored at 1, 7, 14 and 21 days with scanning electron microscopy of the sample surfaces. The temperature of the test vessel was increased up to 75°C and then decreased to 40°C before the biofouling was again monitored over the temperature range of 40-60°C. This was carried out to investigate whether exposure to temperatures above 60°C would have an effect on biofouling profiles. Biofilms generated during this latter experiment were monitored at 1, 7 and 14 days but without scanning electron microscopy of the samples surfaces.

2.7.2 Thermal Pasteurisation

2.7.2.1 Biofilm generation at 45°C

Copper coupons were prepared (as in section 2.7) and immersed for 42 days into an auxiliary third vessel maintained at 45°C which was placed in-line and down-stream from the second vessel. The coupons were then removed from the auxiliary vessel and placed into the second vessel where the temperature was maintained at 60°C and coupons removed over a 15 h period.

2.7.2.2 Biofilm generation at a range of temperatures

Copper and glass coupons were exposed to varying temperatures for 12 day periods starting with 50°C followed by 55°C then 60°C before the temperature was changed to 45°C. Copper and glass coupons were then removed for biofilm enumeration before the temperature was changed to 60°C with more coupons being removed after 1 and 2 h respectively.

2.7.3 Acid treatment of established biofilms

Biofilms were generated on copper coupons for 14 days then extracted aseptically and immersed in 10 % (w/v) citric acid (Sigma, UK) for up to 4 h. The viability of the culture was ascertained at 0.5 h, 1, 2 and 4 h. To study the recolonisation of citric acid treated coupons, biofilms were again generated for 14 days, treated with citric acid for 0.5 h and rinsed twice in sterile distilled water then re-immersed into the vessel. Copper coupons were removed and viability of the biofilm assessed as above. Comparison procedures were repeated using 5% sulphamic acid (Sigma, UK).

2.7.4 Increasing the calcium carbonate concentration of the soft water

Calcium carbonate (Sigma, UK) was added to the continually mixed nutrient bottle supplying vessel 2 resulting in a final concentration of 80 ppm in the continuous culture vessel. The normal concentration for this soft water was less than 20 ppm calcium carbonate.

2.7.5 Laboratory apparatus to simulate corrosion of copper

Two new vessels were assembled as in section 2.5 (page 51). Vessel 1 was supplied with soft water, stored at 5°C to minimise metabolic activity and chemical changes within the water. The water was not exposed to other treatments such as sterilisation. The reason for this was to supply this first vessel with the same soft water as was present in the water circuit of the institutional building where the copper tube failure was occurring. Temperature within the vessel was 40°C, with a flow rate of 70 ml h^{-1} and the culture was stirred at 160 rpm. Effluent from this vessel was pumped through a 10 m copper tube coiled to occupy a drying cupboard which was maintained at 40°C. Upon leaving the copper tube, the water passed through a 0.2 μm capsule filter (Gelman Scientific, UK) such that sterile water without particulate matter was released into the second vessel (prepared as in section 2.5, page 56). As all the bacteria would also have been taken out by the filter the vessel was inoculated with a bacterial culture obtained from the first vessel. Copper coupons were prepared as in section 2.7 and immersed into both vessels such that a comparison could be obtained by the presence or absence of particulate matter and removed from the vessels at 12 months old. Microscopical examination of the copper coupons were compared between those immersed in the first vessel supplied with particulate matter and the second vessel downstream of the copper tube.

A section of copper tubing (25 cm) was removed from the 10 m copper tube using a plumbers cutter. The area was swabbed with 70% alcohol before and after removal. Endcaps were placed over one end and the tube filled with sterile distilled water before the other end was sealed with another endcap. The tube was then sealed in a nylon autoclavable bag and transported to the laboratory. After removing one of the endcaps, the tube was held in a vice while 2 cm were cut from one end, to remove area damaged by the endcaps. Two parallel incisions, 2 cm long, were cut horizontally along the tube and one vertical cut such that a section of copper tube could be removed. This method allows for a section of copper with the least amount of curvature to be removed which does not need to be flattened out for visualisation.

2.8 MONITORING OF THE WATER SUPPLY DURING THE SITE SURVEYS

A Hydrolab Surveyor II, supplied by Thames Water Utilities plc. was used to monitor the physical and chemical parameters (temperature and oxygen) of the hot water supply. This apparatus consisted of five separate sections: display unit, data cable, battery pack (13.9 V), field data logger and Sonde sample circulator (Fig. 2.0). The Sonde apparatus which housed the electrode probes was connected to the display unit via a data cable in a high pressure housing to measure temperature and dissolved oxygen (DO). The probes were calibrated at Thames Water before being taken out on site. A suitable area next to a water tap was chosen for the apparatus and the probe housing was immersed in the manually controlled water flow coming from this tap, with continual measurement of the parameters. Monitoring of the temperature and DO commenced at about 1700 h and continued until the following morning. The outlet of the cistern tanks was flushed for one minute before measuring the temperature. Five samples (approximately 100 ml) were manually decanted from the tap, immediately filtered and stored at 5°C for assimilable organic carbon (AOC) analysis. The AOC is

the carbon available to the microorganisms for growth and is indicated by ATP determination. The procedure is based upon the principle that the more AOC i.e. nutrients available to the bacteria then the more ATP will be produced with results expressed as units of ATP (equivalent to 10^{-10}g ATP l^{-1}) (Stanfield and Jago, 1987). Analysis of water chemistry and coliform counts were carried out at Thames Water Utilities Plc., New River Head, London.

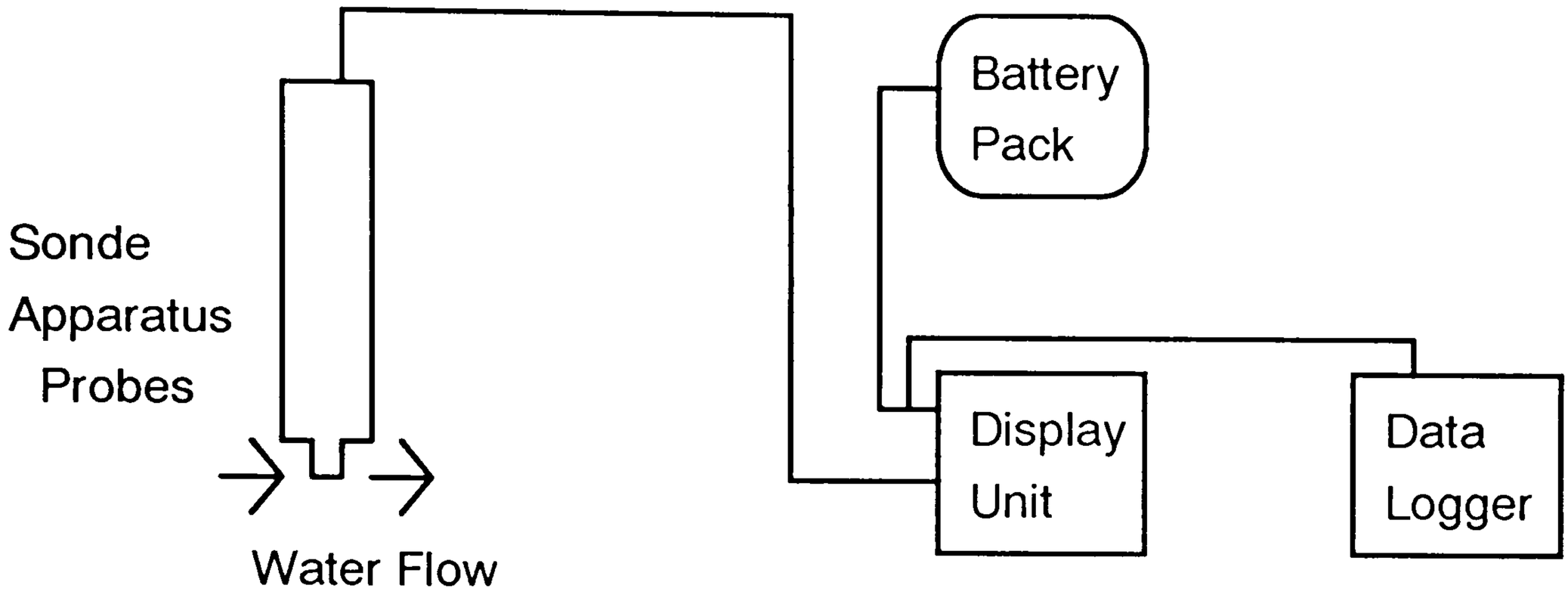


Fig. 2.0 Hydrolab surveyor II which was used to monitor the water parameters.

2.9 EXTRACTION OF COPPER PIPES

Approximately 0.5 m of copper tubing was selected for removal from the area of the building where monitoring was to be carried out. A 1 l sterile container was filled from the tap at the end of the circuit from which the section was to be remove`. The water was then turned off and, after draining, a section of copper tube was cut out. Visual inspection of the internal surface was carried out and the appearance was recorded with a 35 mm camera while the tube was held up to the light. After sealing the tube at one end with sterile endcaps, (sterilised using a portable automatic autoclave, Prestige, UK) the tube was filled with water from the 1 litre sterile container, sealed at the other end and stored at 5°C before being transported back to the laboratory.

2.10 ANALYSIS OF THE COPPER PIPING DURING THE SITE SURVEYS

In the laboratory, the copper pipes were placed in an anaerobic cabinet maintained with 80% N_2:10% H_2:10% CO_2, to prevent injury to any facultative or obligatory anaerobic bacteria present in the biofilm. A sample of the water phase from the pipe was used to quantify the planktonic bacteria and approximately 1 cm^2 of the surface was aseptically scraped for the detection of anaerobic bacteria in the biofilm. Aerobic diluents were also prepared for the detection of aerobic bacteria. Where appropriate particular tubercles were removed with 6M HCl, then rinsed in sterile distilled water before observing the surface for the characteristic pepper pot pitting. Sections of the copper tube were also taken for SEM analysis.

2.11 CHANGE FROM CONTINUOUS CULTURE TO BATCH CULTURE

Following the aseptic extraction of copper coupons from the vessel at 60°C the effluent from vessel one at 30°C was diverted such that it did not act as a seed for vessel 2 which was still supplied with sterile media. The number of planktonic bacteria (per ml) present in vessel two, in batch mode, was then monitored over a 5 day period.

2.12 MICROSCOPICAL EXAMINATION OF BIOFILMS AND PLANKTONIC POPULATIONS

Aliquots of 9 ml were aseptically extracted from each vessel, to which was added 1 ml of a 0.2 % stock solution of 2-(p-iodophenyl)-3-(-p-nitrophenyl)-5-phenyltetrazolium chloride (INT) (Fluka Ltd, UK) in sterile distilled water, final concentration of 0.02%, and incubated at 30°C for 1 hour. After incubation the suspension was stained further

with a 1 ml aliquot of 0.2% stock solution of acridine orange (AO, Sigma, UK) (final working concentration of 0.02%), in sterile distilled water and after 2 minutes was filtered through a 47 mm, 0.2 μm polycarbonate membrane (Nuclepore, UK) using a buchner funnel and drawn through using a hand vacuum pump (Nalgene). Both stains were pre-filtered through a 0.2 μm filter (Sartorious) prior to use. The filter was then microscopically examined in the fluorescence mode to count bacterial cells whose DNA and RNA had stained with AO. The filter was also examined in transmission mode to count those metabolically active cells which had reduced the INT dye to a red insoluble dye, visible within the cell. Up to 10 fields were counted per mode to obtain average counts. An example of the calculation is shown below:

Number of bacteria = number in field of view x area of filter / area of field of view

Area of filter = πr^2

Diameter of working area of filter = 37 mm

i.e. radius = 18.5 mm

= 3.14 x 18.5 x 18.5

= 1075 sq. mm

Area of field of view (x150) = πr^2

Diameter of field of view = 100 μm

i.e. radius = 50 μm

= 3.14 x 50 x 50

= 7853 μm or 0.00785 sq. mm

Number of bacteria (per filter) = average number in field of view x 1075 / 0.00785

= average number in field of view x 136942

The result can then be calculated to obtain the number of bacteria per ml.

2.12.1 Conventional light microscopy (adapted)

Microscopical examination of the filters was carried out using a Nikon Labophot-2 which combines both epi-fluorescence and differential interference contrast (DIC) (Fig. 2.4). A B-2A filter block was used for the epi-fluorescence. This has a 510 nm wavelength dichroic mirror, an excitation filter of 450-490 nm wavelength and a barrier filter of 520 nm wavelength. An IGS (immuno-gold system) block was used for DIC. The objective lenses were non-contact M Plan Apo lenses of 40 (0.5 numerical aperture, NA), 100 (0.8 NA) and 150 times (0.95 NA). Light source was a 100 W halogen lamp. Neutral density filters were used where necessary to suppress high background fluorescence. Fig. 2.5 demonstrates the route of image processing of samples.

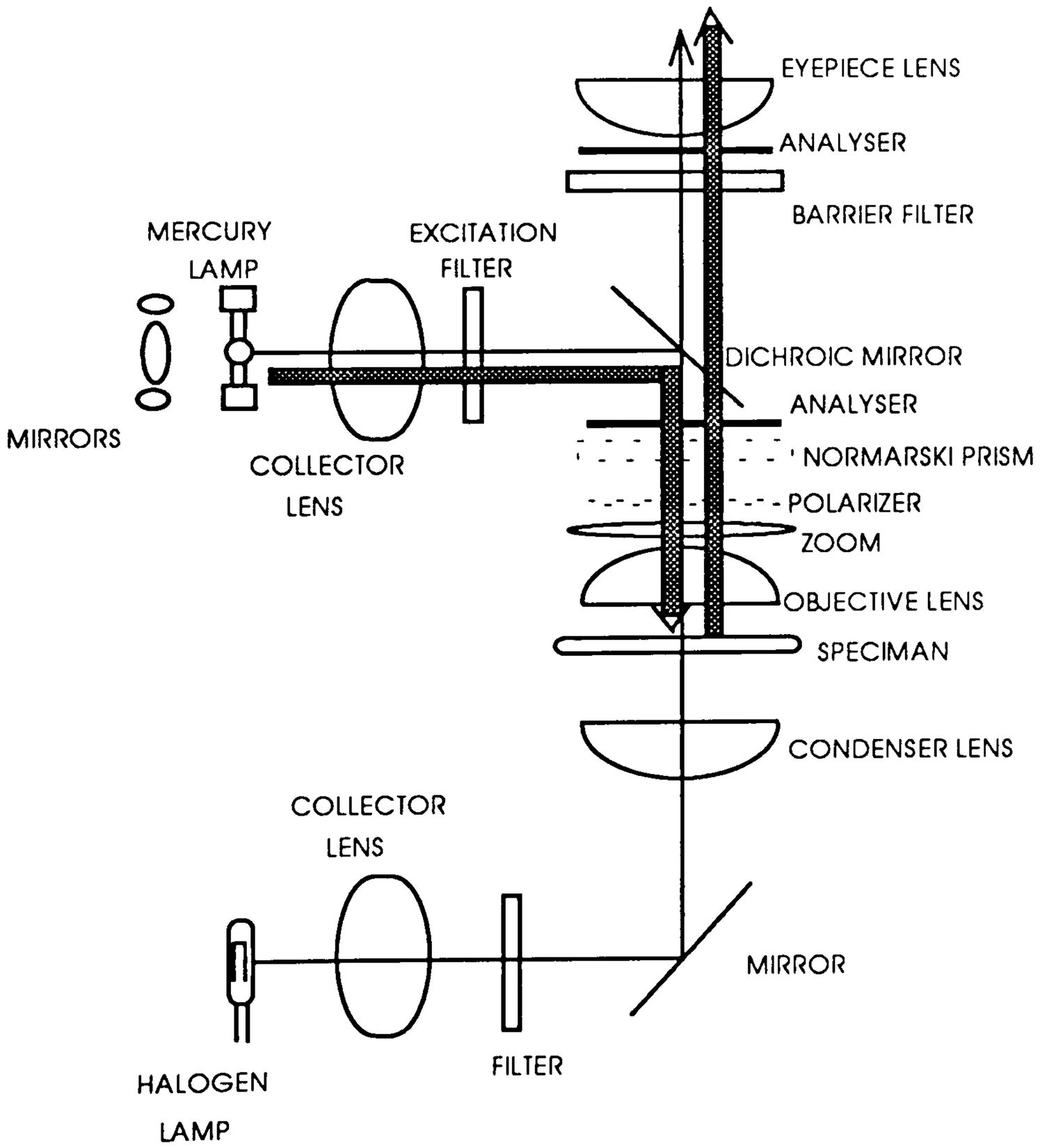


Figure 2.4 Schematic of adapted light microscope which consists of a conventional light microscope with episcopic UV fluorescence and DIC. Adaptations include; siting

of the polariser above the specimen (allowing opaque specimens to be viewed); enlarging the filter block housing to accommodate four filter blocks and mirror plates in the mercury lamp housing to increase the signal output.

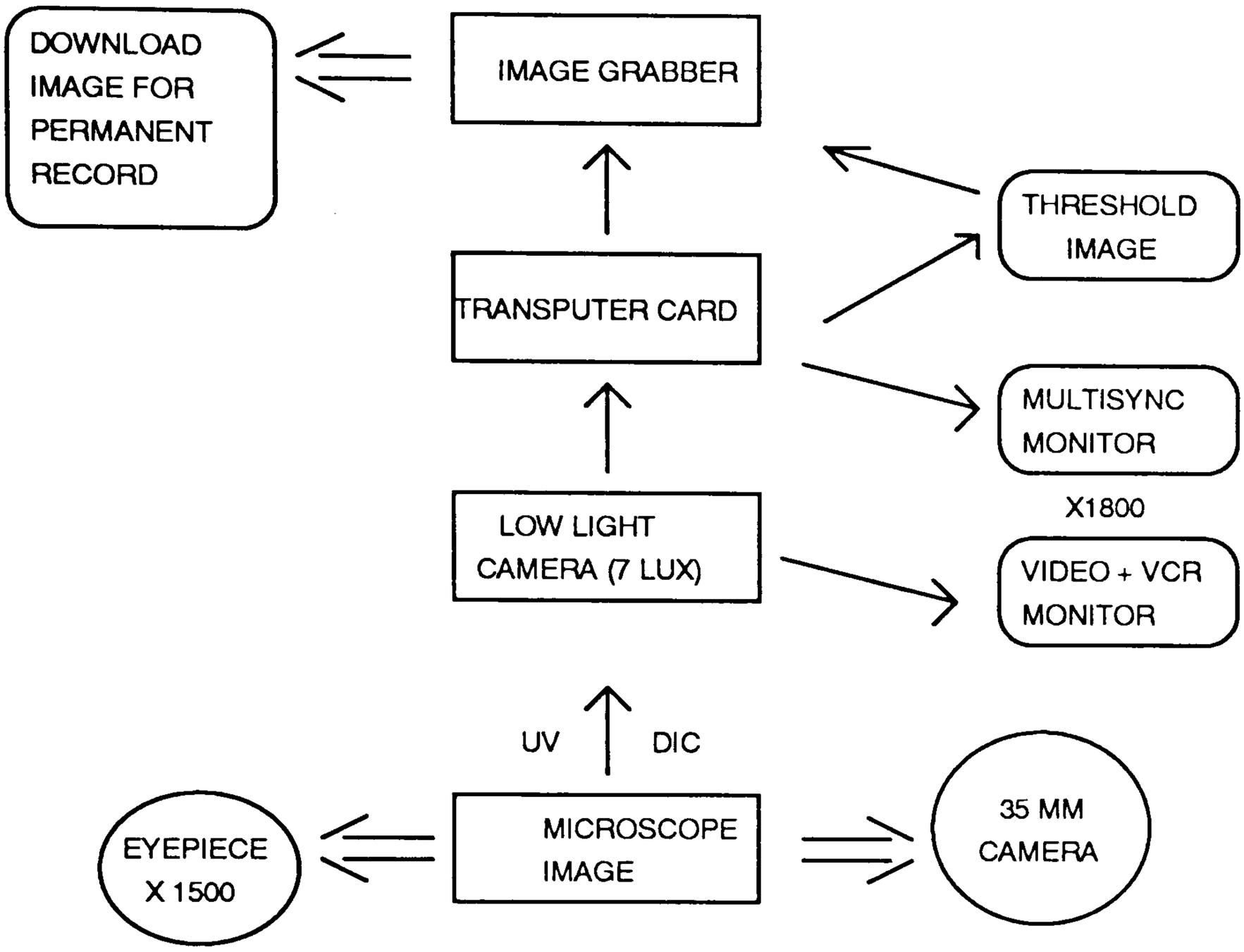


Figure 2.5 Process of imaging samples through the microscope.

2.12.2 Scanning Electron Microscopy (Traditional Preparation)

The glass and copper coupons were immersed into 30 % absolute alcohol immediately after being taken from the laboratory model. After 15 and 30 min they were placed into 50% and 70% absolute alcohol respectively. Following immersion in 90% absolute alcohol (45 min) the coupons were placed in osmium tetroxide (5%) (BDH) for two hours before being placed into a dessicator. After transportation to the SEM suite, the coupons were gold sputtered before being viewed in a Cambridge SEM. Sample sputtering and image processing were carried out at CAMR by A. B. Dowsett. As the magnification of each print was known, a square template was cut out, allowing the number of bacteria within each print and so on each tile to be calculated. At least

10 areas were enumerated to obtain a mean value which was multiplied by the magnification resulting in the number of bacteria per cm^2.

2.12.3 Scanning Electron Micrography (Cryogenic Freezing Unit)

Samples of the copper tube were sectioned and maintained hydrated in a petri dish. An XL40 with cryogenic unit (Philips) based at Thames Water Utilities plc., Reading was used to examine the samples from the copper tube under the supervision of Dr. K. Colquohoun. The copper tube samples were then individually attached to an SEM sample holder in the transporter pot using SEM adhesive. The nitrogen slushing chamber was evacuated and a slush prepared by allowing the nitrogen to solidify. When gas was admitted, the end cap was removed before immersing the sample into the nitrogen slush. After freezing, the sample was placed into the microscope observation chamber via the transporter pot and sputter coated for 2 min at 1 mA with gold in an argon plasma. The specimen was then viewed.

2.12.4 Environmental SEM (ESEM)

The ESEM based at the Medical School at the University of Manchester is a fully integrated general purpose microscope and the samples were investigated under the supervision of Dr. Nick Long. A four-stage differential pumping system in the electron-optical column allows the entire specimen chamber to be maintained at gas pressures higher than those permitted in conventional SEM. Chamber pressure was maintained steady by means of a fully automated electronic pressure servo system enabling pressures between 1-50 torr.

Within the chamber low energy secondary electrons from the beam impact on the specimen surface and are accelerated towards the detector electrode by a moderate

electric field. The secondary electron detector is based upon the principle of gas ionisation. Successive collisions in the ambient gas molecules liberate more free electrons, resulting in a proportional cascade of current within the gas phase, where positive ions serve to effectively neutralise the destructive buildup of excess electron charge at the specimen. Image analysis of the results was carried out as below.

Images captured via a colour video camera (JVC TK-1085E) were then relayed via a 0.4x wide field lens to the Microeye TC image analysis transputer card and software (Digithurst, Royston) operated under the Windows 3 (Microsoft) environment on a PC 386 compatible computer (Elonex, London) (Fig. 2.5). The photographed images were relayed to a multisync monitor (Taxan 775; capable of automatically switching between non-interlaced and interlaced modes when the appropriate signal is recognised) for image analysis. Each grabbed image was framed with an 8 cm x 7 cm box on the screen to allow for analysis of a constant area. A threshold limit was set up to allow the soft are to identify biofilm against copper and a field and object scan carried out.

2.12.5 Scanning Confocal Laser Microscopy

Two vessels were assembled as in section 2.5, page 51. Copper coupons were prepared as in section 2.7, page 58, and immersed into both vessels such that a comparison could be obtained from the presence or absence of particulate matter. The coupons were removed from the vessels at 12 months old. Coupons were prepared in duplicate. One set were removed from the bung assembly and placed on hydrated tissue in a sterile petridish which was then sealed with parafilm to prevent leakage of water. The second set remained on the tile assembly which was put into a universal and sealed with parafilm such that the coupons would remain moist.

2.12.5.1 Scanning confocal Laser microscopy procedures

An MRC-600 (Biorad, Ltd.) scanning confocal laser microscope, located in the Biology department of the University of Saskatchewan, Saskatoon, Canada was used to analyse the biofilm samples and was supervised by Keith Hanson. The MRC-600 was fitted with an argon laser, maximum emission at 488 nm and excitation at 514 nm wavelength, and was mounted in the upright position above an optical light microscope (Microphot SA, Nikon ltd). The images from two different fluorescent markers were imaged simultaneously using an excitation filter and dichroic (DC) mirror to direct the image to either photomultiplier (PMT) 1 or 2 (Fig. 2.6). These filters could be changed without disrupting the optical alignment of the microscope thus allowing imaging of a single field of view under different spectral conditions. Facilities included a z-axis stepping motor providing precise increments of 1/1000 revolutions or multiples, essential for accurate optical sectioning using the aplano oil objective lenses. Images were relayed to a 486 processor in an IBM PC/AT compatible desktop computer where they were integrated and digitised with a Kalman true-running-averaging filter. To visualise the surface of the copper tube, fluorescein (0.1%) was used as a negative stain. Bacteria were stained with either FITC or RITC. For fluorescein, imaging optical filters with a 488 nm and 510 nm wavelength were used, while for rhodamine imaging the 514 nm and 580 nm wavelength beam splitter were used. As an indicator of pH, 5-(and-6)-carboxy-2',7'-dichlorofluorescien (Molecular Probes, USA), was used as the excitation and emission wavelengths decrease due to acidification and would therefore indicate metabolic activity within the biofilm. In this procedure RITC was used to stain protein on the bacterial cell wall to complement the corresponding image of the pH indicator. The images were not subjected to any form of restoration e.g. nearest neighbour, delinear or non-linear deblurring methods.

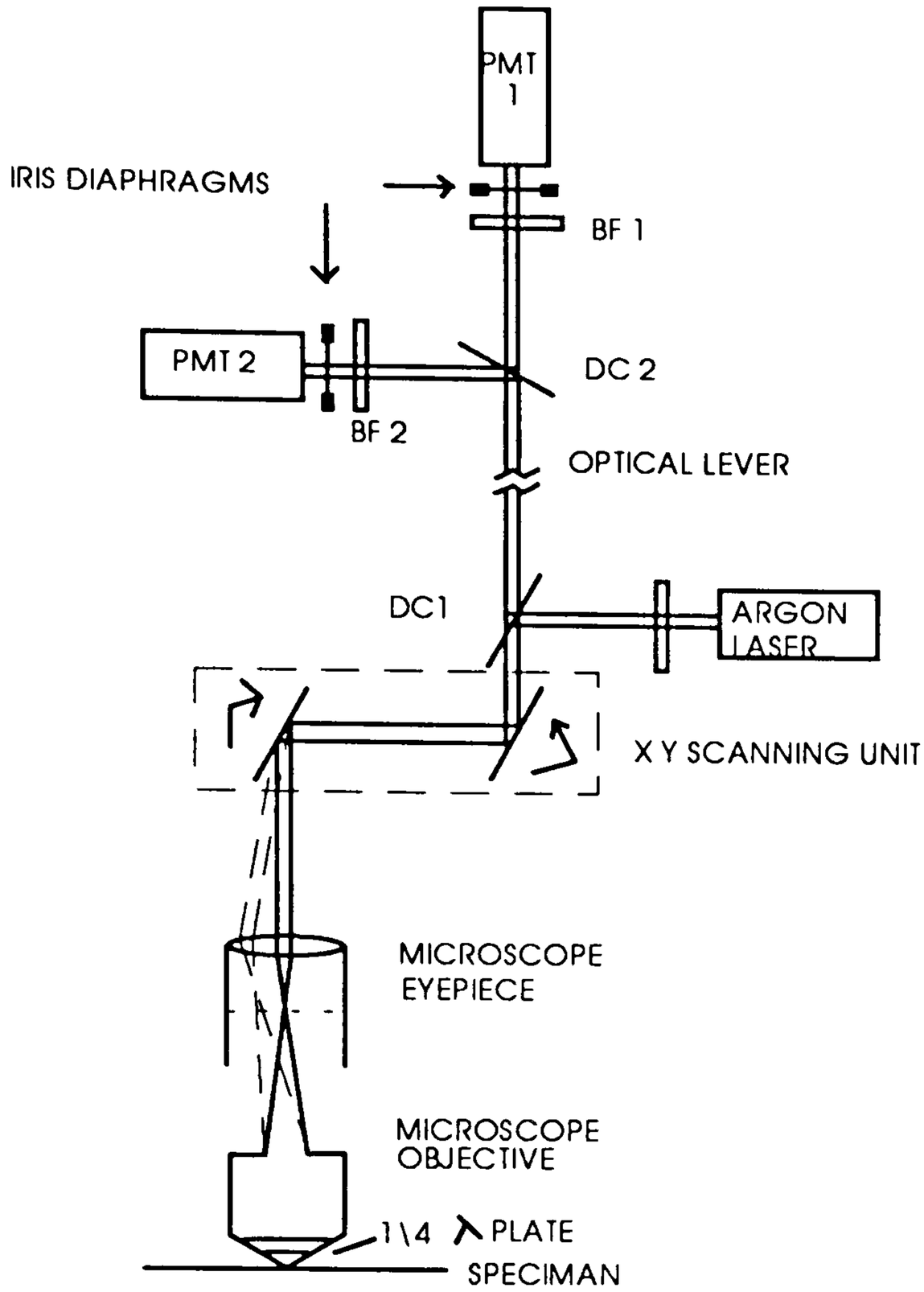


Figure 2.6 Simplified diagram of the confocal laser light path exhibiting both photomultiplier tubes PMT and dichroic mirrors (DC).

2.13 STATISTICAL ANALYSIS

All standard plate counts were carried out in duplicate and the mean reported. Biofilm counts were enumerated from one tile, however, periodically three coupons of the same material were analysed to ascertain the reproducibility of the technique. In all cases the errors were found to be not greater than 10% of the mean value.

The following criteria were met in order for the Wilcoxon Signed Rank Test to be used and so other tests were excluded.

a) Looking at a difference between two experimental conditions.

b) Each subject in one condition matched with a subject in the other condition.

c) There is an interval scale of measurement.

d) Data for the two groups were not normally distributed.

The Wilcoxon Signed Rank Test has been utilised for testing for significance of difference between two samples which are related. For this test each subject or pair are subtracted from the other, giving a d value which is then ranked. The ranks are then summed resulting in a T value. With the use of statistical tables the T value can be looked up to obtain the probability (p value) and if the T value is less than or equal to the value given in the table then it is significant at that particular level.

CHAPTER 3

HOSPITAL SURVEYS

3.1 INTRODUCTION

An unusual form of corrosion in copper pipes in domestic water circuits has occurred since the 1980's, resulting in pitting and perforation of copper tube in such diverse areas as Scotland, Saudi Arabia and West Germany. This unique problem could not be explained simply in terms of chemical corrosion per se and suspicion has fallen on the possible involvement of microorganisms. In central Scotland the water systems of three hospitals had been identified as being affected by this unique form of corrosion. The Glasgow Evening Times (18 June 1987) reported that corroded pipes in two of the hospitals may cost as much as £3 million pounds to replace. Moreover, the escape of aerosolised water sprays through perforated tubing could pose a potential health risk, particularly if *Legionella* spp. are present in the water or able to grow in biofilms (Colbourne & Dennis, 1988; Keevil *et al.* 1988) adjacent to the perforations. Even in the absence of such pathogens, aerosolised aquatic bacteria may be involved in processes giving rise to humidifier fever and other lung infections. Growth of individual bacterial species form complex microbial consortia and the development of biofilms is markedly affected by the local environment, including changes in nutrient availability, pH, temperature, oxygen concentration, redox potential and metals concentration (Ellwood *et al.* 1982; Keevil *et al.* 1987, 1988; Glenister *et al.* 1988). Biofilm which is resistant to the toxic effects of copper may well harbour and protect potential pathogens which are normally inhibited by this metal (Burns *et al.* 1967; Gadd, 1992; Bitton and Feihofer, 1978; States *et al.* 1985).

Initially it was suggested that the copper corrosion was caused by the water supply but this was refuted by the water companies who suggested that the problem was due to tubes provided by the copper pipe fabricators. In view of the economics of replacing copper piping, estimated at £3M, the problem had to be investigated and it was the copper tube manufacturers who addressed this particular enigma of pepper pot-pitting of copper tube. In 1987 they commissioned a survey with the remit to investigate the

water supply, condition of the copper pipe work and to obtain an inoculum with which to initiate the laboratory model (Keevil *et al.* 1987). Following discussions with the appropriate authority (Scottish Office for Health) access was gained to two hospitals in 1987, the Victoria Infirmary and the Glasgow Royal Maternity, where this unusual form of corrosion was occurring, primarily in the hot water circuit. The strategy of the site survey was to investigate the water chemistry and microbiology of the water, at the inlet and at various locations in the hospital through to the faucets of the hot water supply. The temperature and dissolved oxygen profiles of the hot water were monitored continuously overnight with periodic samples taken to assess the assimilable organic carbon (AOC). AOC is one of the limiting factors for heterotrophic bacterial growth and so is at least in part responsible for bacterial proliferation (Ribas *et al.* 1991; van der Kooij *et al.* 1982; Stanfield and Jago, 1987). Copper tubing was also removed to be examined for the presence of microorganisms and corrosion on the internal surface. The inoculum for the laboratory model was obtained from the Victoria Infirmary and water from this particular hospital was also utilised in the laboratory model to simulate the environmental conditions under which the copper tube failures were occurring.

In February 1989, the Victoria Infirmary was revisited along with the Inverclyde Hospital in Greenock, Scotland where this form of corrosion had also been observed. As a comparison, in February 1989, visits were arranged to two institutional buildings on the East coast of Scotland where the problem had not been reported, the Eastern General, Edinburgh and the Stratheden Hospital, near Cupar in Fife. The main objective of this survey was to monitor the water parameters overnight for changes in the temperature, dissolved oxygen and assimilable organic carbon as well as to carry out microbiological analysis of the water and pipe surface.

3.2 MATERIAL AND METHODS

In each of the hospitals, the water supply parameters such as temperature and dissolved oxygen concentration were monitored over night, with water samples taken for assimilable organic carbon, chemical and microbiological analysis (standard plate counts) of the water at various locations in the buildings as detailed in sections 2.`8 and 2.9 (pages 62 and 63). Sections of copper pipes were identified for removal for microbiological analysis (standard plate counts) and visualisation of corrosion using light and scanning electron microscopy as detailed in section 2.12 (page 67).

3.3 RESULTS

3.3.1 First site survey, 1987

3.3.1.1 Site A Victoria Infirmary

This hospital site was supplied with mains water from Loch Catrine in the Trossachs area, north of Glasgow. The continuous monitoring equipment was positioned in the outpatients department which received hot water via a recirculating loop from a calorifier maintained at 45°C. This calorifier was supplied with water at 9.9°C and pH 9.2 from a storage cistern which was in a very poor condition due to the absence of a cover. It had a storage capacity of 3000 gallons with a surface area of 130 square feet. A plank of wood had been placed along the top of the tank to allow passage across it and the paint on the ceiling above the tank was observed to be flaking and peeling.

(i) Continuous monitoring of the temperature, oxygen and AOC of the hot water supply

The incoming water supplying the cistern tank had an AOC of 7.4 (ATP x 10^{-10} g l^{-1}, defined as units of ATP) but in the tank itself the AOC was recorded as 12.4 units of ATP. The amount recovered from three different taps downstream of the calorifier varied between 4.8-7.8 units of ATP. When the temperature was monitored overnight it was initially at 52°C and fluctuated between 38-58°C until 20.30 h and 38-41°C thereafter until 07.00 h when it increased to 53°C (Fig. 3.0). The dissolved oxygen was between 7-9 mg l^{-1} up to 19.00 h after which, less than 0.5 mg l^{-1} was recorded. At 06.30 h the DO increased back to 8 mg l^{-1}.

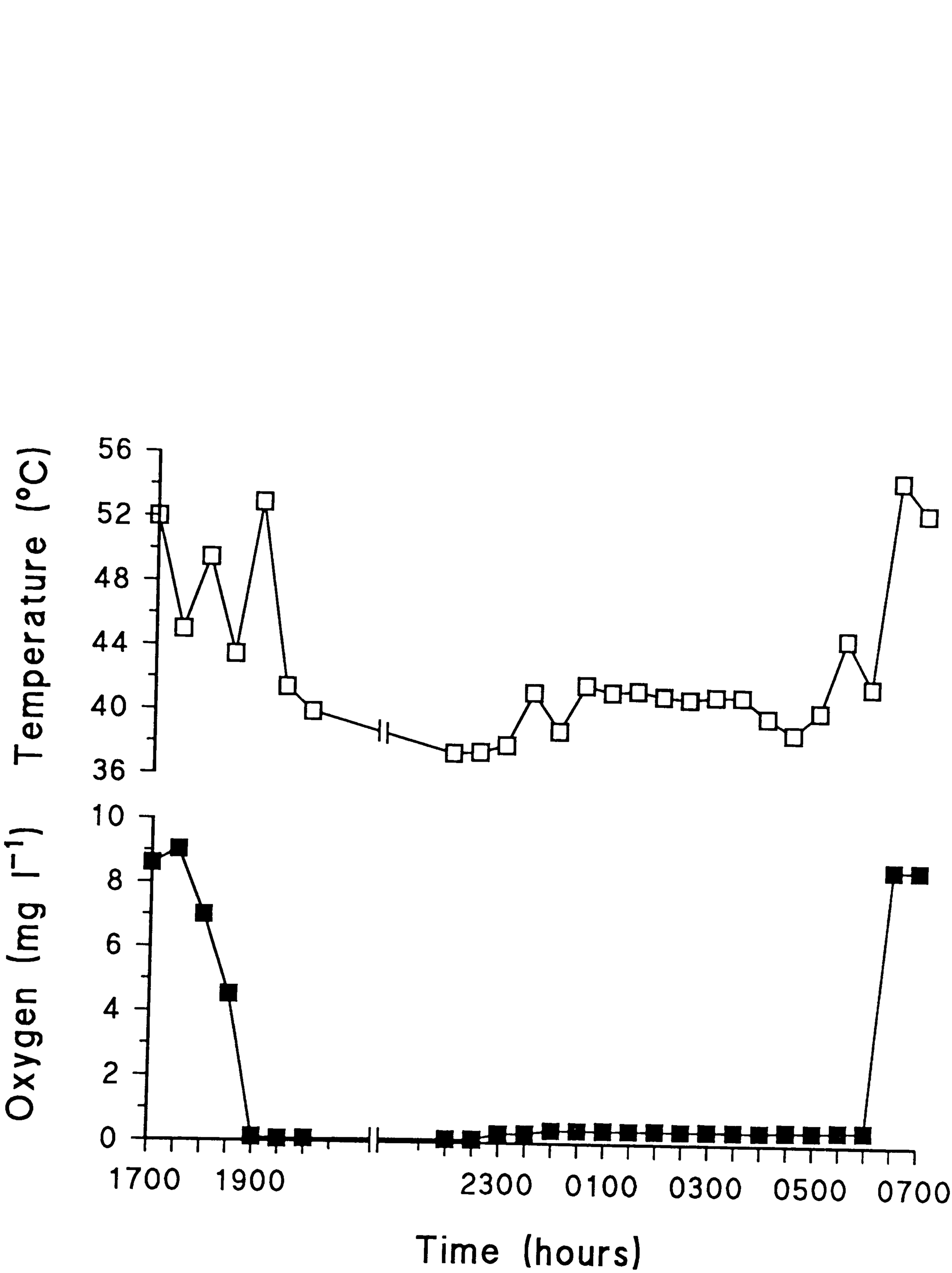


Figure 3.0 Continuous overnight monitoring of the temperature and dissolved oxygen profile during the first site-survey at the Victoria hospital in 1987.

(ii) Internal examination of the copper tubing

Copper tubing (approx. 0.5 m), approximately 100 m from the calorifier, was removed from the hot water circuit of the Outpatients department. Externally the tubing was covered in copper corrosion deposits and the lagging when removed was wet indicating that perforations had occurred in this section. Internally a large number of tubercles were present on the surface (Fig. 3.1). The water from inside this pipe contained black deposits.

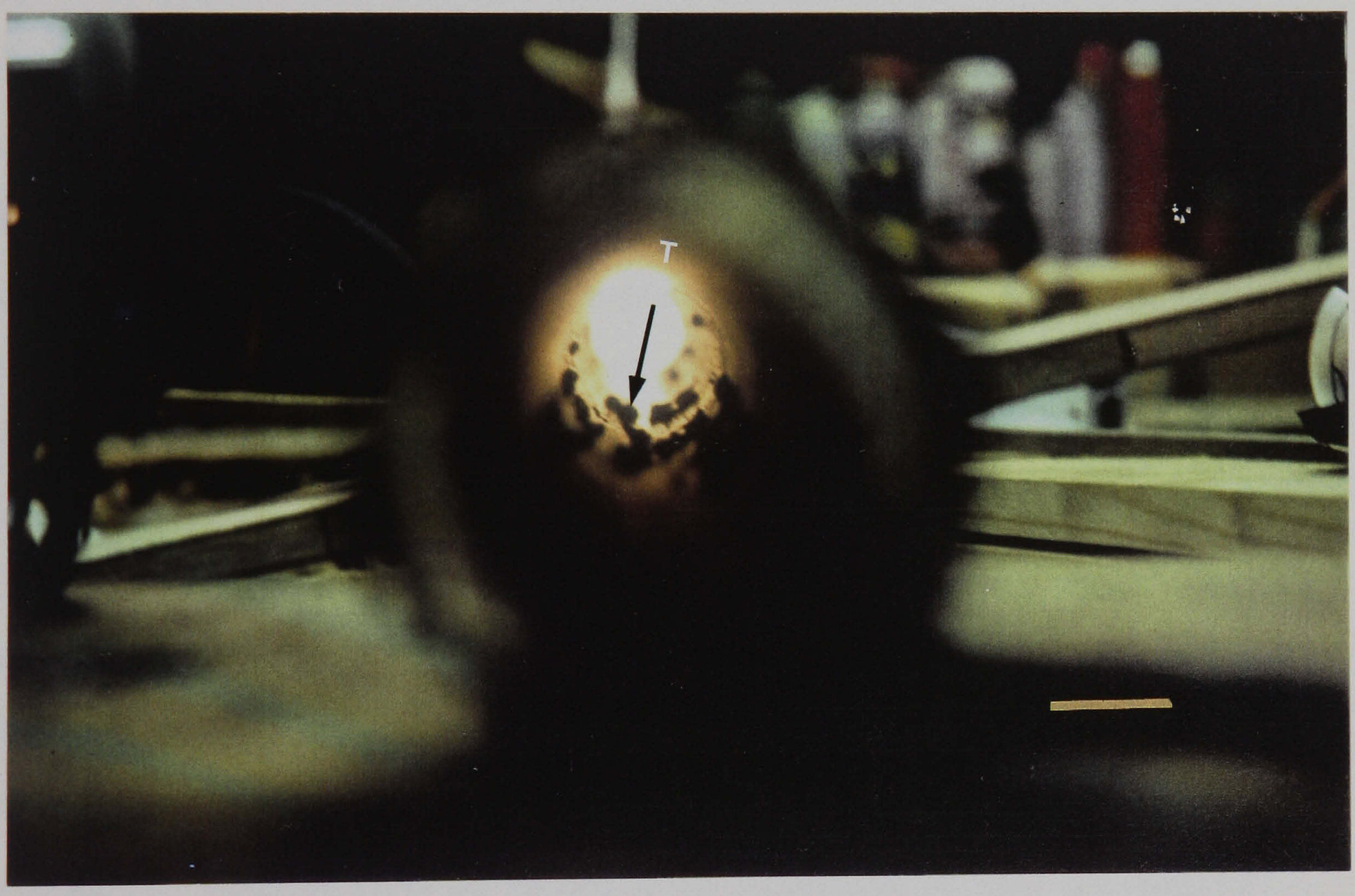


Figure 3.1 View of the internal area of the copper tube removed from the Victoria hospital outpatients department during the first site survey in 1987 (Marker bar denotes 10 mm and T denotes the position of the tubercles).

(iii) Microbiological analysis of the water and copper tube surfaces

The general microbiological condition of the source water was bacteriologically satisfactory with only 280 cfu ml^{-1} recovered from the water which was at 9.9°C when it entered the building (Table 3.0). The temperature of the source water was stored at 10°C in the cistern tank where the number of bacteria recovered by standard plate count procedure was 500 cfu ml^{-1} with only 1.0×10^3 cfu ml^{-1} recovered from the first hot tap from the calorifier. However, 5.0×10^7 cfu per swab and 1.0×10^7 cfu per swab, respectively, were recovered from one of the walls and a copper ballcock in the holding tank (Table 3.1, page 83). From the tap in the nurses home where the monitoring apparatus was positioned only 1.0×10^3 cfu ml^{-1} were recovered from a water sample however 5.0×10^7 cfu per swab were recovered from the tap surface. Although fungi were only recovered from the tank, sulphate-reducing bacteria were recovered from all the cistern and hot water samples tested. Chemical analysis (Table 3.2, page 84) was carried out on water samples from several different sites, such as the first hydrant coming into the building, cistern tank, first tap off the calorifier and two other hot taps down stream of the water circuit. The colour of the water entering the building was slightly brown at a value of 13 Hazen units and remained so throughout the water system. Initially the pH was 9.3 but decreased at each site down to 7.6. Similarly the amount of solids present decreased at each sample site from 81 mg l^{-1} to 37 mg l^{-1}. All other chemical parameters remained relatively constant apart from iron which increased from 64 to 332 μg l^{-1}, copper from 10 to 332 μg l^{-1} and zinc from 12 to 25 μg l^{-1}. Visualisation of the surface of the copper pipe by SEM demonstrated that the thick slimy layer on the surface was composed of biofilm material (Fig. 3.2). Organisms recovered from the surfaces included *Methylobacterium* spp., *Alcaligenes* spp., *Flavobacterium* spp. and *Pseudomonas* spp., fungi and sulphate-reducing bacteria.

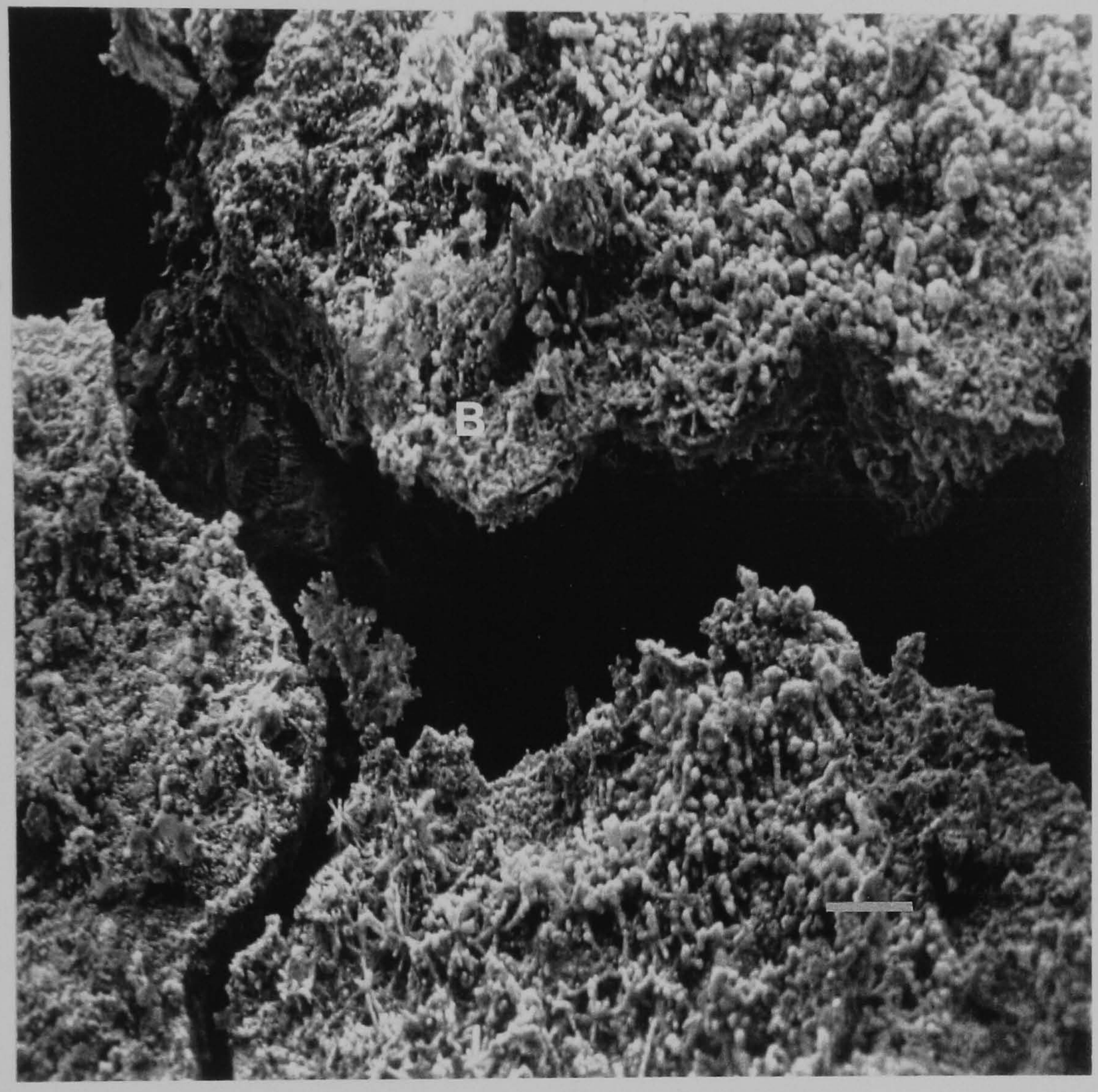


Figure 3.2 SEM of the surface of the copper pipe removed from the Victoria Infirmary during the first site survey in 1987 (Marker bar denotes 10 μm and B denotes the biofilm layer).

Table. 3.0 Microbiological analysis of the sample sites during the first site-survey at the Victoria Hospital.

Site A I Victoria Infirmary

	Hydrant	Tank	Tank Sediment	1st tap	Site 1	Site 2
Gram negative spp.[1]	280	500	nt	1000	1000	80
Legionella spp.[1]	0	0	0	0	0	0
Fungi[2]	2	7	2	0	0	0
SRB[2]	1	6	0	10	6	5
AOC[3]	7.4	12.4	nt	4.8	7.8	5

No coliforms or *Pseudomonas aeruginosa* were detectable. [1] denotes cfu ml^{-1}: [2] denotes cfu per 100 ml and [3]denotes units of ATP: 1st tap (of calorifier): Site 1 was a sample obtained from the hot tap obtained from the outpatients department and site 2 was a sample taken from a hot tap in the nurses home: nt denotes not tested.

Table 3.1 Comparison of the number of bacteria recovered from swabs and water samples from various sites at the Victoria Infirmary, Glasgow.

Sample	Temp (°C)	swab (x 10^7 cfu)	ml^{-1} (x 10^3 cfu)	OGN (%)	Ps.spp (%)	M. spp. (%)
Hydrant	10	nt	0.2	40	40	40
Holding tank	10	nt	0.5	40	40	20
Holding tank (wall)	nt	5.0	nt	40	40	20
Holding tank (Cu ballcock)	nt	1.0	nt	70	20	10
Tap (nurses home)	17-48	5.0	nt	40	40	20
Tap (nurses home)	17-48	nt	1	0	50	50

nt denotes not tested. OGN denotes Other Gram-negative bacteria; Ps. spp. denotes *Pseudomonas spp.*; M.spp. denotes *Methylobacterium spp.*

Table 3.2 Results of the chemical analysis of water sampled at the Victoria Infirmary.

Victoria Infirmary	S1	S2	S3	S4	S5
Temperature (initial)	-	10	23	28	17
Temperature (after flush)	10	-	51	43	48
pH	9.3	8.6	7.8	7.6	7.6
Colour, Hazen units	13	13	13	13	13

mg l^{-1}

Solids	81(81)a	44(44)	50(50)	46(46)	37(37)
Total Organic Carbon (as C)	1.6	1.6	1.6	1.6	1.6
Ammoniacal Nitrogen (as N)	<0.2	0.2	0.2	<0.2	0.2
Carbon Dioxide	0.1	0.1	0.1	0.2	0.2
Total Oxid. Nitrogen (as N)	<0.2	0.2	0.2	0.2	<0.2
Chloride (as Cl)	<5.0	5.0	5.0	<5.0	5.0
Sulphate (as $S0_4$)	3.0	4.0	4.0	3.0	3.0
Sulphide	<0.003	<0.003	<0.003	<0.003	<0.003
$KMnO_4$ oxidisability	2.4	2.6	2.3	1.7	2.4
Reactive Phosphorous (as P)	<0.1	<0.1	<0.10	<0.1	<0.1
Total Hardness as ($CaCO_3$)	<20	<20	<20	<20	<20
Calcium	5.0	4.0	4.0	3.0	3.0
Magnesium	0.60	0.7	0.6	0.6	0.60
Sodium	3.3	3.3	3.3	3.1	3.3
Potassium	0.3	0.3	0.3	0.3	0.3
Dissolved Oxygen	11.1	11.3	12.6	11.7	12.3

$\mu g\ l^{-1}$

Aluminium, Total	33	35	33	39	48
Iron	64(25)	74(35)	139(46)	111(63)	332(67)
Lead	<5.0	<5.0	<5.0	<5.0	<5.0
Manganese, Total	10(<10)	<10	<10	<10	24(<10)
Copper	10(10)	10(10)	139(46)	111(63)	332(67)
Zinc	12(10)	20(12)	10(10)	16(13)	25(13)

Data are expressed as total dissolved plus insoluble concentrations in parentheses. S1 denotes hydrant supply; S2 denotes storage tank; S3 denotes 1st tap off calorifier; S4 denotes hot tap, site one: S5 denotes hot tap, site two; Oxid. denotes oxidised.

3.3.1.2 Site B Glasgow Royal Maternity

This hospital site also received its water supply from Loch Catrine. The water in the cisterns, which had a sealed cover and were relatively clean, was found to be 15°C even though the source water was at 10°C. Two weeks prior to the visit the tank had been cleaned, bitumen painted and chlorinated before re-installing. Water from the first tap off the cistern was measured at 26°C prior to flushing. The cistern tank supplied a vertical calorifier which was thermostatically controlled at 50°C. Water from the base of the calorifier was measured at 27°C, but at the outlet to the hot water circuit the water was measured at 56°C. Sulphate-reducing bacteria and *Legionella bozmanii* were recovered from the unflushed drain; however, after flushing, neither of the above bacteria were recovered.

(i) Continuous monitoring of the temperature and oxygen of the hot water supply

Being from the same source, Loch Catrine, the chemical quality of the water was very similar to that received by the Victoria Infirmary (data not shown). There was no overnight monitoring of the temperature, dissolved oxygen or AOC water at this site.

(ii) Internal examination of the copper tubing

The copper tubing chosen for removal was on the 4th floor of the paediatrics department. The tubing was found to be externally clean and tidy with no signs of corrosion and was reported to have been in service for approximately 30 years. Visual examination showed that there were a few tubercles and only a thin layer of material deposited on the inner surface. (Fig. 3.3). SEM results indicated a relatively thin layer of material present on the surface (Fig. 3.4).

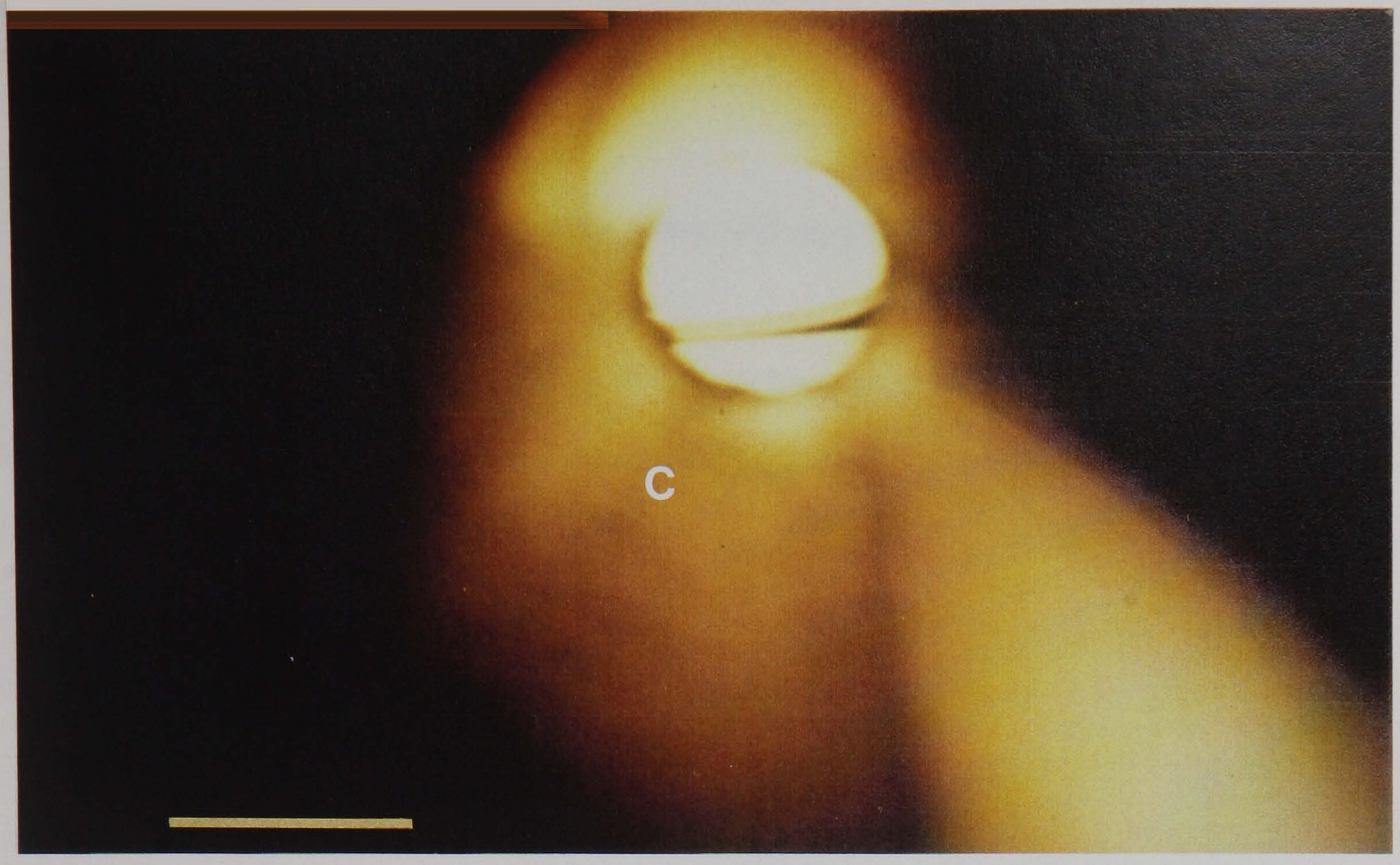


Figure. 3.3 Visualisation of the internal surface of copper tube samples removed from the Glasgow Royal Maternity (Marker bar denotes 10 mm and C denotes the copper surface).

Figure. 3.4 SEM of the surface of the copper tube removed from the Glasgow Royal Maternity (Marker bar denotes 10 μm; C denotes the copper surface and B denotes the biofilm layer).

(iii) Microbiological analysis of the water and copper tube surfaces.

The water examined from the Glasgow Royal Maternity was also bacteriologically satisfactory with no coliform indicators being detected. The number of bacteria recovered from a water sample from the tank was only 50 cfu ml^{-1} (Table 3.3), however 1.0 x 10^8 cfu per swab (Table 3.4) were recovered from the tank wall. Samples taken immediately when the drain valve of the calorifier was opened contained 3.6 x 10^6 cfu ml^{-1} and the temperature was 27°C, however, after the tap was flushed for approximately 1 min it had risen to 56°C with only 1.0 x 10^3 cfu ml^{-1} of bacteria being recovered. From the first hot tap after the calorifier, the temperature was 59°C and only 2.0 x 10^3 cfu ml^{-1} were recovered from the water sample from this tap, however 2.5 x 10^7 cfu per swab was recovered from this tap. The water from the tap furthest from the calorifier in the paediatrics department was recorded at 56°C with only 1.0 x 10^3 cfu ml^{-1} being recovered from the water sample but 5.0 x 10^7 cfu per swab from the tap. Although fungi were present in the cistern and calorifier they were not detected down-stream. The number of aerotolerant microorganisms in the vertical calorifier was only 1.0 x 10^3 cfu ml^{-1} with 600 cfu ml^{-1} of *Legionella* spp. recovered. No SRB were detected in any of the samples from this site.

Table 3.3 Microbiological analysis of the sample sites during the first site-survey at the Glasgow Royal Maternity.

Site B Glasgow Royal Maternity					
	Hydrant	1st tap off tank	Vertical calorifier	1st Tap	Site1 off cal.
Gram-negative spp.[1]	50	50	1000	2000	1000
Legionella spp.[1]	0	0	600	0	0
Fungi[2]	2	12	3	0	0
SRB[2]	0	0	0	0	0
AOC[3]	8.1	3.4	nt	1.4	2.2

No coliforms or *Pseudomonas aeruginosa* were detectable. [1] denotes cfu ml^{-1} and [2] denotes cfu 100 ml^{-1}. [3] denotes units of ATP. 2nd hot tap denotes the tap furthest from the calorifier which was on the 3 rd floor in the paediatrics block: nt denotes not tested.

Table 3.4 Comparison of the number of bacteria recovered from swabs and water samples from various sites at the Glasgow Royal Maternity.

Sample	Temp(°C)	swab (x 10^3cfu)	ml^{-1} (x 10^3cfu)	OGN (%)	Ps. spp. (%)	M. spp. (%)
Holding tank(wall)	15	10	nt	50	30	20
Vertical cal(before flush)	27	nt	3600	75	25	0
(after flush)	59	nt	1	40	40	20
First Hot Tap (after cal)	59	2.5	nt	0	100	0
	59	nt	2	90	10	0
Tap furthest from calorifier	56	5.0	nt	90	10	0
	56	nt	1	100	0	0

nt denotes not tested

3.3.2 Second Site Survey, February 1989

3.3.2.1 Site A, Victoria Infirmary

This hospital was investigated in 1987 (Section 3.2) and was also studied during the second survey in 1989 because the pepper pot-pitting corrosion was still occurring. The laboratory block was chosen as the building in which to operate the monitoring apparatus as this was where copper tube failures were still being reported since the original visit in 1987. The hot water supply came from a calorifier fed by a cistern on the roof of the main hospital. Although the cisterns had been renovated since 1987, they were observed to be in a rather poor condition with badly fitting lids. The cisterns fed a single coal-fired calorifier which dispensed hot water to the whole hospital. As mixer valves were not used on water outlets, the hot water supplied to faucets was maintained at 43°C, as this temperature would minimise scalding of hospital staff and patients.

(1) Continuous monitoring of the temperature, oxygen and assimilable organic carbon (AOC) of the hot water supply.

Monitoring of the temperature, oxygen and AOC (reported as units of ATP) commenced at 17.30 h at a faucet in an office of the laboratory building. Initially the water temperature was 43°C but decreased to 33°C by 20.00 h and then fluctuated between 27-37°C until 05.00 h the following morning before increasing to 45°C at 05.30 h (Fig. 3.5). The water supplying this faucet was found to be highly aerated, containing between 8 - 10 mg l^{-1} of dissolved oxygen. Although the incoming water was found to contain 4.0 units of ATP at 17.30 h this decreased to 1.5 units of ATP at 18.00 h and continued to decrease for the remainder of the monitoring period.

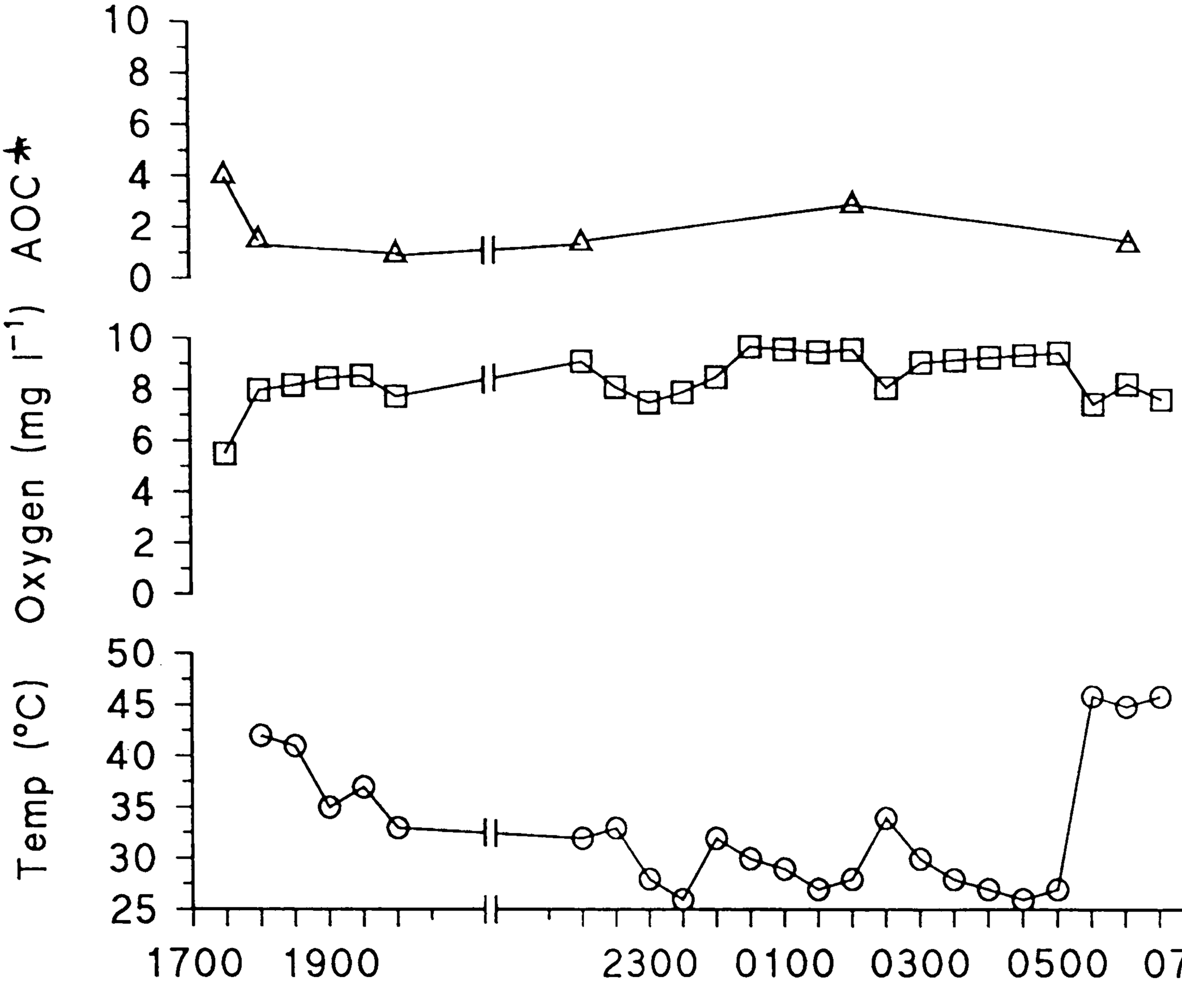


Figure 3.5 Continuous overnight monitoring of the temperature, dissolved oxygen and AOC at the Victoria Infirmary during the second survey in 1989. * denotes AOC as units of ATP.

(ii) Internal examination of the copper tubing.

When the water was extracted from the pipe it was found to contain a large quantity of dark brown flocculate deposits. This soft water was found to have a total hardness of <20 mg l^{-1} (as $CaCO_3$). Sulphides were present at < 0.01 mg l^{-1} and chloride at < 10 mg l^{-1}. The internal surface was covered in a series of tubercles and green copper carbonate which was distributed over the entire surface (Fig. 3.6a). One particular tubercle can be seen in Fig 3.6b and when this tubercle was removed with 6M HCl the characteristic pepper pot-pitting was evident (Fig. 3.6c).

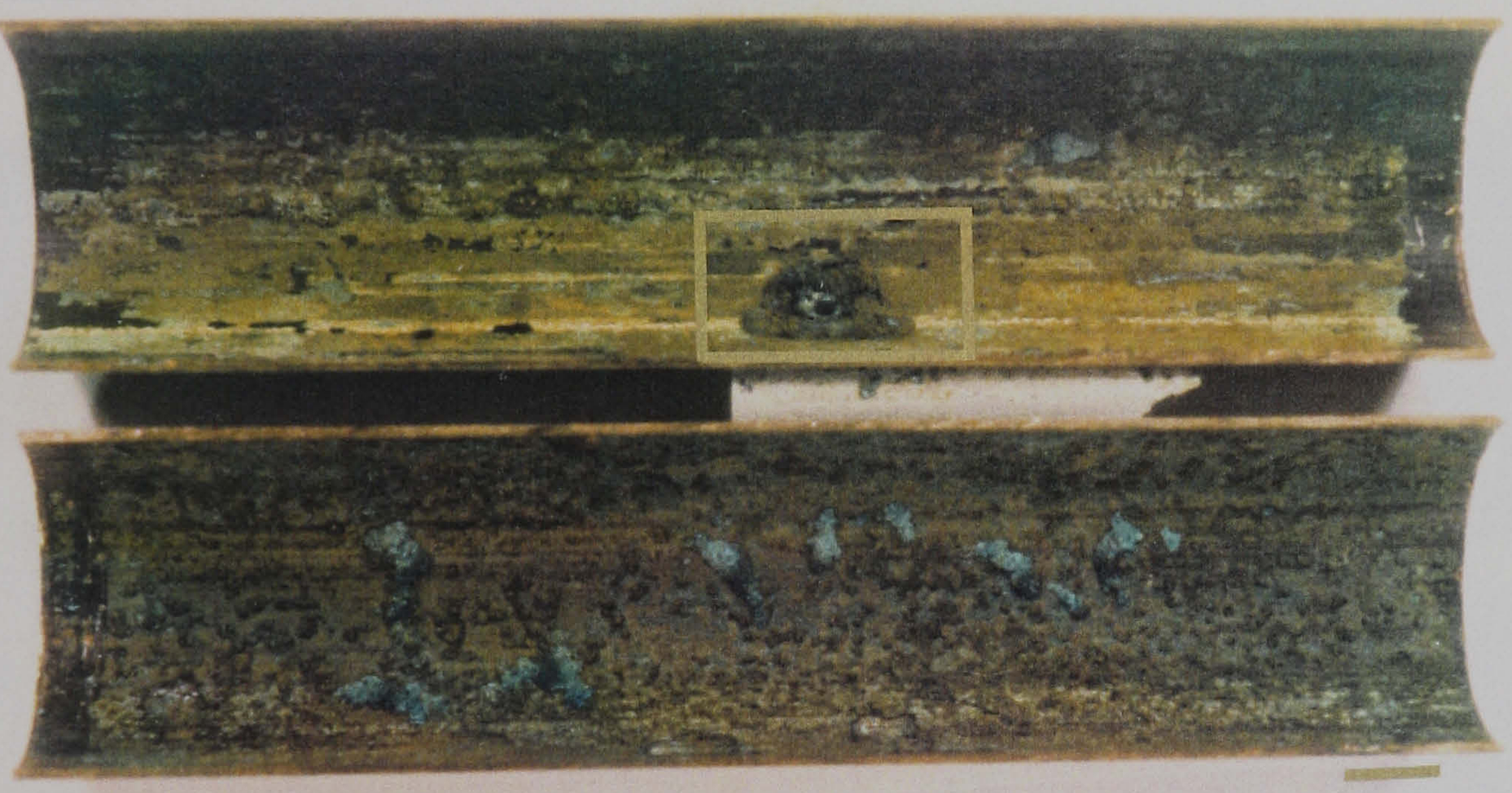


Figure 3.6a The internal surface of a section of copper tubing illustrating green copper carbonate corrosion products (Marker bar denotes 10mm).

Fig. 3.6b A large tubercle present on the copper tube surface as shown in the enclosed area in Fig 3.6a (Marker bar denotes 10 mm).

Fig. 3.6c Exposed view of etched copper surface illustrating pepper pot-pitting corrosion (Marker bar denotes 1 mm; C denotes the copper surface and P denotes the pits).

(iii) Microbiological analysis of the water and copper tube surfaces.

There was a total of 5.4 x 10^4 cfu cm^{-2} from the water that was transported within the pipe section of which the *Pseudomonas* spp. and *Methylobacterium* spp. each represented 5 % with the other Gram-negative bacteria (OGN) being present at 90 % (Table 3.5 and 3.6, page 106/7). From the surface of the pipe section 2.8 x 10^3 cfu cm^{-2} were recovered, however, *Pseudomonas* spp. represented 83 % and *Methylobacterium* spp. 17 % with no OGN being recovered.

3.3.2.2 Site C, Inverclyde Hospital.

Corrosion in this particular site had been reported by the on-site plumbers as being of the pepper pot-pitting type and the number of failures were recognised as significant. Although failures had been reported to be occurring predominantly in the hot water circuit, they had also been cited as the reason for failures in the cold water system. The incoming mains water was sampled from a drain valve in the basement (floor A) and was found to be at 9.4°C, pH 8.4 and DO 8.4 mg l^{-1}. Hot water was produced by direct fire heaters and recirculated round the hospital. No mixer taps were found in this building and the water was maintained at a temperature which would reduce the possibility of scalding of patients and staff. The temperature of the water from the first tap after the direct fire heater was 47°C.

(i) Continuous monitoring of the temperature, oxygen and AOC of the hot water supply.

The monitoring equipment was set up at a hot water faucet farthest from the direct fire heater in level L. Throughout the night the temperature of the hot water varied between 45°C and 50°C (Fig. 3.7). Monitoring commenced at 1700 h when the temperature of the water was 47°C. This then decreased to 45°C at 20.30 h before rising to 48°C at 22.30 h. The temperature was then maintained at 46-48°C until 07.00 h. Initially the oxygen concentration was 8 mg l^{-1} at 17.00 h but by 17.30 this

had decreased to 5 mg l^{-1} before stabilising at 6 mg l^{-1}. By 03.00 h it had increased to 7 mg l^{-1} then steadily decreased to 4 mg l^{-1} until 06.30 h when it increased to 8 mg l^{-1} at 07.00 h. The AOC was initially 6.0 units of ATP at 07.30 and decreased to 1.0 unit of ATP 20.30 h. At 01.30 h it was 8.0 units ATP with 8.5 units of ATP detected at 07.00 h

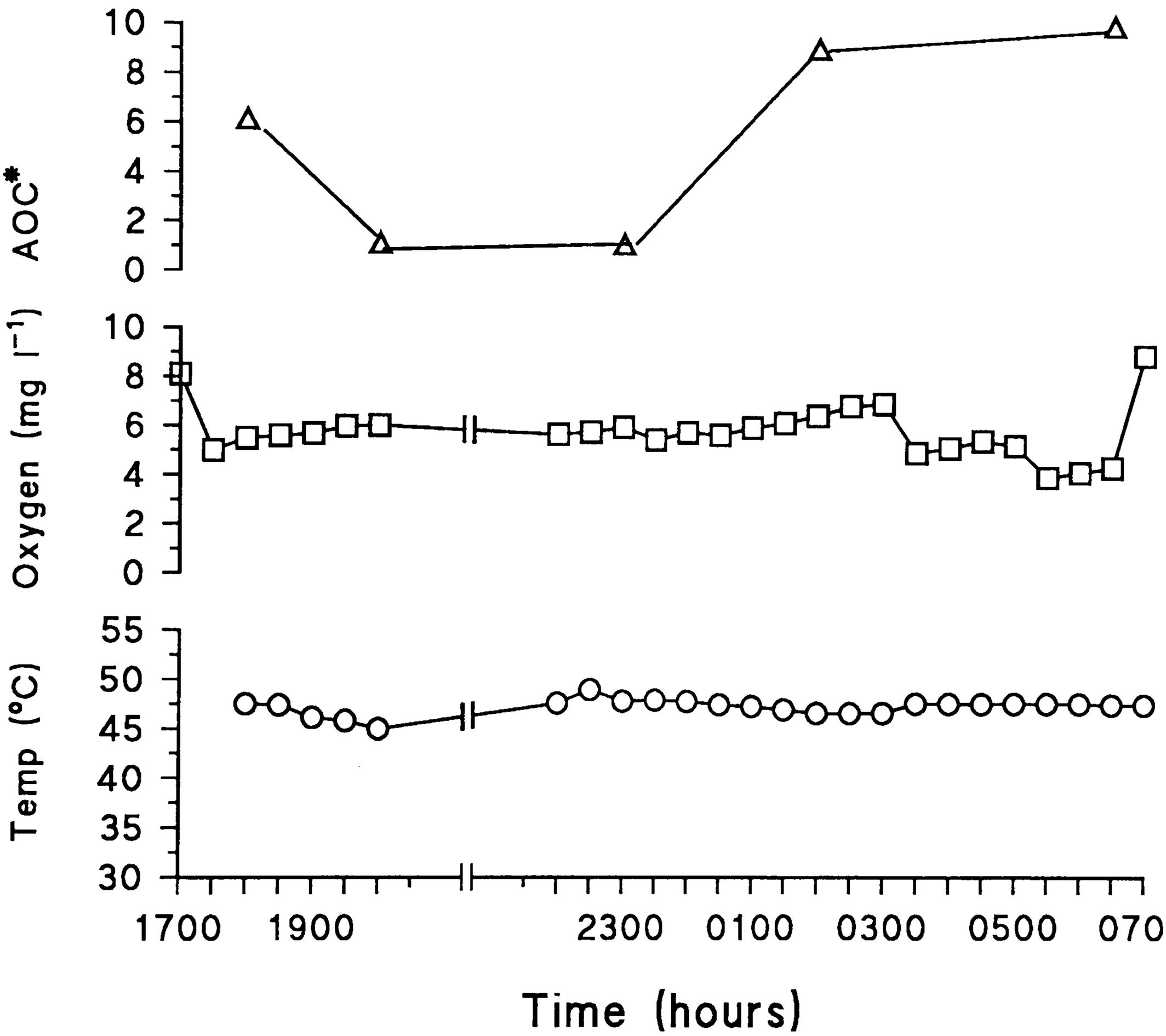


Figure 3.7 Continuous overnight monitoring of the temperature, dissolved oxygen and AOC at the Inverclyde hospital during the second survey in 1989. * denotes AOC as units of ATP.

(ii) Internal examination of the copper tubing.

The inner surface of the pipe which was extracted from a horizontal section of the plumbing of this hospital was completely covered in a thick brown coating which when scraped away exposed the copper carbonate corrosion products beneath (Fig. 3.8). Pitting was not evident on the inner surface of the pipe.

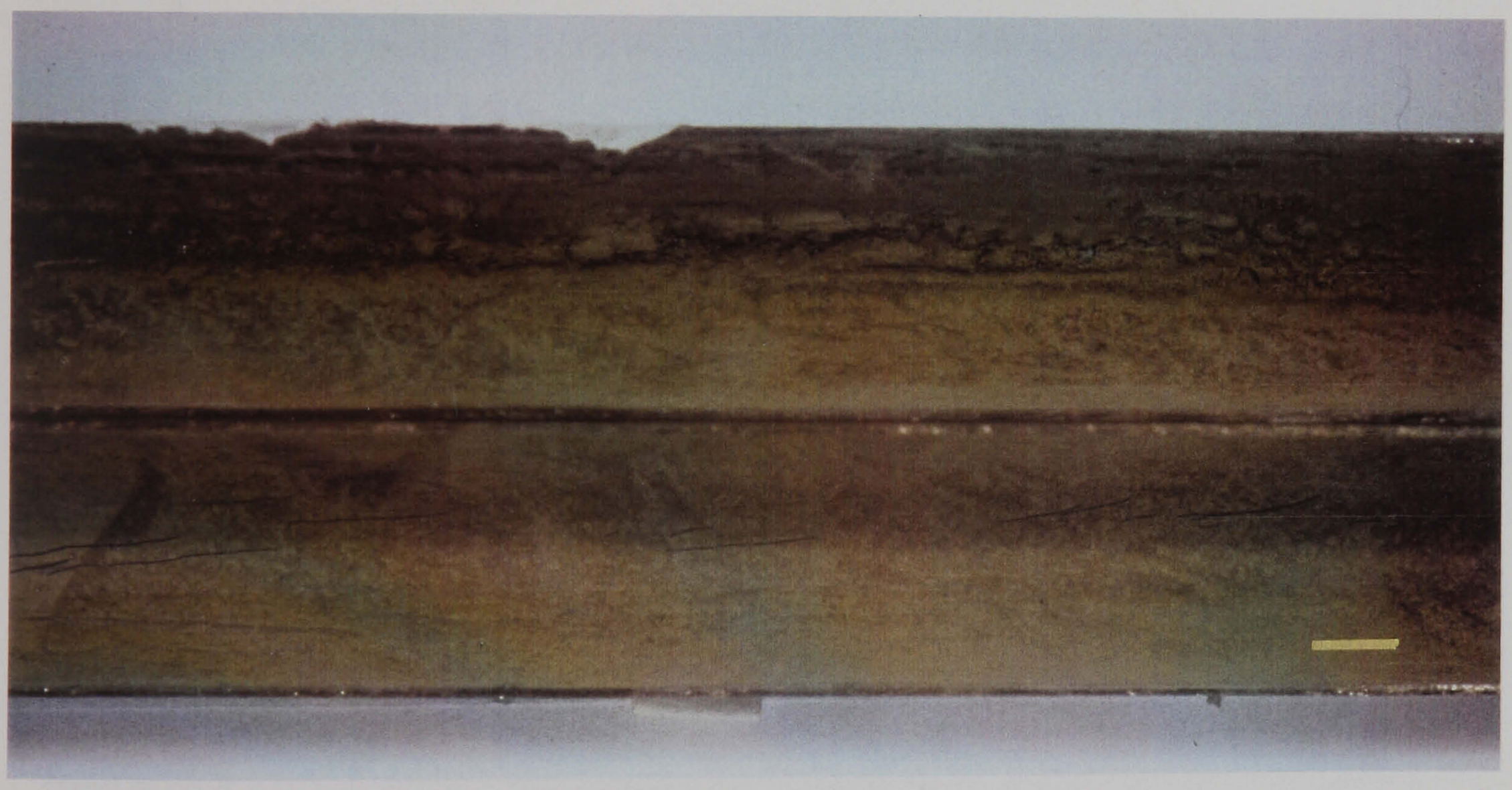


Figure. 3.8 Internal surface of the copper tube removed from the Inverclyde hospital during the second survey in 1989 (Marker bar denotes 10 mm).

(iii) Microbiological analysis of the water and copper tube surfaces.

The water taken from the inside of the pipe from site B contained a large amount of dark brown flocculate deposit. The number of bacteria recovered from the pipe surface and the planktonic phase was greater than 1.0×10^4 cfu cm^{-2} and ml^{-1} (confluent growth from maximum dilutions) respectively with other Gram-negative bacteria predominating (Table 3.5 and 3.6, pages 106 and 107). Sulphate-reducing bacteria were recovered from the internal surface of the pipe taken from this site.

3.3.2.3 Site D, Eastern General Hospital, Edinburgh, Scotland.

This was one of the control sites which had been chosen because pepper pot-pitting had not been reported. The steam-heated calorifier in this hospital was maintained at 55-60°C, with most of the water recirculated at this temperature. An energy management system monitored and controlled the water temperature at various locations in the hospital. All the faucets in the main hospital complex had mixer controls fitted which lowered the temperature of the water to 40-45°C to minimise scalding of patients and personnel. A non-recirculating section was chosen for monitoring as this was infrequently used and would represent the worst case of possible copper deterioration. The vertical copper pipe (approximately 10 years old) from which a 0.5 m section was removed was found to be neatly lagged and labelled.

(i) Continuous monitoring of the temperature, oxygen and AOC of the hot water supply.

The particular oxygen probe in the Sonde apparatus was found to be vulnerable to damage at temperatures greater than 50°C and so to prevent damaging the probe the water from the faucet in the kitchen department was adjusted to 45°C. The artificially reduced temperature was initially 43-45°C and decreased steadily throughout the night to 31°C the following morning (due to the thermostat being turned down to protect the DO probe) and may have had an influence on the other measurements (Fig. 3.9). The DO was initially measured at 12 mg l^{-1} but immediately decreased to 8 mg l^{-1} and was maintained at this concentration for the remainder of the monitoring period. Initially the AOC was recorded at 2.3 units of ATP before decreasing to 1.8 and 1.2 units of ATP at 19.00 h and 03.00 h before increasing again to 2.0 units of ATP at 07.00 h.

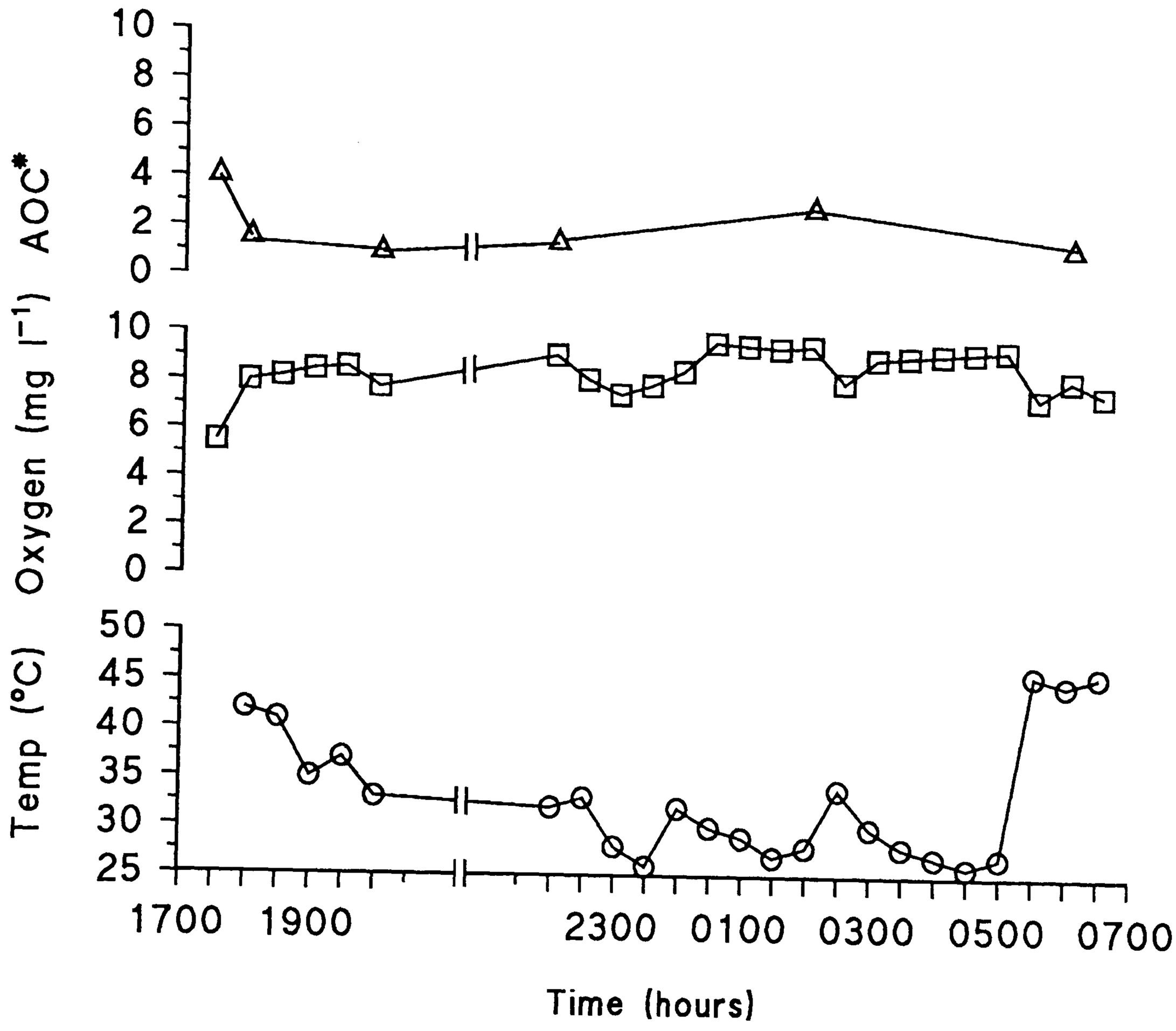


Figure 3.9 Continuous overnight monitoring of the temperature, dissolved oxygen and AOC at the Eastern General Hospital during the second survey in 1989. * denotes AOC as units of ATP.

(ii) Internal examination of the copper tubing

The vertical section of copper tubing which was removed from this hospital was found to contain a thin patchy layer of brown material on its surface with no tubercles or pitting attack taking place (Fig. 3.10).

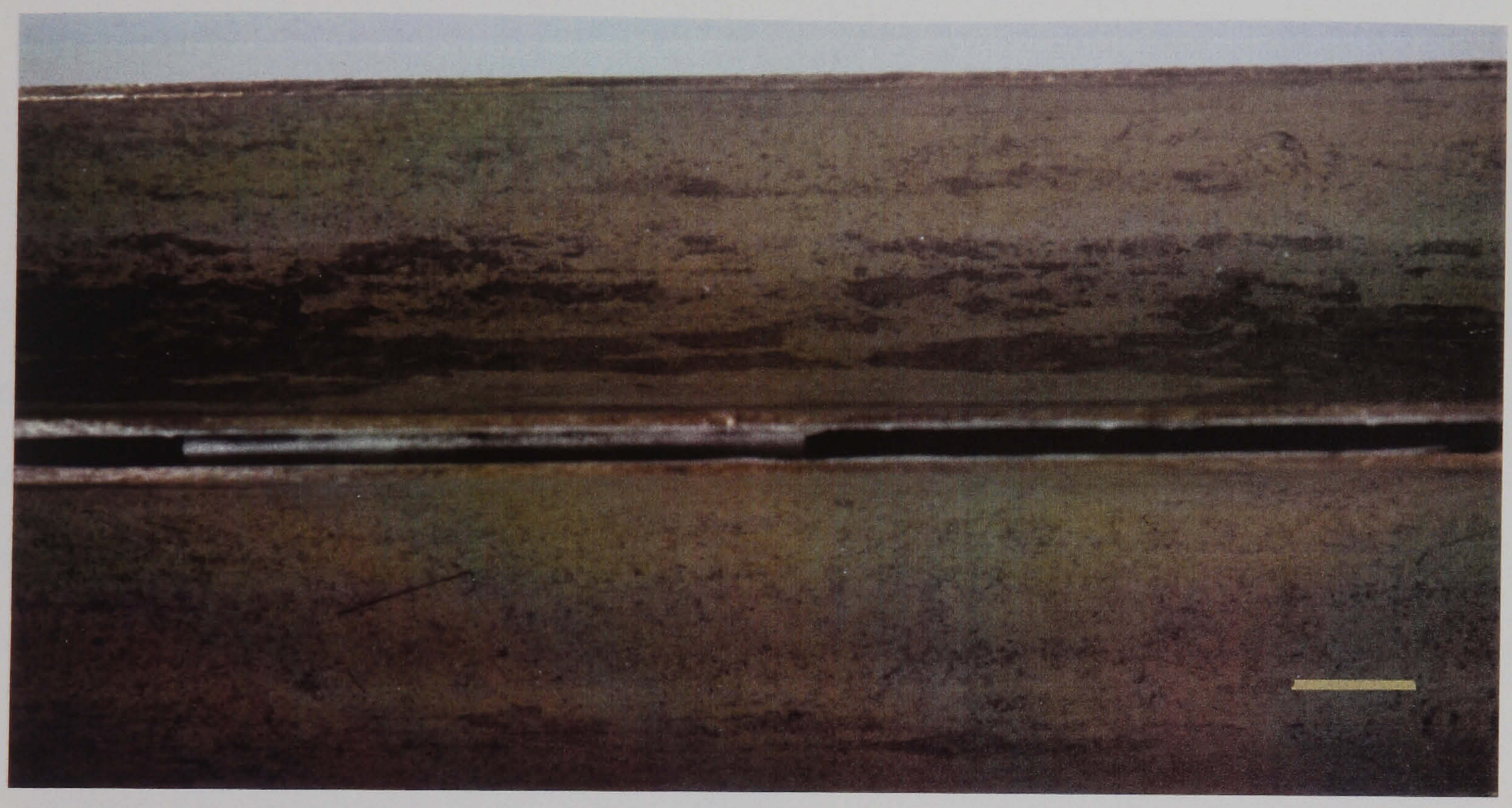


Figure 3.10 Internal surface of the copper tube removed from the Eastern General Hospital during the second survey in 1989 (Marker bar denotes 10mm).

(iii) Microbiological analysis of the water and copper tube surfaces.

A total of 1.4 x 10^4 cfu cm^{-2} were recovered from the thin patchy brown material on the inner surface of the copper pipe with *Pseudomonas* spp. dominating the other Gram-negative bacteria found to be present (Table 3.5 and 3.6, page 106/7). As expected with little material being observed on the surface, there was only a small amount of brown deposit material present in the water. Only 1.6 x 10^4 cfu ml^{-1} were recovered from the water phase with other Gram-negative bacteria predominating over *Pseudomonas* spp. However *Methylobacterium* spp. were found to be present in the water phase but not in the sample taken from the surface of the pipe. No SRB were recovered from this particular hospital.

3.3.2.4 Site E, Stratheden Hospital

This hospital was located near Cupar on the East coast of Scotland. The calorifier was heated to between 55-60°C and water was distributed on a recirculating system to all the units of the hospital. Mixer valves were fitted at the faucets to lower the temperature to 43°C, again to minimise scalding of patients and personnel. Pepper pot-pitting corrosion had not been reported at the Stratheden hospital.

(i) Internal examination of the copper tubing.

The copper tubing was removed from the hot and cold circuits of a relatively new children's block as it had already been reported as having failed in both the hot and cold circuits. When examined the hot and cold copper tubing were found to be running in parallel and close together with no evidence of lagging resulting. Upon examining the internal surface of the pipes both the hot and the cold (Fig. 3.11) were found to be covered in a thin patchy layer of material upon the surface between which the copper surface itself could be observed, with no evidence of the pepper pot-pitting corrosion.

Figure 3.11 Internal surface of the copper tube removed from the Stratheden Hospital during the second survey in 1989 (Marker bar denotes 10 mm).

(ii) Microbiological analysis of the water and copper tube surfaces.

The water sample from the copper tube extracted from the hot water circuit was found to be relatively clear with only a slight brown tinge. Bacterial numbers recovered from this relatively colourless water sample were 1.6×10^4 cfu ml^{-1} with only other Gram-negative organisms being identified. Only 2.8×10^3 cfu cm^{-2} were recovered from the surface of the copper pipe. Of this *Pseudomonas* spp. represented 16% of the population with the majority being other Gram-negative bacteria.

A large quantity of brown deposit was present in the yellow-tainted water from the copper pipe removed from the cold water circuit. 1.6×10^4 cfu ml^{-1} were obtained from the water phase of this pipe which was the same number of bacteria as from the water sample taken from the hot water circuit. *Pseudomonas* spp. represented 3% of this population with the remainder being other Gram negative bacteria. 2.8×10^3 cfu cm^{-2} were recovered from the surface of the cold water pipe which was also the same as that in the hot water sample. However in the biofilm from this cold water pipe *Pseudomonas* spp. pre-dominated at 60 % of the population with the rest being other Gram negative bacteria.

(iii) Continuous monitoring of the temperature, oxygen and AOC of the hot water supply.

The hydrolab surveyor II was operated in a toilet cubicle of the nurses home and was supplied with hot water from a shower head. The temperature of the shower unit was adjusted to a constant 44°C throughout the monitoring period may have had an effect on the other measurements taken (Fig. 3.12). The DO measured a constant 8.0 mg l^{-1} and the AOC 0.8 units of ATP.

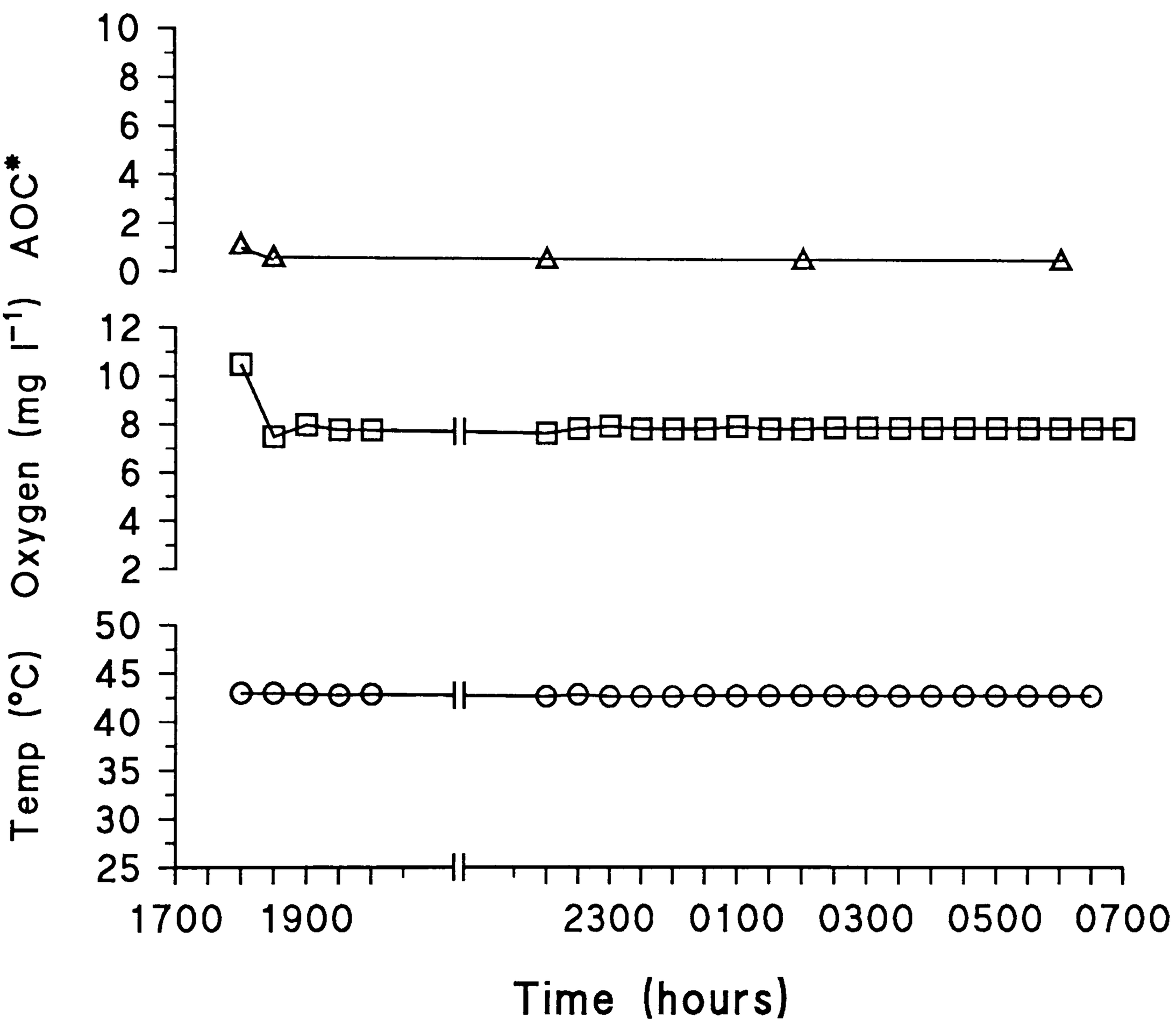


Figure. 3.12 Continual overnight monitoring of the dissolved oxygen and AOC of the hot water at the Stratheden Hospital during the second survey in 1989. * denotes AOC as units of ATP.

Table 3.5 Bacteriology and physical characteristics of copper tubes extracted from the hospital sites.

Site	Cal. Temp(°C)	Plank. Phase ($cfu\ ml^{-1}$)	Biofilm Phase ($cfu\ cm^{-2}$)	Brown Deposit
Victoria (Hot)	48	5.4×10^4	2.8×10^3	+++++
Inverclyde (Hot)	47	$>1 \times 10^4$	$>1 \times 10^4$	+++++
Eastern Gen. (Hot)	60	1.6×10^4	1.4×10^3	+
Stratheden (Hot)	60	1.6×10^4	2.8×10^3	+
Stratheden (Cold)	9.9	1.6×10^4	2.8×10^3	++

Cal. denotes calorifier and Plank denotes planktonic. Bacterial determinations were obtained from a single sample.

Table 3.6 Representative ratios of bacteria from copper tube from the second survey.

Victoria(Hot)	GN[a]	*Ps* spp.[a]	*Meth* spp.[a]	SRB[b]	Leg.[a]
Biofilm	0	83	17	-	0
Planktonic	90	5	5	-	0

Inverclyde (Hot)	OGN[a]	*Ps* spp.[a]	*Meth* spp.[a]	SRB[b]	Leg.[a]
Biofilm	100	0	0	+++	0
Planktonic	100	0	0	+++	0

East. Gen. (Hot)	GN[a]	*Ps* spp.[a]	*Meth* spp.[a]	SRB[b]	Leg.[a]
Biofilm	33	67	0	-	0
Planktonic	50	40	10	-	0

Stratheden (Hot)	OGN[a]	*Ps* spp.[a]	*Meth* spp.[a]	SRB[b]	Leg.[a]
Biofilm	100	0	0	0	0
Planktonic	84	16	0	-	0

Stratheden (Cold)	GN[a]	*Ps* spp.[a]	*Meth* spp.[a]	SRB[b]	Leg.[a]
Biofilm	40	60	0	-	0
Planktonic	97	3	0	-	0

a, percentage; b, denotes presence: -, absence of SRB; + presence of SRB. nt denotes not tested. OGN denotes other Gram-negative bacteria; Ps. spp. denotes *Pseudomonas spp.*; Meth. spp. denotes *Methylobacterium spp.*; Leg denotes *Legionella* spp.

3.4 Discussion

A total of five hospitals were investigated during the two site surveys that were carried out in 1987 and 1989. The Victoria Infirmary and Glasgow Royal Maternity were reported to be suffering from pepper pot pitting corrosion of their copper pipework and were investigated in 1987. The Victoria Infirmary and Inverclyde Hospital, reported to be suffering from this unusual form of copper corrosion, were visited in 1989. Two other sites (Stratheden and Eastern General Hospitals) were also inspected in 1989 and were regarded as control sites as they had not reported a problem with pepper pot-pitting corrosion of copper tubing. However, corrosion of copper tubing was reported to be occurring in the hot and cold runs of copper tubing within a new children's ward of the Stratheden Hospital. When examined, it was found that the hot and cold tubes were running in parallel for about 5 metres with no evidence of lagging. Therefore, there was heat transfer between the pipes decreasing the temperature in the hot and increasing the temperature in the cold pipe which may have led to the observed corrosion which was not due to pepper pot-pitting.

3.4.1 Examination of incoming water and storage conditions

The incoming water was found to be 9.9°C at the hospitals reported to be suffering from corrosion of the copper tubing. In the water sample from the hydrant at the Victoria Infirmary only 200 cfu ml^{-1} were detected with only 50 cfu ml^{-1} at the Glasgow Royal Maternity. No coliforms were detected in any of the water samples tested indicating that the water was of an acceptable bacteriological standard for drinking water quality. Indeed only 1000 cfu ml were recovered from water samples taken from the tap furthest from the calorifier at the Glasgow Royal Maternity and in the nurses home at the Victoria infirmary. However a total bacterial number of 3.6 x

10^6 cfu ml^{-1} including a *Legionella* spp., later identified as *Legionella bozemanii* by indirect immunofluorescent labelling, were detected in the base of the calorifier in the Glasgow Royal Maternity. This calorifier had been desludged and descaled approximately 12 months previously and *L. bozemanii* was only detected in the initial flush, which was measured at 27°C, from this calorifier indicating non-uniform heating. Further flushing resulted in water samples at 56°C with only 1000 cfu ml^{-1} being recovered and no *Legionella* spp. in this hotter water. Thus, the reduced temperature in the calorifier permitted the growth of *L. bozemanii,* which has been associated with human pneumonia (Brenner *et al.* 1980), and a 3600-fold increase in the total number of bacteria, in comparison to water samples where the temperature was 56°C. The presence of *Legionella.* spp within the base of the calorifier could indeed act as a seed for the rest of the water circuit where growth could resume in the water system where temperatures of 56°C could not be maintained.

Fungi were detected during the first survey in the cistern tanks and other samples taken from the calorifier at the Glasgow Royal Maternity but they were not detected in samples taken downstream of the calorifier. Fungal strains such as *Aspergillus* are known to produce gluconic and oxalic acids and have been shown to attack cement (Perfettini *et al.* 1989). Therefore, although fungi were not detected downstream of the calorifier their metabolic products which may also be aggressive to metal surfaces such as copper may well have been present. However, their presence in the cistern tanks and calorifier indicates the possibility of seeding the rest of the water circuit with fungi.

Other microorganisms which have been well documented in the corrosion of metals are sulphate-reducing bacteria (SRB) (Hamilton, 1985). SRB are strict anaerobes which grow by oxidising certain organic compounds or H_2 with sulphate or other sulphur compounds as terminal electron acceptors, and reduces them to sulphide ions which are highly reactive and corrosive to metals. SRB were found extensively at all but one

site at the Victoria Infirmary (tank sediment) examined in the first survey 1987 but no SRB were found at the Glasgow Royal Maternity. In the second survey in 1989 SRB were also detected in the pipe sample extracted from the Inverclyde Hospital but not at the Victoria Infirmary. Neither were SRB detected at the control sites, the Eastern General Hospital and Stratheden Hospital. Thus far, SRB have been detected in two out of the three hospitals which were reporting an unusual number of copper tube failures due to pepper pot-pitting. Low numbers of SRB have been implicated in the corrosion of copper/nickel piping systems even when sulphides could not be detected (Little *et al.* 1989), indicating that when present in low numbers they may have a role to play in corrosion .

As mentioned above the quality of the water supplying all the sites was found to be bacteriologically satisfactory for drinking purposes. However, the storage tanks at the Victoria Infirmary were found to be lacking a cover, allowing debris and peeling paint from the roof to fall into this tank which was supplying water to the calorifier. Indeed, this extraneous material falling into the open tank may have eventually added to the increase in the AOC from 7.4 units of ATP in the incoming water to 12.4 units of ATP (41 % increase) and the presence of 5.0×10^7 cfu per swab from the wall of the cistern tank. LeChevallier *et al.* (1987) also utilised AOC (according to the method of Van der Kooij *et al.* 1982) to indicate a 37 % increase in nutrient consumption between three sites in a distribution system. Even two years later these tanks were found to be in an unsatisfactory condition with badly fitting lids giving access to dirt and insects that would increase the organic loading of the water. At the Glasgow Royal Maternity the tanks were found to be sealed and in a very good condition. However, this was later found to be due to the tanks having been cleaned, painted in bitumen and chlorinated two weeks before the survey was carried out. Due to the short turnaround in restoring and reinstating the tanks, care has to be taken as bitumen paint requires a recommended curing period. If this curing was not carried out the paint may not operate as efficiently as a corrosion protective layer (Colbourne, 1985) and may even

leach nutrients into the water supply. The plumbers informed us that prior to refurbishment the tanks possessed a layer of slime on the inner walls with silt present on the bottom indicating problems with maintenance. Even after being refurbished 1.0 x 10^8 cfu per swab were recovered from the wall of this cistern tank, indicating that it was quickly being recolonised by the bacteria present, even though the tank looked to be in a very good condition. Refurbishment of the cistern tank may have accounted for the absence of SRB in the tank and after the hydrant, however, it would not account for their absence from the incoming water before the cistern tank.

Water was not stored at the Inverclyde Hospital, as the hot water was supplied by direct fire heaters. Upon visiting the two control sites, the Eastern General and Stratheden Hospitals, the water storage tanks were found to be clean and tidy and have the appearance of being maintained regularly.

3.4.2 Examination of the water system parameters

The Hydrolab Surveyor was utilised to monitor the temperature and dissolved oxygen of the hot water supply at the Victoria Infirmary (first and second survey), Inverclyde, Eastern General and Stratheden Hospitals. In the first survey at the Victoria Infirmary the temperature of the hot water was initially measured at approximately 50°C and started to decrease gradually from 17.30 h to approximately 40°C . The temperature recovered the following morning at 06.00 h. The dissolved oxygen concentration was also monitored overnight and followed a similar profile to the temperature. Initially the dissolved oxygen concentration was measured at approximately 8 mg l^{-1} and shortly after 18.00 h it was found to decrease to virtually 0 mg l^{-1} and only increased again at 06.00 h concurrent with the increase in the temperature.

In the second survey at the Victoria Infirmary the temperature was initially measured at

43°C at 17.30 h and then decreased to 27°C overnight before increasing again to 45-47°C at 05.30 h the following morning. Overnight the dissolved oxygen fluctuated between 7.0 and 9.0 mg l^{-1} and there was no decrease as was observed during the first monitoring period at this site two years earlier. Refurbishment of the cistern tank may have accounted for the absence of SRB which are strict anaerobes and which were found at all but one site tested at the Victoria Infirmary two years earlier. Increasing the speed at which the hot water was recirculated to increase aeration and stabilise the water temperature was a recommendation from the first survey and would account for the constant aeration during monitoring in 1989. Increasing the aeration of the water by increasing the speed of the recirculation pumps could have resulted in a positive reduction potential which may discourage the growth of anaerobic SRB. Water samples were taken from the hot water supply periodically throughout the monitoring for analysis of the AOC. The AOC was initially measured at 4.0 units of ATP and decreased to 1.0 unit of ATP before increasing at 02.30 h to 3.0 and was measured at 1.5 unit of ATP at 06.00 h.

Monitoring of the water parameters at the Inverclyde Hospital revealed that the temperature was relatively constant at 45-47°C. However, the oxygen concentration, which was initially measured at 8.0 mg l^{-1}, decreased to between 5-6.0 mg l^{-1} overnight before increasing to 9.0 mg l^{-1} at 07.00 h. The AOC was measured at 6.0 units of ATP and decreased to 1.0 unit of ATP till 10.00 after which it increased to 9.0 units of ATP.

The temperature of the hot water from the calorifier at the Eastern General Hospital was between 55-60°C. Unfortunately one of the drawbacks of using a housing containing various probes to measure parameters in a hot water system is that the oxygen probes are not designed to operate at temperatures above 50°C. Where necessary the temperature of the hot water was decreased to prevent damage to the dissolved oxygen probe at the site of monitoring and so may have affected the other

measurements. This also occurred at the Stratheden Hospital and so the temperatures represented at both these sites are artefacts. Mixer valves were fitted to decrease the temperature to 47°C for the end user to minimise patient scalding. After initially being measured at 12.0 mg l^{-1} the dissolved oxygen concentration at the Eastern General Hospital was constant at 8.0 mg l^{-1} which was similar to the trend observed at the Stratheden Hospital. After being measured at 2.5 units of ATP the AOC at the Eastern General Hospital dropped to 1.5 units of ATP and then decreased to 1.0 unit of ATP before returning to 2.0 units of ATP at 17.00 h the following morning. At the Stratheden Hospital the AOC was measured at 1.0 unit of ATP at the start of the monitoring period and decreased to 0.5 units of ATP and did not increase again.

Maximum AOC concentrations were found at the Inverclyde Hospital and Victoria Infirmary at 9.0 and 4.0 units of ATP respectively, thus providing microorganisms within these water systems with a greater concentration of nutrients for metabolism and growth than in the Eastern General and Stratheden Hospitals, where only 2.0 units of ATP or less were detected.

3.4.3 Examination of the copper tubing surfaces

The copper tubing removed during the site surveys were brought back to the laboratory for examination. Copper tube removed from the Victoria Infirmary (both surveys) and the Inverclyde Hospital were examined by light and scanning electron microscopy as well as SEM and were found to have a thick glutinous layer associated with the surfaces. Using light microscopy and Gram-staining the glutinous layer was found to be composed of bacteria, predominantly Gram-negative rods. Tubercles were found to be present on the surface surrounded by a glutinous layer, and when the tubercles were scraped away a series of steep sided pits, typical of pepper pot-pitting were revealed. Previous examination of tubercles in distribution systems has revealed

that they were found to contain sulphate-reducing bacteria as well as a range of aerobic heterotrophic bacteria (Tuovinen *et al.* 1980) and that the tubercles exhibited a clear correlation with pitting corrosion in cast iron pipes. LeChevallier *et al.* (1987) also detected tubercles in water distribution pipelines and correlated them with a large number of bacteria, in particular, coliforms. Although Tuovinen and Hsu (1982) did not detect coliforms they demonstrated that tubercles present a niche in which bacteria can survive and even be protected against chlorination. However, when the copper pipes removed from the Glasgow Royal Maternity, Eastern General Hospital and the Stratheden Hospital were examined, they were found to have a thin layer of material on the surface with no indication of tubercles. From the microbiological quantification there was a higher number of microorganisms recovered from Inverclyde Hospital than from the other three sites. Although the same number of bacteria were recovered from the surface of the other three sites there was a greater number present in the water of the pipe from the Victoria Infirmary suggesting that bacteria may have sloughed off the surface in transit.

3.5 CONCLUSIONS

In summary, the surveys set out to identify reasons why particular hospitals were experiencing severe copper tube corrosion due to pepper pot-pitting and others were not. At the Glasgow Royal Maternity, Stratheden Hospital and Eastern General Hospital pepper pot-pitting corrosion of copper tube was not considered a problem, the temperature of the recirculating water circuit was 55°C with the latter two having a low AOC concentration. This relatively high temperature and low AOC concentration may have been the controlling factor in reducing the presence of bacteria within the water circuit, indicated by the thin layer of deposit and biofilm present on the surface of pipes removed from those sites.

The hospitals where pepper pot-pitting corrosion was present were the Victoria Infirmary and Inverclyde Hospital and the hot water circuit was monitored between 40-46°C. In the first survey in 1987 the AOC concentration at the Victoria Infirmary was 12 units of ATP and 4.0 units of ATP in the second survey in 1989 and 9.0 units of ATP at the Inverclyde Hospital. The presence of a high concentration of nutrients in the form of AOC and a relatively low temperature of between 40-46°C would allow the prolific growth of the heterotrophic bacteria present in the water circuit and on the copper pipe leading to a decrease in the DO as was observed during monitoring. The presence of tubercles and a thicker biofilm on the copper pipe surface of the latter two sites correlates with increased bacterial growth due to favourable conditions.

Parameters such as a relatively low temperature and high AOC concentration resulting in a decrease in the dissolved oxygen concentration and the presence of a thick biofilm correlates with the occurrence of pepper pot-pitting corrosion in the copper tubing. The aerobic facultative bacteria present in the biofilm on the copper surface would interact with the fungi present resulting in a complex consortia forming a framework in which the biofilm can grow. SRB where present in this complex biofilm network would establish within an anaerobic niche to enrich the complexity and aggressive nature of the biofilm on the copper surface.

The results were used to identify parameters which may have contributed to the encouragement of the pepper pot-pitting corrosion in order to establish and where necessary to modify the laboratory model. The primary aim of the model was to simulate the environmental parameters at the Victoria Infirmary to reproduce the fouling of the copper tubing and to develop methods to control or prevent such fouling. Temperature was chosen as the main parameter with which to focus on by establishing a laboratory model to simulate the conditions under which this particular corrosion was occurring.

In conclusion the hospitals which were examined had locations that were reporting failures in their copper tubing due to pepper pot-pitting corrosion. The water supplying these sites contained a relatively high concentration of assimilable organic carbon (AOC). As this water was from an upper catchment area (peatland) the water would have contained the breakdown products of humic and fulvic acids resulting in the increased AOC providing the nutrients for microbial growth.

Therefore, with the decrease in temperature of the water system overnight microorganisms present at the surface as a biofilm would become metabolically active with the resultant decrease in AOC and dissolved oxygen concentration due to bacterial metabolism and respiration.

Particulate matter in the water would become enmeshed in the biofilm resulting in microcolonies forming into tubercles. It is directly beneath these tubercles that the pepper pot-pitting corrosion was perforating the copper tubing.

The presence of the bacterial microcolony would result in the formation of electrochemical cells due to concentration gradients across the copper surface. In association with the physical structure of the microcolonie resulting in concentration gradients the metabolic activity of the microorganisms would lead to an aggressive environment directly at the copper surface. In conclusion the metabolically active biofilm appears to have a direct role in the formation of pepper pot-pitting.

CHAPTER 4.0

LABORATORY MODELLING OF BIOFOULING.

4.1 INTRODUCTION

Bacterial association with copper tube had been observed in all the pipe samples recovered from the institutional buildings where corrosion was occurring (Chapter 3.0). In the sites where corrosion was reported to be a problem, operation of the hot water system at relatively low temperatures (46°C) would have stimulated a metabolically active bacterial biofilm. Such biofilm could have been responsible for the decrease in the AOC and the observed drop in the dissolved oxygen concentration. The aim of the laboratory model was to simulate the fouling of copper tube under conditions as close as possible to those found in hot water circuits where copper failures were occurring. For this purpose, water from the Victoria Infirmary was used as the medium in which to grow a bacterial inoculum, taken from the inside surface of a corroded copper tube obtained from the same site.

Many laboratory models have been developed to study bacterial growth (Chapter 1), but the important criterion is that one understands the limitations of the laboratory apparatus. A model cannot replace the real environment but can provide a controlled situation in which to study growth or a particular parameter which one decrees as being important. In the present study a continually flowing water circuit and the ability of organisms to colonise the plumbing tube material (copper) under particular conditions had to be simulated.

To simulate the continually flowing water circuit it was proposed to set up two continuous culture laboratory vessels in series with the first vessel being utilised primarily to grow up an inoculum from the copper pipe surface. The stabilised culture in the first vessel would be grown and used to continuously feed a second vessel, where copper coupons would be immersed in the culture, thus simulating attachment to copper pipes in a continually flowing water circuit. With coupons suspended in the

second vessel, parameters could be altered, even to the detriment of the culture in that particular vessel to determine the effect on it of variable parameters. If the culture was diminished then when conditions became favourable growth would result as the vessel would be continually challenged with culture from the first vessel where conditions are consistent. Initially the apparatus was utilised to simulate the fouling of copper tube at different temperatures to determine whether the profile of biofouling in the hot water system could be reproduced in the laboratory. Following this, the effect of temperatures greater than 60°C was investigated on developing and developed biofilms, as well as bacteria in the planktonic phase.

Copper tubing in domestic and institutional buildings is guaranteed for 25 years however a small number of failures have been reported in a few isolated cases within this guarantee period. Water supplied to domestic and institutional buildings is not sterile (Gibbs and Hayes, 1988) and contains a range of microorganisms such as *Pseudomonas* spp., *Methylobacterium* spp. and *Flavobacterium* spp. as well as opportunistic pathogens such as *Aeromonas* spp. The detrimental effect of biofilms has been documented particularly in reference to SRB and MIC of mild steel (Hamilton, 1985). The type of copper tube failure identified in the present study was unusual and bacterial involvement had been suspected following a number of independent studies (Fischer *et al.* 1988; Chamberlain *et al.* 1988: Keevil *et al.* 1987) and site surveys (Walker *et al*, 1991) (see Chapter 3). Control measures to eradicate biofilm using acid treatment has been investigated (Fischer *et al.* 1992). Reiber *et al.* (1987) successfully demonstrated a 40 % reduction in the corrosion of copper plumbing material by increasing the hardness of the water to passivate the copper tube surface. Therefore a laboratory rig was also established involving two continuous culture vessels separated by a 10 m length of copper tubing. Soft water containing particulate matter was supplied to the first vessel and copper tube but the water was then passed through an inline cartridge filter before it was pumped into the second vessel, thus allowing for a comparison of particulate matter on biofilm development.

Visualisation of bacterial attachment and growth has been extensively studied by Caldwell and Lawrence, (1986) using light microscopy. In this present study a light microscope with adapted differential interference contrast (DIC) and UV-fluorescence was also utilised to view bacteria on glass surfaces that had been immersed in the laboratory model as a control to gauge the amount of biofouling against other materials. The glass surface being flat presents an ideal surface on which to view, using DIC, the biofouling taking place. However, materials used in domestic plumbing circuits and cooling towers are generally opaque with only a few of the plastic materials allowing transmissible light to pass through them, albeit with some difficulty. Even so, the plastics present a relatively smooth flat inner surface to view biofouling by DIC. The larger the diameter of the pipe, the less the curvature and the greater the amount of area which will be in view in the focal plane. It is in circumstances where curved pipe has to be examined for evidence of biofouling that the long focal length non-contact metallurgical lenses are extremely useful. DIC is superior to phase contrast microscopy and, since they do not need any prior preparation, samples can be observed rapidly without the introduction of artefacts. DIC is commonly used with transmitted light but biofilms may be dense and occur readily on opaque materials.

For material such as copper and other metals the biofilm on the surface can be examined with DIC but the individual bacteria are often difficult to visualise. For this reason fluorochromes such as acridine orange have been utilised to observe the individual bacteria and microcolonies on copper and to enhance visualisation on glass. For counting purposes the use of microscopical techniques to obtain direct total and viable counts in a short period of time can be very informative. Acridine orange (Daley and Hobbie, 1975) has been used to enumerate total bacterial numbers but the resulting range of colours from yellow to green of the individual bacteria does not necessarily equate to viability especially on heat treated cells at 60°C (Back and Kroll, 1991). Hobbie *et al.* (1977) suggest that the most active and dead bacteria will

fluoresce red and inactive or slow growing bacteria will fluoresce green. However, it has been used successfully to identify intracellular from extracellular enteropathogens in Hela cells (Miliotis, 1991). One of the disadvantages of the technique is the quenching or fading of the fluorescence.

An established technique of investigating viable bacteria is to use tetrazolium salts such as 2-(*p*-iodophenyl)-3-(nitrophenyl)-5-phenyl tetrazolium chloride (INT) (Zimmerman *et al.* 1978). Respiring bacteria that possess an active electron transport system will reduce INT to INT-formazan. Thus INT can be used in conjunction with other stains to distinguish viable bacteria from the total number of bacteria viewed microscopically. Vesey *et al.* (1990) combined an immunofluorescent assay (IFA) with INT for the rapid identification and enumeration of viable *Legionella pneumophila* serogroup 1. In that study IFA was used to obtain the total number of *L. pneumophila* serogroup 1 while INT was used to indicate viable cells.

The present study incorporated the use of a light microscope (Nikon Labophot 2) equipped with episcopic DIC to view opaque materials. A mercury lamp combined with UV-fluorescence and immuno-gold blocks facilitated immunolabelling studies. Key features of this particular microscope were the long focal length, non-contact metallurgical objectives that avoided the need for coverslips or oil contact with specimens. Therefore reflected episcopic light or fluorescence was used to view biofilms using procedures that attempted to keep biofilm distortion to a minimum.

Two major techniques were chosen to study corrosion and biofilm development on samples extracted from the laboratory rig. These were environmental SEM (ESEM) and confocal laser microscopy.

ESEM allows the structure of the biofilms to be examined without prior preparation of the sample, thus preventing the introduction of artefacts such as shrinkage due to

fixation, or loss of sample due to frequent changes of buffers and dehydrating agents (Chang and Rittman, 1986). The procedure operates on the principle of an SEM, however the specimen chamber is maintained under higher pressures so that hydrated samples can be viewed in their natural wet environment. As the specimen is maintained at approximately 6 torr pressure then altering the pressure in the chamber will alter the amount of water which surrounds the specimen e.g. decreasing the pressure will increase the sublimation of water from the surface. Although of primary use in the food industry it is at present gaining favour among biologists (Danilatos, 1991; Little, 1991). Confocal laser microscopy has enabled the structure of multi-species biofilms to be examined (Cummins *et al.* 1992) and in the present study this apparatus was utilised to obtain a better understanding of biofilm and its affect on the metalic substrata. Thus from developing the laboratory model to simulate a particular problem in a water system, techniques were developed to study colonisation, biofilm development and control as well as to investigate possible corrosion mechanisms that may be occurring.

4.2 MATERIALS AND METHODS

The laboratory model was based upon two continuous culture vessel linked in-series to simulate a flowing water circuit. Using this type of model the first vessel was used to simulate a water storage tank feeding the water circuit down-stream, that is, the second vessel. Materials, such as glass, silicone rubber and titanium, used in the design of the model (section 2.5, page 51) were chosen due to their inert nature. These materials would not leach or impart metals or nutrients into the culture. Release of such compounds may otherwise influence the chemistry of the water and/or bacterial growth in the vessel. An environmental inoculum source of micro-organisms was obtained from the surface of a corroded copper pipe (section 2.4, page

50) and inoculated into the first vessel. Biofilm development was ascertained by immersing plumbing tube materials (coupons) into the second vessel and removing coupons from the vessel at selected time periods (section 2.7, page 58). Conditions within the second vessel were altered to determine the effect of temperature and water chemistry (carbonate concentration) (sections 2.7.1 and 2.7.4, page 59) on biofilm development. To determine the effect of cleaning agents to remove biofilms, coupons were taken from the culture vessel and treated with either citric (10 %) or sulphamic (5 %) acid (section 2.7.3, page 60). The coupons were then re-immersed into the culture vessel to assess recolonisation. To complement standard plate count procedures to evaluate viable cell numbers, various microscopy techniques (light microscopy, DIC, epi-fluorescence, SEM and ESEM) were used to visualise the morphology of the biofilms (section 2.12, page 64). Further microscopy studies, using a scanning confocal laser microscope, were carried out to evaluate the effect of particulate material and bacterial metabolism on the corrosion of copper coupons (section 2.12).

4.3 RESULTS

4.3.1 Simulation of environmental conditions causing corrosion

Background

The previously described results obtained during the site surveys indicated that the temperature of the hot water circuit in the corroded site fluctuated between 34-52°C overnight (Fig. 3.0, page 78). The continuous culture laboratory model was set up to simulate this temperature cycle and investigate fouling of copper coupons over 40-60°C. The culture inoculum was established at 40°C in the filter sterilised tap water and maintained at 40°C with specimen material coupons immersed in the vessel for 21 days. Biofilm generation over the temperature range of 40-60°C was examined by increasing the temperature by 5°C increments 7 days after each 21 day biofouling experiment.

4.3.2 Biofilm development of copper surfaces

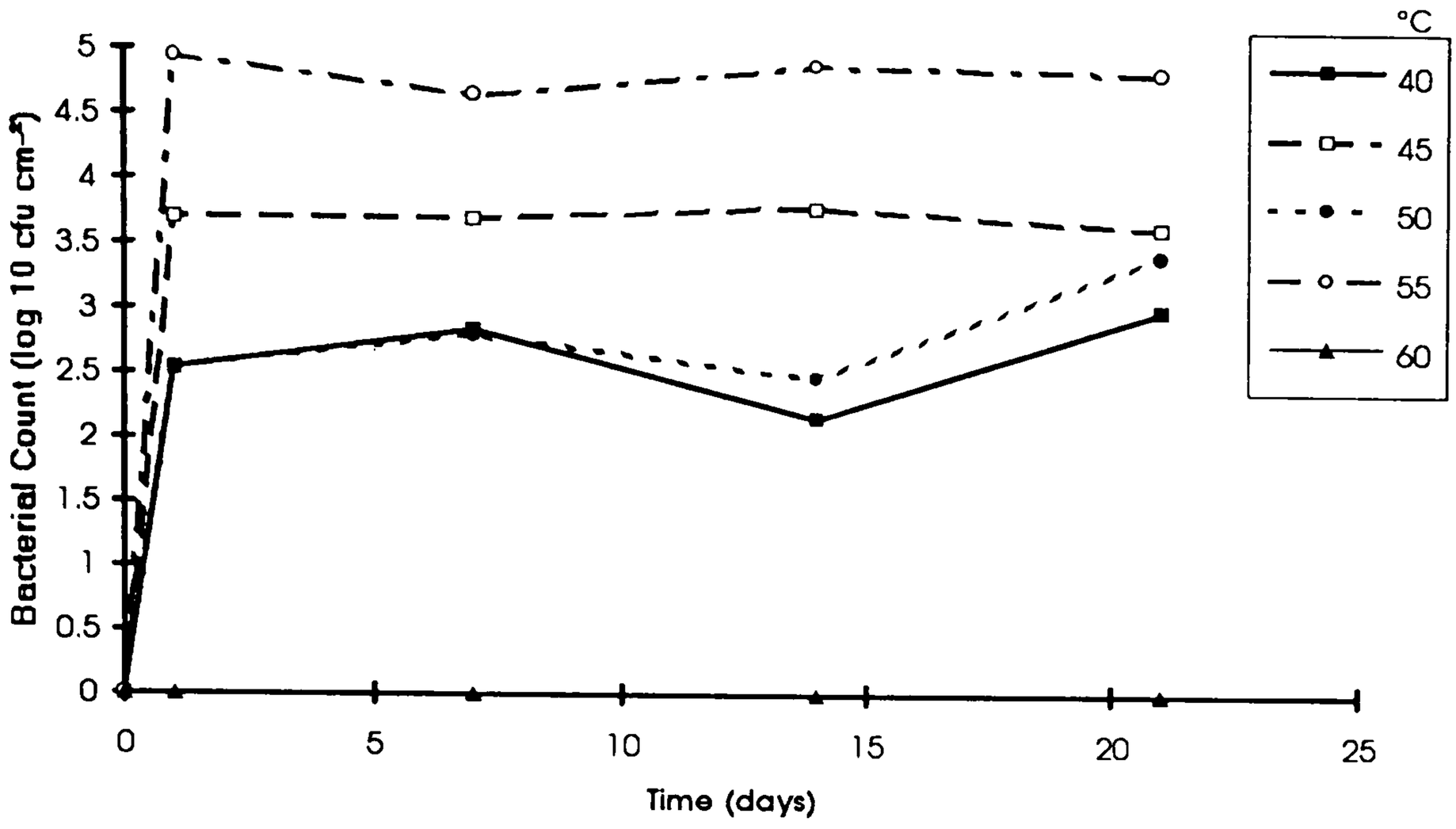


Figure 4.0 Colonisation of copper in Glasgow water between 40-60°C.

Colonisation of the copper surfaces occurred rapidly within 24 h of the copper coupons being placed within the culture over the temperature range of 40-55°C. During this period recovery of viable bacteria ranged between 2.5 (40°C and 45°C) and 4.9 (55°C) Log 10 cfu cm^{-2}. Although similar numbers were obtained from coupons at 40°C & 50°C (2.5 Log 10 cfu cm^{-2}), greater numbers of viable bacteria were recovered at 45°C (3.7 Log_{10} cfu cm^{-2}) and 55°C (4.9 Log_{10} cfu cm^{-2}). As time proceeded the number of bacteria recovered from 45 and 55°C remained stable while those recovered from 40 and 50°C increased from 2.5 Log_{10} cfu cm^{-2} to 2.9 and 3.4 Log_{10} cfu cm^{-2} respectively. In comparison when the temperature was increased to 60°C no viable bacteria were recovered from the coupons. There was no significant difference between the number of bacteria obtained at 40 & 50°C ($p = >0.05$). In contrast the differences between 40 & 45°C, 40 & 55°C, 45 & 50°C, 45 & 55 °C and 50 & 55 °C ($p = <0.05$) were significant.

4.3.2.1 Profiles of the microbial types recovered from copper (40-60° C)

(i) Percentage profile of microorganisms on copper at 40°C.

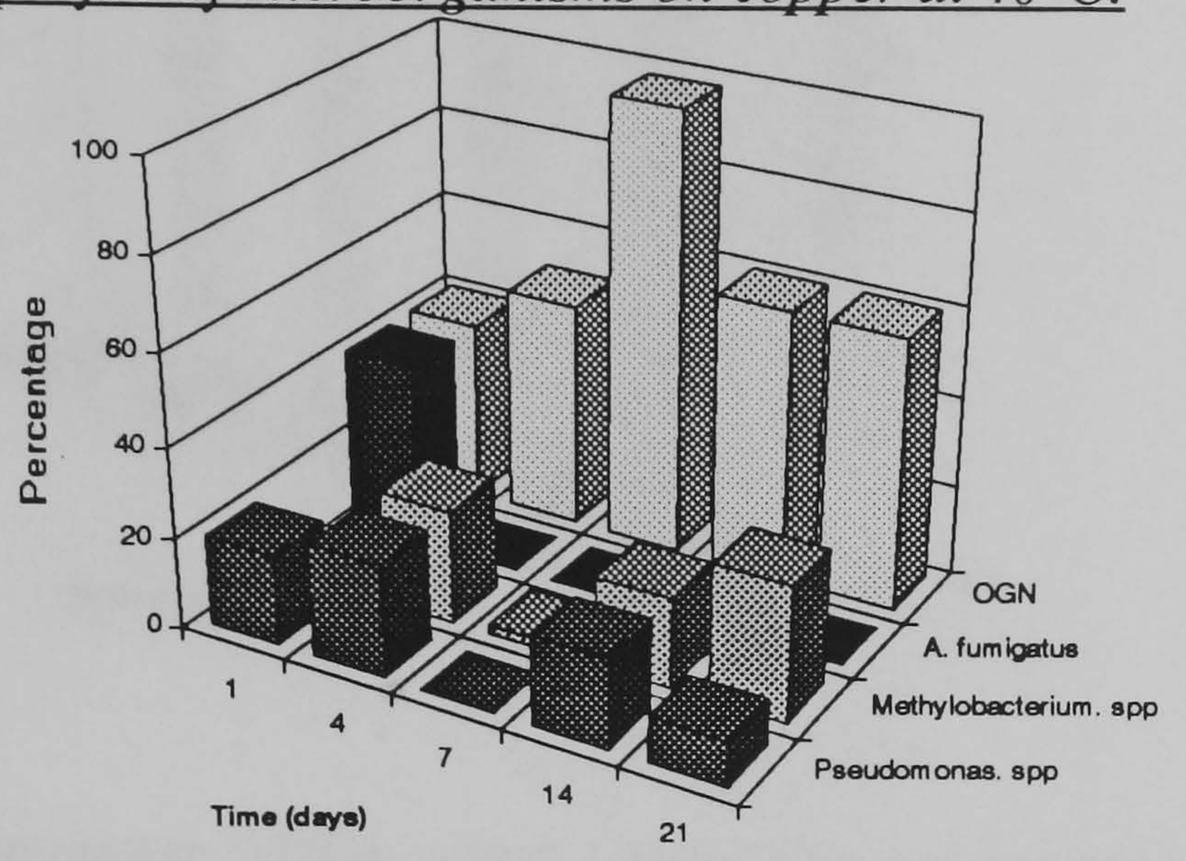


Figure 4.1 Percentage profile of microorganisms on copper at 40°C.

Table 4.0 Percentage profile of microbial species on copper at 40°C.

Species / Days	1	4	7	14	21
Pseudomonas spp.	20	25	0	20	10
Methylobacterium spp.	0	25	2	20	30
Aspergillus fumigatus	40	0	0	0	0
Gram Negative Bacteria	40	50	98	60	60

Aspergillus fumigatus was only detected at day 1 at 40 %. *Pseudomonas* spp. were recovered on all but day 7 between 10-25 %. *Methylobacterium* spp. were not recovered on day 1 but were detected at between 2-30 % thereafter, where as the OGN dominated throughout the time course at 40% or greater.

(ii) Percentage profile of microorganisms on copper at 45°C.

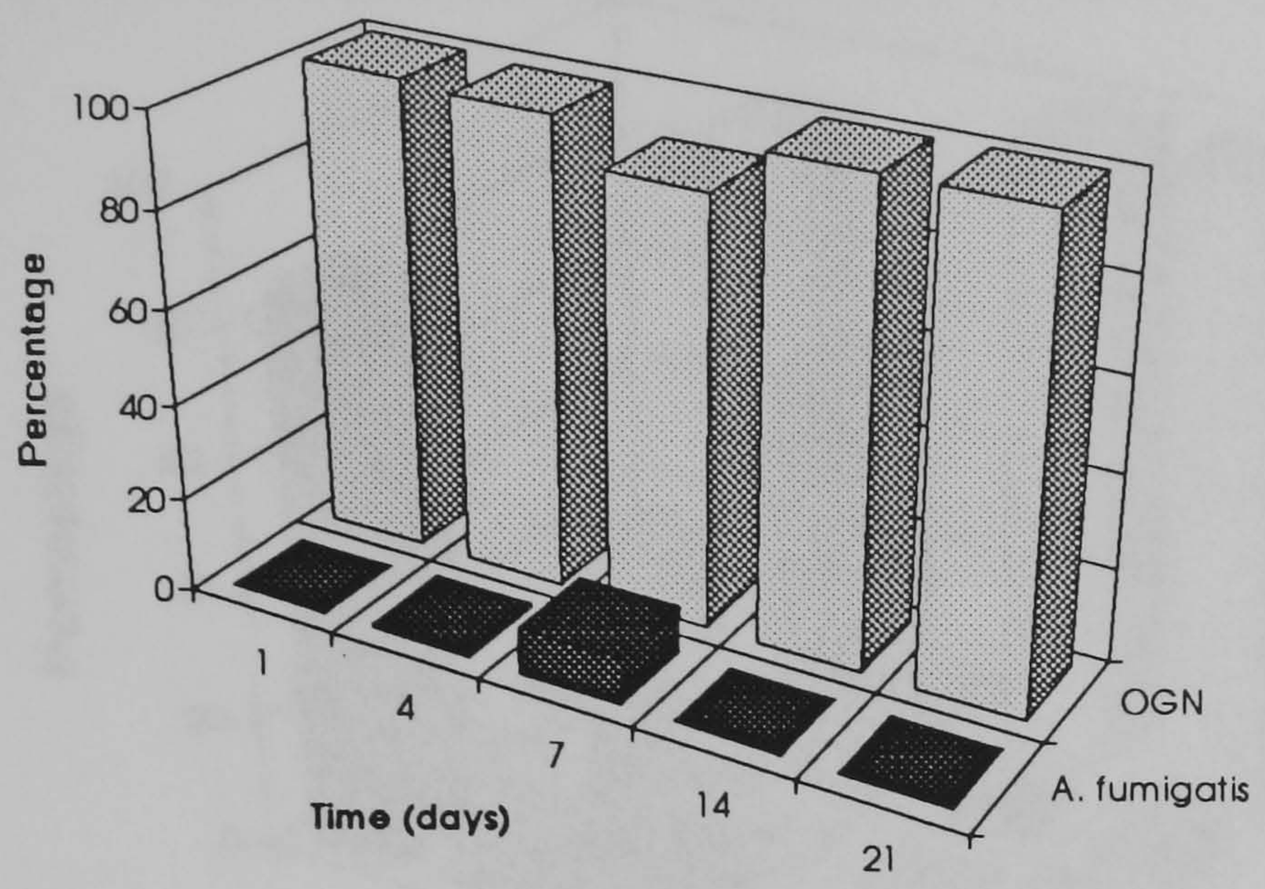


Figure 4.2 Percentage profile of microorganisms on copper at 45°C.

Table 4.1 Percentage profile of microbial species on copper at 45°C.

Species \ Days	1	4	7	14	21
Pseudomonas spp.	0	0	0	0	0
Methylobacterium spp.	0	0	0	0	0
Aspergillus fumigatus	0	1	10	0	0
Gram Negative Bacteria	100	99	90	100	100

From the copper surface immersed in the culture vessel at 45°C the OGN bacteria dominated over the time course of the experiment with *A. fumigatus* being present at days 4 and 7 at 1% and 10 % respectively.

(iii) Percentage profile of microorganisms on copper in soft water at 50°C

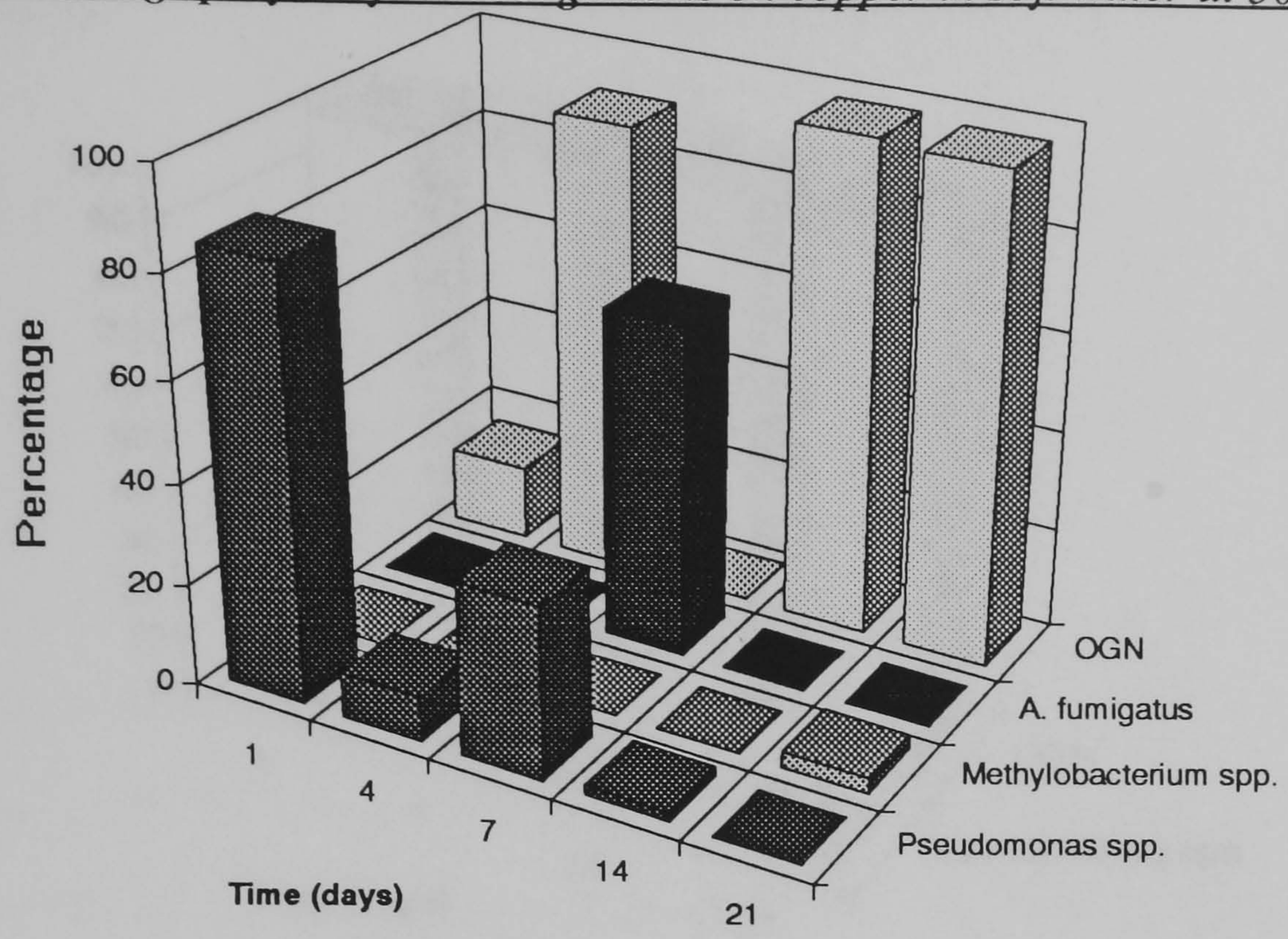


Figure 4.3 Percentage profile of microorganisms on copper at 50°C.

Table 4.2 Percentage profile of microbial species on copper at 50°C.

Species / Days	1	4	7	14	21
Pseudomonas spp.	85	9	34	2	0
Methylobacterium spp.	0	0	0	0	3
Aspergillus fumigatus	0	0	66	0	0
Gram negative bacteria	15	91	0	98	97

Pseudomonas spp. were recovered as the dominant species at day 1 and declined at day 4 but they recovered at day 7 to represent 34 % of the population. They were succeeded by OGN at day 4. *A. fumigatus* only dominated at day 7 and was succeeded by the OGN that dominated at >90 % at days 14 and 21 respectively.

(iv) Percentage profile of bacteria on copper in soft water at 55°C

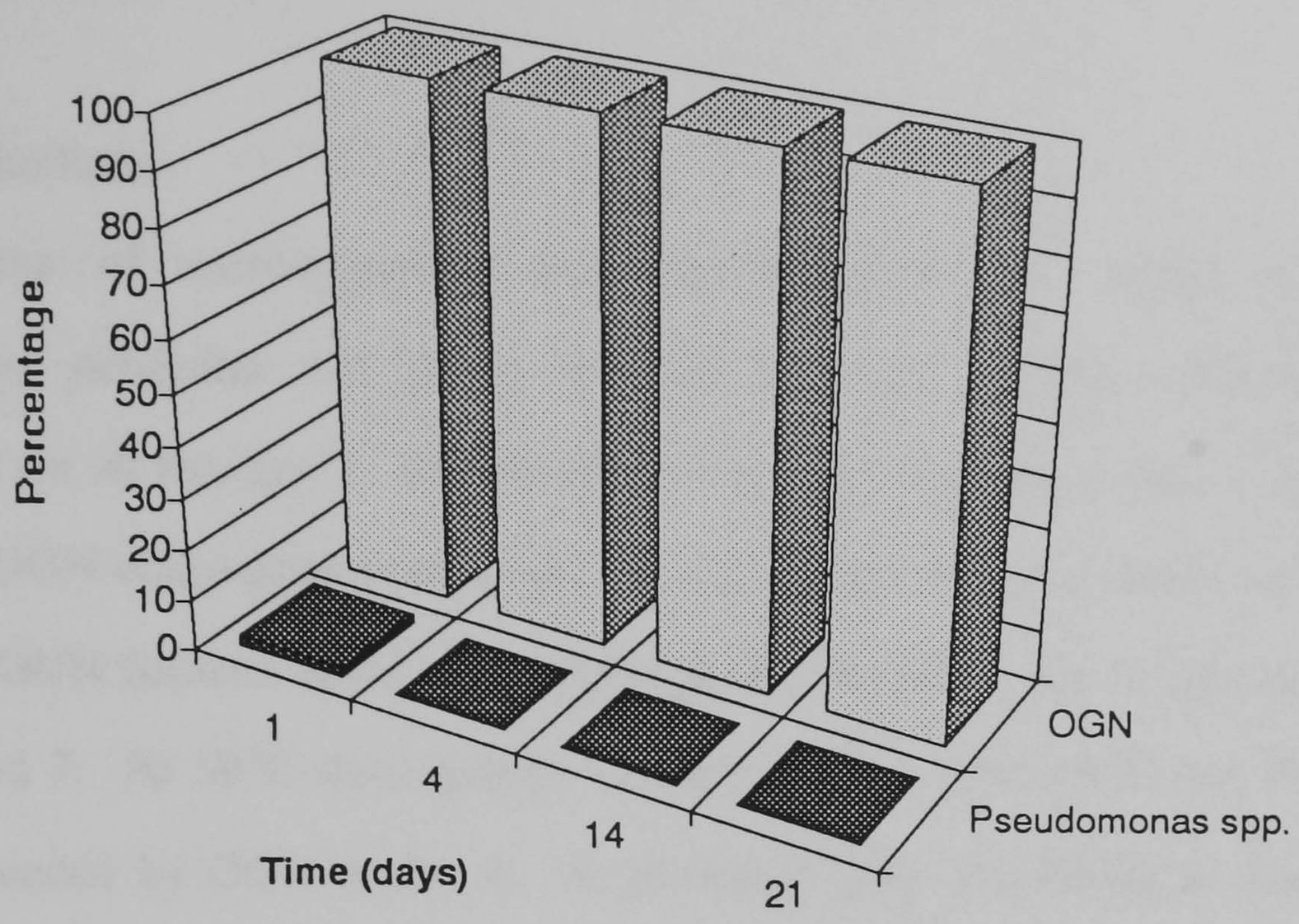


Figure 4.4 Percentage profile of bacteria on copper at 55°C.

Table 4.3 Percentage profile of microbial species on copper at 55°C.

Species / Days	1	4	7	14	21
Pseudomonas spp.	2	0	0	0	0
Methylobacterium spp.	0	0	0	0	0
Aspergillus fumigatus	0	0	0	0	0
Gram Negative Bacteria	98	100	100	100	100

As the temperature was increased to 55°C only two groups of bacteria were observed with the other Gram-negative (OGN) bacteria dominating from day 1 to day 21. *Pseudomonas* spp. were present only at day 1 at less than 5% of the population and not at any time after day 1.

(v) In Summary

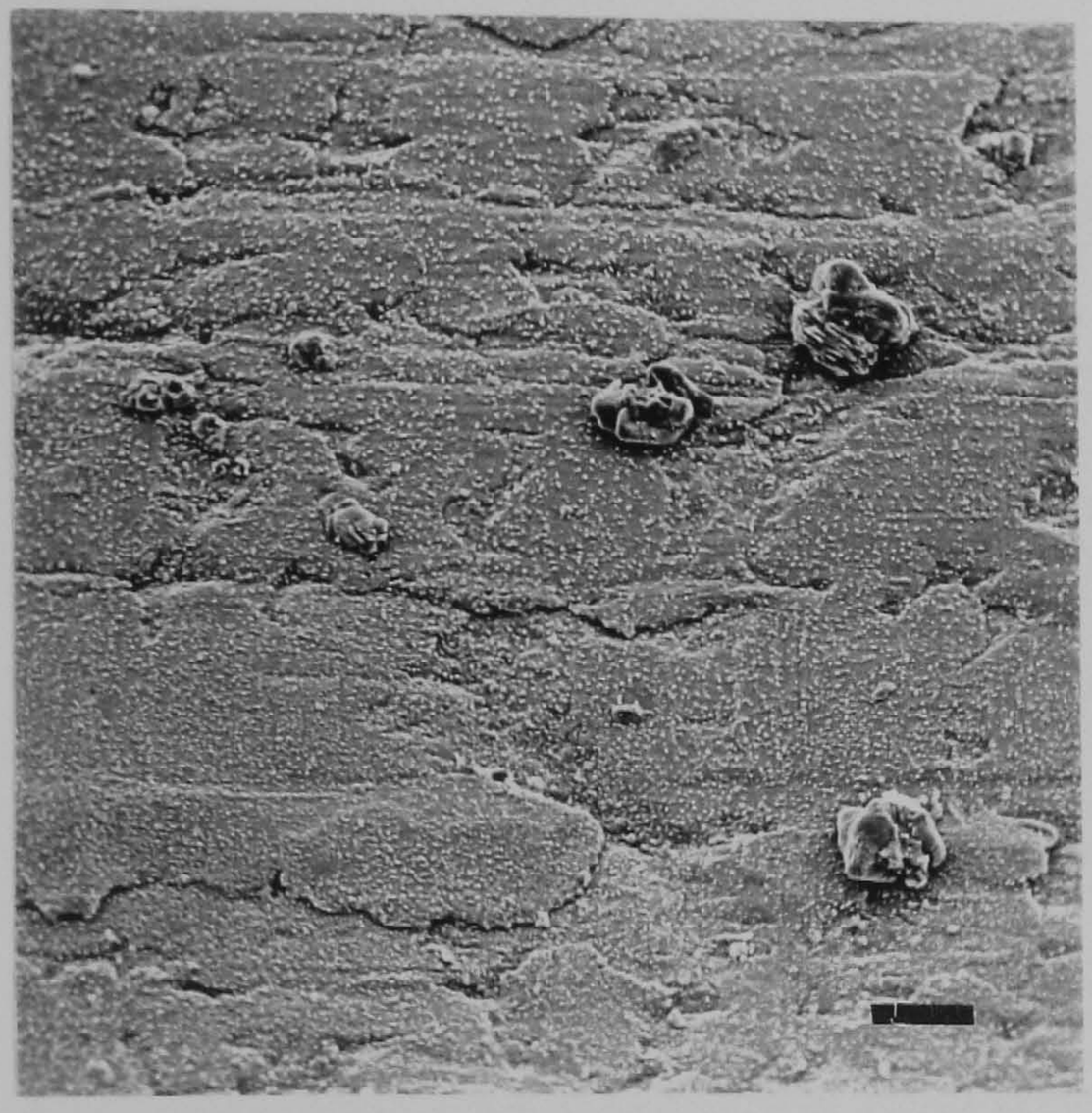
Copper Surfaces

Four groups of microorganisms were identified from the copper at 40°C with *Aspergillus fumigatus* not being detected after day 1 and *Pseudomonas* spp. recovered on all but day 7. *Methylobacterium* spp. were recovered at all but day 1 with the OGN dominating at all days. At 45°C there was a decrease to two species with the OGN bacteria dominating although *A. fumigatus* was transiently present at days 4 and 7. At 50°C three groups of bacteria were recovered with *Pseudomonas* spp. succeeded by OGN at day 4. *A. fumigatus* only dominated at day 7 and was succeeded by the OGN. As the temperature was increased to 55°C the species diversity decreased such that OGN bacteria dominated throughout with the only other species *Pseudomonas* spp. not recovered after day 1.

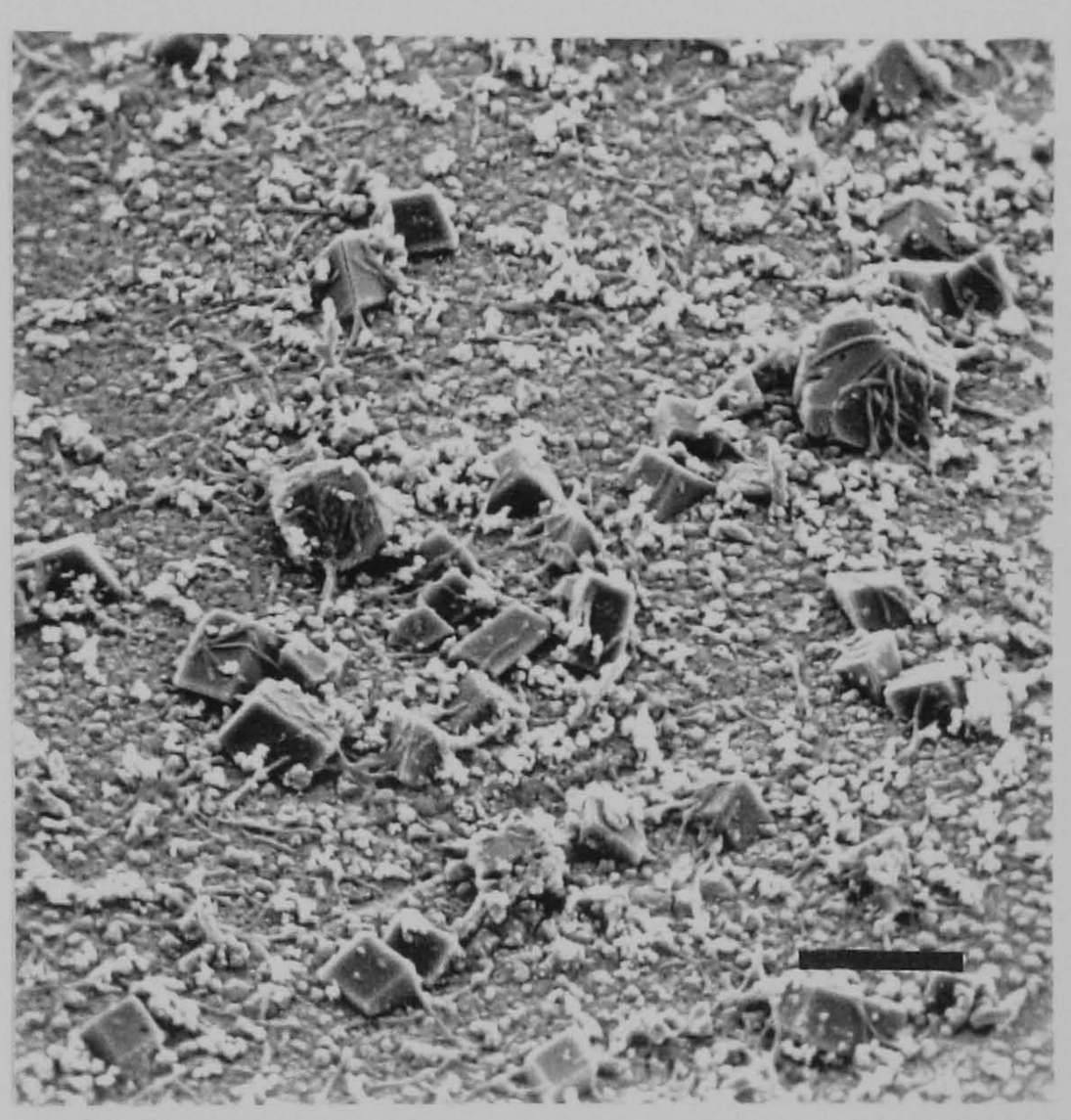
4.3.2.2 SEM's of copper coupons exposed to 40-60° C.

It was evident from the results of the scanning electron micrographs that at 40°C no bacteria could be observed at day 1 (Fig. 4.5, page 132). However, from the micrographs of 7 day coupons, 4.9 Log $_{10}$ bacteria cm^{-2} could be observed on and around the copper carbonate crystals (Table 4.4) Debris was apparent at day 7 and is also seen at day 14, although bacteria cannot be identified in these micrographs. From coupons immersed for 21 days, bacteria can be observed readily between the particulate matter although enumeration of bacteria on the surface could not be carried out as discrimination of individual bacteria was not possible. Only individual bacteria were identifiable on coupons immersed at 45°C for up to 7 days and at days 14 and 21 the bacteria were observed to be held in a mesh like material that could not yield a bacterial count (data not shown). Similarly bacteria could not be seen on coupons from 50°C at days 1 and 7 but at days 14 and 21 there were 4.6 and 4.5 Log $_{10}$ bacteria cm^{-2} respectively. Again at 55°C bacteria were not present on the coupons extracted from day 1 and 7 as well as day 14 (Fig. 4.6). However, 4.9 Log $_{10}$ bacteria cm^{-2} were counted on the coupons removed after 21 days (Table 4.7). When the coupons of copper which were immersed in the vessel at 60°C were investigated no bacteria could be observed on any of the coupons.

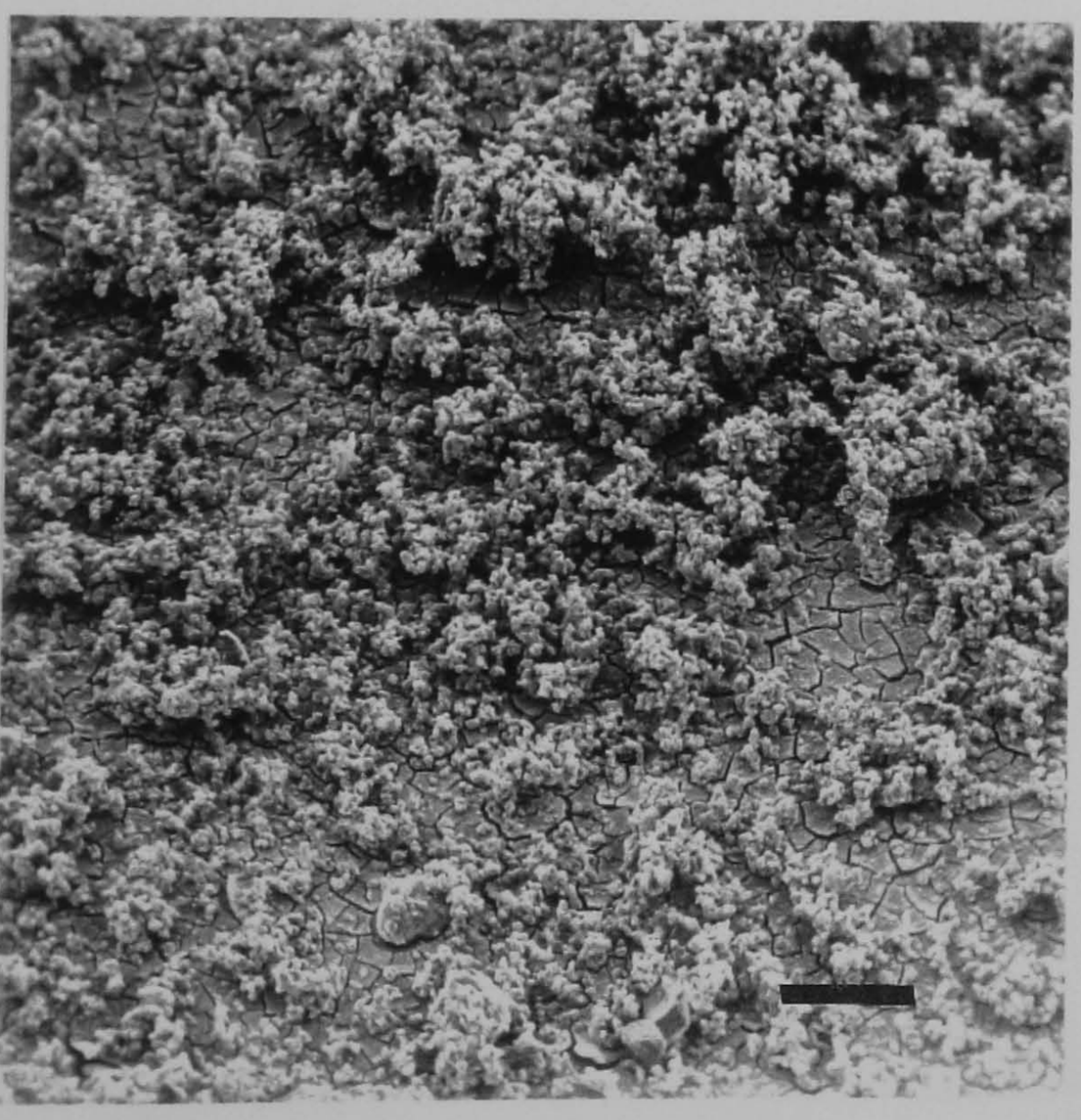
Figure 4.5 SEM of copper coupons exposed to temperatures of 40℃ (Marker bar denotes 10 μm).



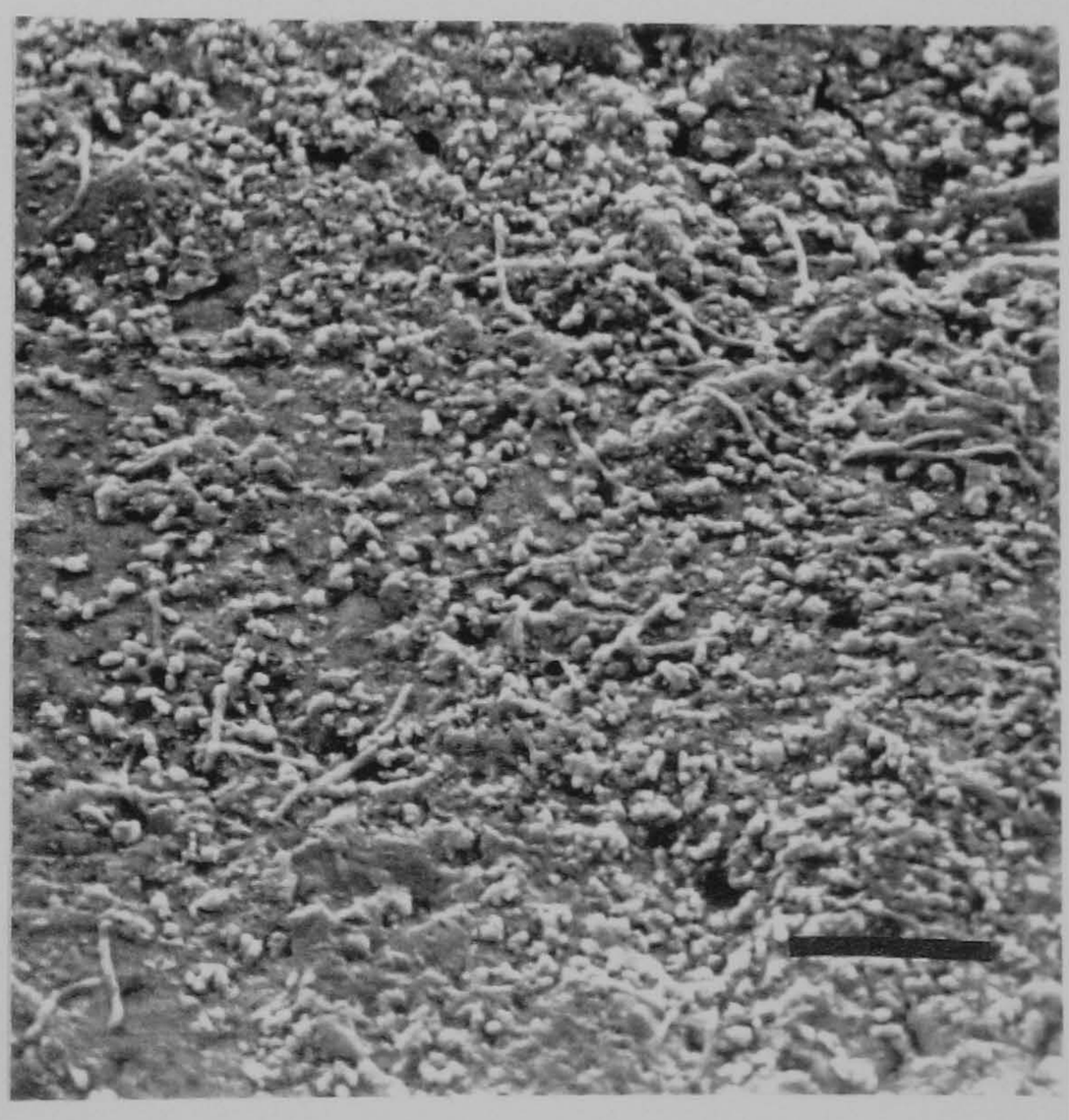
(A) 1 Day



(B) 7 Day



(C) 14 Day

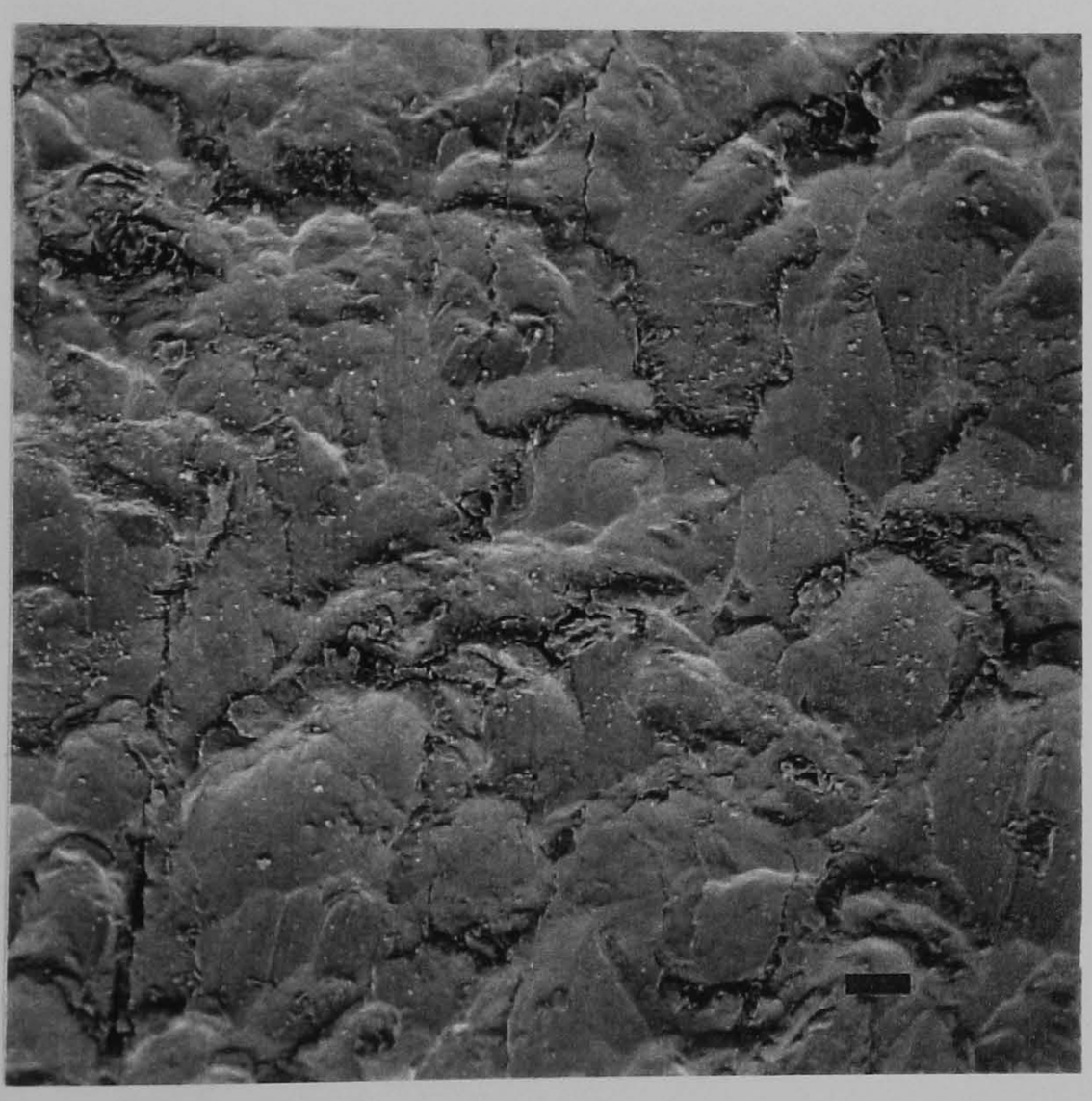


(D) 21 Day

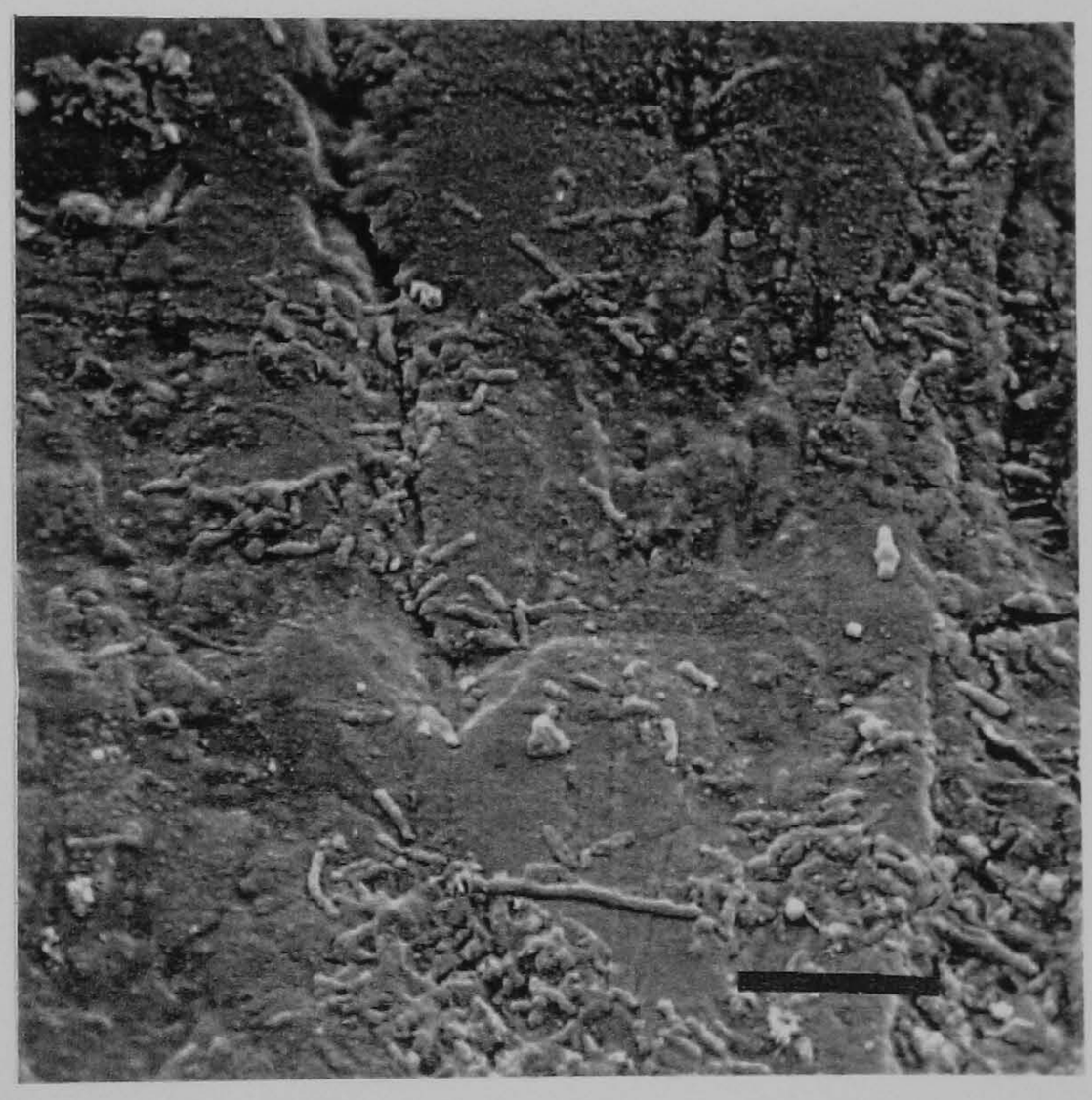
Figure 4.6 SEM of copper coupons exposed to temperatures of 55°C (Marker bar denotes 10 μm).

(A) 1 Day

(B) 7 Day



(C) 14 Day



(D) 21 Day

Figure 4.7 SEM of copper coupons exposed to temperatures of 60°C (Marker bar denotes 10 μm).

(A) 1 Day

(B) 7 Day

(C) 14 Day

(D) 21 Day

Table 4.4 Counts extrapolated from the total number of bacteria observed on the electron micrographs of biofilm generated on copper at 40°C

Day	Total Count	Error (±)	Log	Viable Count (Log)
1	0	-	-	2.5
7	94500	22050	4.9	2.8
14	0	-	-	2.2
21	nc	-	-	2.9

nc denotes no count

Table 4.5 Counts extrapolated from the total number of bacteria observed on the electron micrographs of biofilm generated on copper at 45°C

Day	Total Count	Error(±)	Log	Viable Count (Log)
1	0	-	-	3.7
7	0	-	-	3.8
14	nc	-	-	3.6
21	nc	-	-	3.7

nc denotes no count

Table 4.6 Counts extrapolated from the total number of bacteria observed on the electron micrographs of biofilm generated on copper at 50°C

Day	Total Count	Error(±)	Log	Viable Count (Log)
1	0	-	-	2.5
7	0	-	-	2.8
14	54990	6110	4.7	2.4
21	nc	-	-	3.43

nc denotes no count

Table 4.7 Counts extrapolated from the total number of bacteria observed on the electron micrographs of biofilm generated on copper at 55°C

Day	Total Count	Error	Log	Viable Count (Log)
1	0	-	-	4.9
7	0	-	-	4.7
14	0	-	-	4.85
21	83600	21660	4.92	4.8

nc denotes no count

4.3.3 Biofilm development of glass surfaces

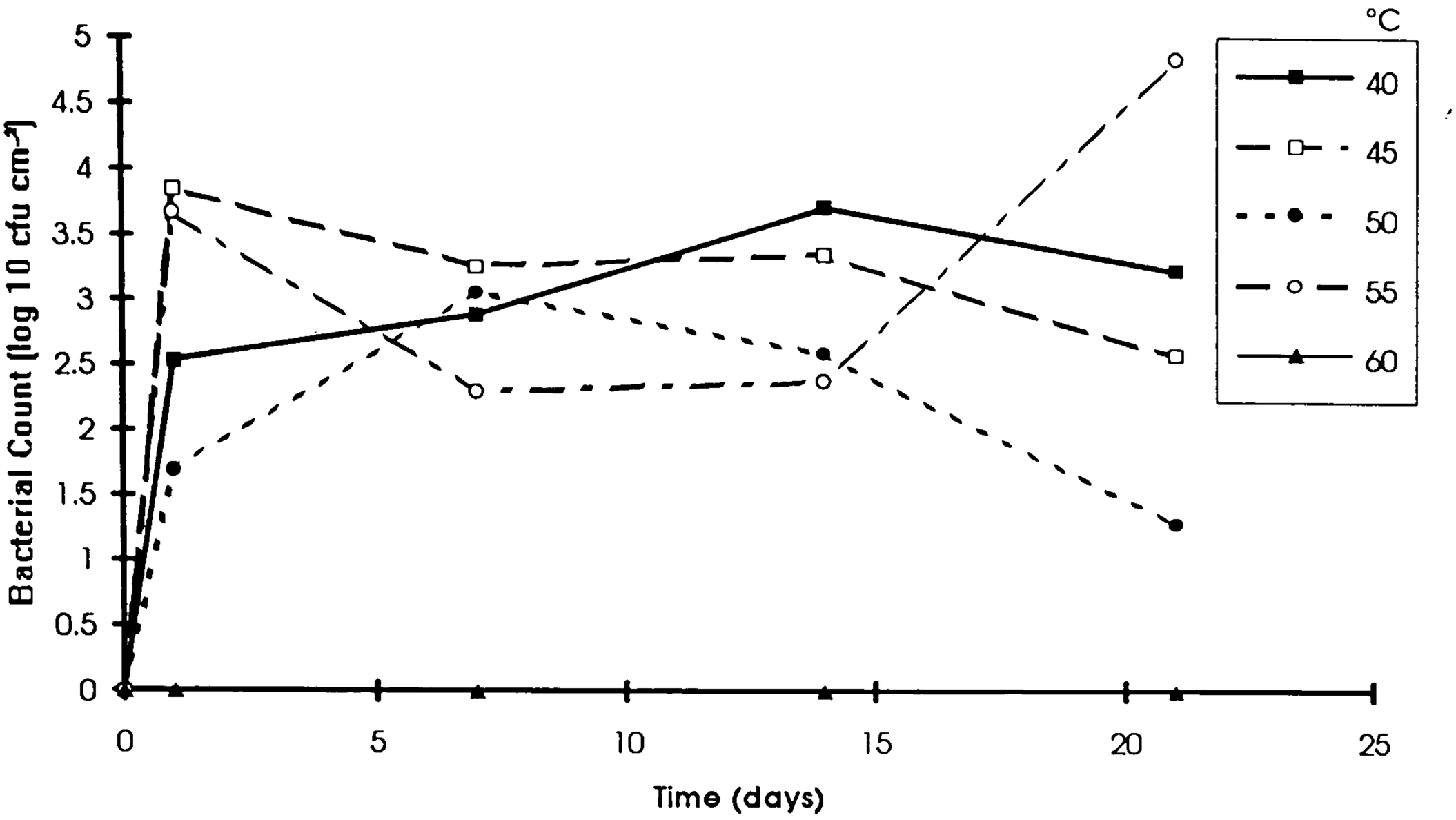


Figure 4.8 Colonisation of glass in the presence of copper.

From the biofilms examined at day 1 the lowest recovery of bacteria was at 50°C at 1.7 Log $_{10}$ cfu cm^{-2} with a maximum at 45°C of 3.8 Log $_{10}$ cfu cm^{-2} bacteria. At day 7 the recovery ranged from 2.3 Log$_{10}$ cfu cm^{-2} at 55°C to 3.4 Log $_{10}$ cfu cm^{-2}. A similar range of bacteria were recovered at day 14, 2.0 - 3.4 Log $_{10}$ cfu cm^{-2}, except at 55°C where 4.8 Log $_{10}$ cfu cm^{-2} bacteria were recovered. The range of viable bacteria recovered at day 21 ranged from 1.5 Log$_{10}$ cfu cm^{-2} at 50°C to 2.8 & 3.4 Log $_{10}$ cfu cm^{-2} bacteria being recovered at 45°C & 40°C respectively. At 55°C, 4.8 Log $_{10}$ cfu cm^{-2} were recovered. In comparison no bacteria were obtained from coupons immersed in the vessel at 60°C. There were no statistical differences obtained between 40 & 45°C and 45 & 55°C. In comparison the differences between 40 & 50°C, 45 & 50°C and 50 & 55°C are statistical different (P = 0.046, P = 0.027 and P = 0.046) respectively.

4.3.3.1 Profiles of the microbial types recovered from glass coupons (40-60° C).

(i) Percentage profile of microorganisms on glass at 40°C

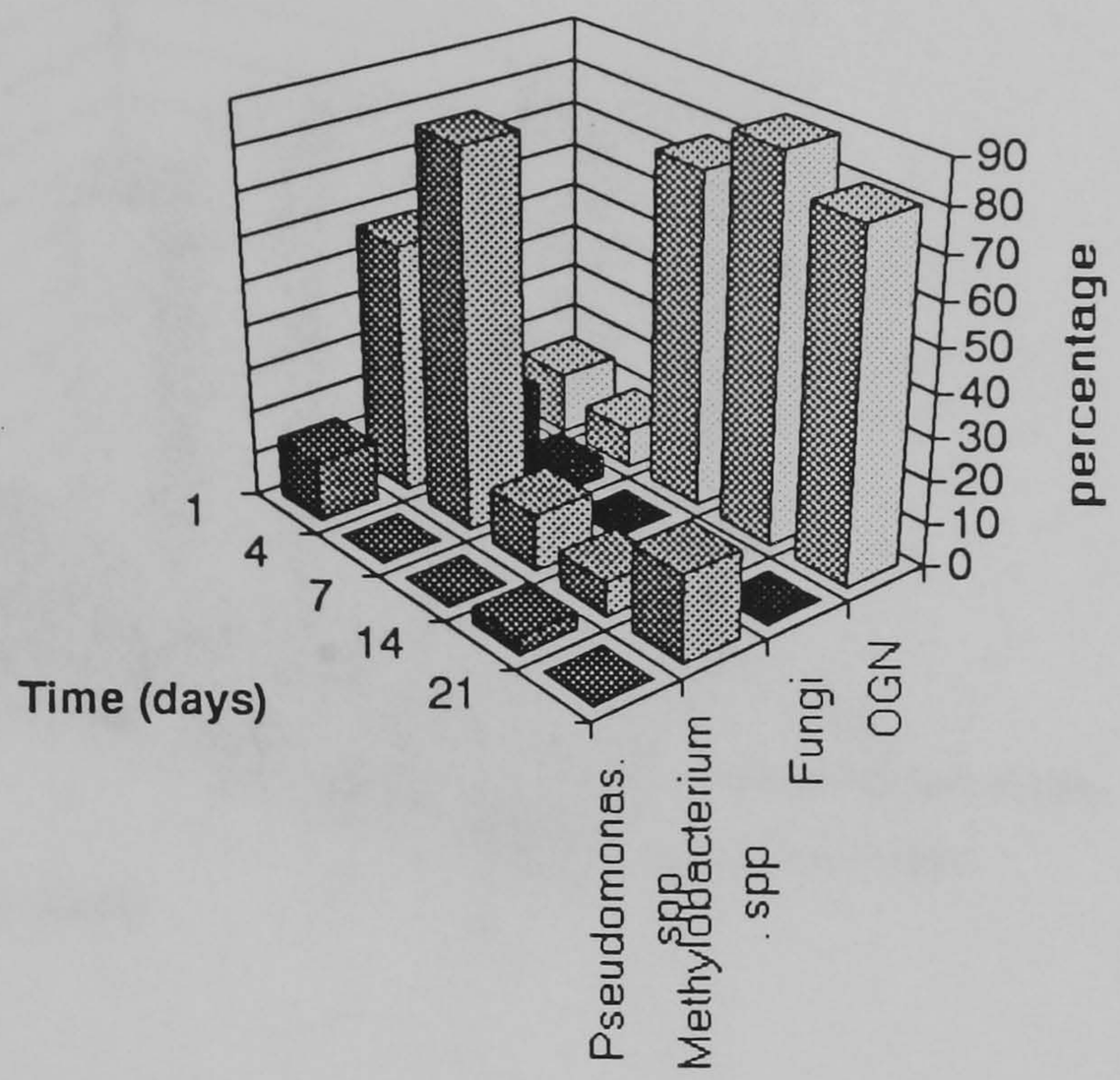


Figure 4.9 Percentage profile of microorganisms on glass at 40°C.

Table 4.8 Percentage profile of microbial species on glass at 40°C.

Species / Days	1	4	7	14	21
Pseudomonas spp.	12	0	0	4	0
Methylobacterium spp.	64	86	13	8	20
Aspergillus fumigatus	12	5	0	0	0
Gram negative bacteria	12	9	77	88	80

Pseudomonas spp. were recovered on day 1 at 12% and at 4% at day 14. *A. fumigatus* was only recovered at days 1 & 4 at 12% and 5% respectively. *Methylobacterium* spp. dominated at days 1 & 7 at 64% & 86% but were only recovered at less than 20% up to day 21. OGN were only recovered at 12% & 9% at day 1 & 7 before dominating the population at > 80% for the remainder of the experiment.

(ii) Percentage profile of bacteria on glass in soft water at 45°C.

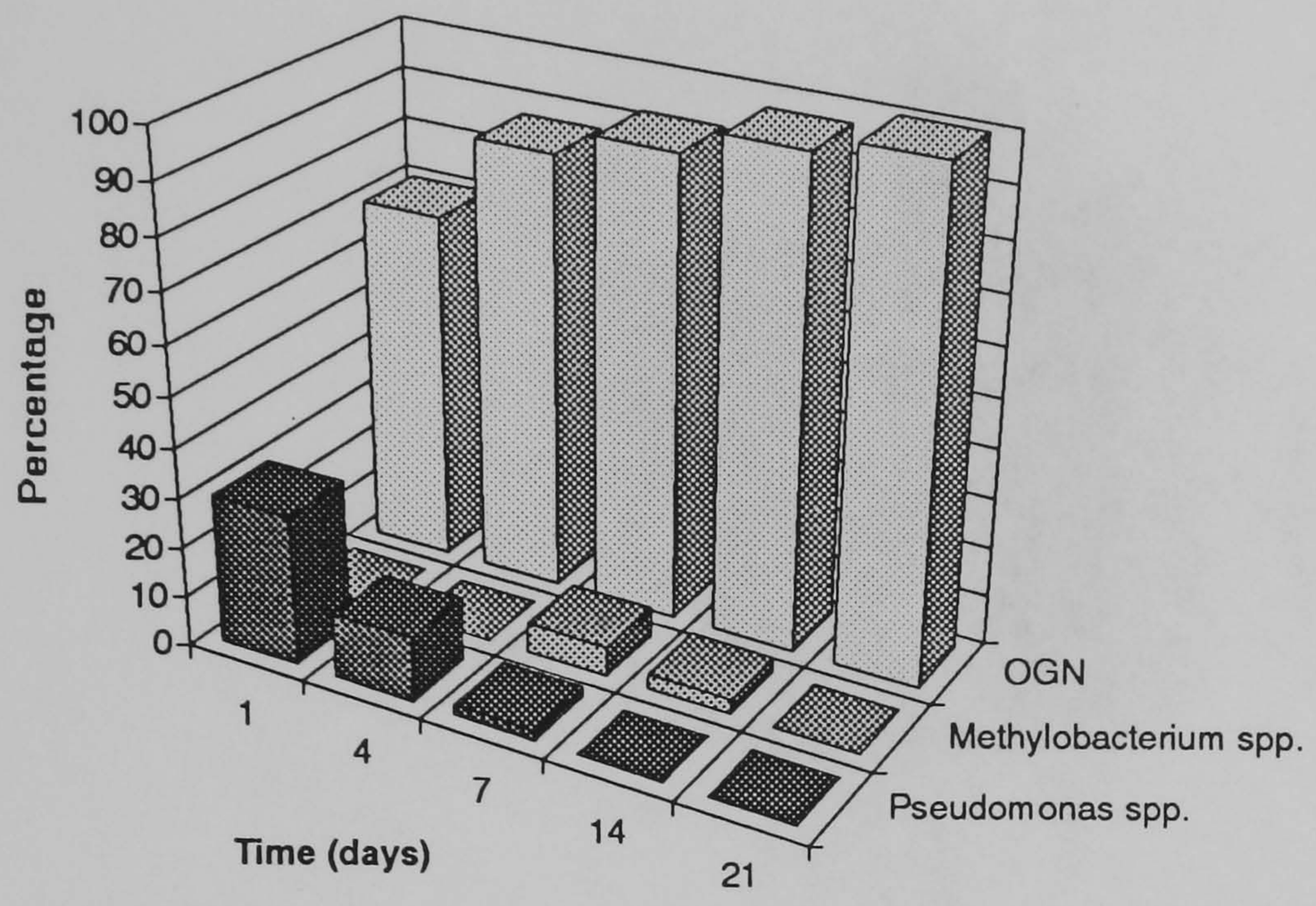


Figure 4.10 Percentage profile of bacteria on glass at 45°C.

Table 4.9 Percentage profile of bacterial species on glass at 45°C.

Species / Days	1	4	7	14	21
Pseudomonas spp.	30	13	2	0	0
Methylobacterium spp.	0	0	6	3	0
Gram negative bacteria	70	87	92	97	100

Recovery of bacteria from glass at 45°C was dominated by OGN from day 1 to day 21. *Pseudomonas* spp. were present on day 1 at 30 % but steadily declined as part of the flora until day 14 when they were not detected. *Methylobacterium* spp. were only present in detectable numbers at days 7 and 14 but represented less than 10 % of the total population.

(iii) Percentage profile of microorganisms on glass at 50°C in soft water.

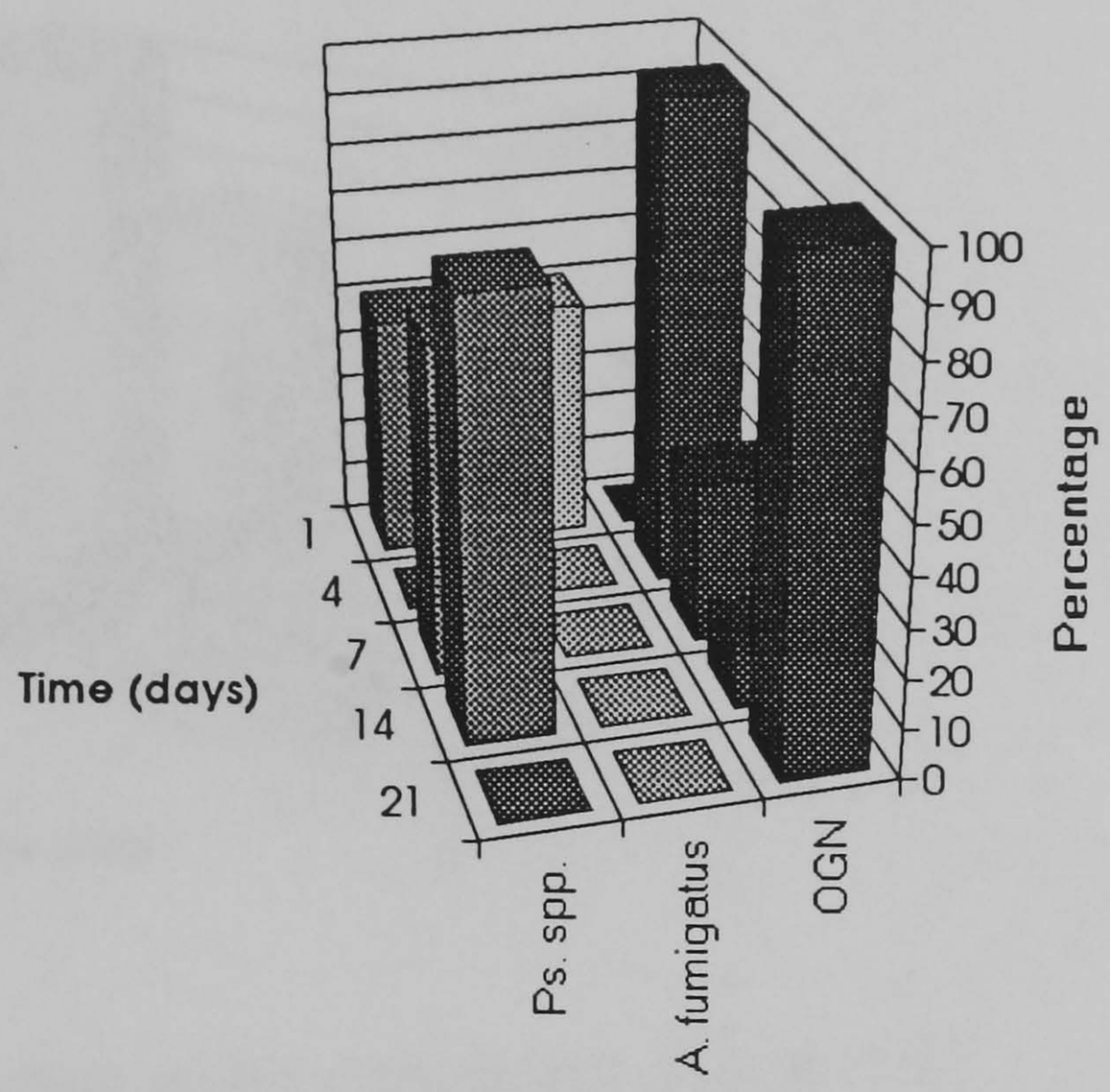


Figure 4.11 Percentage profile of microorganisms on glass at 50°C.

Table 4.10 Percentage profile of microbial species on glass at 50°C.

Species / Day	1	4	7	14	21
Pseudomonas spp.	50	0	67	87	0
Aspergillus fumigatus	50	0	0	0	0
Gram negative bacteria	0	100	33	13	100

At this temperature *Pseudomonas* spp. and *A. fumigatus* were recovered in equal numbers at day 1 but only OGN were detected at day 4. At day 14 *Pseudomonas* spp. dominated over OGN which were the only bacteria present at day 21.

(iv) Percentage profile of bacteria on glass at 55°C in soft water.

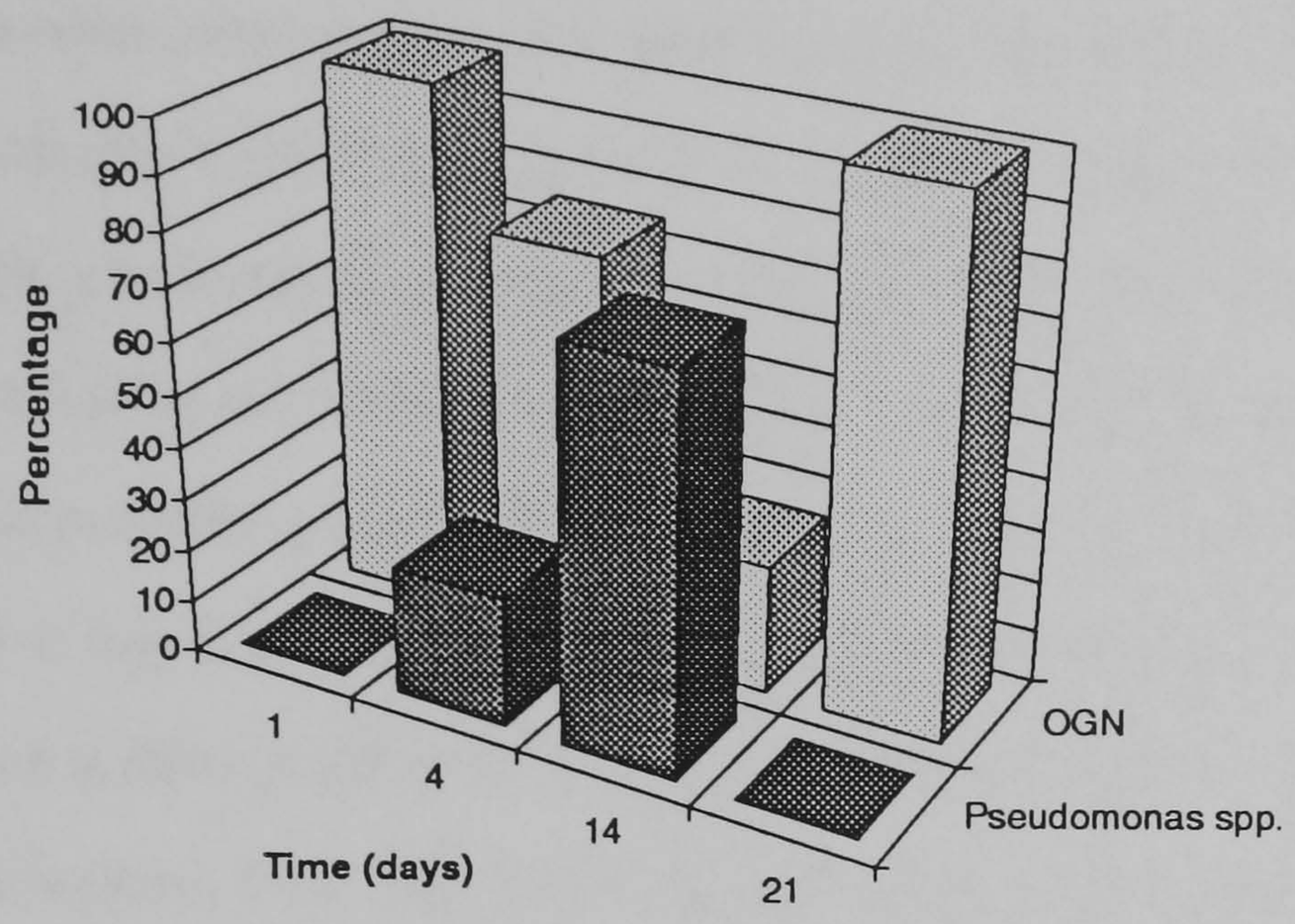


Figure 4.12 Percentage profile of bacteria on glass at 55°C.

Table 4.11 Percentage profile of bacterial species on glass at 55°C.

Species / Day	1	7	14	21
Pseudomonas spp.	0	25	75	0
Aspergillus fumigatus	0	0	0	0
Gram negative bacteria	100	75	25	100

The OGN dominated at all but day 14 where they were succeeded by the *Pseudomonas* spp. which were only present at day 4 and day 14.

4.3.3.2 SEM of glass coupons exposed to 40-60° C.

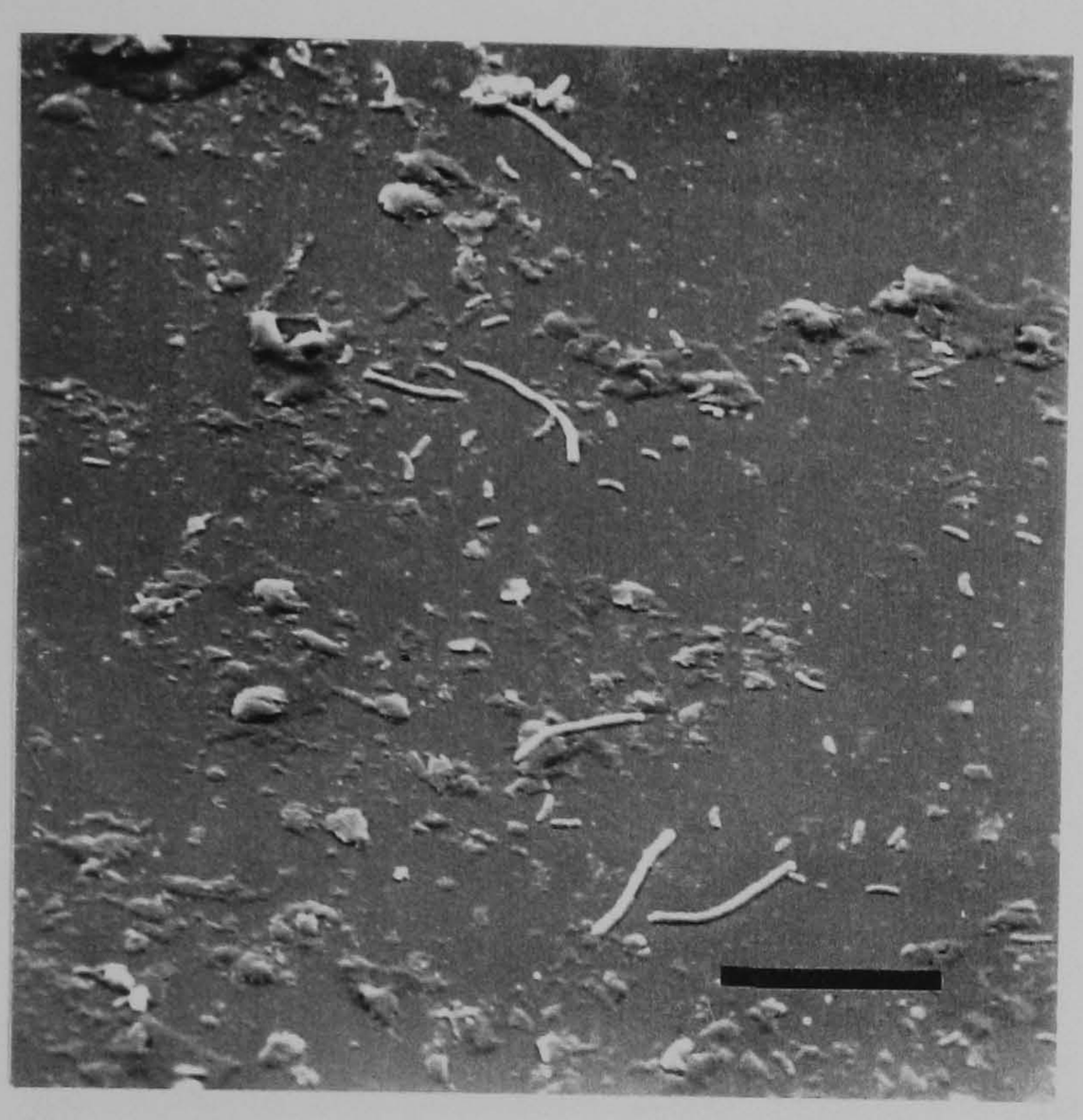
Bacteria were observed on the glass coupons extracted from the culture vessel at 40°C from day 1 (4.77 Log $_{10}$ bacteria cm^{-2}) to day 21 (4.70 Log $_{10}$ bacteria cm^{-2}). Although not shown, similar profiles were observed at 45°C and 50°C. At 45°C, 4.61 Log $_{10}$ bacteria cm^{-2} were counted at day 1 and 4.19 Log $_{10}$ bacteria cm^{-2} at day 21. From the coupons immersed in the culture at 50°C, 3.45 Log $_{10}$ bacteria cm^{-2} were counted at day 1 and 4.51 Log $_{10}$ bacteria cm^{-2} at day 21. At 55°C there appears to have been a slow build up with only a few bacteria spread over the surface at day 1, which correlates with only 3.64 Log $_{10}$ bacteria cm^{-2} counted on the coupons. The number of bacteria enumerated from the micrographs was 4.49 and 4.74 Log $_{10}$ bacteria cm^{-2} at days 7 and 14 respectively. At day 21 a microcolony can be observed over the surface with the number in individual bacteria counted remaining high at 4.72 Log $_{10}$ bacteria cm^{-2}. Particulate matter can be seen on the glass coupons which had been immersed in the vessel at 60°C. Indeed one or two bacteria can be seen on the coupons extracted at day 7.

Glass Surfaces

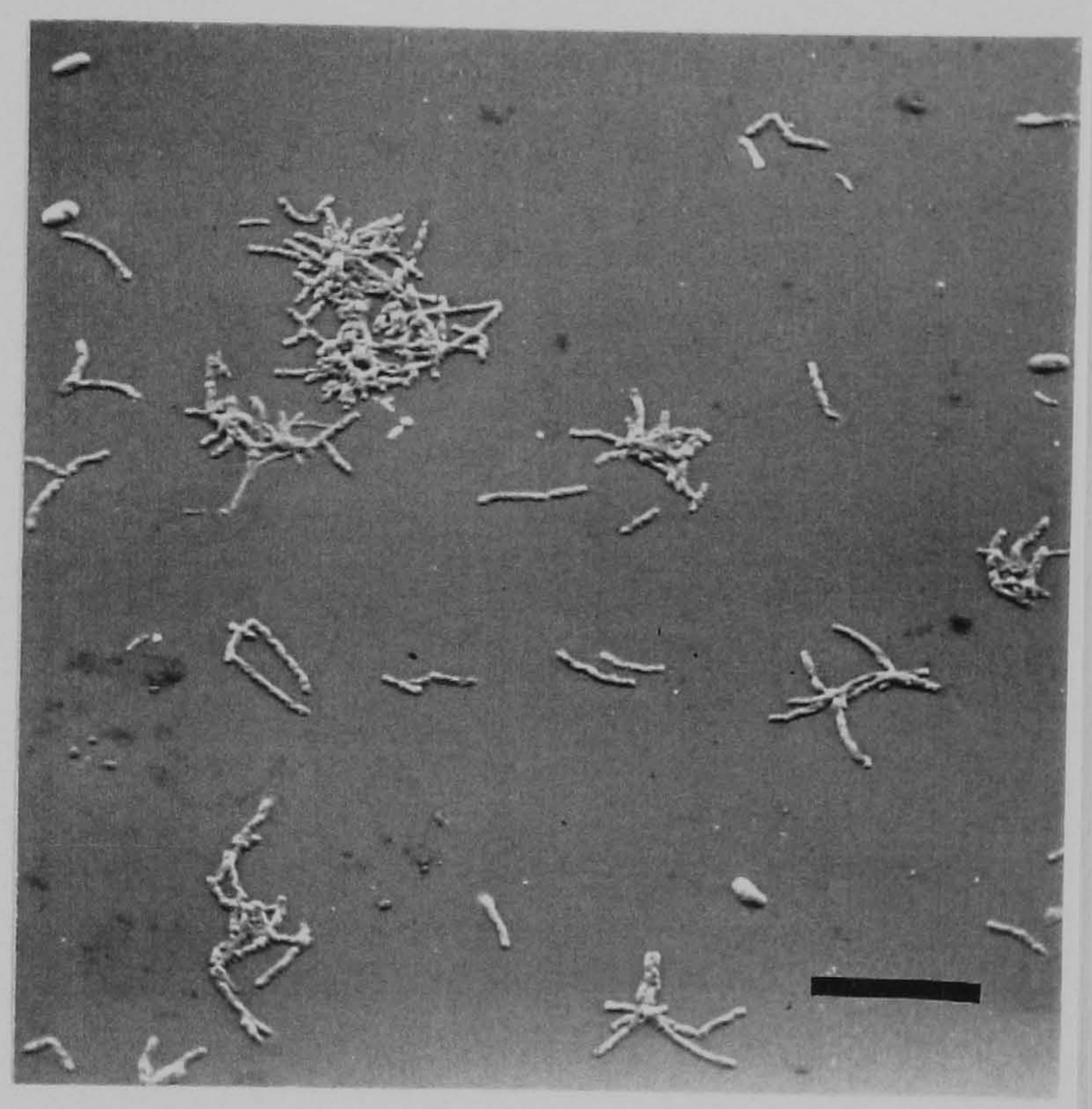
As in the population profiles from the copper surfaces the same four groups of microorganisms were identified from the glass coupons at 40°C. On the glass coupons *Methylobacterium* spp. dominated at day 1 and 4 but were succeeded by the OGN which dominated thereafter. From glass coupons at 45°C the *Methylobacterium* spp. were transiently present at days 7 and 14. *Pseudomonas* spp. were initially present but did not form part of the consortia after day 7. The OGN dominated over the time course. At 50°C *A. fumigatus* was present at day 1 but was not recovered after this. The *Pseudomonas* spp. and the OGN exhibited transient dominance with the OGN succeeding at day 21. As with the copper surface at 55°C there were only two species recovered from the glass coupons at 55C, *Pseudomonas* spp. and OGN, the latter of which dominated.

At 40°C the four bacterial groups were present on both copper and glass surfaces. *A. fumigatus* and OGN dominated at day 1 on copper but on glass the *Methylobacterium* spp. dominated at day 1 and 4. Although the *Pseudomonas* spp., *Methylobacterium* spp. and *A. fumigatus* were present the OGN dominated until day 21. *A. fumigatus* was initially present at day 1 (copper) and at days 1 and 4 on glass but not thereafter. *Pseudomonas* spp. was transiently present on both surfaces and apart from day 1 (copper) *Methylobacterium* spp. were also present as part of the population. On copper at 45°C the species diversity decreased with *A. fumigatus* only recovered at day 7 with OGN dominating from day 7 to day 21. On both copper and glass the species diversity increased again as the temperature was increased to 50°C. On copper the *Pseudomonas* spp. dominated at days 1, 7,and 14 (with *A. fumigatus* on glass at day 1). At days 4 and 21 the OGN dominated on both copper and glass. At 55°C the species diversity decreased again with only *Pseudomonas* spp. and OGN bacteria being recovered. On copper the OGN dominated from day 1 to 21 and on glass the *Pseudomonas* spp. only dominated at day 14.

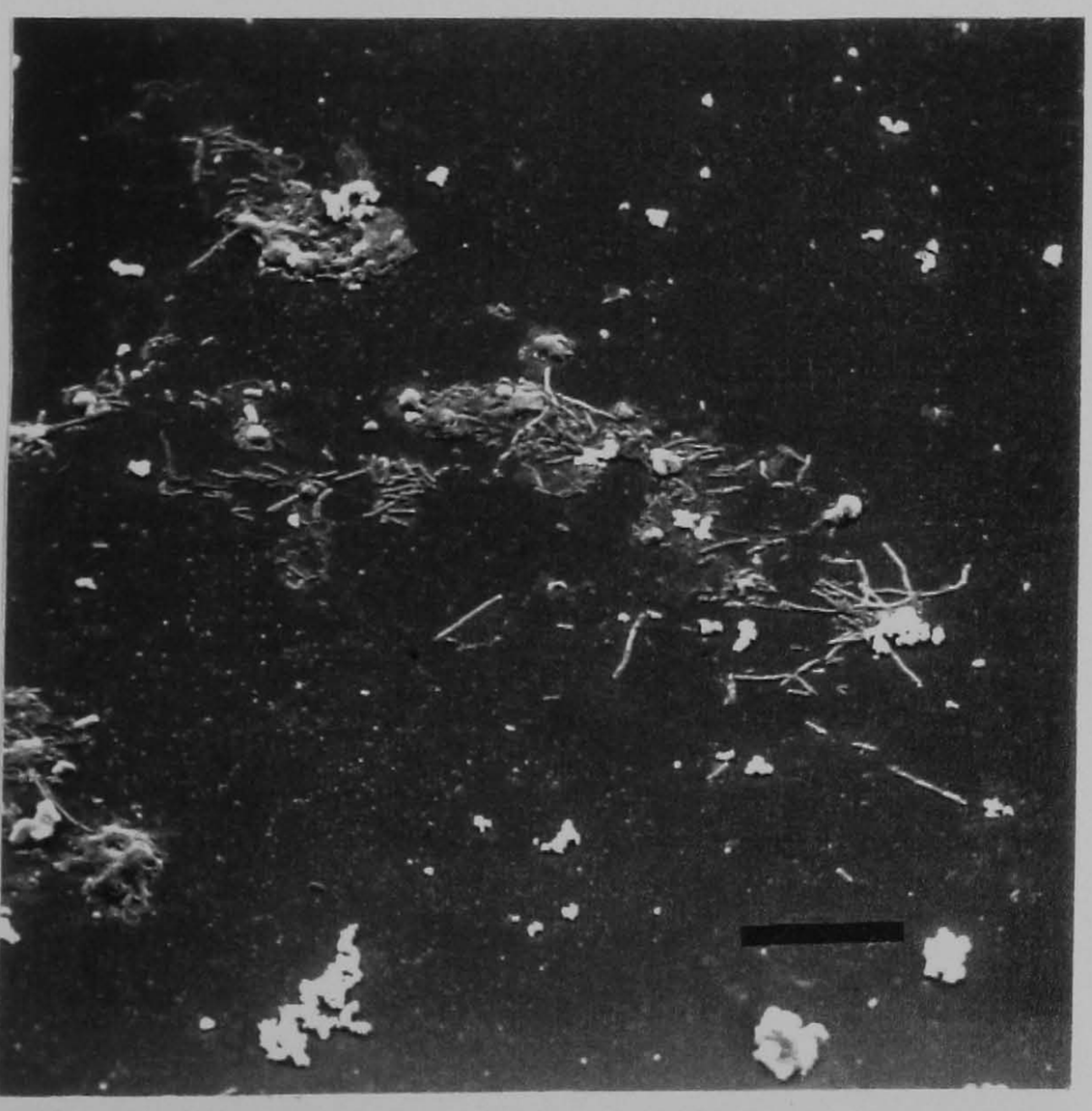
Figure 4.13 SEM of glass coupons exposed to temperatures of 40°C (Marker bar denotes 10 μm).



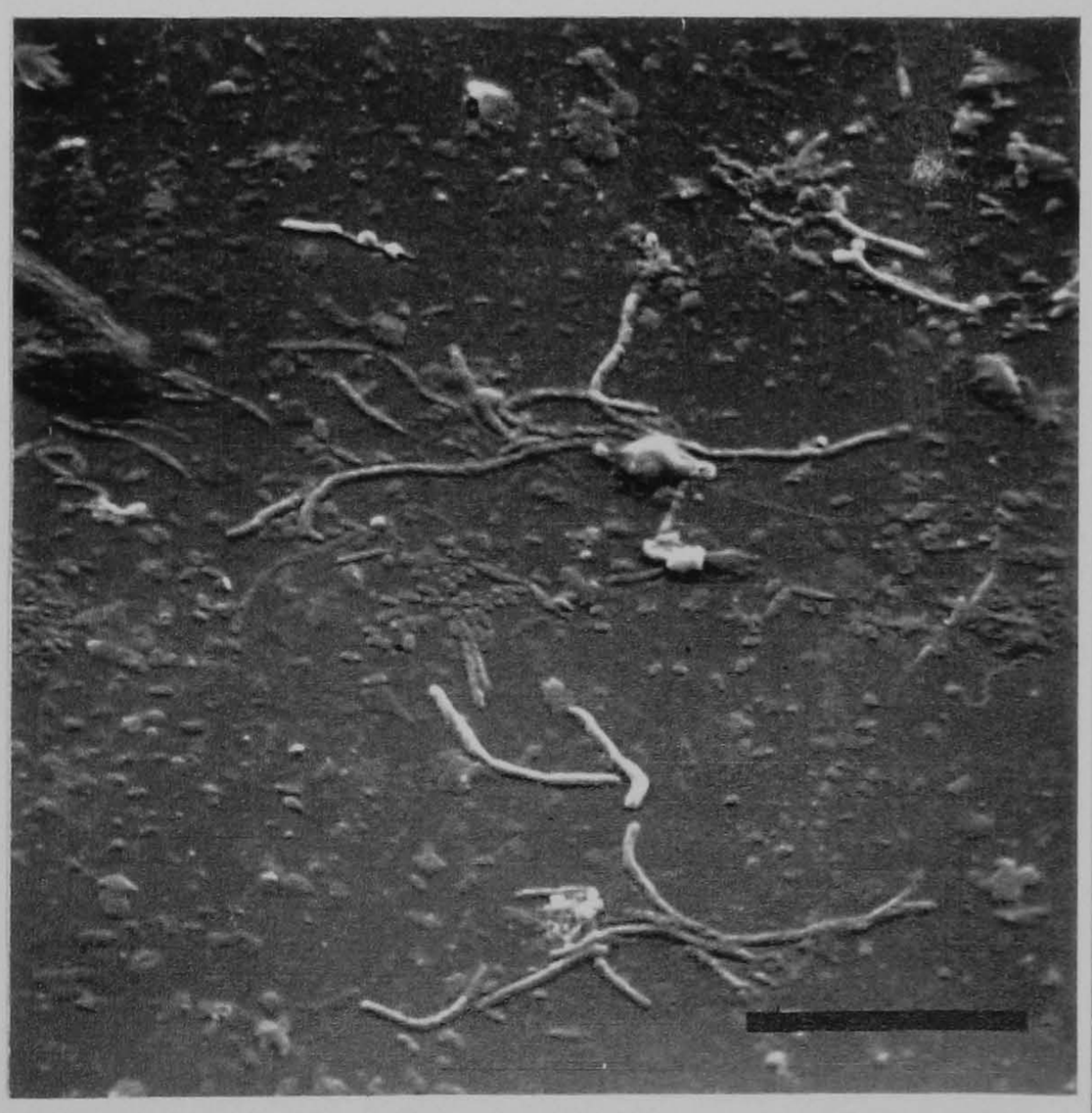
(A) 1 Day



(B) 7 Day

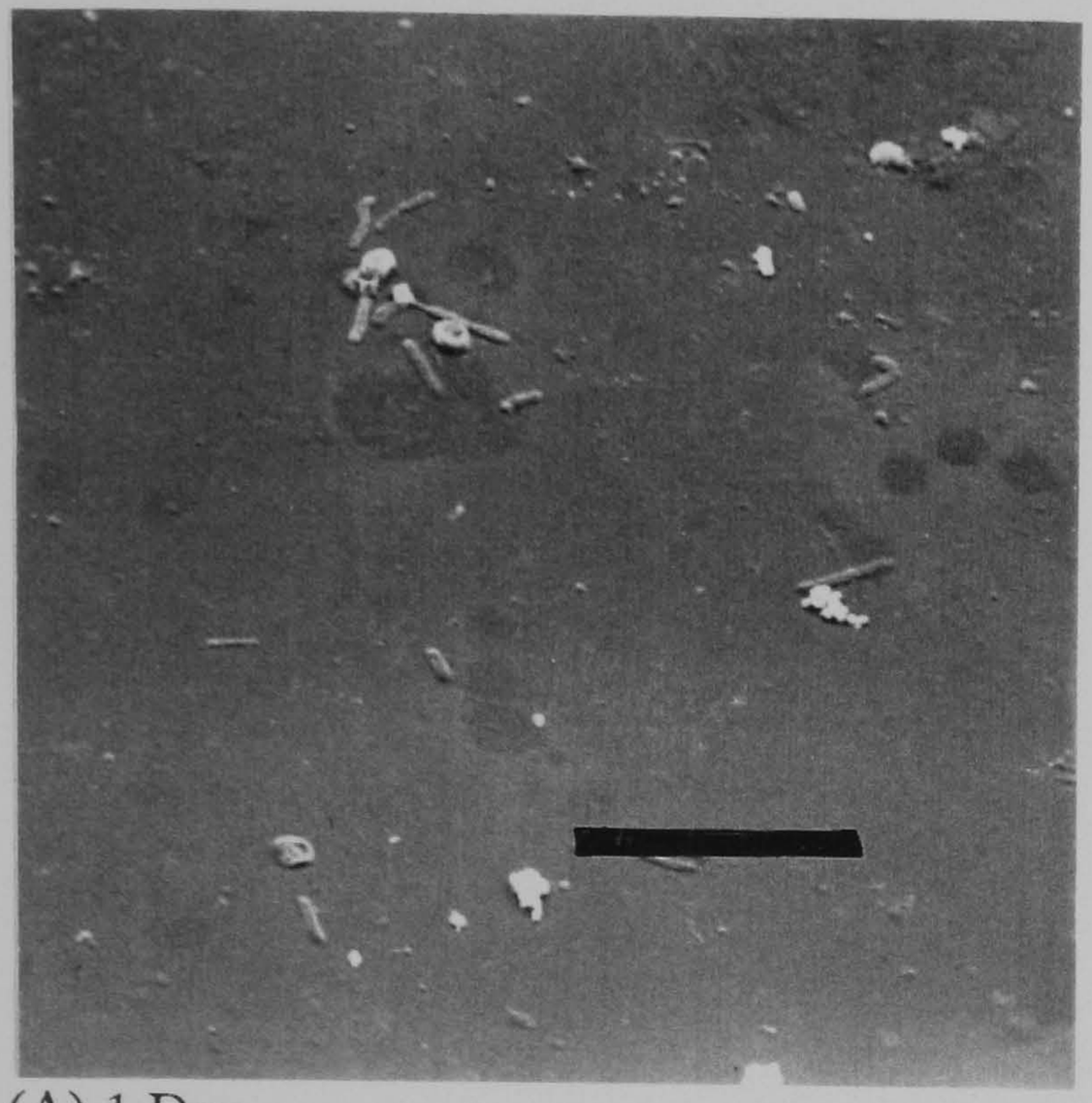


(C) 14 Day

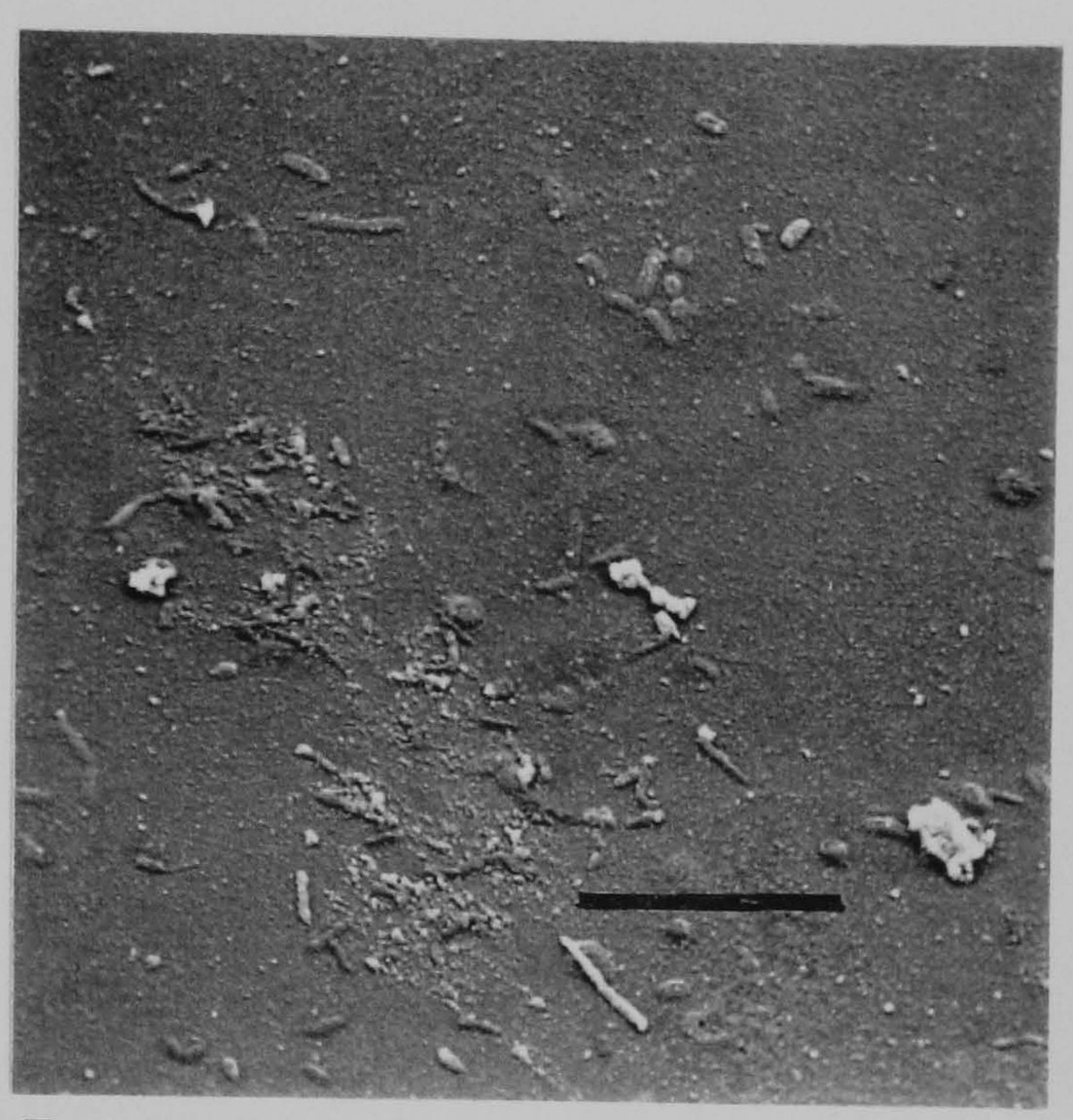


(D) 21 Day

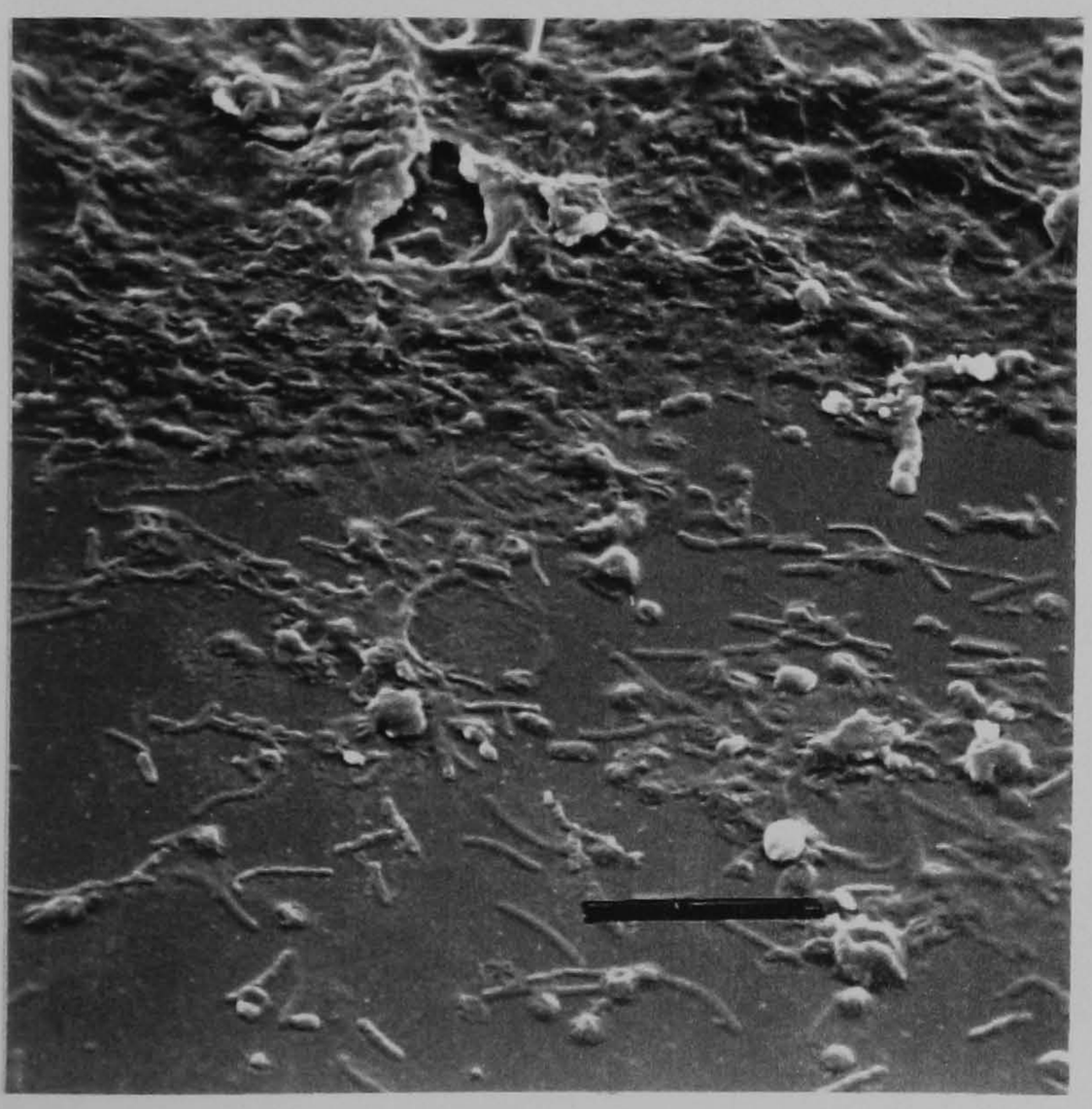
Figure 4.14 SEM of glass coupons exposed to temperatures of 55°C (Marker bar denotes 10 μm).



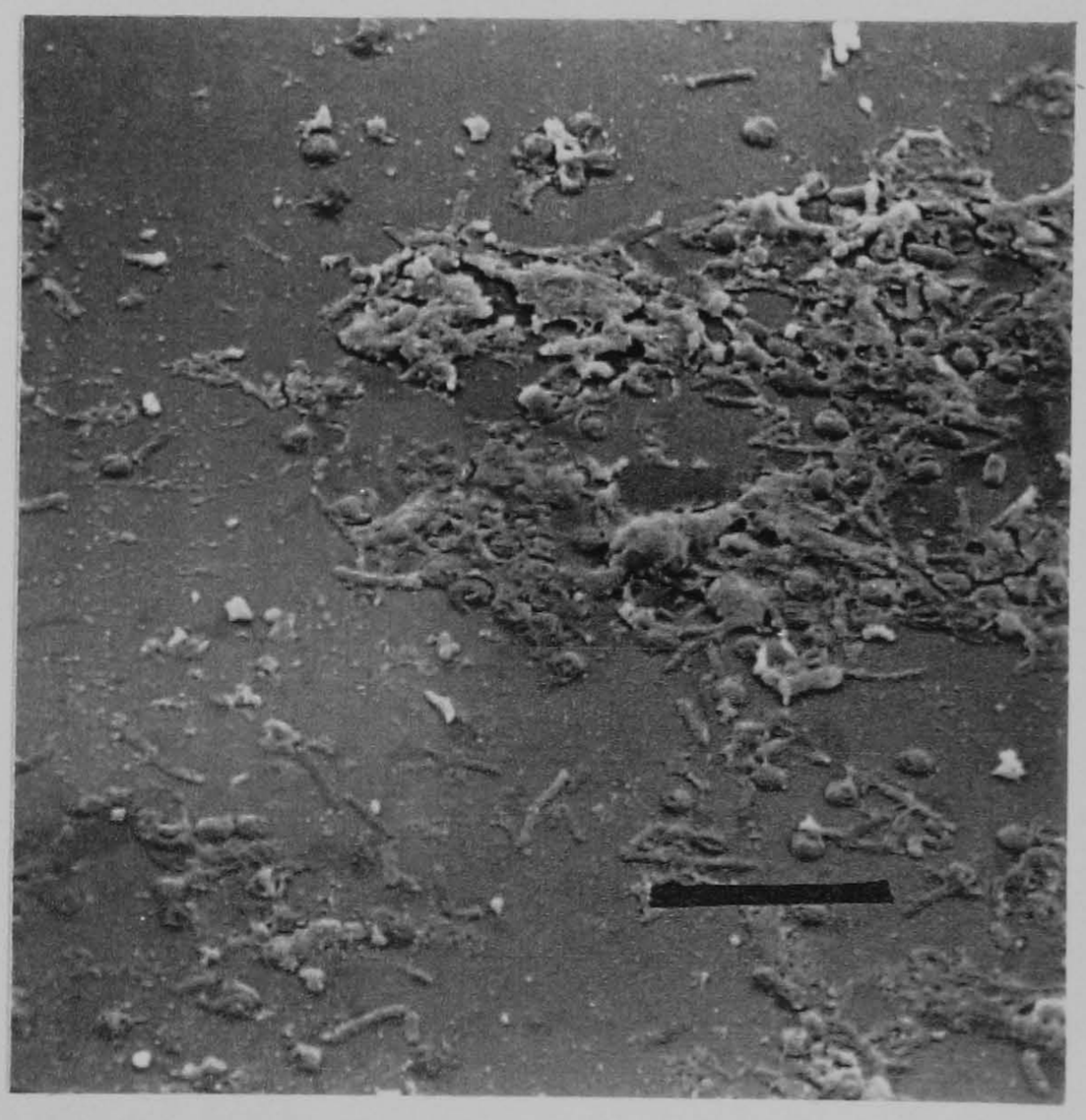
(A) 1 Day



(B) 7 Day

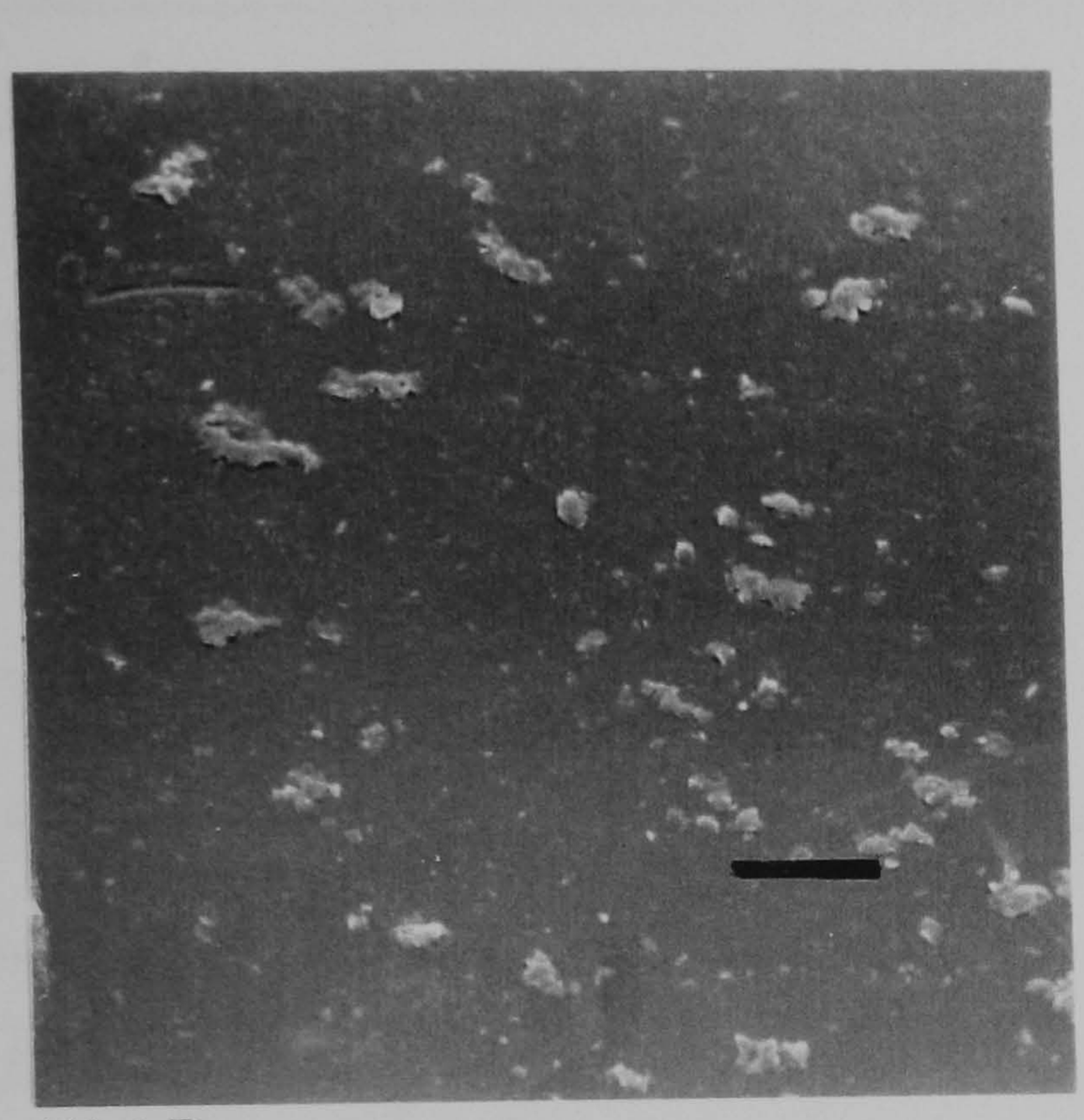


(C) 14 Day

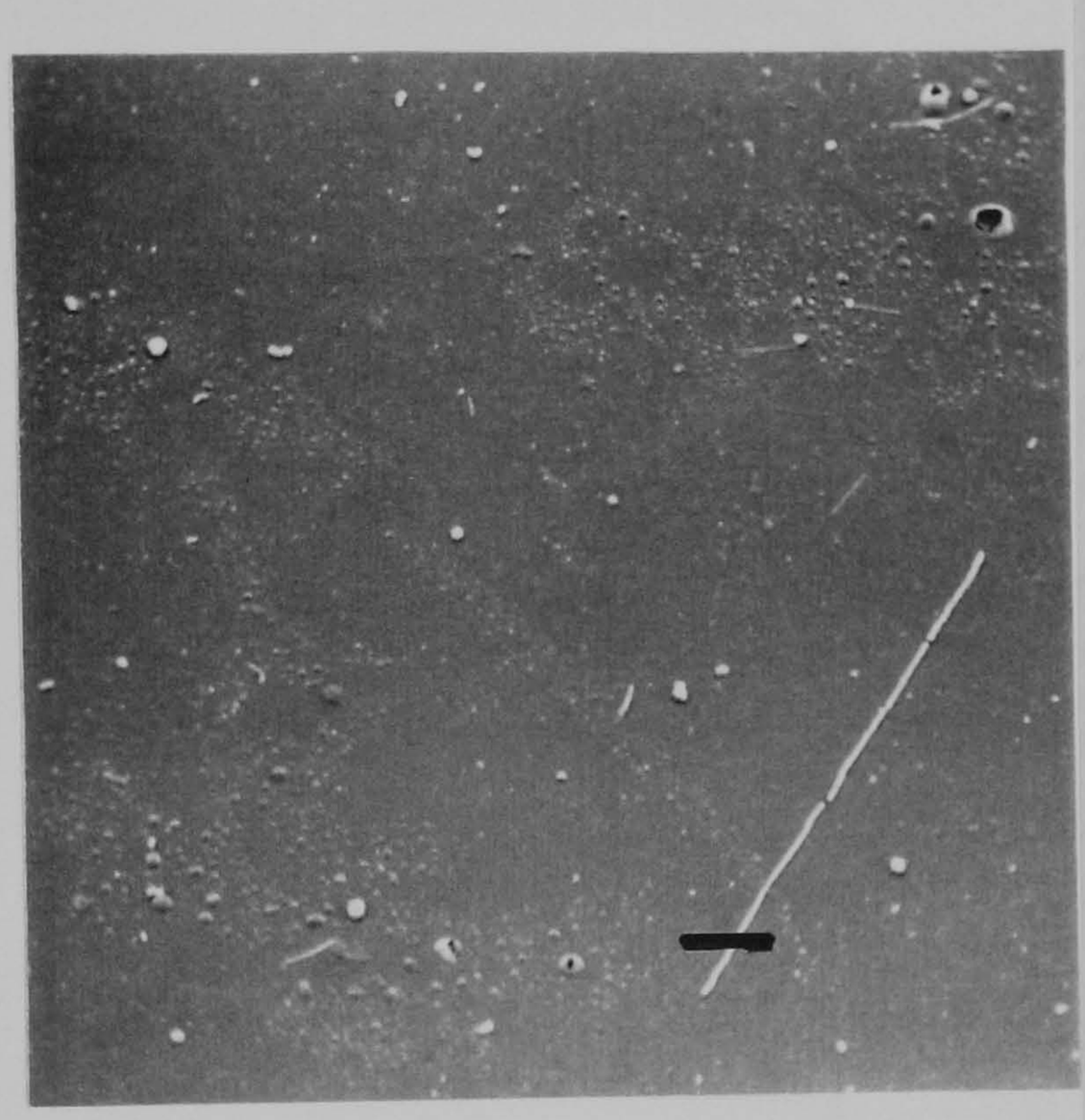


(D) 21 Day

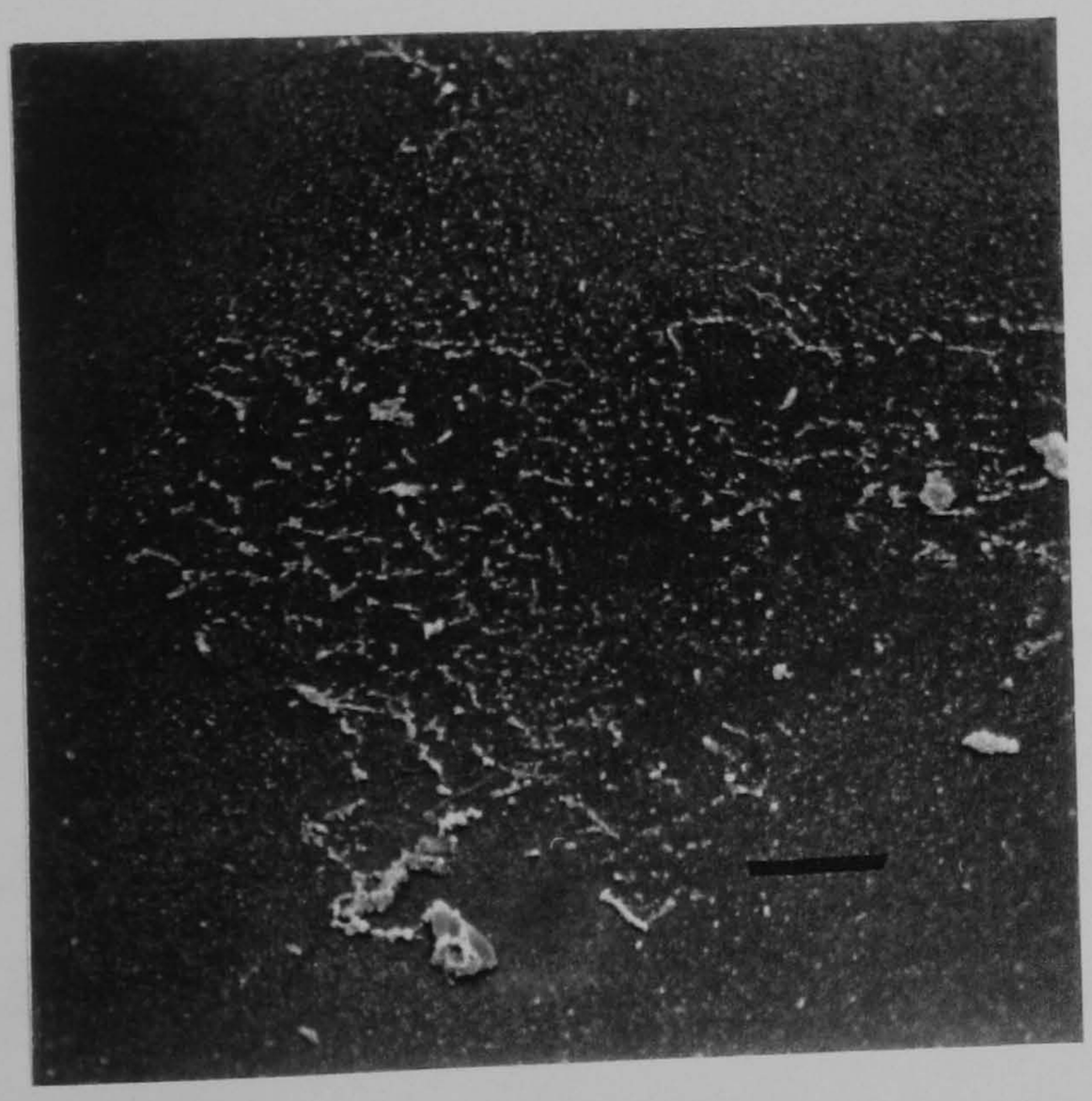
Figure 4.15 SEM of glass coupons exposed to temperatures of 60°C (Marker bar denotes 10 μm).



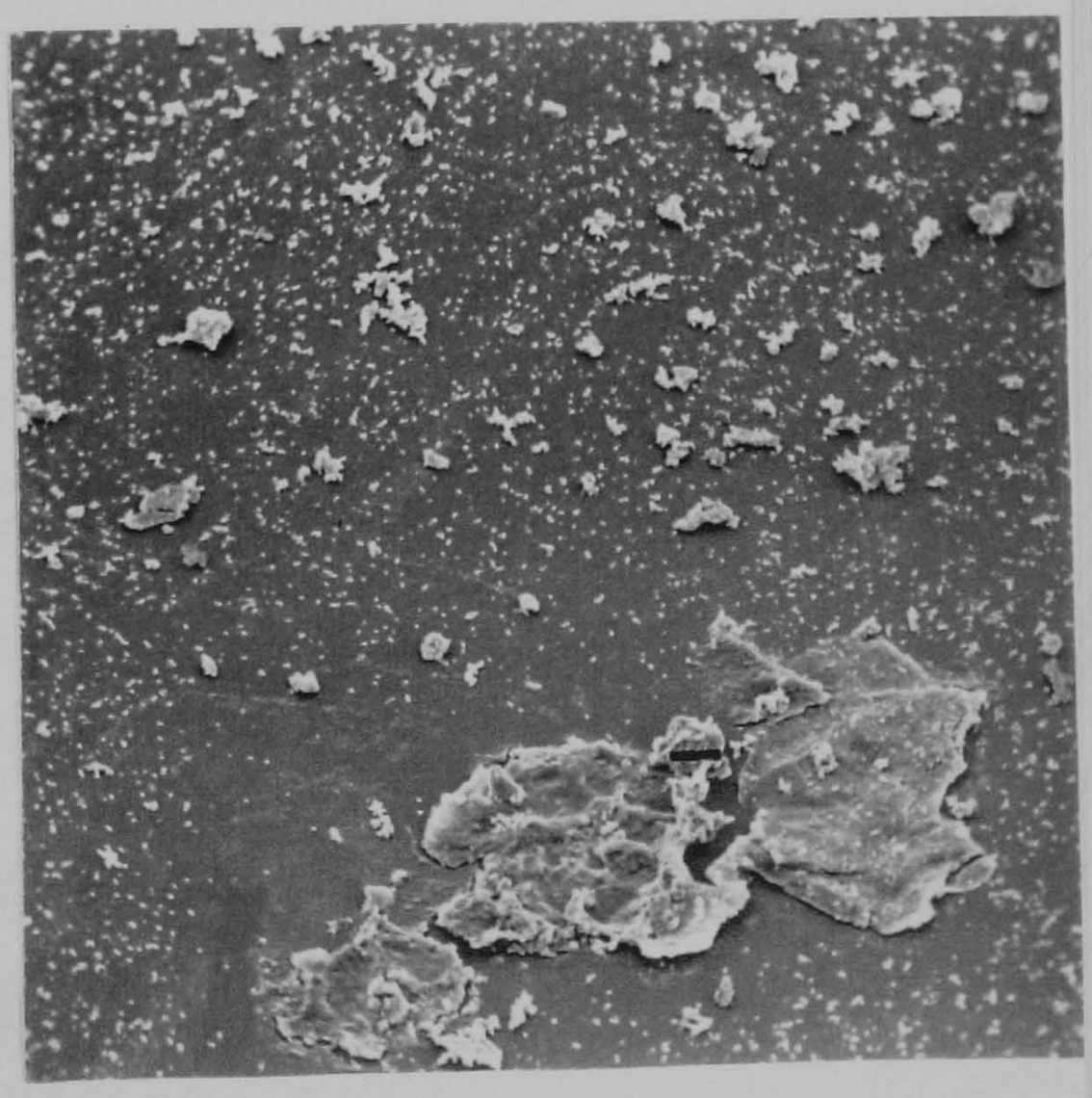
(A) 1 Day



(B) 7 Day



(C) 14 Day



(D) 21 Day

Table 4.12 Counts extrapolated from the total number of bacteria observed on the electron micrographs of biofilm generated on glass at 40°C

Day	Total Count	Error(±)	Log	Viable Count (Log)
1	59600	12800	4.77	2.54
7	68400	45300	4.8	2.9
14	30100	3500	4.47	3.7
21	50400	6900	4.7	3.26

Table 4.13 Counts extrapolated from the total number of bacteria observed on the electron micrographs of biofilm generated on glass at 45°C

Day	Total Count	Error(±)	Log	Viable Count (Log)
1	40800	25500	4.6	3.84
7	17100	14200	4.23	3.27
14	38815	2800	4.6	3.37
21	15540	24300	4.19	2.6

Table 4.14 Counts extrapolated from the total number of bacteria observed on the electron micrographs of biofilm generated on glass at 50°C

Day	Total Count	Error(±)	Log	Viable Count (Log)
1	1425	1425	3.45	1.69
7	70200	33000	4.84	3.07
14	22950	15000	4.36	2.6
21	32760	6384	4.51	1.3

Table 4.15 Counts extrapolated from the total number of bacteria observed on the electron micrographs of biofilm generated on glass at 55°C

Day	Total Count	Error(±)	Log	Viable Count (Log)
1	4400	2800	3.64	3.66
7	31080	9250	4.5	2.3
14	55000	70404	4.74	2.39
21	53460	16170	4.72	4.88

4.4 REPEAT OF BIOFILM DEVELOPMENT BETWEEN 40-60°C.

4.4.1 Repeat biofilm development of copper surfaces

After studying colonisation of glass and copper between 40°C and 60°C the temperature was raised up to 80°C in 5.0°C increments before returning to 40°C. The ability of the bacteria to colonise the surface of copper and glass coupons was then examined again to see if exposure to increased temperatures had altered the profile of bacterial colonisation of the surfaces between 40 - 60°C

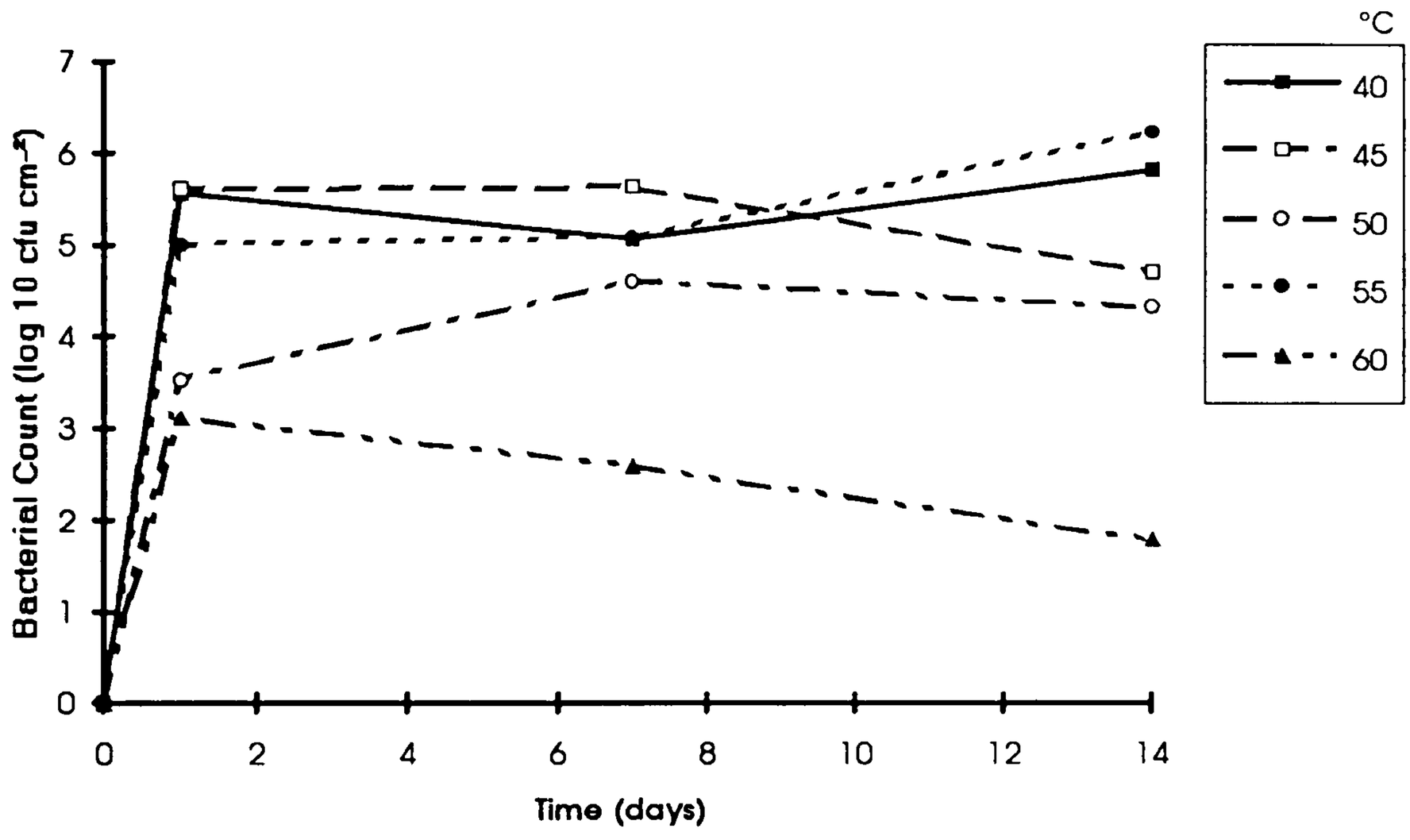


Figure 4.16 Colonisation of copper coupons in Glasgow water after temperature of culture had been increased to 80°C.

Rapid colonisation of the copper occurred at 3.5 - 5.8 Log $_{10}$ cfu cm^{-2} (40-55°C) within 24 hours of the surfaces being immersed in the culture. Bacteria were recovered from the copper coupons between 40°C and 55°C. Bacterial numbers recovered at 40°C, 50°C and 55°C remained constant or increased (4.7 - 6.2 Log $_{10}$ cfu cm^{-2}) until day 14. At 45°C the number of bacteria recovered at day 14

decreased by 0.9 Log $_{10}$ cfu cm^{-2}. Although bacteria were recovered from coupons which were exposed to the culture at 60°C, only 3.9 Log $_{10}$ cfu cm^{-2} viable bacteria were detected at day 1 and this number decreased to 2.3 Log$_{10}$ cfu cm^{-2} at day 14. There were no significant differences between the bacterial numbers recovered between 40 & 55°C and 45°C & 55°C ($p = >0.05$). However there were statistical difference between 40°C & 45°C, 40 & 50°C, 45 & 50°C, 50 & 55°C, 40 & 60°C, 45 & 60°C and 55 & 60°C where $p = <0.05$).

(i) Percentage profile of bacteria recovered from copper coupons at 40°C

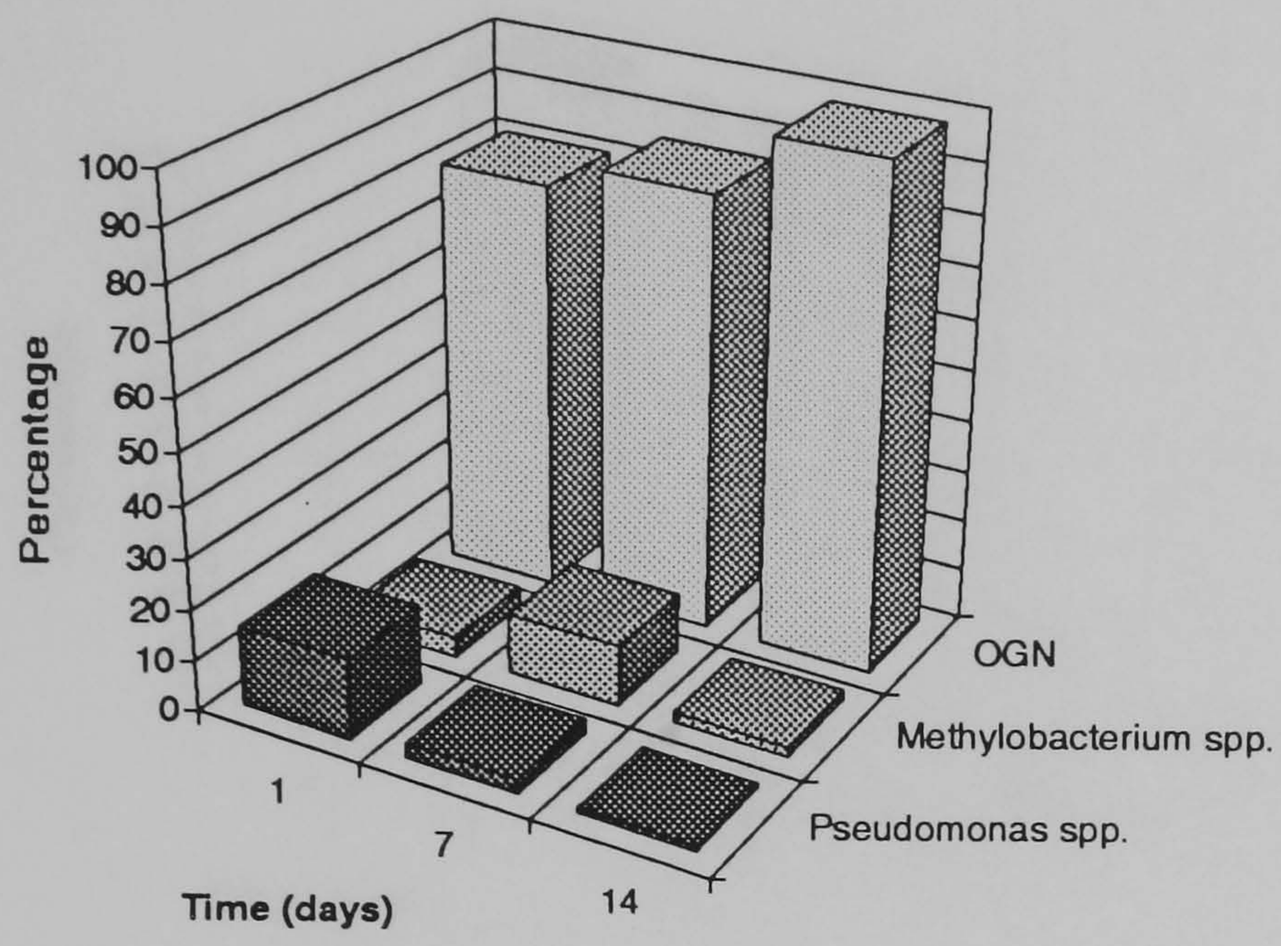


Figure 4.17 Percentage profile of bacteria on copper at 40°C in Glasgow water after 80°C temperature cycle.

Table 4.16 Percentage profile of microbial species on copper at 40°C.

Species / Days	1	7	14
Pseudomonas spp.	16	3	1
Methylobacterium spp.	4	12	2
Aspergillus fumigatus	0	0	0
Gram negative bacteria	80	85	97

Although the *Pseudomonas* spp. were present at 16 % at day 1 their proportions declined to 3 & 1 % at days 7 & 14 respectively. *Methylobacterium* spp. were present throughout all days with a maximum of 12 % at day 7, with the OGN bacteria predominating at 80, 85 and 97 % respectively.

(ii) Percentage profile of bacterial recovered from copper coupons at 45°C

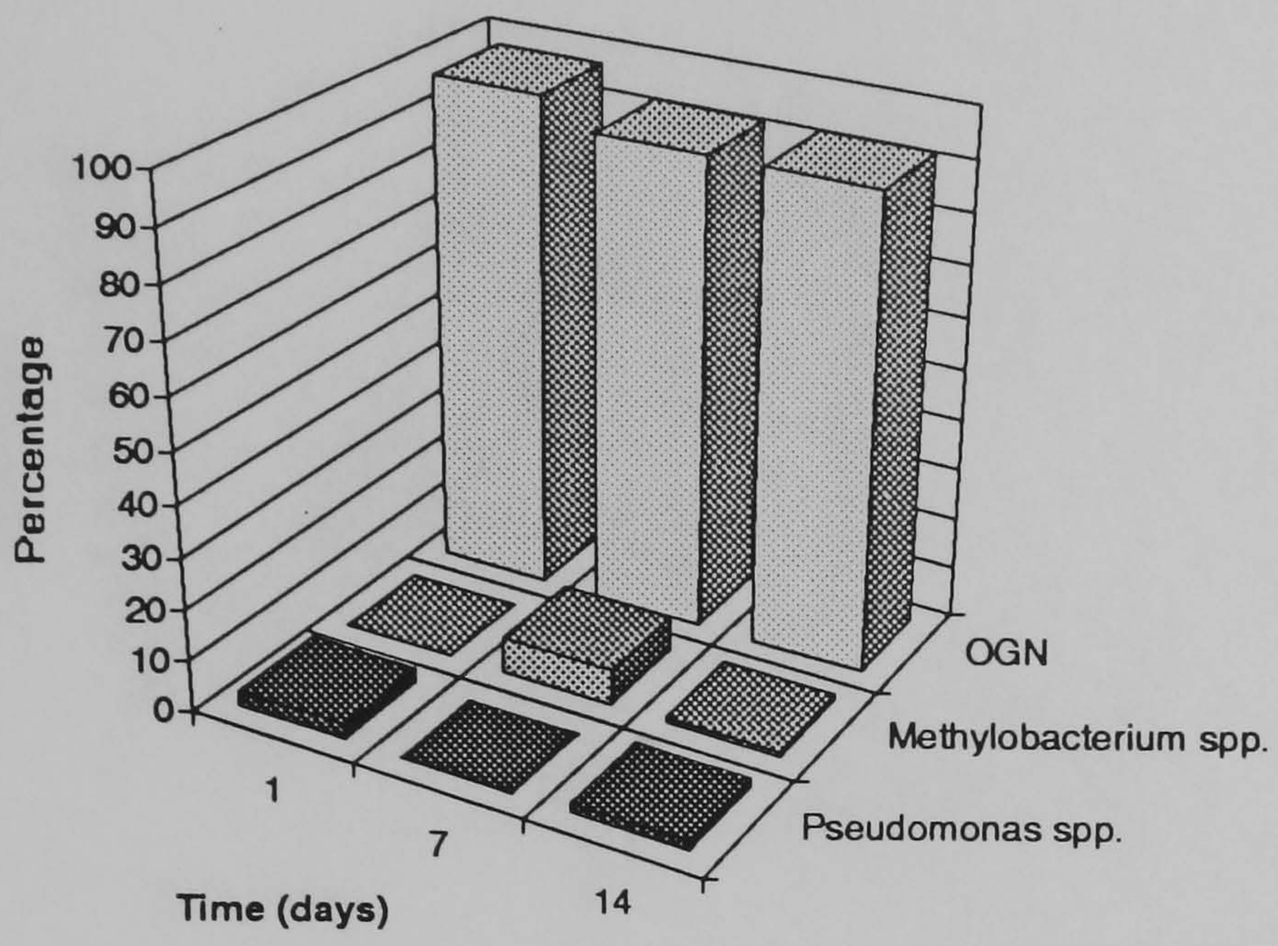


Figure 4.18 Percentage profile of bacteria on copper at 45°C in Glasgow water after 80°C temperature cycle.

Table 4.17 Percentage profile of microbial species on copper at 45°C.

Species / Days	1	7	14
Pseudomonas spp.	3	0	1
Methylobacterium spp.	0	7	2
Aspergillus fumigatus	0	0	0
Gram negative bacteria	97	93	97

OGN dominated from day 1 to day 14 at 97, 93 and 97 % respectively with *Pseudomonas* spp. and *Methylobacterium* spp. being present at less than 10%.

(iii) Percentage profile of bacteria recovered from copper coupons at 50°C

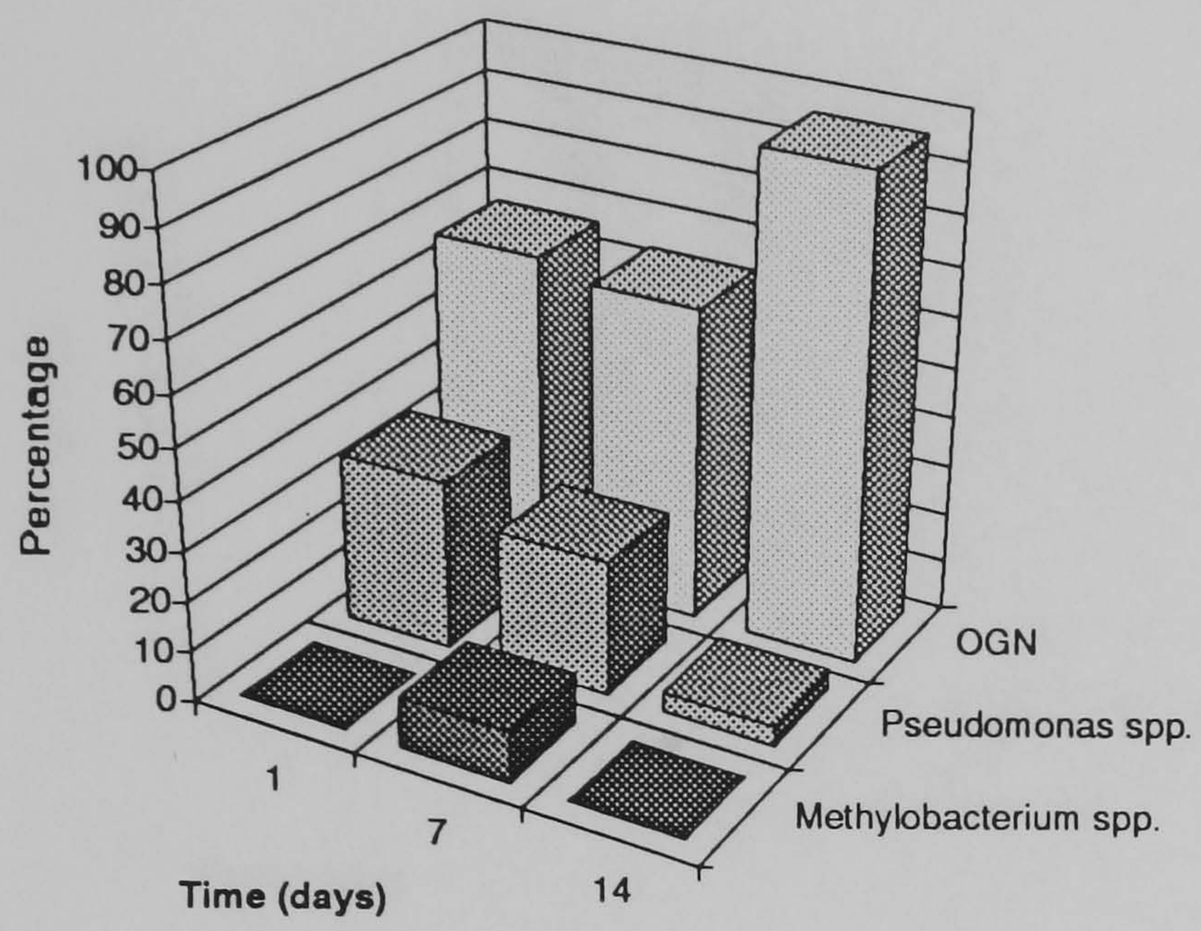


Figure 4.19 Percentage profile of bacteria on copper at 50°C in Glasgow water after 80°C temperature cycle.

Table 4.18 Percentage profile of microbial species on copper at 50°C.

Species / Days	1	7	14
Pseudomonas spp.	34	27	4
Methylobacterium spp.	0	10	0
Aspergillus fumigatus	0	0	0
Gram negative bacteria	66	63	96

Methylobacterium spp. were present at 10% at day 7 but were absent from the populations recovered at day 1 and 14. At day 1 the *Pseudomonas* spp. represented 34 % of the population but declined to 27 % and 4 % respectively. The OGN bacteria dominated from day 1 at 66%, day 7 at 63 % and 96 % at day 14.

(iv) Percentage profile of bacteria recovered from copper at 55°C

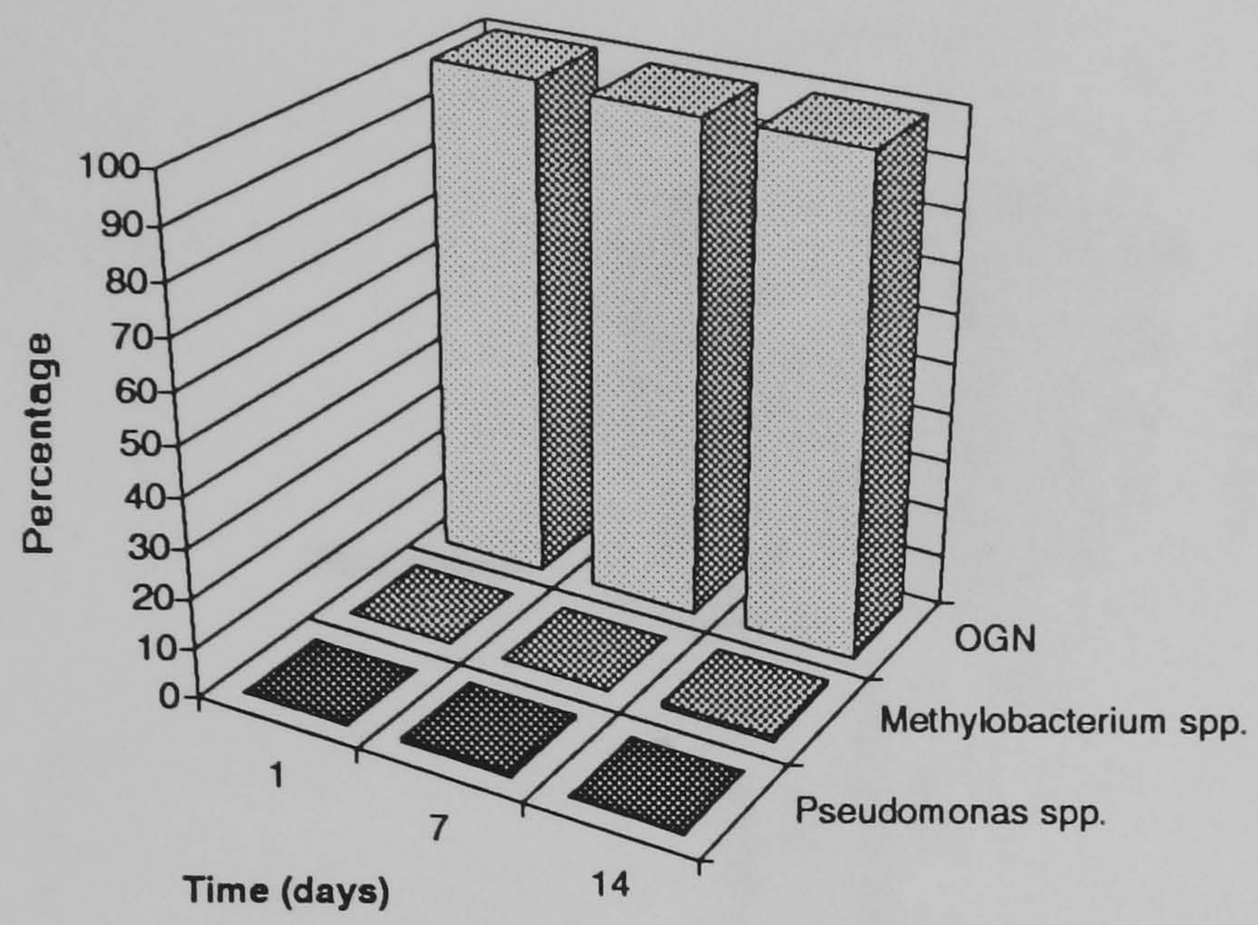


Figure 4.20 Percentage profile of bacteria on copper at 55°C in Glasgow water after 80°C temperature cycle.

Table 4.19 Percentage profile of microbial species on copper at 55°C.

Species / Days	1	7	14
Pseudomonas spp.	0	0	0
Methylobacterium spp.	0	0	1
Aspergillus fumigatus	0	0	0
Gram negative bacteria	100	100	99

The OGN bacteria dominated from day 1 to day 14 with only 1 % *Methylobacterium* spp. being present at day 14.

(v) Percentage profile of bacteria recovered from copper coupons at 60°C

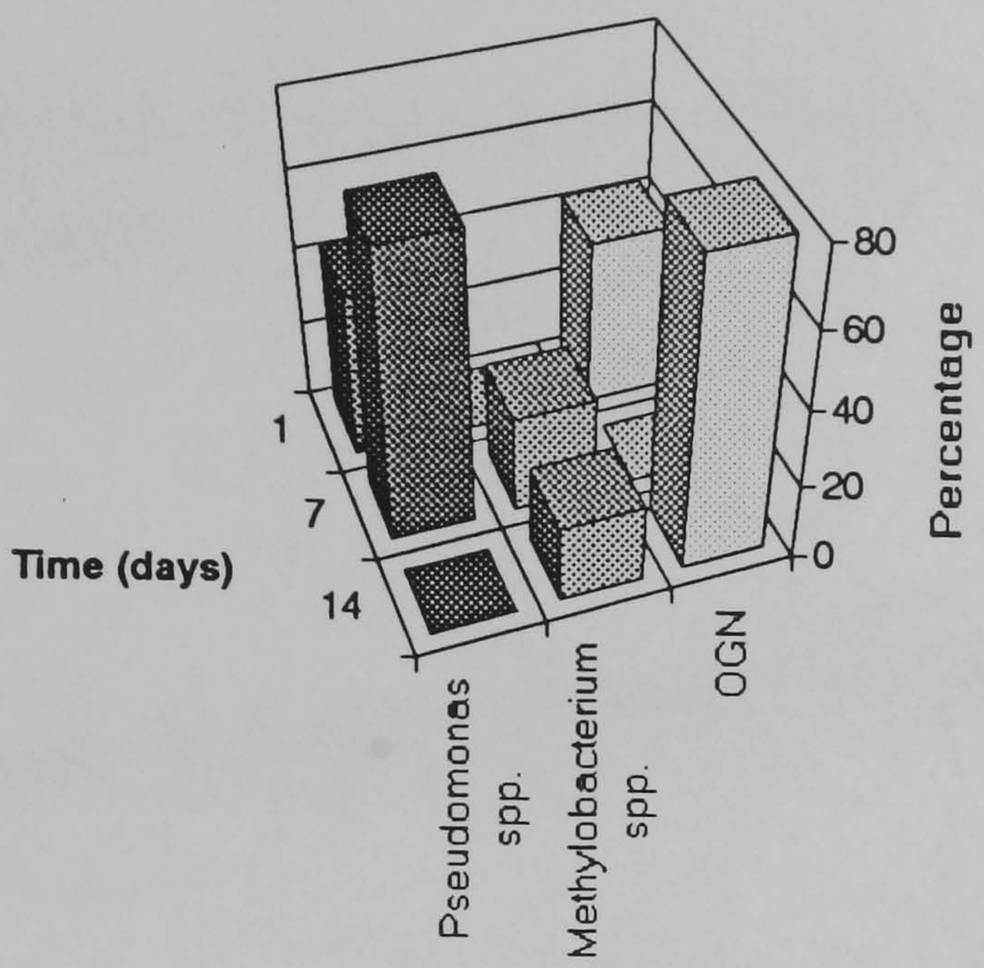


Figure 4.21 Percentage profile of bacteria on copper at 60°C in Glasgow water after 80°C temperature cycle.

Table 4.20 Percentage profile of microbial species on copper at 60°C.

Species / Days	1	7	14
Pseudomonas spp.	46	75	0
Methylobacterium spp.	0	25	20
Aspergillus fumigatus	0	0	0
Gram negative bacteria	54	0	80

Pseudomonas spp. and OGN bacteria were recovered at approximately 50 % on day 1 with the *Pseudomonas* spp. dominating at day 7 but were not detectable at day 14. At day 7 the OGN were not detected but succeeded at day 21 at 80 % of the population. The *Methylobacterium* spp. were not detected until day 7 at 25 % and remained present at 20 % of the total population at day 14.

4.4.2 Repeat biofilm development of glass surfaces

Recovery of viable bacteria from glass coupons immersed into the vessel after the culture was exposed to 80°C.

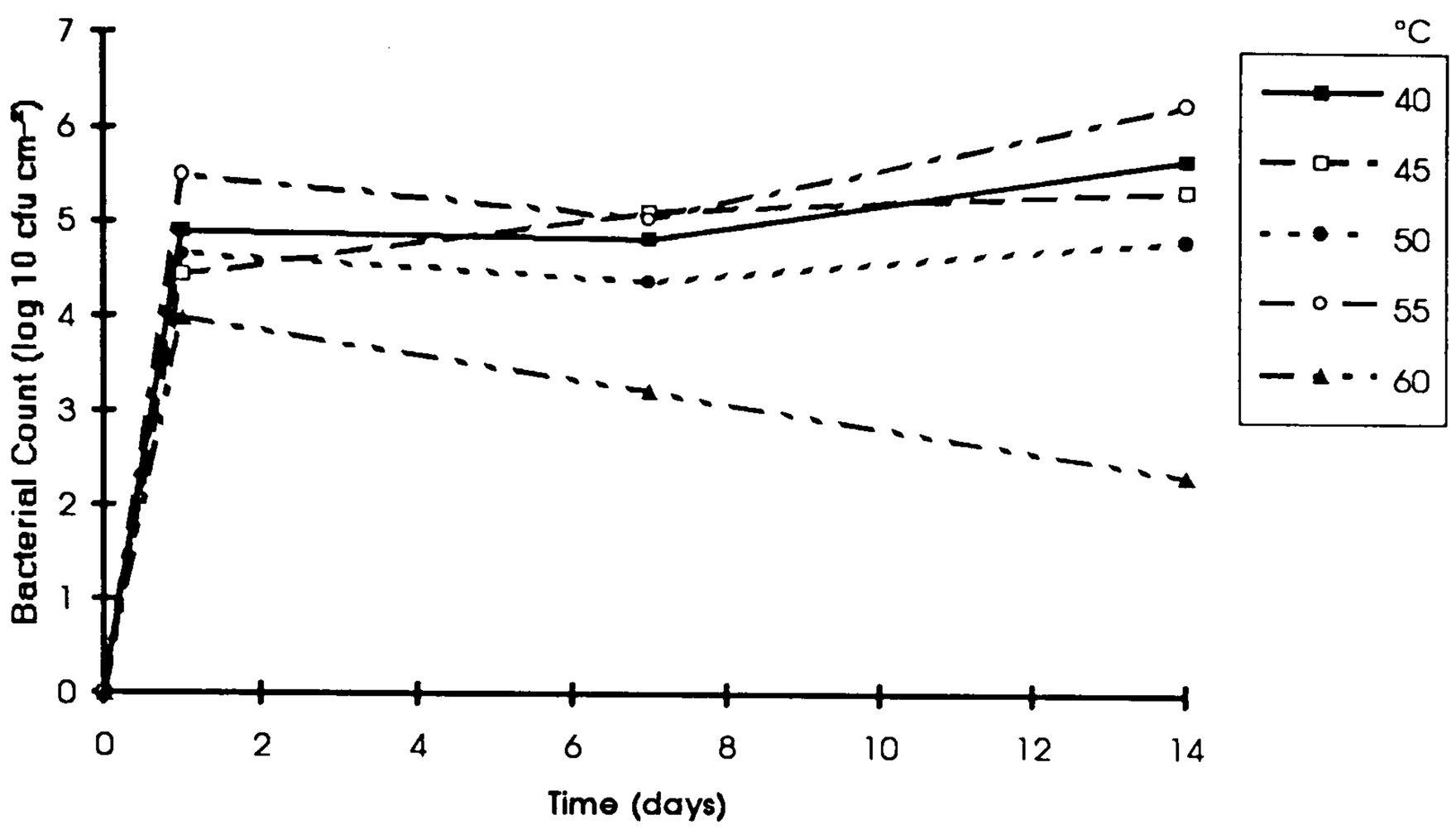


Figure 4.22 Colonisation of glass in the presence of copper after 80°C temperature cycle.

Recovery of bacteria from the glass control surfaces ranged from 3.9 - 5.5 Log $_{10}$ cfu cm^{-2} at all temperatures between 40-60°C, indicating rapid colonisation. At day 7 the number of bacteria recovered at 60°C had decreased to 3.6 Log $_{10}$ cfu cm^{-2} but between 40 - 55°C the number remained relatively constant in ranging from 4.7 - 5.8 Log $_{10}$ cfu cm^{-2} . The number of bacteria recovered at 60°C decreased again to 2.8 Log $_{10}$ cfu cm^{-2} at day 14. However the recovery of bacteria at day 14 ranged from 4.9 - 6.7 Log $_{10}$ cfu cm^{-2} exhibiting an increase at all temperatures between 40-60°C. There was no significant difference between the bacterial numbers retrieved from coupons at 40 & 45°C or 45 & 50°C (p= >0.05). In comparison a statistical difference was apparent between 40 & 50°C, 40 & 55°C, 50 & 55°C, 40 & 60°C, 45 & 60°C, 50 & 60°C and 55 & 60°C where p= <0.05).

(i) Percentage profile of bacteria recovered from glass at 40°C

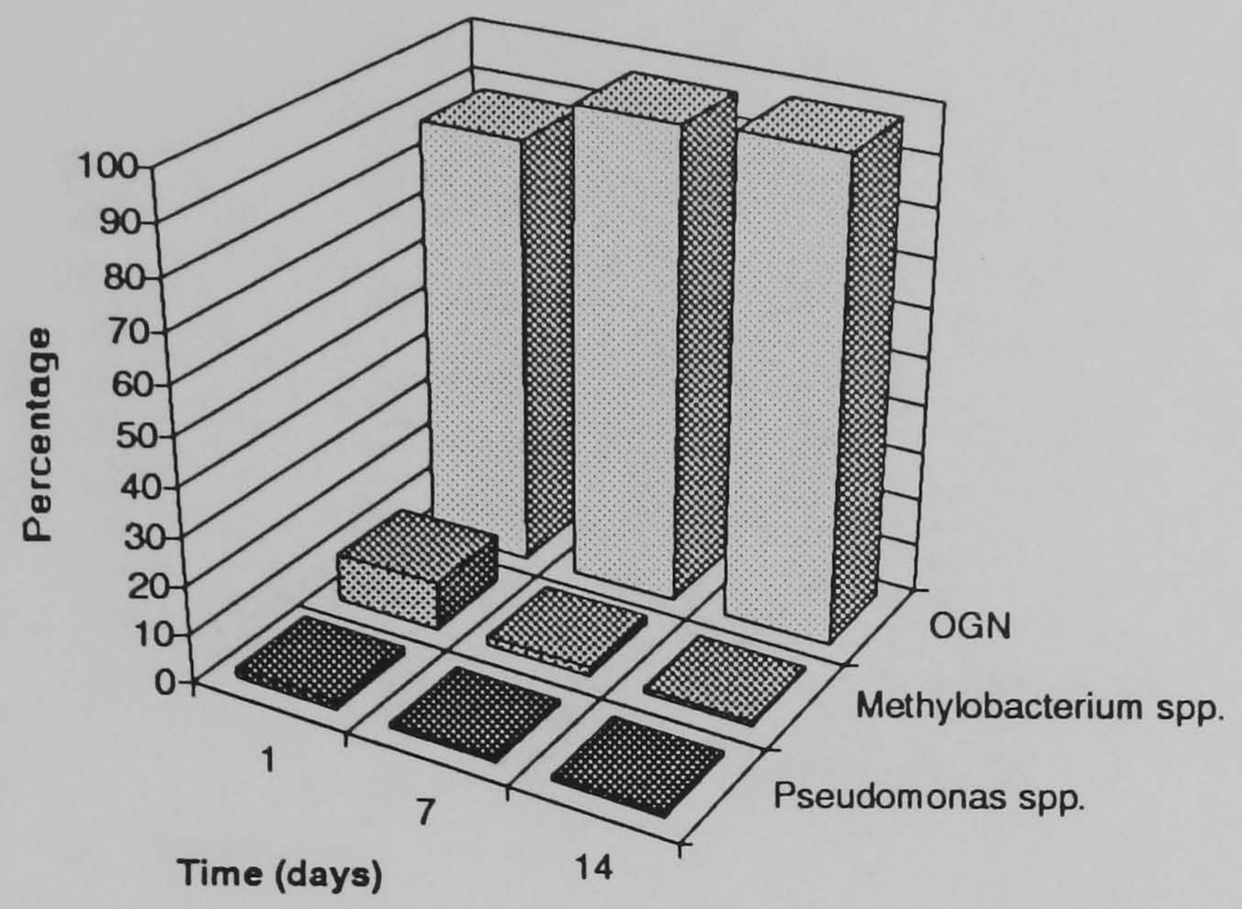


Figure 4.23 Percentage profile of bacteria on glass at 40°C in Glasgow water after 80°C temperature cycle.

Table 4.21 Percentage profile of microbial species on glass at 40°C.

Species / Days	1	7	14
Pseudomonas spp.	2	1	1
Methylobacterium spp.	10	2	1
Aspergillus fumigatus	0	0	0
Gram negative bacteria	88	97	98

At 40°C the OGN bacteria dominated at > 97 % of the consortia. *Methylobacterium* spp. were present at 10 % of the population but decreased to 2 % then 1 % by day 7 and 14 respectively. Recovery of *Pseudomonas* spp. was at less than 2 % of the total population.

(ii) Percentage profile of bacteria recovered from glass coupons at 45°C

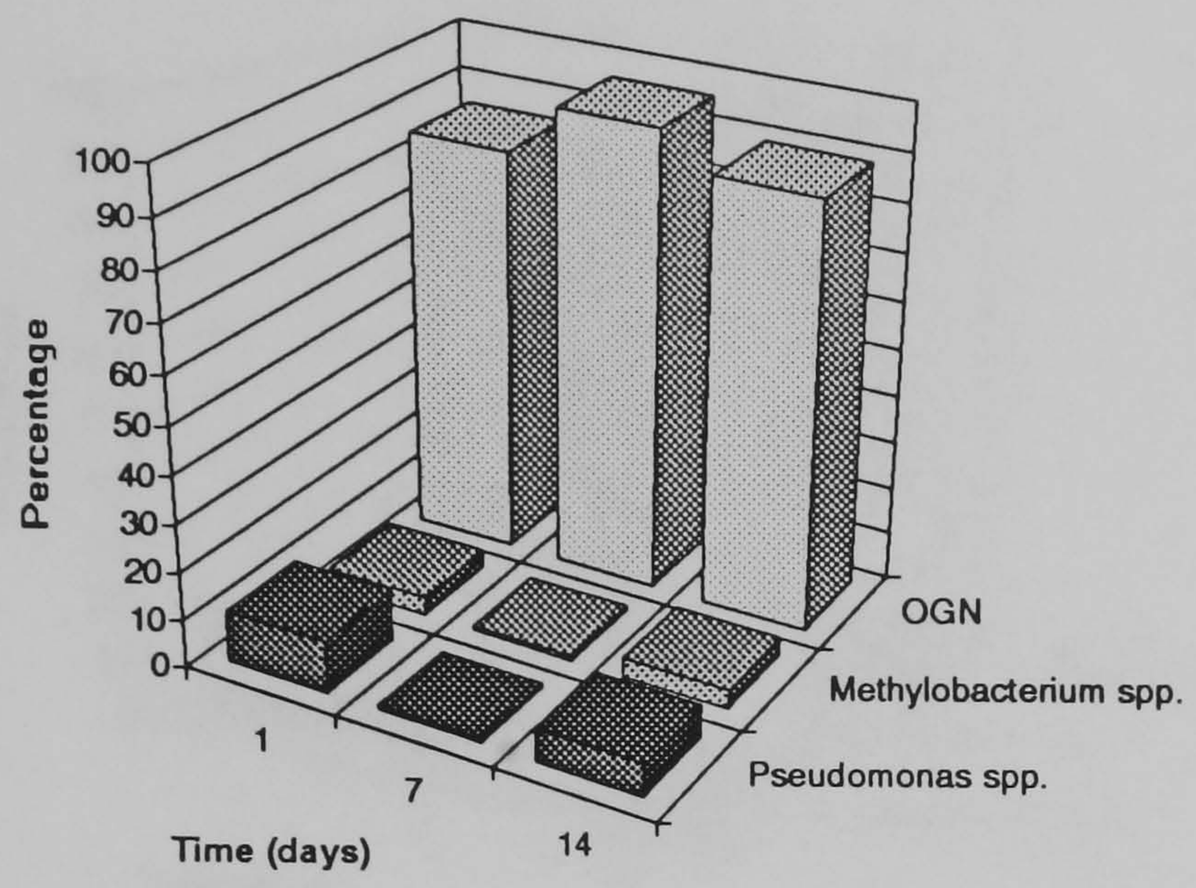


Figure 4.24 Percentage profile of bacteria on glass at 45°C in Glasgow water after 80°C temperature cycle.

Table 4.22 Percentage profile of microbial species on glass at 45°C.

Species / Days	1	7	14
Pseudomonas spp.	11	1	7
Methylobacterium spp.	4	1	4
Aspergillus fumigatus	0	0	0
Gram negative bacteria	85	98	89

From day 1 to day 14 the OGN bacteria dominated at 85 %, 96 % and 89 %. *Methylobacterium* spp. and *Pseudomonas* spp. were recovered at < 11 % of the population.

(iii) Percentage profile of bacteria recovered from glass at 50°C

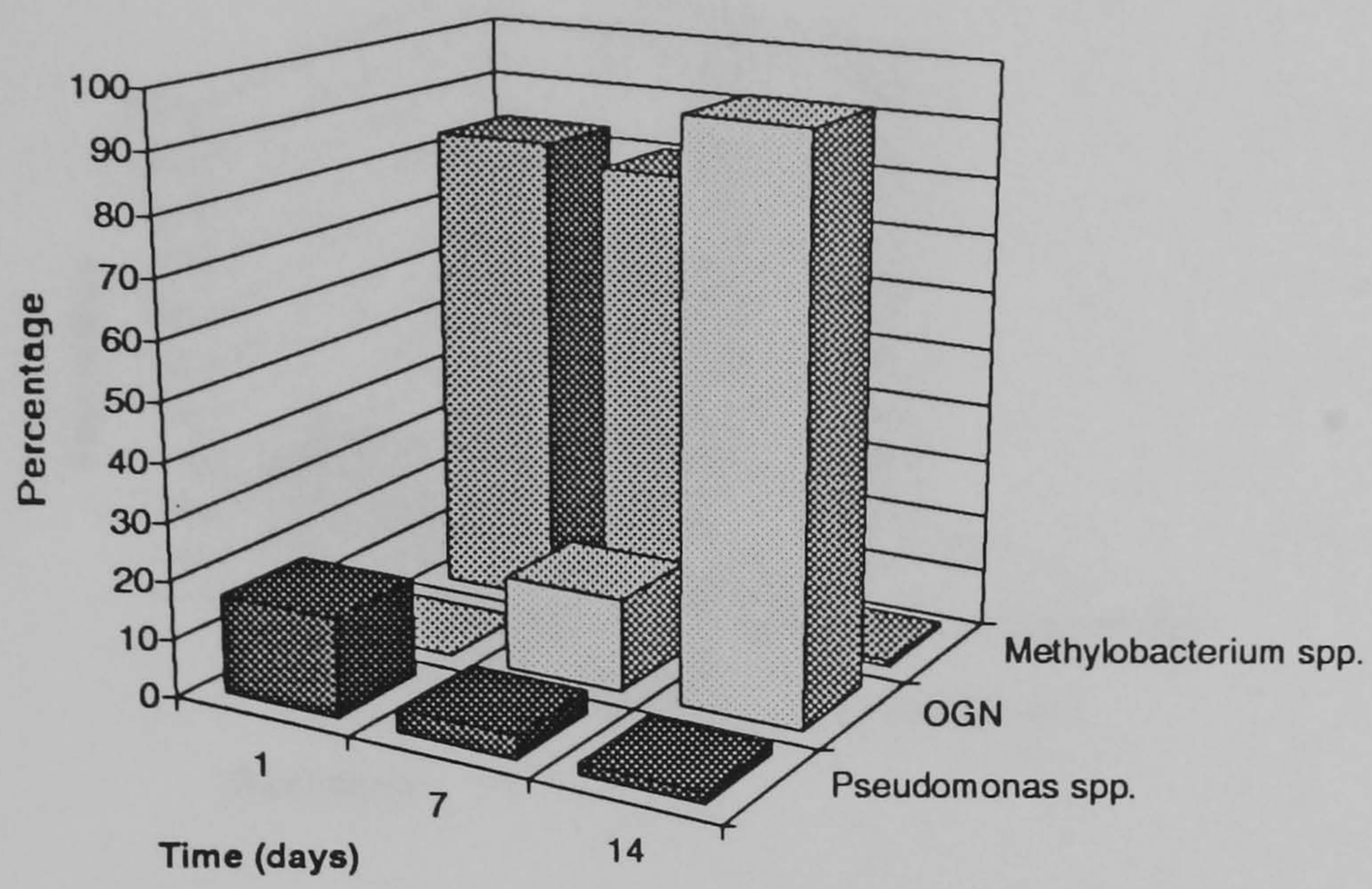


Figure 4.25 Percentage profile of bacteria on glass at 50°C in Glasgow water after 80°C temperature cycle.

Table 4.23 Percentage profile of microbial species on glass at 50°C.

Species / Days	1	7	14
Pseudomonas spp.	17	4	2
Methylobacterium spp.	0	79	1
Aspergillus fumigatus	0	1	0
Gram negative bacteria	83	16	97

Although the *Methylobacterium* spp. dominated at day 1, 83 %, they were succeeded by the OGN bacteria at day 7 but dominated again at day 14 at 97 %. *Pseudomonas* spp. were recovered at 17 % of the population at day 1 but decreased to 4 & 2 % at day 7 & 14.

(iv) Percentage profile of bacteria recovered from 55°C

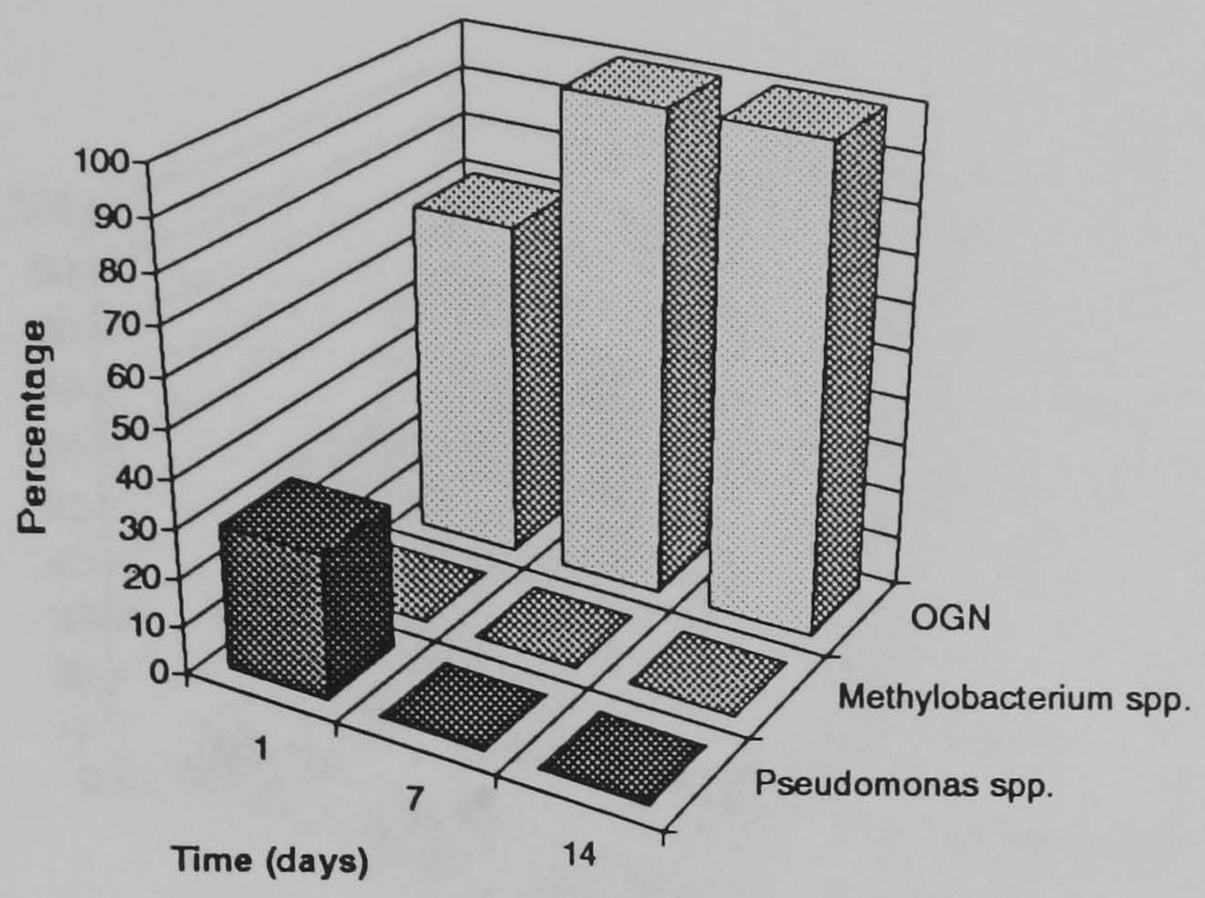


Figure 4.26 Percentage profile of bacteria on glass at 55°C in Glasgow water after 80°C temperature cycle.

Table 4.24 Percentage profile of microbial species on glass at 55°C.

Species / Days	1	7	14
Pseudomonas spp.	30	0	0
Methylobacterium spp.	0	0	0
Aspergillus fumigatus	0	0	0
Gram negative bacteria	70	100	100

The OGN bacteria dominated at 70 and 100%. *Pseudomonas* spp. were only recovered at day 1 at 30 %.

(v) Percentage profile of bacteria recovered from glass tile immersed in the culture at 60°C

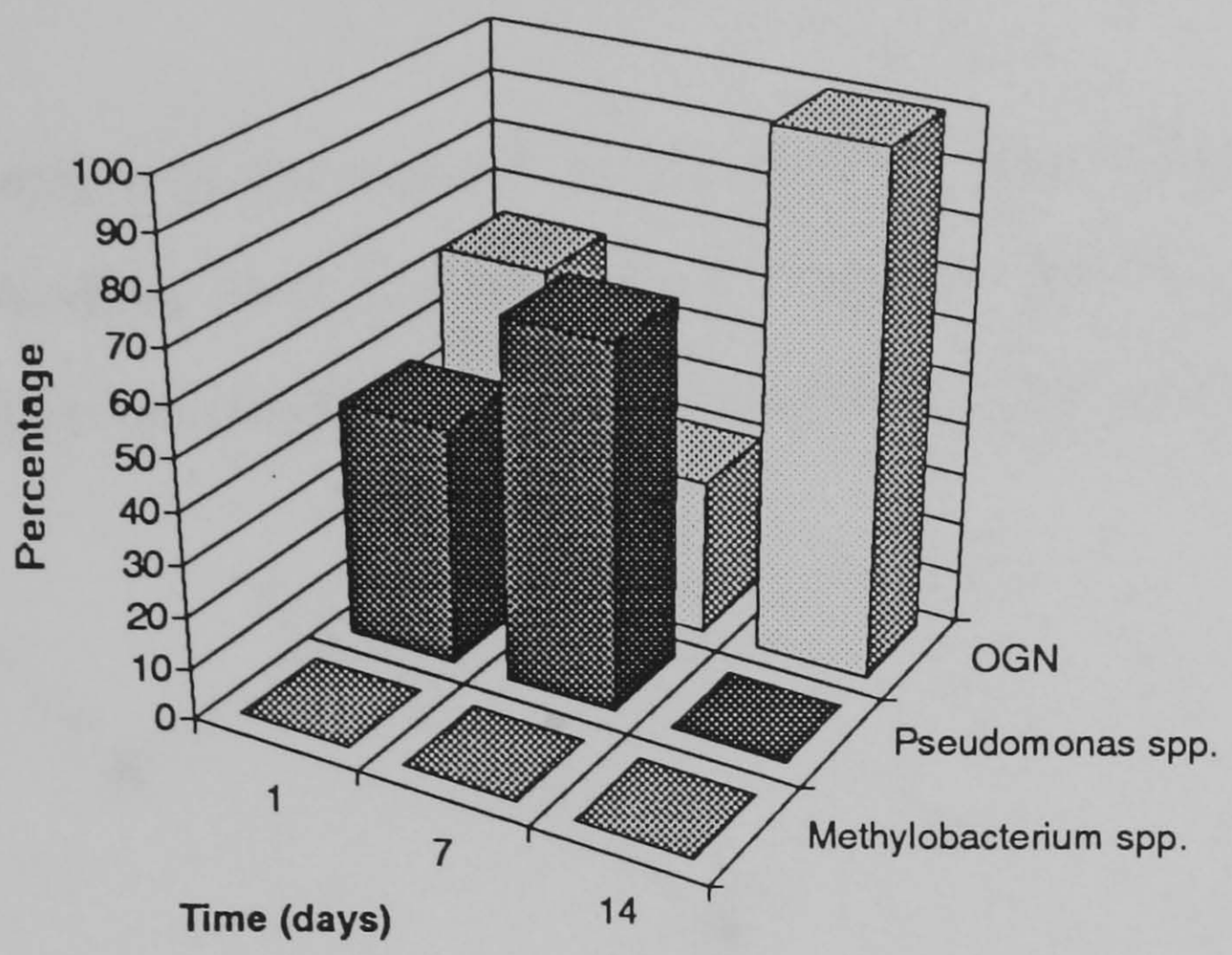


Figure 4.27 Percentage profile of bacteria on glass at 60°C in Glasgow water after 80°C temperature cycle.

Table 4.25 Percentage profile of microbial species on glass at 60°C.

Species / Days	1	7	14
Pseudomonas spp.	46	70	0
Methylobacterium spp.	0	0	0
Aspergillus fumigatus	0	0	0
Gram negative bacteria	64	30	100

At day 1 the OGN bacteria dominated at 64 % compared to 46 % of *Pseudomonas* spp. By day 7 the OGN bacteria were present at 30 % and had been succeeded by the *Pseudomonas* spp. at 70 %. However the OGN dominated at day 14 at 100 %. No *Methylobacterium* spp. were recovered.

4.5 PLANKTONIC POPULATIONS IN THE CONTINUOUS CULTURE VESSELS

As bacteria present in the aqueous environment are those primarily responsible for establishing biofilms over the temperature range of 40-55°C, bacteria within the planktonic phase were examined for their response to varying temperatures.

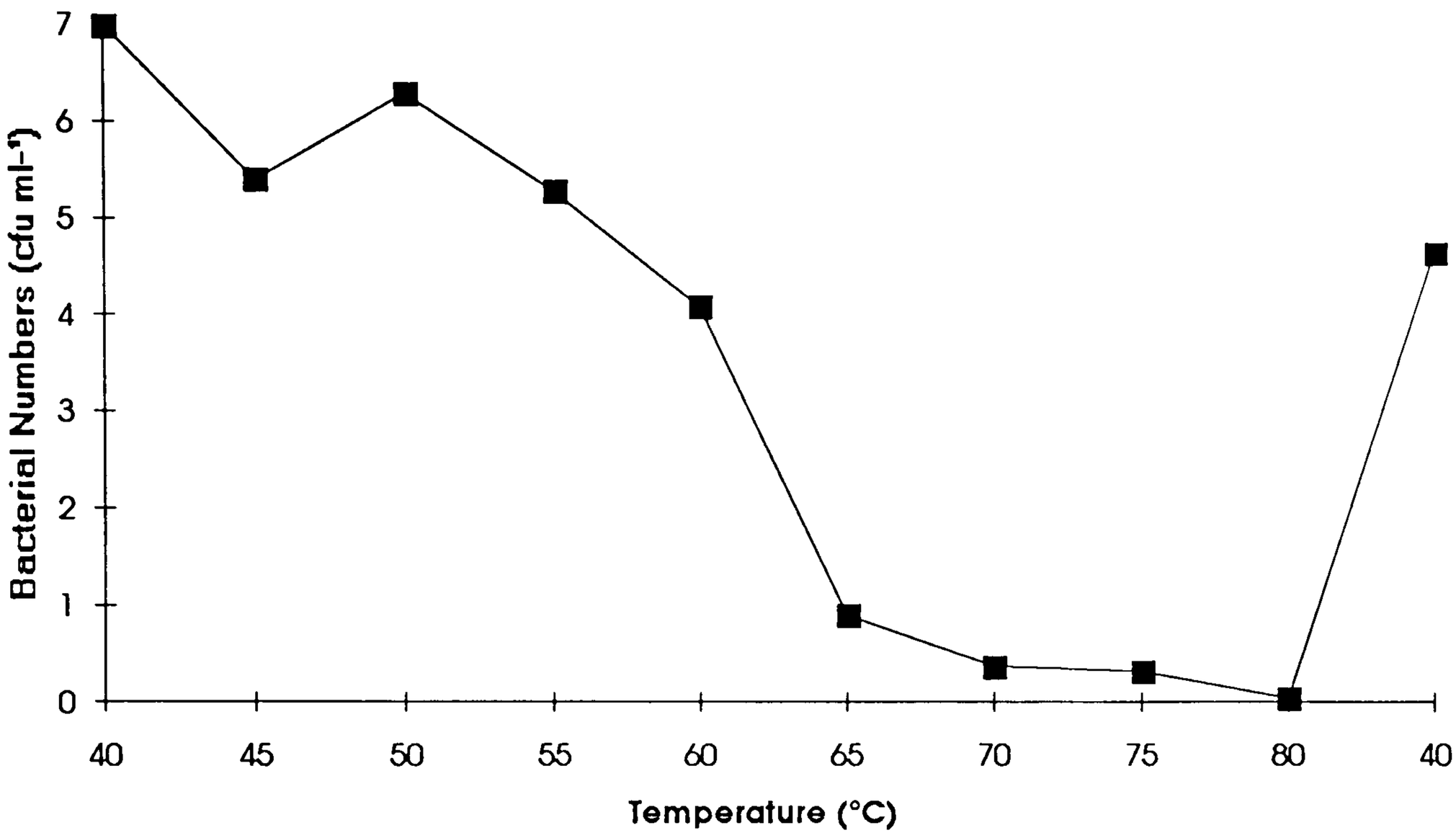


Figure 4.28 Effect of temperature changes on bacterial numbers in the planktonic phase (each value represents the mean of at least three separate measurements).

From a mean value of 7.0×10^5 cfu ml^{-1} at 40°C there was a drop in the number of bacteria to 5.4×10^5cfu ml^{-1} as the temperature was increased to 45°C. This was followed by an increase to 6.3×10^5 cfu ml^{-1} at 50°C. When the temperature was changed to 55°C the number of bacteria recovered was 5.3×10^5 cfu ml^{-1} with 4.1×10^5 cfu ml^{-1} at 60°C. However increasing the temperature to 65, 70, 75 and 80°C resulted in a decrease in the number of viable bacteria recovered from the aqueous phase to 9.1×10^4, 3.8×10^4, 3.2×10^4 and 4.6×10^3 cfu ml^{-1} respectively. Following a temperature change to 40°C, 4.7×10^5 cfu ml^{-1} were present.

Table 4.26 Number of planktonic bacteria in vessels 1 and 2.

Vessel 1(cfu/ml) 30°C	log_{10} (cfu/ml)	Vessel 2 Temp (°C)	Vessel 2 (cfu/ml)	Log 10 (cfu/ml)
6.0×10^5	5.78	40	7.0×10^5	5.84
6.4×10^5	5.80	45	5.4×10^5	5.73
5.2×10^5	5.72	50	6.3×10^5	5.79
4.4×10^5	5.64	55	5.3×10^5	5.72
4.0×10^5	5.60	60	4.5×10^5	5.65
3.6×10^5	5.56	65	9.1×10^4	4.7
4.6×10^5	5.66	70	3.8×10^4	4.58
1.5×10^5*	5.17	75	3.3×10^4	4.50
no count	no count	80	4.6×10^3	3.66
2.4×10^5*	5.34	40	$4.7\ 10^5$	5.67

* denotes less than three counts per average per sample

The number of bacteria present in vessel one, where the temperature was maintained at 30°C ranged from 1.5×10^5 cfu ml^{-1} to 6.4×10^5 cfu ml^{-1}, an average of 4.9×10^5 cfu ml^{-1} (5.6 $\log_{10}$) over the first seven months sampling. In the second vessel where the temperature was increasing from 40°C in 5°C increments the number of bacteria present in the planktonic phase varied from 7.0×10^5 cfu ml^{-1} at 40°C to 4.6×10^3 cfu ml^{-1} at 80°C. When the temperature of the vessel was returned to 40°C the bacterial numbers recovered were found to be greater than 4.0×10^5 cfu ml^{-1}.

(i) Percentage profile of planktonic phase during temperature fluctuations.

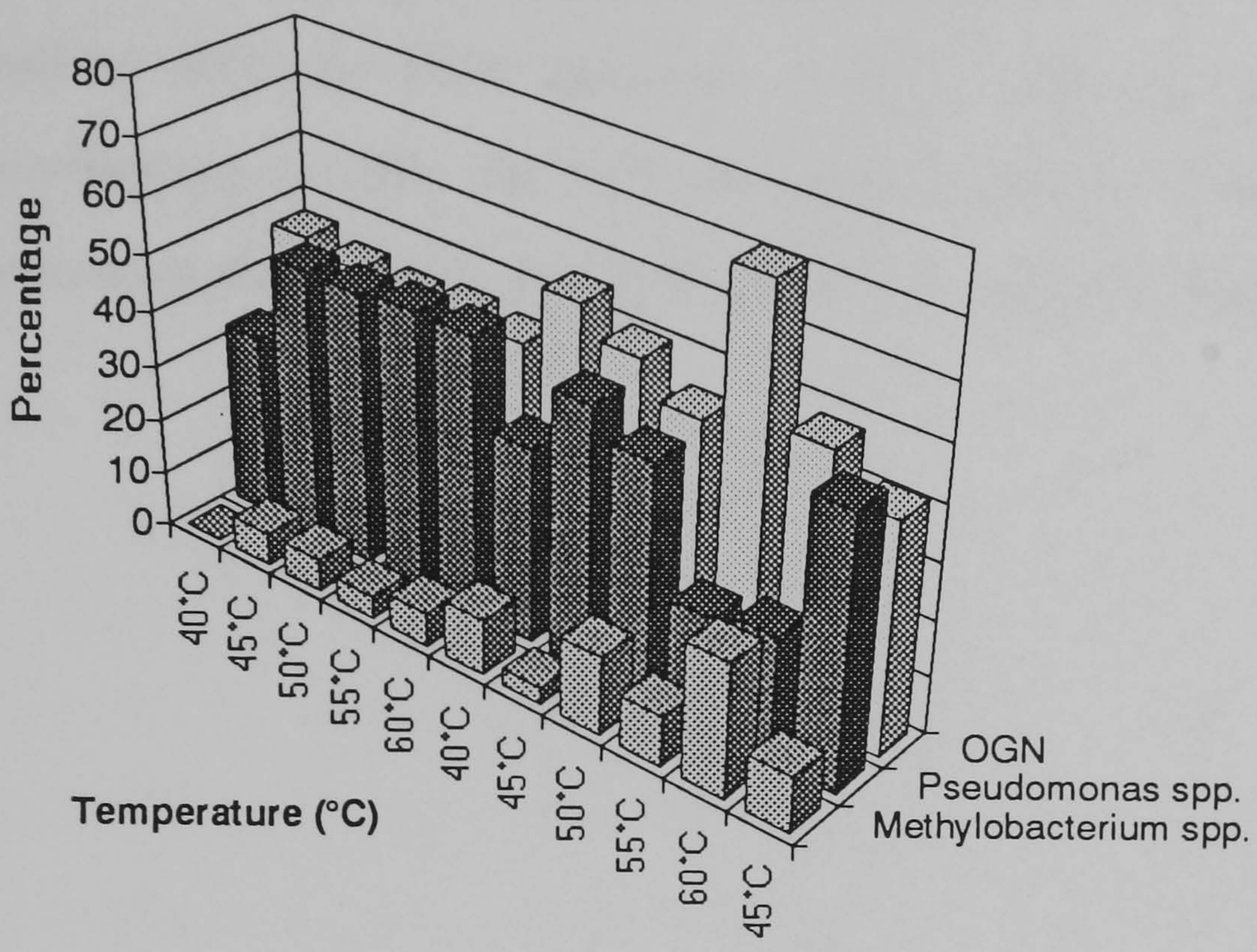


Figure 4.29 Percentage profile of bacteria in the planktonic phase during temperature cycling (each value represents the mean of at least three separate measurements).

Table. 27 Percentage profiles of bacterial species in the planktonic species during temperature cycling.

Species / Temperature	40°C	45°C	50°C	55°C	60°C	40°C	45°C	50°C	55°C	60°C	45°C
Methylobacterium spp.	0	6	6	4	6	10	3	14	9	25	10
Pseudomonas spp.	41	49	49	50	50	35	47	42	20	23	48
Gram negative	59	45	45	46	44	55	50	44	71	50	42

In the water phase the populations of bacteria present were the OGN, *Pseudomonas* spp. and *Methylobacterium* spp. During the temperature increments, the OGN represented 48.5 % of the population with *Pseudomonas* spp. at 40.5 % of the population on average. *Methylobacterium* spp. were present on average at 8.3 % of

the total population. During the first temperature gradient of 40-60°C, *Pseudomonas* spp. and OGN were in equal percentages of the population but when the temperature was returned to 40°C the OGN dominated at 55°C, with an increase in the *Methylobacterium* spp. to 10%. The OGN dominated again at 55°C and 60°C in the second temperature gradient with the *Methylobacterium* spp. increasing to 25 % at 60°C.

4.6 BIOFILM CONTROL

4.6.1 Control of fouling by Pasteurisation

From monitoring the hot water circuit in the hospital where the pepper pot corrosion was occurring it was established that the water temperature was maintained between 35-55°C. Using the laboratory model it was demonstrated that bacteria would form a biofilm between 40-55°C but not at 60°C. After repeating the experiment of biofouling between 40-60°C bacteria were recovered from surfaces immersed in the culture at 60°C, but the numbers were still reduced compared to the bacterial numbers at the lower temperatures. Therefore 60°C was chosen to study the effect of heat treatment by pasteurising established biofilms. Initially the biofilms were established in the chemostat at 45°C for 14 days before exposure to 60°C. To investigate if temperature fluctuations would alter the effect of pasteurisation, biofilms were matured between the temperatures of 40-60°C for 14 days before being pasteurised

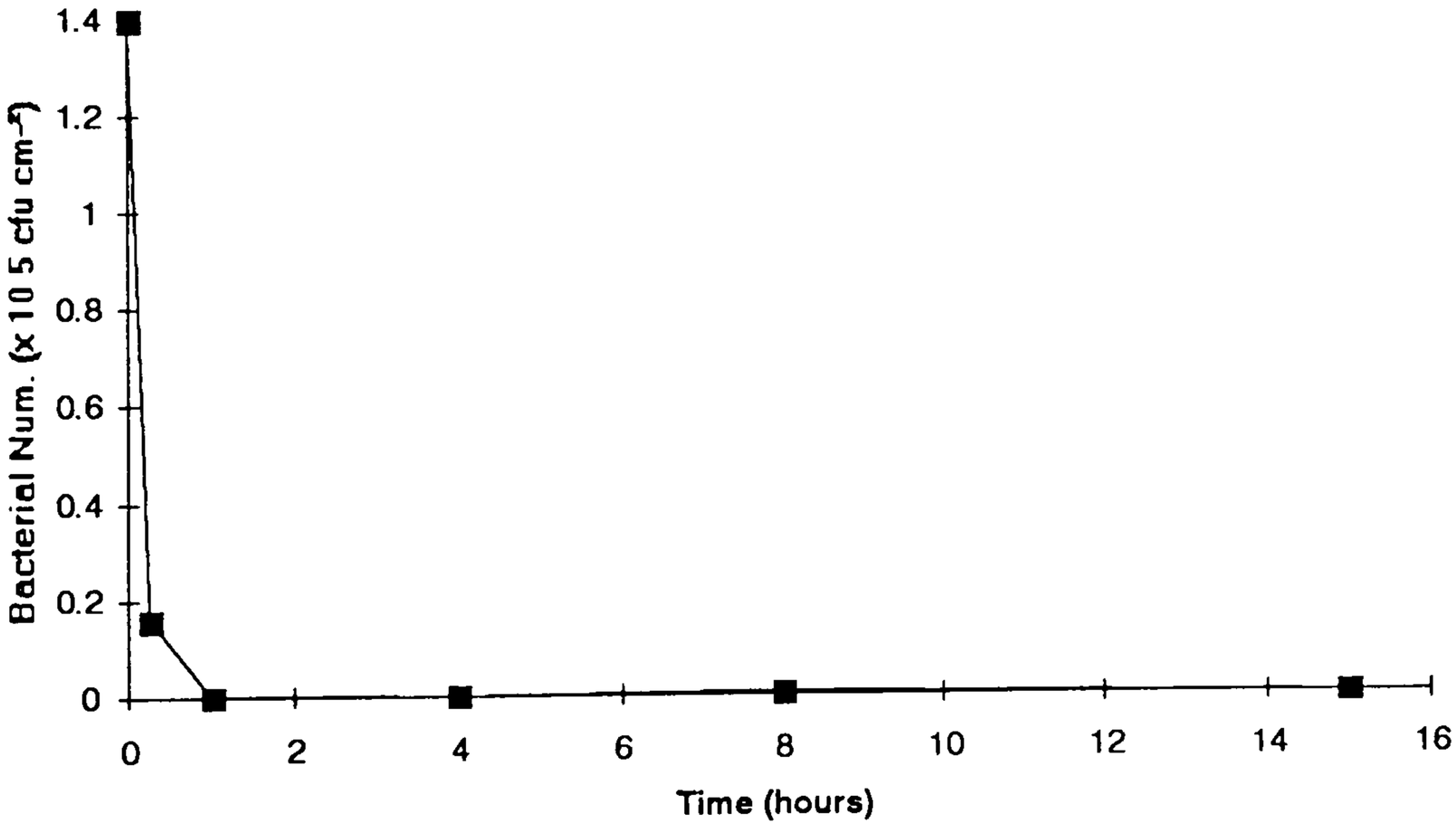


Figure 4.49 Pasteurisation at 60°C of mature biofilm established on copper at 45°C. Prior to pasteurisation 1.4 x 10^5 cfu cm^{-2} were recovered from copper surfaces matured in the chemostat for 42 days at 45°C. However after 15 minutes pasteurisation at 60°C, 1.6 x 10^3 cfu cm^{-2} were recovered, representing a 98.9 % decrease in recovery of biofilm bacteria. After 1 h pasteurisation a 99 % decrease in viability was achieved and was maintained for 15 days.

(i) Percentage profile of biofilm before and after pasteurisation

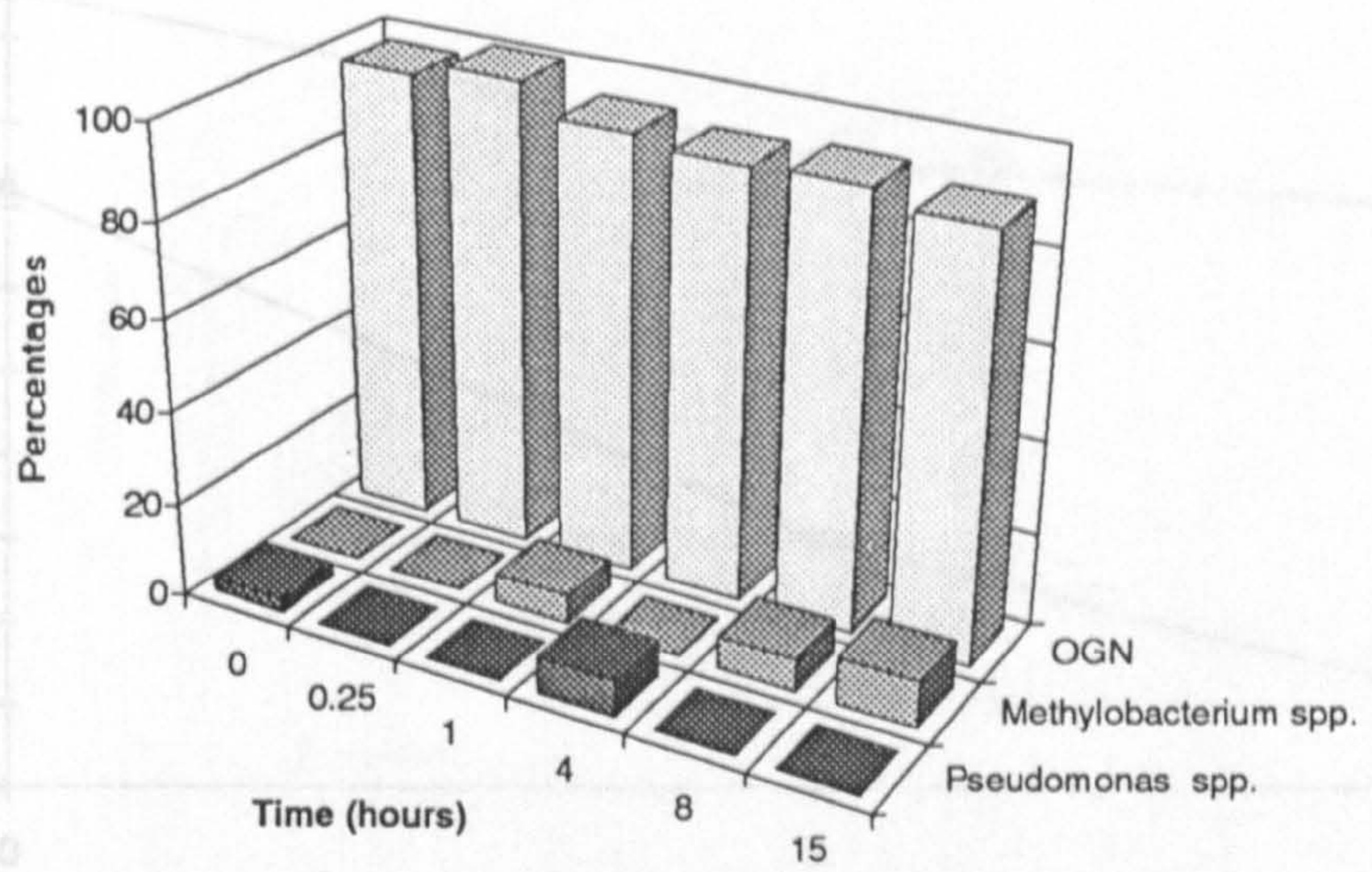


Figure 4.50 Percentage profile of biofilm matured at 45°C and pasteurised at 60°C.

Species / Time (h)	0	0.25	1	4	8	15
Pseudomonas spp.	3	0	0	8	0	0
Methylobacterium spp.	0	0	6	0	7	10
Gram negative bacteria	97	100	94	92	93	90

Table 4.28 Percentage profile of biofilm matured at 45°C and pasteurised at 60°C.

Prior to pasteurisation *Pseudomonas* spp. were present at 3 % and Gram negative bacteria at 97 % of the total population. After 15 min of exposure to 60°C only Gram negative bacteria were detected. *Methylobacterium* spp. were however recovered at 1, 8 and 15 h at 6 %, 7 % and 10 % respectively with *Pseudomonas* spp. also present at 8 % at 4 h.

4.6.1.1 Effect of Pasteurisation at 60°C on pre-established biofilm.

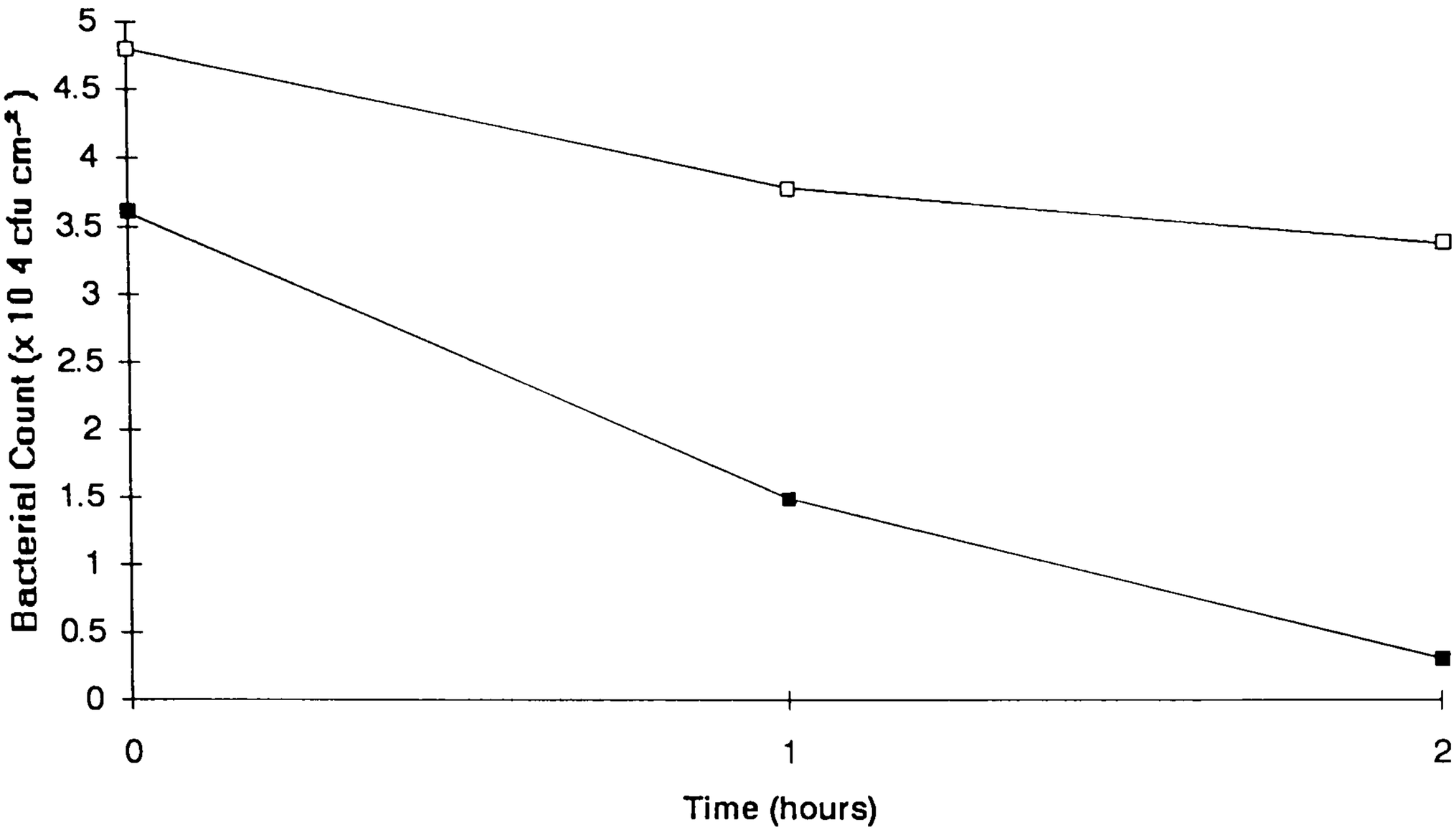


Figure 4.51 Pasteurisation at 60°C of mature biofilm established on copper and glass between 40-60°C. Biofilm recovered from νcopper and oglass surfaces.

After 14 days maturation 3.6 x 10^4 cfu cm^{-2} were recovered from the copper surfaces. Following pasteurisation at 60°C the number of bacteria recovered from the copper surfaces decreased to 1.5 x 10^4 cfu cm^{-2} and 3.1 x 10^3 cfu cm^{-2} after 1 h and 2 h respectively. This decrease in bacterial numbers represented a 59 % and 92 % reduction in viability of the biofilm after 1 h and 2 h respectively. The bacterial numbers recovered from glass surfaces were 4.7 x 10^4 cfu cm^{-2} after 14 days maturation between 40-60°C. After pasteurisation at 60°C for 1 h there was a 22 % decrease in the viability to 3.7 x 10^4 cfu cm^{-2} followed by a further decrease of 25 % to 3.6 x 10^4 cfu cm^{-2} after 2 h pasteurisation.

(i) Percentage profile of pasteurised biofilm.

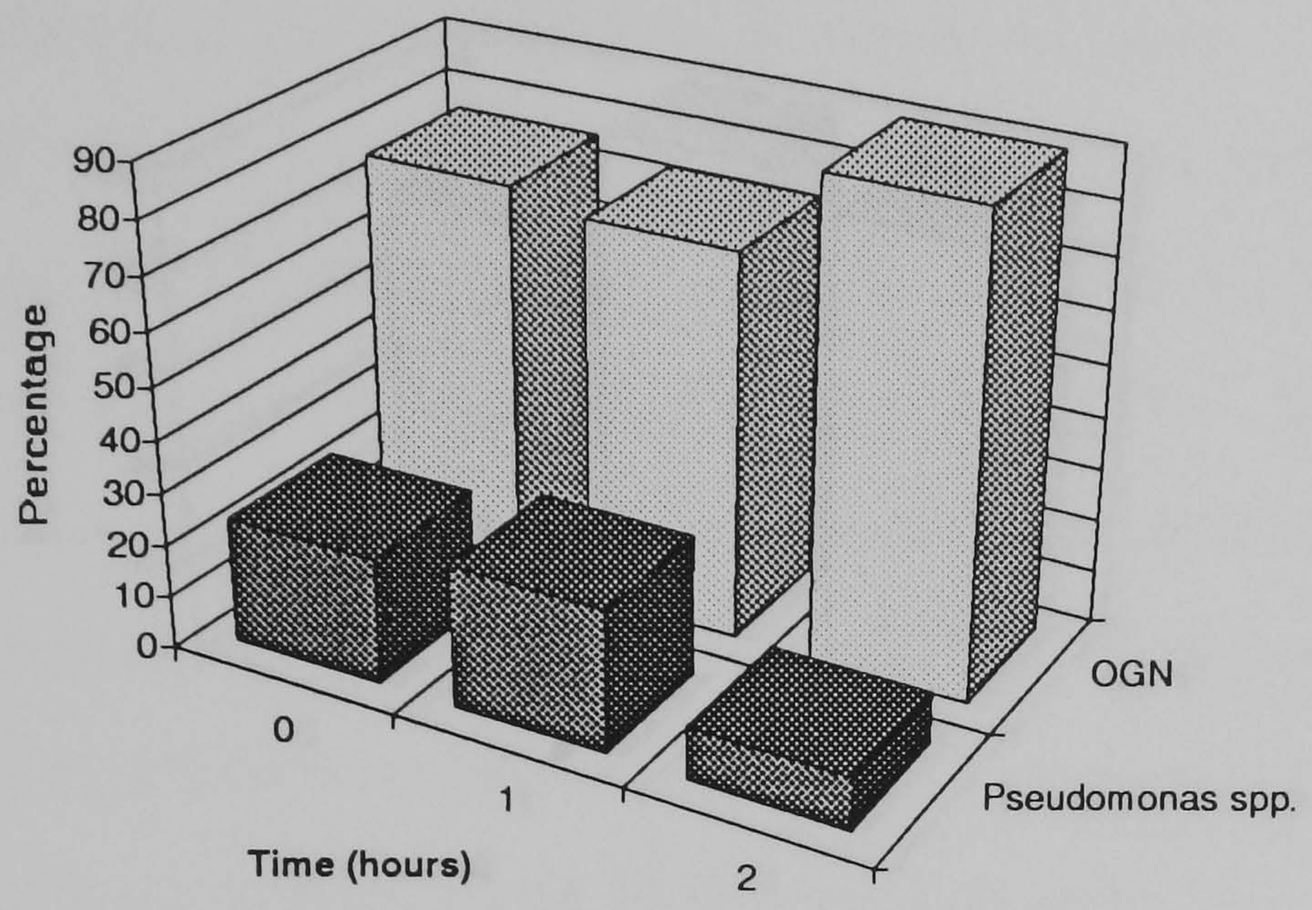


Figure 4.52 Percentage profile of bacteria on copper before and after pasteurisation at 60°C.

Species / Time (h)	0	1	2
Pseudomonas spp.	24	27	10
Gram negative bacteria	76	73	90

Table 4.29 Percentage profile of biofilm from copper before and after pasteurisation at 60°C.

Two bacterial types were recovered from the copper surfaces. The Gram negative bacteria dominated with the *Pseudomonas* spp. being recovered at 24 % of the population before pasteurisation. After 1 h pasteurisation the percentage profiles were still very similar even though the total numbers had been reduced. After 2 h at 60°C the *Pseudomonas* spp. were reduced to 10% of the population.

(ii) Percentage profile of pasteurised biofilm.

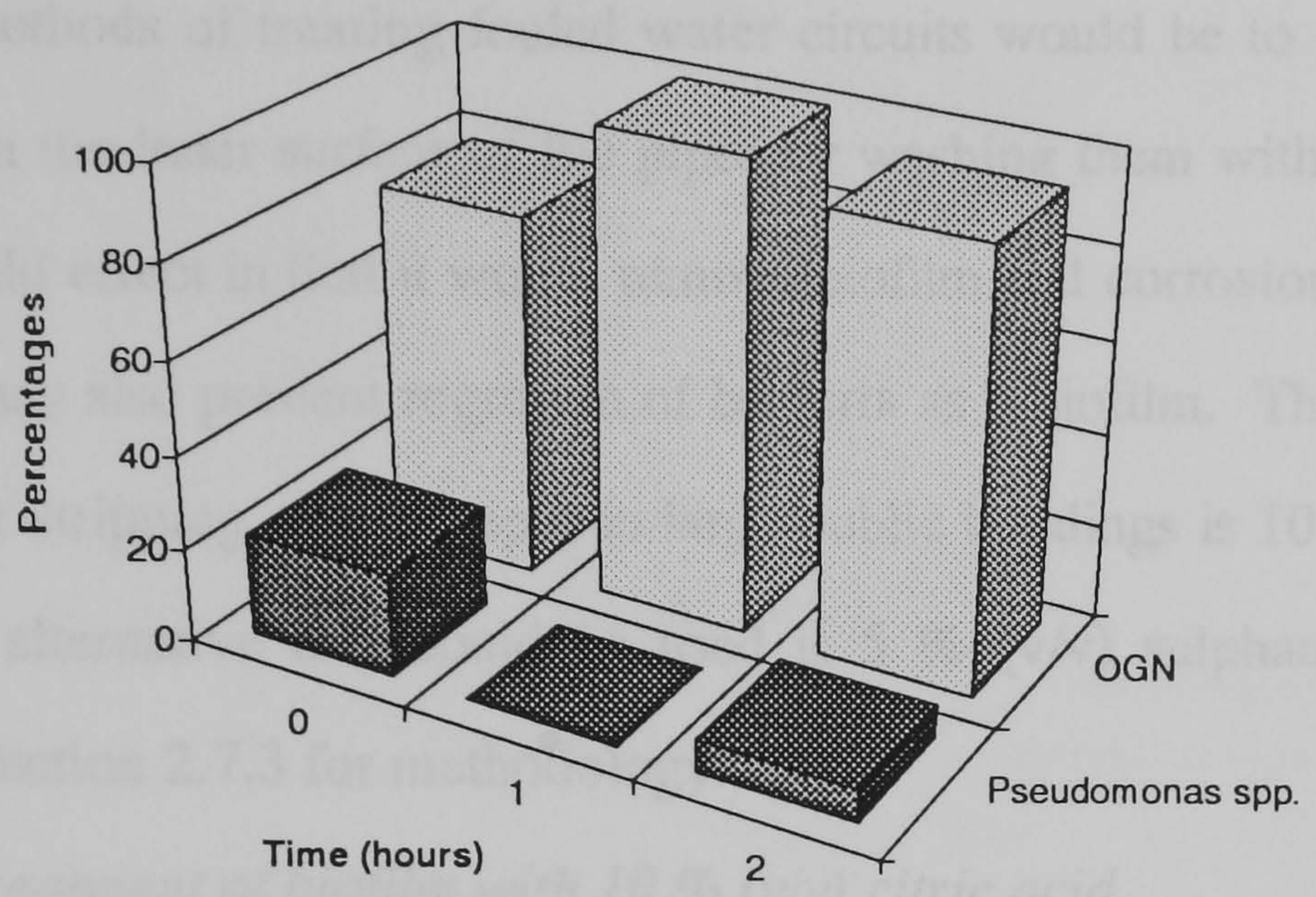


Figure 4.53 Percentage profile of bacteria on glass before and after pasteurisation at 60°C.

Species / Time (h)	0	1	2
Pseudomonas spp.	22	0	7
Gram negative bacteria	78	100	93

Table 4.30 Percentage profile of bacteria from glass before and after pasteurisation at 60°C.

Before pasteurisation *Pseudomonas* spp. were recovered at 22 % of the population but after pasteurisation the Gram negative bacteria dominated. No *Pseudomonas* spp. were recovered after 1 h pasteurisation. However after 2 h pasteurisation *Pseudomonas* spp. represented 7 % of the population.

4.6.2. Acid treatment of established biofilm

One of the methods of treating fouled water circuits would be to disrupt and remove any biofilm on the inner surface of the pipes by washing them with acids. This would have a two fold effect in that it would remove biofilm and corrosion products from the surface and may also prevent regrowth of bacteria as a biofilm. The only acid allowed to be used for stripping copper pipes in large public buildings is 10 % (v/v) citric acid. However an alternative that could be used is 5 % (v/v) sulphamic acid. Refer to Chapter 2.0 section 2.7.3 for methodology.

4.5.1.1 Treatment of biofilm with 10 % (v/v) citric acid.

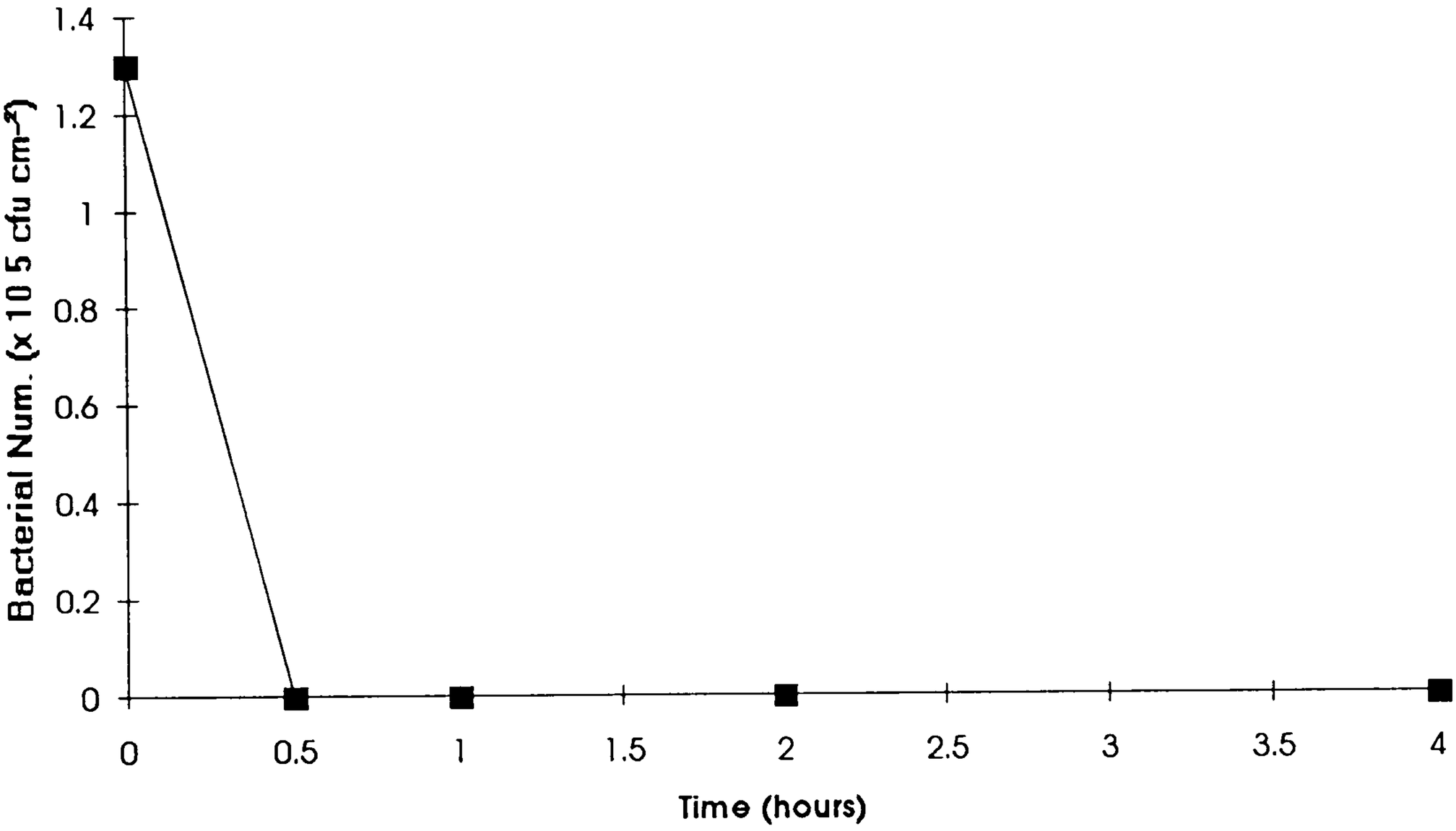


Figure 4.54 Citric acid (10 % v/v) treatment of 14 day old biofilms on copper matured at 45°C.

Prior to treatment with citric acid 1.3×10^5 cfu cm^{-2} were recovered from a 14 day old biofilm on copper. The biofilms were then exposed to 10 % v/v citric acid and after 30 min, < 60 cfu cm^{-2} were recovered. As there was greater than a 99 % inhibition after half an hour then this was chosen as the time period over which to treat mature biofilm before they were replaced back into the chemostat to study recolonisation.

(i) Percentage profile of bacteria before and after acid treatment.

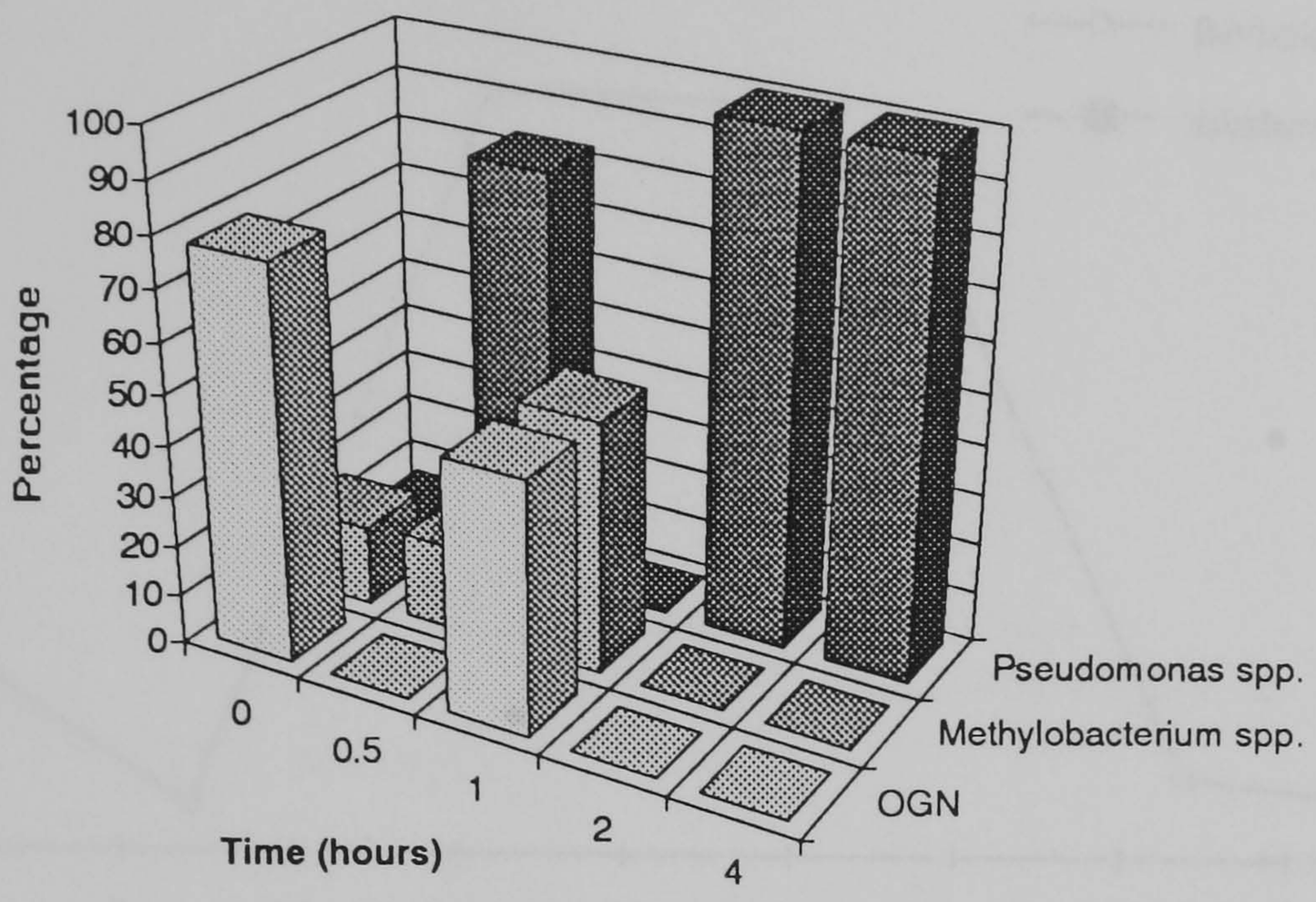


Figure 4.55 Percentage profile of copper surfaces before and after treatment with 10 % (v/v) citric acid.

Species / Time (h)	0	0.5	1	2	4
Gram negative bacteria	78	0	50	0	0
Methylobacterium spp.	16	17	50	0	0
Pseudomonas spp.	6	83	0	100	100

Table 4.31 Percentage profile of copper surfaces before and after treatment with 10 % (v/v) citric acid.

Prior to citric acid treatment the Gram negative bacteria dominated the biofilm at 78 % of the total population within the 14 day old consortium on the copper surface with the *Methylobacterium* spp. at 16 % and the *Pseudomonas* spp. representing 6 % of the total population. Following 0.5 hour treatment with citric acid *Pseudomonas* spp. dominated the biofilm.

4.6.2.2 Recolonisation of citric acid treated coupons

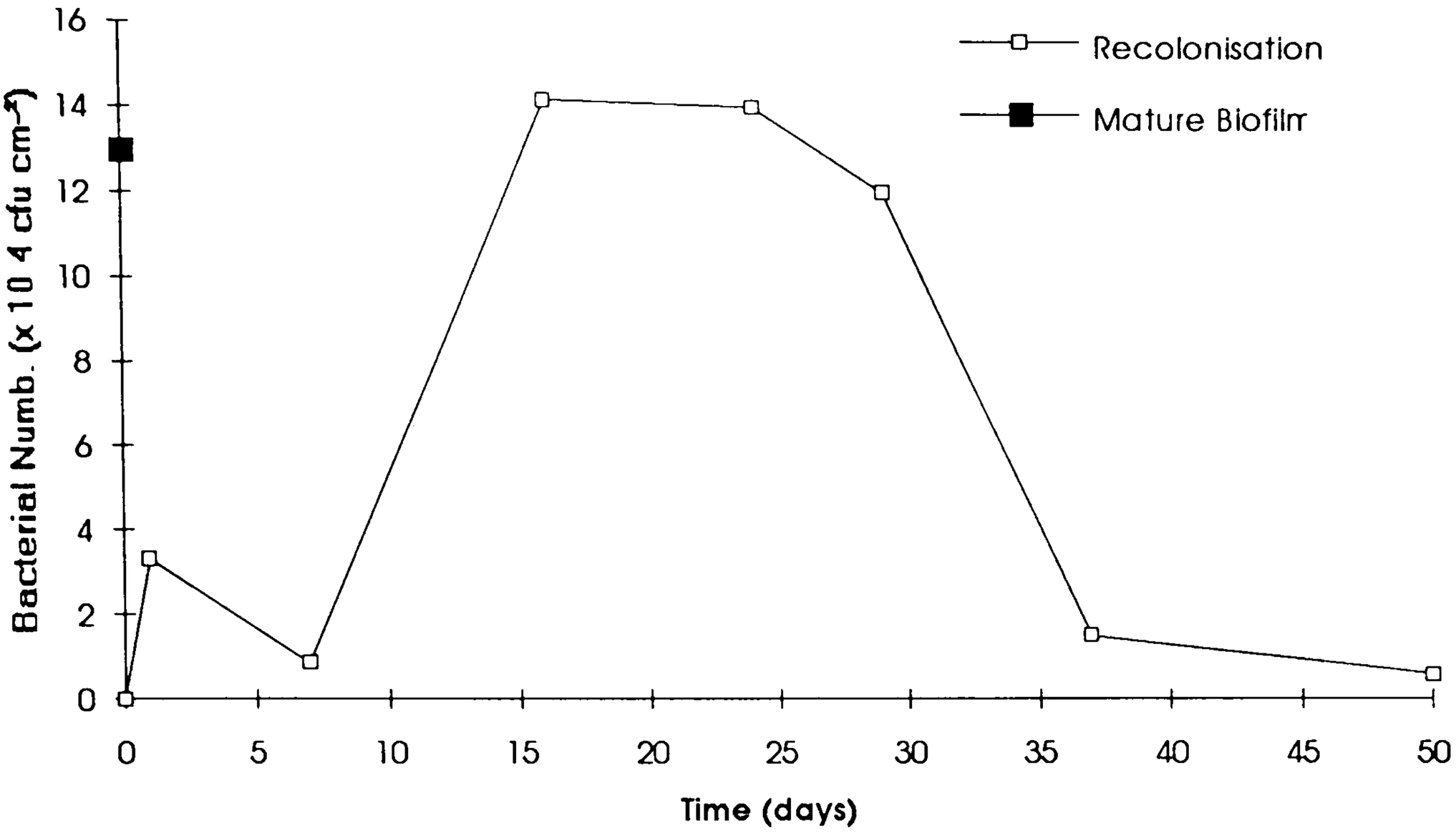


Figure 4.56 Recolonisation of copper coupons over 50 days following treatment for half an hour with 10 % v/v citric acid .

Prior to treatment with citric acid 1.3×10^5 cfu cm^{-2} were recovered from a 14 day old biofilm on copper. Following treatment with citric acid, 3.3×10^4 cfu cm^{-2} were recovered from the copper coupons with only 8.5×10^3 cfu cm^{-2} at day 8. From day 16 to 29, $> 1.2 \times 10^5$ cfu cm^{-2} were recovered from the copper surfaces. However, by day 37 there was a decrease in the number of bacteria recovered to 1.5×10^4 cfu cm^{-2} with 6.0×10^4 cfu cm^{-2} at day 50.

(i) Percentage profile of citric acid treated coupons.

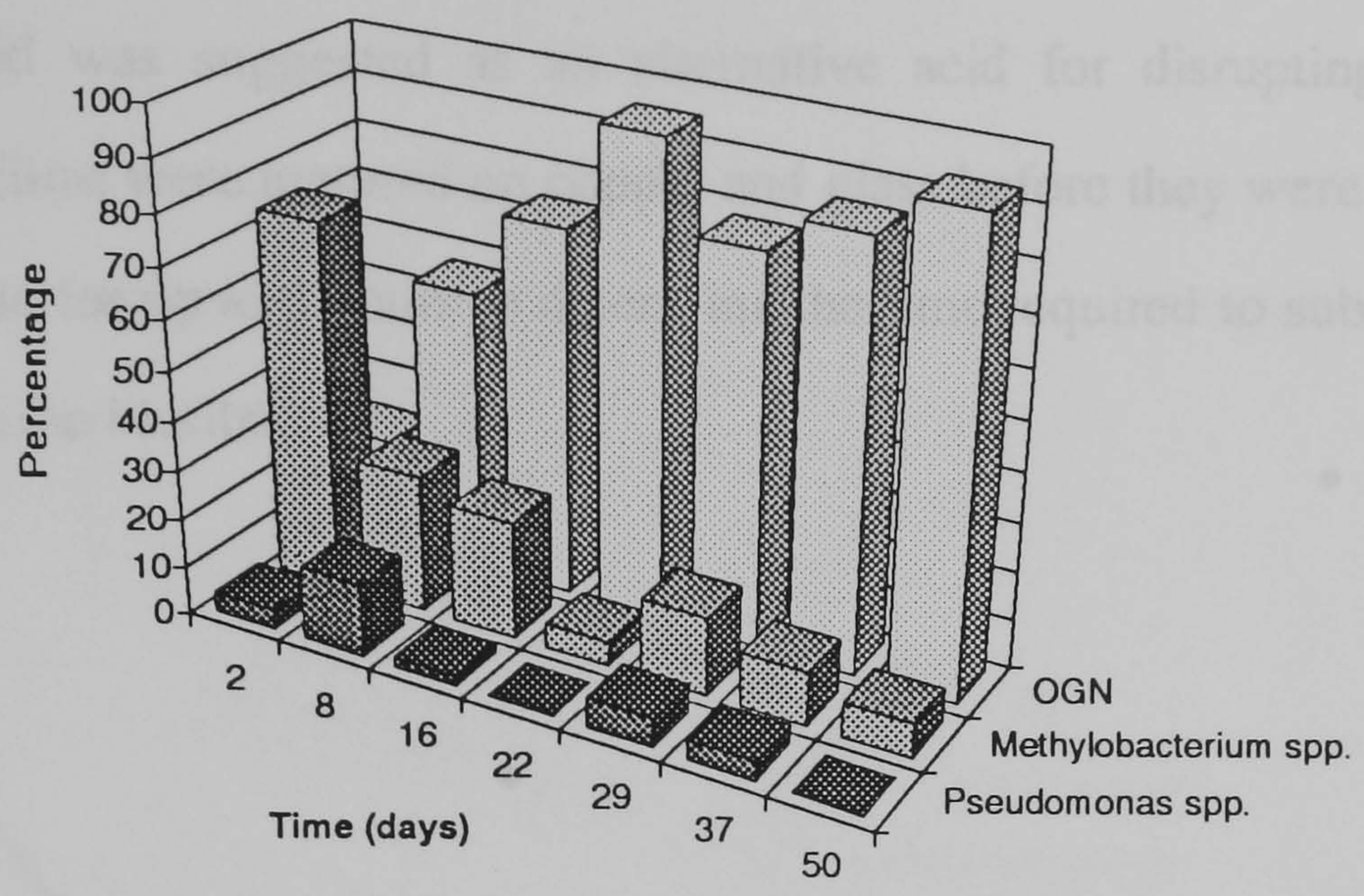


Figure 4.57 Percentage profile from citric acid treated copper coupons recolonised over 50 days.

Species / Time (days)	2	8	16	22	29	37	50
Pseudomonas spp.	4	15	2	0	6	4	0
Methylobacterium spp.	74	28	24	5	16	11	7
Gram negative bacteria	22	57	74	95	78	85	93

Table 4.32 Percentage profile from citric acid treated copper coupons recolonised for 50 days.

The Gram negative bacteria steadily increased over the 50 days representing 80 % or more after day 22. In contrast the *Methylobacterium* spp. were dominant within the first 24 hours 74 % of the population but then declined in numbers as a proportion of the population. The *Pseudomonas* spp. only represented less than 10 % of the population.

4.6.2.3 Treatment of biofilms with sulphamic acid.

Sulphamic acid was suggested as an alternative acid for disrupting and removing biofilms. Biofilms were matured on copper and glass before they were exposed to 5 % (v/v) sulphamic for up to 2 hours to determine the time required to substantially reduce the viability of the biofilm.

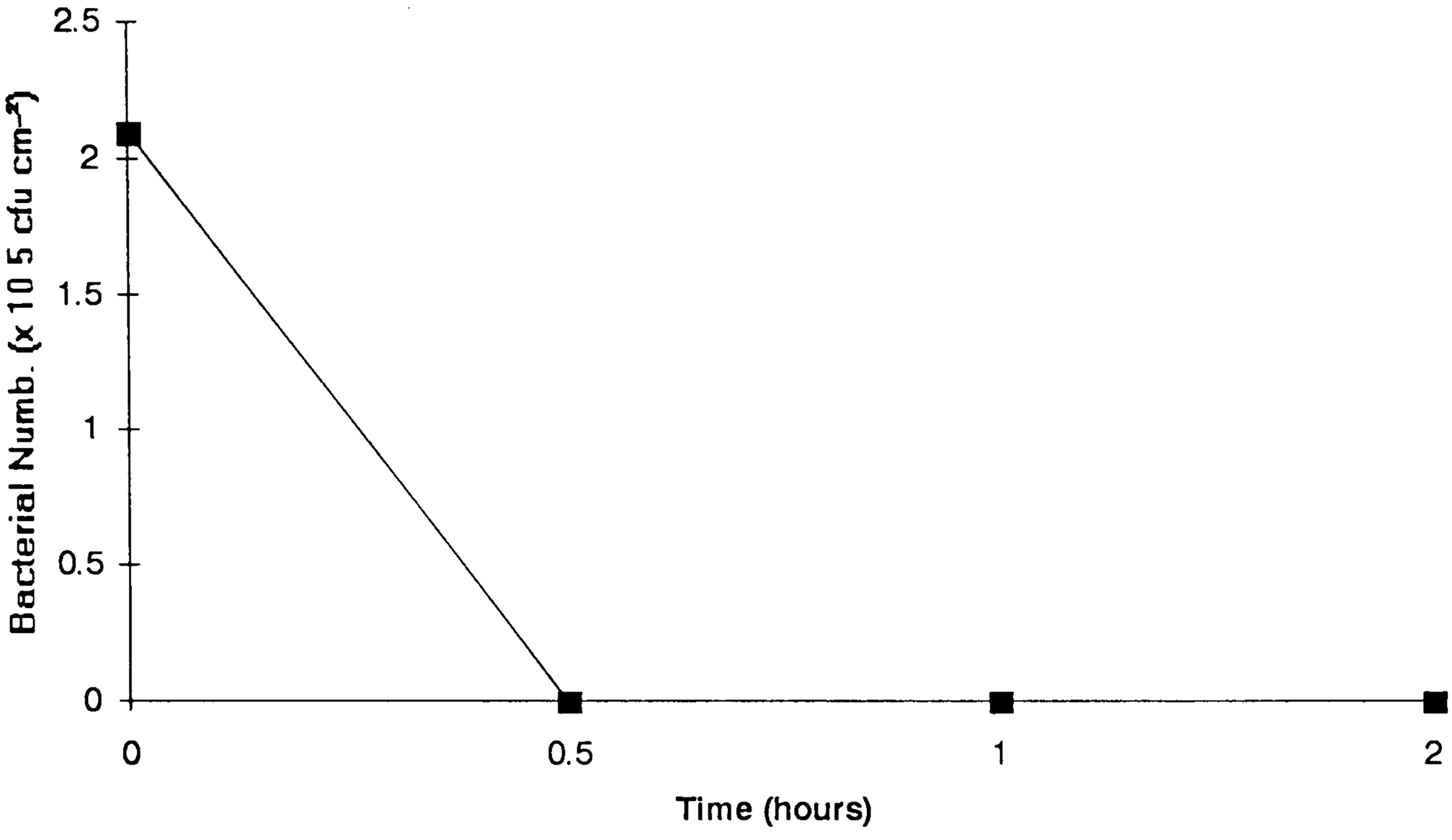


Figure 4.58 Sulphamic acid (5 % v/v) treatment of 14 day old biofilms on copper established at 45°C.

A total of 2.1 x 10^5 cfu cm^{-2} were recovered from 14 day old biofilms. However, only half an hour treatment with 5 % (v/v) sulphamic acid was required to achieve a complete reduction in the viability of the biofilm. Therefore when studying the effect of sulphamic acid on the recolonisation of copper coupons they were first treated with 5 % (v/v) sulphamic acid for half an hour prior to being replaced in the chemostat.

(i) Percentage profile of bacteria treated with sulphamic acid.

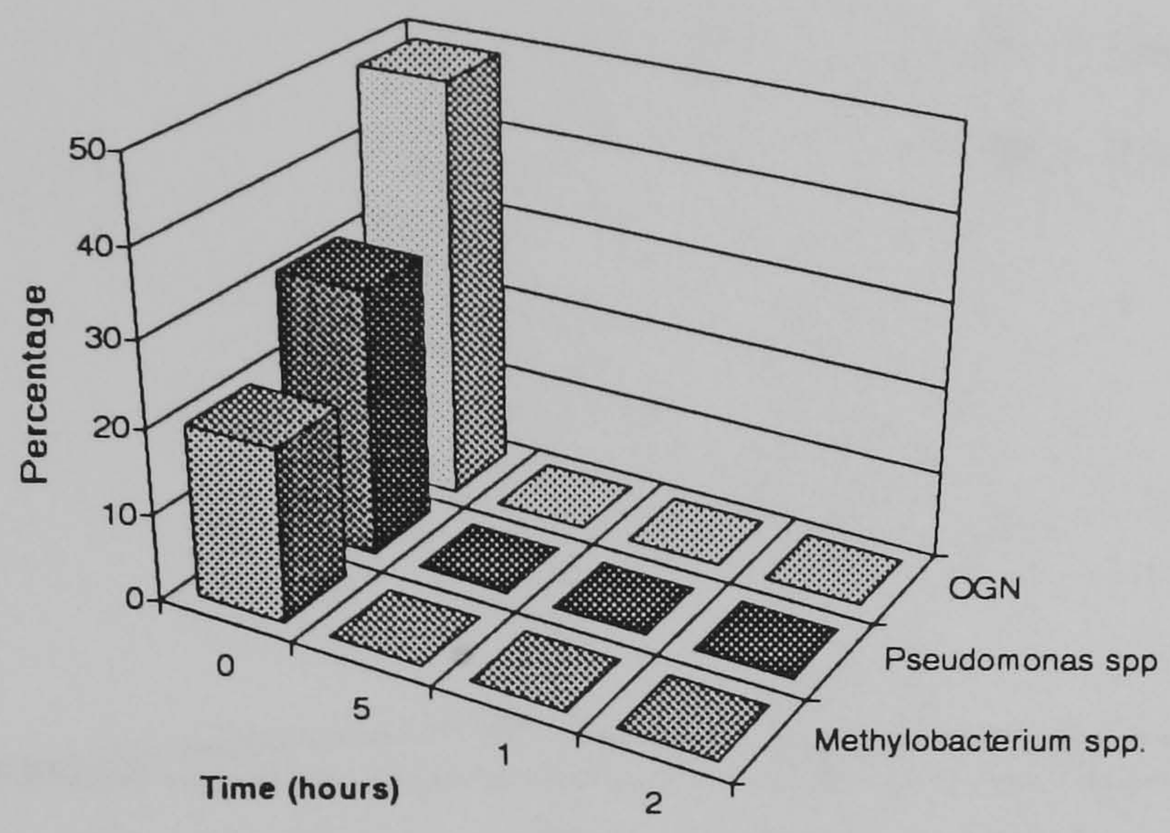


Figure 4.59 Percentage profile of sulphamic acid treated biofilms on copper established at 45°C.

Species / Time (h)	0	5	1	2
Methylobacterium spp.	20	0	0	0
Pseudomonas spp	31	0	0	0
Gram negative bacteria	49	0	0	0

Table 4.33 Percentage profile of sulphamic acid treated biofilms on copper established at 45°C.

The population from the 14 day old biofilm composed of 49 % Gram negative bacteria, 31 % *Pseudomonas* spp. and 20 % *Methylobacterium* spp. however, no species were detected after half an hour treatment with sulphamic acid.

4.6.2.4 Recolonisation of sulphamic acid treated coupons.

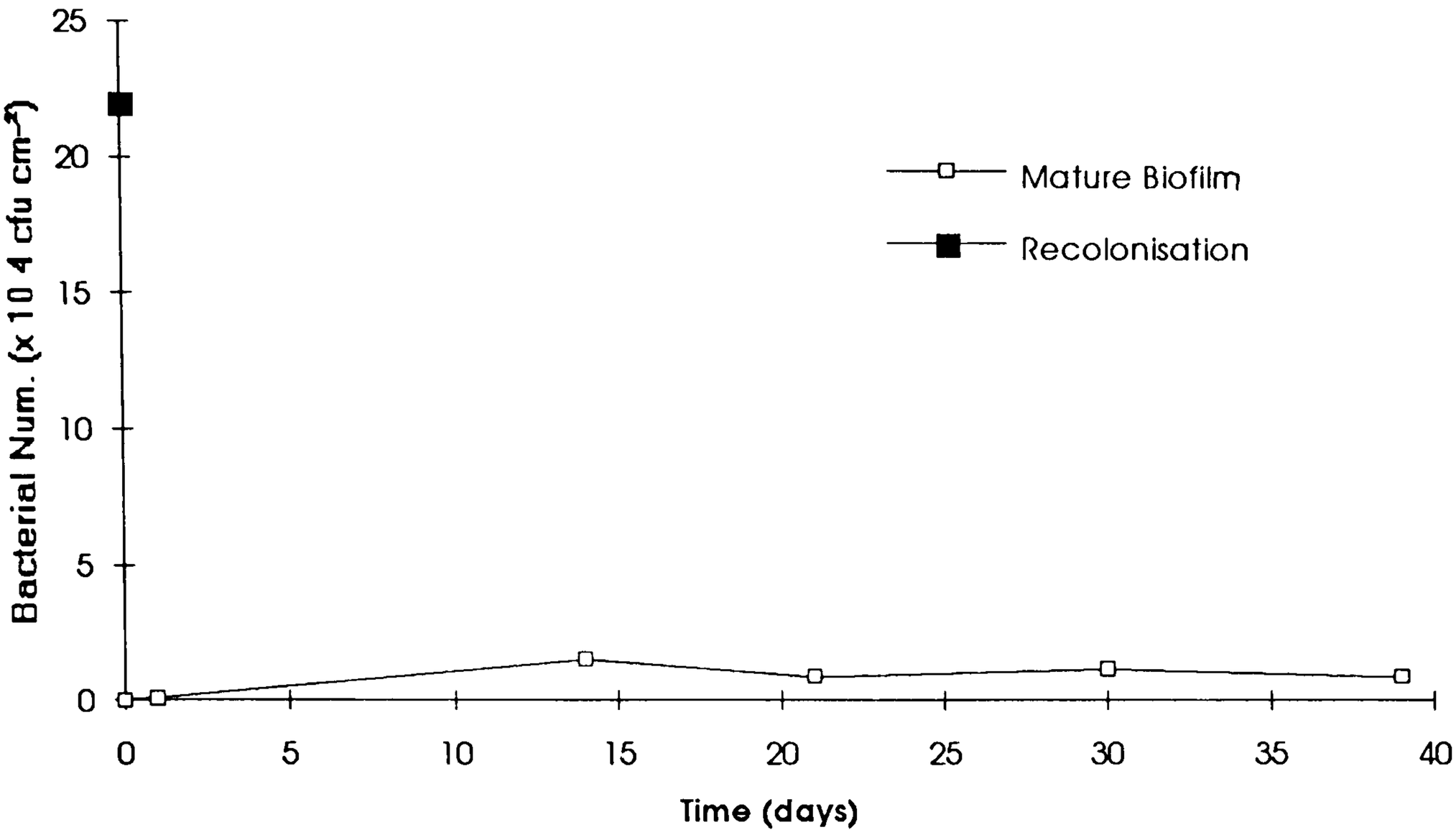


Figure 4.60 Recolonisation of copper coupons for 39 days after being treated for half an hour with sulphamic acid.

Recolonisation of the sulphamic acid treated coupons occurred at 855 cfu cm^{-2} in 24 hours but by day 14 this had risen to 1.5 x 10^4 cfu cm^{-2}. At day 21 only 8.7 x 10^3 cfu cm^{-2} were recovered from the treated coupons but by day 30 this had increased to 1.1 x 10^4 cfu cm^{-2} and decreased to 8.7 x 10^3 cfu cm^{-2} at day 39.

(i) Percentage profile of bacteria treated with sulphamic acid.

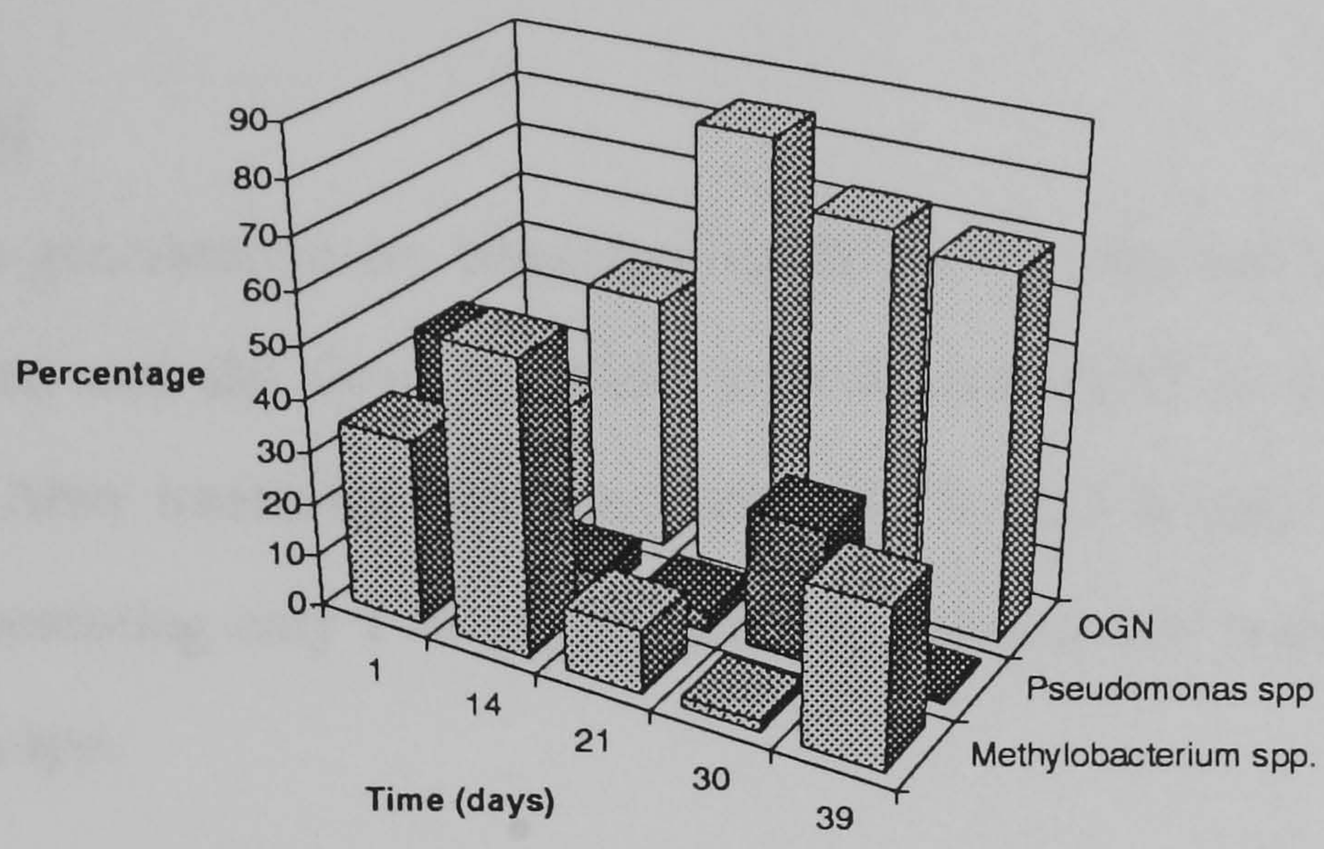


Figure 4.61 Percentage profiles of copper coupons recolonised for 39 days which were initially treated for half an hour with sulphamic acid.

Species / Time (days)	1	14	21	30	39
Methylobacterium spp.	35	56	12	2	30
Pseudomonas spp.	44	5	4	26	1
Gram negative bacteria	21	49	84	72	69

Table 4. 34 Percentage profile of copper coupons recolonised for 31 days which were initially treated for half an hour with sulphamic acid.

Primarily the *Pseudomonas* spp. dominated as the initial colonisers at day 1 at 44% of the population but steadily decreased in numbers as a proportion of the population. However the Gram negative bacteria steadily increased representing 84 % at day 21. Although the *Methylobacterium* spp. dominated at day 14 the numbers decreased thereafter as a proportion of the population.

(ii) In Summary

Citric Acid

Biofilms were generated in the laboratory model for 14 days and 1.3 x 10^5 cfu cm^{-2} were recovered and the Gram negative bacteria dominated as a proportion of the population. After treatment with the citric acid for 0.5 h only 60 cfu cm^{-2} were detected, representing only 1 % of the biofilm population and were dominated by the *Pseudomonas* spp.

Biofilms were established for 14 days at 45°C, extracted from the chemostat and treated with citric acid for 15 min (as this time period had eradicated 99 % of the viable biofilm) before being re-immersed into the chemostat at 45°C. Recolonisation was followed for 50 days (Fig. 4.56). Before citric acid treatment 1.39 x 10^5 cfu cm^{-2} recovered at day 14 however, less than 3.3 x 10^4 cfu cm^{-2} were recovered up to day 8. From day 14 to day 29 more than 1.0 x 10^5 cfu cm^{-2} were recovered from the copper coupons. At day 37 the number of bacteria recovered decreased by then exhibited an increase to 60 x 10^3 cfu cm^{-2} at day 50. As far as the population profiles were concerned the *Methylobacterium spp.* dominated immediately after treatment with citric acid but then declined as the Gram negative bacteria steadily increased.

4.8.5.iv Sulphamic Acid

Sulphamic acid was chosen as an alternative to citric acid. However using 5 % (v/v) sulphamic acid the viability of bacteria in the biofilm was completely reduced (Fig. 4.58). As with the biofilm removed from the culture for citric acid treatment the population was dominated by the Gram negative bacteria with the *Pseudomonas spp.* and *Methylobacterium spp.* also present. The recolonisation of copper coupons immersed in sulphamic acid (5 % v/v) for 0.5 h can be observed in (Fig. 4.60). Plotted at zero on the x-axis is the 210 x 10^3 cfu cm^{-2} recovered for the 14 day old biofilm before it was treated with sulphamic acid. At 14 days only 15 x 10^3 cfu cm^{-2} were

recovered from the copper coupons which was a maximum for the 40 day recolonisation. Species diversity within the biofilm was dominated by the *Pseudomonas spp.* within 24 and the *Methylobacterium spp.* at day 14 but thereafter the Gram negative bacteria steadily increased until day 50.

4.7 INFLUENCE OF WATER CHEMISTRY ON BIOFOULING

Calcium carbonate concentration was increased from < 20 ppm in the soft water in the media supplying only vessel two such that this vessel had a final working concentration of 70-80 ppm.

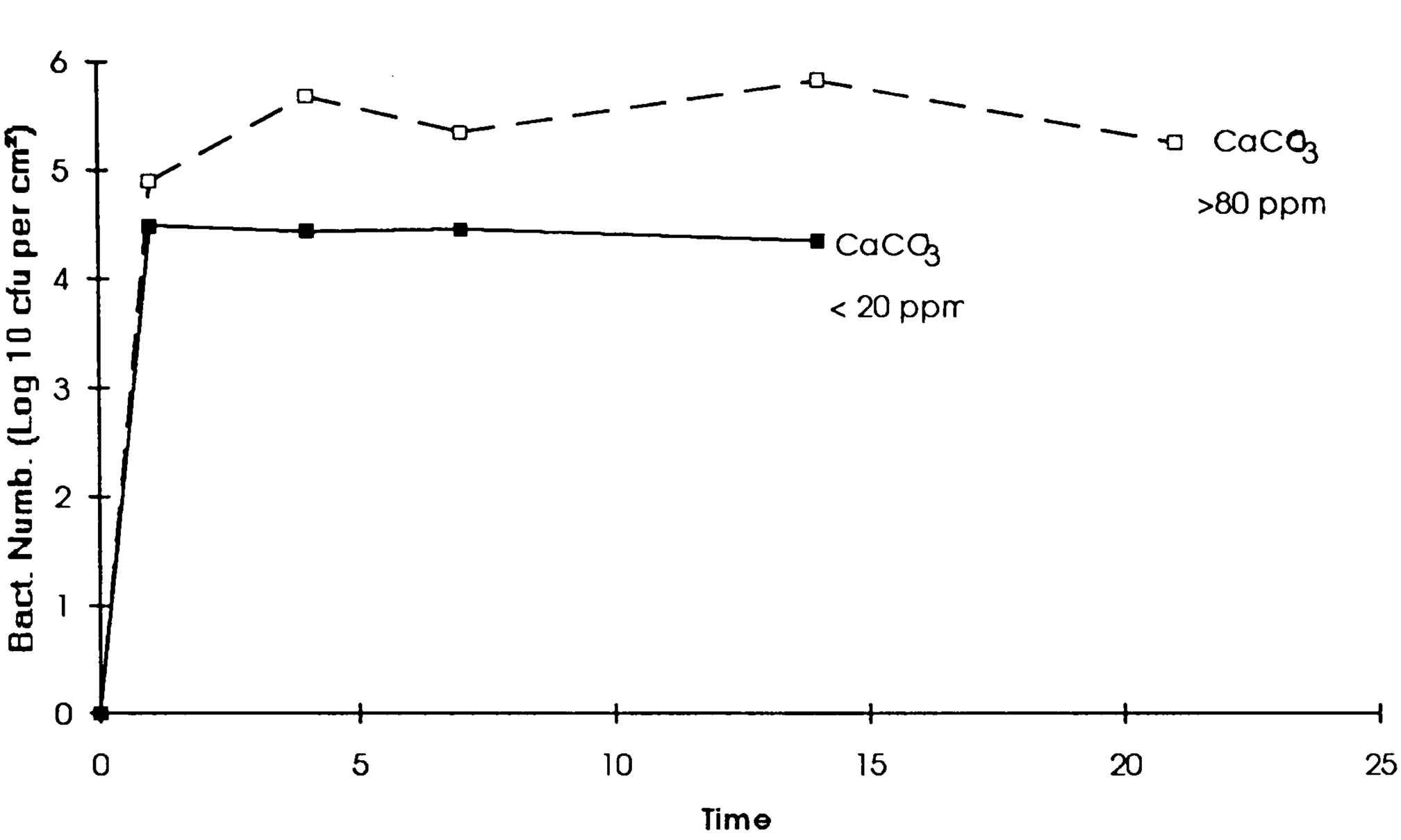


Figure 4.31 Colonisation of copper before and after additional $CaCO_3$.

Initially in the unaltered soft water the colonisation of copper occurred at 4.49 Log $_{10}$ cfu cm^{-2} at day 1 and 4.44, 4.47 and 4.38 Log $_{10}$ cfu cm^{-2} at day 4, 7, and 14 respectively. Correspondingly when the concentration of calcium carbonate was increased to 80 ppm in the culture the number of viable bacteria recovered from the biofilm in 24 h was 4.9 Log $_{10}$ cfu cm^{-2} with 5.7 Log $_{10}$ cfu cm^{-2} at day 4. The number of bacteria recovered from the biofilm then decreased to 5.3 Log $_{10}$ cfu cm^{-2} at day 21.

4.8 VISUALISATION OF COPPER SURFACES (ESEM)

4.8.1 Influence of particulate matter on biofouling

The principle of environmental SEM is the visualisation of specimens without prior preparation. Hydrated specimens were loaded onto the stage and the chamber adjusted to a pressure of 7.0 torr. Subsequently as the pressure in the chamber was decreased water present on the surface was sublimed off to reveal the morphology of the specimen below. In Fig. 4.32 the presence of bacteria and debris on the surface are clearly visible as is a small area of copper surface. Image analysis revealed that the average area covered was equivalent to 32.3 % with 600 objects being identified (Table 1). The bacteria are observed in greater detail in Fig. 4.33 where the microcolony of biofilm and debris can be seen to be physically open with 5 μm spaces present which may form a series of water channels.

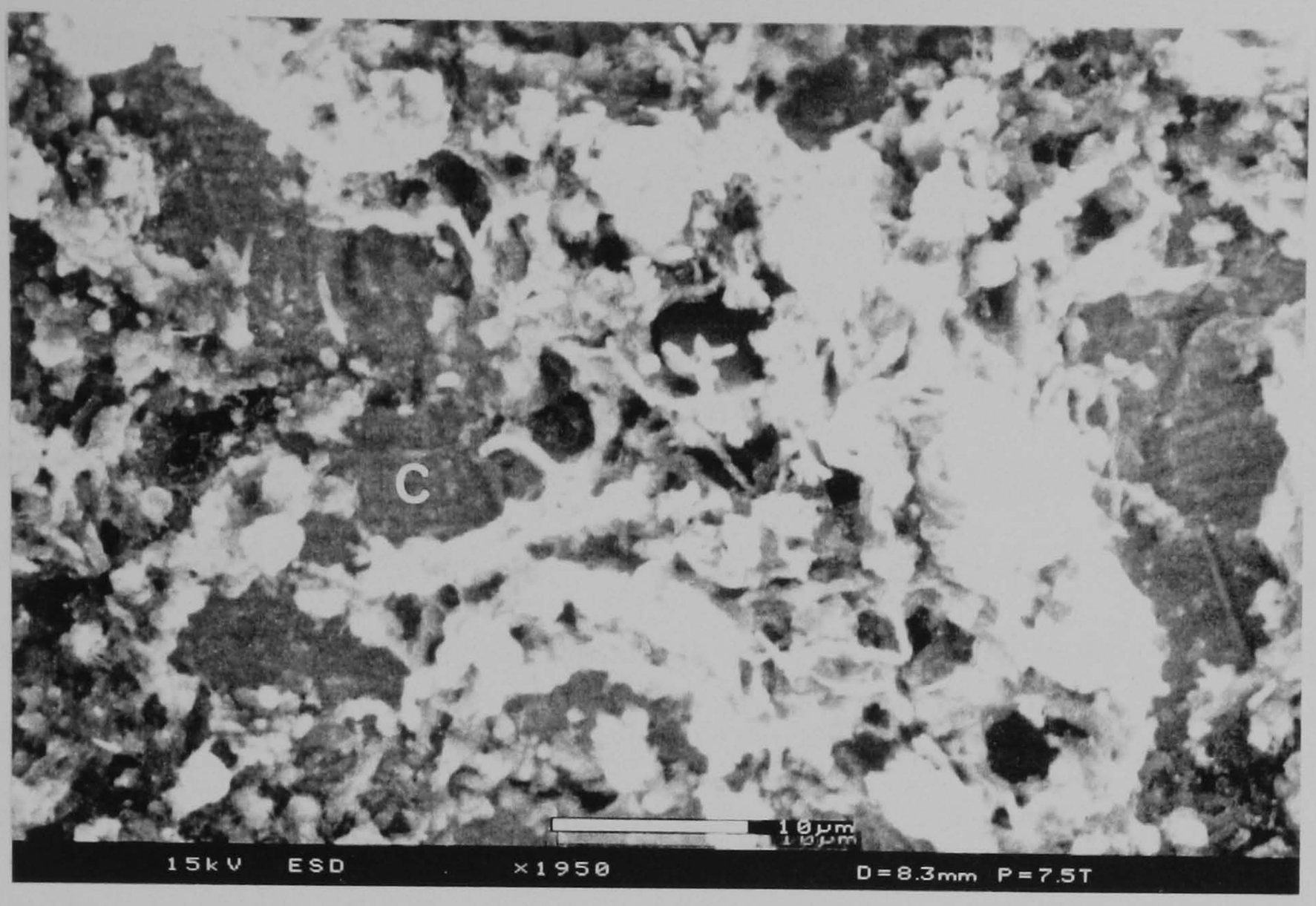


Figure 4.32 ESEM of copper coupon surface from culture supplied with particulate matter (marker bar denotes 10 μm). C denotes copper surface.

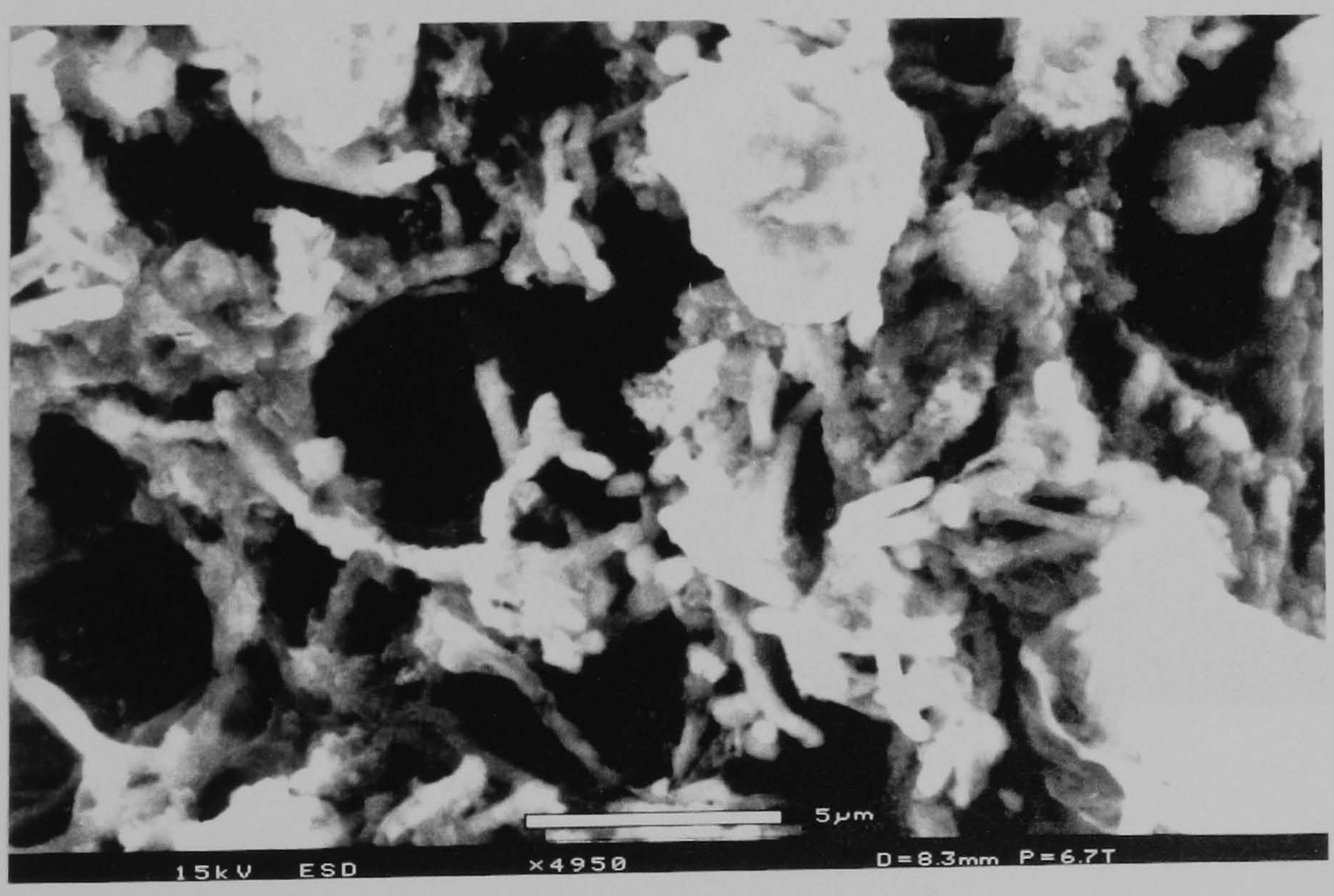


Figure 4.33 ESEM of copper coupon surface from culture supplied with particulate matter (marker bar denotes 5 μm).

4.8.2 Biofouling in the absence of particulate matter

The surface of the copper tile is relatively free from debris as the original milling lines are still visible Fig. 4.34. Although a microcolony of bacteria is visible there is very little particulate matter and debris on the surface. When the image was analysed the total percentage area covered was 29.8 % with 147 identifiable objects. At increased magnification, Fig. 4.35 bacteria are observed in the crevices in the copper surface. The only appreciable amount of debris found did not resemble particulate matter as it was too smooth and consistent and may have been tissue which attached to the tile surface during transportation, Fig. 4.36. However either side of this debris the naked copper surface is clearly visible.

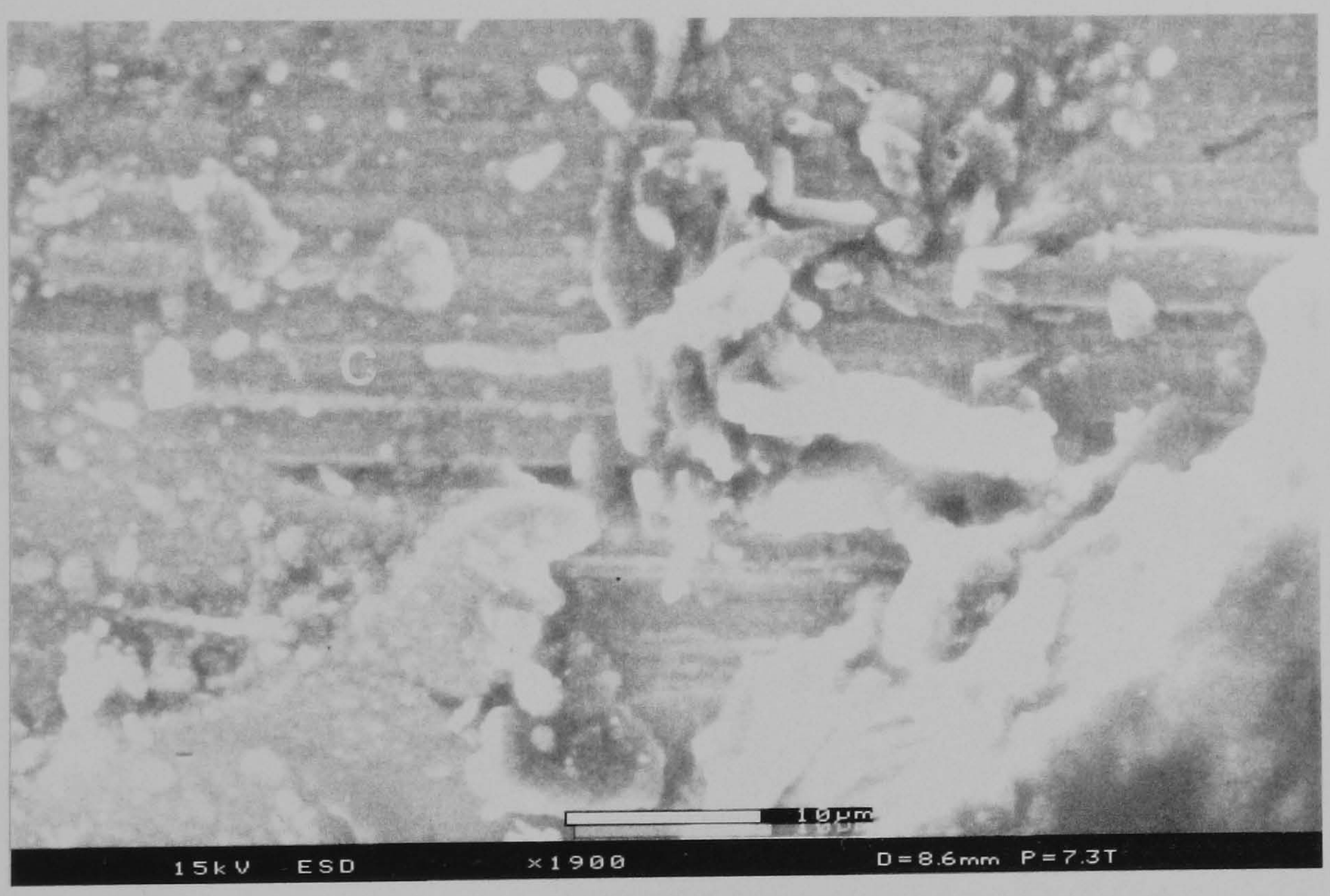


Fig. 4.34 ESEM of copper coupon surface from filtered culture (marker bar denotes 10 μm). C denotes the copper surface.

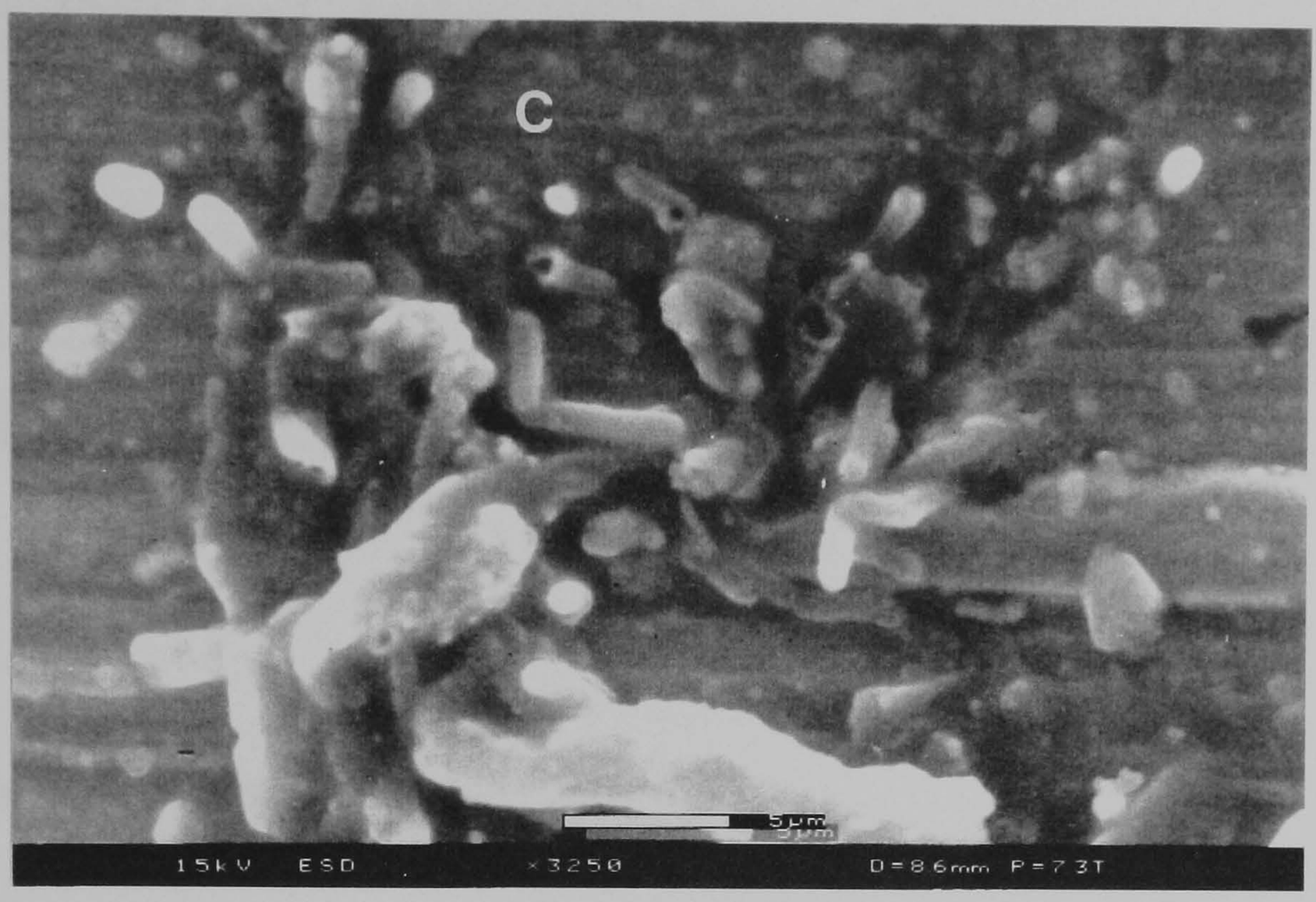


Figure 4.35 ESEM of copper coupon surface from filtered culture (marker bar denotes 5 μm). C denotes the copper surface.

Figure 4.36 Naked copper coupon surface as observed by ESEM from filtered culture (marker bar denotes 10 μm). C denotes the copper surface.

Table 4.9 ESEM area 1. Analysis of the area visualised by ESEM.

Field evaluation	Average (Fig. 1)	Average (Fig. 3)
% Area	32.3	29.8
Counted objects	600	147

4.8.3 Biofouling in the presence of particulate matter

The surface of the copper tube was covered completely in bacteria Fig. 4.37 (marker bar denotes 5 μm). The bacterial flora are relatively dense with the top of a hydrated microcolony clearly visible. No naked copper surface was visible in this specimen.

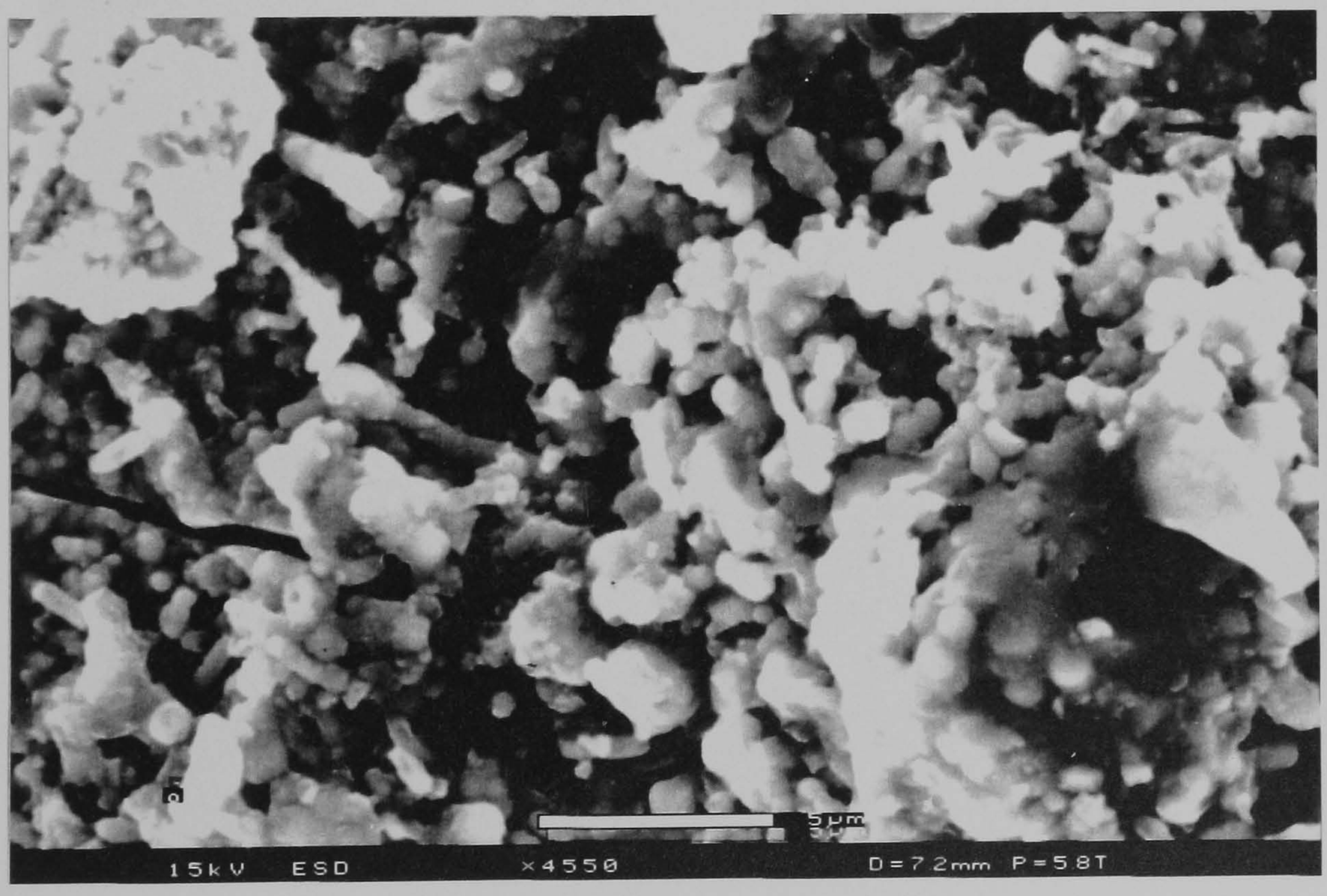


Fig. 4.37 ESEM of copper tube surface supplied with culture containing particulate matter (marker bar denotes 5 μm).

4.8.4 Scanning confocal laser microscope (SCLM)

4.8.4.1 Choice of coupons for SCLM analysis

During transportation, the coupons in the universals appeared to have lost part of the biofilm resulting in debris in the bottom of the universal. The hydrated coupons, retained in moist tissues in the petri dish, did not appear to suffer from detachment of appreciable amounts of biofilm and so were chosen for analysis.

4.8.4.2 Comparison of surface topology

Fluorescein was utilised to visualise the topology of the copper surfaces. The surface of copper coupons from the vessel supplied with filtered soft water exhibited a uniform and smooth surface morphology as indicated by the unchanging fluorescence over the surface (Fig. 4.38). When viewed in the horizontal (xz sagital sectioning) mode the surface was also uinform (Fig. 4.39).

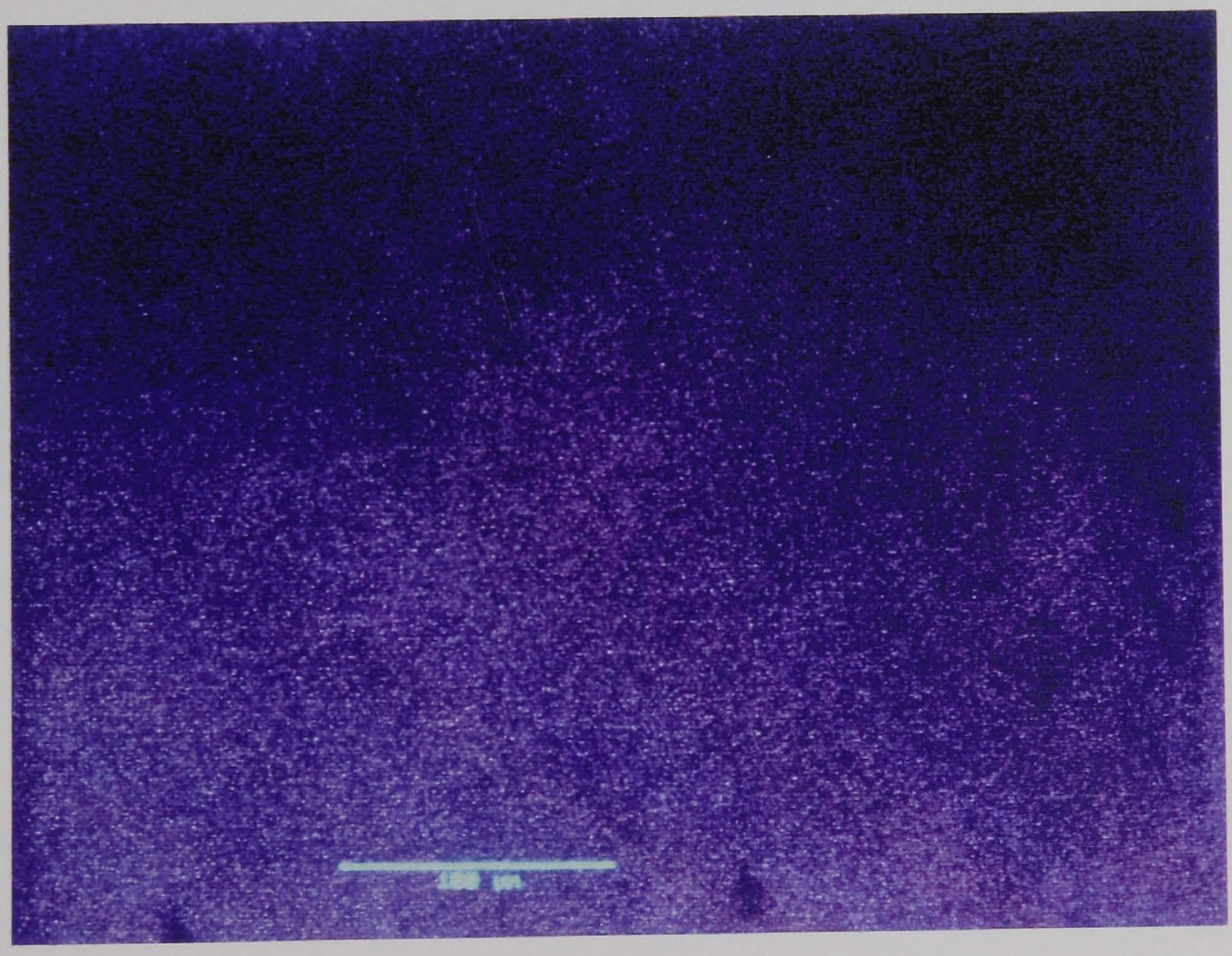


Fig. 4.38 Direct view of copper surface supplied with filtered soft water (marker bar denotes 100 μm).

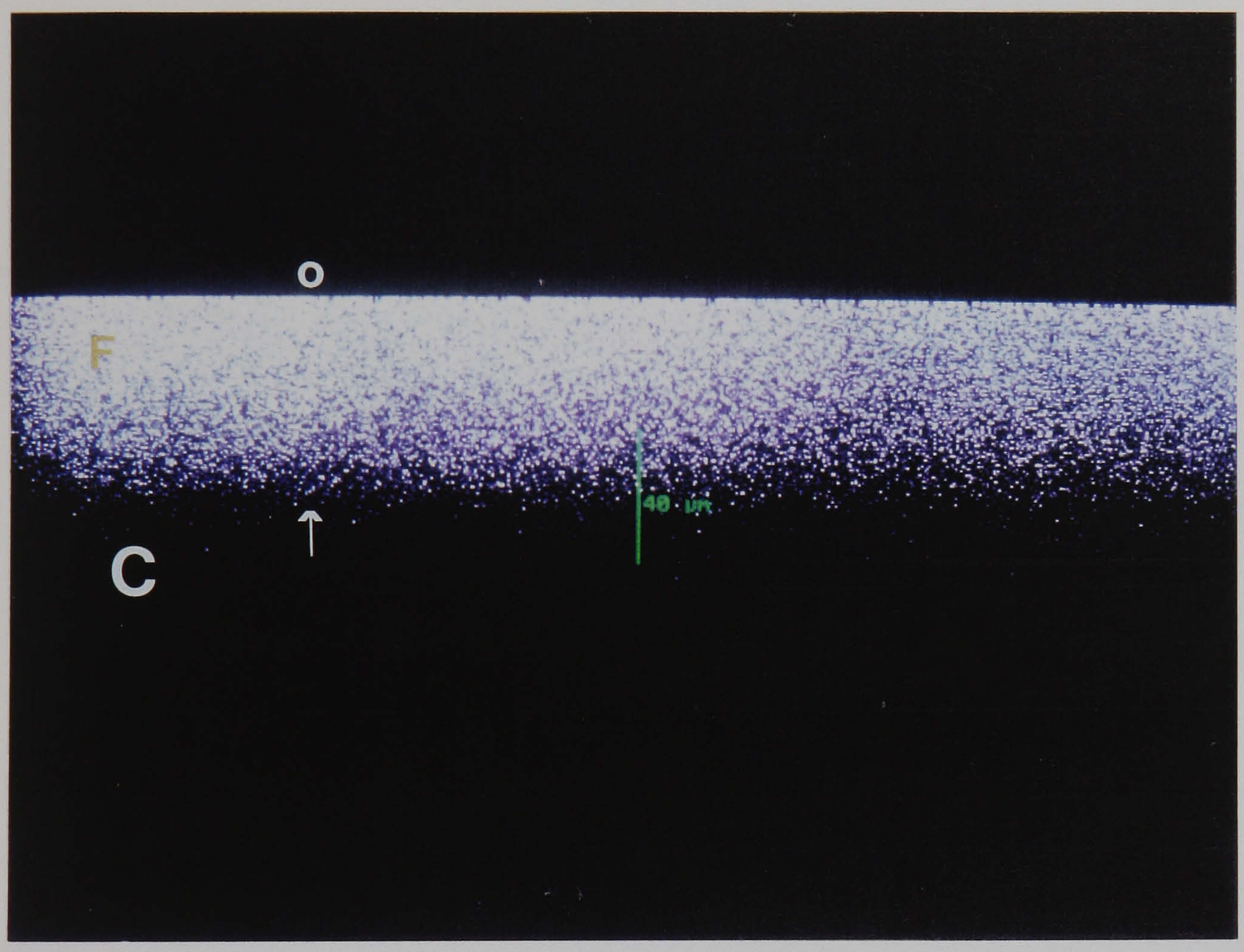


Fig. 4.39 An xz sagital sectioning of copper surface supplied with filtered soft water (marker bar denotes 40 μm). F denotes the fluorescein on top of C the uniform copper surface with the arrow indicating the inner surface of the copper tube and O indicating the outer surface.

Copper coupons extracted from the vessel supplied with particulate matter exhibited an uneven surface with many peaks and troughs as indicated by the patchy fluorescence pattern (Fig. 4.40). An xz sagital through the surface revealed pits of up to 40 μm in depth (Fig. 4.41).

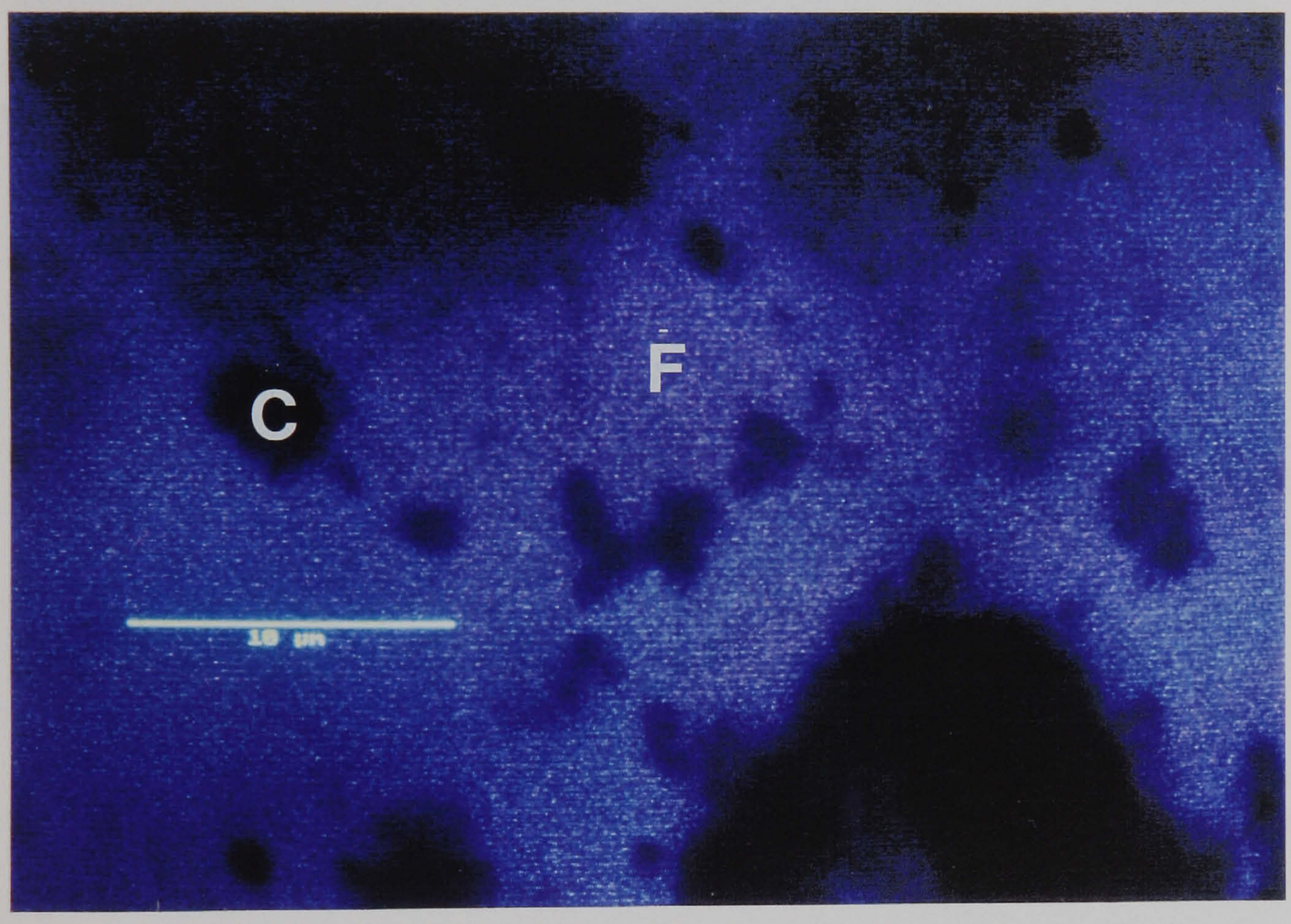


Figure 4.40 Patchy mosaic surface of copper coupons immersed in soft water supplied with particulate matter (marker bar denotes 10 μm). C denotes the copper surface and F the fluorescein.

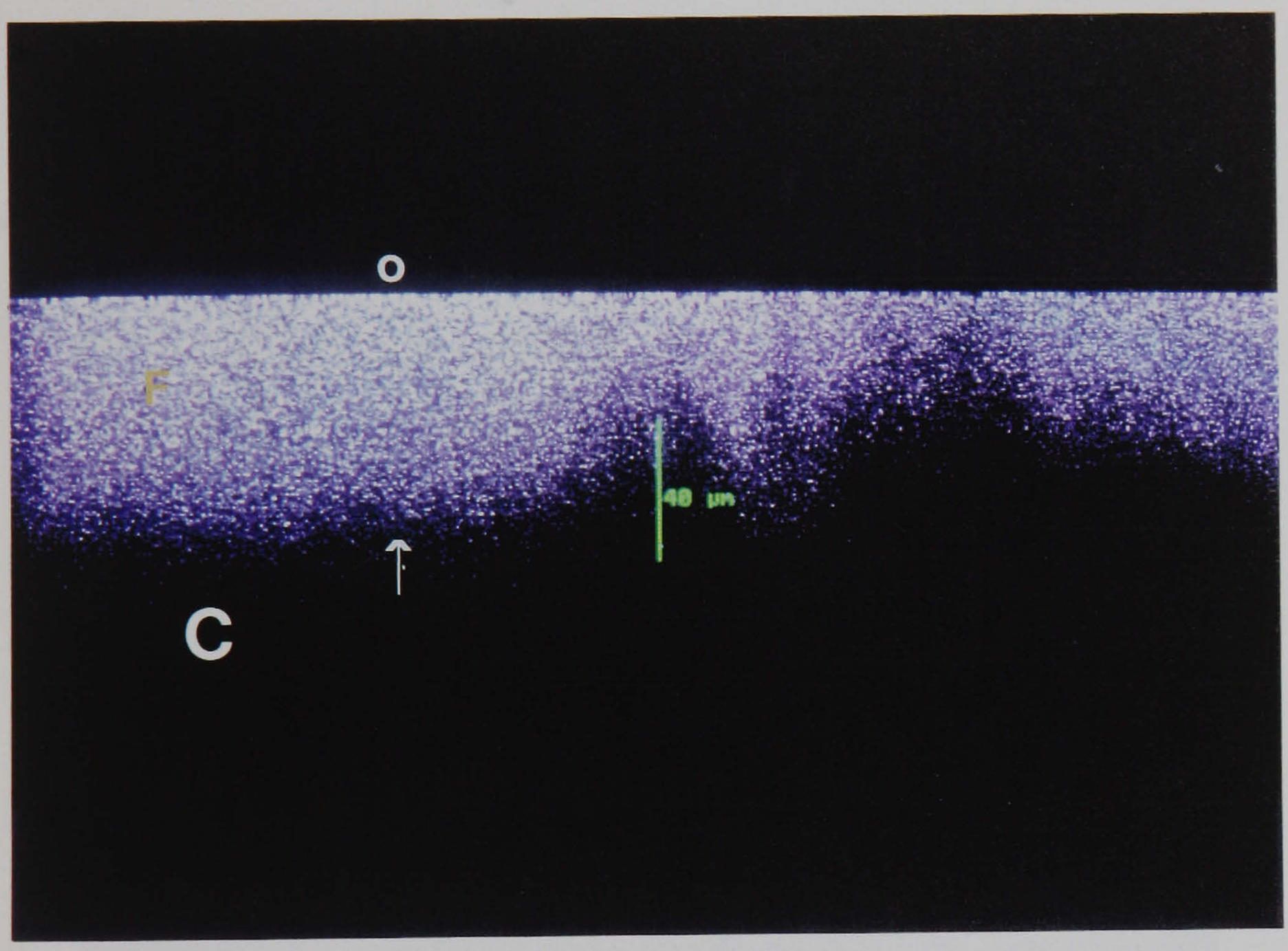


Figure. 4.41 An xz sagital section through the surface revealed pits of up to 40 μm in the copper coupons immersed in water supplied with particulate matter (marker bar denotes 40 μm). F denotes the fluorescein on top of the uneven copper surface (C) with the arrow indicating the inner copper surface and (O) indicating the outer surface).

4.8.4.3 Visualisation of bacteria on the copper surfaces

RITC was utilised to stain the bacteria with fluorescein to study the copper surface on a tile removed from the vessel supplied with particulate matter. Fig. 4.42 demonstrates the bottom of a pit (left hand side image) distributed around which are bacteria (right hand side image).

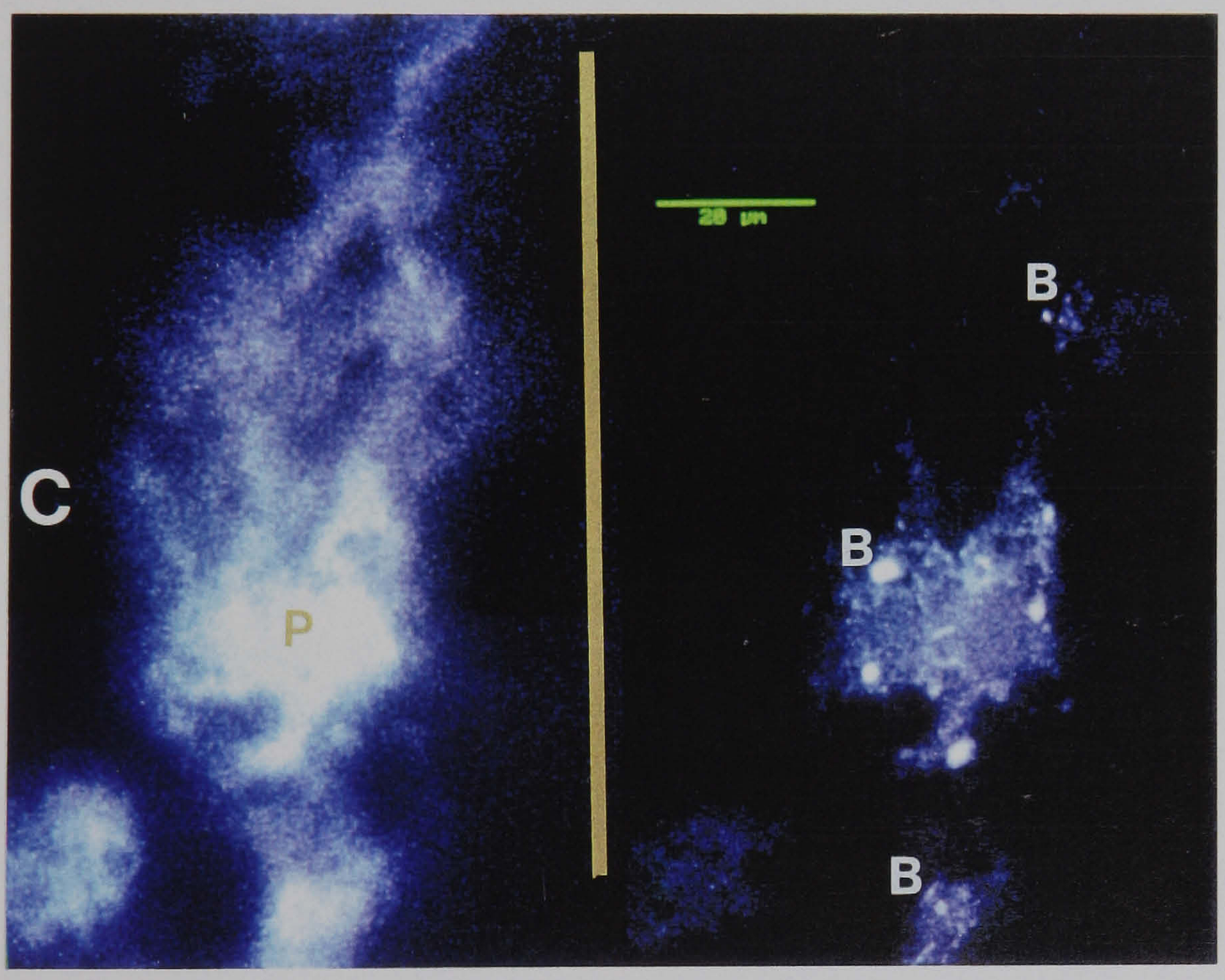


Figure 4.42 Demonstrates the bottom of a pit (left hand side image) distributed around which are bacteria (right hand side image) (marker bar denotes 20 μm). C denotes the copper surface; P denotes the pit and in the right hand image B denotes the position of the bacteria.

Using an xz sagital section the bacteria were observed to be located on the walls and in the base of the pit in monochrome (Fig. 4.43) and with the facility of colour enhancement (Fig.4.44)

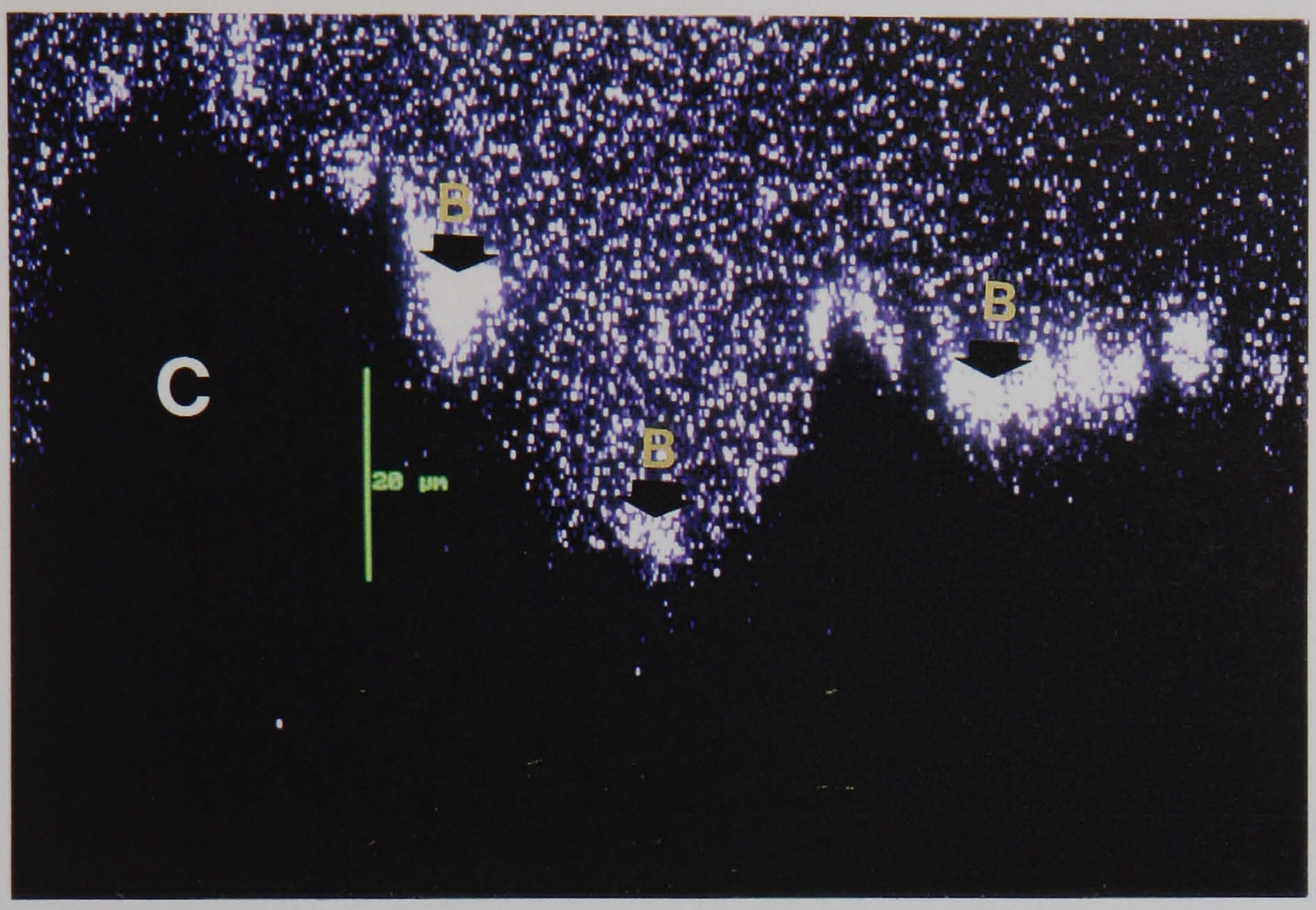


Figure 4.43 Monochrome xz sagital section of bacteria in pit (marker bar denotes 20 μm). C denotes the copper surface and B denotes the position of the bacteria.

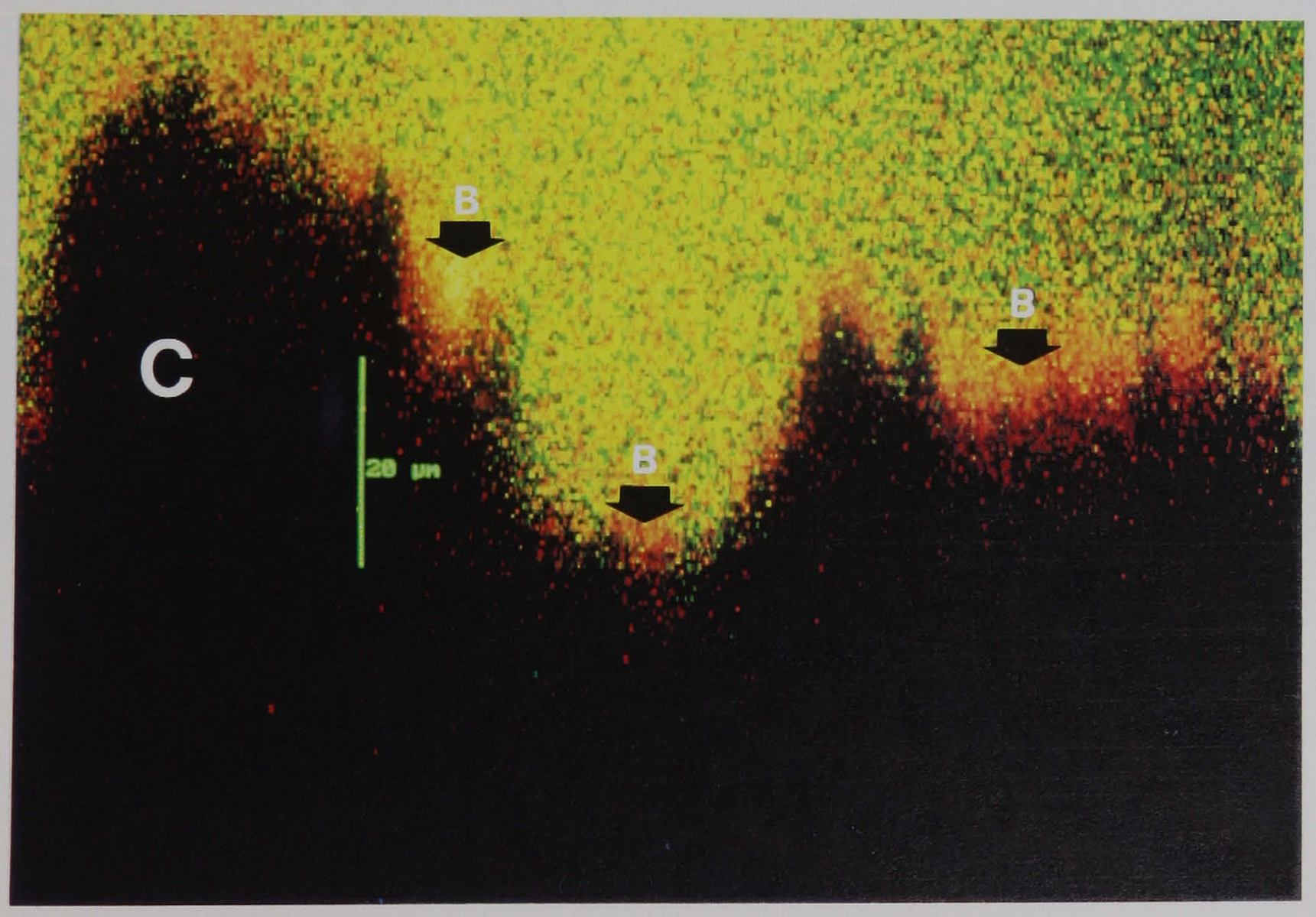


Figure 4.44 Colour enhanced image of xz sagital section of bacteria in pit (marker bar denotes 20 μm). C denotes the copper surface and B denotes the position of the bacteria.

4.8.4.4 Determination of metabolic activity of the bacteria

The fluorescence spectrum of stain 5-(and-6)-carboxy 2',7'-dichlorofluorescien (CDF) decreases due to acidification and so can be utilised as an indicator of bacterial metabolic activity. Copper surfaces were flooded with CDF then the cells stained with RITC. The surface topology is illustrated in left hand image of Fig. 4.45 while on the right hand image the bacteria can be identified.

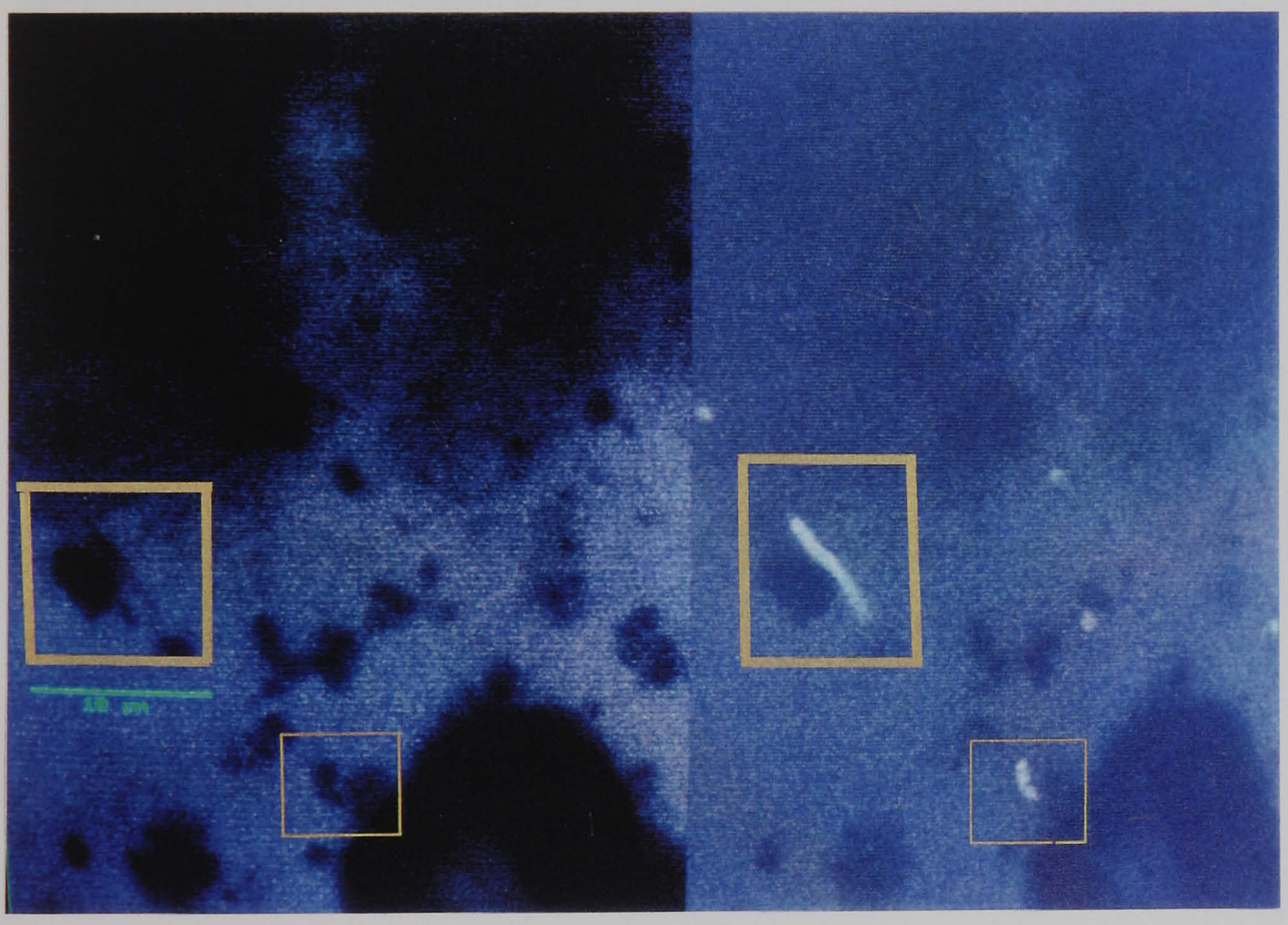


Figure 4.45 Split screen image of surface (left) and bacteria (right) (marker bar denotes 10 μm). The enclosed areas highlight the position of the bacteria and decreased intensity of fluorescence.

When both the images of Fig. 4.46 were merged a number of the areas of acidification can be seen to be associated with the presence of bacterial cells indicative of cell metabolism.

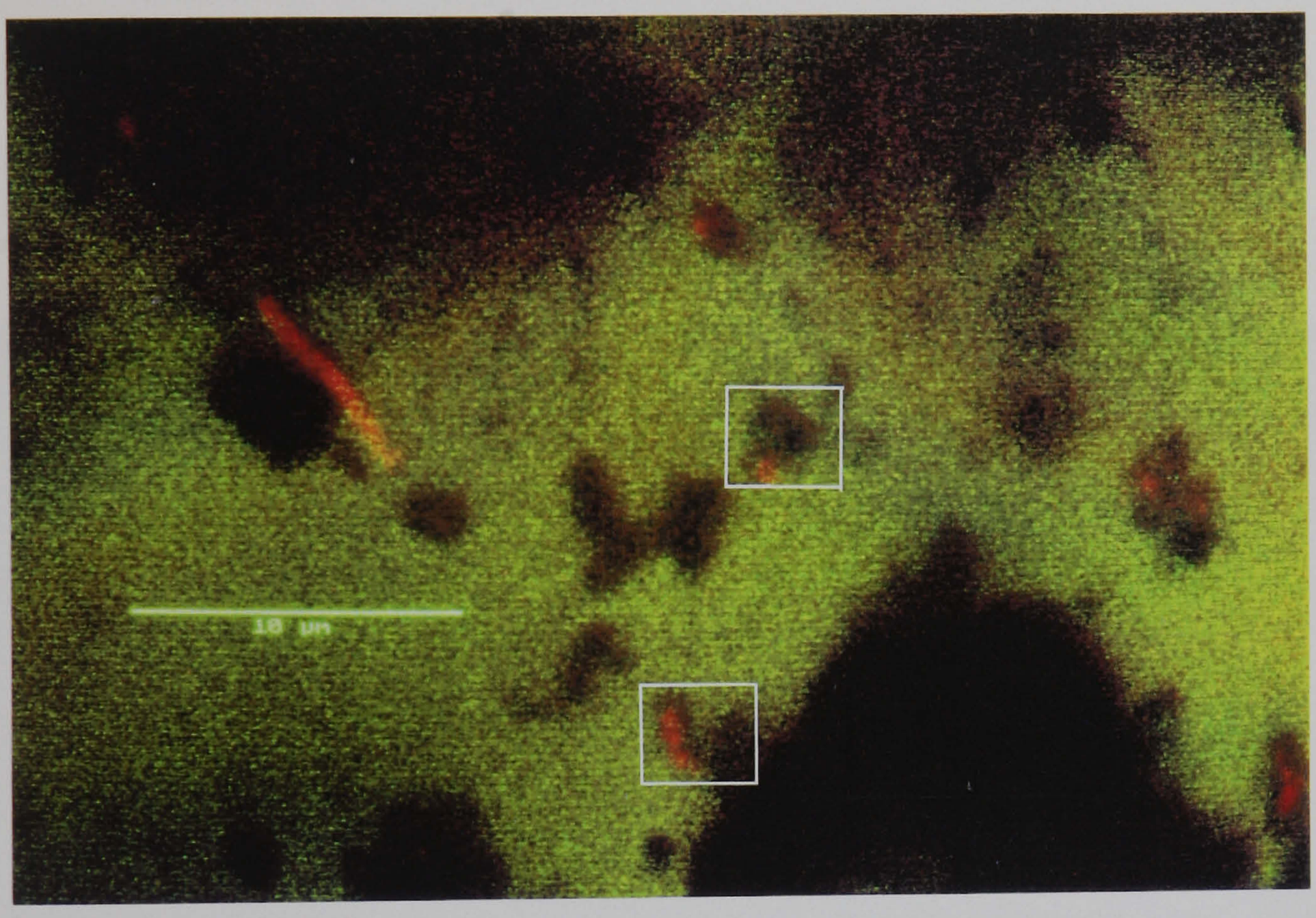


Figure 4.46 Association of bacteria and zones of acidification on the surface of the copper tile (marker bar denotes 10 μm). The enclosed areas highlight the position of the bacteria and decreased intensity of fluorescence.

4.8.5 Visualisation of surfaces using epifluoresence, SEM and SCLM.

After twelve months operation sections of the copper tube were removed periodically to be examined for fouling and signs of corrosion using epiflourescence and scanning electron microscopy.

Fig 4.47 shows that fungi were visible on the surface utilising differential interference contrast. However greater discrimination (Fig. 4.48) was obtained after staining the nucleic acids of the cells using acridine orange. Focusing further down into the specimen (Fig. 4.49), individual bacteria could be discriminated on the surface

Figure 4.47 Discrimination of fungi on the copper tube surface using differential interference contrast, x 1000 (marker bar denotes 10μm). F denotes the position of the fungi.

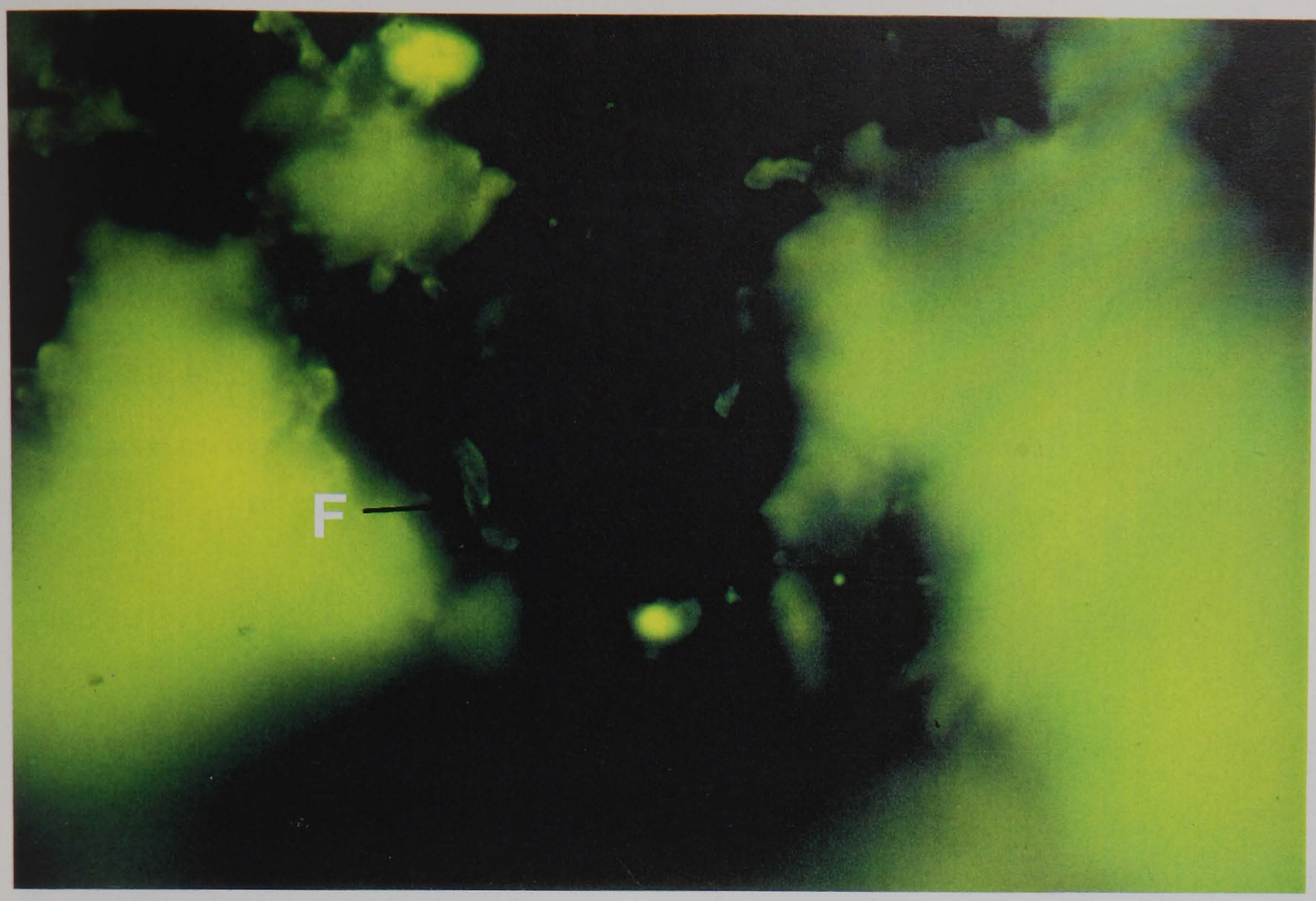


Figure 4.48 Greater differentiation of fungi was obtained after staining the nucleic acids of the cells using acridine orange, x 1000 (marker bar denotes 10μm). F denotes the position of the fungi.

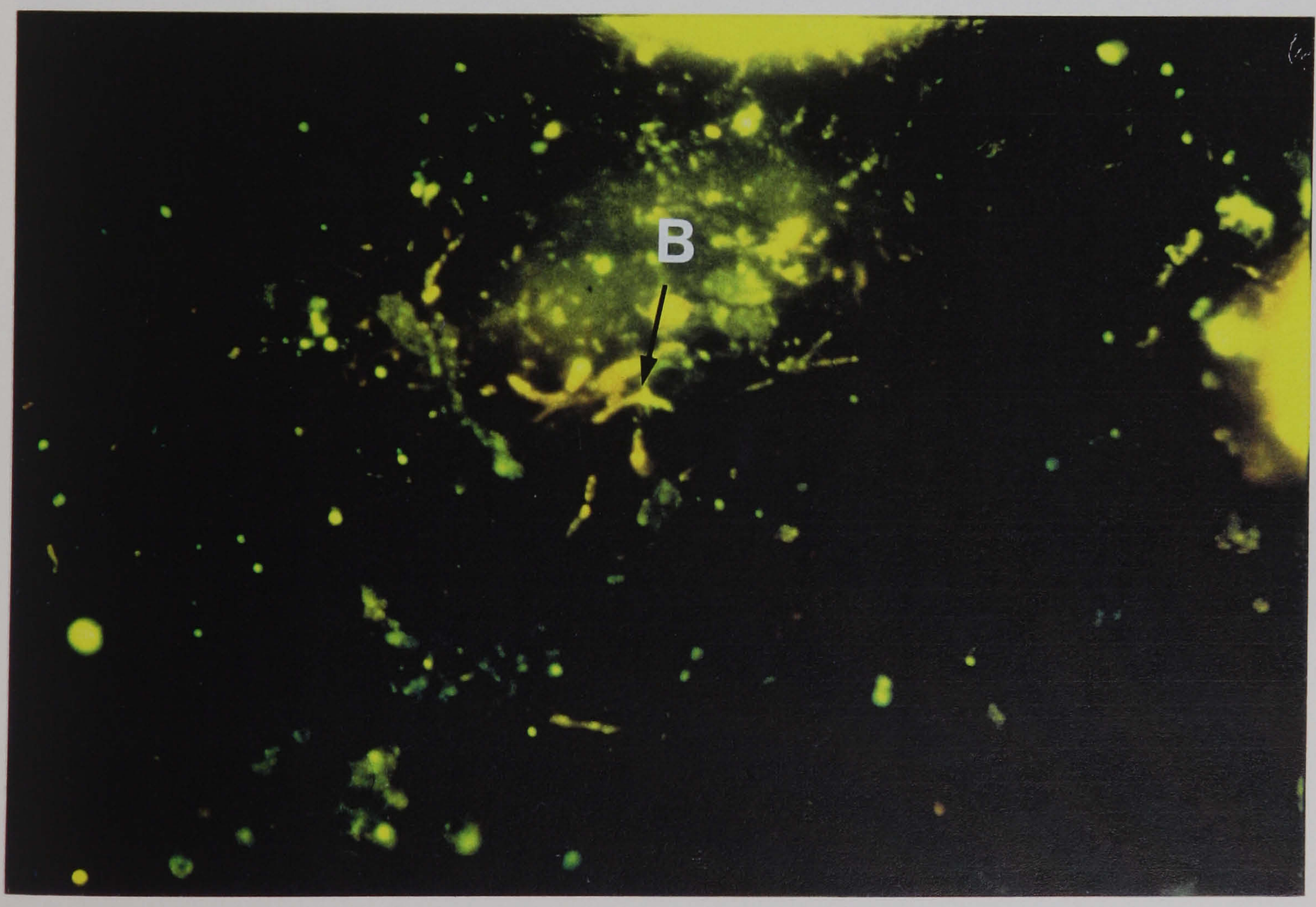


Figure. 4.49 Individual bacteria could also be identified on the copper tube surface, x 1000 (marker bar denotes 10 μm). B denotes the position of the bacteria.

Other copper specimens from the copper tube were visualised using a scanning electron microscope equipped with a cryogenic stage enabling the specimen to be frozen using liquid nitrogen. The specimen was viewed directly but no discrimination was available of the sample and so it was then sputter coated with gold before visualisation. In Fig. 4.50 (x 1862) a number of bacteria can be visualised entwined in a threaded matrix which covers the surface in a matrix.

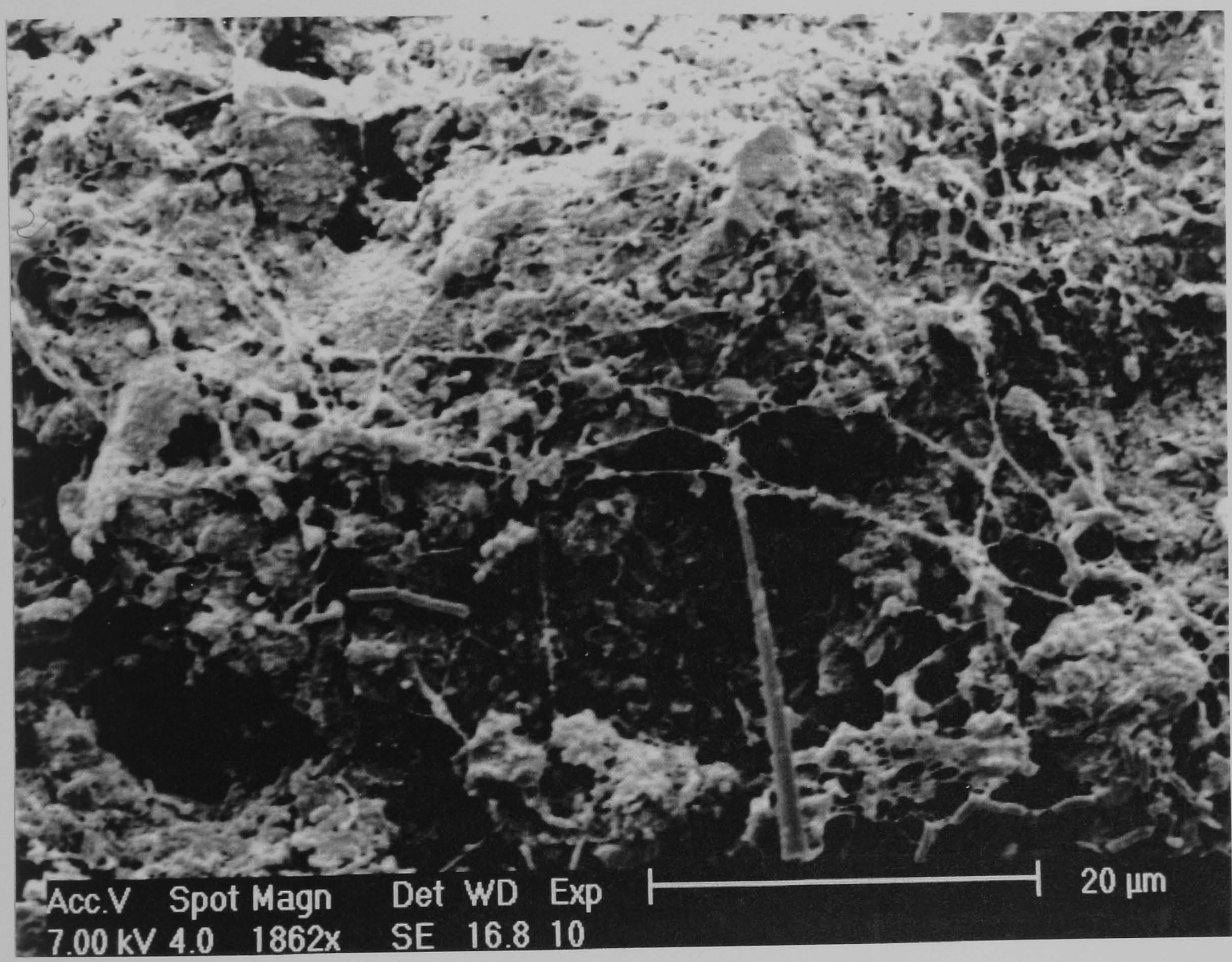


Figure 4.50 A number of bacteria can be visualised entwined and connected in a hydrated network, x 1862 (marker bar denotes 5 μm)).

When the surface of the copper tube specimens were viewed using the ESEM (Fig. 4.51) the bacteria were observed to covered in a slime and were difficult to identify until the magnification was increased to 8500 times.

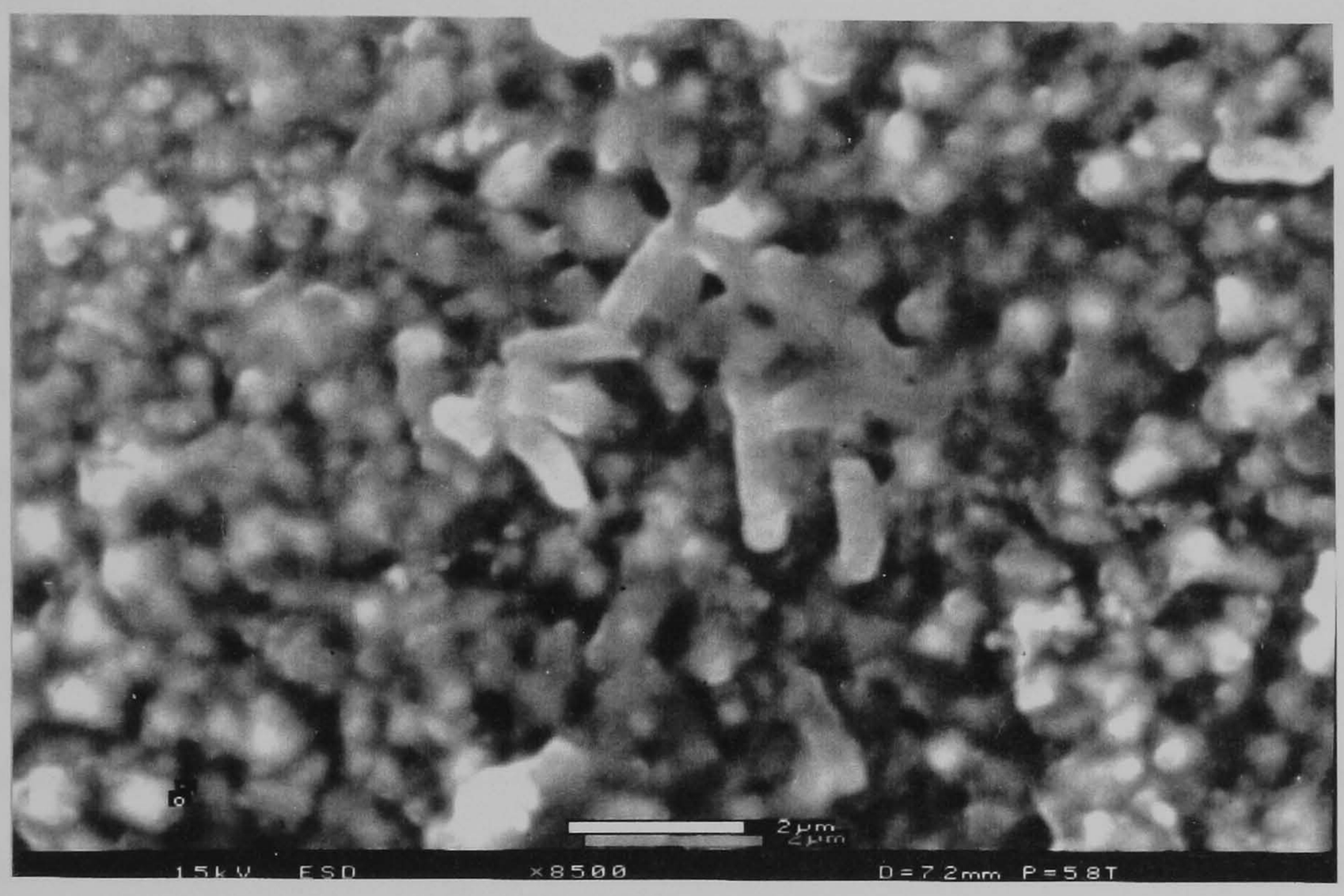


Figure 4.51 Utilising the ESEM the bacteria were observed to be enclosed in a hydrated slime (marker bar denotes 2 μm).

4.9 Discussion

The remit of the laboratory model was to simulate a domestic water system of an institutional building and to investigate the parameters under which colonisation of copper tube was occurring. As described in the material and methods (section 2.5, page 51) the medium used to grow the mixed microbial consortia was filter sterilised tap water with no added carbon sources. The tap water was obtained from the site where copper tube corrosion was occurring. Preparation of the water medium was based on a study by Colbourne *et al.* (1988b) whose method of filtration was used to obtain a sterile, chemically unaltered, natural water medium for use in continuous culture models. The culture vessels used in the present study were composed of inert materials such as glass, titanium and silicone to prevent ingress of exogenous nutrients or metals that may otherwise have altered the water chemistry. Two continuous culture vessels were linked in-series to simulate a water system. The first vessel was used to grow the inoculum under standard and stable conditions to simulate a water tank or calorifier that would produce an inoculum to seed the system i.e. the second vessel, down stream. According to the dynamics of continuous culture, effluent from this first vessel would be composed of starved or spent cells and media. Therefore the second vessel also received supplemental sterile culture medium to revitalise the spent cells flowing in from the first vessel. Biofouling of copper plumbing tube sections suspended in the second vessel was then examined under different conditions to simulate a laminar flow water system being constantly challenged by microorganisms. The advantage of using two vessels in series was that parameters could be changed to study the effect on the planktonic and biofilm phase in the second vessel without affecting the constant inoculum coming from the first vessel.

4.9.1 Colonisation of Copper and glass surfaces

Section 3.4 (page 108) discussed biofilms that were associated with copper tube corrosion at the Victoria Infirmary and Inverclyde Hospitals where the hot water temperatures were between 40-46°C. However in the control sites, Glasgow Royal Maternity, Stratheden hospital and Eastern General Hospital where the water was found to be approximately 55°C, pepper pot pitting corrosion of copper tube was not considered to be a problem. Biofouling was studied in the laboratory model by investigating the ability of a mixed microbial consortium to develop on a substratum in tap water from the Victoria Infirmary between 40-60°C. It was an important factor of this study that the laboratory model was being utilised to simulate a domestic water system and so no other exogenous carbon source was added to the water. Thus, the sole nutrient source for the microbial inocula was the filter sterilised tap water as occurred in the water circuit.

Initially, biofilms were developed in the laboratory model on copper and glass surfaces between 40-55°C. The biofilm coupons had previously been cleaned by degreasing in alcohol followed by autoclaving. However, even though the substrata were subjected to a cleaning procedure they would be instantaneously modified after exposure to the water. This would result from the adsorption of an organic film onto the surface and may have influenced bacterial attachment (McEldowney and Fletcher, 1986; Fazio, *et al.* 1982). Wangersky (1976) demonstrated that such organic layers can consist of glycoproteins, proteoglycans as well as humic residues. Considering that the filter sterilised soft tap water was from an upland catchment area then its typical brown colour (particularly evident by the non-dissolved portion retained after filtering-results not shown) was most probably due to the decomposition of peat, resulting in mainly humic and fulvic acids.

Colonisation rapidly occurred on coupons immersed in the laboratory model within 24 hours between 40-55°C and the type of biofilm observed was characterised by microcolonies dispersed over the surface. A similar non-uniform attachment was reported by Sly *et al.* (1988) who investigated the colonisation of glass over 28 days with biofilms reaching steady state at 7 days. From the results of Banks and Bryers (1992) microcolony formation may not only be a result of growth from the individual bacteria that initially attached to the surface. In their study they presented results where cells of *P. putida* and a *Hyphomicrobium* spp. deposited onto cells of their own species at a much greater rate than to clean glass surfaces. A similar phenomena was also reported by Pringle and Fletcher (1983). Ellwood *et al.* (1982) demonstrated that surface association increased growth rate and Dawson *et al.* (1981) also reported a beneficial effect of increased substrata area on microbial growth but only at low nutrient concentrations. Attachment to surfaces increased the resistance of *Escherichia coli* to cupric ions (Hicks and Rowbury, 1988) thus demonstrating another mechanism by which surface attachment and growth increased bacterial survival.

Bacteria were not initially recovered from nor visualised on surfaces immersed at 60°C in the culture vessel. However, the number of bacteria recovered from the planktonic phase was only decreased by 13 % after an increase from 55°C to 60°C. This would indicate that although bacteria were still growing they had appeared to have lost the ability to attach to either glass or copper surfaces to form a biofilm perhaps due to a physiological change. Maximum numbers were recovered from both glass and copper surfaces at 55°C. Following exposure to 60°C, the culture temperature was increased to 80°C before being returned to 40°C. Upon repeating the temperature profile of 40-60°C (section 4.4, page 149) a greater number of bacteria were recovered from biofilms, representing a 2.0 Log_{10} cfu cm^{-2} difference, in comparison to those obtained previously (section 4.3). Maximum numbers were again recovered from surfaces that had been immersed into the model at 55°C in

comparison to 40-50°C. These results are in agreement with those in section 4.3, suggesting a preference for growth at that higher temperature. Biofilm development was still controlled at temperatures above 55°C representing a 3.0-fold log $_{10}$ decrease at 60°C.

The importance of temperature in this study is two fold. Firstly, pepper-pot pitting corrosion of copper tube occurred in hospitals where the hot water system was maintained between 40-46°C, but in control hospitals with hot water temperatures greater than 50°C this form of corrosion did not occur (Keevil *et al.* 1989). Secondly, temperatures > 50°C are recommended for the control of *L. pneumophila* (Anon, 1990) within water systems. This is of primary importance within hospitals where this water borne pathogen has been found in the water phase and biofilm from fixtures and fittings (Plouffe *et al.* 1983; Colbourne *et al.* 1984) of water maintained <56°C.

Therefore, there does appear to be a correlation with bacteria associated with pepper pot-pitting corrosion and the presence of *L. pneumophila* in domestic hot water systems that are maintained below 56°C. The number of bacteria recovered from biofilms on glass and copper surfaces were similar between 40-55°C. Other researchers (Fletcher and Loeb, 1979; Pringle and Fletcher, 1983) demonstrated increased bacterial attachment to hydrophobic plastics with little or no surface charge e.g. polyethylene. However, they also found decreased numbers of bacteria attached to hydrophilic metals with a positive charge e.g. platinum and less to hydrophilic negatively charged surfaces e.g. glass. In this particular study there was no difference between glass and copper.

4.9.2 Population profiles on copper and glass

Four groups of microorganisms were identified in the biofilms including *Aspergillus fumigatus, Pseudomonas* spp., *Methylobacterium* spp. and Gram negative bacteria. At 40°C the four microbial groups were present on both copper and glass surfaces with the Gram negative bacteria dominating. *Pseudomonas* spp., *Methylobacterium* spp. and *A. fumigatus* were transiently present on both surfaces. At 45°C the species diversity decreased as only *A. fumigatus* and the Gram negative bacteria that dominated were present. On biofilms recovered from copper and glass the species diversity increased as the temperature was increased to 50°C. Although all four species were present there was a transient dominance between *Pseudomonas* spp. and the Gram negative bacteria. At 55°C the species diversity decreased again with the *Pseudomonas* spp. being dominated by the Gram negative bacteria.

4.9.3 Comparison of total (SEM) and viable plate counts

Counting viable bacteria using standard plate count methods relies on counting colonies that have grown from single cells. There are many problems with this technique for counting bacteria including, under-estimation of viable bacterial numbers (Peele and Colwell, 1981), agar incompatibility and nutrient shock (Reasoner and Geldriech, 1985) as well as the time-period required for incubation (Jones and Simon, 1975; Gibbs and Hayes, 1988). However, it still remains the most practised technique for obtaining viable counts of bacteria. Also, viable plate counting is also very useful for recovering bacteria for studies of population profiles as well as culturing bacteria for identification, as was carried out in this study. In addition to the results obtained by standard plate count methods the photo-micrographs from SEM examination were studied to provide an alternative technique for assessing bacterial biofilms.

Scanning electron micrographs of copper coupons removed from the culture vessel demonstrated that bacteria were present at day 21 between 40-55°C, although on some days no bacteria were observed on the coupons e.g. day 1 at 40°C as well as days 1, 7 and 14 at 55°C (section 4.3.2.2, page 131). However, no bacteria were observed on any of the copper coupons extracted from 60°C. This correlates with no viable bacteria being recovered from copper coupons immersed in the vessel at 60°C and as suggested in section 4.81 there may have been a physiological change in the bacteria that prevented them forming biofilms. In the samples where no bacteria were visible by SEM the bacteria may have been buried within the corrosion product on the surface as demonstrated by Blunn, (1987). Alternatively, the biofilm may have been removed during preparation of the samples for SEM. Indeed, Chang and Rittman (1986) reported the loss of biofilm owing to the harsh sample preparation for SEM. Using scanning and transmission electron microscopy Eighmy *et al.* (1983) were able to maintain the morphology of ageing biofilms using the facility of critical point drying prior to transmission electron microscopy. Van Neeren *et al.* (1990) used freeze-drying, freeze-substitution and critical point-drying to study bacteria in polymer beads but also found that shrinkage occurred with all three methods. Richard's and Turner, (1984) also demonstrated the removal of slime and bacteria from pumice during critical point drying, however they were able to minimise this loss using sputter-cryo examination.

4.9.3.1 Visualisation of bacteria on copper surfaces

To enhance the visualisation of bacteria on copper surfaces, Bremmer *et al.* (1992) obtained a smooth layer by polishing copper surfaces with 0.05 μ alumina particles that resulted in increased bacterial counts in comparison to unpolished surfaces. The copper surfaces in this study had not been polished as this would have deviated from the concept of simulating conditions under which the fouling was occurring in the domestic hot water circuit on unpolished copper tube surfaces. The roughness of the

unpolished surface will have provided areas in which the bacteria would have been difficult to observe using SEM. Crevices and milling lines are often colonised first as they are areas of low shear and so would provide suitable sites for initial colonisation as described by Richards and Turner (1984) for pumice stone. Although not shown, individual bacteria were present in the micrographs of coupons extracted from 45°C at days 1, 4 and 7 but at days 14 and 21 bacteria were held in a layer of glutinous like material. Observing bacteria initially as a single bacterium (day 1) then as a microcolony followed by a complex network covering the surface indicates growth from individual bacteria into microcolonies occurring over the copper surface. Banks and Bryers (1992) also demonstrated preferential attachment of bacteria to bacteria rather than bacteria to surfaces that would result in enlarged microcolonies. At 50°C bacteria were not identifiable until days 14 and 21 where the bacteria were interwoven between the mesh like glutinous material on the copper surface. Indeed on copper surfaces bacteria to bacteria attachment may have been preferential considering the toxicity of copper to bacteria (Versteegh *et al.* 1989; Pyle *et al.* 1992)

The bacterial numbers calculated from the micrographs were found to be greater than the viable counts obtained from scraped coupons. In two (at 40°C and 50°C) of the three samples where bacteria could be individually counted on the copper surface there was 1.0 Log_{10} cm^{-2} difference between the total and viable counts. In the third sample at 55°C there was only a 0.1 Log_{10} cm^{-2} difference. Comparing culturable counts against microscopic enumeration, Liebert *et al.* (1983) found that the microscopic counts on formvar coated copper electron microscopic grids differed by 0.2-1.0 Log_{10} bacterial counts.

4.9.3.2 Visualisation of bacteria on glass surfaces

The number of bacteria attached to glass coupons as visualised by SEM was also enumerated. On glass coupons the bacteria were easily observed. In agreement with the viable numbers, attachment occurred rapidly within 24 hours. In the case of total bacteria observed, the numbers were relatively constant at 40°C from day 1 to day 21 (page 147), whereas, the viable numbers increased from day 1 to day 14, followed by a decrease on day 21. The total bacteria observed was greater than the number obtained by standard plate count technique. At 45°C the total bacterial numbers were also at least 1.0 Log_{10} cfu cm^{-2} greater than the viable numbers recovered. With an increase in the temperature to 50°C both total and viable numbers increased from day 1 to reach a maximum at 50°C on day 7 before decreasing again on day 14. Although the viable numbers then decreased again the total numbers in fact increased.

At 55°C the total numbers increased from day 1 and again from day 7 to day 14. and remained constant on day 14 and 21. However the viable numbers decreased from day 1 but then exhibited a 2-fold increase at day 21 suggesting that the viable number recorded on day 7 could be subject to a large degree of error and may indeed be of a higher value. In tables 4.12 to 4.15 (page 147) the errors for the counts have been tabulated and this demonstrates the large range of errors that result when calculating total numbers in biofilms. The results obtained from the micrographs are based upon the actual numbers obtained from specific areas of the coupons which have been photographed by an independent operator. In doing so the operator has tried to produce a set of micrographs which are representative of the whole area of each coupon. Therefore, the glass coupons immersed in the continuous culture vessel exhibit microcolonies surrounded by sparse areas (page 144). It is by observing the micrographs that a picture of how the biofilm forms is achieved and that the large errors are incorporated. Biofilms in this present study were not homogenous layers of cells, as was also demonstrated by Weber *et al.* (1978), who studied the physical and

structural characteristics of microorganisms on activated charcoal in water and waste water applications. Whereas, Wimpenny (1988) designed a laboratory model to develop biofilms of 300 μ in depth, the results presented here demonstrate that the biofilm obtained in the continuous flowing model are heterogeneous in their nature resembling a mosaic and are not 300 μ deep. However, Wimpenny (1988) operated a model to investigate biofilm physiology at different depths for which the thick and constantly reproducible biofilm generator was immensely useful. Total counts were obtained from every glass tile immersed in the continuous culture vessel (tables 4.12 - 4.15) whereas bacteria were difficult to observe on copper coupons (table 4.4 - 4.7).

4.9.4 Effect of temperature on the planktonic population

Vessel one, where conditions were constant, was used to establish the inoculum. The temperature was maintained at 30°C as this was the lowest temperature at which surveyed hot water systems had been found to operate (section 3.3, page 77). This first vessel was maintained to supply a constant inoculum, an average of 4.9×10^5 cfu ml-1 (5.6 $\log_{10}$) over the first seven months, to the second vessel where biofilm generation was carried out. It was during this seven months that the temperature of the second vessel was changed from 40°C to 70°C. Fluctuations in the number of bacteria from the planktonic phase between 40-60°C do not appear to be temperature dependent as bacterial numbers are similar in both vessels. Only when the temperature was changed to 65°C was a 1.0 Log_{10} cfu ml^{-1} decrease in planktonic bacterial numbers observed. The number of bacteria recovered from biofilms are scraped from 1 cm^2 and cannot be directly compared to the number recovered from 1.0 ml of the planktonic phase. Bacterial biofilm numbers were similar at 40°C and 50°C, at 2.5 Log_{10} cfu cm^{-2} and were higher at 45°C at approximately 3.7 Log_{10} cfu cm^{-2}. Indeed, the greatest number of bacteria were recovered from copper coupons at 55°C with no biofilm bacteria recovered at 60°C. This is in contrast to 4.5

x 10^5 cfu ml^{-1} of viable bacteria in the planktonic phase. Therefore, the bacteria are viable but are unable to form biofilms. Bacteria extracted from the planktonic phase were viable as they were recovered on agar plates after incubation at 30°C, but were the bacteria actually growing in that second vessel? The resident time spent in the second vessel may not have been long enough to be bactericidal, in which case 60°C may only have been bacterio-static. As there was no growth on plates incubated at 60°C (results not shown) the population was not composed of thermophiles or alternatively this agar was not sufficient for the recovery of stressed or thermally injured bacterial.

Spent cells and media, that is, the effluent from chemostat one, D = 0.05, was pumped into chemostat two which also received 75 ml per h filtered sterile soft water media resulting in a total flow rate of 100 ml per h or D = 0.2. Considering that chemostat two receives 25 ml per h from chemostat one then if growth does not occur the number of bacteria flowing into chemostat two will be the same as that leaving chemostat one. As chemostat two receives another 75 ml media the flow rate within it will be 4 times faster than that in chemostat one and so for every ml extracted from chemostat two there should only be 25 % the number of bacteria from chemostat one. However, the number of bacteria recovered from the planktonic phase between 40-60°C is similar between the two vessels. Therefore, growth was occurring within the planktonic phase at 60°C even though biofilms were not initially generated. Bacterial numbers in vessel two were only reduced to 25 % of that retrieved from vessel one (30°C) when the temperature was increased to 65°C. This indicates that in a continually flowing system of two vessels linked in-series that 65°C was also only bacterio-static. Indeed, when the temperature was increased to 70°C <10 % of the viable bacteria flowing in from vessel one were recovered from vessel two with a further decrease in the planktonic numbers at 80°C. Therefore, temperatures of 65°C were bacterio-static while temperatures above this were bactericidal. Bacterial numbers only recovered when the temperature was returned to 40°C. However, the

results show the importance of a recirculation system for the dissemination and growth of bacteria that are able to remain viable even though conditions are unfavourable.

4.9.4.1 Percentage profiles characteristics

Planktonic populations were initially dominated by the Gram negative bacteria at 40°C similar to those from copper and glass surfaces. While the Gram negative bacteria continued to dominate in the biofilms there was a change in the planktonic phase with Gram negative bacteria succeeding from 45-60°C. At 55°C there was a decrease in the species diversity as *Methylobacterium* spp. were not recovered from the biofilm but were still present in the planktonic phase. The above results, where different bacteria dominate under different conditions, illustrates the value of approaching a study of a mixed microbial consortia from a holistic point of view. In other studies where pure culture strains have been used to study colonisation then no data would have been obtained on the importance of other bacterial strains on the process (Wright *et al.* 1991). Information obtained from population profile studies are important if biofilm control using chemical means is to be considered. Historically, biocides have been chosen due to the number and type of bacteria recovered from the water phase (Costerton and Geesey, 1979). However, results from this present study demonstrate that different bacterial species exist under different conditions and so one biocide chosen to act against a certain planktonic population may not be as efficacious against the biofilm that may contain a different species of bacteria.

During the repetition of the temperature profile the ratios of the bacterial types changed as the Gram negative bacteria predominated and the *Methylobacterium* spp. represented a greater proportion of the biofilm. Indeed, at 55°C and 60°C the *Pseudomonas* spp. that dominated in the first temperature profiles were also succeeded by the *Methylobacterium* spp. This switch in the dominance of planktonic

bacteria may have contributed to the presence of bacteria on the surfaces when the coupons were removed from the culture at 60°C in the repeat experiments (section 4.4, page 149).

4.9.5 Control of Fouling

Water treatment plants and distribution networks function to provide potable water to existing legal standards and to ensure that there is a sufficient quantity at every point within the supply area (Block, 1992). Existing legal standards are set to ensure that water leaving treatment plants does not contain pathogens even though only less than 4 % of distributed water is used for human consumption (Block, 1992). Most pipe surfaces are colonised by organisms such as diatom, algae, filamentous and rod shaped bacteria (Allen, *et al.* 1980) and therefore water leaving water treatment plants and entering the domestic water supply should be free from pathogens but may not be sterile. In the majority of hot and cold water circuits this may not lead to any problems, however, attachment of organisms to pipework will cause an increase in fluid frictional resistance resulting in increased power consumption for pumped systems and also reduced capacity (Characklis, 1981). Methods to control the presence of bacteria in water distribution systems include chemical mechanisms such as increasing the free chlorine residual concentration (LeChevallier, 1987) or physical mechanisms including flow driven nylon brushes (Nickels, *et al.* 1981) to remove biofilm (pigging).

As biofilms had been implicated in the copper corrosion process, mechanisms of retarding biofouling and maintaining a biofilm free surface in the copper pipe network required investigation. Using biocides or disinfectants was not considered by the relevant authorities and so thermal pasteurisation was suggested to control biofouling in the hot water system. However, for water circuits that were already fouled the

biofilm would have to be removed from the surfaces. The possibility of using citric acid to remove biofilm from copper tubes surfaces in the County Hospital, Hellersen, (Germany) was discussed (Fischer *et al.* 1991) as it was the only promising reagent permitted by German food law. In response to a plan to use citric acid in site work the method was also evaluated in the laboratory along with the use of sulphamic acid for comparison as it was indicated that this may also be used to remove biofilm.

4.9.5.1 Effect of pasteurisation on biofilms

Thermal pasteurisation, for the control of *Legionella pneumophila,* by raising the temperature of the whole hot water system to 60°C for at least one hour with the temperature at the outlets reaching 60°C has been recommended in the Health and Safety report (Anon, 1990). Calorifiers should routinely be maintained at 60°C with at least 50°C attainable at the taps. From the initial laboratory results biofilms were generated at 55°C but were controlled at 60°C. Therefore 60°C was used to for pasteurisation. Biofilm was established at 45°C (Fig. 3.4a) and after only 15 minutes exposure to 60°C there was a 99 % reduction in the recovery of biofilm bacteria. The Gram negative bacteria dominated before and after pasteurisation. Dewailly and Jolly, (1991) reported that the dissemination of *L. pneumophila* occurred only when the outlet water temperature was below 56°C indicating the thermal pasteurisation may have beneficial results in the control of *L. pneumophila* and may also be preventing fouling.

Biofilms were also generated on copper and glass control surfaces with the temperature being changed sequentially from 50°C, 55°C, 60°C then to 45°C over a 50 day biofilm development period. After 1 h exposure to 60°C the number of viable bacteria recovered from copper surfaces had decreased by 59 % and by 92 % after 2h. The decrease in the viability of bacteria from glass surfaces was only 21 % and 30% after 1 and 2 h pasteurisation at 60°C respectively. Such results may indicate a

synergistic effect between thermal pasteurisation and the presence of copper surfaces on bacterial viability in comparison to the results obtained on glass. Gram negative bacteria dominated on both surfaces before and after pasteurisation (Fig. 4.5).

Copper toxicity (Bartlett *et al.* 1974) has been recorded for over 100 years and may have contributed to the 92 % decrease in bacterial recovery from copper coupons pasteurised at 60°C in comparison to only a decrease of 21 % from glass coupons. Versteegh *et al.* (1989) were concerned about the recovery of *Aeromonas* spp. coliforms and faecal streptococci from water samples containing copper and recommended the addition of disodium-ethylene-diamino-tetraacetate (Na_2EDTA) to neutralise the toxic effect of copper. An investigation of copper toxicity on the growth of coliform bacteria indicated that cells injured by the presence of copper may have an impaired respiratory system. The binding of copper to the thiol groups of bacterial respiratory enzymes may have inhibited enzyme function (Domek, *et al.* 1984). However copper is an essential metal required for several bacterial enzymes, many of which are involved in biological electron transfer of oxygen utilisation (Petola *et al.* 1993). A number of functions are recognised by which bacteria are able to reduce the toxic effects of copper. Bitton and Friehofer, (1978) compared a polysaccharide producer, *Klebsiella aerogenes* against a non-polysaccharide producing mutant and found that when exposed to copper, the polysaccharide producing strain exhibited increased survival rates. Protection afforded by polysaccharides that chelate copper has also been shown to protect marine bacteria from the toxic effects of copper (Corpe, 1975). West *et al.* (1990) demonstrated that bacteria colonising glass in the presence of copper pipe produced significant quantities of exopolymer as a defence mechanism against leaching copper ions. Marszalek *et al.* (1979) also detected bacteria that secreted extracellular mucoid as a protection mechanism in the presence of toxic metallic ions. Another mechanism of resistance has been found in cells of *Pseudomonas syringae* that were recovered from plants to which antimicrobial copper compounds are applied for plant disease control. These

copper resistant strains were found to be carrying DNA that encoded a periplasmic copper binding protein. Therefore this sequestration of copper outside the cytoplasm has been proposed to act as another protection mechanism. Such defensive mechanisms by bacteria against the toxic ions of copper would no doubt be of benefit in the fouling of copper tubes in water systems maintained between 35-50°C as was found in the sites experiencing corrosion in the site survey.

4.9.5.1 Treatment of established biofilms with acids

The county hospital in Hellersen (Germany) was built in 1982 and opened in 1986 and the first copper tube failures due to pitting corrosion occurred within a few months (Fischer, *et al*, 1992). As well as replacing 30 % of the pitted copper pipe they also treated sections with 10 % (v/v) citric acid in an effort to stop the corrosion.

Citric acid was used in the County Hospital in Hellersen as a mechanism of preventing further corrosion by removing the biofilm and corrosion products to leave a clean copper surface. However, after the citric acid rinsing, the formation of corrosion products and biofilms in the treated hospital copper tube sections started to occur again (Fischer *et al.* 1992b). Using citric acid in the present laboratory model it was clear that bacterial biofilms recovered to similar numbers within 14 days of treated copper coupons being replaced into the culture vessel. In comparison recolonisation of copper coupons treated with sulphamic acid (5 %) only represented 6 % of that obtained after 14 days maturation. Two possible reasons may explain why the citric acid treated coupons were recolonised so quickly. Firstly, it was considered that all of the citric acid may not have been rinsed from the coupons before re-immersion into the culture vessel and that some of the residue may have been converted to citrate (at neutral pH) which may be a nutrient source for certain types of bacteria e.g. *Klebsiella*. One group of the Gram negative bacteria have been found to be citrate utilisers but there was no positive identification. Alternatively, Gadd and White

(1989) state that citric acid is an efficient chelating agent providing an initial pellicle layer on the surface. Therefore, if residual citric acid was present on the coupons which were re-immersed into the culture then it may be possible that the citric acid would have either chelated copper ions and/or the conversion to citrate would have provided a nutrient source for certain bacteria which would proliferate on the surface.

Considering the above results, citric acid does not appear to have prevented the re-occurrence of biofouling in the laboratory model or for that matter in the hospitals where copper tube failures have reappeared (Fischer *et al.* 1992b). The laboratory results with sulphamic acid indicate that it could have reduced rapid recolonisation and may have been a more appropriate cleanser than citric acid.

4.9.6 Altering the chemistry of the soft water

The total hardness of the soft water in central Scotland was less than 30 ppm as was the total alkalinity indicating a very soft and weakly buffered water. Due to this the potential for deposition of protective carbonate films is minimal and excessive metal corrosion is a common problem in such type of waters (Reiber, 1987). An alternative mechanism of protecting copper surfaces from corrosion is the provision of such a protective layer on the surface.

By increasing the hardness and alkalinity of the water by the addition of calcium carbonate it was intended to provide a homogenous oxidised protective coating on the copper surfaces. Reiber, (1987) successfully demonstrated an approximate 40 % reduction in the corrosion of copper plumbing material by increasing the concentration of $CaCO_3$ three-fold. Increasing the carbonate concentration within the water supply to a unit of a hospital in central Scotland to decrease the corrosion rate was suggested. However, although this mechanism of protection was to decrease or

prevent corrosion of the copper surfaces its effect upon the bacteriology of the source water was not known. Therefore, the laboratory model was used to ascertain if altering the water hardness by the addition of calcium carbonate would have any effect on the formation of biofilms.

A comparison of colonisation of copper coupons in the absence and presence of additional calcium carbonate revealed that greater numbers of viable biofilm bacteria were recovered during periods of higher concentrations of calcium carbonate. As well as providing a protective layer on the surface of the copper the carbonate may also be protecting the bacteria from bacterio-static or bactericidal properties of the copper. In an investigation of pitting corrosion in a distribution pipeline Tuovinen *et al.* (1980) found a large number of tubercles on cast iron pipes were associated with bacteria and pitting corrosion. In one particular site where reduced pitting corrosion was observed it was indicated that less tuberculation perhaps arose due to the protection of a higher concentration of $CaCO_3$ in comparison to the other sites. Lining pipes with a layer of $CaCO_3$ was then suggested as a mechanism to prevent the corrosion process. As such results by Tuovinen *et al.* (1980) appear to contradict those obtained in this present study.

4.9.7 Visualisation of copper and biofilm formation

4.9.7.1 Environmental SEM

The idea of using an ESEM is that the morphology of the biofilms that are examined should not collapse as the structure is maintained under pressure when the water is sublimed off. Maintaining the morphology of the specimen is an important feature of any visualisation technique chosen to study the topography of biofilms. An important criterion with this method is that it is the surface, inclusive of biofilm which is being studied. If one wished to look at the copper surface direct then the biofilms would

have to be removed. Therefore artefacts may then be introduced into the sample and as such one has to identify the advantages which this method can offer and also recognise the limitations of the technique. Those limitation are readily understood when other techniques are used which can simultaneously study the bacteria and surface topography e.g. SCLM, however this technique is unable to reproduce the type of morphological information obtained from an SEM.

Image analysis was used to compare surface morphology of the copper coupons extracted from the laboratory model. On copper coupons supplied with particulate matter, 600 countable objects were identified, with only 147 countable objects identified on the coupons from the vessel not supplied with particulate matter. When operating the image-analysis, identifiable objects i.e. the bacteria have to be labelled. This is carried out by a measure of intensity as the bacteria are intensified in comparison to the background (Fig 4.33-4.37). However, in the case of the tile from the vessel with no particulate matter the tile surface is intensified because the bacteria are present in a crevice of the surface and more water had to be sublimed off (Fig. 4.34). Danilatos *et al.* (1984), was able to demonstrate that spores of *Bacillus apiarius* retained their shape whether wet or dry when visualised with the ESEM and so the morphology of the bacteria on the copper surface would expect to be true.

Due to sublimation of the water, areas of the surface have become intensified resulting in the differential between the two surfaces not being greater. Translating these identifiable objects into areas then in comparison only 24 % of the tile not supplied with particulate matter was covered with biofilm material. The copper pipe which also had water containing particulate matter flowing through it had less copper surface visible (Fig. 4.32).

These results indicate that particulate matter may have a role in encouraging the growth and density of biofilm on surfaces. 5 μm spaces or channels were also demonstrated in the infrastructure of the biofilm and may allow the passage of water

which would replenish the biofilm with fresh nutrients to maintain differential corrosion cells.

The development of high gas pressure technology has enabled the generation of high quality definitive images of hydrated matter not before imaged with electron microscopy (Little, 1991). The gas itself contributes to the amplification of signals and so acts as a detector (Danilatos, 1991).

4.9.7.2 Scanning Confocal Laser Microscopy

Architectural analysis using SEM has been the main technique to date for studying biofilm morphology although shrinkage has been reported to occur (Woldringh, 1977). Chang and Rittamn (1986), reported the visualisation of sparse biofilms owing to the harsh sample preparation for SEM. Recent techniques such as ESEM have enabled structural analysis with hydrated specimens (Little, 1991) which ensured structural reproducibility. However, such techniques that analyse surface topology provide little information on the surface contours beneath a biofilm, nor do they allow for analysis of the viability of bacterial biofilms.

The application of a light microscope equipped with episcopic DIC and UV fluorescence to visualise the topography and viability of biofilms has been demonstrated by Keevil *et al.* (1992). However, this technique is limited by the lack of resolution at higher magnifications of 1500 x and again biofilms have to be removed to visualise the surface below. The results gained using SCLM demonstrated the potential for non invasive imaging of an intact fully hydrated living biofilm. SCLM enables optical thin sections to be analysed such that out of focus material does not interfere with the immediate image. Available from the information generated was the expansion of the horizontal image to a cross section or vertical sagital (xz) section, providing a side on view of the specimen.

4.9.7.3 Surface analysis

Fluorescein (0.1%) was used as a negative stain to visualise the copper surface. With this technique deposits could be identified on the surface as could contours such as pits. The copper surface itself appears dark (Fig. 4.52, page 219). Comparisons were made between copper coupons from the vessel supplied with unfiltered water and the one supplied with filtered water. Variations were not evident in the horizontal direct view of the surface of the copper coupons supplied with filtered water (Fig. 4.38, page 187). When a sagital section was generated the surface was uniform with no pits or mounds (Fig. 4.39, page 188). As bacteria were present in this system this may indicate that bacteria are not primarily responsible for the type of corrosion identified as pepper pot pitting. In contrast copper coupons that had been immersed into the vessel supplied with unfiltered had numerous mounds or pits that are out of focus and so appear black (Fig. 4.40, page 189).

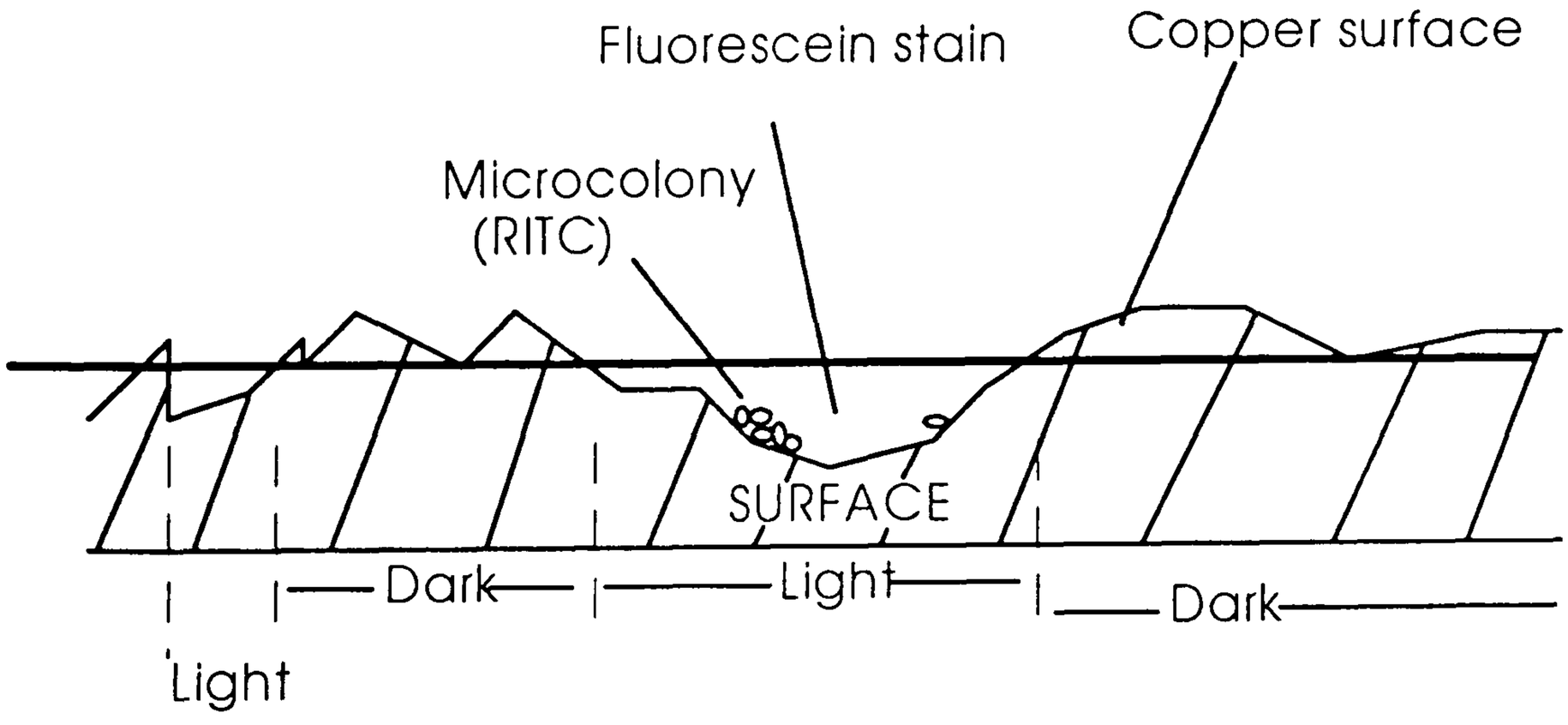


Fig 4.52. Schematic of negatively stained surface using fluorescein and RITC stained bacteria on the copper surface.

4.9.7.4 Visualisation of bacteria on the copper surfaces

On coupons from the unfiltered water, one particular pit was focused on (left hand image) with the corresponding right image demonstrating bacteria (Fig. 4.42, page 191). The association of bacteria within these areas was elucidated using RITC with images observed in both the horizontal (xy) (Fig. 4.42) and sagital xz sections (Fig. 4.43 and 4.44, page 192). By generating such images, it is possible to visualise the bacteria in and around the pit walls. Similar techniques have been utilised by Cummins *et al.* (1992) to demonstrate, using a CLSM, that the development of a *Streptococcus sanguis* biofilm was critically dependent upon the presence of *Actinomyces viscosus*. For identification of *Streptococcus sanguis* and *Actinomyces viscosus* they utilised RITC and FITC respectively.

4.9.7.5 Determination of bacterial metabolic activity

Analysis of metabolic activity of bacteria was carried out using 5-(and-6)-carboxy-2',7'-dichlorofluorescein with RITC to visualise the bacteria. The excitation and emission wavelength of 5-(and-6)-carboxy-2',7'-dichlorofluorescein decreases due to acidification as the emission intensity declines as the pH decreases. The surface topography was observed in photomultiplier 1 (left hand image) and the bacteria, positively stained with RITC, were viewed in the second photomultiplier tube (right hand image) (Fig. 4.45). When the two images were merged and colour enhanced a halo was found to surround the bacterial cells on the surface (Fig. 4.46). Therefore, darker areas immediately surrounding the bacteria could be indicative of a pH change due to acidification and hence the presence of metabolically active bacteria. Graber *et al.* (1986) demonstrated that four different fluoroprobes used to measure intracellular pH were subject to artefacts induced by self quenching and protein binding. Normally the measurement is based upon the ratio of excitation or emission at two different

wavelengths but as yet SCLM are unable to do this (Bassnett *et al.* 1990).

These images confirm the heterogeneity of biofilm associated with surfaces as has been demonstrated above with the light microscope, SEM and ESEM. Cummins *et al.* (1992) have also used a SCLM to demonstrate such a heterogeneity in the initial development of plaque biofilms. It is this heterogeneity that has been postulated to be important in the corrosion process and has also been confirmed by Bremmer *et al.* (1992), using atomic force microscopy to study hydrated biofilms on copper. Bremmer *et al.* (1992) demonstrated the difficulty in observing bacteria on copper tube surfaces that had not been polished smooth. The methods afforded by the SCLM negated such problems and therefore the results presented in this study are a truer reflection of the real environmental situation of the biofilm.

Although we cannot be certain that the pits in the copper tubes are the result of microbial colonisation and activity, these images do suggest a link between the deterioration of the surfaces and the presence of particulate material and bacteria. The involvement of particulate matter alone can be disregarded as the control institutions which maintained their hot water systems above 55°C did not suffer from pepper pot pitting. The ability of bacteria to create acidified zones on the copper surfaces was also demonstrated with this technique. The bacteria appear to aggravate and initiate pitting zones. This will provide differential corrosion cells resulting in areas under the respiring colonies becoming anoxic relative to the surrounding uncolonised areas. Thus, pitting already initiated by the presence of particulate material will be accelerated. Little *et al.* (1991) suggested that corrosion currents flow between peaks and troughs on metal surfaces and in agreement with this an explanation may be proposed that involves the association of bacteria and particulate material in the corrosion process.

In conclusion SCLM is an extremely useful, quick and simple technique for the study

of surface topology, bacterial morphology and viability without disruption, artefacts and with minimal specimen preparation. This is very important as although other techniques and instruments are excellent at the individual analysis of these properties, the SCLM enables not only the topology of the surface to be investigated but also analysis of a viable, metabolically active and hydrated biofilm to be carried out *in situ*. A significant feature of this technique is the elimination of out of focus information resulting in a more definitive examination of sample material.

4.9.8 Visualisation of copper tube surfaces; Epifluorescence, SEM and SCLM

Working with live biofilms it was extremely important for us to visualise biofilms with minimum treatment and disruption of the cells as possible. Historically biofilms are often thought to consist of a homogenous layer on a surface (Costerton *et al.* 1987) but studies by Keevil *et al.* (1989) have demonstrated that biofilms often consist of microcolonies on a surface. Ellwood *et al.* (1982) illustrated that bacterial attachment and biofilm development was preferred to growth in the planktonic phase. Ellwood and his colleagues also indicated that surface associated organisms can grow at approximately twice the rate of the same organisms in the water phase. Hicks and Rowbury, (1988) demonstrated that attachment to glass beads decreased the sensitivity of *Escherichia coli* to cupric ions while those in the water phase were killed upon exposure to divalent copper. Therefore, attachment increased survival because the surface not only enabled the bacteria to obtain nutrients but also afforded protection to bacteria from toxic ions such as copper.

Light microscopy offers a number of rapid techniques for examining bacteria e.g. Gram staining and cell counting chambers. However, it has been limited by maximum magnifications of 1000-1500 times and the difficulty in coping with opaque samples

using transmitted light although fluorescence has allowed the visualisation of microorganisms. The development of 150 times objective lenses has increased the magnification capabilities of light microscopes and episcopic differential interference has enabled microorganisms on opaque surfaces to be differentiated. Though episcopic DIC is most advantageous when the background is flat as on glass, with the bacteria observed as peaks. The visualisation of bacteria on glass surfaces using light microscopy (transmission mode) has been studied by Lawrence and Caldwell (1987) who demonstrated several novel colonisation manoeuvres such as packing, spreading, shedding and rolling, each of which was associated with a specific species from a natural stream population. However, materials used in domestic plumbing circuits and cooling towers are generally opaque with only a few of the plastic materials allowing transmissible light to pass through them, albeit with some difficulty. Even the plastics present a relatively smooth flat inner surface to view biofouling by DIC. The larger the diameter of the pipe the greater the amount of area which will be in view in the focal plane. It is in circumstances where curved pipe has to be examined for evidence of biofouling that the long focal length non contact metallurgical lenses are an advantage. For material such as copper and other metals the biofilm on the surface can be examined with DIC but the individual bacteria are difficult to discriminate on the copper surface although larger organisms such as fungi can be identified (Fig. 4.47). Due to this, fluorescent stains such as acridine orange and carboxyfluorescein have been utilised to observe the individual bacteria and microcolonies on copper (Figures 4.48 and 4.49) For counting purposes the use of microscopical techniques to obtain direct total and viable counts in a short period of time can be informative. Acridine orange (Daley and Hobbie, 1975) is a stain which has been used mainly for the enumeration of total bacterial numbers in a sample but the resulting range of colours from yellow to green of the individual bacteria does not necessarily equate to viability especially on heat treated cells at 60°C (Back and Kroll, 1991). Hobbie *et al.* (1977) suggested that the most active and dead bacteria will fluoresce red and inactive or slow growing bacteria will fluoresce green. AO detects

nucleic acids in a conjugation format with the fluorescence wavelength of AO differing according to the amount of DNA and RNA present in a cell. DNA, the double helix of nucleic acid forms a strong conjugate with AO and produces a green fluorescence whereas RNA produces a weak conjugate where the positively charged fluorochrome stacks on the negatively charged phosphoric base of the RNA and fluoresces red. Dennis and Bremer, (1974) produced evidence that in an *E. coli* cell under balanced growth conditions, 20% of the cells nucleic acid was composed of RNA and only 3% of DNA. Therefore, bacterial cells under balanced growth conditions should fluoresce Red and those slower growing cells which contain less RNA will fluoresce green. AO has been used successfully to identify intracellular from extracellular enteropathogens in Hela cells (Miliotis, 1991). On the copper pipe samples it was difficult to obtain an indication of viability as the range of colours varied. Another disadvantage of fluorescence was the quenching or fading of the fluorescence that occurs over a short time period. With the light microscope, biofilms have not been visualised as a flat, thick homogenous layer but as a patchy film for which the term 'mosaic' aptly describes the biofouling. Surface colonisation through the formation of discrete microcolonies leading to the development of the biofilm has also been reported by Korber *et al.* (1989). They observed that motility aided the spatial distribution of previously attached bacteria in comparison to non-motile species of *Ps. fluorescens.* As discussed earlier, electron microscopy has been used to obtain increased magnification of specimens in excess of the magnification and resolution of light microscopy. To combat the harsh pre-treatments of fixation and dehydration a cryogenic stage was used to freeze the hydrated biofilm. However, as observed in Fig. 4.50 of stringy biofilm and as described by Richards and Turner, (1984) even this technique produces artefacts of fibrillar networks. A demonstration of such artefacts was also displayed by Paerl, (1985), exhibiting association of bacteria and a marine cyanobacterium. One possible explanation forwarded for this artefact of a stringy biofilm could be the concentration of salts present in the water phase. As the water is removed under vacuum a concentration of the salts present in

the water phase may result in aggregation with the surface tension as a result of the molecules holding the products together as a string (Colquohoun, 1993).

Utilising the high pressurised sample chamber provided by the ESEM the bacteria can be observed to be encased in a hydrated matrix demonstrating that water channels exist within the matrix that binds the bacteria together. ESEM has a number of advantages in that there is no prior preparation of samples, no staining and where the facility is available EDAX analysis of the surface material can be carried out. However, this technique allows no analysis of bacterial viability or surface deterioration without removal of the biofilm.

4.10 CONCLUSIONS

The proposed model based upon continuous culture vessels has proven sufficient to study the colonisation of copper surfaces. Whereas, the planktonic population were able to survive temperatures of up to including 60°C the biofilms were controlled at temperatures above 55°C. Therefore, temperature has been shown to be an influencing factor in the survival and growth of the aquatic consortium. However, this biofilm controlling temperature was not able to control the planktonic population and another increase of 5°C to 65°C was required for a kill in the planktonic to be achieved. Therefore, at 60°C, survival of the planktonic population for longer periods of time than the biofilm would mean that the planktonic will reseed sections of the water system where the temperature falls below 60°C.

The continuous culture laboratory model has provided a small scale simulator of a water system in which to model the effect of physical and chemical change in the planktonic phase and/or biofilm bacteria. This was necessary as biofilm had been associated with pepper pot pitting corrosion of copper tube in the hot water system in

a hospital in central Scotland.

Initially the biofilms were unable to form above 55°C but after exposing the culture to temperatures up to 80°C bacteria were recovered from surfaces immersed at 60°C. Although biofouling was controlled at 60°C, higher temperatures than this were required to obtain a significant decrease in the planktonic population numbers.

Therefore even water systems operated at 60°C will not completely kill bacteria in the planktonic or biofilm phase but will exert control over fouling that will take place. In pipe sections where hot water flow is stagnant, such as toilet sinks and shower units that are used infrequently, dead ends or un-lagged sections of pipe will result in temperature loss or in the case of un-lagged cold pipe sections the temperature will increase (particularly in the winter when the building temperature is greater). The change in temperature will result in environmental changes that are favourable to bacterial growth that may lead to biofilms that harbour potential pathogens or lead to sites of corrosion.

A comparison of total counts against those obtained by viable plate counts indicated that not all the bacteria were recovered. This may have been due to a number of reasons including, non-viability, injury, agar incompatibility or nutrient shock. A major advantage of viable plate counts is not only the provision of an actual representation of the viable bacteria but also the population profiles under different conditions. For example the Gram negative bacteria may have dominated in the biofilm but they were succeeded in the planktonic phase by the *Pseudomonas* spp. These results have to be considered if biocide control is chosen as an option with which to eradicate biofilms where the choice of biocide used is determined by the presence of a particular species of bacteria.

Exposure of biofilms to 60°C for a short period of time, known as pasteurisation was

examined. Although this dramatically decreased the viability of biofilms that had been generated at 40°C there appeared to a thermal resistance of bacteria that had been exposed to 60°C during maturation. However, the results indicated a possible synergistic action between copper and thermal inactivation of the bacteria in comparison to glass controls.

Citric and sulphamic acid achieved a complete eradication of biofilms. However, re-growth occurred on coupons treated with citric acid whereas those treated with sulphamic acid appeared to control re-growth for up to 50 days.

Although providing a uniform layer of carbonate on copper surfaces is known to decrease corrosion it was found that there was a greater number of bacteria recovered from surfaces immersed in culture media with the higher calcium carbonate concentration. Considering these results it would be of immense value to any establishment considering such treatments to monitor biofouling of pipe work during addition of calcium carbonate to the water system.

A number of techniques have been used to visualise biofilms in this study. Initially SEM was used with traditional dehydration and fixation with osmium tetroxide but the potential for loss and damage to sections of the biofilm led to other methods being investigated (Fig 4.5 - 4.7). A cryogenic stage was utilised to freeze and maintain the biofilm specimen intact but this resulted in a fibrous network and as suggested this may be due to a concentration effect of salts and organic matter.

To overcome potential loss and shrinkage of biofilm an ESEM was used to view the sample. Advantages of this technique are that wet samples can be placed into the specimen chamber without prior preparation or staining. This procedure enables higher pressures, not normally obtained with a standard SEM, and so biological specimens remain in their true morphological shape. Biofilm was observed to be

greater on the samples removed from the vessel that were supplied with unfiltered water, than from the vessel where it was filtered out (Fig. 4.32-4.37). The results may indicate a synergistic role of particulate matter in the generation of biofilms on copper pipes.

Although of immense value in studying the true morphology of biofilms the ESEM also has disadvantages in that it has to be combined with some other technique if bacterial viability or corrosion is to be assessed. Copper surfaces that were immersed in the vessel supplied with filtered water were examined by SCLM and did not exhibit any signs of corrosion (Fig. 4.38) indicating that bacteria alone were not responsible for pepper pot pitting corrosion. However, corrosion was evident on the surface of those copper coupons immersed in the vessel supplied with particulate matter. Not only were bacteria present on the surface, on the walls and in the bottom of pits but they were also shown to be associated with localised acidic zones.

Copper tube sections were also examined by ESEM, SCLM and by an adapted light microscope. The light microscope was modified to provide episcopic DIC and fluorescence and demonstrated the range of flora developing on the copper surface from fungi to bacteria that appeared to be just colonising the surface demonstrating the complexity of biofilms.

Therefore the association of particulate matter, presence of bacteria and temperatures that allow prolific metabolic activity do appear to contribute to the pepper-pot pitting corrosion of copper tubing.

In summary the laboratory simulation model has demonstrated an association between temperature and biofouling in a soft water system maintained below 55°C. At temperatures above this biofilms were controlled or reduced as was found in the control hospital during the site survey. The results demonstrate a possible association

between temperature, particulate matter and bacteria in the process of pepper pot pitting. However, it must be stressed that one must be very careful when extrapolating such results to environmental situations since each water system has its own peculiarities.

CHAPTER 5

COLONISATION OF PLUMBING TUBE MATERIALS WITH *LEGIONELLA PNEUMOPHILA*.

5.1 INTRODUCTION

The aetiological agent of legionnaires' disease, *L. pneumophila* has been found to be ubiquitous in water (Fliermán *et al.* 1979 and 1981). Although environmental sources of community acquired disease are largely unknown, potable water has been identified by Stout *et al.* (1992) as the probable environmental reservoir for *L. pneumophila* for 8 out of 20 patients with confirmed and community acquired legionnaires' disease. Bartlett *et al.* (1983) found that 66% of hospitals and hotels had *Legionella* spp. in their water systems. Fischer-Hoch *et al.* (1981) identified plumbing systems as a source of infection in a hospital after eliminating the air-conditioning cooling-tower facility as a factor. Many other nosocomial legionellosis cases have been associated with hospital distribution systems (Marrie *et al.* 1992). As the present study has examined biofouling of copper used in domestic water circuits (section 4.3) the investigation was broadened to ascertain the survival of this particular pathogen in the continuous culture laboratory model. Consequently the inoculum was changed to one retrieved from an outbreak of Legionnaires' disease in Cavtat in the former Yugoslavia (supplied by Dr. John V. Lee, PHLS, UK). Several materials including copper and plastic plumbing materials were chosen as the substratum upon which to compare the generation of biofilms.

Bacterial cells contain DNA and RNA and can therefore be stained for direct enumeration using fluorescent nucleic acid stains such as acridine orange (Hobbie *et al.* 1977). Staining of viable bacterial cells is often variable depending upon conditions utilised and so Zimmerman *et al.* (1978) used a metabolic marker 2-(p-iodophenyl)-3-(-p-nitrophenyl)-5-phenyltetrazolium chloride (INT) to indicate viable cells. As respiring cells possess an active electron transport system (ETS) the ETS can be used to measure the ability of bacteria to reduce the colourless water soluble metabolic indicator INT-chloride to INT-formazan, a water insoluble red dye which is

accumulated within the respiring cell. This method has been used successfully as a rapid assay for the detection of viable *Legionella pneumophila* in environmental samples (Vesey *et al.* 1990).

Previously, Wright *et al.* (1991) utilised a defined medium to study susceptibility of pure culture *L. pneumophila* biofilms to biocides. The aim of this study was to generate biofilms composed of a mixed consortia including *L. pneumophila* in filter sterilised tap water that was representative of environmental conditions where the organism was found.

5.2 MATERIALS AND METHODS

Two continuous culture vessels were established (section 2.5, page 51) and inoculated with a complex mixed microbial consortia, including *L. pneumophila*, that was obtained from an outbreak of Legionnaires' disease in Cavtat in the former Yugoslavia (supplied by Dr. John V. Lee, PHLS, UK). Biofilms were developed on and quantified from copper, polybutylene, polyethylene and cPVC surfaces at 40°C and 60°C (section 2.6 and 2.7 page 58).

5.3 RESULTS

5.3.1 Simulation of a hot water circuit at 40°C and 60°C.

Initially the culture was maintained at 40°C to monitor colonisation of copper, cPVC, polybutylene and polyethylene with a mixed consortium containing *L. pneumophila* serogroup 1. The temperature was then changed to 60°C to determine the effect of temperature on colonisation and survival in the water phase of this consortium.

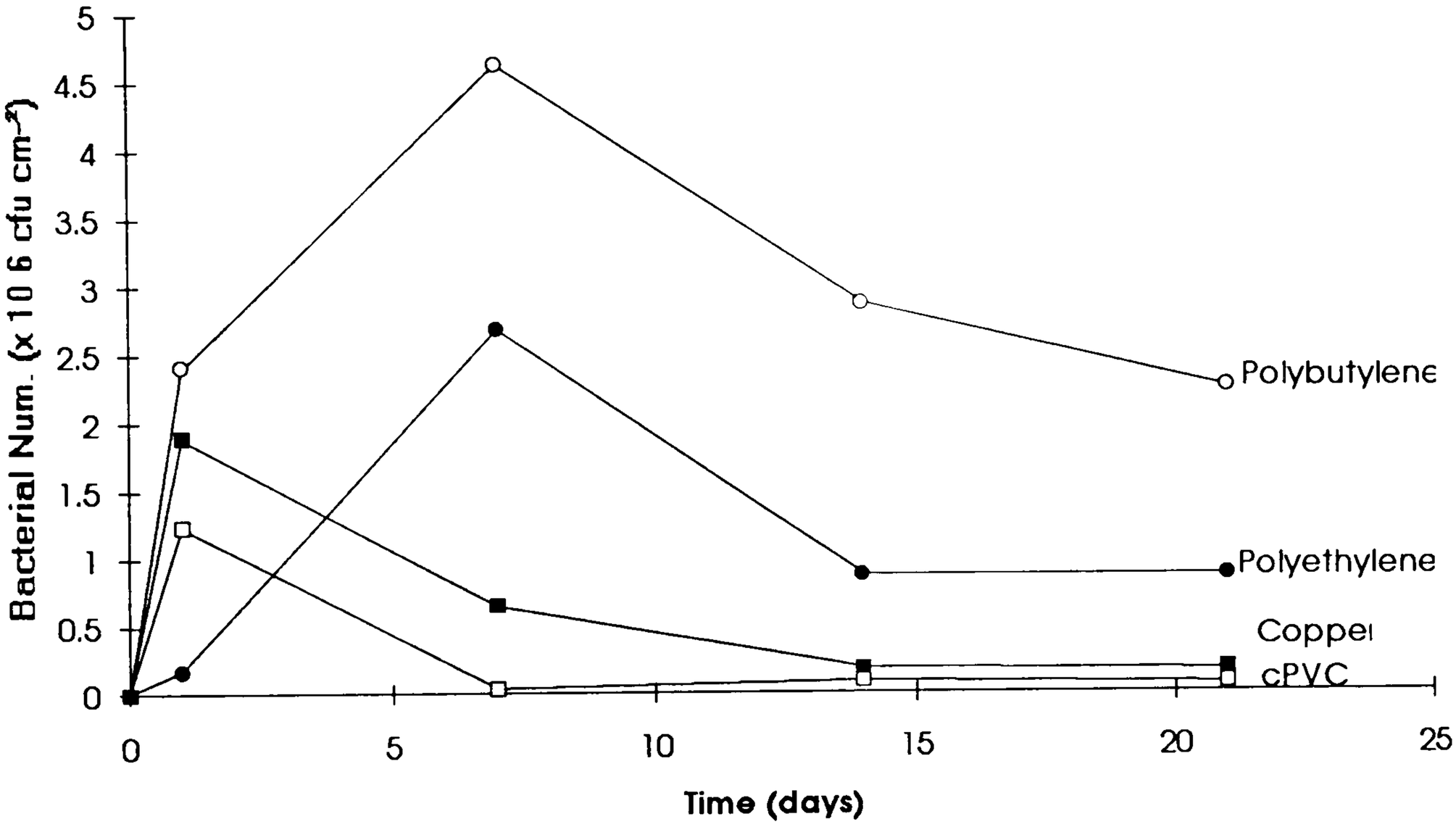


Fig. 5.1 Colonisation (total count) of copper, cPVC, polybutylene and polyethylene in Glasgow water with the Yugoslavian inoculum at 40°C.

Copper, polybutylene and cPVC were rapidly colonised in the soft water at 1.8×10^6 cfu cm^{-2}, 2.4×10^6 cfu cm^{-2} and 1.2×10^6 cfu cm^{-2} respectively at day 1 while polyethylene was only colonised at 1.7×10^5 cfu cm^{-2}. By day 7 the number of bacteria recovered from polybutylene and polyethylene had increased to 4.6×10^6 cfu cm^{-2} and 2.7×10^6 cfu cm^{-2} and then decreased to 2.9×10^6 cfu cm^{-2} and 8.8×10^5

cfu cm^{-2} respectively. Although bacterial numbers recovered from polybutylene decreased further to 2.2 x 10^6 cfu cm^{-2}, after 21 days polyethylene remained at 8.8 x 10^5 cfu cm^{-2}. However, from day 7 to day 21 the recovery of viable microorganisms from both copper and cPVC decreased so that there were only 1.7 x 10^5 and 2.0 x 10^5 cfu cm^{-2} respectively at day 21.

5.3.1.1 Recovery of Legionella pneumophila from the materials in soft water at 40°C

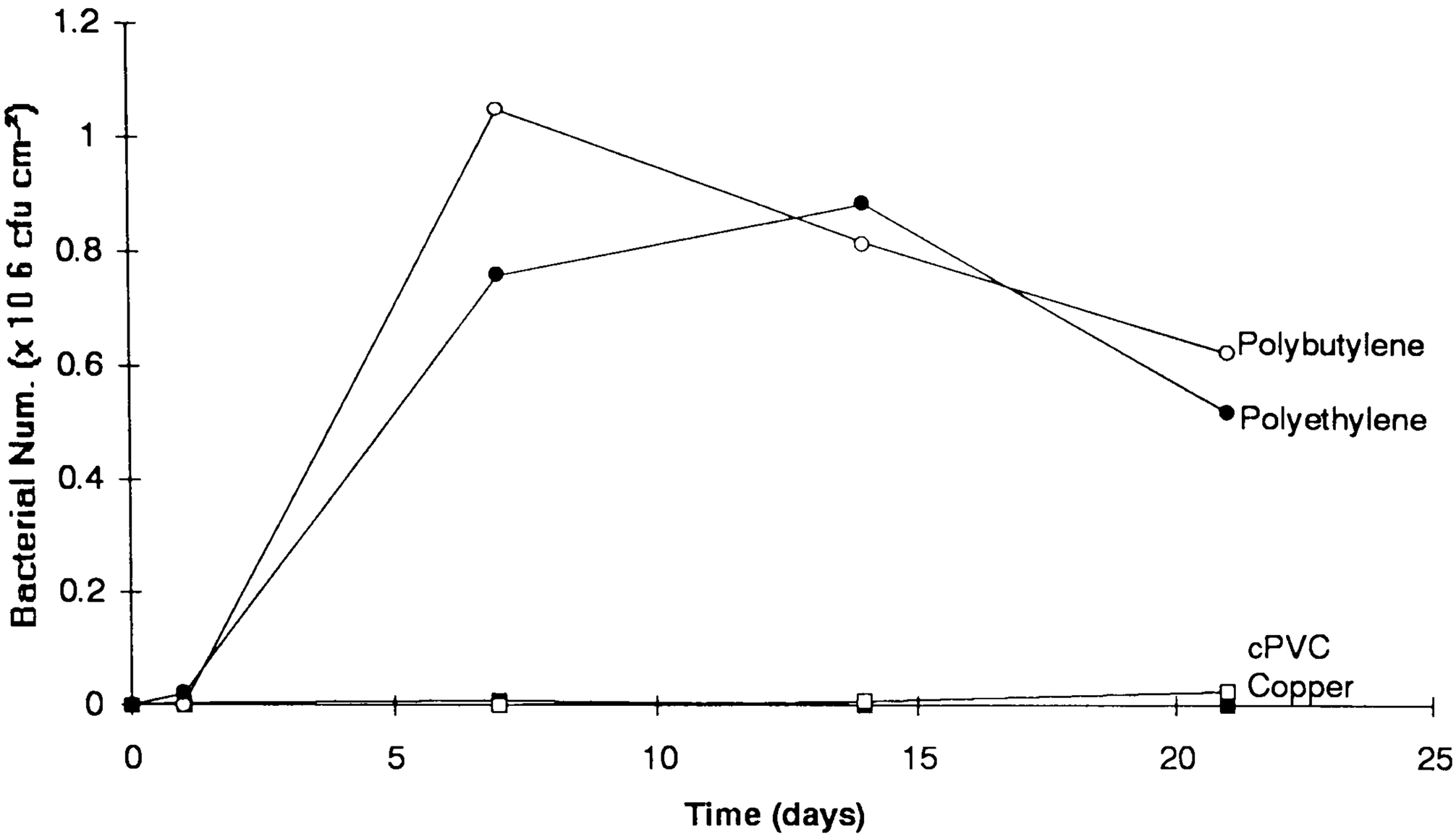


Fig. 5.2 Colonisation of copper, cPVC, polybutylene and polyethylene by *L. pneumophila* at 40°C.

At day 1 legionellae were recovered at 1.4×10^3, 2.0×10^3 and 3.5×10^3 cfu cm^{-2} from polybutylene, polyethylene and copper with no recovery of bacteria from cPVC. By day 7, 2.0×10^3 cfu cm^{-2} were recovered from cPVC and 8.0×10^3 cfu cm^{-2} from copper. Number of Legionella recovered from copper then decreased at day 14 with no recovery of Legionella at day 21. The number of Legionella recovered from cPVC increased to 7.5×10^3 cfu cm^{-2} at day 14 and then to 2.4×10^4 cfu cm^{-2} at day 21. However, recovery of Legionella from polybutylene and polyethylene dramatically increased at day 7 to 1.0×10^6 cfu cm^{-2} and 7.6×10^5 cfu cm^{-2} with 6.3×10^5 and 5.2×10^5 cfu cm^{-2} being recovered at day 21 respectively.

5.3.1.2 Recovery of Planktonic bacteria in the soft water at 40°C.

The number of bacteria present in the water phase was also determined, while the plumbing materials were immersed in the culture.

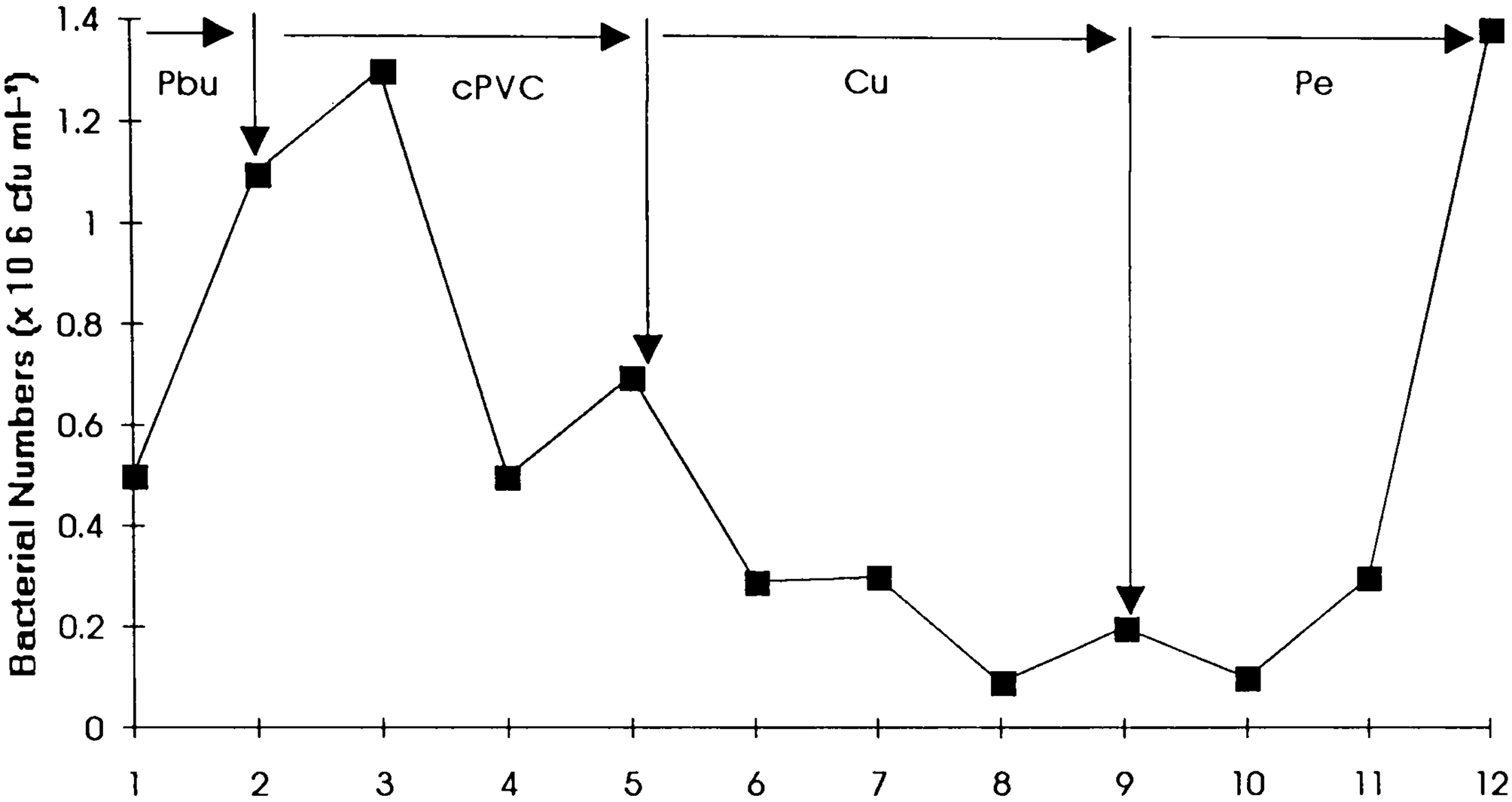


Fig. 5.3 Total bacterial numbers present in the planktonic phase of Glasgow water with Yugoslavian inoculum at 40°C.

Prior to immersion of the materials into the culture 5.1×10^5 cfu ml^{-1} were recovered from the planktonic culture. After polybutylene coupons were immersed into the culture the number of bacteria recovered from the planktonic phase increased to 1.1×10^6 cfu ml^{-1}. Following the immersion of cPVC into the culture the number of bacteria recovered continued to increase further to 1.3×10^6 cfu ml^{-1}. The bacterial numbers decreased to 5.9×10^5 before increasing to 7.7×10^5 cfu ml^{-1} while cPVC was immersed into the culture. Copper coupons were then suspended in the culture and planktonic bacteria recovered decreased to 2.9×10^5 cfu ml^{-1} followed by a slight increase to 3.3×10^5 cfu ml^{-1}. Bacterial numbers in the planktonic phase then decreased further to 9.2×10^4 cfu ml^{-1} while copper was suspended in the culture and

was at 2.4 x 10^5 cfu ml^{-1} prior to removal of copper coupons. When polyethylene was immersed into the culture 1.4 x 10^5 cfu ml^{-1} were initially recovered followed by 3.2 x 10^5 cfu ml^{-1}. Counts then increased to 1.4 x 10^6 cfu ml^{-1}.

5.3.1.3 Presence of L. pneumophila in the planktonic phase of soft water at 40°C.

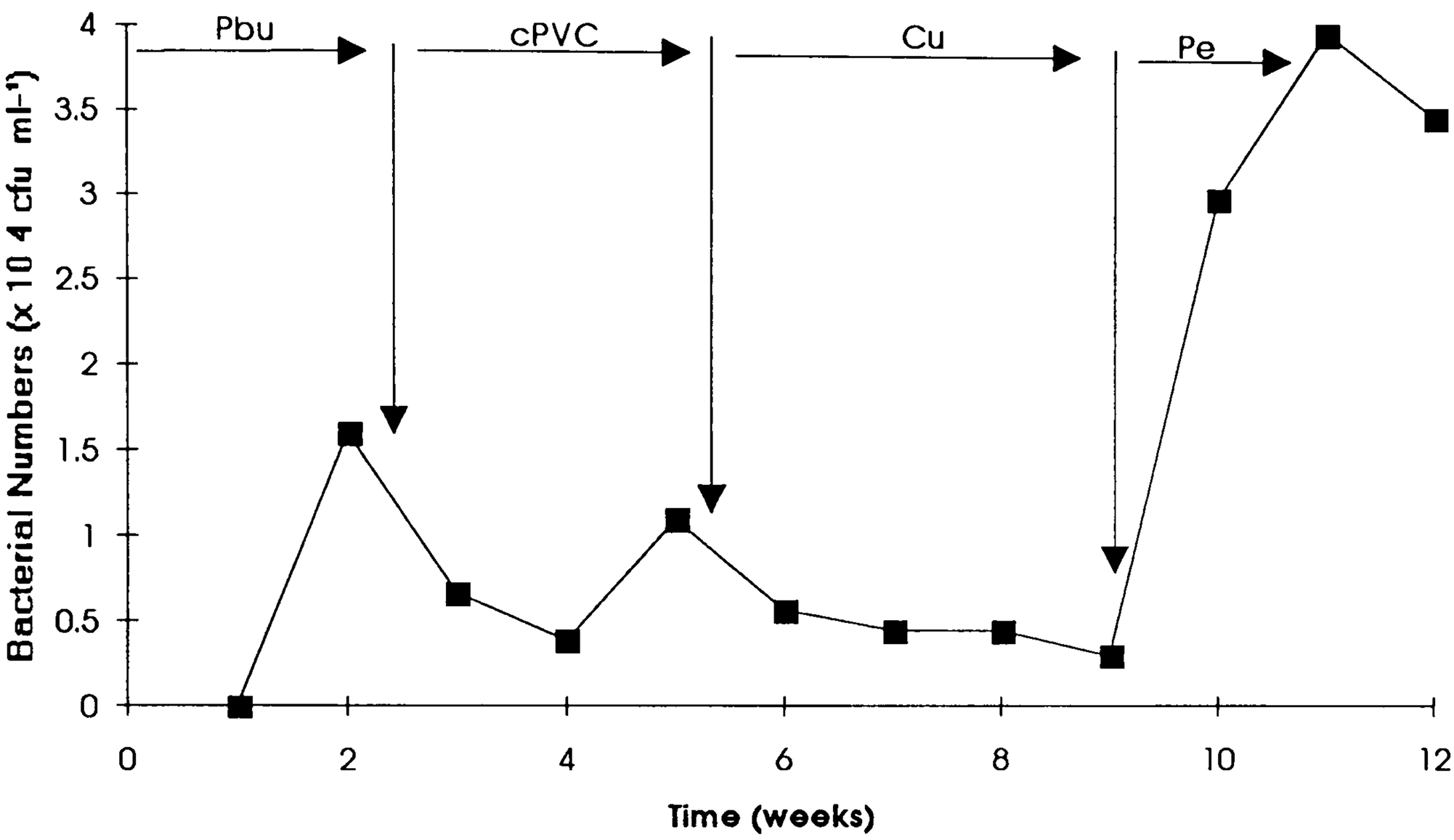


Figure 5.4 Colonisation of plumbing tube materials by *L. pneumophila* at 40°C in the planktonic phase of soft water.

Before polybutylene was immersed into the culture 20 legionellae ml^{-1} were recovered from the planktonic phase but afterwards legionellae numbers increased to 1.6 x 10^4 cfu ml^{-1}. With a change of material to cPVC the numbers initially decreased to 3.9 x 10^3 cfu per m before increasing to 1.1 x 10^4 cfu ml^{-1}. When copper coupons were immersed in the culture legionellae numbers decreased consistently to 3.0 x 10^3 cfu ml^{-1} and upon the introduction of polyethylene numbers increased to 3.0 x 10^4 cfu ml^{-1}.

5.3.1.4 Microscopical comparison of planktonic bacterial numbers and viability.

Table 5.2 Vessel 1 at 30°C.

Weeks	Total (AO)	Viable (INT)	Viable (SPC)
1	5.2×10^7	3.6×10^6	3.0×10^4
2	4.9×10^6	1.2×10^6	6.7×10^4
3	4.6×10^6	0.7×10^6	4.8×10^4
4	3.5×10^6	2.0×10^6	Confluent growth
5	6.5×10^6	2.8×10^6	2.6×10^4
6	5.3×10^6	2.6×10^6	10×10^4
7	2.8×10^6	1.0×10^6	0.8×10^4
8	4.3×10^6	0.4×10^6	3.6×10^4
9	0.4×10^6	0.02×10^6	1.0×10^4

SPC denotes standard plate count; AO denotes acridine orange; INT denotes bacterial cells enumerated by viable staining. All counts represent cfu ml^{-1}.

In vessel one, where conditions were constant, 3×10^4 cfu ml^{-1} were recovered by viable plate counts in week 1. Whereas, using microscopy techniques, 3.6×10^6 cfu ml^{-1} of bacteria were enumerated and identified as being metabolically active due to INT reduction. The total number of bacteria enumerated using microscopy methods (AO) was 5.2×10^7 cfu ml^{-1} in week 1 and this does appear to be high in comparison to the other counts and may have been a dilution error. For example, week 2 is more representative of counts in this vessel, with 6.7×10^4 cfu ml^{-1} recovered from the viable plate count and 1.2×10^6 enumerated using INT and a total of 4.9×10^6 enumerated using AO.

Table 5.3 Vessel 2 at 60°C

Time (wk.)	Total (AO)	Viable (INT)	Viable (SPC)
8	1.1×10^7	9.4×10^5	20
9	6.4×10^6	3.1×10^5	45
10	5.6×10^6	9.8×10^5	1500
11	3.0×10^6	1.3×10^5	90
12	6.8×10^6	9.1×10^5	900
13	4.7×10^6	0.8×10^5	500
14	2.4×10^6	1.0×10^6	360
15C	1.6×10^6	1.6×10^5	1100
16B	3.5×10^5	0.5×10^5	0

SPC denotes standard plate counts. All counts represent cfu ml^{-1}.

Microscopical enumeration of the culture in vessel two indicates that a total of 1.1×10^7 cfu ml^{-1} bacterial cells were present on week 1. The total number of viable cells in the culture, identified by INT reduction, was only 9.4×10^5 cfu ml^{-1}, however, using standard plate count procedures only 20 cfu ml^{-1} were recovered. A similar result was obtained for the other 8 weeks in which vessel 2 was in continuous mode. When the vessel was switched to batch mode there was a total of 3.5×10^5 cfu ml^{-1} from AO and 5.4×10^4 cfu ml^{-1} viable cells enumerated using INT. No growth was obtained using viable plate counts.

5.3.2 Simulation of hot water circuit at 60°C

Simulation of a hospital water system operated at 60°C.

5.3.2.1 Biofouling of materials at 60°C

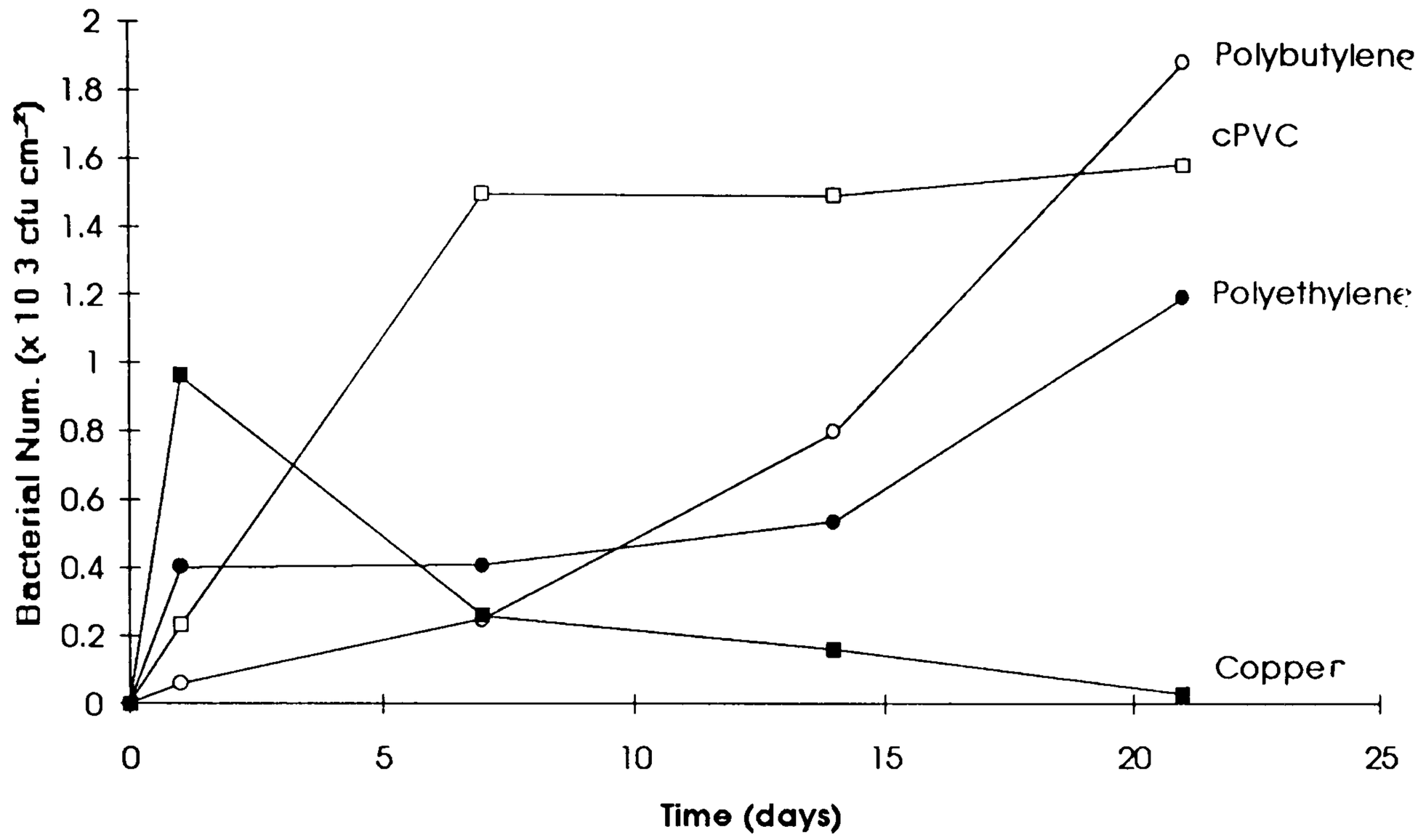


Fig.5.5 Colonisation on Copper, Polybutylene, Polyethylene and cPVC in Glasgow water at 60°C.

There were 65 cfu cm^{-2} recovered from Polybutylene surfaces at 1 day, 252 cfu cm^{-2} at day 7, with 800 and 1.9 x 10^3 cfu cm^{-2} respectively at days 14 and 21. Initially 400 cfu per cm^{-2} were recovered from polyethylene at 1 day, 415 and 545 cfu per cm^{-2} respectively at days 7 and 14 with 1.2 x 10^3 cfu cm^{-2} but at day 21 there was an increase to 1 215 cfu per cm^{-2}. Although only 230 cfu cm^{-2} were recovered from cPVC on day 1 the numbers recovered at days 7, 14 and 21 were 1.5, 1.5 and 1.6 x 10^3 cfu cm^{-2} respectively. There was a total of 960 cfu per cm^{-2} recovered from copper surfaces at 1 day, 260 and 160 respectively at days 7 and 14 with only 30 cfu per cm^{-2} at day 21.

5.3.2.2 Recovery of L. pneumophila from materials at 60°C.

No legionellae were recovered from any materials while the culture was maintained at 60°C.

5.3.2.3 Recovery of Planktonic bacteria in soft water at 60°C.

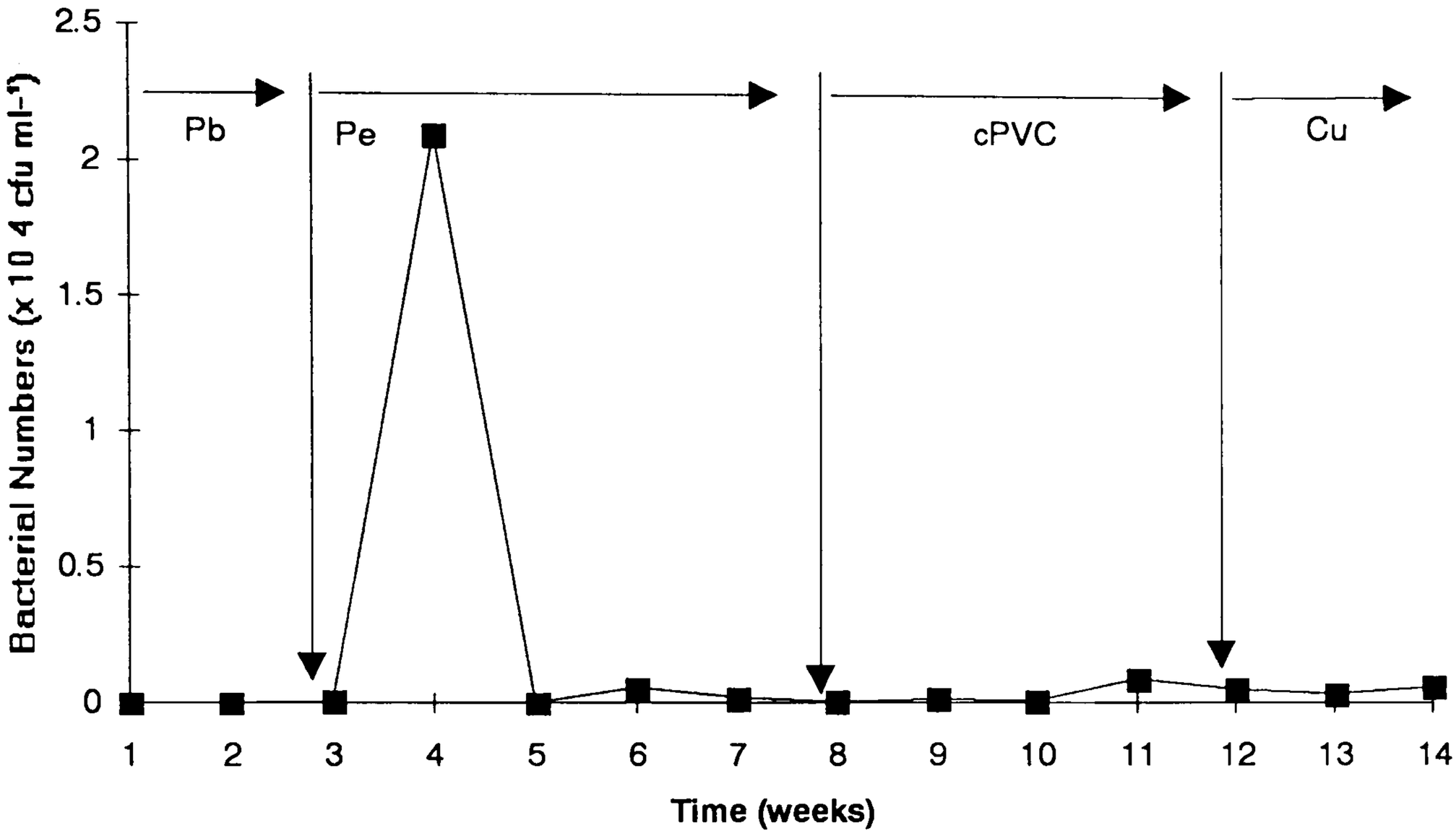


Fig. 5.6 Planktonic population at 60°C in Glasgow water with Yugoslavian inoculum.

Number of bacteria recovered at 60°C from the planktonic phase with polybutylene material immersed in the culture was less than 100 cfu ml^{-1}. Within 7 days of polyethylene being immersed into the culture, 2.2×10^4 cfu ml^{-1} were recovered. Less than 600 cfu ml^{-1} were recovered for remainder of the time that polyethylene was present. With cPVC in the culture 1.5×10^3 cfu ml^{-1} or less were recovered from the planktonic phase. Copper coupons were then immersed to determine colonisation in soft water at 60°C. In this case bacterial numbers recovered from the planktonic phase was less than 900 cfu ml^{-1}.

5.3.2.4 Recovery of Planktonic L. pneumophila in soft water at 60°C.

No planktonic *L. pneumophila* were recovered from the culture maintained at 60°C.

5.3.3 Change of culture vessel from continuous to batch mode

There was an average of 587 cfu ml^{-1} of planktonic bacteria recovered from the culture with copper immersed at 60°C. Following the extraction of copper coupons the effluent from vessel one was diverted so that it did not act as a seed for vessel two. Within 24 hours of switching to batch culture no bacteria were recovered from the vessel at 60°C.

5.4 DISCUSSION

Nosocomial legionnaires' disease has been associated with *L. pneumophila* contamination of potable hot water systems of hospitals (Wadowsky *et al.* 1982; Plouffe *et al.* 1983; Timbury *et al.* 1986 and Marrie *et al.* 1992). As legionellae have been isolated from municipal water treatment plants which adhered to accepted guidelines for water quality, treatment plants have been suspected of seeding domestic water circuits (Hsu *et al.* 1984; Colbourne *et al.* 1988a; Colbourne and Dennis, 1989). States *et al.* (1987) were able to isolate *L. pneumophila* from river water but it was not detected within any of the stages within a conventional water treatment plant. As this treatment plant maintained a chlorine residual throughout legionellae may occur there sporadically or in low numbers. However, temperatures between 20-45°C, low pressure, stagnant water, presence of metals and microorganisms are known to encourage growth and multiplication of *L. pneumophila* in water systems (Arnow *et al.* 1982; Anand *et al.* 1983; Ciesielski *et al.* 1984; States *et al.* 1984; Stout *et al.* 1985; Makin and Hart, 1991). The optimal temperature range for growth of legionellae is 35-37°C but the bacterium will grow over the range of 25-42°C (Hoge and Breiman 1991) and Makin and Hart (1991) recorded the presence of legionellae at a temperature of 50°C. In an investigation of hot water devices Alary and Jolly (1991) showed that 43% of cases reported as culture positive for legionellae also proved positive in the scrapings from peripheral outlets such as shower heads and faucet taps. Such results demonstrate the presence of biofilm as a survival niche for legionellae. Control measures such as chlorination (Cunliffe 1990) and raising of hot water temperatures (Plouffe *et al.* 1983) have contributed towards a reduction in nosocomial Legionnaires' disease.

During this study the growth of *L. pneumophila* within a mixed consortium on different plumbing materials in a simulated hot water circuit at 40°C and 60°C was

investigated. The temperature of 40°C was chosen as the minimum at which to operate a hot water system with reduced heating costs and reduced risk of patient scalding in respect to the water circuit being operated at 60°C. The higher temperature of 60°C was chosen in line with the HSS (Anon, 1990) guidelines which stipulate that hot water systems should be maintained above 50°C. A temperature lower than 55°C was not chosen as it was found (Chapter 3) that biofilms were still forming within the laboratory model operating at 55°C.

5.4.1 Simulation of a hot water circuit operating at 40°C

5.4.1.1 Biofouling of plumbing tube materials

Growth of the bacterial consortia resulted in a rapid colonisation of polybutylene, copper and cPVC within 24 hours. Bacterial numbers on polyethylene continued to increase up to 7 days exposure to the total consortia and along with polybutylene in particular continued to support greater numbers of bacteria. Due to the number of additives such as alkyl phthalates as plasticisers, butylated hydroxytoluene as antioxidant, stearates as lubricants and thioethers as heat stabilisers, some plastic pipes actively encourage the growth of microorganisms (Burman and Colbourne 1977). In comparison recovery of bacteria from cPVC and copper surfaces decreased after 24 hours.

Recovery of *L. pneumophila* from polybutylene and polyethylene at 40°C, was 100-fold greater than that recovered from cPVC, and copper surfaces. Although total numbers of bacteria recovered from the cPVC decreased after 24 hours, the number of legionellae actually increased over the time period that cPVC was exposed to the culture. Similarly there was a decrease in the total bacterial numbers and legionellae recovered from copper over the 21 day period of exposure to the consortia. No

legionellae were recovered at day 21. Recent evidence (Makin and Hart, 1990) suggests that approved listed materials (Anon, 1987) conforming to British Standard 6700, may become colonised with legionellae particularly where they are continuously subjected to temperatures which favour growth of this species. In a laboratory batch model to study colonisation of PVC, Vess *et al.* (1993) visualised biofilm as a heterogeneous mosaic of microcolonies on the PVC and was able to recover *Ps. aeruginosa* after 7 days prolonged iodopher treatment. States *et al.* (1985) cited that high concentrations of copper (10 and 100 mg l^{-1}) produced toxic effects on *L. pneumophila* and that low concentrations (0.5 and 1.0 mg l^{-1}) did not appear to be detrimental. The copper concentration of the cultures was measured by atomic absorption (results not shown) at 0.1 mg l^{-1} and is at the low concentrations that States *et al.* (1985) suggest would not be detrimental to bacterial growth. However, in that particular study the growth of planktonic but not sessile bacteria was tested against an analytical reagent-grade copper sulphate. Hicks and Rowberry (1988) used cupric sulphate and found that concentrations of 1.5 mg l^{-1} were capable of killing a copper resistant, plasmid-carrying *E. coli* when in the planktonic phase. But when the same cells were attached to glass beads they became resistant to concentrations of 7.5 and 15 mg l^{-1} of divalent copper ions. In a comparison of copper and polyvinyl chloride (PVC) Bezanson *et al.* (1992) studied *in situ* colonisation using a sampling device (Robins Device) on the return end of a hot-water supply in a hospital (unfortunately the temperature of the return was not cited). They found that more legionellae were recovered more often from PVC than from copper and similar to our findings, colonisation of copper did not persist for the duration of the study. Similarly Schoenen *et al.* (1988) utilised a model hot water system and found that legionellae did not persist on copper for the duration of the experiment. In another hot water (45°C) model system, Schofield and Wright, (1984) and Schofield and Locci (1985) examined rubber and copper materials extracted after ten weeks exposure to legionellae and found that copper was the least colonised in comparison to rubber. In this present study recovery of legionellae from copper peaked at day 7 then decreased

with none recovered at day 21. These results suggest that there are factors related to the cPVC surface and more so the copper surface that inhibit or suppress colonisation by *L. pneumophila*. Colbourne *et al.* (1984) demonstrated that legionella were able to survive within a biofilm on plastic and rubber plumbing circuit fixtures and fittings despite the introduction of control measures such as chlorination and increased temperature. However, in a test protocol (Colbourne and Brown, 1979) to test microbial growth potential of water supply materials unplasticized PVC passed the test whereas plasticised PVC failed. The test was based on differences in dissolved oxygen between water samples containing materials and a control that did not.

Copper has been attributed with the ability to suppress fungi and bacteria and has consequently been used in agriculture for many years to control plant infections (Bitton and Friehofer, 1978; Cooksey and Azad, 1992). In the water industry copper has been shown to suppress not only coliforms (Domek *et al.* 1984) but also *L. pneumophila* (West *et al.* 1989; Landeen *et al.* 1989) and other microorganisms (Singh and McFeters, 1987). Copper ions are believed to interfere with enzymes involved in cellular respiration (Domek *et al.* 1984) and to bind at specific sites to DNA (Liebe and Stuechr, 1972a and b). Mechanisms of resistance to copper involve internal complexation, mainly utilised by eukaryotes (Gadd and White, 1989), while bacterial cells have been shown to efflux heavy metals such as zinc (Neis, 1992) and copper (Brown, *et al.* 1992) actively to prevent accumulation within the cell. Bacteria have also been shown to be able to complex toxic divalent cations by the production of surface active polymers (Corpe, 1975). Organisms may rely on several survival strategies, for example metallothionein synthesis is a mechanism of copper resistance in yeast but copper binding around the cell wall and transport across the cell membrane (as discussed above) may also be components of the total cellular response (Gadd and White, 1989).

5.4.1.2 Growth in the planktonic phase at 40°C

Total bacterial numbers in the planktonic phase doubled to > 1 x 10^6 cfu ml^{-1} when polybutylene surfaces were immersed in the culture. With cPVC 5.9 x 10^5 cfu ml^{-1} were recovered but after the immersion of copper coupons the planktonic flora decreased to 9.2 x 10^4 cfu ml^{-1}. Bacterial numbers recovered from the planktonic phase was 1.4 x 10^5 cfu ml^{-1} after the immersion of polyethylene and then exhibited a 2-fold followed by a 10-fold increase in recovery. Therefore with copper present in the culture the number of recovered bacteria decreased. Recovery of legionellae from the planktonic phase followed a very similar pattern to that of total numbers indicating that there may be a link in the number of legionellae to the total population. The decrease in total planktonic bacteria with copper present in the planktonic phase was 8.3-fold while legionellae exhibited a 3.6 fold decrease. With polybutylene the number of legionellae exhibited an 800-fold increase in numbers, a 10-fold increase in the presence polyethylene, and only a 2.8-fold increase in the number of legionellae with cPVC present in the culture.

These results indicate that plastic materials polybutylene, polyethylene and to a lesser extent cPVC encourage growth of not only total numbers but also legionellae within the planktonic phase. In a study of the microbial growth potential of materials in potable water, Colbourne (1985) stated that materials donate organic compounds either through leaching or by exposure at the surface. From Fig. 5.3 it appears that cPVC may indeed leach nutrients into the water phase rather than at the material surface. The growth at surfaces of certain plastics materials can be self perpetuating, e.g. polybutylene and polyethylene (Fig. 5.1 and 5.3). This would not only support biofilm growth but also result in increased microbial activity in the water phase (Colbourne, 1985). In a study of the assimilable organic carbon to determine the potential of a water to support growth van der Kooij *et al.* (1982) demonstrated that a much higher AOC was produced in the presence of plasticised PVC. Bezanson *et al.*

(1992) also cultured the water flowing through an *in situ* copper sampling device and recorded numbers ranging from the equivalent of 200-1000 cfu ml^{-1}. In comparison numbers recovered from the planktonic phase of the present study using filter sterilised tap water ranged from 20-40000 cfu of legionellae ml^{-1}. This represents a 40-fold increase on the maximum obtained by Bezanson *et al.* (1992). In contrast, Wright *et al.* (1991) who utilised a defined nutrient media with added nutrient sources, obtained 1.2×10^7 cfu of legionellae ml^{-1}. This is a 300-fold increase on the maximum recovered from the planktonic phase of the continuous culture model using tap water as the nutrient source and results in artificially high legionellae numbers not usually encountered in potable water systems.

5.4.2. Simulation of a hot water system operated at 60°C

As well as operating the continuous culture model to simulate a hot water system maintained at 40°C the model was also operated at 60°C according to guidelines (Anon, 1990) for the control of legionellae. Total fouling was dramatically reduced in comparison to that at 40°C e.g. maximum colonisation of polybutylene was 4.6×10^6 cfu cm^{-2} at 40°C while at 60°C 1900 cfu cm^{-2} were recovered. There was also a different profile of fouling for the three plastic plumbing materials. Bacterial numbers recovered from polybutylene and polyethylene increased the longer the coupons were immersed into the culture and was still increasing at day 21 when 1900 and 1215 cfu cm^{-2} were recovered respectively. By day 7 the number of bacteria recovered from cPVC had reached 1600 cfu cm^{-2} and was maintained at this number up to and including day 21. Although 1000 cfu cm^{-2} were recovered from copper surface within 24 hours the numbers of bacteria recovered continued to decrease such that only 30 cfu cm^{-2} were recovered at day 21. Thus at 60°C copper plumbing tube material continued to suppress biofilm growth and may act in synergy with thermal pasteurisation as indicated in chapter 3 section 4.5 to control fouling. The maximum

number of bacteria recovered from the plastics was only > 1 x 10^3 cfu cm^2 with polybutylene, polyethylene and cPVC exhibiting increased colonisation in comparison to copper.

5.4.2.1 Growth in planktonic phase at 60°C

In contrast to >1 x 10^6 cfu ml^{-1} being present when the culture was maintained at 40°C, less than 100 cfu ml^{-1} were recovered initially at 60°C. Although 2.2 x 10^4 cfu ml^{-1} were recovered while polyethylene was present in the culture this was not representative of the bacterial numbers recovered at this temperature and may have been due to an aggregate of cells from vessel one or a heating element failure. With the temperature maintained at 60°C the maximum number of bacteria recovered from the planktonic phase was 150 cfu ml^{-1} and at all sample points fewer bacteria were recovered.

Other studies have demonstrated legionellae control using temperatures >55°C. Plouffe *et al.* (1983) found that in a survey of six buildings only two were consistently negative for *L. pneumophila.* The hot water storage temperature was maintained at 43-45°C in both these buildings, whereas the other four buildings which were negative for *L. pneumophila* maintained their hot water between 58-60°C. Such results clarify the importance of thermal inactivation of bacteria particularly for *L. pneumophila.* Dennis *et al.* (1984b) reported that in batch culture at 50°C and 54°C *L. pneumophila* survived longer than a coliform, *Pseudomonas* spp. and a *Micrococcus* spp.. Similar results were obtained by Stout *et al.* (1986) at 60°C between *L. pneumophila* and a *Pseudomonas* spp. These results indicate that relatively high temperatures are likely to favour the growth of legionellae at the expense of other environmental organisms. In a risk assessment of domestic hot water systems Alary and Joly (1991) reported that legionellae were recovered from 39 % of hot water systems where hot water was supplied by an electric heater, with no recovery of legionellae where hot water was

supplied by oil or gas heater. In the latter the heat source is normally located at the bottom of the heater and so even when sludge does accumulate it is maintained at too high a temperature for legionellae survival. Electric calorifiers (heating element located on the side of the electric heater) operated at recommended temperatures of >55°C have been implicated as reservoirs for multiplication and growth of *L. pneumophila* (Bhopal and Barr, 1991). This is due to an accumulation of sludge and the presence of cold water spots below the heating element protecting microorganisms and allowing growth to occur at 30-40°C. Stout *et al.* (1986) suggested that thermostat set points be set at 65°C to 70°C to achieve a temperature of 60°C at the bottom of calorifier tanks and at outlets. In a study of mechanisms of control of *L. pneumophila* Muraca *et al.* (1987) used a model plumbing system (closed circuit but flowing) to demonstrate that 20 minutes at 60°C was required to achieve a 1 log drop in numbers of surviving *L. pneumophila.* Using heat inactivation a 5 log kill was achieved quicker than with chemical mechanisms of inactivation such as chlorine and ozone.

Heimberger *et al.* (1991) reported that thermal pasteurisation of a hot water system should not be relied upon to completely control legionellae. In a hospital where the hot water system was maintained at 50°C, the complete water system was exposed to hot water flushing at 75°C for 15 minutes at all outlets and chlorination of the hot water tanks. However, after 1 month *L. pneumophila* was cultured from several outlets and only continual chlorination of 1.5-2.0 ppm and regular heat flushing of water tanks prevented legionellae from multiplying in the water circuit. Howells *et al.* (1986) also reported an outbreak of nosocomial legionnaires' disease in a hospital eight weeks after the hot water temperature of 55-60°C was decreased by 10°C. Such results indicate the tenacity of this bacterium to survive, perhaps in a biofilm in the water circuit (Colbourne *et al.* 1984) and to proliferate when conditions become favourable. The survival and recalcitrance of *L. pneumophila* may be due to its growth within a biofilm as suggested above or it being associated with other bacterial

species, protozoa such as *Tetrahymena* sp. (Barbaree *et al.* 1986) and amoebae (Rowbotham, 1980) such as *Acanthamoeba polyphaga* (Barker *et al.* 1992). There is no doubt of the co-cultivation and multiplication of *L. pneumophila* within free-living amoeba (Anand *et al.* 1983) which are ubiquitous in water and have actually been isolated from the laboratory model (Rowbotham, 1991). However, States *et al.* (1993) have recorded that multiplication of *L. pneumophila* within *Hartmonella vermiformis* does not significantly increase heat resistance of *L. pneumophila* to short term exposure to heat.

Over the last two decades there has been a change in guidance for control of temperatures in hospital hot water systems which has resulted in a reduction of the temperature from 60°C to between 40°C and 45°C. Although this change was initially introduced to conserve energy it was later (in the USA) made a mandatory regulation that temperatures should not exceed 43°C to minimise scalding of patients in hospital wards (Joint Commission of Accreditation on Hospitals, 1981) - a similar guideline was followed in the United Kingdom. In 1983 the Joint Commission of Accreditation allowed each hospital to determine its maximal hot water temperature. Therefore although the use of high temperatures (60°C) have been shown to eradicate legionellae from the laboratory model, *in situ* hospital staff have to be aware of the danger of scalding as temperatures of 60°C can cause partial thickness burns with a contact time of 5s (Makin and Hart, 1991).

From microscopical examination of planktonic bacterial counts in vessel two at 40°C the viable plate counts are 100-fold lower than the viable INT count of which the total number of bacteria present on the filter as determined by AO counting is >2-fold. Liebert *et al.* (1983) found that culturable counts were only approximately 10-fold lower than direct microscopic counts using AO. In the second vessel at 60°C the total (AO) bacterial numbers were >5-fold more than the viable numbers (INT) however, number of bacteria detected by viable plate counts was less than 1500 cfu ml^{-1}.

When the materials trial was completed the effluent flow from vessel one was diverted and ran to waste, such that vessel two only received sterile media and was not seeded with spent cells and media. This was carried out to ascertain the survival of planktonic bacteria at 60°C. Within 24 hours no viable bacteria were recoverable from the planktonic phase by agar plate culture, yet 5.4×10^4 cfu ml^{-1} still had an active electron transport system that was capable of reducing the metabolic indicator INT. When the culture temperature was maintained at 60°C and was not seeded with effluent from the vessel at 30°C no bacteria were recovered from the planktonic phase within 24 hours. When the culture was reseeded with the effluent from the vessel at 30°C the population was recoverable by viable plate count indicating that, when constantly challenged with a bacterial consortium, 60°C may control but is unable to kill the bacteria. This has importance in hot water systems where the temperature in parts of the system may fall below 60°C and so provide a favourable environment for multiplication and growth of bacteria which will reseed the rest of the system. Extracted formazan has been measured spectrophotometrically to quantify electron transport activity (Blenkinsopp and Lock 1990) but this was not a suitable method to use in these experiments as the volume of biomass was not large enough (results not shown). Fry and Zia (1982) suggested a relationship between cell size and viability with the possibility that small cells could be dormant (Stevenson, 1978) and therefore unculturable (Hoppe, 1976). Torrela and Morita (1981) discussed that heterotrophic bacteria may have evolved mechanisms for survival in being resistant to starvation by becoming very small. Small cells would have a minimum nutritional requirement and turnover of cell components but may still be unculturable. Such mechanisms may account for the number of bacteria which appear to be viable according to the results of the microscopy (INT) but may have been injured to such an extent that they did not survive the trauma of culturing on agar. Arguably this may also have been the case for the legionellae but immunofluorescence labelling and metabolic indicators were not utilised in this particular study to see if legionellae were still present and or viable in the aqueous phase of the culture. Those injured and hence unculturable bacteria

may have recovered under more favourable conditions to form another bacterial population of aquatic and biofilm bacteria including legionellae.

5.5 CONCLUSIONS

The growth of legionellae in the environment is of major concern to those responsible for the public health. This applies particularly in hospitals where many patients are immunocompromised and are therefore more susceptible to infections. However, the publicity which is attracted by Legionnaires disease means that it attains a high profile in the eyes of the public and those responsible for their health to the extent that other issues which may be as serious may be put aside. Therefore, much emphasis and effort is placed upon not only detecting this waterborne pathogen but also in it's control.

From this study *L. pneumophila* can grow in water as part of a mixed consortium and will colonise a range of materials including copper and cPVC, both of which appear to suppress legionellae growth in comparison to other plastic materials at 40°C. A material that suppresses the growth of legionellae, however, is not sufficient to control its growth or the consortium at 40°C without some other form of physical or chemical control.

Increasing the temperature of the model system to 60°C clarified that this will control the presence of legionellae and the consortium on the surfaces of materials particularly in the presence of copper. The planktonic bacteria were however, able to survive at 60°C as indicated by INT and would potentially colonise a surface downstream where conditions were more favourable. This may also apply to injured and unculturable legionellae. In many studies of hot water systems the use of temperatures of 60°C and above in the calorifier and at all outlets have been shown to eradicate legionellae to prevent nosocomial legionnaires' disease. However, when the temperature has been returned to less than 50-55°C the recovery of bacteria may occur resulting in potential cases of legionnaires' disease. Temperature control has only been temporary

and deemed to fail as there is no residual effect on the bacterial population after the temperature has been reduced to less than 55°C.

Alternative mechanisms such as chemical treatment have to be cost effective and since a residual exists in the water system they can be operated at less than 50°C which also helps to prevent cases of patient scalding. However, the environmental issue of disposal is also of importance and has to be considered.

Where temperature is used as the method to control legionellae within hot water systems maintaining the temperature at or above 60°C would only control legionellae if the temperature is rigorously maintained at all faucet and shower outlets.

Maintenance and control of any mechanisms employed to control legionellae must be strictly adherent to the guidelines recommended otherwise this tenacious persistent human pathogen will continue to re-emerge.

CHAPTER 6.0

CONCLUDING DISCUSSION

6.1 BACKGROUND

The process of corrosion involves many biological and environmental factors. Pepper pot pitting corrosion observed in this study did not entirely lie within the boundaries of classical types of corrosion, so it has been difficult to explain. In this concluding discussion a proposal involving many different aspects of bacterial growth and corrosion have been drawn together to provide a theoretical mechanism of pepper pot pitting. Attachment of bacteria to surfaces has been shown to enhance not only their survival but also their growth (Costerton Geesey, 1979). Hicks and Rowbury (1988) demonstrated that attachment to glass beads decreased the sensitivity of *Escherichia coli* to cupric ions while those in the water phase were killed thus attachment to a surface increased survival. Therefore in that study formation of a biofilm was an advantage for survival and perhaps similarly for water borne bacteria and pathogens in water systems. Problems in water systems due to biofouling such as microbially induced corrosion of substrata have been well recorded and documented (Iverson, 1987). Pitting corrosion of copper by classical mechanisms has been classified into three typical corrosion mechanisms

Type 1 Corrosion

Type 1 pitting occurs in cold hard water supplied from bore holes and the pitting propensity depends on pH, dissolved oxygen, chloride, sulphate, sodium, nitrate concentrations, low organic carbon and high dissolved inorganic ions. The pits contain soft crystalline cuprous oxide and cuprous chloride under a film of cuprous oxide crystals covered by basic copper carbonate (Fig. 6.1). Campbell (1950) reported that pitting corrosion of copper from cold water circuits was due to the presence of a glossy black film found beneath the corrosion carbonate scale. Under X-ray analysis the film was found to be composed of 2% copper and predominantly an amorphous

substance of very low X-ray absorption such as carbon. The carbon residue may have arisen from a) graphite in the extrusion lubricant, b) breakdown of lubricant during drawing and c) cracking of residual bore lubricant during the bright annealing operation (Cornwell *et al.* 1973) but was basically a result of fabrication.

Two mechanisms were proposed for the effect of carbon scale on copper. The first was that the carbon scale would act as an efficient cathode acting in conjunction with smaller anodes where the carbon film was broken. Alternatively the carbon film may act as a concentration cell creating differentials of oxygen with the production of a large number of small pits. The failures reported by Campbell (1950) were unusual as they occurred in pipes with a service of less than 2 years. The above author also determined that the extent of corrosion increased as the quantity of carbon on the copper surface increased and suggested that the source was residual lubricant from fabrication of the tubes. There appeared to be a questionable relationship in both cold and hot water circuits as the deposits in hot pipes usually contain silt as bulky residue which were unidentifiable from carbon scale (Campbell, 1950).

Cornwell *et al.* (1973) examined carbon scale on copper pipes and found that the pitting was induced by a hard water. Chemical analysis of the water supplying those particular water circuits in Scotland with failed copper tubes suggested a water type similar to that used by Cornwell *et al.* (1973) as a control for a non-pitting water i.e. soft water with relatively low total dissolved solids at 180°C. Interestingly the non-pitting water used by Cornwell also had a high organic matter content as measured by the method of Campbell (1954).

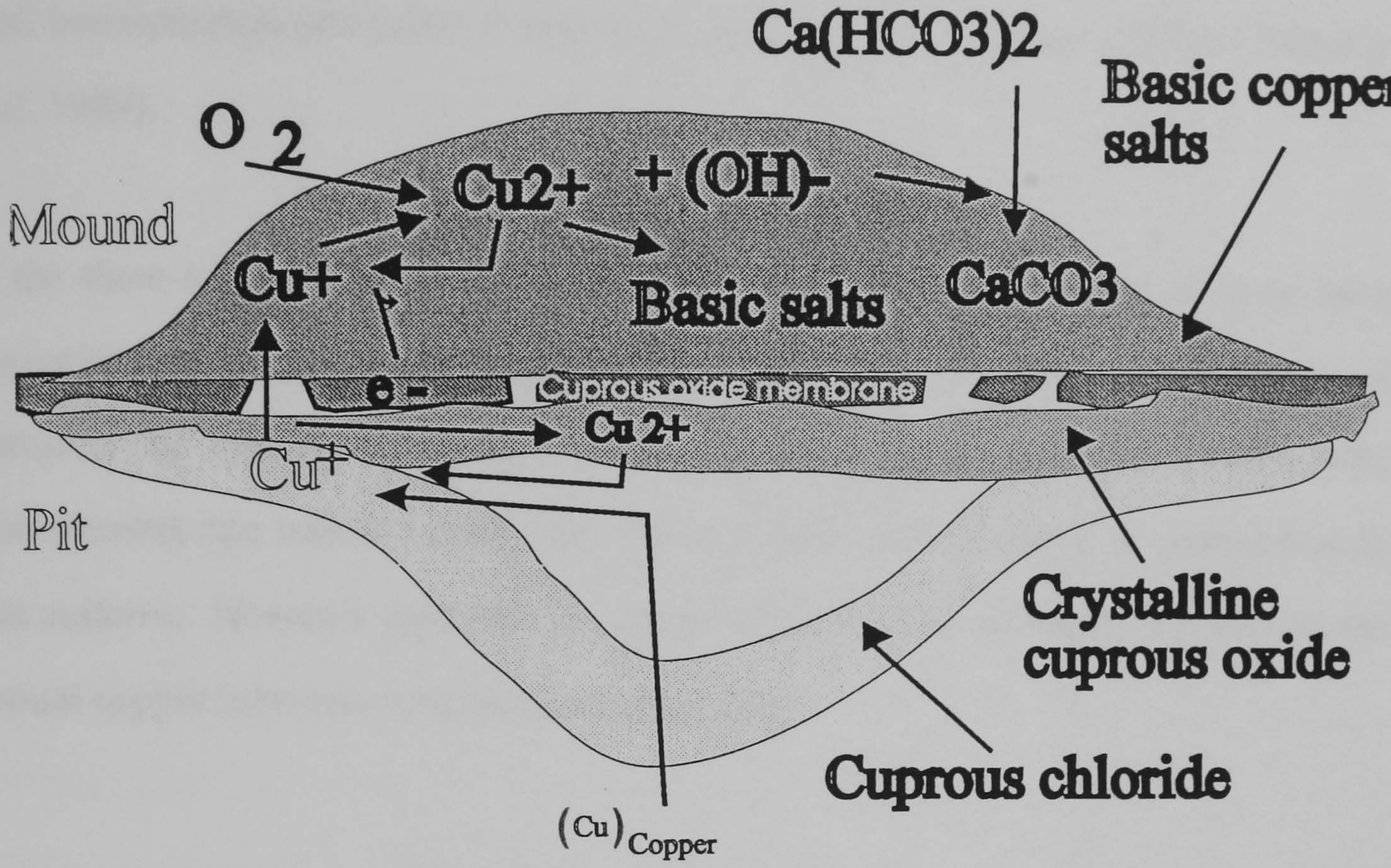


Figure 6.1 Diagrammatic representation of the arrangement of corrosion products and of the reaction involved in pitting corrosion of copper. (Lucey 1967)

Type 2 Corrosion

Type 2 pitting (Holm *et al.* 1962; Mattson and Fredrikson, 1966). Pits contain crystalline cuprous oxide and are covered by tubercles composed of copper oxides and basic copper sulphate. An adherent cupric oxide/cuprous oxide layer exists over the unpitted surfaces. Characteristically this type of pitting only occurs in the hottest section of hot water circuits where the temperatures are typically in excess of 60°C.

Type 3 Corrosion

Type 3 pitting is infrequent and occurs in pipes carrying cold water with a high pH, low hardness, low mineral and low organic content where the pits are characterised by small hemispherical pits under a common covering of basic copper sulphate (Shalaby *et al.* 1989).

Of the three types of copper pitting that have so far been discussed all have been categorised with recognised mechanisms. The promotion and acceleration of corrosion by bacteria in copper alloys was reported by Rogers (1948) who demonstrated that mixed cultures resulted in a more severe attack in comparison to pure cultures. However there did not appear to be any link between bacteria and the unusual copper tube corrosion until more recently.

6.2 INTERACTION OF BIOFILMS IN PEPPER POT PITTING CORROSION

The type of pitting which occurred in copper pipes from the water systems in Scotland resembled Type 1 corrosion in that pits were hemispherical and contained soft crystalline cuprous oxide with varying amounts of cuprous chloride under a cuprous oxide membrane. The pitting also resembled Type 2 corrosion as oxide on the surface between pits was largely cupric with tubercles above the pots being basic copper sulphate often with a cupric oxide on part of the deposit itself. Therefore it is a combination of both Type 1 and Type 2 corrosion.

In the soft water plumbing circuit I have hypothesised how the biofilm develops and becomes involved in the corrosion process described as pepper pot pitting. Environmental aquatic systems contain organic matter as dissolved organic material (DOM), in the range of 25-72% with a mean of 42% (Reuter and Perdue, 1977). Humic acids account for 50% of this group and are thought to be refractory, relatively

unknown hydrophilic acids (30%) and the simple compounds such as carbohydrates, carboxylic acids, amino-acids, hydrocarbons. Hydrophilic acids are thought to be composed of volatile fatty acids and hydroacids as well as complex polyelectrolyte acids that probably contain many hydroxyl and carboxyl groups. Such hydrophilic acids would certainly support microbial growth. Therefore it would appear that 50% of dissolved organic carbon, termed the assimilable organic carbon may be able to support microbial growth. AOC, of the soft upland Scottish water was four times higher than that found in harder lowland river waters.

Dissolved organic matter, present in the soft water may form a pellicle on the copper surface providing a buffering region for the initial contact of bacteria onto the copper surface (Fig. 6.1 (1)). Bacteria will be transported from the water phase by convection but once in the 40 μm viscous sublayer active transport will drive them to the surface where they will come into contact with this initial pellicle. At the surface, bacteria will be limited to utilising DOC in the pellicle as a nutrient source. In the viscous sublayer convective transport of nutrients will be zero and the movement of substrates will be under the control of molecular diffusion. Bacteria will also be protected from the Cu^{2+} ions which have complexed with organic matter (Fig. 6.1 (2)). For bacterial cells that come into contact with Cu^{2+} ions they may use a mixture of defence mechanisms from chelation which may be internal (Gadd and White, 1989) or external such as exo-polysaccharides (Marszalek, 1979) and/or exclusion (Rouch, 1985). Formation of microcolonies (Fig. 6.1 (3)) will lead to differential concentration cells caused by varying concentrations of oxygen, acids (metabolic acids) and exopolysaccharides (Fig. 6.1 (4). Bacteria present in tubercles on surfaces of copper pipes removed from hot water circuits of buildings suffering from pepper pot pitting and from the laboratory model suggest that bacteria had found a niche in which to survive.

6.2.1 Bacterial Metabolism

Site surveys indicated that copious biofilms contained greater numbers of organisms that correlated with increased likelyhood of corrosion. As bacteria were recovered from the copper tubes they were obviously not killed by copper ions suggesting copper resistance mechanisms. Although this does not suggest the cause it does indicate a relationship. This increased copious layer linked with greater corrosion rates is not unsimilar to the study of abiotic corrosion by Campbell (1950) who demonstrated that the extent of corrosion increased as the quantity of carbon on the copper surface increased. Using the laboratory model it was possible to simulate environmental conditions under which this particular type of corrosion was occurring and to form biofilms at temperatures up to and including 55°C. With the use of the SCLM (section 4.7.2) these bacteria have been shown to be present in pits as well as on the copper surfaces and are responsible for production of localised acidified zones. Bacterial metabolism results in the secretion of organic acids during fermentation of organic substrates. The rate and type of corrosion would depend on the species of organisms and the available substrate e.g. hydrogen sulphide from *Desulfovibrio desulfuricans* and sulphuric acid from *Thiobacillus thioxidans*. Such metabolic products may result in a physical shift in corrosion as they are trapped at the bacterial metal interface. Organic acids of the TCA cycle such as citrate and fumarate were able to form metallic acids under aerobic conditions when incubated with copper, tin and zinc (Burns *et al.* 1967). Amino-acids such as dicarboxylic acids may also be aggressive to copper (Gordon *et al.* 1983). However copper surfaces present in filtered soft water in the laboratory model (section 4.7.1) did not exhibit corrosion or pitting which only occurred when both bacteria and particulate matter was present (section 4.4). When examining corrosion of carbon steel, Pope (1992) demonstrated that when microbial community members (*Enterobacter* spp., *Clostridium* spp. and *Desulfovibrio* spp.) were grown together the production of acetic acid was 10 times greater than when they were grown in pure culture. This indicates the efficacy of co-

cultivation of bacteria as has been carried out in the present laboratory model. Pope (1992) also reported that organic acid production and pitting were only significant under low nutrient conditions, again supporting the role for a laboratory model where the sole carbon source is tap water.

Results with the DIC, fluorescence, SEM and ESEM presented images of the biofilm as a heterogeneous patchy film like a 'mosaic' over the surfaces. This is in contrast to the thick 300μm film formed in the model by Wimpenny (1988) developed for physiology studies. Surface colonisation through the formation of discrete microcolonies in biofilm development has also been reported by Korber *et al.* (1989). With the SCLM I was able to demonstrate that individual bacteria can be associated with the formation of localised acidified zones on the copper surface.

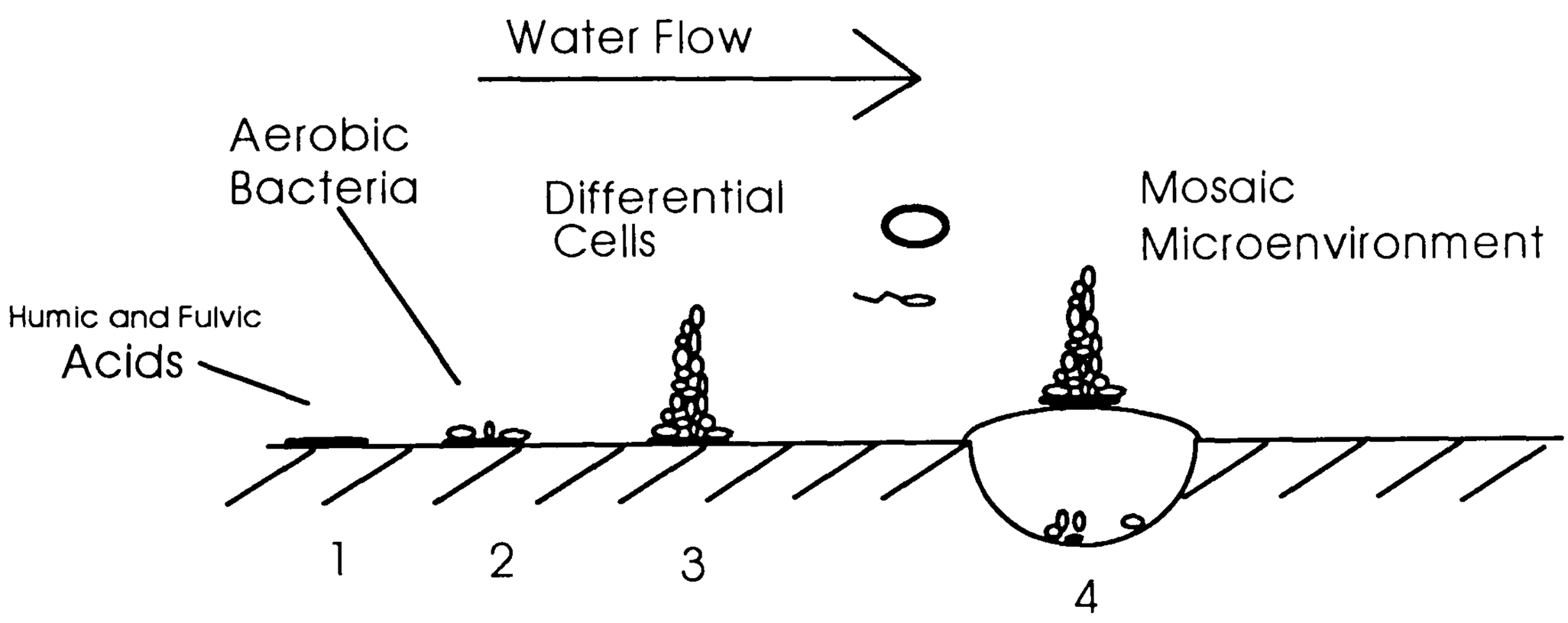


Figure 6.1 Schematic of microcolony formation resulting in sites of pitting corrosion. (1) Formation of pellicle on the metal surface resulting in passivation. (2) Deposition of bacteria to form differential concentration cells (oxygen, EPS, acids). (3) Growth of microcolonies to form local anodic and cathodic sites through the production of metabolic products as well as chelation of copper and metallic divalent compounds by the exopolysaccharides of the bacteria. (4) Interaction of microcolonies and biofilm

with pits forming in the metal surface.

The formation of colonies constitutes the creation of local cathodes or anodes (Little *et al.* 1990). Non uniform or mosaic colonisation of a metal surface by a biofilm results in the formation of differential aeration cells, where areas under respiring colonies are depleted of oxygen, relative to the non-colonised areas of naked metal. The movement of aggressive ions such as chloride to anodic sites would also be prevented as would outward diffusion of metabolites and corrosion products. The association of microcolonies with each other will set up initial sites of anodes and cathodes under, between and within each of the microcolonies. Such initiation will lead to numerous sites of corrosion being set up in a very small proximity (microns). This physical association may create the initiation of corrosion sites that represents the corrosion cell formation which leads to pepper pot pitting.

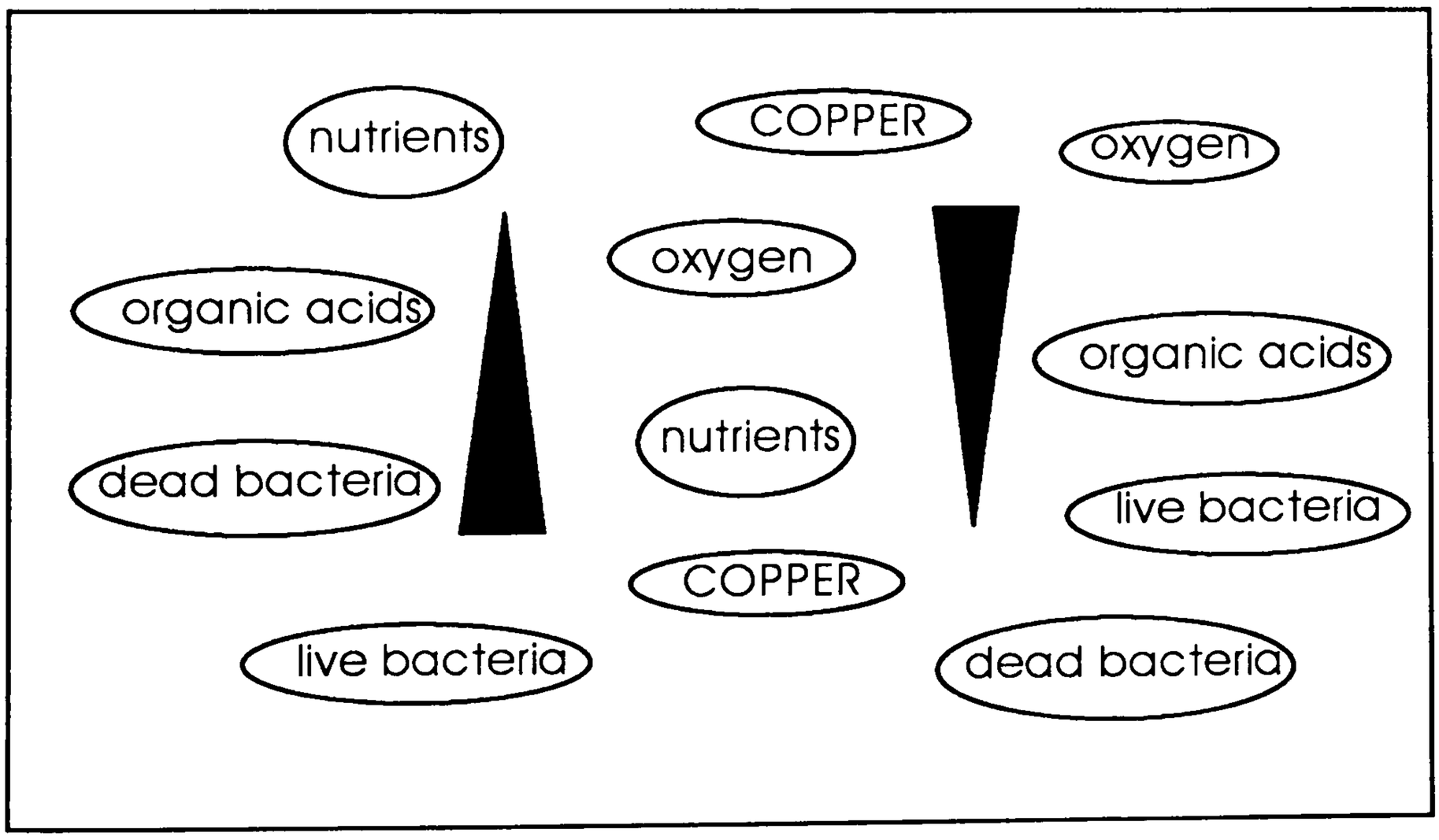


Figure 6.2 Schematic diagram of corrosion initiation and propagation on copper surfaces. Arrows indicate increasing and decreasing concentrations of components.

6.2.3 Role of polysaccharide in the corrosion process.

Copper ions will complex organic material such as humic acids and polysaccharide ligands in the presence of a biofilm. Exopolysaccharides were first demonstrated on copper surfaces by Chamberlain (1988). Biofilms have been demonstrated to support the dissolution of copper in the anodic reaction and so increase the rate of corrosion (Geesey *et al.* 1989). Furthermore the production of H^+ in neutral aqueous environments yields hydroperoxides (H_2O_2). Cu^+ reduces hydroperoxides, found extensively in corrosion products (Brown *et al.* 1992), which attack metabolic products (e.g. pyruvate) to form peracids which are known to be strong acids. It is these peracids which can oxidise Cu^+, found mainly in the corrosion pits and at the interface between the copper surface and biofilm, to Cu^{2+} which has been detected mainly in the biofilm (Paradies, *et al.* 1992).

As other bacteria attach to the copper surface, grow and multiply the heterogeneous patchy layer of bacteria begins to form a mosaic of microlonies on the surface. The mosaic microcolonies have a third lateral dimension to them as they grow out into the planktonic phase (one can presume this would enhance nutrient chelation). A fourth dimension is the physical growth of microcolonies resulting in death, recycling of nutrients and sloughing from the biofilm into the planktonic phase. It is the presence of the biofilm in water systems that are suspected for the reseeding of treated waters (pasteurisation and chlorination). Interaction between the biofilm and the water phase will occur as bacteria leave and enter each phase. Biofilm will also provide nutrients for amoeba and protozoa that will not only graze and to some extent control the biofilm but will increase the species diversity of the population.

In common with Cornwell *et al.* (1973) who demonstrated that removal of the carbon layer on the copper pipe reduced and prevented corrosion Fischer *et al.* (1992a) removed biofilm and reduced copper tube perforation after citric acid treatment but

only temporarily. Laboratory results indicated that the biofouling could be controlled by maintaining the hot water temperature greater than 55°C. From the results of the site surveys it was clear that not only was biofouling controlled but also that fewer copper tube failures occurred in hospitals operating their hot water systems at temperatures greater than 50°C. Therefore, even though the water contained a high concentration of AOC, and so had the ability to support microbial growth the bacteria were unable to form microcolonies and could not utilise this AOC or the dissolved oxygen concentration at the higher temperatures.

6.3 GROWTH OF LEGIONELLAE IN WATER AND IT'S IMPLICATIONS FOR THE SPREAD OF LEGIONELLOSIS

Legionellosis occurs through the dissemination of aerosols and immuno suppressed people are particularly at risk. In this investigation pathogenic bacteria such as *L. pneumophila* were of interest as this particular human pathogen has often been associated with water and surfaces of water circuits in hospitals. As the phenomena of pitting corrosion was occurring within the hot water circuit of a hospital the opportunity for this bacterium to be aerosolised was present although this particular route of infection had never been documented. The results demonstrate the ability of *L. pneumophila* to survive in environmental conditions similar to that in which corrosion was occurring (<50°), where increased temperatures (>55°C) not only control the presence of *L. pneumophila* but also control the presence of biofouling bacteria. Therefore the recommendations for the control of Legionella parallel those for the control of this particular type of corrosion. Where a protocol is instigated for the control of one the chances of the other occurring decrease.

In the hospital where corrosion was occurring, sections of the copper tube have been

replaced in alternative materials , for example platic plumbing tubes. If the water system is operated at a temperature > 55°C then the total population including *L. pneumophila* will be controlled. However, if the temperature of the system cannot be controlled, then pronounced bacterial proliferation may occur where the temperature decreases to 50°C or less, as pasteurisation has no residual effect. The presence of plastic plumbing materials may exacerbate this growth. Results obtained in this study are therefore very important. Copper has been shown to possess bactericidal/static properties, while the plastic materials appears to result in an increased number of the water borne pathogen *L. pneumophila.* Although the results have demonstrated this phenomenon for only a short period of time the long term use of plastic material in systems will have to monitored closely for biofouling.

6.4 FURTHER WORK

6.4.1 Influence of sulphate-reducing bacteria in the corrosion process

These bacteria were isolated from two of the sites where pepper pot pitting was occurring but their role in this process has been dismissed due to the low number that were detected and that other investigators did not detect sulphide. Previous investigations (Hamilton, 1985) have studied the growth of SRB in defined media or in open estuaries (Little, 1989). Extending the study to determine if they would grow in filter sterilised tap water as the sloe media and carbon source may indicate if they have a role in pepper pot pitting.

6.4.2 Model plumbing system rigs

The use of rigs within the hospital where the corrosion was occurring would be of immense value. In some way this would take the role of the laboratory model closer

to a simulation of all the parameters involved in the biofouling process but this particular approach was out with the remit of this study. By operating an experimental rig apparatus the parameters of temperature, particulate matter, presence of bacteria could be separated to ascertain their individual emphasis on the phenomena of pepper pot pitting. The scaling up a laboratory model to an experimental rig has to take into consideration that problems of control, sterility and integrity will also be compounded. The rig would provide a truer representation of the scale of the water circuit.

6.4.3 Electrochemical testing

Although this particular study did not investigate corrosion mechanisms involved in this particular type of corrosion, the use of electrochemistry would be of immense value for the detection and quantification of microbial influenced corrosion of copper surfaces. Determination of the influence of bacterial microcolonies, particulate matter and temperature on the corrosion potential may have added strength to the argument of the holistic approach to the mechanism of pepper pot pitting. However, electrochemical techniques provide average readings for a surface area and therefore fail to provide information on localised corrosion that may be measured using recently developed techniques such as electrochemical impedance systems and electrochemical noise assays.

A number of other investigators have studied the involvement of polysaccharide pick up or chelation of copper. Recently Geesey and Bremmer (1992) reported the production of polysaccharide by bacterium CC18 that actually protects copper surfaces by passivating the surface to prevent leaching of copper. Interacting this bacterium into a mixed population may provide useful information as to what happens when the polysaccharide of other bacteria are present i.e. would the passivation be stabilised or unstabilised? An ion chromatogram could be used to determine which

particular species of copper is taken up by which particular polysaccharides from which bacteria.

6.4.4 Atomic Force Microscopy

Having studied surface topography with a number of techniques there is another format of microscopy becoming available to the microbiologist. Conventionally used to study oxidation at the metal surface this particular microscope may present two areas where it could be interest to biofouling and corrosion. Firstly this microscope is now being used by microbiologists to visualise bacteria and providing very interesting initial results. With its ability to study oxidation at the surface, comparison of different bacterial growth conditions and their effect on corrosion rates may be able to studied using this instrument.

6.4.5 Legionella and amoebae

The number *Legionella pneumophila* recovered from the culture in the presence of copper and from the biofilms on the copper surface was, in general, less than what was recovered from the water phase in the presence of, and from the surface of plastic plumbing tube materials. Rowbotham (1980) has indicated that this water borne human pathogen is an intracellular organisms, and suggests that this may be an obigatory mechanism of survival. Although amoeba have not been studied in this present investigation, it would be interesting to determine whether the different material have an effect on the growth of the amoeba. For example, if copper was to have a negative effect on the growth of the amoeba then such results explain the decrease in recovery of *Legionella pneumophila* observed in this study and may support the work of Rowbotham (1980)

6.5 CONCLUDING REMARKS

From the site surveys and laboratory experiments that have been carried out there does appear to be a role for bacteria in pepper pot pitting. A whole range of environmental and biological factors determines whether or not this type of corrosion will occur or continue.

Each factor involved in corrosion and biofouling is a single entity that may or may not interact having different effects on either bacterial growth or the metallic surface.

Corrosion is composed of a series of anodic and cathodic reactions that will readily occur in the absence of bacteria and can be affected by the presence water, particulate matter on the pipe surface, other metals such as zinc, iron, welded joints and annealment.

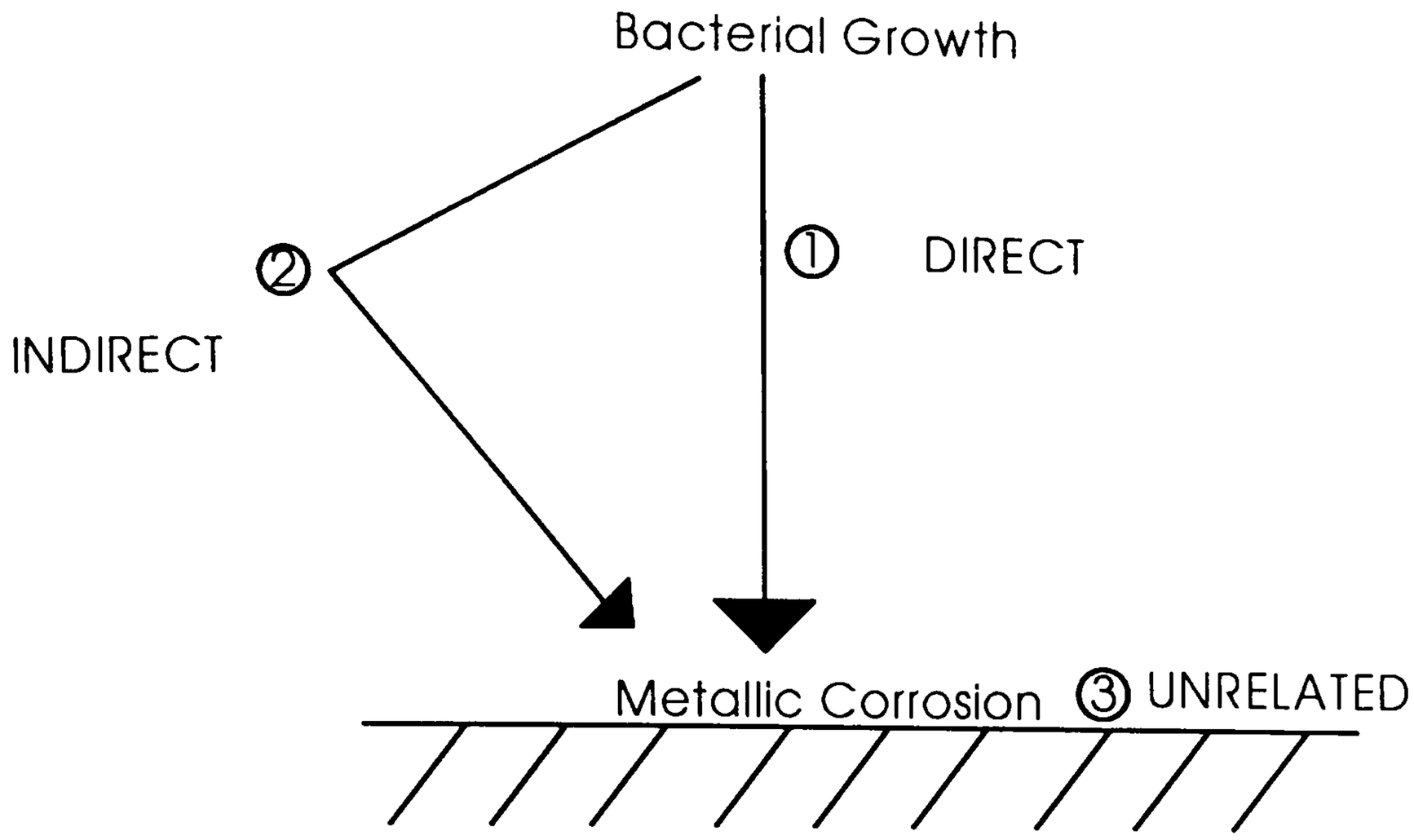
Biofilms represent the attachment of bacteria to a surface and growth into microcolonies with the resultant production of metabolic acids, exopolysaccharide and creation of concentration gradients when consumption is greater than transportation. In the water phase the physical flow or convective transport of solutes and nutrients are controlled in bulk phase by the flow rate. At the surface, in particular the viscous sublayer, movement of substrates and metabolic products are controlled by molecular diffusion. This in turn controls the growth of the bacteria directly in the 40 μm layer. As the biofilm matures and becomes established over a greater area of the pipe surface it will start to have an effect on fluid dynamics and heat dissipation.

Another entity that combines both the above parameters is heterogeneity. The metallic copper surface will be fabricated with minute inherent purities with grain

boundaries, milling lines presenting heterogeneic sites at which corrosion may manifest. It has been stressed that the biofilm itself is composed of discrete microcolonies forming a heterogeneous mosaic in the horizontal mode. Also discussed earlier is the lateral dimension of biofilms, providing sites of varying height and depth with the biofilm stack being thicker at their base providing strength and rigidity to stacks that have been found to protrude up to 100μm from the surface.

It has been suggested by some authors that heterogeneity may disappear as a biofilm matures, thickens and reach steady state (Videla, 1992) although there was no evidence of confluent biofilms in this present study even after developing biofilms for after 2 years. Some investigators of biofilms have modelled such systems using dead pan depth simulators. Wimpenny *et al* (1988) produced a model to simulate a 300 μm deep biofilm, Gilbert *et al.* (1991) has modelled uniform biofilms impelled onto a filter, for growth rate studies and Angell and Chamberlain (1991) utilised a defined medium to provide uniform biofilm on copper surface. Importantly the investigator has to define what is one attempting to study.

In this particular study of copper tube corrosion the growth of mixed microbial communities on the copper surfaces was examined with water from a domestic water system as the sole carbon and energy source. In contrast to the above research groups (except Angell *et al.* (1991)who later switched to an artificial water with no carbon source) who developed homogenous biofilms from a monolayer up to 300 μm all the biofilms formed using our laboratory rigs using either 1 cm^2 coupons or section of copper pipe exhibited this heterogeneous mosaic nature that continued for a period up to 2 years.



There are a number of affects that the presence of bacteria can have on corrosion of a metal surface. Firstly there may be no interaction or involvement of bacteria in the corrosion process. Alternatively the corrosion reaction can be influenced due to the production of metabolic acids, metal pickup by exopolysaccharides, creation of concentration cells, all of which will increase the corrosion potential. Bacteria however can become directly involved in the corrosion process through metabolic activity where autotrophic bacteria use anodic reaction products as an energy source. It is the latter two reactions where bacterial biofilms either influence and or induce corrosion of the copper surface that we have used to postulate how the corrosion has occurred. Primarily the bacteria will play a role in the initiation of corrosive sites within a very localised and confined environment due to the presence of numerous microcolonies on the surface. As the biofilm matures, enlarges and grows it no longer influences the corrosion process in the pits directly below the microcolony but bacterial will slough to resettle else where in the pipe line. Importantly the pit formation will then be driven as the corrosion potential increases with the likely event that perforation will eventually occur.

With the presence of particulate matter creating an increased surface area for bacterial growth and also creating concentration cells, the likely hood of pitting would be

increased. The number of initiated sites would therefore be increased in the presence of both bacterial microcolonies and particulate matter leading to the formation of multiloci, that would initiated corrosion sites to create pepper pot-pitting.

CHAPTER 7.0

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NHS National Services Scotland

SHFN 30
Part A: Manual

Information for Design Teams, Construction Teams, Estates & Facilities and Infection Prevention & Control Teams

Health Facilities Scotland
Engineering and Environment

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Contents

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1. Introduction and scope

Note: The Project Team referred to throughout the document is the team of NHS staff assembled to fulfil the role of 'The Client' and to manage the delivery of the project. Through the various stages of the project it may include NHS Project Managers, Clinicians, Estates staff and Infection Prevention and Control specialists.

1.1 This guidance consists of two parts:

- **SHFN 30 Part A: Manual**: This provides Built Environment Infection Prevention and Control information for Design Teams, Construction Teams, Infection Prevention and Control Teams and Estates & Facilities Teams;
- **SHFN 30 Part B: HAI-SCRIBE:** comprises the Implementation and Assessment Process which describes the process for identifying, eliminating or managing built environment infection control risks. It also describes the key personnel involved in this process together with their roles and responsibilities and the fact that collaboration among all those involved in the process is pivotal to its success.

It is envisaged that participants will use the HAI-SCRIBE document (SHFN 30 Part B) to help them identify, manage and record built environment infection control risks. The same Group will use the Manual document (SHFN 30 Part A) for sourcing information to help in the decision making process so that identified risks can either be eliminated or successfully managed.

Questionsets and Pro-formas

1.2 Arrangements have been made to make available on the HFS Website, separately, the portfolio of Questionsets and Pro-formas for each stage of project development suitable for photocopying and application to individual projects as appropriate.

1.3 Additionally, compliance with these guidance documents can ensure that there are facilities in place to help fulfil the mandatory requirements outlined in the National Infection Prevention and Control Manual produced by Health Protection Scotland.

1.4 The Project Team members and contributors from various disciplines will take different advice from the guidance and it is the ensuing debate and analysis which will improve the quality of the delivered facility.

1.5 This Manual is intended to provide an insight to the key factors within the built environment which can impact on the prevention and control of infection and will also be useful as a guide for best practice in existing healthcare facilities.

1.6 In the future due to changing patient populations and changing healthcare needs there may be different factors to be considered when planning accommodation. These include the increase in the ageing population, caring for Bariatric patients, and more focus on community-based care.

1.7 The design of the built healthcare environment plays a fundamental role in infection prevention and control. The increasing threat of antimicrobial resistant organisms and other emerging pathogens in healthcare may present new and more difficult challenges in future healthcare facility design and planning efforts.

1.8 A system of recording projects, signing-off plans and meeting notes by all participating parties will be needed. The completion of questionsets in the 'Implementation strategy and assessment process' part of this guidance will fulfil most of this requirement. It is important that the Project Team sign-off each stage of the project having taken advice from Estates & Facilities, Infection Prevention & Control representatives and other appropriate disciplines.

Note: To manage or mitigate infection risks requires knowledge from many sources. Input from the Project Team will not only include Infection Prevention and Control Teams (IPCT). Estates and Facilities Teams and Design and Construction Teams also have important roles to play in managing or mitigating these risks. However, it is not expected that any single group will possess full knowledge or experience of another's discipline. It is expected, therefore, that there will be an ongoing liaison during each stage of development where appropriate specialist knowledge from all sources of relevant expertise can be derived and incorporated into the design team appointments, project briefing, contract conditions, specification and quality control of construction and maintenance.

2. Risk assessment

Identifying risk

2.1 The time taken to plan or refurbish a healthcare facility can vary from a relatively short period in the case of urgent renovation, to as long as three or four years for a major capital build project. It is therefore important that all members of the Project Team are notified of capital bids at the earliest opportunity. The Infection Prevention and Control Team need to be involved in the first planning meetings. Most meetings thereafter will require some input from them.

2.2 To avoid mistakes and pitfalls the Project Team must consider issues including:

- how will the product, equipment, room or premises be used?
- what possible solutions are available?
- what are the budgetary limitations?
- which prevention and control of infection principles apply?
- which external regulations apply?
- what does the evidence suggest in relation to the specific context?
- what are the laws governing the project?
- what standards and guidelines apply from architectural and engineering bodies, Health Facilities Scotland, local and national government departments and accrediting agencies?
- which product or design best balances the infection prevention and control requirements with employee and patient safety and satisfaction, and cost constraints?
- what legal requirements are required under Health & Safety law?

Common pitfalls

2.3 Common pitfalls arise from a number of pressures, for example, the pressure to choose the cheapest products or design.

Note: The best products or designs may be more expensive initially but in the long term they will probably realise cost benefits as they may prevent outbreaks, or they may last longer and require less maintenance and be more durable.

Assessing risk

2.4 Designing premises that prevent the transmission of infectious agents to patients, healthcare workers and visitors is an important component of prevention and control of infection programme or plan.
Outbreaks of infection have been related to the design, plan, layout, function and/or finish of the built environment. Thus, risk assessment is a fundamental imperative in the planning and design stages of a healthcare facility. It is often overlooked or compromised throughout the lifecycle of the project. It has not been unknown for the clinical outcome of a well-intentioned risk assessment to create other problems. There is therefore a need to verify that these outcomes are themselves risk assessed.
Disseminating good specialist advice relating to Infection Prevention and Control throughout all phases of construction and renovation projects will reduce risks. There will be instances when it is not possible to achieve the ideal. This applies particularly to refurbishment projects within existing accommodation and is often related to spatial issues. In these circumstances the aim should be to make the best use of available facilities.

Note: Failure to assess properly risks affecting prevention and control of infection can lead to expensive redesign later and expose the patient and healthcare worker to unnecessary risks. It is important to bear in mind that any control measures put in place to prevent the spread of infection during a building stage and subsequent maintenance of any project take into account the effect that they would have on patients and staff in the surrounding areas.

Source

2.5 Building professionals must be aware of the risks associated with construction projects and that the environment can be a reservoir for potentially infectious agents. The source is the person, animal, object or substance from which an infectious agent is transmitted to a host. The immediate healthcare environment can be a potential reservoir of micro-organisms and source of infection or contamination, therefore, Designers and Planners need to consider eliminating potential sources of infection by practising good design, for example:

- adequate storage facilities;
- choice of materials, avoiding unnecessary surfaces that may become reservoirs for infectious agents;
- ensuring materials and surfaces can be cleaned and maintained.

3. Procurement and construction process

Overview

3.1 The procurement and construction of a healthcare facility are highly complex processes and require input from a wide variety of sources.

3.2 Infection Prevention and Control advice is essential in relation to procurement at the design and planning stage of a project. There is a case for stipulating that Designers for healthcare projects should be able to demonstrate their knowledge and understanding of prevention and control of infection in relation to current guidance. The NHS Project Team needs to confirm this in the course of interviewing Design Teams *prior to their appointment*.

3.3 The specification of building materials, especially surface finishes, healthcare facility equipment etc. should take account of the input from the Project Team who are best placed to ensure that requirements are met, based on risk assessment.

Securing appropriate skills

3.4 HAI-SCRIBE aims to manage infection risks through the use of a prevention and control of infection questionnaire, as set out in the Implementation Strategy and Assessment Process section of this guidance. The system highlights the need for a multi-disciplinary team of specialists with appropriate skills to ensure its implementation. This is an essential requirement in terms of the evaluation of the site for development. Where issues such as contaminated land or suspected geological faults arise, specialist advice should be obtained.

4. The Planning Process

General overview

4.1 In general the stages of a typical healthcare building project are:

- establishing the 'need to build' and obtaining agreement from Scottish Government Health and Social Care Department (SGHSCD) where required;
- appointment of a design team;
- preparing a project brief and carrying out feasibility studies;
- preparing a business case and securing funding;
- developing the design;
- appointment of a contractor;
- construction of the building works;
- handover;
- NHS commissioning of the building i.e. installing loose furnishings and equipment and training staff;
- occupation.

Business Case process

4.2 The preparation of a business case is the process that supports NHS Board submissions for funding of new projects. A business case must convincingly demonstrate that there is a need for a new building, alteration or refurbishment to improve the delivery of healthcare services and that the project is economically sound, financially viable and will be properly managed by the NHS Board.

4.3 Details of the business case process can be found in the Scottish Capital Investment Manual which can be found on the Scottish Government Health and Social Care Directorate website at: www.scim.scot.nhs.uk/.

4.4 It is important at this stage to identify and involve key people who have a direct interest in the end product including members of the Project Team along with other specialists or departmental heads as required. Specifically at this stage, they need to:

- establish the goals of prevention and control of infection;
- agree the agenda for prevention and control of infection design and planning;
- communicate prevention and control of infection imperatives throughout the course of the project, but especially at the initial stages;
- work through conflicting issues to reach an optimum compromise;

- determine available resources that can be used and recognise the cost benefits of not cutting corners on prevention and control of infection issues.

The brief/concept/feasibility study

4.5 The planning process starts with the identification of a 'need' by the users. The development of this need will involve feasibility studies to enable a design brief or output specification to be developed with consideration given to the following:

- the effect additional beds or departments will have on policies such as waste management, linen and catering, etc.;
- the effect of extra theatres would have on decontamination services, workflow, etc.;
- additional specialised areas that will probably require extra infection prevention and control and laboratory input as well as specialist advice which may not be available in-house e.g. bed space and size of departments, etc., plus engineering services needs such as ultra-clean ventilation, showers, baths, etc.

Space planning

4.6 The planning of the building can contribute to reducing the risk of transmission of micro organisms. For example internal and external routes identified for removal of dirty laundry, segregated recyclates and residual wastes, need to be carefully planned.

4.7 The location of departments, theatres, wards and rooms needs to take account of good prevention and control of infection practice and ensure that workflows are designed to inhibit infection spread.

4.8 Similarly, the detailed design of the building elements can contribute to reducing the risk of transmission of micro organisms e.g. selection of finishing materials for floors, walls and ceilings; designing the ventilation system to inhibit the spread of contamination.

4.9 A number of design and layout issues could contribute to the risk of transmission of micro-organisms. For example, the ventilation system needs to inhibit contamination spread rather than contribute to it. Internal and external routes identified for removal of dirty laundry, waste food, healthcare waste, similarly need to be carefully planned.

Concept Design/ Developed Design

4.10 Drawings at a scale 1:200 will be available at this stage. They will assist the Project Team in determining clean and dirty traffic flow patterns and confirming room relationships and adjacencies. In addition to verifying compliance with the appropriate Scottish Health Planning Notes (SHPN) or Health Building Notes (HBN), the Project Team should be asked review

these plans to comment where their specialist knowledge may assist in the decision-taking process regarding issues such as:

- confirming operational procedures;
- setting out traffic flow patterns;
- establishing baseline and future staffing profiles;
- establishing baseline and future revenue budgets;
- establishing equipment requirements;
- providing equipment bays;
- strategy for equipping;
- procurement and selection of furnishings and equipment;
- missing rooms;
- appropriate placing and accessibility of hand hygiene facilities;
- ventilation systems including the level of filtration where specialised ventilation is required;
- water supply, heating and plumbing;
- surface finishes: ceilings, walls, work surfaces, floor coverings and furnishings;
- storage (including waste collection points and delivery areas) and DSRs equipment cleaning areas;
- ancillary areas;
- single rooms;
- isolation rooms;
- changing facilities;
- providing flexibility of space: e.g. to allow for cohort nursing (a full glossary of terms can be found in Appendix 2);
- lifts;
- pneumatic delivery systems.

Particular issues to be addressed by the Project Team

4.11 The Project Team must ensure that prevention and control of infection implications are not compromised by reducing standards set by NHS guidance or by overcrowding in clinical areas and they should communicate their views to the Project Manager for further action.

Technical design

4.12 Drawings at a scale of 1:50 will be available at this stage confirming more precise detail such as the number and location of sanitary fittings, equipment, furnishings, etc.

4.13 The Project Manager, with advice from the Project Team, will also need to consider the prevention and control of infection issues around:

- workflow;
- wash-hand basins: types, numbers and location;
- fixtures/fittings/flooring;
- waste water and sewage/body fluid disposal;
- ventilation;
- heating and lighting;
- water systems;
- suction/medical gases;
- storage systems;
- ward kitchens/pantry.

NHS guidance on the design and/or installation of the above can be found in planning notes and technical memoranda available on the HFS website.

4.14 To assist with understanding and mitigating risks associated with bacterial contamination of water distribution and supply systems, it is recommended that the NHS Board should have in place a Water Safety Plan (WSP) as outlined in SHTM 04-01 providing a risk management approach to the microbiological safety of water and establishing good practice in local water distribution and supply. Those organisations with robust water management policies for *Legionella* will already have in place much of the integral requirements for delivering a WSP.

Note: Refer to Health Protection Scotland Guidance for neonatal units (NNUs) (levels 1, 2 & 3), adult and paediatric intensive care units (ICUs) in Scotland to minimise the risk of *Pseudomonas aeruginosa* infection from water.

	Process and corresponding RIBA Plan of Work Stage	**Planning process Time Period**	**Issues to consider**	
Design Stage	0:Strategic Definition		Space Catering Specialist area Engineering facilities Laundry	Waste Cleaning/disinfection/ sterilisation
	1:Preparation and Brief	1 in 200 (some preliminary designs) 1:500 →		
	2:Concept Design/3:Developed Design	1 in 200 draft activity data sheets equipment lists usually wish lists →	Storage (linen, waste, patient equipment, domestic equipment) Ancillary areas Changing facilities	Lifts Pneumatic delivery systems Patient placement Single rooms Isolation rooms
	Outline business case			
	3:Developed Design/ 4:Technical Design (Depending on Procurement Route)	1 in 50: fixtures and fitting (fixed items Group 1) →	Ventilation Heat/light Water systems Sewerage Vacuum	Wash-hand basins Storage systems Ward kitchens Workflow Fixture and fittings
Procurement	Full business case			
	Tender			
	5:Contract			
Delivery	Construction		Equipment Space Specialist equipment	
	6:Handover & close-out	→		
	7: In use		Check for any changes made to original agreement/plan	

Table 1: Project Development Chart

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Typical Key Stages of Project Team Input

1. **The Brief/Concept/Feasibility study: Project Team should contribute to the review of operational policies and procedures, such as:**
   - adding beds to ward area may require an additional sluice or single rooms;
   - adding extra theatres will need a review of decontamination services for instruments.
   - additional specialised areas will need extra prevention and control of infection input;
   - traffic flows.
2. **Concept design/developed design: Sketch plans at 1:200 scale available at this stage, the Project Team needs to give a broad view of prevention and control of infection issues e.g. rooms missing, wards without ancillary areas such as disposal rooms or dirty utility.**
3. **Technical design: (1/50 designs – early period)**
   There is a need to finalise locations of rooms for correct workflows/prevention and control of infection practice, i.e. wards, theatres.
4. **Technical design: (1/50 designs – later period)**
   Need to discuss finer details within rooms: location and type of fixtures and fittings, e.g. hand-wash basins/types of basins; airflows in theatres, flooring.
5. **Construction:** A designated individual should be appointed particularly if the new build is attached to an existing healthcare building, to ensure that control measures prevent risks to patients.
6. **Equipment: decisions on equipment should be made as an ongoing process, but it is at this stage that it will be seen that previous equipment 'wish-lists' may not fit the rooms/departments or are now outdated. It is important that Project Teams also have input during this period (especially if it is a PFI/PPP build).**
7. **Commission/equipping: Project Teams must have input during this stage if costly and dangerous mistakes are to be avoided.**
8. **In use: this is an important stage in which lessons learnt can be highlighted for future projects, both within NHS Boards and throughout NHSScotland. Post-project evaluation is mandatory and results should be available to other NHS Boards.**

Table 2: The Key Stages of the Planning Process and examples of Project Team input

Accommodation areas/internal environment/general services	Examples: Key issues and areas to be considered
Accommodation areas	
Bed areas: Single-bed rooms.	Placement of patients at high-risk. En-suite facilities. Doors on bays.
Dirty utility/clean utility.	Standardisation of rooms/choice of equipment. Appropriate storage. Space.
Domestic services room.	Space, adequate sinks and storage.
Workflow/layout.	Standard ward area versus specialised area.
Bed planning.	Elective. Emergency.
Linen services and facilities.	Storage, transport and handling.
Catering/kitchen areas.	Furnishing, fixtures and fittings plus workflow crucial for HACCP. Commercial systems e.g. cook-chill versus in-house systems.
Intensive care unit/High dependency unit (ITU/HDU).	Single rooms versus 4/6 bed bays.
Clinical wash-hand basins.	Number dependent on room types. Correct wash hand basin specifications. Facilities to ensure compliance with hand hygiene. Located to encourage staff use.
Staff change areas/storage of uniforms.	Type of uniform provided inline with national uniform policy.
Decontamination facilities. Central Decontamination Unit/Local Decontamination Unit (CDU/LDU).	Operational policy dictated by choice of decontamination strategy.
Equipment.	Bed/mattresses. Purchase versus hire. Endoscopes/instruments. Cleaning/disinfection-requirement. Patient specific. Enough equipment available. Area for Decontamination facilities.

Table 3: Infection control issues for the Project Team to consider in the Capital Planning Process.

Specialty areas		
Critical care. Ultra clean ventilation. Theatres. Hydrotherapy. Mortuaries. SCBUs and maternity.	Renal units. Oncology. Neurology. Paediatrics. Decontamination units. Pharmacy aseptic dispensary.	Every specialist area will have different requirements and infection control issues so cannot be planned as standard departments.
Internal environment		
Ventilation.		Single rooms, bays, theatres, pacing rooms, treatment rooms, internal sanitary areas, enhanced single bed rooms with positive pressure lobby for isolation.
Heating/ventilation.		Dust-free options i.e. hidden heat panels versus radiators. Minor procedure rooms.
Lighting.		Quantity. The use of sealed units.
Furnishings, fittings and artwork.		Walls/floors/ceilings – hygiene versus aesthetics.
Water.		Dead-legs. Water turnover. Appropriate temperature for hot and cold systems. Water coolers/fountains.
General services		
Disposal of waste.		NHS versus Private Sector. Storage.
Communications.		IT systems (timely information on pathology, etc, operational policies, infection control policies, procedures and training).
Emergency plans.		Water storage if water cut off/heating/medical gases and vacuum/suction/emergency generator, ventilation, etc.

Table 3 continued: Infection control issues for the Project Team to consider in the Capital Planning Process.

Note: This is not an exhaustive list

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Design Development stages

4.15 It is during the design stages that the Project Manager should verify with the Infection Prevention and Control Team that advice given previously is being followed up. As members of the Design Team, drawings and specifications should be available to them to explain how the design fulfils their requirements at the 1:200 and 1:50 plan stages of the project. Suggestions for improvement in operability are encouraged at this stage.

Note: Plans should be physically signed-off on completion of this stage to confirm full collaborative agreement. This is set out in Part B - Implementation Strategy section of this documentation.

4.16 In alteration or refurbishment projects, consideration should also be given to the impact on existing local facilities, e.g. ventilation, water supplies, etc.

Note: The Project Manager will need to recognise that value engineering will take place and that collective decisions should be taken on the basis of value for money.

Provision of single-bed room accommodation and bed space

4.17 Reference should be made to SHPN 04-01: 'Adult in-patient facilities'. CEL 27(2010) Provision of SHPN single room accommodation and bed spacing states that for:-

New build facilities

For all new-build hospitals and other healthcare facilities which will provide inpatient accommodation there should be a presumption that all patients will be accommodated in single rooms unless there are clinical reasons for multi-bedded rooms to be available. These reasons should be clearly identified and articulated in the appropriate Business Case and will be subject to Scottish Government agreement as part of the Business Case approval process.

Refurbishment of existing healthcare facilities

For projects where existing accommodation is being refurbished it is recognised that each building to be refurbished will present unique problems. Taking into account the constraints of the existing building, a minimum of 50% single room accommodation will be allowed but close to 100% will be expected. Issues related to the adaptability of existing engineering services will have to be assessed.

Bed space

4.18 In relation to the issue of bed spacing for multi-bedded rooms, the current advice remains unchanged. That is, taking into account the ergonomic criteria, primarily the space required for patient handling and other activities which take place in the immediate vicinity of the bed, it is recognised that the minimum bed

space should not be less than 3.6m wide x 3.7m deep. Further guidance can be found in the notebox following paragraph 4.27.

4.19 When carrying out refurbishment work to existing multi-bedded ward accommodation, the NHS Boards should seek to achieve this bed spacing. This may require considering reducing the number of beds in the room and a risk based approach should be applied. NHS Boards should also seek to achieve this bed spacing standard in accommodation which is not being refurbished or replaced. Again a risk based approach should be applied.

Sizing of space

4.20 As indicated above in new build projects the bed provision will be in single rooms and the optimum space standards are set out in SHPN 04-01: 'Adult in-patient facilities'. Where single bedroom accommodation is not possible in the alteration or refurbishment of existing wards and the minimum bed space of not less than 3.6m wide x 3.7m deep cannot be achieved then a risk assessment will be required to establish that appropriate space between beds is provided in accordance with the type of clinical intervention to be undertaken in the immediate patient environment.

4.21 Design, accessibility and space in patient areas all contribute to ease of manual handling, cleaning and maintenance.

4.22 Spacing must take into account access to equipment around the bed and access for staff to hand hygiene facilities. Sufficient space for equipment (e.g. hoists) is a health and safety issue for staff and patients.

4.23 Where it is not possible to meet the guidance recommendations set out in SHPNs and HBNs, Healthcare facilities must provide sufficient sanitary facilities including showers/bathrooms to ensure easy access, convenience and independence.

4.24 The principle should be to maintain sufficient space for ergonomic reasons to allow activities to take place safely, such as moving of equipment, patient lifting and movement, as well as ongoing maintenance. The exact space needed will vary according to numbers and activity of staff, type of patient, and environmental factors such as ventilation and humidity. Health Building Notes (HBN) 00-03: 'Clinical and clinical support spaces' and HBN 00-02: 'Sanitary spaces' provide details on calculating the optimum spaces required.

4.25 Particular issues for consideration sizing space include:

- patient groups;
- transmission of micro-organisms;
  - avoiding cross-infection;
  - the environment and its role in cross infection;
  - shared equipment;
  - movement of patients.

- management of issues:
  - clinical pressures;
  - best use of single rooms;
  - avoiding unnecessary movement of patients between areas.

Bed density

4.26 The increase in the prevalence of antibiotic–resistant bacteria and immuno-compromised in-patients was one of the compelling reasons for mandating the maximum provision of en-suite single rooms.

4.27 Provision of isolation/single rooms used to segregate patients will help prevent the spread of micro-organisms, especially those transferred by the airborne route or those easily disseminated into the immediate patient environment.

Note: The source of guidance related to the provision of single bedrooms and bed spacing requirements can be found in Scottish Health Planning Note 04-01: 'Adult in-patient facilities' and CEL 27 (2010) issued by Health Finance Directorate of the Scottish Government 20 July 2010.

4.28 As previously described, the provision of adequate space around the bed can significantly improve the quality of the patient's experience and aid the clinical and healing process. Clinicians and carers need adequate space around the bed, arranged in a functionally suitable way, to undertake their work efficiently and safely, making the most effective use of resources. Facilities should also serve the psychological needs of patients and their families providing a place of safety and privacy.

Departmental issues

4.29 There are some departments in a healthcare facility where infection risk is higher. The adjacency of these departments should be arranged so as not to increase further the risk of infection.

4.30 For example, departments with patients at a higher risk of contracting infection should be located and serviced to minimise risk of contamination from departments where patients are an infection risk.

4.31 For particular information on the content and conditions to be maintained within various rooms reference should be made to the Scottish Health Planning Notes (SHPN) or Health Building Notes (HBN) still applicable in Scotland that are appropriate to the department under review.

Interior finishes, fixtures and fittings

Note: Throughout this section of the document there is frequent reference to interior finishes, fixtures and fittings not being physically affected by detergents and disinfectants. Health Facilities Scotland National Cleaning Specification provides details on cleaning procedures and frequencies for use within NHS Scotland Healthcare Facilities. Additionally, Appendix 11 of Health Protection Scotland's belonging to National Infection Prevention and Control Manual gives guidance on the management of blood and body fluid spillages and states that use of:

10,000ppm available chlorine disinfectant is recommended for disinfection of surfaces contaminated with spills of blood or certain body fluids (cerebrospinal fluid; peritoneal fluid; pleural fluid; synovial fluid; amniotic fluid; semen; vaginal secretions; breast milk; any other body fluid with visible blood).

1,000ppm available chlorine disinfectant is recommended for disinfection of surfaces contaminated with spills of urine/faeces/vomit/sputum only.

In addition, the Transmission Based Precautions section of the same document states 1,000ppm available chlorine disinfectant is recommended for environmental decontamination when caring for: patients with symptoms of infection; asymptomatic patients who are suspected or incubating an infection; or patients colonised with an infectious agent (i.e. Transmission Based Precautions).

Among other things, consideration should be given to meeting the requirements set out in these documents when selecting interior finishes, fixtures and fittings.

Flooring in clinical areas

(SHTM 61: Flooring)

4.32 Flooring must be seamless, impermeable, slip-resistant, easily cleaned and appropriately wear-resistant. There should be coving between the floor and the wall to prevent accumulation of dust and dirt in corners and crevices. Any joints should be welded or sealed to prevent accumulation of dirt and damage due to water ingress. Wood, tiles and flooring with unsealed joints are difficult to keep clean and should be avoided.

4.33 In areas where frequent wet cleaning methods are employed, floors should be of a material that is unaffected by the agents likely to be used, such as a disinfectant solution of 1,000 parts per million available chlorine.

4.34 Floors that are particularly subject to traffic when wet (bathrooms, kitchens) should be seamless, impermeable and slip-resistant, but be easily cleaned. Consideration will be required as to the suitability of existing cleaning equipment and its compatibility with new floor finishes.

4.35 Carpets are not recommended in clinical areas. Exceptions may include palliative care setting and audiology departments, however if there is a risk of blood/body fluid contamination in these areas the carpets should be able to

withstand exposure to a disinfectant solution of 10,000 parts per million available chlorine.

Walls

(SHTM 56: Partitions)

4.36 Smooth wipable impermeable surfaces are recommended in clinical areas and design should ensure that surfaces are easily accessed and will not be physically affected by detergents and disinfectants. Additional protection to walls should be considered to guard against gouging and impacts from bedhead and trolley movements. Surfaces should be free from fissures and crevices. Floors or walls penetrated by pipes, ducts and conduits should be sealed to prevent entry of pests and ease cleaning.

Ceilings

(SHTM 60: Ceilings)

4.37 Smooth jointless impermeable ceilings should be used in operating theatres and special ventilated isolation rooms.

4.38 Suspended ceilings may be installed in general clinical areas and other areas. Smooth wipable impermeable surfaces are recommended in clinical areas and design should ensure that surfaces are easily accessed.

4.39 Dust and fungal spores may accumulate on the upper surfaces of ceiling tiles over time and dispersal on removal of tiles may pose an inhalation risk to highly immuno-compromised patients. An HAI-SCRIBE review should be carried out before such work is undertaken.

Note: Routine and repetitive maintenance activities do not require fresh risk assessments on every occasion they are carried out.

Doors

(SMTM 56: Doors)

4.40 Doors should be cleanable, that is, smooth, wipable and have impermeable surfaces to ensure that surfaces will not be physically affected by detergents and disinfectants. This applies especially in clinical areas where contamination with blood or body fluid is a possibility.

4.41 Doors should have handles that can be easily cleaned and dried. Additional protection to doors should be considered to guard against gouging and impacts from bed and trolley movement. Particular advice related to mental health units is contained in Appendix 3.

Windows

(SHTM 55: Windows)

4.42 Windows should be sealed and unopenable in operating theatres. Consideration should be given to the elimination of windows in such accommodation. Windows should be sealed and unopenable in ICUs, Neonatal, Oncology and Haematology departments and special ventilated isolation rooms. Internal ledges to all windows should be avoided to prevent build up of dust and clutter. Sloping ledges should be considered in clinical areas.

Fixtures and fittings

4.43 All surfaces should be easily accessed, wipable and will not be physically affected by detergents and disinfectants. All work surfaces should be impermeable, designed for easy cleaning and be free of fissures and unsealed joints. They should be able to withstand the effects of regular cleaning with both detergents and disinfectants.

4.44 Gaps, ledges, etc., should be eliminated or minimised as they will harbour dust, particularly where fixtures and fittings interact with walls and floors making them difficult to clean.

Sanitary fittings

(SHTM 64 Sanitary assemblies and HBN 00-02 Sanitary spaces)

Hand hygiene facilities

4.45 Compliance with hand hygiene guidelines can be improved by conveniently placed and well-designed hand hygiene facilities. The importance of facilities to encourage and facilitate good hand hygiene practices should be high on the list of priorities when designing and planning new healthcare premises or refurbishment of existing premises is being undertaken.

Wash-hand basin design

(SHTM 64 Sanitary Facilities)

Clinical wash-hand basins - Specification

4.46 The dimensions of a clinical wash-hand basin should be large enough to contain most splashes and therefore enable the correct hand-wash technique to be performed without excessive splashing of the user or surrounding surfaces. This can also occur if the water outlet is placed too high above the basin.

4.47 Clinical wash-hand basins should be wall-mounted using concealed brackets and fixings. They should also be sealed to a seamless waterproof splash-back to allow effective cleaning of all surfaces. It should be noted that tile grouting is difficult to keep clean.

4.48 They should not have a plug or a recess capable of taking a plug. A plug allows the basin to be used to soak and reprocess equipment that should not be reprocessed in such an uncontrolled way.

4.49 Clinical wash-hand basins should not have overflows as these are difficult to clean and become contaminated.

4.50 Taps should not be aligned to run directly into the drain aperture, as contamination from the waste outlet could be mobilised and splashing could occur.

Clinical wash-hand basins - Provision

4.51 The location and provision of clinical wash-hand basins should ensure that they are all readily available and convenient for use. The location of clinical wash-hand basins is as important as the bed-to-basin ratio. Multi-bed room rooms' basins should be located to ensure access by staff with the minimum travel between patient and basin; for example, one clinical wash-hand basin on each side of the entrance or at opposite sides of the room.

4.52 Taps in augmented care wards should not have flow straighteners (aerators), as Biofilm can develop on flow straighteners, rosettes and aerators. It is therefore recommended that these are removed. However, the decision to remove flow straighteners, rosettes and aerators should be based on risk assessment, as their removal can create turbulent flow at increased pressure resulting in splashing of surrounding surfaces and flooring.

4.53 Hand hygiene facilities to support the practices as set out in Health Protection Scotland's National Infection Prevention and Control Manual should be readily available in all clinical areas. There should be sufficient numbers and appropriate sizes of clinical wash-hand basins to encourage and assist staff to conform readily to hand hygiene practices as set out in the HPS manual.

4.54 Guidelines for the appropriate numbers and location of clinical wash-hand basins in wards are given in Scottish Health Planning Note 04-01 'Adult in-patient facilities' and in other clinical areas in Health Building Note 00-03 Clinical and clinical support spaces. In order to encourage good practice and to give reasonable access, it is recommended that:

- in en-suite single bedrooms a clinical wash-hand basin should be located in the bedroom and a general wash-hand basin for patient's personal hygiene in the en-suite;
- in four bedded rooms there should be two clinical wash-hand basins in the room and a general wash-hand basin for patient's personal hygiene in the en-suite. (Note that there should be no more than four beds in a multi-bed room in line with Health Building Note 04-01); Space may preclude this being provided in refurbishment projects within existing premises and risk assessments may accept this situation given the provision of alcohol-based hand rub facilities as the first choice for routine hand hygiene;
- in intensive care and high dependency units (critical care areas), a clinical wash-hand basin should be available by each bed space. It should be noted,

however, that under-usage of basins encourages colonisation with Legionella and other microorganisms. Whilst there should be sufficient hand wash stations for hand washing, the provision of more than is necessary presents an avoidable risk of infection from water. Advice on number and location of hand wash stations in clinical areas should be sought from the IP&CT.

Note: Outlets that are used infrequently are a potential problem with water stagnation in all clinical areas. Measures to control the spread of microorganisms in healthcare premises include the regular use of alcohol-based hand-rubs, and this can result in a significant reduction in the use of hand-wash basins. There has also been a trend to providing an enhanced provision of hand wash basins resulting in reduced throughput of water to each. Under-use of taps encourages colonisation with *Legionella* and other microorganisms such as *Pseudomonas* spp. Designers should be aware of these issues and, accordingly, consider how they might impact on the frequency of use of hand washing.

4.55 NHS Boards should have policies in place to avoid contamination of the delivery system and ensure that clinical wash-hand basins are not used for other purposes such as emptying of patient bathing water into the water delivery system where they can colonise existing biofilms.

4.56 HBN 00-03 'Clinical and clinical support spaces' and HBN 00-02 'Sanitary spaces' give guidance on activity spaces required for clinical wash-hand basins including in primary care and out-patient settings, where clinical procedures or examination of patients/clients are undertaken. A clinical wash-hand basin should be accessible to where the procedure is carried out.

General wash-hand basins

4.57 All en-suite facilities should have a wash-hand basin for use by patients.

4.58 All toilet facilities should have a wash-hand basin. Wash-hand basins should not have overflows as these are difficult to clean and become contaminated.

4.59 Taps should not be aligned to run directly into the drain aperture.

4.60 All general wash-hand basins should be sealed to a seamless waterproof splash-back.

4.61 HBN 00-02: 'Sanitary spaces' gives guidance on activity spaces for en-suites, showers, baths and changing facilities.

4.62 SHTM 64 gives details of sanitary assemblies for other areas such as theatre scrubs, kitchens etc.

Note: For guidance on mental health and learning disability settings, see Appendix 3.

Water/taps

4.63 Health and Safety regulations (The Workplace (Health, Safety and Welfare) Regulations, 1992) require that both hot and cold running water should be available in areas where employees are expected to wash their hands.

4.64 Hands should always be washed under running water; mixer taps allow this to be practised in safety in healthcare settings where hot water temperatures may be high to control *Legionella* spp. (see Scottish Health Technical Memorandum 04-01).

4.65 Taps can be fitted with thermostatic mixing valves (TMVs) to ensure that the temperature of the water delivered does not cause scalding etc (no greater than 41°C). TMVs are recommended in most healthcare settings depending upon outcomes of local risk assessments. TMVs should be sited within the tap or on pipework immediately prior to the taps. Taps should be capable of accommodating point-of-use filters which may have to be retro-fitted at some time following an outbreak of Legionellosis or *Pseudomonas* infection. (Scottish Health Technical Memorandum 04-01 refers).

4.66 There have been multiple observations of TMV colonisation with *Pseudomonas* spp. including *Pseudomonas aeruginosa* particularly in older TMVs. This observation includes colonisation with multiple antibiotic-resistant strains. This is most significant in high dependency units (for example, intensive therapy units, special care baby units, and burns units) where patients may be particularly susceptible to colonisation and infection with this opportunist pathogen. Conventional manual mixer taps may not be as prone to such colonisation and may be appropriate in situations where monitored patients are confined to their beds and consequently there may be under-usage at these outlets.

4.67 Consideration should be given to the provision of removable, accessible, TMVs and/or taps or taps with removable spouts in high dependency accommodation. By holding a float of spares, decontamination could be undertaken without prolonged interruption to hot and cold water supplies.

4.68 A local risk assessment of patient susceptibility to *Pseudomonas* infection versus scald risk where patients operate taps could be used to inform the use of TMVs or conventional manual mixer taps.

4.69 Non-TMV taps are also available for certain applications (for example, kitchens and cleaners' sinks). These taps allow the user free rein to determine the temperature of the water delivered at the point of use. However, a local risk assessment should be undertaken first.

4.70 Taps should be easy to turn on and off without contaminating the hands and be elbow/wrist operated or sensor operated.

4.71 Taps discharging directly into a drain hole can cause splashing, which could disperse contaminated droplets. The tap outlet flow should not discharge directly into the waste aperture.

4.72 Swan-neck tap outlets are not recommended for new build projects nor in refurbishment schemes, as they do not fully empty after use. Strainers, aerators (flow straighteners) and anti-splash fittings at outlets are recommended not to be used as they become colonised with bacteria. Adjustments to flow may be required to minimise splash risks. Careful consideration as to the appropriateness should be given to the need to provide sensor taps in clinical wash hand basins.

4.73 Where water systems are closed down, a *Legionella* risk assessment should be undertaken. This should include the risk bacterial overgrowth in dead-legs poses to adjacent water systems. Flushing and hyperchlorination should also be considered when the system is reinstated.

Alcohol based hand rub/Soap dispensers

4.74 Liquid soap dispensers should be wall-mounted at all wash-hand basins and be designed to be operated without contamination from the user's hands coming into direct contact with the dispensing mechanism. Dispensers should not be refillable but be of a disposable, single cartridge design (see Appendix 3 for guidance on mental health units).

4.75 Alcohol based hand rub dispensers should be available to staff as near to each individual patient as possible, subject to local risk assessment. Users and IPC teams should liaise and advise on the precise position and number of these units in clinical areas (Further information can be found in CNO (2005)1).

Hand drying

4.76 Paper hand-towel dispensers should be conveniently placed by all wash-hand basins (clinical and non clinical).

4.77 The use of paper towels in rolls should be discouraged. They are difficult to tear off without contaminating the remaining roll.

4.78 Fabric towels are a source of cross-contamination and must not be used for hand hygiene.

4.79 Hot-air hand dryers reduce paper waste and may be considered for use in public areas of healthcare facilities. Many machines dry hands more slowly than paper towels, and these should not be installed for staff use in clinical areas. They are noisy and should not be used in clinical areas where patients could be disturbed.

4.80 Hands-free waste bins, sack holders or receptacles, with appropriate colour-coded waste bags, should be provided by each wash-hand basin.

Sinks and slop-hoppers

4.81 Using sinks for both hand-washing and the cleaning of equipment is not allowed as this will significantly increase the risk of hand and environmental contamination. Dirty utility rooms should contain:

- a hopper;
- a macerator;
- a separate sink for cleaning equipment;
- a clinical wash-hand basin;
- space to accommodate colour-coded disposal bags for bagging waste.

4.82 Convenient access to these is important, as contaminated fluids such as patients' wash-water should not be emptied down clinical wash-hand basins in adjacent ward areas.

Note: Equipment for destruction of disposable bedpans or cleansing non-disposable bedpans may generate significant noise. Care should be taken to eliminate this spreading to adjacent accommodation.

4.83 Slop-hoppers should be provided in areas where dirty waste water, is disposed, e.g. domestic services room, cleaners' cupboards/areas for cleaning equipment. Hoppers should be provided in dirty utility rooms where required for the disposal of small amounts of liquid waste e.g. from urinalysis. (Further detail is provided in HBN 00-03 Clinical and clinical support spaces).

Soft furnishings

4.84 Soft furnishing used within clinical areas should be chosen for ease of cleaning and compatibility with detergents and disinfectants. They should be covered with material that is impermeable, preferably seam-free or heat-sealed.

Curtains and blinds

4.85 Privacy curtains become contaminated with micro-organisms which can be transmitted to staff hands. Where patients may be particularly susceptible to infection, curtains should have fittings that allow quick and convenient replacement. Consideration should be given to disposable curtains for which such fittings are common.

4.86 In new-build or refurbished augmented care units, consideration should be given to having separate curtains for each multi-bed space sufficiently separated such that staff can easily and correctly identify which curtain belongs to which bed space.

4.87 Reusable curtains should be able to withstand decontamination in healthcare laundering processes.

4.88 There should be a local policy on the changing of privacy curtains both for routine changing when the curtains become soiled and after discharge of a patient with a known or suspected infection. The policy for changing of privacy curtains both for routine changing when the curtains become soiled and after discharge of a patient with a known or suspected infection should reflect the practice set out in the National Cleaning Services Specification.

4.89 Window blinds are not recommended in clinical areas for new-build or refurbishment applications but where currently in place they require to be readily and regularly cleaned as part of local policy.

Equipment

4.90 The purchase of fixed equipment (Group 1&2) will normally take place before the operational commissioning period. (A full definition of Group 1&2 equipment can be accessed in Appendix 1).However, it is important during the design, construction and equipment scheduling stages that there is consultation with the Infection Prevention and Control Team in discussion of equipment. Some of this will be purchased/fitted by the Contractor and may have significant design implications. All equipment must be compatible with the need for prevention and control of infection and all equipment must be compliant with decontamination guidance.

4.91 Technical commissioning of the building, services and equipment should include any areas that require inspection and testing to demonstrate compliance with prevention and control of infection standards, i.e. theatres, hydrotherapy pools, isolation/segregation rooms and clean rooms in pharmacy and Central Decontamination Units (CDUs). There is a legal requirement for compliance in CDUs and pharmacies.

Procurement Stages

Infection Prevention and Control Expertise in Procurement activities

4.92 Infection Prevention and Control Specialist input is essential at the procurement stage of any construction/refurbishment project. This input is initially required when consideration is being given to the selection of Architects and Designers following interview.

Tender/contract

4.93 The Project Manager should seek the views of the Project Team as part of the tender evaluation process and scoring of relevant sections of tenders/contracts to assess competence in relation to the technical nature of the build.

Health & Safety expertise

4.94 Prevention and Control of HAI is a Health and Safety concern and the actions or omissions of those involved in the provision or operation of the facility could become evidence in any legal action stemming from an infection. For this reason it is essential that, as with other considerations of professional competence, all those involved in the design and planning are able to demonstrate that appropriate expertise was in place and advice sought.

Legislative issues

4.95 Before any work commences, there is a need to be aware of all legislative issues, which apply to the project. Examples of relevant legislation may include

- The Health and Safety at Work etc Act 1974;
- The Construction (Design and Management) Regulations 2007 (CDM);
- The Provision and Use of Work Equipment Regulations (PUWER) 1998;
- The Control of Substances Hazardous to Health (COSHH) Regulations 2002.

An expanded list appears in the References section of this document.

Delivering a safe environment

4.96 A number of pieces of legislation put the primary responsibility for the safety of the facility, including HAI, on the employer, usually the NHS Board. In construction procurement the 'employer' sets the resource, assesses the competence of the Design Team and evaluates the output. This means the employer should lead on setting the quality culture that will deliver a safe environment.

Delivery/Construction Stages

4.97 HAI-SCRIBE provides additional information on infection prevention and control.

Construction (new build)

4.98 When the project is a new-build, the largest risk is at the beginning of the project where there may be excavations of large amounts of soil together with its transportation away from the site. NHS Project Managers should visit the site at appropriate and mutually convenient times, as soon as possible after the Contractor has taken ownership of the site, meeting with the Contractor and observing work practice and familiarising themselves with the layout of the various departments. This will help them to detect any unidentified problems or ones caused by design changes. Any changes identified should be risk assessed in compliance with the Management of Health and Safety at Work and recorded.

Construction (new-build attached to existing site or refurbishment)

4.99 Involvement of Project Teams in refurbishment projects is important not only for ensuring that 'designed-in' prevention and control of infection is achieved, but also for assessing the potential risks to patients in existing buildings from dust, dirt and pathogens.

Note: The Health and Safety file and method statement should be reviewed prior to handling over the site to the contractor. It should include clear indications as to how waste is transferred, controlled and the site managed. By listing the HAI control measures in the Health & Safety file or similar documents the design team will have the opportunity to evaluate the suitability of the proposed controls prior to commencing HAI-SCRIBE assessment.

4.100 Measures that limit the spread of dust, dirt and pathogens during construction may include the following:

- undertaking work in winter as the risk is lower for *Aspergillus* spp. and other fungal infections. Clinical teams would need to bear in mind the impact of winter bed pressures and Norovirus outbreaks when planning work over this period;
- cleaning and vacuuming areas under construction and the surrounding areas frequently;
- placing adhesive floor strips outside the door to the construction area to trap dust; these should be replaced regularly to remain effective;
- sealing windows, doors and roof-space to control dust;
- installation of temporary sealed partitions where appropriate;
- provision of barriers which should be physically robust, smooth and easy to clean;
- damp-mopping the area just outside the door to the construction area daily or more often if necessary;
- using a high-efficiency particulate air (HEPA) filtered vacuum to clean areas daily or more often if necessary eg where there is a greater risk of infection spread or a greater need for control of infection;
- transporting debris in containers with tightly fitting lids, or covering debris with a wet sheet;
- all debris should be bagged and sealed for removal at convenient times. This would reduce the risk associated with frequent travel. Follow-on cleaning of the traffic routes would be required as appropriate;
- not hauling debris through patient-care areas;
- removing debris after normal work hours through an exit restricted to the construction personnel;
- designating an entrance, a lift and a hallway that the construction workers must use outwith times that it would be used by patients, visitors or healthcare workers;
- shampooing carpets when the construction project is completed;
- commissioning hotel services regarding cleaning during construction stage.

Note: The Project Manager or delegated person should monitor the effectiveness of dust control measures and any signs of dust accumulation outwith the contained area. The frequency would be based on the risk assessment of surrounding clinical areas.

4.101 HAI-SCRIBE control measures must be clearly documented, followed and recorded. Similarly, a daily checklist is maintained as a minimum during the progress of the construction project and signed off by the designated appropriate person.

Barriers		N/A
Construction signs posted for the area	Yes/No	
Doors properly closed and sealed	Yes/No	
Floor area clean, no dust tracked	Yes/No	
Air handling		
All windows closed behind barrier	Yes/No	
Negative air pressure at barrier entrance	Yes/No	
Negative air pressure machine running	Yes/No	
Project area		
Debris removed in covered container daily	Yes/No	
Waste materials in appropriate container	Yes/No	
Routine cleaning done on job site	Yes/No	
Traffic control		
Restricted to construction workers and necessary staff only	Yes/No	
All doors and exits free of debris	Yes/No	
Dress code		
Appropriate for the area (e.g., Theatres, CDU)	Yes/No	
Required to enter	Yes/No	
Required to leave	Yes/No	

Table 4: Daily construction survey

Surveillance and monitoring during renovation or construction work

4.102 Incidences of *Aspergillosis* and *Legionellosis* associated with environmental changes arising from construction and renovation work have been reported (Fournel *et al* 2010, Boivin *et al* 2012).Therefore the need for additional surveillance and environmental monitoring may be identified by the Project Team through Risk Assessment.

4.103 Where any patients may be placed at risk, it is important that an appropriate risk assessment be carried out. This would be undertaken in advance of any demolition works or disturbance/alterations to the building fabric/ventilation systems. Advice on patient groupings should be obtained from clinicians.

4.104 Since the airborne spores of *Aspergillus* spp. can travel significant distances, this will apply generally to all works in the immediate vicinity or within the boundary of the healthcare site. The need would be dependent on the HAI Risk classification such as type 3 or type 4. Particular care will be required in Transplant units and other accommodation for Immuno-compromised patients.

Delivery/Commissioning Stage

4.105 Upon completion of construction, the facility must be brought into use; the complexity of the task involved generally means that a Commissioning Manager and Commissioning Team will be needed. Senior managers, infection prevention and control teams, specialist teams and users should be fully involved in the process. The commissioning entails:

- drafting operational procedures;
- establishing baseline and future staffing profiles;
- establishing baseline and future revenue budgets;
- establishing final equipment requirements;
- identifying policy issues for referral to the Commissioning Team or the construction project team;
- identifying staff training needs;
- establishing the occupation programme for each user function, for incorporating into the overall masterplan.

4.106 The Project Team may also need to be involved in processes for:

- transfer of facilities;
- phased or staged occupation;
- strategy for equipping;
- selection of equipment;
- storage and subsequent cleaning/disinfection of any furniture or equipment;
- commissioning domestic services for cleaning;
- site visits;
- artwork;
- furnishing and fittings including decorating;
- interior finishes and fixtures;
- post-handover period;
- decommissioning of redundant facilities;
- period of handover to operational management.

Note: Although this must be robustly resisted, commissioning of building services is frequently curtailed to meet deadlines or put in the hands of inadequately qualified or inexperienced personnel. This is invariably to the detriment of user satisfaction, operational efficiency, HAI risk and running costs and should be avoided.

Post Project Evaluation

4.107 The purpose of post-project evaluation is to improve project appraisal, design, management and implementation. This typically takes place 12 months post-handover and is a learning process that should not be seen as a means of allocating blame. There are three stages:

- project appraisal;
- monitoring and evaluation of the project;

- review of project operations.

4.108 It is useful for members of the Project Team to be included at this stage in the evaluation teams that are reviewing project alternatives. The outcomes (activity and its consequences) of the project will not be amenable to evaluation until the facility has been in use for some time. However, if the project is part of a phased refurbishment or new build, valuable lessons can be learned and implemented during ongoing project work.

Note: It is important that the project is evaluated in terms of its original objectives, not in the light of any new legislation or development.

4.109 Reference should be made to the HAI-SCRIBE questionsets in Part B - the Implementation Strategy and Assessment Process section of this guidance relating to the design and planning stage of any development.

Logistics

4.110 The design of the healthcare facility must realistically consider the logistics of a functioning facility. It is essential that systems are in place which will inhibit the spread of infection and resources and personnel are managed so that they do not contribute to the risk of infection.

4.111 Examples of logistical issues to consider include:

- the delivery and distribution of clean materials and people via connecting corridors and lifts;
- the collection, transportation and storage pending removal or disposal of waste materials;
- the separation of clean and dirty traffic flows;
- clinical workflows.

4.112 These issues require careful planning and design which recognise the potential for infection spread through the mismanagement of such issues.

Summary

4.113 The following are the main issues for designers and Project Team personnel to consider in designing a healthcare facility. However, the infection risk should be assessed in conjunction with other risks as conflicts can arise (e.g. with respect to the needs of dementia patients).

4.114 Design to facilitate cleanliness and cleaning:

- use finishes that are impermeable, smooth, seamless and durable, as far as practicable;
- cove hard flooring up the walls for a short distance to provide an easy to clean junction;

- eliminate or minimise dead-legs and blind ends in water systems, both in the original design and as the systems are modified;
- provide hands-free operation for as many facilities as is practicable – for example: bins, taps, lights, sanitary equipment, flushing, doors;
- consider integral blinds as an alternative to curtains at internal windows.

4.115 To facilitate safe working practices (for example, tidiness, and hand hygiene):

- provide sufficient space for activities to take place and to avoid cross-contamination between adjacent spaces;
- provide sufficient storage for patients' possessions and for all supplies to discourage clutter;
- ensure proper segregation and management of waste, including healthcare waste and linen;
- provide sufficient domestic waste receptacles;
- provide bedside waste disposal facilities for patient use;
- eliminate or minimise difficult to clean gaps and ledges or horizontal surfaces such as window sills which encourage clutter;
- provide enough wash-hand basins and soap dispensers;
- plan for and deliver good separation of clean and dirty activities;
- provide sufficient space for storage and preparation of cleaning equipment and materials;
- provide suitable facilities for cleaning of equipment.

4.116 Design for easy cleaning:

- it is always best practice to maintain a visibly clean environment that is free from dust and soilage, and acceptable to patients, their visitors and staff;
- good design can make cleaning immeasurably easier, for example
  - using finishes that are easy to clean;
  - in clinical areas, flooring should be seamless and smooth, slip-resistant, easily cleaned and appropriately wear-resistant.
- consultation should take place with the local IPC team prior to purchase and on planning.

4.117 The Infection Prevention and Control Team should be consulted throughout a building or renovation project and their advice and recommendations taken into account and documented.

5. Typical rooms: purpose and content

Note: For the purposes of this guidance, the following terminology is used (A full Glossary of terms can be found in Appendix 2):

a. **Multi-bed room** is a room that contains more than one bed. It is best practice for these to have both en-suite toilet with shower, clinical wash-hand basin and doors to the main ward area.

b. **Single-bed room** is a room with space for one patient and usually contains as a minimum: a bed; locker/ wardrobe; and clinical wash-hand basin**. (NB: single-bed rooms without en-suite sanitary facilities are not recommended).**

c. **En-suite single-bed room** this is the same as 'b' but with en-suite shower, WC and wash-hand basin. (In new build, space for a social support zone for overnight stay and a clinical support zone is also provided).

d. **Enhanced Single room (with en-suite facilities)** this is the same as 'c' but with a ventilation system that prevents uncontrolled escape of infectious aerosols from the room to adjacent areas. It can also provide a degree of dilution of infectious aerosols in the room for the safety of staff and visitors. The room should have extract ventilation that exceeds its supply, such that gaps in its fabric leak inwards not outwards.

e. **Enhanced Single room (with en-suite facilities and ventilated lobby)** this is the same as 'd' but with a lobby having positive pressure ventilation.

SHPN 04:01 Supplement 1: Within this guidance Isolation facilities either suite/room with specialised ventilation are parts d & e.

Generic rooms

Note: Information on sanitary fittings, taps, etc. is contained in paragraphs 4.45 – 4.73. For further information on room contents, refer to Activity Data Base (ADB) sheets generally issued as part of briefing information.

Isolation Facilities

5.1 The primary aim of Project Team is to prevent the spread of infection between patients, visitors and staff by control or containment of potentially pathogenic organisms. Many of these organisms can be controlled by basic IPC practices such as hand hygiene and environmental cleanliness and this can be facilitated by single room isolation. A small proportion of patients requiring isolation will require isolation facilities as per d & e. (SHPN 04-01 Supplement 1: 'Isolation facilities in acute settings').

5.2 The key to effective isolation on general wards is the provision of sufficient en-suite single-bed rooms to prevent patients known to be a risk for spreading

infections being cared for in open ward areas. Single rooms reduce the risk of cross-infection for non-airborne diseases. Most patients requiring segregation/isolation on general wards can be isolated effectively in en-suite single rooms.

5.3 NHS Boards should audit the use of en-suite single-bed rooms to determine local requirements.

Note: In Accident & Emergency departments, where it is feasible to do so, a dedicated room should be provided for patients with a known or suspected infectious agent/disease transmitted wholly or partly by the airborne route. If source isolation is required, this room should be at negative pressure to the corridor; a lobby is not required. This room should be suitable for general use when not required for isolation.

5.4 Multi-bed rooms can also be used to cohort patients with the same infection if they have en-suite toilet and shower, and a door to the main ward area. The possible need for this should be considered at the design stage.

5.5 Storage of, and ready access to, clean disposable PPE to support the practices set out in Health Protection Scotland's National Infection Prevention and Control Manual is important to encourage its use plus appropriate waste receptacles for disposal once worn.

5.6 Gloves and aprons and other disposable PPE should be sited at the entrance to single-bed rooms.

5.7 Additional storage facilities will be required for the care and treatment of patients in isolation facilities, especially if the isolation is likely to last for some time:

- the storage of the minimum amount of supplies needed;
- lockable provision for personal clothing and possessions. (see Appendix 3, paragraph 3/11 for additional information).

Design

5.8 Scottish Health Planning Note 04, Supplement 1 – 'Isolation facilities for infectious patients in acute settings' provides guidance on the facilities required for isolating infectious patients on acute general wards (source isolation). It also provides guidance on the ventilation parameters for an enhanced single bed room and ventilated lobby.

Ceilings

5.9 Removable ceiling tiles are not advised for specialist ventilated isolation rooms/suites (SHTM 60).

Doors

5.10 Doors design is critical to the design of a specialist ventilation isolation room/suite. For specific guidance on source isolation, refer to Scottish Health Planning Note 04-01, Supplement 1 – 'Isolation facilities for infectious patients in acute settings'.

Enhanced single room with en-suite facilities and ventilated lobby 'e'

5.11 Lobbies provide an area for staff to undertake hand hygiene and to don and remove PPE. (SHPN 04: Supplement 1).

Engineering requirements for special ventilated isolation rooms/suites

5.12 Maintenance programme and revalidation programmes should be established for specialised ventilated isolation rooms to ensure the design criteria are maintained and met at all times. Although it is impossible to give specific maintenance frequencies, each unit should be included in a Planned Preventive Maintenance (PPM) programme that includes pressure/air flow monitoring equipment.

Recommendations

- single-bed rooms with en-suite sanitary facilities are optimum for infection prevention and control design;
- there should be sufficient en-suite single-bed rooms to prevent patients known to be a risk for spreading infections being cared for in open ward areas. Healthcare providers should audit the use of en-suite single-bed rooms to determine where further local requirements and adaptations are greatest;
- the provision of additional isolation facilities should be considered when designing new healthcare buildings and renovating existing buildings.

Ancillary Areas

5.13 It is important that ancillary areas are of an acceptable standard to support effective infection prevention and control. Clean and dirty areas should be in separate rooms and the workflow patterns of each area should be clearly defined.

5.14 The design and finish of ancillary areas should facilitate good cleaning, have facilities for hand hygiene, and sufficient storage for supplies and equipment together with provision for the removal of Personal Protective Equipment to waste or to wash.

5.15 Infection Prevention and Control issues are determined on:

- the use of the ancillary area;
- who will have access; and
- what type of activity will be carried out there

5.16 Ancillary areas include:

- dirty utility;
- clean utility;
- clean linen store;
- domestic services rooms (DSRs);
- decontamination facility/disposal room;
- day room/patient waiting areas;
- play areas;
- nappy-changing area;
- storage;
- visitors' toilets;
- laundry departments;
- changing accommodation;
- treatment room.

5.17 Key activity spaces for each of the above functions are described in HBN 00-03. SHPN 04-01 and SHPN 36 describe the design requirements for the above rooms in hospital or community facilities.

Dirty utility room

(SHPN 04-01, SHPN 36 and HBN 00-03)

5.18 A dirty utility room should include facilities for:

- cleaning items of equipment;
- testing urine;
- disposal of body fluids;
- decontamination of commodes;
- temporarily holding items requiring reprocessing;
- hand hygiene.

5.19 Space and facilities for holding, reprocessing or disposal of bedpans, urinals and emesis (vomit) bowls are required. Commodes, unused bedpans, urinals, vomit bowls and linen bag carriers can also be stored. Closed storage is required for aprons and gloves. Storage cupboards should be provided.

5.20 A working stock of clean goods should be stored within a Dirty Utility Room. Clean goods would include unused bedpans & urinals and cleaned commodes.

5.21 Where commodes are to be used, there should be sufficient space allowed for their decontamination and storage of a working stock.

5.22 A clinical wash-hand basin is necessary plus a deep sink for equipment with draining board (or macerator, if available) for urine disposal and a separate deep sink for decontaminating equipment.

5.23 There needs to be clear demarcation achieved between clean/unused equipment and soiled/dirty equipment. A defined clean-to-dirty workflow is also required.

Clean utility room

(SHPN 04-01 and HBN 00-03)

5.24 A clean utility room is required where drugs and lotions may be stored and prepared, a supply of clean and sterile supplies may be held and dressing trolleys prepared. Designated hand hygiene facilities are required but must be positioned sufficiently far away from infusate preparation to prevent splashing and contamination.

5.25 The room should be located adjacent to the treatment area.

5.26 It is important that planners/design teams think about the type of storage facilities provided. There are three options: cantilevered units, mobile units or units fixed to the floor with no gaps.

5.27 It is important that sufficient dedicated worktop area is provided to enable aseptic preparation to be carried out, e.g. preparation of intravenous infusion. This provision should be sufficiently distant from the wash hand basin as to prevent contamination.

5.28 Storage facilities should be able to be cleaned easily and quickly while protecting clean stores and equipment from dust and contamination. Sloping surfaces should be provided up to ceiling level to permit cleaning.

Clean linen store

(SHPN 04-01 and HBN 00-03)

5.29 Clinical areas should have designated areas for the storage of clean linen to maintain the cleanliness of the linen and allow easy access. Storage should be on slatted shelving or racking and be off the floor. Where shelving is fixed, it should be provided with kick boarding provided to avoid the need to clean the floor underneath. Shelving should be cleanable and not harbour dust.

Treatment room

(SHPN 04-01 and HBN 00-03)

5.30 A treatment room may be required for in-patient examination or investigations on the ward. It will certainly be needed in primary care settings and will require different design features according to its planned use, for example, immunisation, wound dressing or surgical intervention and investigations.

5.31 A clinical wash-hand basin should be provided (see Health Building Note 00-03).

5.32 Carpets should not be used in a treatment room.

5.33 Space should be available to allow for the storage of equipment and sterile supplies.

Disposal room

(SHPN 04-01)

5.34 This area should be secure and not be accessible to patients/public.

5.35 The disposal room is for temporary storage of supplies and equipment that have to be removed for cleaning, reprocessing or disposal, for example, items to be returned to the sterile services department (SSD).

5.36 The sizing and location of disposal rooms should be considered at the design stage, taking into account the predicted levels and types of waste to be generated and the planned operational policies relating to frequency and work flow of waste and linen collection.

D.S.R. (Domestic service room)

(HBN 00-03)

5.37 This room is used to deliver day-to-day cleaning services for a defined area. Cleaning materials and equipment in daily use should be stored in cupboards within this room.

Note: It should be noted that the requirements for DSRs have recently been under review by the domestic services review group.

5.38 The room should be provided with a sink with draining board and slop-hopper as well as a wash-hand basin situated well away from the equipment washing sink and slop hopper. There should be unrestricted access to the sink and slop-hopper.

5.39 Space should be provided for segregation and storage of mops, buckets and other cleaning equipment vacuum cleaner and scrubbing/polishing machine (for hard floors) and for lockable COSHH cupboard for cleaning supplies.

Day room/patient waiting areas

(HBN 00-03)

5.40 There is often conflict between the aesthetics of these areas and the prevention of contamination of the environment or furnishings and ease of cleaning/disinfection. This is especially the case in waiting areas such as in accident and emergency departments, primary care and minor injury units.

5.41 It is important that where blood and body-fluid spillages may occur, the environment should be able to be decontaminated effectively. Use of carpets should be the exception and then only after much consideration and risk assessment.

Note: There are special requirements for Mental Health Units which are categorised as low risk.

Play area

(HBN 00-03)

5.42 All equipment, finishes and furnishing will be wipable, impermeable and be able to withstand cleaning and disinfection. This is particularly important for play mats and soft floor coverings.

Nappy-changing area

(HBN 00-03)

5.43 Facilities for disposal of soiled nappies and for hand washing in the immediate environment are required along with a regular cleaning programme of equipment used.

5.44 The area for nappy-changing will have a surface that can be easily cleaned and disinfected.

Staff/Visitors' toilets

(SHPN 04-01 and HBN 00-02)

5.45 These are heavily used and will provide enough space with wipable, impermeable, durable finishes to maintain a high standard of cleanliness.

5.46 There will be provision of disposal facilities for sanitary waste in both women's, assisted, disabled and unisex toilets.

5.47 The number of toilets, wash-hand basins and hand drying facilities provided will be sufficient for the size of the facility (see Health Building Note 00-02). Minimum numbers for staff and patient toilets and visitor toilets in non-public areas are determined by NHS guidance documents. Provision for visitors in public areas will be determined by the Scottish Building Control technical standards.

5.48 Hand drying should be by single-use paper hand towels or hot air hand driers. If a facility is, in or closely adjacent to, areas where patients may be sleeping, hot air hand driers will be avoided due to noise.

Equipment storage

(SHPN 04-01, SHPN 36, and SHTM 63)

5.49 Storage areas need to be appropriate for the operational requirements of each clinical area.

5.50 The need for sufficient secure storage should not be underestimated. Many briefs start with sufficient storage, but this space is often lost to other areas during the design process. This can have implications for both clinical practice and infection prevention and control.

5.51 Storage away from areas of clinical activity is required for both small and bulky items of equipment to minimise clutter, enabling efficient environmental cleaning.

5.52 All healthcare premises need a storage area for large pieces of equipment such as beds, mattresses, hoists, wheelchairs and trolleys that are not currently in use. The use of equipment libraries can be an effective way of storing, maintaining and decontaminating large or electrical equipment.

5.53 Cleaning equipment, laundry and healthcare (including clinical) waste need to be stored in separate purpose-built areas to prevent cross-contamination.

5.54 Sufficient and appropriate storage will protect equipment from damage, contamination and dust, which may potentially carry microorganisms, but should also allow free access to floors and shelves for cleaning.

Storage for patients' possessions

(HBN 00-03)

5.55 Adequate space should be allocated for the storage of patients' possessions. Wardrobes and lockers used for storage of patients' possessions should be selected to be easily and efficiently cleaned. Louvre doors should not be fitted, as they are difficult to keep clean.

5.56 Consideration and risk assessment should inform choice of furniture, vandalism and ligature issues affecting all types of accommodation.

Out-patient and day surgery changing facilities

(HBN 00-03)

5.57 In areas such as out-patients, imaging and minor injuries units, it will be necessary to provide sufficient changing/storage facilities for patients if clothing has to be removed and kept safe. These should be included at the planning stage and should be able to be cleaned easily.

Clinical staff changing

(HBN 04-01 and HBN 00-02)

5.58 By providing staff changing facilities, sanitary facilities, showers and sufficient locker space for outdoor clothing staff will be able to change out of their uniform on-site. Wash-hand basins and shower facilities for staff should be made available and easily accessible in case of substantial blood or body fluid contamination. There needs to be sufficient storage for clean scrub suits and footwear. Facilities for disposal should also be available. Specialist departments will require local specialist staff changing (eg theatres and aseptic suites). Where these are not available, staff should change and contaminated uniforms bagged.

Maintenance staff changing

(HBN 04-01 and HBN 00-02)

5.59 Changing facilities should be provided for maintenance staff who undertake activities that could expose them to contamination. There should also be access to showers in case of significant contamination.

- appropriately sized changing facilities should be provided for staff, to encourage them to change out of their uniform on-site;
- wash-hand basins and sanitary facilities should be included in showers in the event of contamination by blood or body fluid.

Linen cupboard

5.60 Each ward should have an area for the storage of clean linen which, in new build accommodation, should be purpose-designed. The area used for the storage of clean linen should ensure that linen is not exposed to contaminants. The areas are required to have:

- good ventilation;
- adequate lighting;
- impermeable flooring that is easy to clean and fitted with coving between the floor and the wall to avoid accumulation of dust and dirt in corners and crevices;
- smooth, impermeable and easy to clean slatted shelving to ensure free flow of air.

5.61 If linen trolleys are used to store linen within the ward area, they should be managed so that:

- they are kept clean and tidy and enclosed with an impervious covering to ensure that linen is not exposed to dust;
- linen bags are not left open or lying on the floor with the potential for exposure to dust which may potentially carry micro-organisms;

- appropriate procedures are in place to allow cleaning of linen trolleys.

Used linen storage

5.62 The following types of linen should be segregated at source before sending to the laundry;

- used linen;
- infectious linen;
- heat labile linen.

Central or local NHS Laundry facilities

Note: Prior to installation, it is important to ensure that validation, testing and recording of the laundry process (including thermal disinfection) can be undertaken, as this is vital for the effective decontamination of laundry in NHS settings. This is the responsibility of the maintenance manager or engineer.

5.63 The layout of laundry areas must be designed to ensure that effective cleaning can be undertaken. Finishes to walls, floors, work surfaces and equipment must be capable of withstanding regular cleaning and the impact of mechanical cleaning equipment. The area should be large enough to allow access for decontamination trolleys.

5.64 Laundry facilities should provide:

- suitable space for laundry machinery;
- suitable storage for used linen and for separation of used and laundered linen;
- storage space which is designed to prevent odours from migrating from storage areas to adjacent areas;
- storage space designed to accommodate trolleys, etc., used in the transportation of linen;
- appropriate facilities to allow the segregation of used linen, heat labile linen and infectious linen, in appropriate containers which are clearly identifiable;
- suitable facilities to allow compliance with hand hygiene practices;
- a laundry policy to ensure infection risks are minimised;
- a ventilation system that will minimise the level of airborne contamination and dust to minimise the risk of cross infection.

If processing infectious linen suitable vent pipes should be routed to a safe area outwith the laundry and effluent from the drains must be sealed from the machine to the drainage area outwith the laundry.

5.65 Ward based machines (industrial or domestic):

- ward based machines must not be used within the NHS for processing 'infectious linen' or 'contaminated uniforms';
- as it is costly and difficult to validate domestic washing machines, these should only be used in areas agreed by the IP&CT such as rehabilitation units for patients' own laundering or laundering of heat labile baby clothes. Validation and thermal disinfection processes is not required or suitable for domestic machines;
- it is preferable to install industrial type machines in ward areas as in the long term these are more cost effective due to durability, in addition some models have temperature recording facilities that can be used to ensure thermal disinfection is reached but this is not a requirement in this setting.

5.66 Tumble driers should be used to further support thermal disinfection where domestic washing machines are used.

Catering/food hygiene

(HBN 04-01)

5.67 There should be facilities for staff who prepare and serve food to wash their hands. Additionally;

- in centralised kitchens, physical separation must be provided for storage, preparation and cooking areas including any equipment that is used which is effectively done by use of colour coding;
- cooked and raw products must be physically separated at all times;
- ward kitchens should have a separate staff wash-hand basin with non-touch taps, liquid soap and paper towels;
- storage areas such as cupboards must be clean and intact;
- the refrigerator should have a thermometer either built in or separate and this should record daily temperatures to ensure the fridge is 5°C or below.

Waste management

5.68 Guidance on the management of all wastes arising within healthcare facilities or wherever NHSScotland services are delivered is provided in Scottish Health Technical Note (SHTN) 3. SHTN 3 is published for use by NHS Boards' staff and its contractors and comprises the following parts:

- Part A: Summary of requirements – best practice overview;
- Part B: Waste management policy template;
- Part C: Compendium of regulatory requirements;
- Part D: Exemplar waste procedures; and,
- Part E: Waste prevention and re-use guide.

5.69 Many of the regulatory requirements for NHS Boards' wastes are captured within 'Duty of Care' under the Environmental Protection Act 1990 (as amended).

Responsibilities under 'duty of care'

5.70 The 'Duty of Care' is described in Section 34 of the Environmental Protection Act 1990. The Act was recently amended in Scotland by the Waste (Scotland) Regulations 2012. Guidance on its use and interpretation can be found in the 'Duty of Care – A Code of Practice' published in October 2012.

5.71 The Code of Practice outlines the obligations of those involved in the waste management chain from waste producer to final disposal. It requires producers and others who are involved in the management of waste to prevent its escape and take all reasonable measures to ensure that the waste is dealt with appropriately from the point of production to the point of final disposal. In order to comply with this requirement NHS Boards should:

- ensure that waste is segregated in a manner which allows for the recovery of materials;
- ensure that a written description accompanies all waste movements, adequately describing the type and quantity of waste;
- ensure that those who manage the waste and sites receiving the waste are authorised to do so; and,
- maintain records of all waste movements.

5.72 One of the main responsibilities under duty-of-care, which has major implications for IPC and the built environment, is to ensure that waste is stored safely on-site. Essentially:

- storage areas at ward and unit level should be secure and not publicly accessible;
- storage areas should be sufficient in size to allow packaged waste to be segregated and to avoid waste of different classifications being stored together in the same area;
- SHTN 3 provides further detail on waste segregation, receptacles and storage.

Waste segregation and storage

5.73 Any new capital developments should have enough space for waste receptacles to be located close to the point of waste production.

5.74 Healthcare wastes such as potentially infectious waste and pharmaceutical waste should be segregated into colour-coded receptacles in accordance with SHTN 3. Healthcare waste receptacles should not be accessible to the public.

5.75 Receptacles for recyclates should be easily accessible and clearly marked using the best practice colour coding specified in SHTN 3. Receptacles for

recyclates should be available in all locations where domestic waste is produced.

5.76 Residual waste is the name given to domestic waste once recyclates have been segregated at source. This waste should be placed into clear (preferable) or black bags. Receptacles for this waste stream should be clearly labelled.

5.77 Dedicated secure storage areas for waste are best located at entrances to wards or departments, preferably with access from both ward and hospital corridor to facilitate collection by authorised personnel only.

5.78 Storage for used linen should be in a clearly designated area separate from waste. This should minimise any risks of used linen being accidentally taken for disposal or waste being taken to the laundry.

5.79 Dedicated waste storage areas should be able to be cleaned easily and efficiently. The holding area should be of sufficient size to hold wheeled-bins and waste sacks ensuring that healthcare waste is clearly segregated from other wastes to avoid contamination.

5.80 A designated, secure area is also necessary to hold receptacles from the whole site (central waste yard) from which waste can be collected for off-site treatment and recycling. Guidance on the design and facilities required in waste storage areas is available in SHTN 3.

Note: Similar consideration will be required to route, contain and retain waste arising from construction activities in order to prevent debris and dust permeating clinical areas.

Waste receptacles

5.81 Comprehensive guidance on the size and colours of waste receptacles is available in SHTN 3. Waste receptacles should be of suitable size to meet waste arisings taking collection arrangements into consideration. Receptacles should be easy to clean, hands-free (i.e. foot operated) and comply with the requirements of SHTM 83: 'Firecode'.

5.82 Lids of waste receptacles that are used for healthcare waste need to be capable of being cleaned and disinfected. Avoid attaching temporary labels that would inhibit effective cleaning.

Healthcare waste (including healthcare waste generated in primary care and community settings)

5.83 In healthcare facilities such as care homes and primary care settings, all waste should be contained appropriately and kept secure at all times.

Note: There are special requirements for MHUs and Custodial accommodation.

5.84 The system and frequency of collection of waste service needs to be taken into account when planning facilities. Areas for temporary storage e.g. holding bays and/or intermediate rigid receptacles such as wheeled bins may be required.

Temporary storage facilities should be washable, secure and animal-proof. Only rigid lockable receptacles should be stored in external areas.

5.85 There should be a strict routine for removing waste to ensure it does not remain uncollected for extended periods.

Storage capacity

5.86 Storage areas need to be fit for purpose and a suitable size to allow different waste types to be stored safely and separately. Collection frequencies including contingency requirements (in the event of a failure in waste collection) should be taken into consideration when specifying the size of storage areas. The design of the facility should also take account of accessibility and space needed for vehicles collecting the waste.

Waste segregation

5.87 The storage area should be sufficient for different waste streams to be segregated pending collection in line with local policy. This will normally (at minimum) require that domestic wastes, including source segregated recyclates is to be kept separate from healthcare wastes (such as orange bags) taking into consideration appropriate treatment and disposal routes. See SHTN 3 for further details.

Note: The Waste (Scotland) Regulations 2012 have effectively banned the use of food waste disposal units (macerators) and food waste digesters involving the discharge of 'treated food' into the public sewer network.

6. Engineering services

Note: This section discusses various aspects of engineering services and the Infection Prevention and Control implications of each.

Heat emitters and temperature control

General

6.1 The selection of heat emitters will not only have a spatial impact but also on infection prevention and control.

Wall-mounted radiators

6.2 Options to ensure safety are as follows:

- low surface temperature heat emitters should be used;
- where existing conventional radiators are being retained, guards/covers should be fitted. Ease of covers removal to facilitate cleaning is essential. (paragraphs 6.3 and 6.4 also refer);
- temperature controls should fail to a safe position.

6.3 Of these options, covered heat emitters have raised the most prevention and control of infection concern. Heat emitter covers allow dust to build up beneath and inside the heat emitter grille. This dust has been found to contain potentially pathogenic organisms, and when heat emitters are switched on during the winter months, dust and bacteria are dispersed by heat convection to the ward area.

6.4 Where heat emitter covers are used, regular planned maintenance and cleaning should be undertaken to prevent the problems described.

6.5 When installing wall-mounted heat emitters, it is necessary to provide adequate space underneath the emitter to allow easy access for cleaning machinery to be used. Gaps and dust traps should be minimised.

Note: Ceiling-mounted radiant panels are intrinsically safe as hot surfaces are out of reach while also eliminating dust-traps.

Pipe-work siting and access

6.6 Where pipe-work is surface mounted it should be contained in a smooth-surfaced box that is easy to clean.

6.7 Penetrations where pipes and cables pass through walls above false ceilings should be sealed.

Heating, general ventilation and lighting grilles

6.8 Heating, ventilation and lighting grilles need to be accessed easily for inclusion in cleaning programmes by cleaning and estates staff.

Ventilation

Ventilation ductwork

6.9 Ventilation ductwork should be installed in such a way that it can be accessed. (This is important for extract ductwork as this has the most significant accumulations of lint and dust requiring removal, particularly if heat reclamation systems are used).

Specialised ventilation

6.10 The same basic principle applies for all clinical areas whereby positive pressurisation is maintained by providing supply ventilation in cleanest areas cascading to dirty areas where negative pressure will be achieved. This will inhibit the spread of contamination.

6.11 In healthcare premises, certain activities will necessitate the provision of ventilation equipment with additional special features in order to achieve and maintain specific conditions. For infection prevention in specialist areas such as operating theatres, ventilation should ensure contaminated air does not enter designated clean areas by ensuring that air flows from the cleanest to sequentially less clean areas. This direction of air flow prevents contaminated air passing in the opposite direction.

Note: See Scottish Health Technical Memorandum 03-01 Parts A and B for comprehensive guidance on the design, installation and operational management of ventilation systems in healthcare premises.

6.12 The following will usually have specialised ventilation requirements for infection prevention in:

- operating department;
- source isolation;
- bronchoscopy and sputum induction rooms, where a risk assessment has indicated a tuberculosis risk;
- protective isolation accommodation for highly immuno-compromised patients;
- cardiac catheter, interventional radiology units;
- microbiology containment laboratories;
- mortuaries.

Note: For information on ventilation for Isolation Rooms refer to Paragraphs 5.8 - 5.12.

Split and cassette air-cooling units

6.13 Only units that are readily amenable to regular cleaning in a working hospital unit should be used. If installed they should be cleaned as part of a regular planned maintenance scheme. Particular consideration should be paid to the accessibility of the condensate drip tray for cleaning and to the disruption to normal use of the accommodation while maintenance is being undertaken. A preferred solution would be not to install these units in critical patient areas.

Chilled beam units

6.14 These comprise heat-exchange beams in a ceiling through which is passed water to cool or heat air that passes across them. They should be installed so that they can operate without generating condensate. They must be accessible for regular cleaning and maintenance.

Hot and cold water systems

Note: Reference should be made to Scottish Health Technical Memorandum 04-01: Parts A and B for comprehensive guidance on the design, installation and operational management of water systems in healthcare premises.

6.15 The Water Quality (Scotland) 2010 Regulations contain provisions to ensure that the drinking water supply within buildings to which the public has access remains wholesome and is not adversely affected by the local distribution system.

6.16 Immuno-compromised patients are at particular risk from cryptosporidium. Very low numbers of cryptosporidium cysts can occasionally occur in mains potable water.

Storage and distribution of water

6.17 Many organisms capable of causing disease, particularly in highly susceptible hospital patients, such as *Pseudomonas* and *Legionella*, have been isolated from hospital water systems. Preventive measures include:

- routine inspection of water storage tanks with cleaning as required;
- identifying and removing dead-legs and blind ends;
- keeping cold water systems cold and hot water systems hot; and
- ensuring rapid turnover in water storage.

6.18 Temperature control is the preferred strategy for reducing the risk from *Legionella* spp. in water systems. This will require temperature monitoring on a regular basis. The recommended test frequencies are given in Scottish Health Technical Memorandum 04-01, Part B. It is good practice to ensure that hot and cold water pipe-work is insulated and separated. Cold water pipes should also be segregated from other heat sources and preferably not in the same service-ways to avoid unwanted heat transfer to the cold water supply.

6.19 Chemical and other water treatments that have been shown to be capable of controlling *Legionella* spp. to some extent may also be considered. They will only work in systems that are amenable to their use, for example those that do not have dead-legs and blind ends.

6.20 Scottish Health Technical Memorandum 04-01, Part B – 'Operational policy' provides guidance on the monitoring and maintenance of water systems (including water storage).

Sanitary facilities

6.21 WCs, urinals, bathrooms and showers should be designed to be easily cleaned and maintained. Wash-hand basins should be provided adjacent to WCs and urinals.

6.22 Showers are generally more practical than baths in the clinical situation and are easier to keep clean. Any fixture within a shower such as a seat should be easily cleanable, without small gaps and dust traps.

6.23 To minimise the possibility of bacterial colonisation of shower heads, they should be regularly cleaned and de-scaled.

6.24 Bidets may present infection risks, depending on design and patient group. The appliance should be rimless with an over-rim water supply. They are most frequently specified in maternity units. Therefore, if used, they should conform to the specifications given in SHTM 64: 'Sanitary assemblies' and HBN 00-02: 'Sanitary spaces'. Baths and birthing pools in Maternity units should be easy to clean and not of a ™Jacuzzi type.

Note: SHTM 64 'Sanitary Assemblies' and HBN 00-02 'Sanitary spaces' contain guidance to assist the design team in the selection, specification and application of sanitary assemblies in healthcare buildings. They also give guidance on the appropriate cleaning and maintenance regimes.

Wet rooms

6.25 These require high quality water-resistant cladding on walls to prevent mould.

Water fittings

6.26 Water fittings (washers, etc.) should not support microbiological growth. All fittings should satisfy the requirements of the Water Supply (Water Fittings) Regulations 1999.

6.27 Flexible hoses used in water supply systems should be identified and risk-assessed for the possibility of contamination with harmful microorganisms. Where flexible hoses must be used (for example, on essential equipment such as hi-low baths), they must be lined with a suitable alternative to ethylene propylene diene monomer (EPDM), and be Water Regulations Advisory Scheme (WRAS)-approved. Care should be taken to avoid kinking or distorting them during installation (see Health Facilities Scotland Safety Action Notice

SAN (SC) 09/03 Flexible water supply hoses risks of harmful micro-organisms and paragraph 11.35 of SHTM 04-01 Part A).

Ice for patient consumption

6.28 Where suitable for use, ice machines should be of a type that dispenses ice by a non-touch nozzle.

6.29 Ice should be made directly from water that is of drinking quality. Ice for the immuno-compromised should be made by putting sterile water into single-use ice-making bags, then into a conventional freezer.

Further guidance can be found in the Safety Action Notice (SAN) 06/46

Electrical services

Lighting

Note: Efficient lighting in all areas of wards or departments enables cleaning staff to undertake cleaning more effectively. The Chartered Institution of Building Services Engineers' LG2 – 'Healthcare and hospital lighting' gives guidance on lighting levels in healthcare facilities. SHTM 06-01 also refers.

Luminaires

6.30 Luminaires should be selected and installed to eliminate or minimise ledges/gaps/dust traps and, as far as is practicable, be accessible and easily cleanable.

Bedhead services

6.31 Bedhead services should be smooth, accessible and easy to wipe clean. Ledges, gaps and dust traps should be eliminated or minimised.

6.32 Sufficient dedicated 13-amp socket outlets should be provided in corridors and in individual rooms to enable cleaning appliances with 9m long leads to operate over the whole department.

6.33 Where possible, socket outlets should be provided flush-mounted or in trunking systems to enable easy cleaning and prevent the build up of dust.

Patient entertainment systems

6.34 Radio and TV headsets should be capable of being cleaned or disinfected between patient uses or be single use, whichever is the most economical method to adopt.

6.35 Risk mitigation measures should be considered, including the implications of power interruption when all electrical fittings are either non-touch of sensor operated.

Wastewater and sanitation

6.36 Wastewater is generated from a huge number of tasks carried out in healthcare buildings, which range from domestic cleaning, hand-washing, specialist laundries, surgical operations and areas such as renal dialysis units. Most of this wastewater contains pathogenic microorganisms and must be disposed of via a safely contained internal drainage system into the external waste water sewerage system.

Internal drainage system

6.37 An internal drainage system should use the minimum amount of pipe work, retain water and be airtight at joints and connectors. It should be sufficiently ventilated to retain the integrity of water seals.

6.38 The design should comply with the relevant British Standards and Codes of Practice, including BS EN 12056, Scottish Building Standards Technical Handbook and recommendations for spatial and access requirements for public health engineering services are contained in The Chartered Institution of Building Services Engineers' Guide G, 2014.

6.39 Provision for inspection, rodding and maintenance should be located to minimise disruption or possible contamination, eg access points should not be sited in clean clinical areas.

Bedpan washer-disinfectors/macerators

6.40 Where reusable bedpans are used, ward areas require adequate and suitable bedpan washer-disinfectors that comply with BS EN ISO standards 15883-Parts 1-3: 2009, IEC 610010-2-040: 2005 and SHTM 2030 Part 1, 2 and 3.

6.41 Where fitted, bedpan washer-disinfectors should be installed according to the Scottish Water Bylaws 2004 Part 2 (4) and using fittings listed on the Water Supply Regulations Advisory Scheme (WRAS) directory.

6.42 When considering installation of bedpan macerators, it should be established that both internal drains and the external sewerage system can cope with the model proposed.

6.43 Where recommended by the manufacturer reusable supports should be decontaminated in the washer disinfector. Further advice should also be obtained from the Infection Prevention and Control team.

Medical gases and vacuum systems

6.44 Scottish Health Technical Memorandum 02-01 gives guidance regarding piped medical gases and vacuum systems and includes recommendations on: emergency procedures; power failure; access for cleaning contaminated vacuum systems; training and communication; maintenance and infection risk.

Pneumatic air tube transport systems

6.45 Guidance for the design and management of pneumatic transport systems can be found in Scottish Health Technical Memorandum 08-04.

6.46 The pneumatic piping system should be designed to permit cleaning and disinfection of the tubing.

Computer equipment

6.47 Prior to purchasing computers or hand held devices which are to be used in clinical areas it is important that these must be able to withstand cleaning and disinfection compatible with the device. As with other equipment this should be monitored for signs of damage.

7. Importance of maintenance

7.1 Good design and equipment selection will ensure future maintenance is easy and cost effective. A planned maintenance system should be set up to start at the same time as handover or occupancy. A record of Planned Preventive Maintenance needs to be kept. Regular reviews of the building fabric should be undertaken as accidental damage to smooth surfaces makes effective decontamination difficult to achieve. The use of soft, difficult to decontaminate fabrics must be, as far as possible, avoided.

Access for maintenance

7.2 There should be adequate space to allow maintenance work to be carried out. Measures such as locating isolating or regulating valves or ventilation ductwork dampers and access panels outwith clinical or patient occupied areas (e.g. corridors) will reduce the need for unwanted intrusion by estates staff.

Reference should be made to SHTM 03-01 and SHTM 04-01.

8. Demolition

8.1 Work of this type will require a building warrant and a Decommissioning Team should be established. The Decommissioning Team usually needs to include a CDM Co-ordinator and consideration should be given to the likely spread of dust/dirt which the works will cause. Issues such as limitation of airborne fungal contamination need to be considered. (The role of CDM coordinator is currently under review by the Health & Safety Executive).

Decontamination of buildings and equipment

8.2 Reference should be made to records containing asbestos survey data before commencement of any activities. Buildings should be thoroughly cleaned after all furniture etc has been removed. Airborne decontamination methods should be considered to minimise the risk prior to demolition. Equipment should be decontaminated prior to reuse elsewhere or final disposal. The Decommissioning Team will have to risk assess health and safety issues with the advice of the CDM Co-ordinator and NHS Board's Health & Safety department.

Effect upon adjacent healthcare premises

8.3 There are health and safety issues which the Decommissioning Team will have to risk assess and consider with the advice of the CDM Co-ordinator. Additional cleaning may be required due to the additional dust likely to be caused. Ventilation filters in areas likely to be subject to a high airborne dust load should be checked and changed if necessary, prior to demolition works starting. An overloaded filter can collapse and cause contamination. Filters should also be checked and changed if necessary once work is complete.

Planning for demolition works

8.4 Prevailing wind direction and the distance of the demolition works from occupied areas are key considerations when planning demolition works.

8.5 The demolition Project Plan should contain details of measures to be taken to minimise contamination of other areas. The person responsible for each control measure should also be named.

8.6 On completion of the work, the success or otherwise of the control outcomes should be formally assessed and the lessons learned disseminated widely, including outwith the organisation, for the benefit of colleagues involved in similar projects.

8.7 There have been instances where hospital sites with dangerous materials such as healthcare waste and asbestos have disposed of these within the hospital site. Decontamination of the site intending to be disposed of is the responsibility of the owner, eg healthcare body. Contaminated land may need

to be disposed of as special waste and can be extremely expensive as the soil removed must also be classified as special waste.

Appendix 1: Equipment groups

Equipment supplied for new building schemes can be one of four categories:

Group 1 items are specified at the design stage and are supplied and fixed under the terms of the building/engineering contract and funded within the works cost. These are generally fixtures and fittings or plant/equipment which are permanently wired/installed, e.g.

- sanitary fittings;
- specialised equipment items best suited to central purchasing arrangements;
- cupboards, worktops, shelving;
- excluded from this Group will be large medical equipment/fixtures and items subject to late selection or procurement by the NHS Board e.g. CT Scanners, Linear Accelerators, Autoclaves.

Group 2 Items are installed under the terms of building/engineering contracts, but are supplied or purchased by the NHS Board under a separate equipment budget. They may have implications in respect of space or building services e.g.

- paper towel dispensers;
- soap/scrub dispensers;
- washer/disinfectors;
- washing machines.

Group 3 Items are purchased directly by the Client and may have implications in respect of space, construction or engineering services e.g.

- small refrigerators;
- loose furniture;
- monitors;
- trolleys.

Group 4 Items may have storage implications but otherwise have no impact on space or engineering services e.g.

- small medical devices;
- computers, laptops;
- small loose equipment.

Appendix 2: Glossary

(Applicable to all parts of this Guidance)

Airborne (aerosol) transmission: The spread of infection from one person to another by airborne particles (aerosols) containing infectious agents.

Airborne particles (aerosols): Very small particles that may contain infectious agents. They can remain in the air for long periods of time and can be carried over long distances by air currents. Airborne particles can be released when a person coughs or sneezes, and during aerosol generating procedures (AGPs).

***Aspergillosis*:** A fungal infection caused by *Aspergillus* spp., commonly found in soil, decaying vegetable matter, damp cellars, building materials and ventilation systems. The most common mode of transmission is by the airborne route, for example dispersal of contaminated aerosol. In fact, airborne *aspergillosis* is a risk to patients with highly compromised immunity.

Cleaning: The process of physically removing contamination including soil, dust, large numbers of micro-organisms and the organic matter that protects them.

Cohorting: Placing a group of two or more patients (a cohort) with the same confirmed infection in the same room or area.

Cohort Nursing: Use of a dedicated team of healthcare staff to care for a cohort of patients, and who do not care for any other patients.

Contact transmission: The spread of infectious agents from one person to another by contact. This can be either direct contact, or indirect contact (via a contaminated object/fomite).

Contamination: The presence of an infectious agent on a body surface; also on or in clothes, bedding, toys, surgical instruments or dressings, or other inanimate articles or substances including water and food.

Cross-infection: The transmission of infection from one person to another.

Dead-legs: In a water supply and distribution system, pipes that are capped off or rarely used, or regions of pipework which are not scavenged by flow.

Disinfection: The reduction of the number of micro-organisms to a safe or relatively safe, level but not usually the destruction of spores.

Healthcare associated infections (HAI): Infections that occur as a result of medical care, or treatment, in any healthcare setting.

Heat labile: That which is likely to be damaged or destroyed by the normal heat disinfection process.

Immunocompromised patient: Any person whose immune response is impaired or deficient, usually because they have a disease or are undergoing treatment. People who are immunocompromised are more vulnerable to infection.

Indirect contact: A mode of transmission of infection involving fomites or vectors.

Non-touch (taps): Includes elbow/wrist operated or infrared sensor taps.

Pathogen: A bacterium, virus, or other micro-organism that can cause disease.

Reservoir (of infection): Any person, animal, plant, soil or substance, or a combination of these, in which an infectious agent can live and multiply, on which it depends primarily for survival, and where it reproduces itself in such a manner that it can be transmitted to a susceptible host: the natural habitat of an infectious agent.

Single room/En-suite single room/Isolation room/Bay: For the purposes of this document, the following terminology is used:

a. **Multi-bed room** is a room that contains more than one bed. It is best practice for these to have both en-suite toilet with shower, clinical wash-hand basin and doors to the main ward area;

b. **Single-bed room** is a room with space for one patient and usually contains as a minimum: a bed; locker/ wardrobe; and clinical wash-hand basin**. (NB: single-bed rooms without en-suite sanitary facilities are not recommended.)**;

c. **En-suite single-bed room** is the same as 'b' but with en-suite shower, WC and wash-hand basin. . (In new build, space for a social support zone for overnight stay and a clinical support zone is also provided);

d. **Enhanced Single room (with en-suite facilities)** this is the same as 'c' but with a ventilation system that prevents uncontrolled escape of infectious aerosols from the room to adjacent areas. It can also provide a degree of dilution of infectious aerosols in the room for the safety of staff and visitors. The room should have extract ventilation that exceeds its supply, such that gaps in its fabric leak inwards not outwards;

e. **Enhanced Single room (with en-suite facilities and ventilated lobby)** this is the same as 'd' but with a lobby having positive pressure ventilation.

Spore: Some species of bacteria, particularly those of the genera *Bacillus* and *Clostridium*, which are significant cause of infection in humans, develop highly resistant structures called spores when they are exposed to adverse conditions, such as a lack of nutrients or water. Spores are resistant to disinfectants and to high or low temperatures. They may remain viable for many years until environmental conditions improve, the spores germinate and the bacterial cell inside starts to multiply again.

Sterilisation: The process of removing or destroying micro-organisms including spores, usually by heat or chemical means.

Thermostatic mixing valves: Valves that mix the hot and cold water of the system to provide water at a predetermined temperature.

Appendix 3: Infection control in Community Care facilities, Mental Health units, custodial facilities and accommodation for patients with learning disabilities.

3/1 The need to minimise the risk of cross-infection remains important in accommodation of these types, but other factors such as maintaining a homely ambience, ligature risks and the creation of a positive therapeutic environment will need to be taken into consideration.

3/2 The IPC requirements for those using mental health environments should be made in conjunction with health and safety teams, risk management teams and clinicians when advising on the built environment. Specific design guidance for mental health units comprises SHPN 35, Health Building Note 03-01 – 'Adult acute mental health units'. Additionally, the Department of Health's Environmental Design Guide: Adult Medium Secure Services should also be consulted.

For dementia settings, additional considerations are discussed in the "dementia design checklist" (Health Facilities Scotland, 2007).The University of Stirling's Dementia Services Development Centre has also produced guidance on Design Features to assist patients with dementia in general hospitals and emergency departments.

Recommendations

3/3 Creating/maintaining a non clinical feel to the environment can be achieved by using furnishings and fittings that are manufactured especially for this setting, and are easy to clean and maintain. For example, wood-effect vinyl can be used to create a less clinical environment, but cleanliness can be maintained. Vinyl is easy to maintain and will require less frequent replacement.

3/4 In some specialties for example where there is a potential for self harm, vitreous china (porcelain) basins and toilets would present a risk to a vulnerable patient; alternatives such as resin or stainless steel should be considered. Cleaning of these materials should, however, be considered carefully.

3/5 There should be sufficient access to hand hygiene facilities for staff. Siting of clinical wash-hand basins should be carefully considered and may need to be restricted to supervised areas such as the clean utility room, treatment rooms and dirty utility room. In addition, the provision of staff-held hand gel is essential. Where necessary, the use of patient wash-hand basins in en suite rooms can be used with care to avoid recontamination of hands.

3/6 Where required in the likes of secure mental health units, hand dryers or vandal-proof integral hand-wash dryers in communal toilets may provide a safer option for hand hygiene while encouraging those in the service to clean hands.

3/7 Where single rooms are used for source isolation, risk assessment should inform the storage of protective clothing, soap and paper towels, healthcare waste receptacles etc. Risk assessment will determine the need for fixtures and fittings to be of the anti-ligature type. It should be noted that where rooms are used for isolation it is acceptable for the room to contain only a healthcare waste receptacle. Receptacles (bins) for other streams such as recyclates and residual waste are not required and should be discouraged.

3/8 Assessment of the need for a macerator or bedpan washer-disinfector should be undertaken. If a specific dirty utility room is not required, alternative procedures should be in place.

3/9 DH's 'Environmental design guide: adult medium secure services' advises on floor coverings to reduce risk of harm to self or others.

3/10 Consideration should be given to the use of underfloor heating where patients are susceptible, vulnerable or of low sensitivity. There is a need, however, to allocate space to accommodate above-floor manifolds and such systems can be slow to react to changes in temperature requirements due to inherent inertia.

3/11 Design guidance on storage space for Patients belongings can be found in SHPN 04, SHPN 35 and HBN 03-01.

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NHS Greater Glasgow and Clyde

Property, Procurement & Facilities Management Directorate

Water Systems Audit at the Queen Elizabeth University Hospital

Phyllis Urquhart, Compliance Manager

Start Date: 11th August 2017

End Date: 18th August 2017

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18/08/2017

Purpose:

The purpose of the audit is to carry out an Audit of the existing water systems at the Queen Elizabeth University Hospital.

Design:

This audit was designed to assess compliance with the Scottish Hospital Technical Memorandums (SHTM) and associated legislation at the Queen Elizabeth University Hospital and the aim is to identify any gaps and try to support the QEUH Staff. This Audit does not aim to repeat the findings of the Authorising Engineer's report available via the following link:- \\XGGC.SCOT.NHS.UK\GGCData\FolderRedirects\GRI3\URQUHPH771\My Documents\WATER LITERATURE\REPORTS\AE Audits. Estates Managers in attendance during the audit were Mr James Guthrie, Mr Thomas Romeo and Mr Bernie McCulloch.

Results

In accordance with SHTM04-01:Water safety for healthcare premises Part G: Operational procedures and Exemplar Written Scheme, Section 3 Planned maintenance procedures and Part B: Operational management and associated documentation the following findings were noted:

1. No record of the "High Risks" areas in the Hospital.
2. Sentinel point sensors are not sited on all water assets. Reported as design cost saving.
3. Sentinel Planned Preventative Maintenance (PPM) paperwork is not signed or dated.
4. Paperwork documentation regularly not signed or dated.
5. Calorifiers PPMs required (Design did not include Plate Heat Exchangers).
6. Point of Use Heaters at for site and CMB PPMs outstanding.
7. No external mains valve flushing and flushing routines evident.
8. Quarterly email of little used outlets communication outstanding.
9. Thermostatic mixing valve (TMV) and mixing valve sanitisation and maintenance checks required.
10. High Risk Areas TMV PPMs frequency non-compliant.
11. Contractor maintenance records outstanding for shower head and flexible hoses de-scale and sanitisation.
12. Risk Assessment and written scheme required details all associated water systems documentation.
13. Calorifier frequency checks review required.
14. Emergency alarms are not being monitored by staff and the escalation process is not managed in respect of out of specification planned preventative maintenance works.
15. PPM returns checking incomplete.
16. Management duties and responsibilities review required.
17. No management communication in respect of alterations and/or change of use works (or cascading of information evidence from senior management).
18. No record of areas not in use and/or requiring flushing, such as Old Special Care Baby Unit and Spinal Injuries for example.
19. Record of TMV3 Domestic Services Room removal programme outstanding.
20. DMA record management required.
21. Emergency Contacts list not available to all staff.
22. Staff are not familiar with the occupancy use within Retained and new sites.
23. Annual tank PPMs should be checked by Duty Management.
24. Tank capacity and use to be recorded.
25. Records confirm no incidents since 10 February 2017 which requires management review.
26. PPMs for air handling outstanding and management checks required.
27. No Competent Persons or Authorised Persons on site and recorded and no associated training.
28. Weekly water system check for chloramines (where required) outstanding.
29. Annual descaling, cleaning and disinfection of strainers (including angle valve strainers) or frequency as indicated by the rate of fouling or other risk factors, e.g. areas with high risk patients).

30. Accessible drawings should be made available to all staff.

'Conclusion / Discussion / Recommendations / Actions'

In conclusion recommendation to address and incorporate the outstanding findings should be taken with immediate effect to reduce the Board's exposure to risk.

P Urquhart 18th August 2017

Written Scheme
For Legionella Control

Queen Elizabeth University Hospital (Adult)
& Royal Hospital for Sick Children

December 2016 Update

WRITTEN SCHEME

This document sets out in writing guidance to assist the NHS Trust to create a written scheme to manage and control the risks from exposure to legionella bacteria within the Queen Elizabeth University Hospital complex (Adult and Children's hospitals). This document has been updated from the initial Written Scheme Guidance based on information as supplied by NHS GG&C Estates in December 2016.

The guidance includes domestic hot and cold water systems with reference to other systems as identified by NHS Estates to DMA Water Treatment guided by SHTM 04-01 and L8/HSG 274.

Building Overview

The Queen Elizabeth University Hospital (comprising the Royal Hospital for Sick Children and the Adult's Hospital) is a 1109 bedded Adult Hospital and a 256 bedded Children's Hospital. This facility has the biggest Critical Care complex and one of the biggest Emergency Departments in Scotland. The facility offers acute specialist inpatient care, medical day care services and also outpatient clinics servicing the local population.

The 14-floor adult hospital and contains 1,109 beds and state of the art Emergency, Acute Receiving, Critical Care, Theatres and Diagnostic Services.

The new children's hospital, with a separate identity and entrance, is adjoined to the adult hospital, with 256 beds over five storeys replacing the original Royal Hospital for Sick Children located in Yorkhill.

The children's hospital provides a large number of specialist services to the West of Scotland and the wider population of Scotland in addition to the full range of secondary care services to people of Greater Glasgow and Clyde. Specialist services include: cardiology and cardiac surgery, renal and bone marrow transplantation. For a number of these specialised services, the children's hospital is recognised as the sole provider in Scotland.

The construction phase ended in January 2015 with phased occupancy of patient areas beginning in April 2015 and full working occupancy achieved in the summer of 2015.

Risk Assessment

The assessment of risk is an on-going process and not merely a paper exercise. The Dutyholder should arrange to review the assessment regularly and specifically when there is reason to suspect it is no longer valid.

The Risk Assessment should be reviewed to ensure it remains relevant in a fully functioning hospital as wards and department designations change.

Ongoing assessment reviews shall be required. An indication of when to review the assessment and what to consider should be recorded and this may result from, e.g.:

- a change to the water system or its use;
- a change to the use of the building/ward/clinical etc. areas;
- new information available about risks or control measures (e.g. updated legislation/SHTMs);
- the results of checks indicating that control measures are no longer effective;
- changes to key personnel;
- a case of legionnaires' disease/legionellosis associated with the system.

Greater Glasgow and Clyde Health Board Written Scheme and Policies and SHTM 04-01 Part G provides further guidance on this matter.

WRITTEN SCHEME

Management structure:

SHTM 04-01 Part B Section 2 gives guidance on Management Responsibilities and Section 6 provides guidance on hierarchy and designated staff functions along with definitions of individual positions and responsibilities. This is mirrored in Greater Glasgow and Clyde Health Board Written Scheme and Policies. These should be used when assigning specific job roles and populating the Legionella Management Hierarchy.

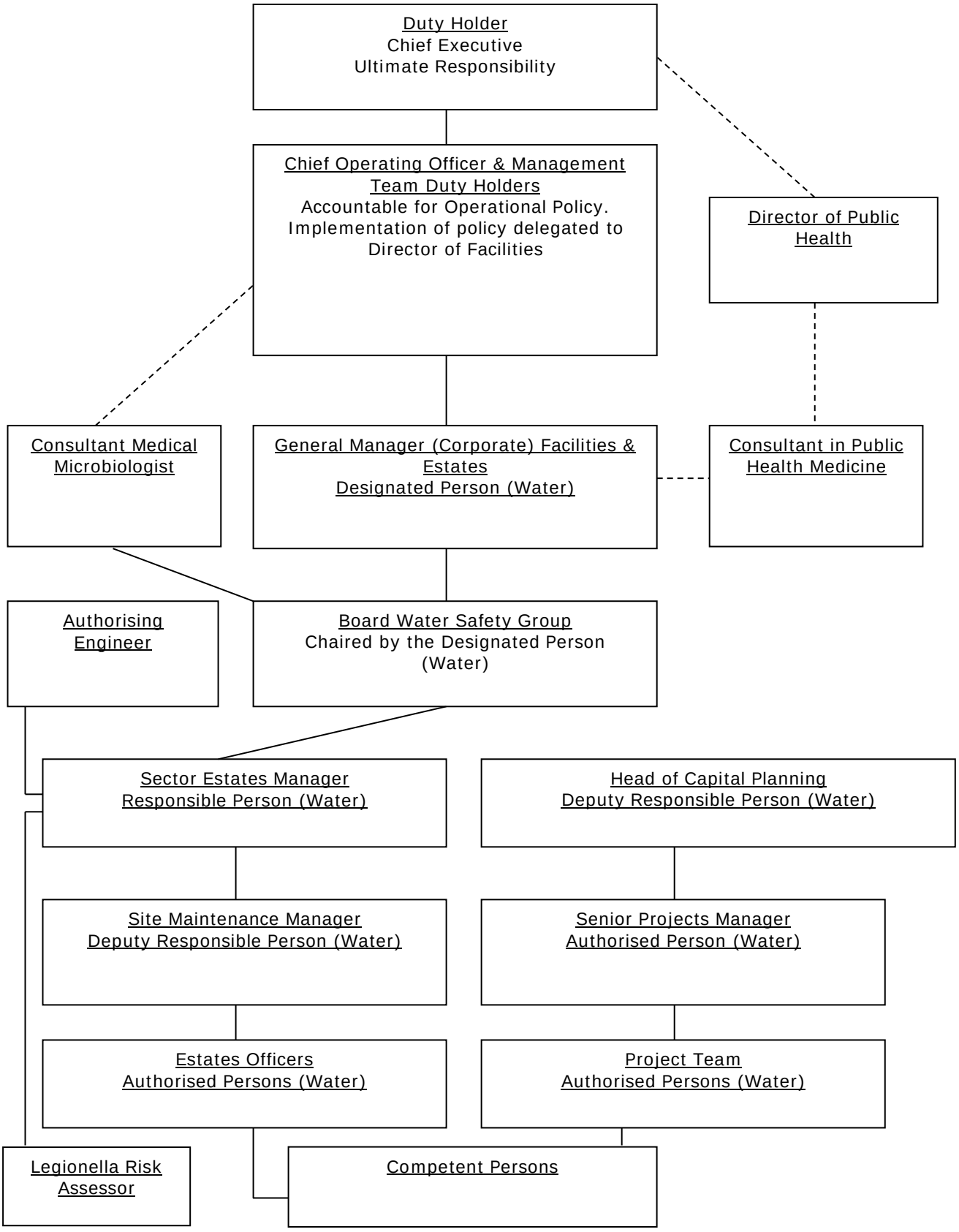
Management should implement a programme of staff training to ensure that those appointed to devise strategies and carry out control measures are appropriately informed, instructed and trained, and should be assessed as to their competency. It is also essential that they have an overall appreciation of the practices affecting water hygiene and safety and that they can interpret the available guidance and perform their tasks in a safe and technically competent manner. The rate of change in building service technology is not great, but knowledge of harmful bacteria continues to grow and management should review the competence of staff on a regular basis, and refresher training should be given; records of training attendance would need to be maintained. Although training is an essential element of ensuring competence, it should be viewed within the context of experience, knowledge and other personal qualities that are needed to work safely. Competence is dependent on specific needs of individual installations and the nature of risks involved.

A training matrix for all persons involved in the management and/or carrying out control measures (e.g. flushing, maintenance/ppm tasks) should be created and maintained.

The management structure and roles/responsibilities should include management of contractors and communication between Estates and local duty holders in Ward/Departments for identification of underused outlets or other control issues.

WRITTEN SCHEME

Greater Glasgow and Clyde Written Scheme Hierarchy Diagram

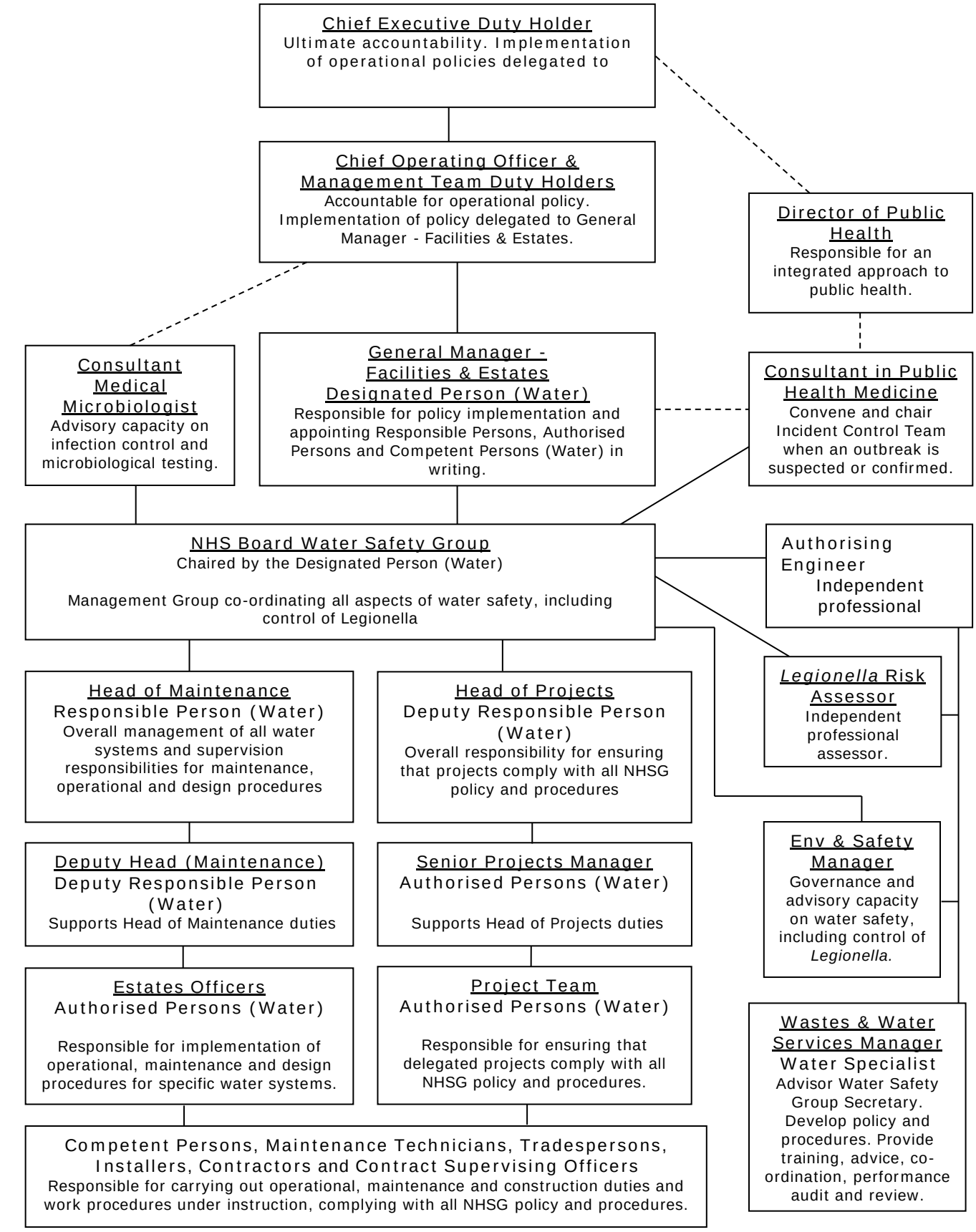


Please refer to Hierarchy Appointment Table for named individuals for the roles above assigned within NHS GG&C.

N.B. Ensure all actions are recorded and stored in the site L8 Legionella Logbook

WRITTEN SCHEME

SHTM 04-01 Part G Written Scheme Hierarchy Diagram



Please refer to Hierarchy Appointment Table for named individuals for the roles above assigned within NHS GG&C.

N.B. Ensure all actions are recorded and stored in the site L8 Legionella Logbook

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WRITTEN SCHEME

Greater Glasgow and Clyde Written Scheme Hierarchy Appointment Table

Legionella Role	Name	Appointment	Generic Title	Phone
The Duty Holder	Robert Calderwood		Chief Executive	[redacted]
Duty Holders	Grant Archibald		Chief Operating Officer	
Duty Holders	David Louden		Director of Facilities	
Designated Person (Water)	Mary Ann Kane	In writing by CEO for CE	Associate Director of Facilities	
Designated Person (Water)	Alan Gallacher	In writing by CEO for CE	General Manager Estates (Corporate Compliance)	[redacted]
Authorising Engineer (Water)	Dennis Kelly (via LCI Ltd)	In writing by Associate Director of Facilities	Appointed Engineer from Appointed Organisation	[redacted]
Legionella Risk Assessors	Allan McRobbie David Watson Mike Kinghorn DMA Water Treatment Ltd	In writing by Responsible Person (Water) Estates	AM - Compliance Manager DW - Director MK - Director	[redacted]
Responsible Person (Water) Estates	Ian Powrie	In writing by General Manager Estates (Corporate Compliance)	Head of Maintenance (Sector Estates Manager, South & Clyde)	[redacted]
Deputy Responsible Person (Water) Capital Projects	Hazel McIntyre	In writing by General Manager Estates (Corporate Compliance)	Head of Projects	
Deputy Responsible Person (Water), Estates and Authorised Person (Water)	Colin Purdon (QEUH Retained Estate) David Brattey (QEUH Adult's and Children's)	In writing by General Manager Estates (Corporate Compliance)	Deputy Head of Maintenance (Site)	[redacted]
Authorised Person (Water) Estates	Jim Guthrie (QEUH Adult's and Children's)	In writing by General Manager Estates (Corporate Compliance)	Duty Manager	
Competent Person (water)	Mick Daniels Arthur Burns Jason Weir Mark McInally Robert Malloy David Sickling	In writing by General Manager Estates (Corporate Compliance)	Estates Technicians (Plumber)	

Notes:
Appointments should be confirmed in writing. All persons appointed should be named in the above table. Where there are more than one member of staff nominated for a Legionella Role (e.g. Authorised and Competent Persons) each of these should be named along with the appropriate escalation pathway.

Date of training for all persons should also be recorded on this table as and when completed.

A similar table is provided within SHTM 04-01 Part G.

WRITTEN SCHEME

Others Involved

Legionella Role	Name	Appointment	Generic Title	Phone
Infection Prevention & Control	Theresa Inkster	To be confirmed	Consultant Medical Microbiologist	
Laboratory Services	Pat Millar	To be confirmed	Biomedical Scientist	
Governance and Advisor	Phyllis Urquhart	To be confirmed	Compliance Manager (Legionella)	
Public Health	Ian Kennedy	To be confirmed	Consultant in Public Health Medicine	
O H & S Manager	John Green	To be confirmed	Health & Safety Manager	
HSE	Health and Safety Executive			

All training and competency assessments provided to and received by all NHS Board personnel involved in water systems should be recorded in the individual's personal training file and the national NHS eKSF system and site logbook.

The Authorising Engineer should conduct a regular annual assessment review of competency and training requirements and shall make Training Programme recommendations to the Responsible Person (Water) for approved courses run by approved training organisations and where appropriate by the manufacturers of equipment.

WRITTEN SCHEME

Summary of L8 Management Tasks Required for L8 and SHTM 04-01 Compliance	Guidance Documents	Allocated to
2A Regular check to ensure that legislation and guidance has not changed	L8 HSG 274 Pt 2 SHTM 04-01	NHS Estates
2B Regular review of all policies relating to legionella control (e.g. Maintenance, Water Treatment, Water Management, Energy) to ensure still valid and correct	L8 HSG 274 Pt 2 SHTM 04-01	NHS Estates
2C Regular review of L8 Management Structure to ensure up-to-date and accurate	L8 HSG 274 Pt 2 SHTM 04-01	NHS Estates
2D Regular review of communication lines to ensure still accurate and correct	L8 HSG 274 Pt 2 SHTM 04-01	NHS Estates
2E Regular review of escalation & emergency procedures to ensure still valid and correct	L8 HSG 274 Pt 2 SHTM 04-01	NHS Estates
2F Regular review of duties allocated to site staff and ensure accurate and recorded	L8 HSG 274 Pt 2 SHTM 04-01	NHS Estates
2G Regular review of duties of sub-contractors and ensure accurate and recorded and contractors are suitably qualified/competent for tasks assigned to them (e.g. Water Hygiene contractors should be LCA Approved, Plumbing contractors should be SNIPEF and Water Safe Registered)	L8 HSG 274 Pt 2 SHTM 04-01	NHS Estates
2H Regular review of staff training requirements and update training matrix	L8 HSG 274 Pt 2 SHTM 04-01	NHS Estates
2I Regular review of method statements and risk assessments to ensure still valid and correct	L8 HSG 274 Pt 2 SHTM 04-01	NHS Estates
2J Regular review of site documentation to ensure all records up to date and present	L8 HSG 274 Pt 2 SHTM 04-01	NHS Estates
2K Regular update of "Patient Risk Rating" register for all areas of hospital.	SHTM 04-01 Part B	NHS Estates
2L Regular review of sentinel outlet locations register.	SHTM 04-01 Part B	NHS Estates
2M Regular review of primary, sub-ordinate and tertiary hot flow and return loops to reflect any system alterations.	HSG 274 Pt 2	NHS Estates
2N Regular review of plant and equipment maintenance schedules.	Manufacturer's Instructions	NHS Estates
2O Regular review of BEMS temperature sensor locations to reflect any system alterations	HSG 274 Pt 2	NHS Estates
2P Regular review of schematic/as-fitted drawings to ensure up-to-date and accurate	L8 HSG 274 Pt 2 SHTM 04-01	NHS Estates
2R Regular review of L8 risk assessment Factors which may require a review of the assessment include; • a change to the water system or its use; • a change to the use of the building/ward/clinical etc. areas; • new information available about risks or control measures (e.g. updated legislation/SHTMs); • the results of checks indicating that control measures are no longer effective; • changes to key personnel; • a case of legionnaires' disease/legionellosis associated with the system.	L8 STHM 04-01 Part B	NHS Estates

N.B. By "Regular" DMA would advise a Quarterly or 6 monthly review of all tasks above or as and when there are changes in system operation, management or other control parameters which would warrant a review of any particular task. (e.g. if change of use or changes in legislation or any other factor which could affect validity any of the current documentation)

WRITTEN SCHEME

Description of Water Services

There are 2 separate incoming mains water supplies serving the Adults and children's hospital building. These enter the building in the basement manifold room and basement tank room and run into the tank room to serve 4 off Raw Water storage tanks. These incoming mains both have double check valves and water meters fitted as they enter the building. The water meters are linked to the BMS system and allow the user to cross reference the quantity of water used against the quantity indicated on the external meter. This will highlight if there are any leaks on the external water main.

Each mains supply feeds a separate side of each split Raw Water storage tank ensuring continuity of supply if one of the mains services was to be in interrupted or contaminated.

From the Raw Water tanks the water is then filtered through the filtration plant before being stored in the potable bulk cold water storage tanks. All cold water storage tanks are 2 compartment tanks and are piped in such a way as to allow tank maintenance without disrupting the water supply to the building.

There are 10 domestic water storage tanks in the building:

- 4 No. 50,000 Litre Raw water storage break tanks
- 4 No. 135,000 Litre Potable bulk cold water storage tanks
- 2 No. 2000 Litre Trade water storage tank

There are 2 No. water booster sets in the water tank room. Each booster set is set to a different set point pressure depending on which plantroom it serves. In the event of failure each booster can also be switched to the other set point pressure.

- BS01 – Feeding Plantroom 31, 32 & 33 - 7.7 Bar
- BS02 – Feeding Plantroom 21, 22 & 41 – 5 Bar

From the 2 No. water booster sets there are 8 domestic water systems:

- Plantroom 21
    - Via a Pressure reducing valve (PRV) the BCWS feed 21CAL01/02/03
- Plantroom 22
    - Via a Pressure reducing valve (PRV) the BCWS feed 22CAL01/02/03
- Plantroom 31 – 122
    - BCWS feeds 31CAL01/02/03
- Plantroom 31 – 128
    - Via a Pressure reducing valve (PRV) the BCWS feeds 31CAL07/08/09
- Plantroom 31 – 129
    - BCWS feeds 31CAL04/05/06
- Plantroom 32
    - BCWS feeds 32CAL01/02/03
- Plantroom 33
    - BCWS feeds 33CAL01/02/03
- Plantroom 41
    - BCWS feeds 41CAL01/02/03

The water supply into each plantroom is metered by a CWS flow meter. This allows for monitoring of specific parts of the system for energy purposes.

From the plantroom supply the BCWS is distributed to each riser and the bank of calorifiers. The water in the calorifiers is heated via a plate heat exchanger (feed from the MTHW circuit) on each calorifier skid.

The BCWS and HWS F&R are then distributed together allowing for positive separation of systems/plantrooms on the floors. The hot water is circulated to the outlet and back to the calorifiers by a hot water return pump so that temperature is maintained throughout the system. This ensures hot water is available within 1 minute at every outlet.

N.B. Domestic water system description above as provided by Brookfield Multiplex.

WRITTEN SCHEME

Drawings

Schematic/As-fitted drawings were generated as part of the hospital construction and supplied to NHS GG&C. The availability of accurate as-fitted drawings is essential for the safe operation of hot and cold water service systems. Schematic drawings of the system with numbered and labelled valves will reduce confusion and save time in trying to identify appropriate isolating valves and other system components.

The locations of as-fitted drawings and schematics should be recorded in the water system logbook(s) along with instruction on how to access them should these only be held electronically. Any alterations to the system should be recorded on all copies drawings (e.g. paper and electronic copies).

Separate schematic drawings should be prepared and displayed in in a frame in the relevant plantroom, complete with valve schedule such that all plant items, control valves etc. can be identified.

Correct and safe operation of the system

Mercury Engineering have provided documentation relating to General Start-up and Shut Down procedures for both the domestic hot and cold water systems, along with fault finding procedures and a PPM schedule for the system which should be followed. This documentation should be retained and included within the site logbook.

Water temperature, system design/installation, frequency of use, water turnover and cleanliness of the system are the most significant factors in determining the risk potential.

Incoming mains water should be delivered to site into the CWSTs at less than 20°C.

Primary water treatment is carried out by Scottish Water. NHS should confirm whether this is in the form of Chloramination or Chlorination and an appropriate monitoring regime formulated.

The water stored within the tanks should be no more than 2°C higher than the incoming mains, and less than 20°C

Cold water should be delivered to outlets (and cold feed to thermostatic mixing valves) at less than 20°C within 2 minutes of outlet being run, and not more than 2°C above outlet water source temperature.

Hot water should be stored at a minimum of 60°C, with the entire body of the calorifier achieving this temperature for a minimum period of 1 hour per day. Hot water return temperatures should maintain a minimum temperature of 55°C[1] at all times.

Hot water should be delivered to outlets (and hot feed to thermostatic mixing valves) at more than 55°C, within 1 minute of outlet being run.

All plant should be maintained in accordance with the relevant manufacturers, and installer's instructions and the appropriate guidance documents (e.g. SHTM 04-01, L8/HSG 274).

Where deficiencies are found in the control parameters required the suitable escalation and remedial/corrective action procedures should be implemented.

All other uses of water should also be considered and appropriate action taken, as these may not be appropriate in an augmented care setting (e.g. use of ice machines, drinking water fountains, bottled water dispensers etc.). Where required, they should be considered as part of the risk assessment as there is an increased risk in compromised patients for legionella infection to occur following aspiration of ingested water contaminated with legionella.

No point of use filters for legionella control or background chemical dosing systems for legionella control are fitted at present. Details of any future policy decisions to fit, operate and maintain or remove point of use filters to/from specific points in the systems should be referenced in this written scheme and site logbook.

[1] 55°C being the control parameter DMA advised as being the design return temperature to the calorifiers on domestic hot water. (SHTM 0401 requires 50°C. HSG 274 Part 2 is contradictory, requiring 50°C in paragraph 2.156 and 55°C in Table 2.1.)

WRITTEN SCHEME

Initial tasks required to aid compilation of PPM schedules/registers within site written scheme	Guidance Documents	Allocated to
1A. Identify, label and record all plant, valves and services	HSG 274 Pt 2 SHTM 04-01 (Part B)	NHS Estates
1B. Identify, label and record sentinel outlets on hot and cold water services.[2]	SHTM 04-01 (Part B)	NHS Estates
1C. Identify, label and record all "drinking" and "non-drinking" water outlets	SHTM 04-01 (Part B)	NHS Estates
1D. Identify, label and record all primary, sub-ordinate and tertiary flow and return loops and their access points for temperature profile/mapping	HSG 274 Pt 2	NHS Estates
1E. Identify, label and record all BEMS temperature sensor locations for temperature profile/mapping	HSG 274 Pt 2	NHS Estates
1F. Identify, label and log all mixing devices (TMVs) with a unique identification as well as identification of its type. Hot and cold water pressures also need to be measured and recorded for each mixing device together with all the test parameters from the in-service tests	SHTM 04-01 (Part B)	NHS Estates
1G. Identify, label and log all "other uses of water" (e.g. use of ice machines, drinking water fountains, bottled water dispensers etc.)	HSG 274 Pt 2	NHS Estates

[2] Sentinel outlets are normally those that – on a hot water service – are the first and last outlets on a recirculating system with additional points on larger systems where monitoring of primary, sub-ordinate and tertiary loops is required. On cold water systems (or non-recirculating hot water systems), they are the closest and furthermost from the storage tank (or water heater). The choice of sentinel taps should also include other outlets that are considered to represent a particular risk, for example those installed in accommodation in which particularly susceptible patients are treated, or others identified in the risk assessment and temperature mapping exercise as having the least satisfactory temperature performance.

WRITTEN SCHEME

Summary of ppm tasks required within site written scheme to aid compliance with SHTM 04-01 and L8/HSG 274	Guidance Documents	Allocated to
1. Daily water draw-off should form part of the daily cleaning process.	HSG 274 Pt 2 SHTM 04-01 (Part B)	Facilities / Clinical
2. Daily check the flow and return temperatures on the domestic hot water calorifier systems using the temperature gauges fitted or a suitable surface temperature probe (should BEMS be non-operational)	SHTM 04-01 (Part G)	NHS Estates
3. Daily check of BEMS incidents and faults	SHTM 04-01 (Part G)	NHS Estates
4. Incoming Water Mains - maintain in accordance with installation/design guidelines, ensuring alteration of incoming mains lines to run at least daily. (DMA advised 9 hourly swap over).	Brookfield Maintenance Schedule	BEMS (NHS Estates)
5. Cyclical alteration of CWST booster pumps (ensuring every pump runs at least weekly)	HSG 274 Pt 2 SHTM 04-01 (Part B)	BEMS (NHS Estates)
6. Daily check to ensure entire body of calorifier(top, middle, base) reaches 60°c for a period of 1 hour each day (generally at a time of low use e.g. Early morning/late evening)	HSG 274 Pt 2 SHTM 04-01 (Part A)	BEMS (NHS Estates)
7. Daily flushing of all outlets[3] in "High Risk Areas"/ICUs. Hot and cold outlets should be flushed for a minimum of 3 minutes and until the water temperature stabilises in line with current temperature profile.[4]	SHTM 04-01 (Part G) Risk Control Notice 11/04	Facilities / Clinical
8. Twice-weekly flushing of all outlets in unoccupied areas and low use/sporadically used outlets. Hot and cold outlets should be flushed for a minimum of 3 minutes and until the water temperature stabilises in line with current temperature profile.[5]	HSG 274 Pt 2 SHTM 04-01 (Part B)	NHS Estates
9. Twice weekly flushing of emergency/deluge shower for a minimum of 3 minutes and the water temperature stabilises in line with current temperature profile.	SHTM 04-01 Part G Risk Control Notice 11/04	NHS Estates
10. Twice weekly flushing of deadlegs/blind ends where these cannot be removed. All deadlegs should be flushed for a minimum of 3 minutes and until the water temperature stabilises in line with current temperature profile. [2]	HSG 274 Pt 2 SHTM 04-01 (Part B)	NHS Estates
11. Weekly water system check for chloramines (if required)	SHTM 04-01 (Part G)	N/A
12. Weekly check to ensure that non-return valves shut off tightly. Remove covers and examine further if they do not.	Brookfield Maintenance Schedule	NHS Estates
13. Weekly check of water levels within water tanks	Brookfield Maintenance Schedule	NHS Estates
14. Check spray taps for satisfactory spray, where necessary remove spray orifice and clean, remove any accumulation of scale. *(DMA understands no spray taps fitted though this should be confirmed)*	Brookfield Maintenance Schedule	NHS Estates
15. Monthly (minimum) manual test to confirm water system pumps operating correctly	HSG 274 Pt 2 SHTM 04-01 (Part B)	NHS Estates
16. Monthly calorifier storage temperatures checks at top (flow) and return pipework Flow temperature – min 60°C, return temperature – min 55°C[6]	HSG 274 Pt 2 SHTM 04-01 (Part B)	BEMS (NHS Estates)

Task frequencies described above are for guidance only. Frequencies may vary dependent on system conditions highlighted during routine monitoring or as risk assessment is updated.

[3] All outlets advised to be flushed daily in NHS GG&C Standard Operating Procedure (SOP) For Minimising The Risk Of Pseudomonas Aeruginosa Infection From Water

[4] Ensure aerosol creation is kept to a minimum when flushing of low use outlets and deadlegs.

[5] Ensure aerosol creation is kept to a minimum when flushing of low use outlets and deadlegs.

[6] 55°C being the control parameter DMA advised as being the design return temperature to the calorifiers on domestic hot water. (SHTM 0401 requires 50°C. HSG 274 Part 2 is contradictory, requiring 50°C in paragraph 2.156 and 55°C in Table 2.1.)

N.B. Ensure all actions are recorded and stored in the site L8 Legionella Logbook

WRITTEN SCHEME

Summary of ppm tasks required within site written scheme to aid compliance with SHTM 04-**01 and L8/HSG 274 (cont...)**	Guidance Documents	Allocated to
17. Monthly temperature checks on hot outlets at sentinel, little-used & selected outlets. >55°c within 1 minute (also note potential scald risks and out of spec TMVs)[7] to create a temperature profile of building and monitor flow and return system with all primary flow and return loops being monitored monthly, sub-ordinates quarterly and tertiary loops annually.	HSG 274 Pt 2 SHTM 04-01 (Part B)	NHS Estates
18. Monthly temperature checks on cold outlets at sentinel, little-used & selected outlets. <20°c within 2 minutes to create a temperature profile of building and monitor heat gain within the cold water system.[4]	HSG 274 Pt 2 SHTM 04-01 (Part B)	NHS Estates
19. Monthly check to ensure CWST overflows are unobstructed	Brookfield Maintenance Schedule	NHS Estates
20. Monthly flushing of expansion vessels as not 'flow through' design	HSG 274 Pt 2	NHS Estates
21. Quarterly descaling, cleaning and disinfection of showerheads & hoses & spray outlets, or replace with replace with new disinfected Shower Head and Hose (or frequency as indicated by the rate of fouling or other risk factors, e.g. areas with high risk patients)	HSG 274 Pt 2 SHTM 04-01 (Part B)	NHS Estates
22. Quarterly each calorifier and any associated storage/buffer vessels should be flushed through its drain valve by opening the drain valve 3 times, each time for a 3 minute period.	SHTM 04-01 (Part G)	NHS Estates
23. Quarterly servicing TMV's or mixer valves, including fail safe tests and cleaning/disinfection of strainers within "Designated High Risk Area"/ICUs (more frequently if manufacturer recommends, or if 'drift' in excess of 1°C at mixed outlet temperature highlighted during temperature monitoring or other maintenance)	HSG 274 Pt 2 SHTM 04-01 (Part G)	NHS Estates
24. Six monthly servicing TMV's or mixer valves, including fail safe tests and cleaning/disinfection of strainers. (more frequently if manufacturer recommends, or if 'drift' in excess of 1°C at mixed outlet temperature highlighted during temperature monitoring or other maintenance)	HSG 274 Pt 2 SHTM 04-01 (Part B)	NHS Estates
25. Six monthly CWST condition inspection noting appearance of water, stagnation, odour, rust, scale, sediment, debris, paint/liner condition and bio film accumulation and tank lid fitting ok and insulation condition	Industry Good Practice	NHS Estates
26. Six monthly CWST temperature checks (summer and winter) on tank supply and stored water at opposite side from tank inlet if possible (inlet and stored water should be <20°C, with stored water no more than 2°C warmer than make-up water.)	HSG 274 Pt 2 SHTM 04-01 (Part B)	NHS Estates
27. Six monthly chemical and microbiological water samples from water tanks which feed drinking water outlets	BS 8558	NHS Estates
28. Annually arrange for samples to be taken from hot water calorifiers/water heaters in order to note condition of drain water.	SHTM 04-01 (Part B)	NHS Estates
29. Annual cleaning and disinfection CWST *and downservices* (more frequently if required dependant on CWST inspection & sample results). TVC and Legionella samples should be taken upon completion of disinfection works. Please Note: *Due to the system design and installation complete disinfection of all downservices fed from the Raw and Bulk water storage tanks may not be practical as "high risk" system such as renal dialysis is fed from these tanks. Alternative protocols/method statements for local disinfections should be prepared and maintained.*	SHTM 04-01 (Part B) SHTM 04-01 (Part G)	NHS Estates
30.[A] Annual descaling, cleaning and disinfection of strainers (including angle valve strainers) (or frequency as indicated by the rate of fouling or other risk factors, e.g. areas with high risk patients)	HSG 274 Pt 2 SHTM 04-01 (Part B)	NHS Estates

Task frequencies described above are for guidance only. Frequencies may vary dependent on system conditions highlighted during routine monitoring or as risk assessment is updated.

Notes:
[A] – Brookfield Maintenance Schedule advises this task is carried out on a monthly basis.
[B] – Brookfield Maintenance Schedule advises this task is carried out on a six monthly basis.

[7] Representative outlets include conventional and mixed-temperature taps; 20% of the total number installed throughout the premises would be tested annually on a rotational basis: that is, all taps checked every five years.

WRITTEN SCHEME

Summary of ppm tasks required within site written scheme to aid compliance with SHTM 04-**01 and L8/HSG 274 (cont...)**	Guidance Documents	Allocated to
31. [B] Annual internal inspection and cleaning/descaling of the calorifier/water heater with disinfection/pasteurisation upon completion	HSG 274 Pt 2 SHTM 04-01 (Part B)	NHS Estates
32. Annual inspection of vibration coupling on pumps/plant, replacing as necessary (more frequently if recommended by manufacturer)	HSG 274 Pt 2	NHS Estates
33. Annual inspection of plant and pipework insulation, repairing where necessary.	SHTM 04-01 (Part B)	NHS Estates
34. Biennial stratification checks on plate heat exchangers/calorifiers. These checks should extend over a period of seven (7) days using a logging device to establish that the water temperature at the base of the vessel achieves 50ºC.	SHTM 04-01 (Part G)	BEMS (NHS Estates)
35. Arrange for microbiological samples to be taken from water system which represent the complexity of the water system(s) and particularly in areas of concern. All sampling should be carried out in accordance with BS 7592:2008 and all analysis by a UKAS accredited laboratory.[8]	HSG 274 Pt 2 SHTM 04-01 (Part C) GG&C Written Scheme	NHS Estates
36. [C] Pasteurisation/disinfection of calorifier/water heaters carried out as and when required dependent on temperature monitoring and sample results	HSG 274 Pt 2 SHTM 04-01 (Part B)	NHS Estates
37. Turnover test on cold water storage system. Checks should be carried out to ensure that volume of water stored is no more than would generally be used in a normal 12 hour period.	HSG 274 Pt 2 SHTM 04-01 (Part B)	NHS Estates
38. As required descaling of taps/outlets (including aerators and flow straighteners) (frequency dependent on inspection results and hardness of water on site)	Industry Good Practice	NHS Estates
39. All EPDM flexi hoses (where fitted to articulated taps/outlets e.g. assisted baths) should be WRAS approved and should be replaced every 2 years if alternative materials cannot be used.	Industry Good Practice	NHS Estates
40. All plant items should be maintained in accordance with manufacturer's instructions and maintenance schedules, with tasks/duties allocated and recorded.	Manufacturer's Instructions	NHS Estates
41. Filtration equipment (Elga) – maintain in accordance with manufacturers guidelines, ensuring alteration of filtration sets to run at least daily. (DMA advised 9 hourly swap over).	Elga Brookfield Maintenance Schedule	BEMS (NHS Estates)

Task frequencies described above are for guidance only. Frequencies may vary dependent on system conditions highlighted during routine monitoring or as risk assessment is updated.

Notes:
[C] – Brookfield Maintenance Schedule advises this task is carried out on a monthly basis.

[8] Sampling regime should be formulated by site/client based on the known history of the water systems and the details included within this risk assessments, with assistance of specialist legionella consultant (e.g. DMA) if necessary. Although L8 does not specifically request legionella sampling, in cases where there are incorrect distribution or supply temperatures, water quality issues or other factors which may increase the likelihood of legionella proliferation and dissemination sampling should be carried out. For further guidance please refer to HSG 274 Part 2, SHTM 04-01 and BS 7592:2008

WRITTEN SCHEME

Other Risk Systems Identified to DMA

System / service	Task	Minimum Frequency
3A. MRI Chillers Wet/Dry (Adiabatic Cooling)	Depending on the actual design and operation of these units they may require to be registered with the local authority under the NCTEC Notification Requirements (See HSG 274 Part 1 Para 1.18 – 1.21 inclusive of Figure 1.4 and Info Box 1.1). These may also require ongoing treatment or monitoring programmes to be implemented depending on assessment. Maintain in accordance with manufacturers/installers instructions. Consider use of POU disinfection system such as UV for spray water.	TBC
	Connection point to MRI unit(s) should be included in site flushing regime and have suitable backflow protection fitted.	Twice weekly as part of site flushing regime
3B. Emergency Showers	HSG 274 Part 3 recommends minimum six monthly flushing of emergency/deluge shower, though Risk Control Notice 11/advises "flush through and purge to drain twice per week– source SHTM 04-01 Part G. NHS Estates should formulate an appropriate flushing regime and maintain in accordance with manufacturers/installers instructions.	Twice weekly as part of site flushing regime
3C. Dental Chairs/System	HSG 274 Part 3 states "Drain down, clean, flush and disinfect all system components, pipework and bottles twice daily. Disinfectant contact time as recommended by manufacturer. Take microbiological measurements (Refer to Decontamination HTM 01-05)	Twice daily
	SHTM 04-01 Part G states "Drain down and clean at the end of each working day".	Daily
	HTM 01-05 provides advice and recommendations for on-going maintenance and this should be followed in addition to manufacturers and installers instructions.	As per manufacturers/installers instructions.
	Take microbiological measurements – refer to *Decontamination Health Technical Memorandum 01-05: Decontamination in primary care dental practices*[5]	As indicated by bespoke risk assessment *(to be carried out by others)*
3D. Hydrotherapy Pool	Maintain in accordance with manufacturers/installers instructions and "PHLS Hygiene for Hydrotherapy Pools" and Pool Water Treatment Advisory Group (PWTAG) Code of Practice (Feb 2015).	Bespoke written scheme should be created for the hydrotherapy pool based on PHLS/PWTAG and manufacturers/installers instructions.

WRITTEN SCHEME

System / service	Task	Minimum Frequency
3E. Air Conditioning & Ventilation	Maintain in accordance with manufacturers/installers instructions and SHTM 03-01 and SHTM 04-01 Part G.	Maintenance regime/Written Scheme should be created based on SHTMs and manufacturers/installers instructions.
	This may include:	
	Inspect, clean & log glass traps	Monthly
	Humidity Section Inspection, Cooling Section Inspection and Ventilation Plant Inspection and Disinfection	Six monthly
3F. Steam Humidification	Maintain in accordance with manufacturers/installers instructions and SHTM 03-01 and SHTM 04-01 Part G. Offline at time of survey.	Maintenance regime/Written Scheme should be created based on SHTMs and manufacturers/installers instructions.
3G. Medical Gases/Medical Equipment (e.g. Nebulisers, incubators, etc.)	Conduct a risk assessment of each system, preferably using an assessment team comprising members knowledgeable in legionella management and control, as well as those familiar with the design and operation of the system and Infection Control/Clinical staff where appropriate. Control procedures within appropriate SHTM (or other relevant guidance) for system being assessed should be taken in to account during assessment(s). Any water softeners or other filtration equipment connected to these systems should be assessed at this time. Devise a control scheme based on the risk assessment.	Monitoring, inspection, and testing frequencies to be determined as indicated by bespoke risk assessment *(to be carried out by others)*
3H. Sprinkler System	Minimise aerosol creation during maintenance procedures. Consider wearing suitable masks to prevent ingestion as recommended by the FIA guidance. Maintain in accordance with manufacturers/installers instructions.	As per manufacturers/installers instructions.
3I. 12th Floor Heli-pad fire suppression system	Minimise aerosol creation during maintenance procedures. Consider wearing suitable masks to prevent ingestion as recommended by the FIA guidance. Maintain in accordance with manufacturers/installers instructions.	As per manufacturers/installers instructions.
	Include all points on the 12th floor Trades system (including inlet to fire tank) in site flushing regime.	Twice weekly as part of site flushing regime
3J. Irrigation System	Include in site flushing regime. Additional flushing may also be required (outlets run for extended periods) to bring temperatures on distribution system down particularly during periods of low use (e.g. in winter when irrigation system is not required to operate frequently). Maintain in accordance with manufacturers/installers instructions.	Twice weekly as part of site flushing regime
3K. Water Softeners	Maintain in accordance with manufacturers/installers instructions (including cleaning and disinfection of resin and brine tanks). Ensure aerosol creation is minimised during maintenance and testing procedures.	As per manufacturers/installers instructions.

Task frequencies described above are for guidance only. Frequencies may vary dependent on system conditions highlighted during routine monitoring or as risk assessment is updated.

WRITTEN SCHEME

System / service	Task	Minimum Frequency
3L. Endoscopy Wash	Maintain in accordance with manufacturers/installers instructions and current NHS (SHTM) protocols. Ensure aerosol creation is minimised during maintenance and testing procedures.	Maintenance regime/Written Scheme should be created based on SHTMs and manufacturers/installers instructions.
3M. Renal Dialysis (Adult)	Maintain in accordance with manufacturers/installers instructions, current NHS (SHTM) protocols and "Clinical Practice Guideline by the UK Renal Association of Renal Technologists". Ensure aerosol creation is minimised during maintenance and testing procedures.	Maintenance regime/Written Scheme should be created based on SHTMs and manufacturers/installers instructions.
3N. Renal Dialysis (Children's)	Maintain in accordance with manufacturers/installers instructions, current NHS (SHTM) protocols and "Clinical Practice Guideline by the UK Renal Association of Renal Technologists". Ensure aerosol creation is minimised during maintenance and testing procedures.	Maintenance regime/Written Scheme should be created based on SHTMs and manufacturers/installers instructions.
3O. Arjo Bath	Maintain in accordance with manufacturers/installers instructions. Where flexible hoses (i.e. internal to bath unit) cannot be removed then replacing with alternative WRAS approved hoses with linings other than EPDM should be considered.	As required
3P. Closed Chilled Systems	Minimise aerosol creation during maintenance procedures. Maintain in accordance with manufacturers/installers instructions.	As required
3Q. Closed Heating Systems	Minimise aerosol creation during maintenance procedures. Maintain in accordance with manufacturers/installers instructions.	As required
3R. Decorative Bubble Lamps	Maintain in accordance with manufacturers/installers instructions and ensure aerosols minimised during maintenance.	As required

Task frequencies described above are for guidance only. Frequencies may vary dependent on system conditions highlighted during routine monitoring or as risk assessment is updated.

WRITTEN SCHEME

Incident Plan

In the event of plant failure suppliers and installers guidance should be consulted. The location of all relevant literature should be recorded in the site logbook (e.g. Mercury fault finding guidance).

Mains and Stored Water

Currently there is no legal maximum water supply temperature from the Licensed Provider. In practice the water supply temperature to boundary point will be subject to seasonal variation. In winter this would normally be expected to be in the 5°C – 10°C range and in summer up to 20°C.

The following staged risk assessment escalation procedure should be employed where the water temperature in Cold Water Storage Tanks is 20°C or higher.

Stage 1 - Verification

- Where tepid cold water occurrence (i.e. ≥20°C) is reported from any numbers of cold water outlets, from maintenance/ppm, flushing procedures, from BEMS monitoring, or from the manual monitoring of storage tanks, the person identifying, or making a report must notify the relevant Authorised Person (Water) as soon as the problem is identified and confirm this in writing within 24 hours;

- The Authorised Person (Water) should liaise with the person identifying the problem and verify the problem by independently re-checking by means of taking the water temperature of the appropriate cold water storage tank, the temperature of each incoming mains supplies at the site boundary point (and building entry points of other buildings within the Southern General Hospital served by the same mains lines[9]) and the outflow distribution temperature;

- If the cold water storage temperature is confirmed as being 20°C or higher at any of the above noted points, then the Authorised Person (Water) should record this in writing as well as conducting continuous monitoring of the incoming cold water mains, the cold water storage and the outflow temperatures to establish the temperature profiles and in more detail over at least a one week period to determine the level of risk;

- If only one of the incoming mains lines is ≥20°C the consideration should be given to switching to the other mains supply until such times as "out-of-specification" mains line has returned to compliant parameters. Ensure if either mains line is non-operational it is included in a daily flushing regime and treated as per escalation procedures to follow.

- The Authorised Person (Water) should also review the Water Safety Log Book and take into account the recent water system history specifically to include:
    - the primary water treatment levels (for mains cold water supplied with Chlorine or Chloramination treatment);
    - any water sampling results;
    - system monitoring data including temperature monitoring and water quality chlorine or chloramination checks;
    - recent maintenance history; recent alterations, changes or additions to the water system;
    - any other changes made by Duty Holders or users of the water system;
    - On reviewing continuous monitoring temperature profiles action as Stage 2, 3 or 4 as appropriate of this escalation procedure should be undertaken. The Authorised Person (Water) will ensure that the Responsible Person (Water) is notified immediately in writing at each stage and also recorded in the Water Safety Log Book.

[9] Should other buildings within the Southern General not fall under the remit of the same Authorised Person (Water) then corresponding SGH Authorised Person (Water) should be notified of the issue to allow actions to be carried out. This escalation chain should be recorded in Greater Glasgow and Clyde Written Scheme Hierarchy Appointment Table.

WRITTEN SCHEME

Stage 2 - Initial Action – High Incoming Mains Cold Water Temperature

- Where the incoming mains cold water is 18°C or higher for more than a 48 hour period the Responsible Person (Water) should contact Business Stream (the Licensed Provider) who will work with Scottish Water to establish the reasons and determine a resolution. Continuous monitoring should continue and recorded in the risk assessment.

Stage 3 - water temperatures fluctuating above and below 20°C (but not higher than 25°C)

- Where water temperatures are fluctuating above and below 20°C in a regular cyclical manner over 72 hour periods in response to regular user water demand (but not higher than 25°C) and are more than 2°C higher than the incoming cold water mains supply temperature at the building entry point, then continuous monitoring should be continued by the Authorised Person (Water). The reason(s) for failure(s) should be identified and rectified as soon as possible. This should be recorded by updated risk assessment (specifically in relation to the patient risk rating – where there may be increased risk and appropriate actions may be required to mitigate exposure. An up to date register of all areas and their subsequent patient risk ratings should be maintained).

- considerations for failures include:
  - accuracy of temperature sensors (requiring recalibration);
  - temperature sensors being located in water (requiring reposition where tank storage levels been reduced and sensor no longer sensing stored water);
  - inappropriate standby tank configuration;
  - temperature sensor in standby system;
  - temperature sensor measuring stagnation (requires reposition);
  - inappropriate siting (not in a cool location);
  - heat gain to the tank and pipework (due to lack of appropriate insulation or located close to heat gain from other heat sources);
  - storage capacity not minimised to match daily use (12 hours storage is recommended);
  - ingress of hot water through cross connection or mixing valve failure (i.e. from DHW system or MTHW systems);

Stage 4 - water temperatures fluctuating above and below 25°C (and rarely below 20°C)

- In this situation continuous monitoring should be continued by the Authorised Person (Water), the reason(s) for failure(s) (as Stage 3) identified and rectified on an urgent basis. This should be recorded by updated risk assessment (specifically in relation to the patient risk rating – where there will be an increased risk and appropriate actions will be required to mitigate exposure. An up to date register of all areas and their subsequent patient risk ratings should be maintained);

- In this situation a permanent solution, such as ventilation for the plant room, or changing the water storage arrangements, or forming a circulating distribution system (with or without chilling depending on the circumstances) would require to be implemented;

- The Authorised Person (Water) should, unless instructed in writing to the contrary by Responsible Person (Water) implement the following:
  - arrange to drain the tank contents and clean if necessary *(and/or carry out local disinfections where appropriate)*;
  - inform the users of the failed system that they must not draw off any water from the affected system until further notice;
  - suitable disinfection of the tank and/or distribution system shall be carried out.
    Please Note: *Due to the system design and installation complete disinfection of all downservices fed from the Raw and Bulk water storage tanks may not be practical as "high risk" system such as renal dialysis is fed from these tanks. Alternative protocols/method statements for local disinfections should be prepared and maintained*;
  - thereafter the tank/local area being disinfected shall be brought back into service;
  - finally the users shall be informed that the system is back in operation.

The Authorised Person (Water) shall complete an Incident Report Record Form. An entry should also be made in the Water Safety Log Book and the Responsible Person (Water) should be notified in writing as soon as possible.

WRITTEN SCHEME

Hot Water Services

When hot water storage or distribution temperatures fall below those required (60°C storage, 55°C at outlets and returning to calorifier) these will almost inevitably be caused a mechanical fault. Appropriate maintenance procedures, including the Mercury Fault Finding guidance documents, should be created and referenced to assist in timely rectification.

This escalation procedure (taken from SHTM 04-01 Part G) should be employed if the Calorifier/Plate Heat Exchangers outflow temperature falls below 45ºC.

The table below should be used to decide on the actions necessary in the event of a plant breakdown such as power failure or steam supply failure.

Breakdown leading to temperature <45ºC, lasting for:	Risk Category	Action
<12 hrs	High	Verify
	Significant	Verify
	Moderate	Verify
>12 hrs	High	Thermally pasteurise
	Significant	Verify
	Moderate	Verify
>24 hrs	High	Thermally pasteurise
	Significant	Thermally pasteurise
	Moderate	Verify
>72 hrs	High	Thermally pasteurise
	Significant	Thermally pasteurise
	Moderate	Thermally pasteurise

In the event of a reduction in domestic hot water temperature the Authorised Person (Water) should be notified in writing as soon as possible. The reason for failure must be identified and rectified as soon as possible.

The Authorised Person (Water) shall notify the Duty Holder and users on the failed system that they must not draw off any hot water from the affected services until further notice.

The relevant Duty Holder shall ensure that their staff are aware of the situation, and that they in turn shall prevent patients from using affected services.

Where thermal pasteurisation is to be carried out, the temperature of the calorifier or plate heat exchanger shall be raised to 70ºC, and the water shall be circulated throughout the affected distribution system for at least one 1 hour. Each tap or appliance should be run in sequence until full temperature is achieved (this should be measured). To be effective the temperature in the calorifier or plate heat exchanger should be high enough to ensure that all distribution outlets receive water at a temperature of greater than 60ºC. Ensure the return flow to the calorifier or plate heat exchanger is no less than 55ºC.

The Authorised Person (Water) shall inform users that the system is back in operation.

Bacteriological samples should be taken in consultation with the Infection Prevention and Control team.

The Authorised Person (Water) shall complete an Incident Report Record and ensure the Responsible Person (Water) is notified in writing as soon as possible. Maintain hard copy records in the Water Safety Log Book.

WRITTEN SCHEME

Guidance for System Disinfections

SHTM 04-01 Part A Table 3: Water systems cleaning and disinfection

System / Service	Circumstance Requiring Cleaning and Disinfection	Frequency
Domestic Cold Water and Domestic Hot Water Tanks	New installations and modifications or additions.	As required
	Re-commissioning empty/unused tanks.	As required
	Tank temperature exceeds 25°C. (Check with Risk Assessment).	As required
	Tank contains moderate sediment, i.e. a complete covering of the tank base.	As required
	Evidence of tank corrosion (check with Risk Assessment).	As required
	Any contamination of tank (by organic, by vermin or vermin faeces or similar).	As required
	Gross organic contamination e.g. large number of dead insects, feathers, animal or bird bodies etc.	As required
	Regular programme for high-risk healthcare category, with disinfection* where identified in the local Written Scheme (check with Risk Assessment).	Annually
	Regular programme for medium risk healthcare category, with disinfection* where identified in the local Written Scheme (check with Risk Assessment).	2 Yearly
	Regular programme for non-healthcare premises, with disinfection where identified in the local Written Scheme (check with Risk Assessment).	5 Yearly
Domestic Cold Water Distribution System	New installations and modifications or additions.	As required
	Temperature exceeds 25°C. (Check with Risk Assessment).	As required
	Any contamination of tank (by organic, by vermin or vermin faeces or similar).	As required
	Gross organic contamination e.g. large number of dead insects, feathers, animal or bird bodies etc.	As required
Domestic Hot Water Calorifier, Storage/Buffer Vessels	New installations and modifications or additions.	As required
	Temperature has fallen below 45°C.	As required
	Re-commissioning of empty/unused plant.	As required
	Any contamination of header tank (by organic, by vermin or vermin faeces or similar).	As required
	Regular programme.	Annually
Domestic Hot Water Distribution System	New installations and modifications or additions.	As required
	Temperature has fallen below 45°C.	As required
	Any contamination of header tank (by organic, by vermin or vermin faeces or similar).	As required
Air Handling Units	Any contamination (by organic, by vermin or vermin faeces or similar).	As required
	Gross organic contamination e.g. large number of dead insects, feathers, animal or bird bodies etc.	As required
	Chiller battery, drip trays and drainage pipework.	6 monthly

Notes:

- Due to the system design and installation complete disinfection of all downservices fed from the Raw and Bulk water storage tanks may not be practical as "high risk" system such as renal dialysis are fed from these tanks. Alternative protocols/method statements for local disinfections should be prepared and maintained.
- NHS/HFS Confined Spaces policies, procedures and guidance should be considered when preparing safety risk assessments and method statements for disinfection works where applicable.
- Please note that disinfectant chemical and the concentration/contact times may impact on plant and equipment warranties. This should be considered as part of any disinfection procedures.

WRITTEN SCHEME

Microbiological Sampling (Legionella)[10]

Sampling requirements and frequency are to be formulated by NHS and written scheme should be updated as appropriate. Infection Control input should also be sought with regards to sampling protocols and requirements.

Legionella testing may be required:

- In systems where the temperature control regimes are not consistently achieved, frequent testing e.g. weekly should be carried out to provide early warning of loss of control. Once the system is brought back under control as demonstrated by monitoring, the frequency of testing should be reviewed
- Weekly checks are recommended until the system is brought under control;
- When an outbreak is suspected or has been identified;
- In wards with at-risk patients (As designated by Infection Control) – for example those who are immuno-compromised (e.g. Ward 2A, Ward 4B)

As a minimum, samples should be taken as follows:

- From the cold water storage and the furthermost outlet from the tank, on every loop;
- From the calorifier flow, or the closest tap to the calorifier, and the furthermost tap on the hot water service circulating system (these should be identified on sentinel outlet register);
- Additional samples should be taken from the base of the calorifier via drain valves;
- From areas where the target control parameters are not met (i.e. where temperatures are below 55°c for hot water systems or ≥20°c for cold water systems);
- From areas subject to low usage, stagnation, excess storage capacity, dead legs, excessive heat loss, crossflow from the water system or other anomaly.
- "High Risk" Patient Areas (As designated by Infection Control)
- Additional random samples may also be considered appropriate where systems are known to be susceptible to colonisation.

The temperature control regime is the preferred strategy for reducing the risk from *Legionella* and other waterborne organisms in water systems. This will require monitoring on a regular basis. The recommended test frequencies for various outlets are set out in Table 2 in Section 7.

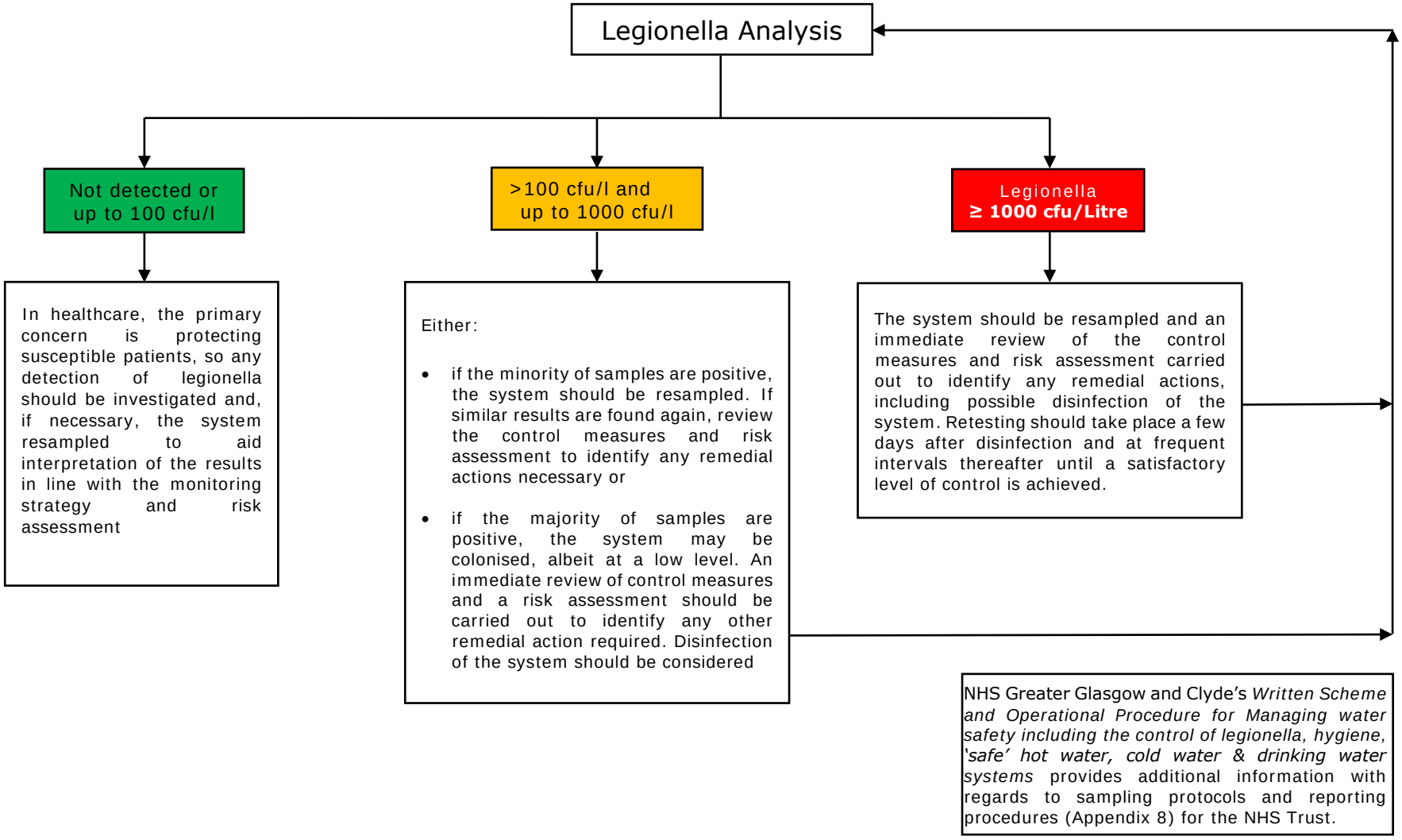
HSG 274 Part 2 Table 2.3 Actions to be taken following legionella sampling in hot and cold water systems in healthcare premises with susceptible patients

Legionella bacteria (cfu/l)	Recommended actions
Not detected or up to 100 cfu/l	In healthcare, the primary concern is protecting susceptible patients, so any detection of legionella should be investigated and, if necessary, the system resampled to aid interpretation of the results in line with the monitoring strategy and risk assessment
>100 cfu/l and up to 1000 cfu/l	Either: • if the minority of samples are positive, the system should be resampled. If similar results are found again, review the control measures and risk assessment to identify any remedial actions necessary or • if the majority of samples are positive, the system may be colonised, albeit at a low level. An immediate review of control measures and a risk assessment should be carried out to identify any other remedial action required. Disinfection of the system should be considered
>1000 cfu/l	The system should be resampled and an immediate review of the control measures and risk assessment carried out to identify any remedial actions, including possible disinfection of the system. Retesting should take place a few days after disinfection and at frequent intervals thereafter until a satisfactory level of control is achieved

[10] Sampling regime should be formulated by site/client based on the known history of the water systems and the details included within this and previous risk assessments, with assistance of specialist legionella consultant (e.g. DMA) if necessary. For further guidance please refer to HSG 274 Part 2, SHTM 04-01 Parts 2 & 3, Greater Glasgow and Clyde Written Scheme and Operational Procedure and BS 7592:2008

WRITTEN SCHEME

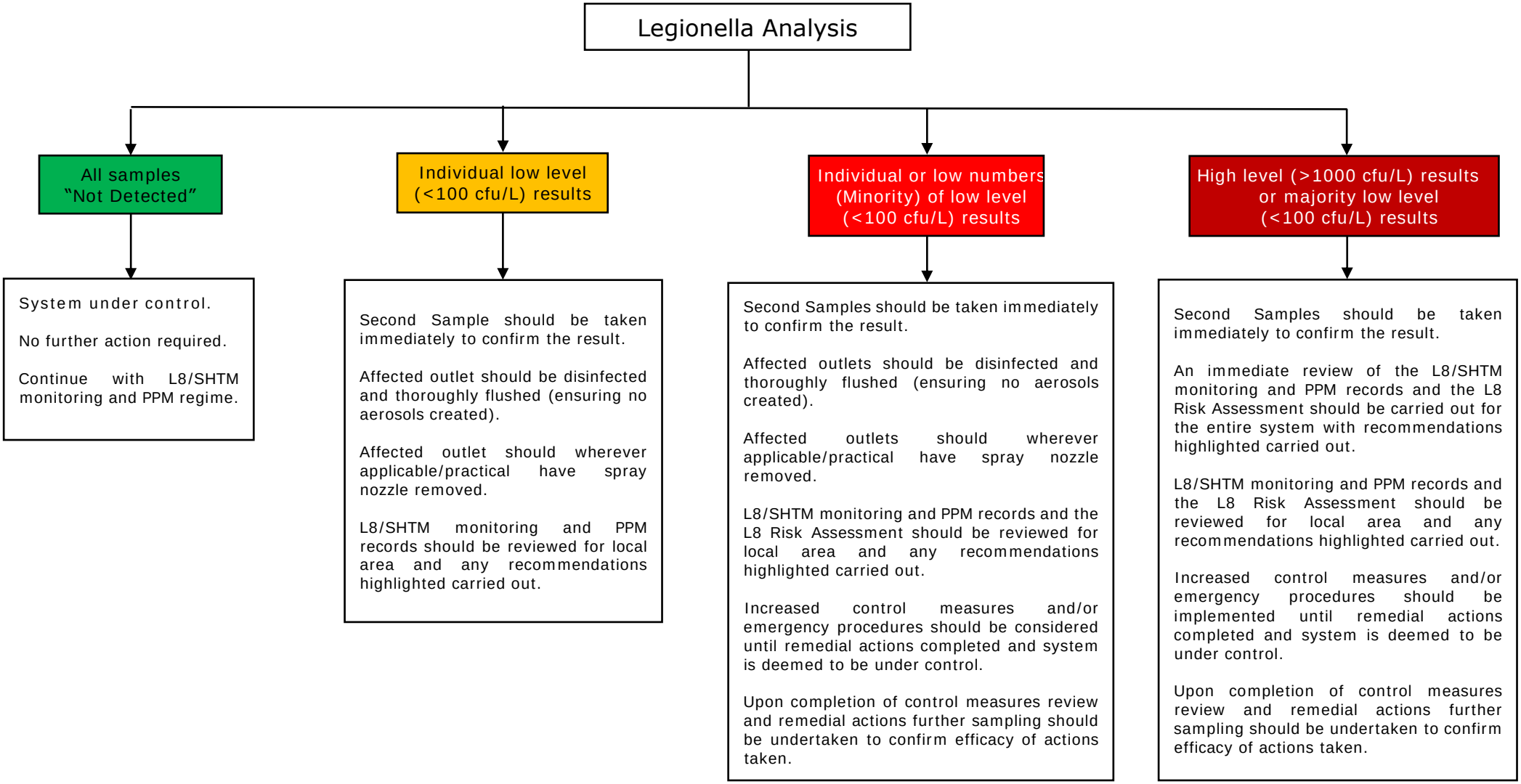
Legionella Sample Out-Of-Spec Results Escalation Procedure (L8/HSG 274 Part 2 and SHTM 04-01)



N.B. Ensure all actions are recorded and stored in the site L8 Legionella Logbook

WRITTEN SCHEME

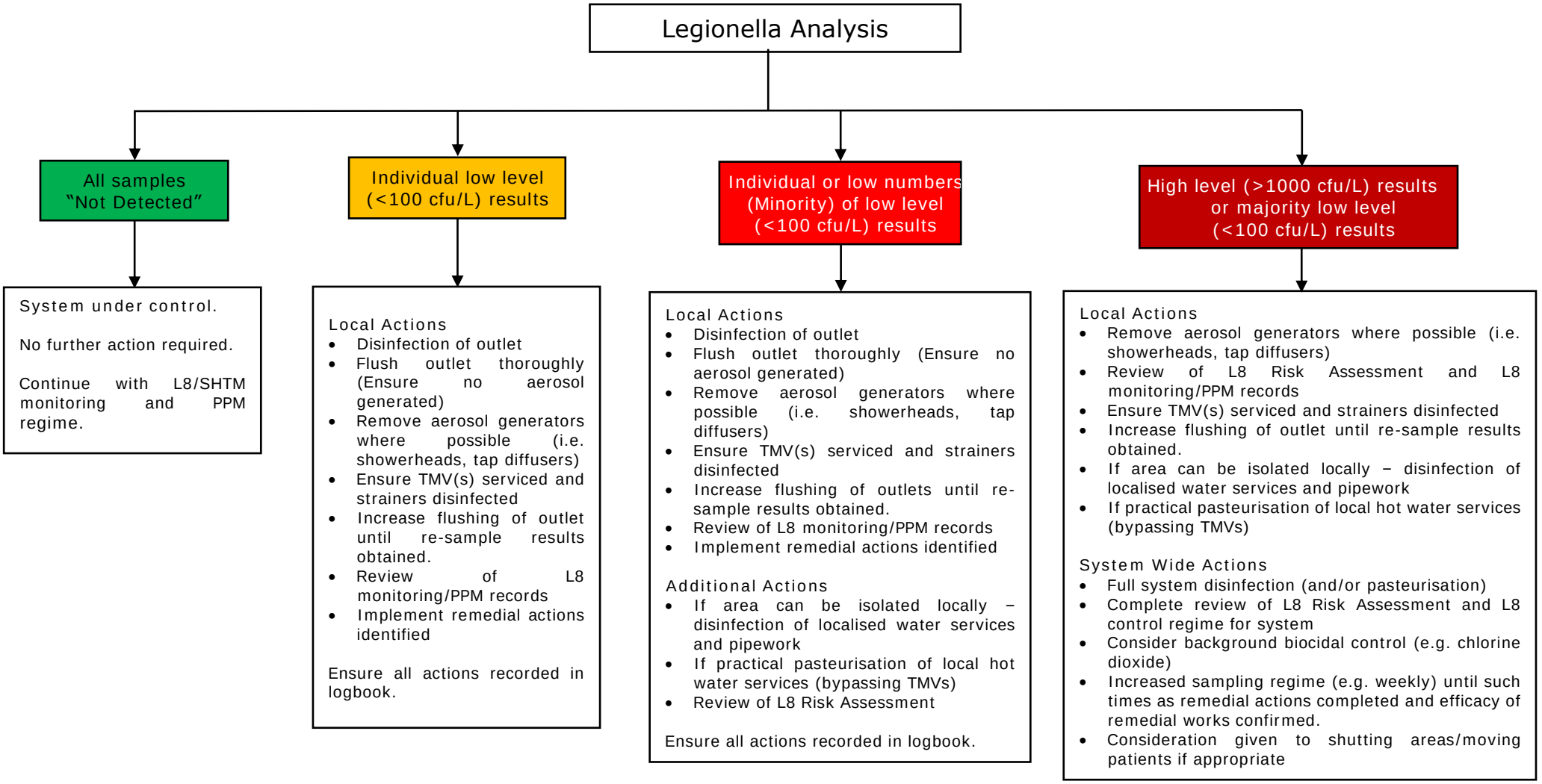
Legionella Sample Out-Of-Spec Results Escalation Procedure (Practical Guidance)



N.B. Ensure all actions are recorded and stored in the site L8 Legionella Logbook

WRITTEN SCHEME

Legionella Sample Out-Of-Spec Results Remedial Actions Guidance



N.B. Ensure all actions are recorded and stored in the site L8 Legionella Logbook

WRITTEN SCHEME

Microbiological (Potable / TVC) and Chemical Sampling

SHTM 04-01 Part C states:

Although TVCs are in themselves innocuous the testing procedures are intended to provide an early warning system whereby elevated TVCs should trigger some form of action to determine the identity of the organism and implement the appropriate treatment.

From BS 8558:2015

"…regular analyses of water samples should be carried out at intervals not exceeding six months wherever drinking water is stored.

Periodic chemical and microbiological analysis of water samples is a useful guide to the condition of an installation. For new installations in large buildings or complexes and where extensive repairs or alterations have been carried out to such installations, water samples should be collected and analysed.

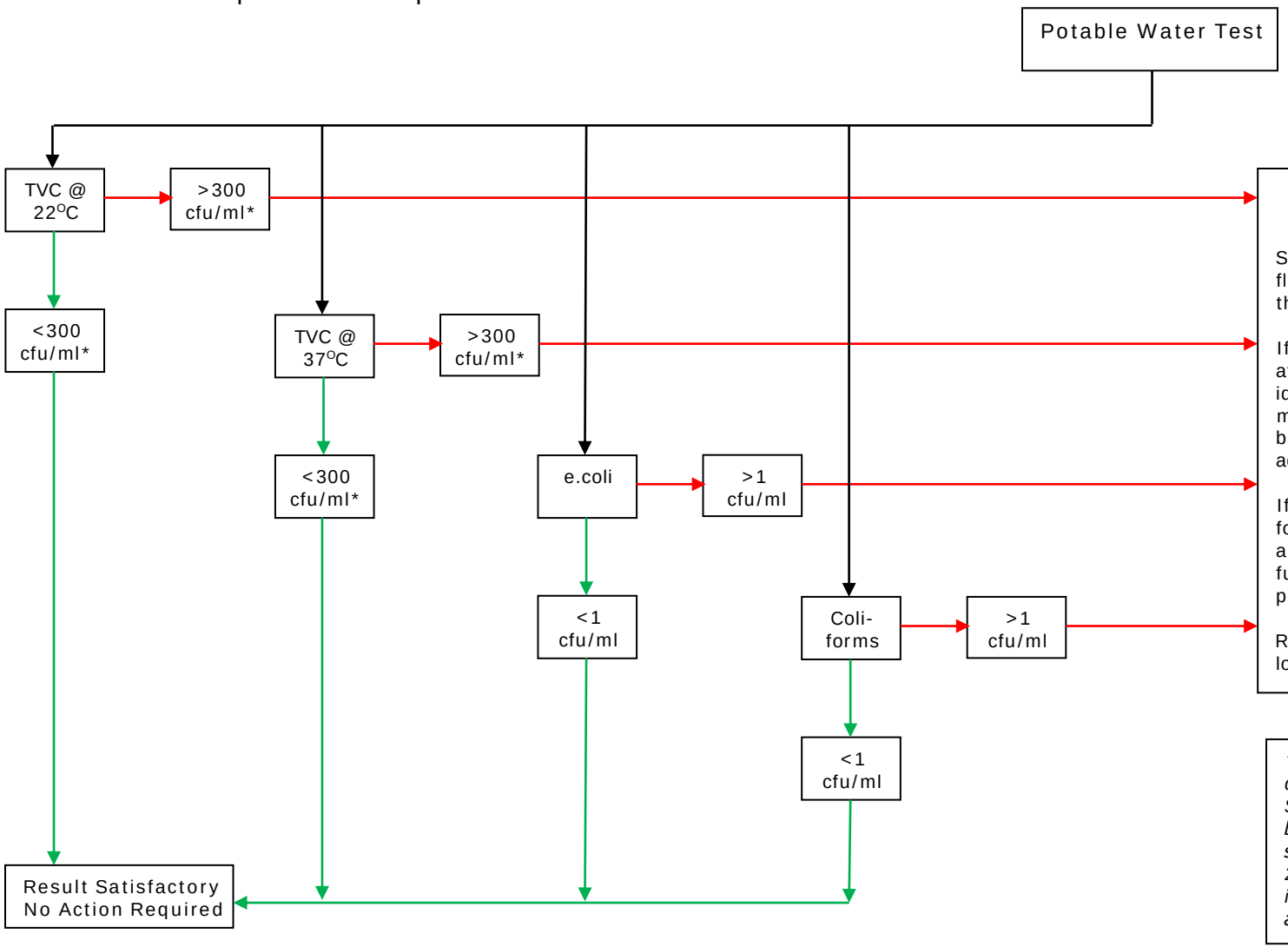
Where samples indicate poor water quality, investigations should be undertaken to establish the cause and appropriate rectification carried out. Rectification can include removal of disused pipework, insulation of pipework and flushing. Further sampling should be conducted after rectification to determine whether this has resolved the problem.

Exceptionally, disinfection of the water system may be undertaken:

a) *for both the hot and cold water system, as described in PD 855468; and*
b) *for the hot water system only, by thermal disinfection procedures (see the HSE's Approved Code of Practice L8, Legionnaires' disease – The control of Legionella bacteria in water systems [26] and HSG274 Part 2 [30]).″*

WRITTEN SCHEME

Potable Water Sample Out-Of-Spec Results Escalation Procedures



Result(s)
Out of Specification

Sample point should be thoroughly flushed and cleaned/disinfected and then sample point re-sampled.

If 2nd Resample then area around the affected outlet should be inspected to identify potential problems, and control measures and risk assessment should be consulted to identify any remedial actions required.

If multiple out of specification results for a single system are identified then a full system disinfection in addition to further investigation to ascertain potential contamination issues.

Record actions and findings in site logbook.

** Please note that there are no definitive guidance limits for TVC. Scottish water advise that there should be "no abnormal change" and BS 8558 states "e.g. TVC results in excess of a 2 log difference above that found in incoming mains water, corrective action should be taken"*

N.B. Ensure all actions are recorded and stored in the site L8 Legionella Logbook

WRITTEN SCHEME

The Course of Action for Suspected Nosocomial Legionnaires' Disease

from SHTM 04-01 Part G

Suspected or confirmed incident or outbreak

NHS Board will follow the guidance presented in the following regulatory and mandatory guidance documents:

- HSE ACOP L8 "The control of *Legionella* bacteria in water systems", see Appendix 2;
- SHTM 04-01 "Water safety for healthcare premises", Part B, Appendix 1;
- HPN2, "Guideline on management of *Legionella* incidents, outbreaks and clusters in the community";
- The *NHS Board* "Outbreak Plan".

Legionellosis is an atypical and potentially life-threatening form of pneumonia (Legionnaires' Disease). The majority of cases are isolated although outbreaks can occur (including large community outbreaks and hospital outbreaks).

In the event of a nosocomial case(s) of Legionnaires' disease *NHS Board* will follow the Health Protection Network's (HPN) – *'Guideline on Management of Legionella, Incidents, Outbreaks and Clusters in the Community'* (2009), SHTM 04-01 and *NHS Board's* Outbreak Plan.

An outbreak is defined in HSE ACOP L8 by the Public Health Laboratory Service (PHLS) as two or more confirmed cases of *Legionellosis* occurring in the same locality within a six month period. However:

- HPN2 sets out and defines:

Incident	A (first) single case – presumptive or confirmed- where based on the evidence there are concerns about actual or suspected threats to the safety or quality of water systems that could require intervention to protect the public's interest.
Sporadic case	A single case not associated with any other case. No other case may be linked to probable source of exposure in last 2 years.
Outbreak	Two or more cases in the same locality for which there is strong epidemiological evidence of a common source of infection, with or without microbiological evidence, occurring within a 6 month period of the onset of illness from the first case confirmed.
Linked case	Two or more cases associated with a single source with dates of onset more than 6 months apart but less than 2 years apart.
Probable Nosocomial	Legionnaires' disease in a person who was in hospital for between one and nine of the ten days before the onset of symptoms and either became ill in a hospital associated with one or more previous cases of Legionnaires' disease or yielded an isolate that was indistinguishable (by monoclonal antibody subgrouping [mAB] or by molecular typing methods) from isolates obtained from the hospital water system at about the same time.
Possible Nosocomial	Legionnaires' disease in a person who was in hospital for between one and nine of the ten days before the onset of illness in a hospital not previously known to be associated with any case of Legionnaires' disease and where no microbiological link has been established between the infection and the hospital.

The *NHS Board* "Outbreak Plan" defines an outbreak and incident as:

- "An outbreak is defined either as two or more linked cases of the same illness or when the observed number of cases exceeds the number expected;
- An incident is defined as a case of communicable disease that has actual or potential serious implications for the public's health e.g. VHF or measles in a health care setting. An Incident Management Team (IMT) should be established using the approach described in this plan."

WRITTEN SCHEME

Actions

A nosocomial case(s) of Legionnaires' disease (definite/probable/possible) should be investigated immediately.

An Incident Management Team (IMT) or an Outbreak Control Team (OCT) will be convened for a single case or an outbreak of nosocomial Legionnaires' disease respectively;

The IMT/OCT will be convened by the Consultant in Public Health Medicine (CPHM) with responsibility for Health Protection (or the duty CPHM). The CPHM will lead and co-ordinate the investigation and control of the incident/outbreak in close collaboration with the Infection Prevention and Control Doctor. Further information on the roles and responsibilities of the different members of the IMT/OCT can be found in NHS Board's Outbreak Plan;

In the event of a case(s) of nosocomial Legionnaires' disease the following people/groups will be members of IMT/OCT and will be briefed by the CPHM:

- Consultant in Public Health Medicine (IMT/OCT Chair);
- Consultant Physician (involved with care of case);
- Consultant Medical Microbiologist/Infection Prevention and Control Doctor;
- Infection Prevention and Control Nurse;
- Health Protection Nurse Specialist;
- Facilities & Estates Department ;
- Environmental Health Officer;
- Health & Safety Executive;
- Health Protection Scotland;
- Reference Laboratory;
- Corporate Communications (*NHS Board*);
- Other members from partner agencies as decided by IMT/OCT Chair.

Guidance on the general response to a case(s) of nosocomial Legionnaires' disease can be found in the HPN Guidance, Section 3.1.1.2 and NHS Board's Outbreak Plan.

WRITTEN SCHEME

Contact details in the event of a confirmed or suspected incident:

Legionella Role	Name	Title	Phone
Designated Person (Water)	Mary Ann Kane	Associate Director of Facilities	
Designated Person (Water)	Alan Gallacher	General Manager Estates (Corporate Compliance)	[redacted]
Responsible Person (Water) Estates	Ian Powrie	Head of Maintenance (Sector Estates Manager, South and Clyde)	[redacted]
Deputy Responsible Person (Water), Estates and Authorised Person (Water)	Colin Purdon David Brattey	Deputy Head of Maintenance (Site)	[redacted]
Infection Control	Theresa Inkster	Consultant Medical Microbiologist	
Laboratory Services	Pat Millar	Biomedical Scientist	
Authorising Engineer	Dennis Kelly (via LCI Ltd)	Appointed Engineer from Appointed Organisation	[redacted]
Governance and Advisor	Phyllis Urquhart	Compliance Manager (Legionella)	
Public Health	Ian Kennedy	Consultant in Public Health Medicine	
O H & S Manager	John Green	Health and Safety Manager	
Health and Safety Executive			
Health Protection Scotland		Duty Epidemiologist advised by Public Health	
Reference Laboratory Microbiologist		Duty Microbiologist advised by Public Health	

When it is unclear whether there is a threat to public health the CPHM may choose to convene a Problem Assessment Group (PAG) in order to undertake an initial assessment of the problem and determine if an IMT is required. Further information on the role of the PAG can be found in the Scottish Government guidance on the *Management of Public Health Incidents: Guidance on the Roles and Responsibilities of NHS led Incident Management Team: October 2011*.

WRITTEN SCHEME

The general response to an incident or outbreak may include:

- investigation of all potential sources of *Legionella* infection. This shall include checking recent maintenance work and project work that may have been carried out on water or air handling systems;
- identifying the location of any medical equipment used for dental care, respiratory therapy and within Haemodialysis units;
- identifying off-site information such as excavation or earth moving works, alterations to water supply and drainage;
- shutting down any processes which are capable of generating and disseminating airborne water droplets and keeping them shut down until sampling procedures and any remedial cleaning or other work has been done. Final clearance to restart the system may be required;
- taking water samples from the system before any emergency disinfection being undertaken. This will help the investigation of the cause of the illness. The investigating officers from the local authority may take samples or require them to be taken;
- co-operating fully in an investigation of any plant that may be suspected of being involved in the cause of the outbreak. This may involve, for example:-
  - tracing of all pipework runs;
  - detailed scrutiny of all operational records;
  - statements from plant operatives and managers;
  - statements from water treatment contractors or consultants;
- any emergency cleaning and disinfection will be undertaken in accordance with *NHS Board* procedures;
- the Designated Person (Water) shall brief relevant Estates staff so that they are aware of the event and can respond to phone calls etc as instructed. The briefing shall include instructions that any comments to outside parties are agreed by Infection Prevention and Control;
- records shall be kept of all relevant information, including that provided by other departments.

Emergency cleaning and disinfection of water systems

If a water system, other than a cooling system, is implicated in an outbreak of Legionnaires ' disease, emergency treatment of that system should be carried out as soon as possible. This will involve disinfection as set out in Section 17 of SHTM 04-01 Part A and site method statements.

WRITTEN SCHEME

Documentation and Records

The documentation and records of all work undertaken to prevent the growth and spread of Legionella require to be maintained and performance reviewed by the Authorised Person. An index of all relevant documentation and records including location of supporting documentation identified in SHTM 04-01 Part G such as 'Operational Procedures for the Written Scheme', Control of 'Water Records Forms' and 'Guidance for Alterations to Water Systems' should be formulated.

Examples of forms and procedures which may be used in formulation of the written scheme are provided below and in SHTM 04-01 Part G.

WRITTEN SCHEME

Appendix 1

Example Low Use (Sporadically Used) Outlet Flushing Responsibility Structure

Document Review Date	
Reviewed By	

Area/Ward	Location	Outlets Identified as Requiring Flushing	Locally Nominated Responsible Person (LNRP)	Person(s) Flushing Tasks Delegated To	Frequency of Flushing Required	Last update from LNRP (Date)
e.g. Haemo-oncology Ward	Fourth Floor Ward 4B		Ward Sister (?)		Daily	
e.g. Restaurant and Visitor Dining	First Floor		Domestics (?)		Twice Weekly	
e.g. Main Kitchen	Third Floor		Domestic (?)		Twice Weekly	
e.g. Roof Garden	Third Floor		Estates (?)		Twice Weekly	
e.g. Schiehallion Ward	Ward 2A Children's Hospital		Ward Sister (?)		Daily	

N.B. This register is in addition to the daily water draw-off from all outlets which should form part of the daily cleaning process.

WRITTEN SCHEME

Appendix 2

Example Register **of 'Little' or 'Sporadically' Used Outlets and Showers**

Area / Ward		Document Completion Date	
Location		Completed By	

Room	Outlets Identified as Requiring Flushing	Dates Outlet(s) identified as requiring flushing	Reason	Frequency of Flushing Required	Dates Outlet(s) confirmed as no longer requiring flushing	Reason
e.g. 7	Toilet WHB, WC & Shower	01/01/15	Bedridden user	Twice Weekly		
e.g. DSR	All	01/01/15	Used as Store	Twice Weekly		
e.g. 12	All Outlets	01/01/15	Room Empty	Twice Weekly		

N.B. This register is in addition to the daily water draw-off from all outlets which should form part of the daily cleaning process.

WRITTEN SCHEME

Appendix 3

Example Method Statements

Method statements for mechanical tasks (e.g. checks to ensure pumps operating correctly, water tank level checks, TMV servicing) should be referenced or inserted into this section.

All record sheets should be signed by person carrying out the task with date and time of operation recorded.

Sentinel Outlets and Outlet Temperature Monitoring

Equipment required: Calibrated Thermometer with surface and immersion probe, Sentinel & Outlet Register
Method of identifying and recording outlet locations/asset number (e.g. barcode, QR, IR) and data capture method to be confirmed.

1. At each sentinel outlet location, inspect outlet and note any issues (e.g. out of order outlets, scale build-up, damaged diffusers).
2. Run cold tap for 2 minutes and monitor temperature throughout.
3. Record temperature after 2 minutes and any observations (e.g. heat gain/spike, temperature slow to fall, discoloured water etc.)
4. If temperature is 20°C or above (or anomalous with current temperature profile) record along with any noticeable reason for high temperature.
5. Run hot tap in first sentinel location for 1 minute and monitor temperature throughout.
6. Record temperature after 1 minute and any observations (e.g. heat loss, temperature slow to rise, discoloured water etc.) If temperature is out with the set-point temperature for TMV record along with any noticeable reason for temperature variation.
7. As almost all outlets are Thermostatically controlled (Thermostatic Mixing Taps or Thermostatic Mixing Showers) direct hot temperatures at sentinel outlets and the majority of other outlets cannot routinely be recorded. Therefore direct hot and cold outlets within each area should be measured (e.g. within DSRs, Staff Kitchens, Clean Utility) to provide representative temperatures of the hot supply temperatures within each area.
8. Repeat procedures 1 - 6 for each sentinel outlet location and Step 7 for each Ward/Area.
9. Repeat procedures 1 - 6 for subsample of other outlets, aiming to cover 20% of outlets over the course of 12 months, with all outlets being monitored over a 5 year period (or a pre-defined period of time).
10. If unused outlets or unrecorded deadlegs or other issues are observed these should be recorded to allow remedial actions to be taken and appropriate registers to be updated.

Hot Flow and Return Loop Temperature Monitoring

Equipment required: Calibrated Thermometer with surface contact probe, Register of primary, sub-ordinate and tertiary hot flow and return loops
Method of identifying and recording flow and return locations (e.g. barcode, QR, IR) and data capture method to be confirmed.

1. Using contact probe record temperature at flow and return principle loops (monthly), sub-ordinate loops (Quarterly) and tertiary loops (annually) to create a temperature profile of building and monitor flow and return system. If temperature is 55°C or below record any noticeable reason for low temperature. Hot flow and return loops can be accessed within risers through the Adult's and Children's Hospital.

Where appropriate temperatures should be compared to those from BEMS to identify any discrepancies.

N.B. Ensure all actions are recorded and stored in the site L8 Legionella Logbook

WRITTEN SCHEME

Calorifiers Temperature Monitoring

Equipment required: Calibrated Thermometer with surface contact probe, Calorifier Register
Method of identifying and recording calorifier locations/asset number (e.g. barcode, QR, IR) and data capture method to be confirmed.

1. At each calorifier inspect pipework & plant and note any relevant issues.
2. Record temperature of hot water flow as close to each calorifier as possible. If temperature is below 60°C record any obvious reason for low temperature and follow appropriate escalation procedures.
3. Record temperature of hot water return as close to each calorifier as possible (to confirm return is flowing correctly into all 3 linked calorifiers. If temperature is below 55°C record any obvious reason for low temperature and follow appropriate escalation procedures.

Where appropriate temperatures should be compared to those from BEMS to identify any discrepancies.

Flushing Calorifier Drain/Base

Equipment required: Calibrated Thermometer with immersion probe, Calorifier Register, Suitable PPE
Method of identifying and recording calorifier locations/asset number (e.g. barcode, QR, IR) and data capture method to be confirmed.

1. At each calorifier inspect pipework & plant and note any issues, and ensure safe to proceed.
2. Attach hose to drain of calorifier and run to drain in plantroom.
3. Suitable isolation should be carried out to ensure calorifier base is purged and not supply/distribution pipework only (e.g. isolate cold feed supply valve)
4. Test drain to ensure working correctly and will open/close safely. Record and escalate any faults as appropriate.
5. Calorifier drains should be opened and water flushed to drain until water runs clear and for a further 3 minutes. This procedure should be repeated 3 times for each calorifier.
6. Record temperature of water running from the calorifier base.
7. Close calorifier drain and dispose of collected water (if applicable)
8. Record water quality discharged from drain (e.g. clear, dirty for 10 seconds). Where water quality is poor and/or temperature indicates potential legionella control problems this should be escalated as appropriate.
9. Repeat procedure for each of the 3 linked calorifiers.

Cold Water Storage Tank Inspection

Equipment required: Calibrated Thermometer with immersion probe, CWST Register, Suitable PPE, Camera, Torch
Method of identifying and recording calorifier locations/asset number (e.g. barcode, QR, IR) and data capture method to be confirmed.

1. At each CWST inspect pipework & plant and note any issues, and ensure safe to proceed.
2. Check security of tank lid and hatch(es).
3. Check integrity of rodent screens on overflow/warning pipes.
4. Check integrity of tank lid vents.
5. Open lid hatch(es) and inspect internal surfaces for signs of contamination/fouling and water clarity/quality within the tank. Record observations and escalate any faults as appropriate.
6. Take photographs of internal condition of tank, and any other relevant issues.
7. Record temperature of make-up water[11] noting which supply this relates to (e.g. Govan Road, Raw CWST 1A/B) and stored water as remote from inlet as possible - both should be below 20ºC. Any variation of 2ºC may indicate excess storage or low turnover and should be escalated as appropriate.

[11] This step should be repeated to ensure all supplies are recorded on each inspection cycle.

WRITTEN SCHEME

Cleaning, Descaling and Disinfection of Showerheads and Hoses (in-situ)

Equipment required: Outlet (or Shower) Register, Showerhead Plus Legionella specific descaler/degreaser, suitable lidded container, manual cleaning utensils (e.g. clean cloth, small soft brush)
Method of identifying and recording outlet/shower locations/asset number (e.g. barcode, QR, IR) and data capture method to be confirmed.

1. At each shower location, inspect outlet and record any issues (e.g. out of order outlets, scale build-up, damaged fittings, heads, hoses)
2. Remove shower head (and hose where applicable).
3. Dismantle removable parts (if possible) and physically clean.
4. Submerge the components in a solution of Showerhead Plus Legionella specific descaler/degreaser (maximum dilution 3-1) for a minimum time of 2 minutes ensuring colour is still yellow indicating active product present.
5. Remove components and flush disinfectant solution from external surfaces using fresh water.
6. Replace showerhead (and hose), purge vigorously with fresh water and return to normal service.
7. If adjustable showerhead is noted as present this should be recorded and escalated as appropriate for replacement.
8. Record actions and any issues and escalate as appropriate.
9. Where significant fouling is recorded frequency of cleaning, descaling and disinfection should be reviewed.

Flushing of Low Use/Sporadically Used Outlets

Equipment required: Calibrated Thermometer with surface and immersion probe, Register of 'Little' or 'Sporadically' Used Outlets and Showers.
Method of identifying and recording outlet/shower locations/asset number (e.g. barcode, QR, IR) and data capture method to be confirmed.

1. At each outlet location, inspect outlet and note any issues (e.g. out of order outlets, scale build-up, damaged diffusers).
2. Each outlet(s) shall be opened and flushed for a minimum of 3 minutes and the water temperature stabilises in line with current temperature profile.
3. WCs (where fitted) should be flushed on entry to the room and again prior to leaving room, whilst the other outlets are being flushed.
4. Where connection points are fitted awaiting equipment installation (or other deadlegs) these should be flushed as per point 2.
5. Flushing of multiple outlets at the same time (and indeed may be advantageous) in a room/area is perfectly acceptable so long as all outlets are flushed as per Point 2.
6. Record actions and any issues and escalate as appropriate.

Flushing Notes:

- Minimise aerosol creation wherever possible (E.g. do not fit showerheads until rooms are to be occupied)
- If flushing multiple outlets simultaneously care should be to ensure sinks etc. do not overflow.

N.B. Ensure all actions are recorded and stored in the site L8 Legionella Logbook

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Authorising Engineer Water Systems Management and Compliance Audit of NHS Water Systems

Site Address:		
Queen Elizabeth University Hospital and the Royal Hospital for Children, 1345 Govan Rd, Govan, Glasgow, G51 4TF		
Date of Audit:	**Auditor:**	**Staff Interviewed:**
23rd July 2018	Dennis Kelly – Authorising Engineer (Water)	Andy Wilson – Sector Estates Manager (RP) (part of the audit process Colin Purdon – Site Manager Operational Estates (DRP) Melville MacMillan – Estates Manager (AP)

Date of Previous Survey:

The previous audit was completed on the 4th May 2017. This new audit will look at the management of the NHS GGC QEUH Campus. It will focus however, from a task completion point of view, on the new QEUH and RHC on the Campus.

A pre audit set up meeting was held on the morning of the 23rd July. In attendance at that meeting were Alan Gallacher, General Manager, Ian Powrie, Deputy General Manager, Andy Wilson, Sector Estates Manager, Colin Purdon, Senior Estates Manager Site Manager Operational Estates, Melville MacMillan Estates Manager, and Phyllis Urquhart, Compliance Manager along with Dennis Kelly, Authorising Engineer (Water). The scope of the audit was agreed as described in the paragraph above.

Site General Description:

The QEUH and RHC property is a new build 12 storey multi functional state of the art hospital with 7436 rooms. There are 1280 single en suite bedrooms and 30 operating theatres. The hospital has a number of acute areas where Pseudomonas may be considered to be an issue. Infection Control controls sampling in these areas.

There are two mains supplies into the hospital building. Mains water is first stored in four raw water storage tanks (Numbered 1a,

1b, 2a & 2b). It then goes through a filtration system before being stored in the filtered water storage tanks. There are eleven cold water storage tanks in the property. These are as follows:-

- Four raw water storage tanks of 100,000 litres each (located in basement tank room (tanks 1a,1b,2a & 2b);
- Four filteredwater storage tanks of 275,000 litres each (located in basement tank room);
- Two trade water storage tank of 2,800 litres. This tank serves the Helipad fire suppression systems and the bib tap in the plant rooms (Plantroom 21);
- Fire suppression cold water storage tank below the helipad.

From the filtered water storage tanks water is distributed throughout the hospital. There are two booster sets delivering water to the cold water outlets and to the calorifiers in the various plant rooms throughout the hospital. In the hospital there are twenty four calorifiers split between 8 plant rooms (3 in Plantroom 21; 3 in Plantroom 22; 9 in Plantroom 31; 3 in Plantroom 32; 3 in Plantroom 33 & 3 in Plantroom 41)

Executive Summary:

A previous audit was completed of the QEUH and RHC in May 2017. Since that time there has been a microbiological issue in the hot and cold water systems in the RHC hospital. This issue has resulted in a significant level of focus in terms of providing the correct risk reductions processes and procedures in the properties.

One of the key recommendations from the previous audit was that an updated risk assessment should be undertaken and this has now been delivered. This is being used to more clearly define the required processes and procedures which should be delivered at the site.

It is therefore pleasing to note, and is worthy of positive comment, that there have been significant improvements and advances in the delivery of the water based risk reduction processes since the previous audit was completed in 2017.

While the improvement is to be commended, there still remain a number of issues that should be addressed. Many of these are required in the task definition and delivery area. As an example these would include issues such as clearly defining and delivering a little used outlet flushing regime that meets the requirements of the SHTM and HSG standards.

There are also a number of higher level issues which require further clarification including the levels of TMT servicing and Legionella sampling.

In summary therefore, there is a significant level of improvement apparent since the completion of the last audit. There are a number of items still to be addressed, and it is to be hoped that this document will assist in allowing that delivery to be completed.

Description of Levels of Risk and Recommended Timescale for Actions:

		Recommended Time Scale for Completion of Recommendations
Very High	Urgent Remedial Action – Lp growth and aerosol opportunity with susceptible people present on site	**1 month from date of audit**
High	Remedial Action is needed but not immediately – Lp growth opportunity is present	**2 months from date of audit**
Medium	Acceptable risk but some concerns– Lp likely to be controlled but improvements should be sought	**3 months from date of audit**
Low	Risk controlled and acceptable	**Not applicable**

Levels of Risk found during the Audit:

The audit process reviews the following 9 areas.:-

Audited Topic	Level of Risk
Risk Assessment	
Schematic Drawings	
Management and Competency	

Written Scheme Monitoring and Records	
Correct and Safe Operation	
On Going Water Treatment	
Cleaning and Disinfection Procedures	
New Build and Refurb Capital Projects	
Water Safety Group	

The colour coding of each of the above items reflects the highest level of risk that was attributed in the relevant question set below.

Summary of Recommendations

Recommendations	Risk Level	Recommended Completion Date	Signature
Recommendations from the Risk Assessment Section			
1. It is recommended that NHS GGC come to a firm decision on when the risk assessment for the QEUH and the RHC should be reviewed or redone. The performance of the risk reduction processes and procedures should be used when making this decision.		**Complete** **Will be complete by end January 2019.**	
Recommendations from the Schematic Drawings Section			
2. A check should be completed to ensure that any changes made to the pipework systems would be reflected in amendments made to the drawings.		**Complete.** **This is covered within the Written Scheme; Page 20; Procedure P1C10 as an annual check.**	
3. It is recommended that drawings are reviewed annually to ensure that they are up to date.		**Complete.** **This is covered**	

		within the Written Scheme; Page 20; Procedure P1C10 as an annual check.	
Recommendations from the Management and Competency Section			
4. It is recommended that if plumbing contractors are used for remedial work on the hot and cold water systems, that their details are included in the written scheme.		**Ongoing** **'Permit to work' (PtW) - safe system of work process being developed by Lead AP (Mel McMillan).**	
5. The Policy document should be reviewed no later than November 2018.		**Complete.** **The Policy has been reviewed and a new review date of 31st July 2019 agreed.**	
6. The Written Scheme and Operational Procedures document should be reviewed no later than December 2018.		**Ongoing** **Revision E will be completed and ratified by Sector water Group (outwith meeting) by end January 2019.**	

7. If any contractors are used for plumbing work, or risk reduction work on the water systems, then they should be asked for proof of competency for the organisation and for the involved staff.		**Complete.** **This is covered within the Permit to Work system which will be incorporated into the Written Scheme.**	
8. It is recommended that all review meetings with contractors are minuted and that copies of the minutes are placed in the records section of the written scheme.		**Complete.** **All minutes are held within the SGH Shared Drive and referenced within the Written Scheme clause 3.9.**	
9. It is recommended that a reference is made in the written scheme as to where the details and scores of the competency checks can be found.		**Complete.** **This is covered in Written Scheme Clause 3.4. All scores and competency checks for estates in-house staff (APs & CP's) are held within the SGH shared drive; folder name**	

		Water Quality. Contractors do not, at this present time, go through the same process as internal staff and this is being reviewed. Contractors have to pass all training and educational qualifications of staff working on water systems to the water AP for approval.	
Recommendations from the Written Scheme, Monitoring and Records Section			
10. Given the size of the task in addressing the water based risk issues in the QEUH and RHC hospitals it is recommended that consideration is given to the use of an electronic based control and recording system		**<u>Complete.</u> NHSGG&C are considering an e-log book system for the Board.**	
11. The updated forms that are required for the monitoring and recording system should be completed and put into use as soon as possible.		**<u>Complete.</u> All forms for monitoring & recording are being used widely and are**	

		covered within the Written scheme - section 4.	
12. It is recommended that this task matrix is created as soon as possible and the information from the matrix are reflected in the written scheme.		**Complete.** **All covered in Written Scheme Page 35.**	
13. Records need to be made available as proof that the required tasks are being completed satisfactorily and on time. Going forward the need to deliver completed acceptable records should be highlighted as a definitive requirement.		**Complete.** **All records for tasks are held in the estates managers office (ie Lead AP).**	
14. Complete quarterly shower and hose cleaning and descaling and ensure that appropriate records are kept in the log book.		**Ongoing.** **Being done on retained estates only.**	
15. Ensure that all records are signed and dated by the relevant Estates staff.		**Complete.** **All records signed off by estate staff. Copies of forms held within Written Scheme - section 4.**	
16. With regard to any records that are recorded on the BMS system, a check requires to be made to ensure that the results being recorded are within acceptable levels.		**Complete.** **BMS records the following;** • **Calorifier**	

		temperatures; • **End of line temperatures;** • **Hot/Cold flow & return temperatures.** **Where these are outwith the parameters an Incident Form 004 is completed. This is all documented within the Written Scheme section 4.**	
17. It is recommended that the process for the taking and recording of the sentinel hot and cold water temperatures is reviewed to see whether there are options that can be employed which can overcome the need to remove lift off panels. If outlets can be identified then they need to be listed and added to the log book and FM First to ensure that they are monitored monthly.		**Complete.** **An HAI Scribe is now in place to carry out this action. This is reflected in the Written Scheme.**	
18. If a temperature recording process can be identified that gives suitable information which will allow confidence in the water systems operation, then the appropriate staff require to be trained in how to take and record the temperatures.		**Ongoing.**	
19. NHS GGC should decide on what the servicing protocol is to become for all the TMT's/TMV's in the two hospitals, and once confirmed, the protocol should be implemented across the hospitals.		**Ongoing.** **This will be actioned once**	

		the chemical dosing of the system is completed.	
20. The service requirement should also be defined and if required, implemented, for the Contour taps in the QEUH and RHC.		**Ongoing. This will be actioned once the chemical dosing of the system is completed.**	
21. The service requirement should also be defined and if required, implemented, for the TSV's in the QEUH and RHC.		**Ongoing. This will be actioned once the chemical dosing of the system is completed.**	
22. Flushing of little used outlets is an issue and a hospital wide process, engaging all the involved parties, requires to be defined and implemented as soon as possible to ensure that little used outlets are correctly flushed.		**Complete. This is covered within Written Scheme clause 5.5. All records held within the estates managers (ie Lead AP) office.**	
23. Ensure that all involved staff have been trained in the operation and use of the incident forms that form part of the written scheme.		**Ongoing. This will be completed by the**	

		Lead AP during January 2019 (toolbox talk).	
24. As there are "high risk areas" in the hospitals, and as there has also been an issue with the microbiology in the water systems, it is recommended that the need for Legionella sampling is reviewed and altered if required.		**Ongoing Needs discussed with Infection Control.**	
25. It is recommended therefore that legionella sampling is reinstated in the POU filtered areas in order that an understanding of what is happening microbiologically in the hot and cold water can be had.		**Complete. This has been overtaken by events around the installation of a dosing system within the QEUH and the resultant checks needing to be put in place.**	
26. It is therefore recommended that a sampling protocol, covering what species should be monitored, how often, and from where, is agreed with the NHS GGC Infection Control team.		**Ongoing Needs discussed with infection Control.**	
27. It is recommended that a copy of the DMA Canyon method statements are added to the written scheme, or that reference is made in the written scheme as to where the method statements can be found.		**Complete. Covered within the Written Scheme. These are held in the SGH Shared drive folder Water Quality.**	

Authorising Engineer Water Systems Management and Compliance Audit of NHS Water Systems

Recommendations from the Correct and Safe Operation Section			
28. It is recommended that a statement of correct and safe operation is created for the QEUH and RHC hospitals and that these statements are added to the written scheme.		**Complete.** **See Written scheme Page 31; Clause 4.1.1**	
29. It is recommended that a process which records the removal of the risk assessment identified dead legs, as well as any dead legs which are found subsequently, is defined and recorded in the written scheme.		**Ongoing.** **Being formalised by AP/SEM and will be included in the written Scheme.**	
30. It is recommended that a process, which should list the little used outlets and the appropriate flushing requirements, is created for the areas that fall under the control of the Estates Department.		**Ongoing.** **Being formalised by AP/SEM and will be included in the written Scheme.**	
31. It is recommended that a procedure for checking that the automatic switching of booster pumps is occurring requires to be put in the written scheme.		**Complete.** **This is covered within the Written Scheme Clause 4.2; Procedure P1C3**	
Recommendations from the Ongoing Water Treatment Section			
32. It is recommended that the filtration system service work is included in the written scheme, or that a reference to the process is made in the written scheme.		**Complete.** **This is covered within the Written Scheme**	

		clause 4.33 – Filtration Plant Checks. Information is also held in the SGH Shared Drive and the Veolia Portal online.	
Recommendations from the Cleaning and Disinfection Procedures Section			
33. It is recommended that reference is made as in the training section of the written scheme as to where the training records can be found.		**<u>Complete.</u> Covered within Written Scheme Clause 3.4**	
34. Check with DMA if there are staff members whose records require to be added to the written scheme. Reference the G drive location of the DMA training records in the written scheme.		**<u>Complete</u> Contractor training requirements are discussed at the monthly contractor review meetings. Records are then forwarded and held on SGH shared drive.**	
Recommendations from the New Build and Refurb Capital Projects Section			
None			

Recommendations from the Water Safety Group Section			
35. It is recommended that in keeping with the practices at other Boards, the AE is asked to attend more of the WSG meetings.		**Complete.** **The AE will be invited along to the Board Water Group as required.**	

A summary of the recommendations by risk level can be found at the end of this report.

Risk Assessment	Y/N U/K, N/A or Partial	Comments	Risk Level
Is there a written risk assessment in place for the building water systems?	**Y**		
Was the risk assessment completed and delivered to site within the past two years?	**Y**	The risk assessment covering the QEUH and the RHC buildings was completed by DMA Canyon Ltd on 8th September 2017 with the outlets being surveyed on the 10th, 12th, 13th, 16th, 20th and 24th 2017. A further meeting was held with Estates management staff on 30th January 2018 to complete a gap analysis.	
Does the site/organisation have plans with regard to reviewing or redoing the risk assessment?	**N**	The current risk assessment is under constant review as improvements are made to the existing water system and the risk reduction processes. It was stated at the time of the audit that there are no concrete plans for reviewing or redoing the	

		RA at this stage. The risk assessment document recommends that the latest recommended review date should be September 2018. The SHTM 04-01 document is based on the old HSE L8 guidance, and this recommended that a risk assessment should be reviewed or redone every two years. It is recommended that NHS GGC come to a firm decision on when the risk assessment for the QEUH and the RHC should be reviewed or redone. The performance of the risk reduction processes and procedures should be used when making this decision.	
Does the risk assessment address all the water systems in the building?	**N**	The risk assessment that is being reviewed for the purposes of this audit covers the QEUH and the RAC. These two buildings are the focus of this audit. The risk assessment addresses all the systems with the exception of the Hydrotherapy Pool, the renal systems, endoscope wash water and any other systems under he control of Medical Physics.	
Are there any systems that are defined as being excluded from the assessment in the RA scope?	**Y**	The Hydrotherapy Pool is clearly stated as not being part of the RA process. However, the showers and outlets associated with the Hydrotherapy pool are part of the risk assessment process. The Physiotherapy Department is undertaking doing the chemistry and microbiological tasks required for the pool water. tests. The emergency shower and bib tap in the pool plant room are	

Authorising Engineer Water Systems Management and Compliance Audit of NHS Water Systems

		flushed twice per week by the Estates Department.	
Does the risk assessment review the current risk reduction processes and procedures that are currently in use at the site?	**Y**	This is addressed by the inclusion of a GAP analysis of the existing water management processes and procedures and this can be found in Section 9 of the new RA document.	
Does the risk assessment contain details of the people/organisations who are involved in the risk reduction processes and procedures? This should include comments on the dutyholder, the responsible person, any deputy responsible persons and also service providers and contractors.	**Y**	The site contact details can be found in Section 3 of the RA document. Personnel changes since the RA was completed mean that these details now require to be updated in the written scheme. The RA states that at the time of the audit that NHS GGC were still to confirm the details of the site management personnel for the operation of the water systems. This issue is highlighted in Section 2, “Recommendations Sections” and is also cross referenced to the Gap Analysis in section 9. The details of the management organisation are now available in the written scheme that is being constructed by the Estates staff.	
Is there an assessment of the competency of all involved parties in the risk assessment?	**Partial**	There is a copy of the Legionella Control Association membership document for DMA Canyon in the document. There is no other contractor involved in the risk reduction processes and procedures on site. There is no comment on the training records of the on site staff although this is covered later on by this audit.	
Does the risk assessment specifically address and comment on evidence of the current defect/remedial action processes and procedures?	**N**	This does not appear to be part of the current RA document. However, this is also commented on further on in this audit.	
Is there an assessment of the susceptibility of	**Y**	This is referred to in the client details section of the RA	

persons who may be affected by the building water systems?		document.	
Is there a schematic diagram provided with the risk assessment?	**N**	This was not part of the scope of supply.	
Is there a new written scheme provided as part of the risk assessment?	**N**	This was not part of the scope of supply.	
Does the assessment contain details of all the component parts of the water systems? This could include tanks, calorifiers, pipework and pipework layout, outlets, TMV's, expansion vessels etc etc etc.	**Y**	As far as can be ascertained all the component parts of the water systems are included in the RA process.	
Is consideration given to system design, flow, temperature and the opportunity for bacteria to grow and develop in the water systems?	**Y**	This is covered in the RA document. For example, mention is made of the usage levels of outlets, whether there is spray generation, dead legs etc	
Does the risk assessment identify any particular areas of spray and aerosol creation?	**Y**	This is covered in Section 7 of the RA document. Showers are identified as spray and aerosol creation elements of the water systems.	
Are areas of low use and low flow identified in the risk assessment?	**Y**	This is also covered in Section 7 of the RA document.	
Are dead legs specifically detailed in the risk assessment?	**Y**	This is covered in the sections of the RA document that relate to the component parts of the water system. Details of this can be found in sections 4, 5, 6 and 7 of the RA document. These sections refer respectively to the Water Source, the Cold Water Storage Tanks, the Calorifiers and the Hot and Cold Water Outlets. Dead legs, where they occur with each component part of the systems, are mentioned in the detail section of the component parts.	
Is there a set of remedial actions clearly identified in the risk assessment?	**Y**	Section 2 of the RA document, titled "Recommendations" has a full list of clearly defined remedial actions.	
Is there a clearly explained risk scoring system	**Y**	The risk scoring system is clearly defined. The definitions can	

in the risk assessment?		be found in Section 12 of the RA document.	
At what level of risk is the building/property/system assessed to be at?	**Y**	The risk is presented by component part of the water system. A summary of the levels of risk can be found in Section 1, Executive Summary, of the RA document. Of the fourteen levels of risk that are listed, three are described as high and the rest as low or medium. It was stated at the time of this audit that actions have been taken to address all three of the areas identified as high risk.	
Are there any areas of augmented care in the hospital?	**Y**	There are areas of augmented care in the hospital. These areas have been identified by Infection Control.	
Have Pseudomonas risk assessments been completed?	**Y**	A pre-occupancy Pseudomonas RA was completed on 27th April 2015. Areas have been identified by infection control where Pa actions are currently taking place. The Estates department, under the SHTM 04-01 guidelines, is responsible for the quality of the water up to the outlet. From the outlet to the patient, the responsibility for water quality moves to clinical staff. There does not appear therefore to be any actions currently required form an Estates Department point of view.	

Recommendations on the Risk Assessment

1. It is recommended that NHS GGC come to a firm decision on when the risk assessment for the QEUH and the RHC should be reviewed or redone. The performance of the risk reduction processes and procedures should be used when making this decision.

Schematic Drawings	Y/N U/K, N/A or Partial	Comments	Risk Level
Are schematic drawings available in the written scheme, or in some other place in the property?	**Y**	As fitted drawings for the QEUH and the RHC are available and are stored electronically in the Zutec system.	
Do the schematic drawings show all the components of the water systems?	**Y**	The drawing are as fitted drawings and therefore show all component parts of the building.	
Have the identified system deadlegs been added to the schematic drawings?	**N**	Dead legs have not been added to the drawings. Not adding the dead legs to the drawings will not lead to an increase in the level of risk.	
Are the water system return legs shown on the schematic drawings?	**Y**		
Are secondary and tertiary loops shown on the schematic drawings?	**Y**		
Have any amendments been made to the schematic drawings?	**Y**	Some amendments have been made in the past after work had been completed on the site.	
If amendments have been made are they signed and dated?	**Y**	A file is kept in the Estates' Office detailing any amendments that have been made to the drawings. The amendments are detailed and signed and dated. A check should be completed to ensure that any changes made to the pipework systems will be reflected in amendments made to the drawings.	
Is there any indication that drawings are regularly inspected and updated if required?	**N**	It is recommended that drawings are reviewed annually to ensure that they are up to date.	
Recommendations on Schematic Drawings			

1. A check should be completed to ensure that any changes made to the pipework systems will be reflected in amendments made to the drawings.
2. It is recommended that drawings are reviewed annually to ensure that they are up to date.

Management and Competency	Y/N U/K, N/A or Partial	Comments	Risk Level
Is there a duty holder nominated in writing?	**Partially**	The Chief Executive is the Duty Holder. The Chief Executive is Jane Grant. It is not known if she is nominated in writing but the policy document states that she is the Duty Holder.	
Is there a responsible person nominated in writing?	**Y**	Andy Wilson, Sector Estates Manager, is the nominated Responsible Person.	
Is there a clearly defined management structure which includes the relevant on site personnel and also all service providers and contractors?	**Y**	The written scheme is in draft form and a copy was provided at the time of this audit. The management structure is clearly defined in the written scheme. The structure also contains the name of the main risk assessor/water hygiene supplier company. No details of plumbing contractors are included. It is recommended that if plumbing contractors are used for remedial work on the hot and cold water systems, that their details are included in the written scheme.	
Is there a clearly defined line of communication in the written scheme?	**Y**	There are clearly defined lines of communication included in the written scheme. Contact telephone numbers are included.	
Are the responsibilities of all involved parties clearly defined in the written scheme?	**Y**	The responsibilities of the involved people are detailed in section 3 of the written scheme.	
Does the organisation have an up to date and current policy document?	**Y**	The current policy document is stated as being due for review in May 2018, but has had a six month extension applied to that	

		review date. This extension was agreed at the Board Water Safety Group meeting. The Policy document should be reviewed no later than November 2018.	
Does the organisation have an up to date and current procedures document?	**Y**	The Written Scheme and Operational Procedures document is available on the shared drive and on the intranet and is due for review in December 2018. The Written Scheme and Operational Procedures document should be reviewed no later than December 2018.	
Do all staff have relevant up to date training in place?	**Y**	There is a comprehensive programme of training in place that is in the process of being delivered to the relevant staff. All training should be completed by the end of July 2018. There are currently 3 CP's who are trained. There are 5 remaining CP staff who will be trained by the end of August. Letters of appointment are made in all cases after the completion of training courses. AP training has also been completed.	
Are copies of the involved on site personnel training records available in the written scheme?	**Y**	Copies of the training certificates, along with copies of the letters of appointment were available in the written scheme	
Is there evidence available in the written scheme of the competency of service provider and contractor staff?	**Y**	There is evidence in the risk assessment, which is part of the written scheme, of the competence of DMA Canyon Ltd. The evidence is a copy of their current LCA membership. There is no evidence of competency for any other contractors that may be used to complete work on the water systems.	

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		If any contractors are used for plumbing work, or risk reduction work on the water systems, then they should be asked for proof of competency for the organisation and for the involved staff.	
Are service providers and contractors LCA registered?	**Y**	The only service provider that is currently used is LCA registered.	
Do the service providers have other means of proving competence?	**N/A**		
Is there a formal contractor management process in place?	**Y**	There is a section in the written scheme, in section 3.13, which details the requirement for review meetings that will be held on a regular basis. The calendar has settings for a meeting on the first Monday of each month.	
Is there evidence available in the written scheme of review meetings with service providers and contractors?	**N**	The contractor review process has only recently been started. As a consequence there are no actions points/minutes currently available in the written scheme.	
Is there any evidence in the written scheme of management reviews of the data and results produced by the monitoring and control processes and procedures?	**Partial**	BMS data is reviewed on a daily basis. This daily review is included in the written scheme as a task. The contractors' records and details will be reviewed as part of the monthly review meeting process. It is recommended that all review meetings with contractors are minuted and that copies of the minutes are placed in the records section of the written scheme.	
Is there evidence that authorised person competency checks have been completed?	**Y**	Competency checks have recently been completed on a number of AP staff and further checks are planned for the near future. It is recommended that a reference is made in the written scheme as to where to where the details and scores of the competency checks can be found.	
Recommendations on Management and Competency			

1. It is recommended that if plumbing contractors are used for remedial work on the hot and cold water systems, that their details are included in the written scheme.
2. The Policy document should be reviewed no later than November 2018.
3. The Written Scheme and Operational Procedures document should be reviewed no later than December 2018.
4. If any contractors are used for plumbing work, or risk reduction work on the water systems, then they should be asked for proof of competency for the organisation and for the involved staff.
5. It is recommended that a reference is made in the written scheme as to where to where the details and scores of the competency checks can be found.

Written Scheme, Monitoring and Records	Y/N U/K, N/A or Partial	Comments	Risk Level
Is there a written scheme in place?	**Y**	There is a written scheme document available on site. It has been under construction for some time and is a significant improvement compared to the documentation presented to the auditor during the last QEUH audit. Recommendations for improvement of the written scheme are made later on in this report.	
Does the written scheme reflect the findings of the risk assessment?	**Partial**	There is a description of the requirement of each type of task in the written scheme document. A matrix for the site will be created identifying the tasks required by building based on the findings of the risk assessment the tasks are made specific to rooms and assets. It is recommended that this matrix is created as soon as possible and the information from the matrix are reflected in the written scheme.	
Is there a logbook, either paper or electronic,	**Partial**	There is a paper based log book available for the site. The	

<table>
<tr><td>defining all the required tasks for the risk reduction processes and procedures?</td><td></td><td>need/delivery of the relevant tasks will be controlled by the FM First system. Updated forms are being created and it was stated that these would be in use within a month. The records for the previous twelve months' tasks are available in the current paper based record system.

Given the size of the task in addressing the water based risk issues in the QEUH and RHC hospitals it is recommended that consideration is given to the use of an electronic based control and recording system

The updated forms that are required for the monitoring and recording system should be completed and put into use as soon as possible.</td></tr>
<tr><td>Are all tasks in the records signed and dated?</td><td>Y</td><td>The tasks in the paper based are signed and dated.</td></tr>
<tr><td>Is the level of completion of the programmed tasks in the written scheme over the past twelve months suitable?</td><td></td><td>Where applicable, comments are made below the table on the listed tasks.

<table>
<tr><th>Task</th><th>Expected</th><th>Actual Records</th></tr>
<tr><td>Tank Inspections</td><td>2</td><td>0 – no records available.</td></tr>
<tr><td>Calorifier Inspections</td><td>1</td><td>Stated that they were completed at the end of 2017 but records not available.</td></tr>
<tr><td>Shower/Spray Heads</td><td>4</td><td>At times with some outlets there were 2 completion records that were available and with other outlets sometimes 3. Some of the records were not signed and dated.</td></tr>
</table>
</td></tr>
</table>

			Cal F and R Temps	12	Continuously monitored on the BMS system. Data is stored indefinitely at the current time.		
			PH Ex F and R Temps	12	None		
			Hot Sentinel Temps	12	6 – there should be twelve monthly temperatures in this section. Temperatures that are recorded are of TMV outlets. It was not possible to find individual hot temperatures being recorded.		
			Hot Sec Loop Temps	12	6 – the HSG guidance allows for quarterly results to be taken here.		
			Hot Represent Temps	1	0 – this is a requirement and should be put into the task list. However, it may be that with the large number of hot temperatures being recorded, that effectively there are representative outlets being tested.		
			Cold Sentinel Temps	12	6 – there should be twelve monthly temperatures in this section.		
			Cold Rep Temps	1	0 – this is a requirement and should be put into the task list. However, it may be that with the large number of hot temperatures being recorded, that effectively there are representative outlets being tested.		
			POU Heater Temps	2	None on site		
			Expansion	2 - 12	3 – this would fall within the HSG		

Vessels		274 guidelines.
TMV's/TMT's servicing	2	DMA have been completing the services in the high risk areas only. Records exist for Dec/Jan 2018. TMT's in the other areas do not appear to have been serviced.
Little used outlet flushing	104	Flushing of little used outlets is commented on in more detail later in this report.
Second Disinf Levels	12	None – not applicable at this stage.

Calorifier Inspections – stated during the audit that they were completed in November 2017. Records not available at the time of the audit. The planner is detailing the fact that the calorifiers will be inspected again starting in October 2018.

Showers – there is a need to ensure that all records are signed and dated. There is some data covering shower cleaning and disinfections but there are various shower cleaning records missing. As an example, in ward 4a, there are records for cleans of showers for 15/6/18, 13/6/17 and then 7/4/17. Therefore at least two cleans were missed between 13th June 2017 and 15th June 2018.

Calorifier Flow and Return Temperatures – While these are recorded on the BMS system, a check requires to be made to ensure that the results are within acceptable levels.

Hot and Cold Sentinel Temperatures – It was noted that all hot temperatures that are being recorded are mixed

		temperatures from TMT/TMV outlets. There are no individual hot temperatures being recorded. This is not acceptable. It is however understood that it might not be possible to remove lift off panels to get to hot and cold supply temperatures because of infection control risks associated with dust. Additionally, only six sets of temperatures were available at the time of the audit. A review of the temperature monitoring process is required to see if it is possible to find non TMV/TMT outlets which could be regarded as acceptable for the provision of the required hot and cold water temperature data. **Calorifier Blowdown** – This is being completed on a monthly basis and records are available for May June July 2018. **Expansion Vessels –** Expansion vessels are now being blowdown on a monthly basis and records exist for May June July 2018. **TMV's and TMT's –** Quarterly servicing was being completed in high risk wards. DMA Canyon has taken over this process and this includes a thermal disinfection being completed on each outlet. Pall filters are now fitted to the outlets and as a consequence the hospital will revert to the standard 6 monthly servicing process with the provision of a minor and major service. The hospital is currently looking at the potential for outsourcing the TMT servicing. It was stated during the audit that a view needs to be taken on the servicing of the Horne thermostatic shower valves.	

		Flushing – on a quarterly basis there is a memo that is sent out from Estates' Department to all heads of department asking them to identify any little used outlet services that would be under their control. Responses to this email are mixed with some giving no response at all. Domestic staff records and procedures will be looked to see if we can incorporate some reference to the completion of flushing during the cleaning process. The flushing of all other "non cleaner" outlets is the responsibility of Estates. However, Estates can only complete the flushing of these outlets if they are informed that they exist.	
Are there any TMV's/TMT's on the site.	**Y**	There are numerous TMT's in the QEUH and the RHC. It is thought that there are no TMV's in the QEUH and RHC buildings. There are however numerous TMV's in the retained estate. It is believed that there are in excess of 2500 TMT's in the QEUH/RHC. A complete asset list of the TMT's exists in the Zutec system – and contains approximately 2500 outlets. There are also approximately 2500 contour taps. Contour taps cannot be isolated because the isolation and strainer valves are behind IPS panels. There are also approximately 1500 TSV showers in the buildings.	
Are the TMV's/TMT's serviced in accordance with manufacturers recommendations?	**N**	See comments above.	
Are the TMV's/TMT's serviced in accordance	**N**	DMA Canyon are servicing the Horne TMT's in high risk areas.	

with D 08 recommendations?		They are being serviced four times per year and it was stated that this is possibly linked to the Pa guidance. There are numerous other valves that do not appear to be being serviced and this issue is commented on above and in the recommendations section below. It was also stated that no servicing of the TMT's had been completed since March 2018.	
Does the written scheme contain any incident plans?	**Y**	Section 5 of the hospital written scheme is titled "Incident and Emergency Procedures". This is a comprehensive section and covers the following – Failure of Control Measures, High Cold Water Temperature Supply to Outlet, Low Hot Water Temperature Supply to Outlet, Calorifier or Heat Exchanger Temperature Fault, Positive Legionella Test Result, Identification of Little Used Water Outlet, Emergency Repairs, Disinfection of Water System and Pseudomonas.	
Is there a copy of the risk assessment in the written scheme?	**Y**	The risk assessments are held electronically but paper copies of the assessment for each building is held in the Estates Office.	
Is there a copy of the training records in the written scheme?	**Y**	Copies of training records are held in section 3 of the written scheme. There is also a training matrix and a training needs analysis in this section.	
Are non conformances addressed in a timely manner?	**Y**	There is an incident reporting procedure in the written scheme that addresses non conformances. An incident report number would be created. The incident report form is in section 5 of the written scheme document. The technician completes form number 004 with details of the incident and also includes the response and actions to the non conformance. Training is required for hospital staff in the use of the forms.	

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		There was only one incident form completed at the time of the audit.	
Does the written scheme contain an “audit trail” for out of specification situations that allows for remedial actions to be tracked through to completion?	**Y**	The completed incident form described above, accompanied by any associated communications and records, is stored in the written scheme.	
Are Legionella samples taken as part of the written scheme tasks?	**N**	They would be taken in response to the situations as described in the SHTM and HSG 274 document. As there are “high risk areas” in the hospitals, and as there has also been an issue with the microbiology in the water systems, it is recommended that the need for Legionella sampling is reviewed and altered if required.	
Is there a specific escalation procedure for positive Legionella results?	**Y**	A specific escalation procedure for positive legionella samples is held in section 5 of the written scheme. Typically, reactive flushing, followed by resampling, would take place, and this would be recorded and records would be stored in the Estates office. In the retained estate Legionella positives are appearing on a regular basis and there are positives in the month of June and July. This issue will be reviewed under another audit that will be completed for a hospital building in the retained estate. There have been no positive Legionella results for the QEUH and the RHC. It was further pointed that no Legionella sampling is being undertaken while the POU filters are installed.	

		It is pointed out that while the filters are installed, this should prevent the escape of any Legionella from the hospitals' water systems. However, the complete lack of sampling for Legionella could mean that the organism might be present in the water systems, particularly given the microbiological issues that have been recently experienced. It is recommended therefore that legionella sampling is reinstated in the POU filtered areas in order that an understanding of what is happening microbiologically in the hot and cold water can be had. There have been other problematic bacterial species found in the water systems in the recent past. It is therefore recommended that a sampling protocol, covering what species should be monitored, how often, and from where, is agreed with the NHS GGC Infection Control team.	
Are Legionella samples being taken in accordance with BS7952:2008?	**Y**	DMA Canyon is currently taking any required samples and it is understood that the DMA staff are trained to take samples.	
Are Pseudomonas samples taken as part of the written scheme?	**N**	This is in line with the Health Protection Scotland Guidance dated July 2017 samples are not taken as a matter of routine.	
Are the Pseudomonas samples taken in line with the guidance given in the HSF, HPS CEL of July 2017?	**N/A**		
Are there copies of method statements for any procedures that are completed in house	**Y**	Section 4 of the written scheme contains all the procedures for the work that is completed in house. As an example the procedures for the inspection of cold water storage tanks was inspected and found to be satisfactory.	

		The text that is on the procedures sheets also is sent out with the FM First tickets to the on site technicians in order that they have details of the methods to be followed.	
Are there copies of method statements for any procedures that are completed by external providers?	**Y**	DMA Canyon method statements are held on the shared drive. DMA Canyon has created method statements for the new tasks completed on site such as flow straightener replacement. It is recommended that a copy of the DMA Canyon method statements are added to the written scheme, or that reference is made in the written scheme as to where the method statements can be found.	

Recommendations on Written Scheme, Monitoring and Records

1. Given the size of the task in addressing the water based risk issues in the QEUH and RHC hospitals it is recommended that consideration is given to the use of an electronic based control and recording system
2. The updated forms that are required for the monitoring and recording system should be completed and put into use as soon as possible.
3. It is recommended that this matrix is created as soon as possible and the information from the matrix are reflected in the written scheme.
4. Records need to be made available as proof that the required tasks are being completed satisfactorily and on time. Going forward the need to deliver completed acceptable records should be highlighted as a definitive requirement.
5. Complete quarterly shower and hose cleaning and descaling and ensure that appropriate records are kept in the log book.
6. Ensure that all records are signed and dated.
7. With regard to any records that are recorded on the BMS system, a check requires to be made to ensure that the results being recorded are within acceptable levels.
8. It is recommended that the process for the taking and recording of the sentinel hot and cold water temperatures is reviewed to see whether there are options that can be employed which can overcome the need to remove lift off panels. If outlets can be identified then they need to be listed and added to the log book and FM First to ensure that they are monitored monthly.
9. If a temperature recording process can be identified that gives suitable information which will allow confidence in the water systems operation, then the appropriate staff require to be trained in how to take and record the temperatures.

10. NHS GGC should decide on what the servicing protocol is to become for all the TMT's/TMV's in the two hospitals, and once confirmed, the protocol should be implemented across the hospitals.
11. The service requirement should also be defined and if required, implemented, for the Contour taps in the QEUH and RHC.
12. The service requirement should also be defined and if required, implemented, for the TSV's in the QEUH and RHC.
13. Flushing of little used outlets is an issue and a hospital wide process, engaging all the involved parties, requires to be defined and implemented as soon as possible to ensure that little used outlets are correctly flushed.
14. Ensure that all involved staff have been trained in the operation and use of the incident forms which form part of the written scheme.
15. As there are "high risk areas" in the hospitals, and as there has also been an issue with the microbiology in the water systems, it is recommended that the need for Legionella sampling is reviewed and altered if required.
16. It is recommended therefore that legionella sampling is reinstated in the POU filtered areas in order that an understanding of what is happening microbiologically in the hot and cold water can be had.
17. It is therefore recommended that a sampling protocol, covering what species should be monitored, how often, and from where, is agreed with the NHS GGC Infection Control team.
18. It is recommended that a copy of the DMA Canyon method statements are added to the written scheme, or that reference is made in the written scheme as to where the method statements can be found.

Correct and Safe Operation	Y/N U/K, N/A or Partial	Comments	Risk Level
Is there a statement of "correct and safe operation" detailing targets for temperatures and other control measures?	**N**	There is no standalone statement of correct and safe operation. However, there target temperatures and required outcomes for all tasks are detailed in the maintenance procedures sheets. The HSG 274 document recommends that a statement of correct and safe operation for the building water systems be created and added to the written scheme. It is recommended that a statement of correct and safe operation is created for the QEUH and RHC hospitals and that	

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		these statements are added to the written scheme.	
Is there evidence in the written scheme that any deadlegs have been removed?	**Y**	There is a fault log in the written scheme that would detail any dead legs that have been removed. The deadlegs identified in the risk assessment have all been examined and some have been found not to be an issue in relation to operation of the hot and cold water systems. An action plan was created from the risk assessment and the details in relation to these dead legs can be found in Smart Sheets. However, evidence of dead leg removal was not to be found in the current written scheme It is recommended that a process which records the removal of the risk assessment identified dead legs, as well as any dead legs which are found subsequently, is defined and recorded in the written scheme.	
Is temperature the primary means of control within the water systems?	**Y**		
Is there any form of water treatment being applied to the water systems?	**Y**	The incoming water is filtered.	
Are little used outlets (LUO's) flushed?	**Partial**	The Estates department sends out an email on a quarterly basis to all departments asking for them to update the list of little used outlets. These departments are asked to complete a sheet and return it to the Estates department. The response also asks them to detail if they are compliant in terms of delivering the required flushing procedures in the areas under their control. There are some departments that do not reply and some who give a "patchy" response.	

		Estates also have a list of outlets that can be removed. The entire process of flushing the little used outlets in both hospitals requires to be reviewed and updated. A recommendation on this is given earlier in this report under the "Written Scheme, Monitoring and Records" section. There is no formal process in place for the flushing of outlets outwith the control of clinical staff. There is awareness that this requires to be done and there is a plan in place to create and implement a formal process. It is recommended that a process, which should list the little used outlets and the appropriate flushing requirements, is created for the areas that fall under the control of the Estates Department.	
Is the flushing of little used outlets recorded in the records system?	**Partial**	This should be recorded from the quarterly returns that should be provided by the various involved parties throughout the hospitals. This is happening on a partial basis and is discussed and covered earlier on in this report.	
Is there any seasonal difference in the use profile of the water systems?	**N**		
Are any pieces of duty standby equipment that require to be switched on a weekly basis, and do the records show that they are being switched?	**Y**	There are two mains two water inlets to the hospitals and these are switched twice a day. Other booster pumps sets were recently checked for pump run information and all have been found to be cycling correctly. It is recommended that a procedure for checking that the automatic switching of booster pumps is occurring requires to be put in the written scheme.	

Are there any flexible connections in the property/	**Y**	There is a flexi hose register for the QEUH and the RHC. Where possible at the Arjo baths the flexible hoses have been removed. The remaining flexible hoses at the Arjo baths are changed every 2 years. A record of these processes is held in the Estates Office.	

Recommendations on Correct and Safe Operation

1. It is recommended that a statement of correct and safe operation is created for the QEUH and RHC hospitals and that these statements are added to the written scheme.
2. It is recommended that a process which records the removal of the risk assessment identified dead legs, as well as any dead legs which are found subsequently, is defined and recorded in the written scheme.
3. It is recommended that a process, which should list the little used outlets and the appropriate flushing requirements, is created for the areas that fall under the control of the Estates Department.
4. It is recommended that a procedure for checking that the automatic switching of booster pumps is occurring requires to be put in the written scheme.

On Going Water Treatment	Y/N U/K, N/A or Partial	Comments	Risk Level
Is there any form of water treatment in use on site?	**Y**	An ultrafiltration process is used on site	
Is there any form of secondary disinfection in place on site?	**N**		
Are the required checks for secondary disinfection levels being completed and recorded on site?	**N/A**		
Are the required levels of disinfection being achieved in the water systems?	**N/A**		

Is there a record of stock levels of biocide in the written scheme?	**N/A**		
Is any of the water base exchange softened?	**N/A**		
Are service records for the base exchange softeners available in the written scheme?	**N/A**		
Is filtration in use in any of the water systems?	**Y**	Ultrafiltration is used on site.	
Are service records for the filtration equipment available in the written scheme?	**Y**	The service records for the ultrafiltration system are held electronically on the shared drive. A clean and inspection of the membrane is completed on an annual basis. An additional disinfection of the units was completed in early July 2018. The report for the disinfection process of the filtration plant was available during this audit. The service work on the filtration system does not appear in the written scheme. It is recommended that the filtration system service work is included in the written scheme, or that a reference to the process is made in the written scheme.	

Recommendations on Ongoing Water Treatment

1. It is recommended that the filtration system service work is included in the written scheme, or that a reference to the process is made in the written scheme.

Cleaning and Disinfection Procedures	Y/N U/K, N/A or Partial	Comments	Risk Level
Are system cleaning and disinfection procedures in use on site?	**Y**	The Cold water storage tanks are cleaned and disinfected. Shower heads and hoses are also cleaned and disinfected.	

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Are the cleaning and disinfection procedures completed by in house staff?	**Y**	Contractors complete storage tank and shower disinfections procedures. In house staff has completed thermal disinfections of the outlets in the past. Any thermal outlet disinfections are now completed by DMA Canyon.	
Are the in house staff trained and competent to complete cleans and disinfections?	**Y**	Training for in house staff in these cleaning and disinfection procedures may not be recorded. It is recommended that reference is made as in the training section of the written scheme as to where the training records can be found.	
Are the contractor's staff trained and competent to complete cleans and disinfections?	**Y**	The DMA Canyon staff have been trained in the required cleaning and disinfection processes and procedures. Training records for DMA staff were available in the shared drive. Some further DMA staff records may be required. Check with DMA if there are staff members whose records require to be added to the written scheme. Reference the G drive location of the DMA training records in the written scheme.	
Are cleaning and disinfection procedures completed as a matter of procedure?	**N**		
Are these cleaning and disinfection procedures completed in response to sampling/inspection results.	**Y**	Decisions are made on whether to clean and disinfect cold water storage tanks based on the inspection findings of the tanks.	
Are there suitable method statements available in the written scheme covering the cleaning and disinfection procedures?	**Y**	DMA Canyon have provided suitable method statements and they also provide completion certificates at the end of each cleaning process.	
If chlorine is used, is the impact of pH considered in the disinfection process.	**Y**		
Are there completion certificates in the written	**Y**		

scheme covering any disinfection procedures that have been undertaken?			
Are localised outlet disinfections in use on site?	**Y**	Thermal disinfections may be completed on outlets in the high risk areas.	
Is there a suitable method statement available in the written scheme covering the localised cleaning and disinfection procedures?	**Y**	The thermal disinfection method statement is supplied by DMA Canyon and it forms part of the thermostatic tap maintenance process method statements.	

Recommendations on Cleaning and Disinfection Procedures

1. It is recommended that reference is made as in the training section of the written scheme as to where the training records can be found.
2. Check with DMA if there are staff members whose records require to be added to the written scheme. Reference the G drive location of the DMA training records in the written scheme.

New Build and Refurb Capital Projects	Y/N U/K, N/A or Partial	Comments	Risk Level
Have any new build or refurbishment projects, which impacted on the water systems, been completed in the past 12 months	**N/A**	This is not currently applicable to the QEUH and RHC.	
Were the implications of this work risk assessed?	**N/A**		
Was the assessment added to the log book and water system records?	**N/A**		
Was the written scheme amended to account for the implications of the new build/amended water systems?	**N/A**		
Were the details of the new systems	**N/A**		

discussed with the Estates Department and any other involved personnel?			
Are minutes of discussions regarding the new water systems recorded and entered into the log book?	**N/A**		
Were systems, if required, cleaned and disinfected?	**N/A**		
Are records of all cleans and disinfections available in the record systems?	**N/A**		
Recommendations on New Build and Refurb Capital Projects			
None			
Water Safety Group	**Y/N U/K, N/A or Partial**	**Comments**	**Risk Level**
Is there a Water Safety Group in place?	**Y**	There are sector water safety group meetings as well as Higher management level Water Group Safety Meetings.	
Does the WSG have all the required groups represented?		The WSG meetings include representatives from the following - Infection control, lead microbiologist or representative, Estates - Site manager operational estates, estates manager/lead AP, facilities general manager is normally the chair of the meeting, Domestic services, representative from Serco for the Langlands unit. Invites are likely to be extended to DMA Canyon in the future. The AE has only been invited top one WSG meeting in the past three years.	

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		It is recommended that in keeping with the practices at other Boards, the AE is asked to attend more of the WSG meetings.	
Are WSG meetings held on a quarterly basis?	**Y**		
Are minutes and actions produced and followed through with the WSG?	**Y**	Copies of the minutes and actions from the WSG meetings are held in the shared drive	

Recommendations on the Water Safety Group

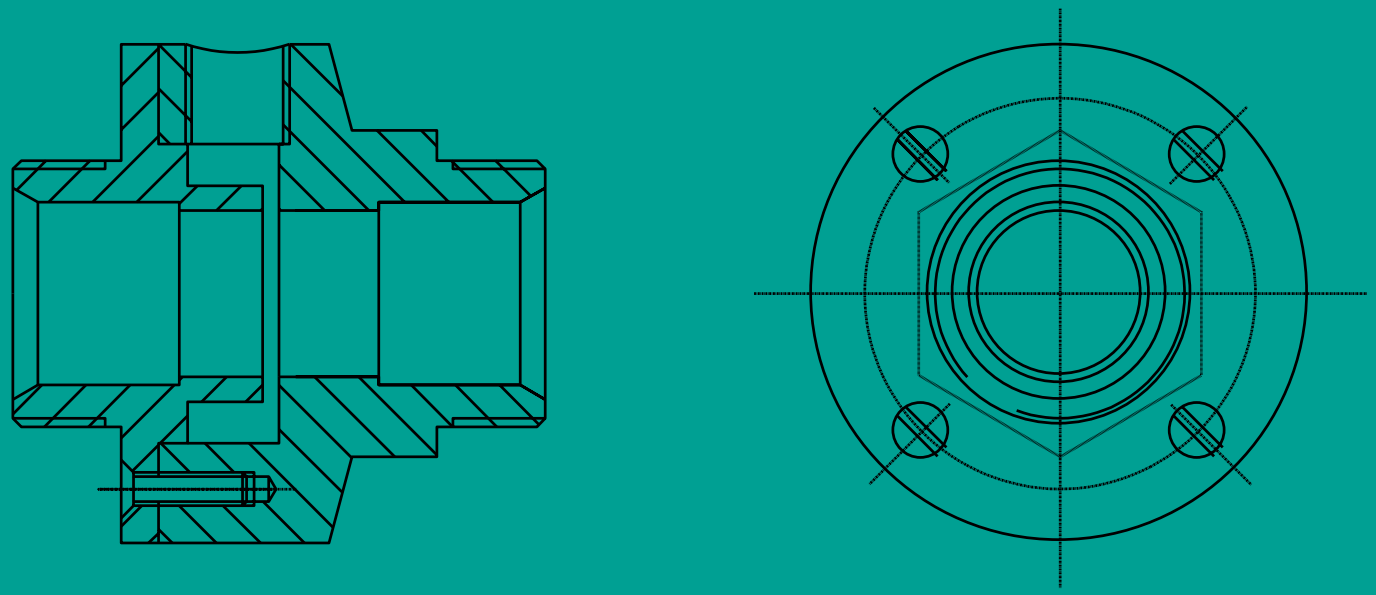
1. It is recommended that in keeping with the practices at other Boards, the AE is asked to attend more of the WSG meetings.

Department of Health

Health Technical Memorandum 04-01: Supplement

Performance specification D 08: thermostatic mixing valves (healthcare premises)

2017 edition



March 2017

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Contents

0. Introduction

It is recognised that users of domestic hot water for ablutionary purposes in health and social care establishments, particularly vulnerable people (see Note below), can be at risk of injury by scalding. The previous edition of this performance specification, published in 1997, was developed in response to a requirement to provide a robust performance-based specification standard for thermostatic mixing valves for use in the healthcare sector that would significantly reduce the risk of water being emitted at an unsafe temperature.

"Vulnerable people" are defined in the Health and Safety Executive's Health Services Information Sheet 6 as:

- children;
- older people;
- people with reduced mental capacity, mobility or temperature sensitivity;
- people who cannot react appropriately, or quickly enough, to prevent injury.

This updated specification has been amended in conjunction with NSF, BuildCert, TMV manufacturers and trade bodies. In addition to amendments to the technical content relating to the performance requirements, material requirements and test methods for thermostatic mixing valves, it contains flowcharts to assist with the on-site:

- auditing of the water supply conditions intended to supply the thermostatic mixing valve;
- commissioning of the thermostatic mixing valve;
- in-service testing of the thermostatic mixing valve.

These flowcharts are intended to assist those responsible for the installation, commissioning and routine in-service testing of thermostatic mixing valves in ensuring that the installed equipment operates as intended by the manufacturer, and delivers safe hot water for the user.

This performance specification is intended to be utilised in conjunction with Health Technical Memorandum 04-01 Part A, Health Technical Memorandum 04-01 Part B and the Health Technical Memorandum 04-01 Addendum, which provides advice in relation to *Pseudomonas aeruginosa* (see References).

0.1 Key certification scheme requirements for Type 3 thermostatic mixing valves

The certification requirements to enable manufacturers to demonstrate compliance with HTM 04-01: Supplement – 'Performance Specification D 08: thermostatic mixing valves (healthcare premises)' were initially established in the mid-1990s following a joint initiative by the four devolved nations (led by NHS Estates) in conjunction with Water Research Centre (now NSF) and thermostatic mixing valve manufacturers.

These requirements have been amended in subsequent years. Historically, recommendations from the BuildCert/NSF Technical Assessment Panel (TAP) in relation to the certification scheme have been presented formally to the TMV Industry Forum where decisions are ratified, minuted and notified to the Department of Health (DH). Where there have been any challenges to the scheme requirements, these have been heard by an independently chaired advisory committee (BuildCert/NSF Advisory Committee). Decisions of this independent committee are also notified to DH.

Any third-party certification schemes for Type 3 thermostatic mixing valves must incorporate ALL of the following key requirements:

- The certification organisation must be UKAS-accredited against BS EN ISO/IEC 17065 and must be open to inspection by DH or its nominated representative.
- The test houses that provide performance results against HTM 04-01: Supplement – 'Performance Specification D 08: thermostatic mixing valves (healthcare premises)' must be UKAS-accredited against BS EN ISO/IEC 17025.
- Test houses must enter into round-robin verification every five years to ensure reproducibility of results.
- Manufacturers' test houses must have additional third-party witness verification of sample selection and testing to ensure full third-party approval is maintained.
- Type 3 approval is issued for five years, after which a full re-test will be required.
- A list of the approved Type 3 valves from the scheme should be freely available online in an easy-to-access format.
- Manufacturers must have in place a UKAS-recognised ISO 9001 quality system.
- Approved Type 3 valves must be performance-audited twice within the five-year approval period with failures notified to DH and systems established to eliminate risks to users.
- Identification (the manufacturer's unique mark or identifier) of Type 3 valves should be verified twice within the five-year approval period.
- Installation documentation provided with Type 3 valves should be verified twice within the five-year approval period.
- Regular liaison with the TMV industry (that is, manufacturers and trade associations) and DH should be maintained to ensure industry has access to the certification scheme and can input directly into the requirements of the approval process.

Any suggested amendments to the requirements in HTM 04-01: Supplement – 'Performance Specification D 08: thermostatic mixing valves (healthcare premises)' should be discussed formally with DH or its nominated representative.

1.0 Scope

This specification specifies the performance, material requirements and test methods for thermostatic mixing valves for use in care establishments (for example hospitals, nursing homes, and residential care homes etc) where the users (for example patients, residents etc), by virtue of their physical or mental condition, are deemed to be at greater risk of injury in their use of domestic hot water than would be the case for normally able persons in their own dwelling. Thermostatic mixing valves complying with this specification are also suitable for other applications where the risk of scalding must be reduced.

Note 1: An assessment of the risk should be carried out.

Thermostatic mixing valves complying with this specification are designated according to operating pressure range and the intended ablutionary application (see Chapter 8).

Note 2: Application for washbasin use is included for those situations where the risk assessment shows that a greater level of protection is necessary.

This specification applies to thermostatic mixing valves installed for ablutionary purposes in care establishments in which the hot and cold water supplies are normally within the limits specified in Table 1 for each operating pressure range and the mixed water temperature is set to the value specified in Table 2 appropriate to the application.

Note 3: Some of the performance requirements represent the application of abnormal water supply conditions outside these limits to ensure that under specified fault conditions the mixed water temperature remains safe.

Thermostatic mixing valves having integral on/off, or flow control, for single-point use are included in the scope of this specification. Thermostatic mixing valves without flow control and those suitable for supplying a small number of outlets are also included.

Note 4: Multiple outlets should not be considered where the length of the downstream dead-leg may aggravate the risk of bacterial growth.

Guidance on this is given in the Department of Health's Health Technical Memorandum 04-01 – 'The control of Legionella, hygiene, "safe" hot water, cold water and drinking water systems. Part A: Design, installation and testing'.

Thermostatic mixing valves with a user-adjustable mixed water temperature up to a pre-set maximum and thermostatic mixing valves intended to be installed and used with no user-accessible adjustment of the mixed water temperature are both included in the scope of this specification.

Note 5: Only thermostatic mixing valves with no user-accessible adjustment of the mixed water temperature should be used for applications in which two or more outlets may discharge simultaneously when operated by two or more users at the same time. Thermostatic mixing valves with user-accessible adjustment of the mixed water temperature may be used with two or more outlets that do not discharge simultaneously (for example, they are supplied through a diverter) provided that the mixed water temperature adjustment is appropriate to each application.

Note 6: When designations of use are referred to in this document, if prefixed by a "/" (forward slash symbol), the valve will have multiple designations of use. For example, a valve designated as HP-B/S/W, LP-B/S is approved for "high pressure bidet, shower and washbasin" and "low pressure bidet and shower use" only.

Thermostatic mixing valves of nominal size up to and including DN 25 are included in the scope of this specification.

Operating pressure range	High pressure	Low pressure
Maximum static pressure (bar)	10	10
Flow pressure, hot and cold (bar)	1 to 5	0.2 to 1
Hot supply temperature (°C)	55 to 65	55 to 65
Cold supply temperature (°C)	5 to 20	5 to 20

Table 1 Conditions for normal use

Application and designation	Mixed water temperature (at point of discharge)(°C)
Bidet (B)	38 max.
Shower (S)	41 max.
Washbasin (W)	41 max.
Bath (44°C fill) (T44)	44 max.
Bath (46°C fill) (T46)	46 max.
Diverter Bath/Shower (D44)	Bath fill 44 max, Shower 41 max
Diverter Bath/Shower (D46)	Bath fill 46 max, Shower 41 max

Note 1: For washbasins, washing under running water is assumed.

Note 2: Bath fill temperatures of more than 44°C should only be available when the bather is always under the supervision of a competent person (e.g. nurse or care assistant).

Note 3: A thermostatic mixing valve having multiple designations (see Note 6 above) (i.e. it is capable of satisfying the requirements of this specification for more than one application) should be re-set on site to suit its other designations.

Note 4: A thermostatic mixing valve having a diverter designation (D) must be capable of changing and controlling the mixed water outlet temperature as defined above when the supply path is changed from bath to shower or shower to bath.

Table 2: Mixed water temperature

2.0 Definitions

Atmospheric discharge nozzle: an integral open outlet water spout that may include aerators, flow straighteners and flow regulators.

Obturator: mechanism that arrests the water flow (on/off control).

Pre-set: in respect of the mixed water temperature, this means that there is no user-accessible adjustment and the mixed water temperature is set to a fixed value. The fixed value is set on commissioning of the installation and shall not exceed the maximum permitted for the application (see Table 2).

Thermostatic mixing valve: valve with one or more outlets, which mixes hot and cold water and automatically controls the mixed water to a user-selected or pre-set temperature.

Note: If provision for controlling the flow rate between no flow and maximum flow is included, this may be by means of a different motion of the temperature control or by a separate control (see Annex G).

Transient: measurement of temperature change over time.

User adjustable: in respect of the mixed water temperature, this means that there is a control accessible to the user which enables the temperature to be adjusted between a pre-determined maximum and some lower value. The pre-determined maximum is set on commissioning of the installation and shall not exceed the maximum permitted for the application (see Table 2).

3.0 Construction

3.1 General

If the thermostatic mixing valve is provided with removable devices (for example, flow rate regulators) in the inlets, and these are intended to be removed on commissioning in order to convert the mixing valve to another designation, then the mixing valve shall be supplied with these devices fitted.

3.2 Materials

All materials in contact with water shall comply with BS 6920 and the current version of the Water Regulations Advisory Scheme's (WRAS) 'WRAS material guidance: a guide for manufacturers, suppliers and test laboratories on the application requirements for WRAS material approval' (see References).

4.0 Sampling

The samples required for testing shall be selected at random from stock. In the event that one sample should fail to satisfy a designation, then Annex D shall be referred to. Annex D describes a provision for the testing of further samples. If two valves fail to satisfy a designation, then no further testing shall be undertaken.

When tested, the thermostatic mixing valve shall be fitted with the anti-backsiphonage devices (for example check valves) required in use. These shall be integral with the mixing valve, or supplied with it, or be specified by the manufacturer. If not fitted to the test samples, these devices shall be fitted in the connected pipework as close as possible to the mixing valve.

For the tests described in Chapters 5, 6 and 7, three samples are required, denoted by A, B and C. These shall be tested in the sequence shown in Figure 1.

Where two applications are served by two separately operating mechanisms sharing common supply connections, each operating mechanism shall be tested as though it were a separate valve.

Only sample A shall be tested for flow rate according to clause 7.3. Where samples B and C utilise alternative inlet connection sizes, the flow rate will need to be verified for the appropriate designation.

For valves with designations D44 and D46, samples A and C shall be tested to the requirements of clauses 7.4 to 7.12 for all relevant applications.

In all other cases, samples A and C shall be tested to the requirements of clauses 7.4 to 7.12 for the designation in each operating pressure range having the highest mixed water temperature setting of those designations, or applications, with the lowest designated flow rate.

For all valves, sample B shall be tested to the requirements of clauses 7.4 to 7.12 for all applications.

Note:

As an example, the performance tests applicable to designations HP-B/W/T44 and LP-B/W/T44 are shown in Figure 2.

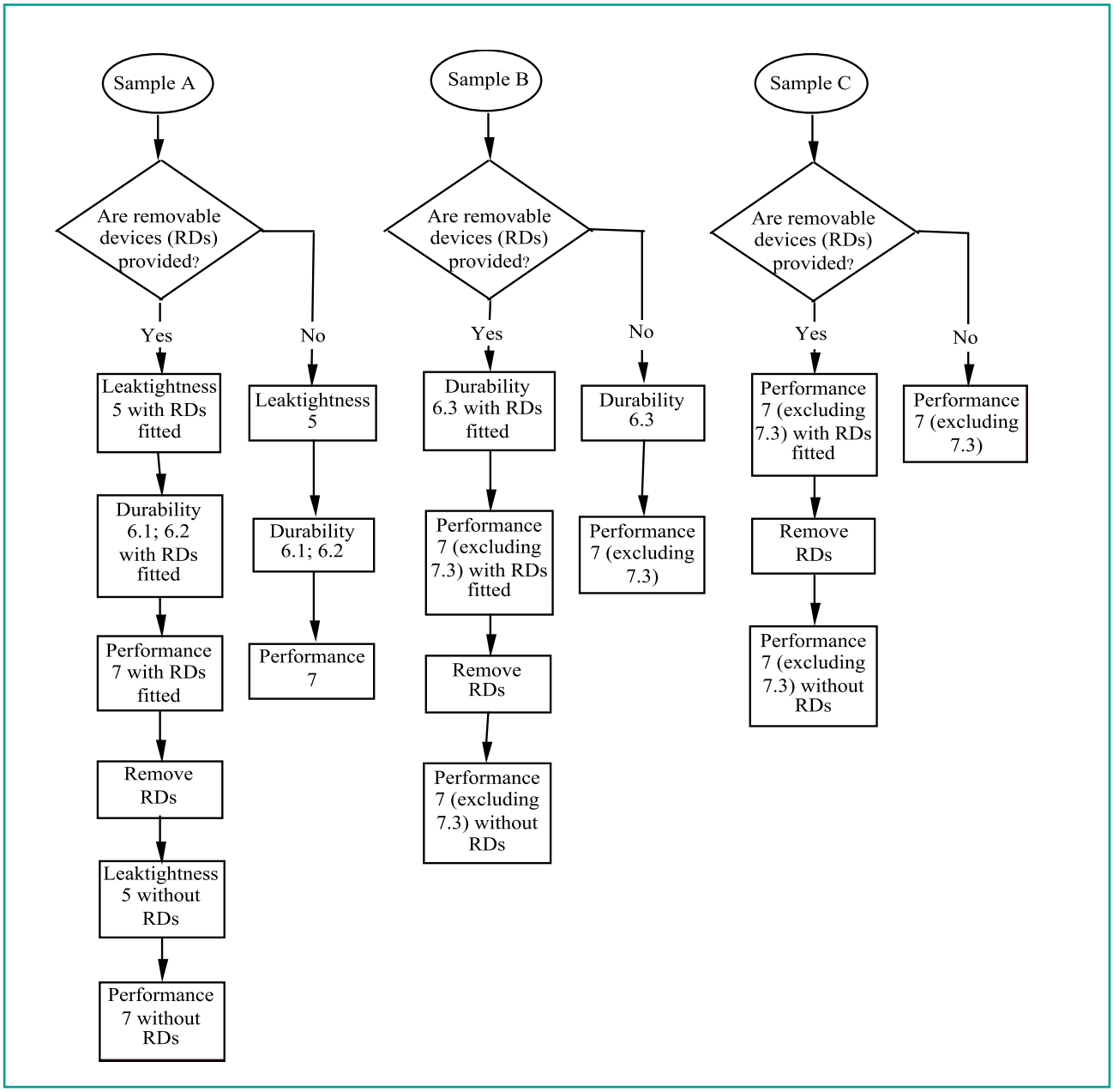
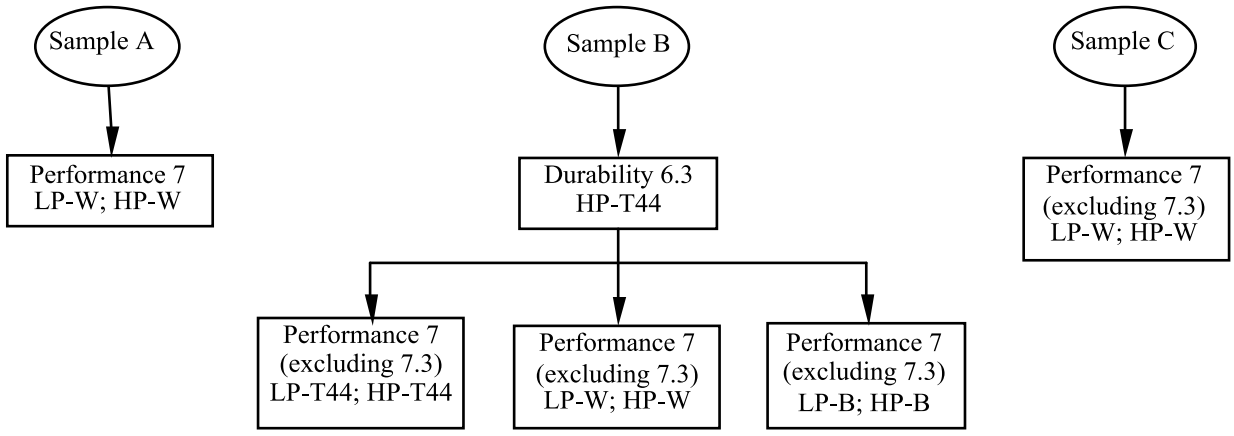


Figure 1 Test sequence



Flow rate tests to be undertaken for bath and other uses.

Figure 2 Example of performance test sequence for designations -HP-B/W/T44 and -LP-B/W/T44

5.0 Leaktightness

5.1 General

Thermostatic mixing valves certified as complying with either BS EN 1111 or BS EN 1287 will be regarded as complying with the leaktightness requirements of this specification. In all other cases the following tests shall be applied and shall be tested without shower hoses.

Note:

The tests described here reproduce almost exactly the text of the ENs referred to.

5.2 Principle

This consists of checking, under cold water pressure, the leaktightness of:

a. the obturator (see clauses 5.4 and 5.5) if provided;

b. the complete mixing valve (see clauses 5.4 and 5.6);

c. diverters with manual control (see clause 5.7) or automatic return (see clause 5.8) if provided.

Note:

Where a diverter with automatic return is regarded as performing an anti-backsiphonage function, additional requirements may be applied.

5.3 Apparatus

A hydraulic test circuit as shown in Figure A.1 capable of supplying the static and dynamic pressures required and of maintaining them throughout the duration of the test.

5.4 Leaktightness of the thermostatic mixing valve upstream of the obturator and of the obturator

In the case of thermostatic mixing valves without obturators (that is, with no on/off or flow control), the outlet orifice shall be artificially closed.

5.4.1 Procedure

- Connect the two water supplies to the mixing valve.
- With the outlet orifice open and the obturator closed, apply a water pressure of 16 ± 0.5 bar to the thermostatic mixing valve for 60 ± 5 s for the full operating range of the temperature control device.

In the case of single sequential thermostatic mixing valves, the control shall be left in the “flow closed” position.

5.4.2 Requirements

a. Verification of leaktightness upstream of the obturator.
For the duration of the test there shall be no leakage or seepage through the walls.

b. Verification of leaktightness of the obturator.
For the duration of the test there shall be no leakage at the obturator.

5.5 Leaktightness of the obturator of the thermostatic mixing valve: cross flow between hot and cold water

In the case of thermostatic mixing valves without obturators (that is, with no on/off or flow control), the outlet orifice shall be artificially closed.

When testing a single sequential thermostatic mixing valve, the control shall be left in the “flow closed” position.

5.5.1 Procedure

- Connect one inlet of the thermostatic mixing valve to the test circuit.
- With the outlet orifice open and the obturator closed, apply a water pressure of 4 ± 0.2 bar to the thermostatic mixing valve for 60 ± 5 s for the full operating range of the temperature control device.
- Repeat the test, reversing the water supply connection to the other inlet.

5.5.2 Requirements

For the duration of the test there shall be no leakage or seepage at the outlet (not applicable to thermostatic mixing valves without obturator) or at the end of the unconnected inlet.

5.6 Leaktightness of the thermostatic mixing valve downstream of the obturator

5.6.1 Procedure

- Connect the two water supplies to the thermostatic mixing valve.
- With the outlet orifice closed and the obturator open, apply a water pressure of 4 ± 0.2 bar to the thermostatic mixing valve for 60 ± 5 s for the full operating range of the temperature control device.
- Repeat the test with a water pressure of 0.2 ± 0.05 bar for 60 ± 5 s.

5.6.2 Requirements

For the duration of the test there shall be no leakage or seepage.

5.7 Leaktightness of the manual diverter of the thermostatic mixing valve

5.7.1 Procedure

- Connect the thermostatic mixing valve, in its position of use, to the test circuit.
- Put the diverter in the bath position, with the bath outlet artificially closed and the shower outlet open.
- Apply the static water pressure appropriate to the designation given in Table 3 for 60 ± 5 s. Observe the outlet to shower.
- Gradually reduce to a static water pressure of 0.2 ± 0.05 bar and maintain for 60 ± 5 s. Observe the outlet to shower.
- Put the diverter in the shower position with the shower outlet artificially closed and the bath outlet open.
- Apply the static water pressure appropriate to the designation given in Table 3 for 60 ± 5 s. Observe the bath outlet.
- Gradually reduce to a static water pressure of 0.2 ± 0.05 bar and maintain for 60 ± 5 s. Observe the bath outlet.

Abbreviated designation	Static water pressure (bar)
All -LP-	2 ± 0.1
All -HP-	4 ± 0.2

Table 3 Test pressures for manual diverters

5.7.2 Requirements

For the duration of the test there shall be no leakage at the outlet points indicated.

5.8 Leaktightness of the diverter with automatic return of the thermostatic mixing valve

5.8.1 Procedure

- Connect the thermostatic mixing valve, in its position of use, to the test circuit with the outlets fully open.
- Put the diverter in the bath position and apply a dynamic water pressure equal to the “initial flow pressure”, appropriate to the designation, given in Table 4 for 60 ± 5 s. Check for leakage at the shower outlet.
- Fit to the shower outlet the hydraulic resistance identified in Table 4 appropriate to the designation (see Figure 3).
- Maintaining the flow pressure at the "initial" value, put the diverter in the "flow to shower" mode. Observe the bath outlet for 60 ± 5 s and note any leakage.
- With the diverter still in the shower position, reduce the dynamic pressure to a value equal to the "reduced flow pressure", appropriate to the designation, given in Table 4. Check that the diverter is not dislodged. Maintain this pressure for

Abbreviated designation	Initial flow pressure (bar)	Reduced flow pressure (bar)	Flow resistance
All -LP-	0.8 ± 0.04	0.2 ± 0.01	Complying with Figure 3 and calibrated to a flow rate of 9 L/min at a flow pressure of 0.2 bar referenced to the datum shown
All -HP-	4 ± 0.2	0.5 ± 0.05	A flow resistance calibrated to a flow rate of 15 L/min at a flow pressure of 3 bar

Table 4 Test pressures and flow resistances for diverters with automatic return

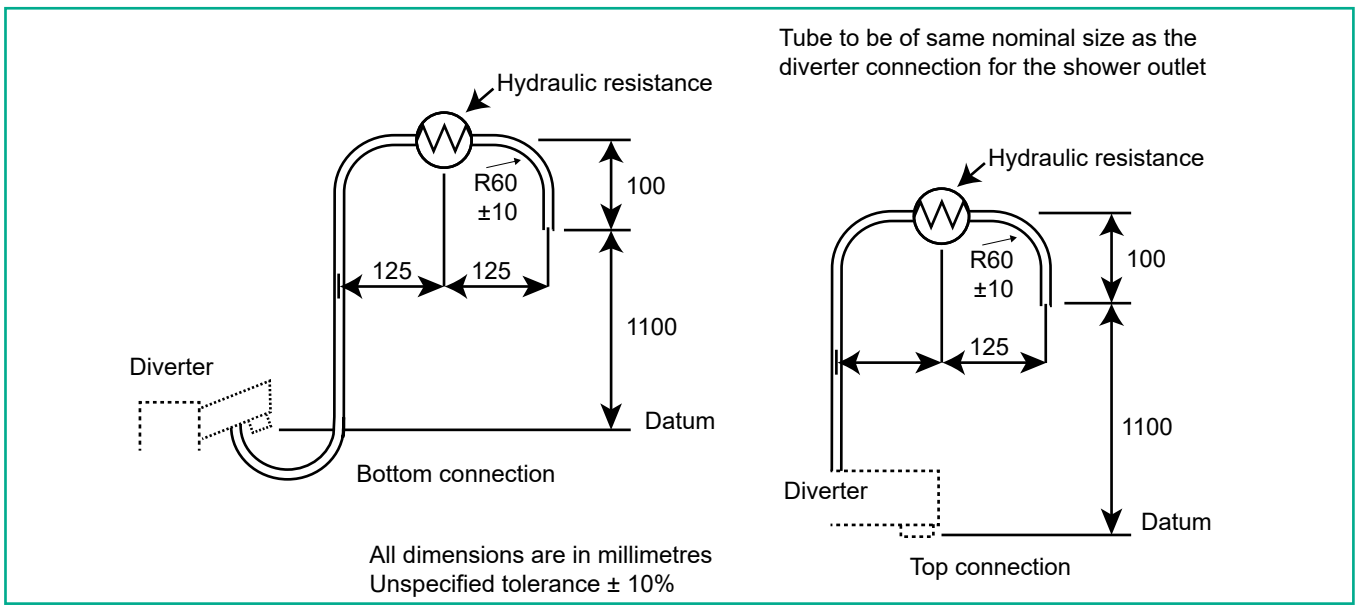


Figure 3 Hydraulic resistance for low pressure diverters with automatic return

60 ± 5 s and observe the bath outlet and note any leakage.

- Turn the water off. Check that the diverter returns to the bath position.
- Disconnect the hydraulic resistance and reopen the flow control and pressure measuring devices. Reapply the dynamic pressure equal to the "reduced flow pressure", appropriate to the designation, given in Table 4 for 60 ± 5 s. Check for leakage at the shower outlet.

5.8.2 Requirements

For the duration of the test there shall be no leakage.

6.0 Durability

6.1 Durability of on/off (flow) control

6.1.1 General

Thermostatic mixing valves certified as complying with either BS EN 1111 or BS EN 1287 will be regarded as complying with the requirements of this specification for the durability of the on/off (flow) control. In all other cases the following tests shall be applied to mixing valves with an on/off (flow) control.

Note:

The tests described here reproduce almost exactly the text of the ENs referred to.

6.1.2 Principle

This consists of subjecting the flow control devices to a specific number of opening and closing movements under specified hot and cold water conditions at the pressure and temperature specified.

6.1.3 Apparatus

A suitable test rig for operating the devices in line with their normal function.

The speed of operation of the control devices is to be set at 60°/s angular velocity (that is, 0.017 s per degree of angle). For linear movement the velocity shall be 0.04 m/s.

Note:

Due to the diversity of product design and especially for single sequential control thermostatic mixing valves, it will be necessary for the test house and manufacturer to liaise to produce a valid test apparatus and agree detailed test specifications.

6.1.4 Procedure

- Connect the thermostatic mixing valve to a suitable test apparatus designed to operate the on-off devices to within 90–95% of their intended travel.
- Supply hot water at a temperature of 65 ± 2°C and cold water at a maximum of 30°C to the mixing valve under test.
- With the thermostatic mixing valve open, adjust the water pressure of the two supply circuits to the appropriate value for the designation given in Table 5 and with the exception of single sequential thermostatic mixing valves set the temperature control device to a mean temperature position of 38°C.
- Subject the thermostatic mixing valve to 50,000 on/off cycles.

Abbreviated designation	Water pressure (bar)
All -LP-	1 max.
All -HP-	4 ± 0.2

Table 5 Supply pressures for durability tests

6.1.5 Requirements

During the test no failure of any component part shall occur.

Verify the leaktightness of the thermostatic mixing valve by the application of the tests given in clauses 5.4 to 5.6.

6.2 Durability of diverters

6.2.1 General

Thermostatic mixing valves certified as complying with either BS EN 1111 or BS EN 1287 will be regarded as complying with the requirements of this specification for the durability of the diverter. In all other cases the following tests shall be applied to mixing valves with a diverter.

Note:

The tests described here reproduce almost exactly the text of the ENs referred to.

This clause specifies two methods of test for the mechanical endurance of diverters of thermostatic mixing valves: one for manual diverters and one for diverters with automatic return and gives the corresponding specifications.

6.2.2 Principle

The principle of the test is to subject the diverter to a specified number of operations, with the thermostatic mixing valve being supplied alternately with cold water, and with hot water at 65 ± 2°C (thermal shocks), in order to test its behaviour over a period of time, taking into account temperature.

6.2.3 Apparatus

6.2.3.1 Manual diverter

- Automatic machine ensuring alternating movement of the diverter at a rate of 15 ± 1 returns per minute.
- Supply circuits comprising a pump or a similar device by means of which the required static pressure can be obtained for cold water at <30°C and hot water at 65 ± 2°C.

6.2.3.2 Diverter with automatic return

- Mechanism for moving the diverter to the shower/shower head position under the conditions defined in clause 5.8.
- Supply circuits identical to those defined in clause 6.2.3.1 but also comprising an automatic quick action valve to cut off the supply to the thermostatic mixing valve under test.

6.2.4 Procedure

6.2.4.1 Manual diverter

- Mount the thermostatic mixing valve, as supplied, on to the machine and connect both inlets to the supply circuits.
- Connect the drive device to the diverter lever by means of a flexible component.
- With the thermostatic mixing valve closed, adjust the water pressure on the two supply circuits to the appropriate value for the designation given in Table 5.
- With the temperature control device set to the full hot position adjust the flow rate to between 4 L/min and 6 L/min at the highest flowing outlet. This flow adjustment shall be made by means of the independently operating on/off (flow) control or, in the absence of this device, by partially obstructing the outlet.
- Subject the diverter to an endurance test of 30,000 cycles, each cycle comprising a return movement between the extreme positions. Note: if the diverter mechanism controls the on/off function of the valve then the mechanism needs to undertake 50,000 operations in accordance with clause 6.1.4.

- Throughout the test, supply the thermostatic mixing valve alternately at both inlets with cold water for 15 min ± 30 s then hot water for 15 min ± 30 s.
- Throughout the test, record any incidence of leaks, deformations, fracture etc.
- After 30,000 cycles, check the leaktightness of the diverter as defined in clause 5.7.

6.2.4.2 Diverters with automatic return

- Fit to the shower outlet the hydraulic resistance identified in Table 4 appropriate to the designation.
- Mount the thermostatic mixing valve as supplied on to a support and connect both inlets to the supply circuits.
- With the thermostatic mixing valve closed, adjust the water pressure on the two supply circuits to the appropriate value for the designation given in Table 5.
- With the temperature control device set to the full hot position adjust the flow rate to a value that just permits proper operation of the diverter. This flow adjustment shall be made by means of the independently operating on/off (flow) control, or in the absence of this device by partially obstructing the outlet.
- Subject the diverter to an endurance test of 30,000 cycles, one cycle being defined as follows:
  - With the diverter in the “flow to bath” position, allow a flow of water for 5 ± 0.2 s through the spout.
  - Move the diverter to the “flow to shower” position and allow a flow of water for 5 ± 0.2 s.
  - Cut off the supply to the thermostatic mixing valve by means of the quick-acting valve; allow the diverter to return to the “flow to bath” position; then reopen the supply.
- Throughout the test, supply the thermostatic mixing valve alternately at both inlets with cold water for 15 min ± 30 s then hot water for 15 min ± 30 s.
- Throughout the test, record any incidence of leaks, deformations, fractures etc.
- After 30,000 cycles, check the leaktightness of the diverter as defined in clause 5.8.

6.2.5 Requirements

During the test, no deformation, component fracture, blockage of the mechanism, leakage from the nozzle or shower/shower head or the diverter control joint shall be noted.

At the end of the test, check the leaktightness:

- in the conditions specified in clause 5.7 for manual diverters;
- in the conditions specified in clause 5.8 for diverters with automatic return.

6.3 Durability of thermostat

6.3.1 General

The durability of the thermostat shall be verified by means of the test described in clause 6.3.3. The test shall be conducted on one of the three samples referred to in Chapter 4 before it is subjected to the tests in Chapter 7.

When the thermostatic mixing valve is suitable for more than one application, the durability of the thermostat need only be verified for the designation which represents the highest operating pressure range, the highest flow rate and the highest mixed water temperature setting of the applicable designations.

The durability cycling shall be carried out using the apparatus described in Annex A.

If the test rig is supplied with recycled water, this shall not deteriorate in quality during the test and shall remain free of grease, debris etc.

6.3.2 Purpose

The purpose of the test is:

a. to subject the thermostat to an accelerated cycle of operations which is representative of the normal operating conditions;

b. to precondition one sample before carrying out the performance tests described in Chapter 7.

Note:

The most common exercise for the thermostat is in responding to a draw-off after a period of non-use (see clause 7.5). The durability cycle represents a large number of these responses, which are unlikely to be able to exceed 25 per day, as cooling to ambient temperature would not then be achieved. Periodic thermal shut-offs are called for at a rate equivalent to about one every three months (2500 cycles).

6.3.3 Procedure

6.3.3.1 Connect the mixing valve to the test rig (see Annex A).

6.3.3.2 Set the flow rate and mixed water temperature in accordance with Table 6, with the water supply pressures and temperatures specified in that table. For mixing valves intended for single-point use, and having an integral atmospheric discharge nozzle, the flow rate may be adjusted by means of the mixing valve's integral flow control. In all cases the flow rate may be adjusted by means of either the tap 6 (see Figure A.1 in Annex A) in the discharge pipework (where used) or a throttling device, such as an orifice plate, fitted to the atmospheric discharge.

If technical information about tap 6 is required, please contact BuildCert/NSF.

6.3.3.3 Having obtained the required settings, provision must be made to prevent the setting of the mixed water temperature and flow rate from being disturbed.

6.3.3.4 Check that the timings given in clause A.1.2.3 are achieved and record the mixed water temperature; then start the cyclic operation of the rig.

6.3.3.5 At intervals of 2500 ± 100 cycles, implement the sequence specified in clause A.1.2.3(d).

6.3.3.6 At intervals of not more than 5000 cycles, check that the water supply pressures and temperatures and the mixed water flow rate are within the limits specified in Table 6 for initial setting. Readjust, if necessary, the water supply pressures, temperatures and the mixed water flow rate to the values specified in Table 6 for checking. The setting of the mixed water temperature control shall not be interfered with unless, after adjustment of the other parameters, the mixed water temperature is more than 1.5 K removed from the actual initial setting. Record the values of all parameters.

	Hot supply		Cold supply		Mixed water	
	Flow pressure (bar)	Temp. (°C)	Flow pressure (bar)	Temp. (°C)	Flow (L/min)	Temp. (°C)
Initial setting	Within operating pressure range (see Table 1)	60 ± 5	Equal to hot supply pressure ±10%	15 ± 5	≥0.5 of available flow rate at applied flow pressure	As Table 9
For checking	Initial setting ±10%	Initial setting ±1 K	Equal to hot supply pressure ± 10%	Initial setting ±1 K	Initial setting ±10%	Initial setting ±2 K

Table 6 Settings for thermostat durability test

6.3.3.7 On completion of 30,000 ± 200 cycles, stop the test and service the mixing valve in accordance with the manufacturer's instructions. After this, subject the valve to the performance tests of Chapter 7.

6.3.4 Requirements

6.3.4.1 The mixed water temperature shall remain within the limits specified in Table 6.

When the operating conditions are checked and adjusted as specified in clause 6.3.3.6, the mixed water temperature, before any readjustment, shall not be more than 2 K removed from the actual initial setting.

6.3.4.2 On completion of the durability cycling, the valve shall satisfy all of the performance requirements specified in Chapter 7.

7.0 Performance

7.1 General

Performance requirements shall be verified by means of the tests described in this specification. The tests are laboratory type tests. The requirements shall be satisfied by each of the samples referred to in Chapter 4. The thermal performance requirements of each sample are summarised in Table 15 at the end of this chapter.

If for any reason the designed function of a TMV prevents the normal test methodology from being utilised, then the designed function must be no less effective.

The applicable performance tests described in clauses 7.3 to 7.12 shall be carried out in the sequence specified in clause 7.2 using the apparatus described in Annex B. The mixing valve shall be installed and commissioned on the test rig in accordance with the manufacturer's instructions. The applicability of some of the tests is determined by the configuration of the controls of the thermostatic mixing valve, and the following exemptions apply:

a. Mixing valves without a diverter are exempt from the test in clause 7.5.

b. Mixing valves in which two applications are not served by two separately operating mechanisms sharing common supply connections are exempt from the test in clause 7.6.

c. Mixing valves with no user-accessible adjustment of the mixed water temperature are exempt from the test in clause 7.8.

d. Mixing valves with single sequential control and integral atmospheric discharge are exempt from the test in clause 7.12.

e. Mixing valves having a flow rate less than 4.5 L/min when tested in accordance with clause 7.3 are exempt from the test in clause 7.12.

Throughout the performance tests described in clauses 7.3 to 7.12, the water supply flow pressures and water supply temperatures shall be maintained within the setting limits specified.

Additional safety features built into the design of the thermostatic mixing valves that preclude testing exactly to the requirements of the performance requirements of D 08 will not be penalised if the valve delivers water at a safe temperature as prescribed by this standard.

7.2 Sequence of tests

a. Flow rate and sensitivity of temperature control – see clause 7.3.

b. Initial setting for thermal performance tests – see clause 7.4.

c. Mixed water temperature overshoot on operation of diverter (manual or automatic return) – see clause 7.5.

d. Mixed water temperature overshoot on operation of second outlet – see clause 7.6.

e. Mixed water temperature overshoot on starting from ambient – see clause 7.7.

f. Mixed water temperature overshoot on adjustment of mixed water temperature – see clause 7.8.

g. Thermal shut-off – see clause 7.9.

h. Stability of mixed water temperature with changing supply pressure – see clause 7.10.

i. Stability of mixed water temperature with changing supply temperature – see clause 7.11.

j. Stability of mixed water temperature at reduced flow rate – clause see 7.12.

7.3 Flow rate and sensitivity of temperature control

7.3.1 Purpose

The purpose of the test is to determine:

a. the flow rate of mixed water;

b. the ease with which the mixed water temperature can be adjusted to the correct value for the intended application.

If a thermostatic mixing valve is suitable for more than one application, this test can be conducted for all of these in a single test if the user adjustment range for mixed water temperature can be set to provide all of the required mixed water temperatures in one setting. Valves suitable for bath use may need to be tested separately as larger inlets are usually provided for bath fill valves.

Thermostatic mixing valves that do not have a conventional temperature control lever for adjusting the mixed water temperature (that is, no angular or linear movement) should be tested and should comply with the requirements of Annex G.

7.3.2 Procedure

7.3.2.1 Connect the mixing valve to the test rig (see Annex B).

7.3.2.2 Fully open any integral flow control. Where outlet pipework is required, also open fully the valve 5 and the tap 6. Ensure that the bleed valves 8 are closed (see Figure B.1).

7.3.2.3 For mixing valves with user adjustment of the mixed water temperature, adjust the maximum mixed water temperature stop so that the full range of mixed water temperatures required in this test is available. For mixing valves with a preset temperature, access the mixed water temperature adjustment.

7.3.2.4 With the pressure losses and supply temperatures specified in Table 8, set the temperature control/adjustment to give a mixed water temperature equal to the first setting specified in Table 7. Where outlet pipework is required, adjust the tap 6 (Figure B.1) to give the required pressure loss.

7.3.2.5 Measure and record the mixed water flow rate and temperature, and record the position of the temperature control/adjustment. Where outlet pipework is required, record the outlet pressure.

Setting	Mixed water temperature (°C)	Comments
1	$T_{a\,-5}^{\,-3}$	–
2	$T_a \pm 1$	–
3	$T_{a\,+5}^{\,+3}$	–
4	lesser of $T_{a\,+9}^{\,+7}$ and $T_{b\,+3}^{\,+1}$	Only if actual setting 3 < T_b + 1
5	$T_{b\,+3}^{\,+1}$	Only if actual setting 4 < T_b + 1

Note:

T_a = lowest maximum mixed water temperature specified in Table 2 for the applications to be covered.

T_b = highest maximum mixed water temperature specified in Table 2 for the applications to be covered.

Table 7 Mixed water temperature settings for determination of flow rate and sensitivity

Abbreviated designation	Hot supply		Cold supply		Required mixed water flow rate (L/min)
	Pressure loss (bar)	Temp. (°C)	Pressure loss (bar)	Temp. (°C)	
-HP-B -HP-S -HP-W -HP, D44, D46 (shower)	1.0 ± 0.05	57 ± 1	1.0 ± 0.05	15 ± 1	≥8
Above designations with suffix E	1.0 ± 0.05	57 ± 1	1.0 ± 0.05	15 ± 1	<8
-HP, T44, T46 -HP, D44, D46 (bath fill)	1.0 ± 0.05	57 ± 1	1.0 ± 0.05	15 ± 1	≥15
-LP-B -LP-S -LP-W -LP, D44, D46 (shower)	0.2 ± 0.01	57 ± 1	0.2 ± 0.01	15 ± 1	≥8
Above designations with suffix E	0.2 ± 0.01	57 ± 1	0.2 ± 0.01	15 ± 1	<8
-LP, T44, T46 -LP, D44, D46 (bath fill)		57 ± 1	0.2 ± 0.01	15 ± 1	≥15

Table 8 Flow rates

7.3.2.6 Set the temperature control/adjustment, maintaining the pressure loss and supply temperatures, to give each of the mixed water temperatures specified in Table 7. At each setting measure and record the mixed water flow rate and temperature, and record the position of the temperature control. Where outlet pipework is required, record the outlet pressure.

7.3.3 Expression of results

Record the flow rates and the sensitivity of the temperature adjustment.

7.3.4 Requirements

7.3.4.1 The flow rate shall at no point be less than the value specified in Table 8 for the designation of valve, except that for those with suffix E the flow rate shall be less than 8 L/min.

7.3.4.2 The sensitivity of the temperature control/adjustment shall be at least 5 degrees angular per K or, in the case of a lever, at least 4 mm per K.

7.4 Initial settings for thermal performance tests

7.4.1 Purpose

The purpose of the settings is to establish, at the commencement of the test sequence, a representative mixed water temperature and flow rate appropriate to the application, with the supply pressures at a mid-value in the operating range.

7.4.2 Settings

7.4.2.1 The initial settings for each designation (see Chapter 8) shall be in accordance with Table 9. These settings shall not be altered or further adjusted during any thermal performance test procedure, except where specified; for example, after initial setting the flow rate shall not be readjusted except in clause 7.12.

7.4.2.2 For mixing valves intended for single-point use, and having an integral atmospheric discharge nozzle, the flow rate shall be adjusted by means of the mixing valve's integral flow

	Hot supply		Cold supply		Mixed water	
Abbreviated designation	Flow pressure (bar)	Temp. (°C)	Flow pressure (bar)	Temp. (°C)	Flow (L/min)	Temp. (°C)
-HP-B	3.0 ± 0.1	57 ± 1	3.0 ± 0.1	15 ± 1	9.0 ± 0.5	38^{-0}_{-2}
-HP-BE	3.0 ± 0.1	57 ± 1	3.0 ± 0.1	15 ± 1	† Q_s ± 0.5	38^{-0}_{-2}
-LP-B	0.6 ± 0.02	57 ± 1	0.6 ± 0.02	15 ± 1	9.0 ± 0.5	38^{-0}_{-2}
-LP-BE	0.6 ± 0.02	57 ± 1	0.6 ± 0.02	15 ± 1	† Q_s ± 0.5	38^{-0}_{-2}
-HP-S -HP-W	3.0 ± 0.1	57 ± 1	3.0 ± 0.1	15 ± 1	9.0 ± 0.5	41^{-0}_{-2}
-HP-SE -HP-WE	3.0 ± 0.1	57 ± 1	3.0 ± 0.1	15 ± 1	† Q_s ± 0.5	41^{-0}_{-2}
-LP-S -LP-W	0.6 ± 0.02	57 ± 1	0.6 ± 0.02	15 ± 1	9.0 ± 0.5	41^{-0}_{-2}
-LP-SE -LP-WE	0.6 ± 0.02	57 ± 1	0.6 ± 0.02	15 ± 1	† Q_s ± 0.5	41^{-0}_{-2}
-HP, D44, D46	3.0 ± 0.1	57 ± 1	3.0 ± 0.1	15 ± 1	See Note 2	
-HP-T44	3.0 ± 0.1	57 ± 1	3.0 ± 0.1	15 ± 1	20 ± 1	44^{-0}_{-2}
-HP-T46	3.0 ± 0.1	57 ± 1	3.0 ± 0.1	15 ± 1	20 ± 1	46^{-0}_{-2}
-LP, D44, D46	0.6 ± 0.02	57 ± 1	0.6 ± 0.02	15 ± 1	See Note 2	
-LP-T44	0.6 ± 0.02	57 ± 1	0.6 ± 0.02	15 ± 1	20 ± 1	44^{-0}_{-2}
-LP-T46	0.6 ± 0.02	57 ± 1	0.6 ± 0.02	15 ± 1	20 ± 1	46^{-0}_{-2}

† Q_s = lowest flow rate recorded in clause 7.3.3.

Note 1: If the specified flow rate is not achievable, then the available flow rate shall be used and recorded.

Note 2: For designations D44, D46 the initial settings above are those appropriate to the outlet being tested, e.g. for HP-D44 use HP-T44 for the bath outlet, and HP-S for the shower outlet.

Table 9 Initial settings for thermal performance tests

control, but if the mixing valve has a sequential control the flow rate cannot be adjusted independently of the temperature and therefore the flow rate will be that resulting at the set temperature. In all other cases the flow rate shall be adjusted by means of the tap 6 in the discharge pipework. This adjustment shall be made with any integral flow control fully open.

7.4.2.3 For mixing valves having a user-adjustable mixed water temperature, the mixed water temperature setting given in Table 9 shall be the maximum available. Having obtained the required settings, the means provided by the manufacturer for limiting the maximum mixed water temperature, locking the mixed water temperature adjustment, or otherwise rendering the adjustment tamper-proof, shall be utilised. Further adjustment of the mixed water temperature during the sequence of tests for a particular designation is not allowed.

Note:

The outlet pressure is not measured in the thermal performance tests and so the measuring line may be closed.

7.5 Mixed water temperature overshoot on operation of diverter (manual or automatic return)

7.5.1 Purpose

The purpose of the test is to determine the characteristic of any transient rise in the mixed water temperature, which may occur when the mixed water flow is diverted from one outlet to another.

7.5.2 Procedure

7.5.2.1 Connect the mixing valve to the test rig and adjust the mixed water temperature and flow rate at each outlet to the initial setting given in Table 9 for the appropriate designation.

7.5.2.2 Operate the diverter to the shower position; allow mixed water to flow for 120 ± 5 s and then measure and record the mixed water temperature.

7.5.2.3 Return the diverter to the bath position. Allow mixed water to flow for 120 ± 5 s and then measure and record the mixed water temperature.

Note:

It may be necessary to repeat the steps in clauses 7.5.2.2 and 7.5.2.3 to ensure stable operation of the valve and constant values of the bath and shower temperatures.

7.5.2.4 By hand and as fast as possible, operate the diverter to the shower position.

7.5.2.5 Monitor and record the mixed water temperature until it has stabilised.

7.5.2.6 In the case of diverters with automatic return, close the flow control of the mixing valve. In the case of manual diverters, allow the mixed water to flow for a further 120 ± 5 s and then, by hand and as fast as possible, operate the diverter to the bath position.

7.5.2.7 Monitor and record the mixed water temperature until it has stabilised.

7.5.2.8 Repeat the procedure to give three sets of results for each test specimen.

7.5.3 Expression of results

Assess the temperature transient obtained during the steps in clauses 7.5.2.5 and 7.5.2.7 to determine the duration at or above each 1 K temperature rise shown in Table 10 for the appropriate application. Refer transient temperature rises to the mixed water temperature appropriate to the outlet.

7.5.4 Requirement

7.5.4.1 The average duration of the transient temperature rise at or above each 1 K temperature rise given in Table 10 for the appropriate application shall be not greater than the values given in Table 10. Individual test results shall not exceed the permitted duration by more than 10%.

7.5.4.2 No steady mixed water temperature after stabilisation shall differ from the actual initial setting of the outlet concerned by more than 2 K.

7.6 Mixed water temperature overshoot on operation of second outlet

7.6.1 Principle

The purpose of the test is to determine the characteristics of any transient mixed water temperature rise which may occur during the operation of the second outlet of a valve having two separately operating thermostatically controlled outlet mechanisms and sharing a common inlet.

7.6.2 Procedure

7.6.2.1 Connect the mixing valve to the test rig and adjust the mixed water temperature and flow rate at each outlet separately to the

Rise in mixed water temperature from actual initial setting (K)				Reference (see Note) (°C)		
Bidet Shower Washbasin	Bath fill up to 44°C	Bath fill up to 46°C	Duration (s)	Bidet	Shower Washbasin	Bath fill
+2	+4	+2	10 or more	40	43	48
+3	+5	+3	6.30	41	44	49
+4	+6	+4	4.00	42	45	50
+5	+7	+5	2.50	43	46	51
+6	+8	+6	1.90	44	47	52
+7	+9	+7	1.20	45	48	53
+8	+10	+8	0.75	46	49	54
+9	+11	+9	0.50	47	50	55
+10	+12	+10	0.25	48	51	56

Note: This temperature is the value corresponding to the permitted temperature rise above the maximum set mixed water temperature.

Table 10: Permitted duration of transient mixed water temperature rise

appropriate initial setting given for that application in Table 9. Set the lowest temperature application first and then the highest.

Note:

Ensure that the other outlet is closed when setting each initial condition.

7.6.2.2 After a stabilisation period of not less than 120 s, ensure that the initial conditions are still within the requirements of Table 9 for that application and record these values.

7.6.2.3 Within 120 s of recording the values in clause 7.6.2.2 for the highest temperature application, rapidly open, by hand and as fast as possible, the outlet appropriate to the lowest temperature application whilst monitoring the mixed water temperature at both outlets. When both mixed water temperatures have stabilised, cease monitoring.

7.6.2.4 Within 120 s of the cessation of monitoring in clause 7.6.2.3, rapidly close, by hand and as fast as possible, the outlet appropriate to the highest temperature application whilst monitoring the mixed water temperature at the other outlet. When the outlet temperature has stabilised, cease monitoring.

7.6.2.5 Within 120 s of the cessation of monitoring in clause 7.6.2.4, rapidly open, by hand and as fast as possible, the outlet appropriate to the highest temperature application whilst monitoring the mixed water temperature at both outlets. When both mixed water temperatures have stabilised, cease monitoring.

7.6.2.6 Within 120 s of the cessation of monitoring in clause 7.6.2.5, rapidly close, by hand and as fast as possible, the outlet appropriate to the lowest temperature application whilst monitoring the mixed water temperature at the other outlet. When the outlet temperature has stabilised, cease monitoring.

7.6.2.7 Repeat the procedure to give three sets of results for each test specimen.

7.6.3 Expression of results

Assess the temperature transients obtained during clauses 7.6.2.3–7.6.2.6 to determine the duration of any temperature rise above the initial conditions recorded in clause 7.6.2.2 in

accordance with the values shown in Table 10 for the appropriate application temperature.

7.6.4 Requirement

7.6.4.1 The average duration of any transient temperature rise for the appropriate application shall be not greater than the values given in Table 10. Individual test results shall not exceed the permitted duration by more than 10%.

7.6.4.2 No steady mixed water temperature after stabilisation shall differ from the actual initial setting of the outlet concerned by more than 2 K.

7.7 Mixed water temperature overshoot on starting from ambient

7.7.1 Purpose

The purpose of the test is to determine the characteristic of any transient rise in the mixed water temperature which may occur when water is drawn off after a prolonged period of non-use.

Note:

Over a period of several hours, the installed mixing valve will cool to ambient temperature. This commonly results in the thermostat adjusting the valve mechanism to fully open the hot water port, and thereby shut off the cold water port. Subsequently, as water is drawn off, the thermostat must respond quickly to limit the temperature of mixed water as hot water flows into the valve.

7.7.2 Procedure

7.7.2.1 Connect the mixing valve to the test rig (see Annex B).

7.7.2.2 Starting from the initial setting (see Table 9), allow mixed water to flow for 2 min ± 5 s and then measure and record the mixed water temperature.

7.7.2.3 Close off the hot and cold water supply valves and open the valve 7 in the cross-over pipe (see Figure B.1). Supply both inlets with cold water at a temperature of 20 ± 1°C at a total flow rate at least equal to half the set flow rate in Table 9.

7.7.2.4 After 5 min ± 15 s close off the mixed water flow. In the case of mixing valves intended for single point use, and having an integral atmospheric discharge nozzle, this shall be achieved by closing the integral flow control. In all other cases close the valve 5 (see Figure B.1) in the discharge pipework.

7.7.2.5 Close the valve 7 and restore the hot and cold water supplies, opening the bleed valves 8 until the set supply temperatures are regained. Ensure that the flow pressures will be the same as before.

7.7.2.6 For mixing valves intended for single-point use, and having an integral atmospheric discharge nozzle, rapidly open, by hand and as fast as possible, the integral flow control to the same position it was in to achieve the initial setting. In all other cases rapidly open, by hand and as fast as possible, the valve 5 in the discharge pipework.

7.7.2.7 Monitor and record the mixed water temperature.

7.7.2.8 Repeat the procedure to give three sets of results for each sample.

7.7.3 Expression of results

The temperature transient obtained shall be assessed to determine the duration at or above each 1 K temperature rise shown in Table 10 for the appropriate designation. For the three test results on each sample, calculate the average duration at each temperature rise. Transient temperature rises shall be referred to the mixed water temperature existing at the start of each of the three tests.

Note:

An example of the assessment of test results is given in Annex E.

7.7.4 Requirements

7.7.4.1 The average duration of the transient temperature rise at or above each 1 K temperature rise shown in Table 10 for the appropriate designation shall not be longer than the values in Table 10. Individual test results shall not exceed the permitted duration by more than 10%.

7.7.4.2 For each result the final mixed water temperature shall not differ from the actual initial setting of the sample concerned by more than 2 K.

7.8 Mixed water temperature overshoot on adjustment of mixed water temperature

7.8.1 Purpose

The purpose of the test is to determine, for thermostatic mixing valves having a user-adjustable mixed water temperature setting, the characteristic of any transient rise in the mixed water temperature which may occur when the mixed water temperature setting is suddenly changed from a cool setting to the maximum setting.

7.8.2 Procedure

7.8.2.1 Connect the mixing valve to the test rig (see Annex B).

7.8.2.2 Starting from the initial setting (see Table 9), allow mixed water to flow for 2 min ± 5 s and then measure and record the mixed water temperature.

7.8.2.3 Adjust the position of the temperature control to give a mixed water temperature of 30 ± 1°C (or, if the lowest temperature available is greater than this, then to the lowest temperature available.)

7.8.2.4 After 3 min ± 15 s rapidly adjust, by hand and as fast as possible, the temperature control to the maximum temperature stop.

7.8.2.5 Monitor and record the mixed water temperature.

7.8.2.6 Repeat the procedure to give three sets of results for each sample.

7.8.3 Expression of results

The temperature transient obtained shall be assessed to determine the duration at or above each 1 K temperature rise shown in Table 10 for the appropriate designation. For the three test results on each sample calculate the average duration at each temperature rise. Transient temperature rises shall be referred to the mixed water temperature existing at the start of each of the three tests.

Note:

An example of the assessment of test results is given in Annex E.

7.8.4 Requirements

7.8.4.1 The average duration of the transient temperature rise at or above each 1 K temperature rise shown in Table 10 for the appropriate designation shall not be longer than the values in Table 10. Individual test results shall not exceed the permitted duration by more than 10%.

7.8.4.2 For each result the final mixed water temperature shall not differ from the actual initial setting of the sample concerned by more than 2 K.

7.9 Thermal shut-off

7.9.1 Purpose

The purpose of the test is to determine the following:

7.9.1.1 In the event of complete and sudden failure of the cold water supply:

a. the characteristic of any transient rise in the mixed water temperature which may occur;

b. the maximum rise in mixed water temperature resulting from prolonging the supply failure.

7.9.1.2 In the event of complete and sudden restoration of the cold water supply following a supply failure:

a. the characteristic of any transient rise in the mixed water temperature that may occur;

b. the steady temperature to which the mixed water returns.

7.9.1.3 In the event of complete and sudden failure of the hot water supply:

That the flow rate decays rapidly to an acceptable leakage rate, or the rate of reduction in mixed water temperature is not excessive.

7.9.1.4 In the event of complete and sudden restoration of the hot water supply following a supply failure:

a. the characteristic of any transient rise in the mixed water temperature that may occur;

b. the steady temperature to which the mixed water returns.

7.9.2 Procedure

7.9.2.1 Connect the mixing valve to the test rig (see Annex B).

7.9.2.2 Starting from the initial setting, isolate any branched take-offs in the cold water supply line, including the cold water pressure measuring line. Also isolate the outlet pressure measuring line, if open.

7.9.2.3 Instantaneously isolate the cold water supply and continuously monitor the mixed water temperature.

7.9.2.4 Leave the cold water supply isolated for 15 min ± 30 s and then instantaneously restore the cold water, ensuring that the flow pressure will be the same as before. Continue to monitor the mixed water temperature.

7.9.2.5 Reconnect the cold water pressure measuring line and, if necessary, readjust the flow pressures. Record the mixed water temperature.

7.9.2.6 Isolate any branched take-offs in the hot water supply line, including the hot water pressure measuring line. Also isolate the outlet pressure measuring line, if open.

7.9.2.7 Instantaneously isolate the hot water supply and simultaneously commence collection of the mixed water discharge. Continuously monitor the mixed water temperature. After 5 ± 0.5 s, commence collection of the mixed water discharge in a separate vessel. The second collection period shall be for 30 ± 0.5 s. The collected volumes may be taken as the time-integrated output of a rate of flow meter provided that the response time of the meter is taken into account.

7.9.2.8 Leave the hot water supply isolated for 5 min ± 15 s and then instantaneously restore the hot water supply, ensuring that the flow pressure will be the same as before, and monitor the mixed water temperature.

7.9.2.9 Reconnect the hot water pressure measuring line and, if necessary, readjust the flow pressures. Record the mixed water temperature.

7.9.2.10 Repeat the procedure to give three sets of results for each sample.

7.9.3 Expression of results

7.9.3.1 The temperature transient obtained for each cold water isolation, for each cold water restoration, and for each hot water restoration shall be assessed to determine the duration at or above each 1 K temperature rise shown in Table 10 for the appropriate designation. For the three results of each of these tests calculate the average duration at each temperature rise. Transient temperature rises shall be referred to the mixed water temperature existing at the start of each of the three tests.

Note:

An example of the assessment of test results is given in Annex E.

7.9.3.2 For the three test results for hot water isolation determine the average volume of water collected in the first 5 s after isolation of the hot water supply and also the average volume of water collected in the subsequent 30 s. Determine the minimum temperature of mixed water during the first 5 s after isolation.

7.9.4 Requirements

7.9.4.1 For cold water isolation and restoration, and for hot water restoration the average duration of the transient temperature rise at or above each 1 K temperature rise shown in Table 10 for the appropriate designation shall not be longer than the values in Table 10. Individual test results shall not exceed the permitted duration by more than 10%. If the water discharges in a cycle (that is, increasing in flow until the valve reacts and flow stops), then each of these transient events shall for the appropriate designation comply with the requirements detailed in Table 10.

7.9.4.2 For each result the final mixed water temperature, after restoration of the cold water supply and after restoration of the hot water supply, shall not differ from the actual initial setting of the sample concerned by more than 2 K.

7.9.4.3 For hot water isolation:

a. During the first 5 seconds after hot water isolation either the average volume of water discharged shall not exceed the appropriate values given in Table 11 or, if this is exceeded, the average reduction in mixed water temperature shall not exceed the appropriate values given in Table 11. Individual test results shall not exceed the permitted volume by more than 10% or the permitted temperature reduction by more than 0.5 K.

b. During the subsequent 30 s the average volume of water discharged shall not exceed the appropriate values given in Table 11. Individual test results shall not exceed the permitted volume by more than 10%.

	During first 5 s after hot water isolation		During 5–35 s after hot water isolation
Application	Reduction in mixed water temperature from actual initial setting (K)	Discharge (L)	Discharge (L)
Bidet	3	0.25	0.75
Shower Washbasin	6	0.25	0.75
Bath fill up to 44°C	9	0.5	1.5
Bath fill up to 46°C	11	0.5	1.5

Table 11 Leakage flow of cold water

7.10 Temperature stability with changing water supply pressure

7.10.1 Purpose

The purpose of the test is to determine:

a. the change in mixed water temperature when one supply pressure is varied over the whole operating pressure range whilst the other supply pressure remains constant;

b. the change in mixed water temperature when one supply pressure is reduced to a very low value whilst the other supply pressure remains constant;

Note: This represents an extreme supply starvation condition.

c. the steady temperature to which the mixed water returns when supply pressure is restored.

7.10.2 Procedure

7.10.2.1 Connect the mixing valve to the test rig (see Annex B).

7.10.2.2 Starting from the initial setting, slowly adjust the cold water supply pressure in steps to the values shown in Table 12.

7.10.2.3 Measure and record the mixed water temperature after each pressure change.

7.10.2.4 With the initial setting regained, slowly adjust the hot water supply pressure in steps to the values shown in Table 12.

7.10.2.5 Measure and record the mixed water temperature after each pressure change.

7.10.2.6 Repeat the procedure to give three sets of results for each sample.

7.10.3 Expression of results

7.10.3.1 For the three test results calculate, for each numbered pressure change, the average change in mixed water temperature from the actual initial setting.

7.10.4 Requirements

7.10.4.1 After each change in supply pressure, the average change in mixed water temperature from the actual initial setting of the sample concerned shall not be greater than the values given in Table 12. Individual test results shall not exceed the permitted temperature change by more than 0.5 K.

	Supply pressure (bar)		Permitted change in mixed water temperature from actual initial setting (K)			
	All -HP	All -LP	Bidet	Shower Washbasin	Bath fill up to 44°C	Bath fill up to 46°C
First change	2 ± 0.1	0.4 ± 0.02	+2/–3	+2/–6	+2/–9	+2/–11
Second change	1 ± 0.05	0.2 ± 0.01	+2/–3	+2/–6	+2/–9	+2/–11
Third change*	0.5 ± 0.02	0.1 ± 0.005	3	+3/–6	+3/–9	+3/–11
Fourth change initial	3 ± 0.1	0.6 ± 0.02	2	2	2	2
Fifth change	5 ± 0.2	1 ± 0.05	+2/–3	+2/–6	+2/–9	+2/–11
Sixth change initial	3 ± 0.1	0.6 ± 0.02	2	2	2	2
* This represents a condition outside the supply conditions for normal use.						

Table 12 Changes in water supply pressure and permitted temperature change

7.11 Temperature stability with changing water supply temperature

7.11.1 Purpose

The purpose of the test is to determine:

a. the change in mixed water temperature when one supply temperature is varied over the whole operating temperature range whilst the other supply remains constant;

b. the steady temperature to which the mixed water returns when the supply temperature is restored.

7.11.2 Procedure

7.11.2.1 Connect the mixing valve to the test rig (see Annex B).

7.11.2.2 Starting from the initial setting, adjust the cold water supply temperature to the values given in Table 13. Dwell at each cold water temperature for more than 2 min.

7.11.2.3 Record the mixed water temperature 2 min ± 5 s after each temperature change.

7.11.2.4 Starting from the initial setting, adjust the hot water supply temperature to the values given in Table 13. Dwell at each hot water temperature for more than 2 min.

7.11.2.5 Record the mixed water temperature 2 min ± 5 s after each temperature change.

7.11.3 Requirements

7.11.3.1 After each change in supply temperature, the change in mixed water temperature from the actual initial setting of the sample concerned shall not be greater than the values in Table 13.

7.12 Temperature stability at reduced flow rate

7.12.1 Purpose

The purpose of the test is to determine, for thermostatic mixing valves having a set flow rate according to Table 9 greater than the appropriate value in Table 14:

a. the change in mixed water temperature when the flow rate is reduced to a low value with unequal supply pressures;

b. the steady temperature to which the mixed water returns when the flow rate and supply pressures are restored.

7.12.2 Procedure

7.12.2.1 Connect the mixing valve to the test rig (see Annex B).

7.12.2.2 Starting from the initial setting, reduce the cold water supply pressure to between 80% and 85% of the set flow pressure.

7.12.2.3 Slowly reduce flow rate to the appropriate value specified in Table 14 maintaining the flow pressures. If the mixing valve incorporates an integral flow control which allows the flow rate to be adjusted independent of the temperature, then this control shall be used to reduce the flow rate. Otherwise the flow rate shall be reduced by means of the tap 6 (see Figure B.1).

7.12.2.4 Measure and record the mixed water temperature after the above procedure.

	Supply temperature (°C)		Permitted temp. change (K)
	Hot water	Cold water	
First change	Actual initial setting minus 5 ± 1 K	Actual initial setting minus 8 ± 1 K	2
Second change	Actual initial setting plus 8 ± 1 K	Actual initial setting plus 5 ± 1 K	2
Third change	Actual initial setting ±1 K	Actual initial setting ±1 K	2

Table 13 Changes in water supply temperature and permitted temperature change

Application	Reduced flow rate (L/min)	Permitted temperature change (K)
Bidet, shower, washbasin	4 ± 0.1	2
Bath fill	10 ± 0.2	2

Table 14 Reduced flow rates and permitted temperature change

7.12.2.5 Restore the cold water supply pressure to the initial setting and then return the flow rate to the initial set value.

7.12.2.6 Measure and record the mixed water temperature.

7.12.2.7 Having regained the initial setting, reduce the hot water supply pressure to between 80% and 85% of the set flow pressure.

7.12.2.8 Slowly reduce flow rate to the appropriate value specified in Table 14 maintaining the flow pressures and using the same control as in clause 7.10.2.3.

7.12.2.9 Measure and record the mixed water temperature after the above procedure.

7.12.2.10 Restore the hot water supply pressure to the initial setting and then return the flow rate to the initial set value.

7.12.2.11 Measure and record the mixed water temperature.

7.12.2.12 Repeat the procedure to give three sets of results for each sample.

7.12.3 Expression of results

7.12.3.1 For the three test results of flow reduction with hot pressure greater than cold calculate the average change in mixed water temperature from the actual initial setting.

7.12.3.2 For the three test results of flow reduction with cold pressure greater than hot, calculate the average change in mixed water temperature from the actual initial setting.

7.12.4 Requirements

7.12.4.1 After the reduction in flow rate, the average change in mixed water temperature from the actual initial setting of the sample concerned shall not be greater than the values given in Table 14. Individual test results shall not exceed the permitted temperature change by more than 0.5 K.

7.12.4.2 After restoration of the supply pressures and flow rate to the initial setting the average change in mixed water temperature from the actual initial setting of the sample concerned shall not be greater than 2 K. Individual test results shall not exceed 2.5 K.

The thermal performance requirements of each sample referred to in Chapter 4 are summarised in Table 15 on the following pages.

Clause No.	Value	Run 1	Run 2	Run 3	Requirement
7.5.2.2	Shower initial	T_0	T_2	T_4	T_0 as Table 9
7.5.2.3	Bath initial	T_1	T_3	T_5	T_1 as Table 9
7.5.2.5	Shower transient	δT_0	δT_2	δT_4	Av. {δT_0, δT_2, δT_4} as Table 10
	Shower final	T_2	T_4	T_6	T_2, T_4, T_6 each = $T_0 \pm 2$
7.5.2.7	Bath transient	δT_1	δT_3	δT_5	Av. {δT_1, δT_3, δT_5} as Table 10
	Bath final	T_3	T_5	T_7	T_3, T_5, T_7 each = $T_1 \pm 2$
7.6.2.2	Lower initial	T_0	T_6	T_{12}	T_0 as Table 9
	Higher initial	T_1	T_7	T_{13}	T_1 as Table 9
7.6.2.3	Lower transient	δT_0	δT_6	δT_{12}	Av. {δT_0, δT_6, δT_{12}} as Table 10
	Higher transient	δT_1	δT_7	δT_{13}	Av. {δT_1, δT_7, δT_{13}} as Table 10
	Lower final	T_2	T_8	T_{14}	T_2, T_8, T_{14} each = $T_0 \pm 2$
	Higher final	T_3	T_9	T_{15}	T_3, T_9, T_{15} each = $T_1 \pm 2$
7.6.2.4	Lower transient	δT_2	δT_8	δT_{14}	Av. {δT_2, δT_8, δT_{14}} as Table 10
	Lower final	T_4	T_{10}	T_{16}	T_4, T_{10}, T_{16} each = $T_0 \pm 2$
	Lower transient	δT_4	δT_{10}	δT_{16}	Av. {δT_4, δT_{10}, δT_{16}} as Table 10
	Higher transient	δT_3	δT_9	δT_{15}	Av. {δT_3, δT_9, δT_{15}} as Table 10
	Lower final	T_6	T_{12}	T_{18}	T_6, T_{12}, T_{18} each = $T_0 \pm 2$
	Higher final	T_5	T_{11}	T_{17}	T_5, T_{11}, T_{17} each = $T_1 \pm 2$
7.6.2.6	Higher transient	δT_5	δT_{11}	δT_{17}	Av. {δT_5, δT_{11}, δT_{17}} as Table 10
	Higher final	T_7	T_{13}	T_{19}	T_7, T_{13}, T_{19} each = $T_1 \pm 2$
7.7.2.3	Initial	T_0	T_1	T_2	T_0 as Table 9
7.7.2.7	Transient	δT_0	δT_1	δT_2	Av.{δT_0, δT_1, δT_2} as Table 10
	Final	T_1	T_2	T_3	T_1,T_2,T_3 each = $T_0 \pm 2$
7.8.2.2	Initial	T_0	T_1	T_2	T_0 as Table 9
7.8.2.5	Transient	δT_0	δT_1	δT_2	Av.{δT_0, δT_1, δT_2} as Table 10
	Final	T_1	T_2	T_3	T_1,T_2,T_3 each = $T_0 \pm 2$
7.9.2.2	Initial	T_0	T_2	T_4	T_0 as Table 9
7.9.2.3	Transient	δT_0	δT_2	δT_4	Av.{δT_0, δT_2, δT_4} as Table 10
7.9.2.4	Transient	δT_0	δT_2	δT_4	Av.{δT_0, δT_2, δT_4} as Table 10

(Continued on next page)

Table 15 Summary of thermal performance requirements for each sample

Clause No.	Value	Run 1	Run 2	Run 3	Requirement
7.9.2.5	Final	T_1	T_3	T_5	T_1,T_3,T_5 each = $T_0 \pm 2$
(7.9.2.7)	(Minimum)	(δT_1)	(δT_3)	(δT_5)	(Av.{δT_1, δT_3, δT_5} as Table 11)
7.9.2.8	Transient	δT_1	δT_3	δT_5	Av.{δT_1, δT_3, δT_5} as Table 10
7.9.2.9	Final	T_2	T_4	T_6	T_2,T_4,T_6 each = $T_0 \pm 2$
7.10.2.2	Initial	T_0	T_{12}	T_{24}	T_0 as Table 9
7.10.2.3	Change 1	T_1	T_{13}	T_{25}	Av. {($T_1 - T_0$),($T_{13} - T_0$),($T_{25} - T_0$)} as Table 12
	Change 2	T_2	T_{14}	T_{26}	Av. {($T_2 - T_0$),($T_{14} - T_0$),($T_{26} - T_0$)} as Table 12
	Change 3	T_3	T_{15}	T_{27}	Av. {($T_3 - T_0$),($T_{15} - T_0$),($T_{27} - T_0$)} as Table 12
	Change 4	T_4	T_{16}	T_{28}	Av. {($T_4 - T_0$),($T_{16} - T_0$),($T_{28} - T_0$)} as Table 12
	Change 5	T_5	T_{17}	T_{29}	Av. {($T_5 - T_0$),($T_{17} - T_0$),($T_{29} - T_0$)} as Table 12
	Change 6	T_6	T_{18}	T_{30}	Av. {($T_6 - T_0$),($T_{18} - T_0$),($T_{30} - T_0$)} as Table 12
7.10.2.5	Change 1	T_7	T_{19}	T_{31}	Av. {($T_7 - T_0$),($T_{19} - T_0$),($T_{31} - T_0$)} as Table 12
	Change 2	T_8	T_{20}	T_{32}	Av. {($T_8 - T_0$),($T_{20} - T_0$),($T_{32} - T_0$)} as Table 12
	Change 3	T_9	T_{21}	T_{33}	Av. {($T_9 - T_0$),($T_{21} - T_0$),($T_{33} - T_0$)} as Table 12
	Change 4	T_{10}	T_{22}	T_{34}	Av. {($T_{10} - T_0$),($T_{22} - T_0$),($T_{34} - T_0$)} as Table 12
	Change 5	T_{11}	T_{23}	T_{35}	Av. {($T_{11} - T_0$),($T_{23} - T_0$),($T_{35} - T_0$)} as Table 12
	Change 6	T_{12}	T_{24}	T_{36}	Av. {($T_{12} - T_0$),($T_{24} - T_0$),($T_{36} - T_0$)} as Table 12
7.11.2.2	Initial	T_0	-	-	T_0 as Table 9
7.11.2.3	Change 1	T_1	-	-	($T_1 - T_0$) as Table 13
	Change 2	T_2	-	-	($T_2 - T_0$) as Table 13
	Change 3	T_3	-	-	($T_3 - T_0$) as Table 13
7.11.2.4	Initial	T_0	-	-	T_0 as Table 9
7.11.2.5	Change 1	T_1	-	-	($T_1 - T_0$) as Table 13
	Change 2	T_2	-	-	($T_2 - T_0$) as Table 13
	Change 3	T_3	-	-	($T_3 - T_0$) as Table 13
7.12.2.2	Initial	T_0	T_4	T_8	T_0 as Table 9
7.12.2.4	Low flow	T_1	T_5	T_9	Av. {($T_1 - T_0$),($T_5 - T_0$),($T_9 - T_0$)} as Table 14
7.12.2.6	Final	T_2	T_6	T_{10}	Av. {($T_2 - T_0$),($T_6 - T_0$),($T_{10} - T_0$)} as Table 14
7.12.2.9	Low flow	T_3	T_7	T_{11}	Av. {($T_3 - T_0$),($T_7 - T_0$),($T_{11} - T_0$)} as Table 14
7.12.2.11	Final	T_4	T_8	T_{12}	Av. {($T_4 - T_0$),($T_8 - T_0$),($T_{12} - T_0$)} as Table 14

8.0 Designation

Thermostatic mixing valves complying with this specification are designated by:

a. the intended operating pressure range;

b. the intended application.

The last element of the designation codes is given in Table 16. In every case this element shall be preceded by “Thermostatic mixing valve-DH Performance Specification D 08”. Elsewhere in this specification, for brevity, the last element only is quoted and is referred to as “Abbreviated designation”.

Where a thermostatic mixing valve is suitable for more than one application, the code can include the final element of each application: for example, “Thermostatic mixing valve-DH Performance Specification D 08 -LP-B/S/W” would be suitable for bidet, shower, or washbasin applications in the low operating pressure range.

Where, for reasons of water economy, a flow rate less than 8 L/min is required for the application, thermostatic mixing valves of -B, -S, and -W designations having a flow rate less than 8 L/min when tested according to clause 7.3 shall carry the designation suffix E.

Code	Operating pressure range	Application
-HP-B	High pressure	Bidet
-HP-S	High pressure	Shower
-HP-W	High pressure	Washbasin
-HP-T44	High pressure	Bath with fill temperature up to 44°C
-HP-T46	High pressure	Bath with fill temperature up to 46°C
-HP-D44	High pressure	Bath (up to 44°C fill) and shower (up to 41°C)
-HP-D46	High pressure	Bath (up to 46°C fill) and shower (up to 41°C)
-LP-B	Low pressure	Bidet
-LP-S	Low pressure	Shower
-LP-W	Low pressure	Washbasin
-LP-T44	Low pressure	Bath with fill temperature up to 44°C
-LP-T46	Low pressure	Bath with fill temperature up to 46°C
-LP-D44	Low pressure	Bath (up to 44°C fill) and shower (up to 41°C)
-LP-D46	Low pressure	Bath (up to 46°C fill) and shower (up to 41°C)

Table 16 Designation codes

9.0 Marking

Thermostatic mixing valves complying with this specification shall be permanently and legibly marked on the product with the manufacturer's name or identification mark and unique model reference, sufficient to enable the designation of the product to be compared with the corresponding information on any certificate of compliance with this specification. Where the marking is applied to a detachable part of the valve (for example a cap or index), this detachable part shall be attached to the valve by means of a fixing that requires a tool, other than a standard screwdriver, to remove the part.

Note:

The durability of the marking should be such that it is unlikely to be removed by normal operation and maintenance. The marking should be positioned so that it can be readily identified.

The unique identification cannot be located:

- where disconnection of the hot and cold pipework is required to verify the product by its unique identification mark;
- on the water supply pipe;
- in such a position that it requires isolation of the water supply and disassembly to verify the product by its unique identification mark.

10.0 Installation and operating instructions

The manufacturer shall provide installation, operating and maintenance instructions. These shall include:

a. information on the designation of the thermostatic mixing valve concerned (see Chapter 8);

b. information on the commissioning and routine in-service tests to be performed as described in Chapter 11;

c. information on the frequency of in-service tests and service work as described in Annex F;

d. information on the need for any anti-backsiphonage devices (for example check valves) required to be installed with the mixing valve together with the specification of such devices. This specification shall be sufficient to enable the combination of mixing valve and anti-backsiphonage devices tested in accordance with this specification to be replicated on site;

e. the need for the inclusion of any isolating valves etc to enable on-site tests to be made;

f. details of suitable outlet fittings (for example draw-off taps etc).

11.0 Commissioning and in-service tests

11.1 Commissioning

11.1.1 Purpose

11.1.1.1 Commissioning ensures that the TMV and the water supplies to it are appropriate and that the valve has been adjusted to provide a mixed water at an appropriate temperature for the intended application of use. It also provides records of the thermal performance of the TMV.

For information, the type-testing detailed in previous clauses in D 08 are not applicable for on-site testing.

11.1.2 Commissioning procedure

11.1.2.1 Check that the TMV is appropriate for the application of use (see Table 17).

Check that the water supplies are appropriate for the installation of the TMV (see Table 18 and Stage 1 (Figure 4)).

Check that the mixed water temperature is appropriate for the application; if required, adjust the mixed water temperature up to a maximum application temperature (as indicated in Table 17) in accordance with the manufacturer's instructions.

Note:

After risk assessment a temperature that is lower than the maximum temperature allowable for the designated installation (vulnerable people) can also be set if deemed appropriate to do so.

Check that the supply pipework is free from debris or detritus.

11.1.2.2 Carry out the following commissioning test sequence (see Stage 2 (Figure 5)):

a. Record the temperature of the hot and cold water supplies adjacent to the TMV. Record the pressures of the hot and cold water supplies at the inlets of the TMV.

Note:

If this measurement is not possible at the inlets to the TMV and is taken elsewhere, then the pressures at the TMV will be lower than the measured values.

b. For all outlets, measure the temperature of the mixed water at the maximum available flow and record.

c. Isolate the cold water supply to the mixing valve and observe the mixed water outlet.

11.1.2.3 If there is a flow stream after 5 s then collect any water discharging into a suitably graduated measuring vessel for 60 s; if the volume of water collected is greater than 120 ml then further investigation is needed.

11.1.2.4 If there is no flow or if the volume of water collected is less than or equal to 120 ml, then restore the cold water supply; after 15 s record the mixed water temperature.

Application and designation	Initial set temperature of the mixed water (at point of discharge)
Bidet (B)	38°C max
Shower (S)	41°C max
Washbasin (W)	41°C max
Bath (44°C fill) (T44)	44°C max
Bath (46°C fill) (T46)	46°C max
Diverter Bath/Shower (D44)	Bath fill 44°C max, Shower 41°C max
Diverter Bath/Shower (D46)	Bath fill 46°C max, Shower 41°C max
Note: Set the mixed water outlet at these maximum initial temperature settings. During the cold water restoration stage the mixed water temperature can deviate by 2°C from these maximum initial settings.	

Table 17 Mixed water temperature

Operating range	High pressure use	Low pressure use
Maximum static pressure	10 bar	
Flow pressure, hot and cold	1 to 5 bar	0.2 to 1 bar
Hot supply temperature	Minimum 55°C	
Cold supply temperature	Maximum 20°C	

Table 18 Conditions for normal use

11.1.2.5 Verify that this temperature does not differ by more than 2°C from the temperature taken in 11.1.2.2 (b) (this is a restoration test after a failure of the cold water supply and some deviation of the mixed water outlet temperature may be expected).

11.1.2.6 If the mixed water temperature differs by more than 2°C from the set temperature taken at 11.1.2.2 (b), then recheck the supply conditions or recommission (see paragraph 11.1.2.7).

11.1.2.7 The valve must then be adjusted and recommissioned in accordance with the manufacturer's instructions.

Note:

Consider checking the following:

- the supply conditions for normal use are within the conditions specified in Table 18;
- the in-line or integral strainers and check valves are clean;
- any isolating valves are fully open;
- the TMV installation has been undertaken in accordance with the manufacturer's instructions;
- the temperature differential of the TMV is appropriate for the supply conditions, in accordance with the manufacturer's instructions;
- the designation of use of the TMV matches the intended application.

11.2 In-service test

11.2.1 Purpose

The purpose of in-service testing is to maintain assured performance and to provide records of the thermal performance of the TMV, all of which should be consistent with this document and the risk assessment carried out by the Water Safety Group.

11.2.2 In-service test procedure

11.2.2.1 Carry out the following in-service test sequence (see Stage 3 (Figure 6)):

a. For all outlets, measure and record the temperature of the mixed water at the maximum available flow. If required, the mixed water temperature may be readjusted up to a maximum temperature as indicated in Table 17.

Note:

After risk assessment, a temperature that is lower than the maximum temperature allowable for the designated installation (vulnerable people) can also be set if deemed appropriate to do so.

b. Isolate the cold water supply to the mixing valve and observe the mixed water outlet.

11.2.2.2 If there is a flow stream after 5 s then collect any water discharging into a suitably graduated measuring vessel for 60 s; if the volume of water collected is greater than 120 ml, then recommissioning or service work is needed.

11.2.2.3 If there is no flow or if the volume of water collected is less than or equal to 120 ml, then restore the cold water supply; after 15 s record the mixed water temperature.

11.2.2.4 Verify that this temperature does not differ by more than 2°C from the temperature taken in 11.2.2.1(a) (this is a restoration test after a failure of the cold water supply and some deviation of the mixed water outlet temperature may be expected).

11.2.2.5 If the mixed water temperature differs by more than 2°C from the set temperature taken at 11.2.2.1(a), then recheck the supply conditions or recommission (see paragraph 11.2.2.6).

11.2.2.6 The valve must then be readjusted and recommissioned in accordance with the manufacturer's instructions.

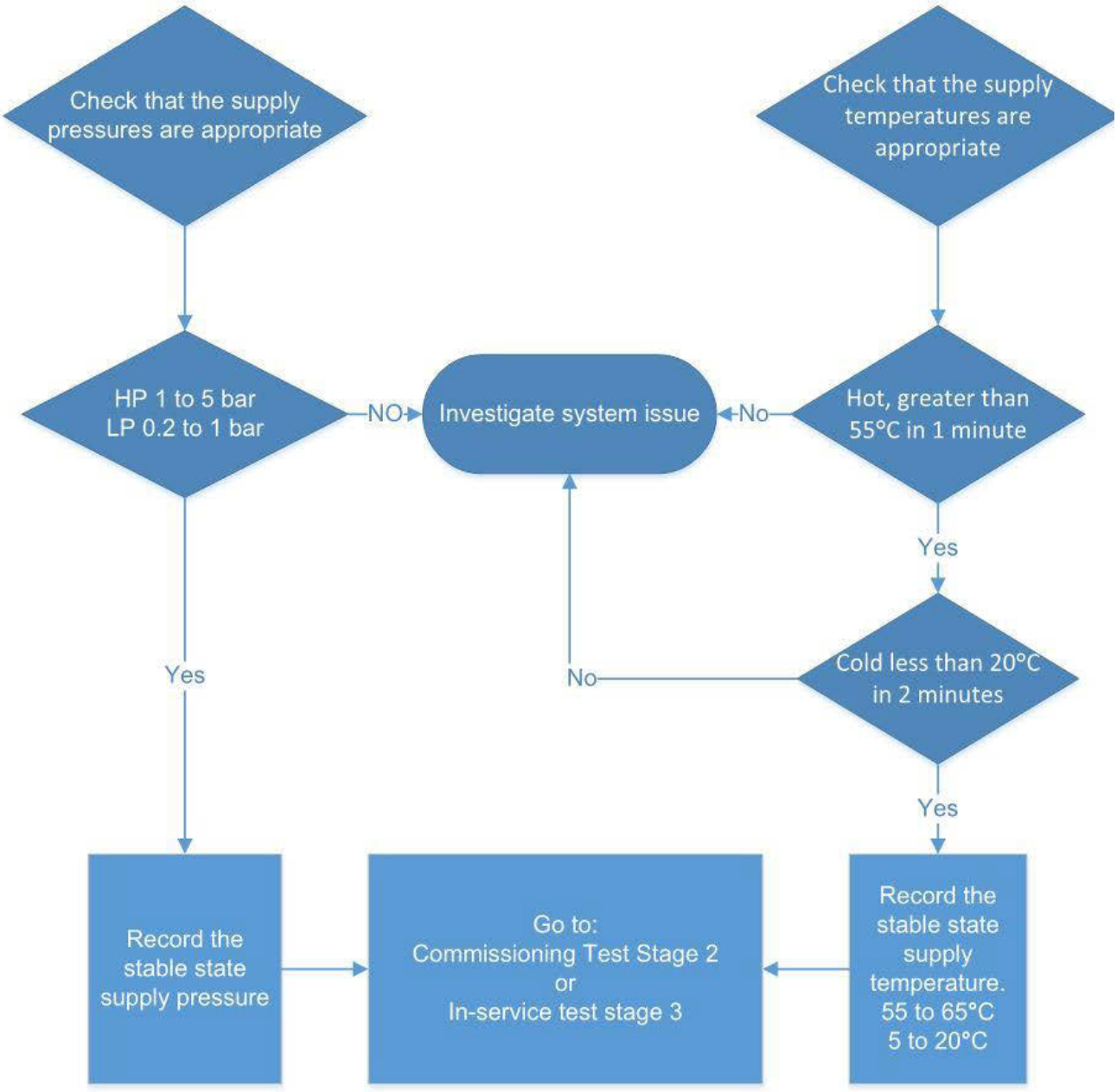


Figure 4 Stage 1: HTM-04-01 confirmation of supply conditions

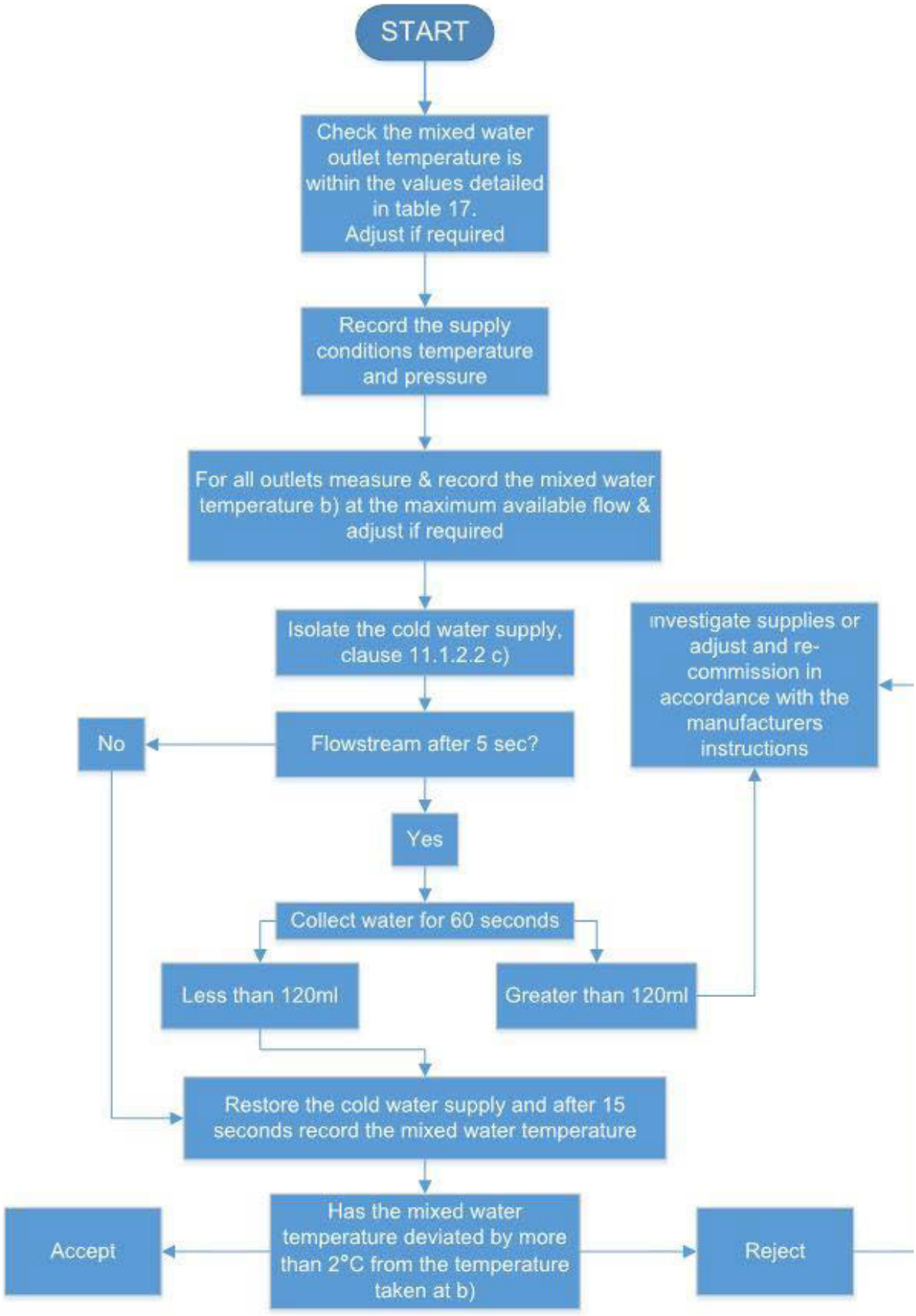


Figure 5 Stage 2: Commissioning procedure

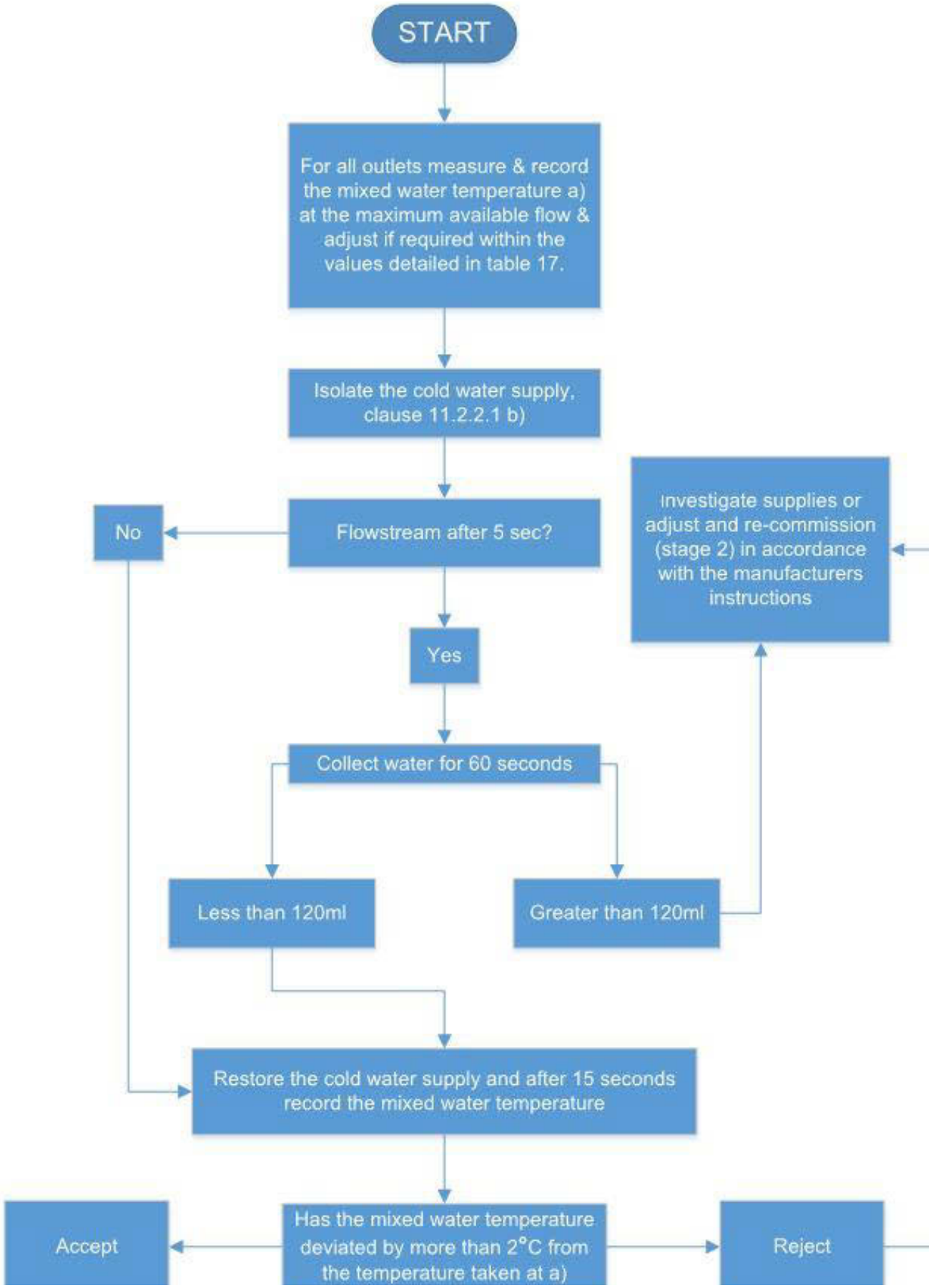


Figure 6 Stage 3: In-service test procedure

TMV test record sheet

Test date:

Valve reference		Location	
Blend setting	˚C	Installation date	
Outlet type Bath/washbasin/shower		Maintenance frequency	
Min temp. diff for the valve	˚C	Maintenance frequency	
Engineer's name:		Maintenance date:	

Supply conditions:

Date	Previous supply conditions	Service detail	Current supply conditions
	˚C	Hot supply temperature	˚C
	˚C	Cold supply temperature	˚C
	bar	Hot supply pressure	bar
	bar	Cold supply pressure	bar
	˚C	Stable mixed water outlet temperature	˚C
	˚C	Temperature differential	˚C

Non-compliance with HTM-04-01. Remedial actions required are as follows:

Commissioning and in-service test results (clauses 11.1 or 11.2)

Test Detail	Result	Observation/comment
Mixed water outlet temperature at maximum flow (*X*)	˚C	
Mixed water outlet temperature at 50% flow	˚C	
Isolate the cold water supply – flow after 5 s?	Yes/No	
Volume of water in 60 s if flow after 5 s*	mL	
Mixed water outlet temperature after water supply restored	˚C	
Deviation from the initial result *X* Greater than 2˚C**	˚C Yes/No	
Deviation from the previous in-service result Greater than 1˚C?	˚C Yes/No	
Strainers/check valves clean?	Yes/No	
Isolation valves fully open?	Yes/No	
Final mixed water outlet temperature	˚C	

*If the volume is more than 120 mL, reset the valve according to manufacturers' instructions and retest.

**If yes, then reset the valve according to manufacturers' instructions and retest.

Frequency of in-service test (Annex F)

Next in-service test date:

Annex A (normative): apparatus for durability test on thermostat

A.1 Test rig

A.1.1 General

The test rig shall comply with Figure A.1 in respect of dimensions, equipment and general arrangement. However, some details will need to differ in order to suit particular mixing valves and water supply facilities.

If the test rig is supplied with recycled water, this shall not deteriorate in quality during the test and shall remain free of grease, debris etc.

A.1.2 Description

A.1.2.1 Inlets

The inlet pipework shall include:

a. a quick acting shut-off valve (7 and 8) with remote actuation, such as a solenoid valve, in each supply;

b. a flow meter (Q_h and Q_c). Alternatively, the mixed water flow rate may be measured by determining the volume of discharge collected in a known time;

c. provision to accommodate a temperature measuring device (T_h and T_c);

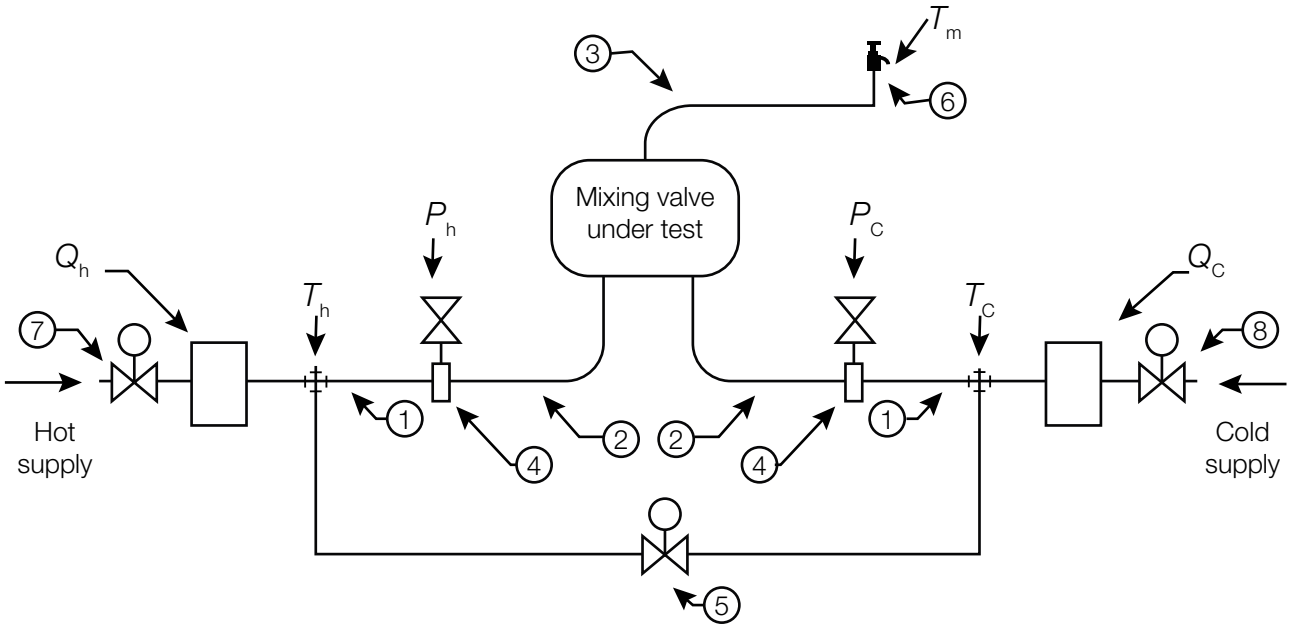


Figure A.1 Test rig for durability test on thermostat

d. a branch to an arrangement for cross-connecting the supplies;

e. a straight pipe 1, of the same nominal bore as the inlet connection of the mixing valve and of a length not greater than 260 mm between the temperature measuring device and the pressure take-off tee 4;

f. a pressure take-off tee 4 complying with Figure A.2 and Table A.1 and of the same nominal size as the pipe 1;

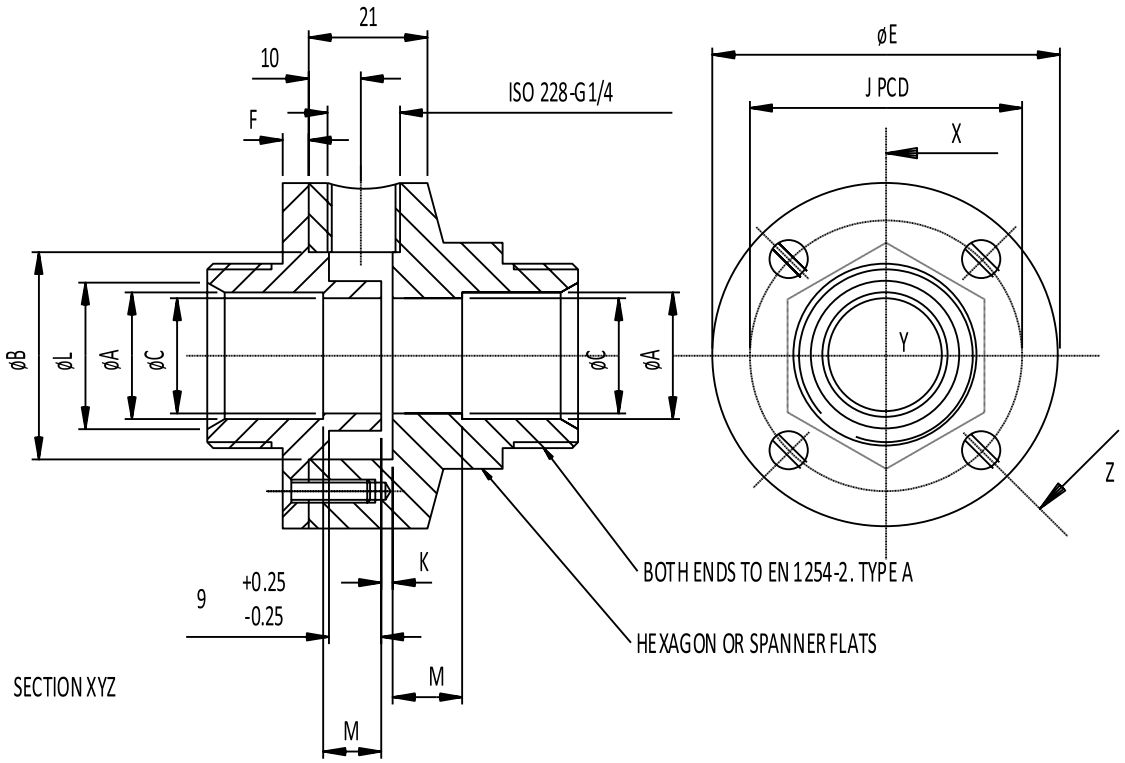
g. a pipe 2 of the same nominal bore as the inlet connection of the mixing valve under test and of a length not greater than 310 mm;

Note:

Pipe elbows and other fittings supplied with the mixing valve are considered to be part of the mixing valve, not part of the test rig.

h. an arrangement for cross-connecting the supplies through a branch containing valve 5. Valve 5 shall be of a quick-acting shut-off type with remote actuation such as a solenoid valve;

i. lagging over the whole length of both inlet pipes between the temperature measuring device and the inlet connection of the mixing valve. This lagging shall be of mineral wool with a thickness of at least 25 mm, or of equivalent insulating value.



Dimensions in millimetres

Note 1: Unspecified tolerance ±1

Note 2: Tube ends to be square, without burrs and inserted to full depth of dimension A

Figure A.2: Pressure take-off tee

Dimensions in millimetres				
DN	10	15	20	25
A	10.2 ± 0.05	15.2 ± 0.05	22.25 ± 0.05	28.25 ± 0.05
B	18.5 ± 0.5	25.5 ± 0.5	35.5 ± 0.5	46.5 ± 0.5
C	9 ± 0.05	13.85 ± 0.05	20.6 ± 0.1	26.6 ± 0.1
E	42	49	59	70
F	4	4	4	4
J	30	37	47	58
K	0.5 ± 0.1	0.6 ± 0.1	0.7 ± 0.1	0.9 ± 0.1
L	13.5 ± 0.5	18.5 ± 0.5	25.5 ± 0.5	32.5 ± 0.5
M	3	5.5	9	12
Size of screws	M4 × 15	M4 × 15	M4 × 15	M5 × 15
Number of screws	4	4	4	4

Table A.1 Dimensions of pressure take-off tees

A.1.2.2 Outlet

For mixing valves that do not have an integral atmospheric discharge nozzle, outlet pipework must be fitted. This shall have a total length between the mixing valve outlet connection and the inlet of the draw-off tap not greater than 610 mm and shall include:

a. a draw-off tap 6 of the same nominal size as the pipe 3. The discharge nozzle of this tap shall be the highest point of the outlet;

b. provision to accommodate a temperature measuring device (T_m).

Note:

Pipe elbows and other fittings supplied with the mixing valve are considered to be part of the mixing valve, not part of the test rig.

A.1.2.3 Operating devices

The valves 5, 7 and 8 shall be operated by means of a timing device in a defined cycle:

a. start with valves 7 and 8 open and valve 5 closed;

b. 10 ± 1 s after the rate of increase in the mixed water temperature has reduced to not more than 1 K/s (see clause A.2.3.3), close valve 7 and open valve 5;

c. 15 ± 1 s after the rate of decrease in the mixed water temperature has reduced to not more than 1 K/s (see clause A.2.3.3), revert to (a);

d. at the frequency specified in clause 6.3.3.5, when at stage (a), 20 s after the rate of increase in the mixed water temperature has reduced to not more than 1 K/s (see clause A.2.3.3), close valve 8. After a further 60 s, revert to (a).

A.2 Measurement of parameters

A.2.1 Pressure measurement

The flow pressures of the hot water supply, P_h, the cold water supply, P_c, and the mixed water, P_m, shall be measured with an accuracy of 1%.

A.2.2 Flow measurement

The flow rates of hot water, Q_h, and cold water, Q_c, shall be measured with an accuracy of 2%. The flow rate of mixed water is the sum ($Q_h + Q_c$). If the mixed water flow rate is

determined by the collection method, the accuracy shall be 3%.

A.2.3 Temperature measurement

A.2.3.1 Mounting

The thermally sensitive part of sensing elements shall be fully immersed.

In the case of the mixed water temperature, the thermometer element shall be rigidly mounted in contact with the water outlet and arranged so that all discharges pass over or along the full extent of the thermally sensitive part of the element. The thermally sensitive part of the element shall be located in air 30–50 mm from the end of the outlet.

A.2.3.2 Accuracy

The temperature of the hot water supply, T_h, the cold water supply, T_c, and the mixed water, T_m, shall be measured with an accuracy of 0.5 K.

A.2.3.3 Rate of change

The rate of temperature change referred to in clause A.1.2.3 shall be determined on the basis of the temperature change in each of two successive periods of 0.5 s.

Annex B (normative): apparatus for performance tests

B.1 Test rig

B.1.1 General

The test rig shall comply with Figure B.1 in respect of dimensions, equipment and general arrangement. However, some details will need to differ in order to suit particular mixing valves and water supply facilities.

B.1.2 Description

B.1.2.1 Inlets

The inlet pipework shall include:

a. a quarter turn spherical plug valve in the supply pipe;

b. a flow meter (Q_h and Q_c);

Note 1: Invalid readings of the flow meters will result if the bleed valve(s) 8 are open.

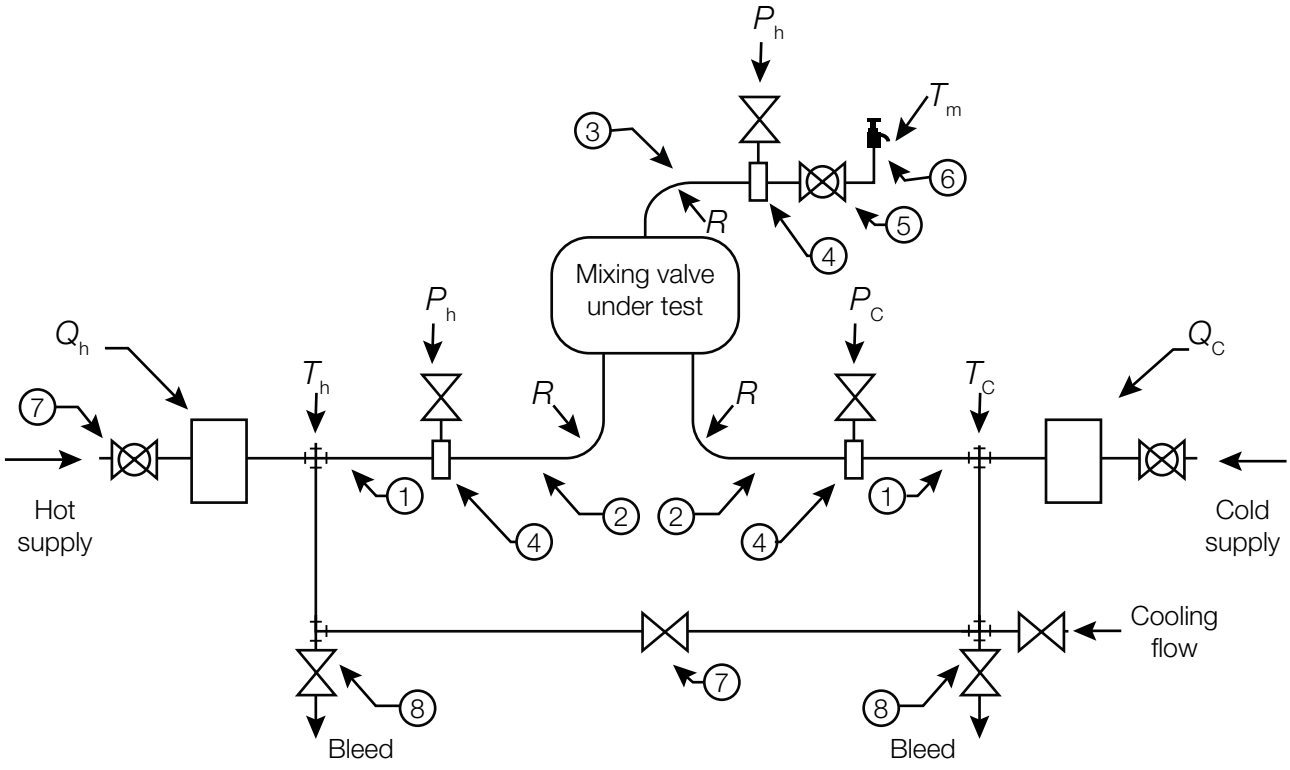


Figure B.1 Test rig for performance tests

c. provision to accommodate a temperature measuring device (T_h and T_c);

d. a branch to bleed valve 8;

e. a straight pipe 1, of the same nominal bore as the inlet connection of the mixing valve and of length 250 ± 10 mm between the temperature measuring device and the pressure take-off tee 4;

f. a pressure take-off tee 4 complying with Figure A.2 and Table A.1 and of the same nominal size as the pipe 1;

g. a pipe 2 of the same nominal bore as the inlet connection of the mixing valve under test and of length 300 ± 10 mm. Only bends of radius $R \geq 4 \times$ the bore of the pipe are permitted in this pipe, and the bends shall not total more than 90°;

Note 2: Pipe elbows and other fittings supplied with the mixing valve are considered to be part of the mixing valve, not part of the test rig.

h. an arrangement for cross-connecting the supplies through a branch containing valve 7 connected between the branches to bleed valves 8;

i. lagging over the whole length of both inlet pipes between the temperature measuring device and the inlet connection of the mixing valve. This lagging shall be of mineral wool with a thickness of at least 25 mm, or of equivalent insulating value.

B.1.2.2 Outlet

For mixing valves that do not have an integral atmospheric discharge nozzle, outlet pipework must be fitted. This shall have a total length between the mixing valve outlet connection and the inlet of the draw-off tap of 600 ± 10 mm and shall include:

a. a pipe 3 between the mixing valve outlet connection and the pressure take-off tee 4. This pipe shall be of the same nominal bore as the outlet connection of the mixing valve under test and of length 300 ± 10 mm. Only bends of radius $R \geq 4 \times$ the bore of the pipe are permitted in this pipe, and the bends shall not total more than 90°;

Note: Pipe elbows and other fittings supplied with the mixing valve are considered to be part of the mixing valve, not part of the test rig.

b. a pressure take-off tee 4 complying with Figure A.2 and Table A.1 and of the same nominal size as the pipe 3;

c. a quarter turn spherical plug valve 5 of the same nominal size as the pipe 3;

d. a draw-off tap 6 of the same nominal size as the pipe 3. The discharge nozzle of this tap shall be the highest point of the outlet provision to accommodate a temperature-measuring device (T_m).

B.2 Measurement of parameters

B.2.1 Pressure measurement

The flow pressures of the hot water supply, P_h, the cold water supply, P_c, and the mixed water, P_m, shall be measured with an accuracy of 1%. The datum for pressure measurement shall be taken at the lowest point of the atmospheric end of the discharge nozzle of the tap 6, or the nozzle of the integral discharge spout etc.

B.2.2 Flow measurement

The flow rates of hot water, Q_h, and cold water, Q_c, shall be measured with an accuracy of 2%. The flow rate of mixed water is the sum ($Q_h + Q_c$).

B.2.3 Temperature measurement

B.2.3.1 Mounting

The thermally sensitive part of sensing elements shall be fully immersed.

In the case of the mixed water temperature, the thermometer element shall be rigidly mounted in contact with the water outlet and arranged so that all discharges pass over or along the full extent of the thermally sensitive part of the element. The thermally sensitive part of the element shall be located in air 30–50 mm from the end of the outlet.

B.2.3.2 Accuracy

The temperature of the hot water supply, T_h, the cold water supply, T_c, and the mixed water, T_m, shall be measured with an accuracy of 0.2 K.

B.2.3.3 Response time

The mixed water temperature shall be measured with instrumentation having a total system response such that a change in reading equal to 90% of a step change is indicated in a time of 0.3 ± 0.05 s. This response time shall be verified by means of the procedure specified in Annex C.

B.2.4 Angular position

The angular position of the temperature control shall be measured with an accuracy of 0.5° angular. Linear movement shall be measured with an accuracy of 0.5 mm.

B.2.5 Duration of transients

Transient events shall be timed to an accuracy of 0.1 s.

Annex C (normative): determination of thermometer response time

C.1 Purpose

The purpose is to determine the response time of the complete water-temperature-measuring system specified in Annex B for the mixed water temperature. This consists of, for example, a sensor (thermometer element or thermocouple) together with all associated equipment necessary to obtain a reading of Celsius temperature.

C.2 Method

The method specified involves plunging the sensor from air at ambient temperature into flowing water at a higher temperature and measuring the time taken for the reading of Celsius temperature to rise by 90% of the difference between the air and water temperatures.

Note:

The method specified is appropriate to the measurements of transient temperatures required by this specification and should provide repeatable results. However, the method should not be regarded as capable of measuring the absolute response time. To do this additional test equipment is needed.

C.3 Apparatus

C.3.1 Water system

A water supply is required which can be adjusted both for temperature and flow rate and which is discharged through a pipe or nozzle into the atmosphere. The minimum dimension A of the water stream discharged into air shall not be less than $5 \times D$, where:

A = smallest cross-section dimension of the water stream in air between the end of the pipe or nozzle and 100 mm from the end of the pipe or nozzle when the flow velocity in the pipe or nozzle is 1 ± 0.1 m/s;

D = the largest cross-section dimension of the immersed part of the thermometer element or sensor.

Note:

In general the cross-section dimensions of the water stream are approximately equal to the cross-section dimensions of the pipe or nozzle.

C.3.2 Measuring equipment

The measuring equipment shall be the same as that used for the tests in Chapter 7. To enable the response time to be determined there shall be provision for synchronising the plunging of the sensor into water with the commencement of the time interval measurement.

Note 1:

Where a data logging system is used, the measured response time will frequently be overestimated, but never underestimated. Although a scan interval of 0.2 s is sufficiently fast to achieve the required accuracy of timing in clause B.2.5, for the determination of thermometer response time this scan interval can overestimate the response time by more than 10% in the range of permitted response times. A scan interval of 0.1 s should not overestimate by more than 0.01 s, and the possible error is reduced by more rapid scanning.

Note 2:

It may be sufficient to manually coordinate the plunging of the sensor into water and the commencement of timing. However, practice is necessary to achieve repeatable results.

C.4 Procedure

C.4.1 In the pipe or nozzle establish a flow of water having a velocity of 1 ± 0.1 m/s. The dimensions of the water stream discharging into the atmosphere shall have the dimensions specified in clause C.3.1.

C.4.2 Measure the air temperature T_a close to the water stream. The air temperature shall be constant ±0.2 K.

Note:

To achieve the required constancy of air temperature, a draught-protected environment may be needed.

C.4.3 Adjust the temperature of the water stream in air T_w such that $(T_w - T_a) = 20 \pm 2$ K. The water stream temperature shall be constant ±0.2 K and the velocity in the pipe or nozzle shall remain at 1 ± 0.1 m/s.

C.4.4 With the test sensor in air close to the water stream, record the temperature that it indicates in association with its connected equipment (transmitter, amplifier, data logger, pen recorder etc). Then simultaneously plunge the sensor into the water stream and commence timing. The attitude of the sensor within the water stream shall be oblique to the flow with the tip of the sensor not more than 100 mm from the end of the pipe or nozzle and with the whole of the sensitive part of the sensor immersed. The temperature indicated by the test sensor and its associated equipment shall be monitored until the indication is constant ±0.2 K.

C.4.5 From a graph of the indicated temperature versus time, determine the response time τ90 as the time taken to reach 90% of the indicated difference $(T_w - T_a)$.

C.4.6 Repeat the procedure in clauses C.4.3 to C.4.5 to give at least five consecutive measurements of τ90 that are constant to within 10% of their average value.

Note:

With the exception of synchronisation (coordination) errors, the errors inherent in the procedure should tend to result in a larger value of response time than the absolute value. For this reason greater confidence may be placed in the smallest values measured, unless they are likely to be the result of synchronisation error.

C.5 Results

The response time τ90 shall be taken as the average of the three smallest values of at least five consecutive measurements of τ90 that are constant to within 10% of their average value.

Annex D (normative): testing of further samples

D.1 In the event that no more than one of the three samples initially selected should fail to satisfy the requirements of the performance tests for a specific designation by margins no greater than those specified in Table D.1, a further two samples may be selected using the same random selection procedure. If the failed valve had been subjected to the durability of thermostat test specified in clause 6.3, then one of the two additional samples shall also be subjected to this test. If the two additional samples satisfy all of the requirements for that failed designation, then the product will be deemed to comply with this specification.

Requirement	Margin of failure
Clauses: 7.5.4.1; 7.6.4.1; 7.7.4.1; 7.8.4.1; 7.9.4.1	+10% on average duration of transient temperature rises.
Clauses: 7.5.4.2; 7.6.4.2; 7.7.4.2; 7.8.4.2; 7.9.4.2; 7.12.4.2	0.3 K on each steady mixed water temperature after restoration of initial supply conditions.
Clause 7.9.4.3	+10% on average leakage volume; 0.5 K on average reduction in mixed water temperature.
Clauses: 7.10.4.1; 7.11.3.1; 7.12.4.1;	0.5 K on average change in mixed water temperature.

Table D.1 Maximum margins of failure

Annex E (informative): assessment of transient values

E.1 An example of a transient temperature variation is shown in Figure E.1. The following information is taken from the graph:

a. The duration at or above 45°C = 2.9 – 0.5 = 2.4 s

b. The duration at or above 46°C = 2.5 – 0.53 = 1.97 s

c. The duration at or above 47°C = 2.25 – 0.57 = 1.68 s

d. The duration at or above 48°C = 1.99 – 0.6 = 1.39 s

e. The duration at or above 49°C = 1.73 – 0.7 = 1.03 s

f. The duration at or above 50°C = 1.52 – 0.7 = 0.82 s

g. The duration at or above 51°C = 1.35 – 0.75 = 0.5 s

h. The duration at or above 52°C = 1.13 – 0.8 = 0.33 s

i. The duration at or above 53°C = <0.25 s

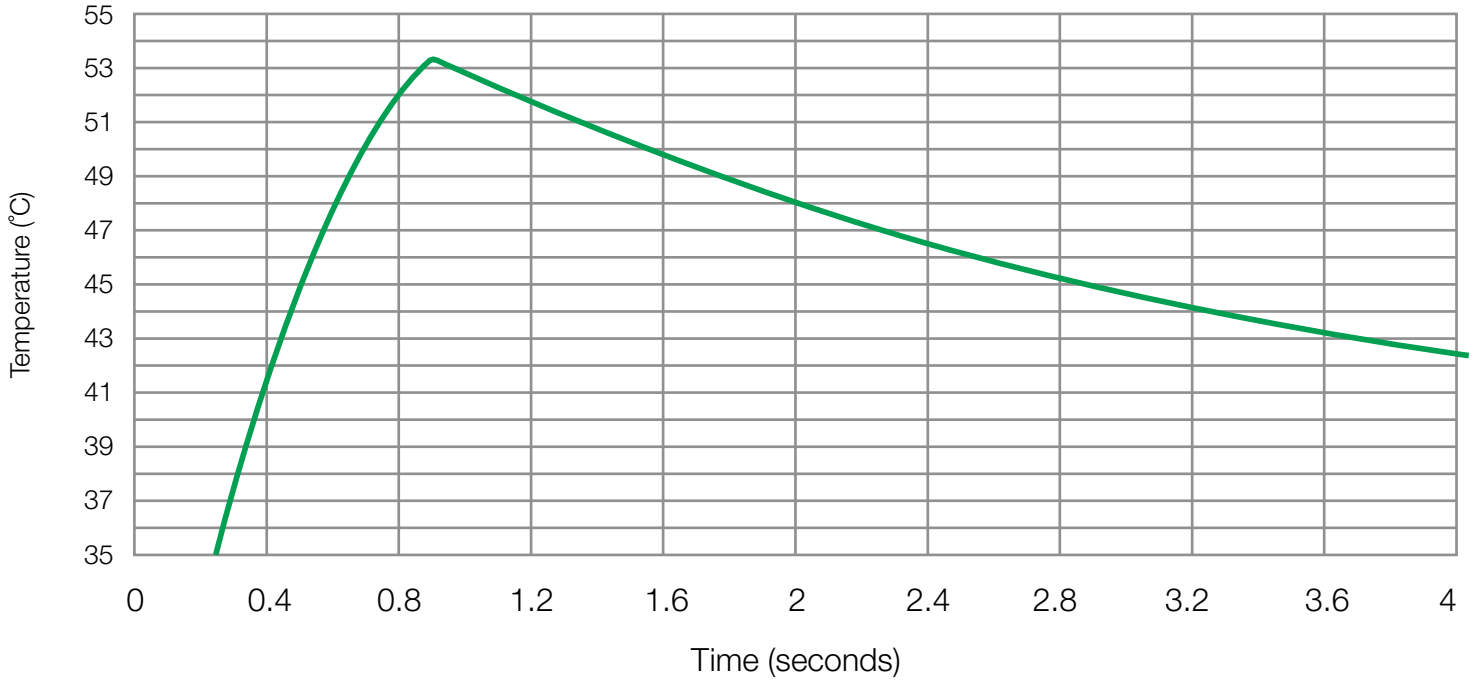


Figure E.1 Example of transient temperature variation

Annex F (informative): frequency of in-service tests

F.1 General

In the absence of any other instruction or guidance on the means of determining the appropriate frequency of in-service testing, the following procedure may be used as a starting point.

The frequency of in-service testing and the specific requirements detailed in the risk assessment undertaken by the Water Safety Group may change due to a number of factors such as varying supply conditions and water quality as these may alter the TMV's performance.

F.1.1 Six to eight weeks after commissioning, carry out the test given in clause 11.2.2.

F.1.2 Twelve to fifteen weeks after commissioning, carry out the test given in clause 11.2.2.

F.1.3 Depending on the results from clauses F.1.1 and F.1.2, several possibilities exist:

a. If no significant changes (for example ≤1 K) in mixed water temperatures are recorded between commissioning and the times given in clause F.1.1, or between commissioning and the times given in clause F.1.2, the next in-service test can be deferred to 24 to 28 weeks after commissioning.

b. If small changes (for example 1–2 K) in mixed water temperatures are recorded in only one of these periods, necessitating adjustment of the mixed water temperature, then the next in-service test can be deferred to 24 to 28 weeks after commissioning.

c. If small changes (for example 1–2 K) in mixed water temperatures are recorded in both of these periods, necessitating adjustment of the mixed water temperature, then the next in-service test should be carried out at 18 to 21 weeks after commissioning.

d. If significant changes (for example >2 K) in mixed water temperatures are recorded in either of these periods, necessitating service work, then the next in-service test should be carried out at 18 to 21 weeks after commissioning.

F.1.4 The general principle to be observed after the first two or three in-service tests is that the intervals of future tests should be set to those which previous tests have shown can be achieved with no more than a small change in mixed water temperature.

Annex G (normative): flowrate and sensitivity test of temperature control (alternative to angular or linear movement)

G.1 General

G.1.1 This Annex details alternative tests for mixing valves that do not have a conventional temperature control lever for adjusting the mixed water temperature. All other test requirements for such products are the same as those specified in the main text of this specification.

G.1.2 The two categories of electronic temperature adjustment covered by this Annex are:

- Category A valves: where the mixed water temperature controller produces a progressive temperature increase/ decrease for the time it is activated.
- Category B valves: where the mixed water temperature controller produces a predetermined step temperature increase/ decrease for each time it is activated.

The indication of temperature adjustment will normally be visual but audible/vibratory indications are acceptable.

G.2 Flow rate and sensitivity of temperature control (alternative to angular or linear movement)

G.2.1 Purpose

The purpose of the test is to:

- determine the flow rate of the mixed water;
- determine the ease with which the mixed water temperature can be adjusted to the correct value for the intended application;
- ensure that the electronic temperature control is not operated inadvertently;
- enable the user to be aware of what the mixed water temperature is doing when making adjustments.

If a thermostatic mixing valve is suitable for more than one designation, this test can be conducted for all of these in a single test if the user adjustment range for mixed water temperature can be set to provide all of the required mixed water temperatures in one setting.

G.2.2 Procedure

G.2.2.1 Connect the mixing valve to the test rig (see Annex B).

G.2.2.2 Fully open any integral flow control. Where outlet pipework is required, also open fully the valve 5 and the tap 6. Ensure that the bleed valves 8 are closed.

G.2.2.3 For mixing valves with user adjustment of the mixed water temperature, adjust the maximum mixed water temperature stop so that the full range of mixed water temperatures required in this test is available. For mixing

valves with a preset temperature, access the mixed water temperature adjustment.

G.2.2.4 With the pressure losses and supply temperatures specified in Table 8, set the temperature control/adjustment to give a mixed water temperature equal to the first setting specified in Table 7.

Where outlet pipework is required, adjust the tap 6 to give the required pressure loss.

G.2.2.5 Record the mixed water flow rate and temperature and record the position of the temperature control/adjustment. Where outlet pipework is required, record the outlet pressure.

G.2.2.6 For category A valves as specified above, activate the temperature controller until the mixed water temperature reaches the values equivalent to settings 2, 3, 4 or 5 in Table 7 as determined by the designation of the mixing valve.

At each setting, record the mixed water flow rate, the temperature and the time to reach each setting. Alternatively the total time taken for the temperature to move from the first to the last setting can be measured and used to calculate the average time taken per position.

For category B valves as specified above, set the temperature control/adjustment to give a mixed water temperature equal to the first setting in Table 7. Activate the temperature controller one increment and measure the incremental change in the mixed water temperature. Continue to activate the temperature controller in single incremental steps measuring flow rate and mixed water temperature change at each setting, until the range determined by settings 1–5 in Table 7 and the designation of the mixing valve have been covered.

Where outlet pipework is required, record the outlet pressure.

For category A and B valves, measure from the sensor the maximum distance required to activate the temperature adjustment as appropriate.

G.2.3 Expression of results

Record the flow rates.

For category A valves, record the flow rate at each of the mixed water temperature settings determined by Table 7. Record the time taken to increase the mixed water temperature from the value equivalent to setting 1 to settings 2, 3, 4 or 5 in Table 7, as determined by the designation of the mixing valve. Alternatively the total time taken for the temperature to move from the first to the last setting can be measured so that an average time per setting can be calculated.

For category B valves, record the temperature change for each incremental adjustment required to increase the mixed water temperature from the value equivalent to setting 1 to settings 2, 3, 4 or 5 in Table 7, as determined by the designation of the mixing valve.

G.2.4 Requirements

For category A valves, the temperature/time increase characteristic specified in Table 7 shall be a maximum of 1 K per second throughout the temperature range.

For category B valves, each step change in temperature shall be 1 K maximum.

The flow rate shall at no point be less than the value specified in Table 8 for the designation of valve, except that for those valves designated with suffix E the flow rate shall be less than 8 L/min.

The maximum distance for activation of the electronic temperature controller shall be 50 mm.

A visual/audible/vibratory indication built into the product is required to inform the user whether the temperature is rising or falling when they are adjusting the mixed water temperature as well

as indicating its maximum and minimum temperature positions.

G.3 Mixed water temperature overshoot on adjustment of mixed water temperature

G.3.1 Purpose

The purpose of the test is to determine, for thermostatic mixing valves having a user-adjustable mixed water temperature setting, the characteristic of any transient rise in the mixed water temperature that may occur when the mixed water temperature setting is suddenly changed from a cool setting to the maximum setting.

G.3.2 Procedure

G.3.2.1 Connect the mixing valve to the test rig (see Annex B).

G.3.2.2 Starting from the initial setting (see Table 9), allow mixed water to flow for 2 min ± 5 s and then measure and record the mixed water temperature.

G.3.2.3 Adjust the position of the temperature control to give a mixed water temperature of 30 ± 1 K (or, if the lowest temperature available is greater than this, to the lowest temperature available).

G.3.2.4 After 3 min ± 15 s rapidly adjust, by hand and as fast as possible, the temperature of the mixed water. For category A valves this shall be done by activating the temperature controller until the mixed water temperature reaches its maximum position. For category B valves this is done by activating the temperature controller as quickly and as many times as is necessary for the mixed water temperature to reach its maximum position.

G.3.2.5 Monitor and record the mixed water temperature.

G.3.2.6 Repeat the procedure to give three sets of results for each sample.

G.3.3 Expression of results

The temperature transient obtained shall be assessed to determine the duration at or above each 1 K temperature rise shown in Table 10 for the appropriate designation. For the three test results on each sample calculate the average duration at each temperature rise. Transient temperature rises shall be referred to the mixed water temperature existing at the start of each of the three tests.

Note:

An example of the assessment of test results is given in Annex E.

G.3.4 Requirements

The average duration of the transient temperature rise at or above each 1 K temperature rise shown in Table 10 for the appropriate designation shall not be longer than the values given in Table 10. Individual test results shall not exceed the permitted duration by more than 10%.

For each result the final mixed water temperature shall not differ from the actual initial setting of the sample concerned by more than 2 K.

References

British and European Standards

BS 6920. Suitability of non-metallic materials and products for use in contact with water intended for human consumption with regard to their effect on the quality of the water. British Standards Institution, 2014.

BS EN 1111. Sanitary tapware. Thermostatic mixing valves (PN 10). General technical specification. British Standards Institution, 1999.

BS EN 1287. Sanitary tapware. Low pressure thermostatic mixing valves. General technical specifications. British Standards Institution, 1999.

Department of Health guidance

Health Technical Memorandum 04-01 – The control of Legionella, hygiene, "safe" hot water, cold water and drinking water systems. Part A: Design, installation and testing.

Health Technical Memorandum 04-01 – The control of Legionella, hygiene, "safe" hot water, cold water and drinking water systems. Part B: Operational management.

Health Technical Memorandum 04-01: Addendum. Pseudomonas aeruginosa – advice for augmented care units.

Water Regulations Advisory Scheme (WRAS) guidance

WRAS material guidance: a guide for manufacturers, suppliers and test laboratories on the application requirements for WRAS material approval.

Further reading

Department of Health (2013). **Health Building Note 00-09**. Infection control in the built environment.

Health and Safety Executive (2014). **Legionnaires' disease HSG274 Part 2**. The control of legionella bacteria in hot and cold water systems.

Health and Safety Executive (2012). **Health Services Information Sheet No 6**. Managing the risks from hot water and surfaces in health and social care.

Chief Medical Officer, Public Health and Sport Directorate

The Scottish Government

CEL 08 (2013)

3 May 2013

3 May 2013

Dear Colleague

Water sources and potential infection risk to patients in high risk units – revised guidance

In CEL 2012(03) we advised of potential infection risks posed by water systems in healthcare facilities and actions required to minimise those risks. This letter replaces CEL 2012 (03).

Since February 2012 substantial further evidence has been gained on potential risks to patients, along with consideration of possible unintended consequences. Revised guidance is accordingly now being issued.

Revised parts A and B of *Scottish Health Technical Memorandum 04-01: Water safety for healthcare premises* (SHTM-04-01) are available.

National Services Scotland *Guidance for neonatal units (NNUs) (levels 1,2,3), adult and paediatric intensive care units (ICUs) in Scotland to minimise the risk of Pseudomonas aeruginosa infection from water* is available.

Boards must ensure that:

- all high risk units where patients may be at increased risk of pseudomonas and related infections are identified and control measures applied
- best practice relating to the use of hand washing facilities is consistently and fully applied
- all taps in all clinical areas in high risk units (manually or automatically) are flushed daily (and a record kept) to minimise the risk of pseudomonal contamination. Flushing should be for a period of **one minute**, first thing in the morning, at the maximum flow rate that does not give rise to any splashing beyond the basin
- domestic staff have been trained in the correct decontamination procedures for sinks, basins and taps in ICUs and neonatal units to minimise the risk of pseudomonas
- they have established a system of clear governance with accountability to the appropriate Executive Director
- they are compliant with revised SHTM-04-01

For action
Board Chief Executives
Directors of Estates/Facilities
HAI Executive Leads
Infection Control Managers
Infection Control Doctors

For information
Directors Nursing
Medical Directors
Directors Public Health
CsPHM (Health Protection)
HAI Task Force
Health Protection Scotland
Health Facilities Scotland
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It is the intention that the Board Water Safety Group will provide an assurance annually to the NHS Board on compliance with the requirement of this CEL through the Board's annual Controls Assurance process. Accordingly, NHS Boards should report annually confirming compliance or, where compliance has not been met, a plan and timescale for achieving compliance.

Further advice may be obtained from National Services Scotland, Health Facilities Scotland (HFS), who should be specifically consulted in relation to new build projects.

As further evidence accrues updates may be issued by NSS.

Yours sincerely

Harry Burns ***Derek Feeley***

SIR HARRY BURNS **DEREK FEELEY**
Chief Medical Officer Director General

References

Independent review of incidents of *Pseudomonas aeruginosa* infection in neonatal units in Northern Ireland - Interim report. The Regulation and Quality Improvement Authority, March 2012

Independent review of incidents of *Pseudomonas aeruginosa* infection in neonatal units in Northern Ireland - Final report. The Regulation and Quality Improvement Authority, May 2012

National Infection Prevention and Control Manual (Chapter 1 - Standard Infection Control Precautions). Health Protection Scotland January 2012

REPORT on Environmental Sampling on 2A and 4B

Dr Christine Peters 22/03/18

Consultant Microbiologist QEUH

Background

In response to two cases of *Cuproavadis pauculus* bacteraemias in children treated on 2A (Haem onc and BMT paediatric ward) a PAG agreed to the testing of water from two outlets on ward 2A - the treatment room and prep room. These were positive for *Cupriavadus pauculus* and the IPCT instigated a number of control measures. Taps and showers were removed and a sample sent to Microbiology for environmental sampling to look specifically for *Cupriavadus pauculus* on 02.03.18 and again on 14.03.18. Further samples from detergents, lotions and wipes were sent on 20.03.18. These were processed to detect Cupriavadis and Stenotrophomonas sp .

Taps and showers are subject to routine maintenance regimes and it is unclear when the last thermal disinfection or the age of the TMV cartilages [4] which may influence the microbiological testing of the fittings.

Laboratory Processing

Standard protocols do not exist for this situation and a pragmatic approach to sampling was taken in response to a rapidly evolving situation[1].

Method appended in Appendix A.

First samples

Taps and showers from 2A 02/03/18 were processed to look for and report on isolation of *Cupriavadus pauculus* .

Taps were dismantled and each component separately sampled. The TMV was only extracted from one tap – this required Estates personnel to get an Allan key and use a substantial amount of force to open. [4]

Visual inspection of the tap components showed discolouration and slime around the rubber seals of the flow directors and flow straightener, as well as green growth on the plastic components of the TMVs.(Photos Appendix 2)

Results

Gram negative oxidase positive colonies that had a good level ID on VITEK MS were reported, but not pursued further if not Cupriavadus . None ID'd as stenotrophomonas. A single isolate of fungus was reported as this is a BMT ward and may have been relevant – ID is awaited from Bristol ref laboratory. Cupriavadus isolates have been sent for typing to Colindale.

The samples from 02/03 identified widespread Cupriavadus in shower heads as well as taps, with a propensity of Cupriavadus to grow in pure form at the air - water interface, although not exclusively

at every outlet. (Photos in appendix 3). Cupriavadus required 48 hours before adequate growth for further identification.

Location	Article	Site	Culture Result
2A room 26	Shower	head inner	Cupriavadis pauculus
2A room 6	shower	, tubing	no Cup
2A room 6	shower	head inner	NG
2A room 26	TAP	cold water filter/director	Cupriavadus pauculus
2A room 15	TAP	spout exit site	Cupriavadus pauculus
2A room 24	TAP	flow straightener	Cupriavadus pauculus
2A room 26	TAP	flow director (labeled filter)	Sphingimonas pauculus + GNBOX not cup
2A room 15	TAP	Hot filter/flow director	Cupriavadis pauculus + GNBOX
2A room 15	TAP	flow straightener	Cupriavadus pauculus pure growth
2A room 15	shower	head	Cupriavadus pauculus + Fungus
2A room 1 5	TAP	cold water filter/filter	GNBOX - not cupr
2A room 26	TAP	Hot filter/flow director	GNBOX - not cupr
2A room 26	TAP	Cold filter/director	GNBOX - not cupr
2A room 26	TAP	TMV	Shingimonas pauculus , no Cup

Second Samples

The second lot of 50 or so showers from 2A were received by the Microbiology lab on 14/03/18 – we sampled only two as discussed with IPCT . Showers and Tap parts (flow straightener and flow directors) came separately from 4B – the flow directors were separately bagged and not labelled as to whether hot or cold , and NO TMVs were sent. On visual inspection, some showers were soapy with detergent bubbles on them, flow straighteners were somewhat slimy around the rubber ring and the metal mesh in one of the taps had clear debri in it and a distinct sulphourous odour (photo appendix B) .

The samples from the second batch of outlets appears to have more biodiversity, with a number of environmental gram negative organisms represented. This may be skewed by the fact that ID was pursued in all isolates beyond VITEK MS, to VITEK GNI and and API20NE, but may also reflect disruption of bio film post treatment [2].

Results

Location	Article	Site	Culture Result
4B Room 94	Shower	Head inner	Cupriavadis pauculus
4B Room 94	Shower	Head outer	Cupriavadis pauculus
4B Room 94	Shower	tubing /hose inner	Cupriavadis pauculus
4B room 94	Tap	flow straightener	Sphingimonas Paucimobilis + Ochrobactrum anthropi
4B Room 94	Tap	flow director A	Sphingimonas Paucimobilis + Ochrobactrum anthropi
4B Room 94	TAP	flow director B	Sphingimonas Paucimobilis + Ochrobactrum anthropi Brevundimonas sp

4B Room 90	Shower	Head inner	Burkholderia sp + ? Comamonas
4B Room 90	Shower	head outer	Burkholderia sp + ? Comamonas
4B Room 90	Shower	tubing inner	Burkholderia sp + ? Comamonas
4B room 90	Shower	Rinse of head	Burkholderia sp + ? Comamonas
4B room 90	TAP	Flow straightener	Shingimonas paucimobilis
4B room 90	TAP	Flow Director A	Shingimonas paucimobilis + Cupriavadis paucimobilis
4B room 90	TAP	Flow Director B	Cupriavadis pauculus + Delfia acidovorans
4B room 88	shower	head inner	Delfia acidovorans + Shingimonas paucimobilis
4B room 88	shower	head outer	Delfia acidovorans + Shingimonas paucimobilis
4B room 88	shower	tubing	Delfia acidovorans + Shingimonas paucimobilis
4B room 88	TAP	flow straightener	shingimonas paucimobilis + Serratia fonticola
4B room 88	TAP	flow director A	shingimonas paucimobilis + Serratia fonticola
4B room 88	TAP	flow director B	shingimonas paucimobilis + Serratia fonticola
4B room 84	Shower	Head inner	Shingimonas paucimobilis + Bevundimonas sp
4B room 84	Shower	head outer	Shingimonas paucimobilis + Bevundimonas sp
4B room 84	Shower	tubing inner	Shingimonas paucimobilis + Bevundimonas sp
4B room 84	Shower	Rinse of head	Shingimonas paucimobilis + Bevundimonas sp
4B room 84	TAP	Flow straightener	Shingimonas paucimobilis + Bevundimonas sp
4B room 84	TAP	flow director A	Shingimonas paucimobilis + Delfia acidovorvans
4B room 84	TAP	flow director B	Shingimonas paucimobilis + Delfia acidovorvans
2A room 13	shower	head inner	cupriavadis pauculus + rhodotorula mucilaginosa candida Guillermondii
2A room 14	shower	head outer	cupriavadis pauculus + rhodotorula mucilaginosa candida Guillermondii
2A room 15	shower	tubing inner	cupriavadis pauculus + rhodotorula mucilaginosa candida Guillermondii
2A room 9	shower	head inner	Cupriavadis pauculus + bordetella bronchisepticum
2A room 9	shower	head outer	Cupriavadis pauculus + bordetella bronchisepticum
2A room 9	shower	tubing inner	Cupriavadis pauculus + bordetella bronchisepticum

Third Group of Samples

Environmental swabs and samples of wipes, lotions and cleaning agents taken on 20/03/18 were only plated to CLED with a mero disc. SABS were not requested.

Only one sample from Disposable wipe was positive : this grew a Pseudomonas species – as yet to be speciated.

Summary

A number of different gram negative species have been isolated from the tap and shower components in 4B and 2A including *Cupriavadus pauculus* which is a rarely reported organism in water and clinical cases . It appears to be very robust and growing almost purely in some flow directors . Of note nothing grew from the copper component of the TMV. The plastic components showed more diversity and levels of growth – although this was not quantitatively sampled and

based purely on observation of single swab . Stenotrophomonas was NOT isolated from any outlet. The maintenance schedule of the complex taps (Appendix D) and showers is essential for prevention of biofilm and long term colonisation of water outlets .

Clinical Significance

All the gram negatives isolated have been described in the literature as potential pathogens in severely immunocompromised patients, particularly neutropenia in the context of BMT and most have been linked to water borne out breaks [3].

Of particular note in RHC there have been clinical cases of

- three cases of bacteraemia with Cupriavadis since the opening of the RHC
- Rhodotorulla bacteraemia
- *Candida guillermondii* has caused colonisation on 2A and infections in NICU
- *Two Breundimonas Bacteraeias in 2A in 2017*
- *Delfia acidovorans bacteraemia in 2017 in 2A*

Burkholderia gladioli is of particular importance for CF patients as it can colonise CF lungs and contribute to respiratory impairment.

Bordatella bronchospetica is more commonly a dog /cat pathogen and has very rarely caused human infections.

Further Microbiology

- It is possible that with the use of a biocide Mycobacterial colonisation of taps may increase[2] and It may be worth testing for this in the new situation.
- As suggested by Peter Hoffman if a further tap could be supplied to the lab we can attempt a quasi quantitative method of culture.
- If required by the IMT we can dig out previous Brevimonas and Delfia sp from bacteraemia isolates and send for typing. This has not been done yet.
- Waste water testing as part of an MSc project in the old ICU at QEUH site in 2015 grew Cupriavadus isolates which may be worth comparing with current isolates

References

1.Public Health England Examining food, water and environmental samples from healthcare environments Microbiological Guidelines 2013

2. Shift in the Microbial Ecology of a Hospital Hot Water System following the Introduction of an On-site Monochloramine Disinfection System Baron et al PLOS: 2014: 9:7 : 1-8

3. Healthcare Outbreaks Associated With a Waster Reservoir and Infection Prevention Strategies

CID: 2016:62 1423 - 1435

4. TAP maintainance instructions: http://www.horne.co.uk/Products/Optitherm/Installation-and-Maintenance/

Appendix A : METHODOLOGY TAPS AND SHOWER S

Cupriavadis investigation

Culture from Taps and shower heads,

- Change Gloves between handling items.
- Clean bench with Trigene between each component being handled.

1 Sterile rayon swab to be placed in fresh sterile H2O , then the area to be sampled by brushing over with swab, covering as extensive an area as possible to maximise sensitivity.

2. Swab to be plated directly on to CLED agar and SAB agar, plated out to single colonies.

SABs omitted from final environmental sampling 20/03/18 and mero disc applied to CLED to aid identification of stenotrophomonas

3. Plates incubated at 37degrees O2

4. Read at 24, 48 hours, and 5 days for fungus

5. Colonies for fungus sent to Mycology ref lab for ID

6 All colony types NLFs to be set up for ID on MALDI

7. Reports to be issued without UKAS accredited comment

Enrichment

1. Component parts small enough to be incubated in Robertson's media for 48 hours
2. If cloudy subbed onto CLED and SAB ONLY if no growth from direct culture

NOTE ALL samples grew organisms – therefore no RBM subbed

Sampled areas

1. Shower
    - Inside shower head
    - Outside shower head
    - Inside tubing
    - Saline flush of head
2. Tap
    - Spout exit
    - Flow straightener/aerator
    - Flow directors
    - Rubber rings

- Filter/metal mesh
- TMV- plastic rings, copper rod, sieve

3. Environmental Swabs:
    - Air freshener
    - domestic trolley
    - Clinell wipes
    - disposable wipes
    - AHG
4. Samples of :
    - Achtichlor
    - magic dazzle
    - moisturiser
    - multi purpose cleaner
    - multi purpose cleaner for grease
    - Titan
    - soap

Appendix B Photos of Water Outlets samples

Shower head –

TAP : Optitherm Horne Tap Nice video on performance and maintanence at :
http://www.horne.co.uk/Products/Optitherm/

TAP Flow Directors

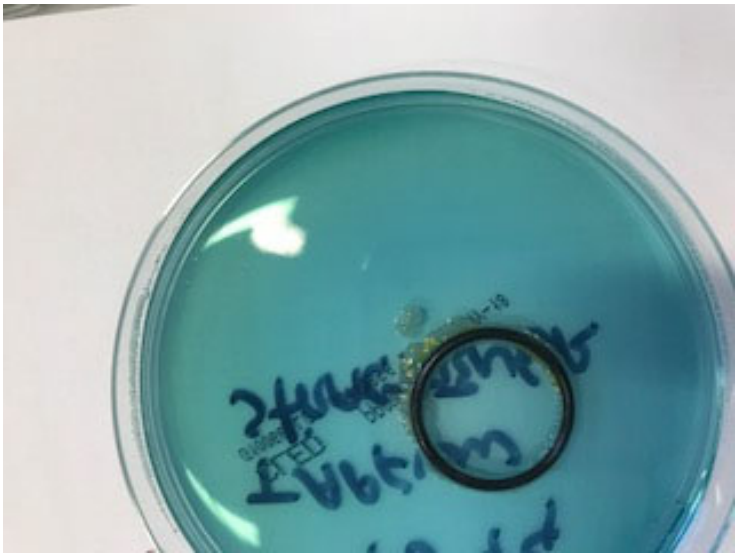
1. 
2. **TAP TMV**

3. 

4. **TAP metal mesh – note grit**

Appendix C Photos of cultures

Ring around flow straightener



Appendix D HORNE Optitherm MAINTENANCE advice

Maintenance of all TMVs and thermostatic taps is essential. If a TMV does not operate properly, there is a risk of someone being scalded. The frequency of maintenance depends upon the condition of the water passing through the TMV. The remarks in 4.1.3 regarding in-service testing apply equally to maintenance. Generally, the thermostatic cartridge should be replaced after three years. The strainer/check-valve cartridges and ceramic disc cartridges should be replaced as necessary.

4.1 IN-SERVICE TESTING

4.1.1 Periodic testing should be carried out to check whether or not any deterioration has occurred in the performance of the Horne OPTITHERM Thermostatic Bib Tap.

4.1.2 A COLD WATER FAILURE TEST should be carried out as described in paragraph 2.7 above. If the water coming from the tap is at a temperature of more than 3°C above the mixed water temperature setting then the Horne OPTITHERM Thermostatic Bib Tap is due for maintenance.

NOTE: A TMV in need of maintenance can be undetectable in normal use and only become apparent when a disruption occurs in the hot or cold water supply pressures or temperatures.

4.1.3 The frequency of in-service testing depends upon the condition of the water passing through the tap. In-service testing must be carried out more frequently in hard water areas than in soft water areas. As a general guide, in-service testing should be carried out at least every twelve months and, where the water is hard, the interval may be less than six months. Experience of local conditions and the in-service testing record will dictate the frequency of in-service testing.

4.2 FLUSHING AND THERMAL DISINFECTION

4.2.1 Horne recommends periodic thermal disinfection in conjunction with high velocity flushing, using the Water Quality Compliance Kit (part no.6006). See paragraphs 1.3 and 1.4. The periodicity of this maintenance should be determined in conjunction with the current best practice.

4.3 CLEANING AND REPLACEMENT OF STRAINERS

4.3.1 Close the isolating valves (13,14) at the back underneath the tap spigot; open the levers and allow the residual water to drain.

4.3.2 Unscrew the main bottom cover (16) using a strap wrench.

4.3.3 Remove the strainer/check-valve cartridges (20,21) using a 12mm hex key or Horne special tool (part no. 23-5459).

4.3.4 The strainer can be removed from the top of the cartridge and cleaned or replaced as necessary.

Queen Elisabeth University Hospital\Royal Hospital for Children

Review of Horne Optitherm Taps for use within designated Critical Areas.

5/06/2018

The purpose of this paper is to review the options for replacing the Horne Optitherm Thermostatic Mixing Tap (TMT) with a suitable TMT without Plastic Flow regulator\Straighter device.

Back Ground:

Further to previous advise provided by **H***ealth Protection Scotland (HPS)\Health Facilities Scotland (HFS) issued via SBAR on 1st April 2014, further concerns have been recorded by the water Incident Management team over the use of TMT utilised within designated high risk patient areas with flow regulators fitted.*

Due to the configuration of the existing distribution system and the operational flow control design of the Horne tap, it is not possible to remove the flow regulator and the Manufacturer are not prepared to modify the design to accommodate the removal of this device as they do not share the same view on its function.

Therefore the Current Water Technical Group (WTG) have concluded that these Horne Optitherm TMT taps bust be replaced with Taps that can facilitate the provision of safe temperature water delivery without utilising the plastic material, matrix type flow straightener that have a know propensity to develop biofilm.

During the review process the issue over flow straightners has been discussed at various forums where water experts recommended that open metal flow strainers would be preferable over plastic matrix versions:

1. *Dr Peter Hoffman Public Health (England): Board Incident Management Team Tele-Conference, Saturday 17th March 201:.* **"Where available metal flow straightners should be adopted"**
2. *M.J. Weinbren [1]: Review:* ***"Plastic aerators/flow straightners (risk of biofilm formation) should be avoided in favour of metallic versions, where necessary."***
3. *Dr Susan Lee, Water Expert Microbiologist Consultant Leegonella Ltd, Meeting report 25th April 2018: "***The trust design should exclude the use of outlets with inserts and opt for more hygienic single bore outlets which are demountable for disinfection."**

There are several Thermostatic Mixing Taps on the Market that are accredited and approved under the following scheme (including the Horne Optitherm):

1. *Water Regulations Advisory Scheme (WRAS)*
2. *Department of Health (DH) Health Technical Memorandum 04-01: Supplement Performance Specification D 08: Thermostatic mixing Valves (healthcare premises).*

[1] M.J Weinbren: Department of Microbiology, Kings Mill Hospital NHS Foundation Trust: Review "The Hand Wash station Friend or Fiend

Queen Elisabeth University Hospital\Royal Hospital for Children

Review of Horne Optitherm Taps for use within designated Critical Areas.

5/06/2018

3. *NSF International TMV3 Certification*

The Clinical TMT outlets that have been reviewed are:

1. *Dart Valley: AquariTherm*
2. *Armitage Shanks: Markwik21*
3. *Delabie: SecuriTherm Bioclip*

All have similar complications and control arrangements, however the AquariTherm has been discounted as it is fitted with a plastic 2 part fused flow straightener.

The Markwick 21 & SecuriTherm Bioclip are similar in construction, format and functionality however the SecuriTherm has an open orifice bio safe anti microbial Nylon flow straightener.

However the Markwick 21 is fitted with a, copper lined open orifice bio-guard anti microbial flow straightener and is available on Procure 22 framework contract.

The Markwick 21 is therefore the preferred option TMT.

However Delabie have Balanced pressure tap that may be of interest, as it does not have thermostatic mixing element complications and therefore may have designed out some of the issues where there is a propensity for biofilm to gather.

I have meeting scheduled for Thursday 7th June to review this product for consideration at Fridays WTG.

The proposed TMT has the facility for panel mounted sensor operation complete with Auto-Flush technology when not used within a set time. Though there are potential concerns over the introduction of further complication of introducing solenoid valves this may be a worthwhile addition to control selected High Risk patient areas.

This option was also identified for consideration in the Susan Lee's water expert report of

Recommendation 1: WTG approve adoption of Markwick MT with Bio guard.
Recommendation 2: WTG to consider adoption of sensor control with auto flush & what if any area's this should be deployed.

Ian Powrie
Deputy General Manager (Estates)

[1] M.J Weinbren: Department of Microbiology, Kings Mill Hospital NHS Foundation Trust: Review "The Hand Wash station Friend or Fiend

Royal Hospital for Children
Ward 2A/2B water test results

Tuesday, 28 March 2023

Including water testing results from Sept 2021 to 15 March 2023

Dominique Chaput, DPhil (Oxon)

Healthcare Scientist (IPC), Scottish Microbiology Reference Laboratories, Glasgow

Context

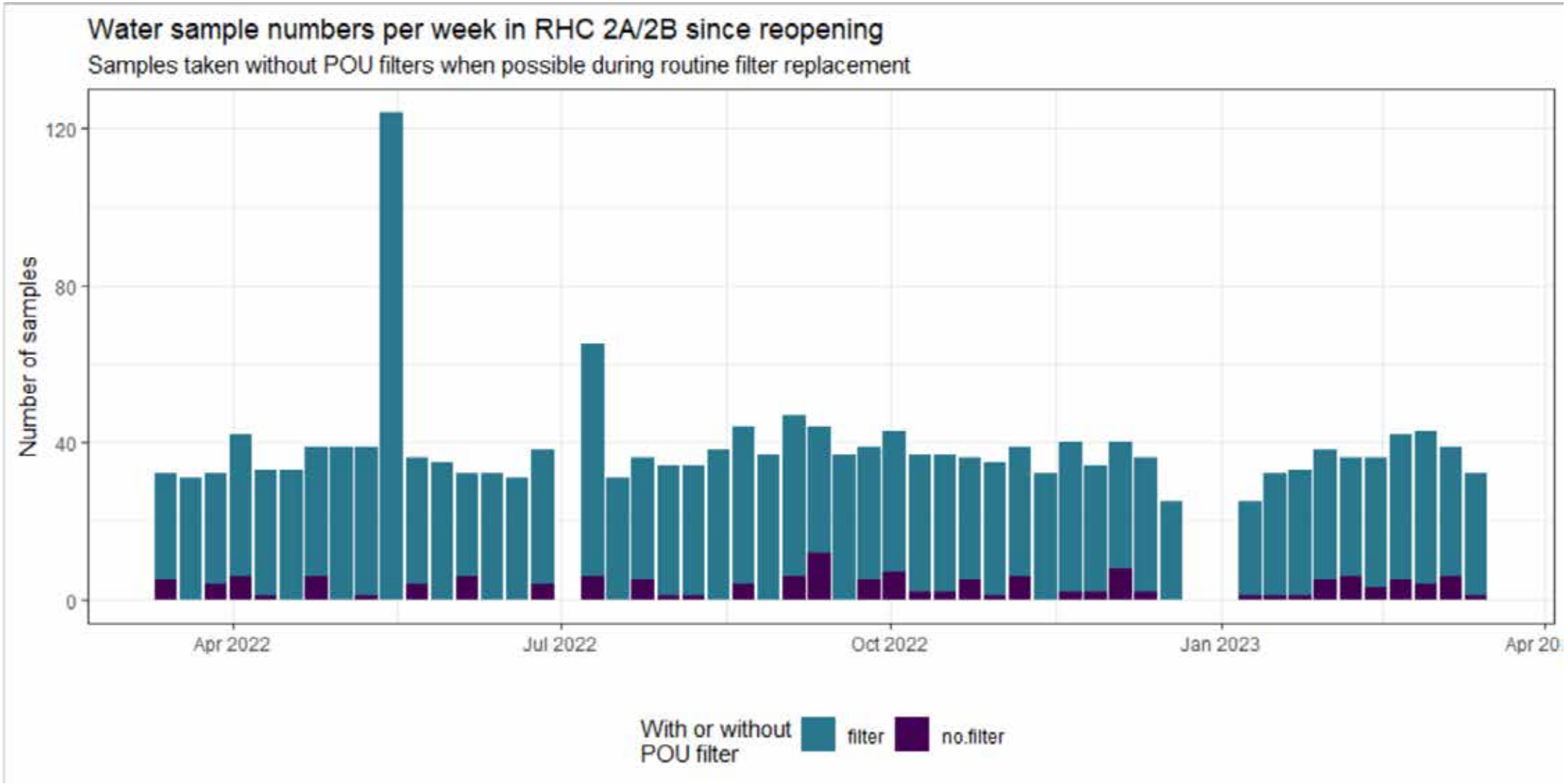
- RHC Ward 2A/2B was closed for refurbishment for an extended period, reopening 9 March 2022
- Prior to reopening, system disinfection/adjustments and intensive water testing were carried out to ensure a safe water supply (overseen by the GGC Water Safety Technical Group). Details in:
  - 2022-02-07_RHC_2A_Assure_updated_figures.pdf
  - 2022-02-18_RHC_2A_updated_water_testing_figures.pdf
  - 2022-03-01_RHC_2A_updated_water_testing_figures_DLC_v2.pdf
- Since reopening, water testing in Ward 2A/2B has proceeded as outlined in WQS 017 Water Management Procedure. Briefly:
  - ¼ of outlets are sampled weekly on a rotational basis (approx. 140 samples per month). Point-of-use (POU) filters were installed immediately prior to reopening, so most samples are taken through these. During routine POU filter replacement, samples are also collected without filters (where possible) to assess system water quality, prior to the new filter being fitted
  - These samples undergo routine potable (TVC37, TVC22, coliforms, E.coli), Pseudomonas, and gram negative (GNB) testing. ¼ of samples per month (rotating) undergo additional testing for atypical mycobacterial species (AMS). Legionella testing occurs monthly (two unfiltered sentinel outlets)

Context

- Out-of-spec thresholds in 2A/2B are the stricter ones set by GGC for ‘high-risk’ areas: 10 CFU/mL for both TVC22 and TVC37, no count for coliforms, E.coli, Pseudomonas, Legionella, GNBs, or AMS. All out of specs trigger immediate action, including (but not limited to):
  - Estates investigate and carry out required work as per SOPs, depending on the type of out of spec result (can include re-sampling, disinfection, filter replacement, etc.)
  - Facilities review flushing and cleaning practices
  - Infection Control review clinical practices when required
  - Where out of specs are post-filter, standard process is to replace with new POU filter and re-sample until a minimum of 3 samples are in spec
  - Where Pseudomonas are detected, standard process is to sample pre- and post-flush (without POU filter) and again through a new POU filter

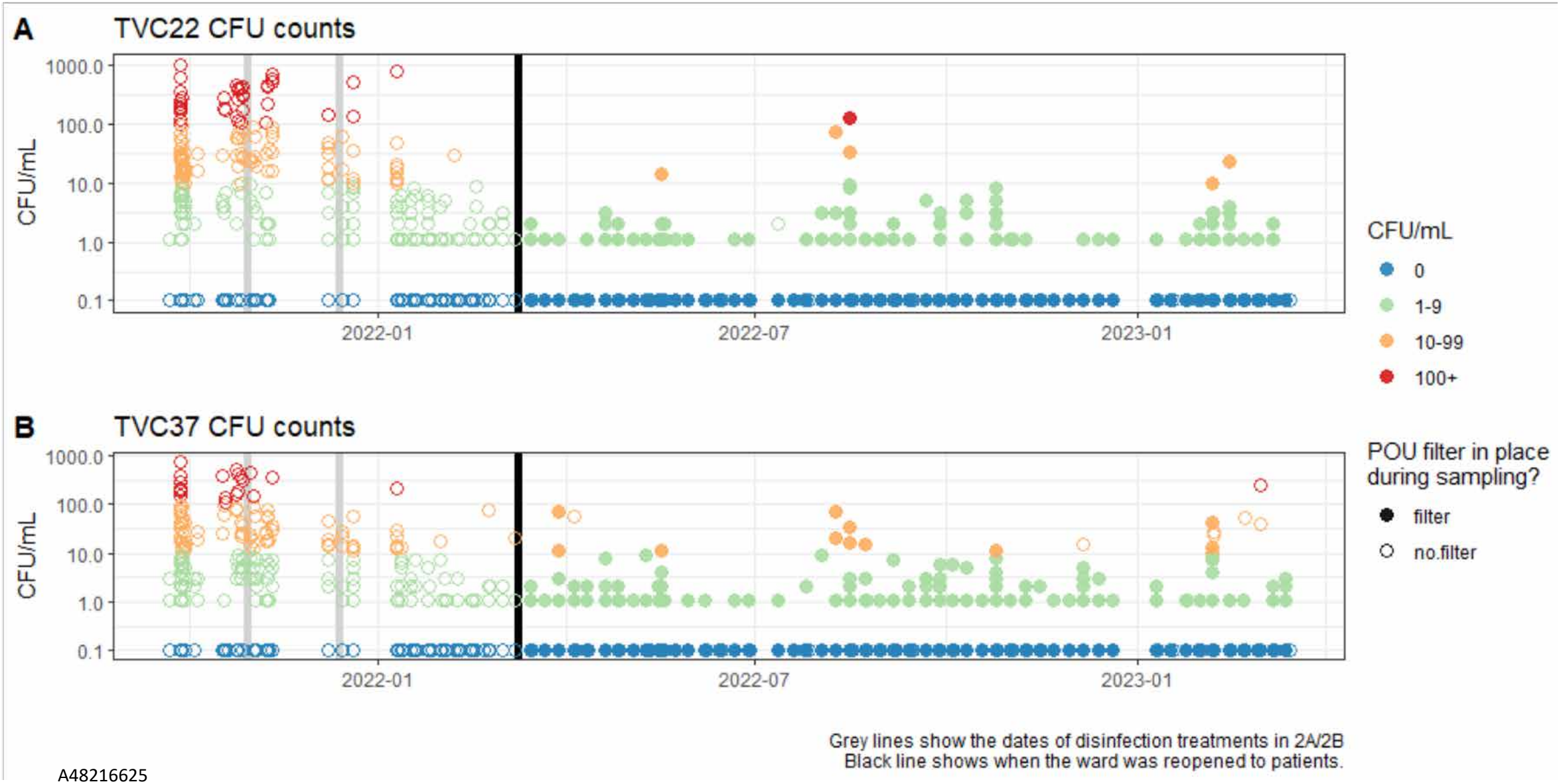
- This document provides a graphical overview of water test numbers and results from Sept 2021 to present (up to March 15 2023). Details on individual samples and any actions that were taken in response to specific out of spec results are outwith the scope of this analysis.

Weekly sample numbers with and without POU filters

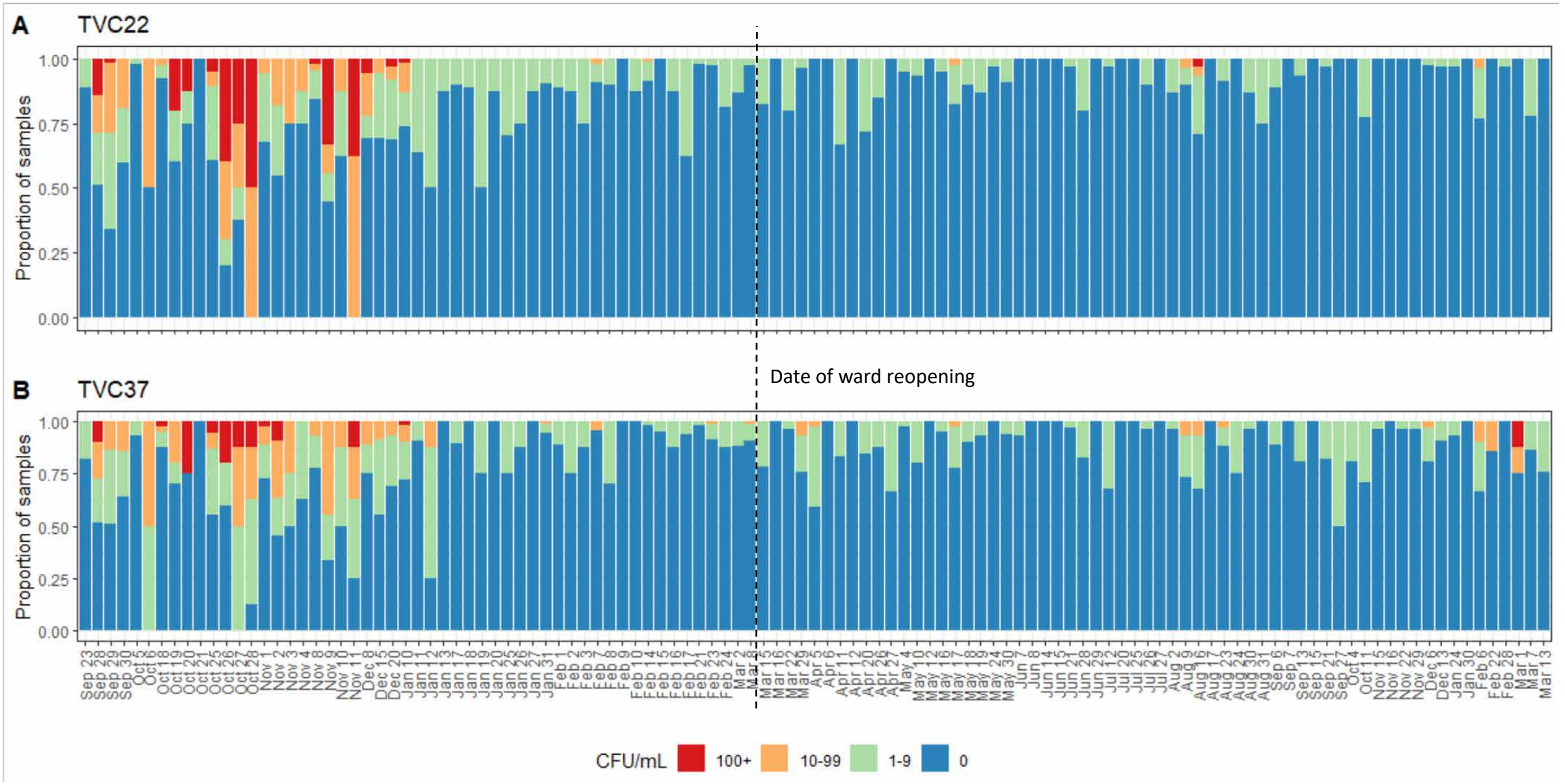


As outlined in WQS 017 Water Management Procedure, ¼ of outlets are sampled weekly on a rotational basis, for a total of approximately 140 samples per month. Most are taken through the POU filters, but where these are due for routine replacement, samples are taken without a filter before the new one is fitted. In total, 1924 water samples were tested between 9 March 2022 and 15 March 2023.

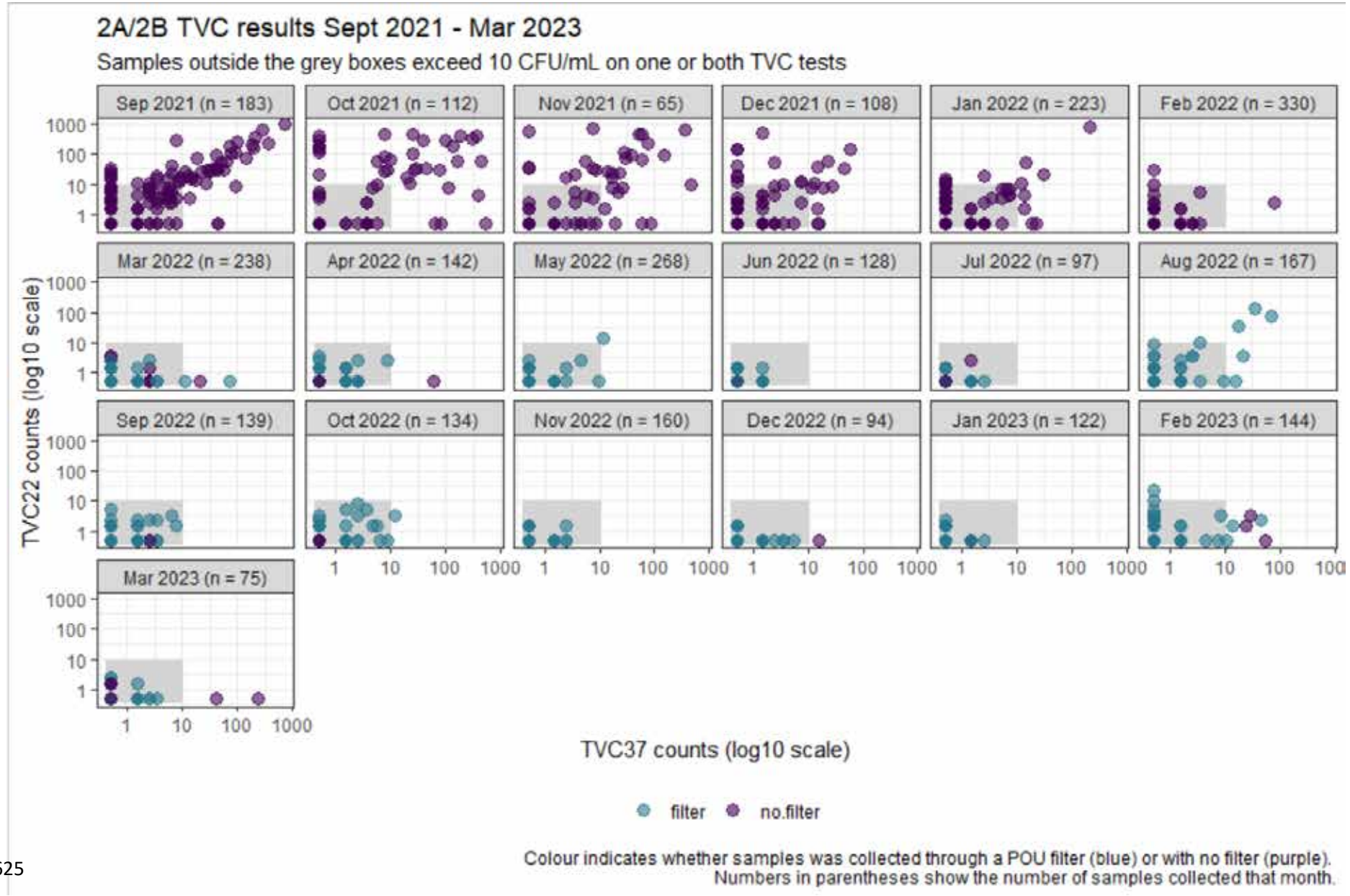
TVC22 and TVC37: Individual samples in each CFU category



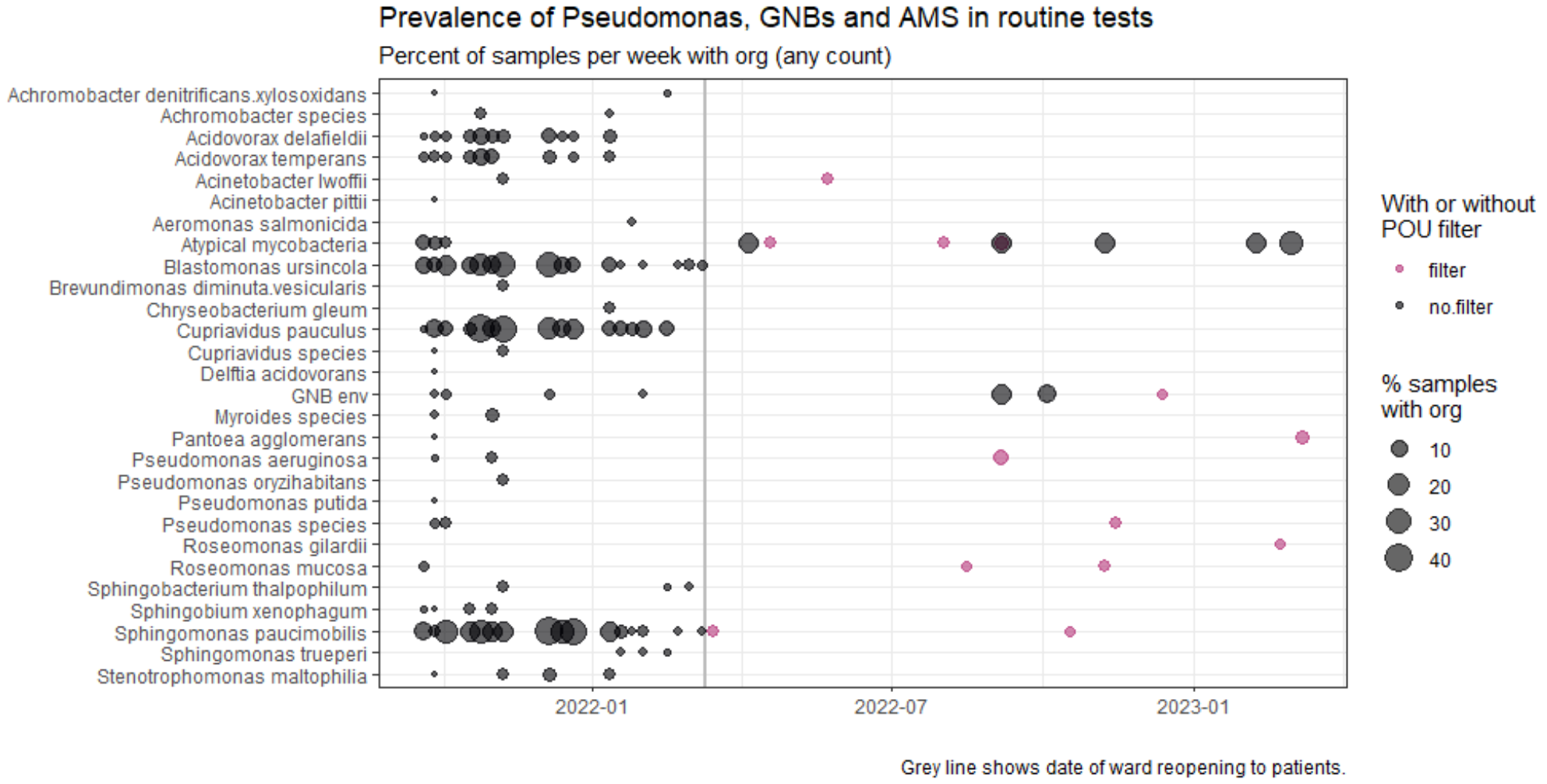
TVC22 and TVC37: Proportion of samples (per sampling day) in each CFU category



TVCs: Individual samples grouped by month

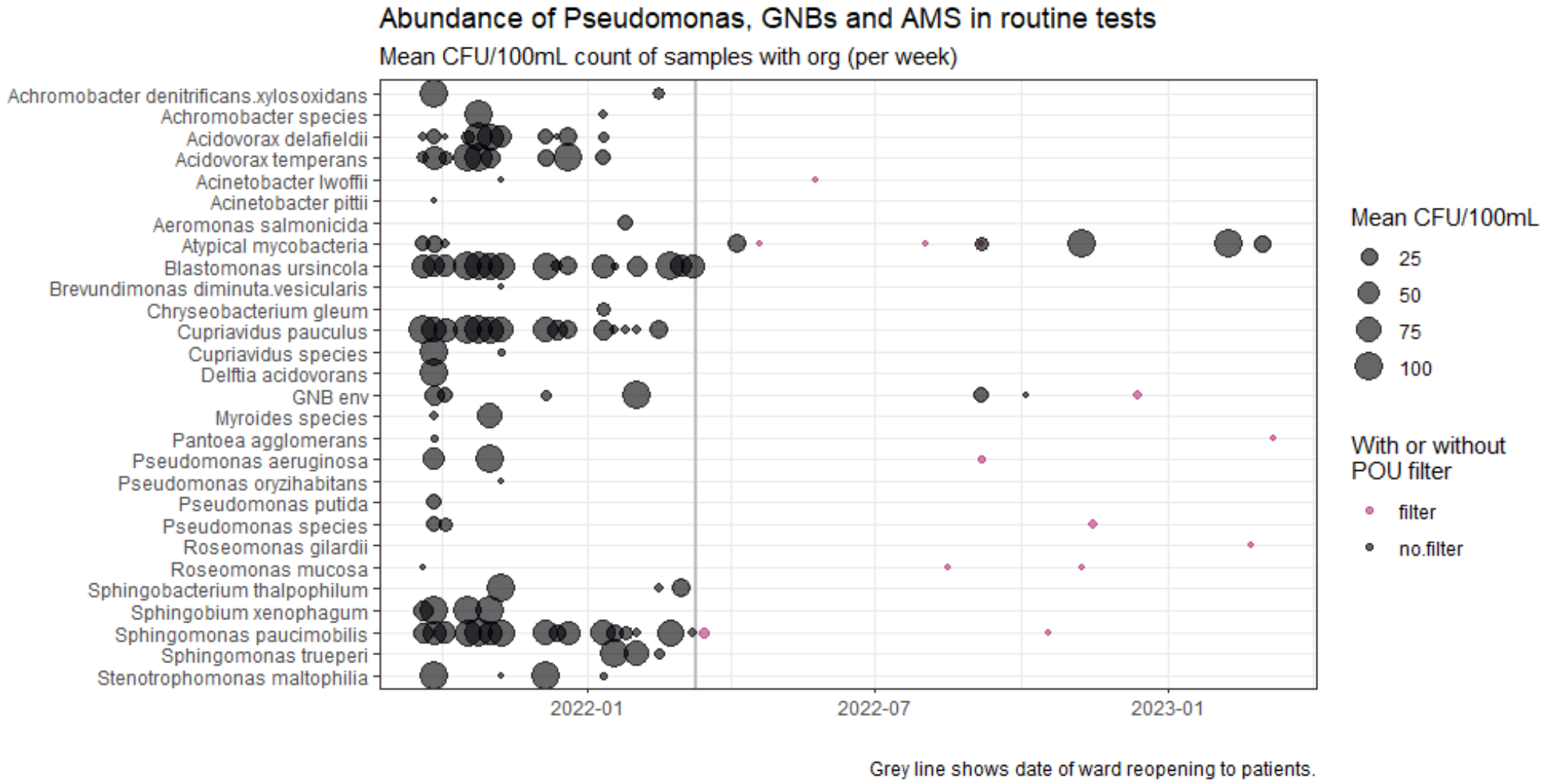


Prevalence of Pseudomonas, GNBs and AMS: % samples per week with any count



Pseudomonas, GNBs and AMS detected only sporadically since reopening. Prevalence was low in samples with POU filters. Where Pseudomonas was detected (with a POU filter), further tests pre-/post-flush without a filter and then through a new filter were all negative, suggesting the initial Pseudomonas result was due to retrograde colonisation of the filter.

Abundance (CFU counts) of Pseudomonas, GNBs and AMS in positive samples



Pseudomonas, GNBs and AMS detected only sporadically since reopening. Where positive, counts from samples with POU filters have been in the low single digits (mostly 1 CFU/100mL).

Summary since reopening on 9 March 2022

- Weekly testing for Pseudomonas, potable (TVC22, TVC37, coliforms, E.coli), gram negative bacteria (GNBs), monthly testing for Legionella and atypical mycobacterial species (AMS)
- 1924 water samples tested (9 March 2022 to 15 March 2023)
- No Legionella, coliforms, or E.coli detected
- No Cupriavidus detected
- Of 1757 potable tests, 1738 (98.9%) were in spec for TVC37, and 1751 (99.7%) were in spec for TVC22 (CFU/mL < 10)
- Of 1777 samples tested for GNBs, 10 (0.6%) were out of spec (i.e. any count)
- Of 1754 samples tested for Pseudomonas, 4 (0.2%) were out of spec (i.e. any count)
- Of 429 samples tested for AMS, 9 (2.1%) were out of spec (i.e. any count). Five of these were without POU filters and the remaining 4 (0.9% of AMS tests), taken through POU filters, had counts of 1 CFU/100 mL
- *All testing points to a well-performing water system*

Royal Hospital for Children Ward 2A/2B water test results

Tuesday, 8 Feb 2022

Including water testing results up to 27 Jan 2022

Dominique Chaput, DPhil (Oxon)

Healthcare Scientist, Scottish Microbiology Reference Laboratories, Glasgow

QEUH water testing overview

New buildings: Adults and RHC

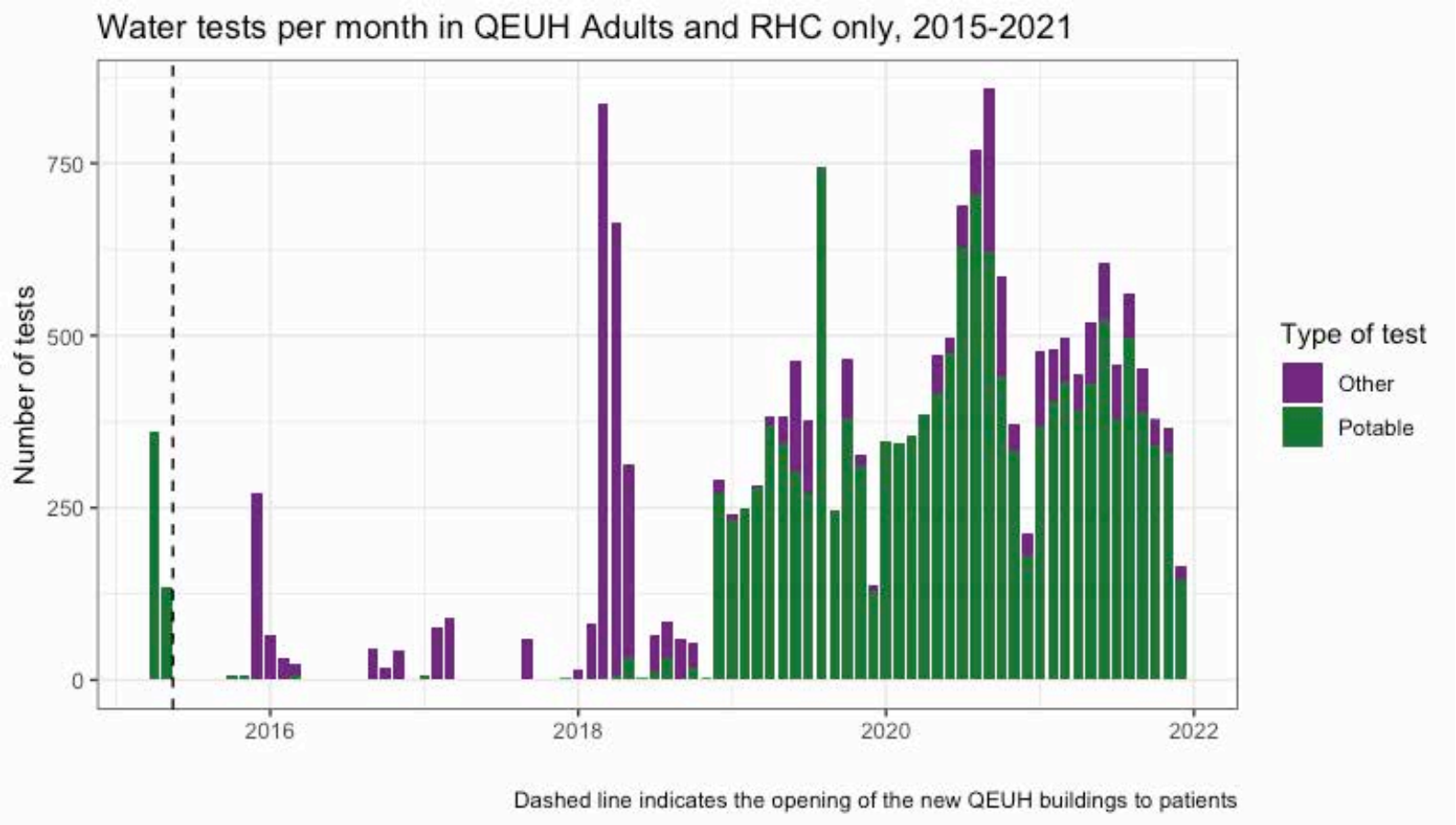
Annual numbers of water samples and tests: QEUH Adults and RHC only

Year	Number of samples[1]	Potable tests	Other tests
2015	782	510	272
2016	225	8	217
2017	235	11	224
2018	2,473	378	2,095
2019	4,302	3,854	448
2020	5,889	5,229	660
2021	5,408	4,630	778
Total	19,314	14,620	4,694

[1]Does not include samples from the retained buildings.

QEUH water testing overview

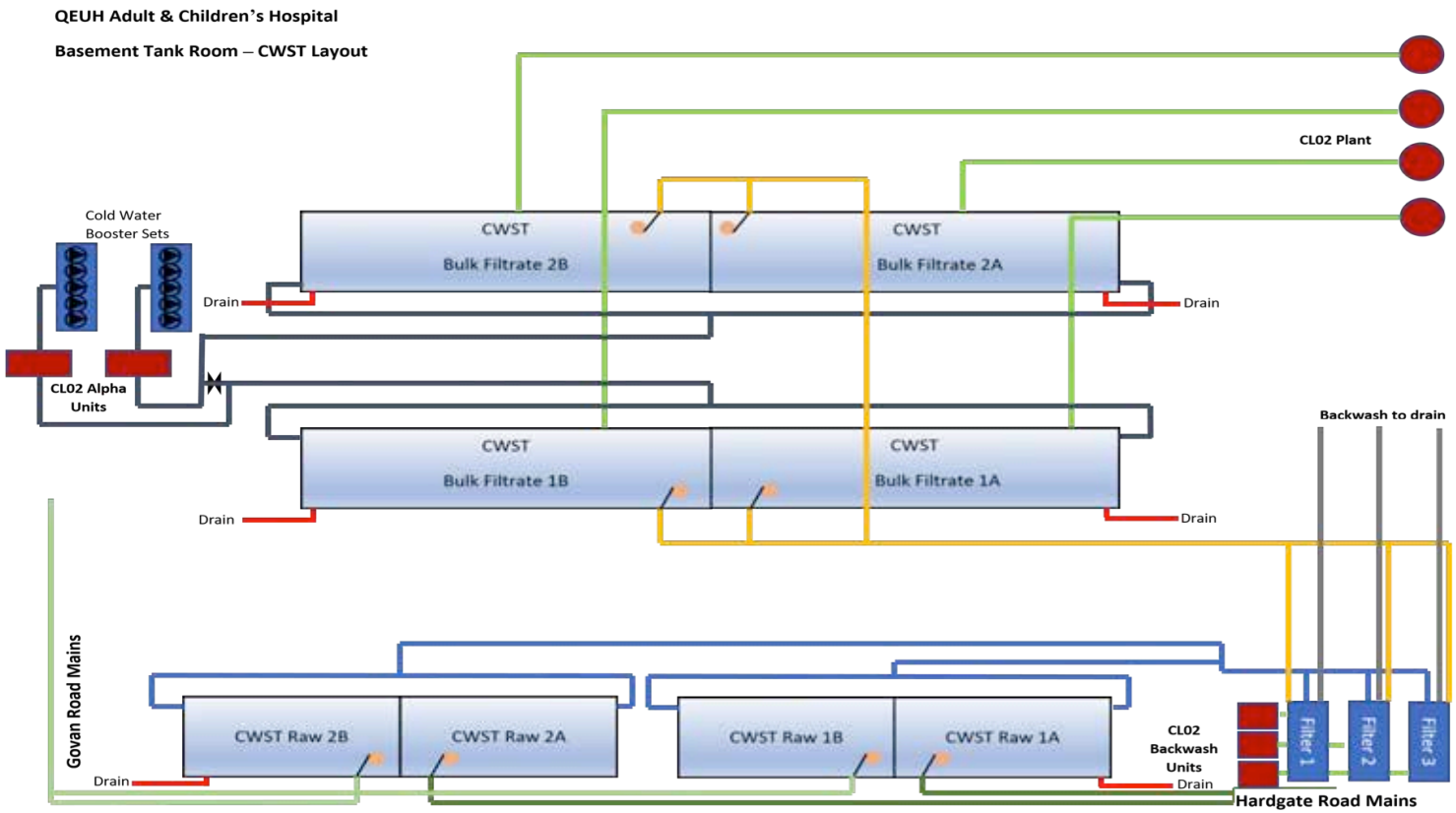
New buildings: Adults and RHC



Big increase in routine testing in the new buildings from Dec 2018, due to installation of chlorine dioxide dosing system

QEUH basement filtration system

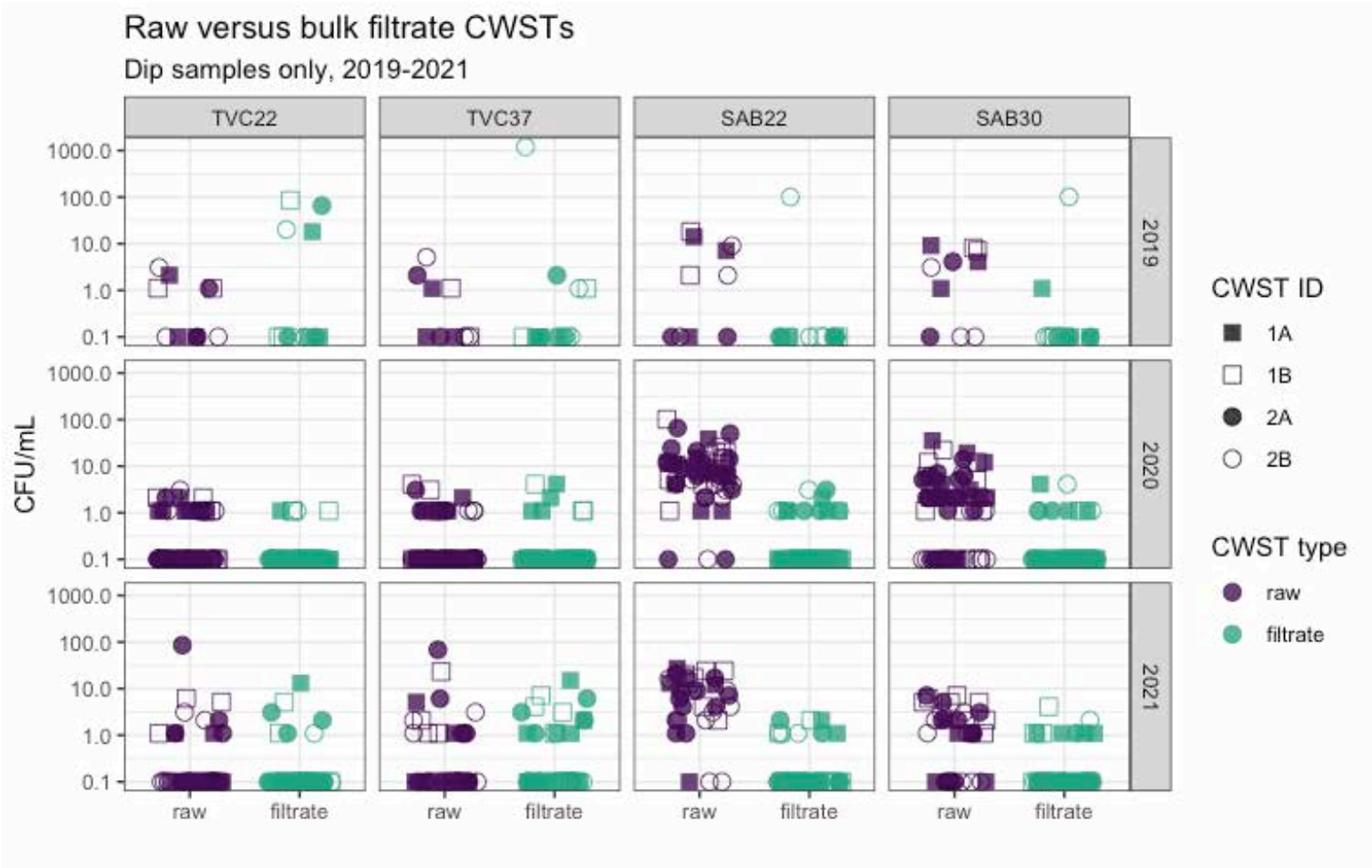
Feeding both Adults and RHC



- Mains water from Govan Road and Hardgate Road fills 4 raw CWSTs
- This water passes through 0.2 um filters units, and is then stored in four bulk filtrate CWSTs
- The filtered water is pumped to the ClO2 plant before distribution through the hospitals

Basement tanks: Pre- vs post-filtration

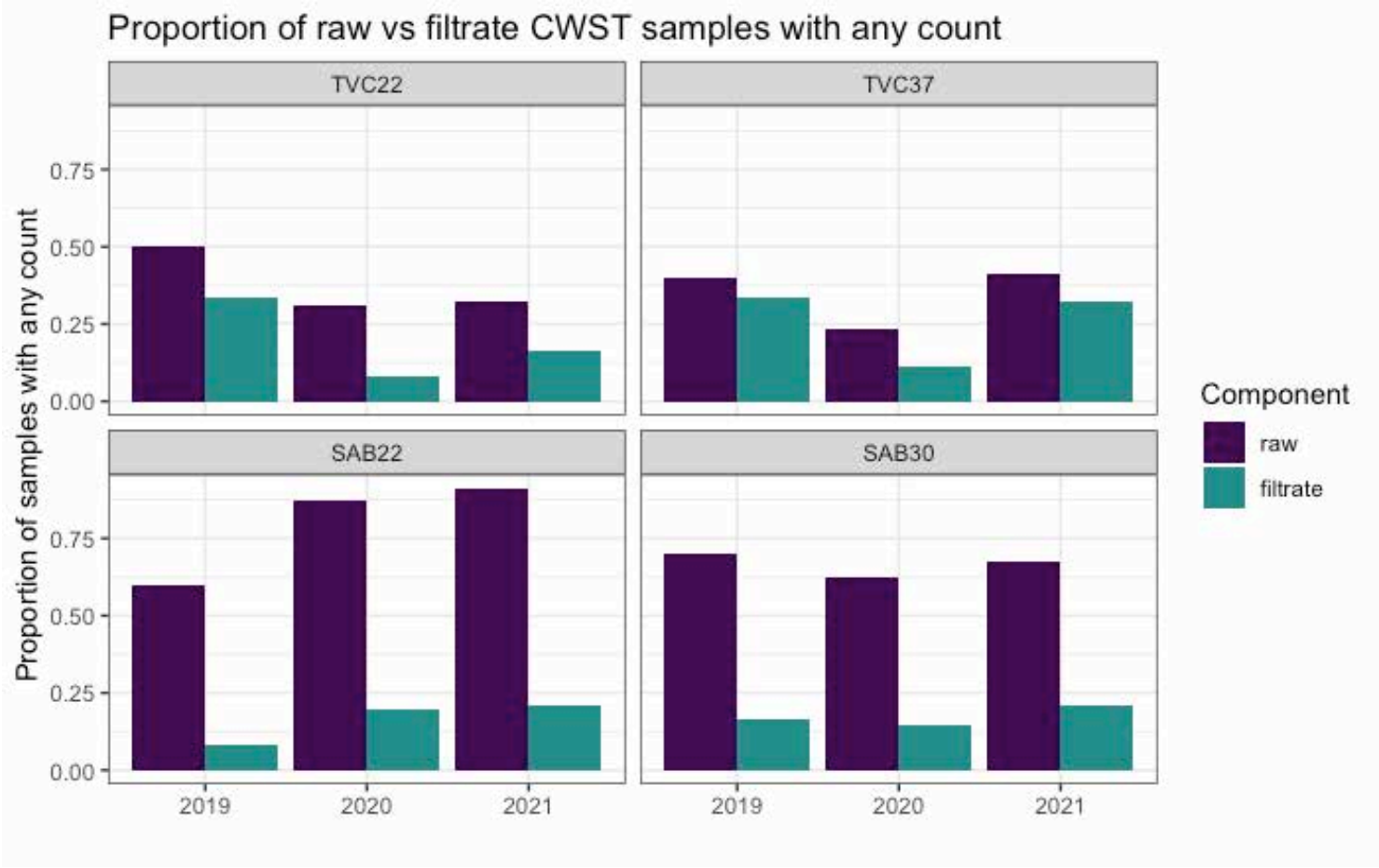
Counts on bacterial (TVC) and fungal (SAB) tests



- Effect of filtration on bacterial TVCs is not clear, as the raw water has very low counts (only one raw sample >10 CFU/mL over a 3-year period)
- Filtration significantly reduces counts on fungal tests ($p<0.05$)
- The tank ID is not significantly linked to counts, so individual tanks are not colonised

Basement tanks: Pre- vs post-filtration

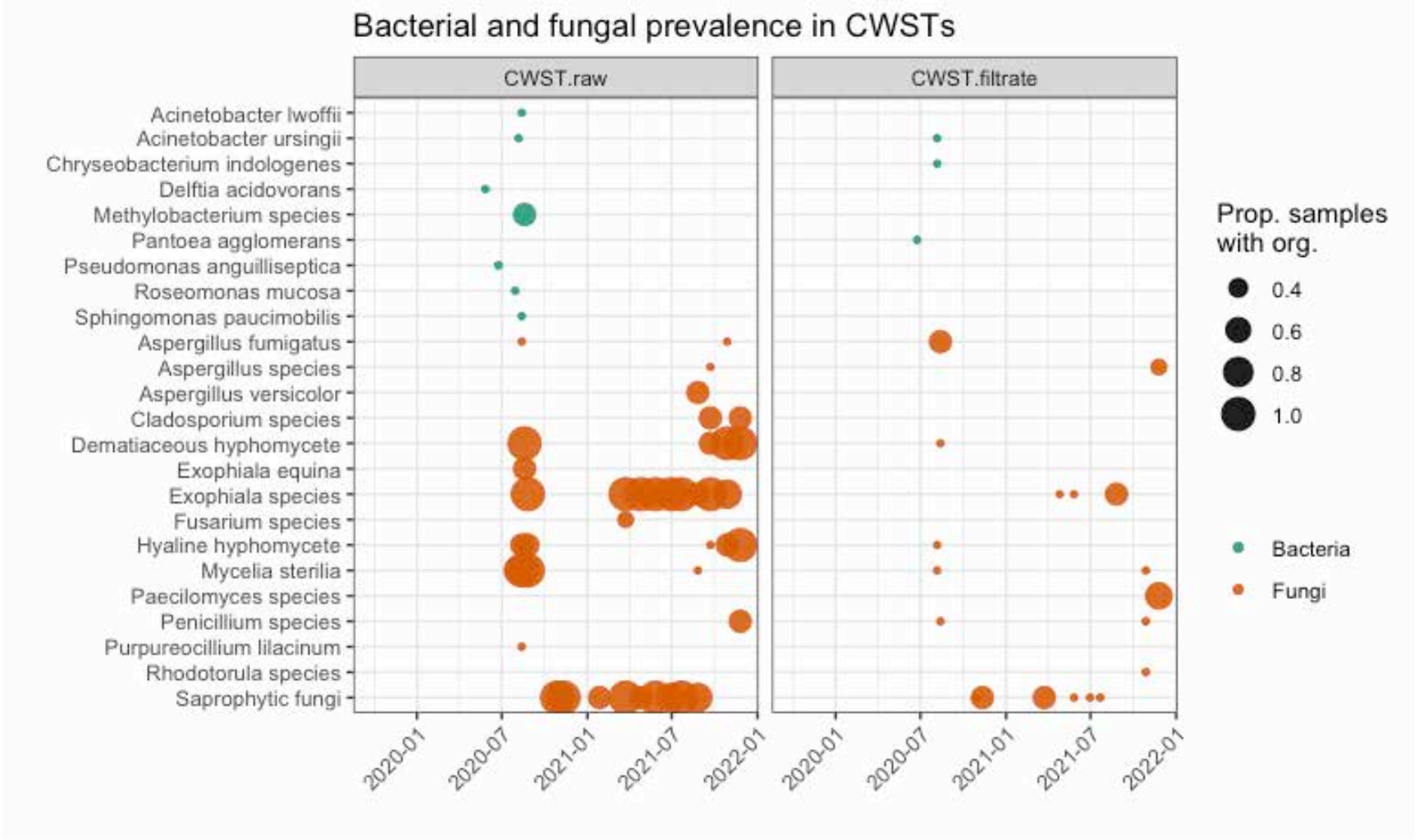
Proportions with bacterial (TVC) and fungal (SAB) counts



- Filtrate CWSTs invariably had fewer samples with any count than raw CWSTs

Basement tanks: Pre- vs post-filtration

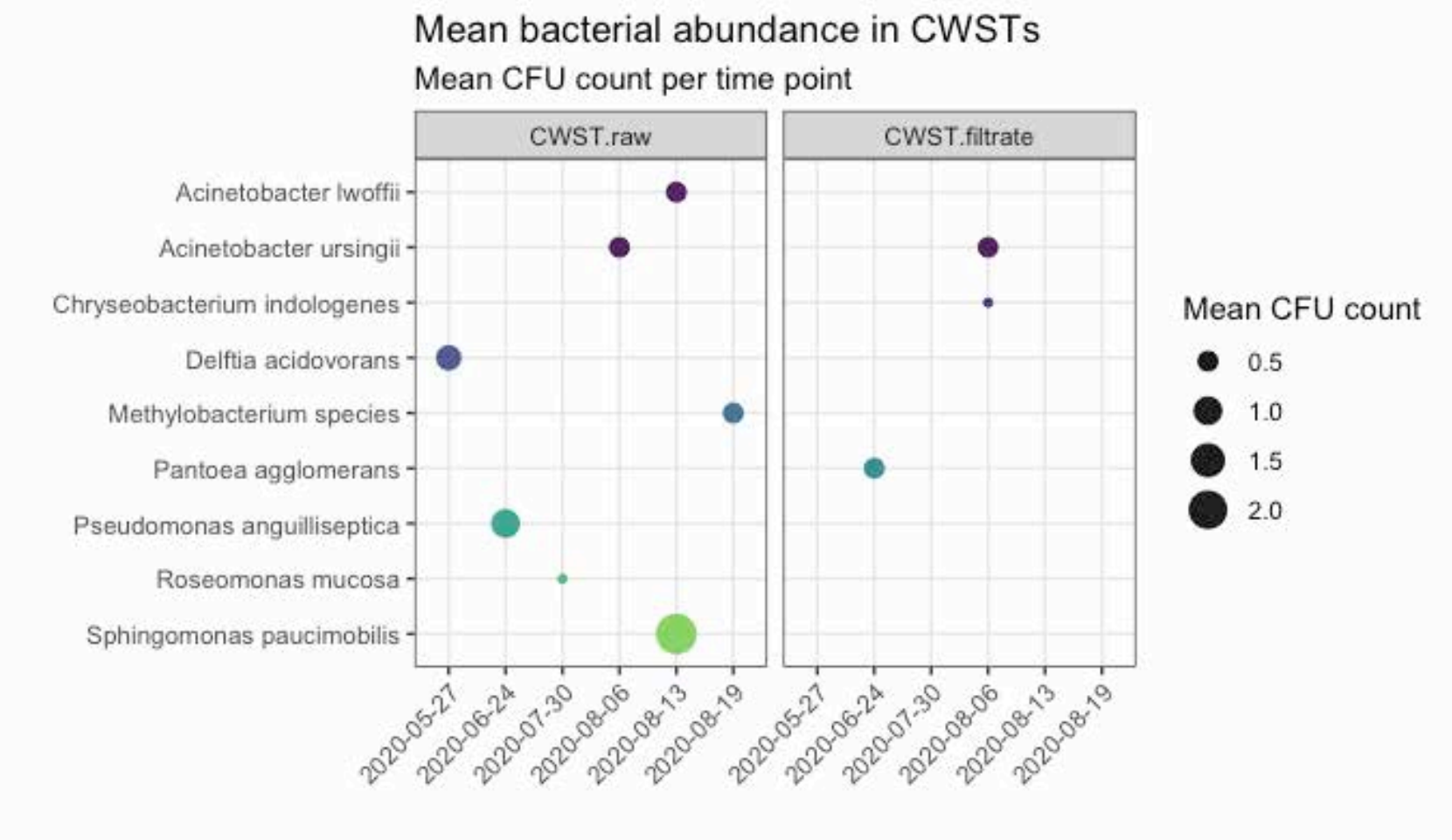
Named bacteria and fungi in CWSTs



- Hardly any bacteria, including GNBs, were identified in the CWSTs over the 3 year period
- Raw CWSTs had more named fungi than filtered CWSTs

Basement tanks: Pre- vs post-filtration

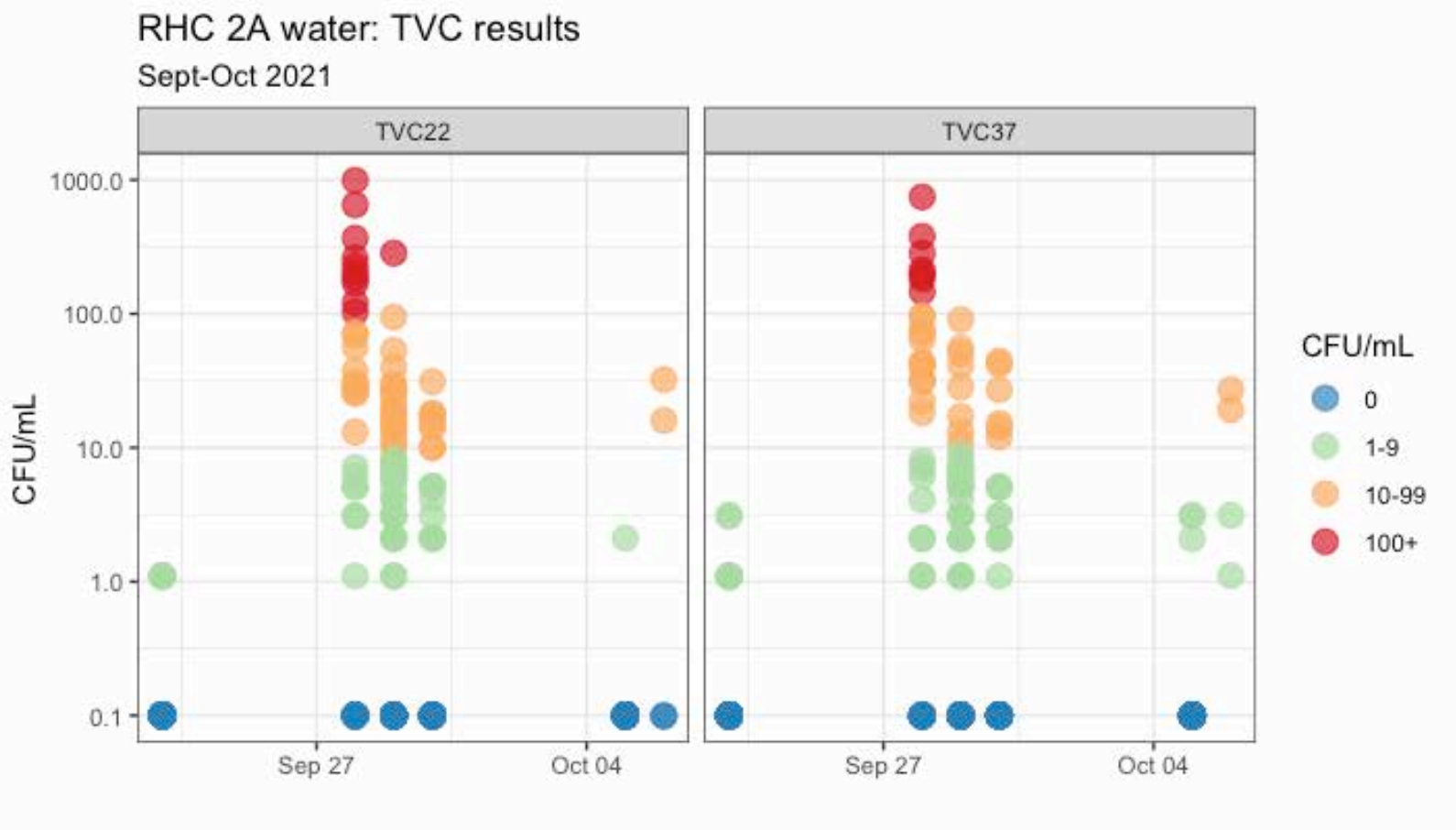
Named bacteria in CWSTs



- GNBs were only detected on six sampling days (out of 36 over a 3 year period)
- Fewer organisms found in the filtered tanks, and at lower counts
- No clear temporal pattern, so the raw and filtered CWSTs do not appear colonised with organisms that shed into the water system

Ward 2A/2B: Sept-Oct 2021

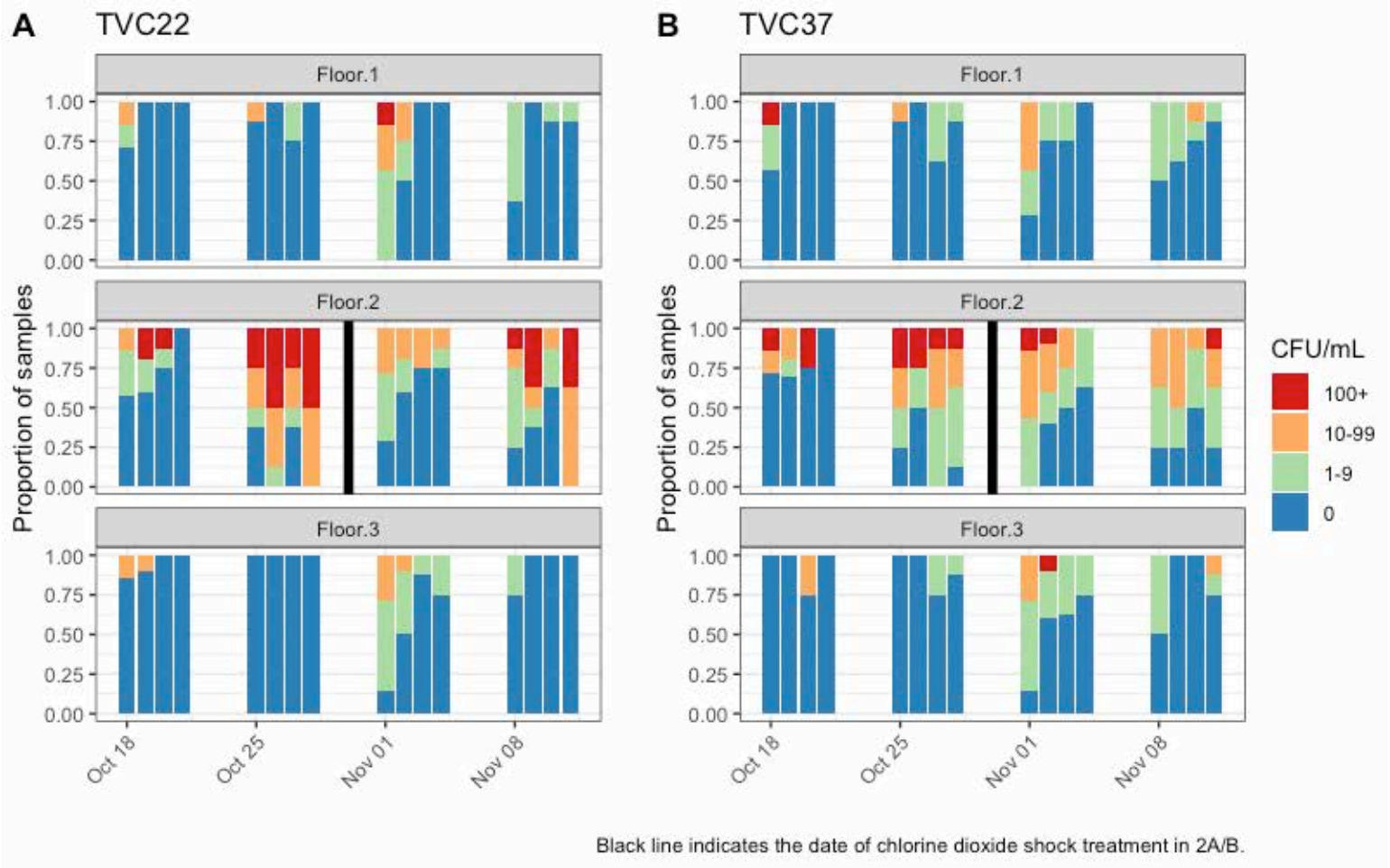
Post-refurbishment water results



- Ward had been closed for refurbishment for an extended period
- Water testing in Sept-Oct showed high TVC22 and TVC37 counts

Ward 2A/2B: Oct-Nov 2021

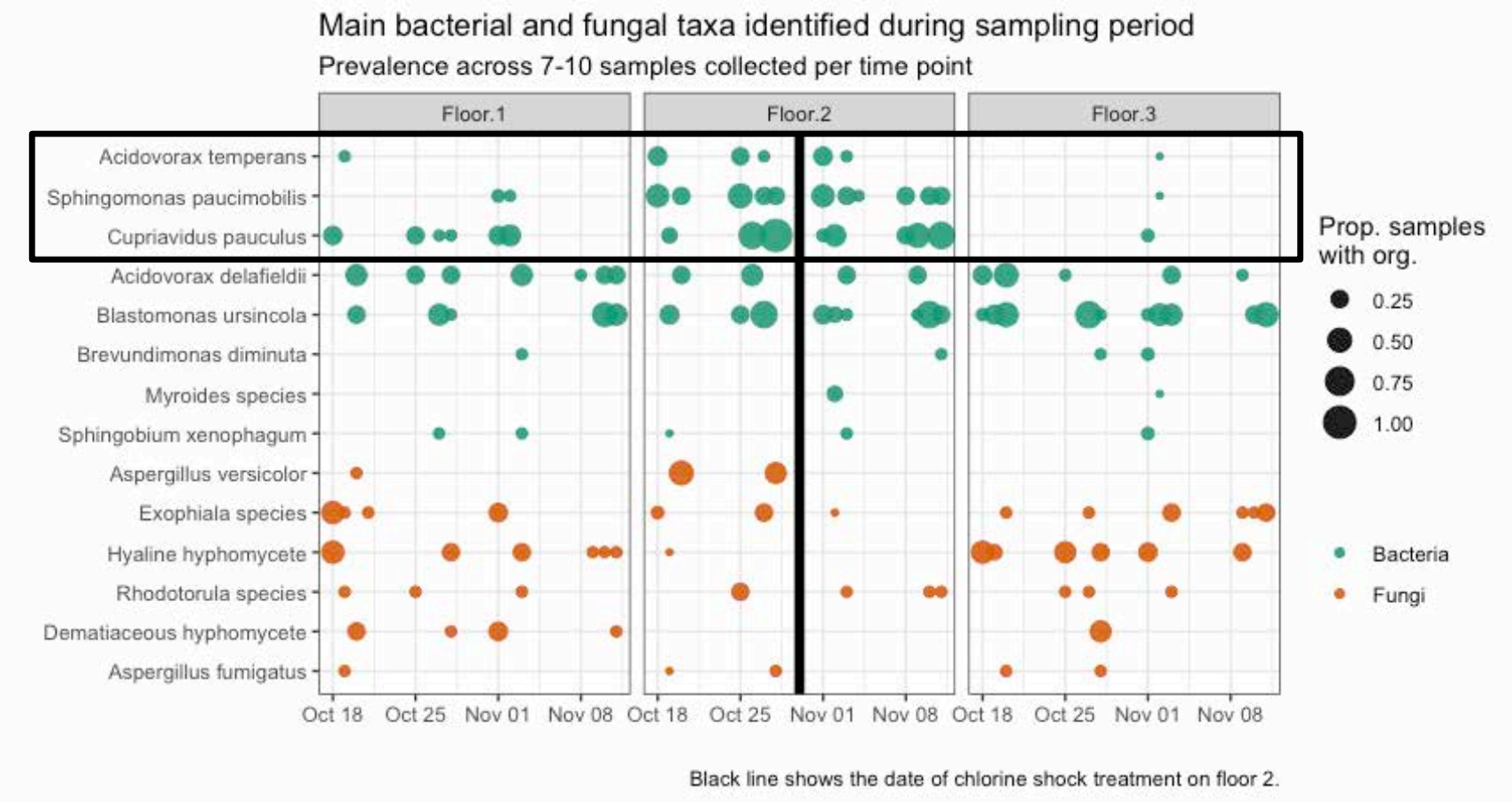
Intensive sampling and first chemical treatment



- Chlorine dioxide treatment in 2A/2B did not significantly decrease TVCs
- 2A/2B had considerably higher TVCs than the floors below and above

Ward 2A/2B: Oct-Nov 2021

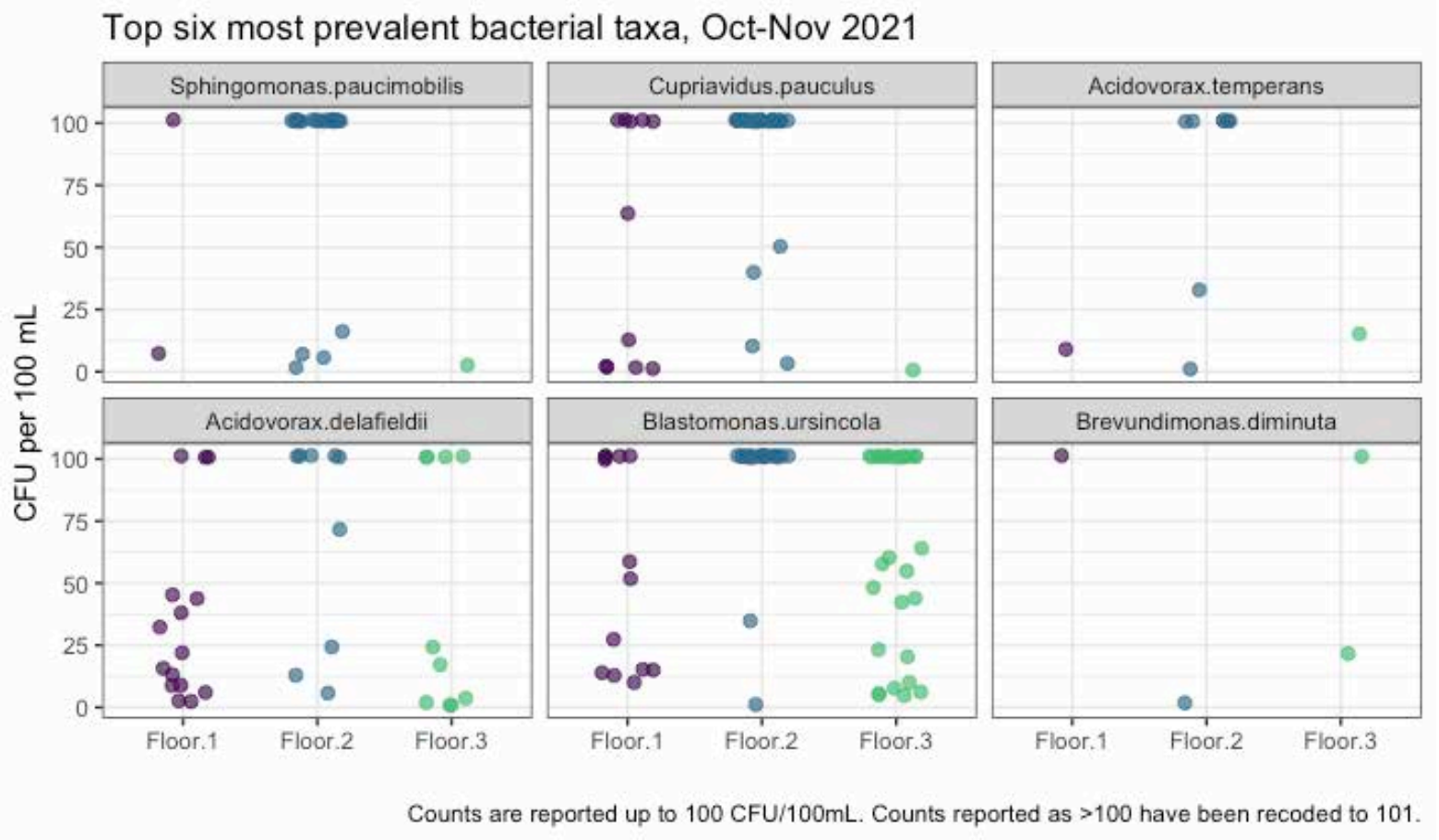
Intensive sampling and first chemical treatment



- *Acidovorax temperans*, *Sphingomonas paucimobilis*, and *Cupriavidus pauculus* were enriched in 2A/2B compared with the other floors
- These are disinfectant-resistant biofilm-forming taxa, and were not affected by chlorine dioxide treatment

Ward 2A/2B: Oct-Nov 2021

Intensive sampling and first chemical treatment



- *Acidovorax temperans*, *Sphingomonas paucimobilis*, and *Cupriavidus pauculus* were enriched in 2A/2B compared with the other floors
- These are disinfectant-resistant biofilm-forming taxa, and were not affected by chlorine dioxide treatment

Ward 2A/2B: Nov-Jan interventions

Following first chemical treatment

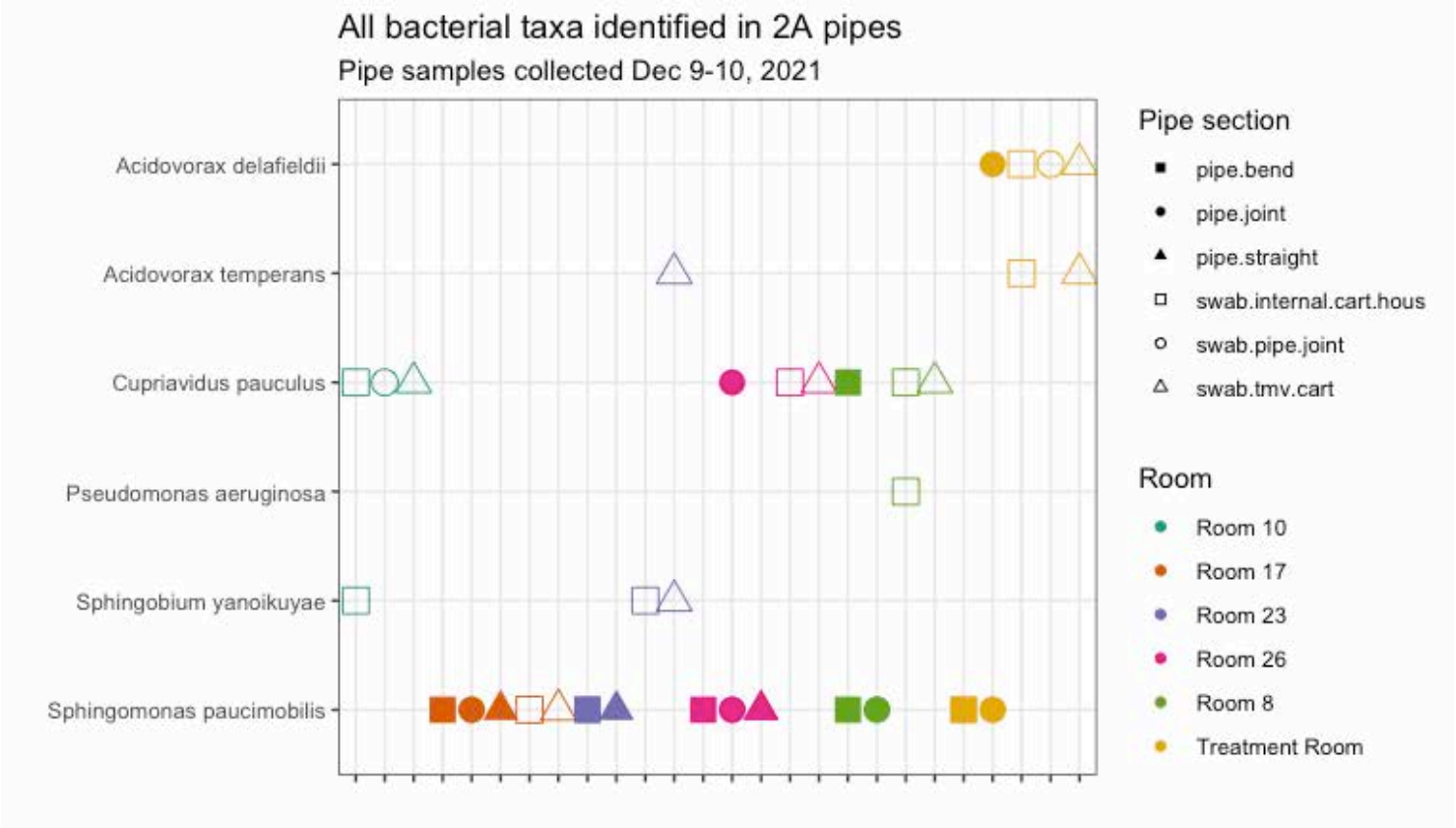
- Chlorine dioxide treatment at the end of Oct did not reduce TVCs down to levels seen on other floors

- Additional tests:
  - Pipe sections removed from six rooms in 2A
  - Old cartridges removed and tested alongside new cartridges (to rule out contamination being introduced by new cartridges)

- Interventions:
  - Increased flushing to more closely mimic an occupied ward
  - Cleaning schedule to clinical standards
  - Hydrogen peroxide / silver ion treatment (2000 ppm H_2O_2) of entire ward 2A/2B on Dec 13
  - All Markwik 21+ taps replaced on Jan 10-12

Ward 2A/2B: Pipes and cartridges

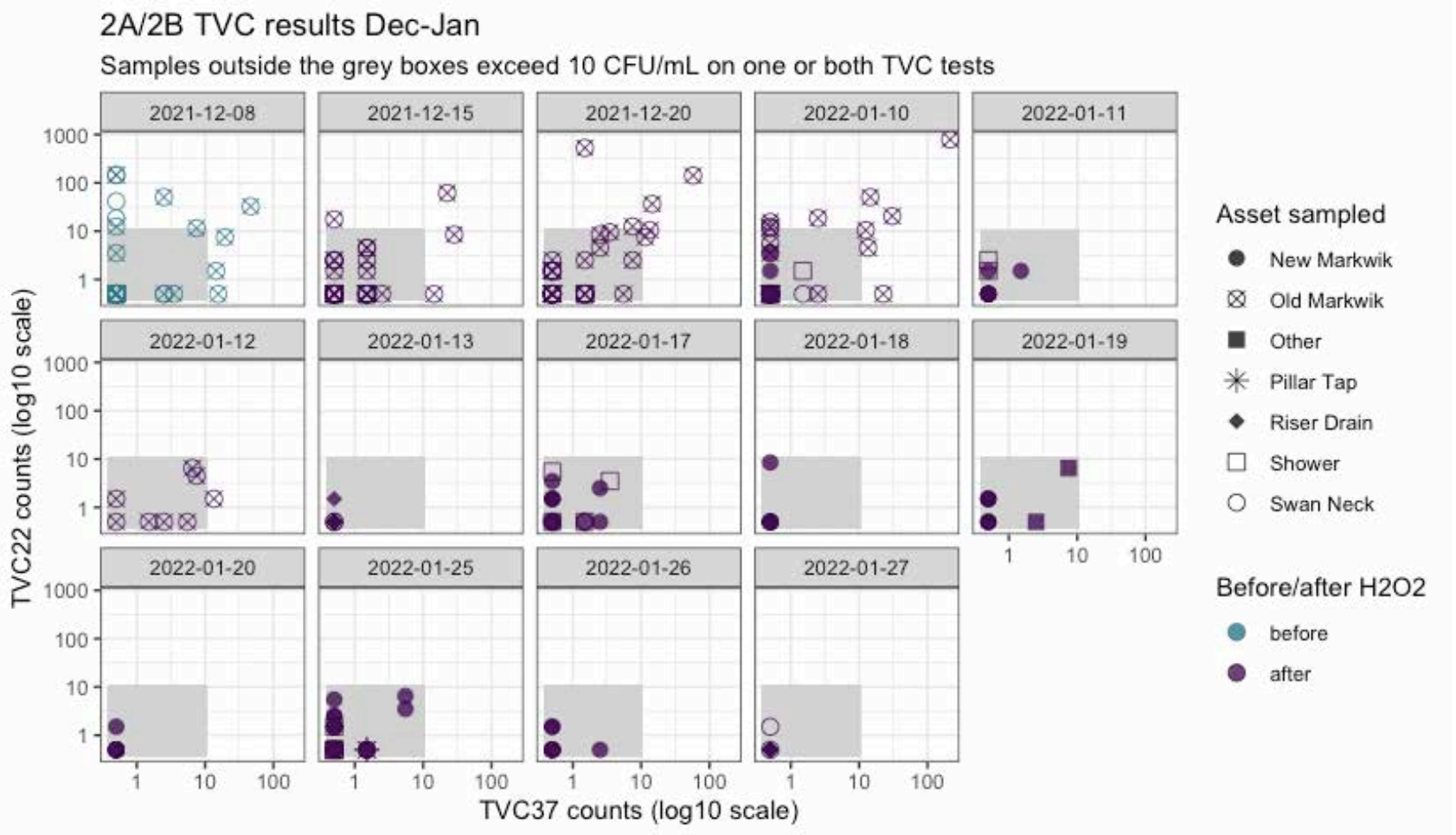
Microbiological analysis



- Pipe samples appeared clean to the naked eye, but testing (swabs/sonication) showed the same biofilm-forming organisms detected in water samples (notably *Sphingomonas paucimobilis* and *Cupriavidus pauculus*)
- These pipe samples were collected *before* the second chemical treatment (H_2O_2 / silver ion on Dec 13)
- Old cartridges were heavily colonised by these same organisms, with high TVCs after sonication (not shown)

Ward 2A/2B: Dec 2021 - Jan 2022

Second chemical treatment and tap replacement

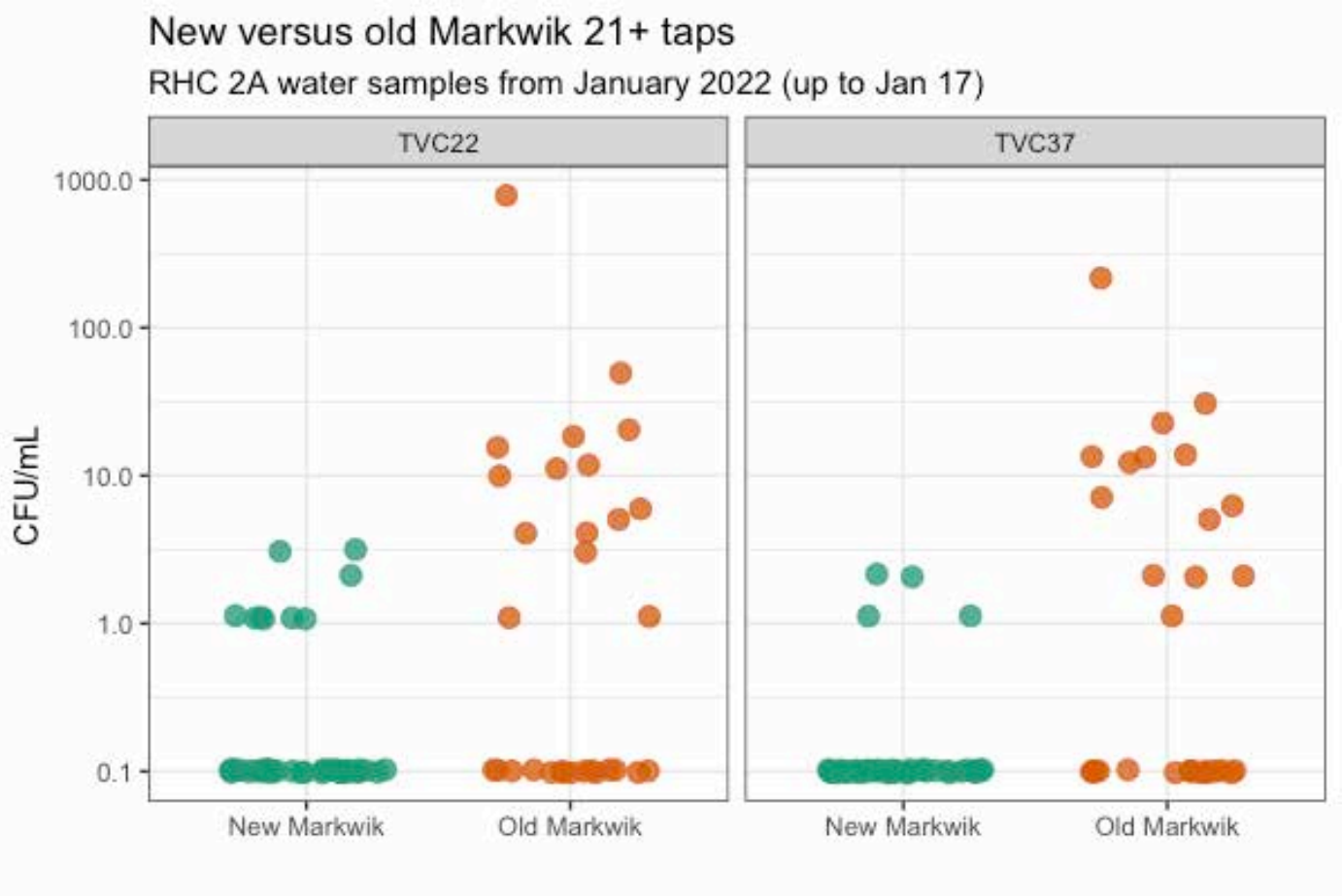


Replacing the Markwik 21+ taps has had a noticeable impact:

- Almost all out-of-spec samples were from old Markwik taps
- There have been no out-of-spec samples in 2A/2B since these were removed (Jan 10-12)

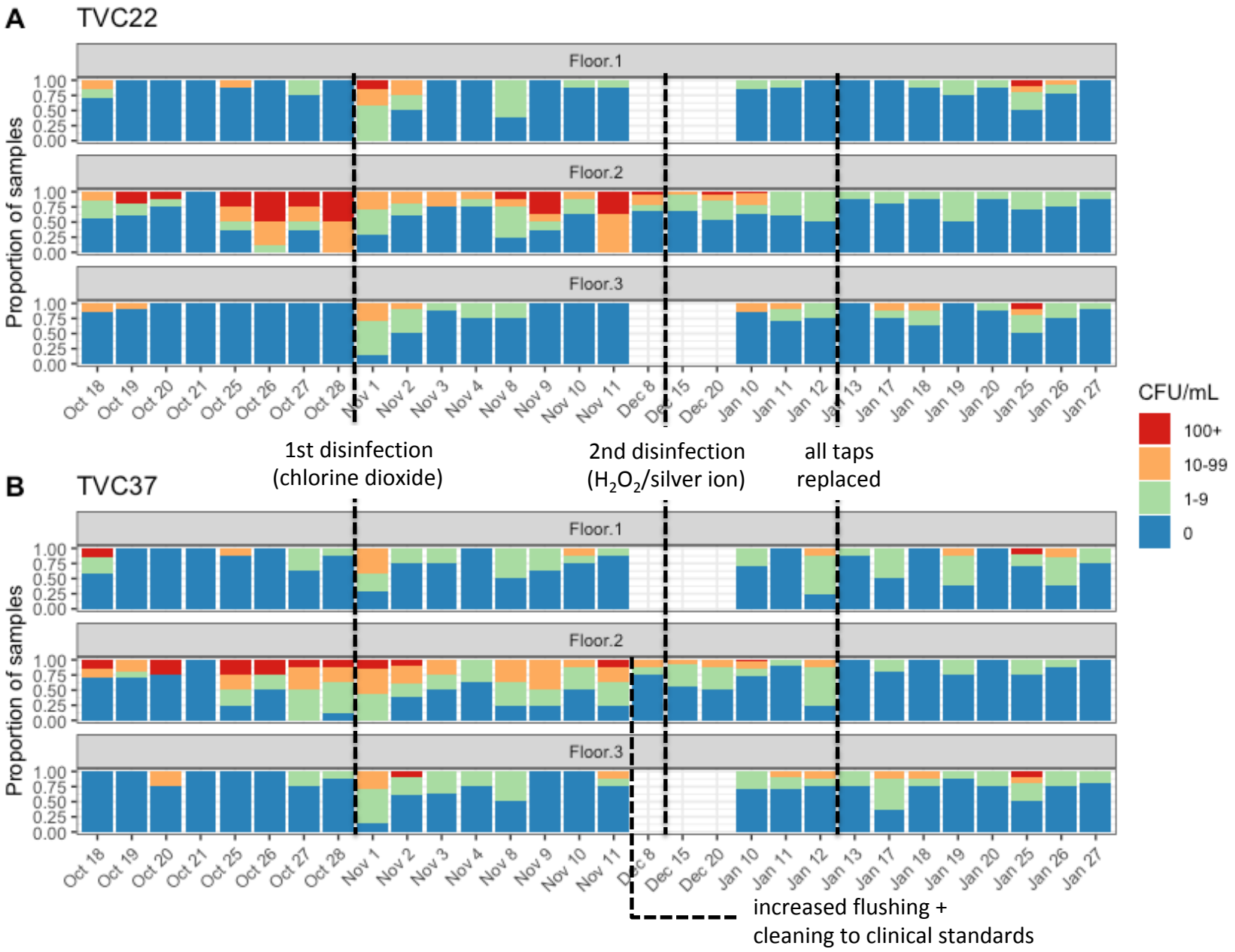
Ward 2A/2B: Jan 2022

Tap replacement



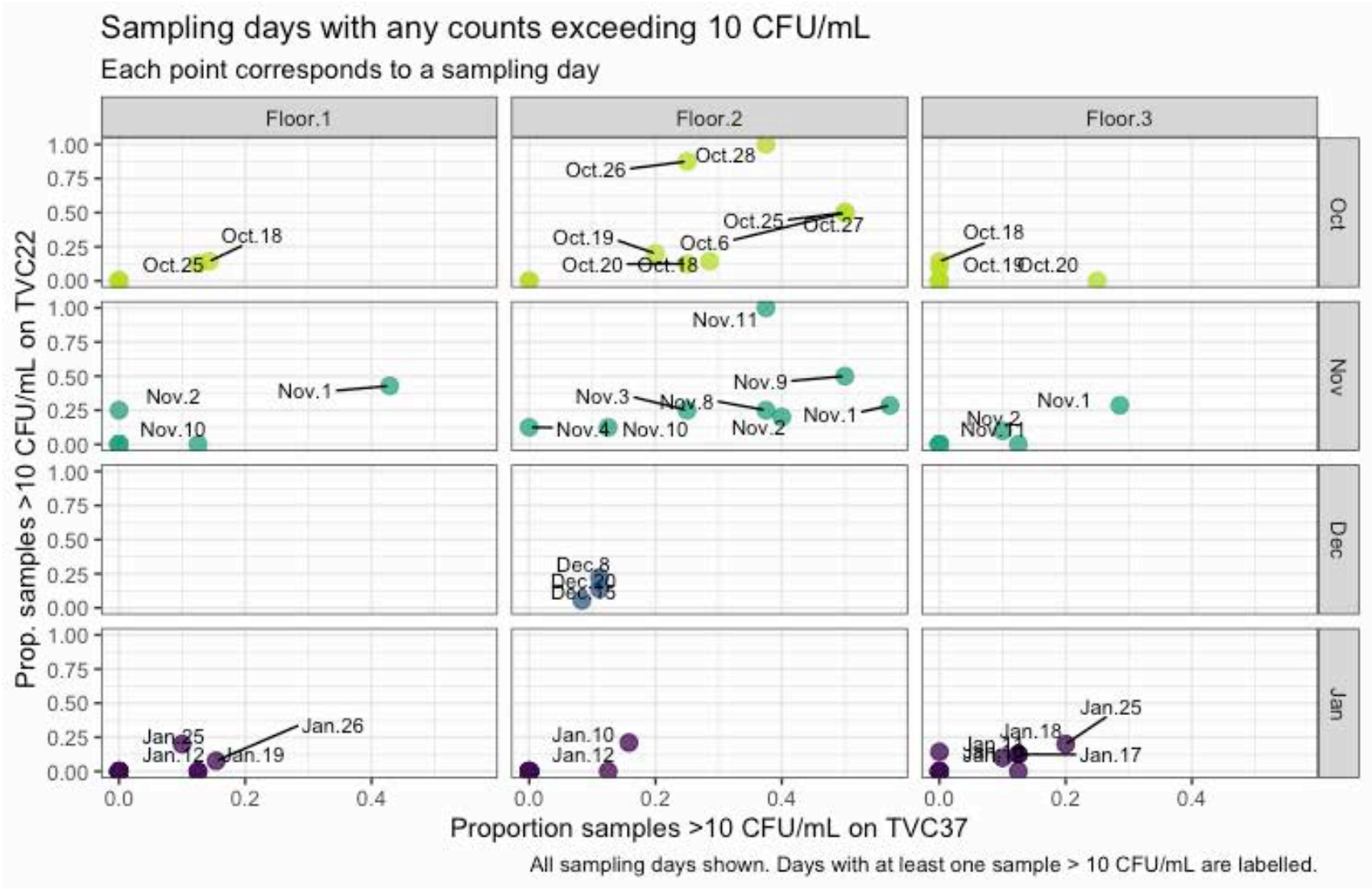
- Taps were changed over the period 10-12 January 2022
- On both TVC22 and TVC37, new Markwik taps have significantly lower CFU counts ($p < 0.01$)

Ward 2A/2B: Oct 2021 - Jan 2022



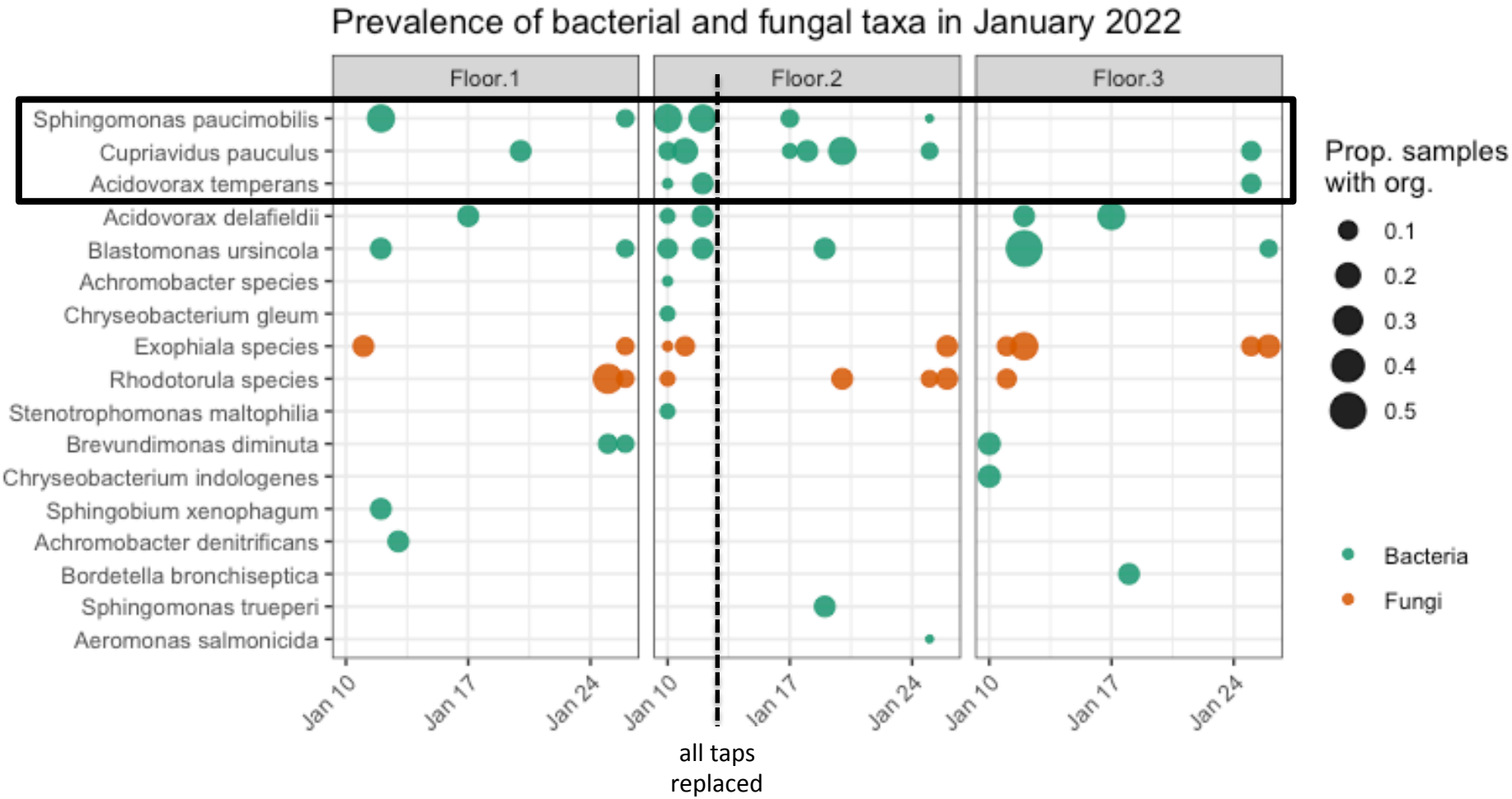
Ward 2A/2B: Oct 2021 - Jan 2022

Overall trend: 2A/2B now similar to floors below/above



Ward 2A/2B: January 2022

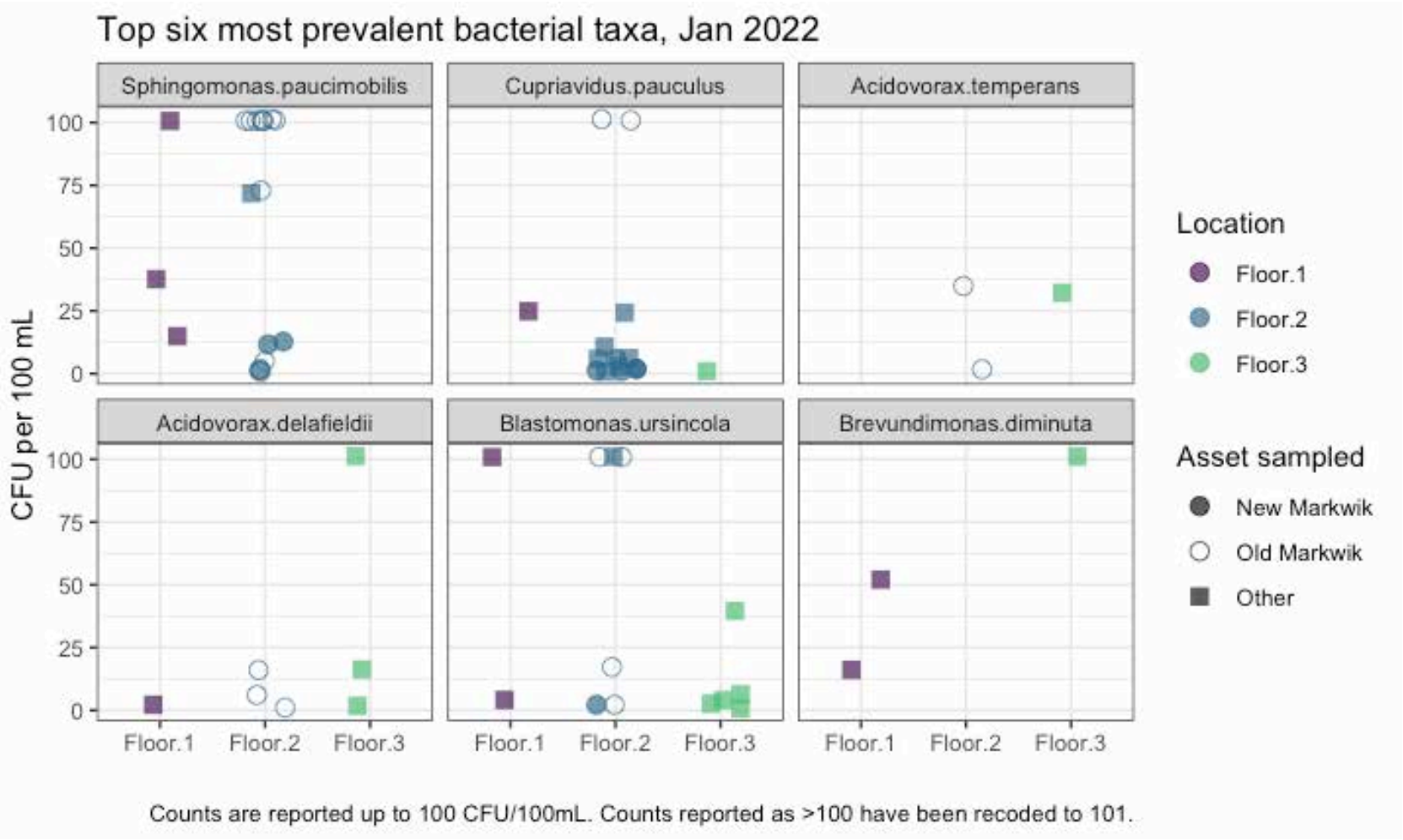
All detected taxa



- Hardly any GNBs detected in 2A/2B since taps were changed
- Two of the taxa previously enriched in 2A/2B were still detected, but at much lower prevalence

Ward 2A/2B: January 2022

Top six most prevalent bacterial taxa



- In January 2022, the three previously enriched taxa were predominantly found in old taps that have now been replaced

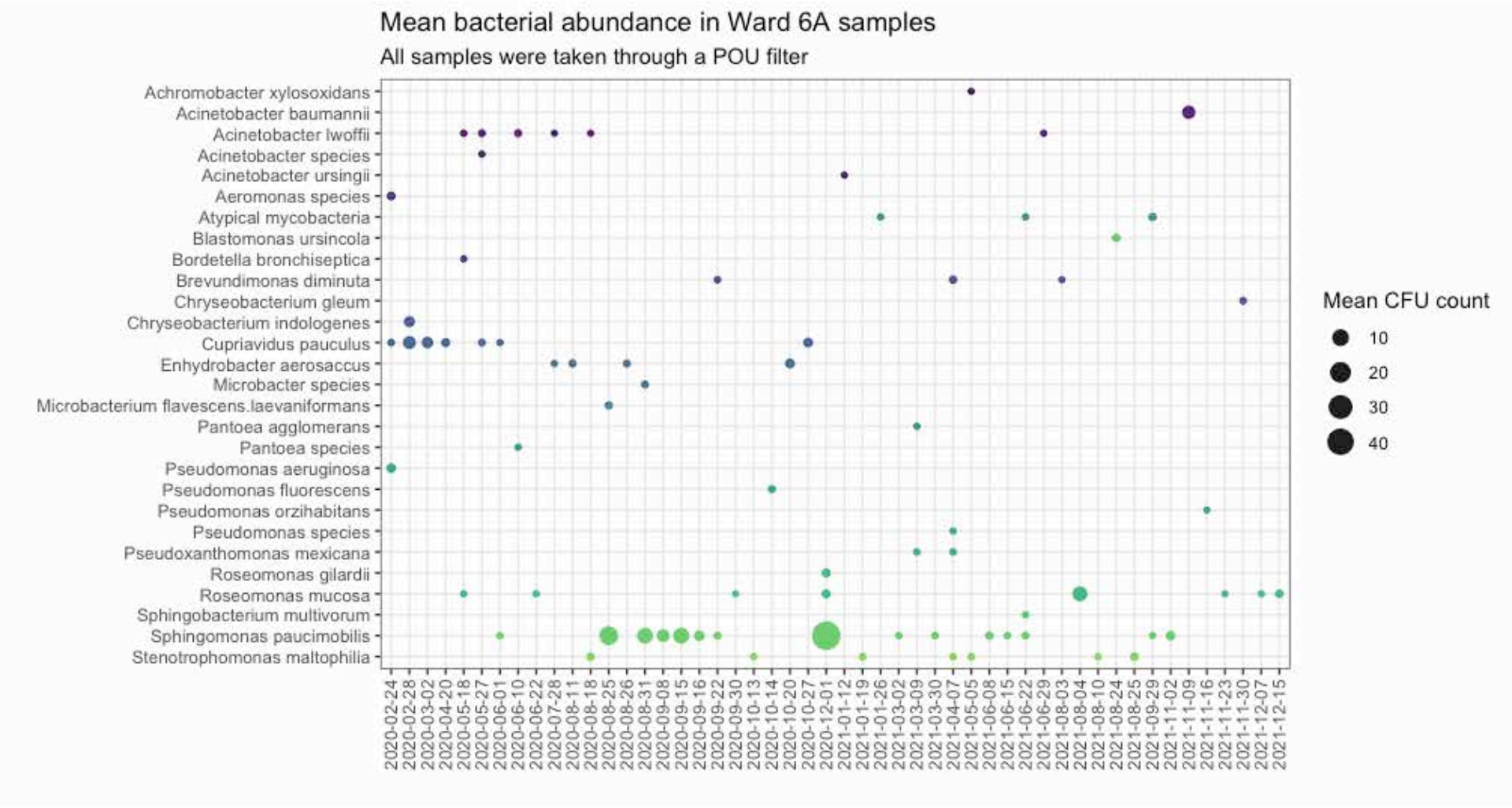
For comparison: Ward 6A 2019-2021

All samples taken through POU filters

Ward 6A has been intensively sampled for over 2 years. POU filters are in place.

For comparison: Ward 6A 2019-2021

All samples taken through POU filters



Ward 6A has been intensively sampled for over 2 years. POU filters are in place.

Summary

- The new QEUH buildings (Adults and RHC) have been extensively sampled on a routine basis since Dec 2018
- The basement filtration system appears to be functioning as expected
- 2A/2B had high TVCs and some enriched taxa in September. Numerous measures were put in place to remedy this:
  - Intensive sampling, including floors above and below, plus pipes and cartridges
  - Chlorine dioxide treatment
  - Hydrogen peroxide/silver ion treatment
  - Increased flushing and cleaning to clinical standards
  - Tap replacement
- TVCs and GNBs in 2A/2B now similar to other floors, and broadly similar to 6A (which has POU filters in place)

Royal Hospital for Children Ward 2A/2B water test results

Tuesday, 1 Mar 2022

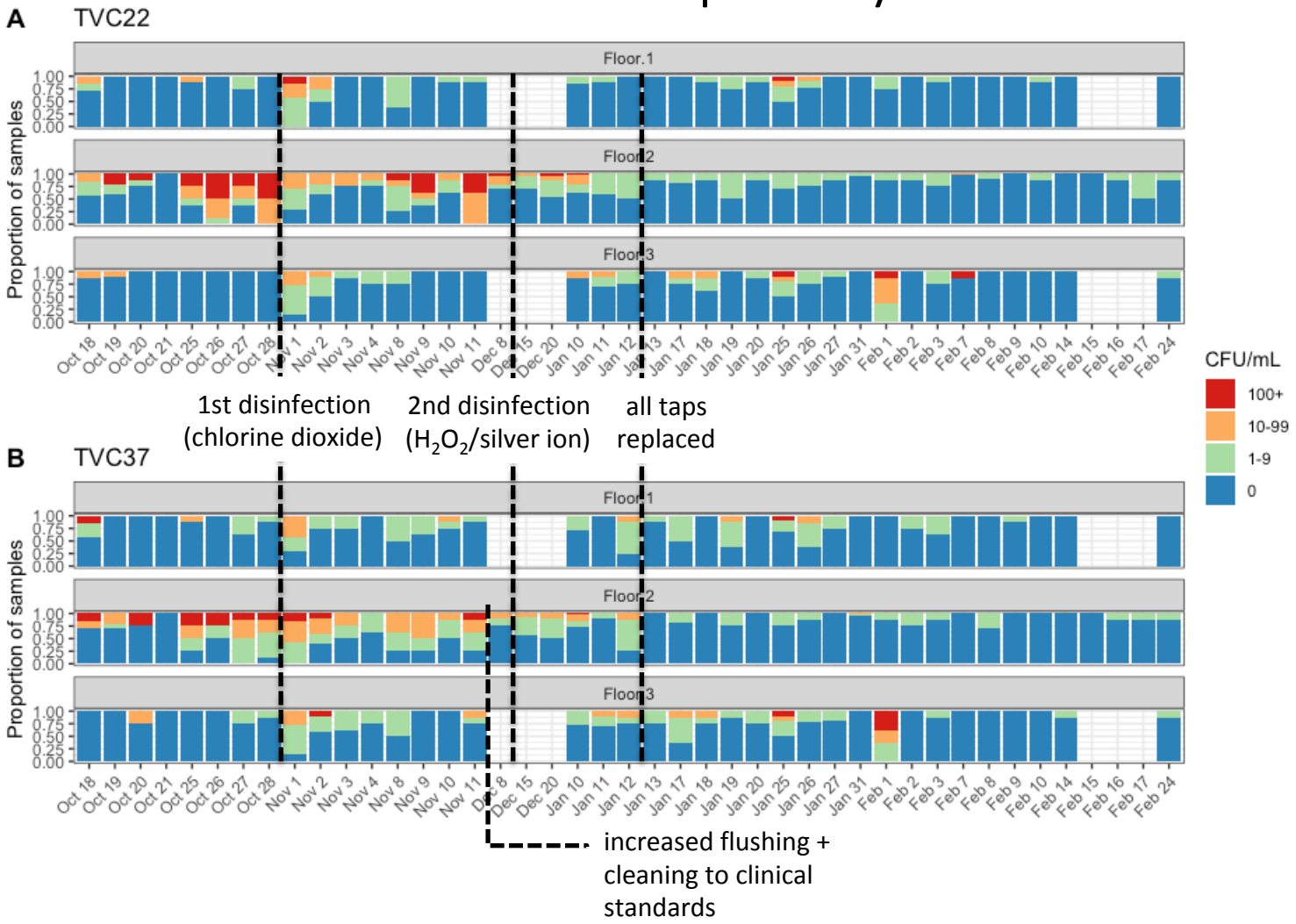
Including water testing results up to 24 Feb 2022

Dominique Chaput, DPhil (Oxon)

Healthcare Scientist, Scottish Microbiology Reference Laboratories, Glasgow

Ward 2A/2B: Oct 2021 - Feb 2022

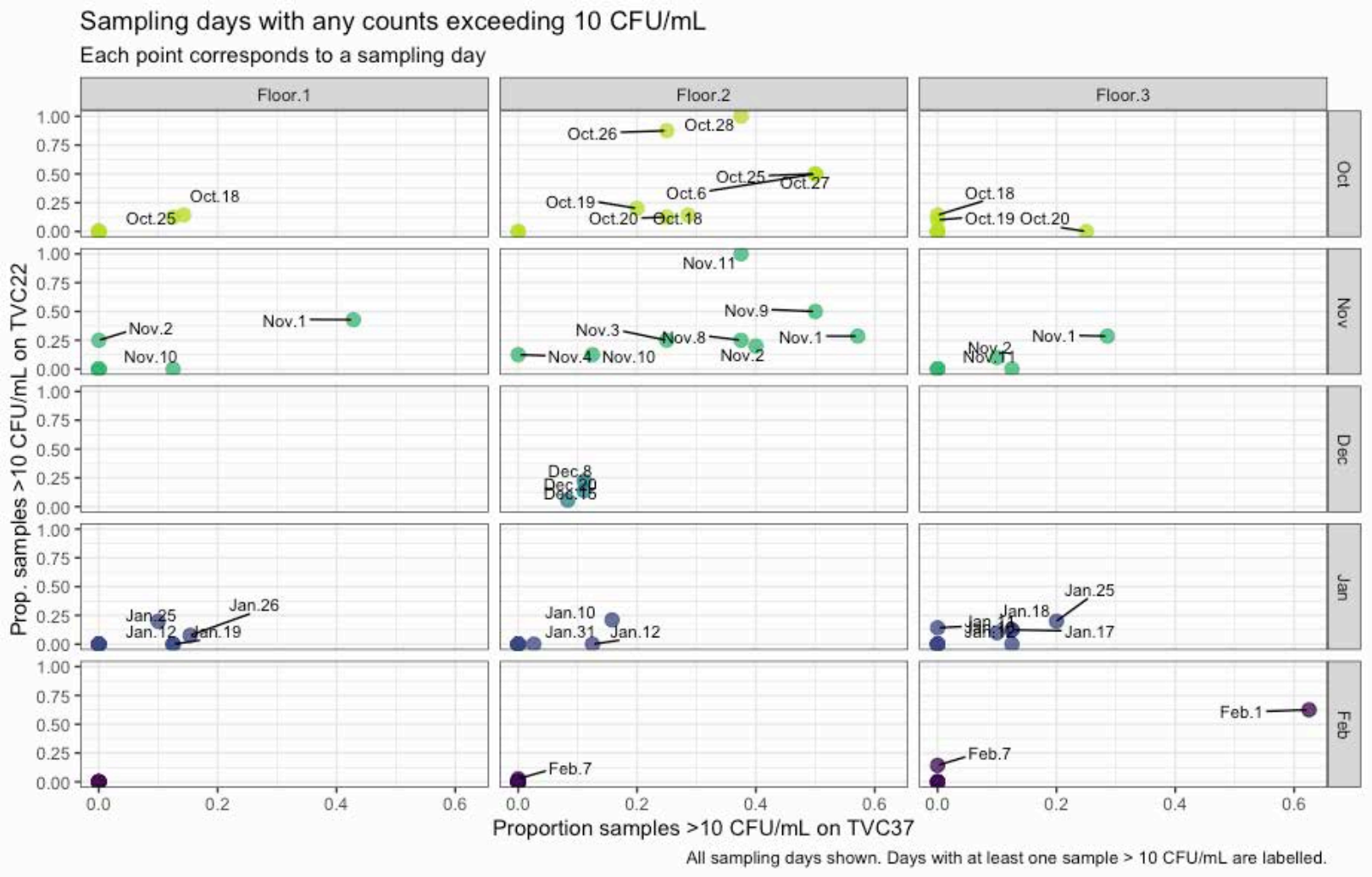
Post-flush samples only



From Jan 13 onwards, the vast majority of samples from floor 2 had no or very low CFU counts on TVC22 and TVC37.
There are no indications that counts are returning to the higher values observed in Oct-Nov.
Test results on floor 2 from Jan 13 onwards are as good as or better than on the other floors.

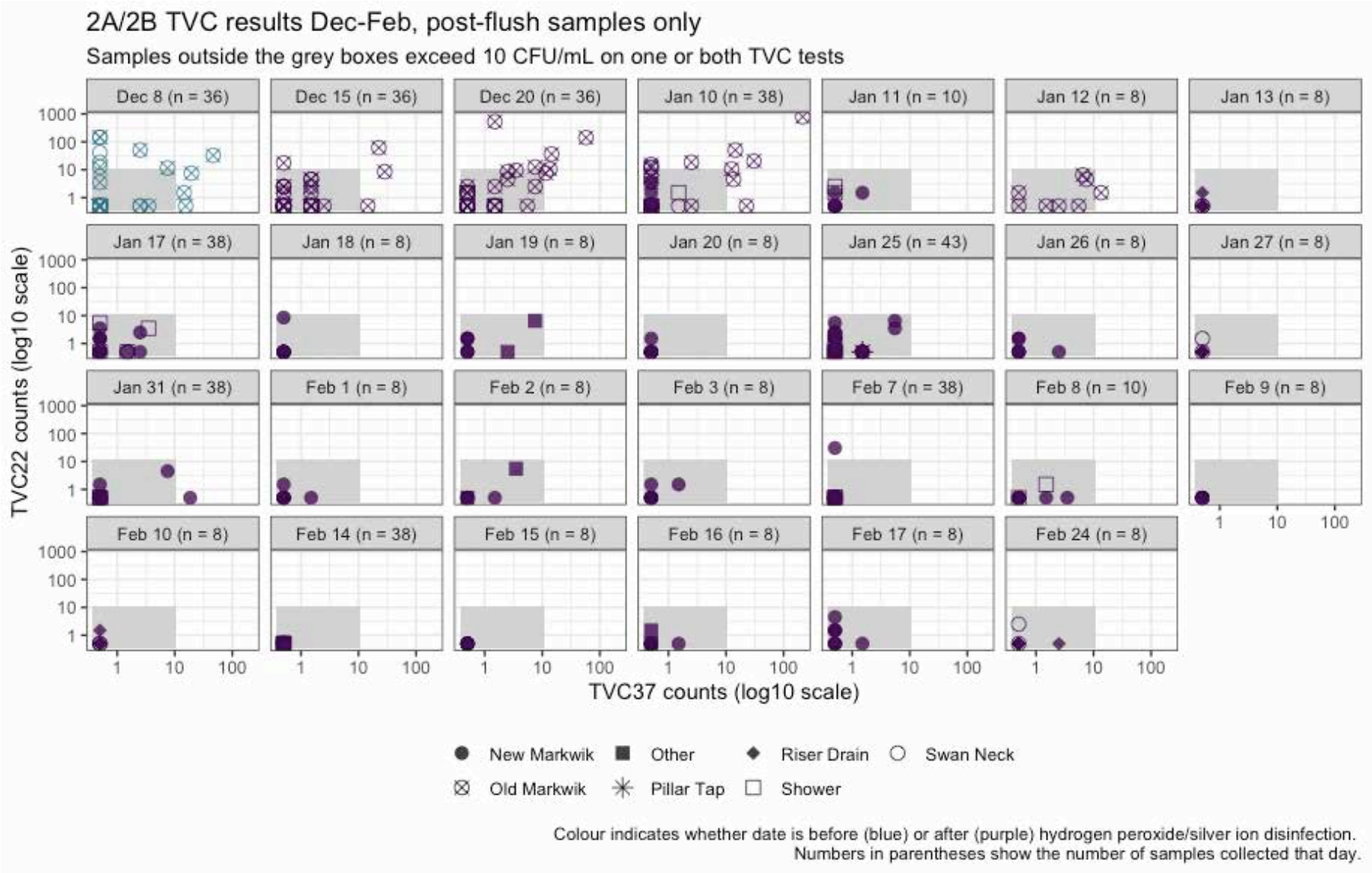
Ward 2A/2B: Oct 2021 - Feb 2022

Daily variability, post-flush samples only



Points in the bottom left corner were days with no out-of-spec samples (high-risk thresholds).
Day-to-day variability on floor 2 is low, with Jan and Feb dates similar to the other floors.

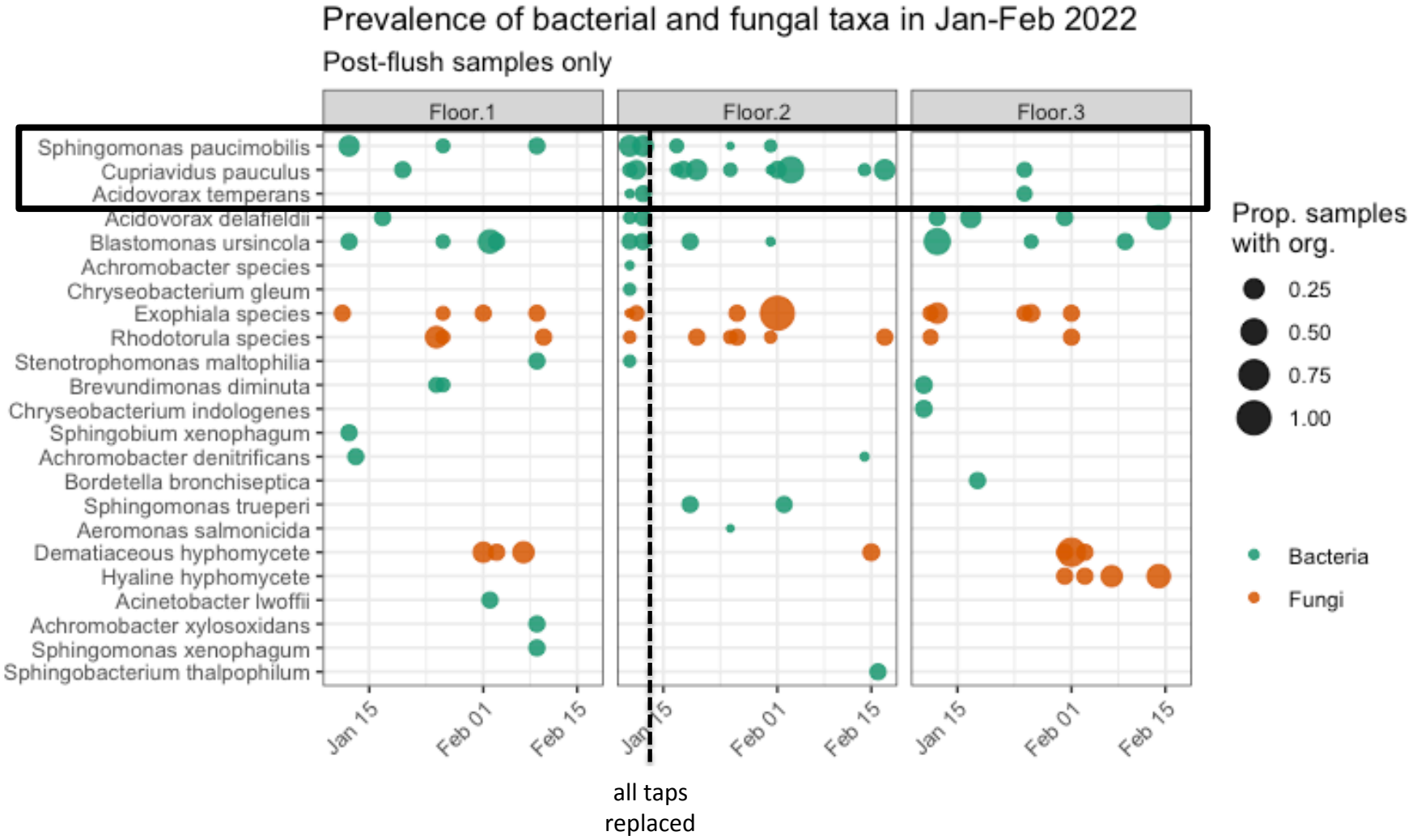
Ward 2A/2B: Dec 2021 - Feb 2022



Points show individual samples. Those in the grey boxes are in spec (high-risk thresholds) on TVC37 and TVC22. Since Jan 12, when taps were changed, the vast majority of samples from all outlet types have been in spec.

Ward 2A/2B: Jan-Feb 2022

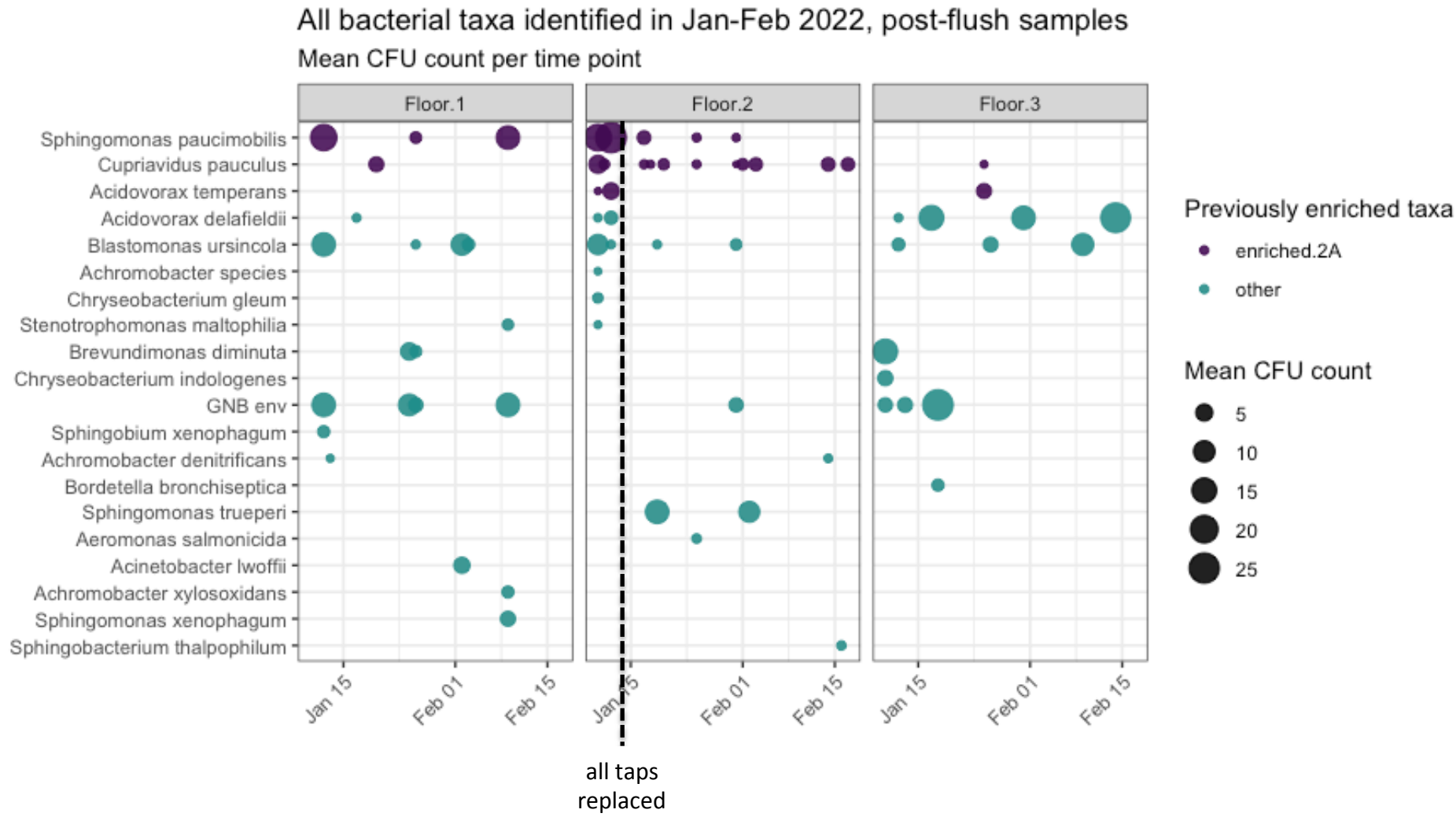
Prevalence of all detected taxa (proportion of samples with org.)



Sphingomonas paucimobilis + *Acidovorax temperans* were previously enriched on floor 2, but that is no longer the case. *Cupriavidus pauculus* is still frequently detected on floor 2, but at lower prevalence and abundance than previously seen.

Ward 2A/2B: Jan-Feb 2022

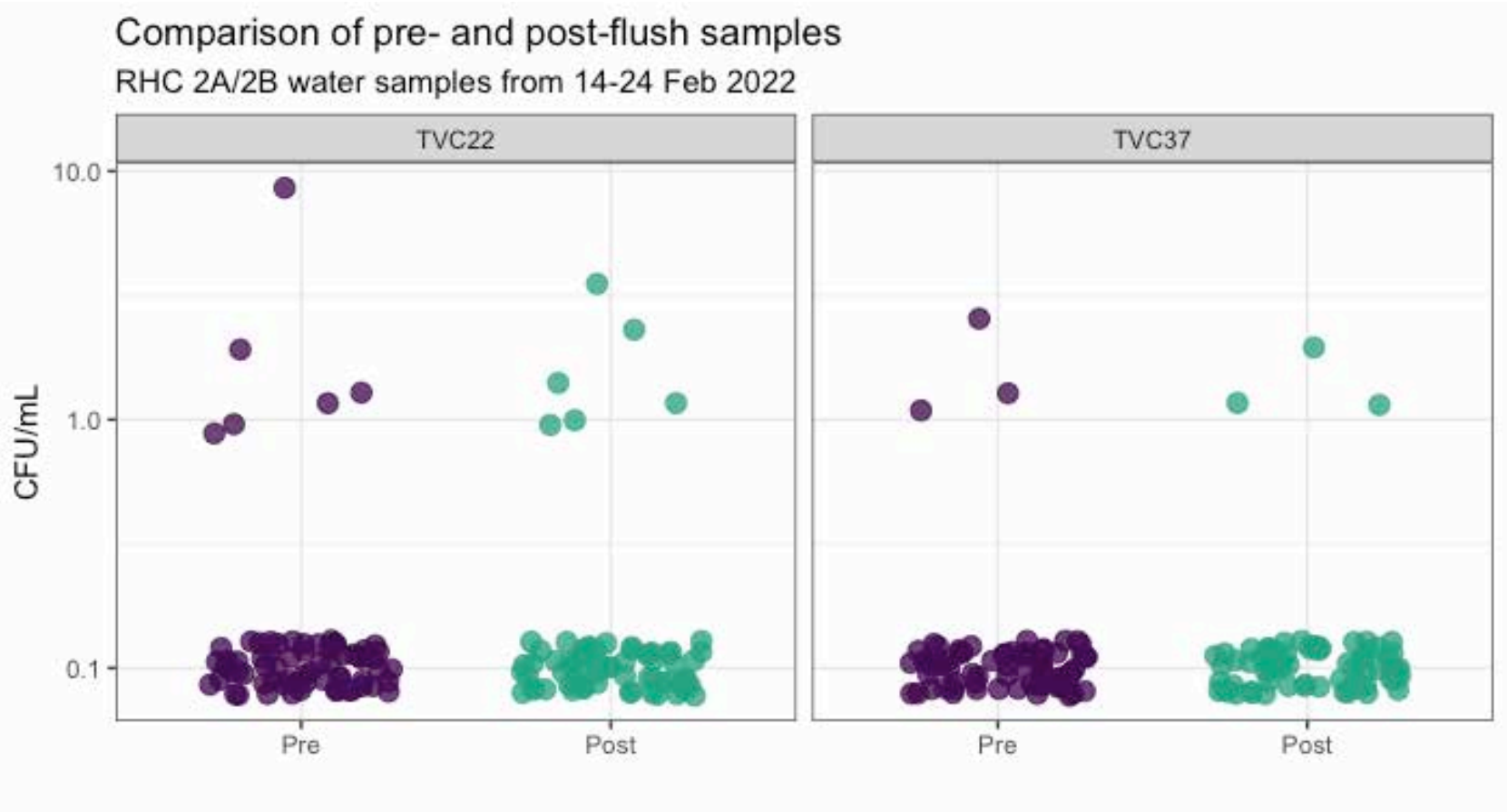
Bacterial abundance (mean CFU/100 mL across all samples)



Sphingomonas paucimobilis + *Acidovorax temperans* were previously enriched on floor 2, but that is no longer the case. *Cupriavidus pauculus* is still frequently detected on floor 2, but at lower prevalence and abundance than previously seen.

Ward 2A/2B: Feb 2022

Pre- versus post-flush samples

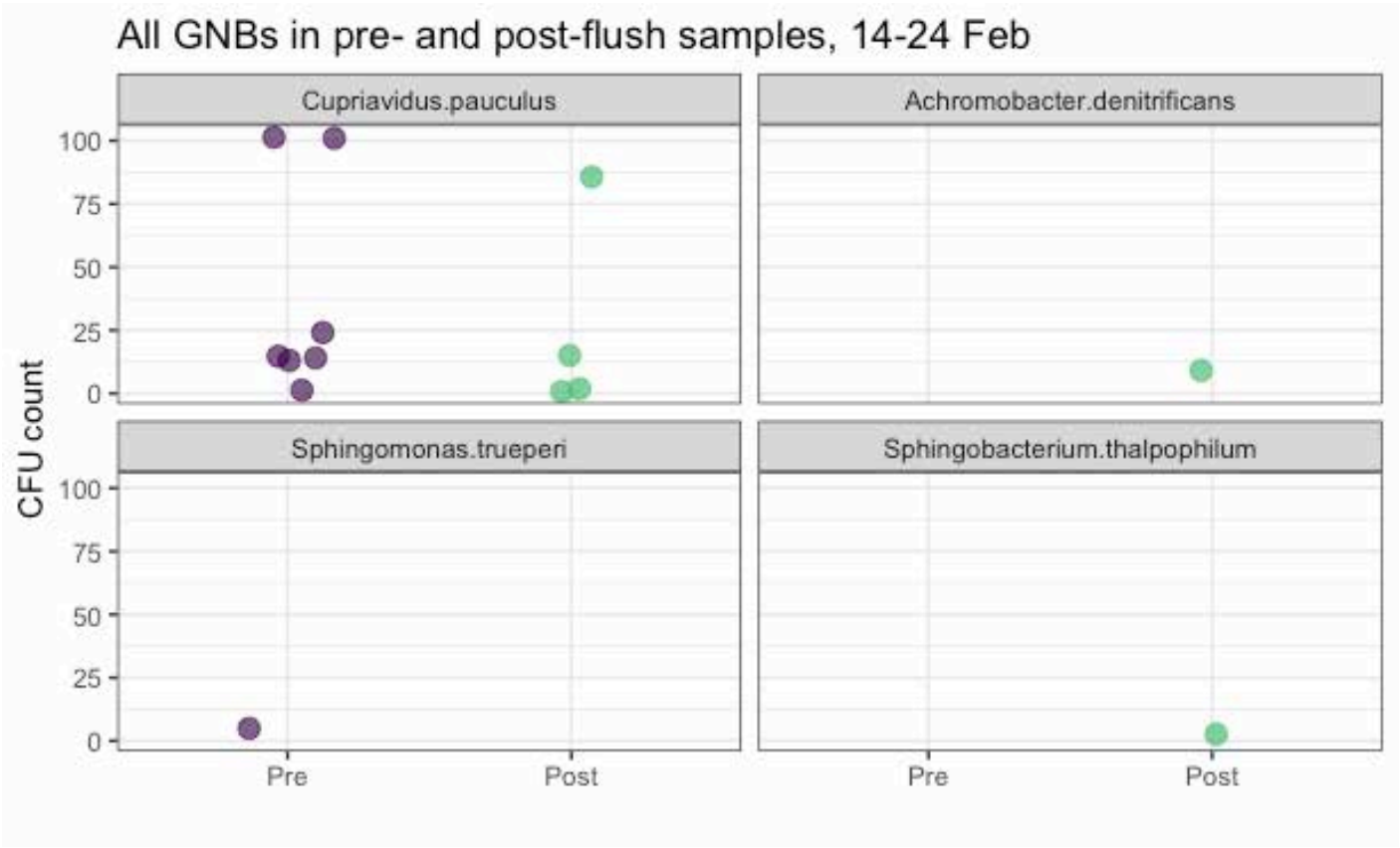


No significant difference between pre- and post-flush TVC22 ($p = 0.218$) or TVC37 ($p = 1.00$) results (zero-inflated generalised linear model with Poisson distribution).

The vast majority of samples from 14-24 Feb had no counts (total = 70 pre-flush and 70 post-flush samples).

Ward 2A/2B: Feb 2022

Pre- versus post-flush samples

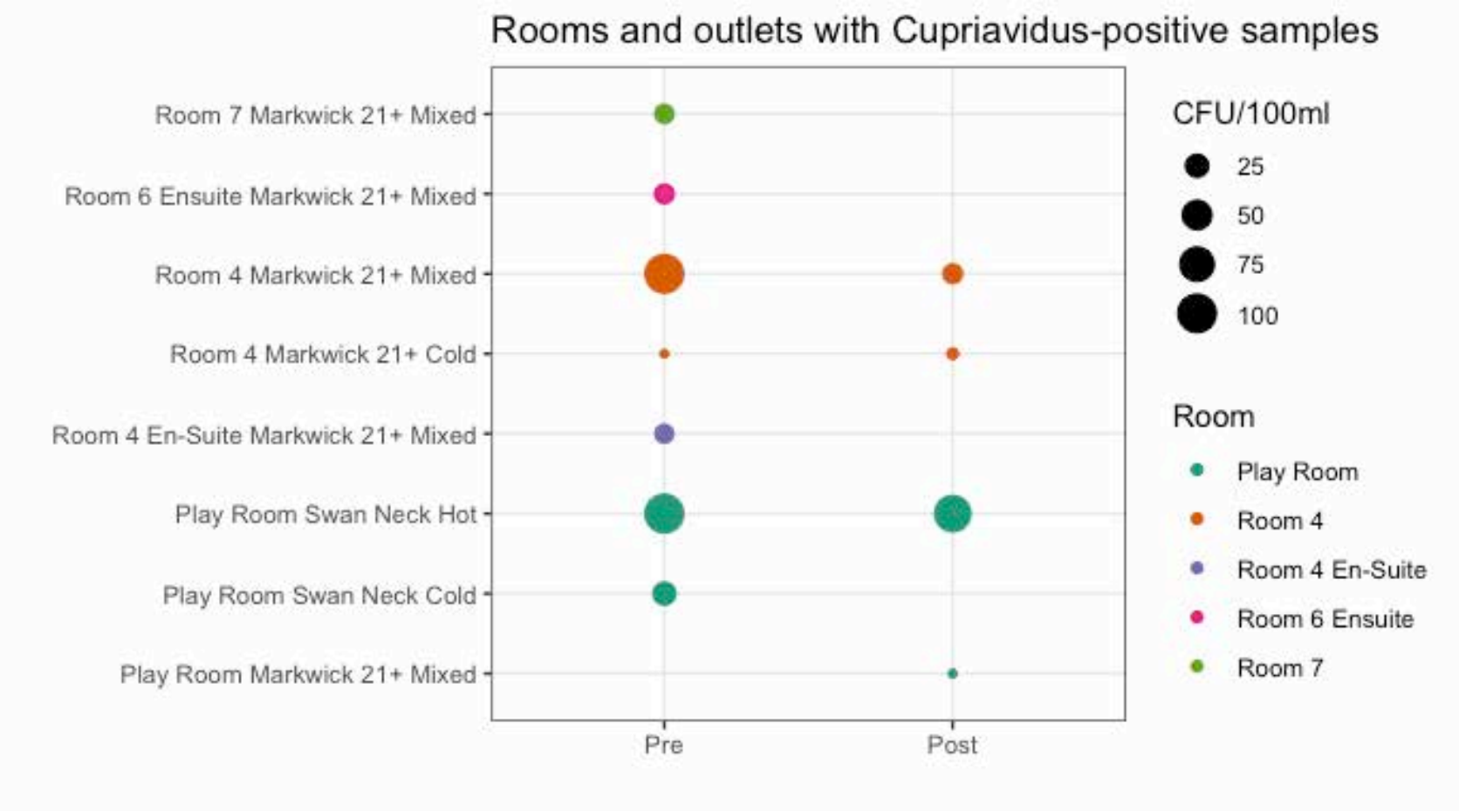


Significantly more *Cupriavidus pauculus* were detected in pre-flush samples (p = 0.0007, zero-inflated GLM with Poisson distribution).

But overall, low prevalence of *C. pauculus* and other organisms.
Points show samples with GNBs, out of 140 samples in total (70 pre-flush, 70 post-flush).

Ward 2A/2B: Feb 2022

Pre- versus post-flush samples, Feb 14-24



Seven pre-flush samples and 4 post-flush samples were positive for Cupriavidus. These were not randomly distributed across the ward.

Most Cupriavidus-positive samples were from the Play Room and Room 4. These outlets have been flagged for disinfection, per the Water Management Procedure.

Ward 2A/2B
Additional pre-flush results

- Pseudomonas results:
  - No counts on Pseudomonas tests in any sample from 2A/2B since mid-November 2021
  - No counts on Pseudomonas tests in any pre-flush sample from 2A/2B

- Legionella results:
  - Pre-flush Legionella testing in 2A/2B in Oct 2021 showed no counts in any sample (n = 186)
  - No Legionella were detected across the whole QEUH Adults and RHC in 2021

Royal Hospital for Children Ward 2A/2B water test results

Friday, 18 Feb 2022

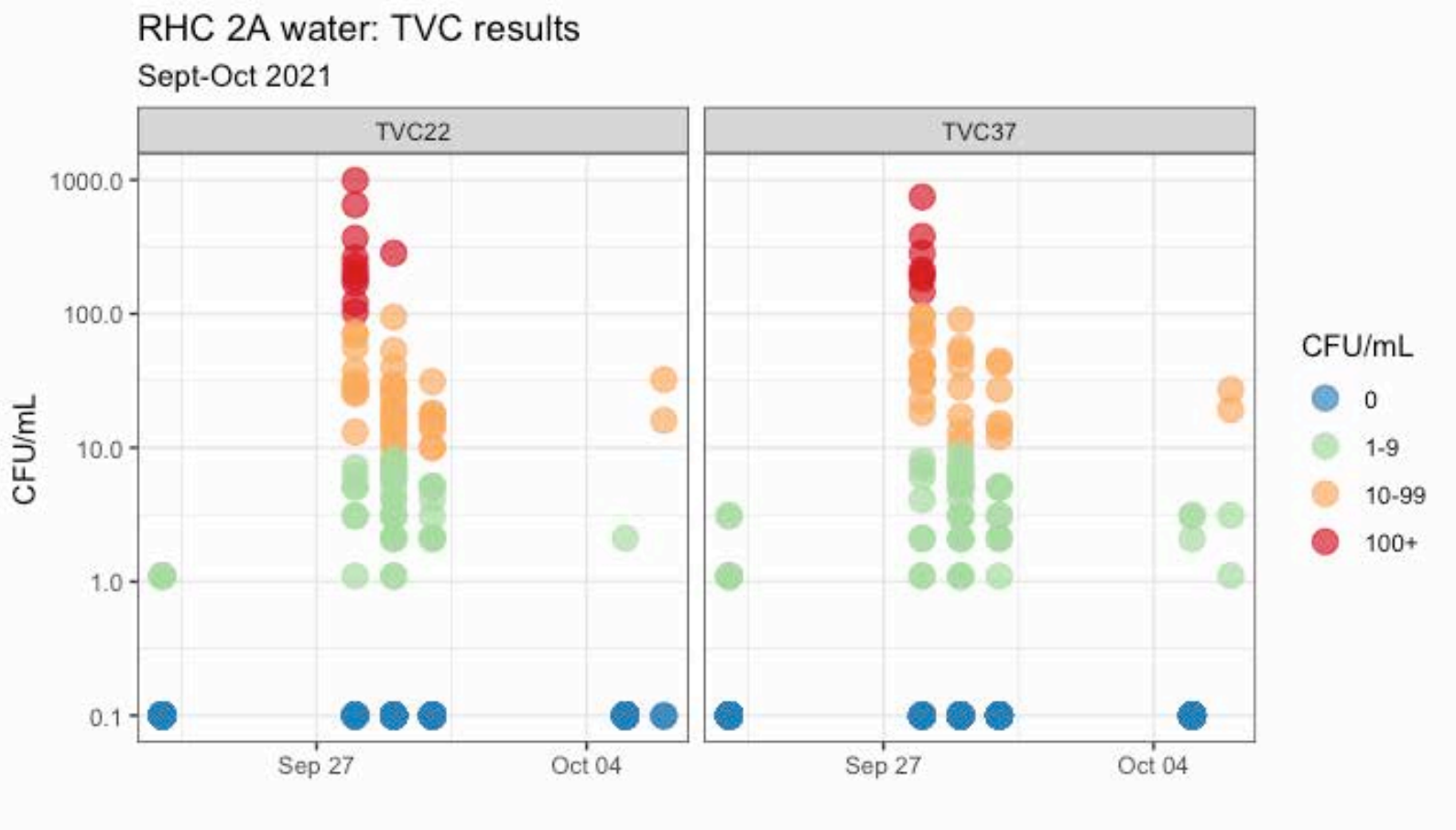
Including water testing results up to 9 Feb 2022

Dominique Chaput, DPhil (Oxon)

Healthcare Scientist, Scottish Microbiology Reference Laboratories, Glasgow

Ward 2A/2B: Sept-Oct 2021

Post-refurbishment water results



- Ward had been closed for refurbishment for an extended period
- Water testing in Sept-Oct showed high TVC22 and TVC37 counts

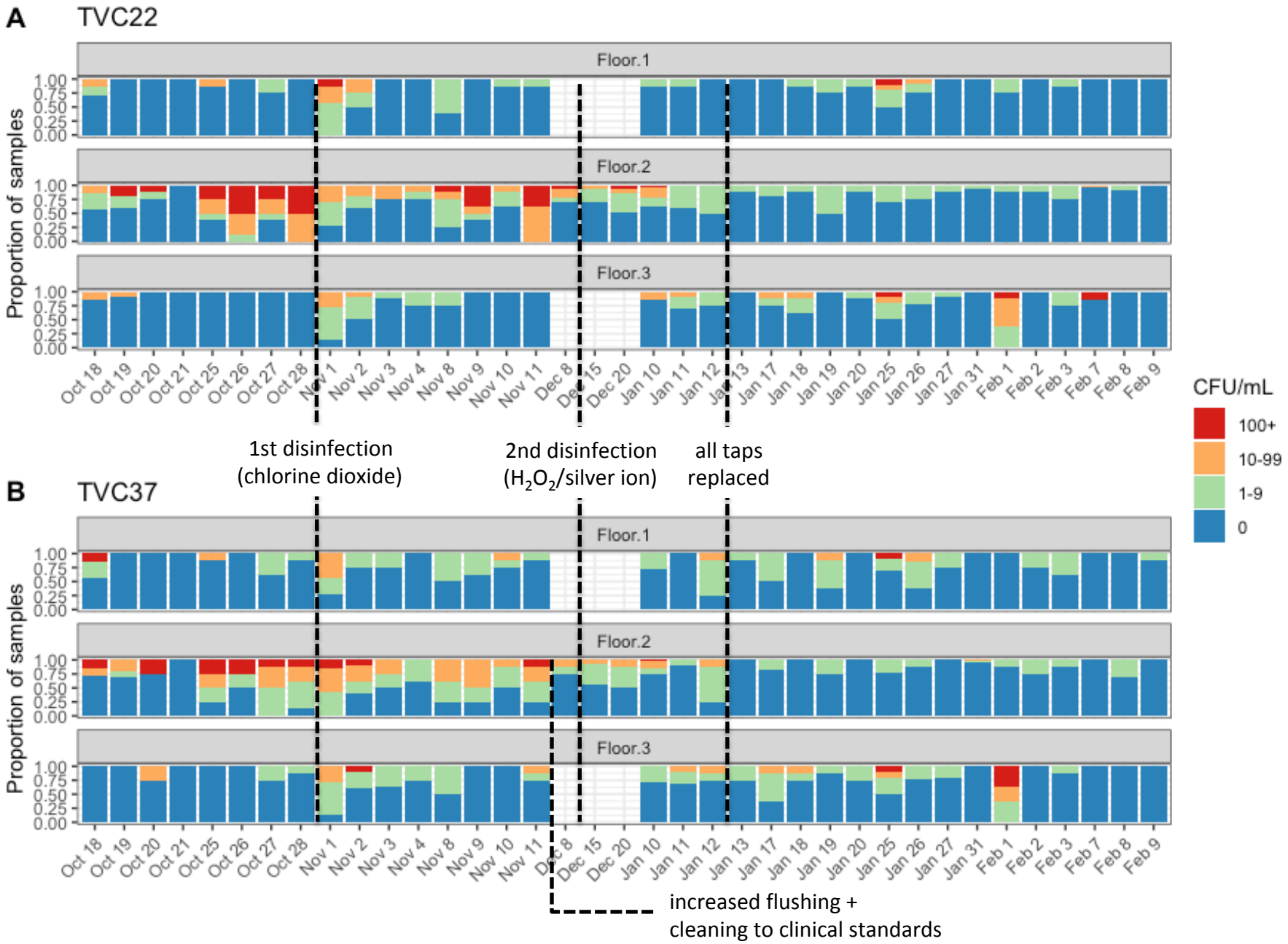
Ward 2A/2B: Oct-Jan interventions

- Chlorine dioxide treatment at the end of Oct did not reduce TVCs down to levels seen on other floors

- Additional tests:
  - Pipe sections removed from six rooms in 2A
  - Old cartridges removed and tested alongside new cartridges (to rule out contamination being introduced by new cartridges)

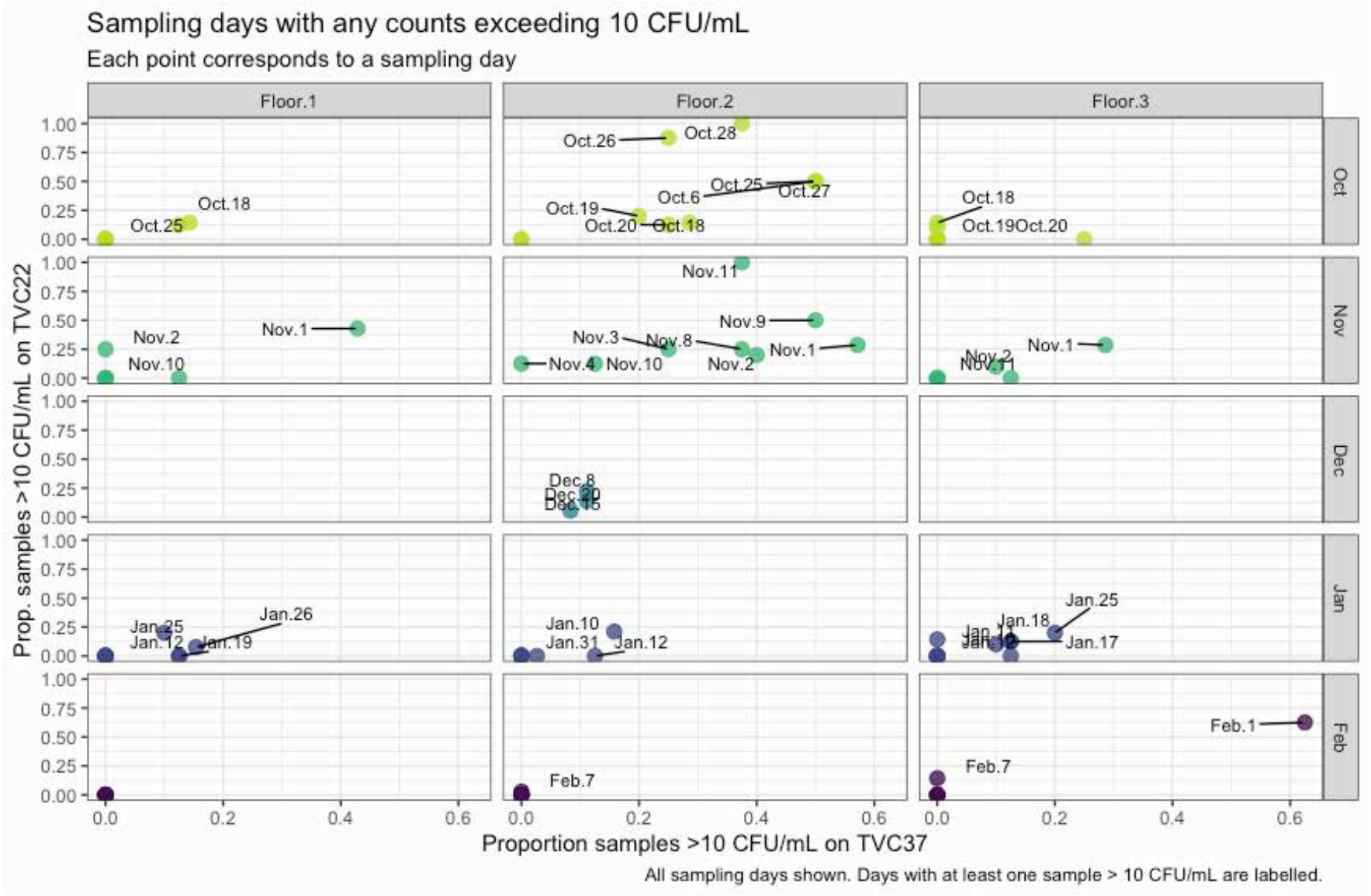
- Interventions:
  - Increased flushing to more closely mimic an occupied ward
  - Cleaning schedule to clinical standards
  - Hydrogen peroxide / silver ion treatment (2000 ppm H_2O_2) of entire ward 2A/2B on Dec 13
  - All Markwik 21+ taps replaced on Jan 10-12

Ward 2A/2B: Oct 2021 - Feb 2022

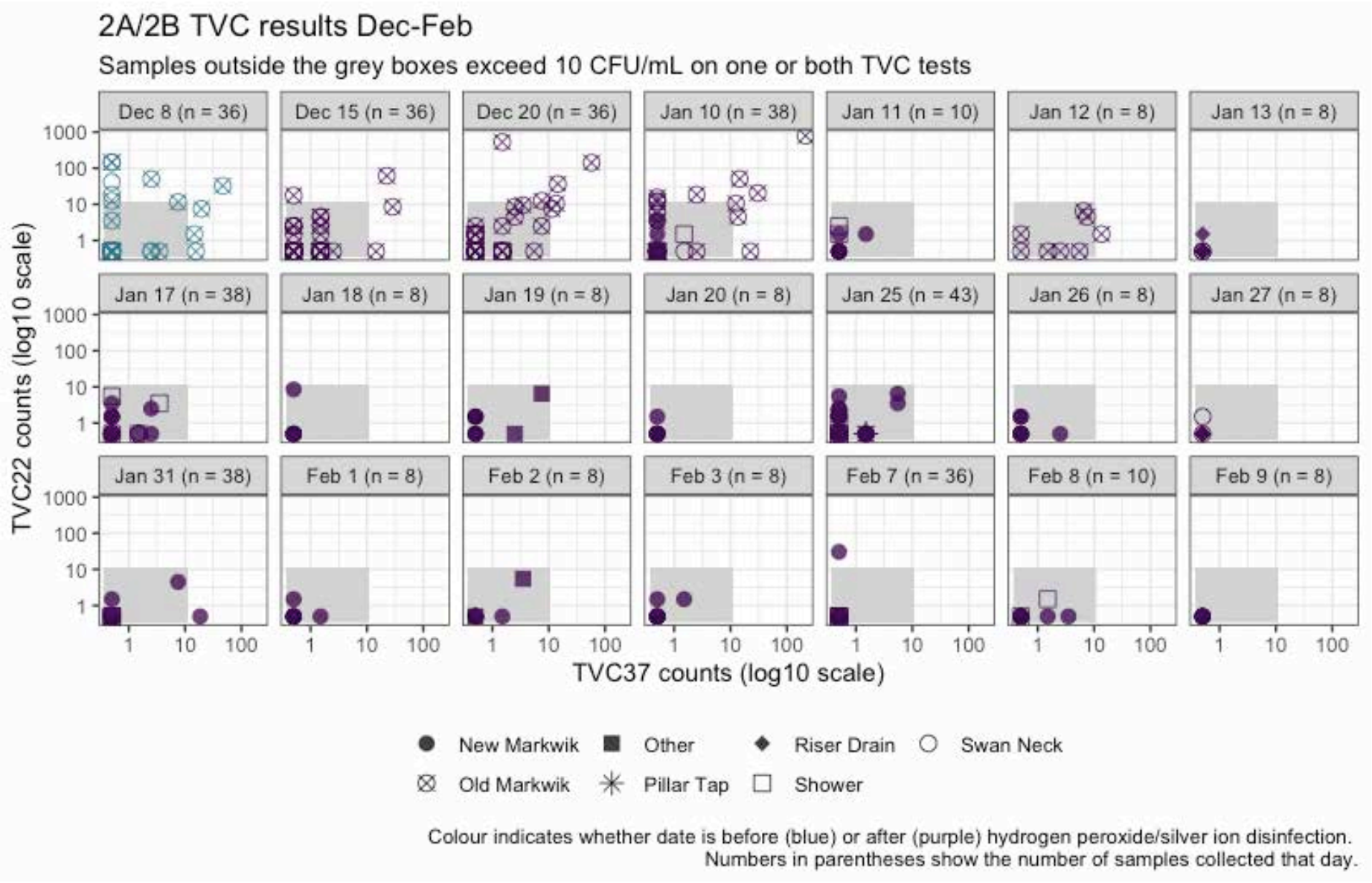


Ward 2A/2B: Oct 2021 - Feb 2022

Daily variability: 2A/2B now similar to floors below/above

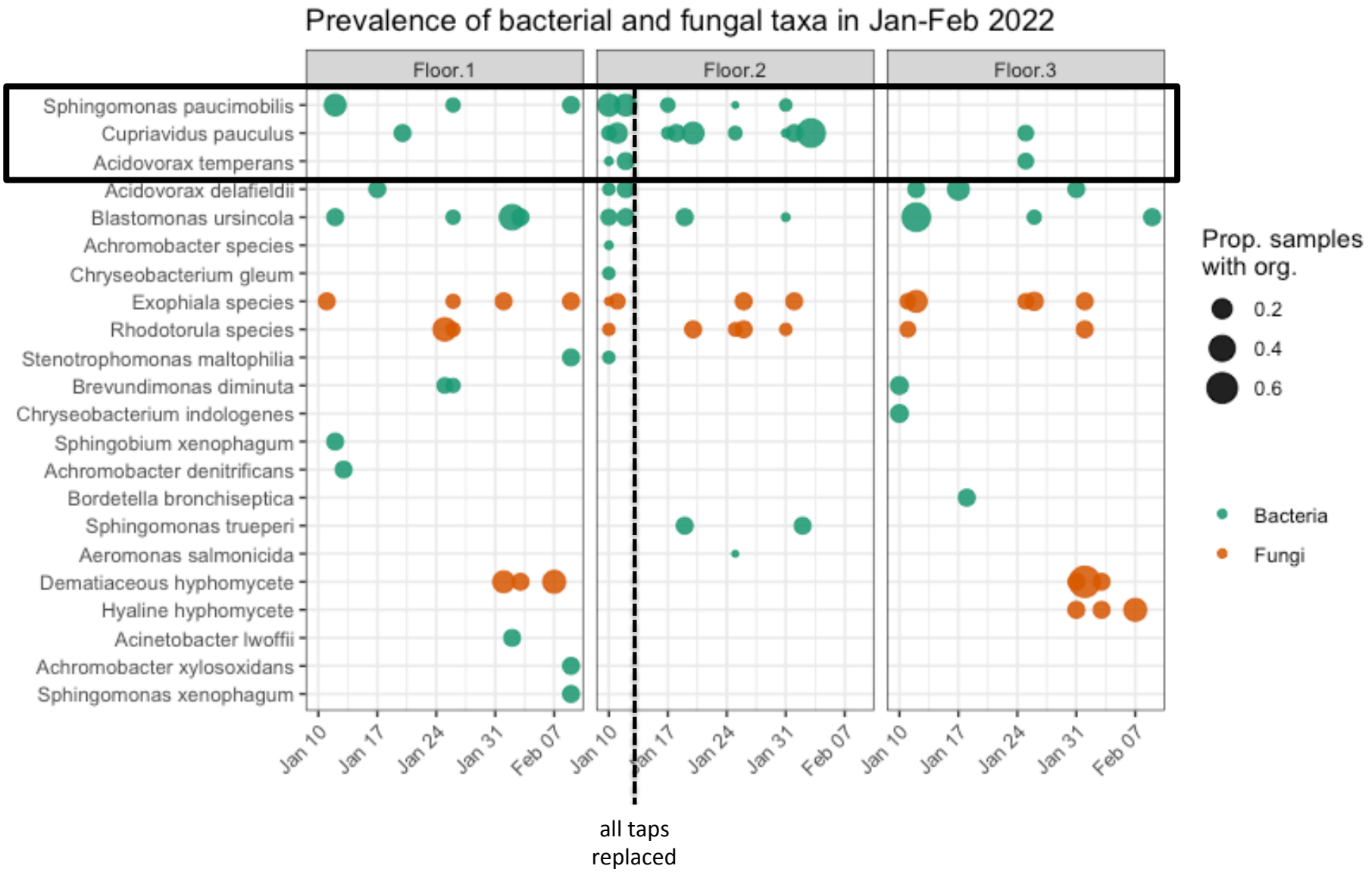


Ward 2A/2B: Dec 2021 - Feb 2022



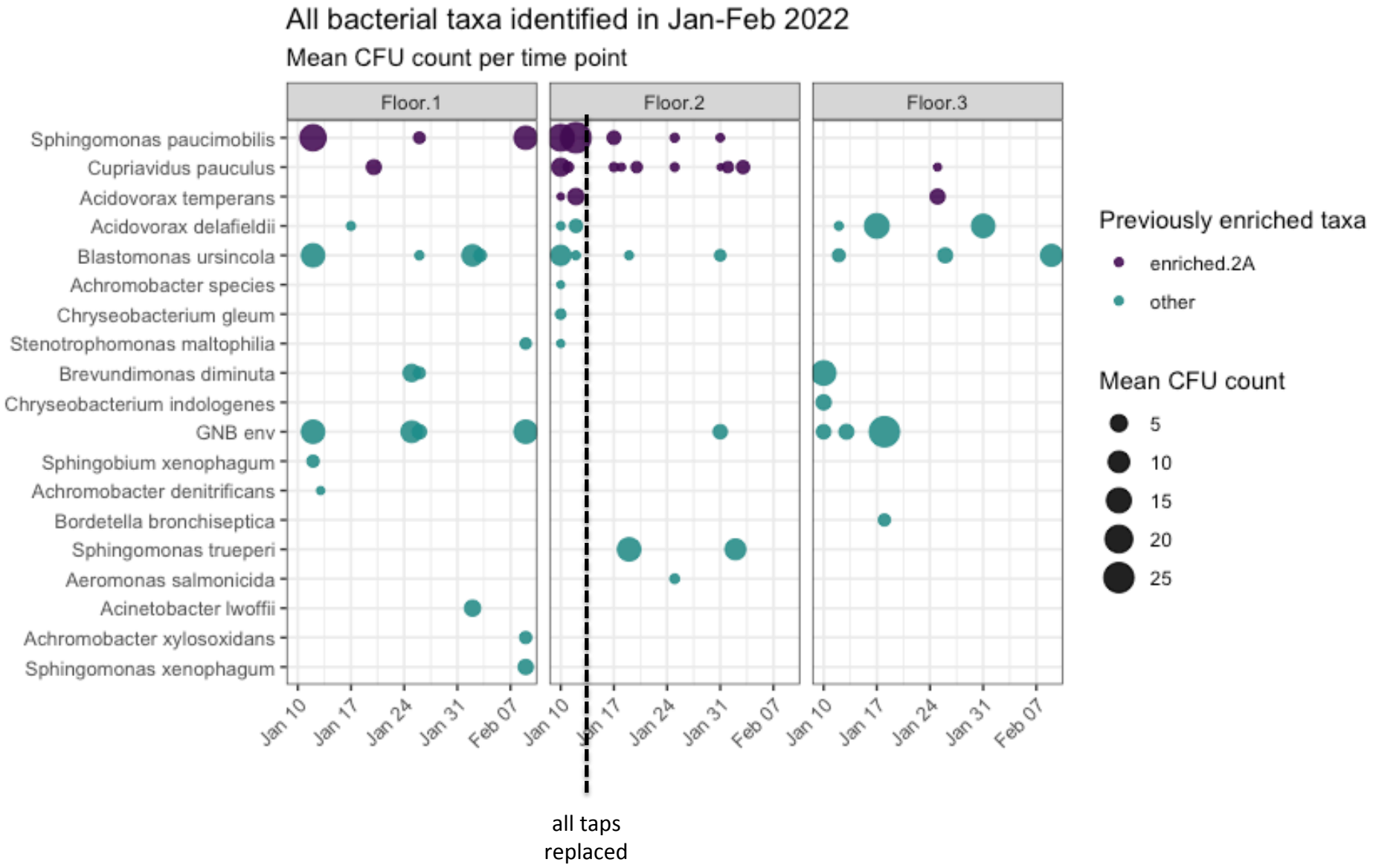
Ward 2A/2B: Jan-Feb 2022

Prevalence of all detected taxa (proportion of samples with org.)



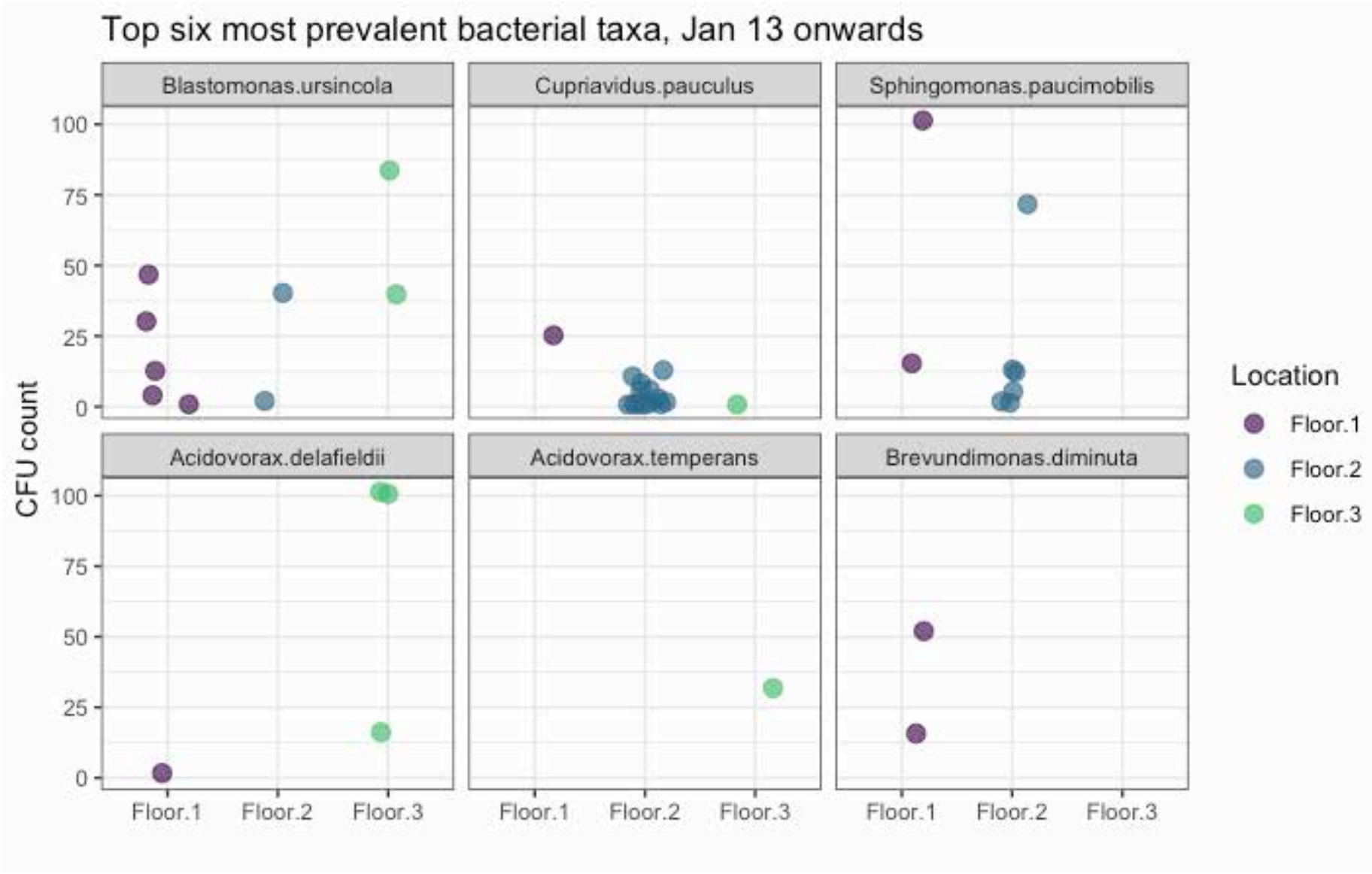
Ward 2A/2B: Jan-Feb 2022

Bacterial abundance (mean CFU/100 mL across all samples)



Ward 2A/2B: Jan-Feb 2022

All samples collected after taps were changed



QEUH Campus Water Systems

WRITTEN SCHEME

Controlling the risks of exposure to Legionella and other harmful bacteria in Water Systems

2023 Rev H

Reviewed by: E. Smith (RP)
K. Clarkson (DRP)
M. MacMillan (Lead AP)
A. Gallacher (Head of Compliance)
M. Feeney (Compliance Manager)

An electronic copy of this document is held on the QEUH Shared Drive at folder path:
S:\SCART Compliance\22 Water\Water Written Schemes\

Table of Contents

1.0 GENERAL OVERVIEW

Note 1: No work will be carried out on the water system without the knowledge and written consent of the Authorised Person (Water).

Note 2: This Written Scheme document is to be read in conjunction with the Operational Procedures for the Written Schemes document and should also be read in conjunction with the Control of Water Records document. For any alterations to the Water System this Written Scheme Document is to be read in conjunction with the Guidance for alterations to water systems document.

1.1 Introduction

This document contains six sections which have been derived from the Risk Assessment to aid the design, installation, maintenance and operational mode of all domestic and process water systems within the premises with respect to the likelihood of the proliferation of waterborne micro-organisms. The assessment also considered the risk of infection presented to building users and the general populous at large, and derived a series of risk ratings and appropriate Remedial Actions and Control Measures, which should be implemented to minimise the presented risks. This Risk Assessment was carried out in a manner consistent with the requirements of *BS8580:2010 Water Quality – Risk Assessments for Legionella Control – Code of Practice*, and is reviewed whenever system alterations or operational considerations may effect a change in the risk.

Section 1 contains an Executive Summary of the recommended control measures and corrective actions together with an overview of the QUEH Site layout and accommodation.

Section 2 contains a record of the logbook inspection, details on the location of records, defects, non-compliance issues, correspondence and archived information.

Section 3 provides information on the management structure associated with the control scheme for the water system and clear definitions of responsibilities held by those named, details of training undertaken and a summary of the designated tasks as detailed in section 4.

This section also provides information on the details of the risk assessment values associated with representative outlets, systems and plant items undertaken since 2013. A generic risk assessment for any positive legionella test results within designated Low Risk locations and a description of the installed plant and equipment with associated schematic layout plans for each of the installed water systems within the site is also contained within this section.

Section 4 of the document details the safe operation of the system and all appropriate Maintenance Procedures (Control Measures) which were derived from the Risk Assessment and recommendations within NHS Greater Glasgow and Clyde Water Systems Safety Policy.

This section of the document contains a task description with associated record (Log) sheet relating to these activities. It should be noted however, that in certain circumstances, specialist contractors are required to implement some Control Measures, and records pertaining to these activities may be held under separate cover. Such activities would typically include those associated with chemical water treatment regimes and drinks vending machines sanitising maintenance.

Refer to Section 2 for the location of records and archived information associated with the maintenance procedures and other control measures.

Section 5 contains supporting information relating to the Control Scheme, and should typically include the recording of system alterations or remedial actions together with utilised materials. Ad hoc maintenance activities should also be recorded in this section, such as system sterilisations which may be required from time to time. This section of the document also contains a glossary of supporting publications, where additional information relating to the risks associated with waterborne micro-organisms, and water quality generally, may be found.

1.2 Executive Summary

The purpose of this Written Scheme document is to assist in the correct and safe operation of the water systems within the QEUH Campus. The document outlines the specific roles, responsibilities, training requirements and regular maintenance procedures to be followed in order to ensure compliance with statutory and mandatory guidance.

Risk Assessments for the water services have been carried out on the instruction of the Board Water Safety Group. DMA Canyon Ltd are presently the appointed Water Systems Risk Assessor and have carried out Risk Assessments within all individual buildings on the campus.

Additionally there are two Hydrotherapy Pools in operation on the campus. These are situated within the New Childrens Hospital, and Spinal Injuries Unit. Separate Risk Assessments have been carried out for both of these facilities by a specialist Swimming Pool Risk Assessment provider.

Risk Assessments require to be reviewed and updated to reflect any changes in-use and / or functions that have taken place since the date of the original Risk Assessment or in the event of control measures becoming ineffective, changes in key personnel or in the event of a case of legionnaires disease / legionellosis associated with the water system. Guidance on the Risk Assessment review procedure is given in Appendix 3.

All documentation and log sheets used to record maintenance activities follow the format contained within guidance document SHTM 04-01 Part G: *Operational Procedures and Exemplar Written Scheme.*

1.3 Overview of Site Accommodation and Premises

The main new-build Adult Hospital building comprises of 12 stories, with the basement housing FM areas and the new-build Childrens Hospital comprising of 4 stories.

On the retained estate there are individual buildings comprising of Neurology, Neurosurgery, Spinal Injuries Unit, PDRU, Maternity, Neo-Natal, Podiatry and Westmarc stand alone with the Teaching and learning and office block new additions.

Full descriptions and information on the individual written schemes are available in the Log book/Risk Assessment folders for each building.

The building codes are as follows:

AC – Minor Injuries Unit
AQ – Acute Medical Block (AMB)
AS – Central Medical Block (CMB)
BC – Neurosurgical Block (INS)
BL – Maternity
BW – Neurology
DA – Spinal Injuries
DB – Maternity Day Surgery
DD – Podiatry
DE – Physically Disabled Rehabilitation Unit (PDRU)
DI – WestMARC
EA – Neo Natal
FA – Multi Storey Car Park 2
FB – Multi Storey Car Park 1
GA – Laboratory Medicine
GB – Energy Centre
HA – Adults Hospital
HB – Childrens Hospital
IA – Teaching & Learning Centre
IB – Office Building
IC – Imaging Centre of Excellence (ICE)

NOTE: ICE building is owned by University of Glasgow (UoG). Facilities management and maintenance is carried out under contract by NHS GG&C on behalf of UoG.

Langland Building is managed via PFI by Serco and MDU is managed via Vanguard.

See Site Map in Appendix 1

2.0 RECORDING

2.1 Written Scheme Inspection Records

Anyone inspecting this written scheme (either as part of the Management Control System or otherwise) is invited to make an entry in this inspection record. **Under no circumstances may this Written Scheme or any part of it be removed from site.**

Date/Time	Comments	Signature	Position
June 2018	Written scheme has been reviewed and re-formatted into this current form (Revision D) by Colin Purdon as part of the water systems review.		Site Manager Operational Estates
Feb 2019	Written scheme has been reviewed and re-formatted into this current form (Revision E) by Colin Purdon as part of the water systems review.		Interim Sector Estates Manager (Deputy Responsible Person)
May 2019 Rev B	Written scheme has been reviewed and re-formatted into this current form (2019 Rev A) by Colin Purdon as part of the water systems review.		Interim Sector Estates Manager (Deputy Responsible Person)
October 2020 Rev C	Written scheme has been reviewed to reflect changes to staff personnel and a review of procedures.		Site Manager Operational Estates
May 2021 Rev D	Written scheme has been reviewed to reflect changes to staff personnel and a review of procedures.		Site Manager Operational Estates
Aug 2022 Rev E	Written scheme has been reviewed to reflect changes to staff personnel and job titles. Additionally modified procedures for WS01 (Page 103)		Site Manager Operational Estates
Jan 2023 Rev F	Minor changes to words regarding daily flushing		Site Manager Operational Estates
May 2023 Rev G	Index section 2 missing now added back in		Site Manager Operational Estates
July 2023 Rev H	Inclusion of Vanguard who carry out maintenance of the MIU Unit and minor changes to wording.		Site Manager Operational Estates

Additional entries should be completed on a separate sheet and inserted in Section 2.1 with this sheet.

2.2 Location of Records and Correspondence

Details of any correspondence, including Risk Assessments/Reviews and Ongoing Monitoring Reports, relating to water services should be entered on the sheet below, recording where held and by whom.

Date	Procedure or Record ref	Description	Held by/location
16/07/18	Flushing Outlets 026	Email correspondence in relation to Flushing DCFP kitchen dishwasher and outlets with John Heron and Adam Wright	Colin Purdon email archive. Hard copy in correspondence logbook

Additional entries should be completed on a separate sheet and inserted in Section 2.2 with this sheet.

2.3 Non-Compliance Issues and Fault Detail Log

Record Form 004

All non-compliance and fault details in relation to the individual systems in each building must be recorded on Record Form 004 and brought to the attention of the Water Systems Lead AP as soon as possible. This process ensures that all non-compliance issues are documented, managed effectively and tracked through to completion and close –out of the issue. Copies of Record Form 004 are to be stored within the shared drive. SCART Compliance/22 Water/.

The process for sampling out of specification is documented in WQS – 017 Procedures in the event of out of specification sample for Legionella and other monitored bacteria, moulds etc.

2.4 Archived Information Record Sheet

All records associated with the management or maintenance procedures within this Written Scheme should be kept for a period of five years after they are no longer current. Records should be kept locally within the main Estates Office. The details of any archived information held separately in secure storage should be recorded in the table below.

Date	Procedure or Record Reference	Description	Held By/Location

Additional entries should be completed on a separate sheet and inserted in Section 2.4

2.5 Equipment Calibration Records

All equipment used for the measurement of temperatures should be calibrated at least annually to ensure the accuracy and consistency of the recording procedures.

Calibration certificates for handheld thermometers are held in hard copy within the QEUH Campus Log Book suite in the main estates office. Electronic copies are also held on the QEUH Shared Drive>Water Quality folder.

3.0 MANAGEMENT ARRANGEMENTS

3.1 Roles & Responsibilities

NHS Greater Glasgow & Clyde Chief Executive – (Duty Holder)	The Chief Executive has ultimate responsibility / accountability for water system safety within NHSGG&C. The responsibilities of the Chief Executive include: • Responsibility for implementation of the relevant mandatory and statutory elements contained within the Health & Safety Commissions Approved Code of Practice and Guidance "Legionnaires Disease. The control of Legionella bacteria in water systems" L8 (ACOP L8), SHTM04-01: The control of Legionella, hygiene safe" hot water, cold water and drinking water systems and CEL 08(2013) water sources and potential risk to patients in high risk units – revised guidance. The implementation of Guidance for neonatal units (NNU's) (levels 1, 2 & 3) adult and paediatric intensive care units ICU's in Scotland to minimise the risk of Pseudomonas aeruginosa infection from water. • Ensuring that adequate resources are provided to meet the Water Systems Safety requirements of NHSGG&C estate. Ensuring that the Water Systems Safety Policy is being implemented at all levels. • Reviewing and monitoring the operation of the Water Systems Safety Policy through the Board Corporate Management Team and ensuring that clear guidelines are provided for this tasked with compliance of legislative and statutory standards. • Appointing the Designated person (Pseudomonas) and Designated Person (Water) to assist in the execution of these responsibilities, who for NHSGG&C are the Infection Control Manager (Pseudomonas) and the Director of Facilities (Water).
NHS Greater Glasgow & Clyde Director of Estates and Facilities – (Duty Holder)	The Director of Estates and Facilities is the Designated Person (Water). They shall be responsible for: • Ensuring that Estates and Facilities staff, through the general management structure is fully aware of the current statutory and mandatory requirements and standards for the provision and maintenance of safe water systems. • Ensuring with the Responsible Person (Pseudomonas) that the Water System Safety Policy is regularly reviewed and updated. • Co-Chair the NHSGG&C Water Systems Safety Group. • Appointing in writing the Responsible Person (Water) at sector level and Deputy Responsible Person(s) (Water) at site level. This shall be the Sector Estates Manager (SEM) and the relevant Site Manager Operational Estates (SMOE)/Site Estates Manager within the Facilities Directorate management structure.

3.1 Roles and Responsibilities (cont)

NHS Greater Glasgow & Clyde Director of Estates and Facilities – (Assistant Duty Holder)	The Assistant Director of Estates and Facilities is the Assistant Designated Person (Water). They shall be responsible for assisting in : • Ensuring that Estates and Facilities staff, through the general management structure is fully aware of the current statutory and mandatory requirements and standards for the provision and maintenance of safe water systems. • Ensuring with the Responsible Person (Pseudomonas) that the Water System Safety Policy is regularly reviewed and updated. • Co-Chair the NHSGG&C Water Systems Safety Group. • Appointing in writing the Responsible Person (Water) at sector level and Deputy Responsible Person(s) (Water) at site level. This shall be the Sector Estates Manager (SEM) and the relevant Site Manager Operational Estates (SMOE)/Site Estates Manager within the Facilities Directorate management structure.
NHS Greater Glasgow and Clyde Infection Control Manager - Designated Person (Pseudomonas)	The Infection Control Manager supported by the Board Infection Control Doctor is the Responsible Person (Pseudomonas). They shall be responsible for: • Ensuring that Infection Control Teams are fully aware of current guidance on Legionella control matters and the minimisation of the risk of Pseudomonas aeruginosa infection from water. • The implementation of Guidance for neonatal units (NNU's) (levels 1, 2 & 3) adult and paediatric intensive care units ICU's in Scotland to minimise the risk of Pseudomonas aeruginosa infection from water. • Ensuring with the Designated Person (Water) that the Water System Safety Policy is regularly reviewed and updated. • Co-Chair the NHSGG&C Water Systems Safety Group. • Appointing in writing the Responsible Person(s) (Pseudomonas) at sector level. This shall be the relevant Infection Control Doctor.
Assistant Head of Estates - Responsible Person (Water)	The Assistant Head of Estates will be appointed as the Responsible Person (Water) at Sector level by the Director of Estates and Facilities in writing. The Sector Estates Manager is responsible for: • Ensuring the effective maintenance of engineering controls installed for the purposes of controlling water systems. • Ensuring that written schemes and risk assessments are in place and reviewed regularly. • Devising and maintaining procedures to ensure the quality of water on premises is maintained. • Ensuring operational procedures are carried out and documented. • Ensuring records are kept of all water systems and their purpose, giving locations recording and maintaining within the Boards estates management system. • Liaise closely with other professionals to ensure legislative and statutory compliance is maintained by the Board.

3.1 Roles and Responsibilities (cont)

3.1 Roles and Responsibilities (cont) **Authorising Engineer (AE)**	An Authorising Engineer acts as an independent professional advisor to the healthcare organisation, appointed by the organisation with a brief to provide services in accordance with Scottish Health Technical Memorandum (SHTM) guidance. He will be appointed in writing by the Director of Facilities/General manager (Estates). The Authorising Engineer acts as an assessor, making recommendations for the appointment of Authorised Persons, monitoring the performance of the service and providing an annual audit to the organisation's Designated Person.
Authorised Person (Water)	The Authorised Person (water) has the key operational responsibility for the service, qualified, sufficiently experienced and skilled for the purpose. They will be nominated by the Authorising Engineer and be able to demonstrate • They application through familiarization with the system and attendance at an appropriate professional course; • A level of experience; • Evidence of knowledge and skills. An important element of the Authorised Person (Water) role is the maintenance of records, quality of service and maintenance of system safety (integrity). The Authorised Person (Water) will also be responsible for establishing and maintaining the roles and validation of Competent Persons (Water) who shall be suitable trained employees of the organisation or appointed contractors. Larger sites may require more than one Authorised Person (Water) for a particular service. The Authorised Person (Water) will be appointed by the General Manager – Capital Planning.

3.1 Roles and Responsibilities (cont)

Head of Capital Planning (Water)	The Head of Capital Planning will be appointed as the Deputy Responsible Person (Water) at Board level by the Director of Estates and Facilities in writing. The General Manager for Capital Planning is responsible for: • Ensuring that any new works undertaken or refurbishment within existing premises shall comply with the requirements of this Policy and the Written Scheme and Operational Procedure for managing Water Safety including The control of *Legionella*, hygiene, 'safe' hot water, cold water and drinking Water systems and The implementation of Guidance for neonatal units (NNU's) (levels 1, 2 & 3) adult and paediatric intensive care units ICU's in Scotland to minimise the risk of Pseudomonas aeruginosa infection from water. • Ensuring that all potential interfaces between an operating system and new and refurbishment works shall meet the approval of the Responsible Person (Water) and Authorised Person (water) as to methodology for making that interface. • Ensuring that any work involving the installation of water services or equipment requiring a water supply shall follow the guidance in SHTM 04-01 and HSE document L8 and shall be certified by the design Engineer as to that compliance. • Ensuring that any works which will affect an operational water service will be discussed with the Estates Authorised Person (Water) prior to arranging that work.
Site Estates Manager Deputy Responsible Person (Water)	The Site Manager Operational Estates (SOME) shall be appointed in writing by the Director of Facilities/General Manager (Estates) in writing as the Deputy Responsible Person (Water) and will also act as the Designated Person Water in the absence of the Designated Person (Water). The Site Maintenance Manager/Site Estates Manager is responsible for: • Ensuring all staff conducting water system maintenance are competent to do so. • Ensuring water system maintenance records are maintained and kept up-to-date. • Regularly checking maintenance records. • Ensuring all work is completed in accordance with the NHS GG&C Estates Procedures.

3.1 Roles and Responsibilities (cont)

Acute Services Directors CH(C)P Directors and Corporate Division Directors	As Senior Managers, NHSGG&C Directors play an intrinsic role in ensuring that water safety is embedded within the culture of the organisation. The responsibilities of Directors include: • Supporting the designated person (Water) and (Pseudomonas) in the development of the Board's overall strategy in relation to water safety and for ensuring implementation within their areas of responsibility; • Ensuring that all staff are made aware of their requirement to attend Water Safety training at the appropriate frequency, as per the NHSGG&C Water Safety Policy and Operational Procedures which underpin this by facilitating staff release from duties to attend training; • Supporting action to address staff who put themselves and/or others at risk from a real or potential water safety incident.
Heads of Service, Departmental Managers, Clinical Managers, Senior Charge Nurse's	All managers who have a responsibility for the day to day management of facilities, staff or services, and/or premises, have water safety responsibilities that include: • Familiarise themselves with the NHSGG&C Water Safety Policy and local control measures including any water risk assessments for their area(s) of responsibility; • Ensuring that persons in the department, clinic or ward are fully aware of their responsibilities and duties in respect of Water Safety, in particular, the action required of them should the area be defined as High Risk by the local Water Safety Group • Ensure that persons in the department, clinic or ward are fully aware of the Infrequently Used Outlets definitions and Operating Procedure which underpins the NHSGG&C Water Safety Policy
Heads of Service, Departmental Managers, Clinical Managers, Senior Charge Nurse's (cont)	• Actively promoting Water Safety within the department or ward by maintaining good housekeeping within the department or ward at all times, ensuring that any flushing or documentation as described in the Water Safety Written Scheme and Operational Procedures documentation is completed on time • Responding appropriately to any water safety concerns that persons in the department, clinic or ward have; • Nominating a responsible person to complete the Monthly Infrequently Used Outlets Audit for each area, forwarding a copy to the Site Maintenance Manager, thereby assisting NHSGG&C to meet its statutory and mandatory requirements; • Ensuring that action is taken on a daily basis to address any access issues identified within the Cleaning Compliance Checklist Sign Off documentation retained in the Facilities Folder. • Liaising with the estates department as required

3.1 Roles and Responsibilities (cont)

Legionella Risk Assessor	The NHS Board appoints in writing a Legionella Risk Assessor with terms of reference to provide services in accordance with BS 8580, SHTM 04-01 and HSE guidance under this Policy. He/she will be appointed in writing by the Director of Facilities/General Manager (Estates)
Competent Person (Water)	The Competent Person (Water) provides skilled installation and/or maintenance of the specialist service. He/she will be appointed, or authorised to work (if a contractor) by the Authorised Person Water). He/she will demonstrate a sound trade background and specific skill in the specialist service, working under the direction of the Authorised Person (Water) in accordance with operating procedures, policies and standards of the service.
Maintenance Tradesperson	A Maintenance Tradesperson is someone who has sufficient technical knowledge and the experience necessary to carry out maintenance and routine testing of the water supply, storage and distribution system.
Installer	The Installer is the person or organisation responsible for the provision of the water storage and distribution system.
Contractor	A Contractor is the person or organisation designated by management to be responsible for the supply, installation, validation and verification of hot and cold water services, and for the conduct of the installation checks and tests in relation to the control of *Legionella*. The NHS Board will expect potential contractors to have suitable qualifications (for example companies/individuals who are members of the *Legionella* Control Association).

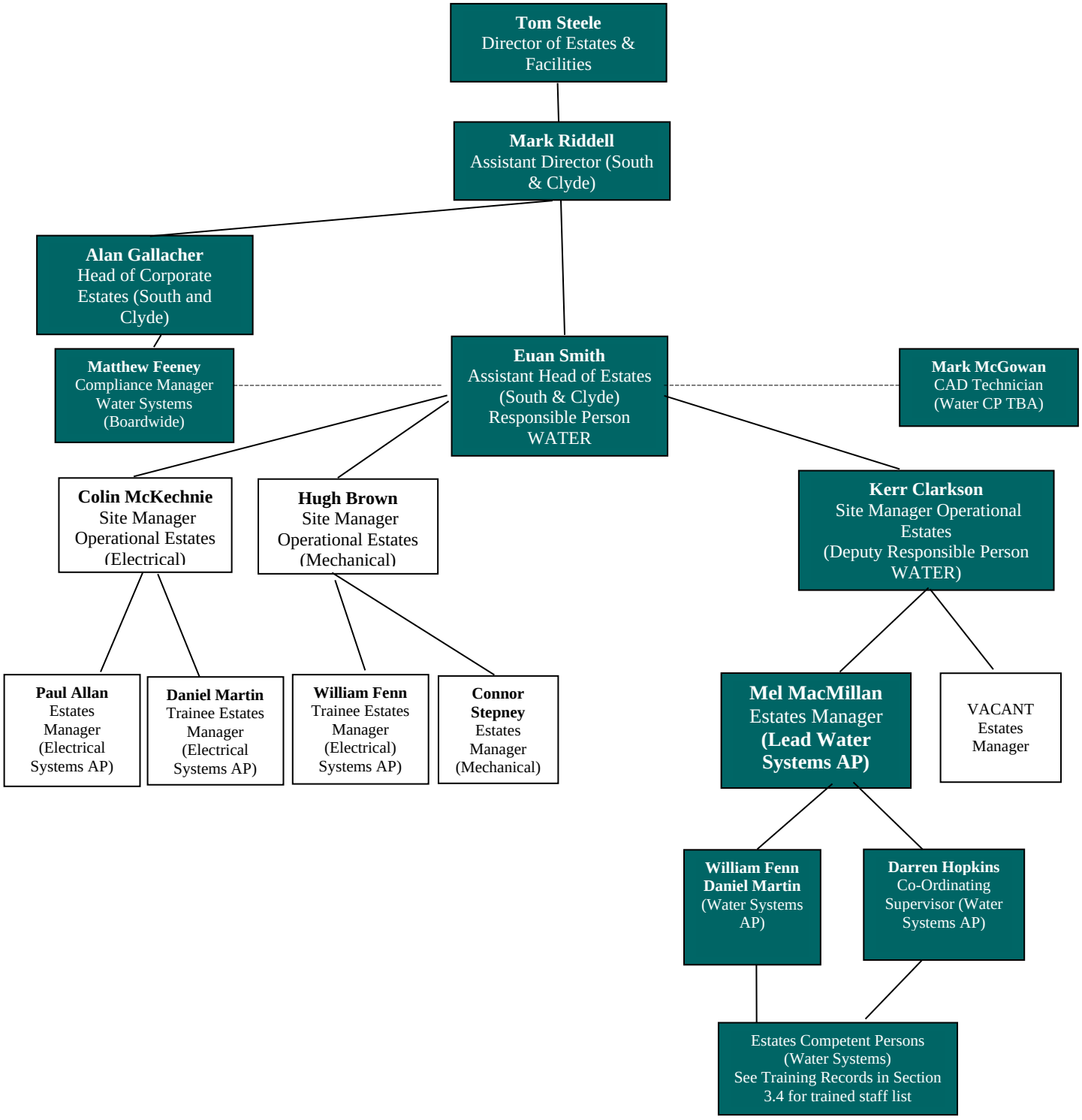
3.1 Roles and Responsibilities (cont)

NHS GG&C South Sector (QEUH) Hierarchy Appointment Table

Designation	Position	Name Tel Number
The Duty Holder	Chief Executive	Jane Grant
Designated Person (Water)	Director of Facilities/General Manager (Estates) Assistant Director (Estates)	Tom Steele Mark Riddell.
Authorising Engineer (Water)	AE	Dennis Kelly [redacted]
Legionella Risk Assessor	DMA Water Services Ltd	David Watson Mike Kinghorn [redacted]
Responsible Person (Water)	Sector Estates Manger (South)	Euan Smith
Deputy Responsible Person (Water)	Site Manager Operational Estates (Building)	Kerr Clarkson
Deputy Responsible Person (Water)	Head of Capital Planning	James Huddleston
Lead Authorised Person	Estates Manager	Mel MacMillan
Authorised Persons	Estates Manager Co-ordinating Supervisor Co-ordinating Supervisor Co-ordinating Supervisor	Darren Hopkins Grant Bennet William Fenn Daniel Martin
Competent Persons	CAD Technician	Mark McGowan
Competent Persons	Plumbers/Engineers	See training records in Section 3.4
Others Involved		
Microbiology	Consultant Microbiologist	Alistair Leonard Linda Bagrade Aleksandra Marek
Infection Control	Director Lead Nurse Lead Nurse	Sandra Devine Gillian Bowskill Lynn Pritchard
Public Health		Dr Iain Kennedy
Laboratory Services		Sandra Higgins

3.2 QEUH Estates Staffing

Management organogram for QEUH Estates Dept as of Oct 2019



3.3 Required Maintenance Tasks

The maintenance and management of the water systems throughout the QEUH Campus is undertaken by a combination of both NHS Staff and external Contractors at the frequencies identified in the following tables.

QEUH Management staff manage and oversee the following tasks:

Procedure Reference	Operation(s)	Record Form Ref	Frequency
P1C1	BMS Temperature Monitoring (**Carried out by NHS Estates**)	**Requires new number**	***Daily***
P1CC1A	Manual Temperature Monitoring for calorifiers (different form used ONLY REQUIRED if no BMS Monitoring	**(005a)**	***Daily***
N/A	Filtration Plant Checks (**Carried out by NHS Estates**)	**028c**	***Twice Daily***
WS01	Daily flushing of all outlets (**Carried out by NHS Facilities**)	**-**	***Daily***
WS01	Deluge shower/Eye wash flushing (**1 off carried out by NHS Estates and 1 off by DMA**)	**(026)**	***Twice Weekly***
WS01	Flushing of little used outlets * frequency based on risk (**Carried out by NHS Clinical**) see page 103	**-**	***Daily or Twice weekly***
P1C3	Pump operation/duty rotation (**Carried out by NHS Estates**)	**(028a)**	***Weekly***
P1C4	Temperature Recording of Sentinel Hot and Cold Water Outlets. (**Carried out by NHS Estates**)	**(005c)**	***Monthly***
P1C4	DHW Calorifier and Buffer Vessel Checks (**Carried out by NHS Estates**)	**(005)**	***Monthly***
P1C6	DWS Calorifier, Expansion Vessel Flushing (**Carried out by NHS Estates**)	**(006) (023)**	***Monthly***
P1C12	Showerhead/hose replacement/disinfection (*No longer carried out as shower head and hoses replaced quarterly)*	**(005b)**	***Quarterly***
WS01	Review of Rarely Used Water Outlets and Changes In-Use (As required by NHS Estates)		***Quarterly***
P1C9	DWS Calorifier / Expansion Vessel Inspection (**Carried out by NHS Estates**)	**(006)**	***Annually***
N/A	Water Services Pipework and Distribution System Checks (**Carried out by NHS Estates during calorfier checks, Plant Room checks and by DMA during Tank Room checks**)		***Annually***
N/A	Vibration coupling inspection (Carried out as part of checks on booster pumps) (**Carried out by NHS Estates**)		***Annually***
N/A	Carry out review of log books and Written Scheme		***Annually (Sep)***
N/A	Carry out review of drawings and schematics		***Annually (Sep)***

3.3 Required Maintenance Tasks (cont)

In addition to the tasks undertaken by NHS directly employed Competent Persons, there are also tasks undertaken by Contractors on a selection of buildings within the campus.

Appointed Service Providers presently undertake the following tasks:

Procedure Reference	Operation(s)	Record Form Ref	Frequency
WS01	Deluge shower/Eye wash flushing (**Carried out by DMA**)	**DMA Records**	***Twice Weekly***
WS01	Flushing Deadlegs and drain valves (**Carried out by DMA**)	**DMA Records**	***Twice Weekly***
WS01	Flushing Intermittently used outlets (**Carried out by DMA**)	**DMA Records**	***Twice Weekly***
	External Water Mains Valve Operation and Flushing Routines		***Monthly***
PIC4	Temperature and CL02 monitoring of outlets (**Carried out by DMA**)	**DMA Records**	***Monthly***
-	PPM Schedule Monthly Visually inspect chemical delivery system, Check chemical suction and delivery lines for correct operation Chemical level check and refill , Cross check measured ClO2 / Chlorite residual test against analyser & Palintest Kit, Check and Adjust controller settings as required (**Carried out by ScotMas**)	**ScotMas Records**	***Monthly***
	PAL Filters on taps outlets (**Carried out by DMA**)	**DMA Records**	
	'TMV' and Mixing Valve Sanitation and Maintenance Checks (**Carried out by DMA**)	Carried out 6 monthly	***Quarterly***
N/A	TMV/TMT & Thermostatic Shower Disinfection and Function Test (HIGH RISK) **Carried out 6 monthly**		***Quarterly***
	Shower Head and Flexible Hose Exchange (**Carried out by DMA**)	**DMA Records**	***Quarterly***
WQS 001	HORNE Tap Flow Restrictor Exchange (**Carried out by DMA**)	**DMA Records**	***Quarterly***
	'TMV/TMT' Tap Outlet Sanitisation and Operational Checks (**Carried out by DMA**)	**DMA Records**	***Six-Monthly***
N/A	TMV/TMT & Thermostatic Shower Disinfection and Function Test (Non-HIGH RISK) (**Carried out by DMA**)	**DMA Records**	***Six-Monthly***
-	Maintenance of filtration units (**Carried out by Veolia**)	**Veolia Records**	***Six-Monthly***
-	6 Monthly Visit– All above, plus, Check ClO2 gas detector functionality and recording levels, Simulate fault circuitry and alarm on Sentinel Monitor, Change probe electrolyte and cross calibration test, Carry out manual Chlorate & Chlorite validation tests (12 representative outlets), Check water meter operation and report o Electrolyte top up, Probe calibrations (**Carried out by Scotmas**)	**ScotMas Records**	***Six-Monthly***
P1C7	CWST Inspection and Temperature Monitoring (**Carried out by DMA**)	**DMA Records**	***Six-Monthly***

3.3 Required Maintenance Tasks (cont)

	'TMV' Tap Outlet Sanitisation and Operational Checks (**Carried out by Vanguard - MIU**)	**Vanguard Records**	***Annual***
	CWST Inspection **(Carried out by DMA)**	**DMA Records**	***Annually***
	Hot and Cold Tap Outlet Sanitisation and Operational Checks **(NOT CARRIED OUT UNLESS ISSUE IDENTIFIED THROUGH SAMPLING)**	**DMA Records**	***Annually***
-	As per 6 monthly and ClO2 & Chlorite Probe membrane cap replacement, Dosing Pump diaphragm valve replacements, Replace ClO2 gas detector cartridge if required **(Carried out by Scotmas)**	**ScotMas Records**	***Annually***
P1C10	Representative Tap Temperature Monitoring Note all tap temperatures are checked through TMT/TMV maintenance **(Carried out by DMA)**	**DMA Records**	***Annually***
	BMS Sensors (**Carried out by Schneider and MCE BMS Providers for respective BMS**)	**Schneider &** **MCE records**	***Annually***

3.4 Training Records

The following NHS personnel are certified to have the required ability, experience, instruction, information and training to carry out the work associated with legionella precautions at QEUH Campus.

NAME	POSITION	NATURE OF TRAINING (QUALIFICATION, TRAINING COURSES ATTENDED)	DATE
Euan Smith	Sector Estates Manager RP	Responsible Person Course ENAP City & Guilds Authorised Person ENWS City & Guilds Managing Water Systems	
Kerr Clarkson Mel MacMillan	Site Manager Operational Estates Manager Lead AP	WHH01 – Legionella Management for Water Systems SHTM-04 01 WH003 - Legionella Control Within Hot and Cold Water Systems	
Daniel Martin William Fenn	Trainee Estates Managers AP	WHH01 – Legionella Management for Water Systems SHTM-04 01 WH003 - Legionella Control Within Hot and Cold Water Systems	
Grant Bennet Darren Hopkins	Co-Ordinating Supervisor AP	WHH01 – Legionella Management for Water Systems SHTM-04 01 WH003 - Legionella Control Within Hot and Cold Water Systems	

Copies of all relevant training records and appointment letters are held electronically on the QEUH Shared Drive within the folder path “Water Quality>Training and Appointments”.

The results achieved by each member of staff during their competency training are held on the central database managed by the Water Systems Compliance Manager.

NAME	POSITION	NATURE OF TRAINING (QUALIFICATION, TRAINING COURSES ATTENDED)	DATE
Martin Inglis	Tech Plumber	Competent Persons	
Andrew Hamilton	Tech Plumber	Competent Persons	
David Fickling	Tech Plumber	Competent Persons	
Mark McInally	Tech Plumber	Competent Persons	
Shawn O'Neill	Tech Plumber	Competent Persons	
Jason Weir	Tech Plumber	Competent Persons	
Adam Gardner	Tech Plumber	TBC	
Robert Grant	Tech Plumber	TBC	
Ryan Ogilvie	Tech Plumber	TBC	
Gavin Goodall	Apprentice	TBC	
Paul Kelly	Apprentice	TBC	
Mark McGowan	CAD Technician	TBC	

Copies of all relevant training records and appointment letters are held electronically on the QEUH Shared Drive within the folder path "Water Quality>Training and Appointments".

The results achieved by each member of staff during their competency training are held on the central database managed by the Water Systems Compliance Manager.

3.5 Training Requirements

A programme of training and procedures to assist in assessing and ensuring the competence of ALL persons responsible for the operation, maintenance, repair and alteration to the water distribution system and associated plant and equipment requires to be progressed, developed and implemented.

QEUH Estates Staff - Interim Training Requirements:

Item	Training Requirement	Applicable to	Target Date for Completion	Date Completed
1	Toolbox talks on Written Scheme Section 4 for staff.	All plumbers		
2				
3				
4				
5				
6				
7				
8				
9				
10				
11				
12				

NOTE:- This table should be updated on a regular basis as part of the review process described in **Section 3.10.**

3.6 Water Systems Risk Assessment

The duly appointed *Legionella* Risk Assessor for *Legionella* and Water Systems Safety will update the *Legionella* risk assessment database as directed by the board.

Risk assessments for each building have been conducted by DMA Water Ltd and are filed in the main Estates Office at QEUH. Each contains details of individual systems and a summary of the associated risks. The risk assessments each contain unique information in regard to the water distribution systems in the buildings and also guidance on the recommended maintenance procedures for mitigating risk.

Risk Assessment Review-Escalations

During the Risk Assessment, whenever an anomaly is discovered on either the hot or cold water systems, the Risk Assessors e-mail the AP (water) with their findings. These anomalies are actioned by creating a FM job for the onsite CP Plumbing Technician. The findings are held in the Estates office in the folder named (Pre Risk Assessment Jobs completed).

Risk Assessment Process for Removal of Identified Items

Points are actioned that have been identified in the Risk Assessment, all drawings are updated to reflect the changes and the Risk Assessment action point is closed.

Risk Assessment Review Schedule

A review of the Risk Assessments MUST be carried out after or during the following:

A change to the water system or its use

A change to the use of the building/ward/clinic/dept etc.

Changes in legislation or updates in control measures

Changes in immediate management or key personnel

Control measures becoming ineffective

Increased micro-bacterial levels found in the water system or a case of legionnaires disease/legionellosis associated with the water system.

Action plan details for each risk assessment are summarised on the Smartsheet tool.

Electronic copies of the Risk Assessments are also held on the QEUH Shared Drive at the folder path

“Water Quality>Risk Assessments”

Further information on reviewing Risk Assessments is detailed in Appendix 3.

3.7 Plant Description and Schematics

Details of the plant in each building and schematic layouts are contained within the individual log books/risk assessments for each building. The log books/risk assessments are stored in the main Estates Office at QEUH.

These details are also held on the Shared Drive

All plant details and system schematics and as-fitted drawings for the Adult & Childrens Hospitals are contained in the ZUTEC cloud based document management system. All Estates Managers and Supervisors have access to these systems.

Additional access accounts can be set up at the request of the QEUH Site Manager Operational Estates.

Brendan.egan[redacted]

3.8 Water Systems Audits/Review Procedures

A duly appointed Authorising Engineer (Water) will audit the entire Water Safety procedures within *NHS Board* annually.

The appointed Authorising Engineer for Water Safety will produce an annual report for management review. *See Section 3.1 pg 18 for current appointments.*

AE Audit

The Lead Authorised Person (Water) must regularly gather and maintain all the relevant information and records, including relevant Water Safety Risk Assessments and Written Schemes.

Working with the Authorising Engineer (Water) and Responsible Person (Water), the relevant Authorised Person (Water) will review and analyse all records for compliance with *Legionella* and other water safety parameters.

The relevant Authorised Person (Water) will detail on these records any deviations from the *Legionella* and other water safety parameters giving a brief description as to the reason for this deviation.

The Audit Programme will consist of planned audits on the following elements, for example:

Risk Assessments;

All documentation associated with this Written Scheme

training review and records;

schematic drawings;

Water Safety Log Books/Maintenance records;

BMS trend log comparison.

A report will be produced summarising the audit for submission to the Sector Water Safety Group.

The Lead Authorised Person (Water) will file locally, all relevant information and maintain hard copy records in the Water Safety Log Books stored within the main Estates Office. All actions identified should be tracked to ensure completion and closure.

Summary of Internal/External Audit Procedures

Frequency	Task	By Whom
Annually	Carry out Authorising Engineers Audit and produce report for submission to Sector Water Safety Group (Section 3.8 WS)	Lead AP, AE,
Annually/May	Carry out annual review of written scheme and produce report for submission to Sector Water Safety Group (Section 3.9 WS)	RP/DRP, Lead AP, Compliance Mgr
6 monthly	Carry out management review (Section 3.10 WS)	RP/DRP, Lead AP, Compliance Mgr
Monthly	Carry out regular audit of SCART topic and update database (Section 3.11 WS)	Lead AP
Monthly	Conduct contractor meetings/audits to ensure compliance with legislation and training requirements.(Section 3.12 WS)	Lead AP

3.9 Written Scheme Audit Procedure

The Written Scheme will be audited at agreed intervals but should be at least annually.

An audit schedule will be prepared to ensure the entire procedure is audited. This should be done in conjunction with the Lead AP (Water Systems), Compliance manager, and Responsible Person (Water Systems). A report should be produced and submitted to the Sector Water Safety Group.

3.10 Management Review

The Responsible Person (Water) will hold regular review meetings to confirm current compliance with Water Safety System requirements, identification of any deficiencies and actions required to resolve staff training needs.

The management review will be based on following:

- Results of internal audits;
- Results of external audits;
- Staff suggestions;
- Training records;
- Operation of the system and procedures over a reasonable historic period (6 to 12 months)

3.11 Water Systems SCART Report

The Lead Authorised Person (Water) must regularly gather and maintain all the relevant information for import into the Campus SCART system.

All evidence confirming the SCART position and justification for risk rating adjustments should be uploaded to the SCART database in electronic format.

3.12 Contractor Management & Audit Report

Contractor Management Process

Regular review meetings should be set up with any contractors working on the water distribution system. Minutes of the meetings are held on the QEUH Estates Shared Drive at the path: SGH Estates>Water Quality>Contractor Meetings.

Discussions should include:

Ongoing works;
Future task programme;
Recording procedures;
RAMS;

Contractor Competency

Regular checks should be performed to ensure that any contractors working on the water distribution system are deemed competent and all operatives are suitably trained to conduct the delegated tasks. Copies of all Risk Assessments and Method Statements should be refreshed and all training records reviewed by the Water Systems AP. Copies are stored on the QEUH Campus Shared Drive in Water Quality.

Contractor Audit Report

A report should be produced at least annually to record the findings of the audit.

3.13 Permit to Work, Water Systems.

The Permit to Work Water Systems as per this written scheme is solely intended to be used when works on the hot and cold water systems and its ancillary equipment are to be completed within the QEUH and RHC campus. This includes break-ins to existing pipe work, removal of dead legs and any new installation works.

The Permit to Work may only be issued to Competent Persons (L8 approved) by the Authorised Person (AP) for water. This includes in house maintenance staff and approved contractors.

The Permit to Work form will include the following;

- Name of the organisation issuing the permit.
- Permit number.
- Name of Authorising Person (AP), including emergency contact details.
- Reasons for the works on the water system, (Plant Preventive Maintenance, Planned repairs or Emergency works).
- Exact location of the works
- Reference to any as built drawing numbers, (for update purposes).
- Name of Competent Person (CP) undertaking the works.
- Hazards and Risks, (copy of Risk assessment and Method Statements (RAMS) to be submitted for approval before start of works)
- Commissioning and Testing.

The above points on the Permit Work are broken into five categories, namely;

Part 1 Description of work and authorisation/permission to proceed.

Part 2 CP acceptance of work and conditions.

Part 3 Confirmation of work completion and engineering test results.

Part 4 Authorisation to use a system.

Part 5 Acceptance of system status by Nurse Manager.

Procedure to be followed for Permit to Work on water systems within the QEUH and RHC;

Sign into Estates office within the Laboratory building on the QEUH and RHC campus.

Receive induction from Authorised Person water.

Provide L8 Competent Person certification to Authorised Person water.

Provide applicable RAMS for the works to be completed.

3.14 Tool Box Talk, Hot and Cold Water Systems.

Estates Tool Box Talk on Hot and Cold water Systems is located on the shared drive / water quality / Estates Tool Talk. This is carried out in the form of a power point presentation.

4.0 MAINTENANCE PROCEDURES

Procedure Reference	Operation
4.1	SYSTEM INFORMATION
4.2	MAINTENANCE PROCEDURES SUMMARY
4.3	WEEKLY MAINTENANCE TASKS
4.4	MONTHLY MAINTENANCE TASKS
4.5	QUARTERLY MAINTENANCE TASKS
4.6	SIX MONTHLY MAINTENANCE TASKS
4.7	ANNUAL MAINTENANCE TASKS
4.9	BI-ANNUAL MAINTENANCE TASKS

NOTE:

Completed Log Sheet to be submitted to either the Authorised Person (Water Systems) or Site Manager Operational Estates for authorisation and copies filed as indicated in Section 2.2.

Due to the volume of information required for the recording of test results for each of the assets being maintained, the Log Sheets provided within this document are for indicative purposes only.

Detailed information on the assets and test records for same will be retained within the specific 'Log Book' for the location being maintained.

4.1 System Information

4.1.1 Correct and Safe Operation of the System

Measures should be in place to ensure that the water system is operated within the specific parameters as detailed in the following paragraphs:

4.1.2 Hot Water System

The storage of domestic hot water should be arranged to ensure that a water outflow temperature of at least 60ºC is achieved. No two water systems are the same and through periodic monitoring operational system performance, the system outflow temperature should be set to over 60ºC to ensure an outflow of 60ºC is achieved under normal draw-off demand and achieve 55°C at the supply to the furthermost draw-off point in the circulating system. It is important to maintain temperatures at above this figure (Legionellae organisms will survive for only a short period of time above this temperature - approximately two minutes).

Periodic performance monitoring and a system of continuous monitoring and recording of water temperatures via a building management system (BEMS) or data logger is essential to ensure compliant system performance.

The outflow water temperature, under prolonged maximum continuous demand (at least 20 minutes) from calorifiers should not be less than 60ºC.

While it is accepted that occasionally under peak instantaneous or prolonged demand the water outflow temperature will fall, it is not acceptable if this occurs frequently (more than twice in any 24 hour period) and/or for long periods (exceeding 20 minutes).

Under no circumstances should the domestic hot water flow temperature fall below 55ºC.

It is recommended that disinfection by pasteurisation is undertaken if the water temperature of the calorifier falls below 45ºC. A minimum domestic hot water circulation (return) temperature of 55ºC shall be maintained during the hours of occupancy.

4.1.3 Cold Water System

All domestic cold water storage cisterns and tanks shall comply with the requirements of the Scottish Water Byelaws.
Duplicate tanks often create a risk of water becoming stagnant in one of them, leading to risk of Legionella, Pseudomonas Spp or similar contamination. Consideration should be given to taking one of the tanks out of service. See guidance in “Guidance for Alterations to Water Systems”.

All cold water storage tanks are to be examined and the temperature tested on a regular summer / winter six monthly cycles and cleaned on an annual basis as required.

Temperatures in cold water storage tanks and the mains inlet to them should be checked during periods of high ambient temperatures (e.g. summer afternoons between June and August). Water temperatures should be less than 20ºC.
At the same time, the furthest and nearest draw off points in the system should be checked to ensure that the water distribution temperatures are less than 20ºC within 1 minute of running the water (at full flow). A similar temperature check regime should be undertaken during the winter months to identify the performance of cold water distribution systems and the impact of heat gain from heating systems.

4.1.4 Cold Water System Dump Valves

The cold water system installed in the Adult & Childrens Hospitals has a dump valve arrangement incorporated into the ground floor, 1st floor and 2nd floor layouts. The positions of the dump valves are shown on the Schneider BMS STRUXUREWARE system and connected via the KNX network.
Operating parameters for the dump valves are as follows:
Open at 23ºC
Close at 20ºC

4.1.5 End of Line Sensors (EOLs)

The hot and cold water system also incorporates End of Line (EOL) sensors which monitor the temperatures at specific sentinel points across all 11 floors of the Adult & Childrens installation. These can also be viewed via the Schneider BMS system.

4.1.6 Sampling

General microbiological and Legionella sampling in hot & cold water systems

Circumstances under which samples are taken:

- prior alterations to an existing water system;
- as part of commissioning process, prior to handover of a new building or introduction of a (altered, refurbished or new) water system into use;
- one week following handover of a new building or new water system;
- as part of the tank cleaning and disinfection process;
- as part of an assessment programme;
- in response to taste, odour or sustained discoloured water complaints.

When such samples are taken, a mains supply sample should be taken as a control to verify whether the supply could be the source of the identified problems. Scottish Water should also be contacted for distribution zone water quality data.

4.1.7 WS01 – Little Used Outlets

Control of Legionella in Water Systems, Intermittently used Water Outlets and Showers, Standard Operating Procedure WS01.

The Estates department is required to ensure that on a quarterly basis the list of ‘intermittent’ or ‘infrequently’ used water outlets or showers is reviewed to ensure it is accurate and up to date. Records of these reviews will be held within the system logbooks held locally.

If after investigation the taps or appliances identified within the reviewed list are deemed not necessary wherever possible the supply should be cut and the appliance removed from the water system. Where this is not possible then pipe work shall be cut back as close to the main circulating line as practicable to ensure that any dead-leg formed is minimised.

Nursing and other staff must be made aware of the issues surrounding legionella contamination and the link to low and underused water outlets and their assistance in formally identifying these possible outlets are sought.

Upon acknowledgement from the clinical staff of any intermittent or infrequently used outlets, the records are held on the Estates shared drive under Water Quality / WS01.

Any request from clinical staff regarding the removal of any intermittent or infrequently used outlets is assessed and surveyed by the AP (Water). If deemed appropriate a job is raised on FM for the Plumbing Technicians to remove, this is documented in the WS01 Records file in the Water Quality file on the shared drive. Subsequent hot and cold water pipe drawings are updated by the CAD Technician CP (water) where and when appropriate.

FILLING IN LOG SHEETS

Good water hygiene depends on maintaining high standards of cleanliness and freshness, together with careful temperature control. This section contains details of checks and recording sheets (marked "Log Sheets") to be filled in when checks and measurements are made to show that the necessary standards are being kept up. Alternatively, where an electronic PPM system is used, Procedure references should be entered.

Follow the instructions within the boxes and make entries as each task is completed. The tasks are all listed at the front of each section e.g. weekly tasks at the front of the weekly section, monthly section, quarterly 6 monthly etc. The summary list of tasks in this section is to remind you of what is required.

The Task and Log Sheets can be copied as required, completed Log Sheets will be filed where indicated in Section 2. **FM First ticket number MUST be included in all logsheets.**

PLANNING

The tasks and forms are organised into weekly, monthly, quarterly and annual sections. Always aim to carry out tasks early in the period when they are due to leave an opportunity to do them later if an emergency delays your plans.

ASK

If you have difficulties with the forms or do not understand the tasks, ask your Supervisor or line manager for clarification or guidance.

CHECKING

Incomplete or incorrect records are unacceptable in that they are misleading and do not do justice to the effort put in to achieve standards. Each log sheet includes a space for comment and tells you to check that all the boxes are complete: do make use of the comment space and double check the form, otherwise the record will have gaps and whoever is responsible for auditing will concentrate on what is missing and may not give you credit for the work that has been done.

LOG INSPECTION

Anyone inspecting this log (either as part of the Management Control System or not) is invited to make an entry in the inspection of Log Book record in front of Section One.

SURVEY

For survey purposes all surveys will be carried out starting left to right, where 2 off access doors are available the left access shall be taken first. Surveys shall be undertaken from top to bottom.

EQUIPMENT FITTINGS AND MATERIALS

Prior to carrying out alterations/ additions to distribution systems, the Water Fittings and Materials Directory published by the Water Regulations Advisory Scheme, should be consulted. This directory lists all materials and fittings approved for use to satisfy the requirements of current Water Byelaws.

Details of all new materials and fittings used in installations should be noted and recorded on the specific work document or project file for future reference.

SYSTEM ADDITIONS AND ALTERATIONS

Any additions, modifications or improvements to the water distribution system are to be noted and recorded and system record's amended to reflect such changes.

HYGIENE PRACTICES

Care should be taken to ensure high levels of personal hygiene, clean hands, clean clothing and PPE or gloves is maintained at all times when working on wholesome water operations. Tools, equipment, instrumentation and material's shall be free from contamination and appropriately disinfected before use.
Items such as pumps and hoses used in contact with water used for domestic purposes must be stored separately, clearly identified (ie colour coded or labelled) and **MUST NOT BE USED FOR ANY OTHER PURPOSE.**

Refer to Section 2.2 for location of maintenance records for the above.

4.2 Maintenance Procedures Summary

This section contains information in relation to the operational and maintenance checks managed by QEUH NHS Staff and appointed contractors to minimise the risk of exposure to *Legionella* and other waterborne micro-organisms within the domestic water systems, and to improve water quality. Procedures are as per the recommendations and exemplar models given in SHTM 04-01 Part G.

Procedure Reference	Operation(s)	Record Form Ref	Frequency
P1C1	BMS Temperature Monitoring (**Carried out by NHS Estates**)	**Requires new number**	***Daily***
P1CC1A	Manual Temperature Monitoring for calorifiers (**different form used ONLY REQUIRED if no BMS Monitoring**)	**(005a)**	***Daily***
N/A	Filtration Plant Checks (**Carried out by NHS Estates**)	**028c**	***Twice Daily***
WS01	Daily flushing of all outlets (**Carried out by NHS Facilities**)	**-**	***Daily***
WS01	Flushing of little used outlets * frequency based on risk (**Carried out by NHS Clinical**) see page 103	**-**	***Daily or Twice weekly***
WS01	Deluge shower/Eye wash flushing (**1 off carried out by NHS Estates and 1 off by DMA**)	**(026)**	***Twice Weekly***
P1C3	Pump operation/duty rotation (**Carried out by NHS Estates**)	**(028a)**	***Weekly***
P1C4	Temperature Recording of Sentinel Hot and Cold Water Outlets. (**Carried out by NHS Estates**)	**(005c)**	***Monthly***
P1C4	DHW Calorifier and Buffer Vessel Checks (**Carried out by NHS Estates**)	**(005)**	***Monthly***
P1C6	DWS Calorifier, Expansion Vessel Flushing (**Carried out by NHS Estates**)	**(006) (023)**	***Monthly***
P1C12	Showerhead/hose replacement/disinfection (***No longer carried out as shower head and hoses replaced quarterly)***	**(005b)**	***Quarterly***
WS01	Review of Rarely Used Water Outlets and Changes In-Use (**Carried out by NHS Estates**)		***Quarterly***
P1C9	DWS Calorifier / Expansion Vessel Inspection (**Carried out by NHS Estates**)	**(006)**	***Annually***
N/A	Water Services Pipework and Distribution System Checks (**Carried out by NHS Estates**)		***Annually***
N/A	Vibration coupling inspection (Carried out as part of checks on booster pumps) (**Carried out by NHS Estates**)		***Annually***
N/A	Carry out review of log books and Written Scheme		***Annually (Sep)***
N/A	Carry out review of drawings and schematics		***Annually (Sep)***

4.3 Required Maintenance Tasks (cont)

In addition to the tasks undertaken by NHS directly employed Competent Persons, there are also tasks undertaken by Contractors on a selection of buildings within the campus.

Procedure Reference	Operation(s)	Record Form Ref	*Frequency*
	CWST Inspection **(Carried out by DMA)**	**DMA Records**	***Annually***
	Hot and Cold Tap Outlet Sanitisation and Operational Checks (**NOT CARRIED OUT UNLESS ISSUE IDENTIFIED THROUGH SAMPLING**)	**DMA Records**	***Annually***
-	As per 6 monthly and ClO2 & Chlorite Probe membrane cap replacement, Dosing Pump diaphragm valve replacements, Replace ClO2 gas detector cartridge if required **(Carried out by Scotmas)**	**ScotMas Records**	***Annually***
P1C10	Representative Tap Temperature Monitoring **Note:** All tap temperatures are checked through TMT/TMV maintenance **(Carried out by DMA)**	**DMA Records**	***Annually***
P1C1 4.3.1	Daily BMS Temperature Monitoring (**Carried out by Estates**)	**(021)**	***Daily***
P1CC1A 4.3.2	Manual Temperature Monitoring ***(only required in absence of BMS)*** (**Carried out by NHS Estates**)	**(005a)**	***Daily***
4.3.3	Filtration Plant Checks (**Carried out by NHS Estates**)	**(028c)**	***Twice Daily***
-	Flushing all outlets (**Carried out by NHS Facilities**)	-	***Daily***
WS01	Flushing Intermittently used outlets (**Carried out by DMA**)	-	***Twice Weekly***
WS01	Flushing Deadlegs and drain valves (**Carried out by DMA**)	-	***Twice Weekly***
WS01	Deluge shower/Eye wash flushing (**Carried out by DMA and NHS Estates**)	**(026)**	***Twice Weekly***
P1C3	Pump operation/duty rotation (**Carried out by NHS Estates**)	**(028a)**	***Weekly***
P1C4	Temperature Recording of Sentinel Hot and Cold Water Outlets. (**Carried out by NHS Estates**)	**(005c)**	***Monthly***
-	Temperature Recording of Sentinel Hot and Cold Water Outlets for CL02 (**Carried out by DMA**)	-	***Monthly***
P1C4	DHW Calorifier and Plate Heat Exchanger Checks (Carried out by NHS Estates)	**(005)**	***Monthly***
-	PPM Schedule Monthly Visually inspect chemical delivery system, Check chemical suction and delivery lines for correct operation Chemical level check and refill , Cross check measured ClO2 / Chlorite residual test against analyser & Palintest Kit, Check and Adjust controller settings as required (**Carried out by ScotMas**)	-	***Monthly***
P1C6	DWS Calorifier, Expansion Vessel Flushing. (**Carried out by NHS Estates**)	**(006) (023)**	***Monthly***
	Replacement of PAL filters (**Carried out by DMA**)		***31 Days or 62 Days***

Procedure Reference	Operation(s)	Record Form Ref	*Frequency*
WQS 001	HORNE Tap Flow Restrictor Exchange (**Carried out by DMA**)		***Quarterly***
	TMV/TMT & Thermostatic Shower Disinfection and Function Test (HIGH RISK)		***Quarterly***
	'TMV' and Mixing Valve Sanitation and Maintenance Checks (**Carried out by DMA**)		***Six-Monthly***
	TMV/TMT & Thermostatic Shower Disinfection and Function Test (Non-HIGH RISK) (**Carried out by DMA**)		***Six-Monthly***
P1C7	CWST Inspection and Temperature Monitoring (Carried out by DMA) (**Carried out by DMA**)	**(003)**	***Six-Monthly***
	TMV' and Mixing Valve Sanitation and Maintenance Checks (**Carried out by DMA**)	**DMA Records**	***Six-Monthly***
N/A	TMV/TMT & Thermostatic Shower Disinfection and Function Test (Non-HIGH RISK) (**Carried out by DMA**)	**DMA Records**	***Six-Monthly***
-	Maintenance of filtration units (**Carried out by Veolia**)	**Veolia Records**	***Six-Monthly***
-	6 Monthly Visit– As per monthly, plus, Check ClO2 gas detector functionality and recording levels, Simulate fault circuitry and alarm on Sentinel Monitor, Change probe electrolyte and cross calibration test, Carry out manual Chlorate & Chlorite validation tests (12 representative outlets), Check water meter operation and report o Electrolyte top up, Probe calibrations (**Carried out by Scotmas**)	**ScotMas Records**	***Six-Monthly***
P1C7	CWST Inspection and Temperature Monitoring (**Carried out by DMA**)	**DMA Records**	***Six-Monthly***
N/A	TMV/TMT & Thermostatic Shower Disinfection and Function Test (Non-HIGH RISK) (**Carried out by Vanguard for MIU only**)	**Vanguard Records**	***Annually***
	CWST Inspection (**Carried out by DMA**)	**-**	***Annually***
	Hot and Cold Tap Outlet Sanitisation and Operational Checks (NOT CARRIED OUT UNLESS ISSUE IDENTIFIED THROUGH SAMPLING)	**-**	***Annually***
-	As per 6 monthly and ClO2 & Chlorite Probe membrane cap replacement, Dosing Pump diaphragm valve replacements, Replace ClO2 gas detector cartridge if required (**Carried out by Scotmas**)	**-**	***Annually***
P1C10	Representative Tap Temperature Monitoring Note all tap temperatures are checked through TMT/TMV maintenance (**Carried out by DMA**)	**-**	***Annually***
P1C9	DWS Calorifier / Expansion Vessel Inspection (**Carried out by NHS Estates**)	**(006)**	***Annually***
	Water Services Pipework and Distribution System Checks (**Carried out by NHS Estates**)		***Annually***
P1C10	Representative Tap Temperature Monitoring (**Carried out by DMA as part of TMV checks**)	**(005)**	***Annually***
	Vibration coupling inspection Carried out monthly as part of checks of Booster sets (**Carried out by NHS Estates**)		***Annually***
	BMS Sensors (**Carried out by Schneider and MCE BMS Providers for respective BMS**)		***Annually***

4.3 Daily Maintenance Tasks

Reference	Operation
4.31	BMS Temperature Monitoring
4.32	Manual Temperature Monitoring
4.33	Filtration Plant Checks

NOTE:

Completed Log Sheet to be submitted to either the Authorised Person (Water Systems) or Site Manager Operational Estates for authorisation and copies filed as indicated in Section 2.2.

Due to the volume of information required for the recording of test results for each of the assets being maintained, the Log Sheets provided within this document are for indicative purposes only.

Detailed information on the assets and test records for same will be retained within the specific 'Log Book' for the location being maintained.

4.31 – BMS TEMPERATURE MONITORING

DAILY

FM First Template No 826

IN ACCORDANCE WITH SHTM 04-01 Part G (*V1 July 2015*) Page 26 para 3.11

RECORD FORM - (021)

PROCEDURE REF - P1C1

SCHEDULE REF – BMS 01

HAISCRIBE/Risk Assessment Ref – N/A See Appendix 4

The following actions must be undertaken **DAILY** as a minimum:

Description of Works

- Refer to the BMS Temperature Monitoring Schedule BMS 01.
- Log onto both STRUXUREWARE BMS and DISTECH BMS front ends and check all temperatures from listed locations.
- Complete Schedule BMS 01 to confirm all temperatures have been checked.
- Any temperatures found outside the defined parameters stated on the BMS Temperature Monitoring Schedule should be investigated and resolved immediately. Details must be entered on Record Form (021) and escalated to the Water Systems AP.

CHECK

1. Record all details of any fault or discrepancy on the FAULT LOG and complete Incident Form (04) and report to Manager.
2. Complete Schedule BMS 01 and Incident form **04** if required, ensuring that you date, sign it and enter FM First ticket number.
3. Return forms to the Water Systems AP.

NOTE: Both Struxureware and Distech BMS systems are capable of generating temperature trend logs. These logs will be checked on a regular basis by the Water Systems AP to confirm accuracy of information.

4.32 – MANUAL TEMPERATURE MONITORING (in absence of BMS)

DAILY

FM First Template No 830

IN ACCORDANCE WITH SHTM 04-01 Part G (*V1 July 2015*) Page 26 para 3.15

RECORD FORM – (005a) (021a)

PROCEDURE REF - P1CC1A

SCHEDULE REF – MTM 01

HAISCRIBE/Risk Assessment Ref – N/A See Appendix 4

The following actions must be undertaken **DAILY** as a minimum:

Description of Works

- Refer to the Manual Temperature Monitoring Schedule MTM 01.
- MANUALLY visit each location and obtain and record temperatures from all plant as listed on Schedule MTM 01.
- Any temperatures found outside the defined parameters stated on the MTM 01 Temperature Monitoring Schedule should be investigated and resolved immediately. Details must be entered on Incident Form (004a) and escalated to the Water Systems AP.

CHECK

1. Record all details of any fault or discrepancy on the FAULT LOG and complete Incident Form (04) and report to Manager.
2. Complete Record Forms (005a) and (004) if required, ensuring that you date, sign it and enter FM First ticket number.
3. Return form to the Water Systems AP.

4.33 – FILTRATION PLANT CHECKS

TWICE DAILY

FM First Template No 836

IN ACCORDANCE WITH BOARD POLICY

RECORD FORM – (028c)

PROCEDURE REF – N/A

HAISCRIBE/Risk Assessment Ref – N/A See Appendix 4

The following actions must be undertaken **TWICE DAILY** as a minimum AM and PM:

Description of Works

- Refer to the Filtration Plant Daily Checks Log sheet (028c).
- Complete all listed checks and ensure plant is running if selected as DUTY, or available to run if selected as STAND-BY.
- Details must be entered on Record Form (028c) and any issues escalated to the Water Systems AP immediately.

CHECK

1. Record all details of any fault or discrepancy on the FAULT LOG and complete Incident Form (04) and report to Manager.
2. Complete Record Forms (028c) if required, ensuring that you date, sign it and enter FM First ticket number.
3. Return form to the Water Systems AP.

4.4 Weekly Maintenance Checks

Reference	Operation
4.41	Flushing of Rarely Used Water Outlets (Twice Weekly)
4.42	Flushing of Deadlegs & Drain Valves (Twice Weekly)
4.43	Rotation of Water Services Duty/Stand-By Pumps
4.44	Operation and Checks to Emergency Deluge Shower/Eye Wash (Twice Weekly)

NOTE:

Completed Log Sheet to be submitted to either the Authorised Person (Water Systems) or Site Manager Operational Estates for authorisation and copies filed as indicated in Section 2.2.

Due to the volume of information required for the recording of test results for each of the assets being maintained, the Log Sheets provided within this document are for indicative purposes only.

Detailed information on the assets and test records for same will be retained within the specific 'Log Book' for the location being maintained.

4.41 – FLUSHING OF INTERMITTENTLY USED WATER OUTLETS

FM First Template No 824

TWICE WEEKLY

IN ACCORDANCE WITH SHTM 04-01 Part G (*V1 July 2015*) Page 101 para 6.36

RECORD FORM - (DMA)

PROCEDURE REF - WS01

HAISCRIBE/Risk Assessment Ref – N/A See Appendix 4

The following actions must be undertaken **TWICE WEEKLY** as a minimum:

Description of Works

- Refer to the locations listed by DMA.
- Estates to arrange for the Schedule to be updated to record on a regular basis.
- Flush water from ALL outlets identified at a minimum frequency of Twice Weekly for a minimum period of 3 minutes per tap outlet taking care not to cause splashing or exposure to water aerosols / droplets.

CHECK

1. Record all details of any fault or discrepancy on the FAULT LOG and complete Incident Form (04) and report to Manager.
2. Complete Record Form ensuring that you date, sign it.
3. DMA to send flushing records to Water Systems AP.

NOTES:

In circumstances where there has been a lapse in the flushing regime, the stagnant and potentially contaminated water from within the shower or tap and associated dead leg should be purged to drain without discharge of aerosols before the appliance is used.

NHSGG&C consider the cleaning of wash hand basins, toilets and showers etc by Domestic Services staff to fulfil the criteria of having been used /flushed.

As part of the ward/departments standard cleaning schedule Domestic Services staff will clean all wash hand basins, showers, baths, WC's and bidets. For the purposes of Legionella and Pseudomonas control the Board deems this to be considered adequate to fulfil guidance on the use of water outlets.

Facilities Management send on flushing records of all taps to Water Systems AP monthly.

Refer to Facilities Procedure - Wash Hand Basin Cleaning (including point of use filter).

4.42 – FLUSHING OF DEADLEGS & DRAIN VALVES

FM First Template No 827

TWICE WEEKLY

IN ACCORDANCE WITH SHTM 04-01 Part G (*V1 July 2015*) Page 101 para 6.36

RECORD FORM - DMA

PROCEDURE REF – WS01

HAISCRIBE/Risk Assessment Ref – N/A See Appendix 4

The following actions must be undertaken **TWICE WEEKLY** as a minimum:

Description of Works

- Refer to the locations listed on Record Form (DMA).
- Estates to arrange for the Schedule to be updated to record on a regular basis.
- Flush water from ALL outlets identified on Record Form on a Weekly basis for a minimum period of 3 minutes per tap outlet taking care not to cause splashing or exposure to water aerosols / droplets. Drain Valves to be purged to ensure the removal of any built up residue in the line.

CHECK

1. Record all details of any fault or discrepancy on the FAULT LOG and complete Incident Form (04) and report to Manager.
2. Complete Record ensuring that you date, sign it and Complete FM work request.
3. Return form to the Water Systems AP.

4.43 – ROTATION OF WATER SERVICES DUTY/STAND-BY PUMPS

FM First Template No 820

WEEKLY

IN ACCORDANCE WITH SHTM 04-01 Part G (*V1 July 2015*) Page 27 para. 3.24

RECORD FORM - (028a)

PROCEDURE REF - P1C3

HAISCRIBE/Risk Assessment Ref – N/A See Appendix 4

The following actions must be undertaken **WEEKLY**:

Description of Works

- Inspect and confirm operation of all listed duty/stand-by pumps by interrogating the programmer to check hours run for each pump motor.
- Check pump rig and associated valves for correct operation, signs of damage, leakage or corrosion.
- Record all details on Record Form (028a)

CHECK

1. Record all details of any fault or discrepancy on the FAULT LOG and complete Incident Form (04) and report to Manager.
2. Complete Record Form (028a) ensuring that you date, sign it and enter FM First ticket number.
3. Return form to the Water Systems AP.

4.44 – OPERATION AND CHECKS TO EMERGENCY DELUGE SHOWERS/EYE WASH

FM First Template No 825

TWICE WEEKLY

IN ACCORDANCE WITH SHTM 04-01 Part G (*V1 July 2015*) Page 57

RECORD FORM - (026c) and DMA record for separate shower.

PRECEDURE REF – WS01

HAISCRIBE/Risk Assessment Ref – N/A See Appendix 4

RISK CONTROL NOTICE - RCN 11/04

The following actions must be undertaken **TWICE WEEKLY**:

Description of Works

- Refer to the locations listed on Record Form (026c) NHS only (DMA complete flushing records).
- Operate shower for a minimum period of 3 minutes taking care not to cause splashing or exposure to water aerosols / droplets. Measure and record temperatures until discharge water drops to the same temperature as the incoming mains water.

  NOTE: For thermostatic showers and taps, the outlet should be flushed on the full cold setting for 2 minutes, then again on the full hot setting for a further 2 minutes, using override setting where available. Cold water should be less than 20^{O}C, Hot water should be between 55^{O}C and 60^{O}C, and Mixed water in the range 41-43°C.

CHECK

1. Record all details of any fault or discrepancy on the FAULT LOG and complete Incident Form (04) and report to Manager.
2. Complete Record Form (026c) ensuring that you date, sign it and enter FM First ticket number.
3. Return form to the Water Systems AP.

4.5 Monthly Maintenance Checks

Reference	Operation
4.51	Sentinel Outlet Temperature Recording
4.52	DWS Calorifier – Temperature Checks & Blowdown
4.53	CL02 checks

NOTE:

Completed Log Sheet to be submitted to Site Estates Manager / Authorised Person (Water) for authorisation and copies filed as indicated in Section 2.20.

Due to the volume of information required for the recording of test results for each of the assets being maintained, the Log Sheets provided within this document are for indicative purposes only.

Detailed information on the assets and test records for same will be retained within the specific 'Log Book' for the location being maintained.

4.51 – SENTINEL OUTLET TEMPERATURE RECORDING

FM First Template No 828

MONTHLY

IN ACCORDANCE WITH SHTM 04-01 Part G (*V1 July 2015*) Page 28 para 3.27

RECORD FORM - (005c)

PROCEDURE REF - P1C4

HAISCRIBE/Risk Assessment Ref – N/A See Appendix 4

The following actions must be undertaken **MONTHLY**:

Description of Work

- Check the temperatures at the sentinel taps as defined in the local plan of the system being checked. NOTE: Where the sentinel is a TMV or TMT the temperature readings should be taken from the pipework or directly from the hot and cold supply.
- Using a calibrated temperature probe, check the temperature of water from the cold water tap does not rise above 20ºC after running the tap for 2 minutes.
- Using a calibrated temperature probe, check the temperature of water from the hot water tap does not drop below 55ºC whilst running the tap for 1 minute.
- Record all temperatures on Record Form (005c).

CHECK

1. Record all details of any fault or discrepancy on the FAULT LOG and complete Incident Form (04) and report to Manager.
2. Complete Record Form **(005c)** ensuring that you date, sign it and enter FM First ticket number. Complete FM Work Request.
3. Return form to the Water Systems AP.

4.52 - DWS CALORIFIER – TEMPERATURE CHECKS & BLOWDOWN

FM First Template No 821

MONTHLY

IN ACCORDANCE WITH SHTM 04-01 Part G (*V1 July 2015*) Page 28 para 3.30

RECORD FORM - (005)

PROCEDURE REF - P1C4

HAISCRIBE/Risk Assessment Ref – N/A See Appendix 4

The following actions must be undertaken **MONTHLY**:

Description of Work

- MANUALLY CHECK and record the flow and return temperatures on the domestic hot water system as defined on Record Form (005), using the temperature gauges fitted or a suitable surface temperature probe.
- MANUALLY CHECK and record the calorifier storage temperature at top and bottom gauges if fitted.
- The flow temperature to be at least 60ºC and the return temperature shall be no less than 55ºC
- MANUALLY CHECK and record the cold water feed temperature using the temperature gauges fitted or a suitable surface temperature probe.
- Blowdown drain valves (if fitted) on all calorifiers and expansion vessels by opening the drain valve 3 times, each time for a 3 minute period. Where required, the hose from the drain valve connection should be discharged to the nearest drain/gulley. If there is no drain valve make note on Record Form 005.
- Check all local pipework to and from calorifier is in good order and all insulation is intact.
- Operate all isolation valves through their full range of motion.
- Check, confirm and record operation of de-stratification pump.
- Record all information on the Record Form (005).

CHECK

1. Record all details of any fault or discrepancy on the FAULT LOG and complete Incident Form (04) and report to Manager.

2. Complete Record Form (**005**) ensuring that you date, sign it and enter FM First ticket number.

3. Return form to the Water Systems AP.

4.53 – CL02 PLANT CHECKS

MONTHLY

FM First Template N/A

IN ACCORDANCE WITH SHTM 04-01

RECORD FORM – N/A

PROCEDURE REF – N/A

HAISCRIBE/Risk Assessment Ref – N/A See Appendix 4

The following actions must be undertaken **MONTHLY**:

Description of Work

- PPM Schedule Monthly Visually inspect chemical delivery system.
- Check chemical suction and delivery lines for correct operation Chemical level check and refill.
- Cross check measured ClO2 / Chlorite residual test against analyser & Palintest kit.
- Check and Adjust controller settings as required.

CHECK

1. Record all details of any fault or discrepancies and report to Water Lead AP who will complete Incident Form (04).

4.6 Quarterly & Other Maintenance Checks

Reference	Operation
4.61	Shower Head and Flexible Hoses Disinfection/Replacement
4.62	DHWS Calorifier and Expansion Vessel - Flush
4.63	HORNE Tap Flow Restrictor Exchange
4.64	Review of Rarely Used Water Outlets and Changes In-Use
4.65	TMV/TMT & Thermostatic Shower Disinfection and Function Test (HIGH RISK)
4.66	PAL filter replacement

NOTE:

Completed Log Sheet to be submitted to either the Authorised Person (Water Systems) or Site Manager Operational Estates for authorisation and copies filed as indicated in Section 2.2.

Due to the volume of information required for the recording of test results for each of the assets being maintained, the Log Sheets provided within this document are for indicative purposes only.

Detailed information on the assets and test records for same will be retained within the specific 'Log Book' for the location being maintained.

4.61 SHOWER HEAD AND HOSE REPLACEMENT

FM First Template No 869
Schedules: 1997 to 2724

QUARTERLY

IN ACCORDANCE WITH SHTM 04-01 Part G (*V1 July 2015*) Page 32 para 3.51

RECORD FORM -See DMA records
PROCEDURE REF - P1C12 CURRENTLY CONTRACTED TO DMA CANYON WATER

HAISCRIBE/Risk Assessment Ref – N/A See Appendix 4

The following actions must be undertaken every **THREE MONTHS**:

NOTE: If PALL filter is fitted it must be left in place and recorded as such on DMA records)

Description of Work

- Exchange shower head and hose assembly inc sealing washers with new disposable unit. Place old shower head and hose assembly into re-sealable plastic bag.
- Check that the new head and hose package is intact;
- Open replacement new shower head and hose assembly sealed packaging, remove and fit following the manufacturer's instructions;
- Run water and flush for 3 minutes in accordance with Legionella Risk Assessment in such a way as to avoid the creation of aerosols;
- Check final temperature for compliance and working order and return shower appliance to use.
- Return redundant sealed bag with shower head and hose assembly to collection point for recycling in accordance with Waste Procedures;
- Record all actions on the Record Form (005b).

CHECK

1. Record all details of any fault or discrepancy on the FAULT LOG and complete Incident Form (04) and report to Manager.
2. Complete Record Form (005b) ensuring that you date, sign it and enter FM First ticket number.
3. Return form to the Water Systems AP.

NOTE: This procedure replaces the previous Clean & Disinfect method from 1st April 2019

4.62 - DWS CALORIFIER AND EXPANSION VESSEL - FLUSH

FM First Template No 821

QUARTERLY

IN ACCORDANCE WITH SHTM 04-01 Part G (*V1 July 2015*) Page 29 para 3.34

RECORD FORM - (006) and (023)

PROCEDURE REF - P1C6

HAISCRIBE/Risk Assessment Ref – N/A See Appendix 4

The following actions must be undertaken every **THREE MONTHS**:

Description of Work

- Flush each Domestic Hot Water Calorifier and Buffer Vessel through its drain valve by opening the drain valve 3 times, each time for a 3 minute period. Where required, the hose from the drain valve connection should be discharged to the nearest drain/gulley.
- Record all actions on the top section of Record Form(006).
- Where the domestic hot water system has a stratification pump(s) fitted to circulate the hot water from the top to the base of the calorifier or the storage/buffer vessel, and the history data shows no sludge deposits during flushing, then this procedure should be risk assessed to determine if the maintenance frequency can be changed. This assessment should be recorded on Record Form (023).

NOTE: this flushing process can air lock the hot water system, so only carry it out when there is no hot water demand and the calorifier is valved off from the system.

CHECK

1. Record all details of any fault or discrepancy on the FAULT LOG and complete Incident Form (04) and report to Manager.
2. Complete Record Forms (006) and/or (023) ensuring that you date, sign them and enter FM First ticket number.
3. Return form to the Water Systems AP.

4.63 – HORNE TAP FLOW RESTRICTOR EXCHANGE

FM First Template No N/A

QUARTERLY

IN ACCORDANCE WITH IC GUIDANCE

RECORD FORM – (See DMA Records)

PROCEDURE REF – WQS 001

HAISCRIBE/Risk Assessment Ref – N/A See Appendix 4

The following actions must be undertaken every **THREE MONTHS**:

Description of Work

PPE:- Surgical gloves should be worn when carrying out this task. Cross contamination of the replacement flow restrictor should be considered and avoided at all times.

Restrictor should only be replaced at outlets without PALL filters. If PALL filter is fitted it should be left in place and noted on Record Form.

- Assemble all tools and materials required to complete task.
- Check with ward staff to ensure access can be granted to each area without Infection Control restriction.
- Remove existing restrictor using the appropriate tool and dispose of the restrictor in general waste.
- Use disinfectant wipes to sanitise tap outlet and tools used before re-fitting new restrictor.
- Change gloves to avoid cross contamination of new components and tools.
- Unpack new restrictor components and insert into tap as per the manufacturer's instructions.
- Test on completion and fill out log sheet to record all relevant information.

CHECK

1. Record all details of any fault or discrepancy on the FAULT LOG and complete Incident Form (04) and report to Manager.
2. Complete Record Form (DMA WATER) ensuring that you date, sign them and enter FM First ticket number.
3. Return form to the Water Systems AP.

4.64 - REVIEW OF INTERMITTENTLY USED WATER OUTLETS/CHANGE IN-USE

IN ACCORDANCE WITH BOARD POLICY

QUARTERLY

RECORD FORM – (001) (026)

PROCEDURE REF – WS01

HAISCRIBE/Risk Assessment Ref – N/A See Appendix 4

The following actions must be undertaken every **THREE MONTHS**:

Description of Work

- Liaise with Site Facilities Manager and Heads of Department to review existing accommodation occupancy and usage on a 3 monthly basis.
- Issue Quarterly circular email to all HoDs requesting to identify little used outlets and to confirm that they have a flushing regime implemented.
- Identify any water services outlets that are not used OR changes to the occupancy.
- Schedule to be updated to record all areas which change in-use, become unoccupied or otherwise out of use.

CHECK

1. Record all details of any dept closures or little used outlets on Record Form (001) and add outlets to flushing register.
2. Ensure outlets are brought to the attention of the maintenance person carrying out the flushing activity and details added to Record Form (026) or arrange with DMA to add to flushing requirements if required. Wards should be carrying out flushing as per requirements and provide evidence on WS01 form.
3. All completed Record Forms to be stored in the building specific Log Book.

4.65 – TMV/TMT & THERMOSTATIC SHOWER DISINFECTION AND FUNCTION TEST (HIGH RISK)

QUARTERLY

FM First Template No

IN ACCORDANCE BOARD POLICY

RECORD FORM - REQUIRES CONFIRMATION IF THIS SHOULD BE CARRIED OUT THREE MONTHLY

PROCEDURE REF -

HAISCRIBE/Risk Assessment Ref – N/A See Appendix 4

The following actions must be undertaken every **THREE MONTHS**:

Description of Work

- Examine all thermostatic taps for scale build-up or other deposits. De-scale any which are not clean.
- Check and remove any installed plastic flow straighteners from tap outlet
- Inspect and Clean and Disinfect filters / strainers by removing and immersing in a solution of 1000ppm free residual chlorine (50cc CLO2 in 5 litres of water) in water for 5 minutes.
- All HORNE Optitherm taps MUST have the flow straightener replaced during three monthly service tasks.
- Pasteurise outlets by over-riding thermostatic controls drawing water through each thermostatic tap until a temperature of 60°C is achieved. Run the tap at this temperature for five minutes. If this is not possible disassemble tap assembly and spray all accessible components with ‘Shower Head plus’ mixed to a 1:3 solution, (one part chemical, 3 parts water) or equal and approved and let stand for 5 minutes.
- Reassemble and verify fail safe operation by isolating hot and cold water supplies separately.
- Ensure thermostatic controls are re-adjusted to permit blending.
- Should controls not be able to be over-ridden, verify the temperatures at the inlet connections to the thermostatic valve utilising a contact type probe and electronic thermometer.
- Run and test tap and record hot and cold water inlet temperatures and mixed water outlet temperature.
- Log all actions.

4.66 – PAL FILTER REPLACEMENT

FM First Template No

31& 62 Day

IN ACCORDANCE WITH AGREED FILTER LOCATIONS

RECORD FORM - DMA RECORDS

PROCEDURE REF -

HAISCRIBE/Risk Assessment Ref – N/A See Appendix 4

The following actions must be undertaken every **31 Days or 62 Days based on filter types and locations**:

Description of Work

- Replace filters prior to end date on tap and shower filters as per programme.
- Process for replacement as per DMA Procedures.
- Log all replacements as per DMA Procedures and record in DMA Records.
- Any issues should be reported to Water Lead AP.

4.7 Six Monthly Checks

Reference	Operation
4.71	TMV/TMT & Thermostatic Shower Disinfection and Function Test (Non-HIGH RISK)
4.72	CWST Inspection and Temperature Monitoring
4.73	Maintenance of filtration units
4.74	CL02 checks

NOTE:

Completed Log Sheet to be submitted to either the Authorised Person (Water Systems) or Site Manager Operational Estates for authorisation and copies filed as indicated in Section 2.2.

Due to the volume of information required for the recording of test results for each of the assets being maintained, the Log Sheets provided within this document are for indicative purposes only.

Detailed information on the assets and test records for same will be retained within the specific 'Log Book' for the location being maintained.

4.71 – TMV/TMT & THERMOSTATIC SHOWER DISINFECTION AND FUNCTION TEST (NON HIGH RISK)

SIX MONTHLY

IN ACCORDANCE WITH BOARD POLICY

ANNUAL FOR MIU

RECORD FORM -

PROCEDURE REF -

HAISCRIBE/Risk Assessment Ref – N/A See Appendix 4

The following actions must be undertaken every **SIX MONTHS**:

Description of Work

- Examine all thermostatic taps for scale build-up or other deposits. De-scale any which are not clean.
- Check and remove any installed plastic flow straighteners from tap outlet
- Inspect and Clean and Disinfect filters / strainers by removing and immersing in a solution of 1000ppm free residual chlorine (50cc CLO2 in 5 litres of water) in water for 5 minutes.
- All HORNE Optitherm taps MUST have the flow straightener replaced during three monthly service tasks.
- Pasteurise outlets by over-riding thermostatic controls drawing water through each thermostatic tap until a temperature of 60°C is achieved. Run the tap at this temperature for five minutes. If this is not possible disassemble tap assembly and spray all accessible components with ‘Shower Head plus’ mixed to a 1:3 solution, (one part chemical, 3 parts water) or equal and approved and let stand for 5 minutes.
- Reassemble and verify fail safe operation by isolating hot and cold water supplies separately.
- Ensure thermostatic controls are re-adjusted to permit blending.
- Should controls not be able to be over-ridden, verify the temperatures at the inlet connections to the thermostatic valve utilising a contact type probe and electronic thermometer.
- Run and test tap and record hot and cold water inlet temperatures and mixed water outlet temperature.
- Log all actions.

4.72 – CWST INSPECTION AND TEMPERATURE MONITORING:

FM First Template No 819

SIX MONTHLY

IN ACCORDANCE WITH SHTM 04-01 Part G (*V1 July 2015*) Page 29 para 3.37

RECORD FORM – Carried out by DMA – refer to records

PROCEDURE REF – P1C7

HAISCRIBE/Risk Assessment Ref – N/A See Appendix 4

The following actions must be undertaken every **SIX MONTHS** seasonally during Summer and Winter:

Description of Work

- Inspect the tank and associated pipework including insulation, valves etc for damage or corrosion and sediment.
- Operate all isolation valves through their full range of motion.
- Check the operation of the ball-valve by pressing down on it and lifting the float to confirm that water flows and stops.
- Inspect the tank overflows if visible. Confirm that there is no blockage or other foreign material and that the mesh screen is not damaged.
- Measure and record the temperature of the water in the tanks, by dipping the thermometer into the top as far from the ball-valve as possible.
- Check and record ambient outside air temp and tank room temp.
- Check the flow and record the temperature of water feeding the tanks. There should be a steady rapid flow when the ball float is down.

CHECK

1. Record all details of any fault or discrepancy on the FAULT LOG and complete Incident Form (04) and report to Manager.
2. Complete Records and send information to Water Systems AP.

4.73 – MAINTENANCE OF WATER FILTRATION UNITS:

FM First Template N/A

SIX MONTHLY

N/A

RECORD FORM – Carried out by Veolia– refer to records

PROCEDURE REF – N/A

HAISCRIBE/Risk Assessment Ref – N/A

The following actions must be undertaken every **SIX MONTHS**:

Description of Work

- Check on feedwater quality
- Check on treated water quality & flows
- The condition of valves & diaphragms
- Operational cycle simulation
- General plant condition & safety
- The condition of system pumps
- The condition of the pre-filters
- Level control function

CHECK

1. Record all details of any fault or discrepancy and pass to Water Lead AP to record on the FAULT LOG and complete Incident Form (04).

4.74 – MAINTENANCE OF CL02 PLANT:

FM First Template N/A

SIX MONTHLY

N/A

RECORD FORM – Carried out by Scotmas– refer to records

PROCEDURE REF – N/A

HAISCRIBE/Risk Assessment Ref – N/A

The following actions must be undertaken every **SIX MONTHS**:

Description of Work

- As per monthly plus :-
- Check ClO2 gas detector functionality and recording levels.
- Simulate fault circuitry and alarm on Sentinel Monitor.
- Change probe electrolyte and cross calibration test.
- Carry out manual Chlorate & Chlorite validation tests (12 representative outlets).
- Check water meter operation and report on Electrolyte top up, Probe calibrations

CHECK

1. Record all details of any fault or discrepancy and pass to Water Lead AP to record on the FAULT LOG and complete Incident Form (04).

4.8 Annual Maintenance Checks

Reference	Operation
4.81	DWS Calorifier / Expansion Vessel Inspection
4.82	Water Services Pipework and Distribution System Checks
4.83	Representative Tap Temperature Monitoring
4.84	Vibration coupling inspection
4.85	BMS Temperature Sensor Test and Calibration
4.86	TMT Maintenance of MIU

NOTE:

Completed Log Sheet to be submitted to either the Authorised Person (Water Systems) or Site Manager Operational Estates for authorisation and copies filed as indicated in Section 2.2.

Due to the volume of information required for the recording of test results for each of the assets being maintained, the Log Sheets provided within this document are for indicative purposes only.

Detailed information on the assets and test records for same will be retained within the specific 'Log Book' for the location being maintained.

4.81 - DWS CALORIFIER/EXPANSION VESSEL INSPECTION

FM First Template No 821

ANNUAL

IN ACCORDANCE WITH SHTM 04-01 Part G (*V1 July 2015*) Page 31 para 3.44

RECORD FORM - (006)

PROCEDURE REF - P1C9

HAISCRIBE/Risk Assessment Ref – N/A See Appendix 4

The following actions must be undertaken **ANNUALLY**

Description of Work

Follow the manufacturers' maintenance instructions from O&M manuals. Record all actions where applicable on Record Form (006) for each system.

- Isolate domestic hot water calorifier or hot, cold or chilled water storage/buffer vessel service valves;
- Heat any domestic hot water calorifier or hot water storage/buffer vessel up until the contents has reached 60ºC and hold at this temperature for a period of at least 1 hour;
- Drain domestic hot water calorifier and expansion vessel and remove inspection hatch;
- Hose out the domestic hot water calorifier or hot and expansion vessel to remove any debris, scale or other deposit. Care should be taken to keep aerosols to a minimum.
- If the domestic hot water calorifier or expansion vessel does not have an inspection hatch, the pipework at the top of the vessel should be disconnected to allow the insertion of a water hose to allow debris to be washed down off internal surfaces;
- Examine the internal and external condition of the domestic hot water calorifier and expansion vessel and pipework, any defects should be reported in writing to the relevant Authorised Person (Water). The safety valve should be checked, overhauled and reset as necessary. The temperature and pressure gauges to be checked for operation.
- On completion of examination and any repairs, the domestic hot water calorifier and expansion vessel should be re-assembled and the following sequence must be undertaken:
- Refill with cold water;
- Drain the domestic hot water calorifier and expansion vessel;
- Refill with cold water, leave cold feed valve open;
- Run domestic hot water calorifier or hot water storage/buffer vessel at a temperature of 60ºC for at least 1 hour. Test the operation of high limit cut-out system if fitted. Check the temperature of the calorifier/vessel top and bottom with a surface thermometer;

- Adjust any controls as necessary.
- Take bacteriological samples from the base of the calorifier and submit to GRI Water Lab for analysis. (THIS TASK TO BE CARRIED OUT BY DMA CANYON WATER)

NOTE: this flushing process can air lock the hot water system, so only carry it out when there is no hot water demand and the calorifier is valved off from the system.

CHECK

1. Record all details of any fault or discrepancy on the FAULT LOG and complete Incident Form (04) and report to Manager.
2. Complete Record Forms (006) ensuring that you date, sign them and enter FM First ticket number.
3. Return form to the Water Systems AP.

4.82 - PIPEWORK AND DISTRIBUTION SYSTEM CHECKS

FM First Template No 829

ANNUAL

IN ACCORDANCE WITH SHTM 04-01 Part G (*V1 July 2015*) Page 31 para 3.

RECORD FORM - (0)

PROCEDURE REF -

HAISCRIBE/Risk Assessment Ref – N/A See Appendix 4

The following actions must be undertaken **ANNUALLY**:

Estates Manager or Water Systems AP will define areas to be checked in each building.

Description of Work

- Check all accessible pipework for damage, or corrosion.
- Check for missing or damaged pipework insulation
- This is carried within the Tank Room by DMA during sampling and tank inspections monthly.
- This is carried out by NHS Estates within Plantrooms during plantroom inspections monthly
- This is carried out as per above procedures and noted on FM First PPM's..

CHECK

1. Record all details of any fault or discrepancy on the FAULT LOG and complete Incident Form (04) and report to Manager.
2. Complete Record Forms as per above procedures ensuring that you date, sign them and enter FM First ticket number.
3. Return form to the Water Systems AP.

4.83 – REPRESENTATIVE TAP TEMPERATURE MONITORING

FM First Template No 917 **ANNUAL**

IN ACCORDANCE WITH SHTM 04-01 Part G (*V1 July 2015*) Page 32 para 3.39

RECORD FORM - (005d)

PROCEDURE REF – P1C10

HAISCRIBE/Risk Assessment Ref – N/A See Appendix 4

The following actions must be undertaken at regular intervals throughout the year to ensure 20% of the requirement is completed **ANNUALLY**:

Description of Work

- OBJECTIVE: Carry out water temperature monitoring to ensure consistency and performance of the system as per design. 20% of all outlets to be assessed annually to ensure entire system is completed within a 5 year period (*ref: SCART2 Question 54)*
- Check the temperatures at a representative number of hot and cold outlets on a rotational basis as defined in the local plan of the system being checked. Lead AP (Water) to define areas to be checked each month.
- Using a temperature probe check the temperature of the cold water tap does not go above 20ºC after running the tap for 2 minutes;
- Using a temperature probe check the temperature of the hot water tap does not go below 55ºC within running the tap for 1 minute;
- If the outlet being tested is protected by a TMV/TMT then temperatures should be taken directly from the supply pipework or by bypassing the thermostatic device by use of an appropriate purging kit.
- Record all temperatures and locations tested on the Record Form (005d) or if carried out by DMA to reflect in records.

CHECK

1. Record all details of any fault or discrepancy on the FAULT LOG and complete Incident Form (04) and report to Manager.
2. Complete Record Forms (005d) ensuring that you date, sign them and enter FM First ticket number.
3. Return form to the Water Systems AP.

4.84 - VIBRATION COUPLING INSPECTION

FM First Template No 831

ANNUAL

IN ACCORDANCE WITH HSG 274 Part 2 *(2014)* Page 19 para 2.35

RECORD FORM - (008)

PROCEDURE REF – WQMS 001

HAISCRIBE/Risk Assessment Ref – N/A See Appendix 4

The following actions must be undertaken **ANNUALLY**:

Description of Work

- Refer to list of vibration coupling locations to be assessed.
- Visually check the condition of the coupling for any signs of leakage, deterioration or corrosion.
- Ensure flexible portion of coupling is intact and free from damage or deterioration.
- Carried out on Cold Water Booster sets as part of the inspection.

CHECK

1. Record all details of any fault or discrepancy on the FAULT LOG and complete Incident Form (04) and report to Manager.
2. Complete Record Forms ensuring that you date, sign them and enter FM First ticket number.
3. Return form to the Water Systems AP.

4.85 – BMS TEMPERATURE SENSOR CALIBRATION

ANNUAL

FM First Template No

IN ACCORDANCE WITH

RECORD FORM -

PROCEDURE REF –

HAISCRIBE/Risk Assessment Ref – N/A See Appendix 4

The following actions must be undertaken **ANNUALLY**:

Description of Work

- This task should be included in the BMS Service Contract Specification.
- All temperature sensors related to domestic hot and cold water services to be checked and calibrated annually.
- All calorifiers, storage tanks, flow and return monitoring devices.
- Include all End of Line (EOL) sensors and cold water flushing devices.
- Records should be kept and made available to the estates dept on request.

4.86 – MAINTENANCE OF WATER FILTRATION UNITS:

FM First Template N/A

ANNUAL

N/A

RECORD FORM – Carried out by Veolia– refer to records

PROCEDURE REF – N/A

HAISCRIBE/Risk Assessment Ref – N/A

The following actions must be undertaken **ANNUALLY**:

Description of Work

- As per 6 monthly and ClO2 & Chlorite Probe membrane cap replacement.
- Dosing Pump diaphragm valve replacements.
- Replace ClO2 gas detector cartridge if required

CHECK

1. Record all details of any fault or discrepancy and pass to Water Lead AP to record on the FAULT LOG and complete Incident Form (04).

4.87 – TMV/TMT & THERMOSTATIC SHOWER DISINFECTION AND FUNCTION TEST (NON HIGH RISK)

IN ACCORDANCE WITH BOARD POLICY

RECORD FORM -

ANNUAL FOR MIU

PROCEDURE REF -

HAISCRIBE/Risk Assessment Ref – N/A See Appendix 4

The following actions must be undertaken **ANNUALLY** :

Description of Work

- Examine all thermostatic taps for scale build-up or other deposits. De-scale any which are not clean.
- Check and remove any installed plastic flow straighteners from tap outlet
- Inspect and Clean and Disinfect filters / strainers by removing and immersing in a solution of 1000ppm free residual chlorine (50cc CLO2 in 5 litres of water) in water for 5 minutes.
- Pasteurise outlets by over-riding thermostatic controls drawing water through each thermostatic tap until a temperature of 60°C is achieved. Run the tap at this temperature for five minutes. If this is not possible disassemble tap assembly and spray all accessible components with 'Shower Head plus' mixed to a 1:3 solution, (one part chemical, 3 parts water) or equal and approved and let stand for 5 minutes.
- Reassemble and verify fail safe operation by isolating hot and cold water supplies separately.
- Ensure thermostatic controls are re-adjusted to permit blending.
- Should controls not be able to be over-ridden, verify the temperatures at the inlet connections to the thermostatic valve utilising a contact type probe and electronic thermometer.
- Run and test tap and record hot and cold water inlet temperatures and mixed water outlet temperature.
- Log all actions.

4.9 Bi-Annual Maintenance Checks

Reference	Operation
4.91	Flexible Hose/Connection Inspection and Exchange
4.92	CWST Drop Test

NOTE:

Completed Log Sheet to be submitted to either the Authorised Person (Water Systems) or Site Manager Operational Estates for authorisation and copies filed as indicated in Section 2.2.

Due to the volume of information required for the recording of test results for each of the assets being maintained, the Log Sheets provided within this document are for indicative purposes only.

Detailed information on the assets and test records for same will be retained within the specific 'Log Book' for the location being maintained.

4.91 – FLEXIBLE HOSE/CONNECTION INSPECTION AND EXCHANGE

FM First Template No

BI-ANNUAL

IN ACCORDANCE WITH QEUH RISK ASSESSMENT RECOMMENDATIONS 2017

RECORD FORM - (009)

PROCEDURE REF – WQMS 002

HAISCRIBE/Risk Assessment Ref – N/A See Appendix 4

The following actions must be undertaken **ANNUALLY**:

Description of Work

- Refer to list of flexible connection locations to be assessed as per WQMS 002.
- Visually check the condition of the coupling for any signs of leakage, deterioration or corrosion.
- Safely isolate the water services and exchange the flexible connection with a BRAND NEW UNUSED replacement.
- Apply tag/label to indicate the intended date of future replacement (todays date + 24 months)
- Record all details on the Record Form (009).

CHECK

1. Record all details of any fault or discrepancy on the FAULT LOG and complete Incident Form (04) and report to Manager.
2. Complete Record Forms (009) ensuring that you date, sign them and enter FM First ticket number.
3. Return form to the Water Systems AP.

4.92 – CWST DROP TESTS

BI-ANNUAL

FM First Template No 819

IN ACCORDANCE WITH

RECORD FORM -

PROCEDURE REF -

HAISCRIBE/Risk Assessment Ref – N/A See Appendix 4

The following actions must be undertaken **ANNUALLY**:

Description of Work

- Shut off mains cold water supply to tank.
- Record the start time and allow tank to drain naturally through usage. DO NOT OPEN THE DRAIN.
- Periodically monitor the tank until usage has reduced tank to exactly half of its starting capacity.
- Record the stop time and estimate the number of hours of storage of water in the tank.
- Record all inspection details on the Record Form (010).

CHECK

1. Record all details of any fault or discrepancy on the FAULT LOG and complete Incident Form (04) and report to Manager.
2. Complete Record Forms (010) ensuring that you date, sign them and enter FM First ticket number.
3. Return form to the Water Systems AP.

5.0 INCIDENT AND EMERGENCY PROCEDURES

Procedure Reference	Operation
5.10	FAILURE OF CONTROL MEASURES
5.20	HIGH COLD WATER SUPPLY TEMPERATURE TO OUTLET
5.30	LOW HOT WATER SUPPLY TEMPERATURE TO OUTLET
5.40	CALORIFIER OR HEAT EXCHANGER TEMPERATURE FAULT
5.50	POSITIVE LEGIONELLA TEST RESULT
5.60	IDENTIFICATION OF LITTLE USED WATER OUTLET
5.70	EMERGENCY REPAIRS
5.80	DISINFECTION OF WATER SYSTEM
5.90	PSEUDOMONAS

NOTE:

Completed Log Sheet to be submitted to either the Authorised Person (Water Systems) or Site Manager Operational Estates for authorisation and copies filed as indicated in Section 2.2.

Due to the volume of information required for the recording of test results for each of the assets being maintained, the Log Sheets provided within this document are for indicative purposes only.

Detailed information on the assets and test records for same will be retained within the specific 'Log Book' for the location being maintained.

THE FOLLOWING PAGES DESCRIBE REMEDIAL ACTIONS TO BE TAKEN IN THE EVENT OF AN INCIDENT, EMERGENCY, OUT-OF-SPECIFICATION TEST RESULT AND / OR WHERE *LEGIONELLA* HAS BEEN IDENTIFIED AND/OR BACTERIA COUNTS BEING INEXCESS OF THE RECOMMENDED LIMITS IN THE WATER SYSTEM ARE IDENTIFIED.

The Health and Safety at Work Act places a duty on employers to ensure, so far as is reasonably practicable, the maintenance of safe working conditions without risks to health, not only to employees, but also to the general public.

The risk to personnel associated with the presence of *Legionella* depends on a number of variables and may be quite low. However, since the actions to eradicate it are straightforward and reasonably practicable, it would be wise to put them in hand without delay if *Legionella* has been identified.

When analysis confirms that the levels of bacteriological contamination are in excess of acceptable limits, and/or the presence of Coliforms or *E.coli* is identified, the procedures recommended in this section should be applied.

5.1 Failure of Control Measures:

Where any reported test result, non-compliance issue or defect is made known which affects the integrity of the water system and indicates the failure of Control Measures and / or increased risk of Legionella the following procedures shall be followed and duly recorded within Section 2.3 of this document and brought to the attention of the relevant Infection Control Team and Water Management Group.

IN ALL CASES THE INCIDENT RECORD FORM (004) SHOULD BE COMPLETED AND INSERTED IN THE BUILDING SPECIFIC WATER SAFETY LOG BOOK.

5.2 High Cold Water Supply Temperature

Incident Plan

In the event of plant failure suppliers and installers guidance should be consulted. The location of all relevant literature should be recorded in the site logbook (e.g. Mercury fault finding guidance).

Mains and Stored Water

Currently there is no legal maximum water supply temperature from the Licensed Provider. In practice the water supply temperature to boundary point will be subject to seasonal variation. In winter this would normally be expected to be in the 5°C – 10°C range and in summer up to 20°C.

The following staged risk assessment escalation procedure should be employed where the water temperature in Cold Water Storage Tanks is 20°C or higher.

Stage 1 - Verification

- Where tepid cold water occurrence (i.e. ≥20°C) is reported from any numbers of cold water outlets, from maintenance/ppm, flushing procedures, from BEMS monitoring, or from the manual monitoring of storage tanks, the person identifying, or making a report must notify the relevant Authorised Person (Water) as soon as the problem is identified and confirm this in writing within 24 hours;

- The Authorised Person (Water) should liaise with the person identifying the problem and verify the problem by independently re-checking by means of taking the water temperature of the appropriate cold water storage tank, the temperature of each incoming mains supplies at the site boundary point (and building entry points of other buildings within the QEUH campus served by the same mains lines) and the outflow distribution temperature;

- If the cold water storage temperature is confirmed as being 20°C or higher at any of the above noted points, then the Authorised Person (Water) should record this in writing as well as conducting continuous monitoring of the incoming cold water mains, the cold water storage and the outflow temperatures to establish the temperature profiles and in more detail over at least a one week period to determine the level of risk;

- If only one of the incoming mains lines is ≥20°C the consideration should be given to switching to the other mains supply until such times as “out-of-specification” mains line has returned to compliant parameters. Ensure if either mains line is non-operational it is included in a daily flushing regime and treated as per escalation procedures to follow.

- The Authorised Person (Water) should also review the Water Safety Log Book and take into account the recent water system history specifically to include:

    - the primary water treatment levels (for mains cold water supplied with Chlorine or Chloramination treatment);
    - any water sampling results;
    - system monitoring data including temperature monitoring and water quality chlorine or chloramination checks;
    - recent maintenance history; recent alterations, changes or additions to the water system;
    - any other changes made by Duty Holders or users of the water system; On reviewing continuous monitoring temperature profiles action as Stage 2, 3 or 4 as appropriate of this escalation procedure should be undertaken. The Authorised Person (Water) will ensure that the Responsible Person (Water) is notified immediately in writing at each stage and also recorded in the Water Safety log book.

Stage 2 - Initial Action – High Incoming Mains Cold Water Temperature

- Where the incoming mains cold water is 18°C or higher for more than a 48 hour period the Responsible Person (Water) should contact Business Stream (the Licensed Provider) who will work with Scottish Water to establish the reasons and determine a resolution. Continuous monitoring should continue and recorded in the risk assessment

Stage 3 - Water temperatures fluctuating above and below 20°C (but not higher than 25°C)

- Where water temperatures are fluctuating above and below 20°C in a regular cyclical manner over 72 hour periods in response to regular user water demand (but not higher than 25°C) and are more than 2°C higher than the incoming cold water mains supply temperature at the building entry point, then continuous monitoring should be continued by the Authorised Person (Water). The reason(s) for failure(s) should be identified and rectified as soon as possible. This should be recorded by updated risk assessment (specifically in relation to the patient risk rating – where there may be increased risk and appropriate actions may be required to mitigate exposure. An up to date register of all areas and their subsequent patient risk ratings should be maintained).

- considerations for failures include:
  - accuracy of temperature sensors (requiring recalibration);
  - temperature sensors being located in water (requiring reposition where tank storage levels been reduced and sensor no longer sensing stored water);
  - inappropriate standby tank configuration;
  - temperature sensor in standby system;
  - temperature sensor measuring stagnation (requires reposition);
  - inappropriate siting (not in a cool location);
  - heat gain to the tank and pipework (due to lack of appropriate insulation or located close to heat gain from other heat sources);
  - storage capacity not minimised to match daily use (12 hours storage is recommended);
  - ingress of hot water through cross connection or mixing valve failure (i.e. from DHW system or MTHW systems);

Stage 4 - water temperatures fluctuating above and below 25°C (and rarely below 20°C)

- In this situation continuous monitoring should be continued by the Authorised Person (Water), the reason(s) for failure(s) (as Stage 3) identified and rectified on an urgent basis. This should be recorded by updated risk assessment (specifically in relation to the patient risk rating – where there will be an increased risk and appropriate actions will be required to mitigate exposure. An up to date register of all areas and their subsequent patient risk ratings should be maintained);

- In this situation a permanent solution, such as ventilation for the plant room, or changing the water storage arrangements, or forming a circulating distribution system (with or without chilling depending on the circumstances) would require to be implemented;

- The Authorised Person (Water) should, unless instructed in writing to the contrary by Responsible Person (Water) implement the following:
  - arrange to drain the tank contents and clean if necessary *(and/or carry out local disinfections where appropriate)*;
  - inform the users of the failed system that they must not draw off any water from the affected system until further notice;
  - suitable disinfection of the tank and/or distribution system shall be carried out.

Please Note: *Due to the system design and installation complete disinfection of all downservices fed from the Raw and Bulk water storage tanks may not be practical as "high risk" system such as renal dialysis is fed from these tanks. Alternative protocols/method statements for local disinfections should be prepared and maintained*;

  - thereafter the tank/local area being disinfected shall be brought back into service;
  - finally the users shall be informed that the system is back in operation.

The Authorised Person (Water) shall complete an Incident Report Record Form. An entry should also be made in the Water Safety Log Book and the Responsible Person (Water) should be notified in writing as soon as possible.

5.3 Low Hot Water Supply Temperature

Incident Plan

In the event of plant failure suppliers and installers guidance should be consulted. The location of all relevant literature should be recorded in the site logbook (e.g. Mercury fault finding guidance).

Mains and Stored Water

Currently there is no legal maximum water supply temperature from the Licensed Provider. In practice the water supply temperature to boundary point will be subject to seasonal variation. In winter this would normally be expected to be in the 5°C – 10°C range and in summer up to 20°C.

The following staged risk assessment escalation procedure should be employed where the water temperature in Cold Water Storage Tanks is 20°C or higher.

Stage 1 - Verification

- Where tepid cold water occurrence (i.e. ≥20°C) is reported from any numbers of cold water outlets, from maintenance/ppm, flushing procedures, from BEMS monitoring, or from the manual monitoring of storage tanks, the person identifying, or making a report must notify the relevant Authorised Person (Water) as soon as the problem is identified and confirm this in writing within 24 hours;

- The Authorised Person (Water) should liaise with the person identifying the problem and verify the problem by independently re-checking by means of taking the water temperature of the appropriate cold water storage tank, the temperature of each incoming mains supplies at the site boundary point (and building entry points of other buildings within the Southern General Hospital served by the same mains lines8) and the outflow distribution temperature;

- If the cold water storage temperature is confirmed as being 20°C or higher at any of the above noted points, then the Authorised Person (Water) should record this in writing as well as conducting continuous monitoring of the incoming cold water mains, the cold water storage and the outflow temperatures to establish the temperature profiles and in more detail over at least a one week period to determine the level of risk;

- If only one of the incoming mains lines is ≥20°C the consideration should be given to switching to the other mains supply until such times as “out-of-specification” mains line has returned to compliant parameters. Ensure if either mains line is non-operational it is included in a daily flushing regime and treated as per escalation procedures to follow.

- The Authorised Person (Water) should also review the Water Safety Log Book and take into account the recent water system history specifically to include:

    - the primary water treatment levels (for mains cold water supplied with Chlorine or Chloramination treatment);

- any water sampling results;
- system monitoring data including temperature monitoring and water quality chlorine or chloramination checks;
- recent maintenance history; recent alterations, changes or additions to the water system;
- any other changes made by Duty Holders or users of the water system;

On reviewing continuous monitoring temperature profiles action as Stage 2, 3 or 4 as appropriate of this escalation procedure should be undertaken. The Authorised Person (Water) will ensure that the Responsible Person (Water) is notified immediately in writing at each stage and also recorded in the Logbook via Incident form (04).

Stage 2 - Initial Action – High Incoming Mains Cold Water Temperature

- Where the incoming mains cold water is 18°C or higher for more than a 48 hour period the Responsible Person (Water) should contact Business Stream (the Licensed Provider) who will work with Scottish Water to establish the reasons and determine a resolution. Continuous monitoring should continue and recorded in the risk assessment.

-

Stage 3 - water temperatures fluctuating above and below 20°C (but not higher than 25°C)

- Where water temperatures are fluctuating above and below 20°C in a regular cyclical manner over 72 hour periods in response to regular user water demand (but not higher than 25°C) and are more than 2°C higher than the incoming cold water mains supply temperature at the building entry point, then continuous monitoring should be continued by the Authorised Person (Water). The reason(s) for failure(s) should be identified and rectified as soon as possible. This should be recorded by updated risk assessment (specifically in relation to the patient risk rating – where there may be increased risk and appropriate actions may be required to mitigate exposure. An up to date register of all areas and their subsequent patient risk ratings should be maintained).

- considerations for failures include:
  - accuracy of temperature sensors (requiring recalibration);
  - temperature sensors being located in water (requiring reposition where tank storage levels been reduced and sensor no longer sensing stored water);
  - inappropriate standby tank configuration;
  - temperature sensor in standby system;
  - temperature sensor measuring stagnation (requires reposition);
  - inappropriate siting (not in a cool location);
  - heat gain to the tank and pipework (due to lack of appropriate insulation or located close to heat gain from other heat sources);
  - storage capacity not minimised to match daily use (12 hours storage is recommended);
  - ingress of hot water through cross connection or mixing valve failure (i.e. from DHW system or MTHW systems);

Stage 4 - water temperatures fluctuating above and below 25°C (and rarely below 20°C)

- In this situation continuous monitoring should be continued by the Authorised Person (Water), the reason(s) for failure(s) (as Stage 3) identified and rectified on an urgent basis. This should be recorded by updated risk assessment (specifically in relation to the patient risk rating – where there will be an increased risk and appropriate actions will be required to mitigate exposure. An up to date register of all areas and their subsequent patient risk ratings should be maintained);

- In this situation a permanent solution, such as ventilation for the plant room, or changing the water storage arrangements, or forming a circulating distribution system (with or without chilling depending on the circumstances) would require to be implemented;

- The Authorised Person (Water) should, unless instructed in writing to the contrary by Responsible Person (Water) implement the following:
  - arrange to drain the tank contents and clean if necessary *(and/or carry out local disinfections where appropriate)*;
  - inform the users of the failed system that they must not draw off any water from the affected system until further notice;
  - suitable disinfection of the tank and/or distribution system shall be carried out.

Please Note: *Due to the system design and installation complete disinfection of all downservices fed from the Raw and Bulk water storage tanks may not be practical as "high risk" system such as renal dialysis is fed from these tanks. Alternative protocols/method statements for local disinfections should be prepared and maintained*;

- thereafter the tank/local area being disinfected shall be brought back into service;
- finally the users shall be informed that the system is back in operation.

The Authorised Person (Water) shall complete an Incident Report Record Form. An entry should also be made in the Water Safety Log Book and the Responsible Person (Water) should be notified in writing as soon as possible. Record on Incident form (04).

Hot Water Services

When hot water storage or distribution temperatures fall below those required (60°C storage, 55°C at outlets and returning to calorifier) these will almost inevitably be caused a mechanical fault. Appropriate maintenance procedures, including the Mercury Fault Finding guidance documents, should be created and referenced to assist in timely rectification.

This escalation procedure (taken from SHTM 04-01 Part G (Draft)) should be employed if the Calorifier/Plate Heat Exchangers outflow temperature falls below 45ºC.

The table below should be used to decide on the actions necessary in the event of a plant breakdown such as power failure or gas supply failure.

Breakdown leading to temperature <45°C, lasting for:	Risk Category	Action
<12 hrs	High	Verify
	Significant	Verify
	Moderate	Verify
>12 hrs	High	Thermally pasteurise
	Significant	Verify
	Moderate	Verify
>24 hrs	High	Thermally pasteurise
	Significant	Thermally pasteurise
	Moderate	Verify
>72 hrs	High	Thermally pasteurise
	Significant	Thermally pasteurise
	Moderate	Thermally pasteurise

In the event of a reduction in domestic hot water temperature the **Authorised Person (Water)** should be notified in writing as soon as possible. The reason for failure must be identified and rectified as soon as possible.
The **Authorised Person (Water)** shall notify the **Duty Holder** and users on the failed system that they must not draw off any hot water from the affected services until further notice.
The relevant **Duty Holder** shall ensure that their staff are aware of the situation, and that they in turn shall prevent patients from using affected services.

Where thermal pasteurisation is to be carried out, the temperature of the calorifier or plate heat exchanger shall be raised to 70ºC, and the water shall be circulated throughout the affected distribution system for at least one 1 hour. Each tap or appliance should be run in sequence until full temperature is achieved (this should be measured). To be effective the temperature in the calorifier or plate heat exchanger should be high enough to ensure that all distribution outlets receive water at a temperature of greater than 60ºC. Ensure the return flow to the calorifier or plate heat exchanger is no less than **55ºC**.

The **Authorised Person (Water)** shall inform users that the system is back in operation.
Bacteriological samples should be taken in consultation with the Infection Prevention and Control team.
The **Authorised Person (Water)** shall complete an Incident Report Record and ensure the **Responsible Person (Water)** is notified in writing as soon as possible. Maintain hard copy records in the Water Safety Log.

5.4 Positive Legionella Test Result

Microbiological Sampling (Legionella)

Sampling requirements and frequency are to be formulated by NHS GG&C and written scheme should be updated as appropriate.

Legionella testing may be required:

- In systems where the temperature control regimes are not consistently achieved, frequent testing e.g. weekly should be carried out to provide early warning of loss of control. Once the system is brought back under control as demonstrated by monitoring, the frequency of testing should be reviewed
- Weekly checks are recommended until the system is brought under control;
- When an outbreak is suspected or has been identified;
- In wards with at-risk patients – for example those who are immuno-compromised ("high risk patient" areas still to be confirmed to DMA).

As a minimum, samples should be taken as follows:

- From the cold water storage and the furthermost outlet from the tank, on every loop;
- From the calorifier flow, or the closest tap to the calorifier, and the furthermost tap on the hot water service circulating system (these should be identified on sentinel outlet register);
- Additional samples should be taken from the base of the calorifier via drain valves;
- From areas where the target control parameters are not met (i.e. where temperatures are below 55°c for hot water systems or ≥20°c for cold water systems);
- From areas subject to low usage, stagnation, excess storage capacity, dead legs, excessive heat loss, crossflow from the water system or other anomaly.
- High Risk Patient Areas
- Additional random samples may also be considered appropriate where systems are known to be susceptible to colonisation.

The temperature control regime is the preferred strategy for reducing the risk from *Legionella* and other waterborne organisms in water systems. This will require monitoring on a regular basis. The recommended test frequencies for various outlets are set out in Table 2 in Section 7.

HSG 274 Part 2 Table 2.3 Actions to be taken following legionella sampling in hot and cold water systems in healthcare premises with susceptible patients

Legionella bacteria (cfu/Litre)	Action required
More than 100 but less than 1,000	Low risk area Estates action only If only one or two samples are positive, system should be re-sampled. If a similar count is found again, a review should be carried out to identify any remedial actions a) If the majority of samples are positive, the system may be colonised, albeit at low level, with Legionella. Disinfection of the system should be considered but an immediate review of control measures and risk assessment should be carried out to identify any other remedial actions required. If remedial action is ineffective further measures will be discussed and approved by the Board Water Safety Group
More than 100 but less than 1,000	High Risk areas Impact on patient care Discuss results with ICD and agree actions and any closure of area.
More than 1,000	Low Risk Estates action only The system should be re-sampled and an immediate review of the control measures and risk assessment carried out to identify any remedial actions, including possible disinfection of the system. If remedial action is ineffective further measures will be discussed and approved by the Board Water Safety Group
More than 1,000	High Risk areas Discuss results with ICD and agree actions and any closure of area.

Communication pathway for Legionella results from water samples:

Water samples are sent to; UKASS-accredited laboratories which provide this service for NHS and other organisations that manage buildings. Reports will come back initially to the estates department.

Negative water samples are recorded as part of the documentation of Legionella control. If they are related to investigation of an “incident” such as a clinical case or a previous positive sample then these results are communicated to those managing that incident.

The information on the report which needs to be communicated is:

- Date of sampling
- Location and type of water outlet
- Identification of the organism, (Legionella pneumophila with serogroup, or Legionella species other than L pneumophila.)
- Count of organisms per Litre.

Estates will

- Inspect the system and take further action in accordance with HSE guidance and locally agreed procedures
- Inform Charge Nurse and or Clinical Nurse Manager of the Clinical Area concerned if appropriate of any control measures being taken/required
- Inform GM for the Sector if appropriate.

The results of this initial risk assessment must be communicated to all those noted above and also to the Facilities General Manager for the site involved.

The Infection Control Manager for Infection Prevention and Control will inform NHS GG&C

If there is impact on patient care then an Incident Management Team (IMT) may be convened to assess the risk and further actions.

Refer to WQS – 017 for out of spec procedure

See table in Appendix 2

5.5 Intermittent or Infrequently Used Water Outlets

If after investigation the taps or appliances identified within the reviewed list, to be updated on a quarterly basis, is deemed not necessary wherever possible the supply pipe work shall be cut back as close to the main circulating line as practicable to ensure that any dead leg formed is minimised and the appliance is removed from the water system.

In circumstances where there has been a lapse in the flushing regime, the stagnant and potentially contaminated water from within the shower or tap and associated dead leg should be purged to drain without discharge of aerosols before the appliance is used.

Where a ward or department is closed or taken out-of-use for an extended period of time e.g.: pending refurbishment, change in-use or other reason, arrangements shall be put in place to ensure the regular flushing and recording of water outlets within such areas. If such closures are considered to be long term or permanent consideration should be given to the disconnection of all water services to the affected areas.

5.6 Emergency Repairs

Emergency repairs may be required at any time and should be undertaken by trained and competent personnel. Such repairs can vary from a simple repair to a section of pipework, replacement of a component or major burst or loss of service. In all such cases the integrity and safety of the water distribution system must be maintained at all times.

5.7 Disinfection of Water System and Components

There are a number of different chemical and thermal disinfection methods available ALL of which shall be undertaken by trained and competent personnel in strict accordance with all Statutory Requirements, Safety Precautions and Manufacturers Instructions.

Disinfection – is the process of destroying or inactivating Pathogenic organisms and is generally applied to the water supply.

Sterilisation – is the process of destroying or inactivating all Organic Life Forms and is generally applied to all systems of transmission and storage materials.

In ALL instances no matter what disinfection method is employed, due regard shall be taken of patient groups, specialist equipment and processes which may be sensitive to the disinfection process being used – eg Renal Dialysis patients **must not** be exposed to Silver Hydrogen Peroxide chemicals as such the RO Water Treatment Plant and Dialysis Machines must be disconnected from the water system until the disinfection process is completed.

Silver Hydrogen Peroxide should NOT be used for a period of 90 days or longer, as required by the Drinking Water Inspectorate.

The disinfection process may be required for the following situations:

REPAIRS -	Repair fittings and exposed pipe ends should be clean and disinfected before use. Such items should be sprayed with a suitable disinfection solution such as a Sodium Hypochlorite @ a strength of 1000 mg/l (1000ppm) with a minimum contact time of 5 minutes or equal and approved.
MINOR ALTERATIONS -	Pipework should be cleaned internally by spraying with a suitable disinfection solution such as a Sodium Hypochlorite @ a strength of 1000 mg/l (1000ppm) or where pipes are long and internal surfaces cannot be reached with sprays then a swab soaked in a solution of 50mg/l (50ppm) with a contact time of one hour or equal and approved.
NEW SUPPLY PIPEWORK -	Pipes are filled with a solution such as a Sodium Hypochlorite @ a strength of 20 mg/l (20ppm) with a contact time of 24 hours. Or Sodium Hypochlorite and water at a strength of 50mg/l (50ppm) for a contact period of one hour. Minimum free chlorine after one hour – 30mg/l (30ppm) or equal and approved
SYSTEM DISINFECTION -	This will include water storage tanks and possibly the water distribution system. The advice and use of Legionella Control Association (LCA) approved contractors will be used for this purpose

NOTE:

Appropriate Method Statements and Risk Assessments will be compiled and obtained prior to any disinfection process commencing. Water Disinfection Risk Based Assessment Form (024) should be completed prior to any disinfection process being carried out. *(SHTM 04-01 Part G (V1 July 2015) Page 38 para 5.9)*

An alternative to chemical disinfection is to pasteurise the system. This involves increasing the temperature to greater than 60°C by increasing the thermostat setting at the calorifier or boiler and recirculation as necessary to maintain this temperature throughout for at least one hour. This should effectively sterilise the calorifier, and kill any *Legionella* organisms present.

The water should be flushed through the system more than once. It is important that all taps are run for at least 5 minutes (preferably longer) at full temperature to ensure that the complete system is pasteurised and that the hot water has reached all parts of the system.

5.8 Pseudomonas SOP

Standard Operating Procedure for minimising the risk of Pseudomonas

This SOP provides direction and guidance for ward based staff to meet their responsibilities as stated in *HPS(2013) Guidance for neonatal units (NNUs) (levels 1,2&3), adult and paediatric intensive care units (ICUs) in Scotland to minimise the risk of Pseudomonas aeruginosa infection from water.* This document refers to critical control points 2 – 4 (inclusive) only. (Critical points 1, 5 and 6 are considered in the NHSGGC Water Safety Policy 2013.

*High Dependency Units (HDUs) which are adjoining/ integrated with an ICU should be included in this guidance.

Responsibilities:

Senior Charge Nurses (SCNs) must:

- Follow this SOP.
- Ensure that they are aware of access issues to wash hand basins. Where access is an issue they must arrange for flushing to occur and document this.
- Keep records of daily flushing for at least one month within the Facilities Folder.
- Inform a member of the local Estates Team if this SOP cannot be followed in relation to flushing water outlets.
- Inform a member of the local Estates Team of infrequently used outlets which could be removed.
- Allow members of the local Estates Team access to complete maintenance as appropriate.

Estates must:

- Undertake actions deemed the responsibility of the local Estates Department as per the Water Safety Policy.
- Keep a record of outlets reported that are deemed to be infrequently used and actions taken by them to remove this risk.
- Provide a report of maintenance actions and issues/ anomalies to the Sector Water Safety Group.
- Support staff locally to undertake their responsibilities in terms of reducing risk associated with pseudomonas.

Domestic Services must:

- Ensure that water outlets are flushed at full flow for 1 minute (not causing splashing) as part of the cleaning process and to ensure for Mixer taps that this ensures and equal mix of cold and hot. If full flow cannot be achieved taps should be flushed for a longer period following assessment.
- Ensure this is the first task completed of the day.
- Record this in the Domestic services Compliance Checklist "Water Outlets"
- Ensure the Checklist is retained within the facilities Folder at ward level for one month.
- Send a copy of flushing records to Water AP and to ensure any rooms/areas which were not flushed are identified.
- Domestic Services Supervisors and Managers must also notify Estates LAP, if they identify any unused areas or outlets as per SHTM04-01 Part G Section 8.3.

Managers must:

- Make this SOP available to their staff.
- Support SCNs in following this SOP.

Water Systems Group must:

- Keep this SOP up-to-date.
- Audit compliance with this SOP.
- Provide guidance via the Water Systems Policy.

5.9 Flushing Water Outlets

Flushing of water outlets is necessary to control the build-up of biofilm in water systems to reduce the risk of transmission of pathogens via the environment and equipment to patients.

The Senior Charge Nurse (SCN) in each unit has responsibility (under current guidance) to ensure that the following recommendations are complied with in their area. The SCN should ensure that:

All little used outlets outlets that are not used at least twice weekly in general areas and daily on high risk area identified on WS01a form. These must be flushed at full flow (but not so that splashing goes beyond the basin. However if taps cannot be flushed on full flow they should be flushed for longer based on specific assessment. The manager responsible for the ward or department must put systems in place for the outlet to be flushed to waste for 3 minutes as per SHTM04-01 Part G Page 111.

Where the outlet may be used by high-risk patients, more frequent flushing may be needed and the frequency should be determined following a risk assessment.

Additionally high high-risk environments (adult, paediatric and Neonatal ICUs and associated HDU's), flushed daily, first thing in am for 1 minute at full flow (but not so that splashing goes beyond the basin). However if taps cannot be flushed on full flow they should be flushed for longer based on specific assessment.

Additionally Facilities (Domestic Services) to ensure that all water outlets are flushed daily where access is available and all outlets flushed for 1 minute at full flow (but not so that splashing goes beyond the basin). However if taps cannot be flushed on full flow they should be flushed for longer based on specific assessment. Records must reflect where access is not available or outlets not able to flush e.g. rooms/areas under Estates, Minor Works, Capital or no access at the weekend.

Domestic Services Supervisors and Managers will also notify Estates if they identify any unused areas or outlets or outlets not able to flush as per requirements of *SHTM04-01 Part G Section 8.3*.

These should be reflected on the department flushing records.

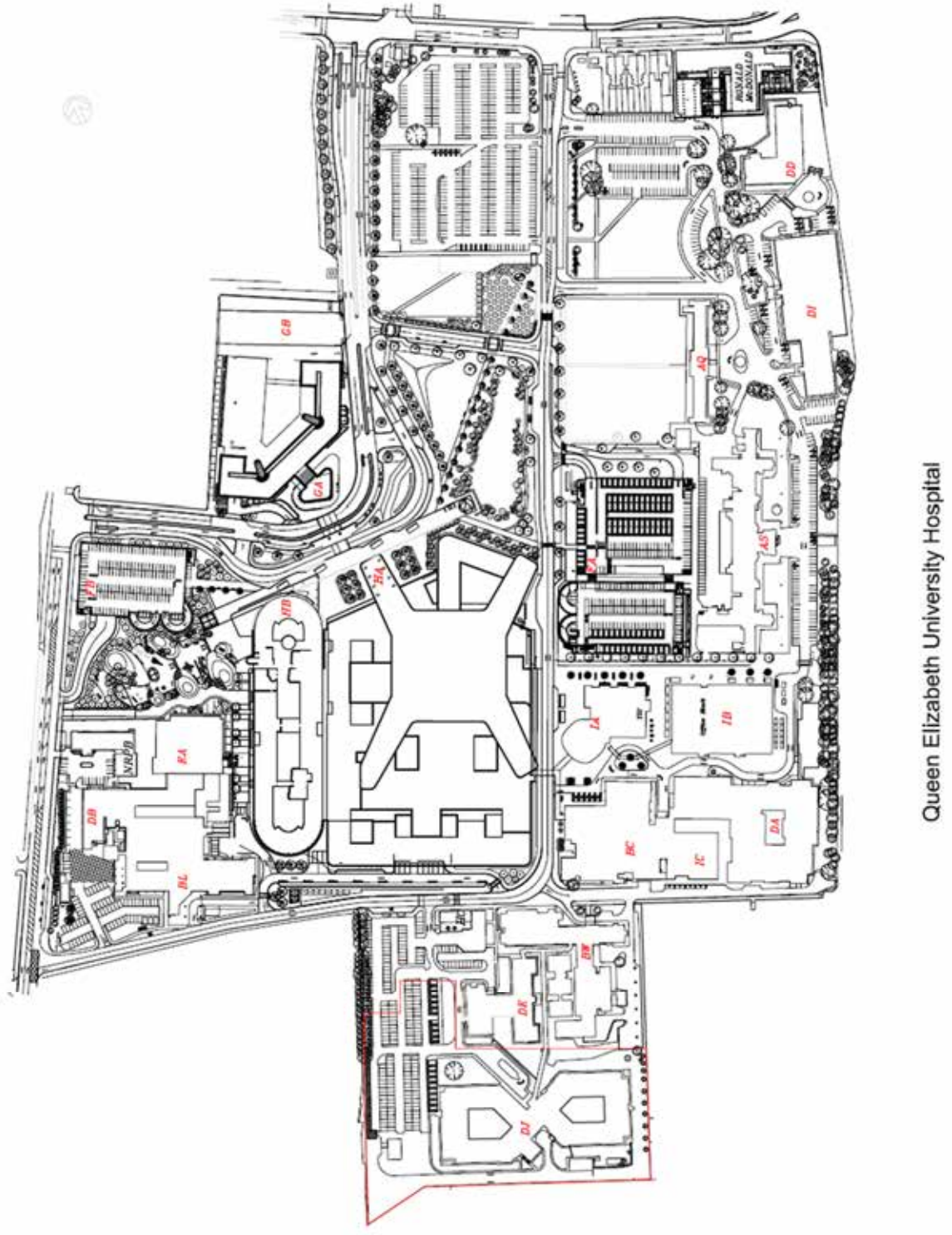
These must be reviewed on a daily basis by the SCN and appropriate action taken when this is identified as not having been completed.

Any problems or concerns relating to the safety, maintenance, reduced usage, any changes in use and cleanliness of all water outlets are identified and reported to the ICT, Facilities and Estates Department as relevant.

For more information refer to NHS Greater Glasgow and Clyde
'Water Systems Safety Policy Written Scheme and Operational Procedures'

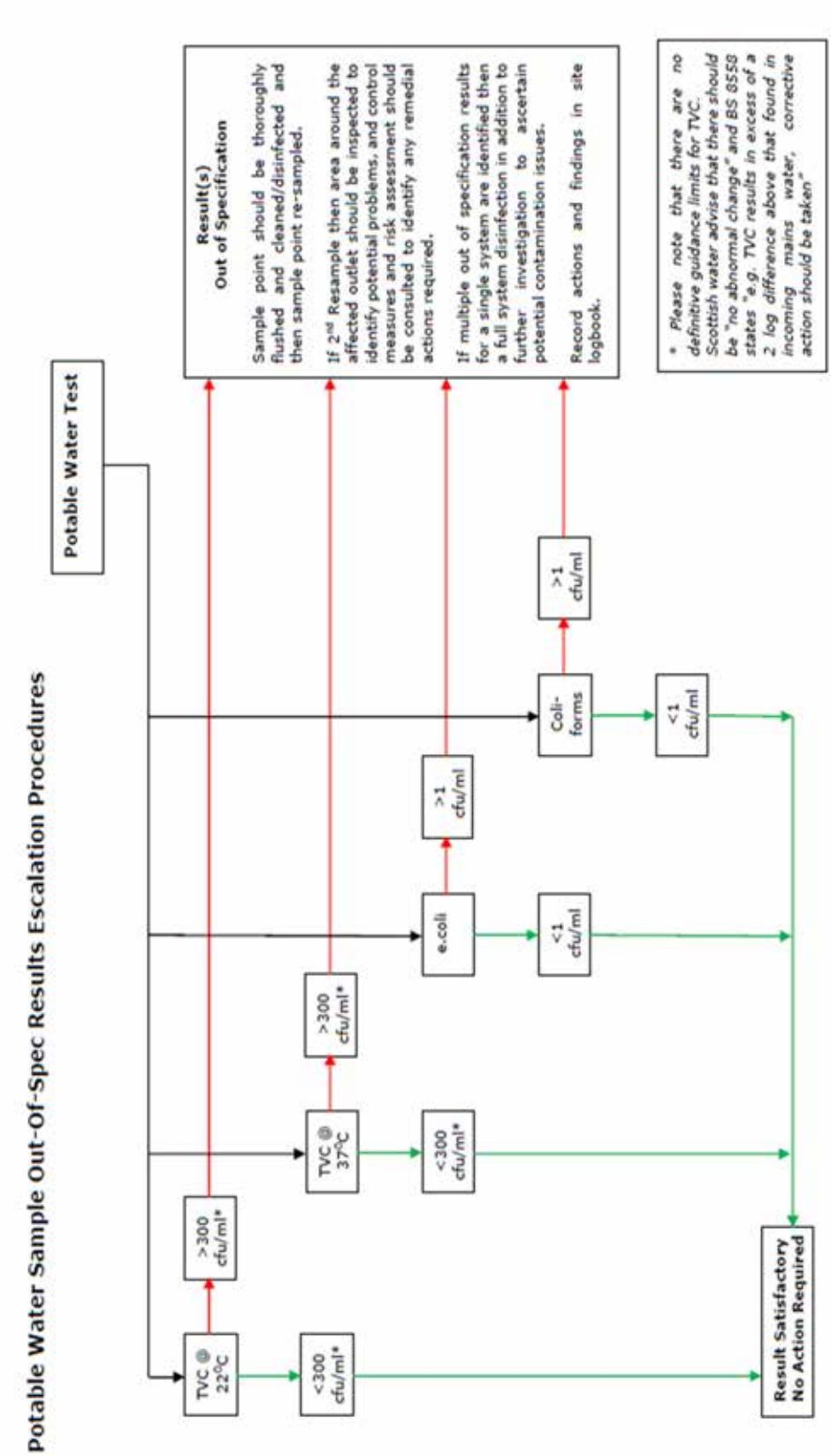
Appendix 1

Site Plan with Block Codes



Appendix 2

Escalation of Sampling Results out-of-spec.



Appendix 3

Risk Assessment Review Guidance

Summary of L8 Management Tasks Required for L8 and SHTM 04-01 Compliance	Guidance Documents	Allocated to
Regular check to ensure that legislation and guidance has not changed	L8 HSG 274 Pt 2 SHTM 04-01	
Regular review of all policies relating to legionella control (e.g. Maintenance, Water Treatment, Water Management, Energy) to ensure still valid and correct	L8 HSG 274 Pt 2 SHTM 04-01	
Regular review of L8 Management Structure to ensure up-to-date and accurate	L8 HSG 274 Pt 2 SHTM 04-01	
Regular review of communication lines to ensure still accurate and correct	L8 HSG 274 Pt 2 SHTM 04-01	
Regular review of escalation & emergency procedures to ensure still valid and correct	L8 HSG 274 Pt 2 SHTM 04-01	
Regular review of duties allocated to site staff and ensure accurate and recorded	L8 HSG 274 Pt 2 SHTM 04-01	
Regular review of duties of sub-contractors and ensure accurate and recorded and contractors are suitably qualified/competent for tasks assigned to them (e.g. Water Hygiene contractors should be LCA Approved, Plumbing contractors should be SNIPEF and Water Safe Registered)	L8 HSG 274 Pt 2 SHTM 04-01	
Regular review of staff training requirements and update training matrix	L8 HSG 274 Pt 2 SHTM 04-01	
Regular review of method statements and risk assessments to ensure still valid and correct	L8 HSG 274 Pt 2 SHTM 04-01	
Regular review of site documentation to ensure all records up to date and present	L8 HSG 274 Pt 2 SHTM 04-01	
Regular update of “Patient Risk Rating” register for all areas of hospital.	SHTM 04-01 Part B	
Regular review of sentinel outlet locations register.	SHTM 04-01 Part B	
Regular review of primary, sub-ordinate and tertiary hot flow and return loops to reflect any system alterations.	HSG 274 Pt 2	
Regular review of plant and equipment maintenance schedules.	Manufacturer’s Instructions	
Regular review of BEMS temperature sensor locations to reflect any system alterations	HSG 274 Pt 2	
Regular review of schematic/as-fitted drawings to ensure up-to-date and accurate	L8 HSG 274 Pt 2 SHTM 04-01	
Regular review of L8 risk assessment with a maximum period of two years between updates. (e.g. if change of use or changes in legislation or any other factor which could affect validity of current assessment)	L8 STHM 04-01	

Appendix 4

HAISCRIBE Risk Assessments

All relevant HAISCRIBE risk assessments produced and approved for Water Systems related tasks are stored on the QEUH Shared Drive within the folder path “

HAI SCRIBE

QEUH Campus Wide

WRITTEN SCHEME

Controlling the risks of exposure to Legionella and other harmful bacteria in Water Systems

Queen Elizabeth University Hospital Campus

December 2018

Revision E

An electronic copy of this document is held on the QEUH Shared Drive at folder path:

SGH Estates Shared>Water Quality>Written Schemes

Table of Contents

1.0 GENERAL OVERVIEW

Note 1: No work will be carried out on the water system without the knowledge and written consent of the Authorised Person (Water).

Note 2: This Written Scheme document is to be read in conjunction with the Operational Procedures for the Written Schemes document and should also be read in conjunction with the Control of Water Records document. For any alterations to the Water System this Written Scheme Document is to be read in conjunction with the Guidance for alterations to water systems document.

1.1 Introduction

This document contains six sections which have been derived from the Risk Assessment to aid the design, installation, maintenance and operational mode of all domestic and process water systems within the premises with respect to the likelihood of the proliferation of waterborne micro-organisms. The assessment also considered the risk of infection presented to building users and the general populous at large, and derived a series of risk ratings and appropriate Remedial Actions and Control Measures, which should be implemented to minimise the presented risks. This Risk Assessment was carried out in a manner consistent with the requirements of *BS8580:2010 Water Quality – Risk Assessments for Legionella Control – Code of Practice*, and is reviewed whenever system alterations or operational considerations may effect a change in the risk.

Section 1 contains an Executive Summary of the recommended control measures and corrective actions together with an overview of the QUEH Site layout and accommodation.

Section 2 contains a record of the logbook inspection, details on the location of records, defects, non-compliance issues, correspondence and archived information.

Section 3 provides information on the management structure associated with the control scheme for the water system and clear definitions of responsibilities held by those named, details of training undertaken and a summary of the designated tasks as detailed in section 4.

This section also provides information on the details of the risk assessment values associated with representative outlets, systems and plant items undertaken in 2013. A generic risk assessment for any positive legionella test results within designated Low Risk locations and a description of the installed plant and equipment with associated schematic layout plans for each of the installed water systems within the site is also contained within this section.

Section 4 of the document details the safe operation of the system and all appropriate Maintenance Procedures (Control Measures) which were derived from the Risk Assessment and recommendations within NHS Greater Glasgow and Clyde Water Systems Safety Policy.

This section of the document contains a task description with associated record (Log) sheet relating to these activities. It should be noted however, that in certain circumstances, specialist contractors are required to implement some Control Measures, and records pertaining to these activities may be held under separate cover. Such activities would typically include those associated with chemical water treatment regimes and drinks vending machines sanitising maintenance.

Refer to Section 2 for the location of records and archived information associated with the maintenance procedures and other control measures.

Section 5 contains supporting information relating to the Control Scheme, and should typically include the recording of system alterations or remedial actions together with utilised materials. Ad hoc maintenance activities should also be recorded in this section, such as system sterilisations which may be required from time to time. This section of the document also contains a glossary of supporting publications, where additional information relating to the risks associated with waterborne micro-organisms, and water quality generally, may be found.

Section 6 contains guidance on Incident Master Log sheets, which should be copied and used to facilitate the recording of control measure activities and the results of monitoring measurements and tests.

1.2 Executive Summary

The purpose of this Written Scheme document is to assist in the correct and safe operation of the water systems within the QEUH Campus.

Risk Assessments for the water services contained within this report were undertaken by DMA Water Ltd for the following buildings within the campus:

Queen Elizabeth University Hospital (QEUH) –

New Childrens Hospital (NCH) –

Maternity Building –

Neonatal Hospital –

Neurology –

Neurosurgery –

Spinal Injuries Unit –

PDRU –

Westmarc –

New Laboratory –

Podiatry –

Additionally there are two Hydrotherapy Pools in operation on the campus. These are situated within the New Childrens Hospital, and Spinal Injuries Unit.

Risk Assessments require to be reviewed and updated to reflect any changes in-use and / or functions that have taken place since the date of the original Risk Assessment or in the event of control measures becoming ineffective, changes in key personnel or in the event of a case of legionnaires disease / legionellosis associated with the water system.

1.3 Overview of Site Accommodation and Premises

The main new-build Adult Hospital building comprises of 12 stories, with the basement housing FM areas and the new-build Childrens Hospital comprising of 4 stories.

On the retained estate there are individual buildings comprising of Neurology, Neurosurgery, Spinal Injuries Unit, PDRU, Maternity, Neo-Natal, Podiatry and Westmarc stand alone with the Teaching and learning and office block new additions.

Full descriptions and information on the individual written schemes are available in the Log book/Risk Assessment folders for each building.

The building codes are as follows:

AQ – Acute Medical Block (AMB)
AS – Central Medical Block (CMB)
BC – Neurosurgical Block (INS)
BL – Maternity
BW – Neurology
DA – Spinal Injuries
DB – Maternity Day Surgery
DD – Podiatry
DE – Physically Disabled Rehabilitation Unit (PDRU)
DI – WestMARC
EA – Neo Natal
FA – Multi Storey Car Park 2
FB – Multi Storey Car Park 1
GA – Laboratory Medicine
GB – Energy Centre
HA – Adults Hospital
HB – Childrens Hospital
IA – Teaching & Learning Centre
IB – Office Building
IC – Imaging Centre of Excellence

NOTE: ICE building is owned by University of Glasgow. UoG have requested that NHS arrange the Risk Assessment and compilation of Written Scheme in July 2018.

See Site Map in Appendix 1

2.0 RECORDING

2.1 Written Scheme Inspection Records

Anyone inspecting this written scheme (either as part of the Management Control System or otherwise) is invited to make an entry in this inspection record. **Under no circumstances may this Written Scheme or any part of it be removed from site.**

Date/Time	Comments	Signature	Position
June 2018	Written scheme has been reviewed and re-formatted into this current form (Revision D) by Colin Purdon as part of the water systems review.		Site Manager Operational Estates
Feb 2018	Written scheme has been reviewed and re-formatted into this current form (Revision E) by Colin Purdon as part of the water systems review.		Interim Sector Estates Manager (Deputy Responsible Person)

Additional entries should be completed on a separate sheet and inserted in Section 2.1 with this sheet.

2.2 Location of Records and Correspondence

Details of any correspondence, including Risk Assessments/Reviews and Ongoing Monitoring Reports, relating to water services should be entered on the sheet below, recording where held and by whom.

Date	Procedure or Record ref	Description	Held by/location
16/07/18	Flushing Outlets 026	Email correspondence in relation to Flushing DCFP kitchen dishwasher and outlets with John Heron and Adam Wright	Colin Purdon email archive. Hard copy in correspondence logbook

Additional entries should be completed on a separate sheet and inserted in Section 2.2 with this sheet.

2.3 Non-Compliance Issues and Fault Detail Log

All non-compliance and fault details in relation to the individual systems in each building should be entered on this example form and held in the associated Building Log book.

Non-Compliance Issues and / or Fault Details	Reported By	Date	Action Taken	Outcome Satisfactory YES/NO

Additional entries should be completed on a separate sheet and inserted in Section 2.3 with this sheet.

2.4 Archived Information Record Sheet

All records within or associated with this manual should be kept for a period of five years after they are no longer current. Such out of date information should be held separately and recorded in the table below.

Date	Procedure or Record Reference	Description	Held By/Location

Additional entries should be completed on a separate sheet and inserted in Section 2.4

2.5 Equipment Calibration Records

All equipment used for the measurement of temperatures should be calibrated at least annually to ensure the accuracy and consistency of the recording procedures.

Calibration certificates for handheld thermometers are held in hard copy within the QEUH Campus Log Book suite in the main estates office. Electronic copies are also held on the QEUH Shared Drive>Water Quality folder.

3.0 MANAGEMENT

3.1 Roles & Responsibilities

NHS Greater Glasgow & Clyde Chief Executive – (Duty Holder)	The Chief Executive has ultimate responsibility / accountability for water system safety within NHSGG&C. The responsibilities of the Chief Executive include: • Responsibility for implementation of the relevant mandatory and statutory elements contained within the Health & Safety Commissions Approved Code of Practice and Guidance "Legionnaires Disease. The control of Legionella bacteria in water systems" L8 (ACOP L8), SHTM04-01: The control of Legionella, hygiene safe" hot water, cold water and drinking water systems and CEL 08(2013) water sources and potential risk to patients in high risk units – revised guidance. The implementation of Guidance for neonatal units (NNU's) (levels 1, 2 & 3) adult and paediatric intensive care units ICU's in Scotland to minimise the risk of Pseudomonas aeruginosa infection from water. • Ensuring that adequate resources are provided to meet the Water Systems Safety requirements of NHSGG&C estate. Ensuring that the Water Systems Safety Policy is being implemented at all levels. • Reviewing and monitoring the operation of the Water Systems Safety Policy through the Board Corporate Management Team and ensuring that clear guidelines are provided for this tasked with compliance of legislative and statutory standards. • Appointing the Designated person (Pseudomonas) and Designated Person (Water) to assist in the execution of these responsibilities, who for NHSGG&C are the Infection Control Manager (Pseudomonas) and the Director of Facilities (Water).
NHS Greater Glasgow and Clyde Director of Facilities- **(Designated Person)**	The Director of Facilities/General Manager (Estates) is the Designated Person (Water). They shall be responsible for: • Ensuring that Facilities staff, through the general management structure is fully aware of the current statutory and mandatory requirements and standards for the provision and maintenance of safe water systems. • Ensuring with the Responsible Person (Pseudomonas) that the Water System Safety Policy is regularly reviewed and updated. • Co-Chair the NHSGG&C Water Systems Safety Group. • Appointing in writing the Responsible Person (Water) at sector level and Deputy Responsible Person(s) (Water) at site level. This shall be the Sector Estates Manager (SEM) and the relevant Site Manager Operational Estates (SMOE)/Site Estates Manager within the Facilities Directorate management structure.

3.1 Roles and Responsibilities (cont)

NHS Greater Glasgow and Clyde Infection Control Manager - Designated Person (Pseudomonas)	The Infection Control Manager supported by the Board Infection Control Doctor is the Responsible Person (Pseudomonas). They shall be responsible for: • Ensuring that Infection Control Teams are fully aware of current guidance on Legionella control matters and the minimisation of the risk of Pseudomonas aeruginosa infection from water. • The implementation of Guidance for neonatal units (NNU's) (levels 1, 2 & 3) adult and paediatric intensive care units ICU's in Scotland to minimise the risk of Pseudomonas aeruginosa infection from water. • Ensuring with the Designated Person (Water) that the Water System Safety Policy is regularly reviewed and updated. • Co-Chair the NHSGG&C Water Systems Safety Group. • Appointing in writing the Responsible Person(s) (Pseudomonas) at sector level. This shall be the relevant Infection Control Doctor.
Sector Estates Manager – Responsible Person (Water)	The Sector Estates Manager will be appointed as the Responsible Person (Water) at Sector level by the Director of Facilities/General manager (Estates) in writing. The Sector Estates Manager is responsible for: • Ensuring the effective maintenance of engineering controls installed for the purposes of controlling water systems. • Ensuring that written schemes and risk assessments are in place and reviewed regularly. • Devising and maintaining procedures to ensure the quality of water on premises is maintained. • Ensuring operational procedures are carried out and documented. • Ensuring records are kept of all water systems and their purpose, giving locations recording and maintaining within the Boards estates management system. • Liaise closely with other professionals to ensure legislative and statutory compliance is maintained by the Board.
Authorising Engineer (AE)	An Authorising Engineer acts as an independent professional advisor to the healthcare organisation, appointed by the organisation with a brief to provide services in accordance with Scottish Health Technical Memorandum (SHTM) guidance. He will be appointed in writing by the Director of Facilities/General manager (Estates). The Authorising Engineer acts as an assessor, making recommendations for the appointment of Authorised Persons, monitoring the performance of the service and providing an annual audit to the organisation's Designated Person.

3.1 Roles and Responsibilities (cont)

Authorised Person (Water)	The Authorised Person (water) has the key operational responsibility for the service, qualified, sufficiently experienced and skilled for the purpose. He/she will be nominated by the Authorising Engineer and be able to demonstrate • His/her application through familiarization with the system and attendance at an appropriate professional course; • A level of experience; • Evidence of knowledge and skills. An important element of the Authorised Person (Water) role is the maintenance of records, quality of service and maintenance of system safety (integrity). The Authorised Person (Water) will also be responsible for establishing and maintaining the roles and validation of Competent Persons (Water) who shall be suitable trained employees of the organisation or appointed contractors. Larger sites may require more than one Authorised Person (Water) for a particular service. The Authorised Person (Water) will be appointed by the Director of facilities/General Manager (Estates).
Head of Capital Planning – Deputy Responsible Person (Water)	The Head of Capital Planning will be appointed as the Deputy Responsible Person (Water) at Board level by the Director of Facilities/General Manager (Estates) in writing. The Head of Capital Planning is responsible for: • Ensuring that any new works undertaken or refurbishment within existing premises shall comply with the requirements of this Policy and the Written Scheme and Operational Procedure for managing Water Safety including The control of *Legionella*, hygiene, 'safe' hot water, cold water and drinking Water systems and The implementation of Guidance for neonatal units (NNU's) (levels 1, 2 & 3) adult and paediatric intensive care units ICU's in Scotland to minimise the risk of Pseudomonas aeruginosa infection from water. • Ensuring that all potential interfaces between an operating system and new and refurbishment works shall meet the approval of the Responsible Person (Water) and Authorised Person (water) as to methodology for making that interface. • Ensuring that any work involving the installation of water services or equipment requiring a water supply shall follow the guidance in SHTM 04-01 and HSE document L8 and shall be certified by the design Engineer as to that compliance. • Ensuring that any works which will affect an operational water service will be discussed with the Estates Authorised Person (Water) prior to arranging that work.

3.1 Roles and Responsibilities (cont)

Site Estates Manager Deputy Responsible Person (Water)	The Site Manager Operational Estates (SMOE)/Site Estates Manager shall be appointed in writing by the Director of Facilities/General Manager (Estates) in writing as the Deputy Responsible Person (Water) and will also act as the Designated Person Water in the absence of the Designated Person (Water). The Site Maintenance Manager/Site Estates Manager is responsible for: • Ensuring all staff conducting water system maintenance are competent to do so. • Ensuring water system maintenance records are maintained and kept up-to-date. • Regularly checking maintenance records. • Ensuring all work is completed in accordance with the NHS GG&C Estates Procedures.
Acute Services Directors CH(C)P Directors and Corporate Division Directors	As Senior Managers, NHSGG&C Directors play an intrinsic role in ensuring that water safety is embedded within the culture of the organisation. The responsibilities of Directors include: • Supporting the designated person (Water) and (Pseudomonas) in the development of the Board's overall strategy in relation to water safety and for ensuring implementation within their areas of responsibility; • Ensuring that all staff are made aware of their requirement to attend Water Safety training at the appropriate frequency, as per the NHSGG&C Water Safety Policy and Operational Procedures which underpin this by facilitating staff release from duties to attend training; • Supporting action to address staff who put themselves and/or others at risk from a real or potential water safety incident.
Heads of Service, Departmental Managers, Clinical Managers, Senior Charge Nurse's	All managers who have a responsibility for the day to day management of facilities, staff or services, and/or premises, have water safety responsibilities that include: • Familiarise themselves with the NHSGG&C Water Safety Policy and local control measures including any water risk assessments for their area(s) of responsibility; • Ensuring that persons in the department, clinic or ward are fully aware of their responsibilities and duties in respect of Water Safety, in particular, the action required of them should the area be defined as High Risk by the local Water Safety Group • Ensure that persons in the department, clinic or ward are fully aware of the Infrequently Used Outlets definitions and Operating Procedure which underpins the NHSGG&C Water Safety Policy

3.1 Roles and Responsibilities (cont)

Heads of Service, Departmental Managers, Clinical Managers, Senior Charge Nurse's (cont)	• Actively promoting Water Safety within the department or ward by maintaining good housekeeping within the department or ward at all times, ensuring that any flushing or documentation as described in the Water Safety Written Scheme and Operational Procedures documentation is completed on time • Responding appropriately to any water safety concerns that persons in the department, clinic or ward have; • Nominating a responsible person to complete the Monthly Infrequently Used Outlets Audit for each area, forwarding a copy to the Site Maintenance Manager, thereby assisting NHSGG&C to meet its statutory and mandatory requirements; • Ensuring that action is taken on a daily basis to address any access issues identified within the Cleaning Compliance Checklist Sign Off documentation retained in the Facilities Folder. • Liaising with the estates department as required
Legionella Risk Assessor	The NHS Board appoints in writing a Legionella Risk Assessor with terms of reference to provide services in accordance with BS 8580, SHTM 04-01 and HSE guidance under this Policy. He/she will be appointed in writing by the Director of Facilities/General Manager (Estates)
Competent Person (Water)	The Competent Person (Water) provides skilled installation and/or maintenance of the specialist service. He/she will be appointed, or authorised to work (if a contractor) by the Authorised Person Water). He/she will demonstrate a sound trade background and specific skill in the specialist service, working under the direction of the Authorised Person (Water) in accordance with operating procedures, policies and standards of the service.
Maintenance Tradesperson	A Maintenance Tradesperson is someone who has sufficient technical knowledge and the experience necessary to carry out maintenance and routine testing of the water supply, storage and distribution system.
Installer	The Installer is the person or organisation responsible for the provision of the water storage and distribution system.
Contractor	A Contractor is the person or organisation designated by management to be responsible for the supply, installation, validation and verification of hot and cold water services, and for the conduct of the installation checks and tests in relation to the control of *Legionella*. The NHS Board will expect potential contractors to have suitable qualifications (for example companies/individuals who are members of the *Legionella* Control Association).

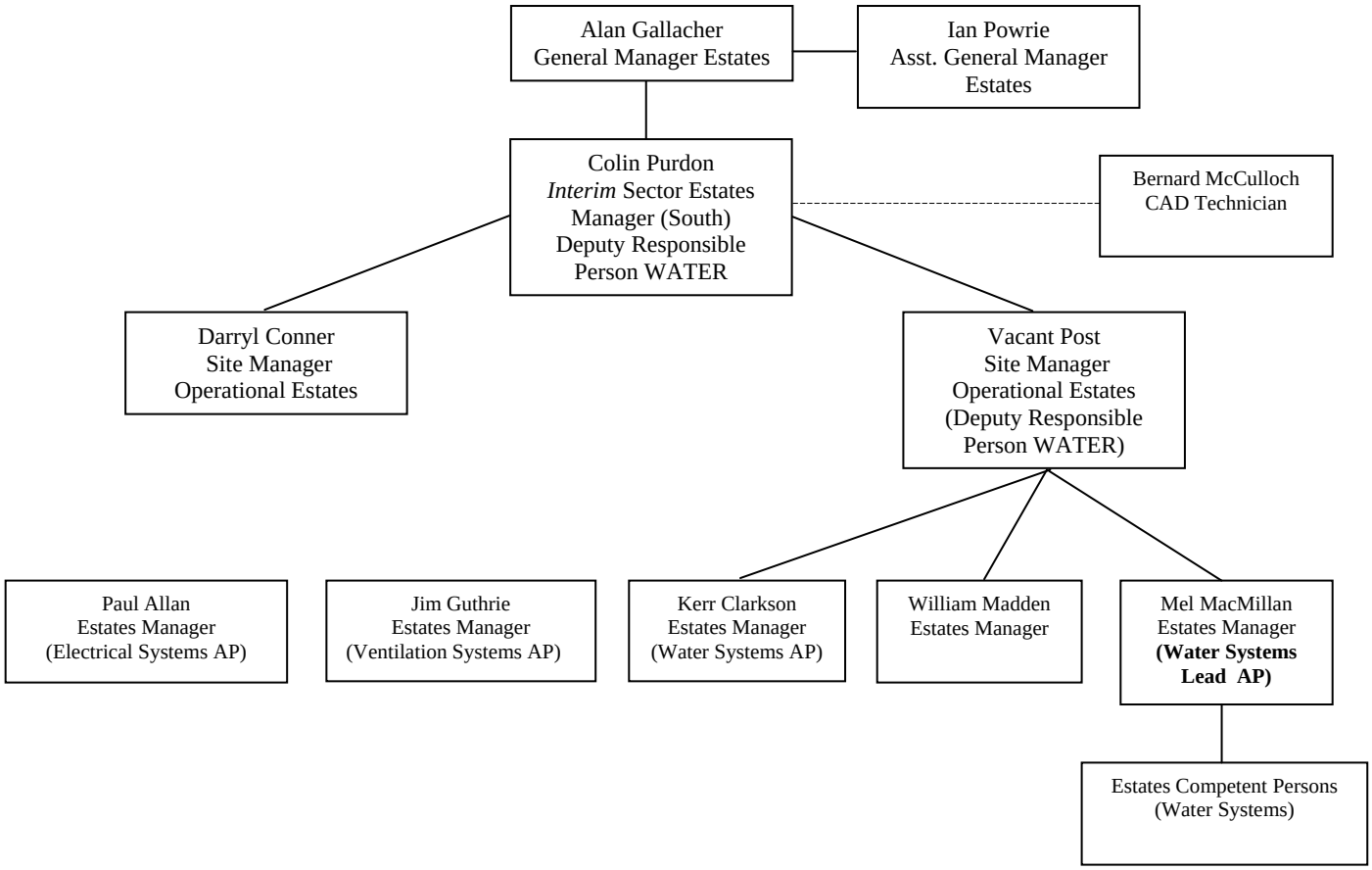
3.1 Roles and Responsibilities (cont)

NHS GG&C South Sector (QEUH) Hierarchy Appointment Table

Designation	Position	Name Tel Number
The Duty Holder	Chief Executive	Jane Grant
Designated Person (Water)	Director of Facilities/General Manager (Estates)	Alan Gallacher Mary-Anne Kane
Authorising Engineer (Water)	Legionella Control International Ltd	Dennis Kelly [redacted]
Legionella Risk Assessor	DMA Water Services Ltd	David Watson Mike Kinghorn Allan McRobbie [redacted]
Responsible Person (Water)	Sector Estates Manger (South)	VACANT
Deputy Responsible Person (Water)	Site Manager Operational Estates	Colin Purdon (QEUH)
Deputy Responsible Person (Water)	General Manager Capital Planning	Hazel McIntyre [redacted]
Lead Authorised Person	Estates Manager	Mel MacMillan
Authorised Persons	Estates Manager Co-ordinating Supervisor Co-ordinating Supervisor	Kerr Clarkson Scott Macer Darren Hopkins Frank Green
Competent Persons	CAD Technician	Bernard McCulloch
Competent Persons	Plumbers/Engineers	See training records in Section 3.4
Others Involved		
Infection Control	Lead Microbiologist	Dr Teresa Inkster
Public Health		Dr Iain Kennedy
Laboratory Services		Janet Young

3.2 QEUH Estates Staffing

Management organogram for QEUH Estates Dept as of Feb 2019



3.3 Required Maintenance Tasks

The maintenance and management of the water systems throughout the QEUH Campus is undertaken by a combination of both NHS Staff and external Contractors at the frequencies identified in the following tables.

QEUH Management staff currently undertake the following tasks:

Procedure Reference	Operation(s)	Record Form Ref	Frequency
P1C1	BMS Temperature Monitoring	**(004)**	Daily
P1CC1A	Manual Temperature Monitoring	**(005a)**	Daily
	Filtration Plant Checks		Twice Daily
WS01	Flushing Intermittently used outlets	**(026)**	Twice Weekly
WS01	Flushing Deadlegs and drain cocks	**(026)**	Twice Weekly
WS01	Deluge shower/Eye wash flushing	**(026)**	Twice Weekly
P1C3	Pump operation/duty rotation	**(028)**	Weekly
P1C4	Temperature Recording of Sentinel Hot and Cold Water Outlets.	**(005)**	Monthly
P1C4	DHW Calorifier and Buffer Vessel Checks	**(005)**	Monthly
P1C12	Showerhead/hose replacement/disinfection	**(005b)**	Quarterly
P1C6	DWS Calorifier, Expansion Vessel Flushing	**(006) (023)**	Quarterly
WQS 001	HORNE Tap Flow Restrictor Exchange		Quarterly
WS01	Review of Rarely Used Water Outlets and Changes In-Use		Quarterly
	TMV/TMT & Thermostatic Shower Disinfection and Function Test (HIGH RISK)		Quarterly
	TMV/TMT & Thermostatic Shower Disinfection and Function Test (Non-HIGH RISK)		Six-Monthly
P1C7	CWST Inspection and Temperature Monitoring	**(003)**	Six-Monthly
P1C9	DWS Calorifier / Expansion Vessel Inspection	**(006)**	Annually
	Water Services Pipework and Distribution System Checks		Annually
P1C10	Representative Tap Temperature Monitoring	**(005)**	Annually
	Vibration coupling inspection		Annually
	Carry out review of log books and Written Scheme		Annually (Sep)
	Carry out review of drawings and schematics		Annually (Sep)

3.3 Required Maintenance Tasks (cont)

In addition to the tasks undertaken by NHS directly employed Competent Persons, there are also tasks undertaken by Contractors on a selection of buildings within the campus.

Appointed Contractors presently undertake the following tasks:

Procedure Reference	Operation(s)	Record Form Ref	Frequency
	External Water Mains Valve Operation and Flushing Routines		Monthly
	'TMV' and Mixing Valve Sanitation and Maintenance Checks		Three-Monthly
	Shower Head and Flexible Hoses De-Scale and Sanitisation		Three-Monthly
	'TMV' Tap Outlet Sanitisation and Operational Checks		Six-Monthly
	CWST Inspection	(003a)	Annually
	Hot and Cold Tap Outlet Sanitisation and Operational Checks		Annually

3.4 Training Records

The following NHS personnel are certified to have the required ability, experience, instruction, information and training to carry out the work associated with legionella precautions at QEUH Campus.

NAME	POSITION	NATURE OF TRAINING (TRADE QUALIFICATION, TRAINING COURSES ATTENDED)	SIGNATURE CERTIFYING OFFICER	DATE
Colin Purdon	*Interim* Sector Estates Manager Deputy RP	Responsible Person Course		
Mel MacMillan	Estates Manager Lead AP	WHH01 – Legionella Management for Water Systems SHTM-04 01 WH003 - Legionella Control Within Hot and Cold Water Systems		
Kerr Clarkson	Estates Manager AP	WHH01 – Legionella Management for Water Systems SHTM-04 01 WH003 - Legionella Control Within Hot and Cold Water Systems		
Scott Macer	Supervisor (Shifts)	WHH01 – Legionella Management for Water Systems SHTM-04 01 WH003 - Legionella Control Within Hot and Cold Water Systems		
Darren Hopkins	Co-Ordinating Supervisor AP	WHH01 – Legionella Management for Water Systems SHTM-04 01 WH003 - Legionella Control Within Hot and Cold Water Systems		
Frank Green	Estates Manager	WHH01 – Legionella Management for Water Systems SHTM-04 01 WH003 - Legionella Control Within Hot and Cold Water Systems		

NAME	POSITION	NATURE OF TRAINING (TRADE QUALIFICATION, TRAINING COURSES ATTENDED)	SIGNATURE CERTIFYING OFFICER	DATE
Martin Inglis	Tech Plumber	Competent Persons		
Andrew Hamilton	Tech Plumber	Competent Persons		
David Fickling	Tech Plumber	Competent Persons		
Peter McCabe	Tech Plumber	Competent Persons		
Mark McInally	Tech Plumber	Competent Persons		
Shawn O'Neill	Tech Plumber	Competent Persons		
Jason Weir	Tech Plumber	Competent Persons		
Paul Shorts	Tech Plumber	Competent Persons		
Bernie McCulloch	CAD Technician	Competent Persons		

Copies of all relevant training records are to be held electronically on the QEUH Shared Drive within the folder path "Water Quality>Training and Appointments".

The results achieved by each member of staff during their competency training are held on the central database managed by the Water Systems Compliance Manager.

3.5 Training Requirements

A programme of training and procedures to assist in assessing and ensuring the competence of ALL persons responsible for the operation, maintenance, repair and alteration to the water distribution system and associated plant and equipment requires to be progressed, developed and implemented.

QEUH Estates Staff - Interim Training Requirements:

Item	Training Requirement	Applicable to	Target Date for Completion	Date Completed
1	Toolbox talks on Written Scheme Section 4 for staff.	All plumbers		
2				
3				
4				
5				
6				
7				
8				
9				
10				
11				
12				

NOTE:- This table should be updated on a regular basis as part of the 6 monthly review process described in **Section 3.11.**

3.6 Water Systems Risk Assessment

Risk assessments for each building have been conducted by DMA Water Ltd and are filed in the main Estates Office at QEUH. Each contains details of individual systems and a summary of the associated risks. The risk assessments each contain unique information in regard to the water distribution systems in the buildings and also guidance on the recommended maintenance procedures for mitigating risk.

Action plan details for each risk assessment are summarised on the Smartsheet tool.

Electronic copies of the Risk Assessments are also held on the QEUH Shared Drive at the folder path "Water Quality>Risk Assessments"

Risk Assessment Review Schedule

A review of the Risk Assessments MUST be carried out after or during the following:

A change to the water system or its use

A change to the use of the building/ward/clinic/dept etc.

Changes in legislation or updates in control measures

Changes in immediate management or key personnel

Control measures becoming ineffective

Increased micro-bacterial levels found in the water system or a case of legionnaires disease/legionellosis associated with the water system

Further information on reviewing Risk Assessments is detailed in Appendix 4.

Risk Assessment Review

During the Risk Assessment, whenever an anomaly is discovered on either the hot or cold water systems, the Risk Assessors e-mail the AP (water) with their findings. These anomalies are actioned by creating a FM job for the onsite CP Plumbing Technician. The findings are held in the Estates office in the folder named (Pre Risk Assessment Jobs completed).

Risk Assessment Process for Removal of Identified Items

Points are actioned that have been identified in the Risk Assessment, all drawings are updated to reflect the changes and the Risk Assessment action point is closed.

3.7 Plant Description and Schematics

Details of the plant in each building and schematic layouts are contained within the individual log books/risk assessments for each building. The log books/risk assessments are stored in the main Estates Office at QEUH.

These details are also held on the Shared Drive

All plant details and system schematics and as-fitted drawings for the Adult & Childrens Hospitals are contained in the ZUTEC cloud based document management system. All Estates Managers and Supervisors have access to these systems.

Additional access accounts can be set up at the request of the QEUH Site Manager Operational Estates.

Brendan.egan[redacted]

3.8 Water Systems Audits/Review procedure

The relevant Authorised Person (Water) must regularly gather and maintain all the relevant information and records, including relevant *Legionella* Risk Assessments and Written Schemes.

Working with the Authorising Engineer (Water) and Responsible Person (Water), the relevant Authorised Person (Water) will review and analyse all records for compliance with *Legionella* and other water safety parameters.

The relevant Authorised Person (Water) will detail on these records any deviations from the *Legionella* and other water safety parameters giving a brief description as to the reason for this deviation.

The relevant Authorised Person (Water) will file locally all relevant information and maintain hard copy records in the Water Safety Log Book.

3.9 Internal audit procedure

The Written Scheme will be audited at agreed intervals but should be at least annually.

An audit schedule will be prepared to ensure the entire procedure is audited. This should be done in conjunction with the Lead AP (Water Systems), Compliance manager, and Responsible Person (Water Systems).

The Audit Programme will consist of planned audits on the following elements:

Risk Assessments;

All documentation associated with this Written Scheme

training review and records;

schematic drawings;

Water Safety Log Books/Maintenance records;

BMS trend log comparison.

A report will be produced summarising the internal audit for submission to the Water Safety Group.

3.10 External audit procedure

A duly appointed Authorising Engineer (Water) will audit the entire *Legionella* and Water Safety Systems within *NHS Board* annually.

A duly appointed Authorising Engineer for *Legionella* and Water Safety Systems will produce an annual report for management review.

A duly appointed *Legionella* Risk Assessor for *Legionella* and Water Safety Systems will update the *Legionella* risk assessment database as directed by the board.

3.11 Management review

The Responsible Person (Water) will hold regular review meetings to confirm current compliance with *Legionella* and Water Safety System requirements, identification of any deficiencies and actions required to resolve staff training needs.

The management review will be based on following:

results of internal audits;

results of external audits;

staff suggestions;

training records;

operation of the system and procedures over the last six months.

3.12 Water Systems SCART Report

The relevant Authorised Person (Water) must regularly gather and maintain all the relevant information for import into the Campus SCART system.

All evidence confirming the SCART position and justification for risk rating adjustments should be uploaded to the SCART database in electronic format.

3.13 Contractor Management & Audit Report

Contractor Management Process

Regular review meetings should be set up with any contractors working on the water distribution system. Minutes of the meetings are held on the QEUH Estates Shared Drive at the path: SGH Estates>Water Quality>Contractor Meetings.

Discussions should include:

Ongoing works;

Future task programme;

Recording procedures;

RAMS;

Contractor Competency

Regular checks should be performed to ensure that any contractors working on the water distribution system are deemed competent and all operatives are suitably trained to conduct the delegated tasks. Copies of all Risk Assessments and Method Statements should be refreshed and all training records reviewed by the Water Systems AP. Copies are stored on the QEUH Campus Shared Drive in Water Quality.

Contractor Audit Report

A report should be produced at least annually to record the findings of the audit.

3.14 Permit to Work, Water Systems.

The Permit to Work Water Systems as per this written scheme is solely intended to be used when works on the hot and cold water systems and its ancillary equipment are to be completed within the QEUH and RHC campus. This includes break-ins to existing pipe work, removal of dead legs and any new installation works.

The Permit to Work may only be issued to Competent Persons (L8 approved) by the Authorised Person (AP) for water. This includes in house maintenance staff and approved contractors.

The Permit to Work form will include the following;

- Name of the organisation issuing the permit.
- Permit number.
- Name of Authorising Person (AP), including emergency contact details.
- Reasons for the works on the water system, (Plant Preventive Maintenance, Planned repairs or Emergency works).
- Exact location of the works
- Reference to any as built drawing numbers, (for update purposes).
- Name of Competent Person (CP) undertaking the works.
- Hazards and Risks, (copy of Risk assessment and Method Statements (RAMS) to be submitted for approval before start of works)
- Commissioning and Testing.

The above points on the Permit Work are broken into five categories, namely;

Part 1 Description of work and authorisation/permission to proceed.

Part 2 CP acceptance of work and conditions.

Part 3 Confirmation of work completion and engineering test results.

Part 4 Authorisation to use a system.

Part 5 Acceptance of system status by Nurse Manager.

Procedure to be followed for Permit to Work on water systems within the QEUH and RHC;

Sign into Estates office within the Laboratory building on the QEUH and RHC campus.

Receive induction from Authorised Person water.

Provide L8 Competent Person certification to Authorised Person water.

Provide applicable RAMS for the works to be completed.

3.15 Tool Box Talk, Hot and Cold Water Systems.

Estates Tool Box Talk on Hot and Cold water Systems is located on the shared drive / water quality / Estates Tool Talk. This is carried out in the form of a power point presentation.

4.0 MAINTENANCE PROCEDURES

Procedure Reference	Operation
4.1	SYSTEM INFORMATION
4.2	MAINTENANCE PROCEDURES SUMMARY
4.3	WEEKLY MAINTENANCE TASKS
4.4	MONTHLY MAINTENANCE TASKS
4.5	QUARTERLY MAINTENANCE TASKS
4.6	SIX MONTHLY MAINTENANCE TASKS
4.7	ANNUAL MAINTENANCE TASKS
4.9	BI-ANNUAL MAINTENANCE TASKS

NOTE:

Completed Log Sheet to be submitted to either the Authorised Person (Water Systems) or Site Manager Operational Estates for authorisation and copies filed as indicated in Section 2.2.

Due to the volume of information required for the recording of test results for each of the assets being maintained, the Log Sheets provided within this document are for indicative purposes only.

Detailed information on the assets and test records for same will be retained within the specific 'Log Book' for the location being maintained.

4.1 System Information

4.1.1 Correct and Safe Operation of the System

Measures should be in place to ensure that the water system is operated within the specific parameters as detailed in the following paragraphs:

4.1.2 Hot Water System

The storage of domestic hot water should be arranged to ensure that a water outflow temperature of at least 60ºC is achieved. No two water systems are the same and through periodic monitoring operational system performance, the system outflow temperature should be set to over 60ºC to ensure an outflow of 60ºC is achieved under normal draw-off demand and achieve 55°C at the supply to the furthermost draw-off point in the circulating system. It is important to maintain temperatures at above this figure (Legionellae organisms will survive for only a short period of time above this temperature - approximately two minutes).

Periodic performance monitoring and a system of continuous monitoring and recording of water temperatures via a building management system (BEMS) or data logger is essential to ensure compliant system performance.

The outflow water temperature, under prolonged maximum continuous demand (at least 20 minutes) from calorifiers should not be less than 60ºC.

While it is accepted that occasionally under peak instantaneous or prolonged demand the water outflow temperature will fall, it is not acceptable if this occurs frequently (more than twice in any 24 hour period) and/or for long periods (exceeding 20 minutes).

Under no circumstances should the domestic hot water flow temperature fall below 50ºC.

It is recommended that disinfection by pasteurisation is undertaken if the water temperature of the calorifier falls below 45ºC. A minimum domestic hot water circulation (return) temperature of 50ºC shall be maintained during the hours of occupancy.

4.1.3 Cold Water System

All domestic cold water storage cisterns and tanks shall comply with the requirements of the Scottish Water Byelaws.

Duplicate tanks often create a risk of water becoming stagnant in one of them, leading to risk of Legionella, Pseudomonas Spp or similar contamination. Consideration should be given to taking one of the tanks out of service. See guidance in “Guidance for Alterations to Water Systems”.

All cold water storage tanks are to be examined and the temperature tested on a regular summer / winter six monthly cycles and cleaned on an annual basis as required.

Temperatures in cold water storage tanks and the mains inlet to them should be checked during periods of high ambient temperatures (e.g. summer afternoons between June and August). Water temperatures should be less than 20ºC.

At the same time, the furthest and nearest draw off points in the system should be checked to ensure that the water distribution temperatures are less than 20ºC within 1 minute of running the water (at full flow). A similar temperature check regime should be undertaken during the winter months to identify the performance of cold water distribution systems and the impact of heat gain from heating systems.

4.1.4 Cold Water System Dump Valves

The cold water system installed in the Adult & Childrens Hospitals has a dump valve arrangement incorporated into the ground floor, 1st floor and 2nd floor layouts. The positions of the dump valves are shown on the Schneider BMS STRUXUREWARE system and connected via the KNX network.
Operating parameters for the dump valves are as follows:
Open at 23ºC
Close at 20ºC

4.1.5 End of Line Sensors (EOLs)

The hot and cold water system also incorporates End of Line (EOL) sensors which monitor the temperatures at specific sentinel points across all 11 floors of the Adult & Childrens installation. These can also be viewed via the Schneider BMS system.

4.1.6 Sampling

General microbiological and Legionella sampling in hot & cold water systems

Circumstances under which samples are taken:

- prior alterations to an existing water system;
- as part of commissioning process, prior to handover of a new building or introduction of a (altered, refurbished or new) water system into use;
- one week following handover of a new building or new water system;
- as part of the tank cleaning and disinfection process;
- as part of an assessment programme;
- in response to taste, odour or sustained discoloured water complaints.

When such samples are taken, a mains supply sample should be taken as a control to verify whether the supply could be the source of the identified problems. Scottish Water should also be contacted for distribution zone water quality data.

4.1.7 WS01 – Little Used Outlets

Control of Legionella in Water Systems, Intermittently used Water Outlets and Showers, Standard Operating Procedure WS01.

The Estates department is required to ensure that on a quarterly basis the list of ‘intermittent’ or ‘infrequently’ used water outlets or showers is reviewed to ensure it is accurate and up to date. Records of these reviews will be held within the system logbooks held locally.

If after investigation the taps or appliances identified within the reviewed list are deemed not necessary wherever possible the supply should be cut and the appliance removed from the water system. Where this is not possible then pipe work shall be cut back as close to the main circulating line as practicable to ensure that any dead-leg formed is minimised.

Nursing and other staff must be made aware of the issues surrounding legionella contamination and the link to low and underused water outlets and their assistance in formally identifying these possible outlets are sought.

Upon acknowledgement from the clinical staff of any intermittent or infrequently used outlets, the records are held on the Estates shared drive under Water Quality / WS01.

Any request from clinical staff regarding the removal of any intermittent or infrequently used outlets is assessed and surveyed by the AP (Water). If deemed appropriate a job is raised on FM for the Plumbing Technicians to remove, this is documented in the WS01 Records file in the Water Quality file on the shared drive. Subsequent hot and cold water pipe drawings are updated by the CAD Technician CP (water) where and when appropriate.

FILLING IN LOG SHEETS

Good water hygiene depends on maintaining high standards of cleanliness and freshness, together with careful temperature control. This section contains details of checks and recording sheets (marked "Log Sheets") to be filled in when checks and measurements are made to show that the necessary standards are being kept up. Alternatively, where an electronic PPM system is used, Procedure references should be entered.

Follow the instructions within the boxes and make entries as each task is completed. The tasks are all listed at the front of each section, weekly tasks at the front of the weekly section, monthly on the monthly and so on. The summary list of tasks in this section is to remind you of what is required.

The Task and Log Sheets can be copied as required, completed Log Sheets will be filed where indicated in Section 2. **FM First ticket number MUST be included in all logsheets.**

PLANNING

The tasks and forms are organised into weekly, monthly, quarterly and annual sections. Always aim to carry out tasks early in the period when they are due to leave an opportunity to do them later if an emergency delays your plans.

ASK

If you have difficulties with the forms or do not understand the tasks, ask your Supervisor or line manager for clarification or guidance.

CHECKING

Incomplete or incorrect records are unacceptable in that they are misleading and do not do justice to the effort put in to achieve standards. Each log sheet includes a space for comment and tells you to check that all the boxes are complete: do make use of the comment space and double check the form, otherwise the record will have gaps and whoever is responsible for auditing will concentrate on what is missing and may not give you credit for the work that has been done.

LOG INSPECTION

Anyone inspecting this log (either as part of the Management Control System or not) is invited to make an entry in the inspection of Log Book record in front of Section One.

SURVEY

For survey purposes all surveys will be carried out starting left to right, where 2 off access doors are available the left access shall be taken first. Surveys shall be undertaken from top to bottom.

EQUIPMENT FITTINGS AND MATERIALS

Prior to carrying out alterations/ additions to distribution systems, the Water Fittings and Materials Directory published by the Water Regulations Advisory Scheme, should be consulted. This directory lists all materials and fittings approved for use to satisfy the requirements of current Water Byelaws.

Details of all new materials and fittings used in installations should be noted and recorded on the specific work document or project file for future reference.

SYSTEM ADDITIONS AND ALTERATIONS

Any additions, modifications or improvements to the water distribution system are to be noted and recorded and system record's amended to reflect such changes.

HYGIENE PRACTICES

Care should be taken to ensure high levels of personal hygiene, clean hands, clean clothing and PPE or gloves is maintained at all times when working on wholesome water operations. Tools, equipment, instrumentation and material's shall be free from contamination and appropriately disinfected before use.
Items such as pumps and hoses used in contact with water used for domestic purposes must be stored separately, clearly identified (ie colour coded or labelled) and **MUST NOT BE USED FOR ANY OTHER PURPOSE.**

Refer to Section 2.2 for location of maintenance records for the above.

4.2 Maintenance Procedures Summary

This section contains information in relation to the operational and maintenance checks managed by QEUH NHS Staff and appointed contractors to minimise the risk of exposure to *Legionella* and other waterborne micro-organisms within the domestic water systems, and to improve water quality. Procedures are as per the recommendations and exemplar models given in SHTM 04-01 Part G.

Procedure Reference	Operation(s)	Record Form Ref	Frequency
P1C1	BMS Temperature Monitoring	**(021)**	Daily
P1CC1A	Manual Temperature Monitoring	**(005a)**	Daily
	Filtration Plant Checks		Twice Daily
WS01	Flushing Intermittently used outlets	**(026)**	Twice Weekly
WS01	Flushing Deadlegs and drain cocks	**(026)**	Twice Weekly
WS01	Deluge shower/Eye wash flushing	**(026)**	Twice Weekly
P1C3	Pump operation/duty rotation	**(028)**	Weekly
P1C4	Temperature Recording of Sentinel Hot and Cold Water Outlets.	**(005)**	Monthly
P1C4	DHW Calorifier and Plate Heat Exchanger Checks	**(005)**	Monthly
P1C12	Showerhead/hose replacement/disinfection	**(005b)**	Quarterly
P1C6	DWS Calorifier, Expansion Vessel Flushing	**(006) (023)**	Quarterly
WQS 001	HORNE Tap Flow Restrictor Exchange		Quarterly
WS01	Review of Rarely Used Water Outlets and Changes In-Use		Quarterly
	TMV/TMT & Thermostatic Shower Disinfection and Function Test (HIGH RISK)		Quarterly
	TMV/TMT & Thermostatic Shower Disinfection and Function Test (Non-HIGH RISK)		Six-Monthly
P1C7	CWST Inspection and Temperature Monitoring	**(003)**	Six-Monthly
P1C9	DWS Calorifier / Expansion Vessel Inspection	**(006)**	Annually
	Water Services Pipework and Distribution System Checks		Annually
P1C10	Representative Tap Temperature Monitoring	**(005)**	Annually
	Vibration coupling inspection		Annually
	Carry out review of log book and control manual		Annually (Sep)
	Carry out review of drawings and schematics		Annually (Sep)

4.3 Daily Maintenance Tasks

Reference	Operation
4.31	BMS Temperature Monitoring
4.32	Manual Temperature Monitoring
4.33	Filtration Plant Checks

NOTE:

Completed Log Sheet to be submitted to either the Authorised Person (Water Systems) or Site Manager Operational Estates for authorisation and copies filed as indicated in Section 2.2.

Due to the volume of information required for the recording of test results for each of the assets being maintained, the Log Sheets provided within this document are for indicative purposes only.

Detailed information on the assets and test records for same will be retained within the specific 'Log Book' for the location being maintained.

4.31 – BMS TEMPERATURE MONITORING

DAILY

FM First Template No 826

IN ACCORDANCE WITH SHTM 04-01 Part G (*V1 July 2015*) Page 26 para 3.11

RECORD FORM - (021)

PROCEDURE REF - P1C1

SCHEDULE REF – BMS 01

The following actions must be undertaken **DAILY** as a minimum:

Description of Works

- Refer to the BMS Temperature Monitoring Schedule BMS 01.
- Log onto both STRUXUREWARE BMS and DISTECH BMS front ends and check all temperatures from listed locations.
- Complete Schedule BMS 01 to confirm all temperatures have been checked.
- Any temperatures found outside the defined parameters stated on the BMS Temperature Monitoring Schedule should be investigated and resolved immediately. Details must be entered on Record Form (021) and escalated to the Water Systems AP.

CHECK

1. Record all details of any fault or discrepancy on the FAULT LOG and report to Manager.
2. Complete Schedule BMS 01 and Record Form (021) if required, ensuring that you date, sign it and enter FM First ticket number.
3. Return forms to the Water Systems AP.

NOTE: Both Struxureware and Distech BMS systems are capable of generating temperature trend logs. These logs will be checked on a regular basis by the Water Systems AP to confirm accuracy of information.

4.32 – MANUAL TEMPERATURE MONITORING

DAILY

FM First Template No 830

IN ACCORDANCE WITH SHTM 04-01 Part G (*V1 July 2015*) Page 26 para 3.15

RECORD FORM – (005a) (021a)

PROCEDURE REF - P1CC1A

SCHEDULE REF – MTM 01

The following actions must be undertaken **DAILY** as a minimum:

Description of Works

- Refer to the Manual Temperature Monitoring Schedule MTM 01.
- MANUALLY visit each location and obtain and record temperatures from all plant as listed on Schedule MTM 01.
- Any temperatures found outside the defined parameters stated on the MTM 01 Temperature Monitoring Schedule should be investigated and resolved immediately. Details must be entered on Record Form (021a) and escalated to the Water Systems AP.

CHECK

1. Record all details of any fault or discrepancy on the FAULT LOG and report to Manager.
2. Complete Record Forms (005a) and (021a) if required, ensuring that you date, sign it and enter FM First ticket number.
3. Return form to the Water Systems AP.

4.33 – FILTRATION PLANT CHECKS

TWICE DAILY

FM First Template No 836

IN ACCORDANCE WITH BOARD POLICY

RECORD FORM – (028c)

PROCEDURE REF – N/A

The following actions must be undertaken **TWICE DAILY** as a minimum AM and PM:

Description of Works

- Refer to the Filtration Plant Daily Checks Log sheet (028c).
- Complete all listed checks and ensure plant is running if selected as DUTY, or available to run if selected as STAND-BY.
- Details must be entered on Record Form (028c) and any issues escalated to the Water Systems AP immediately.

CHECK

1. Record all details of any fault or discrepancy on the FAULT LOG and report to Manager.
2. Complete Record Forms (028c) if required, ensuring that you date, sign it and enter FM First ticket number.
3. Return form to the Water Systems AP.

4.4 Weekly Maintenance Checks

Reference	Operation
4.41	Flushing of Rarely Used Water Outlets (Twice Weekly)
4.42	Flushing of Deadlegs & Drain Cocks (Twice Weekly)
4.43	Rotation of Water Services Duty/Stand-By Pumps
4.44	Operation and Checks to Emergency Deluge Shower/Eye Wash (Twice Weekly)

NOTE:

Completed Log Sheet to be submitted to either the Authorised Person (Water Systems) or Site Manager Operational Estates for authorisation and copies filed as indicated in Section 2.2.

Due to the volume of information required for the recording of test results for each of the assets being maintained, the Log Sheets provided within this document are for indicative purposes only.

Detailed information on the assets and test records for same will be retained within the specific 'Log Book' for the location being maintained.

4.41 – FLUSHING OF INTERMITTENTLY USED WATER OUTLETS

FM First Template No 824

TWICE WEEKLY

IN ACCORDANCE WITH SHTM 04-01 Part G (*V1 July 2015*) Page 101 para 6.36

RECORD FORM - (026a)

PROCEDURE REF - WS01

The following actions must be undertaken **TWICE WEEKLY** as a minimum:

Description of Works

- Refer to the locations listed on Record Form (026a).
- Estates to arrange for the Schedule to be updated to record on a regular basis.
- Flush water from ALL outlets identified on Record Form (026a) at a minimum frequency of Twice Weekly for a minimum period of 3 minutes per tap outlet taking care not to cause splashing or exposure to water aerosols / droplets.

CHECK

1. Record all details of any fault or discrepancy on the FAULT LOG and report to Manager.
2. Complete Record Form (026a) ensuring that you date, sign it and enter FM First ticket number.
3. Return form to the Water Systems AP.

NOTES:

In circumstances where there has been a lapse in the flushing regime, the stagnant and potentially contaminated water from within the shower or tap and associated dead leg should be purged to drain without discharge of aerosols before the appliance is used.

NHSGG&C consider the cleaning of wash hand basins, toilets and showers etc by Domestic Services staff to fulfil the criteria of having been used /flushed

As part of the ward/departments standard cleaning schedule Domestic Services staff will clean all wash hand basins, showers, baths, WC's and bidets. For the purposes of Legionella and Pseudomonas control the Board deems this to be considered adequate to fulfil guidance on the use of water outlets.

4.42 – FLUSHING OF DEADLEGS & DRAIN COCKS

FM First Template No 827

TWICE WEEKLY

IN ACCORDANCE WITH SHTM 04-01 Part G (*V1 July 2015*) Page 101 para 6.36

RECORD FORM - (026b)

PROCEDURE REF – WS01

The following actions must be undertaken **TWICE WEEKLY** as a minimum:

Description of Works

- Refer to the locations listed on Record Form (026b).
- Estates to arrange for the Schedule to be updated to record on a regular basis.
- Flush water from ALL outlets identified on Record Form (026b) on a Weekly basis for a minimum period of 3 minutes per tap outlet taking care not to cause splashing or exposure to water aerosols / droplets. Drain Cocks to be purged to ensure the removal of any built up residue in the line.

CHECK

1. Record all details of any fault or discrepancy on the FAULT LOG and report to Manager.
2. Complete Record Form (026b) ensuring that you date, sign it and enter FM First ticket number.
3. Return form to the Water Systems AP.

4.43 – ROTATION OF WATER SERVICES DUTY/STAND-BY PUMPS

FM First Template No 820

WEEKLY

IN ACCORDANCE WITH SHTM 04-01 Part G (*V1 July 2015*) Page 27 para. 3.24

RECORD FORM - (028a)

PROCEDURE REF - P1C3

The following actions must be undertaken **WEEKLY**:

Description of Works

- Inspect and confirm operation of all listed duty/stand-by pumps by interrogating the programmer to check hours run for each pump motor.
- Check pump rig and associated valves for correct operation, signs of damage, leakage or corrosion.
- Record all details on Record Form (028a)

CHECK

1. Record all details of any fault or discrepancy on the FAULT LOG and report to Manager.
2. Complete Record Form (028a) ensuring that you date, sign it and enter FM First ticket number.
3. Return form to the Water Systems AP.

4.44 – OPERATION AND CHECKS TO EMERGENCY DELUGE SHOWERS/EYE WASH

FM First Template No 825

TWICE WEEKLY

IN ACCORDANCE WITH SHTM 04-01 Part G (*V1 July 2015*) Page 57

RECORD FORM - (026c)

PRECEDURE REF – WS01

RISK CONTROL NOTICE - RCN 11/04

The following actions must be undertaken **TWICE WEEKLY**:

Description of Works

- Refer to the locations listed on Record Form (026c).
- Operate shower for a minimum period of 3 minutes taking care not to cause splashing or exposure to water aerosols / droplets. Measure and record temperatures until discharge water drops to the same temperature as the incoming mains water.

  NOTE: For thermostatic showers and taps, the outlet should be flushed on the full cold setting for 2 minutes, then again on the full hot setting for a further 2 minutes, using override setting where available. Cold water should be less than 20^{O}C, Hot water should be between 55^{O}C and 60^{O}C, and Mixed water in the range 41-43°C.

CHECK

1. Record all details of any fault or discrepancy on the FAULT LOG and report to Manager.
2. Complete Record Form (026c) ensuring that you date, sign it and enter FM First ticket number.
3. Return form to the Water Systems AP.

4.5 Monthly Maintenance Checks

Reference	Operation
4.51	Sentinel Outlet Temperature Recording
4.52	DWS Calorifier – Temperature Checks & Blowdown

NOTE:

Completed Log Sheet to be submitted to Site Estates Manager / Authorised Person (Water) for authorisation and copies filed as indicated in Section 2.20.

Due to the volume of information required for the recording of test results for each of the assets being maintained, the Log Sheets provided within this document are for indicative purposes only.

Detailed information on the assets and test records for same will be retained within the specific 'Log Book' for the location being maintained.

4.51 – SENTINEL OUTLET TEMPERATURE RECORDING

FM First Template No 828

MONTHLY

IN ACCORDANCE WITH SHTM 04-01 Part G (*V1 July 2015*) Page 28 para 3.27

RECORD FORM - (005c)

PROCEDURE REF - P1C4

The following actions must be undertaken **MONTHLY**:

Description of Work

- Check the temperatures at the sentinel taps as defined in the local plan of the system being checked. NOTE: Where the sentinel is a TMV or TMT the temperature readings should be taken from the pipework or directly from the hot and cold supply.
- Using a calibrated temperature probe, check the temperature of water from the cold water tap does not rise above 20ºC after running the tap for 2 minutes.
- Using a calibrated temperature probe, check the temperature of water from the hot water tap does not drop below 50ºC whilst running the tap for 1 minute.
- Record all temperatures on Record Form (005c).

CHECK

1. Record all details of any fault or discrepancy on the FAULT LOG and report to Manager.
2. Complete Record Form **(005c)** ensuring that you date, sign it and enter FM First ticket number.
3. Return form to the Water Systems AP.

4.52 - DWS CALORIFIER – TEMPERATURE CHECKS & BLOWDOWN

FM First Template No 821

MONTHLY

IN ACCORDANCE WITH SHTM 04-01 Part G (*V1 July 2015*) Page 28 para 3.30

RECORD FORM - (005)

PROCEDURE REF - P1C4

The following actions must be undertaken **MONTHLY**:

Description of Work

- MANUALLY CHECK and record the flow and return temperatures on the domestic hot water system as defined on Record Form (005), using the temperature gauges fitted or a suitable surface temperature probe.
- MANUALLY CHECK and record the calorifier storage temperature at top and bottom gauges if fitted.
- The flow temperature to be at least 60ºC and the return temperature shall be no less than 50ºC
- MANUALLY CHECK and record the cold water feed temperature using the temperature gauges fitted or a suitable surface temperature probe.
- Blowdown drain valves (if fitted) on all calorifiers and expansion vessels by opening the drain valve 3 times, each time for a 3 minute period. Where required, the hose from the drain valve connection should be discharged to the nearest drain/gulley. If there is no drain valve make note on Record Form.
- Check, confirm and record operation of de-stratification pump.
- Record all information on the Record Form (005).

CHECK

1. Record all details of any fault or discrepancy on the FAULT LOG and report to Manager.
2. Complete Record Form (005) ensuring that you date, sign it and enter FM First ticket number.
3. Return form to the Water Systems AP.

4.6 Quarterly Maintenance Checks

Reference	Operation
4.61	Shower Head and Flexible Hoses Disinfection/Replacement
4.62	DHWS Calorifier and Expansion Vessel - Flush
4.63	HORNE Tap Flow Restrictor Exchange
4.64	Review of Rarely Used Water Outlets and Changes In-Use
4.65	TMV/TMT & Thermostatic Shower Disinfection and Function Test (HIGH RISK)

NOTE:

Completed Log Sheet to be submitted to either the Authorised Person (Water Systems) or Site Manager Operational Estates for authorisation and copies filed as indicated in Section 2.2.

Due to the volume of information required for the recording of test results for each of the assets being maintained, the Log Sheets provided within this document are for indicative purposes only.

Detailed information on the assets and test records for same will be retained within the specific 'Log Book' for the location being maintained.

4.61 SHOWER HEAD AND HOSE REPLACEMENT

FM First Template No 869
Schedules: 1997 to 2724

QUARTERLY

IN ACCORDANCE WITH SHTM 04-01 Part G (*V1 July 2015*) Page 32 para 3.51

RECORD FORM - (005b)

PROCEDURE REF - P1C12 CURRENTLY CONTRACTED TO DMA CANYON WATER

The following actions must be undertaken every **THREE MONTHS**:

NOTE: If PALL filter is fitted it must be left in place and recorded as such on Record Form (005b)

Description of Work

- Exchange shower head and hose assembly inc sealing washers with new disposable unit. Place old shower head and hose assembly into re-sealable plastic bag.
- Check that the new head and hose package is intact;
- Open replacement new shower head and hose assembly sealed packaging, remove and fit following the manufacturer's instructions;
- Run water and flush for 3 minutes in accordance with Legionella Risk Assessment in such a way as to avoid the creation of aerosols;
- Check final temperature for compliance and working order and return shower appliance to use.
- Return redundant sealed bag with shower head and hose assembly to collection point for recycling in accordance with Waste Procedures;
- Record all actions on the Record Form (005b).

CHECK

1. Record all details of any fault or discrepancy on the FAULT LOG and report to Manager.
2. Complete Record Form (005b) ensuring that you date, sign it and enter FM First ticket number.
3. Return form to the Water Systems AP.

NOTE: This procedure replaces the previous Clean & Disinfect method from 1st April 2019

4.62 - DWS CALORIFIER AND EXPANSION VESSEL - FLUSH

FM First Template No 821

QUARTERLY

IN ACCORDANCE WITH SHTM 04-01 Part G (*V1 July 2015*) Page 29 para 3.34

RECORD FORM - (006) and (023)

PROCEDURE REF - P1C6

The following actions must be undertaken every **THREE MONTHS**:

Description of Work

- Flush each Domestic Hot Water Calorifier and Buffer Vessel through its drain valve by opening the drain valve 3 times, each time for a 3 minute period. Where required, the hose from the drain valve connection should be discharged to the nearest drain/gulley.
- Record all actions on the top section of Record Form (006).
- Where the domestic hot water system has recirculation pump(s) fitted to circulate the hot water from the top to the base of the calorifier or the storage/buffer vessel, and the history data shows no sludge deposits during flushing, then this procedure should be risk assessed to determine if the maintenance frequency can be changed. This assessment should be recorded on Record Form (023).

NOTE: this flushing process will not flush the hot water system, so only carry it out when there is no hot water demand and the calorifier is valved off from the system.

CHECK

1. Record all details of any fault or discrepancy on the FAULT LOG and report to Manager.
2. Complete Record Forms (006) and/or (023) ensuring that you date, sign them and enter FM First ticket number.
3. Return form to the Water Systems AP.

4.63 – HORNE TAP FLOW RESTRICTOR EXCHANGE

FM First Template No N/A

QUARTERLY

IN ACCORDANCE WITH IC GUIDANCE

RECORD FORM – (See DMA Records)

PROCEDURE REF – WQS 001

The following actions must be undertaken every **THREE MONTHS**:

Description of Work

PPE:- Surgical gloves should be worn when carrying out this task. Cross contamination of the replacement flow restrictor should be considered and avoided at all times.

Restrictor should only be replaced at outlets without PALL filters. If PALL filter is fitted it should be left in place and noted on Record Form.

- Assemble all tools and materials required to complete task.
- Check with ward staff to ensure access can be granted to each area without Infection Control restriction.
- Remove existing restrictor using the appropriate tool and dispose of the restrictor in general waste.
- Use disinfectant wipes to sanitise tap outlet and tools used before re-fitting new restrictor.
- Change gloves to avoid cross contamination of new components and tools.
- Unpack new restrictor components and insert into tap as per the manufacturer's instructions.
- Test on completion and fill out log sheet to record all relevant information.

CHECK

1. Record all details of any fault or discrepancy on the FAULT LOG and report to Manager.
2. Complete Record Form (DMA WATER) ensuring that you date, sign them and enter FM First ticket number.
3. Return form to the Water Systems AP.

4.64 - REVIEW OF INTERMITTENTLY USED WATER OUTLETS/CHANGE IN-USE

IN ACCORDANCE WITH BOARD POLICY

QUARTERLY

RECORD FORM – (001) (026)

PROCEDURE REF – WS01

The following actions must be undertaken every **THREE MONTHS**:

Description of Work

- Liaise with Site Facilities Manager and Heads of Department to review existing accommodation occupancy and usage on a 3 monthly basis.
- Issue Quarterly circular email to all HoDs
- Identify any water services outlets that are not used OR changes to the occupancy.
- Schedule to be updated to record all areas which change in-use, become unoccupied or otherwise out of use.

CHECK

1. Record all details of any dept closures or little used outlets on Record Form (001) and add outlets to flushing register.
2. Ensure outlets are brought to the attention of the maintenance person carrying out the flushing activity and details added to Record Form (026)
3. All completed Record Forms to be stored in the building specific Log Book.

4.65 – TMV/TMT & THERMOSTATIC SHOWER DISINFECTION AND FUNCTION TEST (HIGH RISK)

QUARTERLY

FM First Template No

IN ACCORDANCE BOARD POLICY

RECORD FORM -

PROCEDURE REF -

The following actions must be undertaken every **THREE MONTHS**:

Description of Work

- Examine all thermostatic taps for scale build-up or other deposits. De-scale any which are not clean.
- Check and remove any installed plastic flow straighteners from tap outlet
- Inspect and Clean and Disinfect filters / strainers by removing and immersing in a solution of 1000ppm free residual chlorine (50cc CLO2 in 5 litres of water) in water for 5 minutes.
- All HORNE Optitherm taps MUST have the flow straightener replaced during three monthly service tasks.
- Pasteurise outlets by over-riding thermostatic controls drawing water through each thermostatic tap until a temperature of 60°C is achieved. Run the tap at this temperature for five minutes. If this is not possible disassemble tap assembly and spray all accessible components with 'Shower Head plus' mixed to a 1:3 solution, (one part chemical, 3 parts water) or equal and approved and let stand for 5 minutes.
- Reassemble and verify fail safe operation by isolating hot and cold water supplies separately.
- Ensure thermostatic controls are re-adjusted to permit blending.
- Should controls not be able to be over-ridden, verify the temperatures at the inlet connections to the thermostatic valve utilising a contact type probe and electronic thermometer.
- Run and test tap and record hot and cold water inlet temperatures and mixed water outlet temperature.
- Log all actions.

4.7 Six Monthly Checks

Reference	Operation
4.71	TMV/TMT & Thermostatic Shower Disinfection and Function Test (Non-HIGH RISK)
4.72	CWST Inspection and Temperature Monitoring

NOTE:

Completed Log Sheet to be submitted to either the Authorised Person (Water Systems) or Site Manager Operational Estates for authorisation and copies filed as indicated in Section 2.2.

Due to the volume of information required for the recording of test results for each of the assets being maintained, the Log Sheets provided within this document are for indicative purposes only.

Detailed information on the assets and test records for same will be retained within the specific 'Log Book' for the location being maintained.

4.71 – TMV/TMT & THERMOSTATIC SHOWER DISINFECTION AND FUNCTION TEST (NON HIGH RISK)

IN ACCORDANCE WITH BOARD POLICY

SIX MONTHLY

RECORD FORM -

PROCEDURE REF -

The following actions must be undertaken every **SIX MONTHS**:

Description of Work

- Examine all thermostatic taps for scale build-up or other deposits. De-scale any which are not clean.
- Check and remove any installed plastic flow straighteners from tap outlet
- Inspect and Clean and Disinfect filters / strainers by removing and immersing in a solution of 1000ppm free residual chlorine (50cc CLO2 in 5 litres of water) in water for 5 minutes.
- All HORNE Optitherm taps MUST have the flow straightener replaced during three monthly service tasks.
- Pasteurise outlets by over-riding thermostatic controls drawing water through each thermostatic tap until a temperature of 60°C is achieved. Run the tap at this temperature for five minutes. If this is not possible disassemble tap assembly and spray all accessible components with ‘Shower Head plus’ mixed to a 1:3 solution, (one part chemical, 3 parts water) or equal and approved and let stand for 5 minutes.
- Reassemble and verify fail safe operation by isolating hot and cold water supplies separately.
- Ensure thermostatic controls are re-adjusted to permit blending.
- Should controls not be able to be over-ridden, verify the temperatures at the inlet connections to the thermostatic valve utilising a contact type probe and electronic thermometer.
- Run and test tap and record hot and cold water inlet temperatures and mixed water outlet temperature.
- Log all actions.

4.72 – CWST INSPECTION AND TEMPERATURE MONITORING:

FM First Template No 819

SIX MONTHLY

IN ACCORDANCE WITH SHTM 04-01 Part G (*V1 July 2015*) Page 29 para 3.37

RECORD FORM – (003a) (003b)

PROCEDURE REF – P1C7

The following actions must be undertaken every **SIX MONTHS** seasonally during Summer and Winter:

Description of Work

- Check the tank and associated pipework, valves etc for leaks.
- Inspect the tank and associated pipework, valves etc for damage or corrosion and sediment.
- Check the operation of the ball-valve by pressing down on it and lifting the float to confirm that water flows and stops.
- Inspect the tank overflows. Confirm that there is no blockage or other foreign material and that the mesh screen is not damaged.
- Measure and record the temperature of the water in the tanks, by dipping the thermometer into the top as far from the ball-valve as possible.
- Check and record ambient outside air temp and tank room temp.
- Check the flow and record the temperature of water feeding the tanks. There should be a steady rapid flow when the ball float is down.

CHECK

1. Record all details of any fault or discrepancy on the FAULT LOG and report to Manager.
2. Complete Record Forms (003a) and (003b) ensuring that you date, sign them and enter FM First ticket number.
3. Return forms to the Water Systems AP.

4.8 Annual Maintenance Checks

Reference	Operation
4.81	DWS Calorifier / Expansion Vessel Inspection
4.82	Water Services Pipework and Distribution System Checks
4.83	Representative Tap Temperature Monitoring
4.84	Vibration coupling inspection
4.85	BMS Temperature Sensor Test and Calibration

NOTE:

Completed Log Sheet to be submitted to either the Authorised Person (Water Systems) or Site Manager Operational Estates for authorisation and copies filed as indicated in Section 2.2.

Due to the volume of information required for the recording of test results for each of the assets being maintained, the Log Sheets provided within this document are for indicative purposes only.

Detailed information on the assets and test records for same will be retained within the specific 'Log Book' for the location being maintained.

4.81 - DWS CALORIFIER/EXPANSION VESSEL INSPECTION

FM First Template No 821

ANNUALLY

IN ACCORDANCE WITH SHTM 04-01 Part G (*V1 July 2015*) Page 31 para 3.44

RECORD FORM - (006)

PROCEDURE REF - P1C9

The following actions must be undertaken **ANNUALLY**

Description of Work

Follow the manufacturers' maintenance instructions from O&M manuals. Record all actions where applicable on Record Form (006) for each system.

- Isolate domestic hot water calorifier or hot, cold or chilled water storage/buffer vessel service valves;
- Heat any domestic hot water calorifier or hot water storage/buffer vessel up until the contents has reached 60ºC and hold at this temperature for a period of at least 1 hour;
- Drain domestic hot water calorifier and expansion vessel and remove inspection hatch;
- Hose out the domestic hot water calorifier or hot and expansion vessel to remove any debris, scale or other deposit. Care should be taken to keep aerosols to a minimum;
- If the domestic hot water calorifier or expansion vessel does not have an inspection hatch, the pipework at the top of the vessel should be disconnected to allow the insertion of a water hose to allow debris to be washed down off internal surfaces;
- Examine the internal and external condition of the domestic hot water calorifier and expansion vessel and pipework, any defects should be reported in writing to the relevant Authorised Person (Water). The safety valve should be checked, overhauled and reset as necessary. The temperature and pressure gauges to be checked for operation.
- On completion of examination and any repairs, the domestic hot water calorifier and expansion vessel should be re-assembled and the following sequence must be undertaken:
- Refill with cold water;
- Drain the domestic hot water calorifier and expansion vessel;
- Refill with cold water, leave cold feed valve open;
- Run domestic hot water calorifier or hot water storage/buffer vessel at a temperature of 60ºC for at least 1 hour. Test the operation of high limit cut-out system if fitted. Check the temperature of the calorifier/vessel top and bottom with a surface thermometer;
- Adjust any controls as necessary.

- Take bacteriological samples from the base of the calorifier and submit to GRI Water Lab for analysis. (THIS TASK TO BE CARRIED OUT BY DMA CANYON WATER)

NOTE: this flushing process can air lock the hot water system, so only carry it out when there is no hot water demand and the calorifier is valved off from the system.

CHECK

1. Record all details of any fault or discrepancy on the FAULT LOG and report to Manager.
2. Complete Record Forms (006) ensuring that you date, sign them and enter FM First ticket number.
3. Return form to the Water Systems AP.

4.82 - PIPEWORK AND DISTRIBUTION SYSTEM CHECKS

FM First Template No 829

ANNUALLY

IN ACCORDANCE WITH SHTM 04-01 Part G (*V1 July 2015*) Page 31 para 3.

RECORD FORM - (0)

PROCEDURE REF -

The following actions must be undertaken **ANNUALLY**:

Estates Manager or Water Systems AP will define areas to be checked in each building.

Description of Work

- Check all accessible pipework for damage, or corrosion.
- Check for missing or damaged pipework insulation

CHECK

1. Record all details of any fault or discrepancy on the FAULT LOG and report to Manager.
2. Complete Record Forms (0) ensuring that you date, sign them and enter FM First ticket number.
3. Return form to the Water Systems AP.

4.83 – REPRESENTATIVE TAP TEMPERATURE MONITORING

FM First Template No

ANNUALLY

IN ACCORDANCE WITH SHTM 04-01 Part G (*V1 July 2015*) Page 32 para 3.39

RECORD FORM - (005)

PROCEDURE REF – P1C10

The following actions must be undertaken **ANNUALLY**:

Description of Work

- Check the temperatures at the hot and cold taps on a representative number of taps on a rotational basis as defined in the local plan of the system being checked.
- Using a temperature probe check the temperature in the cold water tap does not go above 20ºC after running the tap for 2 minutes;
- Using a temperature probe check the temperature in the hot water tap does not go below 50ºC within running the tap for 1 minute;
- Record all inspection and temperatures on the Record Form (005). Add "Annual Monitoring Procedure" to the Comments / Action box to clarify.

CHECK

1. Record all details of any fault or discrepancy on the FAULT LOG and report to Manager.
2. Complete Record Forms (005) ensuring that you date, sign them and enter FM First ticket number.
3. Return form to the Water Systems AP.

4.84 - VIBRATION COUPLING INSPECTION

FM First Template No

ANNUALLY

IN ACCORDANCE WITH HSG 274 Part 2 *(2014)* Page 19 para 2.35

RECORD FORM - (008)

PROCEDURE REF – WQMS 001

The following actions must be undertaken **ANNUALLY**:

Description of Work

- Refer to list of vibration coupling locations to be assessed.
- Visually check the condition of the coupling for any signs of leakage, deterioration or corrosion.
- Ensure flexible portion of coupling is intact and free from damage or deterioration.
- Record all inspection details on the Record Form (008).

CHECK

1. Record all details of any fault or discrepancy on the FAULT LOG and report to Manager.
2. Complete Record Forms (008) ensuring that you date, sign them and enter FM First ticket number.
3. Return form to the Water Systems AP.

4.85 – BMS TEMPERATURE SENSOR CALIBRATION

ANNUALLY

FM First Template No

IN ACCORDANCE WITH

RECORD FORM -

PROCEDURE REF –

The following actions must be undertaken **ANNUALLY**:

Description of Work

- This task should be included in the BMS Service Contract Specification.
- All temperature sensors related to domestic hot and cold water services to be checked and calibrated annually.
- All calorifiers, storage tanks, flow and return monitoring devices.
- Include all End of Line (EOL) sensors and cold water flushing devices.
- Records should be kept and made available to the estates dept on request.

4.9 Bi-Annual Maintenance Checks

Reference	Operation
4.91	Flexible Hose/Connection Inspection and Exchange
4.92	CWST Drop Test

NOTE:

Completed Log Sheet to be submitted to either the Authorised Person (Water Systems) or Site Manager Operational Estates for authorisation and copies filed as indicated in Section 2.2.

Due to the volume of information required for the recording of test results for each of the assets being maintained, the Log Sheets provided within this document are for indicative purposes only.

Detailed information on the assets and test records for same will be retained within the specific 'Log Book' for the location being maintained.

4.91 – FLEXIBLE HOSE/CONNECTION INSPECTION AND EXCHANGE

FM First Template No **BI-ANNUALLY**

IN ACCORDANCE WITH QEUH RISK ASSESSMENT RECOMMENDATIONS 2017

RECORD FORM - (009)

PROCEDURE REF – WQMS 002

The following actions must be undertaken **ANNUALLY**:

Description of Work

- Refer to list of flexible connection locations to be assessed as per WQMS 002.
- Visually check the condition of the coupling for any signs of leakage, deterioration or corrosion.
- Safely isolate the water services and exchange the flexible connection with a BRAND NEW UNUSED replacement.
- Apply tag/label to indicate the intended date of future replacement (todays date + 24 months)
- Record all details on the Record Form (009).

CHECK

1. Record all details of any fault or discrepancy on the FAULT LOG and report to Manager.
2. Complete Record Forms (009) ensuring that you date, sign them and enter FM First ticket number.
3. Return form to the Water Systems AP.

4.92 – CWST DROP TESTS

BI-ANNUALLY

FM First Template No 819

IN ACCORDANCE WITH

RECORD FORM -

PROCEDURE REF -

The following actions must be undertaken **ANNUALLY**:

Description of Work

- Shut off mains cold water supply to tank.
- Record the start time and allow tank to drain naturally through usage. DO NOT OPEN THE DRAIN.
- Periodically monitor the tank until usage has reduced tank to exactly half of its starting capacity.
- Record the stop time and estimate the number of hours of storage of water in the tank.
- Record all inspection details on the Record Form (010).

CHECK

1. Record all details of any fault or discrepancy on the FAULT LOG and report to Manager.
2. Complete Record Forms (010) ensuring that you date, sign them and enter FM First ticket number.
3. Return form to the Water Systems AP.

5.0 INCIDENT AND EMERGENCY PROCEDURES

Procedure Reference	Operation
5.10	FAILURE OF CONTROL MEASURES
5.20	HIGH COLD WATER SUPPLY TEMPERATURE TO OUTLET
5.30	LOW HOT WATER SUPPLY TEMPERATURE TO OUTLET
5.40	CALORIFIER OR HEAT EXCHANGER TEMPERATURE FAULT
5.50	POSITIVE LEGIONELLA TEST RESULT
5.60	IDENTIFICATION OF LITTLE USED WATER OUTLET
5.70	EMERGENCY REPAIRS
5.80	DISINFECTION OF WATER SYSTEM
5.90	PSEUDOMONAS

NOTE:

Completed Log Sheet to be submitted to either the Authorised Person (Water Systems) or Site Manager Operational Estates for authorisation and copies filed as indicated in Section 2.2.

Due to the volume of information required for the recording of test results for each of the assets being maintained, the Log Sheets provided within this document are for indicative purposes only.

Detailed information on the assets and test records for same will be retained within the specific 'Log Book' for the location being maintained.

THE FOLLOWING PAGES DESCRIBE REMEDIAL ACTIONS TO BE TAKEN IN THE EVENT OF AN INCIDENT, EMERGENCY, OUT-OF-SPECIFICATION TEST RESULT AND / OR WHERE *LEGIONELLA* HAS BEEN IDENTIFIED AND/OR BACTERIA COUNTS BEING INEXCESS OF THE RECOMMENDED LIMITS IN THE WATER SYSTEM ARE IDENTIFIED.

The Health and Safety at Work Act places a duty on employers to ensure, so far as is reasonably practicable, the maintenance of safe working conditions without risks to health, not only to employees, but also to the general public.

The risk to personnel associated with the presence of *Legionella* depends on a number of variables and may be quite low. However, since the actions to eradicate it are straightforward and reasonably practicable, it would be wise to put them in hand without delay if *Legionella* has been identified.

When analysis confirms that the levels of bacteriological contamination are in excess of acceptable limits, and/or the presence of Coliforms or *E.coli* is identified, the procedures recommended in this section should be applied.

5.1 Failure of Control Measures:

Where any reported test result, non-compliance issue or defect is made known which affects the integrity of the water system and indicates the failure of Control Measures and / or increased risk of Legionella the following procedures shall be followed and duly recorded within Section 2.3 of this document and brought to the attention of the relevant Infection Control Team and Water Management Group.

IN ALL CASES THE INCIDENT RECORD FORM (004) SHOULD BE COMPLETED AND INSERTED IN THE BUILDING SPECIFIC WATER SAFETY LOG BOOK.

5.2 High Cold Water Supply Temperature

Incident Plan

In the event of plant failure suppliers and installers guidance should be consulted. The location of all relevant literature should be recorded in the site logbook (e.g. Mercury fault finding guidance).

Mains and Stored Water

Currently there is no legal maximum water supply temperature from the Licensed Provider. In practice the water supply temperature to boundary point will be subject to seasonal variation. In winter this would normally be expected to be in the 5°C – 10°C range and in summer up to 20°C.

The following staged risk assessment escalation procedure should be employed where the water temperature in Cold Water Storage Tanks is 20°C or higher.

Stage 1 - Verification

- Where tepid cold water occurrence (i.e. ≥20°C) is reported from any numbers of cold water outlets, from maintenance/ppm, flushing procedures, from BEMS monitoring, or from the manual monitoring of storage tanks, the person identifying, or making a report must notify the relevant Authorised Person (Water) as soon as the problem is identified and confirm this in writing within 24 hours;

- The Authorised Person (Water) should liaise with the person identifying the problem and verify the problem by independently re-checking by means of taking the water temperature of the appropriate cold water storage tank, the temperature of each incoming mains supplies at the site boundary point (and building entry points of other buildings within the QEUH campus served by the same mains lines) and the outflow distribution temperature;

- If the cold water storage temperature is confirmed as being 20°C or higher at any of the above noted points, then the Authorised Person (Water) should record this in writing as well as conducting continuous monitoring of the incoming cold water mains, the cold water storage and the outflow temperatures to establish the temperature profiles and in more detail over at least a one week period to determine the level of risk;

- If only one of the incoming mains lines is ≥20°C the consideration should be given to switching to the other mains supply until such times as “out-of-specification” mains line has returned to compliant parameters. Ensure if either mains line is non-operational it is included in a daily flushing regime and treated as per escalation procedures to follow.

- The Authorised Person (Water) should also review the Water Safety Log Book and take into account the recent water system history specifically to include:

    - the primary water treatment levels (for mains cold water supplied with Chlorine or Chloramination treatment);
    - any water sampling results;
    - system monitoring data including temperature monitoring and water quality chlorine or chloramination checks;
    - recent maintenance history; recent alterations, changes or additions to the water system;
    - any other changes made by Duty Holders or users of the water system; On reviewing continuous monitoring temperature profiles action as Stage 2, 3 or 4 as appropriate of this escalation procedure should be undertaken. The Authorised Person (Water) will ensure that the Responsible Person (Water) is notified immediately in writing at each stage and also recorded in the Water Safety log book.

Stage 2 - Initial Action – High Incoming Mains Cold Water Temperature

- Where the incoming mains cold water is 18°C or higher for more than a 48 hour period the Responsible Person (Water) should contact Business Stream (the Licensed Provider) who will work with Scottish Water to establish the reasons and determine a resolution. Continuous monitoring should continue and recorded in the risk assessment

Stage 3 - Water temperatures fluctuating above and below 20°C (but not higher than 25°C)

- Where water temperatures are fluctuating above and below 20°C in a regular cyclical manner over 72 hour periods in response to regular user water demand (but not higher than 25°C) and are more than 2°C higher than the incoming cold water mains supply temperature at the building entry point, then continuous monitoring should be continued by the Authorised Person (Water). The reason(s) for failure(s) should be identified and rectified as soon as possible. This should be recorded by updated risk assessment (specifically in relation to the patient risk rating – where there may be increased risk and appropriate actions may be required to mitigate exposure. An up to date register of all areas and their subsequent patient risk ratings should be maintained).

- considerations for failures include:
  - accuracy of temperature sensors (requiring recalibration);
  - temperature sensors being located in water (requiring reposition where tank storage levels been reduced and sensor no longer sensing stored water);
  - inappropriate standby tank configuration;
  - temperature sensor in standby system;
  - temperature sensor measuring stagnation (requires reposition);
  - inappropriate siting (not in a cool location);
  - heat gain to the tank and pipework (due to lack of appropriate insulation or located close to heat gain from other heat sources);
  - storage capacity not minimised to match daily use (12 hours storage is recommended);
  - ingress of hot water through cross connection or mixing valve failure (i.e. from DHW system or MTHW systems);

Stage 4 - water temperatures fluctuating above and below 25°C (and rarely below 20°C)

- In this situation continuous monitoring should be continued by the Authorised Person (Water), the reason(s) for failure(s) (as Stage 3) identified and rectified on an urgent basis. This should be recorded by updated risk assessment (specifically in relation to the patient risk rating – where there will be an increased risk and appropriate actions will be required to mitigate exposure. An up to date register of all areas and their subsequent patient risk ratings should be maintained);

- In this situation a permanent solution, such as ventilation for the plant room, or changing the water storage arrangements, or forming a circulating distribution system (with or without chilling depending on the circumstances) would require to be implemented;

- The Authorised Person (Water) should, unless instructed in writing to the contrary by Responsible Person (Water) implement the following:
  - arrange to drain the tank contents and clean if necessary *(and/or carry out local disinfections where appropriate)*;
  - inform the users of the failed system that they must not draw off any water from the affected system until further notice;
  - suitable disinfection of the tank and/or distribution system shall be carried out.

Please Note: *Due to the system design and installation complete disinfection of all downservices fed from the Raw and Bulk water storage tanks may not be practical as "high risk" system such as renal dialysis is fed from these tanks. Alternative protocols/method statements for local disinfections should be prepared and maintained*;

- thereafter the tank/local area being disinfected shall be brought back into service;
- finally the users shall be informed that the system is back in operation.

The Authorised Person (Water) shall complete an Incident Report Record Form. An entry should also be made in the Water Safety Log Book and the Responsible Person (Water) should be notified in writing as soon as possible.

5.3 Low Hot Water Supply Temperature

Incident Plan

In the event of plant failure suppliers and installers guidance should be consulted. The location of all relevant literature should be recorded in the site logbook (e.g. Mercury fault finding guidance).

Mains and Stored Water

Currently there is no legal maximum water supply temperature from the Licensed Provider. In practice the water supply temperature to boundary point will be subject to seasonal variation. In winter this would normally be expected to be in the 5°C – 10°C range and in summer up to 20°C.

The following staged risk assessment escalation procedure should be employed where the water temperature in Cold Water Storage Tanks is 20°C or higher.

Stage 1 - Verification

- Where tepid cold water occurrence (i.e. ≥20°C) is reported from any numbers of cold water outlets, from maintenance/ppm, flushing procedures, from BEMS monitoring, or from the manual monitoring of storage tanks, the person identifying, or making a report must notify the relevant Authorised Person (Water) as soon as the problem is identified and confirm this in writing within 24 hours;

- The Authorised Person (Water) should liaise with the person identifying the problem and verify the problem by independently re-checking by means of taking the water temperature of the appropriate cold water storage tank, the temperature of each incoming mains supplies at the site boundary point (and building entry points of other buildings within the Southern General Hospital served by the same mains lines8) and the outflow distribution temperature;

- If the cold water storage temperature is confirmed as being 20°C or higher at any of the above noted points, then the Authorised Person (Water) should record this in writing as well as conducting continuous monitoring of the incoming cold water mains, the cold water storage and the outflow temperatures to establish the temperature profiles and in more detail over at least a one week period to determine the level of risk;

- If only one of the incoming mains lines is ≥20°C the consideration should be given to switching to the other mains supply until such times as “out-of-specification” mains line has returned to compliant parameters. Ensure if either mains line is non-operational it is included in a daily flushing regime and treated as per escalation procedures to follow.

- The Authorised Person (Water) should also review the Water Safety Log Book and take into account the recent water system history specifically to include:

    - the primary water treatment levels (for mains cold water supplied with Chlorine or Chloramination treatment);
    - any water sampling results;
    - system monitoring data including temperature monitoring and water quality chlorine or chloramination checks;
    - recent maintenance history; recent alterations, changes or additions to the water system;
    - any other changes made by Duty Holders or users of the water system;
    - On reviewing continuous monitoring temperature profiles action as Stage 2, 3 or 4 as appropriate of this escalation procedure should be undertaken. The Authorised Person (Water) will ensure that the Responsible Person (Water) is notified immediately in writing at each stage and also recorded in the Water Safety Logbook.

Stage 2 - Initial Action – High Incoming Mains Cold Water Temperature

- Where the incoming mains cold water is 18°C or higher for more than a 48 hour period the Responsible Person (Water) should contact Business Stream (the Licensed Provider) who will work with Scottish Water to establish the reasons and determine a resolution. Continuous monitoring should continue and recorded in the risk assessment.

Stage 3 - water temperatures fluctuating above and below 20°C (but not higher than 25°C)

- Where water temperatures are fluctuating above and below 20°C in a regular cyclical manner over 72 hour periods in response to regular user water demand (but not higher than 25°C) and are more than 2°C higher than the incoming cold water mains supply temperature at the building entry point, then continuous monitoring should be continued by the Authorised Person (Water). The reason(s) for failure(s) should be identified and rectified as soon as possible. This should be recorded by updated risk assessment (specifically in relation to the patient risk rating – where there may be increased risk and appropriate actions may be required to mitigate exposure. An up to date register of all areas and their subsequent patient risk ratings should be maintained).

- considerations for failures include:
  - accuracy of temperature sensors (requiring recalibration);
  - temperature sensors being located in water (requiring reposition where tank storage levels been reduced and sensor no longer sensing stored water);
  - inappropriate standby tank configuration;
  - temperature sensor in standby system;
  - temperature sensor measuring stagnation (requires reposition);
  - inappropriate siting (not in a cool location);
  - heat gain to the tank and pipework (due to lack of appropriate insulation or located close to heat gain from other heat sources);
  - storage capacity not minimised to match daily use (12 hours storage is recommended);
  - ingress of hot water through cross connection or mixing valve failure (i.e. from DHW system or MTHW systems);

Stage 4 - water temperatures fluctuating above and below 25°C (and rarely below 20°C)

- In this situation continuous monitoring should be continued by the Authorised Person (Water), the reason(s) for failure(s) (as Stage 3) identified and rectified on an urgent basis. This should be recorded by updated risk assessment (specifically in relation to the patient risk rating – where there will be an increased risk and appropriate actions will be required to mitigate exposure. An up to date register of all areas and their subsequent patient risk ratings should be maintained);

- In this situation a permanent solution, such as ventilation for the plant room, or changing the water storage arrangements, or forming a circulating distribution system (with or without chilling depending on the circumstances) would require to be implemented;

- The Authorised Person (Water) should, unless instructed in writing to the contrary by Responsible Person (Water) implement the following:
  - arrange to drain the tank contents and clean if necessary *(and/or carry out local disinfections where appropriate)*;
  - inform the users of the failed system that they must not draw off any water from the affected system until further notice;
  - suitable disinfection of the tank and/or distribution system shall be carried out.

Please Note: *Due to the system design and installation complete disinfection of all downservices fed from the Raw and Bulk water storage tanks may not be practical as "high risk" system such as renal dialysis is fed from these tanks. Alternative protocols/method statements for local disinfections should be prepared and maintained*;

- thereafter the tank/local area being disinfected shall be brought back into service;
- finally the users shall be informed that the system is back in operation.

The Authorised Person (Water) shall complete an Incident Report Record Form. An entry should also be made in the Water Safety Log Book and the Responsible Person (Water) should be notified in writing as soon as possible.

Hot Water Services

When hot water storage or distribution temperatures fall below those required (60°C storage, 55°C at outlets and returning to calorifier) these will almost inevitably be caused a mechanical fault. Appropriate maintenance procedures, including the Mercury Fault Finding guidance documents, should be created and referenced to assist in timely rectification.

This escalation procedure (taken from SHTM 04-01 Part G (Draft)) should be employed if the Calorifier/Plate Heat Exchangers outflow temperature falls below 45ºC.

The table below should be used to decide on the actions necessary in the event of a plant breakdown such as power failure or gas supply failure.

Breakdown leading to temperature <45ºC, lasting for:	Risk Category	Action
<12 hrs	High	Verify
	Significant	Verify
	Moderate	Verify
>12 hrs	High	Thermally pasteurise
	Significant	Verify
	Moderate	Verify
>24 hrs	High	Thermally pasteurise
	Significant	Thermally pasteurise
	Moderate	Verify
>72 hrs	High	Thermally pasteurise
	Significant	Thermally pasteurise
	Moderate	Thermally pasteurise

In the event of a reduction in domestic hot water temperature the **Authorised Person (Water)** should be notified in writing as soon as possible. The reason for failure must be identified and rectified as soon as possible.
The **Authorised Person (Water)** shall notify the **Duty Holder** and users on the failed system that they must not draw off any hot water from the affected services until further notice.
The relevant **Duty Holder** shall ensure that their staff are aware of the situation, and that they in turn shall prevent patients from using affected services.
Where thermal pasteurisation is to be carried out, the temperature of the calorifier or plate heat exchanger shall be raised to 70ºC, and the water shall be circulated throughout the affected distribution system for at least one 1 hour. Each tap or appliance should be run in sequence until full temperature is achieved (this should be measured). To be effective the temperature in the calorifier or plate heat exchanger should be high enough to ensure that all distribution outlets receive water at a temperature of greater than 60ºC. Ensure the return flow to the calorifier or plate heat exchanger is no less than **55ºC**.
The **Authorised Person (Water)** shall inform users that the system is back in operation.
Bacteriological samples should be taken in consultation with the Infection Prevention and Control team.
The **Authorised Person (Water)** shall complete an Incident Report Record and ensure the **Responsible Person (Water)** is notified in writing as soon as possible. Maintain hard copy records in the Water Safety Log

5.4 Positive Legionella Test Result

Microbiological Sampling (Legionella)
Sampling requirements and frequency are to be formulated by NHS GG&C and written scheme should be updated as appropriate.

Legionella testing may be required:

- In systems where the temperature control regimes are not consistently achieved, frequent testing e.g. weekly should be carried out to provide early warning of loss of control. Once the system is brought back under control as demonstrated by monitoring, the frequency of testing should be reviewed
- Weekly checks are recommended until the system is brought under control;
- When an outbreak is suspected or has been identified;
- In wards with at-risk patients – for example those who are immuno-compromised ("high risk patient" areas still to be confirmed to DMA).

As a minimum, samples should be taken as follows:

- From the cold water storage and the furthermost outlet from the tank, on every loop;
- From the calorifier flow, or the closest tap to the calorifier, and the furthermost tap on the hot water service circulating system (these should be identified on sentinel outlet register);
- Additional samples should be taken from the base of the calorifier via drain valves;
- From areas where the target control parameters are not met (i.e. where temperatures are below 55°c for hot water systems or ≥20°c for cold water systems);
- From areas subject to low usage, stagnation, excess storage capacity, dead legs, excessive heat loss, crossflow from the water system or other anomaly.
- High Risk Patient Areas
- Additional random samples may also be considered appropriate where systems are known to be susceptible to colonisation.

The temperature control regime is the preferred strategy for reducing the risk from *Legionella* and other waterborne organisms in water systems. This will require monitoring on a regular basis. The recommended test frequencies for various outlets are set out in Table 2 in Section 7.

HSG 274 Part 2 Table 2.3 Actions to be taken following legionella sampling in hot and cold water systems in healthcare premises with susceptible patients

Legionella bacteria (cfu/Litre)	**Action required**
More than 100 but less than 1,000	Low risk area Estates action only If only one or two samples are positive, system should be re-sampled. If a similar count is found again, a review should be carried out to identify any remedial actions a) If the majority of samples are positive, the system may be colonised, albeit at low level, with Legionella. Disinfection of the system should be considered but an immediate review of control measures and risk assessment should be carried out to identify any other remedial actions required. If remedial action is ineffective further measures will be discussed and approved by the Board Water Safety Group
More than 100 but less than 1,000	High Risk areas Impact on patient care Discuss results with ICD and agree actions and any closure of area.
More than 1,000	Low Risk Estates action only The system should be re-sampled and an immediate review of the control measures and risk assessment carried out to identify any remedial actions, including possible disinfection of the system. If remedial action is ineffective further measures will be discussed and approved by the Board Water Safety Group
More than 1,000	High Risk areas Discuss results with ICD and agree actions and any closure of area.

Communication pathway for Legionella results from water samples:

Water samples are sent to; UKASS-accredited laboratories which provide this service for NHS and other organisations that manage buildings. Reports will come back initially to the estates department.

Negative water samples are recorded as part of the documentation of Legionella control. If they are related to investigation of an “incident” such as a clinical case or a previous positive sample then these results are communicated to those managing that incident.

The information on the report which needs to be communicated is:

- Date of sampling
- Location and type of water outlet
- Identification of the organism, (Legionella pneumophila with serogroup, or Legionella species other than L pneumophila.)
- Count of organisms per Litre.

Estates will

- Inspect the system and take further action in accordance with HSE guidance and locally agreed procedures
- Inform Charge Nurse and or Clinical Nurse Manager of the Clinical Area concerned if appropriate of any control measures being taken/required
- Inform GM for the Sector if appropriate.

The results of this initial risk assessment must be communicated to all those noted above and also to the Facilities General Manager for the site involved.

The Infection Control Manager for Infection Prevention and Control will inform NHS GG&C

If there is impact on patient care then an Incident Management Team (IMT) may be convened to assess the risk and further actions.

See table in Appendix 2

5.5 Intermittent or Infrequently Used Water Outlets

If after investigation the taps or appliances identified within the reviewed list, to be updated on a quarterly basis, is deemed not necessary wherever possible the supply pipe work shall be cut back as close to the main circulating line as practicable to ensure that any dead leg formed is minimised and the appliance is removed from the water system.

In circumstances where there has been a lapse in the flushing regime, the stagnant and potentially contaminated water from within the shower or tap and associated dead leg should be purged to drain without discharge of aerosols before the appliance is used.

Where a ward or department is closed or taken out-of-use for an extended period of time e.g.: pending refurbishment, change in-use or other reason, arrangements shall be put in place to ensure the regular flushing and recording of water outlets within such areas. If such closures are considered to be long term or permanent consideration should be given to the disconnection of all water services to the affected areas.

5.6 Emergency Repairs

Emergency repairs may be required at any time and should be undertaken by trained and competent personnel. Such repairs can vary from a simple repair to a section of pipework, replacement of a component or major burst or loss of service. In all such cases the integrity and safety of the water distribution system must be maintained at all times.

5.7 Disinfection of Water System and Components

There are a number of different chemical and thermal disinfection methods available ALL of which shall be undertaken by trained and competent personnel in strict accordance with all Statutory Requirements, Safety Precautions and Manufacturers Instructions.

Disinfection - is the process of destroying or inactivating Pathogenic organisms and is generally applied to the water supply.

Sterilisation – is the process of destroying or inactivating all Organic Life Forms and is generally applied to all systems of transmission and storage materials.

In ALL instances no matter what disinfection method is employed, due regard shall be taken of patient groups, specialist equipment and processes which may be sensitive to the disinfection process being used – eg Renal Dialysis patients **must not** be exposed to Silver Hydrogen Peroxide chemicals as such the RO Water Treatment Plant and Dialysis Machines must be disconnected from the water system until the disinfection process is completed.

Silver Hydrogen Peroxide should NOT be used for a period of 90 days or longer, as required by the Drinking Water Inspectorate.

The disinfection process may be required for the following situations:

REPAIRS -	Repair fittings and exposed pipe ends should be clean and disinfected before use. Such items should be sprayed with a suitable disinfection solution such as a Sodium Hypochlorite @ a strength of 1000 mg/l (1000ppm) with a minimum contact time of 5 minutes or equal and approved.
MINOR ALTERATIONS -	Pipework should be cleaned internally by spraying with a suitable disinfection solution such as a Sodium Hypochlorite @ a strength of 1000 mg/l (1000ppm) or where pipes are long and internal surfaces cannot be reached with sprays then a swab soaked in a solution of 50mg/l (50ppm) with a contact time of one hour or equal and approved.
NEW SUPPLY PIPEWORK -	Pipes are filled with a solution such as a Sodium Hypochlorite @ a strength of 20 mg/l (20ppm) with a contact time of 24 hours. Or Sodium Hypochlorite and water at a strength of 50mg/l (50ppm) for a contact period of one hour. Minimum free chlorine after one hour – 30mg/l (30ppm) or equal and approved
SYSTEM DISINFECTION -	This will include water storage tanks and possibly the water distribution system. The advice and use of Legionella Control Association (LCA) approved contractors will be used for this purpose

NOTE:

Appropriate Method Statements and Risk Assessments will be compiled and obtained prior to any disinfection process commencing. Water Disinfection Risk Based Assessment Form (024) should be completed prior to any disinfection process being carried out. *(SHTM 04-01 Part G (V1 July 2015) Page 38 para 5.9)*

An alternative to chemical disinfection is to pasteurise the system. This involves increasing the temperature to greater than 60°C by increasing the thermostat setting at the calorifier or boiler and recirculation as necessary to maintain this temperature throughout for at least one hour. This should effectively sterilise the calorifier, and kill any *Legionella* organisms present.

The water should be flushed through the system more than once. It is important that all taps are run for at least 5 minutes (preferably longer) at full temperature to ensure that the complete system is pasteurised and that the hot water has reached all parts of the system.

5.8 Pseudomonas SOP

Standard Operating Procedure for minimising the risk of Pseudomonas

This SOP provides direction and guidance for ward based staff to meet their responsibilities as stated in *HPS(2013) Guidance for neonatal units (NNUs) (levels 1,2&3), adult and paediatric intensive care units (ICUs) in Scotland to minimise the risk of Pseudomonas aeruginosa infection from water*. This document refers to critical control points 2 – 4 (inclusive) only. (Critical points 1, 5 and 6 are considered in the NHSGGC Water Safety Policy 2013.

*High Dependency Units (HDUs) which are adjoining/ integrated with an ICU should be included in this guidance.

Responsibilities:

Senior Charge Nurses (SCNs) must:

- Follow this SOP.
- Ensure that they are aware of access issues to wash hand basins. Where access is an issue they must arrange for flushing to occur and document this.
- Keep records of daily flushing for at least one month within the Facilities Folder.
- Inform a member of the local Estates Team if this SOP cannot be followed in relation to flushing water outlets.
- Inform a member of the local Estates Team of infrequently used outlets which could be removed.
- Allow members of the local Estates Team access to complete maintenance as appropriate.

Estates must:

- Undertake actions deemed the responsibility of the local Estates Department as per the Water Safety Policy.
- Keep a record of outlets reported that are deemed to be infrequently used and actions taken by them to remove this risk.
- Provide a report of maintenance actions and issues/ anomalies to the Sector Water Safety Group.
- Support staff locally to undertake their responsibilities in terms of reducing risk associated with pseudomonas.

Domestic Services must:

- Ensure that water outlets are flushed at full flow for 1 minute (not causing splashing) as part of the cleaning process
- Ensure this is the first task completed of the day
- Record this in the Domestic services Compliance Checklist "Water Outlets"
- Ensure the Checklist is retained within the facilities Folder at ward level for one month

Managers must:

- Make this SOP available to their staff.
- Support SCNs in following this SOP.

Water Systems Group must:

- Keep this SOP up-to-date.
- Audit compliance with this SOP.
- Provide guidance via the Water Systems Policy.

Flushing Water Outlets

Flushing of water outlets is necessary to control the build-up of biofilm in water systems to reduce the risk of transmission of pathogens via the environment and equipment to patients.

The Senior Charge Nurse (SCN) in each unit has responsibility (under current guidance) to ensure that the following recommendations are complied with in their area. The SCN should ensure that:

All water outlets are flushed in high-risk environments (adult, paediatric and Neonatal ICUs and associated HDU's), daily, first thing in am for 1 minute at full flow (but not so that splashing goes beyond the basin). This must be recorded. This will be completed as part of the Domestic Services local work schedule for the area .This must be reviewed on a daily basis by the SCN and appropriate action taken when this is identified as not having been completed

Any problems or concerns relating to the safety, maintenance, reduced usage, any changes in use and cleanliness of all water outlets are identified and reported to the ICT and the Estates Department as relevant.

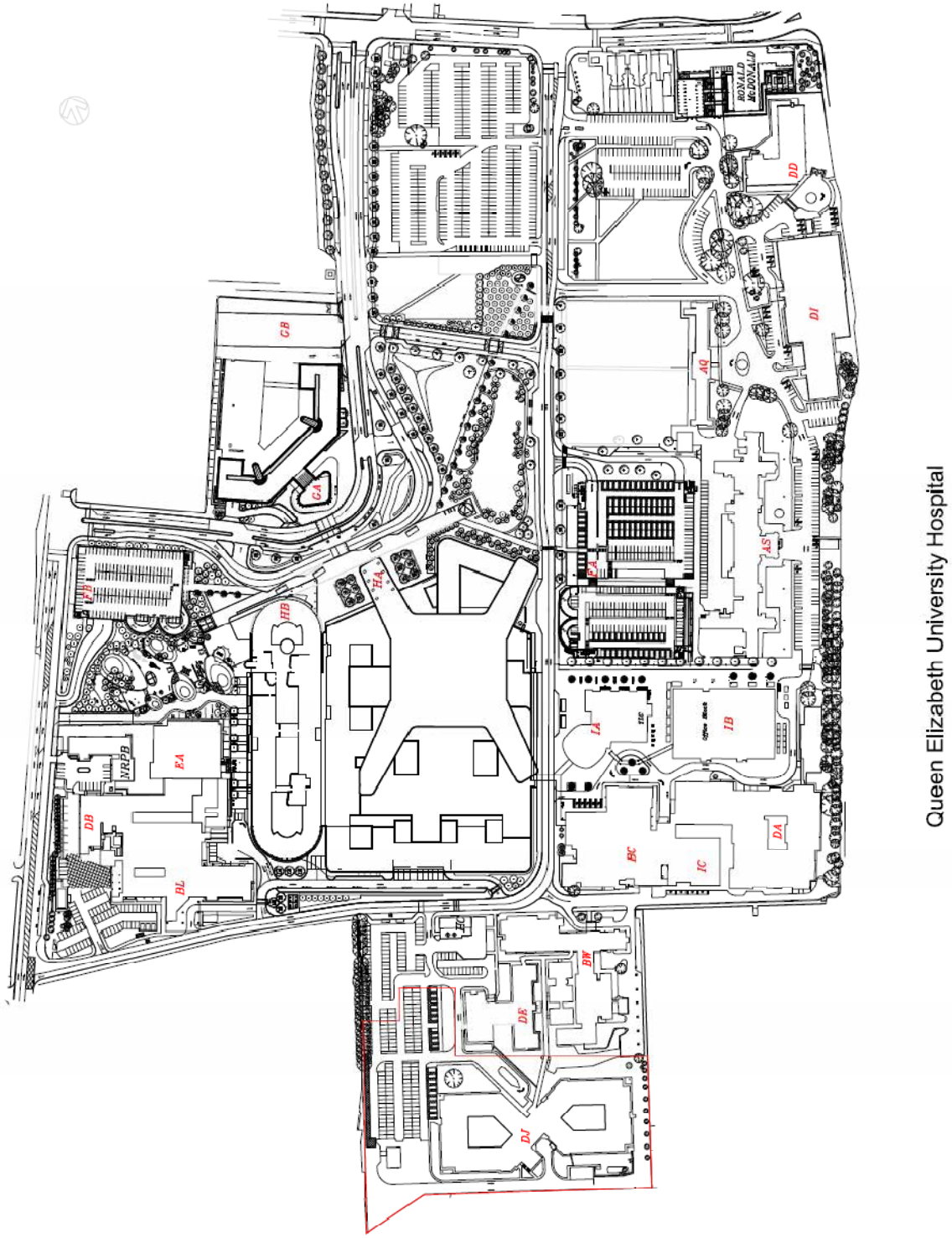
For more information refer to NHS Greater Glasgow and Clyde
'Water Systems Safety Policy Written Scheme and Operational Procedures'

- Appendix 5 – Standard Operating Procedure for minimising the risk of Pseudomonas and
- Appendix 5a – Standard Operating Procedure for minimising the risk of Pseudomonas - Critical Control Assessment Tool.

6.0 Exemplar Documentation

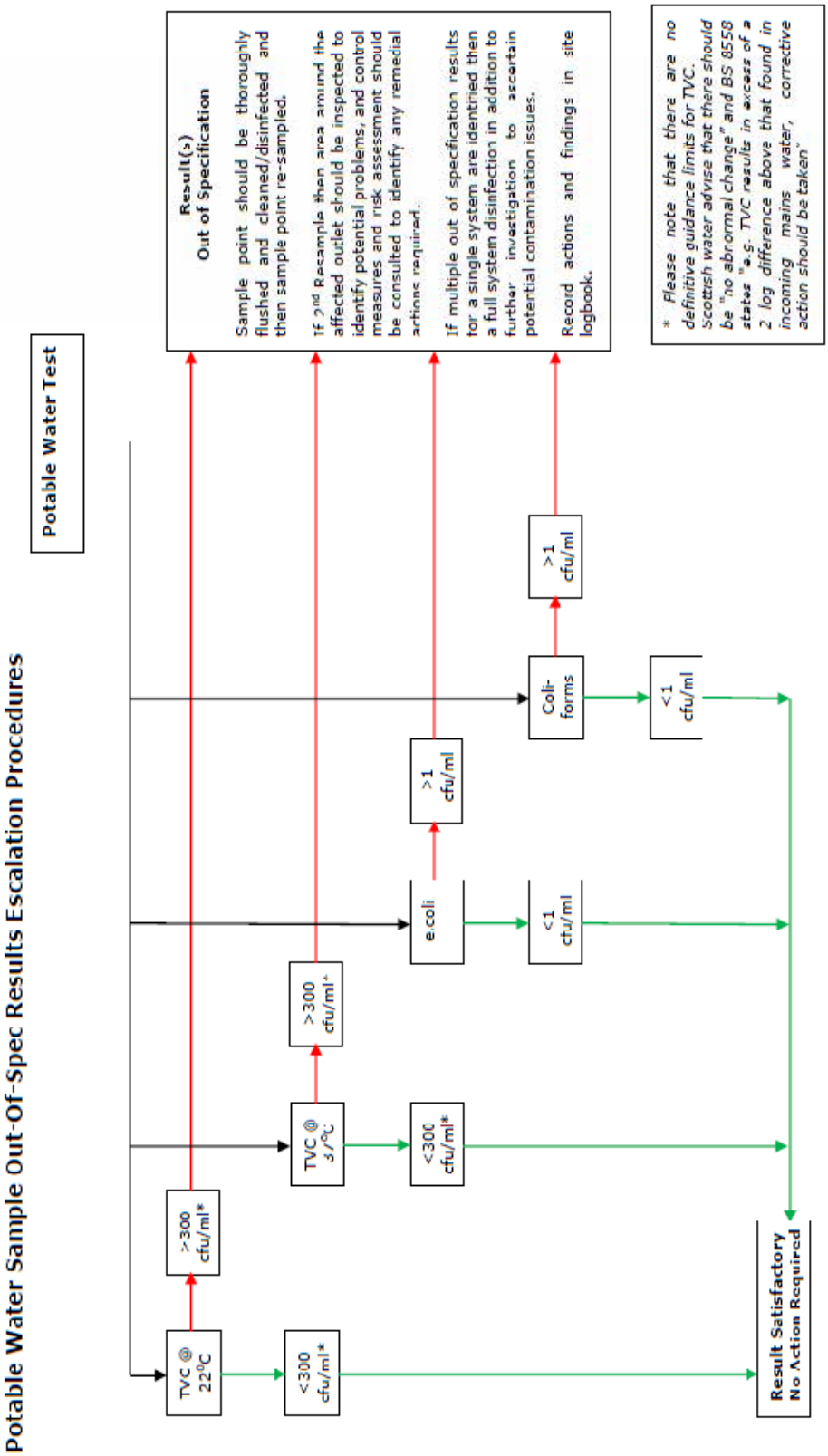
Appendix 1

Site Plan with Block Codes



Appendix 2

Escalation of Sampling Results out-of-spec.



Appendix 3

Maintenance recommendations by Building

Appendix 4

Risk Assessment Review Guidance

Summary of L8 Management Tasks Required for L8 and SHTM 04-01 Compliance	Guidance Documents	Allocated to
Regular check to ensure that legislation and guidance has not changed	L8 HSG 274 Pt 2 SHTM 04-01	
Regular review of all policies relating to legionella control (e.g. Maintenance, Water Treatment, Water Management, Energy) to ensure still valid and correct	L8 HSG 274 Pt 2 SHTM 04-01	
Regular review of L8 Management Structure to ensure up-to-date and accurate	L8 HSG 274 Pt 2 SHTM 04-01	
Regular review of communication lines to ensure still accurate and correct	L8 HSG 274 Pt 2 SHTM 04-01	
Regular review of escalation & emergency procedures to ensure still valid and correct	L8 HSG 274 Pt 2 SHTM 04-01	
Regular review of duties allocated to site staff and ensure accurate and recorded	L8 HSG 274 Pt 2 SHTM 04-01	
Regular review of duties of sub-contractors and ensure accurate and recorded and contractors are suitably qualified/competent for tasks assigned to them (e.g. Water Hygiene contractors should be LCA Approved, Plumbing contractors should be SNIPEF and Water Safe Registered)	L8 HSG 274 Pt 2 SHTM 04-01	
Regular review of staff training requirements and update training matrix	L8 HSG 274 Pt 2 SHTM 04-01	
Regular review of method statements and risk assessments to ensure still valid and correct	L8 HSG 274 Pt 2 SHTM 04-01	
Regular review of site documentation to ensure all records up to date and present	L8 HSG 274 Pt 2 SHTM 04-01	
Regular update of “Patient Risk Rating” register for all areas of hospital.	SHTM 04-01 Part B	
Regular review of sentinel outlet locations register.	SHTM 04-01 Part B	
Regular review of primary, sub-ordinate and tertiary hot flow and return loops to reflect any system alterations.	HSG 274 Pt 2	
Regular review of plant and equipment maintenance schedules.	Manufacturer’s Instructions	
Regular review of BEMS temperature sensor locations to reflect any system alterations	HSG 274 Pt 2	
Regular review of schematic/as-fitted drawings to ensure up-to-date and accurate	L8 HSG 274 Pt 2 SHTM 04-01	
Regular review of L8 risk assessment with a maximum period of two years between updates. (e.g. if change of use or changes in legislation or any other factor which could affect validity of current assessment)	L8 STHM 04-01	

Appendix 5

HAI Scribe, Temperature monitoring Low Risk areas.

Risk Assessment

Temperature monitoring of Plumbing Fittings in hot and cold water system via IPS in Low Risk Areas

Date:
Contractor:
Estates Officer:

SCN/Manager

Infection Control Nurse: Lynn Pritchard LIPCN / Susie Dodd LIPCN / Teresa Inkster LICD

SHFN 30:

HAI-SCRIBE

Question sets and checklists

#

Health Facilities Scotland
Engineering and Environment

October 2018

Introduction

Scottish Health Facilities Note (SHFN) 30 in its 2014 published form comprises two parts:

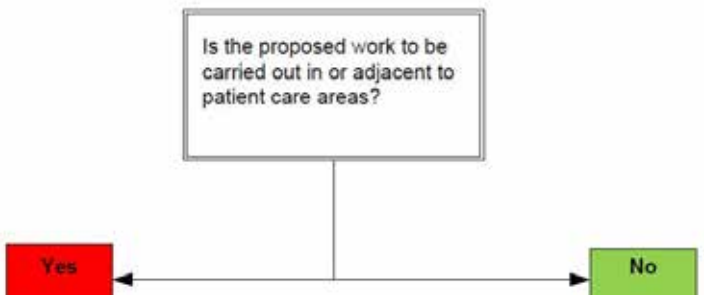
- **Part A**: Manual: Information for Design Teams, Construction Teams, Estates & Facilities and Infection Prevention & Control Teams.
- **Part B**: HAI-SCRIBE Implementation Strategy and Assessment Process.

Both have been published in book form.

It is appreciated that, as familiarity with the use of the procedures grows there will be progressively less need to rely on printed text, eventually leading to situations where question sets and checklists will themselves be sufficient. Photocopying from published books is a ponderous and time-consuming process with a tendency to produce distorted images and/or damage binding. To facilitate the process, therefore, question sets and checklists for each of the four project development stages have been produced in the form of an information pack ready for photocopying and distributing to project teams to assist in the HAI-SCRIBE review procedures as each new Project requires assessment. This pack is only available electronically.

The various proforma, comprising question sets, checklists and certifications, are provided for the following:

- **Development Stage 1:** Initial briefing and proposed site for development:
- **Development Stage 2:** Design and planning:
- **Development Stage 3:** Construction and refurbishment work:
- **Development Stage 4:** Pre-handover check, ongoing maintenance and feed-back.



Type	Construction/Refurbishment Activity
Type 1	**Inspection and non-invasive activities.** Includes, but is not limited to, removal of ceiling tiles or access hatches for visual inspection, painting which does not include sanding, wall covering, electrical trim work, minor plumbing and activities which do not generate dust or require cutting of walls or access to ceilings other than for visual inspection.
Type 2	**Small scale, short duration activities which create minimal dust.** Includes, but is not limited to, installation of telephone and computer cabling, access to chase spaces, cutting of walls or ceiling where dust migration can be controlled.
Type 3	**Any work which generates a moderate to high level of dust, aerosols and other contaminants or requires demolition or removal of any fixed building components or assemblies.** Includes, but is not limited to, sanding of walls for painting or wall covering, removal of floor coverings, ceiling tiles and casework, new wall construction, minor duct work or electrical work above ceilings, major cabling activities, and any activity which cannot be completed within a single work shift.
Type 4	**Major demolition and construction projects.** Includes, but it not limited to, activities which require consecutive work shifts, requires heavy demolition or removal of a complete cabling system, and new construction.

Table 1: Redevelopment and construction activity

Risk to patients of infection from construction work in healthcare premises, by clinical areas	
Risk rating	**Area**
Group 1 Lowest risk	1. Office areas; 2. Unoccupied wards; 3. Public areas/Reception; 4. Custodial facilities; 5. Mental Health facilities.
Group 2 Medium risk	1. All other patient care areas (unless included in Group 3 or Group 4); 2. Outpatient clinics (unless in Group 3 or Group 4); 3. Admission or discharge units; 4. Community/GP facilities; 5. Social Care or Elderly facilities.
Group 3 High risk	1. A & E (Accident and Emergency); 2. Medical wards; 3. Surgical wards (including Day Surgery) and Surgical outpatients; 4. Obstetric wards and neonatal nurseries; 5. Paediatrics; 6. Acute and long-stay care of the elderly; 7. Patient investigation areas, including; • Cardiac catheterisation; • Invasive radiology; • Nuclear medicine; • Endoscopy. Also (indirect risk) 8. Pharmacy preparation areas; 9. Ultra clean room standard laboratories (risk of pseudo-outbreaks and unnecessary treatment); 10. Pharmacy Aseptic suites.
Group 4 Highest Risk	1. Any area caring for immuno-compromised patients*, including: • Transplant units and outpatient clinics for patients who have received bone marrow or solid organ transplants; • Oncology Units and outpatient clinics for patients with cancer; • Haematology units • Burns Units. 2. All Intensive Care Units; 3. All operating theatres; Also (indirect risk) 4. CSSUs (Central Sterile Supply Units).

Table 2: Different areas of health care facility and the risk associated with each area.

	Construction Project Type			
Patient Risk Group	TYPE 1	TYPE 2	TYPE 3	TYPE 4
Lowest Risk	Class I	Class II	Class II	Class III/IV
Medium Risk	Class I	Class II	Class III	Class IV
High Risk	Class I	Class II	Class III/IV	Class IV
Highest Risk	Class II	Class III/IV	Class III/IV	Class IV

Table 3: Estimates the overall risk of infection arising and will indicate the class of precaution that should be implemented

Control measures			
	During Construction Work	After Construction Work	By
Class I	• Execute work by methods to minimise raising dust from construction operations;. • Immediately replace any ceiling tiles displaced during inspection.	• Clean areas by damp dusting with neutral detergent in warm water;. • Vacuum floor and damp mop.	Request via domestic supervisor. Request via domestic supervisor.
Class II	• Provide active means to prevent airborne dust from dispersing into atmosphere; • Water mist work surfaces to control dust while cutting; • Seal unused doors with duct tape; • Block off and seal air vents; • Place dust mat at entrance and exit of work area; • Remove or isolate HVAC system in areas where work is being performed.	• Dampwork surfaces and ledges with neutral detergent solution; • Contain construction waste before transport in tightly covered containers; • Damp mop and/or vacuum with HEPA filtered vacuum before leaving work area; • Remove isolation of HVAC system in areas where work is being performed.	Request via domestic supervisor. Estates staff. Request via domestic supervisor. Estates staff.
Class III	• Remove or Isolate HVAC system in area where work is being done to prevent contamination of duct system; • Complete all critical barriers eg plasterboard, plywood, plastic, to seal area from non work area or implement control cube method (cart with plastic covering and sealed connection to work site with HEPA vacuum for vacuuming prior to exit) before construction begins; • Maintain negative air pressure within work site utilizing HEPA equipped air filtration units; • Contain construction waste before transport in tightly covered containers; • Cover transport receptacles or carts. Tape covering unless solid lid.	• Do not remove barriers from work area until completed project is inspected by the Board's Health & Safety representative and Infection Control Department and thoroughly cleaned by the Board's domestic services staff;. • Remove barrier materials carefully to minimise spreading of dirt and debris associated with construction; • Vacuum work area with HEPA filtered vacuums; • Damp mop area with neutral detergent and warm water; • Remove isolation of HVAC system in areas where work is being performed.	Request by Estates Dept. Contractor/Estates Staff. Request via domestic supervisor. Request via domestic supervisor. Contractor/Estates Staff.

Table 4: Describes the required infection control precautions depending on class of risk

	During Construction Work	After Construction Work	By
Class IV	• Isolate HVAC system in area where work is being done to prevent contamination of duct system; • Complete all critical barriers eg plasterboard, plywood, plastic to seal area from non work area or implement control cube method (cart with plastic covering and sealed connection to work site with HEPA vacuum for vacuuming prior to exit) before construction begins; • Maintain negative air pressure within work site utilizing HEPA equipped air filtration units; • Seal holes, pipes, conduits, and punctures appropriately; • Construct anteroom and require all personnel to pass through this room so they can be vacuumed using a HEPA vacuum cleaner before leaving work site or they can wear cloth or paper coveralls that are removed each time they leave the work site; • All personnel entering work site are required to wear shoe covers. Shoe covers must be changed each time the worker exits the work area; • Do not remove barriers from work area until completed project is inspected.	• Remove barrier material carefully to minimise spreading of dirt and debris associated with construction; • Contain construction waste before transport in tightly covered containers;. • Cover transport receptacles or carts. Tape covering unless solid lid; • Vacuum work area with HEPA filtered vacuums; • Damp dust area with neutral detergent and warm water; • Scrub floor area with neutral detergent in warm water; • Remove isolation of HVAC system in areas where work is being performed.	Contractor. Contractor. Contractor. Request via domestic supervisor. Request via domestic supervisor. Contractor/Estates Staff.

Table 4 cont: Describes the required infection control precautions depending on class of risk

Construction and refurbishment Stage

Project particulars and checklists for Development Stage 3

Development stage 3: Construction and refurbishment work: Checklist to ensure all aspects have been addressed		
HAI-SCRIBE Name of Project	**Temperature monitoring of Plumbing Fittings in hot and cold water system via IPS in Low Risk Wards and Depts**	
Name of Establishment	NHS GG&C	
National allocated number	--	
HAI-SCRIBE Review Team		
HAI-SCRIBE Sign Off		
Completed By (Project Manager) (Print Name)		Date
Signature		Date
Stage 3		

Additional Notes

All works in co-ordination with Department staff

Contractors to report to staff when entering the department.

Doors to the area where the works are being undertaken should remain closed during the period of the works.

Hep vacuum to be used mop clear ant dust and dirt during and after all work of the surrounding floor area.

Following works the sink and fittings should be cleaned using Acticlor wipes (Clorox Wipes) and the PAL filter should be cleaned using Alcohol wipes. These are required to be provided by Estates Dept / Contractor as they will not be available in the ward or Dept.

Safe routes for entry and exit /removal of material agreed with Department Staff.

All Rubbish to be wrapped in dust free plastic bags for removal from department and removed via the agreed route in accordance with Infection Control requirements.

Ward / Dept staff should be notified and advise sought as to whether the patient can remain in the room for the duration of the works or if it is preferred that the room should be vacated for this period.

Development stage 3: HAI-SCRIBE applied to Construction and refurbishment work Prior to the commencement of work		
3.1.1	Brief description of the work being carried out.	**Temperature monitoring of Plumbing Fittings in hot and cold water system via IPS in Low Risk Wards and Dept**
3.1.2	Using the matrix above establish the type and extent of construction and refurbishment /repair work, patients at risk and level of control measures.	**Class I**
	Type of work	**Type 1**
	Patient risk group	**Group 3 Medium Risk**
	Risk class	**Class I**
3.1.3	Identify any potential hazards Associated with this work.	**Potential release of dust when panel removed and wall is exposed**.
3.1.4	Identify any risk associated with the hazards identified above.	**Release of dust / debris to sink and surrounding area during removal works.** **Transfer of dust / dirt to surrounding areas via footwear.** **Noise – disturbance to patients / staff.** **Movement – Emergency movement of patients in working areas.**
3.1.5	Outline the control measures that require to be implemented to eliminate or mitigate the identified risks. Ensure these are entered on the project risk register.	**Room door will remain closed during the duration of the works. Following works the sink and fittings should be cleaned using Actichlor wipes (Clorox Wipes) and the PAL filter should be cleaned using Alcohol wipes. These are required to be provided by Estates Dept / Contractor as they will not be available in the ward or Dept.** **Upon completion if there is any debris on the floor this should be cleaned with detergent wipes and if required should be followed with a domestic clean.** **Any waste generated will be double bagged in clean dust free bags before being removed from the room.** **ON REMOVAL OF THE IPS PANEL THERE IS ANY DISCOLOURATION OR MOULD NOTED THEN THE ROOM SHOULD BE CLOSED OFF AND AN ESTATES SUPERVISOR AND THE INFECTION CONTROL TEAM SHOULD BE CONTACTED.**
	Control measures **As per class I Recommendations.**	
3.1.6	It has been recognised that control measures identified to address the	**Access for staff.**

	project risk may have unintended consequences e.g. closure of windows can lead to increased temperatures in some areas. Such issues should be considered at this point, they should be noted and action to address these taken.	
	Potential problems **None perceived**	
	Control measures **As per class I recommendations.**	
3.1.7	Actions to be addressed **No Requirement**	
By		Deadline

Development stage 3: In terms of infection risk confirmation that the following been addressed		
3.2.1	The population groups most susceptible to infection. Items to be considered: Adjacent rooms, wards and departments Relocation of susceptible patients Have these issues and actions to be taken been noted in actions to be addressed section?	Yes [√] No [ ] N/A [ ] Yes [√] No [ ] N/A [ ]
Comments **Controls as per Class I recommendations.**		
3.2.2	The hours of operation of the construction work and the impact of this on the clinical area. Have these issues and actions to be taken been noted in actions to be addressed section?	Yes [√] No [ ] N/A [ ] Yes [√] No [ ] N/A [ ]
Comments **Work programme discussed and agreed with ward staff and infection control.**		
3.2.3	Separation of construction and healthcare activities including delivery and supply routes, removal of waste and patient transfers. Have these issues and actions to be taken been noted in actions to be addressed section?	Yes [ ] No [√] N/A [ ] Yes [ ] No [√] N/A [ ]
Comments **Work discussed with ward staff and control measures agreed. Any Removal of waste and delivery of tools & materials will be scheduled to minimise disruption to service.**		
3.2.4	The construction of temporary barriers and/or sealing of doors and windows to minimise contamination of the environment by dust and potentially infectious particles created during the construction works. Have these issues and actions to be taken been noted in actions to be addressed section?	Yes [ ] No [ ] N/A [√] Yes [ ] No [ ] N/A [√]
Comments The door to the room should remain closed during the works. None		

Development stage 3: In terms of infection risk confirmation that the following been addressed (continued)		
3.2.5	Airflow patterns including:	
	Internal and external ventilation systems	Yes √ No ☐ N/A √
	Exhaust ventilation	Yes √ No ☐ N/A ☐
	Sealing of doors and windows	Yes √ No ☐ N/A ☐
	Oxygen and Suction points	Yes ☐ No ☐ N/A √
	Air handlers, coils, fans and grilles	Yes ☐ No ☐ N/A √
	Have these issues and actions to be taken been noted in actions to be addressed section?	Yes √ No ☐ N/A ☐
Comments **As per class I Recommendations.**		
3.2.6	Work with sinks or plumbing which could give rise to aerosol water droplets in high risk areas.	Yes √ No ☐ N/A ☐
	Have these issues and actions to be taken been noted in actions to be addressed section?	Yes √ No ☐ N/A ☐
Comments **As per class III/IV Recommendations.**		
3.2.7	Impact on stock storage areas including:	
	Sterile and non-sterile items	Yes √ No ☐ N/A ☐
	Patient care equipment	Yes √ No ☐ N/A ☐
	Medications	Yes ☐ No ☐ N/A √
	Medical records and documentation	Yes √ No ☐ N/A ☐
	Linen and waste facilities including sharps	Yes √ No ☐ N/A ☐
	Have these issues and actions to be taken been noted in actions to be addressed section?	Yes √ No ☐ N/A ☐
Comments **Discuss with ward staff if any equipment is to be removed from the room prior to the works commencing.**		

Development stage 3: During the construction phase have the following been addressed?						
3.3.1	Where external work is being carried out: Prevention of insect and rodent entry and prevention of weather/water entry to internal areas during the construction phase. Have these issues and actions to be taken been noted in actions to be addressed section?		Yes ☐	No ☐	N/A ☑ Yes ☐	No ☐	N/A ☑
Comments **No Requirement.**						
3.3.2	Cleaning of site and adjacent areas both during the construction phase and prior to handover. Have these issues and actions to be taken been noted in actions to be addressed section?		Yes ☑	No ☐	N/A ☐ Yes ☑	No ☐	N/A ☐
Comments **Contractor to keep work area clean and to remove waste material from site on completion of works.** **Following works the sink and fittings should be cleaned using Acticlor wipes (Clorox Wipes) and the PAL filter should be cleaned using Alcohol wipes. These are required to be provided by Estates Dept / Contractor as they will not be available in the ward or Dept.**						
3.3.3	Enforcement of control and reporting system to ensure compliance with above issues. Have these issues and actions to be taken been noted in actions to be addressed section?		Yes ☑	No ☐	N/A ☐ Yes ☑	No ☐	N/A ☐
Comments **Estates Manager will inspect the site regularly and identify any breaches in HAI Scribe.**						
Additional notes - Stage 3 **Unless the contractor feels that there has been a significant amount of debris from removal of the IPS Panel then here will be no additional clean required following the works other than the clean undertaken by Estates/contractor.**						

HAI-SCRIBE Name of Project	

Development stage 3: HAI-SCRIBE applied to the construction / redevelopment phase

Certification that the following documents have been accessed and the contents discussed and addressed at the Infection Control and Patient Protection Meeting held on

Venue		Date	

'Healthcare Associated Infection System for Controlling Risk in the Built Environment' *('HAI-SCRIBE) Implementation Strategy Scottish Health Facilities Note (SHFN) 30: Part B).*

Declaration: We hereby certify that we have co-operated in the application of and where applicable to the aforesaid documentation.

Present

Print name	Signature	Company	Telephone Numbers	Email address
Lynn Pritchard		NHSGGC	[redacted]	Lynn.Pritchard[redacted]
Susie Dodd		NHSGGC		
Teresa Inkster		NHSGGC	[redacted]	

Name of Establishment		National allocated number
HAI-SCRIBE Review Team		
HAI – SCRIBE Sign Off		
Completed by (Print name)	Date	
Signature(s)	Date	
Stage 4		

Appendix 6

HAI Scribe, Temperature monitoring High Risk areas.

Risk Assessment

Temperature Monitoring of Plumbing Fittings in High Risk Areas

Date:

Contractor:

Estates Officer:

SCN/Manager

Infection Control Nurse: Lynn Pritchard LIPCN / Teresa Inkster LICD / Susie Dodds LIPCN

SHFN 30:

HAI-SCRIBE

Question sets and checklist

Introduction

Scottish Health Facilities Note (SHFN) 30 in its 2014 published form comprises two parts:

- **Part A**: Manual: Information for Design Teams, Construction Teams, Estates & Facilities and Infection Prevention & Control Teams.
- **Part B**: HAI-SCRIBE Implementation Strategy and Assessment Process.

Both have been published in book form.

It is appreciated that, as familiarity with the use of the procedures grows there will be progressively less need to rely on printed text, eventually leading to situations where question sets and checklists will themselves be sufficient. Photocopying from published books is a ponderous and time-consuming process with a tendency to produce distorted images and/or damage binding. To facilitate the process, therefore, question sets and checklists for each of the four project development stages have been produced in the form of an information pack ready for photocopying and distributing to project teams to assist in the HAI-SCRIBE review procedures as each new Project requires assessment. This pack is only available electronically.

The various proforma, comprising question sets, checklists and certifications, are provided for the following:

- **Development Stage 1:** Initial briefing and proposed site for development:
- **Development Stage 2:** Design and planning:
- **Development Stage 3:** Construction and refurbishment work:
- **Development Stage 4:** Pre-handover check, ongoing maintenance and feed-back.

Type	Construction/Refurbishment Activity
Type 1	**Inspection and non-invasive activities.** Includes, but is not limited to, removal of ceiling tiles or access hatches for visual inspection, painting which does not include sanding, wall covering, electrical trim work, minor plumbing and activities which do not generate dust or require cutting of walls or access to ceilings other than for visual inspection.
Type 2	**Small scale, short duration activities which create minimal dust.** Includes, but is not limited to, installation of telephone and computer cabling, access to chase spaces, cutting of walls or ceiling where dust migration can be controlled.
Type 3	**Any work which generates a moderate to high level of dust, aerosols and other contaminants or requires demolition or removal of any fixed building components or assemblies.** Includes, but is not limited to, sanding of walls for painting or wall covering, removal of floor coverings, ceiling tiles and casework, new wall construction, minor duct work or electrical work above ceilings, major cabling activities, and any activity which cannot be completed within a single work shift.
Type 4	**Major demolition and construction projects.** Includes, but it not limited to, activities which require consecutive work shifts, requires heavy demolition or removal of a complete cabling system, and new construction.

Table 1: Redevelopment and construction activity

Risk to patients of infection from construction work in healthcare premises, by clinical areas	
Risk rating	**Area**
Group 1 Lowest risk	6. Office areas; 7. Unoccupied wards; 8. Public areas/Reception; 9. Custodial facilities; 10. Mental Health facilities.
Group 2 Medium risk	6. All other patient care areas (unless included in Group 3 or Group 4); 7. Outpatient clinics (unless in Group 3 or Group 4); 8. Admission or discharge units; 9. Community/GP facilities; 10. Social Care or Elderly facilities.
Group 3 High risk	1. A & E (Accident and Emergency); 2. Medical wards; 3. Surgical wards (including Day Surgery) and Surgical outpatients; 4. Obstetric wards and neonatal nurseries; 5. Paediatrics; 6. Acute and long-stay care of the elderly; 7. Patient investigation areas, including; • Cardiac catheterisation; • Invasive radiology; • Nuclear medicine; • Endoscopy. Also (indirect risk) 8. Pharmacy preparation areas; 9. Ultra clean room standard laboratories (risk of pseudo-outbreaks and unnecessary treatment); 10. Pharmacy Aseptic suites.
Group 4 Highest Risk	1. Any area caring for immuno-compromised patients*, including: • Transplant units and outpatient clinics for patients who have received bone marrow or solid organ transplants; • Oncology Units and outpatient clinics for patients with cancer; • Haematology units • Burns Units. 2. All Intensive Care Units; 3. All operating theatres; Also (indirect risk) 4. CSSUs (Central Sterile Supply Units).

Table 2: Different areas of health care facility and the risk associated with each area.

	Construction Project Type			
Patient Risk Group	TYPE 1	TYPE 2	TYPE 3	TYPE 4
Lowest Risk	Class I	Class II	Class II	Class III/IV
Medium Risk	Class I	Class II	Class III	Class IV
High Risk	Class I	Class II	Class III/IV	Class IV
Highest Risk	Class II	Class III/IV	Class III/IV	Class IV

Table 3: Estimates the overall risk of infection arising and will indicate the class of precaution that should be implemented

	Control measures		
	During Construction Work	**After Construction Work**	**By**
Class I	• Execute work by methods to minimise raising dust from construction operations;. • Immediately replace any ceiling tiles displaced during inspection.	• Clean areas by damp dusting with neutral detergent in warm water;. • Vacuum floor and damp mop.	Request via domestic supervisor. Request via domestic supervisor.
Class II	• Provide active means to prevent airborne dust from dispersing into atmosphere; • Water mist work surfaces to control dust while cutting; • Seal unused doors with duct tape; • Block off and seal air vents; • Place dust mat at entrance and exit of work area; • Remove or isolate HVAC system in areas where work is being performed.	• Dampwork surfaces and ledges with neutral detergent solution; • Contain construction waste before transport in tightly covered containers; • Damp mop and/or vacuum with HEPA filtered vacuum before leaving work area; • Remove isolation of HVAC system in areas where work is being performed.	Request via domestic supervisor. Estates staff. Request via domestic supervisor. Estates staff.
Class III	• Remove or Isolate HVAC system in area where work is being done to prevent contamination of duct system; • Complete all critical barriers eg plasterboard, plywood, plastic, to seal area from non work area or implement control cube method (cart with plastic covering and sealed connection to work site with HEPA vacuum for vacuuming prior to exit) before construction begins; • Maintain negative air pressure within work site utilizing HEPA equipped air filtration units; • Contain construction waste before transport in tightly covered containers; • Cover transport receptacles or carts. Tape covering unless solid lid.	• Do not remove barriers from work area until completed project is inspected by the Board's Health & Safety representative and Infection Control Department and thoroughly cleaned by the Board's domestic services staff;. • Remove barrier materials carefully to minimise spreading of dirt and debris associated with construction; • Vacuum work area with HEPA filtered vacuums; • Damp mop area with neutral detergent and warm water; • Remove isolation of HVAC system in areas where work is being performed.	Request by Estates Dept. Contractor/Estates Staff. Request via domestic supervisor. Request via domestic supervisor. Contractor/Estates Staff.

Table 4: Describes the required infection control precautions depending on class of risk

	During Construction Work	After Construction Work	By
Class IV	• Isolate HVAC system in area where work is being done to prevent contamination of duct system; • Complete all critical barriers eg plasterboard, plywood, plastic to seal area from non work area or implement control cube method (cart with plastic covering and sealed connection to work site with HEPA vacuum for vacuuming prior to exit) before construction begins; • Maintain negative air pressure within work site utilizing HEPA equipped air filtration units; • Seal holes, pipes, conduits, and punctures appropriately; • Construct anteroom and require all personnel to pass through this room so they can be vacuumed using a HEPA vacuum cleaner before leaving work site or they can wear cloth or paper coveralls that are removed each time they leave the work site; • All personnel entering work site are required to wear shoe covers. Shoe covers must be changed each time the worker exits the work area; • Do not remove barriers from work area until completed project is inspected.	• Remove barrier material carefully to minimise spreading of dirt and debris associated with construction; • Contain construction waste before transport in tightly covered containers;. • Cover transport receptacles or carts. Tape covering unless solid lid; • Vacuum work area with HEPA filtered vacuums; • Damp dust area with neutral detergent and warm water; • Scrub floor area with neutral detergent in warm water; • Remove isolation of HVAC system in areas where work is being performed.	Contractor. Contractor. Contractor. Request via domestic supervisor. Request via domestic supervisor. Contractor/Estates Staff.

Table 4 continued: Describes the required infection control precautions depending on class of risk

Construction and refurbishment Stage

Project particulars and checklists for Development Stage 3

Development stage 3: Construction and refurbishment work: Checklist to ensure all aspects have been addressed		
HAI-SCRIBE Name of Project	**Temperature monitoring of hot and cold water system via plumb fittings (without removal of the IPS Fitting) in High Risk areas as agreed by IPCT.**	
Name of Establishment	NHS GG&C	
National allocated number	--	
HAI-SCRIBE Review Team		
HAI-SCRIBE Sign Off		
Completed By (Project Manager) (Print Name)		Date
Signature		Date
Stage 3		

Additional Notes

All works in co-ordination with Department staff

Contractors to report to staff when entering the department.

Doors to the area where the works are being undertaken should remain closed during the period of the works.

Hep vacuum to be used mop clear ant dust and dirt during and after all work of the surrounding floor area.

Following works the sink and fittings should be cleaned using Acticlor wipes (Clorox Wipes) and the PAL filter should be cleaned using Alcohol wipes. These are required to be provided by Estates Dept / Contractor as they will not be available in the ward or Dept.

Safe routes for entry and exit /removal of material agreed with Department Staff.

All Rubbish to be wrapped in dust free plastic bags for removal from department and removed via the agreed route in accordance with Infection Control requirements.

Ward / Dept staff should be notified and advise sought as to whether the patient can remain in the room for the duration of the works or if it is preferred that the room should be vacated for this period.

Development stage 3: HAI-SCRIBE applied to Construction and refurbishment work Prior to the commencement of work		
3.1.1	Brief description of the work being carried out.	**Temperature monitoring of hot and cold water system via the plumb fittings**
3.1.2	Using the matrix above establish the type and extent of construction and refurbishment /repair work, patients at risk and level of control measures.	**Class II**
	Type of work	**Type 1**
	Patient risk group	**Group 4 (High Risk)**
	Risk class	**Class II**
3.1.3	Identify any potential hazards Associated with this work.	**Potential water release when plumb fittings removed.**
3.1.4	Identify any risk associated with the hazards identified above.	**Release of debris / water during removal works.** **Transfer of dust / dirt to surrounding areas via footwear.** **Noise – disturbance to patients / staff** **Movement – Emergency movement of patients in working areas** **Access – access to certain areas may be restricted due to patient type**
3.1.5	Outline the control measures that require to be implemented to eliminate or mitigate the identified risks. Ensure these are entered on the project risk register.	**Room door will remain closed during the duration of the works. Following works the sink and fittings should be cleaned using Acticlor wipes (Clorox Wipes) and the PAL filter should be cleaned using Alcohol wipes. These are required to be provided by Estates Dept / Contractor as they will not be available in the ward or Dept.** **Any waste generated will be double bagged in clean dust free bags before being removed from the room.**
	Control measures **As per class II Recommendations.**	
3.1.6	It has been recognised that control measures identified to address the project risk may have unintended consequences e.g. closure of windows can lead to increased temperatures in some areas. Such issues should be considered at this point, they should be noted and action to address these taken.	**Access for staff.**
	Potential problems	

	None perceived	
	Control measures **As per class II recommendations.**	
3.1.7	Actions to be addressed **No Requirement**	
By		Deadline

Development stage 3: In terms of infection risk confirmation that the following been addressed		
3.2.1	The population groups most susceptible to infection. Items to be considered: Adjacent rooms, wards and departments Relocation of susceptible patients Have these issues and actions to be taken been noted in actions to be addressed section?	Yes √ No ☐ N/A ☐ Yes √ No ☐ N/A ☐
Comments **Controls as per Class II recommendations.**		
3.2.2	The hours of operation of the construction work and the impact of this on the clinical area. Have these issues and actions to be taken been noted in actions to be addressed section?	Yes √ No ☐ N/A ☐ Yes √ No ☐ N/A ☐
Comments **Work programme discussed and agreed with ward staff and infection control.**		
3.2.3	Separation of construction and healthcare activities including delivery and supply routes, removal of waste and patient transfers. Have these issues and actions to be taken been noted in actions to be addressed section?	Yes √ No ☐ N/A ☐ Yes √ No ☐ N/A ☐
Comments **Work discussed with ward staff and control measures agreed. Any Removal of waste and delivery of tools & materials will be scheduled to minimise disruption to service.**		
3.2.4	The construction of temporary barriers and/or sealing of doors and windows to minimise contamination of the environment by dust and potentially infectious particles created during the construction works. Have these issues and actions to be taken been noted in actions to be addressed section?	Yes √ No ☐ N/A ☐ Yes √ No ☐ N/A ☐
Comments Room door to remain closed during the duration of the works.		

Development stage 3: In terms of infection risk confirmation that the following been addressed (continued)

3.2.5	Airflow patterns including:	
	Internal and external ventilation systems	Yes [√] No [ ] N/A [√]
	Exhaust ventilation	Yes [√] No [ ] N/A [ ]
	Sealing of doors and windows	Yes [√] No [ ] N/A [ ]
	Oxygen and Suction points	Yes [ ] No [ ] N/A [√]
	Air handlers, coils, fans and grilles	Yes [ ] No [ ] N/A [√]
	Have these issues and actions to be taken been noted in actions to be addressed section?	Yes [√] No [ ] N/A [ ]
Comments **As per class II Recommendations.**		
3.2.6	Work with sinks or plumbing which could give rise to aerosol water droplets in high risk areas.	Yes [√] No [ ] N/A [ ]
	Have these issues and actions to be taken been noted in actions to be addressed section?	Yes [√] No [ ] N/A [ ]
Comments **As per class III/IV Recommendations.**		
3.2.7	Impact on stock storage areas including:	
	Sterile and non-sterile items	Yes [√] No [ ] N/A [ ]
	Patient care equipment	Yes [√] No [ ] N/A [ ]
	Medications	Yes [ ] No [ ] N/A [√]
	Medical records and documentation	Yes [√] No [ ] N/A [ ]
	Linen and waste facilities including sharps	Yes [√] No [ ] N/A [ ]
	Have these issues and actions to be taken been noted in actions to be addressed section?	Yes [√] No [ ] N/A [ ]
Comments **Discuss with ward staff if any equipment is to be removed.**		

Development stage 3:
During the construction phase have the following been addressed?

3.3.1	Where external work is being carried out: Prevention of insect and rodent entry and prevention of weather/water entry to internal areas during the construction phase. Have these issues and actions to be taken been noted in actions to be addressed section?	 Yes ☐ No ☐ N/A ☑ Yes ☐ No ☐ N/A ☑
Comments **No Requirement.**		
3.3.2	Cleaning of site and adjacent areas both during the construction phase and prior to handover. Have these issues and actions to be taken been noted in actions to be addressed section?	Yes ☑ No ☐ N/A ☐ Yes ☑ No ☐ N/A ☐
Comments **Contractor to keep work area clean and to remove waste material from site on completion of works.** **Following works the sink and fittings should be cleaned using Acticlor wipes (Clorox Wipes) and the PAL filter should be cleaned using Alcohol wipes. These are required to be provided by Estates Dept / Contractor as they will not be available in the ward or Dept.**		
3.3.3	Enforcement of control and reporting system to ensure compliance with above issues. Have these issues and actions to be taken been noted in actions to be addressed section?	Yes ☑ No ☐ N/A ☐ Yes ☑ No ☐ N/A ☐
Comments **Estates Manager will inspect the site regularly and identify any breaches in HAI Scribe.**		
Additional notes - Stage 3 **There will be no additional clean required following the works other than the clean undertaken by Estates/contractor.**		

Development stage 3: HAI-SCRIBE applied to the construction / redevelopment phase

Certification that the following documents have been accessed and the contents discussed and addressed at the Infection Control and Patient Protection Meeting held on

Venue		Date	

'Healthcare Associated Infection System for Controlling Risk in the Built Environment' *('HAI-SCRIBE) Implementation Strategy Scottish Health Facilities Note (SHFN) 30: Part B).*

Declaration: We hereby certify that we have co-operated in the application of and where applicable to the aforesaid documentation.

Present

Print name	Signature	Company	Telephone Numbers	Email address
Teresa Inkster		NHSGGC	[redacted]	Teresa.Inkster[redacted]
Lynn Pritchard		NHSGGC	[redacted]	Lynn.Pritchard[redacted]
Susie Dodds		NHSGGC	[redacted]	

HAI-SCRIBE Name of Project		
Name of Establishment		National allocated number
HAI-SCRIBE Review Team		
HAI – SCRIBE Sign Off		
Completed by (Print name)	Date	
Signature(s)	Date	
Stage 4		
Additional notes		

Pseudomonas Report on Water Delivery System

Queen Elizabeth University Hospital
Adult Hospital - Renal Ward 4A

Site Survey Date: 27th April 2016
Next Review Date: As required.

(N.B. This report is in addition to 'Pseudomonas Report on Water Delivery System – South Glasgow University Hospital, 27th April 2015)

VAT Registration No. 743 0970 35 Company Registration Number SC197200
14 Canyon Road, Wishaw ML2 0EG T: 01698 536790 E: office@dmawater.co.uk

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Contact Details

	DMA Water Treatment Ltd
Address	14 Canyon Road Netherton Wishaw ML2 0EG
Telephone No.	01698 536790
Fax No.	01698 360211
e-mail	office@dmawater.co.uk
Website	www.dmawater.co.uk
DMA Contacts	Allan McRobbie Compliance Manager [redacted] Mike Kinghorn Director [redacted] David Watson Director [redacted]

Report

Date of Survey (On Site)	27th April 2016
Surveyor	Allan McRobbie
Assisted By	Darren Waldron

Report reviewed by	David Watson
Position	Director

Surveyor assisted on site by (Site Representative)	No assistance provided
Knowledge of systems being surveyed	N/A

N.B. The findings and recommendations presented in this report have been based on information made available and inspection of areas made accessible by site staff during the survey. DMA are only able to assess areas/systems, which they have been given access to and using information supplied by site personnel. This survey was undertaken only on pipe work/areas that were accessible and visible, and it is possible that some sections remained hidden during the survey. Schematic drawings, where produced, and how services link up, have been assumed to run as indicated using basic engineering principles and our experience. However, no responsibility can be accepted for systems and/or areas, which DMA have not been provided access to, or as a result of incorrect, misleading information supplied or information not provided. No guarantees as to the completeness of the information within this report are provided.

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Client Details

Client	**GG&C QEUH**
Client address	Queen Elizabeth University Hospital 1345 Govan Road Glasgow
Client contact	Ian Powrie
Telephone No.	[redacted]
E-mail	ian.powrie[redacted]
Mobile No.	[redacted]

Site	**Queen Elizabeth University Hospital** **Adult Hospital – ITU and HDU Areas Only**
Site Address	Queen Elizabeth University Hospital 1345 Govan Road Glasgow
Client contact	Ian Powrie
Telephone No.	[redacted]
E-mail	ian.powrie[redacted]
Mobile No.	[redacted]

Report Delivery Method	Electronic

PSEUDOMONAS REPORT

Building Overview

The new 14 floor Queen Elizabeth University Hospital Glasgow (adult) building is one of the largest acute hospitals in the UK and home to major specialist services such as renal medicine, transplantation and vascular surgery, with state-of-the-art Critical Care, Theatre and Diagnostic Services.

The adult hospital is integrated with the children's hospital with separate functions and entrances.

There is a physical link for patients and staff from the hospitals into the Maternity and Neurosciences Institute buildings. The hospitals is also linked to the laboratory buildings via an underground tunnel and pneumatic tube.

Water Services (*Domestic water system description above as provided by Brookfield Multiplex)*

There are 2 separate incoming mains water supplies serving the Adults and children's hospital building. These enter the building in the basement manifold room and basement tank room and run into the tank room to serve 4 off Raw Water storage tanks. These incoming mains both have double check valves and water meters fitted as they enter the building. The water meters are linked to the BMS system and allow the user to cross reference the quantity of water used against the quantity indicated on the external meter. This will highlight if there are any leaks on the external water main.

Each mains supply feeds a separate side of each split Raw Water storage tank ensuring continuity of supply if one of the mains services was to be in interrupted or contaminated.

From the Raw Water tanks the water is then filtered through the filtration plant before being stored in the potable bulk cold water storage tanks. All cold water storage tanks are 2 compartment tanks and are piped in such a way as to allow tank maintenance without disrupting the water supply to the building.

There are 5 water storage tanks in the building:

- 2 No. 100,000 Litre Raw water storage break tanks
- 2 No. 275,000 Litre Potable bulk cold water storage tanks
- 1 No. 2,800 Litre Trade water storage tank

There are 2 No. water booster sets in the water tank room. Each booster set is set to a different set point pressure depending on which plantroom it serves. In the event of failure each booster can also be switched to the other set point pressure.

- BS01 – Feeding Plantroom 31, 32 & 33 - 7.7 Bar
- BS02 – Feeding Plantroom 21, 22 & 41 – 5 Bar

From the 2 No. water booster sets there are 8 domestic water systems:

- Plantroom 21
    - Via a Pressure reducing valve (PRV) the BCWS feed 21CAL01/02/03
- Plantroom 22
    - Via a Pressure reducing valve (PRV) the BCWS feed 22CAL01/02/03
- Plantroom 31 – 122
    - BCWS feeds 31CAL01/02/03
- Plantroom 31 – 128
    - Via a Pressure reducing valve (PRV) the BCWS feeds 31CAL07/08/09
- Plantroom 31 – 129
    - BCWS feeds 31CAL04/05/06
- Plantroom 32
    - BCWS feeds 32CAL01/02/03
- Plantroom 33
    - BCWS feeds 33CAL01/02/03
- Plantroom 41
    - BCWS feeds 41CAL01/02/03

The water supply into each plantroom is metered by a CWS flow meter. This allows for monitoring of specific parts of the system for energy purposes.

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From the plantroom supply the BCWS is distributed to each riser and the bank of calorifiers. The water in the calorifiers is heated via a plate heat exchanger (feed from the MTHW circuit) on each calorifier skid.

The BCWS and HWS F&R are then distributed together allowing for positive separation of systems/plantrooms on the floors. The hot water is circulated to the outlet and back to the calorifiers by a hot water return pump so that temperature is maintained throughout the system. This ensures hot water is available within 1 minute at every outlet.

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Description of Risk[1]

Pseudomonas aeruginosa (Pa), and other similar opportunistic pathogens, are micro-organisms that can cause outbreaks in any healthcare setting where patients are immunocompromised through drugs, disease, invasive device use or the presence of wounds.

There have been serious healthcare associated outbreaks mainly in NNUs and ICUs (adult and paediatric) attributed to Pa where the source of the organism was thought to be tap water.

A review of all blood cultures for Pseudomonas aeruginosa was undertaken in period between 2010 – 2012 to identify areas with significant number of PA isolates. Other than receiving units, the main areas identified were intensive care areas across all NHS GGC sites and the Beatson Oncology Unit (wards 7, 8 and 9). Table 1 shows areas within the NSGH which have been identified as falling in to this category and actions required following risk assessment.

Existing Precautions

Summarise current controls in place	**Describe how they might fail to prevent adverse outcomes.**
• New compliant designed water supply & distribution system. • Well engineered & installed distribution system. • Raw Water supply filtration to 0.2µm. – not present in Neurosurgery • System commissioned in line with current best practice guidance. • Water Safety Systems Policy and Written Scheme • Infection Prevention and Control Environmental Audit • Annual review of epidemiology of pseudomonas in blood culture	Failure to follow Policy and Written Scheme.

Proposed actions to control the problem List the actions required. If action by others is required, you must send them a copy	**By Whom**	**Start date**	**Action due date**
Routine maintenance measures In line with Boards Water Safety System Policy and site specific written scheme:			
• Develop site specific written scheme	**Estates**	**Sept 2014**	**Dec 2014**
• 3 Monthly: Carry out TMT operation test & visual inspection of outlet flow control device.	**Estates**	**Jan 2016**	**Feb 2016**
• 6 Monthly: Service exchange TMT maintenance procedure including: o Visual inspection and manual clean of components. o Full mechanical service & inspection. o Functional testing. o Thermal sanitisation.	**Estates**	**Feb 2015**	**April 2015**

[1] All information on this page is taken from NHS Greater Glasgow and Clyde Risk Assessment Form created in February 2016 by Ian Powrie, John Green, Sandra McNamee and Teresa Inkster.

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Areas where action required to prevent Pseudomonas aeruginosa infection in healthcare settings

Site	Building	Ward/Area	Assessment
Queen Elizabeth University Hospital Campus	Adult Hospital	Renal 4A rooms 041 & 043	Water Safety Written Scheme

N.B. Additional areas of the building were reported in DMA document 'Pseudomonas Report on Water Delivery System – South Glasgow University Hospital, 27th April 2015'. The areas reported in in that document were described as:

Site	Hospital	Ward	Assessment
SGH	NCH	Ward 1D (Paediatric Critical Care)	Water Safety Written Scheme
SGH	NCH	Ward 1E (Cardiology)	Water Safety Written Scheme
SGH	NCH	Ward 2A (Schiehallion)	Water Safety Written Scheme
SGH	NSGH	Adult Critical Care Unit	Water Safety Written Scheme
SGH	NSGH	Coronary Care Unit	Water Safety Written Scheme
SGH	NSGH	Ward 4B (Haemato-Oncology)	Water Safety Written Scheme

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Critical Control Points: The hospital water delivery system

Control Parameters	Satisfactory	Comments
Review site engineering and cleaning protocols to establish that they are in accordance with current guidance including SHTM 04-01 Water safety for healthcare premises, the Control Of Legionella, hygiene 'safe' hot water cold water and drinking water systems, HSE guidance note L8 Approved Code of Practice and guidance and that manufacturers' instructions with regards to installation and maintenance have been followed.	No	Full PPM regime including but not limited to example provided in DMA Legionella Risk Assessment with additional TMV servicing in high risk areas is recommended. Details of PPMs are being formulated as part of a written scheme for water systems.
Ensure taps and thermostatic mixing valves (manual and automated) have been commissioned (including programming auto flush cycles) and routinely validated, as per the manufacturers' instructions.	No	Commissioning records available though incomplete and limited servicing records available.
Ensure that water flowing from the taps does not flow directly into the drain holes (to prevent splash back). Water flow must impact on the basin offset from the drain hole. Flushing (automated or manual) should not result in splashes beyond the hand wash station area.	Yes	
Liaise with the Senior Charge Nurse regarding infrequently used hand wash stations or sinks (used and/or flushed once a day) which should be subjected to a documented flushing regime, risk assessed and regularly reviewed for the need for the hand wash station or sink to be still there. (See Appendix 1 – Number of hand wash stations required).	No	No records available
For automated taps, ensure records of remote flushing are available.	N/A	No automated taps noted during survey
Remove any redundant branches from circulating mains and provide straight couplings on distribution pipework to eliminate residual dead-legs or blind stub-ends created by plugged Tee-pieces.	No	Pipework could not be accessed during the survey which was 'non-intrusive' and we would advise pipework is surveyed to confirm this (e.g. converted toilet)
Check the length of any dead-legs and minimise where possible by taking return leg up to hand wash stations and sinks. (This should be included in a water risk assessment).	TBC	Flow and return pipework was not accessible during 'non-intrusive' survey however information from main contractor including drawings advised DHW flow and return runs above ceiling with no local 'tertiary' flow and return lines to individual outlets.
Before undertaking any modifications to pipework, perform a risk assessment.	No	No records available
Keep records of risk assessments and modifications made.	No	No records available
Consider whether thermostatic mixer valve, where such a valve is considered necessary, can be located closer to the outlet.	No	No records available
Wherever considered necessary, new taps should have integral thermostatic control or be replaced with a thermostatically controlled tap subject to risk assessment.	No	No records available

PSEUDOMONAS REPORT

Control Parameters	Satisfactory	Comments
Carefully select taps to minimise the formation of aerosols. The water flow profile should be compatible with the shape of the hand wash station. Biofilm can develop on flow straighteners and it is recommended that these are removed from taps. In so doing, the increased water flow can create turbulence due to increased pressure resulting in splashing of surrounding surfaces and flooring. It will be necessary for the engineer to adapt the water distribution system using regulating valves to restrict the flow as required. A discharge flow rate from taps of 3 litres per minute will be sufficient to avoid splashing.	No	No records available
Avoid positioning alcohol based hand rub dispensers such that any drips could fall on to the taps or into the basin of the hand wash station.	No	Survey noted gels which can discharge into taps or into the basins

PSEUDOMONAS REPORT

Hot and Cold Water System Information

The vast majority of TMVs installed are TMV taps, (Horne in clinical areas and Markwik in non-clinical areas) with the only exceptions noted being infrared outlets in non-patient area toilets with infrared taps which have a TMV mounted approximately 0.5m from the outlet. All thermostatic mixing valves (TMVs) should be serviced and have fail safe tests carried out routinely and strainers should be cleaned on a regular basis as per manufacturer's recommendations and in accordance with Written Scheme guidance. An enhanced servicing and testing regime should be implemented (quarterly) within the designated risk areas relating to Pseudomonas.

There are alcohol gel wash points at most WHBs throughout the hospital which may discourage/reduce water usage at taps and when dispensed alcohol from gel bottles may drip onto the taps or into the basins.

DMA have been advised by Mercury Engineering that the domestic hot water systems do not operate on a conventional flow and return system, with principle, sub-ordinate and tertiary loops, instead utilising a reverse return circuit. This means that there are longer "deadlegs" to the outlets than SHTM 04-01 advises.

With regards to Pseudomonas control this may place a greater emphasis on the temperature profile and flushing regime required to control the microbiological growth. At the time of reporting NHS Estates were in the process of collating temperature monitoring information at the time of report in order to create temperature profiles of the building. This should be consulted when available to establish any underlying issues in the domestic water delivery system which may contribute to bacterial control issues at outlets.

The pipework within the hospital is generally labelled and insulated throughout, with only a few very short pieces of insulation missing being noted (Please refer to the Legionella Risk Assessment carried out by DMA in April 2015 for any exceptions noted by DMA). It is advised that all missing sections of insulation are replaced.

The cold "outlet" at Horne TMV taps may have reduced usage as mixed hot outlet used preferentially for hand washing purposes could create a small low flow zone with the tap body. Manufacturer should be consulted as to the scale of this low flow zone and any potential impact on both pseudomonas and legionella.

This survey was conducted during working operation of the ward and panels could not be removed.

DMA were advised by Mercury Engineering and Estates that all materials fitted during the construction are WRAs approved and do not support bacterial growth. In particular Horne TMV taps were designed specifically with Legionella and Pseudomonas control in mind. The use of EPDM flexible hoses in some areas may contradict this statement and their use should be reviewed to ensure compliance.

This report covers only the domestic water delivery system to the point of use and does not consider any clinical, medical or environmental factors.

Further guidance can be found in:

- Health Protection Scotland (HPS) document: Guidance for neonatal units (NNUs) (levels 1, 2 & 3), adult and paediatric intensive care units (ICUs) in Scotland to minimise the risk of *Pseudomonas aeruginosa* infection from water
- NHS Greater Glasgow and Clyde Control of Infection Committee document: Standard Operating Procedure (SOP) for Minimising the Risk of *Pseudomonas aeruginosa* Infection from Water
- Department of Health document: Water sources and potential *Pseudomonas aeruginosa* contamination of taps and water systems - *Advice for augmented care units*

PSEUDOMONAS REPORT

Outlet description and comments

Tap/outlet description: Survey date 27/04/16
QEUH Horne Optitherm, ceramic WHB with alcohol gel

Areas fitted? A4 Renw – 043, A4 Renw – 041

Please note: Renw-041 also has a renal dialysis connection point installed in the room. Water from this system is expected to be entirely contained from connection point to drain. Should water from the renal dialysis system be discharged into the room then safety actions may be required.

Splashing? Yes	**Diffusers?** Yes
Flexi Hoses? No access to supply pipework (suspect not fitted in line with other outlets accessed during 2015 survey)	**Drain offset or directly below?** offset
Access to TMV/supply pipework? No access to supply pipework	
TMV or TMV Tap? TMV Tap	**Distance to Tap** Integral to tap
Alcohol dispenser? Yes, when dispensed gel can reach basin	
Deadlegs? No access to supply pipework	
Hot F&R As close as practical to outlet? No access to supply pipework	

PSEUDOMONAS REPORT

Outlet Register

QEUH (New Adults Hospitals) – Renal Ward 4A Rooms 41 & 43

Outlet Type	No fitted in Designated Risk Area
Horne Optitherm, ceramic WHB with alcohol gel	2

N.B. Visitors and staff area not included in outlets and information recorded above.

PSEUDOMONAS REPORT

Recommendations

1. Daily flushing of all outlets[2] in "High Risk Areas"/ICUs. Hot and cold outlets should be flushed for a minimum of 3 minutes and until the water temperature stabilises in line with current temperature profile. Records should be held documenting this. This should include emergency dialysis points in nearby rooms.

2. Minimum of quarterly descaling, cleaning and disinfection of showerheads & hoses & spray outlets or replace with replace with new disinfected Shower Head and Hose (or frequency as indicated by the rate of fouling or other risk factors)

3. Minimum of quarterly servicing TMV's or mixer valves, including fail safe tests and cleaning/disinfection of strainers within "Designated High Risk Area" (more frequently if manufacturer recommends), or if 'drift' in excess of 1°C at mixed outlet temperature highlighted during temperature monitoring or other maintenance

4. Where appropriate all soap dispensers and alcohol based hand rubs should be repositioned in such a way to prevent droplets from falling into the basin of the hand wash stations.

5. Consideration should be given to reducing the water delivery pressures to designated Pseudomonas risk areas (if practical and permitted by SHTM's and manufacturer's instructions) as the majority of outlets are causing splashing due to the pressure.

6. Ensure water delivery system is maintained in accordance in current regulations/standards.

7. Consideration should be given to removing all tap diffusers and flow straighteners, though this may have the unwanted side effect of increasing splashing due to the pressure of the water being delivered to the outlets..

8. Survey and ensure flow and return pipework is as close to the outlets as possible and consider corrective actions where excessive 'dead leg'.

9. Water sampling for Pseudomonas is carried out by NHS Estates. Methodology for works should be reviewed to ensure this complies with current guidance on Pseudomonas sampling.

[2] All outlets advised to be flushed daily in NHS GG&C Standard Operating Procedure (SOP) For Minimising The Risk Of Pseudomonas Aeruginosa Infection From Water

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Authorising Engineer Water Systems Management and Compliance Audit of NHS Water Systems
NHS GGH QEUH and RHC Hospitals Document A – Management Review

QEUH and RHC Hospitals

NHS GGC Annual Water Systems AE Audit

Site Address:
Queen Elizabeth University Hospital and the Royal Hospital for Children Hospital,
1345 Govan Rd,
Glasgow
G51 4TF

Building	QEUH and RHC Hospitals	**Date**	28th February and 1st March 2022	**Auditor**	Dennis H Kelly
Staff Interviewed	Mel MacMillan and Kerr Clarkson of the NHS GGC Estates Department at the QEUH				

Site Description and the Approach used for the Completion of this Audit

This audit was completed on the NHS GGC QEUH and RHC properties only. These hospitals are situated on the Queen Elizabeth University Hospital campus.
The QEUH adult Hospital building comprises of 12 stories, with the basement housing mainly FM areas. Connected to the main building is the RHC Hospital comprising of 4 storeys.
There are two mains water supplies coming into the buildings and these are switched on a regular basis to limit the opportunity for stagnation in the mains water supply pipework.
Raw mains water is held in raw water tanks before being passed through a 0.2-micron membrane filtration process, The water is then stored in treated water storage tanks.
Cold water is then distributed through the hospitals via booster pump sets located in the tank room. Hot water is provided by a number of calorifier heating stations installed throughout the hospitals.
The hospital water systems are secondary disinfected with chlorine dioxide via multiple retrofitted dosing systems located throughout the hospitals.
Given the size of the two hospitals the water systems are large and complex. There are around 1400 en suite bedrooms and in excess of 3500 TMV/TMT's in the buildings.

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Authorising Engineer Water Systems Management and Compliance Audit of NHS Water Systems NHS GGH QEUH and RHC Hospitals Document A – Management Review

This audit of the QEUH and the RHC follows the same approach as was created for the audit of the large number of buildings on the retained estate. Two documents were created for this audit process. The first document is entitled “Authorising Engineer Water Systems Management and Compliance Audit of NHS Water Systems – NHS GGC QEUH and RHC Hospitals, Document A – Management Review”.

This management review document covers the following common sections of the audit:-

- Risk Assessment
- Management and Competency
- Cleaning and Disinfection Procedures
- New Build and Refurb Capital Projects
- Water Safety Group

Part B of the audit Process involves a review of the processes and procedures, essentially the task elements. This section of the audit is called “Authorising Engineer Water Systems Management and Compliance Audit of NHS Water Systems – NHS GGC QEUH and RHC Hospitals Document B – Individual Building Audit Details”. It contains the following sections-

- Risk Assessment Specific to the Building being Audited
- Schematic Drawings
- Written Scheme Monitoring and Records
- On Going Water Treatment
- Task Completion

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Authorising Engineer Water Systems Management and Compliance Audit of NHS Water Systems
NHS GGH QEUH and RHC Hospitals Document A – Management Review

Executive Summary:

This audit of the QEUH and RHC hospital buildings was previously a lengthy and time consuming process. However, the much improved record systems and updated processes that had been developed and successfully implemented since the QEUH/RHC hospital audits were completed in January 2020 and February 2021 have made this a less onerous process.
Congratulations are therefore due to the Estates staff who addressed these issues and then developed and implemented the current processes, along with the water hygiene contractors. The active engagement between the Estates Department and the contractor has been central to many of the improvements on site.
A process that is worthy of note is the implementation of an interview process for contractors that are looking to complete work on the hospital water systems. Competency assessment is crucial to ensure that water systems contractors are delivering the work safely, to the required quality level, and in a way that does not increase patient risk. This approach has led to some contractors implementing training programmes prior to their staff being allowed to work in the hospital environment.
It was also noted that the Smart sheets system, operated in conjunction with the NHS GGC Compliance manager, is being utilised to hold staff training records and copies of the hospital audits. NHS GGC are also actively reviewing the hospital compliance audits using an SOP created for this process. This is an example of a positive development in the water related risk reduction processes on site.
An audit however is likely to identify areas for improvement, and that is the case with this current audit exercise.
There are ten recommendations on this management section audit and this compares favourably to the fourteen recommendations made in the 2021 audit. Additionally, nothing is classified in this section of the audit as being anything greater than medium risk. In the 2021 audit there were some high risk issues.
Finally, sincere thanks are due to Kerr Clarkson and Mel MacMillan for the help and support during this audit process. They should also be recognised for leading the excellent progress that has been made over the past few years in driving the improvement in the processes and the recording of these processes in relation to the operation of the hospital water systems.

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Authorising Engineer Water Systems Management and Compliance Audit of NHS Water Systems
NHS GGH QEUH and RHC Hospitals Document A – Management Review

Description of Levels of Risk:

Very High	Urgent Remedial Action – Lp growth and aerosol opportunity with susceptible people present on site
High	Remedial Action is needed but not immediately – Lp growth opportunity is present
Medium	Acceptable risk but some concerns– Lp likely to be controlled but improvements should be sought
Low	Risk controlled and acceptable

Levels of Risk found during the Audit:

The levels of risk detailed below reflects the highest level of risk identified during the audit of that particular topic.

The audit process reviews the following 8 areas.:-

Audited Topic	Level of Risk
Risk Assessment	
Management and Competency	
Cleaning and Disinfection Procedures	
New Build and Refurb Capital Projects	
Water Safety Group	

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Authorising Engineer Water Systems Management and Compliance Audit of NHS Water Systems
NHS GGH QEUH and RHC Hospitals Document A – Management Review

Summary of Actions				
	Actions	**Risk Level**	**Completed Date**	**Signature**
1.	It is recommended that NHS GGC check that specialists have been engaged to confirm that the information detailed in section 8 of the current risk assessment is reflective of the function of the 15 other water systems on site.			
2.	It is recommended that DMA Canyon are requested to provide details of the competency of the involved staff and that these details are added to the NHS GGC Smartsheet system.			
3.	It is recommended that a check be made as to whether the responsible person for water in NHS GGC has been appointed and is nominated in writing.			
4.	It is recommended that the names in the written scheme document are updated to reflect the current roles with regard to water in NHS GGC.			
5.	It is recommended that a review date for the Written Scheme document is created and that the document review is completed and signed off at the agreed time.			
6.	It is recommended that a full review of the training requirements for NHS GGC staff who are involved with the operation of the QEUH is made as soon as possible, and where appropriate, the required training is put in place.			
7.	It is recommended that the quarterly review meetings are extended in scope to include the tasks completed by NHS Estates staff and not only the tasks undertaken by the contractor.			

8.	It is recommended that an urgent review of the AP and training requirements is made and updated for the QEUH Estates staff, and that were required, appropriate training and checks are completed.			
9.	It is recommended that any method statements for cleaning and disinfection procedures are checked for suitability prior to any work being placed with a contractor and that copies of the method statements are kept in the Written Scheme either electronically or in hard copy.			
10.	It is recommended that a check is made to ensure that all the required groups are attending the Water Safety Group meetings.			

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Authorising Engineer Water Systems Management and Compliance Audit of NHS Water Systems
NHS GGH QEUH and RHC Hospitals Document A – Management Review

Section A1 Risk Assessment		Y/N U/K, N/A or Partial	Comments	Risk Level
A1.1	Does the risk assessment address all the water systems in the building?	Partial	The current risk assessment covers the operation of the hot and cold-water systems in the two hospitals. Section 8 of the current risk assessment details 15 other water systems in the two hospitals and includes a brief description of each system as well as an initial assessment of risk. It further advises that specialists in each field are consulted to confirm the risk assessment detail is reflective of the function of each water system. It is recommended that NHS GGC check that specialists have been engaged to confirm that the information detailed in section 8 of the current risk assessment is reflective of the function of the 15 other water systems on site.	
A1.2	Are there any systems that are defined as being excluded from the assessments in the RA scope?	Y	Although the Hydrotherapy pool was mentioned in the list of additional water systems, the risk assessment document did state that the pool was not assessed in the risk assessment process. However, it did state on page 4 of section 3 of the report that the hydrotherapy pool was "covered under a separate assessment". A recommendation is made to cover this issue in Part B of this audit report.	
A1.3	Does the risk assessment review the current risk reduction processes and procedures that are currently in use at the site?	Y	The current risk reduction processes are reviewed in Section 9 of the document.	
A1.4	Does the risk assessment contain details of the people/organisations	Y	Section 9 of the risk assessment document is entitled "Governance and Documentation Review". This section contains a comprehensive	

	who are involved in the risk reduction processes and procedures? This should include comments on the dutyholder, the responsible person, any deputy responsible persons and also service providers and contractors.		description of the roles and responsibilities for water within the NHS GGC organisation and the named individuals that hold these roles. Since the risk assessment has been completed many of the named persons have changed role. A new risk assessment will amend and update the details when the assessment process is completed. Information on DMA Canyon Ltd, who are the main service provider, can be found at the start of the risk assessment document.	
A1.5	Is there an assessment of the competency of all involved parties in the risk assessment?	Y	Section 9 of the risk assessment details that there were no training records available. It is now known that the training records of the involved NHS GGC staff can be accessed on the Smartsheet system. The risk assessment document states that the DMA Canyon Ltd competency details are filed centrally in their local office and can be accessed by request from DMA Canyon Ltd. Inspection of the current Smartsheet system shows that there are training details for some contractors but that the details for DMA Canyon Ltd were not available on this system. It is recommended that DMA Canyon are requested to provide details of the competency of the involved staff and that these details are added to the NHS GGC Smartsheet system.	
A1.6	Does the risk assessment specifically address and comment on evidence of the current defect/remedial action processes and procedures?	Y	Section 9 of the risk assessment includes a gap analysis which comments on the evidence of the current remedial processes and procedures.	
A1.7	Is there an assessment of the susceptibility of persons who may be affected by the building water systems?	Y	This is covered in Section 1 of the risk assessment document.	

A1.8	Is there a schematic diagram provided with the risk assessment?	N	There are no schematics in the risk assessment document but as fitted drawings for both hospitals are available elsewhere in the Zutec system and are stored electronically. It may be the case that the supply of schematic diagrams was not part of the scope of supply covering the new risk assessment.	
A1.9	Is there a new written scheme provided as part of the risk assessment?	Partial	This may not have been part of the scope of supply agreed with the risk assessment supplier. There is guidance provided in section 10 of the risk assessment document as to what should be included in a written scheme. Site has created a comprehensive written scheme since the current RA has been completed. This written scheme document has also been updated on a number of occasions.	
A1.10	Does the assessment contain details of all the component parts of the water systems? This could include tanks, calorifiers, pipework and pipework layout, outlets, TMV's, expansion vessels etc etc etc.	Y		
A1.11	Is consideration given to system design, flow, temperature and the opportunity for bacteria to grow and develop in the water systems?	Y		
A1.12	Does the risk assessment identify any particular areas of spray and aerosol creation?	Y	This information is detailed and is available in section 7 of the DMA Canyon Ltd risk assessment documents.	
A1.13	Are areas of low use and low flow identified in the risk assessment?	Y	This information is detailed and is available in section 7 of the DMA Canyon Ltd risk assessment documents.	

A1.14	Are deadlegs specifically detailed in the risk assessment?	Y	This information is detailed and is available in section 7 of the DMA Canyon Ltd risk assessment documents. The information on deadlegs can also be found in Section 2, Recommendations, of the risk assessment document.	
A1.15	Is there a set of remedial actions clearly identified in the risk assessment?	Y	The remedial actions are detailed in section 2 in the RA document in the section titled Recommendations.	
A1.16	Is there a clearly explained risk scoring system in the risk assessment?	Y	The risk scoring system is explained in section 2 of the RA document.	
A1.17	Are there any areas of augmented care on the campus?	Y	There are areas of augmented care in the hospital as per the criteria detailed in HPS guidelines.	
A1.18	Have Pseudomonas risk assessments been completed?	Y	This will be done by Infection Control.	

Actions on Risk Assessment

1. It is recommended that NHS GGC check that specialists have been engaged to confirm that the information detailed in section 8 of the current risk assessment is reflective of the function of the 15 other water systems on site.
2. It is recommended that DMA Canyon are requested to provide details of the competency of the involved staff and that these details are added to the NHS GGC Smartsheet system.

Section A2 Management and Competency		Y/N U/K, N/A or Partial	Comments	Risk Level
A2.1	Is there a duty holder nominated on the Board?	Y	There is a copy of an NHS GGC Policy Document dated January 2020 available electronically on site in the Smartsheet system.	

			In appendix 1 of the policy document it states that the Duty Holder is the Chief Executive. A more detailed hierarchy table was also available, naming people who are responsible for the various positions with regard to water.	
A2.2	Is there a responsible person nominated in writing?	Partial	In NHS GGC, the sector estates manager is regarded as the responsible person and this is recorded, and is up to date, in the on-site WSP. It is recommended that a check be made as to whether the responsible person for water in NHS GGC has been appointed and is nominated in writing.	
A2.3	Is there a clearly defined management structure which includes the relevant on site personnel and also all service providers and contractors?	Y	The management structure is defined in appendix 1 of the NHS GGC water policy. It is further defined in Section 3.2 of the Written Scheme document.	
A2.4	Is there a clearly defined line of communication in the written schemes?	Y	This is covered in the management organogram in section 3.2 of the QEUH Campus written scheme. There are some name changes required on the list of named people in the Written Scheme Document. It is recommended that the names in the written scheme document are updated to reflect the current roles with regard to water in NHS GGC.	
A2.5	Are the responsibilities of all involved parties clearly defined in the written scheme?	Y	Roles and responsibilities are defined in table 3.1 of the written scheme.	
A2.6	Does the organisation have an up to date and current policy document?	Y	NHS GGC has a policy document dated as approved in January 2020 and reviewed in January 2021. The document is due to be reviewed in January 2023.	

A2.7	Does the organisation have an up to date and current procedures document?	Partial	NHS GGC has a Written Scheme document for the QEUH Campus. A copy can be found in Smartsheets and is dated as 2021 Rev C. There does not appear to be a review date on this document. It is recommended that a review date for the Written Scheme document is created and that the document review is completed and signed off at the agreed time.	
A2.8	Do all staff have relevant up to date training in place?	Partial	The board wide water skills register available on Smart Sheet lists 19 staff members for the QEUH campus and details the training that each has received. Many of the entries list the fact that training is now out of date and overdue. There is also a list of senior staff members who are competent persons on the Smartsheet system and the training for most of these people is also stated to be up to date although it is noted that refresher training for some is stated as being required by April 2022. It is recommended that a full review of the training requirements for NHS GGC staff who are involved with the operation of the QEUH is made as soon as possible, and where appropriate, the required training is put in place.	
A2.9	Are copies of the site personnel training records available in the written scheme?	Y	There was a note beneath table 3.1 of the QEUH written scheme advising that relevant training records and appointment letters are electronically filed on the QEUH shared drive within folder “Water Quality Training and Appointments”.	
A2.10	Is there evidence available in the written scheme of the competency of service providers’ and contractors’ staff?		This issue is normally addressed at the procurement stage. The water hygiene contractor, DMA Canyon Ltd, is a member of the LCA and training records for the DMA Canyon Ltd staff are available. It is known that the framework plumbing contractor, Morris & Spottiswood, have also had their staff undertake Legionella Awareness training.	

			A record of plumbing contractors is also now kept by the AP Lead for Water. All contractors are formally interviewed to assess their level of competence and understanding prior to them being allowed to work on the Campus water systems. The AP Lead for water is to be commended for this excellent process. Copies of contractor training certificates are kept in the AP Lead for Water's office. Letters of appointment are issued to contractors after the interview process and copies of these letters were also available on site.	
A2.11	Are service providers and contractors LCA registered?	Y	DMA Canyon Ltd is LCA registered. Evidence of the registration is available on the LCA website. The main plumbing contractor is not LCA registered but it should be noted that not many plumbing contractors are registered in the LCA system.	
A2.12	If the suppliers are not LCA registered do they have other means of proving competence?	Y	Staff training certificates have been supplied by Morris and Spottiswood who are the framework plumbing contractor for NHS GGC. It should be noted that very few plumbing organisations are registered with the LCA organisation. The auditor is aware of the fact that Morris and Spottiswoode/Livingston Mechanical have recently completed and are planning on further refresher training.	
A2.13	Is there a formal contractor management process in place or any evidence available in the written scheme of review meetings with service providers and contractors?	Partial	Section 3.12 of the written scheme details that regular review meetings should be held with contractors and that review meeting minutes are to be filed on the QEUH Estates shared drive at path SGH Estates > water quality > contractor meetings. DMA Canyon Ltd contractor review meeting minutes were filed in this location. It is suggested that these meetings are carried out at least quarterly.	
A2.14	Is there any evidence in the written scheme of management reviews of the data and results produced by	Partial	Minuted meetings are held at least quarterly with DMA Canyon Ltd. DMA Canyon Ltd also submit monthly updates as to the various actions that are being undertaken on the water systems.	

	the monitoring and control processes and procedures?		There is close cooperation between NHS GGC Estates and DMA Canyon Ltd. Minuted meetings are also held with Scotmas, this supplier of the chlorine dioxide dosing equipment. It was mentioned on a previous audit that there does not appear to be any review of the risk reduction tasks that are completed by NHS Estates staff on site. It is recommended that the quarterly review meetings are extended in scope to include the tasks completed by NHS Estates staff and not only the tasks undertaken by the contractor.	
A2.15	Is there evidence that authorised person competency checks have been completed?	Y	AP competency checks are carried out by the AE Water as and when requested by site. NHS GGC has completed competency checks on a significant number of staff over the past three years. The Smartsheet system indicates that three staff members have been AP competency checked. Of these, at least one has moved on from working at the QEUH. The remaining two staff members have outdated letters of appointment. It would appear from the Smartsheet system that the current training for the AP's is out of date. It is recommended that an urgent review of the AP and training requirements is made and updated for the QEUH Estates staff, and that were required, appropriate training and checks are completed.	
A2.16	Does the Board have a process for out of specification situations?	Y	DMA Canyon Ltd is the contractor that is used to deliver a number of the on-site risk reduction processes and procedures. DMA sends in a monthly excel spreadsheet summary of what work they have completed. This spreadsheet details the outcome of all the DMA completed monthly check tasks.	

			NHS GGC Estates management staff extract the required remedial actions from the DMA spreadsheet and enter these into the FM 1st system and an FM 1st number is applied to the required jobs. The required jobs are issued to the onsite staff every week under an FM 1st number. The work is completed and the sheets are returned to the Estates managers. For risk reduction tasks that are completed by onsite estates staff, the required tasks are sent to a PDA with an FM 1st number. Any required remedial actions are identified and are fixed at the time they are noted. The action is recorded on the FM 1st job sheet. Any more significant issues are reported as an incident and a specific FM First number and task is issued to the Estates Department staff by the Estates Department management team.	
A2.17	Are non-conformances addressed with appropriate actions and recorded in the written scheme?	Y	The response to non-conformances can be tracked in the Excel spreadsheet system and on FM 1st. Most minor issues are addressed and sorted at the time they are noted.	
A2.18	Does the written scheme contain an "audit trail" for out of specification situations that allows for remedial actions to be tracked through to completion?	Y	FM First is now in place and used as the FM task controlling system and this allows for actions to be tracked through to completion.	
A2.19	Is there a specific escalation procedure for positive Legionella results?	Y	When an issue is apparent it is reported on the microbiological control spreadsheet. The reports are also issued to the microbiologists and also to infection control. This process is detailed on page 93 of the written scheme.	
A2.20	Are Legionella samples being taken and who is taking the samples?	Y	Samples are taken on a programmed basis by DMA Canyon Ltd.	

A2.21	Are Legionella samples being taken in accordance with BS7592:2008?	Y	DMA Canyon Ltd have had staff training in sampling technique. They also have suitable and sufficient RAMS for sampling.	

Actions on Management and Competency

3. It is recommended that a check be made as to whether the responsible person for water in NHS GGC has been appointed and is nominated in writing.
4. It is recommended that the names in the written scheme document are updated to reflect the current roles with regard to water in NHS GGC.
5. It is recommended that a review date for the Written Scheme document is created and that the document review is completed and signed off at the agreed time.
6. It is recommended that a full review of the training requirements for NHS GGC staff who are involved with the operation of the QEUH is made as soon as possible, and where appropriate, the required training is put in place.
7. It is recommended that the quarterly review meetings are extended in scope to include the tasks completed by NHS Estates staff and not only the tasks undertaken by the contractor.
8. It is recommended that an urgent review of the AP and training requirements is made and updated for the QEUH Estates staff, and that were required, appropriate training and checks are completed.

Section A3 Cleaning and Disinfection Procedures		Y/N U/K, N/A or Partial	Comments	Risk Level
A3.1	Are system cleaning and disinfection procedures in use on site?	Y		

A3.2	Are the cleaning and disinfection procedures completed by in house staff?	N	Discussions with the Estates Department indicated that cleans and disinfections of the cold water storage tanks are being completed by DMA Canyon Ltd.	
A3.3	Are the in house staff trained and competent to complete cleans and disinfections?	N/A	This question does not apply as all disinfections are completed by external contractors.	
A3.4	Are the contractor's staff trained and competent to complete cleans and disinfections?	Y	It is understood that DMA Canyon Ltd staff are trained and competent in delivering cleaning and disinfection procedures. The framework plumber staff have also been trained.	
A3.5	Are cleaning and disinfection procedures completed as a matter of procedure?	Y	Cold water storage tanks are cleaned and disinfected by the contractor on an annual basis.	
A3.6	Are these cleaning and disinfection procedures completed in response to sampling/inspection results?	N	It should be noted that after any inspection, if any tanks were found to be dirty, then they would be cleaned and disinfected. The tanks are viewed monthly by DMA Canyon Ltd.	
A3.7	Are there suitable method statements available in the written scheme covering the cleaning and disinfection procedures?	Partial	It is to be assumed that any cleans and disinfections would be completed by a contractor and that the contractor would supply suitable method statements when required. If the contractor is DMA Canyon Ltd then the method statements, which have previously been audited by the contractor, are known to be suitable and sufficient. It is recommended that any method statements for cleaning and disinfection procedures are checked for suitability prior to any work being placed with a contractor and that copies of the method statements are kept in the Written Scheme either electronically or in hard copy.	
A3.8	If chlorine is used, is the impact of pH considered in the disinfection process.	N/A	Spray disinfection using a three percent solution of silver peroxide is used during the cleaning and disinfection process for the cold water storage tanks.	

A3.9	Are there completion certificates in the written scheme covering any disinfection procedures that have been undertaken?	N/A	The DMA Canyon Ltd completion certificates are available and show that silver peroxide is used to complete the disinfections.	
A3.10	Are localised outlet disinfections in use on site?	Y	These local outlet disinfections are undertaken by DMA Canyon Ltd.	
A3.11	Is there a suitable method statement available in the written scheme covering the localised cleaning and disinfection procedures?	Y		
Actions on Cleaning and Disinfection Procedures				
9. It is recommended that any method statements for cleaning and disinfection procedures are checked for suitability prior to any work being placed with a contractor and that copies of the method statements are kept in the Written Scheme either electronically or in hard copy.				
Section A4 New Build and Refurb Capital Projects		**Y/N U/K or Partial**	**Comments**	**Risk Level**
A4.1	Have any new build or refurbishment projects, which impacted on the water systems, been completed in the past 12 months	Y	At the time of this audit a lengthy refurbishment process of wards 2A and 2B was nearing completion. This refurbishment has involved various changes and amendments to the water systems.	
A4.2	Were the implications of this work risk assessed?	Y	At the time of this audit, it was noted that a standalone risk assessment for wards 2A/2B water systems had already been commissioned and	

			would be completed imminently in advance of the wards being put back into use.	
A4.3	Was the assessment added to the logbook and water system records?	Y	This audit has recommended a new risk assessment for the entire two hospitals. The risk assessment that will be imminently completed on 2A/2B will form part of the hospitals' new risk assessment.	
A4.4	Was the written scheme amended to account for the implications of the new build/amended water systems?	Y	It is understood that the written scheme will be amended to ensure that the correct risk reduction processes and procedures are implemented in 2A/2B.	
A4.5	Were the details of the new systems discussed with the Estates Department and any other involved personnel?	Y	The local Estates' Team have been intimately involved in the entire refurbishment process throughout the entire time that this has been underway. In addition, NHS Scotland Assure has taken an overview role of the process. IPC and the Consultant microbiologists are also fully involved at all times in the refurbishment process and in the imminent opening of the wards for use.	
A4.6	Are minutes of discussions regarding the new water systems recorded and entered into the logbook?	Y	The AE is also part of the 2A/2B refurbishment process and can confirm that minutes, notes, and details of the work are available.	
A4.7	Were systems, if required, cleaned and disinfected?	Y	It is known by the AE that disinfections have been recently completed and if required further will be undertaken. There has been a detailed construction phase water safety plan in place for the duration of the work that has been undertaken. Multiple disinfections have been completed over this work phase.	
A4.8	Are records of all cleans and disinfections available in the record systems?	Y		
Actions on New Build and Refurb Capital Projects				

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Authorising Engineer Water Systems Management and Compliance Audit of NHS Water Systems
NHS GGH QEUH and RHC Hospitals Document A – Management Review

None

Section A5 Water Safety Group		Y/N U/K or Partial	Comments	Risk Level
A5.1	Is there a Water Safety Group in place?	Y	NHS GGC holds WSG meetings on a quarterly basis	
A5.2	Does the WSG have all the required groups represented?	U/K	It is recommended that a check is made to ensure that all the required groups are attending the Water Safety Group meetings.	
A5.3	Are WSG meetings held on a quarterly basis?	Y		
A5.4	Are minutes and actions produced and followed through with the WSG?	Y		

Actions on the Water Safety Group

10. It is recommended that a check is made to ensure that all the required groups are attending the Water Safety Group meetings.

Pro Lp Consulting Ltd

Authorising Engineer Water Systems Management and Compliance Audit of NHS Water Systems

Site Address: Queen Elizabeth University Hospital 1345 Govan Rd, Glasgow G51 4TF Telephone**:** 0141 201 1100		
Date of Site Audit: 30th and 31st January 2020	**Auditor:** Dennis H Kelly – Authorising Engineer (Water) Supported by Dennis A Kelly	**NHS Staff Interviewed:** Mel MacMillan – Lead AP Water Systems Phyllis Urquhart – Compliance Manager
Date of Previous Survey: The site was previously audited on the 23rd July 2018		
Site General Description: The site contains a number of hospital buildings with various functions. This audit covers the new adult hospital and the new children hospital only. The new-build adult Hospital building comprises of 12 stories, with the basement housing FM areas. Connected to the main building is the new-build Children's Hospital comprising of 4 storeys.		

There are two mains water supplies coming into the building and these are switched on a regular basis to limit the opportunity for stagnation in the mains water supply pipework.

Raw mains water is held in raw water tanks before being passed through a 0.2 micron membrane filtration process and then stored in treated water storage tanks.

Cold water is then distributed through the hospital via booster pump sets located in the tank room. Hot water is provided by a number of calorifier heating stations installed throughout the hospital.

The hospital water systems are secondary disinfected with chlorine dioxide via multiple retrofitted dosing systems located throughout the hospital.

Given the size of the two hospitals the water systems are large and complex. There are around 1400 en suite bedrooms and in excess of 3500 TMV/TMT's in the buildings.

Executive Summary:

This audit of the management and delivery of the water based risk reduction processes and procedures at the QEUH was completed at a time when the operation of the hospital water systems has undergone a high level of scrutiny.

The audit uncovered concerns regarding the delivery of some of the required risk reduction tasks. Concerns were also found in regard to the ability to evidence that the correct processes and procedures are being delivered and recorded.

It is recognised that the hospital is using the FM First CAFM system. This FM First system should be able to deliver some analysis of levels of task completion. The ability of this system to deliver the completion level analysis depends on tasks being entered into the system and then closed out as they are completed. However no mention was made of this system by the Estates staff that were interviewed at the time of the audit and it would appear that the analysis ability of the FM First system is not being used.

The on-site paper based recording system should provide a complete record of the delivery of the required tasks and this system was reviewed as part of this audit.

There are a number of record folders that are held in the QEUH Estates Office. Some of the records are also held in the electronic Smart Sheet system. These systems were examined as part of this audit. This examination uncovered a number of concerns and these are detailed in this report. Some examples of these are listed here:-

- There are gaps in the QEUH record systems that mean the hospital is unable to evidence that the required risk reduction processes and procedures are being completed. As an example the hospital records indicate that sentinel tap temperatures in the hospitals were only recorded in 5 months out of the past 12.

- In the folder holding the calorifier temperature files the following statement was entered in the section which should have included the November 2019 records for plant room 4.1 – “November checks not carried out due to operational demand”. Additionally, the record states in December 2019 that checks were “not carried out”. This may indicate a resource issue although it is recognised that the function of this report does not cover the examination of, or comments on, the resources available in the hospital.
- There are out of specification results being recorded but no evidence of any wok being completed to address these results. Evidence of this can be found in the calorifier temperature records and details are found in section 4.17 of the report.
- The copy of the risk assessment document that is held in the Smart Sheet system is a “Draft” copy. Additionally, three of the main risk assessment sections, numbers 3, 4 and 7, which contain important information in regard to risk reduction in the hospital water systems, were not available in the Smart Sheet system.
- There is no evidence that any of the remedial tasks identified in the risk assessment document have been completed.
- There is no record of deadleg removal and it is not known if any of the deadlegs discovered during the risk assessment process, or subsequently in the hospital have been removed.
- Incumbent water hygiene contractor DMA Canyon Ltd task completion and outcome records are being sent to QEUH staff but are not being recorded in the hospital record systems. Not having this information in the hospital record systems can lead to a lack of understanding of what is being completed, or more importantly what remains to be completed, as well as not highlighting any issues uncovered during the delivery of the risk reduction processes and procedures that might require remedial action.
- There is no evidence that could be found that some of the chlorine dioxide weekly and monthly tasks are being completed. It was stated during the audit that these tasks may be completed by Scotmas Ltd.
- There are some records which appear up to September 2019 then seem to stop. As an example there is an incident reporting file in the Estates office. There are no incidents recorded after September 2019.

There are a number of contractors involved in the delivery of the required risk reduction procedures with the main one being DMA Canyon Ltd. Consequently, the auditor took the decision to review not only the QEUH records, but also those of DMA Canyon Ltd. The DMA Canyon Ltd records were found to be comprehensive and this examination uncovered that fact that a number of the tasks which are not being recorded in the QEUH record system were being completed by DMA Canyon Ltd. Records of all tasks completed by DMA Canyon Ltd are being sent to the QEUH but does not appear to be entered into the QEUH record systems. Examples of work being completed by DMA Canyon Ltd but not being recorded in the hospital record systems would include cold water storage tank cleaning and disinfections, calorifier inspections, chlorine dioxide level measurements and other chlorine dioxide required tasks.
One of the key recommendations of this audit therefore is that the allocation of the delivery of the required tasks, be it the Estates department staff, clinical staff, cleaning staff or a contractor such as DMA Canyon Ltd is revisited and clear lines of who is responsible for what are drawn up and communicated to the involved parties.

A further recommendation is that the communication process and the exchange of information between the contractors and the hospital is formalised.

As a final observation, while it appears that many of the required tasks are being completed, there is a concern that not all the tasks are either clearly defined or are being undertaken. The records do not provide an opportunity for ease of analysis or inspection and there appears to be records that are missing. Consequently, scrutiny of the records would not provide a high level of confidence that the water systems are being operated in a way that meets the requirements of the guidance or the findings of the risk assessment.

Description of Levels of Risk:

Very High	Urgent Remedial Action – Lp growth and aerosol opportunity with susceptible people present on site
High	Remedial Action is needed but not immediately – Lp growth opportunity is present
Medium	Acceptable risk but some concerns– Lp likely to be controlled but improvements should be sought
Low	Risk controlled and acceptable

Levels of Risk found during the Audit:

The levels of risk detailed below reflects the highest level of risk identified during the audit of that particular topic.

The audit process reviews the following 8 areas.:-

Audited Topic	Level of Risk
Risk Assessment	
Schematic Drawings	
Management and Competency	
Written Scheme Monitoring and Records	
On Going Water Treatment	
Cleaning and Disinfection Procedures	
New Build and Refurb Capital Projects	
Water Safety Group	

Summary of Recommendations			
Recommendations	**Risk Level**	**Completed Date**	**Signature**
Recommendations from the Risk Assessment Section			
1. Ensure the final version of the risk assessment including parts 2, 3 and 7 are received and uploaded to Smart Sheet.			
2. It is recommended that NHS GGC check that specialists have been engaged to confirm that the information detailed in section 8 of the current risk assessment is reflective of the function of the 15 other water systems on site.			
3. It is recommended that DMA Canyon are requested to provide details of the competency of the involved staff and that these details are added to the written scheme.			
4. It is recommended that a check is made on the final risk assessment document to ensure that LUO's are identified.			
5. It is recommended that clarity is sought as to the location of all the areas of augmented care in the QEUH, as defined by Infection Control, and that an assessment is made of the water system installations in the identified augmented care areas.			
Recommendations from the Schematic Drawings Section			
6. It is recommended that schematic drawings are reviewed at least annually and amended and updated to reflect any water system changes.			
Recommendations from the Management and Competency Section			
7. It is recommended that a check be made as to whether the duty holder and responsible person for water in NHS GGC have been nominated in writing.			
8. It is recommended that the NHS GGC new Policy document is ratified and adopted as soon as possible.			

9. It is recommended that the current procedure document is updated to include the results of the most recent organisation review. The updated version should then be loaded to Smart Sheet.			
10. It is recommended that the board wide skills register is checked for completeness and updated if required.			
11. It is recommended that the quarterly review meetings are extended in scope to include the tasks completed by NHS Estates staff and not only the tasks undertaken by the contractor.			
Recommendations from the Written Scheme, Monitoring and Records Section			
12. It is recommended that section 5.0 of the written scheme is reviewed and appropriate corrections made to the numbering system where required.			
13. It is recommended that a review is made of all the deadlegs identified in the risk assessment and of the status of the deadleg removal programme.			
14. It is recommended that the process of communication of the DMA Canyon Ltd task records to the QEUH Estates Department is reviewed and amended as required.			
15. It is recommended that a complete copy of all records relating to the DMA Canyon Ltd risk reduction tasks and procedures are held onsite at the QEUH.			
16. It is recommended that a check is made to see if these required cold water storage tank inspections have been completed. If they have been completed then this should be reflected in the records. If these actions have not been completed then the actions should be addressed as soon as possible.			
17. It is recommended that a check is made to see if the required internal inspections of calorifiers have been completed. If they have been completed then this should be reflected in the records. If these actions have not been completed then the actions should be addressed as soon as possible.			
18. It is recommended that copies of the records of the shower and spray head cleans are held in the QEUH record systems.			

19. It is recommended that a check is made to see if any remedial actions were completed as a result of the above calorifier temperature defects. If actions were completed they should be entered into the remedial action record. If the actions are outstanding then they should be addressed as soon as possible.			
20. It is recommended that a review of the hot outlet temperature monitoring procedures is made to ensure that the tasks are completed on a monthly basis.			
21. It is recommended that a response is completed and recorded to any out of specification situations that are found with the hot water temperatures.			
22. It is recommended that the hot and cold sentinel locations are confirmed and that once they have been confirmed, the current monthly temperature monitoring programme is reviewed to ensure that the appropriate outlets are being included temperature monitoring programme.			
23. It is recommended that the approach to monitoring temperatures in representative outlets is clearly defined and then implemented in the hospital.			
24. It should be confirmed that where fitted all single entry expansion vessel are being appropriately flushed.			
25. It is recommended that NHS GGC formalises its approach to TMV/TMT servicing and institutes the service protocol when it is agreed.			
26. It is recommended that the list of required tasks, based on the most recent risk assessment, is reviewed to ensure that it is comprehensive.			
27. It is recommended once the comprehensive list of tasks is confirmed, that the responsibility for completion of the tasks is assigned to the relevant NHS GGC party or external contractors. All of the involved parties must be made fully aware of the responsibilities.			
28. It is recommended that the lines of communication for the task completion records are clarified and implemented in a way that ensures that NHS GGC records meet the requirements of the guidance.			

29. It is recommended that all sentinel outlets are monitored for levels of chlorine dioxide in accordance with HSG 274 guidance para 2.100.			
30. It is recommended that the QEUH makes weekly checks on the operation of the chlorine dioxide dosing equipment and also the chlorite to chlorine dioxide conversion yield as required in the HSG 274 guidance in para 2.100.			
31. It is recommended that the need for LUO flushing throughout the QEUH is reviewed and is implemented and recorded where required.			
32. It is recommended that a review of the outstanding risk assessment remedial actions is completed and a programme to address the outstanding actions is put into place as soon as possible.			
33. It is recommended that a robust process of recording out of specification results, along with an auditable record of the appropriate remedial actions is created and implemented as soon as possible.			
34. It is recommended that the QEUH written scheme action table for positive legionella results is amended to reflect table 2.3 of the HSG 274 document.			
35. It is recommended that the method statement for taking hot sentinel tap temperatures is amended to ensure that the target temperature is a minimum of 55°C.			
Recommendations from the Ongoing Water Treatment Section			
36. It is recommended that a review is made to see if the checks on the filter plant are being completed. If they are not then they should be reinstated and the appropriate details added to the records system.			
Recommendations from the Cleaning and Disinfection Procedures Section			
37. None It is recommended that the policy on the use of cleans and disinfections in NHS GGC at the QEUH is reviewed and updated if required. This review should include the decision making process for the use of cleans and disinfections and the use and recording of appropriate documentation including inspection reports, method statements, MSDS and cleaning and disinfection certification.			

38. It is recommended that any method statement for cleaning and disinfection procedures are checked for suitability prior to any work being placed with a contractor.			
Recommendations from the New Build and Refurb Capital Projects Section			
39. It is recommended that NHS GGC satisfy themselves with the proposed risk reduction processes and procedures for the additional water system.			
40. It is recommended that any details relating to the operation of this additional water system, and the implications, if any, for the existing water system, are added to the written scheme.			
41. It is recommended in future that any work which has implications for the building water systems is discussed and appropriate records of the discussions are made and stored in the records in the written scheme.			
42. It is recommended that the handover records for the MIU project are checked to ensure that suitable disinfection records are available.			
Recommendations from the Water Safety Group Section			
43. It is recommended that a check is made to ensure that all the required groups are attending the water safety group meetings.			

Question Set with Associated Comments from the Audit				
Section 1 Risk Assessment		**Y/N U/K, N/A or Partial**	**Comments**	**Risk Level**
1.1	Is there a written risk assessment in place for the building water systems?	Y	The current risk assessment was completed by DMA Canyon Ltd and delivered to site January 2019 (draft format). The site survey work was carried out October – December 2018. The sites risk assessment copy is still detailed as being a draft document. In addition sections 3, 4 and 7 of the risk assessment were not available in the draft document. Arrangements were made to deliver the final RA version at the time of this audit. Ensure the final version of the risk assessment including parts 3, 4 and 7 are received and uploaded to Smart Sheet.	
1.2	Was the risk assessment completed and delivered to site within the past two years?	Y	The current risk assessment was completed by DMA Canyon Ltd and delivered to site January 2019 (draft format).The previous risk assessment was also completed by DMA Canyon Ltd and delivered to site January 2018.	
1.3	Does the site/organisation have plans with regard to reviewing or redoing the risk assessment?	Y	It was noted that the QEUH written scheme details that the risk assessment review period is annual. This is therefore within the guidelines for risk assessment stipulated in the SHTM 04-01 document. Smart screen detailed the current risk assessment should be reviewed by April 2021.	

1.4	Does the risk assessment address all the water systems in the building?	Partial	Section 8 of the current risk assessment details 15 other water systems and includes a brief description of each system as well as an initial assessment of risk. It further advises that specialists in each field are consulted to confirm the risk assessment detail is reflective of the function of each water system. It is recommended that NHS GGC check that specialists have been engaged to confirm that the information detailed in section 8 of the current risk assessment is reflective of the function of the 15 other water systems on site.	
1.5	Are there any systems that are defined as being excluded from the assessment in the RA scope?	N	Although the Hydrotherapy pool was mentioned in the list of additional water systems the risk assessment document did state that the pool was not assessed.	
1.6	Does the risk assessment review the current risk reduction processes and procedures that are currently in use at the site?	Y	The current risk reduction processes are reviewed in Section 9 of the document.	
1.7	Does the risk assessment contain details of the people/organisations who are involved in the risk reduction processes and procedures? This should include comments on the dutyholder, the responsible person, any deputy responsible persons and also service providers and contractors.	N	This is normally covered in section 2 or 3 of a DMA Canyon risk assessment document. Section 3 was not available and the details of the management and people could not be found in the files. This is covered with the recommendation made above in point 1.1.	
1.8	Is there an assessment of the competency of all involved parties in the risk assessment?	Y	Section 9 of the risk assessment details the training of all client involved personnel.	

			The risk assessment document states that the DMA Canyon Ltd competency details are filed centrally in their local office and can be accessed by request from DMA Canyon Ltd. It is recommended that DMA Canyon are requested to provide details of the competency of the involved staff and that these details are added to the written scheme.	
1.9	Does the risk assessment specifically address and comment on evidence of the current defect/remedial action processes and procedures?	Y	Section 9 of the risk assessment includes a gap analysis which comments on the evidence of the current remedial processes and procedures.	
1.10	Is there an assessment of the susceptibility of persons who may be affected by the building water systems?	Y	This is covered in Section 1 of the risk assessment document.	
1.11	Is there a schematic diagram provided with the risk assessment?	N	There are no schematics in the risk assessment document but schematics are available elsewhere in the Zutec system and are stored electronically. It may be the case that the supply of schematic diagrams was not part of the scope of supply covering the new risk assessment.	
1.12	Is there a new written scheme provided as part of the risk assessment?	Partial	This may not have been part of the scope of supply agreed with the risk assessment supplier. There is guidance provided in section 10 of the risk assessment document as to what should be included in a written scheme. Site has created a written scheme since the current RA has been completed.	

1.13	Does the assessment contain details of all the component parts of the water systems? This could include tanks, calorifiers, pipework and pipework layout, outlets, TMV's, expansion vessels etc etc etc.	Y		
1.14	Is consideration given to system design, flow, temperature and the opportunity for bacteria to grow and develop in the water systems?	Y		
1.15	Does the risk assessment identify any particular areas of spray and aerosol creation?	N	This would normally appear in section 7, Outlet Asset Register, of the DMA Canyon risk assessment. This section was not available at the time of the audit. It is recommended that a check is made on the final risk assessment document to ensure that LUO's and deadlegs are identified.	
1.16	Are areas of low use and low flow identified in the risk assessment?	N	This would normally appear in section 7, Outlet Asset Register, of the DMA Canyon risk assessment. This section was not available at the time of the audit. Normally in the section each outlet is detailed and a comment made as to the level of outlet usage. See the recommendation for point 1.15 above.	
1.17	Are deadlegs specifically detailed in the risk assessment?	N	This would normally appear in section 7, Outlet Asset Register, of the DMA Canyon risk assessment. This section was not available at the time of the audit. Deadlegs are also covered in section 2 (Recommendations) of the RA document.	

			See the recommendation for point 1.15 above.	
1.18	Is there a set of remedial actions clearly identified in the risk assessment?	Y	The remedial actions are detailed in section 2 in the RA document in the section titled Recommendations.	
1.19	Is there a clearly explained risk scoring system in the risk assessment?	Y	The risk scoring system is explained in section 2 of the RA document.	
1.20	Are there any areas of augmented care in the hospital?	Y	There are areas of augmented care in the hospital as per the criteria detailed in HPS guidelines.	
1.21	Have Pseudomonas risk assessments been completed?	N	It is recommended that clarity is sought as to the location of all the areas of augmented care in the QEUH, as defined by Infection Control, and that an assessment is made of the water system installations in the identified augmented care areas.	

Recommendations on the Risk Assessment

1. Ensure the final version of the risk assessment including parts 2, 3 and 7 are received and uploaded to Smart Sheet.
2. It is recommended that NHS GGC check that specialists have been engaged to confirm that the information detailed in section 8 of the current risk assessment is reflective of the function of the 15 other water systems on site.
3. It is recommended that DMA Canyon are requested to provide details of the competency of the involved staff and that these details are added to the written scheme.
4. It is recommended that a check is made on the final risk assessment document to ensure that LUO's are identified.
5. It is recommended that clarity is sought as to the location of all the areas of augmented care in the QEUH, as defined by Infection Control, and that an assessment is made of the water system installations in the identified augmented care areas.

Section 2 Schematic Drawings		Y/N U/K, N/A or Partial	Comments	Risk Level
2.1	Are schematic drawings available in the written scheme, or in some other place in the property?	Y	There is a note in the Smart Sheet electronic data management system detailing the locations of the soft copies of the drawings as being available on ZUTEC (electronic data storage system). Some examples of drawings were checked in the ZUTEC system as part of this audit.	
2.2	Do the schematic drawings show all the components of the water systems?	Y	The drawings are as fitted and detail the entire system configuration including all component parts.	
2.3	Have the identified system deadlegs been added to the schematic drawings?	N		
2.4	Are the water system return legs shown on the schematic drawings?	Y		
2.5	Are secondary and tertiary loops shown on the schematic drawings?	Y		
2.6	Have any amendments been made to the schematic drawings?	N		
2.7	If amendments have been made are they signed and dated?	N/A		
2.8	Is there any indication that drawings are regularly inspected and updated if required?	Partial	It was stated that drawings will be checked as and when required.	

			It is recommended that schematic drawings are reviewed at least annually and amended and updated to reflect any water system changes.	

Recommendations on Schematic Drawings

6. It is recommended that schematic drawings are reviewed at least annually and amended and updated to reflect any water system changes.

Section 3 Management and Competency		Y/N U/K, N/A or Partial	Comments	Risk Level
3.1	Is there a duty holder nominated in writing?	Y	There is a copy of an NHS GGC Policy Document dated January 2019 available electronically on site. In appendix 1 of the policy document it states that the Duty Holder is the Chief Executive. A more detailed hierarchy table was also available naming people who are responsible for the various positions with regard to water. It is recommended that a check be made as to whether the duty holder for water in NHS GGC have been nominated in writing.	
3.2	Is there a responsible person nominated in writing?	Y	The responsible person is detailed in table 3.1 of the written scheme and named as being Colin Purdon (Interim). There is comment advising that this appointment is to be detailed in writing. It is not known if the responsible person is nominated in writing. This issue is covered in para 3.1 above.	

			Letters of appointment were available for APs and CPs on Smart Sheets.	
3.3	Is there a clearly defined management structure which includes the relevant on site personnel and also all service providers and contractors?	Y	There is clearly deigned management structure in section 3.2 of the written scheme. The service provider is detailed as being DMA Canyon Ltd who are also listed in section 3.1 Roles and Responsibilities.	
3.4	Is there a clearly defined line of communication in the written scheme?	Y	This is covered in the management organogram in section 3.2 of the written scheme.	
3.5	Are the responsibilities of all involved parties clearly defined in the written scheme?	Y	Roles and responsibilities are defined in table 3.1 of the written scheme.	
3.6	Does the organisation have an up to date and current policy document?	Y	NHS GGC has a policy document dated for approval January 2020. At the time of this audit it is not known if this approval has been made. It is recommended that a check is made to see if the Policy Document has been finally approved.	
3.7	Does the organisation have an up to date and current procedures document?	Partial	The current procedures document is filed on Smart Sheet and also available on the hospital intranet. The document is detailed as being version 2 and dated May 17 with the review date being October 19. It was advised during the audit that the document is reviewed annually and that this annual review had recently been completed. A copy of the updated review was not available at the time of the audit.	

			It is recommended that the current procedure document is updated to include the results of the most recent organisation review. The updated version should then be loaded to Smart Sheet.	
3.8	Do all staff have relevant up to date training in place?	Partial	The board wide water skills register available on Smart Sheet lists 20 staff members for the QEUH and details the training received. It could not be confirmed is this information is up to date. It is recommended that the board wide skills register is checked for completeness and updated if required.	
3.9	Are copies of the site personnel training records available in the written scheme?	Y	There was a note beneath table 3.1 of the written scheme advising that relevant training records and appointment letters are electronically filed on the QEUH shared drive within folder 'Water Quality > Training and Appointments'.	
3.10	Is there evidence available in the written scheme of the competency of service provider and contractor staff?	Y	This issue is addressed at the procurement stage. The water hygiene contractor, DMA Canyon Ltd, is a member of the LCA and training records for the suppliers staff are available. It is known that the framework plumbing contractor, Morris & Spottiswood, have recently had their staff undertake Legionella Awareness training.	
3.11	Are service providers and contractors LCA registered.	Y	DMA Canyon Ltd is LCA registered. Evidence of the registration was available in the written scheme document. The main plumbing contractor is not LCA registered but it should be noted that not many plumbing contractors are registered in the LCA system.	
3.12	If the suppliers are not LCA registered do they have other means of proving competence?	Y	Training certificates have been supplied by Morris and Spottiswood who are the framework plumbing contractor for NHS GGC.	
3.13	Is there a formal contractor management process in place or any evidence available in the written	Y	Section 3.12 of the written scheme details regular reviewing meetings should be held with contractors and that review meeting minutes are	

	scheme of review meetings with service providers and contractors?		to be filed on the QEUH Estates shared drive at path SGH Estates > water quality > contractor meetings. DMA Canyon Ltd contractor review meeting minutes were filed in this location and suggest that these meetings are carried out at least quarterly.	
3.14	Is there any evidence in the written scheme of management reviews of the data and results produced by the monitoring and control processes and procedures?	Partial	The minutes of the review meetings with DMA Canyon were available for the past twelve months. As an example the meeting notes from the 17th December 2019 were reviewed. It was noted that these reviews relate only to the tasks undertaken by DMA Canyon. As a consequence therefore it is further noted that there does not appear to be any review of the risk reduction tasks that are completed by NHS Estates staff on site. It is recommended that the quarterly review meetings are extended in scope to include the tasks completed by NHS Estates staff and not only the tasks undertaken by the contractor.	
3.15	Is there evidence that authorised person competency checks have been completed?	Y	AP competency checks are carried out by the AE as and when requested by site. A complete list of the up to date competency checks for AP's was made available by the AE. Details of the appointment of AP's can also be found on the Board Wide Water Skills Register in Smart Sheets	

Recommendations on Management and Competency

7. It is recommended that a check be made as to whether the duty holder and responsible person for water in NHS GGC have been nominated in writing.
8. It is recommended that a check is made to see if the Policy Document has been finally approved.

9. It is recommended that the current procedure document is updated to include the results of the most recent organisation review. The updated version should then be loaded to Smart Sheet.
10. It is recommended that the board wide skills register is checked for completeness and updated if required.
11. It is recommended that the quarterly review meetings are extended in scope to include the tasks completed by NHS Estates staff and not only the tasks undertaken by the contractor.

Section 4 Written Scheme, Monitoring and Records		Y/N U/K, N/A or Partial	Comments	Risk Level
4.1	Is there a written scheme in place?	Y	The written scheme entitled 'Controlling the risk of exposure to Legionella and other harmful bacteria in Water Systems – 2019 Rev B' is available on the Smart Sheet system	
4.2	Is a copy of the written scheme available on site?	Y	An electronic copy of the written scheme is available on the Smart Sheet system. It was noted in the written scheme that the table in Section 5.0 on page 73 – Incident and Emergency Procedures list 9 procedures. Each procedure is described in the ongoing pages of the written scheme. However procedure 5.4, Calorifier or Heat Exchanger Temperature Fault, is not described in the ongoing pages. As a consequence the numbering of the procedures descriptions does not agree with the numbering in the table on page 73 of the written scheme document. It is recommended that section 5.0 of the written scheme is reviewed and appropriate corrections made to the numbering system where required.	

4.3	Is there a statement in the written scheme of the expected "correct and safe operation" processes detailing targets for temperatures and other control measures?	Y	The statement of correct and safe operations for the water systems can be found in section 4.1 of the written scheme document.	
4.4	Is there evidence in the written scheme that any deadlegs have been discovered?	Y	The written scheme details dead leg flushing under procedure WS01. However, there were no records or files pertaining to locations or completions of any flushing actions. Any deadlegs that were discovered during the risk assessment process are recorded in the risk assessment document in the remedial actions section. A number of deadlegs were identified in the QEUH during the risk assessment process.	
4.5	Is there evidence in the written scheme that any deadlegs have been removed?	N	No evidence during this audit that any deadlegs have been removed. In a later discussion with a contractor it was stated that some deadlegs have been removed particularly in plant room areas. However, no evidence could be provided at the time of this audit. It is recommended that a review is made of all the deadlegs identified in the risk assessment and of the status of the deadleg removal programme.	
4.6	Is temperature the primary means of control within the water systems?	Y	Temperature is the primary means of control in the water systems. However the use of temperature as the means of control has recently been supplemented by the addition of multiple chlorine dioxide dosing systems to the hot and cold water systems.	
4.7	Is there any form of water treatment being applied to the water systems?	Y	Chlorine dioxide is applied to the site's main CWST's with supplemental dosing stations located throughout the hospital.	
4.8	Is there any seasonal difference in the use profile of the water systems?	N		

<table>
<tr><td>4.9</td><td>Are any pieces of duty standby equipment that require to be switched on a weekly basis, and do the records show that they are being switched?</td><td>Y</td><td>Hard copy pump swap records are filed in the Estates maintenance office. Twelve sets of monthly records were available covering the last twelve months.</td><td></td></tr>
<tr><td>4.10</td><td>Is there a logbook, either paper or electronic, defining all the required tasks for the risk reduction processes and procedures?</td><td>Y</td><td>There is a master logbook filed on Smart Sheet. This logbook is part of the written scheme document and details procedure numbers for the required risk reduction tasks. These procedure numbers relate to folder numbers where hard copy records of the completed actions are stored.</td><td></td></tr>
<tr><td>4.11</td><td>Are all tasks in the records signed and dated?</td><td>Y</td><td>The records of the tasks that were completed were signed and dated.</td><td></td></tr>
<tr><td>4.12</td><td>Looking over the past twelve months have the required risk reduction tasks been completed on the site?</td><td>Partial</td><td>
<table>
<tr><th>Task</th><th>Expected</th><th>Actual Records</th></tr>
<tr><td>Tank Inspections</td><td>2 – 1 tank inspection and 2 sets of temperatures are required</td><td>None</td></tr>
<tr><td>Calorifier Inspections</td><td>1</td><td>None – no records available at the time of the scheduled audit.</td></tr>
<tr><td>Shower/Spray Heads</td><td>N/A</td><td>N/A as covered by DMA Canyon under their contract with the QEUH. Details for this task are held by DMA Canyon Ltd and comments can be found in the DMA Canyon Ltd specific table further on in this report.</td></tr>
<tr><td>Cal F and R Temps</td><td>12</td><td>10</td></tr>
</table>
</td><td></td></tr>
</table>

PH Ex F and R Temps	N/A	N/A			
Hot Sentinel Temps	12	5			
Hot Sec and Tertiary Loop Temps	4	Unknown			
Hot Rep Temps	1	Unknown			
Cold Sentinel Temps	12	5			
Cold Sub Loop Temps	N/A	N/A			
Cold Rep Temps	1	Unknown			
POU Heater Temps	N/A				
Expansion Vessels	Monthly to six monthly	No records of flushing of the single entry expansion vessels			
TMV's/TMT's	2	One partial record was available at the time of the audit. This covered the theatres and wards 9 – 11 and was dated June 2019. These records were found in the DMA Canyon record system. Please note that these records are for the fail-safe check only			
Little used outlet flushing	104	104 – DMA flushing only.			
QEUH "Specific Tasks" completed by DMA Canyon Ltd					
DMA Canyon Ltd are contracted to carry out the QEUH "specific tasks". These tasks are related to the historical contamination					

and infection issues which have been recorded at the QEUH. These tasks are managed from the "Filter Central" office in plantroom 31 on the 3rd floor. Some of the monitoring and maintenance records to evidence the completion of these tasks are also filed in the 'Filter Central' office and were reviewed as part of this audit. Some of the records, at the time of this audit were reported to be held offsite.

It is recommended that the process of communication of the DMA Canyon Ltd task records to the QEUH Estates Department is reviewed and amended as required.

It is recommended that a complete copy of all records relating to the DMA Canyon Ltd risk reduction tasks and procedures are held onsite at the QEUH.

The outcome of the review of the DMA Canyon Ltd records can be found below.

Shower replacements – on filtered wards hoses only	2 monthly	DMA Canyon Ltd informed the auditor that at the time of this audit the records for this are held offsite in the DMA offices.
Shower replacement – in unfiltered wards	Quarterly	DMA Canyon Ltd informed the auditor that at the time of this audit the records for this are held offsite in the DMA offices.
Shower hose replacement – ward 6A	Monthly	DMA Canyon Ltd informed the auditor that at the time of this audit the records for this are held offsite in the DMA offices.

			Flow straighteners/ diffusers – Optitherms only	Quarterly	Expected 4 sets of records – 4 sets or records are available on site.		
			POU filters (31 days)	Monthly	Used CDU as example: 12 sets of records expected – 13 sets of records available (extra set of records due to loss of water and a required additional change of filters)		
			POU filters (62 days)	Bi-monthly	Used ward 9D as example: 6 sets of records expected – 7 sets of records available (extra set of records due to loss of water and a required additional change of filters)		
			LUO flushing - water cooler supply pipework	3 times per week	Expected 156 and all records available.		
			LUO flushing – 2A and 2B	Daily (inc. weekends)	DMA Canyon Ltd informed the auditor that at the time of this audit the records for this are held offsite in the DMA offices.		
			LUO flushing – plant room flushing	Twice weekly	Commenced May 2019: 8 sets of data expected – 8 sets of records filed and available.		
			ClO2 testing	Weekly	There are 78 sampling locations. These are not all of the sentinel points in the hospital. These sample points were chosen as providing representative levels of ClO2 throughout the hospital water systems. A check should be		

					made to ensure that all sentinel outlets are being monitored in accordance with HSG 274 guidance. A further check should be made to ensure the required weekly checks on the chlorine dioxide dosing equipment are being made and recorded. A check should be made on the conversion yield of the chlorite to chlorine dioxide levels in the water systems.	
				Microbiological sampling sweeps	Monthly	DMA Canyon Ltd informed the auditor that at the time of this audit the records for this are held offsite in the DMA offices.	
			Cold Water Storage Tanks – There were no records available indicating that any tanks inspections had been completed. It is recommended that a check is made to see if these required cold water storage tank inspections have been completed. If they have been completed then this should be reflected in the records. If these actions have not been completed then the actions should be addressed as soon as possible. **Calorifier Inspections –** No records of any calorifier internal inspections were available during the scheduled audit.			

			During the subsequent discussions with DMA Canyon Ltd at the QEUH it was stated that the contractor had completed internal inspections of the calorifiers. It is recommended that a check is made to see if the required internal inspections of calorifiers have been completed. If they have been completed then this should be reflected in the records. If these actions have not been completed then the actions should be addressed as soon as possible. **Shower and Spray heads –** There is a shower head and hose replacement programme in place which is completed under contract by DMA Canyon. Records of these actions are held offsite by DMA Canyon. It is recommended that copies of the records of the shower and spray head cleans are held in the QEUH record systems. **Calorifier Flow and Return Temperatures -** There were 10 sets of records of flow and return temperatures available for the last 12 months. No records were available for the December 2019 and March 2019 F and R temperature tests were. Some of the temperatures in the completed tests records were out of specification and these are detailed below:- • Low DHW return temperatures were recorded in plantroom 21 in January 2020 and November 2019 • Low DHW return temperatures in plantrooms 31 and 32 for January 2020	

			• Low DHW return temperatures in plantroom 22 for November 2019. • Records for November 2019 for plantroom 4.1 detail 'Checks not carried out due to operational demand'. • Records for September 2019 and October 2019 detail that in plantroom 22 the temperature gauge on Cal 1 was faulty. • In plantroom 22 in October 2019 it details that the destrat pump on Cal 1 "requires replacing". There was no evidence in the remedial actions records that any of the above issues had been addressed. It is recommended that a check is made to see if any remedial actions were completed as a result of the above calorifier temperature defects. If actions were completed they should be entered into the remedial action record. If the actions are outstanding then they should be addressed as soon as possible. It was noted on the calorifier flow and return temperature sheets that the calorifiers are being flushed on a monthly basis. **Hot Sentinel Taps –** There were 5 sets of records available covering March 2019 to May 2019, August 2019 and October 2019. Only 3 of those 5 sets of records (March 2019 to May 2019) detailed outlets from level 0 to level 11 in the hospital. August 2019 records detailed level 0 only and October 19 detailed levels 4 -11 only. May 2019 domestic hot water temperatures were <55°C (but >50°C) for a number of outlets on levels 7 to 11.	

			It is recommended that a review of the hot outlet temperature monitoring procedures is made to ensure that the tasks are completed on a monthly basis. It is recommended that a response is completed and recorded to any out of specification situations that are found with the hot water temperatures. **Cold Sentinel Taps** – There were 5 sets of records available covering March 2019 to May 2019, August 2019 and October 2019. Only 3 of those 5 sets of records (March 2019 to May 2019) detailed outlets from level 0 to level 11. August 2019 detailed level 0 only and October 2019 detailed levels 4-11 only. See recommendations above for hot water outlets. **Hot and Cold Secondary Loop Temperatures –** No records were available for these tasks. This may be related to the fact that the locations of the specific outlets that should be temperature monitored were unavailable. It is recommended that the hot and cold sentinel locations are confirmed and that once they have been confirmed, the current monthly temperature monitoring programme is reviewed to ensure that the appropriate outlets are being included temperature monitoring programme. **Hot and Cold Representative Temperatures –** No representative temperatures appear to be taken in the hospital.	

			It is recommended that the approach to monitoring temperatures in representative outlets is clearly defined and then implemented in the hospital. **Expansion vessels –** It was stated during the audit that all single entry expansion vessel have been replaced with flow through types. However a number of single entry expansion vessels were noted on the domestic cold water booster pump sets. It should be confirmed that where fitted all single entry expansion vessel are being appropriately flushed. **TMV's/ TMT's –** There were records available for TMV failsafe testing only for the theatres and wards 9 -11 for June 2019. These records were found in the DMA Canyon record system. DMA Canyon completes the fails safe checks on TMV/TMT's throughout the two hospitals. The contractor has stated that a full set of records is available. It is recommended that NHS GGC formalises its approach to TMV/TMT servicing and institutes the service protocol when it is agreed. **Comments on DMA Canyon Ltd completed tasks specific to the operation of the water systems at the QEUH.** Information and comment on the tasks can be seen above in the spreadsheet entitled **QEUH "Specific Tasks" completed by DMA Canyon Ltd**.	

			During the audit and the subsequent discussions with the main contractor, DMA Canyon Ltd, it became apparent that there are issues of clarity of understanding of who is responsible for the completion of the various risk reduction tasks on site. This confusion extends not only to the QEUH Estates department and the main contractor, but also potentially includes input from NHS GGC clinical and cleaning staff for flushing procedure completion, and other contractors such as Scotmas Ltd on chlorine dioxide generator related tasks. It is recommended that the list of required tasks, based on the most recent risk assessment, is reviewed to ensure that it is comprehensive. It is recommended once the comprehensive list of tasks is confirmed, that the responsibility for completion of the tasks is assigned to the relevant NHS GGC party or external contractors. All of the involved parties must be made fully aware of the responsibilities. It is recommended that the lines of communication for the task completion records are clarified and implemented in a way that ensures that NHS GGC records meet the requirements of the guidance. It is recommended that all sentinel outlets are monitored for levels of chlorine dioxide in accordance with HSG 274 guidance para 2.100. Currently 78 outlets are checked for chlorine dioxide levels on a weekly basis. The HSG 274 guidance calls for monthly testing at sentinel outlets. It is understood that there are in excess of 300 sentinel outlets in the hospital. It may therefore be possible to upgrade	

			the existing testing programme to check chlorine dioxide levels at all of the sentinel outlets by implementing a weekly rolling programme throughout the month. It is recommended that the QEUH makes weekly checks on the operation of the chlorine dioxide dosing equipment and also the chlorite to chlorine dioxide conversion yield as required in the HSG 274 guidance in para 2.100.	
4.13	Are little used outlets (LUO's) listed and are they then flushed?	Partial	Some of the required LUO flushing is completed by DMA Canyon Ltd. Specifically, DMA Canyon Ltd flush the following:- • Three times per week flushing of supply pipes to unused or removed water coolers • Flushing in wards 2A and 2B on a daily basis • Flushing of temporary dosage connections in the plant rooms twice per week Records for this were found in the DMA Canyon Ltd Filter Central office. Water cooler flushing records for Feb and Mar 2019 were not available – this is mentioned earlier in this report. At the time of the audit it could not be confirmed if any other little used outlet flushing was required, or was being completed, in any other part of the hospital. It is recommended that the need for LUO flushing throughout the QEUH is reviewed and is implemented and recorded where required.	
4.14	Is the flushing of little used outlets recorded in the records system?	Partial	Records were available for the DMA Canyon Ltd completed flushing procedures.	

			There was a folder available in the Estates' Office to contain records of flushing completed by parties other than DMA Canyon Ltd. This folder did not contain any flushing records covering the past twelve months. This issue is covered by the recommendation in section 4.13.	
4.15	Do the completed risk reduction processes and procedures meet the requirements of the HSE and HTM guidance.	N	An examination of the records as detailed above indicates that there are gaps in the completion and recording of the required risk reduction processes and procedures. The tasks required to address this situation are covered in the recommendations made above in sections 4.12 and 4.13.	
4.16	Are the remedials actions from the previous risk assessment completed and are they signed and dated?	N	The 2018 DMA risk assessment actions are filed in Smart Sheet and this details 212 recommendations. While some of the actions may have been addressed the records indicate that none of the 212 actions are in progress or have been completed. It is recommended that a review of the outstanding risk assessment remedial actions is completed and a programme to address the outstanding actions is put into place as soon as possible.	
4.17	Were there any out of specification results from the risk reduction processes and procedures in the past 12 months?	Y	There is a hardcopy file in the Estates Office entitled 'Incident report recorded file' with the last entry in this file being September 2019. The concern here is that recording of incidents ceased in September 2019. This concern may be supported by the fact that during an inspection of the calorifier temperature records it was noted that starting in September 2019 a number of defects were recorded. None of these defects were recorded in the Incident report recorded file. The issues that were noted on the calorifier temperature records were as follows:-	

			• September 2019 – plant room 22 Cal 1 temp gauge faulty. • October 2019 – plant room 22 Cal 1 temp faulty, destrat pump needs replaced. • November 2019 – plant room 21. Domestic hot water return temperature 50.7°C and in the same month plant room 22 domestic hot water return temperature was 54° C. • January 2020 – plant room 21 domestic hot water return noted as being below 55°C. • January 2020 – Plant room 31 domestic hot water return noted as being below 55°C. • January 2020 – Plant room 32 domestic hot water return noted as being below 55°C. In addition in November 2019, the records state that “checks not carried out due to operational demand”. This was recorded in regard to plant room 4.1. In December 2019 there is a note in in the calorifier temperature records stating, “not carried out”. Finally, there were no records and no comment for March 2019. At the time of this audit there was a second defect log folder entitled “Non Compliance Issues and Fault Detail Log – Record form 004”. This contained a number of non-conformances but no further information on any remedial actions relating to these non-conformances.	

			It is recommended that a robust process of recording out of specification results, along with an auditable record of the appropriate remedial actions is created and implemented as soon as possible.	
4.18	Are Legionella samples taken as part of the written scheme tasks?	Y	Legionella samples are taken by DMA Canyon Ltd as part of a sweep of microbiological samples taken monthly across the hospital.	
4.19	Does the written scheme contain any incident plans?	Y	A copy of the incident plan could be found in the written scheme document.	
4.20	Is there a copy of the risk assessment in the written scheme?	Y	Please see comments in section 1 of this document.	
4.21	Is there a copy of the training records in the written scheme?	Y	Please see comments in section 3 of this document.	
4.22	Are non-conformances addressed in a timely manner?	N	No evidence could be found to support the fact that non conformances were being completed in a timely manner. The examples detailed in point 4.17 above supports this view.	
4.23	Does the written scheme contain an “audit trail” for out of specification situations that allows for remedial actions to be tracked through to completion?	N	There is an incident reporting procedure in place in a folder entitled “Non Compliance Issues and Fault Detail Log – Record form 004”. A number of non-conformances were identified in this record as part of this audit. There was no further information on any remedial actions relating to these non-conformances. This issue is addressed in section 4.17.	
4.24	Is there a specific escalation procedure for positive Legionella results?	Y	There is a response to a positive legionella result in section 5.4 (page 87) of the QEUH written scheme. It is noted that the action table shown in the written scheme document references table 2.3 of the HSG 274 document. The written scheme document appears to actually reference table 2.2 of the HSG 274 document and this table is not designed for use in healthcare situations. It is recommended that the QEUH written scheme action table for positive legionella results is amended to reflect table 2.3 of the HSG 274 document.	

4.25	Are Legionella samples being taken in accordance with BS7952:2008?	Y		
4.26	Are Pseudomonas samples taken as part of the written scheme?	Y	Pseudomonas samples are taken by DMA Canyon Ltd as part of a sweep of microbiological samples taken monthly across the hospital.	
4.27	Are the Pseudomonas samples taken in line with the guidance given in the HFS, HPS CEL of July 2017?	Y	It is known that the DMA Canyon Ltd staff have been trained in sampling techniques.	
4.28	Are there copies of method statements for any procedures that are completed in house?	Y	Site monitoring tasks method statements are available in the written scheme document. It was noted that the method statement for sentinel temperature monitoring (4.1) detailed the target temperature for a hot water outlet as being 50°C and not 55°C. It is recommended that the method statement for taking hot sentinel tap temperatures is amended to ensure that the target temperature is a minimum of 55°C.	
4.29	Are there copies of method statements for any procedures that are completed by external providers?	Y	Copies of DMA Canyon Ltd method statements could be found in the Filter Central office.	

Recommendations on Written Scheme, Monitoring and Records

12. It is recommended that section 5.0 of the written scheme is reviewed and appropriate corrections made to the numbering system where required.
13. It is recommended that a review is made of all the deadlegs identified in the risk assessment and of the status of the deadleg removal programme.
14. It is recommended that the process of communication of the DMA Canyon Ltd task records to the QEUH Estates Department is reviewed and amended as required.
15. It is recommended that a complete copy of all records relating to the DMA Canyon Ltd risk reduction tasks and procedures are held onsite at the QEUH.

16. It is recommended that a check is made to see if these required cold water storage tank inspections have been completed. If they have been completed then this should be reflected in the records. If these actions have not been completed then the actions should be addressed as soon as possible.
17. It is recommended that a check is made to see if the required internal inspection of calorifiers have been completed. If they have been completed then this should be reflected in the records. If these actions have not been completed then the actions should be addressed as soon as possible.
18. It is recommended that copies of the records of the shower and spray head cleans are held in the QEUH record systems.
19. It is recommended that a check is made to see if any remedial actions were completed as a result of the above calorifier temperature defects. If actions were completed they should be entered into the remedial action record. If the actions are outstanding then they should be addressed as soon as possible.
20. It is recommended that a review of the hot outlet temperature monitoring procedures is made to ensure that the tasks are completed on a monthly basis.
21. It is recommended that a response is completed and recorded to any out of specification situations that are found with the hot water temperatures.
22. It is recommended that the hot and cold sentinel locations are confirmed and that once they have been confirmed, the current monthly temperature monitoring programme is reviewed to ensure that the appropriate outlets are being included temperature monitoring programme.
23. It is recommended that the approach to monitoring temperatures in representative outlets is clearly defined and then implemented in the hospital.
24. It should be confirmed that where fitted all single entry expansion vessel are being appropriately flushed.
25. It is recommended that NHS GGC formalises its approach to TMV/TMT servicing and institutes the service protocol when it is agreed.
26. It is recommended that the list of required tasks, based on the most recent risk assessment, is reviewed to ensure that it is comprehensive.
27. It is recommended once the comprehensive list of tasks is confirmed, that the responsibility for completion of the tasks is assigned to the relevant NHS GGC party or external contractors. All of the involved parties must be made fully aware of the responsibilities.
28. It is recommended that the lines of communication for the task completion records are clarified and implemented in a way that ensures that NHS GGC records meet the requirements of the guidance.
29. It is recommended that all sentinel outlets are monitored for levels of chlorine dioxide in accordance with HSG 274 guidance para 2.100.

30. It is recommended that the QEUH makes weekly checks on the operation of the chlorine dioxide dosing equipment and also the chlorite to chlorine dioxide conversion yield as required in the HSG 274 guidance in para 2.100.
31. It is recommended that the need for LUO flushing throughout the QEUH is reviewed and is implemented and recorded where required.
32. It is recommended that a review of the outstanding risk assessment remedial actions is completed and a programme to address the outstanding actions is put into place as soon as possible.
33. It is recommended that a robust process of recording out of specification results, along with an auditable record of the appropriate remedial actions is created and implemented as soon as possible.
34. It is recommended that the QEUH written scheme action table for positive legionella results is amended to reflect table 2.3 of the HSG 274 document.
35. It is recommended that the method statement for taking hot sentinel tap temperatures is amended to ensure that the target temperature is a minimum of 55°C.

Section 5 On Going Water Treatment		Y/N U/K or Partial	Comments	Risk Level
5.1	Is there any form of water treatment in use on site?	Y	Incoming mains water is treated via a membrane filtration system. The treated mains water is secondary disinfected using chlorine dioxide.	
5.2	Is there any form of secondary disinfection in place on site?	Y	Chlorine dioxide is used to treat all domestic hot and cold water systems in the hospital.	
5.3	Are the required checks as detailed in the HSG 274 document for the use of chlorine dioxide as a secondary disinfectant being completed.	N	Discussions were held with the contractor, DMA Canyon Ltd, who complete the analytical testing of the water systems for chlorine dioxide levels. Tests are completed on the hot and cold water systems at 78 locations throughout the hospital. This does not cover all of the sentinel points in the hospital water systems but was deemed by NHS GGC to be representative of the levels of chlorine dioxide that would be found throughout the hospital water systems.	

			Tests are completed on a weekly basis and a full set of records were available from DMA Canyon Ltd. It is noted in the HSG 274 document that there is a requirement to complete monthly total oxidant and chlorite levels as well as to calculate the conversion yield to chlorine dioxide. It was stated by DMA Canyon Ltd that this is not part of their contracted obligation and that this work may be getting completed by Scotmas and/or the Water Solutions Group. In the HSG 274 guidance in para 2.100, there is a requirement for a weekly check to be made on the operation of the chlorine dioxide generators and also to check and record the levels of feedstock chemicals at each generator. It was stated at the time of the audit that these tasks are not the remit of DMA Canyon Ltd. They may be being completed by Scotmas and/or another contractor. Recommendations relating to this issue can be found earlier in the report in section 4.12	
5.4	Are the required levels of disinfection being achieved in the water systems?	Y	The required levels are being achieved in the cold water systems with readings typically sitting around the 0.3 mg/l level. The levels in the hot water systems are lower at typically 0.02 to around 0.2 mg/l. This is to be expected in the hot water systems.	
5.5	Is any of the water base exchange softened?	N		

5.6	Are service records for the base exchange softeners available in the written scheme?	N/A		
5.7	Is filtration in use in any of the water systems?	Y	Mains water is treated via a membrane filtration system.	
5.8	Are service records for the filtration equipment available in the written scheme?	Y	There was a folder in the Estates' office detailing the service records for the filtration plant. Filter plant 1 had records available for Feb 2019 to Sep 2019 and operational checks were made weekly by NHS GGC Estates staff. Filter plant 2 had records available for weekly checks for Feb 2019 to Jun 2019 and then for Aug and Sep 2019 (apart from August when checks were completed on a daily basis) by Estates staff It appears that there are no records available for dates after September 2019. It is recommended that a review is made to see if the checks on the filter plant are being completed. If they are not then they should be reinstated and the appropriate details added to the records system.	

Recommendations on Ongoing Water Treatment

36. It is recommended that a review is made to see if the checks on the filter plant are being completed. If they are not then they should be reinstated and the appropriate details added to the records system.

Section 6 Cleaning and Disinfection Procedures		Y/N U/K or Partial	Comments	Risk Level
6.1	Are system cleaning and disinfection procedures in use on site?	U/K	It could not be confirmed during this scheduled audit process if cleans and disinfections were being completed on the hospital water systems. There was no documentary evidence available in the record systems to support the fact that cleans and disinfections were being undertaken. Discussions with DMA Canyon Ltd indicated that cleaning and disinfections of the cold water storage tanks has taken place in the past few months. Some cleaning and disinfection procedures were ongoing at the time of writing this report. The lack of clarity on the use of cleaning and disinfection procedures gives rise to concerns that any cleans and disinfections that may be required are not being completed and recorded in a suitable fashion. It is recommended that the policy on the use of cleans and disinfections in NHS GGC at the QEUH is reviewed and updated if required. This review should include the decision making process for the use of cleans and disinfections and the use and recording of appropriate documentation including inspection reports, method statements, MSDS and cleaning and disinfection certification.	
6.2	Are the cleaning and disinfection procedures completed by in house staff?	N	Discussions with the contractor indicated that cleans and disinfections of the cold water storage tanks are being completed by DMA Canyon Ltd.	

6.3	Are the in house staff trained and competent to complete cleans and disinfections?	N/A		
6.4	Are the contractor's staff trained and competent to complete cleans and disinfections?	Y	It is understood that DMA Canyon Ltd staff are trained and competent in delivering cleaning and disinfection procedures.	
6.5	Are cleaning and disinfection procedures completed as a matter of procedure?	U/K	It was noted in the QEUH written scheme on page 92 that there is a recommendation that advice of a contractor should be sought with regard to the need for cleaning and disinfection.	
6.6	Are these cleaning and disinfection procedures completed in response to sampling/inspection results.	U/K	See comment above	
6.9	Are there suitable method statements available in the written scheme covering the cleaning and disinfection procedures?	N	It is stated on page 92 of the written scheme that contactor advice should be sought in regard to any cleaning requirements. It is to be assumed that any cleans and disinfections would be completed by a contractor and that the contractor would supply suitable method statements when required. It is recommended that any method statement for cleaning and disinfection procedures are checked for suitability prior to any work being placed with a contractor	
6.10	If chlorine is used, is the impact of pH considered in the disinfection process.	U/K	This issue would be confirmed by an examination of the suitability of the method statements.	
6.11	Are there completion certificates in the written scheme covering any disinfection procedures that have been undertaken?	N	There were no completion certificates available in the record systems. This issue is covered by the recommendation made in section 6.1 above of this report.	

6.12	Are localised outlet disinfections in use on site?	U/K		
6.13	Is there a suitable method statement available in the written scheme covering the localised cleaning and disinfection procedures?	U/K		

Recommendations on Cleaning and Disinfection Procedures

37. It is recommended that the policy on the use of cleans and disinfections in NHS GGC at the QEUH is reviewed and updated if required. This review should include the decision making process for the use of cleans and disinfections and the use and recording of appropriate documentation including inspection reports, method statements, MSDS and cleaning and disinfection certification.
38. It is recommended that any method statement for cleaning and disinfection procedures are checked for suitability prior to any work being placed with a contractor

Section 7 New Build and Refurb Capital Projects		Y/N U/K or Partial	Comments	Risk Level
7.1	Have any new build or refurbishment projects, which impacted on the water systems, been completed in the past 12 months.	Y	It was stated at the time of the audit that a small refurbishment project had taken place at the minor injuries unit at the rear of the QEUH building. This refurbishment had involved the use of a simple water system which had been taken from the main building water system.	
7.2	Were the implications of this work risk assessed?	U/K	There was no information in the on-site records to suggest that this work had been assessed. It is recommended that NHS GGC satisfy themselves with the proposed risk reduction processes and procedures for the additional water system.	

7.3	Was the assessment added to the logbook and water system records?	N	It is recommended that any details relating to the operation of this additional water system, and the implications, if any, for the existing water system, are added to the written scheme.	
7.4	Was the written scheme amended to account for the implications of the new build/amended water systems?	N	See recommendation in section 7.3.	
7.5	Were the details of the new systems discussed with the Estates Department and any other involved personnel?	U/K		
7.6	Are minutes of discussions regarding the new water systems recorded and entered into the logbook?	N	It is recommended in future that any work which has implications for the building water systems is discussed and appropriate records of the discussions are made and stored in the records in the written scheme.	
7.7	Were systems, if required, cleaned and disinfected?	U/K	It was stated during the audit that the water systems were disinfected and that the records of this would be found in the handover manual for the project. It is recommended that the handover records for the MIU project are checked to ensure that suitable disinfection records are available.	
7.8	Are records of all cleans and disinfections available in the record systems?	U/K	See recommendation in section 7.7.	

Recommendations on New Build and Refurb Capital Projects

39. It is recommended that NHS GGC satisfy themselves with the proposed risk reduction processes and procedures for the additional water system.
40. It is recommended that any details relating to the operation of this additional water system, and the implications, if any, for the existing water system, are added to the written scheme.

41. It is recommended in future that any work which has implications for the building water systems is discussed and appropriate records of the discussions are made and stored in the records in the written scheme.
42. It is recommended that the handover records for the MIU project are checked to ensure that suitable disinfection records are available.

Water Safety Group		Y/N U/K or Partial	Comments	Risk Level
8.1	Is there a Water Safety Group in place?	Y	NHS GGC holds WSG meetings on a quarterly basis	
8.2	Does the WSG have all the required groups represented?	U/K	It is recommended that a check is made to ensure that all the required groups are attending the water safety group meetings.	
8.3	Are WSG meetings held on a quarterly basis?	Y		
8.4	Are minutes and actions produced and followed through with the WSG?	Y		

Recommendations on the Water Safety Group

43. It is recommended that a check is made to ensure that all the required groups are attending the water safety group meetings.

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Authorising Engineer Water Systems Management and Compliance Audit of NHS Water Systems
NHS GGH QEUH and RHC Hospitals Document A – Management Review

Site Address: Queen Elizabeth University Hospital and the Royal Hospital for Children Hospital, 1345 Govan Rd, Glasgow G51 4TF		
Date of Audit: 4th and 5th February 2021	**Auditor:** Dennis Kelly Snr	**NHS Staff Interviewed:** Mel MacMillan – Estates Manager Kerr Clarkson

Site Description and the Approach used for the Completion of this Audit

This audit was completed on the NHS GGC QEUH and RHC properties only. These hospitals are situated on the Queen Elizabeth University Hospital campus.

The QEUH adult Hospital building comprises of 12 stories, with the basement housing FM areas. Connected to the main building is the RHC Hospital comprising of 4 storeys.

There are two mains water supplies coming into the buildings and these are switched on a regular basis to limit the opportunity for stagnation in the mains water supply pipework.

Raw mains water is held in raw water tanks before being passed through a 0.2 micron membrane filtration process and is then stored in treated water storage tanks.

Cold water is then distributed through the hospitals via booster pump sets located in the tank room. Hot water is provided by a number of calorifier heating stations installed throughout the hospitals.

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The hospital water systems are secondary disinfected with chlorine dioxide via multiple retrofitted dosing systems located throughout the hospitals.

Given the size of the two hospitals the water systems are large and complex. There are around 1400 en suite bedrooms and in excess of 3500 TMV/TMT's in the buildings.

Many of the retained estate buildings on the QEUH Campus were audited before Christmas 2020.

This audit of the QEUH and the RHC follows the same approach as was created for the audit of the large number of buildings on the retained estate. Two documents were created for this audit process. The first document is entitled "Authorising Engineer Water Systems Management and Compliance Audit of NHS Water Systems – NHS GGC QEUH and RHC Hospitals, Document A – Management Review".

This management review document covers the following common sections of the audit:-

- Risk Assessment
- Management and Competency
- Cleaning and Disinfection Procedures
- New Build and Refurb Capital Projects
- Water Safety Group

Part B of the audit Process involves a review of the processes and procedures, essentially the task elements, that are specific to each individual building. This section of the audit is called "Authorising Engineer Water Systems Management and Compliance Audit of NHS Water Systems – NHS GGC QEUH and RHC Hospitals Document B – Individual Building Audit Details". This part of the audit covers issues that relate to the specific building that is being audited. It contains the following sections-

- Risk Assessment Specific to the Building being Audited
- Schematic Drawings

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- Written Scheme Monitoring and Records
- On Going Water Treatment
- Task Completion

Executive Summary:

This audit of the QEUH and RHC hospital buildings was previously a lengthy and time consuming process. However, the much improved record systems and updated processes that had been developed and successfully implemented since the QEUH/RHC hospital audit was completed in January 2020 have made this a less onerous process. During the January 2020 QEUH audit there were problems in finding records and evidencing that the required procedures had been completed and generally in providing confidence that much of the risk reduction requirements were being suitably delivered.

Congratulations are therefore due to the Estates staff who addressed these issues and then developed and implemented the current processes, along with the water hygiene contractor. The active engagement between the Estates Department and the contractor has been central to many of the improvements on site.

One of the key comparisons worth noting is that during the January 2020 audit, while the majority of the required tasks were being completed, it was difficult to evidence that fact in the record systems. In this audit it is obvious that these concerns have been addressed. As a consequence, the level of task completion is higher than that of previous audits.

Examples of processes that are now in place, and that were difficult to access or were absent in January 2020 would include up to date logbooks for all the contractor completed tasks as well as electronic records of the Estates department completed tasks. The electronic Scart folder now holds up to date records of many of the procedures, some of which were previously difficult to find. These would include microbiological sampling records and crucially, out of specification recording and tracking through to problem resolution.

Further examples would include the fact that disinfection certificates were more easily accessible during this audit process, as were the records of the required analysis on the chlorine dioxide levels in two hospitals.

A further process that is worthy of note is the implementation of an interview process for contractors that are looking to complete work on the hospital water systems. Competency assessment is crucial to ensure that water systems contractors are delivering the work safely, to the required quality level, and in a way that does not increase patient risk. This approach has led to some contractors implementing training programmes prior to their staff being allowed to work in the hospital environment.

It was also noted that the Smart sheets system, operated in conjunction with the NHS GGC Compliance manager, is being utilised to hold staff training records and copies of the hospital audits. NHS GGC are also actively reviewing the hospital compliance audits using an SOP created for this process. This is an example of a positive development in the water related risk reduction processes on site.

An audit however is likely to identify areas for improvement, and that is the case with this current audit exercise. However, the areas identified are much fewer in number and are more easily addressed and rectified than those uncovered in the January 2020 audit.

There would appear to be an issue with the interface between Estates the NHS GGC Projects group. Where Projects are completing any work on site, that there needs to be close involvement with Estates on the implications for existing building water systems and also for identification of the ongoing risk reduction requirement in the new Project delivered buildings. The AE understands that work is in progress to address this issue.

There are fourteen recommendations on this management section audit.

Finally, sincere thanks are due to Kerr Clarkson and Mel MacMillan for the help and support during this audit process. They should also be recognised for leading the excellent progress that has been made over the past year in driving the improvement in the processes and the recording of these processes in relation to the operation of the hospital water systems.

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NHS GGH QEUH and RHC Hospitals Document A – Management Review

Description of Levels of Risk:

Very High	Urgent Remedial Action – Lp growth and aerosol opportunity with susceptible people present on site
High	Remedial Action is needed but not immediately – Lp growth opportunity is present
Medium	Acceptable risk but some concerns– Lp likely to be controlled but improvements should be sought
Low	Risk controlled and acceptable

Levels of Risk found during the Audit:

The levels of risk detailed below reflects the highest level of risk identified during the audit of that particular topic.

The audit process reviews the following 8 areas.:-

Audited Topic	Level of Risk
Risk Assessment	
Management and Competency	
Cleaning and Disinfection Procedures	
New Build and Refurb Capital Projects	
Water Safety Group	

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Authorising Engineer Water Systems Management and Compliance Audit of NHS Water Systems
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Summary of Actions				
	Actions	**Risk Level**	**Completed Date**	**Signature**
1.	It is recommended that NHS GGC check that specialists have been engaged to confirm that the information detailed in section 8 of the current risk assessment is reflective of the function of the 15 other water systems on site.			
2.	It is recommended that DMA Canyon are requested to provide details of the competency of the involved staff and that these details are added to the written scheme.			
3.	It is recommended that a check be made as to whether the duty holder for water in NHS GGC is aware of his/her water based responsibility.			
4.	It is recommended that a check be made as to whether the responsible person for water in NHS GGC has been appointed and is nominated in writing.			
5.	It is recommended that a check is made to ensure that it is the most current edition of the Written Scheme document that is being used across the site and is also in the SCART system.			
6.	It is recommended that contractor review meetings are held on a regular basis and that notes, bullet point and actions are recorded from these meetings.			
7.	It is recommended that the quarterly review meetings are extended in scope to include the tasks completed by NHS Estates staff and not only the tasks undertaken by the contractor.			
8.	It is recommended that any method statements for cleaning and disinfection procedures are checked for suitability prior to any work being			

	placed with a contractor and that copies of the method statements are kept in the Written Scheme either electronically or in hard copy.			
9.	It is recommended that NHS GGC risk assess the additional water system and then satisfy themselves with the proposed risk reduction processes and procedures for the additional water system.			
10.	It is recommended that any details relating to the operation of this MIU new water system, and the implications, if any, for the existing water system, are added to the written scheme.			
11.	It is recommended that all projects involving new installations, additions or alteration to building water systems are made known to the hospital Estates Department and that the required risk reduction processes and procedures are added to the hospital water safety plan.			
12.	It is recommended in future that any work which has implications for the building water systems is discussed and appropriate records of the discussions are made and stored in the records in the written scheme.			
13.	It is recommended that the handover records for the MIU project are checked to ensure that suitable disinfection records are available.			
14.	It is recommended that a check is made to ensure that all the required groups are attending the Water Safety Group meetings.			

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Authorising Engineer Water Systems Management and Compliance Audit of NHS Water Systems
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Section A1 Risk Assessment		Y/N U/K, N/A or Partial	Comments	Risk Level
A1.1	Does the risk assessment address all the water systems in the building?	Partial	The risk assessment covers the operation of the hot and cold water systems in the two hospitals. Section 8 of the current risk assessment details 15 other water systems in the two hospitals and includes a brief description of each system as well as an initial assessment of risk. It further advises that specialists in each field are consulted to confirm the risk assessment detail is reflective of the function of each water system. It is recommended that NHS GGC check that specialists have been engaged to confirm that the information detailed in section 8 of the current risk assessment is reflective of the function of the 15 other water systems on site.	
A1.2	Are there any systems that are defined as being excluded from the assessments in the RA scope?	Y	Although the Hydrotherapy pool was mentioned in the list of additional water systems, the risk assessment document did state that the pool was not assessed in the risk assessment process. However, it did state on page 4 of section 3 of the report that the hydrotherapy pool was “covered under a separate assessment”.	
A1.3	Does the risk assessment review the current risk reduction processes and procedures that are currently in use at the site?	Y	The current risk reduction processes are reviewed in Section 9 of the document.	
A1.4	Does the risk assessment contain details of the people/organisations who are involved in the risk reduction processes and	Y	Section 9 of the risk assessment document is entitled “Governance and Documentation Review”. This section contains a comprehensive description of the roles and responsibilities for water within the NHS	

	procedures? This should include comments on the dutyholder, the responsible person, any deputy responsible persons and also service providers and contractors.		GGC organisation and also the named individuals that hold these roles. Information on DMA Canyon Ltd, who are the main service provider, can be found at the start of the risk assessment document.	
A1.5	Is there an assessment of the competency of all involved parties in the risk assessment?	Y	Section 9 of the risk assessment details that there were no training records available. the training of all client involved personnel. The risk assessment document states that the DMA Canyon Ltd competency details are filed centrally in their local office and can be accessed by request from DMA Canyon Ltd. It is recommended that DMA Canyon are requested to provide details of the competency of the involved staff and that these details are added to the written scheme.	
A1.6	Does the risk assessment specifically address and comment on evidence of the current defect/remedial action processes and procedures?	Y	Section 9 of the risk assessment includes a gap analysis which comments on the evidence of the current remedial processes and procedures.	
A1.7	Is there an assessment of the susceptibility of persons who may be affected by the building water systems?	Y	This is covered in Section 1 of the risk assessment document.	
A1.8	Is there a schematic diagram provided with the risk assessment?	N	There are no schematics in the risk assessment document but as fitted drawings for both hospitals are available elsewhere in the Zutec system and are stored electronically. It may be the case that the supply of schematic diagrams was not part of the scope of supply covering the new risk assessment.	

A1.9	Is there a new written scheme provided as part of the risk assessment?	Partial	This may not have been part of the scope of supply agreed with the risk assessment supplier. There is guidance provided in section 10 of the risk assessment document as to what should be included in a written scheme. Site has created a comprehensive written scheme since the current RA has been completed. This document ahds also been updated on a number of occasions.	
A1.10	Does the assessment contain details of all the component parts of the water systems? This could include tanks, calorifiers, pipework and pipework layout, outlets, TMV's, expansion vessels etc etc etc.	Y		
A1.11	Is consideration given to system design, flow, temperature and the opportunity for bacteria to grow and develop in the water systems?	Y		
A1.12	Does the risk assessment identify any particular areas of spray and aerosol creation?	Y	This information is detailed and is available in section 7 of the DMA Canyon Ltd risk assessment documents.	
A1.13	Are areas of low use and low flow identified in the risk assessment?	Y	This information is detailed and is available in section 7 of the DMA Canyon Ltd risk assessment documents.	
A1.14	Are deadlegs specifically detailed in the risk assessment?	Y	This information is detailed and is available in section 7 of the DMA Canyon Ltd risk assessment documents. The information on deadlegs can also be found in Section 2, Recommendations, of the risk assessment document.	

A1.15	Is there a set of remedial actions clearly identified in the risk assessment?	Y	The remedial actions are detailed in section 2 in the RA document in the section titled Recommendations.	
A1.16	Is there a clearly explained risk scoring system in the risk assessment?	Y	The risk scoring system is explained in section 2 of the RA document.	
A1.17	Are there any areas of augmented care on the campus?	Y	There are areas of augmented care in the hospital as per the criteria detailed in HPS guidelines.	
A1.18	Have Pseudomonas risk assessments been completed?	Y	Pseudomonas risk assessments are completed on an annual basis.	

Actions on Risk Assessment

1. It is recommended that NHS GGC check that specialists have been engaged to confirm that the information detailed in section 8 of the current risk assessment is reflective of the function of the 15 other water systems on site.
2. It is recommended that DMA Canyon are requested to provide details of the competency of the involved staff and that these details are added to the written scheme.

Section A2 Management and Competency		Y/N U/K, N/A or Partial	Comments	Risk Level
A2.1	Is there a duty holder nominated on the Board?	Y	There is a copy of an NHS GGC Policy Document dated January 2019 available electronically on site. In appendix 1 of the policy document it states that the Duty Holder is the Chief Executive. A more detailed hierarchy table was also available naming people who are responsible for the various positions with regard to water.	

			It is recommended that a check be made as to whether the duty holder for water in NHS GGC is aware of his/her water based responsibility.	
A2.2	Is there a responsible person nominated in writing?	Partial	In NHS GGC, the sector estates manager is regarded as the responsible person and this is recorded, and is up to date, in the on-site WSP. It is recommended that a check be made as to whether the responsible person for water in NHS GGC has been appointed and is nominated in writing.	
A2.3	Is there a clearly defined management structure which includes the relevant on site personnel and also all service providers and contractors?	Y	The management structure is defined in appendix 1 of the NHS GGC water policy. It is further defined in Section 3.2 of the Written Scheme document.	
A2.4	Is there a clearly defined line of communication in the written schemes?	Y	This is covered in the management organogram in section 3.2 of the QEUH Campus written scheme.	
A2.5	Are the responsibilities of all involved parties clearly defined in the written scheme?	Y	Roles and responsibilities are defined in table 3.1 of the written scheme.	
A2.6	Does the organisation have an up to date and current policy document?	Y	NHS GGC has a policy document dated as approved in January 2020. The auditor was informed at the time of this audit that the Written Scheme document is undergoing a review and an update process.	
A2.7	Does the organisation have an up to date and current procedures document?	Partial	NHS GGC has a Written Scheme document for the QEUH Campus. A copy can be found in Smartsheets and is dated as 2019 Rev D. It is known that an updated document is being worked on, and it was stated at the time if this audit that more recent updates may exist in the SCART system.	

			It is recommended that a check is made to ensure that it is the most current edition of the Written Scheme document that is being used across the site and is also in the SCART system.	
A2.8	Do all staff have relevant up to date training in place?	Y	The board wide water skills register available on Smart Sheet lists 19 staff members for the QEUH campus and details the training that each has received. The Smartsheet spreadsheet details the fact that all of the training is currently up to date. There is also a list of senior staff members who are considered to be Responsible persons on the Smartsheet system and the training for these people is also stated to be up to date.	
A2.9	Are copies of the site personnel training records available in the written scheme?	Y	There was a note beneath table 3.1 of the QEUH written scheme advising that relevant training records and appointment letters are electronically filed on the QEUH shared drive within folder “Water Quality Training and Appointments”.	
A2.10	Is there evidence available in the written scheme of the competency of service providers’ and contractors’ staff?		This issue is normally addressed at the procurement stage. The water hygiene contractor, DMA Canyon Ltd, is a member of the LCA and training records for the DMA Canyon Ltd staff are available. It is known that the framework plumbing contractor, Morris & Spottiswood, have also had their staff undertake Legionella Awareness training. A record of plumbing contractors is also now kept by the AP Lead for Water. All contractors are formally interviewed to assess their level of competence and understanding prior to them being allowed to work on the Campus water systems. The AP Lead for water is to be commended for this excellent process. Copies of contractor training certificates are kept in the AP Lead for Water’s office. Letters of appointment are issued to contractors after the interview process and copies of these letters were also available on site.	

A2.11	Are service providers and contractors LCA registered?	Y	DMA Canyon Ltd is LCA registered. Evidence of the registration was available on the LCA website. The main plumbing contractor is not LCA registered but it should be noted that not many plumbing contractors are registered in the LCA system.	
A2.12	If the suppliers are not LCA registered do they have other means of proving competence?	Y	Staff training certificates have been supplied by Morris and Spottiswood who are the framework plumbing contractor for NHS GGC. It should be noted that very few plumbing organisations are registered with the LCA organisation.	
A2.13	Is there a formal contractor management process in place or any evidence available in the written scheme of review meetings with service providers and contractors?	Partial	Section 3.12 of the written scheme details that regular reviewing meetings should be held with contractors and that review meeting minutes are to be filed on the QEUH Estates shared drive at path SGH Estates > water quality > contractor meetings. DMA Canyon Ltd contractor review meeting minutes were filed in this location. It is suggested that these meetings are carried out at least quarterly. It should be noted that more recently meetings will have been suspended because of the influence of the Covid situation in the UK. It is recommended that contractor review meetings are held on a regular basis and that notes, bullet point and actions are recorded from these meetings.	
A2.14	Is there any evidence in the written scheme of management reviews of the data and results produced by the monitoring and control processes and procedures?	Partial	The minutes of the review meetings with DMA Canyon were available for the past twelve months. As an example, the meeting notes from the 17th December 2019 were reviewed. It was noted that these reviews relate only to the tasks undertaken by DMA Canyon. As a consequence, therefore it is further noted that there does not appear to be any review of the risk reduction tasks that are completed by NHS Estates staff on site.	

			It is recommended that the quarterly review meetings are extended in scope to include the tasks completed by NHS Estates staff and not only the tasks undertaken by the contractor.	
A2.15	Is there evidence that authorised person competency checks have been completed?	Y	AP competency checks are carried out by the AE Water as and when requested by site. NHS GGC has completed competency checks on a significant number of staff over the past three years Details of the appointment of AP's can be found on the Board Wide Water Skills Register in Smart Sheets	
A2.16	Does the Board have a process for out of specification situations?	Y	DMA Canyon Ltd is the contractor that is used to deliver a number of the on-site risk reduction processes and procedures. DMA sends in a monthly excel spreadsheet summary of what work they have completed. This spreadsheet details the outcome of all the DMA completed monthly check tasks. NHS GGC Estates management staff extract the required remedial actions from the DMA spreadsheet and enter these into the FM 1st system and an FM 1st number is applied to the required jobs. The required jobs are issued to the onsite staff every week under an FM 1st number. The work is completed and the sheets are returned to the Estates managers. For risk reduction tasks that are completed by onsite estates staff, the required tasks are sent to a PDA with an FM 1st number. Any required remedial actions are identified and are fixed at the time they are noted. The action is recorded on the FM 1st job sheet. Any more significant issues are reported as an incident and a specific FM First number and task is issued to the Estates Department staff by the Estates Department management team.	

A2.17	Are non-conformances addressed with appropriate actions and recorded in the written scheme?	Y	The response to non-conformances can be tracked in the Excel spreadsheet system and on FM 1st. Most minor issues are addressed and sorted at the time they are noted.	
A2.18	Does the written scheme contain an "audit trail" for out of specification situations that allows for remedial actions to be tracked through to completion?	Y	A review of the 2020 logging system states that there were 120 incidents during 2020. The audit trail for all of these can be found in the Scart folder in section 22.	
A2.19	Is there a specific escalation procedure for positive Legionella results?	Y	When an issue is apparent it is reported on the microbiological control spreadsheet. The reports are also issued to the microbiologists and also to infection control. This process is detailed on page 93 of the written scheme.	
A2.20	Are Legionella samples being taken and who is taking the samples?	Y	Samples are taken on a programmed basis by DMA Canyon Ltd.	
A2.21	Are Legionella samples being taken in accordance with BS7592:2008?	Y	DMA Canyon Ltd have had staff training in sampling technique. They also have suitable and sufficient RAMS for sampling.	

Actions on Management and Competency

3. It is recommended that a check be made as to whether the duty holder for water in NHS GGC is aware of his/her water based responsibility.
4. It is recommended that a check be made as to whether the responsible person for water in NHS GGC has been appointed and is nominated in writing.
5. It is recommended that a check is made to ensure that it is the most current edition of the Written Scheme document that is being used across the site and is also in the SCART system.
6. It is recommended that contractor review meetings are held on a regular basis and that notes, bullet point and actions are recorded from these meetings.

7. It is recommended that the quarterly review meetings are extended in scope to include the tasks completed by NHS Estates staff and not only the tasks undertaken by the contractor.

Section A3 Cleaning and Disinfection Procedures		Y/N U/K, N/A or Partial	Comments	Risk Level
A3.1	Are system cleaning and disinfection procedures in use on site?	Y		
A3.2	Are the cleaning and disinfection procedures completed by in house staff?	N	Discussions with the Estates Department indicated that cleans and disinfections of the cold water storage tanks are being completed by DMA Canyon Ltd.	
A3.3	Are the in house staff trained and competent to complete cleans and disinfections?	N/A	This question does not apply as all disinfections are completed by external contractors.	
A3.4	Are the contractor's staff trained and competent to complete cleans and disinfections?	Y	It is understood that DMA Canyon Ltd staff are trained and competent in delivering cleaning and disinfection procedures.	
A3.5	Are cleaning and disinfection procedures completed as a matter of procedure?	Y	Cold water storage tanks are cleaned and disinfected by the contractor on an annual basis.	
A3.6	Are these cleaning and disinfection procedures completed in response to sampling/inspection results?	N	It should be noted that if any tanks, after inspection, were found to be dirty, then they would be cleaned and disinfected.	
A3.7	Are there suitable method statements available in the written	Partial	It is to be assumed that any cleans and disinfections would be completed by a contractor and that the contractor would supply suitable method statements when required. If the contractor is DMA	

	scheme covering the cleaning and disinfection procedures?		Canyon Ltd then the method statements, which have previously been audited by the contractor, are known to be suitable and sufficient. It is recommended that any method statements for cleaning and disinfection procedures are checked for suitability prior to any work being placed with a contractor and that copies of the method statements are kept in the Written Scheme either electronically or in hard copy.	
A3.8	If chlorine is used, is the impact of pH considered in the disinfection process.	Y	This task is completed by DMA Canyon Ltd when they clean and disinfect the cold water storage tanks. The details of the pH measurements can be found on the DMA Canyon Ltd disinfection completion certificates.	
A3.9	Are there completion certificates in the written scheme covering any disinfection procedures that have been undertaken?	Y	The DMA Canyon Ltd completion certificates show that pH levels have been taken into account when using chlorine as a disinfectant.	
A3.10	Are localised outlet disinfections in use on site?	Y	These local outlet disinfections are undertaken by DMA Canyon Ltd.	
A3.11	Is there a suitable method statement available in the written scheme covering the localised cleaning and disinfection procedures?	Y		

Actions on Cleaning and Disinfection Procedures

8. It is recommended that any method statements for cleaning and disinfection procedures are checked for suitability prior to any work being placed with a contractor and that copies of the method statements are kept in the Written Scheme either electronically or in hard copy.

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Section A4 New Build and Refurb Capital Projects		Y/N U/K or Partial	Comments	Risk Level
A4.1	Have any new build or refurbishment projects, which impacted on the water systems, been completed in the past 12 months	Y	It was stated at the time of the audit that a small refurbishment project had taken place at the minor injuries unit at the rear of the QEUH building. This refurbishment had involved the use of a simple water system which had been taken from the main building water system. It should be noted that the AE (Water) is involved in recent discussions on the creation of AP's for the Minor Works Projects Team.	
A4.2	Were the implications of this work risk assessed?	N	There was no information in the on-site records to suggest that this work had been assessed. It is recommended that NHS GGC risk assess the additional water system and then satisfy themselves with the proposed risk reduction processes and procedures for the additional water system.	
A4.3	Was the assessment added to the logbook and water system records?	N	It is recommended that any details relating to the operation of this MIU new water system, and the implications, if any, for the existing water system, are added to the written scheme.	
A4.4	Was the written scheme amended to account for the implications of the new build/amended water systems?	U/K	See recommendation in section A4.2	
A4.5	Were the details of the new systems discussed with the Estates Department and any other involved personnel?	U/K	It is recommended that all projects involving new installations, additions or alteration to building water systems are made known to the hospital Estates Department and that the required risk reduction processes and procedures are added to the hospital water safety plan.	
A4.6	Are minutes of discussions regarding the new water systems	N	It is recommended in future that any work which has implications for the building water systems is discussed and appropriate records of the discussions are made and stored in the records in the written scheme.	

	recorded and entered into the logbook?			
A4.7	Were systems, if required, cleaned and disinfected?	Y	It was stated during the audit that the water systems were disinfected and that the records of this would be found in the handover manual for the project. It is recommended that the handover records for the MIU project are checked to ensure that suitable disinfection records are available.	
A4.8	Are records of all cleans and disinfections available in the record systems?	U/K	See recommendation in section A4.7	

Actions on New Build and Refurb Capital Projects

9. It is recommended that NHS GGC risk assess the additional water system and then satisfy themselves with the proposed risk reduction processes and procedures for the additional water system.
10. It is recommended that any details relating to the operation of this MIU new water system, and the implications, if any, for the existing water system, are added to the written scheme.
11. It is recommended that all projects involving new installations, additions or alteration to building water systems are made known to the hospital Estates Department and that the required risk reduction processes and procedures are added to the hospital water safety plan.
12. It is recommended in future that any work which has implications for the building water systems is discussed and appropriate records of the discussions are made and stored in the records in the written scheme.
13. It is recommended that the handover records for the MIU project are checked to ensure that suitable disinfection records are available.

Pro Lp Consulting Ltd

Authorising Engineer Water Systems Management and Compliance Audit of NHS Water Systems
NHS GGH QEUH and RHC Hospitals Document A – Management Review

Section A5 Water Safety Group		Y/N U/K or Partial	Comments	Risk Level
A5.1	Is there a Water Safety Group in place?	Y	NHS GGC holds WSG meetings on a quarterly basis	
A5.2	Does the WSG have all the required groups represented?	U/K	It is recommended that a check is made to ensure that all the required groups are attending the Water Safety Group meetings.	
A5.3	Are WSG meetings held on a quarterly basis?	Y		
A5.4	Are minutes and actions produced and followed through with the WSG?	Y		
Actions on the Water Safety Group				
14. It is recommended that a check is made to ensure that all the required groups are attending the Water Safety Group meetings.				

L8 Risk Assessment

Client: NHS Greater Glasgow & Clyde

Site: Royal Hospital for Children

Ward 2A & 2B

Site Survey Date: 24 & 25 & 28 February 2022
Latest Recommended Review Date: February 2024

VAT Registration No. 743 0970 35 Company Registration No. SC197200
DMA Canyon Ltd. 14 Canyon Road, Wishaw, ML2 0EG T: 01698 536790 E: office@dmacanyon.co.uk

LEGIONELLA RISK ASSESSMENT

Contact Details

	DMA Canyon Ltd
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Telephone No.	01698 536790
Fax No.	01698 360211
e-mail	office@dmacanyon.co.uk
Website	www.dmacanyon.co.uk
DMA Contacts	Mike Kinghorn Director [redacted] David Watson Director Graeme McCullie Director

Risk Assessor Details

Date of Assessment (On Site)	24 & 25 & 28 February 2022
Risk Assessor	Fraser Murray (Assisted by David Watson)
Assisted By	N/A

Risk Assessor assisted on site by (Site Representative)	No Assistance Provided
Position	N/A
Knowledge of systems being surveyed	N/A

N.B. The findings and recommendations presented in this report have been based on information made available and inspection of areas made accessible by site staff during the survey. DMA are only able to assess areas/systems, which they have been given access to and using information supplied by site personnel. This survey was undertaken only on pipe work/areas that were accessible and visible, and it is possible that some sections remained hidden during the survey. Schematic drawings, where produced, and how services link up, have been assumed to run as indicated using basic engineering principles and our experience. However, no responsibility can be accepted for systems and/or areas, which DMA have not been provided access to, or as a result of incorrect, misleading information supplied or information not provided. No guarantees as to the completeness of the information within this report are provided.

LEGIONELLA RISK ASSESSMENT

DMA Staff Training and Competency

All DMA staff attending site are fully trained and deemed competent by DMA management for the tasks they have been allocated to carryout.

DMA training records are held centrally by DMA Canyon Ltd and have been submitted to NHS GG&C.

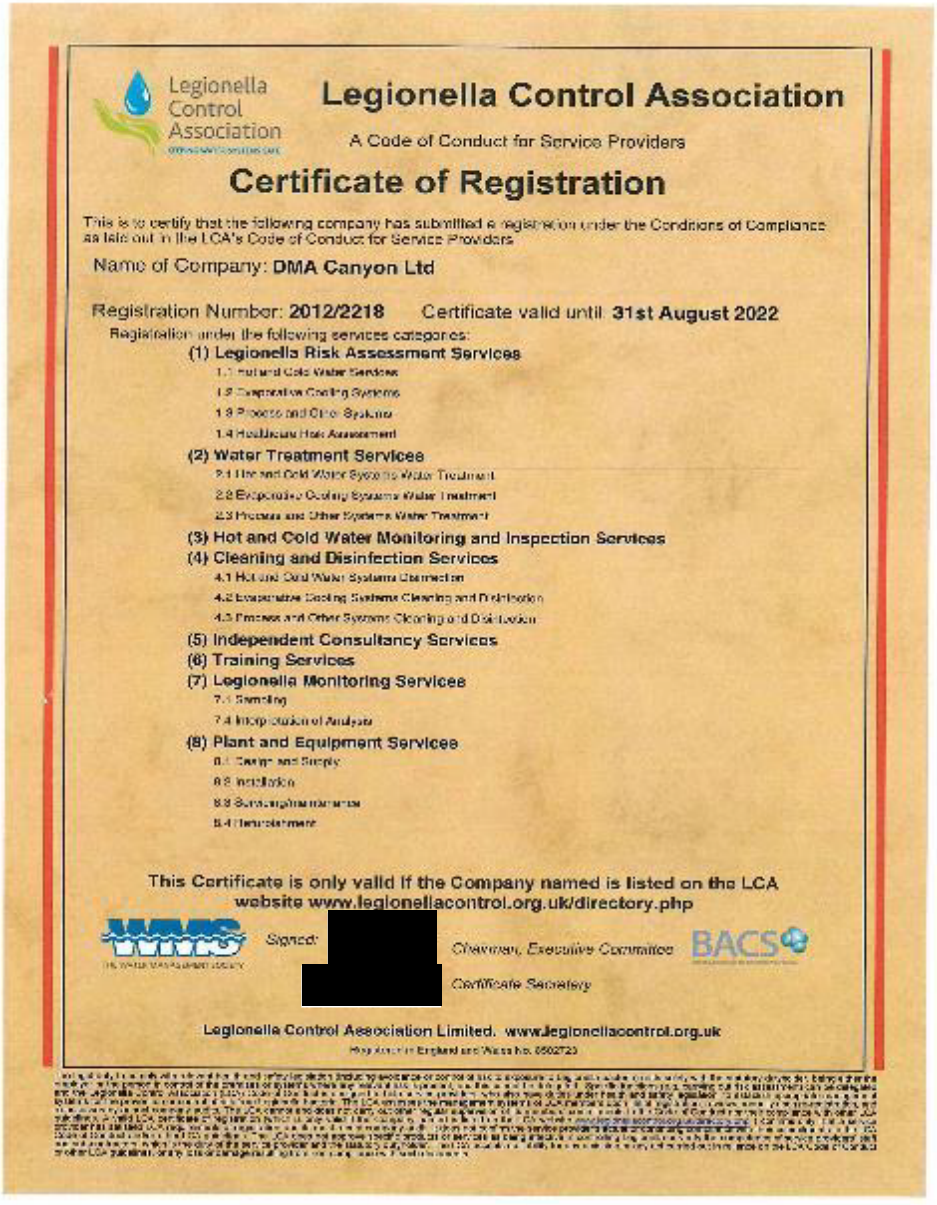
Copies of the relevant personnel training certificates can be supplied upon request.

Training and competency records for site/client/other staff involved in Legionella control should also be held.

DMA will only offer Legionella control services for which we have LCA accreditation.

An up to date copy of our LCA certificate and accreditation details can be found at www.dmacanyon.co.uk

For information on the LCA code of conduct for service providers and other information on the LCA requirements please refer to http://www.legionellacontrol.org.uk/



Legionella Control Association

Legionella Control Association

A Code of Conduct for Service Providers

Certificate of Registration

This is to certify that the following company has submitted a registration under the Conditions of Compliance as laid out in the LCA's Code of Conduct for Service Providers

Name of Company: **DMA Canyon Ltd**

Registration Number: **2012/2218** Certificate valid until: **31st August 2022**

Registration under the following services categories:

(1) Legionella Risk Assessment Services

1.1 Hot and Cold Water Services

1.2 Evaporative Cooling Systems

1.3 Process and Other Systems

1.4 Healthcare Risk Assessment

(2) Water Treatment Services

2.1 Hot and Cold Water Systems Water Treatment

2.2 Evaporative Cooling Systems Water Treatment

2.3 Process and Other Systems Water Treatment

(3) Hot and Cold Water Monitoring and Inspection Services

(4) Cleaning and Disinfection Services

4.1 Hot and Cold Water Systems Disinfection

4.2 Evaporative Cooling Systems Cleaning and Disinfection

4.3 Process and Other Systems Cleaning and Disinfection

(5) Independent Consultancy Services

(6) Training Services

(7) Legionella Monitoring Services

7.1 Sampling

7.2 Interpretation of Analysis

(8) Plant and Equipment Services

8.1 Design and Supply

8.2 Installation

8.3 Servicing/Maintenance

8.4 Refurbishment

This Certificate is only valid if the Company named is listed on the LCA website www.legionellacontrol.org.uk/directory.php

WMS

Signed: [redacted]

Chairman, Executive Committee

Certificate Secretary

BACS

Legionella Control Association Limited. www.legionellacontrol.org.uk

Registered in England and Wales No. 3502723

LEGIONELLA RISK ASSESSMENT

Table of Contents

Section 1

Executive Summary

LEGIONELLA RISK ASSESSMENT

Executive Summary

Site Name	Royal Hospital for Children (QEUH) – Ward 2A & 2B	
Age of building	TBC by Client – advised largely unoccupied/underused for 2-3 years.	
Date water services last upgraded	Evidence of works but no records seen	
Is ward used by potentially "at Risk" groups?	Yes – acute medical conditions (Cancer)	As the ward is used by persons with underlying medical conditions which increases susceptibly to contracting legionellosis (and potentially susceptible to other water borne pathogens) then the requirement to implement a control regime in accordance with L8, HSG 274 and HTM/SHTM 04-01, and other water borne pathogens as directed by ICT/Microbiology is of paramount importance.
Is there a history of legionella colonisation of the water system(s) on site?	No. Sampling sweep in October 2021 across the ward returned "Not Detected" results. Legionella sampling generally across the entire Children's hospital (and the adjoining Adult's hospital) confirms no ongoing legionella contamination issue.	
Water Sources	*Wards 2A and 2B are supplied by the Adult and Children's Hospital incoming town mains supply via the raw water cold storage tanks, filtration system and post filtration cold water storage tanks (CWSTs).* *The post filtration tanks are treated with ClO_2, with additional monitoring/top up stations fitted on the risers post booster pumps.* *In addition to the ClO_2 dosing within the post filtration tanks and on the risers post booster pumps there are additional monitoring/top up stations on the cold water as it enters Plantroom 41 on the supply to the calorifiers (01, 02 & 03) and on the common hot return to the calorifiers.* *Hot and cold water to the ward is delivered via Risers M36 and M39.*	
System Risk	The water systems within Wards 2A & 2B would be considered as "Medium Risk" due to issues around the hot water not being fully balanced at time of survey. Commissioning engineers are carrying out works to commission the system and ensure that all flow and return circuits across the wards are circulating correctly. Upon completion of these works the risk would be considered as "Low Risk".	

LEGIONELLA RISK ASSESSMENT

General System Notes

Is pipework readily accessible?	Pipework runs above ceilings and behind IPS panels and is not routinely accessible (HAI Scribes will be required to access pipework once ward reopens). The majority of the pipework was accessible and visible during the time of survey (however access to pipework and valves above ceilings is very restricted in areas due to other services etc. running in the same space above ceilings).
Is pipework in plant rooms insulated?	N/A for this ward.
Is pipework in pipe chases insulated?	Yes (within Risers M36 and M39)
Is pipework above ceilings insulated?	Yes (Some small sections missing – though these are to be insulated prior to ward reopening)
Is pipework insulated locally to outlets?	Yes
Is accessible pipework labelled?	Yes (though some labelling is incorrect)
Is principle flow and return circuit accessible?	Yes – flow and return accessible within risers.
Is principle flow and return circuit working?	Yes – hot flow and return working within Risers and at calorifiers.
Are all sub-ordinate flow and return circuits accessible?	Pipework runs above ceilings and behind IPS panels and is not routinely accessible. (HAI Scribes will be required to access pipework once ward reopens). The majority of the pipework was mostly accessible and visible during the time of survey (however, access to pipework and valves above ceilings is very restricted in areas due to other services etc. running in the same space above ceilings).
Are all sub-ordinate flow and return circuits working?	There are some issues with flow and return circuits not operating correctly within HOTCT side of ward and one area within BMT, though commissioning engineers working to address this at time of report.
Are low use outlets at end of lines?	End of line points appear to be outlets which should be utilised on a daily basis once ward reopens.

Scope

All accessible domestic hot and cold water systems and pipework within Wards 2A & 2B from risers M36 & M39 onwards were requested to be assessed for Legionella. Pipework was visible and the majority was accessible during the time of survey (however access to pipework and valves above ceilings is very restricted due to other services etc. running in the same space above ceilings).

It has been presumed that all fittings and materials used in the original construction and in all subsequent upgrade works are WRAS approved and suitable for use on the domestic water systems. As the majority of fittings are inaccessible and/or covered in insulation DMA have not verified individual fittings as being WRAS approved.

The survey was carried out at the end of a renovation period which has lasted for over 2 years. During the renovation period a comprehensive flushing regime was implemented on the water services.

This risk assessment covers only the water system installation layout and temperature profile. No review or assessment of the management of the project, commissioning records or ongoing management of the water systems was carried out at this time.

Ward 2A Summary of water services

The water within Ward 2A and 2B is supplied from Risers M36 and M39 in the 2nd floor corridor.

Hot and cold water branches off within each of the risers and supplies different sides of the ward as well as supplying water into adjacent wards/areas.

Riser M39 supplies water to Ward 2A BMT side of the ward and Ward 2B.

Riser M36 supplies water to Ward 2A HOTCT side of the ward and a kitchen within the Anaesthetics department. (Note: this kitchen has moved from the original location to the room next door during the most recent renovation works).

Ward 2A underwent remedial actions to the water system in late 2018/early 2019. This upgrade work on the water system primarily involved the removal of WHBs from the Ante-rooms within the BMT side of the ward and amending the hot flow and return lines to bring them down closer to the outlets within the rooms. Some other minor alterations were made at this time e.g. Arjo bath removed and this bathroom turned into a treatment room and a new treatment room added with a new WHB next to Room 17.

At this time clinical taps within patient rooms and treatment areas (originally HorneOptithems) were replaced with Markwik 21+ TMT taps and all wash hand basins were swapped out and replaced with Armitage wash hand basins with a fin directly under the discharge from the taps. These wash hand basins are designed to minimise splashing when outlets are run. It should be noted though when spouts are misaligned splashing can occur form the WHB out of the confines of the wash hand basin.

Chlorine dioxide (ClO_2) units were installed in the risers supplying Ward 2A/2B at the beginning of these works. Once the main ClO_2 dosing plant was commissioned for the water tanks, and subsequent backup dosing plant on risers, cold supplies into plantrooms and at calorifiers throughout the entire Adult and Children's hospital the ClO_2 dosing units for 2A/2B were decommissioned and removed.

Whilst the main building ClO_2 dosing system was being installed other upgrades to the domestic water systems were carried out, including the installation of an additional filtration unit between raw water and post filter tanks, amendments to the pipework configuration around the CWSTs to allow all three filter units to supply all post filter tanks and the installation of flow-through expansion vessels on the cold supply to the calorifiers in both the Adult and Children's Hospitals.

After these initial upgrade works were completed, the wards reopened for a period as a general ward with the original patient group remaining in Ward 6A within the Adults hospital.

In late 2019 further upgrade works were scheduled for Ward 2A, primarily around the ventilation system. Minimal works were planned for the domestic water system, though some alterations to the layout within Room 21 were carried out, the ensuite bathroom was removed from room 26 to create a patients social space (now referred to as the ETYC) and the main pipework runs in the HOTCT side of the ward had to be stripped out and rerouted to allow for alterations to the ventilation systems located above to be carried out. The pipework within the rooms was unaltered and the pipework from the rooms was reconnected directly onto the new main runs through the corridor.

The schedule for these works was interrupted and delayed by the Covid-19 pandemic through 2020 and 2021.

During all construction works a flushing regime was implemented, initially this was on a 7 days per week basis, dropping to twice per week in January 2021 and then returning to 7 days per week in October 2021, with this regime remaining in place until the ward reopens (anticipated to be 9th March 2022). Whilst the water services were cut off within the HOTCT a temporary cold supply was run in to provide a staff toilet for the contractors and into the TCT Social area to provide a staff canteen. The hot water was looped as it entered the ward to maintain

circulation on the mains lines in the corridor during the construction period. All hot and cold water was maintained as normal in the BMT and Ward 2B areas, with the exception of Room 21.

Within Room 21 and the HOTCT as the pipework was reinstated only cold water was supplied to these areas with the cold lines breached across onto the hot flow and return lines. This allowed the water system to be flushed as required, but without connecting into the main hot recirculating system for the Children's hospital until such times as microbiological sampling had been carried out and acceptable results returned.

The hot water was finally reconnected back onto the main recirculating system for the hospital in February 2022.

In September 2021 microbiological sampling was requested across the entire 2A/2B wards. At this time it was noted that the removable spouts on the Markwik 21+ taps had "de-chromed" and were breaking up. Further investigation on the taps by Armitage revealed further degradation of the other components within the tap. Taps from within Ward 2A/2B were sent off for analysis by Armitage, along with 2 taps from other locations. Reports have been received back from Armitage which highlight chemical attack as being the most likely cause of this degradation (specifically chlorine, with traces of fluorine and phosphorous also being identified cited and as potential causes). Checks on the incoming mains water into the Adult and Children's hospital have highlighted free chlorine levels of up to 0.8 mg/L.

Other taps from areas outwith the Royal Hospital for Children were also sent off for analysis and showed similar signs of degradation even though these had not been treated with ClO_2. Further reports into the potential cause(s) and the impact of the ClO_2 on the taps is being investigated, though no additional reports were available at this time.

Microbiological sampling taken from this time highlighted out of specification results (specifically for Potable analysis and Gram Negative Bacteria/Cupriavidus). Legionella samples taken at this time all returned "not detected" results.

A disinfection of the water system across Ward 2A was instructed and this was carried out in October 2021 using chlorine (25mg/L with a contact time of 2 hours (minimum)).

Further microbiological sampling was then carried out upon completion of the disinfection. It was apparent from these results that the disinfection had had little impact on the microbiological results being returned.

Based on the microbiological results being returned and the condition reports around the tap conditions some pipework sections were removed and replaced, with the pipework sections being submitted to the GRI Lab for analysis. Swab samples were also taken for analysis from the pipework sections and also from the hot and cold strainers, TMV cartridge and tap internal surfaces and submitted to the GRI lab.

Analysis of these samples highlighted that the pipework samples generally had "low" levels of micro-organisms detected, as did the basket strainers from the hot and cold systems on the Markwik 21+ taps. However, the TMV cartridge and the tap internal surfaces generally had much higher levels of micro-organisms detected. The pipework and strainers appeared visibly clean when removed, with the TMV cartridge showing signs of discolouration and degradation.

A further disinfection was then carried out in December 2021, using hydrogen peroxide at 2000mg/L with a contact time of 1 hour (minimum). Microbiological results taken after the disinfection showed some improvement, though a decision had already been taken to replace all Markwik 21+ taps across ward 2A and 2B. This tap replacement project was carried out in early January 2022.

Microbiological results taken at the time when some taps had been replaced, whilst some older taps remained showed a clear distinction between the new and old taps (significantly lower microbiological results from new taps). As the sampling regime continued the results from the new taps were significantly improved from the older taps and could generally be considered to be "within specification" based on parameters and as discussed in meetings about the results with Estates, Clinical, Microbiology and ICT.

During the flushing regime it has been noted that there were black marks being deposited on the WHBs. Similar issues were highlighted previously in the upgrade works. This issue is currently being investigated and samples have been taken and submitted to a laboratory (Intertek) for analysis to try and determine what the material causing the black deposits are. Strainer baskets and TMV cartridges have been removed from the Markwik taps within Ward 2A and 2B and this highlights that the issues appears to be confined to the hot system only. At this stage the deposits do not appear to be having a detrimental impact on the microbiological results being returned. Further investigation and analysis/remedial works are ongoing into this issue at the time of this report.

LEGIONELLA RISK ASSESSMENT

At the time of this report Scotmas had begun preparatory work to install additional ClO_2 generators into risers M36 & M39 on both the hot and cold lines in order to provide scope for additional local control of the ClO_2 levels within Ward 2A & 2B should this be required going forward. It is anticipated that this work shall be completed in April 2022.

Prior to the Wards reopening Point of Use Filters (Pall) shall be fitted to all outlets within the ward and a comprehensive microbiological sampling regime shall be implemented throughout the ward with all outlets being sampled at least monthly for Potable, Pseudomonas and GNB and additionally all outlets being sampled for AMS/NTM on a quarterly basis.

Hot water flow and return temperature monitoring probes have been fitted ward 2A & 2B. 5 probes were installed on HOTCT side, 2 probes on BMT side and 3 probes on Ward 2B and have been tied into the BMS system, with appropriate alarms should the temperature on the lines drop below the control limits.

During the assessment it was highlighted that after the hot water was reconnected to the HOTCT side of the ward some local hot flow and return loops were not circulating properly. At the time of report commissioning engineers are working on the system to balance/commission the system and ensure that all flow and return loops are operating as intended and the correct control temperatures are being achieved.

Section 2

Recommendations

LEGIONELLA RISK ASSESSMENT

Suggested Remedial Action Timescales

Remedial Action Category	Recommended Remedial Action Timescale	Action
1	Immediately / as soon as reasonably practicable	Urgent Significant Investigation & Urgent Remedial Action Required. Senior Management Action Required. Carryout Review of Control Procedures Recommendations within this category should be carried out immediately/as-soon as-is-reasonably practicable. where appropriate remedial actions to rectify the faults cannot be taken immediately/as-soon as-is-reasonably practicable alternative actions to reduce the risk should be carried out, and continue to be carried out, until such times as recommended actions can be completed.
2	As soon as reasonably practicable	Significant Investigation & Remedial Action Required. Senior Management Action Required. Carryout Review of Control Procedures Recommendations within this category should be carried out as-soon as-is-reasonably practicable. Where appropriate remedial actions to rectify the faults cannot be carried out quickly, alternative actions to reduce the risk should be carried out, and continue to be carried out, until such times as recommended actions can be completed.
3	Within 3 months	Investigate/Reduce. Remedial Actions Required. Management responsibility should be specified. Recommendations within this category should be carried out in a timely manner, though simple and/or inexpensive tasks which would reduce the risk should be carried out as-soon-as-reasonably-practicable (e.g. Within 3 months). Additional monitoring/inspection to ensure risk does not increase should be carried out until actions completed.
4	At first available opportunity	Maintain Level Managed by Routine Planned Preventative Maintenance Procedures Whilst recommendations within this category do not significantly Alter the risk it is still advised that these actions are carried out at first available opportunity, typically within a 12 month period of recommendations being made.

For Details of Legionella Management Recommendations please refer to Section 9 of this assessment.

N.B. Prior to any alterations being carried out on fire systems (where recommended) the fire brigade and/or site fire safety consultants should be consulted, and approval of changes received

LEGIONELLA RISK ASSESSMENT

Location / Plant Item	Recommendation	Remedial Action Category	Assigned to	Actions Taken	Completed
Queen Elizabeth University Hospital (Children's Wards 2A & 2B)	As the ward is used by persons with underlying medical conditions which increases susceptibly to contracting legionellosis (and potentially susceptible to other water borne pathogens) then the requirement to implement a control regime in accordance with L8, HSG 274 and HTM/SHTM 04-01, and other water borne pathogens as directed by ICT/Microbiology is of paramount importance.	2			
General System - Hot Flow & Return	Hot flow and return system not fully operational in all areas with multiple tertiary loops found to be failing. Further investigation required with confirmation that current hot flow and return system is balanced correctly throughout. Note: Commissioning engineers clarifying full balancing of system and acceptable F&R temperatures across ward.	2			
Ward 2A Bed 4 (TCT-006)	Hot return not circulating prior to running outlet, with return slowly rising after flushing. Return loop cools when outlet not in use - further investigation required. Note: Upon further investigation it was noted a valve was not fully open. Upon opening (by Estates) circulation and F&R temperatures improved. Commissioning engineers clarifying full balancing of system and acceptable F&R temperatures across ward.	2			
Ward 2A Bed 10 (SCH-049)	Hot return not circulating prior to running outlet, with return slowly rising after flushing. Return loop cools when outlet not in use - further investigation required. Note: Commissioning engineers clarifying full balancing of system and acceptable F&R temperatures across ward.	2			

LEGIONELLA RISK ASSESSMENT

Location/Plant Item	Recommendation	Remedial Action Category	Assigned to	Actions Taken	Completed
Ward 2A Bed 10 En-Suite (SCH-047)	Hot return not circulating prior to running outlet, with return slowly rising after flushing. Return loop cools when outlet not in use - further investigation required. Note: Commissioning engineers clarifying full balancing of system and acceptable F&R temperatures across ward.	2			
Ward 2A Bed 15 (SCH-058)	Hot return not circulating prior to running outlet, with return slowly rising after flushing. Return loop cools when outlet not in use - further investigation required. Note: Commissioning engineers clarifying full balancing of system and acceptable F&R temperatures across ward.	2			
Ward 2A Play/Dining (SCH-062)	Hot return loop not working with pipework branching from low level stainless steel sink supply to join low level return at WHB - further investigation required. Note: Commissioning engineers clarifying full balancing of system and acceptable F&R temperatures across ward.	2			
Ward 2A Room 26 EYTC (SCH-027)	Hot return not circulating prior to running outlet, with return slowly rising after flushing. Return loop cools when outlet not in use - further investigation required. Note: Commissioning engineers clarifying full balancing of system and acceptable F&R temperatures across ward.	2			
Ward 2B Day Stay Room A (DCU-007)	Hot flow and return not working correctly Further investigation require. Note: Upon further investigation it was noted a valve was not fully open. Upon opening (by Estates) circulation and F&R temperatures improved. Commissioning engineers clarifying full balancing of system and acceptable F&R temperatures across ward.	2			
Ward 2A Bed 8 (SCH-044)	Cold supply in direct contact with hot return pipework and uninsulated - this should be addressed with all pipework insulated to prevent heat gain/loss.	2			

LEGIONELLA RISK ASSESSMENT

Location/Plant Item	Recommendation	Remedial Action Category	Assigned to	Actions Taken	Completed
Ward 2A Bed 7 En-Suite (SCH-042)	Cold supply in direct contact with hot return pipework and uninsulated - this should be addressed with all pipework insulated to prevent heat gain/loss.	2			
Ward 2A Bed 6 En-Suite (TCT-009)	Hot return taken from WHB supply with no additional return loop fitted at shower supply (approx. 1.5 metres) - ideally hot flow and return should be taken as close as practical to shower connections. Note: DMA amending pipework within room on 04/03/22 to take F&R as close as practical to shower connection.	3			
Ward 2A Bed 4 (TCT-006)	Short section of uninsulated pipework on cold and hot flow/return in ceiling void at drop to outlet - all pipework should be fully insulated to prevent heat loss/gain.	3			
Ward 2B Main Corridor Ceiling Void Outside Room B	Approximately 0.5 metre of uninsulated cold and hot flow/return pipework in ceiling space - all pipework should be fully insulated to prevent heat gain/loss.	3			
Ward 2A Main Entrance Corridor Ceiling Void	Approximately 1 metre of uninsulated cold and hot flow/return pipework in ceiling space - all pipework should be fully insulated to prevent heat gain/loss.	3			
Ward 2A TCT Social (TCT-002)	No access to return pipework - boxed in behind kitchen panels/walls etc. Further investigation require to confirm flow and return circulating correctly. Note: Commissioning engineers clarifying full balancing of system and acceptable F&R temperatures across ward.	3			
Riser M36 & Riser M38	Sections of insulation missing from hot and cold pipework. However, Scotmas working in the area preparing for installation of new ClO_2 units. Ensure all piepwork is insulated upong completion of works. If prolonged period with no ongoings works it would be advisable to fit temporary insulation.	3			
General System - Pipework Distribution	All distribution pipework should be correctly labelled to current British Standards for identification purposes (Some sections of pipework incorrectly labelled - direction of flow on labelling incorrect).	4			

LEGIONELLA RISK ASSESSMENT

Location/Plant Item	Recommendation	Remedial Action Category	Assigned to	Actions Taken	Completed
General System - Plant Items	All plant items and associated valves should be correctly labelled for identification purposes.	4			

Section 3

Site/Client Details

LEGIONELLA RISK ASSESSMENT

Site/Client Details

Client	GG&C QEUH
Client address	Queen Elizabeth University Hospital 1345 Govan Road Glasgow
Client contact	Kerr Clarkson
Telephone No.	[redacted]
E-mail	kerr.clarkson[redacted]
Mobile No.	[redacted]
Wards Being Assessed	Queen Elizabeth University Hospital Royal Hospital for Children Ward 2A & Ward 2B

Method of Submission	Electronic

LEGIONELLA RISK ASSESSMENT

General Site Details

Site	Queen Elizabeth University Hospital Royal Hospital for Children Ward 2A & Ward 2B
Age of building	Opened in 2015 (Building and Commissioning 2011-2015) Ward closed for a period in late 2018 till early 2019 for water system alterations and then again in late 2019 for an upgrade of the ventilation system with some alterations to the water system. Ward due to reopen 9th March 2022
Years since upgrade/renovation of water services	Alterations to water system made in late 2018 and then again during 2019 - 2022
Purpose/use of Ward	Children's cancer ward
Operational cycle of the water system being assessed?	Continuous
Potentially affected population	Staff, Contractors, Visitors, Patients
Is the building used by "at risk" or "particularly vulnerable" persons	Yes - Acute medical conditions (Cancer)
Total number of people usually in building (including staff/sub-contractors visitors/pupils etc.)	Variable dependant on patient numbers (25 bedrooms within Ward 2A plus Ward B day care unit)
Applicable Legionella standard(s)	L8, SHTM 04-01

LEGIONELLA RISK ASSESSMENT

Identification of Systems and Scope of Assessment

Domestic Water System		Present on site/ward
Evaporative cooling tower or condenser systems (and associated water system)		None within Ward 2A/2B
Fountains and water features		None within Ward 2A/2B
Hydrotherapy Pool		None within Ward 2A/2B
Whirlpool/Arjo Baths		None within Ward 2A/2B
Dental equipment		None within Ward 2A/2B
Vehicle wash systems (inc. Trolley Wash & Power Washing Plant)		None within Ward 2A/2B
Emergency showers		None within Ward 2A/2B
Irrigation systems		None within Ward 2A/2B
Sprinkler/Wet fire-fighting systems		Present within ward Not included within this assessment
Water softeners		None within Ward 2A/2B
Industrial process water systems		None within Ward 2A/2B
Machine coolants		None within Ward 2A/2B
Air washers, wet scrubbers, particle and trivial gas scrubbers		None within Ward 2A/2B
Spray humidifiers		None within Ward 2A/2B
Ultrasonic humidifiers/foggers and water misting systems		None within Ward 2A/2B
Recycled Water Systems		None within Ward 2A/2B
Closed heating water systems (MTHW/LTHW)		Present within ward Not included within this assessment
Closed chilled water systems		Present within ward Not included within this assessment
Other 'at-risk' systems	Renal Dialysis Plant (x2) (Plus other emergency dialysis points within wards)	None within Ward 2A/2B
	Endoscopy Wash/Filtration Unit	None within Ward 2A/2B
	Medical Gases/Medical Equipment (e.g. Nebulisers, incubators etc.)	Present within ward Not included within this assessment
	Emergency Cooling (MRI Chiller)	None within Ward 2A/2B

N.B. Systems assessed in this document as per client specification.

LEGIONELLA RISK ASSESSMENT

Legionella Control Measures Currently Used on Site

What is the primary control method for legionella control for the domestic water systems currently used on site and are there any supplementary or replacement control systems on site?[#]	
	Control measure
Temperature controlled	Primary
Chlorine dioxide[#]	Secondary *[#]Chlorine Dioxide dosing systems being installed in late 2018 and early 2019 to cover domestic water systems within Royal Hospital for Children and the Adults Hospital. Additional dosing units being installed at time of report within risers M36 and M39 to provide additional ClO_2 control within Wards 2A and 2B locally.*
Hydrogen peroxide/silver ion	Not used
Silver/copper ion	Not used
Ultraviolet	Not used
Other (0.2µm filters between Raw and Bulk Tanks)	Secondary
Point of Use Filters on Tap Outlets	Secondary *All outlets within Wards 2A and 2B will be fitted with Point of use filters when ward reopens.*

[#] If any method other than, or in addition to, temperature is used as method of control then details of records/regime can be found in section 9.

Section 4

Water Source

Summary of Risk Potential

Town mains water is generally not expected to present a significant risk for the contamination of a system with legionella, though it may be assumed that legionella in low concentrations could be present in the mains water on occasion. Therefore it must be assumed that it is not practical to prevent legionella entering the water system at some point.

There are, in addition, other bacteria, contaminants and physical factors that can create a risk to mains water users in the building.

Where the water source to the site is from a natural source, e.g. River, lake, spring or private water supply then the potential for legionella contamination increases.

N.B. Unless specifically stated otherwise the incoming mains/water source has been assessed from point of entry to the building. External & underground water services which serve the building and are not visible have not been assessed.

Please refer to water source sheets for specific recommendations and risk ratings.

LEGIONELLA RISK ASSESSMENT

Children's Wards 2A and 2B are supplied by the Adult and Children's Hospital incoming town mains supply via the raw water cold storage tanks, filtration system and post filtration cold water storage tanks (CWSTs).

The post filtration tanks are treated with ClO_2, with additional monitoring/top up stations fitted on the risers post booster pumps.

Hot and cold water to the ward is delivered via Risers M36 and M39.

Please refer to previous Adult and Children's Hospital L8 risk assessment for further details.

Section 5

Cold Water Storage Tanks

Cold Water Storage Tanks (Cisterns)

Cold Water Storage Tanks (CWSTs), in themselves, present a low Legionella risk in general terms. However, where the tanked water supplies other plant that has a high risk factor (e.g. cooling towers, showers, etc.) The potential risk is much higher.

Poor control over water temperature and condition of the stored water, plus the condition of the tank itself, may lead to Legionella colonising and proliferating in the tank and therefore producing possible source of bacteria to infect other water services downstream.

Basic principles being looked at in this section are the physical condition and the design of the CWST and associated pipework, ensuring these comply with the relevant guidelines, and the condition of the water being stored within the water tank. The water stored within the tanks should be no more than 2°C higher than the incoming mains, and less than 20°C

All CWSTs inherently carry the risk associated with the make-up source to the CWST, and these risk factors must be taken into account in determining the actual risk posed by the system as a whole.

Please refer to appropriate sections on Legionella management, CWSTs and water source to determine the inherent risk factors of water being supplied to the CWSTs being assessed in this section.

Risk factors incorporated within this section refer only to the risk factors associated with the CWSTs.

Please refer to individual CWST sheets for specific recommendations and risk ratings.

Cold Water Storage Cisterns (Tanks) Notes

1. On sites containing multiple water tanks it is not always possible to trace and identify which tank feeds which outlets. Whilst DMA make every effort to identify this on occasion it is not possible. For a definitive guide to which outlets are fed from each CWST further investigative work may be required.

2. On sites where water tanks feed services via booster pumps it is not always possible to trace and identify which outlets are tank fed and which outlets are mains fed. Whilst DMA make every effort to identify this on occasion it is not possible. For a definitive guide to which outlets are fed from each CWST further investigative work may be required.

3. It would be advised that in a building where there are times of prolonged low usage (e.g. Schools, colleges) that during the low usage periods the water services within the building are subject to a revised regime that would ensure that all water services are maintained in good condition. The water services must not be left in a situation that through stagnation of the services coupled with potential temperature control issues the conditions occur that promote the growth of microorganisms which could lead to the proliferation of Legionella. This could be achieved by regular weekly flushing of any stored water and dosing tanks/system with biocides approved for drinking water. Prior to reuse of the building and services a heavy flushing regime of the cold and hot water services and elevation of the stored and distributed hot water services at 70ºC should be considered. Once this is carried out the services can be returned to their normal working conditions. All actions taken should be recorded as normal in the log book.

LEGIONELLA RISK ASSESSMENT

Children's Wards 2A and 2B are supplied by the Adult and Children's Hospital incoming town mains supply via the raw water cold storage tanks, filtration system and post filtration cold water storage tanks (CWSTs).

The post filtration tanks are treated with ClO_2, with additional monitoring/top up stations fitted on the risers post booster pumps.

Hot and cold water to the ward is delivered via Risers M36 and M39.

Please refer to previous Adult and Children's Hospital L8 risk assessment for further details.

Section 6

Calorifiers and Water Heaters

Calorifiers and Water Heaters

Calorifiers present a low Legionella risk, however when the calorifier water supplies other associated plant which may have a high risk potential (e.g. Showers etc.), the potential risk from such calorifiers is significantly higher.

Calorifiers have been a major source of proliferation of Legionella.

Poor control over the water temperature and condition of the calorifier are the most significant factors in determining the risk presented by hot water calorifiers to the down water services.

Basic principles being looked at in this section are the physical condition and the design of the calorifiers/water heaters and associated pipework, ensuring these comply with the relevant guidelines, and the condition of the water being stored within the heaters. The water should be stored at a minimum of 60°C, with the entire body of the calorifier achieving this temperature for a minimum period of 1 hour per day. The return temperatures should maintain a minimum temperature of 55°C at all times (design parameter for QEUH Calorifiers as advised by Brookfield/Mercury Engineering).

Risk factors incorporated within this section refer only to the risk factors associated with the calorifiers (or water heaters).

All calorifiers inherently carry the risk associated with the make-up source e.g. CWST, and these risk factors must be taken into account in determining the actual risk posed by the system as a whole. Please refer to appropriate sections on Legionella management, CWSTs and water source to determine the inherent risk factors of water being supplied to the calorifiers being assessed in this section.

Please refer to calorifier sheets for specific recommendations and risk ratings.

Backflow protection: suitable backflow protection should be fitted to all water heaters on pressurised systems (e.g. Mains fed or boosted cold water fed). Before fitting any double check valves or other forms of backflow protection ensure that adequate pressure relief valves are fitted and working in the event of excessive pressure or temperature build up within water heaters.

LEGIONELLA RISK ASSESSMENT

Children's Wards 2A and 2B are supplied by calorifiers 01, 02 & 03 located within Plant Room 41 of the Royal Hospital for Children.

In addition to the ClO_2 dosing within the post filtration tanks and on the risers post booster pumps there are additional monitoring/top up stations on the cold water as it enters Plantroom 41 on the supply to the calorifiers (01, 02 & 03) and on the common hot return to the calorifiers.

Hot and cold water to the ward is delivered via Risers M36 and M39.

Please refer to previous Adult and Children's Hospital L8 risk assessment for further details.

Section 7

Hot and Cold Water Outlets

Showers and other spray outlets

Since showers produce fine water droplets or spray they present a significantly higher risk for the development of Legionnaires ' disease than other types of hot and cold outlets.

Water temperature, system design/installation, showerhead design, frequency of use and cleanliness of the outlet are the most significant factors in determining the risk potential.

Hot and cold water outlets

Hot and cold-water outlets do not normally present a risk for the development of Legionnaires' disease unless the outlets create fine droplets or spray. Outlets that do create sprays/droplets significantly increase the risk.

Water temperature, system design/installation, frequency of use, tap design and cleanliness of the outlet are the most significant factors in determining the risk potential.

Basic principles being looked at in this section are the physical condition, and the design of the water services pipework and outlets, and the temperature profile of the water being distributed to the outlets. There should be no unused outlets or deadlegs (blank-ends) on any parts of the systems. Hot water should be delivered to all outlets at a minimum of 50°C (55°C within healthcare premises) within 1 minute of outlet being run and cold water below 20°C within 2 minutes of being run. Cold water should be no more than 2°C higher at the outlet then the water source for this outlet (e.g. CWST). This section also incorporates details of spray outlets/aerosol generators (showers etc.), low use outlets and unused outlets.

Please refer to outlet sheets for specific recommendations & risk ratings.

Risk factors incorporated within this section of the document are classified as "additional localised risk rating". This refers only to the condition of the localised pipework distribution and services and the risk rating applied is in addition to risk rating of the plant items feeding the services.

All outlets fed from CWSTs or calorifiers etc. Inherently carry the risk associated to these plant items, and these risk factors must be taken into account in determining the actual risk posed by the system as a whole.

Please refer to appropriate sections on legionella management, CWSTs, calorifiers and water source to determine the inherent risk factors of water being supplied to the outlets being assessed in this section.

Hot and Cold Water Outlet Notes

1. Thermostatic mixing valves (TMVs) should be serviced and have fail safe tests carried out routinely (every 6 months) and strainers should be cleaned on a regular basis as per manufacturer's recommendations. Ideally TMVs should feed single outlets and be situated as close as possible to the outlet (preferably TMV Taps should be fitted).

2. All flexi hoses connecting taps/outlets should be WRAS approved and should be replaced every 2 years or sooner if damaged or twisted. Wherever possible DMA would recommend all flexi hoses are removed and connections hard piped. Where flexible hoses cannot be removed then replacing with alternative WRAS approved hoses with linings other than EPDM should be considered. In healthcare premises flexible hoses should only be used on essential equipment subject to vibration or articulation and wherever practical alternative lining materials should be considered with hoses be inspected, assessed and replaced at regular intervals. Refer to HTM/SHTM 04-01 for further details.

3. All lead (Pb) pipework should be removed and replaced with copper or other suitable WRAS approved pipework.

4. Wherever possible, DMA would recommend that spray taps are removed and replaced with taps which do not create an aerosol. Tap diffusers should also be removed where possible to minimise aerosol creation and the build-up of dirt/scale etc. On the diffusers wherever possible. In healthcare premises adjustable flow showerheads should not be fitted (replace with non-adjustable showerheads).

5. Drain cocks fitted at the end of pipe runs should be removed if not required for operational reasons or periodically flushed (weekly) and checks carried out to ensure that inserts/washers etc. are WRAS approved.

6. Adequate backflow protection as per Water Regulations Guide & Water Byelaws (Scotland) – section 6, should be incorporated into the water services within the building. Suitable backflow protection should be fitted to all point of use water heaters, multi point water heaters, tea boilers etc., if not fitted inside heater itself, on pressurised systems (e.g. Mains fed or boosted cold water fed). Before fitting any double check valves or other forms of backflow protection ensure that adequate pressure relief valves/expansion vessels are fitted and working in the event of excessive pressure or temperature build up within water heaters.

7. Water coolers and drinks machines should have regular servicing carried out (generally six monthly) as per manufacturers recommendations.

8. Where passive infra-red (PIR) flush controls are fitted on urinals these have batteries fitted. Make sure these batteries are working and all PIR(s) are serviced every two years or as per manufacturers' recommendations otherwise these may become low flow or deadleg areas.

9. All low use outlets, and all associated pipework, should be removed leaving no deadlegs if outlets no longer required, or incorporated into low use flushing regime.

10. All deadlegs should be removed wherever possible. Where deadlegs are unable to be removed provision to allow flushing of the deadlegs weekly as part of the flushing regime should be made. (i.e. Valves fitted at end of deadlegs to allow flushing to be carried out).

11. All plant items, valves. CWSTS, calorifiers etc. Should be clearly labelled to identify what services and areas they serve.

12. All equipment hoses (e.g. Kitchen/laundry appliances) should be WRAS approved and inspected and replaced on a regular basis.

13. Cold water should be delivered to outlets (and cold feed to thermostatic mixing valves) at less than 20°C within 2 minutes of outlet being run, and not more than 2°Cabove outlet water source temperature (e.g. CWST)

14. Hot water should be delivered to outlets (and hot feed to thermostatic mixing valves) at more than 50°C (55°C in healthcare premises), within 1 minute of outlet being run[1]

[1] Hot supply temperatures in healthcare premises varies from non-healthcare premises. Please refer to HSG 274 Part 2 and HTM/SHTM 04/01 for further details.

LEGIONELLA RISK ASSESSMENT

Location / Room No	Sentinel outlet?	Cold Supply & Temp (°C)	Hot Supply & Temp (°C)	TMV info					Deadlegs Present (Inc. Drain cocks)	Flow & Return Working	Outlet Usage	Outlets in location												Aerosol Created	Non WRAS Material	Flexi Hoses	Comment	Additional Localised Risk Rating
				No. Of TMVs	Access	<2m from outlet?	Mix Temps 37-45°C	No. TMV Fed Outlets				Mains	Cold	Hot	Mixer	Urinals	WCs	Shower	Drinks / vend	Water boiler	Drink fountain	Arjo/whirlpool	Other					
Ward 2A Bed 6 (TCT-010)		CWST 10.7	PR 41 Cals 01-03 (Riser M36) 57.8	1 TMT	OK	Y	Y	1	None Visible	Yes	Unoccupied Flushing Regime				1									Low	None Visible	None Visible		Low
Recommendations:																												
Comments:			Check valves fitted on both hot and cold supplies to TMT.																									
Ward 2A Bed 6 En-Suite (TCT-009)		CWST 10.8	PR 41 Cals 01-03 (Riser M36) 56.2	1 TMT 1 SHWR	OK	Y	Y	2	None Visible	Yes	Unoccupied Flushing Regime				1		1	1						Head Removed Currently	None Visible	None Visible		Low
Recommendations:			Hot return taken from WHB supply with no additional return loop fitted at shower supply (approx. 1.5 metres) - ideally hot flow and return should be taken as close as practical to shower connections. Note: DMA amending pipework within room on 04/03/22 to take F&R as close as practical to shower connection.																									
Comments:			Check valves fitted on both hot and cold supplies to TMT.																									
Ward 2A Bed 5 (TCT-007)		CWST 11.1	PR 41 Cals 01-03 (Riser M36) 58.0	1 TMT	OK	Y	Y	1	None Visible	Yes	Unoccupied Flushing Regime				1									Low	None Visible	None Visible		Low
Recommendations:																												
Comments:			Check valves fitted on both hot and cold supplies to TMT.																									
Ward 2A Bed 5 En-Suite (TCT-008)		CWST 10.9	PR 41 Cals 01-03 (Riser M36) 57.7	1 TMT 1 SHWR	OK	Y	Y	2	None Visible	Yes	Unoccupied Flushing Regime				1		1	1						Head Removed Currently	None Visible	None Visible		Low
Recommendations:																												
Comments:			Check valves fitted on both hot and cold supplies to TMT.																									

LEGIONELLA RISK ASSESSMENT

Location / Room No	Sentinel outlet?	Cold Supply & Temp (°C)	Hot Supply & Temp (°C)	TMV info					Deadlegs Present (Inc. Drain cocks)	Flow & Return Working	Outlet Usage	Outlets in location												Aerosol Created	Non WRAS Material	Flexi Hoses	Comment	Additional Localised Risk Rating
				No. Of TMVs	Access	<2m from outlet?	Mix Temps 37-45°C	No. TMV Fed Outlets				Mains	Cold	Hot	Mixer	Urinals	WCs	Shower	Drinks / vend	Water boiler	Drink fountain	Arjo/whirlpool	Other					
Ward 2A Bed 4 (TCT-006)		CWST 10.5	PR 41 Cals 01-03 (Riser M36) 56.2	1 TMT	OK	Y	Y	1	None Visible	See Comments	Unoccupied Flushing Regime				1									Low	None Visible	None Visible		Medium

Recommendations: Hot return not circulating prior to running outlet, with return slowly rising after flushing. Return loop cools when outlet not in use - further investigation required.
Note: Upon further investigation it was noted a valve was not fully open. Upon opening (by Estates) circulation and F&R temperatures improved. Commissioning engineers clarifying full balancing of system and acceptable F&R temperatures across ward.

Short section of uninsulated pipework on cold and hot flow/return in ceiling void at drop to outlet - all pipework should be fully insulated to prevent heat loss/gain.

Comments: Check valves fitted on both hot and cold supplies to TMT.

Ward 2A Bed 4 En-Suite (TCT-005)		CWST 10.6	PR 41 Cals 01-03 (Riser M36) 56.9	1 TMT 1 SHWR	OK	Y	Y	2	None Visible	Yes	Unoccupied Flushing Regime				1		1	1						Head Removed Currently	None Visible	None Visible		Low

Recommendations:

Comments: Check valves fitted on both hot and cold supplies to TMT.
Hot flow loops around room to pick up shower supply first then feeding the WHB where the hot returns to main distribution.

Ward 2A Bed 3 (TCT-004)		CWST 10.4	PR 41 Cals 01-03 (Riser M36) 56.8	1 TMT	OK	Y	Y	1	None Visible	Yes	Unoccupied Flushing Regime				1									Low	None Visible	None Visible		Low

Recommendations:

Comments: Check valves fitted on both hot and cold supplies to TMT.

Ward 2A Bed 3 En-Suite (TCT-002)		CWST 10.8	PR 41 Cals 01-03 (Riser M36) 56.2	1 TMT 1 SHWR	OK	Y	Y	2	None Visible	Yes	Unoccupied Flushing Regime				1		1	1						Head Removed Currently	None Visible	None Visible		Low

Recommendations:

Comments: Check valves fitted on both hot and cold supplies to TMT.

LEGIONELLA RISK ASSESSMENT

Location / Room No	Sentinel outlet?	Cold Supply & Temp (°C)	Hot Supply & Temp (°C)	TMV info					Deadlegs Present (Inc. Drain cocks)	Flow & Return Working	Outlet Usage	Outlets in location												Aerosol Created	Non WRAS Material	Flexi Hoses	Comment	Additional Localised Risk Rating
				No. Of TMVs	Access	<2m from outlet?	Mix Temps 37-45°C	No. TMV Fed Outlets				Mains	Cold	Hot	Mixer	Urinals	WCs	Shower	Drinks / vend	Water boiler	Drink fountain	Arjo/whirlpool	Other					
Ward 2A TCT Social (TCT-002)		CWST 10.5	PR 41 Cals 01-03 (Riser M36) 57.8	0				0	None Visible	No Access. Hot temp at taps quick to rise.	Unoccupied Flushing Regime		2	2											Impact	None Visible	None Visible		Low

Recommendations: No access to return pipework - boxed in behind kitchen panels/walls etc. Further investigation require to confirm flow and return circulating correctly. Note: Commissioning engineers clarifying full balancing of system and acceptable F&R temperatures across ward.

Comments:

Ward 2A Bed 7 (NSCH-041)	Y	CWST 10.9	PR 41 Cals 01-03 (Riser M36) 57.9	1 TMT	OK	Y	Y	1	None Visible	Yes	Unoccupied Flushing Regime				1									Low	None Visible	None Visible		Low

Recommendations:

Comments: Check valves fitted on both hot and cold supplies to TMT.

Ward 2A Bed 7 En-Suite (SCH-042)		CWST 10.6	PR 41 Cals 01-03 (Riser M36) 57.7	1 TMT 1 SHWR	OK	Y	Y	2	None Visible	Yes	Unoccupied Flushing Regime				1		1	1						Head Removed Currently	None Visible	None Visible		Medium

Recommendations: Cold supply in direct contact with hot return pipework and uninsulated - this should be addressed with all pipework insulated.

Comments: Check valves fitted on both hot and cold supplies to TMT.

Ward 2A Staff Toilet (SCH-040)		CWST 10.5	PR 41 Cals 01-03 (Riser M36) 58.0	1 TMT	OK	Y	Y	1	None Visible	Yes	Unoccupied Flushing Regime				1		1								None Visible	None Visible		Low

Recommendations:

LEGIONELLA RISK ASSESSMENT

Location / Room No	Sentinel outlet?	Cold Supply & Temp (°C)	Hot Supply & Temp (°C)	TMV info					Deadlegs Present (Inc. Drain cocks)	Flow & Return Working	Outlet Usage	Outlets in location												Aerosol Created	Non WRAS Material	Flexi Hoses	Comment	Additional Localised Risk Rating
				No. Of TMVs	Access	<2m from outlet?	Mix Temps 37-45°C	No. TMV Fed Outlets				Mains	Cold	Hot	Mixer	Urinals	WCs	Shower	Drinks / vend	Water boiler	Drink fountain	Arjo/whirlpool	Other					
Ward 2A Bed 8 (SCH-044)		CWST 10.5	PR 41 Cals 01-03 (Riser M36) 56.2	1 TMT	OK	Y	Y	1	None Visible	Yes	Unoccupied Flushing Regime				1									Low	None Visible	None Visible		Medium
Recommendations:	Cold supply in direct contact with hot return pipework and uninsulated - this should be addressed with all pipework insulated to prevent heat gain/loss.																											
Comments:	Check valves fitted on both hot and cold supplies to TMT.																											
Ward 2A Bed 8 En-Suite (SCH-043)		CWST 10.4	PR 41 Cals 01-03 (Riser M36) 57.9	1 TMT 1 SHWR	OK	Y	Y	2	None Visible	Yes	Unoccupied Flushing Regime				1		1	1						Head Removed Currently	None Visible	None Visible		Low
Recommendations:																												
Comments:	Check valves fitted on both hot and cold supplies to TMT. Hot flow loops around room to pick up shower supply first then feeding the WHB where the hot returns to main distribution.																											
Ward 2A Bed 9 (SCH-046)		CWST 10.4	PR 41 Cals 01-03 (Riser M36) 56.8	1 TMT	OK	Y	Y	1	None Visible	Yes	Unoccupied Flushing Regime				1									Low	None Visible	None Visible		Low
Recommendations:																												
Comments:	Check valves fitted on both hot and cold supplies to TMT.																											
Ward 2A Bed 9 En-Suite (SCH-048)		CWST 10.6	PR 41 Cals 01-03 (Riser M36) 57.5	1 TMT 1 SHWR	OK	Y	Y	2	None Visible	Yes	Unoccupied Flushing Regime				1		1	1						Head Removed Currently	None Visible	None Visible		Low
Recommendations:																												
Comments:	Check valves fitted on both hot and cold supplies to TMT. Hot flow loops around room to pick up shower supply first then feeding the WHB where the hot returns to main distribution.																											

LEGIONELLA RISK ASSESSMENT

Location / Room No	Sentinel outlet?	Cold Supply & Temp (°C)	Hot Supply & Temp (°C)	TMV info					Deadlegs Present (Inc. Drain cocks)	Flow & Return Working	Outlet Usage	Outlets in location												Aerosol Created	Non WRAS Material	Flexi Hoses	Comment	Additional Localised Risk Rating
				No. Of TMVs	Access	<2m from outlet?	Mix Temps 37-45°C	No. TMV Fed Outlets				Mains	Cold	Hot	Mixer	Urinals	WCs	Shower	Drinks / vend	Water boiler	Drink fountain	Arjo/whirlpool	Other					
Ward 2A Bed 10 (SCH-049)		10.4	PR 41 Cals 01-03 (Riser M36) 56.1	1 TMT	OK	Y	Y	1	None Visible	See Comments	Unoccupied Flushing Regime				1									Low	None Visible	None Visible		Medium
Recommendations:			Hot return not circulating prior to running outlet, with return slowly rising after flushing. Return loop cools when outlet not in use - further investigation required. Note: Commissioning engineers clarifying full balancing of system and acceptable F&R temperatures across ward.																									
Comments:			Check valves fitted on both hot and cold supplies to TMT.																									
Ward 2A Bed 10 En-Suite (SCH-047)		CWST 10.6	PR 41 Cals 01-03 (Riser M36) 57.2	1 TMT 1 SHWR	OK	Y	Y	2	None Visible	No	Unoccupied Flushing Regime				1		1	1						Head Removed Currently	None Visible	None Visible		Medium
Recommendations:			Hot return not circulating prior to running outlet, with return slowly rising after flushing. Return loop cools when outlet not in use - further investigation required. Note: Commissioning engineers clarifying full balancing of system and acceptable F&R temperatures across ward.																									
Comments:			Check valves fitted on both hot and cold supplies to TMT.																									
Ward 2A Bed 11 (SCH-050)		10.3	PR 41 Cals 01-03 (Riser M36) 57.7	1 TMT	OK	Y	Y	1	None Visible	Yes	Unoccupied Flushing Regime				1									Low	None Visible	None Visible		Low
Recommendations:																												
Comments:			Check valves fitted on both hot and cold supplies to TMT.																									
Ward 2A Bed 11 En-Suite (SCH-051)		CWST 10.5	PR 41 Cals 01-03 (Riser M36) 58.0	1 TMT 1 SHWR	OK	Y	Y	2	None Visible	Yes	Unoccupied Flushing Regime				1		1	1						Head Removed Currently	None Visible	None Visible		Low
Recommendations:																												
Comments:			Check valves fitted on both hot and cold supplies to TMT.																									

LEGIONELLA RISK ASSESSMENT

Location / Room No	Sentinel outlet?	Cold Supply & Temp (°C)	Hot Supply & Temp (°C)	TMV info					Deadlegs Present (Inc. Drain cocks)	Flow & Return Working	Outlet Usage	Outlets in location												Aerosol Created	Non WRAS Material	Flexi Hoses	Comment	Additional Localised Risk Rating
				No. Of TMVs	Access	<2m from outlet?	Mix Temps 37-45°C	No. TMV Fed Outlets				Mains	Cold	Hot	Mixer	Urinals	WCs	Shower	Drinks / vend	Water boiler	Drink fountain	Arjo/whirlpool	Other					
Ward 2A Bed 12 (SCH-053)		CWST 10.3	PR 41 Cals 01-03 (Riser M36) 58.1	1 TMT	OK	Y	Y	1	None Visible	Yes	Unoccupied Flushing Regime				1									Low	None Visible	None Visible		Low
Recommendations:																												
Comments:			Check valves fitted on both hot and cold supplies to TMT.																									
Ward 2A Bed 12 En-Suite (SCH-052)		CWST 10.4	PR 41 Cals 01-03 (Riser M36) 57.9	1 TMT 1 SHWR	OK	Y	Y	2	None Visible	Yes	Unoccupied Flushing Regime				1		1	1						Head Removed Currently	None Visible	None Visible		Low
Recommendations:																												
Comments:			Check valves fitted on both hot and cold supplies to TMT.																									
Ward 2A Bed 13 (SCH-054)		CWST 10.5	PR 41 Cals 01-03 (Riser M36) 58.3	1 TMT	OK	Y	Y	1	None Visible	Yes	Unoccupied Flushing Regime				1									Low	None Visible	None Visible		Low
Recommendations:																												
Comments:			Check valves fitted on both hot and cold supplies to TMT.																									
Ward 2A Bed 13 En-Suite (SCH-056)		CWST 10.5	PR 41 Cals 01-03 (Riser M36) 58.0	1 TMT 1 SHWR	OK	Y	Y	2	None Visible	Yes	Unoccupied Flushing Regime				1		1	1						Head Removed Currently	None Visible	None Visible		Low
Recommendations:																												
Comments:			Check valves fitted on both hot and cold supplies to TMT. Hot flow loops around room to pick up shower supply first then feeding the WHB where the hot returns to main distribution.																									

LEGIONELLA RISK ASSESSMENT

Location / Room No	Sentinel outlet?	Cold Supply & Temp (°C)	Hot Supply & Temp (°C)	TMV info					Deadlegs Present (Inc. Drain cocks)	Flow & Return Working	Outlet Usage	Outlets in location												Aerosol Created	Non WRAS Material	Flexi Hoses	Comment	Additional Localised Risk Rating
				No. Of TMVs	Access	<2m from outlet?	Mix Temps 37-45°C	No. TMV Fed Outlets				Mains	Cold	Hot	Mixer	Urinals	WCs	Shower	Drinks / vend	Water boiler	Drink fountain	Arjo/whirlpool	Other					
Ward 2A Public Toilet (SCH-037)		CWST 10.6	PR 41 Cals 01-03 (Riser M36) 58.2	1 TMT	OK	Y	Y	1	None Visible	Yes Returns from TCT-002	Unoccupied Flushing Regime				1		1								None Visible	None Visible		Low

Recommendations:

Comments: Check valves fitted on both hot and cold supplies to TMT.

Ward 2A Clean Utility (SCH-030)		CWST 10.7	PR 41 Cals 01-03 (Riser M36) 58.1	1 TMT	OK	Y	Y	1	None Visible	Yes	Unoccupied Flushing Regime				1		1								None Visible	None Visible		Low

Recommendations:

Comments: Check valves fitted on both hot and cold supplies to TMT.

Ward 2A Bed 2 (SCH-033)		CWST 10.4	PR 41 Cals 01-03 (Riser M36) 58.1	1 TMT	OK	Y	Y	1	None Visible	Yes	Unoccupied Flushing Regime				1										Low	None Visible	None Visible		Low

Recommendations:

Comments: Check valves fitted on both hot and cold supplies to TMT.

Ward 2A Bed 2 En-Suite (SCH-032)		CWST 10.5	PR 41 Cals 01-03 (Riser M36) 58.3	1 TMT 1 SHWR	OK	Y	Y	2	None Visible	Yes	Unoccupied Flushing Regime				1		1	1							Head Removed Currently	None Visible	None Visible		Low

Recommendations:

Comments: Check valves fitted on both hot and cold supplies to TMT.
Hot flow loops around room to pick up shower supply first then feeding the WHB where the hot returns to main distribution.

LEGIONELLA RISK ASSESSMENT

Location / Room No	Sentinel outlet?	Cold Supply & Temp (°C)	Hot Supply & Temp (°C)	TMV info					Deadlegs Present (Inc. Drain cocks)	Flow & Return Working	Outlet Usage	Outlets in location												Aerosol Created	Non WRAS Material	Flexi Hoses	Comment	Additional Localised Risk Rating
				No. Of TMVs	Access	<2m from outlet?	Mix Temps 37-45°C	No. TMV Fed Outlets				Mains	Cold	Hot	Mixer	Urinals	WCs	Shower	Drinks / vend	Water boiler	Drink fountain	Arjo/whirlpool	Other					
Ward 2A Bed 14 (SCH-057)		10.6	PR 41 Cals 01-03 (Riser M36) 57.4	1 TMT	OK	Y	Y	1	None Visible	Yes	Unoccupied Flushing Regime				1									Low	None Visible	None Visible		Low
Recommendations:																												
Comments:			Check valves fitted on both hot and cold supplies to TMT.																									
Ward 2A Bed 14 En-Suite (SCH-055)		CWST 10.5	PR 41 Cals 01-03 (Riser M36) 58.0	1 TMT 1 SHWR	OK	Y	Y	2	None Visible	Yes	Unoccupied Flushing Regime				1		1	1						Head Removed Currently	None Visible	None Visible		Low
Recommendations:																												
Comments:			Check valves fitted on both hot and cold supplies to TMT.																									
Ward 2A Bed 15 (SCH-058)		10.4	PR 41 Cals 01-03 (Riser M36) 56.0	1 TMT	OK	Y	Y	1	None Visible	See Comments	Unoccupied Flushing Regime				1									Low	None Visible	None Visible		Medium
Recommendations:			Hot return not circulating prior to running outlet, with return slowly rising after flushing. Return loop cools when outlet not in use - further investigation required. Note: Commissioning engineers clarifying full balancing of system and acceptable F&R temperatures across ward.																									
Comments:			Check valves fitted on both hot and cold supplies to TMT.																									
Ward 2A Bed 15 En-Suite (SCH-059)		CWST 10.3	PR 41 Cals 01-03 (Riser M36) 57.8	1 TMT 1 SHWR	OK	Y	Y	2	None Visible	Yes	Unoccupied Flushing Regime				1		1	1						Head Removed Currently	None Visible	None Visible		Low
Recommendations:																												
Comments:			Check valves fitted on both hot and cold supplies to TMT.																									

LEGIONELLA RISK ASSESSMENT

Location / Room No	Sentinel outlet?	Cold Supply & Temp (°C)	Hot Supply & Temp (°C)	TMV info					Deadlegs Present (Inc. Drain cocks)	Flow & Return Working	Outlet Usage	Outlets in location												Aerosol Created	Non WRAS Material	Flexi Hoses	Comment	Additional Localised Risk Rating
				No. Of TMVs	Access	<2m from outlet?	Mix Temps 37-45°C	No. TMV Fed Outlets				Mains	Cold	Hot	Mixer	Urinals	WCs	Shower	Drinks / vend	Water boiler	Drink fountain	Arjo/whirlpool	Other					
Ward 2A Bed 16 (SCH-061)		CWST 10.3	PR 41 Cals 01-03 (Riser M36) 58.2	1 TMT	OK	Y	Y	1	None Visible	Yes	Unoccupied Flushing Regime				1									Low	None Visible	None Visible		Low
Recommendations:																											
			Check valves fitted on both hot and cold supplies to TMT.																								
Ward 2A Bed 16 En-Suite (SCH-060)		CWST 10.4	PR 41 Cals 01-03 (Riser M36) 58.0	1 TMT 1 SHWR	OK	Y	Y	2	None Visible	Yes	Unoccupied Flushing Regime				1		1	1						Head Removed Currently	None Visible	None Visible		Low
Recommendations:																											
Comments:			Check valves fitted on both hot and cold supplies to TMT. Hot flow loops around room to pick up shower supply first then feeding the WHB where the hot returns to main distribution.																								
Ward 2A Bed 1 (SCH-028)		CWST 10.5	PR 41 Cals 01-03 (Riser M36) 57.7	1 TMT	OK	Y	Y	1	None Visible	Yes	Unoccupied Flushing Regime				1									Low	None Visible	None Visible		Low
Recommendations:																											
Comments:			Check valves fitted on both hot and cold supplies to TMT.																								
Ward 2A Bed 1 En-Suite (SCH-031)		CWST 10.7	PR 41 Cals 01-03 (Riser M36) 57.9	1 TMT 1 SHWR	OK	Y	Y	2	None Visible	Yes	Unoccupied Flushing Regime				1		1	1						Head Removed Currently	None Visible	None Visible		Low
Recommendations:																											
Comments:			Check valves fitted on both hot and cold supplies to TMT.																								

LEGIONELLA RISK ASSESSMENT

Location / Room No	Sentinel outlet?	Cold Supply & Temp (°C)	Hot Supply & Temp (°C)	TMV info					Deadlegs Present (Inc. Drain cocks)	Flow & Return Working	Outlet Usage	Outlets in location												Aerosol Created	Non WRAS Material	Flexi Hoses	Comment	Additional Localised Risk Rating
				No. Of TMVs	Access	<2m from outlet?	Mix Temps 37-45°C	No. TMV Fed Outlets				Mains	Cold	Hot	Mixer	Urinals	WCs	Shower	Drinks / vend	Water boiler	Drink fountain	Arjo/whirlpool	Other					
Ward 2A Play/Dining (SCH-062)		CWST 10.3	PR 41 Cals 01-03 (Riser M36) 55.8	1 TMT	OK	Y	Y	1	None Visible	No	Unoccupied Flushing Regime		1	1	1									Impact	None Visible	None Visible		Medium
Recommendations:			Hot return loop not working with pipework branching from low level stainless steel sink supply to join low level return at WHB - further investigation required. Note: Commissioning engineers clarifying full balancing of system and acceptable F&R temperatures across ward.																									
Comments:			Check valves fitted on both hot and cold supplies to TMT.																									
Ward 2A Room 26 EYTC (SCH-027)	Hot Far Cold Far	CWST 10.6	PR 41 Cals 01-03 (Riser M36) 56.2	1 TMT	OK	Y	Y	1	None Visible	See Comments	Unoccupied Flushing Regime				1									Low	None Visible	None Visible		Medium
Recommendations:			Hot return not circulating prior to running outlet, with return slowly rising after flushing. Return loop cools when outlet not in use - further investigation required. Note: Commissioning engineers clarifying full balancing of system and acceptable F&R temperatures across ward.																									
Comments:			Check valves fitted on both hot and cold supplies to TMT.																									
Ward 2A Main Entrance Corridor Ceiling Void		CWST N/A	PR 41 Cals 01-03 (Riser M36) N/A	N/A					None Visible	Yes	N/A													N/A	None Visible	None Visible		Low
Recommendations:			Approximately 1 metre of uninsulated cold and hot flow/return pipework in ceiling space - all pipework should be fully insulated to prevent heat gain/loss.																									
Comment:			"Anaconda" flexible connections in main ward corridor ceiling space.																									
Ward 2A DSR (SCH-087)	Hot Near Cold Near	CWST Not Run	PR 41 Cals 01-03 (Riser M39) Not Run	2 TMT	OK	Y	Y	2	None Visible	Yes	Unoccupied Flushing Regime		1	1	2										None Visible	None Visible	1 x Swan Neck Tap, 1 x Mop Sink	Low
Recommendations:																												
Comments:			Drainage in area scheduled for repair with outlets currently flushed into buckets until reinstated to full use. Check valves fitted on both hot and cold supplies to TMT.																									

LEGIONELLA RISK ASSESSMENT

Location / Room No	Sentinel outlet?	Cold Supply & Temp (°C)	Hot Supply & Temp (°C)	TMV info					Deadlegs Present (Inc. Drain cocks)	Flow & Return Working	Outlet Usage	Outlets in location												Aerosol Created	Non WRAS Material	Flexi Hoses	Comment	Additional Localised Risk Rating
				No. Of TMVs	Access	<2m from outlet?	Mix Temps 37-45°C	No. TMV Fed Outlets				Mains	Cold	Hot	Mixer	Urinals	WCs	Shower	Drinks / vend	Water boiler	Drink fountain	Arjo/whirlpool	Other					
Ward 2A Staff Pantry (SCH-090)		CWST 10.6	PR 41 Cals 01-03 (Riser M39) 58.1	1 TMT	OK	Y	Y	1	None Visible	Yes	Unoccupied Flushing Regime		1	1	1					1					None Visible	None Visible	1 x Swan Neck Tap	Low

Recommendations:

Comments: Drainage in area scheduled for repair with outlets currently flushed into buckets until reinstated to full use.
Check valves fitted on both hot and cold supplies to TMT.

Ward 2A Treatment Room (Old Bathroom) (SCH-079)		CWST 10.4	PR 41 Cals 01-03 (Riser M39) 58.4	1 TMT	OK	Y	Y	1	None Visible	Yes	Unoccupied Flushing Regime				1										None Visible	None Visible	1 x Wash Trough	Low

Recommendations:

Comments: Check valves fitted on both hot and cold supplies to TMT.

Ward 2A (SCH-083)		CWST 10.2	PR 41 Cals 01-03 (Riser M39) 58.5	1 TMT	OK	Y	Y	1	None Visible	Yes	Unoccupied Flushing Regime				1										None Visible	None Visible		Low

Recommendations:

Comments: Check valves fitted on both hot and cold supplies to TMT.

Ward 2A Waste Disposal (SCH-084A)		CWST 10.3	PR 41 Cals 01-03 (Riser M39) 58.0	1 TMT	OK	Y	Y	1	None Visible	Yes	Unoccupied Flushing Regime				1									1	None Visible	None Visible	1 x Macerator	Low

Recommendations:

Comments: Check valves fitted on both hot and cold supplies to TMT.

LEGIONELLA RISK ASSESSMENT

Location / Room No	Sentinel outlet?	Cold Supply & Temp (°C)	Hot Supply & Temp (°C)	TMV info					Deadlegs Present (Inc. Drain cocks)	Flow & Return Working	Outlet Usage	Outlets in location												Aerosol Created	Non WRAS Material	Flexi Hoses	Comment	Additional Localised Risk Rating
				No. Of TMVs	Access	<2m from outlet?	Mix Temps 37-45°C	No. TMV Fed Outlets				Mains	Cold	Hot	Mixer	Urinals	WCs	Shower	Drinks / vend	Water boiler	Drink fountain	Arjo/whirlpool	Other					
Ward 2A Bed 17 (SCH-066)		CWST 10.5	PR 41 Cals 01-03 (Riser M39) 57.9	1 TMT	OK	Y	Y	1	None Visible	Yes	Unoccupied Flushing Regime				1									Low	None Visible	None Visible		Low

Recommendations:

Comments: Check valves fitted on both hot and cold supplies to TMT.

Ward 2A Bed 17 En-Suite (SCH-065)		CWST 10.2	PR 41 Cals 01-03 (Riser M39) 57.5	1 TMT 1 SHWR	OK	Y	Y	2	None Visible	Yes	Unoccupied Flushing Regime				1		1	1						Head Removed Currently	None Visible	None Visible		Low

Recommendations:

Comments: Check valves fitted on both hot and cold supplies to TMT.
Hot flow loops around room to pick up shower supply first then feeding the WHB where the hot returns to main distribution.

Ward 2A Bed 18 (SCH-067)		CWST 10.4	PR 41 Cals 01-03 (Riser M39) 58.0	1 TMT	OK	Y	Y	1	None Visible	Yes	Unoccupied Flushing Regime				1									Low	None Visible	None Visible		Low

Recommendations:

Comments: Check valves fitted on both hot and cold supplies to TMT.

Ward 2A Bed 18 En-Suite (SCH-069)		CWST 10.4	PR 41 Cals 01-03 (Riser M39) 58.2	1 TMT 1 SHWR	OK	Y	Y	2	None Visible	Yes	Unoccupied Flushing Regime				1		1	1						Head Removed Currently	None Visible	None Visible		Low

Recommendations:

Comments: Check valves fitted on both hot and cold supplies to TMT.
Hot flow loops around room to pick up shower supply first then feeding the WHB where the hot returns to main distribution.

LEGIONELLA RISK ASSESSMENT

Location / Room No	Sentinel outlet?	Cold Supply & Temp (°C)	Hot Supply & Temp (°C)	TMV info					Deadlegs Present (Inc. Drain cocks)	Flow & Return Working	Outlet Usage	Outlets in location												Aerosol Created	Non WRAS Material	Flexi Hoses	Comment	Additional Localised Risk Rating
				No. Of TMVs	Access	<2m from outlet?	Mix Temps 37-45°C	No. TMV Fed Outlets				Mains	Cold	Hot	Mixer	Urinals	WCs	Shower	Drinks / vend	Water boiler	Drink fountain	Arjo/whirlpool	Other					
Ward 2A Bed 19 (SCH-072)		CWST 10.4	PR 41 Cals 01-03 (Riser M39) 58.2	1 TMT	OK	Y	Y	1	None Visible	Yes	Unoccupied Flushing Regime				1									Low	None Visible	None Visible		Low
Recommendations:																												
Comments:			Check valves fitted on both hot and cold supplies to TMT.																									
Ward 2A Bed 19 En-Suite (SCH-070)		CWST 10.6	PR 41 Cals 01-03 (Riser M39) 58.3	1 TMT 1 SHWR	OK	Y	Y	2	None Visible	Yes	Unoccupied Flushing Regime				1		1	1						Head Removed Currently	None Visible	None Visible		Low
Recommendations:																												
Comments:			Check valves fitted on both hot and cold supplies to TMT. Hot flow loops around room to pick up shower supply first then feeding the WHB where the hot returns to main distribution.																									
Ward 2A Bed 20 (SCH-074)		CWST 10.5	PR 41 Cals 01-03 (Riser M39) 58.0	1 TMT	OK	Y	Y	1	None Visible	Yes	Unoccupied Flushing Regime				1									Low	None Visible	None Visible		Low
Recommendations:																												
Comments:			Check valves fitted on both hot and cold supplies to TMT.																									
Ward 2A Bed 20 En-Suite (SCH-076)		CWST 10.2	PR 41 Cals 01-03 (Riser M39) 57.8	1 TMT 1 SHWR	OK	Y	Y	2	None Visible	Yes	Unoccupied Flushing Regime				1		1	1						Head Removed Currently	None Visible	None Visible		Low
Recommendations:																												
Comments:			Check valves fitted on both hot and cold supplies to TMT. Hot flow loops around room to pick up shower supply first then feeding the WHB where the hot returns to main distribution.																									

LEGIONELLA RISK ASSESSMENT

Location / Room No	Sentinel outlet?	Cold Supply & Temp (°C)	Hot Supply & Temp (°C)	TMV info					Deadlegs Present (Inc. Drain cocks)	Flow & Return Working	Outlet Usage	Outlets in location												Aerosol Created	Non WRAS Material	Flexi Hoses	Comment	Additional Localised Risk Rating
				No. Of TMVs	Access	<2m from outlet?	Mix Temps 37-45°C	No. TMV Fed Outlets				Mains	Cold	Hot	Mixer	Urinals	WCs	Shower	Drinks / vend	Water boiler	Drink fountain	Arjo/whirlpool	Other					
Ward 2A Room 21 Radiation Shield Room (SCH-081)		CWST 10.5	PR 41 Cals 01-03 (Riser M39) 57.6	1 TMT	OK	Y	Y	1	None Visible	Yes	Unoccupied Flushing Regime				1									Low	None Visible	None Visible		Low
Recommendations:																												
Comments: Check valves fitted on both hot and cold supplies to TMT.																												
Ward 2A Radiation Room 21 Shield Room En-Suite (SCH-082)		CWST 10.3	PR 41 Cals 01-03 (Riser M39) 58.2	1 TMT	OK	Y	Y	1	None Visible	Yes	Unoccupied Flushing Regime				1		1	1						Head Removed Currently	None Visible	None Visible		Low
Recommendations:																												
Comments: Check valves fitted on both hot and cold supplies to TMT. Hot flow loops around room to pick up shower supply first then feeding the WHB where the hot returns to main distribution.																												
Ward 2A Relatives Room En-Suite (SCH-085)		CWST 10.7	PR 41 Cals 01-03 (Riser M39) 58.1	1 TMT	OK	Y	Y	1	None Visible	Yes	Unoccupied Flushing Regime				1									Low	None Visible	None Visible		Low
Recommendations: Check valves fitted on both hot and cold supplies to TMT.																												
Ward 2A Room 22 (SCH-010)		CWST 10.7	PR 41 Cals 01-03 (Riser M39) 57.9	1 TMT	OK	Y	Y	1	None Visible	Yes	Unoccupied Flushing Regime				1									Low	None Visible	None Visible		Low
Recommendations:																												
Comments: Check valves fitted on both hot and cold supplies to TMT.																												

LEGIONELLA RISK ASSESSMENT

Location / Room No	Sentinel outlet?	Cold Supply & Temp (°C)	Hot Supply & Temp (°C)	TMV info					Deadlegs Present (Inc. Drain cocks)	Flow & Return Working	Outlet Usage	Outlets in location												Aerosol Created	Non WRAS Material	Flexi Hoses	Comment	Additional Localised Risk Rating
				No. Of TMVs	Access	<2m from outlet?	Mix Temps 37-45°C	No. TMV Fed Outlets				Mains	Cold	Hot	Mixer	Urinals	WCs	Shower	Drinks / vend	Water boiler	Drink fountain	Arjo/whirlpool	Other					
Ward 2A Room 22 En-Suite (SCH-007)		CWST 10.6	PR 41 Cals 01-03 (Riser M39) 57.6	1 TMT	OK	Y	Y	1	None Visible	Yes	Unoccupied Flushing Regime				1		1	1						Head Removed Currently	None Visible	None Visible		Low
Recommendations:																											
Comments:			Check valves fitted on both hot and cold supplies to TMT. Hot flow loops around room to pick up shower supply first then feeding the WHB where the hot returns to main distribution.																								
Ward 2A Room 23 (SCH-011)		CWST 10.5	PR 41 Cals 01-03 (Riser M39) 58.2	1 TMT	OK	Y	Y	1	None Visible	Yes	Unoccupied Flushing Regime				1									Low	None Visible	None Visible		Low
Recommendations:																											
Comments:			Check valves fitted on both hot and cold supplies to TMT.																								
Ward 2A Room 23 En-Suite (SCH-015)		CWST 10.7	PR 41 Cals 01-03 (Riser M39) 57.9	1 TMT	OK	Y	Y	1	None Visible	Yes	Unoccupied Flushing Regime				1		1	1						Head Removed Currently	None Visible	None Visible		Low
Recommendations:																											
Comments:			Check valves fitted on both hot and cold supplies to TMT.																								
Ward 2A Room 24 (SCH-017)		CWST 10.6	PR 41 Cals 01-03 (Riser M39) 58.0	1 TMT	OK	Y	Y	1	None Visible	Yes	Unoccupied Flushing Regime				1									Low	None Visible	None Visible		Low
Recommendations:																											
Comments:			Check valves fitted on both hot and cold supplies to TMT.																								
Ward 2A Room 24 En-Suite (SCH-016)		CWST 10.3	PR 41 Cals 01-03 (Riser M39) 57.6	1 TMT	OK	Y	Y	1	None Visible	Yes	Unoccupied Flushing Regime				1		1	1						Head Removed Currently	None Visible	None Visible		Low
Recommendations:																											
Comments:			Check valves fitted on both hot and cold supplies to TMT. Hot flow loops around room to pick up shower supply first then feeding the WHB where the hot returns to main distribution.																								

LEGIONELLA RISK ASSESSMENT

Location / Room No	Sentinel outlet?	Cold Supply & Temp (°C)	Hot Supply & Temp (°C)	TMV info					Deadlegs Present (Inc. Drain cocks)	Flow & Return Working	Outlet Usage	Outlets in location												Aerosol Created	Non WRAS Material	Flexi Hoses	Comment	Additional Localised Risk Rating
				No. Of TMVs	Access	<2m from outlet?	Mix Temps 37-45°C	No. TMV Fed Outlets				Mains	Cold	Hot	Mixer	Urinals	WCs	Shower	Drinks / vend	Water boiler	Drink fountain	Arjo/whirlpool	Other					
Ward 2A Room 25 (SCH-020)		CWST 10.4	PR 41 Cals 01-03 (Riser M39) 58.1	1 TMT	OK	Y	Y	1	None Visible	Yes	Unoccupied Flushing Regime				1									Low	None Visible	None Visible		Low

Recommendations:

Comments: Check valves fitted on both hot and cold supplies to TMT.

Ward 2A Room 25 En-Suite (SCH-023)	Hot Far Cold Far	CWST 10.4	PR 41 Cals 01-03 (Riser M39) 58.2	1 TMT	OK	Y	Y	1	None Visible	Yes	Unoccupied Flushing Regime				1		1	1						Head Removed Currently	None Visible	None Visible		Low

Recommendations:

Comments: Check valves fitted on both hot and cold supplies to TMT.
Hot flow loops around room to pick up shower supply first then feeding the WHB where the hot returns to main distribution.

Ward 2A Parent Kitchen (SCH-077)		CWST 10.7	PR 41 Cals 01-03 (Riser M39) 57.6	2 TMT	OK	Y	Y	2	None Visible	Unable to access (hot temp rose quickly)	Unoccupied Flushing Regime				2									Low	None Visible	None Visible		Low

Recommendations:

Ward 2A Clean Utility (SCH-014)		CWST 10.5	PR 41 Cals 01-03 (Riser M39) 58.2	2 TMT	OK	Y	Y	2	None Visible	Yes	Unoccupied Flushing Regime				2								1	Low	None Visible	None Visible	1 x Macerator	Low

Recommendations:

Comments: Check valves fitted on both hot and cold supplies to TMT.

Ward 2A Treatment Room (No Code)		CWST 10.8	PR 41 Cals 01-03 (Riser M39) 57.6	1 TMT	OK	Y	Y	1	None Visible	Yes	Unoccupied Flushing Regime				1									Low	None Visible	None Visible		Low

Recommendations:

Comments: Check valves fitted on both hot and cold supplies to TMT.

LEGIONELLA RISK ASSESSMENT

Location / Room No	Sentinel outlet?	Cold Supply & Temp (°C)	Hot Supply & Temp (°C)	TMV info					Deadlegs Present (Inc. Drain cocks)	Flow & Return Working	Outlet Usage	Outlets in location												Aerosol Created	Non WRAS Material	Flexi Hoses	Comment	Additional Localised Risk Rating
				No. Of TMVs	Access	<2m from outlet?	Mix Temps 37-45°C	No. TMV Fed Outlets				Mains	Cold	Hot	Mixer	Urinals	WCs	Shower	Drinks / vend	Water boiler	Drink fountain	Arjo/whirlpool	Other					
Ward 2B Staff Toilet (DCU-017)	Hot Near Cold Near	CWST 10.6	PR 41 Cals 01-03 (Riser M39) 57.0	1 TMT	OK	Y	Y	1	None Visible	Yes	Unoccupied Flushing Regime				1		1							Low	None Visible	None Visible		Low
Recommendations:																												
Comments:			Check valves fitted on both hot and cold supplies to TMT.																									
Ward 2B Dirty Utility (DCU-018)		CWST 10.4	PR 41 Cals 01-03 (Riser M39) 58.4	2 TMT	OK	Y	Y	2	None Visible	Yes	Unoccupied Flushing Regime				2								1	Low	None Visible	None Visible	1 x Macerator	Low
Recommendations:																												
Comments:			Check valves fitted on both hot and cold supplies to TMT.																									
Ward 2B Consulting Room 5 (DCU-019)		CWST 10.4	PR 41 Cals 01-03 (Riser M39) 58.4	1 TMT	OK	Y	Y	1	None Visible	Yes	Unoccupied Flushing Regime				1									Low	None Visible	None Visible		Low
Recommendations:																												
Comments:			Check valves fitted on both hot and cold supplies to TMT.																									
Ward 2B Consulting Room 4 (DCU-020)		CWST 10.3	PR 41 Cals 01-03 (Riser M39) 58.1	1 TMT	OK	Y	Y	1	None Visible	Yes	Unoccupied Flushing Regime				1									Low	None Visible	None Visible		Low
Recommendations:																												
Comments:			Check valves fitted on both hot and cold supplies to TMT.																									

LEGIONELLA RISK ASSESSMENT

Location / Room No	Sentinel outlet?	Cold Supply & Temp (°C)	Hot Supply & Temp (°C)	TMV info					Deadlegs Present (Inc. Drain cocks)	Flow & Return Working	Outlet Usage	Outlets in location												Aerosol Created	Non WRAS Material	Flexi Hoses	Comment	Additional Localised Risk Rating
				No. Of TMVs	Access	<2m from outlet?	Mix Temps 37-45°C	No. TMV Fed Outlets				Mains	Cold	Hot	Mixer	Urinals	WCs	Shower	Drinks / vend	Water boiler	Drink fountain	Arjo/whirlpool	Other					
Ward 2B Consulting Room 3 (DCU-021)		CWST 10.6	PR 41 Cals 01-03 (Riser M39) 57.9	1 TMT	OK	Y	Y	1	None Visible	Yes	Unoccupied Flushing Regime				1									Low	None Visible	None Visible		Low
Recommendations:																												
Comments:			Check valves fitted on both hot and cold supplies to TMT.																									
Ward 2B Consulting Room 2 (DCU-023)		CWST 10.4	PR 41 Cals 01-03 (Riser M39) 57.7	1 TMT	OK	Y	Y	1	None Visible	Yes	Unoccupied Flushing Regime				1									Low	None Visible	None Visible		Low
Recommendations:																												
Comments:			Check valves fitted on both hot and cold supplies to TMT.																									
Ward 2B Consulting Room 1 (DCU-024)		CWST 10.6	PR 41 Cals 01-03 (Riser M39) 57.8	1 TMT	OK	Y	Y	1	None Visible	Yes	Unoccupied Flushing Regime				1									Low	None Visible	None Visible		Low
Recommendations:																												
Comments:			Check valves fitted on both hot and cold supplies to TMT.																									
Ward 2B Clean Utility (DCU-022)		CWST 10.6	PR 41 Cals 01-03 (Riser M39) 58.3	1 TMT	OK	Y	Y	1	None Visible	Yes	Unoccupied Flushing Regime				1									Low	None Visible	None Visible		Low
Recommendations:																												
Comments:			Check valves fitted on both hot and cold supplies to TMT.																									

LEGIONELLA RISK ASSESSMENT

Location / Room No	Sentinel outlet?	Cold Supply & Temp (°C)	Hot Supply & Temp (°C)	TMV info					Deadlegs Present (Inc. Drain cocks)	Flow & Return Working	Outlet Usage	Outlets in location												Aerosol Created	Non WRAS Material	Flexi Hoses	Comment	Additional Localised Risk Rating
				No. Of TMVs	Access	<2m from outlet?	Mix Temps 37-45°C	No. TMV Fed Outlets				Mains	Cold	Hot	Mixer	Urinals	WCs	Shower	Drinks / vend	Water boiler	Drink fountain	Arjo/whirlpool	Other					
Ward 2B Accessible Toilet (DCU-005)	Hot Far Cold Far	CWST 10.8	PR 41 Cals 01-03 (Riser M39) 57.8	1 TMT	OK	Y	Y	1	None Visible	Yes	Unoccupied Flushing Regime				1		1							Low	None Visible	None Visible		Low
Recommendations:																											
Comments:			Check valves fitted on both hot and cold supplies to TMT.																								
Ward 2B Day Stay Room A (DCU-007)		CWST 10.6	PR 41 Cals 01-03 (Riser M39) 55.9	1 TMT	OK	Y	Y	1	None Visible	No	Unoccupied Flushing Regime				1									Low	None Visible	None Visible		Medium
Recommendations:			Hot flow and return not working correctly Further investigation require. Note: Upon further investigation it was noted a valve was not fully open. Upon opening (by Estates) circulation and F&R temperatures improved. Commissioning engineers clarifying full balancing of system and acceptable F&R temperatures across ward.																								
Comments:			Check valves fitted on both hot and cold supplies to TMT.																								
Ward 2B Day Stay Room A En-Suite (DCU-008)		CWST 10.5	PR 41 Cals 01-03 (Riser M39) 57.6	1 TMT	OK	Y	Y	1	None Visible	Yes	Unoccupied Flushing Regime				1		1							Low	None Visible	None Visible		Low
Recommendations:																											
Comments:			Check valves fitted on both hot and cold supplies to TMT.																								
Ward 2B BMT Day Ward Room B (DCU-011)		CWST 10.4	PR 41 Cals 01-03 (Riser M39) 57.7	1 TMT	OK	Y	Y	1	None Visible	Yes	Unoccupied Flushing Regime				1									Low	None Visible	None Visible		Low
Recommendations:																											
Comments:			Check valves fitted on both hot and cold supplies to TMT.																								

LEGIONELLA RISK ASSESSMENT

Location / Room No	Sentinel outlet?	Cold Supply & Temp (°C)	Hot Supply & Temp (°C)	TMV info					Deadlegs Present (Inc. Drain cocks)	Flow & Return Working	Outlet Usage	Outlets in location												Aerosol Created	Non WRAS Material	Flexi Hoses	Comment	Additional Localised Risk Rating
				No. Of TMVs	Access	<2m from outlet?	Mix Temps 37-45°C	No. TMV Fed Outlets				Mains	Cold	Hot	Mixer	Urinals	WCs	Shower	Drinks / vend	Water boiler	Drink fountain	Arjo/whirlpool	Other					
Ward 2B BMT Day Ward Room B Accessible Toilet (DCU-009)		CWST 10.3	PR 41 Cals 01-03 (Riser M39) 58.1	1 TMT	OK	Y	Y	1	None Visible	Yes	Unoccupied Flushing Regime				1		1							Low	None Visible	None Visible		Low
Recommendations:																												
Comments:			Check valves fitted on both hot and cold supplies to TMT.																									
Ward 2B Public Toilet (DCU-013)		CWST 10.8	PR 41 Cals 01-03 (Riser M39) 57.5	1 TMV	OK	Y	Y	1	None Visible	Yes	Unoccupied Flushing Regime				1		1							Low	None Visible	None Visible	I.R Tap with Fitted T-Safe Filter	Low
Recommendations:																												
Comments:			Check valves fitted on both hot and cold supplies to TMT.																									
Ward 2B Main Corridor Ceiling Void Outside Room B		CWST N/A	PR 41 Cals 01-03 (Riser M39) N/A	N/A					None Visible	Yes	N/A													N/A	None Visible	Yes		Low
Recommendations:			Approximately 0.5 metre of uninsulated cold and hot flow/return pipework in ceiling space - all pipework should be fully insulated to prevent heat gain/loss.																									
Comment:			"Anaconda" flexible connections in main ward corridor ceiling space.																									

Section 8

Other 'At Risk Systems'

LEGIONELLA RISK ASSESSMENT

No other systems "at risk" systems being assessed as part of this survey.

All other "at risk" systems should have a suitable L8 risk assessment carried out with an appropriate L8 monitoring regime implemented.

HSG 274 Legionnaire's disease: Technical guidance Part 3: The control of legionella bacteria in other risk systems provides guidance on identification and frequency of inspections for these systems.

We would advise systems are installed and maintained in accordance with manufacturers instructions, HSG 274 part 3 and industry good practice and aerosol creation is minimised during operation and maintenance procedures.

Other system identified on site which may require to be assessed (generally within the hospital):

- Closed Heating Systems
- Closed Chilled Systems (including chilled beams)
- Air Handling Plant and Equipment
- Fire Suppression Systems
- Endoscopy Systems
- Renal Systems
- Hydrotherapy Pools (and associated plant)
- Reverse Osmosis Systems
- Endoscopy Wash Systems
- Humidification Systems (DMA understands these have all been disconnected/removed from within QEUH A&C)
- Medical Gases
- Other Medical equipment

Note system above may require input from Clinical/ICT and/or other specialist contractors.

Section 9

Legionella Control & Documentation

LEGIONELLA RISK ASSESSMENT

Legionella control and documentation

Inadequate management, lack of training and poor communication have all been identified as contributory factors in outbreaks of legionnaires' disease. This is particularly important where several people are responsible for different aspects of the treatment or precautions.

Communications should be 'fail-safe'. The record system is the method to ensure that precautions continue to be carried out and that information is available for checking what is done in practice.

Legionella Management Structure

Where "there is a reasonably foreseeable risk and it is reasonably practicable to prevent exposure or control the risk from exposure, the person on whom the statutory duty falls should appoint a person or persons to take managerial responsibility and to provide supervision for the implementation of precautions."

Legionella management structure	
Is there a legionella management structure in place?	This assessment covers the physical survey only. The management structure should be established specifically by site and also as part of the wider NHS Greater Glasgow & Clyde estate structure in conjunction with current L8 risk assessment works carried out by DMA Canyon. These structures and responsibilities will be addressed as a separate exercise through NHS Estates and other relevant parties.
Is management structure recorded in legionella management documentation?	
Are lines of communication clearly defined and recorded within the log book/written scheme?	
Is management structure adequate for legionella management control?	

LEGIONELLA RISK ASSESSMENT

Persons identified within site documentation as having responsibility for legionella control:

Position	Name	Deputy
Statutory Duty Holder	This assessment covers the physical survey only. The management structure should be established specifically by site and also as part of the wider NHS Greater Glasgow & Clyde estate structure in conjunction with current L8 risk assessment works carried out by DMA Canyon. These structures and responsibilities will be addressed as a separate exercise through NHS Estates and other relevant parties.	
Designated Responsible Person		
Building Manager		
Site Engineer		
Legionella Consultant(s)		
Contractors(s)		
Others		
Who has operational control of the water systems on site? (e.g. Site/facilities company/maintenance company etc.)		NSH GG&C Capital have had control of the water systems and ward areas during the renovation phase (late 2019 till present). Operational control will transfer to NHS GG&C Estates once ward is handed over and wards returned to normal use.

Previous risk assessment & drawings	Produced by
Previous L8 risk assessment	No specific Assessment covering Wards 2A/2B only have been carried out previously.
Review of previous assessment	N/A
System drawings	Original as fitted drawings available with updates for the alterations made during the renovation phase (as carried out by MPMH/James Frew). No drawings appear to be available which include the alterations made during the water system upgrade/alterations in late 2018/early 2019. DMA have been requested to hand mark-up the latest version of the drawings to capture the alterations made during previous works and GG&C Estates will have these amended on the CAD drawings.

Training	
Are training records held in logbook/record system?	This assessment covers the physical survey only. Training and competency will be addressed as a separate exercise through NHS Estates and other relevant parties. DMA training records have been submitted to NHS GG&C.
Are competency records held in logbook/record system?	
Have training requirements been established?	

LEGIONELLA RISK ASSESSMENT

Written scheme	
Is there a written scheme in place and recorded in site log book?	This assessment covers the physical pipework survey only. Management of the water systems and Written Scheme requirements will be addressed as a separate exercise through NHS Estates and other relevant parties.
Are all tasks/duties assigned to named individuals or sub-contractors?	
Are suitable method statements maintained in log book for all tasks/duties?	
Is there an emergency procedure plan in place?	
Are there procedures in place to deal with "out-of-specification" results?	
Does written scheme include instructions for safe operation of plant (and precautions if required)?	
Are procedures for start-up and shut-down of plant included within written scheme?	

LEGIONELLA RISK ASSESSMENT

L8 monitoring		
Is a water systems monitoring regime already in place?		
Are monitoring records held in suitable logbook/record system?		
Do L8 monitoring records include:	Flushing of low use outlets?	Entire ward has been on a flushing regime since renovation works started.
	Outlet temperature monitoring?	During flushing all taps are tun until hot and cold temperature stabilise in line with expected temperatures at TMT (approx. 41°C), direct hot, (Approx. 60°C) and cold (variable dependant on season though always <20°C)
	Calorifier temperature monitoring	N/A
	Water heater temperature monitoring	N/A
	Shower/Spray Descaling	All showerheads removed during the renovation works.
	Tank Inspections	N/A
	Calorifier Base Flushing	N/A
	Calorifier Inspections	N/A
	C&D of Water Systems	Disinfections of the system were carried out in October and December 2021. All local alterations had clean working and component disinfection procedures in place.
	TMV Servicing/Testing	New TMTs were installed across the wards in January 2022 with servicing /commissioning at installation.
	Maintenance/Service Records	N/A
	Pumps alternating	N/A
	Biocidal Control	ClO_2 levels are checked when microbiological sampling is carried out. Microbiological sampling has been carried out on a regular basis since October 2021.
	Other (Specify)	
Do all records indicate who carried out works? (e.g. Signed/Dated)		Yes
Are out of specification results recorded and appropriate remedial actions taken and logged?		Yes
Do records go back 5 years?		DMA records cover the renovation period.

Note: Tasks as described above relate only to works carried out by DMA Canyon Ltd as instructed by NHS GG&C.

LEGIONELLA RISK ASSESSMENT

Microbiological sampling	
Is there a microbiological sampling regime in place?	Microbiological sampling regime has been in place since September 2021
Frequency of samples taken?	Various sweeps have been undertaken with samples moving to 4 x weekly since January 2021
Are legionella samples taken as part of sampling regime?	A full legionella sampling sweep was undertaken across the ward in September 2021. All results returned as "not detected", which is line with the rest of the Adult and Children's hospital (where no positive legionella results have been returned during routine sampling during this period).
Are potable samples taken as part of sampling regime?	Yes
Are pseudomonas samples taken as part of sampling regime?	Yes
Are other microbiological samples taken?	Yes. Samples are also taken for Gram Negative Bacteria (GNB), specifically Cupriavidus and SAB (yeast/mould).
Does sampling regime adequately reflect the complexity and scope of the water system?	Yes
Are suitable remedial actions and resamples taken after out of specification sample results recorded?	Yes. All Markwik 21+ taps were swapped out during January 2022 as microbiological results indicated that the taps were potentially the source of the out of specification results.
Is there a history of Legionella colonisation of the water systems on site?	No

Logbook/Record Auditing	
Is an audit system in place for legionella management and control?	This assessment covers the physical survey only. Management of the water systems and Written Scheme requirements will be addressed as a separate exercise through NHS Estates and other relevant parties.

LEGIONELLA RISK ASSESSMENT

Summary of Governance Tasks Recommended for L8 and SHTM 04-01 Compliance	Guidance Documents
Regular check to ensure that legislation and guidance has not changed	L8 HSG 274 Pt 2 SHTM 04-01
Create register and regularly review all policies relating to legionella control (e.g. Maintenance, Water Treatment, Water Management, Energy) to ensure still valid and correct	L8 HSG 274 Pt 2 SHTM 04-01
Regular review of Water Systems Management Structure to ensure up-to-date and accurate	L8 HSG 274 Pt 2 SHTM 04-01
Regular review of communication lines to ensure still accurate and correct	L8 HSG 274 Pt 2 SHTM 04-01
Regular review of escalation & emergency procedures to ensure still valid and correct	L8 HSG 274 Pt 2 SHTM 04-01
Regular review of duties allocated to site staff and ensure accurate and recorded (including any changes in use of wards/departments).	L8 HSG 274 Pt 2 SHTM 04-01
Regular review of roles allocated to individual departments in relation to the water systems and ensure accurate and recorded	L8 HSG 274 Pt 2 SHTM 04-01
Regular review of duties of sub-contractors to ensure accurate and recorded and contractors are suitably qualified/competent for tasks assigned to them (e.g. Water Hygiene contractors should be LCA Approved, Plumbing contractors should be SNIPEF and Water Safe Registered, etc.)	L8 HSG 274 Pt 2 SHTM 04-01
Create register and regularly review staff training and competency requirements and update training matrix	L8 HSG 274 Pt 2 SHTM 04-01
Create register and regularly review PPM requirements, method statements, SOPs and risk assessments to ensure still valid and correct	L8 HSG 274 Pt 2 SHTM 04-01
Create register and regularly review remedial work progress	L8 HSG 274 Pt 2 SHTM 04-01
Regular review of site documentation to ensure all records up to date and present	L8 HSG 274 Pt 2 SHTM 04-01
Create register and regularly review "Patient Risk Rating" for all areas of hospital (including any changes in use of wards/departments).	SHTM 04-01 Part B
Create register and regularly review sentinel outlet locations register (inc. Sentinel TMV/TMTs).	SHTM 04-01 Part B
Create register and regularly review little-used outlet locations register (input from clinical staff required, and including any changes in use of wards/departments)	SHTM 04-01 Part G
Create register and regularly review deadlegs/blind ends locations register (input from clinical staff required, and including any changes in use of wards/departments)	SHTM 04-01 Part G
Create register and regularly review POU/Anti-microbial (PALL) filters locations (and manufacturer's/types of filters fitted)	SHTM 04-01 Part G
Create register and regularly review TMV/TMT locations and manufacturer/model.	SHTM 04-01 Part G
Create register and regularly review shower & spray outlet locations (including emergency/deluge showers)	SHTM 04-01 Part G
Create register and regularly review primary, sub-ordinate and tertiary hot flow and return loops to reflect any system alterations.	HSG 274 Pt 2
Create register and regularly review and record all plant, valves, equipment and services and their associated maintenance schedules).	HSG 274 Pt 2 SHTM 04-01 Part B

Cont...

LEGIONELLA RISK ASSESSMENT

Summary of Governance Tasks Recommended for L8 and SHTM 04-01 Compliance	Guidance Documents
Create register and regularly review BEMS temperature sensor locations to reflect any system alterations	HSG 274 Pt 2
Create register and regularly review schematic/as-fitted drawings to ensure up-to-date and accurate	L8 HSG 274 Pt 2 SHTM 04-01
Create register and regularly review all backflow prevention device locations/type (E.g. Check valves, RPZs etc.) to reflect any system alterations.	L8 HSG 274 Pt 2 SHTM 04-01
Create register and regularly review all flexible hoses locations (EPDM) (E.g. at Arjo baths, Pressure reducing valves etc.) to reflect any system alterations.	SHTM 04-01
Create register of drains to be cleaned and disinfected and frequency	TBC by Client
Review of water systems risk assessment as a "live" document (DMA recommend a maximum period of 2 years). An indication of when to review the assessment and what to consider should be recorded and this may result from, e.g.: • a change to the water system or its use; • a change to the use of the building where the system is installed; • new information available about risks or control measures; • the results of checks indicating that control measures are no longer effective; • changes to key personnel; • a case of legionnaires' disease/legionellosis associated with the system.	L8 STHM 04-01

N.B. By "Regular" e.g. a Quarterly or 6 monthly review of all tasks above or as and when there are changes in system operation, management or other control parameters which would warrant a review of any particular task. (e.g. if change of use or changes in legislation or any other factor which could affect validity of the current documentation)

Section 10

Written Scheme Guidance

L8 RISK ASSESSMENT

Note: *The summary tasks highlighted below relate only to Wards 2A & 2B specifically. Please refer to previous Adult and Children's Hospital L8 risk assessment for further details of tasks recommended for the water system generally/as a whole.*

Summary of ppm tasks recommended within site Written Scheme/Water Safety Plan	Recommended
Daily review of BEMS records (temperature records, alarms etc.)	Yes
Daily water draw-off should form part of the daily cleaning process.	Yes
Daily flushing of all outlets in "High Risk Patient" Areas. Hot and cold outlets should be flushed for a minimum of 3 minutes and until the water temperature stabilises in line with current temperature profile.	Yes Ward 2A/2B have been included within designated "High Risk Areas"
Twice-weekly flushing of all outlets in unoccupied areas and low use/sporadically used outlets. Hot and cold outlets should be flushed for a minimum of 3 minutes and until the water temperature stabilises in line with current temperature profile (<20°C for cold water and >55°C for hot water) (or until removal is carried out)[1 & 2]	Yes
Twice weekly flushing of dead legs/blind ends (inc CWST Drain pipework where these cannot be removed) where these cannot be removed. Hot and cold outlets should be flushed for a minimum of 3 minutes and until the water temperature stabilises in line with current temperature profile (<20°C for cold water and >55°C for hot water) (or until removal is carried out)[1 & 2]	No deadlegs have been identified within this assessment for Wards 2A/2B
Weekly measurement of the concentration of chlorine dioxide at the sentinel taps – the concentration should be at least 0.1 mg/l (or as advised by WSG); and adjust the chlorine dioxide dosage to establish the required residual at the sentinel sample points.	Yes
Monthly test the treated water for both chlorine dioxide and total oxidant/chlorite representative outlets to verify the dosage rate and conversion yield.	Yes (Continual monitoring incorporated into Scotmas ClO_2 monitoring stations for CWSTs)
31 Day (or 62 day/92 day dependant on filters used) changing of tap/showerhead POU/Anti-microbial filters within wards	Yes
Monthly temperature checks on hot outlets at sentinel, little-used & selected outlets. >55°C within 1 minute (also note potential scald risks and out of spec TMVs) to create a temperature profile of systems.	Yes
Monthly temperature checks on cold outlets at sentinel, little-used & selected outlets. <20°C within 2 minutes to create a temperature profile of building and monitor heat gain within the cold water system (Actual temperature for cold water will vary according to season).	Yes
Monthly temperature checks on all primary flow and return loops to confirm they are at a minimum of 55°C and to create a temperature profile of the whole system.	Yes (monitored on BMS)
Monthly/Quarterly take temperatures (ideally on a rolling monthly rota to ensure all covered on a quarterly basis) at return legs of subordinate loops to confirm they are at a minimum of 55°C and to create a temperature profile of the whole system.	Yes (Where practical and accessible) HAI Scribes may be require to access pipework. New flow and return probes have been fitted , 5 on HOTCT side, 2 on BMT, 3 on 2B F&R loops across 2A/2B which will be monitored on the BMS.
Monthly/Annually take temperatures (ideally on a rolling monthly rota to ensure all covered over a defined period, as agreed by WSG) at return legs of tertiary loops to confirm they are at a minimum of 55°C and to create a temperature profile of the whole system	Yes (Where practical and accessible) HAI Scribes may be require to access pipework. New flow and return probes have been fitted, 5 on HOTCT side, 2 on BMT, 3 on 2B F&R loops across 2A/2B which will be monitored on the BMS.

Cont....

L8 RISK ASSESSMENT

Summary of ppm tasks recommended within site Written Scheme/Water Safety Plan	Recommended
Quarterly[1] replacement of shower hoses (or frequency as indicated by the rate of fouling or other risk factors)	Yes All showers to be fitted with POU filters. Shower hoses to be replaced at least quarterly as POU filters exchanged.
Quarterly inspection and cleaning of system strainers (including angle valve strainers) and on "Anaconda" flexible connections on hot lines (or frequency as indicated by the rate of fouling or other risk factors, e.g. areas with high risk patients)	Yes (Where practical and accessible) HAI Scribes may be require to access pipework.
Quarterly checks on the satisfactory operation of TMV/TMTs or mixer valves within designated "High Risk Patient" areas/ICUs (more frequently if manufacturer recommends – or if 'drift' in excess of 1°C at mixed outlet temperature (Note: NHS GG&C have implemented a +-2°C permissible drift) when highlighted during temperature monitoring or other maintenance) including thermal pasteurisation where practical and as directed by ICT/manufacturer's instructions.	Yes Ward 2A/2B designated as "High Risk Area"
Quarterly during periods of Change - Water System Sampling (at random water outlets in "High Risk Patient" areas) in Water Systems still serving High Patient Risk Areas	Yes Ward 2A/2B designated as "High Risk Area"
Arrange for microbiological samples to be taken from water system which represent the complexity of the water system(s) and particularly in areas of concern and for agreed suite of microbiological analysis. All sampling should be carried out in accordance with method statements as agreed with ICT and WSG and all analysis by a UKAS accredited laboratory.[2]	Yes
Annual inspection of plant and pipework insulation, repairing where necessary.	Yes (Where practical and accessible) HAI Scribes may be require to access pipework.
Annual test to ensure that plant temperature, pressure gauges and thermostats are accurate (Also note during routine temperature monitoring where appropriate)	Yes (Where practical and accessible) HAI Scribes may be require to access pipework.
Reports have been received intimating that high levels of Pseudomonas and Legionella bacteria have been found in water samples taken from outlets fed by flexible hoses lined with ethylene propylene diene monomer (EPDM) due to colonisation of the lining, although it is possible that other lining materials and washers within couplings could be similarly affected. Wherever practical these should be replaced with services hard piped. Where this is not practical should be given to changing EPDM flexible hoses and other lining materials and washers. Where changing to alternative materials is not practical periodic (e.g. six monthly) monitoring should be implemented on EPDM hoses, with hoses swapped out as necessary dependant on sample results and/or rate of fouling witnessed.	N/A
All plant and equipment should be serviced and maintained in accordance with manufacturers recommendations	Yes
All serviceable components (e.g. pressure and temperature relief valves, backflow prevention devices) should be serviced and maintained in accordance with manufacturers recommendations.	Yes

Cont....

[1] HSG Part 2 recommends that all showers are cleaned and descaled quarterly at least quarterly. SHTM 04-01 Part G recommends that this should be carried out "Three-monthly for high risk areas and as required elsewhere, but at least once annually".

[2] Sampling regime should be formulated by site/client based on the known history of the water systems and the details included within this and previous risk assessments, with assistance of specialist legionella consultant (e.g. DMA) if necessary. Although L8 does not specifically request legionella sampling in cases where there are incorrect distribution or supply temperatures, water quality issues or other factors which may increase the likelihood of legionella (and other bacterial) proliferation and dissemination sampling should be carried out. For further guidance please refer to HSG 274 Part 2, HTM/SHTM 04-01 and BS 7592:2008

L8 RISK ASSESSMENT

Proposed Sampling Regime[4]

Sampling regime implemented will be as requested by WSG, Clinical Staff, Microbiology, ICT and Estates. An ongoing sampling regime to test for Potable Analysis, Gram Negative Bacteria and Pseudomonas across outlets on a rolling weekly basis to ensure all outlets within Wards are sampled monthly, with AMS/NTM to be incorporated into the sampling regime so all outlets are tested quarterly has been proposed for these wards.

Note: Task frequencies described above are for guidance only. Frequencies may vary dependent on system conditions highlighted during routine monitoring. Suitable Method Statements/SOPs should be generated and agreed by WSG and/or relevant parties and followed for each task.

Healthcare Improvement Scotland | Inspections and reviews
To drive improvement

Unannounced Inspection Report – Safety and Cleanliness of Hospitals

Queen Elizabeth University Hospital (including Institute of Neurosciences and Royal Hospital for Children)

NHS Greater Glasgow and Clyde

29–31 January 2019

NHS SCOTLAND

A48216625

We inspect acute and community hospitals across NHSScotland. You can contact us to find out more about our inspections or to raise any concerns you have about cleanliness, hygiene or infection prevention and control in an acute or community hospital or NHS board by letter, telephone or email.

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www.healthcareimprovementscotland.org

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Contents

Summary of inspection

About the hospital we inspected

1. Queen Elizabeth University Hospital, Glasgow opened in April 2015. This acute hospital has 1,677 beds with a full range of healthcare specialties, including a major emergency department. In addition to the 14-floor hospital building, the hospital site retains a number of other services in adjacent facilities. This includes maternity services, the Royal Hospital for Children, Institute of Neurosciences, and the Langlands Unit for medicine of the elderly and rehabilitation.

About our inspection

2. At the request of the Cabinet Secretary for Health and Sport, we carried out an unannounced inspection to the Queen Elizabeth University Hospital, the Institute of Neurosciences and the Royal Hospital for Children, NHS Greater Glasgow and Clyde, from Tuesday 29 to Thursday 31 January 2019.

3. We previously inspected the Queen Elizabeth University Hospital in December 2016 and, in January 2017, carried out a follow-up inspection to the emergency department, immediate assessment unit and clinical decisions unit. These two inspections resulted in 10 requirements and two recommendations. We then carried out a follow-up inspection in August 2017. That inspection resulted in one requirement from the December 2016 and January 2017 inspection being carried forward.

4. We previously inspected the Royal Hospital for Children in September 2016. This inspection resulted in two requirements.

5. The inspection reports are available on the Healthcare Improvement Scotland website www.healthcareimprovementscotland.org

6. The inspection team was made up of a senior manager from Healthcare Improvement Scotland, six inspectors, a member of staff from the Scottish Government's national workforce team, an independent clinical advisor, with support from a project officer.

Inspection focus

7. We focused on:

   - Standard 1: Leadership in the prevention and control of infection
   - Standard 6: Infection prevention and control policies, procedures and guidance, and
   - Standard 8: Decontamination.

8. In **Queen Elizabeth University Hospital**, we inspected the following areas:

- emergency department
- immediate assessment unit
- ward 1C (acute stroke)
- ward 4C (haematology and oncology)
- ward 5D (general medicine)
- ward 6D (cardiology)
- ward 7D (respiratory)
- ward 8A (medicine for the elderly)
- ward 9A (general surgical), and
- ward 10D (orthopaedic trauma).

9. In the **Institute of Neurosciences**, we inspected the following areas:

- ward 60 (high dependency unit)
- ward 61 (intensive therapy unit)
- ward 64 (neurosurgery), and
- ward 67 (neurology).

10. In the **Royal Hospital for Children**, we inspected the following areas:

- neonatal intensive care unit
- paediatric intensive care unit
- special care baby unit, and
- ward 2C (acute receiving).

11. We carried out observations of staff compliance with hand hygiene practices in all wards inspected. However, we also carried out hand hygiene audits in the following areas:

- emergency department
- immediate assessment unit
- neonatal intensive care unit
- paediatric intensive care unit
- ward 6C (cardiology)
- ward 6D (cardiology)
- ward 8A (medicine for the elderly and general medical), and

- ward 9D (general surgical).

12. We received 63 completed patient questionnaires.

What NHS Greater Glasgow and Clyde did well

- Good staff compliance with standard infection control precautions, including hand hygiene.
- Good staff knowledge about how to manage a blood spill and also transmission-based precautions.

What NHS Greater Glasgow and Clyde could do better

- Develop a strategy that provides assurance to themselves that the cleaning of high activity areas is carried out to an appropriate standard.
- Must improve the governance around estates and facilities issues in regards to cleaning, environmental damage and water management.
- Must strengthen the governance around infection prevention and control.

13. Detailed findings from our inspection can be found on page 7.

What action we expect NHS Greater Glasgow and Clyde to take after our inspection

14. This inspection resulted in 14 requirements and one recommendation.

15. The requirements are linked to compliance with the Healthcare Improvement Scotland *Healthcare Associated Infection (HAI) Standards* (February 2015). A full list of the requirements and recommendations can be found in Appendix 1.

16. An improvement action plan has been developed by the NHS board and is available on the Healthcare Improvement Scotland website www.healthcareimprovementscotland.org

17. We expect NHS Greater Glasgow and Clyde to carry out the actions described in its improvement action plan to address the issues we raised during this inspection. These actions should be completed within the time frames given in Appendix 1.

18. We would like to thank NHS Greater Glasgow and Clyde and, in particular, all staff and patients at the Queen Elizabeth University Hospital, the Institute of Neurosciences and the Royal Hospital for Children for their assistance during the inspection.

19. The flow chart in Appendix 2 summarises our inspection process. More information about our safe and clean inspections, methodology and inspection tools can be found at www.healthcareimprovementscotland.org

Key findings - ward inspection

Standard 1: Leadership in the prevention and control of infection

20. It is vital that an NHS board has good governance to assurance itself of safe patient care. This is laid out in the Scottish Government's guidance, *NHS Scotland Health Boards and Special Health Boards - Blueprint for Good Governance* (2019). Although there are formal meetings between the estates team and the infection prevention and control team, our inspection has highlighted a lack of robust communication between these teams to provide effective governance to senior hospital management. We have expanded on this in the report.

What NHS Greater Glasgow and Clyde did well

21. During the inspection, we were provided with evidence that NHS Greater Glasgow and Clyde's medical director is the executive Board member leading on infection prevention and control and is chair of the infection control committee.

22. The Scottish Government requires NHS boards to report on a range of key infection prevention and control indicators. NHS Greater Glasgow and Clyde monitors and reports on these key performance indicators such as infection rates for *Clostridium difficile* infection *(C diff)* and *Staphylococcus aureus* bacteraemias (SABs). These performance indicators are reported in the NHS board's Healthcare Associated Infection Reporting Template (HAIRT), discussed at the sector and NHS board infection control committee meetings and also at the Board meetings. Minutes of these meetings are available on NHS Greater Glasgow and Clyde's website. We reviewed the latest published quarterly data and this demonstrates that the NHS board is performing within control limits for all indicators.

23. The infection prevention and control team monitors alert organisms and we also saw that microbiologists carry out clinical surveillance. We saw systems in place that identify and communicate outbreaks. The NHS board uses the Healthcare Infection Incident Assessment Tool (HIIAT) to assess infection-related incidents and to review the actual and potential impact.

24. We saw evidence of the infection prevention and control governance structure in the NHS board papers. This governance structure provides an overview of infection prevention and control priorities across NHS Greater Glasgow and Clyde.

25. There is a clear infection prevention and control work plan with well-defined responsibilities from the Board to ward level. The work plan is approved by the NHS board's infection control committee.

26. The authorised person for ventilation at the Queen Elizabeth University Hospital spoke with members of the inspection team and shared detailed validation and planned preventative maintenance schedules. This provided assurance that all current systems in place are being managed in line with national standards.

What NHS Greater Glasgow and Clyde could do better

27. During our inspection, staff informed us about shortages of both nursing and domestic staff. We received advice from the Scottish Government workforce department and carried out an analysis of nursing establishment. We identified that nursing processes are good and, whilst sickness and maternity leave was above predicted absence, supplementary staffing has been utilised. However, we were informed that there is a 14.5% absence and 10% vacancy rate for domestic staff. Facilities Management at Queen Elizabeth University Hospital had streamlined the recruitment process for domestic staff to reduce timescales.

28. We were made aware of some challenges in the working relationships between senior staff in the infection prevention and control team and the estates department. A good working relationship is essential to ensure optimal patient care. As a result of our inspection, this was brought to the attention of the Chief Executive of NHS Greater Glasgow and Clyde for action.

29. During our inspection, we were told of examples where it was felt that senior management have not reacted to concerns regarding the environment that can have an effect on clinical care. For example:

- not reacting to the clinical concerns raised by senior charge nurses, in particular relating to the cleaning of vents that can affect patient safety, and
- not taking on board the concerns of clinical staff during estates meetings.

30. Senior managers told us that NHS Greater Glasgow and Clyde requires additional infection control doctors to help with the assessment and mitigation of infection risks presented by the built environment. Infection control staff also told us that the infection prevention and control team at the Royal Hospital for Children would benefit from having more infection prevention and control nurses.

31. We were shown a clinicians' report from 2017 that detailed 27 issues within the Queen Elizabeth University Hospital and the Institute of Neurosciences. We raised this with NHS Greater Glasgow and Clyde's senior management. We were provided with an action plan for these issues, however we were not assured actions had been taken to resolve some of the issues. We asked for

further information to clarify what actions had been taken. However, we still have some concerns regarding:

- the use of cleaning agents, and
- the cleaning of temperature control valves.

32. We noted that some infection control risks, such as water and ventilation, are outwith the scope of infection prevention and control. We were told that the groups responsible for managing these have infection prevention and control team input. However, NHS Greater Glasgow and Clyde acknowledged that some elements of the governance arrangements within the estates and facilities teams require to be strengthened, including the relationship with the infection prevention and control team.

33. During the inspection, we saw evidence that suggested significant gaps in maintenance and improvement of the care environment. We found a number of areas where the environment was in a poor state of repair. Estates management provided a list of at least 300 outstanding jobs without evidence of a plan to complete these. We are unsure how the facilities monitoring tool (FMT), currently used in the site, provides the NHS board with assurance of a safe and clean patient environment. For example, the facilities monitoring tool can record that an area has been cleaned, for example walls and floors. However, the tool is unable to record if the area is damaged. Where an area is damaged, this can prohibit effective cleaning.

34. The infection prevention and control teams use an audit tool in the wards. Some of the total audit results we saw were marked as high, even though individual elements in some cases were low. This may give false assurance. More detail is reported under Standard 6.

35. NHS Greater Glasgow and Clyde has strategic, operational and quality assurance systems in place. However, because of the issues with the facilities management tool, and the infection prevention and control audit tool (IPCAT) highlighted later in this report, we were not assured that these provide sufficient assurance to senior management.

36. The infection prevention and control data team reports were unvarying in format and lacked narrative. It was not easy for us to identify themes from the audit data so we were not assured that improvements would result from these audits.

37. We saw evidence of waterborne infection risks being discussed at the water safety group meeting. Within the minutes of the group, we saw evidence that domestic services staff were to carry out flushing regimes. However, as discussed later in the report, our inspection findings did not assure us that this

is being carried out. Our discussions with staff identified that there was a lack of clarity around who should be carrying this out.

38. There is no clear governance structure for ventilation at present within NHS Greater Glasgow and Clyde. However, specialised ventilation is discussed at the theatre users management group and the statutory compliance audit and risk group. Minutes of these groups were provided and we noted an action concerning critical care vents was recorded. There was no evidence provided on further action being taken.

- **Requirement 1:** NHS Greater Glasgow and Clyde must improve the governance arrangements in both estates and infection prevention control teams to assure themselves of safe patient care in line with Scottish Government's guidance, *NHS Scotland Health Boards and Special Health Boards - Blueprint for Good Governance* (2019).

Standard 6: Infection prevention and control policies, procedures and guidance

What NHS Greater Glasgow and Clyde did well

39. NHS Greater Glasgow and Clyde has adopted the current version of Health Protection Scotland's *National Infection Prevention and Control Manual*. This manual describes standard infection control precautions and transmission-based precautions. These are the minimum precautions that healthcare staff should take when caring for patients to help prevent cross-transmission of infections. There are 10 standard infection control precautions, including hand hygiene, the use of personal protective equipment (such as aprons and gloves), how to care for patients with an infection, and the management of linen, waste and sharps. The transmission-based precautions describe how to care for patients with known or suspected infections and how to help prevent cross-transmission of infections.

40. In all of the wards inspected, staff we spoke with knew how to access the latest version of the manual and policies and procedures through the staff intranet.

41. Staff spoken with described a good working relationship with the infection prevention and control team. Some areas told us they had regular visits from the team who provide support and advice. We were told if staff contacted the team for advice they would visit the ward in a timely manner or give verbal advice over the telephone. The team is contactable by telephone during office hours. The microbiologist is available out of hours for guidance and patient-specific advice.

42. NHS boards are required to measure staff compliance with standard infection control precautions. The frequency of this compliance monitoring is determined by individual NHS boards.

43. We saw evidence of several infection control audit systems in place in all areas inspected. This was carried out by both ward level staff and the infection prevention and control team.

44. Nurses and midwives in charge of the wards inspected told us that standard infection prevention and control audits are carried out on the wards at least every 6 months by ward staff.

45. The infection prevention and control team carries out ward audits using NHS Greater Glasgow and Clyde's infection prevention and control audit tool. The tool focuses more on clinical practice rather than environmental issues. We were told that this had been introduced to help avoid duplication of findings from the facilities monitoring tool.

46. We saw evidence of the infection prevention and control team carrying out these audits. This audit is made up of four sections, including standard infection control precautions and quality improvement audits. An overall compliance score is given. Each ward and department is audited at least once every year, but done more frequently if the overall compliance score falls below 80%. The results are scored red (less than 65% compliance), amber (65–79% compliance), green (80% compliance and above) and gold (91% compliance and above). Areas with red audit results are re-audited within 3 months, amber within 6 months and green and gold within 12 months. Where non-compliances are identified during the audit, an action plan is automatically generated.

47. Wards that could access the audits showed us the report, the corresponding action plan and the completed actions. We were told that the senior charge nurse would email audit feedback to ward staff or discuss this during the safety briefing at the start of a shift. A safety briefing is used as a communication tool which focuses on patient safety issues and is one of Scottish Patient Safety Programme's 10 essentials of safety. We were told that issues and learning from the audit results and action plans are also shared at the monthly senior charge nurse meeting and the lead nurse, chief nurse, directorate and clinical governance meetings.

48. We saw infection prevention and control audit results displayed in the wards for staff, patients and visitors. The audit information displayed was easy to read. However, most information was not dated and it was therefore unclear if the audit information was up to date.

49. During the inspection, we saw generally good staff compliance with standard infection control precautions, including the management of linen, waste and

sharps. Clean linen was stored in covered trolleys keeping them free from dust and we saw staff handling used and contaminated linen appropriately.

50. We observed generally good hand hygiene compliance as part of our inspection.

51. We also carried out a focused hand hygiene audit in clinical areas. During the audit, of the 163 occasions where staff should have carried out hand hygiene, we saw 152 opportunities were taken. The majority of staff we observed during this audit were nursing and medical staff. We saw that staff hand hygiene technique was good.

52. In the Royal Hospital for Children, a senior charge nurse told us that they had noticed a decrease in staff compliance with hand hygiene when new medical fellows joined the ward team. As a result, the senior charge nurse now meets with all new medical staff for a training session on the importance of hand hygiene.

53. We saw alcohol-based hand rub available at the entrance to most wards, in patient rooms and in corridor areas. However, at the time of our inspection, we saw alcohol-based hand rub dispensers were empty at the entrance of three wards.

54. Hand hygiene audits are carried out monthly. The hand hygiene audit results were available on an electronic data management system.

55. All wards and departments inspected displayed posters about standard infection control precautions which staff could refer to. This included information on waste management, linen management and how to manage a blood spill.

56. The majority of staff we spoke with had good knowledge of blood and body fluid management and what action to take in the event of a needle-stick injury.

57. Of the 63 people who responded to our survey during our inspection, 92% stated that ward staff always wash their hands. The majority of the remaining respondents were not sure.

58. Any non-compliances with standard infection control precautions were raised at the time of inspection and some of these issues are reported in the 'What NHS Greater Glasgow and Clyde could do better' section below.

59. Due to the small number of patients in isolation at the time of our inspection, we had limited opportunities to observe patients being cared for in isolation. Where we could observe this, it was done well. Staff we spoke with were knowledgeable about transmission-based precautions and could describe the isolation process. The majority of staff we spoke with said the infection

prevention and control team would be involved with the management of the patient, when necessary.

What NHS Greater Glasgow and Clyde could do better

60. In the clinical areas we inspected, we reviewed their most recent infection prevention and control audits. We saw evidence of gold scores being given, but at least one section of the audit scored 33%. An overall score for this audit is aggregate for all the separate sections. We were concerned assurance would be taken from the overall high score, without recognising the low scores within the separate sections.

61. We saw evidence of ward-based standard infection control audits taking place in all areas inspected. However, in some of the areas inspected, when the senior charge nurse was not available, the nurse in charge at the time of the inspection could not always access these audit results or action plans. We were concerned this was a person-dependent system.

- **Recommendation a:** NHS Greater Glasgow and Clyde should ensure that access to audit information is not person dependent to ensure the continuity of the audit programme.

62. During our inspection, we saw some non-compliances with standard infection control precautions.

- One nurse was carrying a container with body fluids to the sluice room without wearing any personal protective equipment. We raised this with the senior charge nurse at the time of our inspection.
- In one area there were large, lockable waste bins that were unlocked. These bins were in a corridor accessible by patients, creating a risk of unauthorised access. The bins were locked when we returned to the ward later.
- We saw staff performing catering duties who did not carry out hand hygiene after contact with the patient or patient's surroundings. Any non-compliances with standard infection control precautions were raised with nursing staff at the time of our inspection.
- We observed a member of medical staff preparing an intravenous infusion in an area of the clean preparation room very close to a sink. This was within splash contamination distance of this sink. We raised this with the nurse in charge and medical staff at the time of our inspection. Nursing staff we spoke with told us they would not prepare intravenous infusions in this area but would use a clean area away from potential splash contamination.

63. Senior management told us there were no functioning negative pressure isolation rooms in the hospital. These rooms are required for some infectious diseases. However, we are aware that NHS Greater Glasgow and Clyde has plans to rectify this. During our inspection, we asked for the guidance provided to staff in the event one of these rooms is required. This was not provided.

- **Requirement 2**: NHS Greater Glasgow and Clyde must ensure functioning negative pressure isolation rooms are available in the hospital in line with Healthcare Facilities Scotland, *Scottish Health Planning Note* 04.
    - Where these are not available, staff are provided with clear guidance on how to manage a situation where a patient would require this type of isolation.

64. During the inspection, staff we spoke with were not clear about who was responsible for carrying out water flushing on the unused or less frequently used water outlets. Nursing staff told us they sometimes run the water, but there was no sign-off sheet to record this. Domestic staff told us they sometimes run showers when they had not been used by patients. However, they could not confirm what water outlets had been run or when. It was not clear from discussions with staff if the water had been run. We also found the following.

- On one ward, we saw that running unused or less frequently used water outlets was on the domestic task list. It is automatically marked as complete unless the domestic changes it manually to incomplete.
- One ward had two unused baths that had not been identified by staff as infrequently used water outlets that would need flushing.
- Another ward had a bath that had not been working for 3 years. Staff were unclear about how this water outlet could be flushed.
- Staff were unaware that ensuite showers, unused because of the patient's health condition, would require regular flushing. Staff told us that they would run the shower before the patient uses it.
- One ward had a closed patient room due to a leaking ensuite shower. Staff were unclear about how long it had been like this and if any flushing regime was in place to mitigate any potential risks.

65. The majority of staff we spoke with were unclear about their roles in the flushing regimes.

66. Throughout the inspection, there was inconsistent recording to evidence that water flushing had taken place. In the evidence provided by NHS Greater Glasgow and Clyde, we saw that flushing regimes is a standing agenda item on

the south sector water safety group meeting. Within these minutes it is stated that flushing regimes should be undertaken by domestic services staff.

67. NHS boards are required to comply with guidance to reduce the risk of *Pseudomonas aeruginosa* infection in high risk areas. This is detailed in Health Protection Scotland's *Guidance for neonatal units (NNUs) (levels 1,2 & 3), adult and paediatric intensive care units (ICUs) in Scotland to minimise the risk of Pseudomonas aeruginosa infection from water* (2014).

68. During the inspection, we spoke with ward staff in the Royal Hospital for Children about what they do with water outlets to reduce the risk of *Pseudomonas aeruginosa* infection in high risk areas. The current Health Protection Scotland guidance states that all taps must be '…flushed daily, first thing in the morning, at maximum flow rate…for a period of one minute and recorded.' We found in one high risk area that it was unclear who was responsible for carrying out the water flushing and there were no records that this was being carried out.

    - **Requirement 3**: NHS Greater Glasgow and Clyde must ensure all staff involved in the running of water are clearly informed of their roles and responsibilities in this and a clear and accurate record is kept to allow early identification of any water outlets that are not being run.

69. In some wards inspected, we saw bladeless fans were being used in high risk areas to keep the air cool. In August 2018, Health Protection Scotland issued guidance to all NHS boards advising them not to use this type of bladeless fan, due to concerns about the ability to effectively clean them. We were provided with a ward-based risk assessment, which did not take into account Health Protection Scotland's advice.

    - **Requirement 4:** NHS Greater Glasgow and Clyde must ensure all clinical areas across the NHS board comply with the current national guidance for the use of bladeless fans.

70. In the Royal Hospital for Children, we saw that expressed breast milk on wards was appropriately stored in designated fridges and freezers. We were shown temperature recording charts which demonstrated regular checks of the fridge and freezer temperatures. We found two wards were using temperature charts that did not state the correct safe storage temperature guidelines for expressed breast milk. However, we noted that all temperature recordings on these two wards were within the accepted temperature range. The temperature recording charts should:

    - be specific for expressed breast milk

- describe the correct temperature range, and
- state the actions to be taken if the temperature falls outside this range.

71. We highlighted this issue at the time of our inspection.

    ■ **Requirement 5:** NHS Greater Glasgow and Clyde must ensure that information on the expressed breast milk recording charts is in line with national guidance. This will ensure that the storage of expressed breast milk is managed in a way that reduces the risk to patients.

Standard 8: Decontamination

What NHS Greater Glasgow and Clyde did well

72. The standard of environmental cleaning was generally good across the wards inspected. Any exceptions to this are detailed in 'What NHS Greater Glasgow and Clyde could do better' section below. We saw domestic staff cleaning patient rooms thoroughly and those rooms that had been recently cleaned were clean and dust free.

73. We saw an improvement in the standard of cleaning in the immediate assessment unit since our inspections in 2016 and 2017. The domestic supervisor told us that since our first inspection in 2016, they have changed shift patterns so staff start earlier in the morning. The aim is to provide a thorough handover from the night shift domestic staff to the day shift domestic staff. The domestic supervisor told us they felt this system worked well in this area.

74. Ward staff told us there was a good relationship with the domestic services team and they described the escalation process they would use to raise issues to the domestic services management. The majority of areas were well organised and clutter free enabling access for cleaning.

75. Domestic staff spoken with had a good knowledge of their role and responsibilities. They told us that they use the colour-coded system for cleaning equipment. Staff also told us the precautions they would take when cleaning a patient's room being cared for with infection control precautions. We noted some variation in staff knowledge on the correct procedure to clean a wash hand basin. This is detailed in the 'What NHS Greater Glasgow and Clyde could do better' section below.

76. We inspected a variety of near-patient equipment across all wards and departments. This included intravenous stands and pumps, procedure trolleys, commodes, blood gas analysers, patient chairs, patient monitoring equipment, incubators and beds. Nursing staff have the responsibility for the cleanliness

and maintenance of patient equipment. We found the majority to be clean and well maintained, with exceptions detailed in the 'What NHS Greater Glasgow and Clyde could do better' section below.

77. We saw that ward staff have a standard operating procedure for bed space checklists and we saw the majority were completed by nursing staff daily and weekly.

78. We saw that the nurse in charge of each ward carries out a weekly cleaning assurance checklist. This is a spot check on several pieces of equipment as an assurance of the standard of equipment cleaning in the wards. This was completed on all wards.

79. Of the people who responded to our survey during our inspection:

- 96% stated that they thought the standard of cleanliness on their wards was good, and
- 100% stated that the equipment used by staff for their care was clean.

80. Some patients we spoke with or who responded to our survey said:

- 'I could not fault standard of cleanliness, I had visitors in, one had been in another hospital, could not believe amount of times staff were in and out cleaning surfaces.'
- 'The staff are always cleaning equipment, washing their hands and making sure everyone's bed is changed daily.'
- 'Cleanliness on ward is good but corridors and other areas is terrible.'

What NHS Greater Glasgow and Clyde could do better

81. During our first day of inspection, we found issues with environmental and patient equipment cleaning in the emergency department. We found the following:

- body fluid and grime contamination on the toilet seat hinges in the reception and patient areas
- removable grime on panels below wash hand basins in patient toilets, patient cubicles, treatment areas and the sluice room
- dusty and gritty floors throughout the department
- removable grime on alcohol based hand rub dispensers
- dust on patient monitoring equipment, sterile storage shelving and anaesthetic machines in the resuscitation department
- contamination on the underside of dressing trolleys, and

- two patient transfer trolleys, ready for use, contaminated with what appeared to be blood.

82. We returned to the department the following day, although cleaning had been undertaken, there was no significant improvement and there were also additional issues with cleanliness in the department. Domestic management for the department told us that with the high numbers of patients in the department, it can be difficult to gain access to patient bays to carry out domestic cleaning. Nursing staff in the department told us they felt that pressures on nursing time and the number of patients coming through the department each day was the reason for the below standard level of cleaning of patient equipment. We returned on the third day of our inspection and additional cleaning was in progress.

■ **Requirement 6:** NHS Greater Glasgow and Clyde must develop a strategy that ensures the environment in the emergency department is clean and patient equipment is clean and ready for us. This will ensure infection prevention and control can be maintained.

83. During the inspection, we saw issues with cleanliness in other areas of the hospital, for example:

- marked walls with removable contamination
- dust on bumper bars and on skirting boards
- dust in corners of patient rooms and bathrooms
- staining on curtains and chairs
- dust and grit in storage areas
- dust, dirt and grime in patient-shared spaces such as day rooms
- removable contamination under toilet roll dispensers, and
- large amounts of dust and grime in public areas behind lockable waste bins.

84. We were told that domestic staff are responsible for the cleaning of bed frames and mattresses when a patient is discharged. Senior charge nurses told us that this has placed pressure on the domestic resource for their area. Some domestic staff told us that this cleaning task places considerable pressure on their time to do their routine cleaning duties. We were told that corridors and shared social areas would not be cleaned as a priority and that store rooms, sluice areas and toilets may not be cleaned until later in the day.

85. We noted that NHS Greater Glasgow and Clyde's standard operating procedure for the cleaning of near-patient healthcare equipment describes the cleaning of the bed base only as being the responsibility of domestic staff.

86. We found several bed frames and mattresses in wards and corridors that, although labelled as clean and ready for use, were contaminated. Staff told us it was difficult to monitor this due to beds being transferred from ward to ward as patients moved.

- **Requirement 7:** NHS Greater Glasgow and Clyde must ensure the patient environment, and patient equipment, is clean and ready for use to reduce the risk of cross infection.

87. During our inspection, a number of staff said they had concerns about the level of domestic resource provided on their wards. Senior charge nurses are expected to sign a weekly assurance checklist for works completed by domestic staff. All senior charge nurses expressed concern around this practice and felt that there was not enough staff to carry out domestic cleaning in order to sustain a high standard of environmental cleanliness. We were told that staff had raised this issue with domestic supervisors and lead nurses. Ward staff felt environmental cleanliness was better on those wards where domestic resources had been increased.

88. During the inspection, there was an inconsistent approach for the system for domestic cleaning sign-off. In some areas, we were told the domestic supervisor signs off domestic cleaning electronically from somewhere else in the hospital. Within this system there did not appear to be any requirement for the domestic supervisor to visit the ward to sign off the cleaning. We were not assured that this remote sign-off would provide assurance of the domestic supervisor's day-to-day supervision of the domestic staff.

- **Requirement 8:** NHS Greater Glasgow and Clyde must ensure that domestic supervisors sign off domestic cleaning schedules as complete with evidence and satisfaction that the domestic cleaning has been complete as detailed within the cleaning schedule.

89. The majority of domestic staff told us there were not enough mop heads for them to clean wards and departments. This issue was identified at our previous inspections in 2016 and 2017. For example, in one area that has 28 bays, domestic staff receive 14 mop heads. The domestic supervisor told us they were unaware of this problem and would encourage domestic staff to alert them if they have not received enough mop heads.

- **Requirement 9:** NHS Greater Glasgow and Clyde must ensure domestic staff have the necessary equipment to perform their cleaning duties to keep the environment clean and safe.

90. Waste water from domestic cleaning should be disposed of in the domestic services room. In one ward, we saw that this was not functioning. We were told that domestic staff were emptying dirty water into the ward's sluice room sink. There is a potential to create a risk of splash contamination. Senior staff were unaware of the condition of the domestic services room and how used water was being disposed of.

91. We saw domestic services rooms in other areas that were damaged and partially functioning. For example, exposed pipe work, no hot water supply to a sink and a waste disposal did not flush.

- **Requirement 10:** NHS Greater Glasgow and Clyde must provide staff with suitable and functioning domestic services rooms to minimise the risk of cross contamination from the disposal of soiled water after the cleaning regime.

92. During the inspection, we spoke with domestic staff and a domestic supervisor about the products used for cleaning sanitary fittings. Domestic staff told us they were using different products for cleaning wash hand basins and toilets. For example, some staff said they use:

- a chlorine-releasing disinfection and detergent on sanitary fittings during the winter months
- a chlorine-releasing disinfectant and detergent for cleaning the toilet only, and
- detergent on all other sanitary fittings.

93. Current guidance states that sanitary fittings, including wash hand basins, should be cleaned with 1,000 parts per million of chlorine. During the inspection, we saw NHS Greater Glasgow and Clyde's standard operating procedure for the cleaning of near-patient healthcare equipment. The procedure states that sinks and wash hand basins should be cleaned with a chorine-based product.

94. During the inspection, we asked staff to demonstrate the order of how they would clean a hand wash basin. Some staff could demonstrate this in line with national guidance. However, in other areas, staff did not demonstrate this in the right order in line with current guidance.

- **Requirement 11**: NHS Greater Glasgow and Clyde's senior management must ensure all staff are aware of the correct method for cleaning hand wash basins, and the correct cleaning products are used to clean all sanitary fittings in line with current national guidance.

95. In some areas of the site, the fabric of the building is in a very poor state of repair and therefore cannot be effectively cleaned.

96. During our inspection, we saw a significant amount of estates issues, including:

- damage to wooden surfaces and walls
- damaged and exposed wood in panels under sinks
- damage to the flooring in patient rooms
- evidence of dirty and dusty ventilation panels
- skirting boards peeling away from walls
- multiple chipped and damaged bed frames, and
- water ingress above a wash hand basin and in an area where staff store clean equipment.

97. Nursing staff told us this was an ongoing issue which they reported almost daily.

98. We were provided with recent facilities monitoring tool scores for the Queen Elizabeth University Hospital and many of the areas had recorded consistently high compliance results. This was not reflective of what we found during our inspection of the condition of the hospital environment.

■ **Requirement 12:** NHS Greater Glasgow and Clyde must ensure that the built environment is effectively monitored to ensure it is maintained to allow effective cleaning to ensure effective infection prevention and control.

99. Ward staff told us they report repair and maintenance jobs using the estates electronic reporting system. However, they said outstanding estates jobs can show on the system as complete or can disappear. Staff also said they often have to chase up estates jobs. We were told that delays in completing a job are often not communicated to ward staff.

100. We viewed this electronic reporting system as well as paper records kept by some staff. We saw that many estates jobs remain outstanding for long periods of time.

■ **Requirement 13:** NHS Greater Glasgow and Clyde must ensure the estates reporting system is reliable and effective and acted on. Staff should also be informed of timescales for completion.

101. In some areas inspected, we saw significant levels of dust in ventilation panels. Nursing staff told us they had expressed their concern on several occasions.

We requested evidence of planned preventive maintenance for these ventilation panels, but this was not provided. In one ward's empty patient room, large pieces of dust had fallen from the vent.

- **Requirement 14**: NHS Greater Glasgow and Clyde must ensure ventilation panels are clean and free from dust.

Appendix 1: Requirements and recommendations

The actions Healthcare Improvement Scotland expects the NHS board to take are called requirements and recommendations.

- **Requirement:** A requirement sets out what action is required from an NHS board to comply with the standards published by Healthcare Improvement Scotland, or its predecessors. These are the standards which every patient has the right to expect. A requirement means the hospital or service has not met the standards and we are concerned about the impact this has on patients using the hospital or service. We expect that all requirements are addressed and the necessary improvements are made within the stated timescales.
- **Recommendation:** A recommendation relates to national guidance and best practice which we consider a hospital or service should follow to improve standards of care.

Prioritisation of requirements

All requirements are priority rated (see table below). Compliance is expected within the highlighted timescale, unless an extension has been agreed in writing with the lead inspector.

Priority	Indicative timescale
1	Within 1 week of report publication date
2	Within 1 month of report publication date
3	Within 3 months of report publication date
4	Within 6 months of report publication date

Standard 1: Leadership in the prevention and control of infection			
Requirement		HAI standard criterion	Priority
1	NHS Greater Glasgow and Clyde must improve the governance arrangements in both estates and infection prevention control teams to assure themselves of safe patient care in line with Scottish Government's guidance, *NHS Scotland Health Boards and Special Health Boards - Blueprint for Good Governance* (2019) (see page 10).		**1**

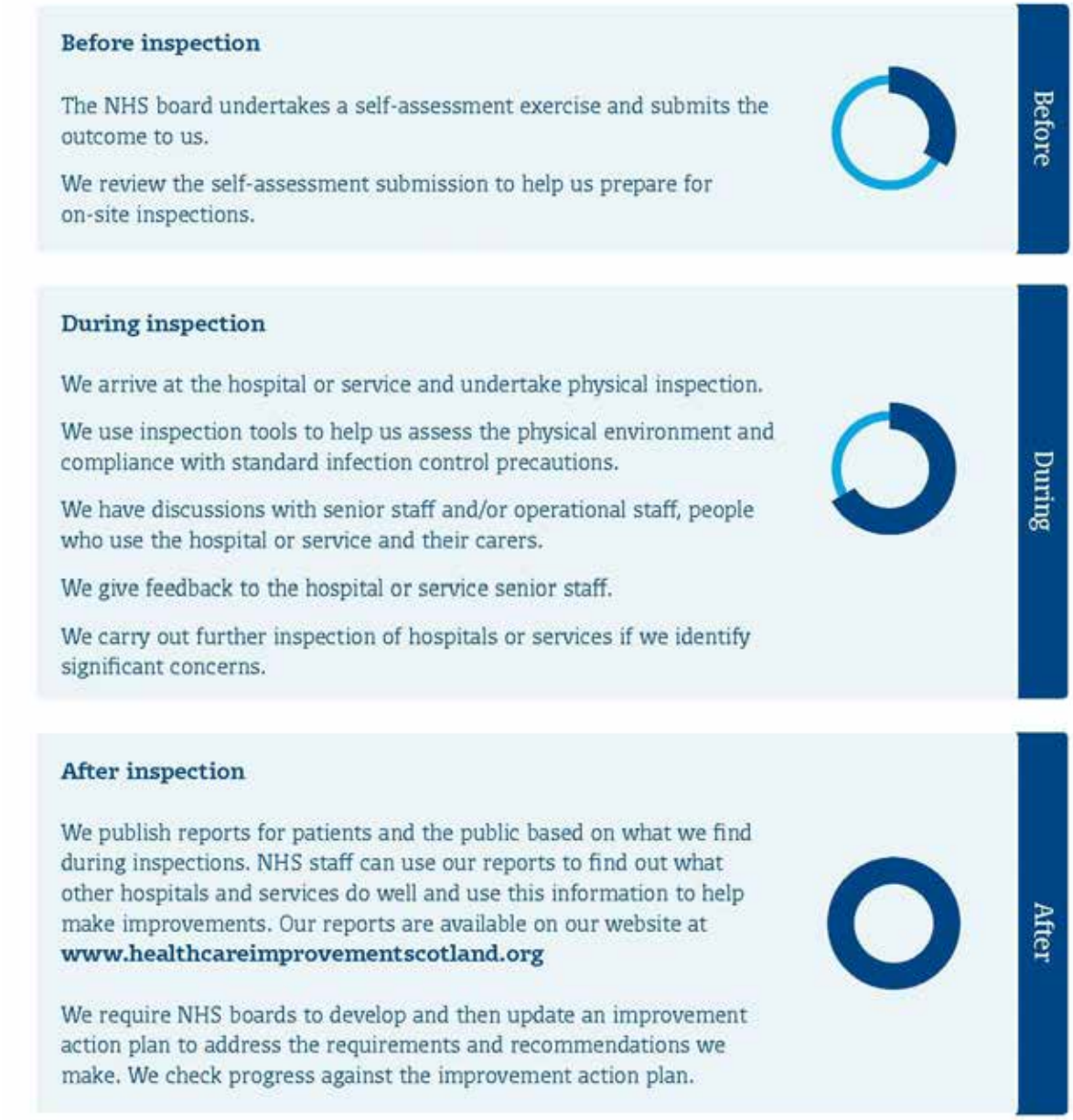
Standard 6: Infection prevention and control policies, procedures and guidance			
Requirements		HAI standard criterion	Priority
2	NHS Greater Glasgow and Clyde must ensure functioning negative pressure isolation rooms are available in the hospital in line with Healthcare Facilities Scotland, Scottish Health Planning Note 04. • Where these are not available, staff are provided with clear guidance on how to manage a situation where a patient would require this type of isolation (see page 14).	**6.5 and 8.1**	**1**
3	NHS Greater Glasgow and Clyde must ensure all staff involved in the running of water are clearly informed of their roles and responsibilities in this and a clear and accurate record is kept to allow early identification of any water outlets that are not being run (see page 15).	**6.5**	**1**
4	NHS Greater Glasgow and Clyde must ensure all clinical areas across comply with the current national guidance in relation to the use of bladeless fans (see page 15).	**6.5**	**2**
5	NHS Greater Glasgow and Clyde must ensure that information on the expressed breast milk recording charts is in line with national guidance. This will ensure that the storage of expressed breast milk is managed in a way that reduces the risk to patients (see page 16).	**6.5**	**1**
Recommendation			
a	NHS Greater Glasgow and Clyde should ensure that access to audit information is not person dependent to ensure the continuity of the audit programme (see page 14).		

Standard 8: Decontamination			
Requirements		HAI standard criterion	Priority
6	NHS Greater Glasgow and Clyde must develop a strategy that ensures the environment in the emergency department is clean and patient equipment is clean and ready for use. This will ensure infection prevention and control can be maintained (see page 18).	**8.1**	**1**
7	NHS Greater Glasgow and Clyde must ensure the patient environment, and patient equipment, is clean and ready for use to reduce the risk of cross infection (see page 19).	**8.1**	**1**
8	NHS Greater Glasgow and Clyde must ensure that domestic supervisors sign off domestic cleaning schedules as complete with evidence and satisfaction that the domestic cleaning has been complete as detailed within the cleaning schedule (see page 19).	**8.2**	**2**
9	NHS Greater Glasgow and Clyde must ensure domestic staff have the necessary equipment to perform their cleaning duties to keep the environment clean and safe (see page 19).	**8.1**	**1**
10	NHS Greater Glasgow and Clyde must provide staff with suitable and functioning domestic services rooms to minimise the risk of cross contamination from the disposal of soiled water after the cleaning regime (see page 20).	**8.1**	**2**
11	NHS Greater Glasgow and Clyde's senior management must ensure all staff are aware of the correct method for cleaning hand wash basins, and the correct cleaning products are used to clean all sanitary fittings in line with current national guidance (see page 20).	**8.1**	**2**
12	NHS Greater Glasgow and Clyde must ensure that the built environment is effectively monitored to ensure it is maintained to allow effective cleaning to ensure effective infection prevention and control (see page 21).	**8.1**	**1**

13	NHS Greater Glasgow and Clyde must ensure the estates reporting system is reliable and effective and acted on. Staff should also be informed of timescales for completion (see page 21).	**8.4**	**2**
14	NHS Greater Glasgow and Clyde must ensure ventilation panels are clean and free from dust (see page 22).	**8.1**	**1**

Appendix 2: Inspection process flow chart

We follow a number of stages in our inspection process.



More information about our inspections, methodology and inspection tools can be found at
www.healthcareimprovementscotland.org/HEI.aspx

You can read and download this document from our website.
We are happy to consider requests for other languages or formats.
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Healthcare Improvement Scotland | Inspections and reviews
To drive improvement

Inspection Report

Unannounced inspection to
The Queen Elizabeth University Hospital campus
NHS Greater Glasgow and Clyde

7–8 and 20 June 2022

A48216625

Healthcare Improvement Scotland is committed to equality. We have assessed the inspection function for likely impact on equality protected characteristics as defined by age, disability, gender reassignment, marriage and civil partnership, pregnancy and maternity, race, religion or belief, sex, and sexual orientation (Equality Act 2010). You can request a copy of the equality impact assessment report from the Healthcare Improvement Scotland Equality and Diversity Officer by emailing his.contactpublicinvolvement@nhs.scot

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Contents

About our inspection

In December 2021, the Scottish Government commissioned Healthcare Improvement Scotland (HIS) to provide wider independent assurance of infection prevention and control measures at the Queen Elizabeth University Hospital campus, NHS Greater Glasgow and Clyde, following concerns raised in the Scottish Parliament about potential cases of nosocomial *Aspergillus* infection. This wider independent assurance is focused on the systems and processes in place for infection prevention and control at the Queen Elizabeth University Hospital campus, including their current implementation at the time of the inspection, and assesses if any current broader concerns require action.

We attempted to undertake an unannounced inspection of infection prevention and control measures at the Queen Elizabeth University Hospital campus on Tuesday 22 March 2022. However, as a result of the unprecedented pressures experienced throughout the hospital campus at the time of this inspection, the decision was made to postpone the more detailed inspection and revert to our safe delivery of care inspection methodology. That inspection resulted in six areas of good practice and five requirements. The inspection report is available on the Healthcare Improvement Scotland website www.healthcareimprovementscotland.org.

We returned to the Queen Elizabeth University Hospital campus in June 2022 to undertake the infection prevention and control measures inspection.

The new Infection Prevention and Control Standards were published in May 2022. These applied to adult health and social care settings and replaced the Healthcare Associated Infection (HAI) Standards (2015). In May 2022, the chief nursing officer (CNO) contacted all NHS boards to inform them Healthcare Improvement Scotland will use these standards as a basis for inspection after a 3-month implementation period to embed the new standards. The implementation period concluded on Monday 8 August 2022. These standards were not applied to this inspection, as they were not implemented at the time of the onsite inspection work. However, where we have made requirements, we have highlighted how the improvement in line with the requirement will also demonstrate compliance with both the HAI standards (2015) and the new Infection Prevention and Control Standards (2022).

The following HAI standards (2015) form the main focus of the inspection:

- Standard 1: (Leadership in the prevention and control of infection)
- Standard 3: (Communication between organisations and with the patient or their representative)
- Standard 4: (HAI Surveillance)
- Standard 6: (Infection prevention and control policies, procedures and guidance)

- Standard 7 (Insertion and maintenance of invasive devices), and
- Standard 8: (Decontamination).

Although not within the scope of the HAI standards (2015), the inspection also considered staffing levels within the hospital campus at the time of the inspection. This is described within the summary of findings.

Background

In recent years, there have been ongoing considerations and concerns around the systems, processes and governance for infection prevention management and control at the Queen Elizabeth University Hospital campus and the Royal Hospital for Children.

In response to this, the chief executive of NHS Scotland and director general for health and social care escalated the Queen Elizabeth University Hospital campus and Royal Hospital for Children to Stage 4 of the NHS Scotland Board Performance Escalation Framework. This stage is defined as significant risks to delivery, quality, financial performance or safety; senior-level external transformational support is required. To support NHS Greater Glasgow and Clyde with ensuring appropriate governance is in place to increase public confidence in the matters raised, and ensure the delivery of safe, accessible, high-quality, person-centred care at the Queen Elizabeth University Hospital campus and Royal Hospital for Children, an oversight board was convened in November 2019.

In January 2019, at the request of the cabinet secretary for health and sport, we carried out an unannounced inspection of the Queen Elizabeth University Hospital campus, including the Institute of Neurological Sciences and the Royal Hospital for Children. That inspection resulted in 14 requirements and one recommendation. In November 2019, a further inspection was carried out that resulted in two requirements and one recommendation. The inspection reports are available on our website. This report outlines the improvement work the NHS board has implemented and has ongoing as a result of these inspections.

The chief executive of NHS Scotland and director-general for health and social care notified NHS Greater Glasgow and Clyde's chief executive that the NHS board had been de-escalated to Stage 2 on the NHS Scotland Board Performance Escalation Framework on 16 June 2022. Stage 2 is defined as some variation from the plan and possible delivery risk if there is no action. The oversight board for NHS Greater Glasgow and Clyde has now been stepped down.

This inspection does not attempt to duplicate any of the work carried out by the oversight board, or make a judgement on the systems or processes involved in this

work. It is also separate from any other ongoing investigations or legal action concerning the hospital campus.

The inspection was commissioned following concerns about *Aspergillus* at the hospital campus, but it is important to note that the purpose of this inspection is to provide independent assurance on the current wider infection prevention and control systems. Therefore, this inspection considers, but is not solely focused on, *Aspergillus*.

The NHS website (www.nhs.uk) provides the following description of aspergillosis as a condition caused by *Aspergillus* mould. 'Aspergillosis is caused by inhaling tiny bits of mould. You cannot always prevent aspergillosis as it is almost impossible to avoid *Aspergillus* mould. This mould is found in many places such as soil, compost, rotting leaves, plants, trees, crops, dust, damp buildings and air conditioning systems. You cannot catch *Aspergillus* from someone else or from animals. Aspergillosis is rare in healthy people. Risk is increased if people have a long-term condition or a weakened immune system. For example, having chemotherapy or had an organ transplant, had tuberculosis in the past, severe flu or COVID-19 and needed artificial ventilation.'

As this inspection was commissioned in response to concerns relating to *Aspergillus*, we requested information on the number of *Aspergillus*-related outbreaks reported within Scotland. We were told from August 2021 to the end of May 2022, no new outbreaks of *Aspergillus*-related infection were reported to Antimicrobial Resistance and Healthcare Associated Infection (ARHAI) Scotland as outlined in Chapter 3 of the National Infection Prevention and Control Manual (NIPCM).

Our focus

The inspection sought assurance on the following.

- Infection prevention and control leadership.
- Communication between the organisation and the patients or representatives.
- Surveillance of alert organisms.
- Infection control practice, including the application of standard infection control precautions (SICPs) and transmission-based precautions (TBPs).
- The care environment and care equipment.
- The built environment, such as cleanliness and the management of the built environment in relation to infection prevention and control.
- Planned programmes of maintenance, including ventilation.
- Staffing levels within the hospital campus.

Our inspection methodology can be found on our website: www.healthcareimprovementscotland.org.

About the hospital we inspected

The Queen Elizabeth University Hospital, Glasgow, opened in April 2015. The campus has 1,860 beds with a full range of healthcare specialities, including a major emergency department. In addition to the 14-floor hospital building, the Royal Hospital for Children is situated on the campus. The hospital campus also retains a number of other services in adjacent facilities. This includes maternity services, the Institute of Neurological Sciences, and the Langlands Building for medicine of the elderly and rehabilitation.

About this inspection

We carried out an unannounced onsite inspection of the Queen Elizabeth University Hospital campus on Tuesday 7–Wednesday 8 June 2022, and Monday 20 June 2022.

Prior to commencing our onsite inspection, we sought expert advice on *Aspergillus* from an independent expert, Professor David Denning (see Appendix 2 for biographical details). Before and during the course of the inspection, we held several discussions with Professor Denning and sought advice on what wider infection prevention and control practices should be in place to reduce the risks of *Aspergillus* infection within the acute hospital environment. Professor Denning highlighted the lack of national guidance in infection prevention and control for addressing risks associated with *Aspergillus* and protecting patients. It was agreed that if robust infection prevention and control practices, in line with current national infection prevention and control guidance, are in place, this should reduce the risks of infection from *Aspergillus* within the acute hospital environment.

In the **Queen Elizabeth University Hospital,** we inspected the following areas:

- acute receiving general medicine (ARU2)
- emergency department
- intensive care unit
- specialist assessment treatment area (SATA)
- wards 4B, 4C, 6A, 6B, 7A, 7B, 7C, 8C, 9B, 11A, 11C, and 11D.

In the **Institute of Neurological Sciences**, we inspected the following areas:

- wards 60 and 62

In the **Langlands Building**, we inspected the following area:

- ward 56

In the **maternity unit**, we inspected the following area:

- ward 47

In the **Royal Hospital for Children**, we inspected the following areas:

- neonatal Unit Level 1
- wards 1D, 2A, 2B and 3A.

In the following areas, we inspected the insertion and care of patients' invasive devices. Our findings are reported under Standard 7.

Queen Elizabeth University Hospital:

- acute receiving gastroenterology (ARU 3), acute receiving medicine for the elderly (ARU 4 DME)
- high dependency units 2 and 6 (critical care)
- wards 4B, 4D, 5D, 8A, 8D, 9C and 9D.

Maternity Unit:

- ward 48

Royal Hospital for Children:

- ward 3B and 3C

We spoke with 33 patients or their representatives in the following areas:

- Queen Elizabeth University Hospital: **wards 5A, 5C, 8A and 9A.**
- Institute of Neurological Sciences: **wards 65, 68 and the Philipshill Spinal Injuries Unit.**
- Maternity Services: **ward 50.**
- Royal Hospital for Children: **wards 1C and 2C.**

During our inspection, we:

- inspected the hospital environment
- observed staff practice and interactions with patients
- spoke with ward staff and patients
- accessed patients' health records, monitoring reports, policies and procedures
- met with senior hospital clinical and management staff, and
- met with the members of the senior executive team.

As part of our inspection, we asked NHS Greater Glasgow and Clyde to provide evidence of its policies and procedures relevant to this inspection.

We held discussion sessions with NHS Greater Glasgow and Clyde to discuss the evidence provided and the inspection findings. We held discussion sessions with the following members of staff.

- HAI (Healthcare Associated Infection) executive lead. This is the executive nurse director for NHS Greater Glasgow and Clyde.
- Infection control doctors and nurses.
- Senior estates managers.
- Senior facilities managers.
- Senior management responsible for staffing levels.
- The director of infection prevention and control.
- The medical director, associate medical director and clinical governance managers.

Throughout our inspection, we met with our independent *Aspergillus* expert to seek advice on our findings. This is described within the report.

The findings detailed within this report relate to our observations of the areas we inspected at the time of this inspection, review of evidence and discussion sessions with the NHS board.

We would like to thank NHS Greater Glasgow and Clyde and, in particular, all staff at the Queen Elizabeth University Hospital campus for their assistance during our inspection. We have found the NHS board's approach to have been one of openness and transparency, including responding to large volumes of evidence requested as part of the inspection process.

Summary of findings

Our summary findings from the inspection, areas of good practice, recommendations and any requirements identified are highlighted as follows. Detailed findings from the inspection are included in the section 'What we found during this inspection'.

At the time of this inspection, as observed during our previous safe delivery of care inspection in March 2022, the Queen Elizabeth University Hospital campus was experiencing a significant range of pressures, including increased hospital admissions, increased waiting times in emergency departments and reduced staff availability. These pressures are not isolated to this hospital campus, with similar pressures being experienced across NHS Scotland.

There was visible senior leadership across the hospital campus and clear evidence of ensuring staff felt psychologically safe to raise concerns including staffing-related concerns.

On the first day of our inspection, senior managers told us that 27 wards across the hospital campus scored a risk rating of red at the start of the day. This can result from staff numbers or the staff skill mix not being optimal. This may create a risk to patient safety, or issues affecting patient safety and requires immediate attention by the hospital team.

As observed during our March 2022 safe delivery of care inspection, we again observed lead nurses, site managers and chief nurses working together, communicating and problem-solving to try and reduce the identified risks and improve safety. However, even with attempts to mitigate the risks, many clinical areas continued to score a red risk rating. We observed in real-time, open and transparent discussions relating to workforce risks, with clear reporting and documentation of the escalations or mitigations that were put in place to promote the delivery of safe care and support staff wellbeing.

We reviewed workforce data that NHS Greater Glasgow and Clyde supplied. We could see that despite increased funding for the clinical workforce, due to the current Scotland-wide recruitment issues, vacancies remained high.

Despite the significant staff shortages across the campus, staff within the clinical areas told us they felt supported by senior leadership, and we observed clear communication throughout the inspection. We observed that most infection prevention and control practices carried out by staff working across all roles to support care delivery was generally good, and in line with infection control guidance and standards.

The patients and families we spoke with described the care they received as good. They were happy with the cleanliness of the hospital and the infection control practices of the staff caring for them.

To support this inspection, we requested a significant amount of evidence and information. We found that NHS Greater Glasgow and Clyde co-operated fully in sharing information to support the inspection process.

We saw evidence of good infection prevention and control leadership within the hospital campus, with senior managers and leaders demonstrating good knowledge of their roles and responsibilities. They promoted an open and transparent culture with good communication and supportive teamwork across the multidisciplinary team to support the infection prevention and control team. Examples of this will be described within the report.

We regularly consulted with Professor Denning throughout the inspection. The management of fungal infections such as Aspergillus is often complex, with diagnostic uncertainty, co-morbidity and polypharmacy characteristic of the management in typically unwell, immunocompromised patients. The team within the hospital campus appeared to demonstrate a vigilant approach towards infections related to Aspergillus. However, this report highlights there is limited national guidance for infection prevention and control management and response specific to Aspergillus. This means patient protection relies on professional opinion and interpretation of a highly expert topic which may lead to a lack of a standard approach across NHS Scotland.

Guidance on heating, ventilation and air-conditioning in intensive care, as well as guidance on refurbishment and building projects is available and contains some reference to *Aspergillus.* For example, Scottish Health Facilities Note (SHFN) 30 Part A: Manual Information for Design Teams, Construction Teams, Estates & Facilities and Infection Prevention & Control Teams. However, there is limited supplementary guidance on the infection prevention and control management and response to *Aspergillus*-related infection once an infection is identified. This may impact on potential outbreaks, relating to the healthcare environment being consistently identified. Many countries outside the UK have some level of guidance for infection control practitioners on protecting patients from *Aspergillus*-related infection. Healthcare Improvement Scotland will recommend to Scottish Government that analogous guidance to support a standard approach across NHS Scotland should be considered.

This inspection resulted in **nine areas of good practice, two recommendations** and **four requirements**. The scope of this inspection has been far wider than any previous inspection we have undertaken of the HAI standards (2015). This will impact on the total number of requirements, recommendations and areas of good practice identified as a result of this inspection.

We expect NHS Greater Glasgow and Clyde to address the requirements. The NHS board must prioritise the requirements to meet national standards. An improvement action plan has been developed by the NHS board and is available on our website: www.healthcareimprovementscotland.org.

Areas of good practice

Standard 1	
1	We observed an open, transparent and supportive culture in relation to infection prevention and control **(see page 19).**

Standard 3	
2	Patients and their representatives described good communication on infection, prevention and control considerations **(see page 23).**

Standard 4	
3	NHS Greater Glasgow and Clyde have a process to identify infection prevention and control alert triggers within the system and follow a clear process to act and minimise further risks **(see page 25).**

Standard 6	
4	NHS Greater Glasgow and Clyde developed a standard operating procedure (SOP) to identify the best place to care for patients with a specific infection that may require care areas with specialist ventilation **(see page 32).**
5	Good staff compliance with standard infection control precautions and transmission-based precautions (**see page 32.**

Standard 7	
6	Peripheral venous cannulas (PVC) devices were monitored twice a day **(see page 35).**
7	The Royal Hospital for Children carry out audits of peripheral venous cannulas (PVC) and central venous cannulas (CVC) daily **(see page 35).**

Standard 8	
8	The domestic service 10-step quality improvement planner was a good tool for improvement **(see page 44).**
9	The cleanliness and condition of the hospital environment was good **(see page 44).**

Recommendations

Standard 7

a NHS Greater Glasgow and Clyde should consider the method of sharing information with patients about their invasive devices. This will support patients to proactively care for their devices and be aware of risks and signs and symptoms of infection **(see page 36).**

Standard 8

b NHS Greater Glasgow and Clyde should consider a review of the electronic estates reporting system, to enhance the prioritisation allocation and communication for both the estates team and staff within the clinical areas **(see page 44).**

Requirements

Standard 3

1 NHS Greater Glasgow and Clyde must ensure that specialist infection prevention and control advice is recorded within the ward-level patient care record to inform care planning. This will ensure that patients are well informed, including information on when their isolation period will end **(see page 23).**

This is to comply with the Healthcare Associated Infection (HAI) Standards (2015) criterion 3.6. This will also comply with the new Infection Prevention and Control Standards (2022) criterion 3.1.

Standard 6

2 NHS Greater Glasgow and Clyde must ensure cleaning of tracheostomies is in line with guidance, not performed in clinical wash hand basins and staff have the correct information and support to do this safely **(see page 32)**.

This is to comply with the National Infection Prevention and Control Manual and Healthcare Associated Infection (HAI) Standards (2015) criterion 6.11. This will also comply with the new Infection Prevention and Control standards (2022) criterion 6.1.

Standard 6 (continued)

3 NHS Greater Glasgow and Clyde must ensure that systems and processes in place support clinical staff who are assuming a more senior role in managing a clinical area. This will include but is not limited to the senior charge nurse's responsibilities concerning infection prevention and control **(see page 32)**.

This is to comply with the National Infection Prevention and Control Manual and Healthcare Associated Infection (HAI) Standards (2015) criterion 6.11. This will also comply with the new Infection Prevention and Control Standards (2022) criteria 2.3.

Standard 8

4 NHS Greater Glasgow and Clyde must take steps to improve the governance and reporting of critical systems within the built environment. This should include but not be limited to:

A more robust system to ensure the infection prevention and control team is informed of ventilation performance validation reports in real-time to ensure any non-compliance that may impact infection control is identified and actioned at the earliest opportunity.

When approval is sought from committee members within the infection prevention and control governance structure, this is treated as a priority for all members with clear recorded evidence of approval or non-approval by required committee members. This will ensure clear accountability within infection prevention and control governance structures.

Ensure attendance by members of committees in the infection prevention and control governance structure, such as the NHS board water safety group, is a priority. When attendance is not possible, a deputy should attend, as recommended by the Vale of Leven Hospital Inquiry Report.

The governance water management structure is either fully applied or adapted to reflect the requirements of the reporting structure to ensure the NHS board is fully informed of any NHS board water safety group issues.

Review the system currently in place for quarterly reporting of flushing of water outlets to ensure a robust and effective process (see page 45).

This is to comply with the National Infection Prevention and Control Manual, the Vale of Leven Hospital Inquiry Report (2014) Recommendation 59, and Healthcare Associated Infection (HAI) Standards (2015) criterion 8.4. This will also comply with the new Infection Prevention and Control Standards (2022) Criteria 4.2 and 8.2.

What we found during this inspection

Standard 1

- **Leadership in the prevention and control of infection**

We observed an open, transparent and supportive culture in relation to infection prevention and control across the hospital campus. Senior managers and the clinical team were knowledgeable about their roles and responsibilities.

We observed open and transparent leadership from senior executive management throughout the:

- infection prevention and control service
- hospital site management
- clinical staff, and
- estates and domestic service management.

This was demonstrated through various sources, and we will aim to describe this throughout this inspection report.

There was very good co-operation throughout the inspection process, and we observed an open and responsive culture during this inspection. This is highlighted as an area of good practice for the staff and management within the NHS board, who were working under the same significant unprecedented pressures being felt across NHS Scotland. These pressures are associated with increased COVID-19 cases, increased demands for access to the hospital and inpatient beds, and high levels of staff shortages.

At the Queen Elizabeth University Hospital campus, several patient safety huddles are carried out throughout the day for the various sites/directorates. They are attended by senior managers responsible for the hospital campus, including senior clinical staff and support services such as estates and domestic service managers. We attended some of the safety huddles, where we observed good teamwork with open and transparent communication about staffing levels, environmental issues, bed numbers and patient wait times in admission areas such as the emergency department. The availability of domestic staff was also discussed to ensure prioritised cleaning in the clinical areas.

As with our previous inspection of the hospital campus in March 2022, we observed senior managers and clinical staff from across the hospital campus working together to try to reduce risks associated with the unprecedented increased pressures. However, not all of the risks could be reduced. We observed the risks, such as

staffing levels being highlighted, and 27 wards remained with a risk scoring of red even after mitigation. We observed a high level of awareness and understanding of where risks remained high. We also saw evidence of this being reported in the hospital's daily situation report, which is submitted at 11.00am each day to the Scottish Government.

The Healthcare Associated Infection (HAI) executive lead is the executive board member assigned to lead on infection prevention and control for the NHS board. This now sits under the remit of the executive nurse director for the NHS board. The new HAI executive lead explained they had, until 8 weeks prior to the inspection, been a member of the oversight board during the previous two and a half years working as the director of infection prevention and control before taking on the role of the executive nurse director and HAI executive lead. The director of infection prevention and control role is responsible for the delivery of infection prevention and control for all of NHS Greater Glasgow and Clyde. This role is now occupied by the previous interim infection prevention and control manager. We observed a good working relationship with good communication between the HAI executive lead and the director of infection prevention and control.

The HAI executive lead and director of infection prevention and control described the work that had been undertaken over the past 2 years to improve:

- communication
- the profile of infection prevention and control, and
- the relationships across the multidisciplinary teams who support the delivery of effective infection prevention and control.

During our discussion sessions with the wider infection prevention and control team, they all described the same processes, the accountability framework and communication through newly established team meetings. This provides some assurance that, at all levels, the team members who deliver the operational work are aligned with the systems and processes described by the executive-level team. There appears to be a whole system approach to infection prevention and control.

During the discussion session, the infection prevention and control team described the systems and processes in place to ensure the expertise and leadership of infection prevention and control within the hospital campus. We met with some lead infection prevention and control nurses, infection control doctors and the director of infection prevention and control. The team spoke clearly of their roles and responsibilities. They displayed a dedicated team ethos with colleagues describing a supportive and collaborative approach to infection prevention and control. This includes regular team meetings across all the disciplines involved, such as microbiology, virology, lead infection control nurses and infection control doctors, and estates colleagues.

We requested evidence to understand how the NHS board addresses local infection prevention and control issues. We were provided with the infection prevention and control accountability framework for NHS Greater Glasgow and Clyde. We saw minutes of key meetings of this working in practice. However, we noted some improvements that could be made around reporting from the NHS board water safety group to the NHS board's infection control committee (BICC), in line with the accountability framework. This is reported under Standard 8.

Staff we spoke with in the clinical environments across the hospital campus all described good contact and access to infection prevention and control advice from the team.

We also read the NHS Greater Glasgow and Clyde board papers that are available to the general public online. We saw that infection control is a standing item on the agenda from the board papers, with the HAI reporting template (HAIRT) being presented and discussed at this meeting. This is a national mandatory reporting tool all NHS boards are required to complete. We saw this was being used to provide the NHS board with oversight of the progress of HAI targets. This includes information on *clostridium difficile* infections (CDI) and *staphylococcus aureus* bacteraemia (SAB) cases, along with incidents and outbreaks and the control measures and investigations to be undertaken. The HAIRT report clearly defines what criteria are met to determine an HAI. We saw how the NHS board executive and management teams monitor infection prevention and control key performance indicators from the meeting minutes.

We saw within the HAIRT report that the Royal Hospital for Children reported an incident in the first quarter of the year. The report documented the investigations and management of the incident demonstrated through the control measures that were put in place. Communications and the actions taken concerning this incident were easy to follow within the wider evidence supplied to the inspection team. We saw procedures and processes in place to assess the problem, consider the possible reasons and put the risk management and controls in place. This provides a level of assurance that the systems and processes currently in place around incident and outbreak response, and the management and actions concerning infection control, align with a culture of openness and transparency. It was possible to see the NHS board oversight and assurance through the reporting structures within the HAIRT. We saw the initial assessment of the incident through evidence provided by the problem assessment group, comprised of senior clinical staff, senior infection prevention and control team members, estates managers, domestic managers and general managers who attend this group. This process was in line with NHS Greater Glasgow and Clyde's incident management process framework and national mandatory guidance and reporting policy.

We saw a culture of learning from incident reporting and outbreaks, with the infection prevention and control team taking the lead and assessing the situation

when an incident or outbreak is identified. We saw this completed in line with the National Infection Prevention and Control Manual (NIPCM). We also saw evidence of these incidents being reported and discussed through the Acute Infection Control Committee (AICC) and the BICC.

Throughout the inspection, we saw evidence of policies, procedures and guidance to support staff to understand that infection control is everybody's business. Senior managers and leaders within the NHS board were knowledgeable about their roles and responsibilities, demonstrating an open and inclusive culture. We observed teamwork across the different disciplines, for example domestic teams, estates teams, infection prevention and control, and clinical staff.

We were provided with evidence of the infection control risk register. This is a framework in which the identified risks can be recorded and actions detailed and instigated to reduce each risk's probability and impact. Each risk has an owner, such as the director of infection prevention and control, an infection control doctor or the HAI executive lead. These risks had review dates, and the operational and NHS board-level committees oversee these risks. This supports the recognition of infection control risks that exist when delivering safe and effective infection prevention and control. For example, NHS Greater Glasgow and Clyde have recognised that, although systems may fail, steps have been taken to reduce the likelihood or impact on the service delivery if this was to occur.

We were provided with a copy of NHS Greater Glasgow and Clyde's duty of candour policy. The duty of candour procedure is a legal duty that sets out how organisations should tell those affected that an unintended or unexpected incident appears to have caused harm or death. They must apologise and meaningfully involve them in a review of what happened.

NHS Greater Glasgow and Clyde's duty of candour policy explains the principles and the process to ensure the legal obligations of duty of candour are fulfilled. This policy highlights that a report of the duty of candour incidents will be provided to the clinical and care governance group each year for review. In some other evidence provided, we could see that where an incident had been identified, such as a healthcare associated infection, the duty of candour is discussed by the team investigating and managing the incident. We saw it was recorded within this documentation if the patient or their representatives had been informed. However, in instances where, the clinical team were to decide if there is a place for the duty of candour process, it was not clear within the incident management meeting documentation, if this had been carried out. We discussed this with the infection prevention and control team, who explained that as part of investigating an infection related incident, the team members might advise the clinical team responsible for the patient's care that they should consider the duty of candour. We saw evidence in the infection prevention and control incident management process framework that the duty of candour will be considered at the beginning and throughout incident

management. All incident management team members are required to follow NHS Greater Glasgow and Clyde's duty of candour policy. Within the policy are links to the National Education Scotland's (NES) online learning modules on the duty of candour for staff to access. We met with NHS Greater Glasgow and Clyde's medical director, who is responsible for the duty of candour for the NHS board and the clinical governance support unit. They explained the systems and processes in place to ensure the duty of candour is carried out in accordance with the policy. We were presented with information on an internal audit carried out in 2021; during this time, the duty of candour policy was under review. The audit confirmed through sample testing that appropriate specialist teams had consistently carried out the duty of candour investigations. Each investigation culminated in a summary report outlining the key issues raised and recommendations for improvement.

Area of good practice

Standard 1	
1	We observed an open, transparent and supportive culture in relation to infection prevention and control.

Standard 3

- **Communication between organisations and with the patient or their representatives**

We observed good systems with the infection prevention and control team responding to incidents of infection, which is well documented within the infection prevention and control systems. However, this was less effective in the ward-based systems.

Patients and their representatives described having the required information, with some describing communication as excellent.

We saw evidence that where infection risks to the patient are identified, appropriate actions are taken to minimise these risks. When infection control incidents were identified, we saw evidence of communication with the patient and their representatives. We saw the infection prevention and control team's electronic system, a computerised software package purchased by NHS Greater Glasgow and Clyde. This system provides real-time laboratory results to the infection prevention and control team, alerting them when a patient is identified as having an infection. This allows the infection prevention and control team to take action and advise the clinical team caring for the patient.

During our inspection, we spent time with the infection prevention and control team, and we saw that infection control nurses had allocated wards throughout the

hospital campus. They are responsible for providing specialist infection prevention and control advice to the ward, and surveillance and support to clinical staff providing ward-based care. We saw from the patient records within the electronic infection prevention and control system that the wards were visited or telephoned weekly where a patient had an identified infection that would require infection control advice. All the infection control records reviewed were current and up-to-date and documented the advice that was provided.

We observed ward-based staff communicating with the infection prevention and control team. This appeared to be good, with staff describing a good relationship with the infection prevention and control team and knowing who to contact for advice when needed.

We observed infection prevention and control nursing staff contacting the wards promptly when patients with an identified infection were admitted or transferred from other wards or hospitals. We saw from the electronic infection prevention and control system the specific advice given to the ward. During the inspection, we observed instances of this advice being carried out. This included advising staff caring for patients in isolation in single rooms to follow the correct infection prevention and control precautions. For example, putting on an apron before entering the room and performing hand hygiene during care activities. However, clinical staff providing ward-based care currently do not have access to the electronic infection prevention and control system. Although this system recorded that the patient or their representatives had been communicated with regarding their condition, it was unclear where this information was documented in the patient's record for ward-based clinical staff to review.

During our inspection, the inspection team randomly selected 20 cases of the most recent patients from the infection prevention and control system with a confirmed or suspected infection requiring isolation to follow up on their care. The majority of patients the inspection team was able to follow up on were patients with COVID-19.

We spoke with patients who had COVID-19, and they told us they had not received any specific information about their COVID-19 infection. We raised this with ward staff and the infection prevention and control nurses, who confirmed this. They explained this was due to a large number of admissions to the hospital with a COVID-19 infection. However, information leaflets were available throughout the hospital. One patient, who tested positive for COVID-19 on admission, said they had not experienced any symptoms and were unsure when their isolation period would end. The infection control nurses told us that although they did not routinely visit all patients who had a confirmed COVID-19 infection, they would telephone the ward to give advice due to the high numbers of patients. We saw evidence of their contact with the ward, and the advice they provided was recorded within the infection control electronic system. Patients who had other types of infection told us they, and

their relatives, had been given information from either an infection control nurse or a doctor.

Within the patient care records reviewed in the ward areas, the majority documented the confirmed infection and the date they had completed the test. However, there was no care plan detailing the correct precautions or any specific advice the infection prevention and control team provided. Despite this, we observed that patients with any infection or suspected infection were cared for in single rooms and appropriate infection prevention and control precautions were in place.

During our discussion session with the infection prevention and control team, they described different methods for sharing and documenting this advice within the ward-level patient care record. This included using standard stickers detailing advice and using other electronic patient record systems for patients who had been in intensive care areas. However, this was not observed during our inspection.

Although we did not see evidence of the infection prevention and control advice or care plans within the ward-level patient care records, we did observe the correct infection control precautions in place for the patients with a known or suspected infection.

The potential impact of the infection prevention and control advice not being recorded in the ward-held patient care record was observed in one area. A patient had completed their isolation period; however, their side room had not yet had a deep clean in line with national guidance and local policy. However, we were satisfied that enhanced daily cleaning had been carried out in this area, including using chlorine-based cleaning products in line with national guidance. The deep clean is an additional clean that would involve disposing of all disposable equipment and deep cleaning all the patient equipment and the environment. We raised this at the time of the inspection and ward staff arranged for the deep clean to be carried out.

To understand the patients and their representatives views of their care concerning infection prevention and control within the hospital campus, we spoke with 35 patients or their representatives across eight wards. These patients were randomly selected and did not necessarily have a known or suspected infection. The patients were receiving care within different areas of the hospital. They were asked if they would be happy to provide general feedback regarding communication, cleanliness and staff practice concerning infection prevention and control.

Within the Royal Hospital for Children, a parent shared that they found communication excellent in the hospital. They said they were always well informed by all staff groups concerning their child's care, the reasons for treatments and any possible side effects. They highlighted that some possible adverse effects caused them anxiety, but they understood that staff wanted them to have all the relevant

information. Staff would provide reassurance when they were feeling overwhelmed and anxious by the volume of information they received.

All of the other patients we spoke with said they had received clear guidance about the current infection control measures for COVID-19. They received this either by letter before a planned admission, at the point of admission to the hospital, or within the ward or department where they were being cared for. This information had been provided verbally by staff.

Patients and visitors also told us that they had been given information about coming to the hospital, the ability to visit and any precautions they were required to take. Overall, those we spoke with expressed confidence in the precautions within the hospital and the guidance they had been given by staff. Patients and visitors described the hospital buildings as having clear information and signage with access to hand gel and masks at the entrance to the hospital and within wards and departments. All patients or their representatives told us they would speak to a nursing staff member if they had concerns. None of the patients or their representatives complained about infection control practices.

In March 2022, some wards were reopened within the Royal Hospital for Children following renovation and refurbishment. We saw evidence of the NHS board communicating and engaging with the public in a detailed communication plan for reopening the wards. This included providing social media posts and letters with updates for the parents, a walk-through video of the ward with the ward staff describing the changes in the ward, talking with families directly and arranging for each family to have a tour of the ward. We could not follow up on this communication's effectiveness as this was before the onsite inspection work. However, the plan does detail key steps in informing and assuring the patients and their families on the move back to the renovated wards.

We were also provided with a joint statement from the NHS board and NHS Scotland Assure. NHS Scotland Assure was launched in June 2021 to improve the quality and management of healthcare construction and refurbishment projects across NHS Scotland. This statement was released before the reopening of the wards and detailed the work that had been carried out. It thanked those who had contributed to fundraising and described the benefits for the patients and families the renovated facilities would bring. This communication acknowledged this had been a challenging time for those patients and families who had not had access to the wards during the renovation period.

An area of communication that could be improved does not relate to communication with the patients, or their representatives, but to communication with domestic staff. Some domestic staff we spoke with highlighted that they do not have access to work email accounts. They told us they felt this would be a more effective and reliable way to share information with them. Currently, domestic staff rely on information being shared with them by the domestic supervisors, from staff on the

wards and through handover documentation. We raised this with senior managers for domestic services, who agreed that email access for this staff group would be beneficial. This had been considered, but it was not currently being progressed.

Area of good practice

Standard 3	
2	Patients and their representatives described good communication on infection, prevention and control considerations.

Requirement

Standard 3	
1	NHS Greater Glasgow and Clyde must ensure that specialist infection prevention and control advice is recorded within the ward-level patient care record to inform care planning. This will ensure that patients are well informed, including information on when their isolation period will end. **This is to comply with the Healthcare Associated Infection (HAI) standards (2015) criterion 3.6. This will also comply with the new Infection Prevention and Control Standards (2022) criterion 3.1.**

Standard 4

- **HAI Surveillance**

We observed that NHS Greater Glasgow and Clyde has a surveillance system that can assure a rapid response to hospital acquired infections (HAI).

Ward surveillance data

During our inspection, we observed surveillance data in 10 wards to understand if this information was displayed in a way for the patients and the public to see. Most wards displayed the number of days since the ward last had an HAI. We saw that the information displayed varied across the different areas. For example, in the critical care wards visited, we saw the area displayed the number of days since the last ventilator associated pneumonia was identified. This would only apply to areas where patients are cared for on a ventilator.

NHS boards' surveillance of infections

From the evidence submitted and reviewing the electronic reporting system, NHS Greater Glasgow and Clyde has an infection control surveillance programme, incorporating national mandatory guidance and local surveillance of infections and alert organisms. These are specific organisms or conditions that may require further

investigation or input and advice from the infection prevention and control team, for example *methicillin-resistant Staphylococcus aureu*s (MRSA) or COVID-19. We saw evidence of this in practice when the infection prevention and control team responded to newly alerted infections reported to them through this electronic system.

We also saw evidence of NHS Greater Glasgow and Clyde's HAI reporting template report. This is prepared by the infection prevention and control team for the HAI executive lead and reported through the NHS Greater Glasgow and Clyde infection control governance structure to the NHS board. Within this report, infections are reported, including those that are government targets, for example CDI infection rates and other incidents and outbreaks.

We were provided with evidence of the triggers built into the electronic infection prevention and control system that allows prompt detection and response to a variance of normal limits. For example, when two cases of infection are identified with links to one area within a specific timeframe. We saw evidence of action taken by the infection prevention and control team through various groups, including problem assessment groups and incident management teams.

Within the evidence provided by NHS Greater Glasgow and Clyde, we identified suspected cases of *Aspergillus*-related infection discussed at the AICC. We requested further information and were provided with the evidence of a problem assessment group that had been convened by one of the infection control doctors in response to two suspected cases of *Aspergillus* infection. We saw that immediate action was taken, an assessment of the situation was made, and control measures were implemented to reduce any additional risk. This included closing the area to any other patients, assessing the area and any potential system failures or environmental concerns and checking that the ventilation had been through the correct checks. During the assessment of this incident by the infection prevention and control team, the clinical team within the hospital campus identified that there had not been two cases of *Aspergillus*-related infection. An error with processing the samples within the laboratory led to the initial concern of two positive results. The process within the laboratory is not within the scope of this inspection.

This was an example of a trigger within the system working, and the infection prevention and control team and wider multidisciplinary team responding to the trigger. We discussed the NHS board's approach to this incident with our independent *Aspergillus* expert. They agreed that the NHS board was appropriate with the actions taken, and the NHS board appeared to be taking a very vigilant view of infection related to *Aspergillus*.

This is evidence of NHS Greater Glasgow and Clyde's incident management process framework, described within Standard 1 of this report. The framework describes the process to follow when identifying an incident that may result from a trigger within the system. We saw evidence of the process within this document being followed

through the evidence we requested concerning incidents and outbreaks across the hospital campus.

Area of good practice

Standard 4	
3	NHS Greater Glasgow and Clyde have a process to identify infection prevention and control alert triggers within the system and follow a clear process to act and minimise further risks.

Standard 6

- **Infection prevention and control policies, procedures and guidance**

NHS Greater Glasgow and Clyde demonstrated evidence-based infection prevention and control measures, such as implementing and adhering to the guidance within the National Infection Prevention and Control Manual (NIPCM). This includes good practice in standard infection prevention control precautions such as hand hygiene. However, this report highlights limited national guidance for infection prevention and control management and response specific to *Aspergillus.* Current reliance on professional opinion and interpretation in practice is problematic for this complex and highly expert topic and may lead to a lack of standard approach across NHS Scotland.

The current version of the NIPCM has been adopted by the NHS board and is accessible by all staff. Staff were able to show us how they accessed this guidance.

Within the evidence supplied, NHS Greater Glasgow and Clyde provided additional guidance documents they had produced such as the incident management process framework. The infection prevention and control team developed this document that the BICC approved. It clearly describes the process the NHS board should follow in the event of infection control-related incidents or outbreaks. This supports the guidance within the NIPCM, *Chapter 3 - Healthcare Incidents, Outbreaks and Data Exceedance*. This document provides a detailed and systemic approach with clear steps for teams to follow in identifying, managing and recording incidents and outbreaks when they occur. Within further evidence provided by the NHS board, we saw this policy being followed in identifying incidents, investigations and planned actions when infection incidents occurred.

In reviewing further information on the response to infection related to *Aspergillus*, NHS Greater Glasgow and Clyde confirmed that a single case of healthcare associated *Aspergillus*-related infection would not necessarily be treated as an incident or outbreak. The reason for this is NHS Greater Glasgow and Clyde consider a single case would not meet the definition of an incident or outbreak defined in Chapter 3 of the NIPCM.

The definitions within the NIPCM are:

An exceptional infection episode:

- A single case of an infection that has severe outcomes for an individual patient OR has major implications for others (patients, staff and/or visitors), the organisation or wider public health, e.g., infectious diseases of high consequence such as VHF or XDR-TB, botulism, polio, rabies, diphtheria.

A healthcare associated infection outbreak:

- Two or more linked cases with the same infectious agent associated with the same healthcare setting over a specified time period or
- A higher than expected number of cases of HAI in a given healthcare area over a specified time period.

A healthcare infection data exceedance

- A greater than expected rate of infection compared with the usual background rate for the place and time where the incident has occurred.

A healthcare infection incident should be suspected if there is:

- A single case of an infection for which there have previously been no cases in the facility (e.g. infection with a multidrug-resistant organism (MDRO) with unusual resistance patterns or a post-procedure infection with an unusual organism).

Guidance within the NIPCM then explains that, following recognition of an incident or outbreak described above, the infection prevention and control team should undertake an initial assessment, utilising the Healthcare Infection Incident Assessment Tool (HIIAT). This should then be reported to Antimicrobial Resistance and Healthcare Associated Infection (ARHAI) Scotland through the electronic outbreak reporting tool.

We sought advice from ARHAI Scotland who confirmed that a single case of healthcare associated Aspergillus-related infection would meet the definition within the national guidance and should have the HIIAT applied and then be reported through the electronic outbreak tool. This inspection highlights a divergence in the interpretation of this guidance within the NIPCM. This may require further review across NHS Scotland to understand if interpretations differ in other NHS boards. As discussed earlier in this report, no new outbreaks of Aspergillus-related infection were reported to ARHAI Scotland from August 2021 to May 2022. This could indicate systemic under-reporting of Aspergillus-related infections within Scotland but understanding if this is the case is out with the scope of this inspection.

Within the other evidence supplied by NHS Greater Glasgow and Clyde, the NHS board demonstrated oversight and awareness of Aspergillus-related infections across the hospital campus. This showed that, when cases were identified, the infection prevention and control team took action to understand the situation and assess for a

potential cause. This included a review of any potentially related cases of Aspergillus-related infection either 30 days before or 30 days after microbiology laboratory identification. From the information provided, we were assured that there were infection prevention and control systems and processes in place to be alert to potential triggers within the system and to take action to respond to these.

We sought advice from our external independent Aspergillus expert who acknowledged that the 30 day marker was an appropriate point to establish and review all new cases. However, he suggested that when applying the review period for any potentially linked cases, NHS Greater Glasgow and Clyde may wish to consider a commencement point of 30 days from initial signs of infection rather than 30 days from identification of infection. He believes this may be more effective in identifying possible related cases given the potential for delay in testing for aspergillosis and insensitivity of each individual diagnostic test.

This lack of clarity highlights the need for more specific national guidance for infection prevention and control management and response specific to Aspergillus infection. The current over-reliance on professional opinion and interpretation in practice for what is often a complex clinical and infection control topic is not desirable. The development of guidance to support a more standardised infection prevention and control approach across NHS Scotland is advised. Healthcare Improvement Scotland will be recommending to Scottish Government that national guidance to support a standard approach to the infection prevention and control management of Aspergillus infection across NHS Scotland should be considered and developed.

For the wider application of infection prevention and control practice, standard infection control precautions (SICPs) and transmission-based precautions (TBPs) are described within the NIPCM. There are 10 SICPs, including patient placement, hand hygiene, the use of personal protective equipment (such as aprons and gloves), management of patient care equipment and the care environment, safe management of blood and fluid spillages, linen and waste management and prevention and exposure management (such as sharps injuries). The additional TBPs should be followed by all staff at all times when caring for patients to help prevent cross-transmission of infection.

During our inspection, we observed generally good compliance with SICPs and TBPs.

In the newer parts of the hospital campus, the majority of patient rooms are single rooms. Patients in multi-bed bay areas with a confirmed or suspected infection were placed in a side room.

NHS Greater Glasgow and Clyde have also developed a standard operating procedure (SOP) to support staff in identifying the best place to care for patients with a specific infection that may require a specialist room to reduce the risk of circulating air between the room and the corridor. For example, a patient with chicken pox or

measles, or to protect patients with very low immunity. The information within the SOP details the specific rooms across NHS Greater Glasgow and Clyde, including the Queen Elizabeth University Hospital campus, which should be used when patients require specific enhanced isolation facilities. We discussed this with the infection prevention and control team, who told us that they use this SOP to help advise clinical staff on the best placement for the patient's needs.

One of the key precautions in infection prevention and control is practising good hand hygiene. At our previous safe delivery of care inspection in March 2022, we gave NHS Greater Glasgow and Clyde a requirement to ensure that all staff carry out hand hygiene at appropriate moments. Since that inspection, we saw improvement actions have been put in place. This includes training sessions for staff and staff groups, such as porter and facilities services, to carry out hand hygiene audits. Other improvement actions included raising awareness through the topic of the week sessions. At these sessions, specific topics are discussed using guidance on the correct practice, focusing on the importance of good hand hygiene. During this inspection, we saw good improvement in hand hygiene across all staff groups, with the majority of staff carrying out hand hygiene in line with guidance.

The patients we spoke with told us about mixed experiences with getting help with their own hand hygiene.

- Most areas had easily accessible hand wipes or gel within reach of patients. In some instances, we heard these items were in lockers, and patients required assistance to access them.
- All patients we spoke with described getting assistance with personal care when required.
- Patients who could not independently access hand washing facilities told us they had not been offered assistance with washing their hands before meal times. We raised this with staff and senior managers during our inspection.
- All of the patients and relatives we spoke with told us that they were aware of staff washing their hands at the correct times, such as before or after touching the patients or their surroundings.

Personal protective equipment (PPE), such as gloves and aprons, are used by staff to protect them from risks associated with the task being carried out. This will protect both staff and patients. For example, if a patient has an infection, the use of PPE will help prevent the staff member's uniform from becoming contaminated, with gloves helping to protect from physical contamination and hand hygiene carried out before putting on and on the removal of the gloves.

We observed the storage and use of PPE was good. This includes storing PPE to prevent potential environmental contamination and staff wearing gloves, aprons and face masks correctly in line with guidance. However, we observed staff wearing gloves when not required in one ward area. This may result in staff not carrying out

hand hygiene at the correct times. We raised this with the ward and managers during our inspection for immediate action.

We observed good compliance with linen and waste management.

- Clean linen was stored to prevent contamination.
- Used and infectious linen was managed appropriately, stored and handled properly, with the linen trolley buggy taken to the point of care and bagged correctly.

In the majority of instances, sharps management was good. However, some temporary closures were not in use. These prevent needles or sharps protruding from the sharps bin. This was highlighted to staff and the closures were put in place.

Staff told us they would challenge colleagues who do not adhere to the guidance in the NIPCM, and we observed this during our inspection. We saw a staff member ask their colleague to remove and replace their facemask as it was sitting under their nose. This is good practice and all staff should feel confident in reminding colleagues of the best practice guidance. This is particularly important when staff work under extreme pressure with many competing priorities.

Across several of the clinical areas inspected, we identified that multipack boxes of tongue depressors were in use. Staff told us these were being used to view the patient's palate and throat. We saw that these were stored in open shelving, or on patient equipment, with lids of the boxes open. These were large multipack boxes, meaning several staff members may access the box. We discussed options with the NHS board to reduce the risk of cross-contamination arising from people accessing the multipack boxes and touching the tongue depressors and the risk of environmental contamination from the boxes lying open on shelves for long periods of time. NHS Greater Glasgow and Clyde agreed to move to individually wrapped tongue depressors to reduce any possible risk from the multipack boxes.

At our previous inspection in March 2022, we gave NHS Greater Glasgow and Clyde a requirement to ensure clinical wash hand basins were used only for hand hygiene and not for other things, such as disposing of liquids and teeth brushing. During this inspection, the majority of areas inspected were using clinical wash hand basins for the correct purposes.

However, in one area, we observed staff cleaning respiratory equipment (tracheostomies) in the clinical wash hand basin. By doing this, there is a risk of contaminating the clinical wash hand basin. We raised this with senior managers during our inspection and they confirmed this is not the practice that the infection prevention and control team would advise. However, when we returned to the area 10 days after the initial findings, this practice continued to be in place. The senior charge nurse in the area explained that they had been sent a copy of NHS Greater Glasgow and Clyde's procedure for cleaning tracheostomies, but due to the ward being busy and staff sickness, they had not had the time to change the practice and

were not clear how it would work in this area. We raised this again with senior managers, who assured us support would be provided in this area to change this practice. During our subsequent discussion session with the infection prevention and control team, they confirmed the lead infection prevention and control nurse had visited the area to provided information on how to clean the equipment safely and confirmed this practice was now being carried out in line with the guidance supplied to the ward.

At our previous inspection in March 2022, NHS Greater Glasgow and Clyde were required to ensure the Specialist Assessment and Treatment Area (SATA) had sufficient hand hygiene facilities, appropriate storage and access to PPE and adequate placement of patients. These issues were all addressed at the time of our previous inspection. We assessed this again during this inspection and found the improvements made during the last inspection had been sustained.

The majority of the patient care equipment was clean and ready for use. However, in one ward, we found several pieces of equipment were not clean. This included equipment trolleys, intravenous stands, bed frames and a blood glucose monitoring machine with a small amount of blood contamination. We identified other issues within this ward, such as a lack of awareness of the necessary checks the nurse in charge should carry out. This included checking equipment cleanliness and running water in the less frequently used water outlets. We raised this with ward and hospital management. We were told that, due to staff sickness at a senior level within the ward, the staff team had been working to continue to provide care, however were not aware of all of the roles and tasks that would normally be carried out by the senior staff. This had been the situation for several months. We discussed this with managers responsible for this ward and the impact the lack of support can have on the ward or clinical area when a staff member is required to move into a more senior role quickly. We were assured by the senior management team that support would be provided immediately.

We returned to this area 10 days after our initial inspection. We were assured that progress had been made and staff were now receiving support. The equipment we checked was clean. There were processes in place for the nurse in charge to check the cleaning schedules, and the chief nurse for this area was providing support. This support included walk rounds of the area to check the cleanliness of patient equipment and the environment, and that systems and processes were in place. The chief nurse also provided real-time feedback to staff on their findings. Staff we spoke with described this input from the senior management team as very supportive and collaborative. In response to the issues highlighted in this area, NHS Greater Glasgow and Clyde have developed a new checklist that they are currently trialling to support other charge nurses who may have to step up quickly into a more senior role. The checklist includes roles and tasks that should be completed either daily, weekly, monthly, quarterly or 6-monthly. It also includes many other elements of the senior change nurse role that were identified within this area.

In the same clinical area, we also identified that the clinical preparation room was small and was shared with another clinical area. This resulted in a limited work surface in the preparation area. During our return visit to this area, we observed staff preparing intravenous (IV) medications within splash distance of the disposal sink used to dispose of ice. This is a risk as there can be contamination from the disposal sink to the clean area required for the aseptic preparation of IV medications. We discussed this with the nurse in charge and the infection prevention and control team who confirmed a trolley was now in place and was being used to prepare IV medications.

In another clinical area, we found chairs torn, with some contamination on the inside parts of the damaged chairs. We raised this with ward managers at the time of our inspection, and it was identified that the chairs had not been included in the ward cleaning schedule. Therefore, the chairs appeared to have been missed during cleaning and cleanliness checks. We returned to the ward 10 days after our initial visit and saw this had been addressed and the damaged chairs removed. We observed that chairs were now included in the cleaning schedules, and we found the chairs to be clean.

We observed that ward areas carry out SICPs audits every 6 months, with additional hand hygiene audits carried out each month. We saw evidence of the current audits being carried out with documented improvements. Where improvements were required, for example if any of the SICPs observed were not compliant with the national guidance, we saw evidence of action taken to improve this.

From the evidence provided by the NHS board, the oversight board recommended in 2020 that NHS Greater Glasgow and Clyde undertake a review of its programmes of audit relating to infection prevention and control, in line with the Healthcare Improvement Scotland (HIS) framework for quality planning and improvement. The aim is to ensure consistency in audit score ratings and a stronger link to a continuous culture of improvement.

The changes to the NHS Greater Glasgow and Clyde's SICPs audit programme reflect a shift in responsibility from the infection prevention and control teams to local clinical management teams, underpinned by organisational governance structures ensuring strategic oversight.

The infection prevention and control team confirmed the infection control-led audit programme will audit:

- all high-risk areas such as intensive care units annually
- 20% of wards on an annual rolling programme, and
- wards, where SICPs audits have been requested as part of actions agreed at an incident management team, align with the NHS Great Glasgow and Clyde incident process framework.

During our discussion with infection prevention and control staff, they told us about the new programme of infection control audits currently in development. They hope to implement this in October 2022.

Areas of good practice

Standard 6	
4	NHS Greater Glasgow and Clyde developed a standard operating procedure (SOP) to identify the best place to care for patients with a specific infection that may require care areas with specialist ventilation.
5	Good staff compliance with standard infection control precautions and transmission-based precautions.

Requirements

Standard 6	
2	NHS Greater Glasgow and Clyde must ensure cleaning of tracheostomies is in line with guidance, not performed in clinical wash hand basins and staff have the correct information and support to do this safely. **This is to comply with the National Infection Prevention and Control Manual and the Healthcare Associated Infection (HAI) Standards (2015) criterion 6.11. This will also comply with the Infection Prevention And Control Standards (2022) criteria 6.1**.
3	NHS Greater Glasgow and Clyde must ensure that systems and processes in place support clinical staff who are assuming a more senior role in managing a clinical area. This will include but is not limited to the senior charge nurse's responsibilities concerning infection prevention and control. **This is to comply with the National Infection Prevention and Control Manual and the Healthcare Associated Infection (HAI) Standards (2015) criterion 6.11. This will also comply with the Infection Prevention And Control Standards (2022) criteria 2.3**.

Standard 7

- **Insertion and maintenance of invasive devices**

We found good practice in the insertion and care of invasive devices observed during this inspection.

Invasive devices are medical devices introduced into the body either through a break in the skin or an opening in the body, for example a vascular access device.

A vascular access device is a tube inserted into a main vein or artery to provide access to veins for the delivery of intravenous medications, monitoring blood pressure and collecting blood samples. Vascular access devices are significant causes of HAIs, and bloodstream infections associated with central venous device insertion are a major cause of morbidity. The risk of infection is greatly reduced by complying with all parts of the process for safe insertion and maintenance of the device and its removal as soon as it is no longer needed.

The invasive devices we reviewed as part of this inspection were peripheral venous cannulas (PVC) and central venous catheters (CVC). PVCs are designed to be used for short-term uses such as intravenous fluids and medications. A CVC or central line is a catheter with a tip that lies within large veins. When a patient has an invasive device in place, they should be informed of the signs and symptoms of the risks associated with the device.

We checked 35 PVC/CVCs across the hospital campus during our inspection. We found that two of the wards we attended to inspect invasive devices in the hospital campus had no patients with a PVC or CVC in place, demonstrating that using devices is avoided and removed when no longer needed. This is good practice.

We observed that staff follow key practice recommendations on how and when invasive devices should be used, maintained, monitored and removed. These procedures include using an aseptic technique when inserting the device, using the correct antiseptics and dressings, and removing the device as soon as it is no longer needed. From observations of the invasive device sites, care plans and discussions with staff and patients:

- PVCs were checked at least twice daily, and no PVCs were in place for longer than the recommended 72 hours.
- All CVC devices were checked daily. All of these devices had been in for less than 7 days or had had their dressing changed every 7 days, in line with best practice guidance.
- All patients had an appropriate dressing that was transparent to allow staff to observe the insertion site for any signs of infection.
- No patients with a PVC or CVC had signs of infection at the insertion site.

- In the Royal Hospital for Children, all parents or representatives of the patients told us they were well informed of the need for the invasive device. They were all aware of the risks associated with the device. They emphasised staff were very good at explaining these risks.

Documenting the date and time of insertion of a PVC is an important step to ensure it is not left in place too long. We found that the insertion date was documented for most patients with a PVC. NHS Greater Glasgow and Clyde's policy states that PVCs should be monitored twice daily. This is an area of good practice and is over and above the national guidelines for monitoring these devices once per day.

Two patients with a PVC did not have a care plan in place for the device.

- One patient's PVC had just been inserted. Nursing staff confirmed that the care plan had been put in the patient's notes but had not yet been completed.
- One patient did not have a care plan in place or any evidence of this being started. However, the patient had no obvious signs or symptoms of infection at the site of the device. Nursing staff confirmed that the patient was to have a PVC inserted later in the week. As it was not clear when the device had been inserted, this device was removed to reduce the risk of it being in for too long.

Most patients we spoke with within the adult hospital had not been informed of the risks associated with their device or could not remember if they had been informed. In some cases, they had been very unwell when it was inserted. Although information leaflets were in a patient information folder in all patient rooms, most patients were unaware of the folder and did not know the information was there.

Guidance on the insertion of a CVC states maximum precautions must be taken to ensure the healthcare worker uses sterile barrier precautions to minimise the risk of infection to the patient. These include carrying out a surgical scrub, wearing sterile protective clothing such as a gown and gloves, using a sterile drape to protect the patient, and using care plans to document the insertion procedure.

The CVC insertion documentation we reviewed stated aseptic technique had been carried out. We discussed this procedure with the vascular access service staff, clinical staff caring for the patients, the infection prevention and control team, and some patients with a CVC in place. All staff could describe the procedure followed when the CVC was inserted, and everyone we spoke with described the aseptic technique correctly. On one ward, we observed a dressing change being carried out. This was done in line with the national guidance by using an aseptic technique and cleansing the skin with the correct cleansing agent. All CVCs had a transparent dressing in place to allow staff to monitor the site for signs of infection. Within the adult hospital, all CVCs observed had a chlorhexidine-impregnated sponge dressing at the entrance site for the line. This is a practice to help reduce the risk of infection that goes above current best practice guidance.

Through our observations, review of evidence and discussions with staff, we found staff respond when there is any indication of infection risks with a commitment to improvement through appropriate investigations and actions. Staff within the vascular access service, the infection prevention and control team and the renal ward told us that, due to the increased complexity and severity of patients' illness and restrictions on services as a result of the COVID-19 restrictions, invasive devices such as CVCs had increased. As this is an invasive procedure, this carries the risk of increased infections relating to the invasive devices. A short-life working group including staff from health and safety, learning and development, nursing leads, an infectious diseases consultant and an infection prevention and control nurse had been formed to carry out a range of improvement work relating to these devices. This included education, audits and communication by adding vascular access devices to ward safety briefs and handovers.

The benefit of including the vascular access devices within the ward safety brief and staff handovers is that all staff are made aware of patients who have additional care needs due to the invasive device at the start of their shift. This reminds staff to carry out the daily review of the device, monitor for signs of infection, and consider the continued need for the device or if it can be removed.

We discussed with the infection prevention and control team what actions would be taken when an infection relating to a PVC or CVC was identified. This includes an investigation to establish the reason for the infection and determine if the infection could have been avoided. If it was an avoidable infection, it is reported. The clinical team providing care for the patient then work to identify any lessons learned from the incident. The infection control team would be included in the review process and offer support where they can. We saw evidence of this process being carried out.

Monthly PVC and CVC line care audits are carried out. However, within the Royal Hospital for Children's wards, we saw that they carry out these audits daily as an extra precaution. This is an example of staff within the area working above and beyond expectations to improve patient safety. We saw that the audit results, including those carried out by the infection prevention and control team, consistently scored 100%. This was reflective of what we observed during our inspection. We considered this exceptional practice within these areas.

Areas of good practice

Standard 7	
6	Peripheral venous cannulas (PVC) devices were monitored twice a day.
7	The Royal Hospital for Children carry out audits of peripheral venous cannulas (PVC) and central venous cannulas (CVC) daily.

Recommendation

Standard 7

a NHS Greater Glasgow and Clyde should consider the method of sharing information with patients about their invasive devices. This will support patients to proactively care for their devices and be aware of risks and signs and symptoms of infection.

Standard 8

- **Decontamination**

We found a good standard of cleaning, and the environment was mostly in a good state of repair. Domestic and clinical staff described good teamwork and satisfaction with the systems in place to ensure a clean and safe environment. The infection prevention and control team and estates managers told us about good working relationships between the teams, with all colleagues expressing positive working relationships across these teams. However, the robustness of governance structures and reporting relating to the built environment is an area for improvement.

The cleanliness of the environment within the hospital campus inspected was mostly good. This reflects the work that has been carried out since 2019 at our previous infection control-related inspections within the hospital campus. Previous inspections identified issues with the systems and processes to monitor the cleanliness of the environment and the equipment available to staff for effective cleaning. We were told that the learning from previous inspections had resulted in changes in the domestic services assurance mechanism to drive improvements.

During this inspection, we identified very few exceptions to the standard of cleanliness of the environment. In one of the older buildings within the hospital campus, we saw black markings on the window seals. The estates and facilities teams were unaware of this before we raised this with them. We saw evidence that the NHS board then took action to address this by starting a programme of having the seals cleaned by a professional company with plans to replace all of the seals in that area. The date for completion had not been agreed upon due to patients needing to be removed from the area to complete the work. However, we were told this is currently being reviewed.

The domestic team, which includes domestic staff, supervisors and facilities managers, are responsible for ensuring the care environment is clean with a reactive and responsive element to these roles. We were told there is 24-hour domestic support, including a supervisor and domestic staff. This would be required if, for

example, emergency work is required to be carried out in a clinical area overnight. That area cannot be used until it has been cleaned.

During the hospital safety huddles, domestic managers were asked if all clinical areas had the appropriate domestic staffing. We spoke with the domestic staff and managers, who were knowledgeable about their roles and responsibilities. The only exception we observed was the method applied to cleaning a clinical wash hand basin. We raised this with domestic managers, who addressed this through the facilities' quality improvement programme. This is reported later in this section.

We acknowledge the hard work within the hospital campus to have maintained this good standard of cleaning under very challenging conditions, such as COVID-19, staffing pressures and increased bed pressures. These can directly impact domestic services, such as additional cleaning requirements and workload. During our discussion session with facilities managers, they told us that NHS Greater Glasgow and Clyde decided to over employ domestic staff during the pandemic to ensure the required additional cleaning duties could be achieved. We saw evidence of these additional posts within the data provided by the NHS board.

Steps are described to prevent and manage ventilation HAI incidents within the NIPCM. One of the guidance points to prevent an incident or outbreak in all settings is that ventilation systems will require maintenance and cleaning. Cleaning schedules should incorporate regular visual inspection of ventilation grilles for lint and dust accumulation. We observed the ventilation grilles in the inspected areas to monitor for dust build-up. We observed the majority of these ventilation grilles were clean. The only exception was in the emergency department, where we identified some had a build-up of dust. We raised this with the estates team, who are responsible for the programme of cleaning these grilles. We were informed that the ventilation grilles in the emergency department had been cleaned within their programmed expected frequency. However, due to the inspection findings, this frequency has increased to ensure they remain dust free in this area. This is a significant improvement from our previous inspection in 2019, where ventilation grilles were found to have a heavy build-up of dust.

Another guidance point to prevent incidents and outbreaks concerning ventilation is that high-risk areas should monitor ventilation performance annually. The technical information and the volume of reports do not fall within the inspection team’s area of expertise. Therefore, to ensure ventilation monitoring within this hospital campus, we asked for the specific ventilation performance validation reports of two high-risk areas randomly selected by the inspection team.

Within one of the reports provided, we saw some maintenance actions were required to be taken to address some minor faults or damage to the fabric of the area supplied by the ventilation system. We saw that action had been taken to rectify some of these faults, except for one room area where some damage to the flooring had been identified. However, access was restricted due to patient care

needs. We were informed that the estates team are in regular contact with the clinical area to identify when this rectification work could be completed. In the other report, we saw that there had been a 15-month gap between the validation reports. However, the NHS board also provided documentation to show that they had attempted to carry this out within the year, but they could not gain access at the time due to a patient being cared for in that area who could not be moved to carry out the work.

We saw evidence that when access was not possible to carry out the ventilation performance validation, there was clear documentation signed by the staff responsible for that clinical area stating that access could not be permitted due to patient care needs. We saw that the ventilation performance validation was carried out when access to the area was possible.

We discussed how the ventilation performance validation reports are shared with the wider multidisciplinary team. We were told they will now be shared formally at the new ventilation group. The first meeting of this group was in June this year. We were provided with the terms of reference and the minutes of the first meeting. We could see the group membership had representation from the estates, clinical and infection prevention and control teams. However, prior to the establishment of this meeting, we were told sharing these ventilation reports was a more informal process, with the estates team contacting the infection prevention and control team if any failures or poor scores were reported. The infection prevention and control team also confirmed this process. Although we recognise these reports will now be included in the new ventilation group, there must be an improved formal system for sharing these reports in real-time rather than waiting to be presented at a scheduled meeting. This will ensure the infection prevention and control team are formally aware of report findings on receipt of the report. This will reduce the need to rely on estates colleagues to alert them to any potential infection control concerns that may require the immediate infection prevention control team to immediately act upon or provide advice.

In March 2022, wards 2A and 2B within the Royal Hospital for Children on the Queen Elizabeth University Hospital campus, were re-opened after refurbishment. NHS Scotland Assure provided support to NHS Greater Glasgow and Clyde throughout the refurbishment process. However, this project was not subject to a Key Stage Assurance Review as the project pre-dated this process.

The information submitted to NHS Scotland Assure by NHS Greater Glasgow and Clyde is out with the scope of this inspection or the expertise of the inspection team to interpret.

We discussed the governance processes within the NHS board for the reopening of the wards with senior managers within NHS Greater Glasgow and Clyde. We were told when information was being shared to support the reopening of the wards, an email was sent to the NHS board water safety group and the BICC members. This

provided a link to the electronic platform where the documents that were to be shared were stored, with the confirmation of approval being requested within the email. We were provided with evidence of this email trail. However, we noted only 13 of approximately 35 people responded to this email as requested.

During our discussion with senior managers, we were told that a non-reply would also be considered approval. We believe the NHS board could strengthen the governance around this process to ensure clear accountability within the governance structures.

During our onsite inspection, we observed the healthcare associated infection system for controlling risks in the built environment (HAI scribe) process being applied during our inspection and through the evidence provided by the NHS board. HAI scribe is a tool that should be used to identify infection risks when carrying out building work in the clinical environment and is used to manage and mitigate identified risks. The HAI scribe should be completed before works are carried out in clinical areas to reduce the risk of contamination from the building work affecting the clinical care environment. This ensures processes are in place to support NHS boards' compliance with the guidance within the NIPCM.

We observed work being carried out, including cleaning ventilation systems in several areas. We saw that control measures were in place to reduce the risk of contamination of the environment during the cleaning process. This included screening the area off to prevent any dust or debris from leaving and cleaning the area before reopening the clinical area. We were provided with the HAI scribe risk assessment for this process. The estates and infection prevention and control teams explained that this is one of a suite of standard HAI scribes that the NHS board have put together to allow works carried out at regular frequencies to go ahead.

We saw that the infection prevention and control and estates teams produced these HAI scribe risk assessments and that the control measures for carrying out these works were assessed and stipulated within the documents. These are then used and followed by the staff carrying out the work. Both teams described these processes well and spoke highly of the teamwork between both departments in completing these pieces of joined-up work.

The management of water systems within the healthcare environment is essential. It is recognised that water sources are a potential infection risk, especially to patients in high-risk units. NHS boards have a large volume of guidance to be followed, including a robust system and evidence of safe water management systems, a water safety group responsible for developing and maintaining a water safety plan, risk assessments and actions to mitigate risks.

We reviewed NHS Greater Glasgow and Clyde's water management policy. The policy clearly described the NHS board's roles and responsibilities for water safety.

One of the actions to reduce the risk of water sources being a potential infection risk is that water outlets, such as taps, should be flushed regularly in high-risk areas. This should be at least daily with a record kept. We found that all the areas inspected were flushing the taps daily, including the less frequently used outlets. This is a significant improvement as it was previously highlighted as a requirement from the January 2019 inspection. The only exception was in one area where staff in charge of the area were unaware that they were responsible for checking the flushing had been carried out. We were assured that domestic staff in this area were flushing and could see records of this. However, the sink in the sluice was the nursing staff's responsibility and there were no effective checks to ensure this was being carried out. We raised this during our inspection. This has been reported under Standard 6 (see requirement 3).

Another key step is the correct method of cleaning clinical wash hand basins. We observed domestic staff cleaning clinical wash hand basins and discussed the cleaning process they followed. We identified that several domestic staff were cleaning the basin incorrectly. For example, moving from inside the wash bowl to the taps. There is a risk of moving any contamination from the inside of the bowl to the tap using this method. The process of cleaning clinical wash hand basins has been raised as an area for improvement with a requirement made at the January 2019 inspection. However, the improvement actions from this previous requirement had not been successfully maintained as we identified this again as an area for improvement. We raised the incorrect cleaning processes with managers who addressed this by carrying out additional staff training. We were told a quality improvement process had been implemented as a result of the previous inspection findings. We will discuss this process in more detail later in this section.

During our inspection, we observed that several areas across the hospital campus had point-of-use water filters. These are filters attached to taps and are intended to reduce the bacterial contamination from the tap water that may occur as the water passes through the tap. We were told that senior clinical staff decided to put the filters on the taps in response to a clinical incident that had happened previous to the timeframe within the scope of this inspection. All the filters we observed were within their use-by date. Estates managers could provide evidence of the replacement regime for the filters. We saw within the BICC minutes that removing these filters is being considered, but this has not been agreed.

We were provided with evidence of risk assessments for water safety, while some of these had not been carried out for several years we were informed that risk assessments would be carried out if any significant work or water system changes were made, or in line with the NHS boards water safety policy. Estate managers told us the hospital campus was undergoing a water safety risk assessment at the time of our inspection. However, due to the size of the hospital campus, this takes approximately 6 months to complete.

Within the evidence submitted by the NHS board, we saw regular NHS board water safety group meetings had taken place. These appear to have a good representation of different staff groups, including estates managers and the infection prevention and control team. However, we did note some members of this group had not been in attendance for several meetings. We highlighted this to the NHS board. We noted that estate managers had raised the issue at the new ventilation meeting, where it requested that if people cannot attend, they must send a deputy in their place. This is in line with Vale of Leven Hospital Inquiry Report (2014), recommendation 59, which states, 'Health Boards should ensure that attendance by members of committees in the infection prevention and control structure is treated as a priority. Non-attendance should only be justified by illness or leave or if there is a risk of compromise to other clinical duties, in which event deputies should attend where practicable'.

We were provided with NHS Greater Glasgow and Clyde's governance reporting system for water management for the hospital campus. There are several layers of water safety management, with the operational aspects reporting to the NHS board water safety group. This group then reports to the infection control in the built environment group, who then report to the NHS BICC. Within the BICC minutes are formal updates from the estates and facilities team, including updates on water issues and ventilation. However, we could not see a clear formal update from either group in line with the governance reporting structure provided by NHS Greater Glasgow and Clyde within the updates or reporting within the BICC minutes. Within the estates and facilities updates in the minutes we could see evidence of estates managers highlighting reported low compliance rates with some water flushing requirements. This had been raised as a concern.

We discussed this with the estates team, who explained that emails are sent to all department managers each quarter requesting that they confirm all water outlets, including the less frequently used outlets, are flushed in line with the policy. However, the response from the department managers has been low. Estate managers explained that the low response is concerning as this is the system currently in place to monitor compliance with the flushing of water outlets that are not within the remit of domestic services to flush. This is why they had highlighted and raised it at the BICC for action. We were told that although compliance rates by returning the quarterly confirmation have improved, it remains low.

At the January 2019 inspection, a requirement was made to improve the governance arrangements for the estates and infection prevention and control teams. During this inspection, we saw evidence of governance arrangements in place, including estate issues being reported that may impact infection prevention and control within the infection prevention and control governance structures. This includes water safety issues, ventilation and general estate issues. However, a new requirement to further improve the governance and reporting structure is detailed below.

This inspection has not identified any significant concerns in the hospital campus for water management or ventilation. It would not be within the scope of the inspection or expertise of the inspection team to interpret the technical documents and scale of the work required to ensure the safety systems and processes within the hospital campus. However, our wider inspection findings are that the governance and reporting of these essential systems should be strengthened to ensure an effective and co-ordinated approach to maintaining a safe hospital environment.

We observed that the condition and fabric of the buildings on the hospital campus were generally good. This is a significant improvement from previous inspections of the hospital campus. One of the improvements is the refurbishment programme that is now in place within the Institute of Neurological Sciences. This programme of work was reported at our previous inspection in March 2022.

When a repair to the environment or work is required in the clinical areas, staff in that area use an electronic reporting system. Each ward is responsible for reporting any issues in their ward and department. All the ward staff we spoke with were familiar with the reporting system and confirmed that it is routinely used to report environmental damage that needs to be repaired or replaced. This includes broken equipment, damaged surfaces, water ingress and damaged flooring. Some ward staff informed us that they were updated on the progress of their repair requests through the reporting system.

We observed the reporting system and saw mandatory fields that must be completed, such as reporting the job as an emergency, urgent or routine and then prioritising the job. For emergency repairs, we were told it is common for the ward and department staff to phone estates supervisors' directly, requesting immediate action. These requests will also be required to be entered into the electronic system. We saw that planned preventative maintenance of the environment is also recorded in this system and allows estate supervisors to monitor progress and allocate work.

Once a repair or work has been requested, the electronic system allocates a priority which determines the suggested response time. A colour-coding system is used to indicate which jobs are overdue. A supervisor will then allocate a job to a member of the estates team. For example, to a joiner, electrician or plumber. Due to difficulties in the electronic system, including an ineffective prioritisation system and lack of access to an update to ward staff once a repair has been requested, this system relies heavily on estates supervisors understanding the system, prioritising the work and following up to ensure all works are carried out.

We were told about other difficulties with the electronic system. For example, if a repair cannot be completed by the staff attending due to requiring different expertise, such as a plumber, or they need some additional equipment. In that case, the repair is often closed off in the system and must be re-entered by the staff.

Estates managers also explained that, due to the size of the hospital campus, it could be difficult to stay on top of the reported jobs. Most staff we spoke with in clinical areas were satisfied with the reporting system and that works were carried out. However, some told us they often have to follow up on job requests as it is unclear whether these are being actioned or not.

Estates managers told us how information is shared with clinical colleagues at hospital safety huddles. Staff can raise priority concerns such as infection control or health and safety issues. We were told having members of the estates team at the huddle meant that any concerns could be actioned quickly. During the safety huddles we attended, we heard discussions about the environment. We also saw evidence of regular estates, facilities and infection prevention and control safety huddles that occur several times a week. At these huddles, issues with the built environment or cleaning are highlighted, and actions are agreed upon. Overall, staff were happy with the level of service that they received from the estates department.

We were shown a quality improvement programme the facilities team have introduced for domestic services. This is a 10-step planner that has been evolving over the past 3 years. We were told it was initially put in place in response to findings from one of our previous inspections, with a desire to make improvements to deliver the best domestic cleaning and staff practice outcomes.

The 10-step planner is a system of audits of domestic cleaning and staff knowledge, in addition to the current frequency required within the NHS national cleaning specification. It combines domestic supervisor audits and enhanced audits with a supervisor. The aim is to identify domestic cleaning issues more quickly and rectify these. For example, the national guidance followed by all NHS boards requires emergency departments to be audited every 2 weeks. As part of this improvement system, the hospital campus monitors these areas weekly as they have identified them as high-use areas.

To ensure the audit scores robustness and drive for improvement, assistant managers undertake a further mechanism of verification audits to verify the supervisor audits. This means that a verification audit is carried out to assess the same area that a domestic supervisor has recently audited to ensure a standardised approach to these audits. If either audit identifies a need for rectifications, such as the need to review staffing, development needs for staff, additional cleaning or re-auditing, this is actioned. We saw evidence of this system during our inspection when we raised concerns about the cleaning method for clinical wash hand basins that were not in line with current guidance. We saw this had been discussed with domestic staff. Education sessions were provided with another layer of assurance delivered by an independent programme of audits to verify the improvement work had been successful.

This 10-step planner programme of audits is used to plan the delivery of the audits and track the areas where verification audits are undertaken. The planner also

provides oversight on the scores achieved within different areas of responsibility and locations on the hospital site. This enhanced system is committed to delivering assurance mechanisms for domestic cleaning services above the national specification. We observed that the domestic cleaning standard was good throughout the inspected areas.

Most of the patients or their representatives we spoke with described being satisfied with the cleanliness of the wards, departments, toilets and bathroom facilities. Everyone we spoke with felt they could raise a concern about cleanliness if they had any. Within several areas we visited, patients described a noticeable team approach to the cleanliness and tidiness of the environment, where nursing staff and domestic staff worked well together to keep the environment clean and tidy. Overall, the feedback from patients and their representatives was that they had confidence in the ability of staff within the hospital campus to maintain a safe and clean environment.

Areas of good practice

Standard 8	
8	The domestic service 10-step quality improvement planner was a good tool for improvement.
9	The cleanliness and condition of the hospital environment was good.

Recommendation

Standard 8	
b	NHS Greater Glasgow and Clyde should consider a review of the electronic estates reporting system, to enhance the prioritisation allocation and communication for both the estates team and staff within the clinical areas.

Requirement

Standard 8

4 NHS Greater Glasgow and Clyde must take steps to improve the governance and reporting of critical systems within the built environment. This should include but not be limited to:

- A more robust system to ensure the infection prevention and control team is informed of ventilation performance validation reports in real-time to ensure any non-compliance that may impact infection control is identified and actioned at the earliest opportunity.
- When approval is sought from committee members within the infection prevention and control governance structure, this is treated as a priority for all members with clear recorded evidence of approval or non-approval by required committee members. This will ensure clear accountability within infection prevention and control governance structures.
- Ensure attendance by members of committees in the infection prevention and control governance structure, such as the NHS board water safety group, is a priority. When attendance is not possible, a deputy should attend, as recommended by the Vale of Leven Hospital Inquiry Report.
- The governance water management structure is either fully applied or adapted to reflect the requirements of the reporting structure to ensure the NHS board are fully informed of any NHS board water safety group issues.
- Review the system currently in place for quarterly reporting of flushing of water outlets to ensure a robust and effective process.

This is to comply with the National Infection Prevention and Control Manual, the Vale of Leven Hospital Inquiry Report (2014) Recommendation 59, and Healthcare Associated Infection (HAI) Standards (2015) criterion 8.4. This will also comply with the new Infection Prevention and Control Standards (2022) Criteria 4.2 and 8.2.

Appendix 1 – List of national guidance

The following national standards, guidance and best practice were current at the time of this inspection. This list is not exhaustive.

- Winter (21/22), Respiratory Infections in Health and Care Settings Infection Prevention and Control (IPC) **(NHS National Services Scotland, April 2022)**
- National Infection Prevention and Control Manual **(NHS National Services Scotland, April 2022)**
- Information for staff on Aspergillus spp. (Health Protection Scotland 2016)
- COVID-19: Guidance for maintaining services within health and care settings Infection prevention and control recommendations **(Public Health England, April 2022)**
- Guidance for Staff and Managers on Coronavirus **(NHS Scotland, May 2022)**
- SHFN 30 Part A: Manual Information for Design Teams, Construction Teams, Estates & Facilities and Infection Prevention & Control Teams **(Health Facilities Scotland 2014)**
- SHFN 30 Part B: HAI-SCRIBE Implementation strategy and assessment process **(Health Facilities Scotland 2014)**
- Health and Social Care Standards (Scottish Government, June 2017)
- Healthcare Associated Infection (HAI) standards **(Healthcare Improvement Scotland, February 2015)**
- Health Technical Memorandum 03-01 Specialised ventilation for healthcare premises Part B: The management, operation, maintenance and routine testing of existing healthcare ventilation systems **(NHS England 2021)**
- Infection Prevention and Control Standards **(Healthcare Improvement Scotland, May 2022)**
- The Code: Professional Standards of Practice and Behaviour for Nurses and Midwives **(Nursing and Midwifery Council, October 2018)**
- Generic Medical Record Keeping Standards **(Royal College of Physicians, November 2009)**
- Allied Health Professions (AHP) Standards **(Health and Care Professionals Council Standards of Conduct, Performance and Ethics, January 2016)**
- Health and Care (Staffing) (Scotland) Act **(Acts of the Scottish Parliament, 2019)**
- Quality of Care Approach – The Quality Framework First Edition: September 2018 **(Healthcare Improvement Scotland, September 2018)**

Appendix 2 – Biography (Professor David W. Denning)

Dr David Denning is Professor of Infectious Diseases and Global Health at the University of Manchester and an infectious diseases clinician with expertise in fungal diseases.

He serves as the Chief Executive of Global Action for Fungal Infections (GAFFI). Dr Denning managed the UK's National Aspergillosis Centre, Manchester from 2009-2020. He has published extensively (>700 academic papers) and has a citation H-index of 125. He has been the managing editor of the Aspergillus website since 1998 (www.Aspergillus.org.uk).

He leads LIFE (Leading International Fungal Education (http://fungaleducation.org/), which is focused on improving patient outcomes through online education and the Aspergillus Website (www.Aspergillus.org.uk). GAFFI (www.GAFFI.org) advocates for universal access to fungal diagnostics and antifungal therapies. He is also a member of the SEARO Task Force on Antimicrobial Resistance (AMR).

He led the British Society for Medical Mycology guidelines for the diagnosis of serious fungal diseases published in Lancet Infectious Diseases in 1995. He is a longstanding member of the Infectious Disease Society of America Aspergillosis Guidelines group, the European Society for Clinical Microbiology and Infectious Diseases Aspergillosis Guidelines group and recently joined the One World Guideline for Aspergillosis.

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Health Building Note 00-09:
Infection control in the built environment

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DH INFORMATION READER BOX

Policy	Clinical	**Estates**
HR / Workforce	Commissioner Development	IM & T
Management	Provider Development	Finance
Planning / Performance	Improvement and Efficiency	Social Care / Partnership Working

Document Purpose	Best Practice Guidance
Gateway Reference	18521
Title	HBN 00-09 - Infection control in the built environment
Author	DH, Estates & facilities
Publication Date	**March 2013**
Target Audience	NHS Trust CEs, Care Trust CEs, Foundation Trust CEs , Medical Directors, Directors of PH, Directors of Nursing, Allied Health Professionals, Communications Leads, Emergency Care Leads
Circulation List	PCT Cluster CEs, SHA Cluster CEs
Description	This guidance, aimed at all providers of NHS care, discusses the various stages of a capital build project from initial concept to post-project evaluation. It highlights the major infection prevention & control (IPC) issues and risks to address at each particular stage to achieve designed-in IPC.
Cross Ref	The Health and Social Care Act 2008: Code of Practice on the prevention and control of infections and related guidance
Superseded Docs	Health Facilities Note 30 - Infection control in the built environment
Action Required	N/A
Timing	**N/A**
Contact Details	Phil Ashcroft Estates & Facilities Quarry House Quarry Hill LS2 7UE [redacted]
For Recipient's Use	

Health Building Note 00-09: Infection control in the built environment

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"… the infection prevention and control (IPC) team should be consulted throughout every stage of a capital project and their views taken into account…"

Executive summary

Preamble

Health Building Note 00-09 supersedes and replaces all versions of Health Facilities Note 30 (HFN30).

Introduction

The importance of a clean, safe environment for all aspects of healthcare should not be underestimated. It is important that healthcare buildings are designed with appropriate consultation, and the design facilitates good infection prevention and control (IPC) practices and has the quality and design of finishes and fittings that enable thorough access, cleaning and maintenance to take place. Good standards of basic hygiene, cleaning and regular planned maintenance will assist in preventing healthcare-associated infection (HCAI); only if the built environment reflects these needs are schedules more likely to be successful not only in being undertaken on a proactive and reactive basis but also in reducing contamination and risks to patients.

Research and investigation have consistently confirmed that the healthcare environment can be a reservoir for organisms with the potential for infecting patients. For HCAIs to be reduced, it is imperative that IPC measures are "designed-in" at the very outset of the planning and design stages of a healthcare facility and that input continues up to, into and beyond the final building stage.

Designed-in IPC means that designers, architects, engineers, facilities managers and planners work in collaborative partnership with IPC teams, healthcare staff and the users to deliver facilities in which IPC needs have been anticipated, planned for and met.

Health Building Note 00-09

This guidance discusses the various stages of a capital build project from initial concept through to post-project evaluation and highlights the major IPC issues and risks that need to be addressed at each particular stage to achieve designed-in IPC.

The principles of this guidance can be applied to all healthcare facilities (guidance on mental health settings is included in this revision – see Appendix 1). Although the specific recommendations or processes it outlines may not necessarily be relevant to all types of healthcare facility or organisation, they may become more applicable as certain healthcare services and functions are decentralised.

The most important points raised by the document are the need:

- for an awareness of appropriate Health Building Notes and Health Technical Memoranda pertinent to new build or refurbishment projects;
- for timely, comprehensive and collaborative partnership between all parties to achieve IPC goals specific to each construction project;
- for all stakeholders to understand the basic principles of "designed-in" IPC;
- to understand and assess the risks of infection relating to construction projects and the physical environment;
- for robust project management in relation to IPC considerations for all new-build and refurbishment projects;
- for a system of signing-off plans and meeting notes to include all participating parties including the IPC team;
- for quality control throughout the duration of the construction project;
- to regularly consult with and update all relevant parties throughout the project;
- to continually monitor developments.

Exclusions

This document does not deal with the operational management of IPC issues (for example, dealing with outbreaks on a ward) or day-to-day standard IPC precautions. These issues will be dealt with locally via the healthcare organisation's own policies and procedures on IPC.

This guidance does not apply to prison hospitals.

Important

It is essential that the IPC team are consulted throughout every stage of a capital project and their expertise taken into account.

Contents

1.0 Policy and legislation

1.1 High standards of environmental hygiene and clinical practice in healthcare facilities have been identified as being important in minimising the risk of the transmission of infection. The design, planning, construction, refurbishment and ongoing maintenance of the healthcare facility also have an important role to play in the prevention and control of infection. The physical environment has to assist, not hinder, good practice.

1.2 The Chief Medical Officer's report on infections and the rise of antimicrobial resistance (Davis, 2013) stated that the design, construction and maintenance of healthcare facilities have a substantial bearing on the risk of developing a healthcare-associated infection.

1.3 It is important that infection prevention and control (IPC) is designed-in at the planning and design stages of a new-build or refurbishment project and that input continues up to the final build stage. Designed-in IPC means that designers, architects, engineers, facilities managers and planners work in collaborative partnership with IPC teams to deliver facilities in which IPC needs have been planned for, anticipated and met.

1.4 This guidance highlights IPC issues and risks that need to be addressed at each particular stage to achieve designed-in infection control. The principles of this guidance can be applied to all healthcare facilities.

1.5 The information outlined in this document follows the general principles given in the 'The Health and Social Care Act 2008: Code of Practice on the prevention and control of infections and related guidance' (the HCAI Code of Practice). This Code of Practice sets out criteria against which a registered provider will be judged on how it complies with the registration requirement for cleanliness and infection control. Not all criteria will apply to every regulated activity.

1.6 The law states that the HCAI Code of Practice must be taken into account by the Care Quality Commission when it makes decisions about registration against the cleanliness and infection control requirement. The regulations also say that providers must have regard to the Code when deciding how they will comply with registration requirements. Therefore, by following the Code, registered providers will be able to show that they meet the requirement set out in the regulations. However, the Code is not mandatory. A registered provider may be able to demonstrate that it meets the regulations in a different way (equivalent or better) from that described in this document. The Code aims to exemplify what providers need to do in order to comply with the regulations.

2.0 Understanding the planning process

Important

The infection prevention and control (IPC) team should be consulted throughout every stage of a capital project and their views taken into account.

Introduction

2.1 For IPC teams to effectively participate in the planning process for both new-build and refurbishment projects, it is essential for them to understand the process from its inception to completion and commissioning.

2.2 It is important that the IPC team and the chief executive officer sign-off each stage of the project. This will ensure that IPC is considered throughout. An example IPC checklist that can be adapted for use during the different stages of a capital project is shown in Appendix 2.

2.3 IPC is a fundamental imperative in the planning and design stages of a healthcare facility, yet it is often overlooked or compromised throughout the lifecycle of the project. IPC teams should be involved throughout all phases of construction and renovation projects to reduce IPC risks. Failure to assess these risks properly can lead to expensive redesign later and expose the patient and healthcare worker to infection hazards.

2.4 To provide and maintain a clean and appropriate environment in premises that facilitate the prevention and control of infections, the HCAI Code of Practice states that a healthcare provider should ensure that it has:

a. made a suitable and sufficient assessment of the risks to the person receiving care with respect to IPC;

b. identified the steps that need to be taken to reduce or control those risks;

c. recorded its findings in relation to the first two points;

d. implemented the steps identified; and

e. put appropriate methods in place to monitor the risks of infection to determine whether further steps are needed to reduce or control infection.

The planning process

2.5 This section explains the planning process, which comprises the following stages (see Figure 1):

a. Preparation of a business case to support the viability of the project.

b. Project funding.

c. Concept/feasibility study.

d. Design stage.

e. Contract.

f. Project monitoring/construction.

g. Pre-handover inspections (“snagging”).

h. Commissioning the facility.

i. Post-project evaluation.

2.6 The aim is to prompt those with overall responsibility for managing capital schemes to include IPC advice at the right time in order to prevent costly mistakes.

Stages of IPC input

Preparation of a business case to support the viability of the project

2.7 The preparation of a business case is the process that supports a healthcare organisation’s submission for funding of new capital projects.

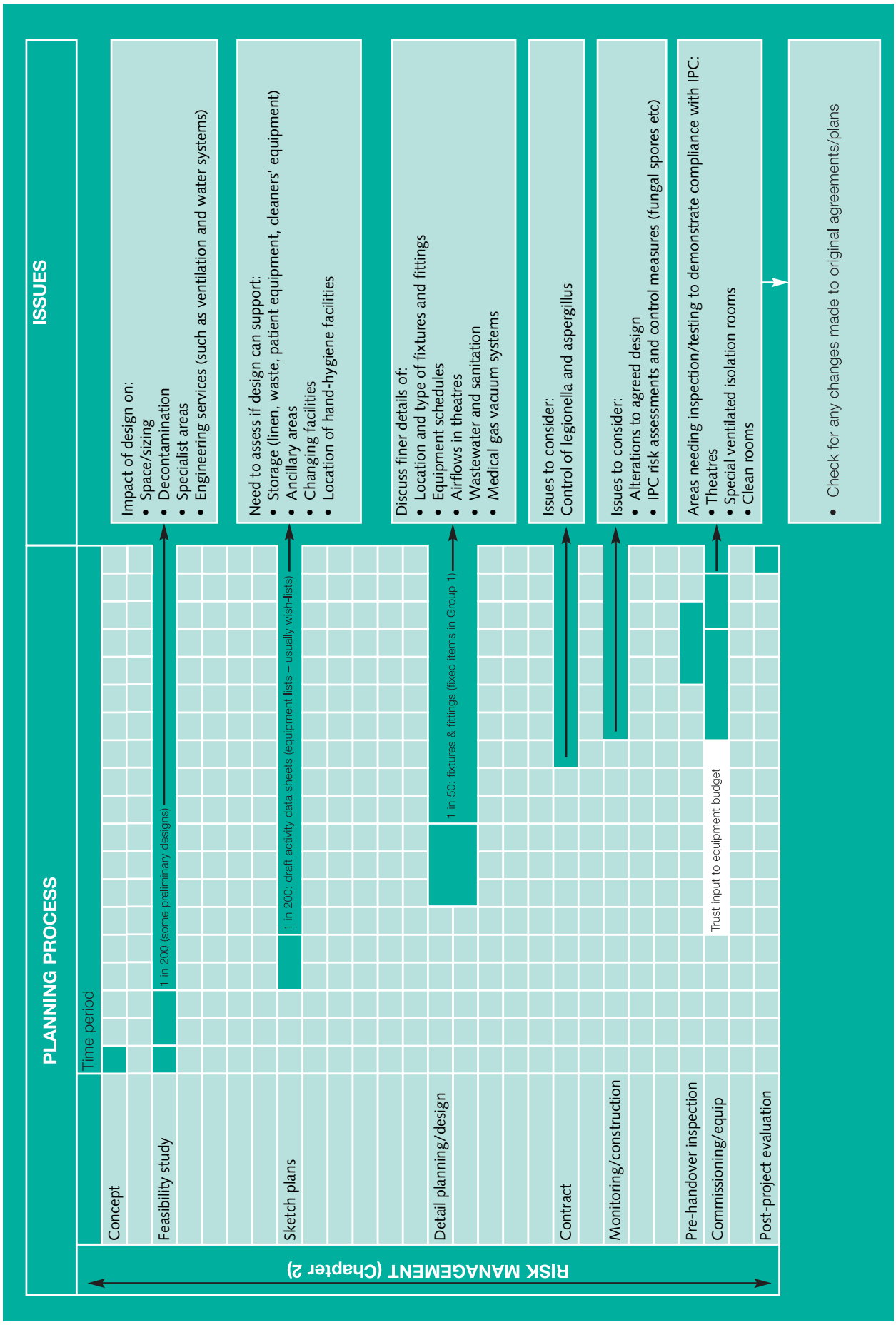

Figure 1 The planning process

2.8 A business case should convincingly demonstrate that the project is economically sound, is financially viable (affordable to the providers and purchasers) and will be well-managed. Above all, a business case for any investment should show that it will benefit patients.

2.9 The involvement and support of a wide range of managers and staff may be vital to the success of the business case, both to determine the requirement and scope of the investment and also to participate in subsequent stages of planning.

2.10 It is important therefore at this stage to identify and involve key people who have a direct interest in the end product; this will include members of the IPC team along with other leading clinicians, nursing managers and departmental heads.

2.11 Normally the input from the project team should be managed by the project director, but for larger and more complex schemes a project manager, reporting to the project director, may be appointed to conduct the detailed work and manage the business case team.

2.12 Specifically at this stage, the project team will:

- set the strategic context;
- define objectives and benefit criteria;
- generate options;
- measure the benefits;
- identify/quantify costs;
- assess sensitivity to risk;
- identify the preferred option;
- present the outline business case.

Issues to be addressed by the IPC team

2.13 Issues to be addressed by the IPC team at this stage will include:

- storage (including waste collection points and delivery areas) and equipment cleaning areas;
- flooring;
- dirty utilities;
- cleaners' rooms;
- hand-washing facilities;
- furnishings and fittings;
- appropriate finishes which permit efficient cleaning methods, equipment and safe chemicals to be used;
- types and numbers of isolation facilities;
- specific products with IPC implications and applicable regulations (for example, type of pipes, *Legionella* precautions).

2.14 Specifically at this stage, the IPC team will need to:

- agree the requirements for IPC in the design and planning of the project;
- assess the progress of the building/refurbishment project in relation to compliance with IPC specifications – any unexpected proposed deviations from the infection-control specification needs to be agreed with the IPC team at the earliest opportunity;
- ensure that the designers/planners recognise the benefits of not cutting corners on IPC issues.

Project roles and responsibilities

2.15 A comprehensive approach to planning will include consultation with the appropriate specialists from inception through to post-project evaluation.

2.16 The project organisation (see Figure 2) should comprise (relative to the size of the project):

a. Internal organisation of the healthcare provider:
   - Healthcare provider's management board (should monitor cost and progress of all capital investment projects at regular meetings. If problems are identified, it needs to be satisfied that appropriate steps are being taken).
   - Chief executive officer (given the project-specific role, title, and responsibility of project owner).

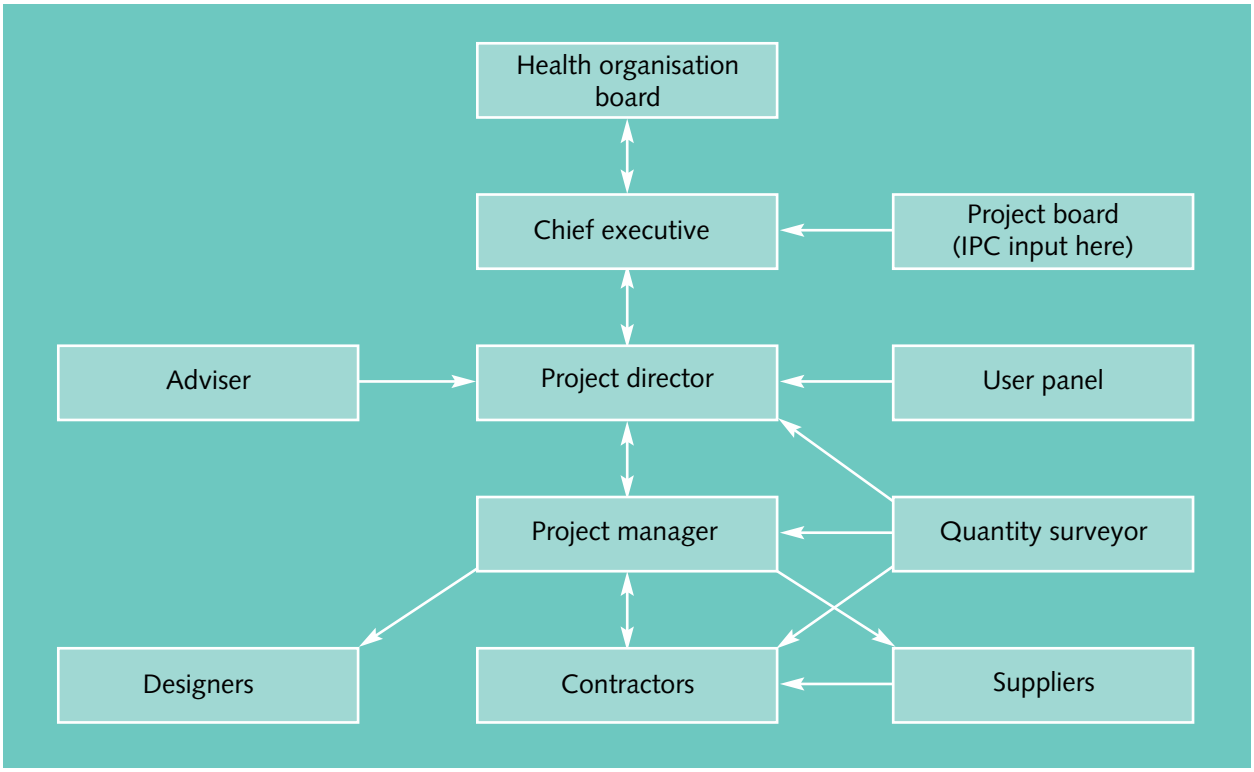

Figure 2 Project organisation

- Project board (comprising senior staff within the provider organisation who have an interest in the project and whose activities will be affected by the project, for example staff from clinical areas such as IPC).
- Project director (responsible for project management).
- Professional adviser (experienced in construction and design, especially of healthcare facilities).
- User panel (representatives of each of the relevant service departments, in each case authorised to define their department's needs and to review and agree how those needs are to be met) along with patients and carers.

b. External resources:

- Project manager.
- Other consultants.

Project funding

Capital projects funded through private finance initiatives

2.17 The contract between the purchaser and the private sector supplier is critical and it is important that the service representatives/key stakeholders and particularly in this instance the IPC team are clear about the options available and the evidence to back up any decisions they advise on.

2.18 The IPC team will need to make sure that certain criteria are embedded into the contract in such a way that important decisions on design or build do not go ahead without being signed off by them. The team will need:

- access to all relevant and up-to-date plans and information on operational policies;
- access to any meetings deemed relevant to them or timely minutes from those meetings that they cannot attend;
- access to sites and departments as building work progresses at the appropriate time in the construction programme, for example environmental rounds with checklists based on project objectives;

- regular communication between the internal project manager and the project team;
- involvement in decision-making for any category of equipment the project team will purchase;
- involvement in any contracts for support services (such as catering, cleaning, linen, or sterile services) that the project team may be providing;
- access to certain areas for any microbiological testing deemed necessary at commissioning and prior to handover, for example theatres, pharmacies and clean rooms in sterile services departments.

Concept/feasibility study

2.19 The planning process starts with the identification of a "need" by the users. The development of this need will involve feasibility studies to enable a design brief or output specification to be developed.

2.20 Where existing facilities are being modified or extended, the IPC team should review all operational policies and procedures, for example:

- the effect the number of beds or departments will have on current policy and practice such as sterile services, catering, waste disposal and cleaning;
- contracts for support services such as catering, cleaning, linen, sterile services etc that the project team may be providing;
- additional specialist areas that may require additional IPC and laboratory services (consideration should also be given to acquiring specialist advice from external agencies);
- location and relationships between departments;
- the number of surgical instruments and provision of decontamination facilities when planning extra theatres;
- impact of proposed design on ventilation and water systems;
- future maintenance requirements that minimise the potential risks to patients and allow for it to be effectively carried out.

2.21 To assist with understanding and mitigating the risks associated with bacterial contamination of water distribution and supply systems, it is recommended that organisations should develop a water safety plan (WSP), which provides a risk-management approach to the microbiological safety of water and establishes good practice in local water distribution and supply. Those organisations with existing robust water management policies for *Legionella* will already have in place much of the integral requirements for developing a WSP.

Note:

For further guidance, see:

- Health Technical Memorandum 04-01: 'The control of *Legionella*, hygiene, "safe" hot water, cold water and drinking water systems'; and
- Health Technical Memorandum 04-01: 'Addendum: *Pseudomonas aeruginosa* – advice for augmented care units'.

Design stage

2.22 The design brief or output specification should highlight the importance of design solutions for IPC.

2.23 At this stage, the IPC team will need to follow up any input they have had in the initial design brief. Sketch plans should be available to the team to explain how the design brief fulfils their requirements at the 1:200 sketch design and 1:50 scale detail design stages of the project. Suggestions for improvement in operability are important at this stage.

2.24 At the end of each part of the design stage, the project team and the IPC team will be required to sign-off the information issued and reviewed. This signifies that the design-brief requirements and changes agreed during discussions have been incorporated. Any subsequent changes made after sign-off should be made via a "change protocol", which can have significant cost and programme implications for the project.

Sketch plans (1:200 scale designs)

2.25 At this stage, 1:200 scale outline departmental layout drawings showing rooms outlined within departments will be available and discussions held with the design team. The IPC team needs to assess whether the facility is designed to support the prevention and control of infection. Examples include:

- confirming operational procedures;
- establishing baseline and future staffing profiles;
- establishing baseline and future revenue budgets;
- establishing equipment requirements;
- strategy for equipping;
- procurement and selection of furnishings and equipment;
- missing rooms/facilities;
- appropriate placing and accessibility of hand-hygiene facilities;
- single-bed rooms suitable for patient isolation and special ventilated isolation rooms;
- ventilation and air-conditioning systems including the level of filtration where specialised ventilation is required;
- water supply, heating and plumbing;
- storage for:
  - personal protective equipment (PPE)
  - movable equipment
  - clean patient items
  - clean linen
  - healthcare waste, including sharps, and used linen;
- surfaces: ceilings, walls, work surfaces, floor coverings and furnishings;
- utility rooms: dirty, clean, holding, workrooms, cleaners' rooms;
- changing rooms;
- pneumatic delivery systems.

Detail planning/design (1:50 scale designs) – early period

2.26 At this point the 1:50 scale designs indicating equipment and furniture layouts and room data sheets will be available. There may be two or more stages to the consultation process.

Detail planning/design (1:50 scale designs) – later period

2.27 The IPC team will need to discuss finer details such as location and type of fixtures and fittings (for example, type and size of wash-hand basins and airflows in theatres). Room elevations of selected typical generic rooms should also be made available.

2.28 Equipment schedules for groups 1, 2 and 3 (see next page) based on room data sheets/layouts are prepared at this stage. It is important that there is active involvement of the IPC team at this point, as it may have significant design implications. This will ensure that this equipment is compatible with IPC needs and also that proper inspection and testing can be agreed.

2.29 A final review of room layouts, equipment, fittings and room data sheets should be carried out at the end of this stage, as this is where the final sign-off by the project team and the IPC team occurs.

2.30 Any changes made during construction or after completion could have a significant adverse impact on costs and the building project.

2.31 Items available for transfer from an existing facility should also be identified, which will allow schedules for new equipment to be prepared and costs identified.

Group 1

Items that are supplied and fixed under the terms of a building/engineering contract and funded within the works cost. These are generally large items of plant/equipment that are permanently wired/installed, for example:

- specialist equipment best suited to central purchasing arrangements;
- taps, sinks and wash-hand basins.

Excluded from this group will be items subject to late selection due to considerations of technical change, for example radiodiagnostic equipment.

Group 1 items are specified at the design stage.

Group 2

Items that have implications in respect of space/construction/engineering services and are installed under the terms of building engineering contracts, but are purchased by the healthcare provider under a separate equipment budget, for example:

- paper towel dispensers;
- soap/scrub dispensers;
- cupboards;
- shelving;
- washer-disinfectors, including bedpan washer-disinfectors or macerators;
- washing machines;
- worktops.

Group 3

Items that have implications in respect of space and/or construction/engineering services and are purchased and delivered/installed directly by the healthcare provider, for example:

- small refrigerators;
- furniture;
- ventilators;
- monitors;
- trolleys.

Group 4

Items that may have storage implications but otherwise have no impact on space or engineering services, for example surgical instruments.

Contract

2.32 Tender documents sent to potential companies should include any statements the healthcare provider/project team may have about IPC that may affect any successful contractor's employees. It should also comprise IPC requirements such as the control of *Legionella* and other microorganisms (for example, aspergillus).

Project monitoring/construction

Construction

2.33 Monitoring will not normally be required by the IPC team until the works are at a stage when site visits can be arranged. At this point, the IPC team should visit the site so that that they can make a suitable ongoing assessment of the layout of the departments. This will facilitate the team to identify any differences/problems from the agreed design.

Surveillance and monitoring during renovation or construction work adjacent to an existing facility

2.34 Where patients with increased susceptibility to infection may be placed at risk, it is important that an appropriate risk assessment is carried at an early stage in advance of any building works, including disturbance/alterations to the water system/building fabric/ventilation systems (see Appendix 3).

2.35 Quality assurance of IPC interventions during building work should be based on a suitable and sufficient risk assessment of the precautions needed and frequent audit of the control measures in the risk assessment.

2.36 Since airborne fungal spores can travel significant distances, this will apply generally to all works in the immediate vicinity or within the boundary of the healthcare facility. It is strongly advised that any recommendations informed by the risk assessment should be incorporated into the building (see Appendix 3) or engineering project so as to minimise risk both during construction and in future use.

2.37 Where water systems are closed down, a *Legionella* risk assessment should be undertaken. This should include the risk bacterial overgrowth in dead-legs pose to adjacent water systems. Flushing

and hyperchlorination should also be considered when the water system is reinstated.

See Health Technical Memorandum 04-01 and Health Technical Memorandum 04-01: 'Addendum: *Pseudomonas aeruginosa* – advice for augmented care units'.

Pre-handover inspections

2.38 The IPC team should conduct periodic walk-round inspections (commonly referred to as "snagging" visits) during the construction works and also at the completion of the construction works prior to formal handover. They should raise any concerns and outstanding items with the project manager responsible for the capital scheme, with issues that constitute a high risk being appropriately prioritised. The project manager should then address these issues with the contractor and ensure the necessary works are completed prior to formal handover of the construction project.

Commissioning the facility

2.39 Upon completion of construction, the facility should be brought into use; depending on the complexity of the task involved, a commissioning manager and team may be needed. Senior managers, specialist teams and users should be fully involved in the process.

2.40 Technical commissioning of the building, services and equipment should include any areas that require inspection and testing to demonstrate compliance with IPC standards (for example, theatres, hydrotherapy pools, special ventilated isolation rooms/suites and clean rooms in pharmacies and sterile services departments). Sufficient time should be built into the commissioning schedule to enable this and any rectification of identified problems.

2.41 The commissioning team should establish smaller working groups that:

- identify policy issues for referral to the commissioning team or the construction project team;
- identify staff training and orientation needs;
- establish the occupation programme for that user function, for inclusion into the overall commissioning master plan.

2.42 By understanding the commissioning process, the IPC team should ensure that they are fully consulted and engaged in any working groups in which their expertise will have an impact or in which requirements to modify services may have repercussions on other aspects of IPC.

2.43 The IPC team should also be involved in processes for:

- analysis of commissioning data;
- transfer of facilities;
- phased or staged occupation;
- storage and subsequent cleaning/disinfection of any furniture or equipment;
- approval of engineering commissioning data for operating theatres;
- commissioning tests (for example, microbiological air-sampling for operating theatres, water testing);
- approval of engineering commissioning data for special ventilated isolation room(s);
- site visits;
- staff orientation and training;
- post-handover period;
- decommissioning of redundant facilities;
- period of handover to operational management;
- confirming communication of procedures with internal and external agencies/users (for example, ambulance service and patient information leaflets).

Post-project evaluation

2.44 The purpose of the post-project evaluation is to improve project appraisal, design, management and implementation. It typically takes place 12 months post-handover and is a learning process that should not be seen as a means of allocating blame. There are three stages:

a. project appraisal;
b. monitoring and evaluation of project;
c. review of project operations.

2.45 It is at the third stage when it is useful for the IPC team to be included in the evaluation teams that are reviewing project objectives. The outcomes (activity and its consequences) of the project will not be amenable to evaluation until the facility has been in use for sometime. However, if the project is part of a phased refurbishment or new build, valuable lessons can be learned and implemented during ongoing project work.

2.46 It is important that the project is evaluated in terms of its original objectives, not in the light of any new legislation or development. Performance indicators may be used if these can be measured retrospectively. Measurable objectives may include:

- activity data;
- patient satisfaction surveys etc;
- compliance with *Legionella* risk assessments.

3.0 Designing a healthcare facility: issues to consider

Examples of design principles

Design to facilitate cleanliness & cleaning
• Use finishes that are impervious, smooth and seamless, as far as practicable. • Run hard flooring up the walls for a short distance to provide an easy-to-clean coving. • Eliminate or minimise dead-legs and blind ends in water systems, both in the original design and as the systems are modified. • Consider hands-free operation of utilities (for example, sensor taps, automatic lights, movement sensors for toilet flushes etc). • Consider hands-free operation of other facilities (for example, automatic doors, proximity-sensors etc). • Consider integral blinds as an alternative to curtains at internal windows.
Encourage desired behaviour (for example, tidiness, hand hygiene)
• Provide sufficient space for activities to take place and to avoid cross-contamination between adjacent bed spaces. • Provide sufficient storage for patients' possessions and for all supplies to discourage clutter. • Ensure proper segregation and management of waste, including clinical waste and linen. • Provide sufficient domestic waste receptacles. • Provide bedside waste disposal facilities for patient use. • Design-out unnecessary horizontal surfaces (for example, window sills) in order to discourage clutter. • Provide enough wash-hand basins and antimicrobial hand-rub dispensers. • Plan for and deliver good separation of clean and dirty activities. • Provide sufficient space for storage and preparation of cleaning equipment and materials. • Provide suitable facilities for cleaning of equipment.
Design for easy cleaning
• It is always best practice to maintain a visibly clean environment that is free from dust and soilage, and acceptable to patients, their visitors and staff. • Good design can make cleaning immeasurably easier, for example: – Use finishes that are easy to clean. – In clinical areas, flooring should be seamless and smooth, slip-resistant, easily cleaned and appropriately wear-resistant. – Use threshold matting on all external entrances. The type should allow for expected through traffic and easy cleaning. – Supply pipework should always be concealed. • There may be pressure to choose the cheapest products/design. Attention to whole-life costs, including the costs of cleaning and maintenance, is important. Consult with the IPC team before purchase/on planning.

Important

The IPC team should be consulted throughout a building or renovation project and their advice and recommendations taken account of and documented.

3.1 The recommendations in this section should be applied to the planning, design and maintenance of all healthcare buildings – both new build and refurbishments. They offer a planning checklist that can be used throughout the design and planning process. Not all items will need to be included in every project, but using the checklist will ensure areas with IPC implications are not missed. Timing will vary from project to project but refer to Chapter 2 for the sequence of the project process.

3.2 The IPC team should have an integral role in ensuring other members of the project team are appropriately informed of any prevention and control-of-infection issues that may arise when:

- an initial site is being considered for development;
- the healthcare facility is being designed;
- the healthcare facility is being constructed or undergoing refurbishment;
- the healthcare facility is operational.

3.3 The participation of the IPC team in all phases of planning and construction and renovation is essential.

3.4 For the purposes of this document, the following terminology is used:

a. Multi-bed room – this is a room that contains more than one bed. It is best practice for multi-bed rooms to have both en-suite WC/shower and doors to the main ward area.

b. Single-bed room – this is a room with space for one patient and usually contains as a minimum: a bed; locker/wardrobe; and clinical wash-hand basin plus a small cupboard with worktop. (Note: single-bed rooms without en-suite sanitary facilities are not recommended.)

c. En-suite single-bed room – as (b) but with en-suite shower, WC and wash-hand basin.

d. Special ventilated isolation room – this is as (c) but with a ventilation system that prevents uncontrolled escape of infectious aerosols from the room to adjacent areas. It can also provide a degree of dilution of infectious aerosols in the room for the safety of staff and visitors. The room should have extract ventilation that exceeds its supply, such that gaps in its fabric leak inwards not outwards.

e. Special ventilated isolation suite – as (d) but with a lobby.

f. Isolation facilities – an umbrella term used in this document for room types (b)–(e).

For design guidance on critical care areas, see Health Building Note 04-02 – 'Critical care areas'.

For guidance on mental health units, see Appendix 1.

Sizing/space

3.5 The provision of sufficient space in clinical areas, particularly for each bed space, is one of the most important considerations in the planning and design of in-patient accommodation. A risk-based approach should be taken to ensure that the environment is appropriate for carrying out clinical activities and undertaking manual handling operations while maintaining a good standard of infection control.

3.6 Spacing should take into account the amount of, and easy access to, equipment around the bed area and access for staff to clinical wash-hand basins. The principle should be to maintain sufficient space for activities to take place and to avoid cross-contamination between adjacent bed spaces. The exact space needed will vary according to numbers

and activity of staff and type of patient (see 'Recommendations' after paragraph 3.12).

3.7 Mode of transmission of infection should also be taken into account. This includes:

- direct transmission;
- indirect transmission via fomites (for example, articles such as hoists, mobile X-ray units etc); and
- splash, droplet and airborne transmission.

3.8 The route of spread of infection is a basic concept in preventing cross-infection, and spacing has direct implications for the prevention of infection.

Patient groups

3.9 Floor/bed space is influenced by the type of healthcare facility and the type of patient care. There are four distinct patient groups:

- patients requiring acute care, which includes trauma, multi-organ failure, medical emergencies, planned major surgery and other life-threatening emergencies plus obstetric and neonatal care;
- patients with chronic conditions or sub-acute conditions;
- patients using mental health or learning disability in-patient services (note: this guidance does not apply to domiciliary care services that provide support in people's own homes);
- patients requiring ambulatory care, which includes diagnostic services, day surgery, minor injuries and attendance at primary care facilities and walk-in centres.

3.10 The first three patient groups will require in-patient care. The volume of care and the degree of intervention, diagnostic equipment and movement of staff around the patient dictates the bed space needed.

Privacy and dignity: same-sex accommodation

3.11 The need to deliver the highest standards of privacy and dignity applies equally to all areas of a healthcare facility. Achieving these high standards will usually mean ensuring that men and women do not have to sleep in the same room or share toilet and washing facilities. Patients should not have to pass through areas used by the opposite sex to reach their own facilities.

3.12 Same-sex accommodation can be provided in:

- same-sex wards, where the whole ward is occupied by men or women only;
- single rooms;
- mixed wards, where men and women are in separate bays or rooms.

Recommendations

- The provision of sufficient space in clinical areas, particularly for each bed space, is one of the most important considerations in the planning and design of in-patient accommodation. A risk-based approach should be taken to ensure that the environment is appropriate for carrying out clinical activities and undertaking manual handling operations while maintaining a good standard of infection control. Health Building Note 04-01 – 'Adult in-patient accommodation' states:

  "Ergonomic studies have established that most activities carried out at the bedside can be accommodated within the dimensions 3600 mm (width) × 3700 mm (depth). This represents the clear bed space and does not include space for fixed storage, preparation and worktops."

- For IPC reasons, it is imperative that staff are able to attend to one patient without impinging on the bed space or equipment of a neighbouring patient. In the majority of cases, the dimensions in Health Building Note 04-01 should be adequate (although bed spaces for critical care areas need to be greater for reasons of circulation space and the equipment used in these areas).
- It is also important that the physical environment complies with disability access requirements and does not compromise the privacy and dignity of patients.
- Spacing should take into account the amount of and easy access to equipment around the bed area and access for staff to clinical wash-hand basins.

Isolation facilities

See paragraph 3.4 for definitions.

The role of isolation facilities in preventing cross-infection

3.13 The primary aim of IPC is to prevent the spread of infection between patients, visitors and staff by control or containment of potentially pathogenic organisms. Many of these organisms can be controlled by basic IPC practices such as hand hygiene and environmental cleanliness, and this can be facilitated by single-bed room isolation. A small proportion of patients requiring isolation will require special ventilated isolation facilities.

3.14 The key to effective isolation on general wards is the provision of sufficient en-suite single-bed rooms to prevent patients known to be a risk for spreading infections being cared for in open ward areas. Single rooms reduce the risk of cross-infection for non-airborne diseases. Most patients needing segregation/isolation on general wards can be isolated effectively in en-suite single rooms.

3.15 A risk assessment should be used to inform decisions regarding which patients to nurse in single-bed rooms. Healthcare providers should audit the use of en-suite single-bed rooms to determine where further local requirements and adaptations are greatest.

3.16 Multi-bed rooms can also be used to cohort infectious patients if they have an en-suite WC and shower, and a door to the main ward area. The possible need for this should be considered at the design stage.

3.17 Clinical wash-hand basins should be provided in addition to the general wash-hand basin provided for patients.

3.18 Storage of, and ready access to, clean PPE is important to encourage its use plus appropriate waste receptacles for its disposal once worn.

3.19 Gloves and aprons should be sited outside single-bed rooms, ideally in lobbies.

3.20 Additional storage facilities will be required for the care and treatment of patients in isolation facilities, especially if the isolation is likely to last for some time:

- the storage of supplies retained in the room (for example, PPE);
- personal clothing and possessions (see also Appendix 1 on mental health settings).

3.21 In accident & emergency departments, a dedicated room should be provided for patients with a known or suspected infectious disease. If airborne isolation is required, this room should be at negative pressure to the corridor; a lobby is not required. This room should also be suitable for general use when not required for isolation (see Health Building Note 15-01 – 'Accident & emergency departments').

Note:

It may be necessary to cohort-nurse a group of infectious patients in a multi-bed room if insufficient single-bed rooms are available. This can be more easily achieved where wards are divided into two- or four-bedded rooms with en-suite sanitary facilities, which can be isolated further by closure of doors to the areas. When IPC guidelines are adhered to, research has demonstrated that cohort-nursing can successfully control and contain infection in hospital facilities.

Design

3.22 Health Building Note 04-01 provides guidance on en-suite single rooms.

3.23 Health Building Note 04-01, Supplement A – 'Isolation facilities for infectious patients in acute settings' provides guidance on the facilities required for isolating infectious patients on acute general wards (source isolation). It also provides guidance on the ventilation parameters for a special ventilated isolation room/suite.

Ceilings

3.24 Removable ceiling tiles are not advised for special ventilated isolation rooms/suites.

Doors

3.25 Doors are critical to the design of a special ventilated isolation room/suite. For specific guidance on source isolation, refer to Health Building Note 04-01, Supplement A.

Lobbies

3.26 Lobbies facilitate staff compliance with hand-washing and use of PPE. They may also be essential with some types of special ventilated isolation rooms.

Engineering requirements for special ventilated isolation rooms/suites

3.27 Planned maintenance and revalidation – maintenance and revalidation programmes should be established for special ventilated isolation rooms to ensure the design criteria are maintained and met at all times. Although it is impossible to give specific maintenance frequencies, each unit should be included in a planned preventative maintenance that includes pressure/air flow monitoring equipment.

Recommendations

- Single-bed rooms with en-suite sanitary facilities are optimum for infection prevention.
- There should be sufficient en-suite single-bed rooms to prevent patients known to be a risk for spreading infections being cared for in open ward areas. Healthcare providers should audit the use of en-suite single-bed rooms to determine where further local requirements and adaptations are greatest.
- The provision of additional isolation facilities should be considered when designing new healthcare buildings and renovating existing buildings.

Hand-hygiene facilities

Note:

This section should be read in conjunction with paragraphs 3.178–3.190 on safe hot and cold water systems.

3.28 Compliance with hand-hygiene guidelines can be improved by conveniently placed and well-designed hand-hygiene facilities. The importance of facilities to encourage and facilitate good hand-hygiene practices should be high on the list of priorities when designing and planning new healthcare premises or refurbishment of existing premises is being undertaken.

Wash-hand basin design

See also Health Building Note 00-10 Part C – 'Sanitary assemblies' and Health Building Note 00-02 – 'Sanitary spaces'.

Clinical wash-hand basins

3.29 The dimensions of a clinical wash-hand basin should be large enough to contain most splashes and therefore enable the correct hand-wash technique to be performed without excessive splashing of the user. This can also occur if the water outlet is placed too high above the basin.

3.30 Clinical wash-hand basins should be wall-mounted using concealed brackets and fixings. They should also be sealed to a waterproof splash-back to allow effective cleaning of all surfaces.

3.31 They should not have a plug or a recess capable of taking a plug. A plug allows the basin to be used to soak and reprocess equipment that should not be reprocessed in such an uncontrolled way.

3.32 Clinical wash-hand basins should not have overflows, as these are difficult to clean and become contaminated.

3.33 Taps should not be aligned to run directly into the drain aperture, as contamination from the waste outlet could be mobilised (see Health Building Note 00-10 Part C).

3.34 Healthcare providers should have policies in place ensuring that clinical wash-hand basins are not used for other purposes such as emptying of patient bathing water, as this may transfer strains to the water supply system where they can colonise existing biofilms.

See also Appendix 1 on mental health settings.

General wash-hand basins

3.35 All en-suite facilities should have a wash-hand basin for use by patients and their visitors.

3.36 All toilet facilities should have a wash-hand basin.

3.37 Overflows should not be provided as these are difficult to clean and become contaminated.

3.38 Taps should not be aligned to run directly into the drain aperture.

3.39 All general wash-hand basins should be sealed to a waterproof splash-back.

See also Appendix 1 on mental health settings.

Clinical wash-hand basin provision

3.40 All clinical wash-hand basins should be accessible and should not be situated behind curtain rails. Inconveniently located or insufficient clinical wash-hand basins are two of the main reasons that healthcare staff do not comply with hand-hygiene protocols. There is a need to review the numbers and placement of clinical wash-hand basins as well as their dimensions (see Health Building Note 00-10 Part C; Health Building Note 00-02; and Health Technical Memorandum 04-01 – 'Addendum: *Pseudomonas aeruginosa* – advice for augmented care units').

3.41 Hand-hygiene facilities should be readily available in all clinical areas. There should be sufficient numbers and appropriate sizes of clinical wash-hand basins to encourage and assist staff to readily conform to hand-hygiene protocols.

3.42 The location and provision of clinical wash-hand basins should ensure that they are all readily available and convenient for use. Having a clinical wash-hand basin easily available at all times is more important than compliance to a precise bed-to-basin ratio. For example, in a multi-bed room, if two clinical wash-hand basins are placed side-by-side, both on the same side of the entrance, only the one closest to the entrance will get significant use – the other will form a dead-leg in the water distribution system. While it may be marginally more complex in terms of plumbing, there should be one clinical wash-hand basin on each side of the entrance or at opposite sides of the room.

3.43 Guidelines for the appropriate numbers of clinical wash-hand basins in clinical areas are given in Health Building Note 04-01 and Health Building Note 11-01 – 'Facilities for primary and community care services'. To encourage good practice and to give reasonable access, it is recommended that:

- A minimum of one clinical wash-hand basin in each single-bed room is required. En-suite single-bed rooms should have a general wash-hand basin for personal hygiene in the en-suite facility in addition to the clinical wash-hand basin in the patient's bedroom.
- In intensive care and high dependency units (critical care areas), a clinical wash-hand basin should be available by each bed space. It should be noted, however, that under-usage of basins encourages colonisation with *Legionella* and other microorganisms. Designers should be aware of this and, accordingly, should balance ease of staff hand-washing with the avoidance of under-used wash-hand basins (see also Health Technical Memorandum 04-01 – 'Addendum: *Pseudomonas aeruginosa* – advice for augmented care units').
- Two clinical wash-hand basins in multi-bed rooms (note that there should be no more than four beds in a multi-bed room in line with Health Building Note 04-01).

For guidance on mental health settings, see Appendix 1.

3.44 In primary care and out-patient settings, where clinical procedures or examination of patients/clients is undertaken, a clinical wash-hand basin should be close to where the procedure is carried out (see Health Building Note 00-03 –'Clinical, clinical support and specialist spaces').

3.45 Health Building Note 00-10 Part C also gives details of sanitary assemblies for other areas such as kitchens and patient wash areas.

Water/taps

3.46 Health and safety regulations (The Workplace (Health, Safety and Welfare) Regulations, 1992) require that both hot and cold running water should be available in areas where employees are expected to wash their hands.

3.47 Hands should always be washed under running water; mixer taps allow this to be practised in safety in healthcare settings where hot water temperatures may be high to control *Legionella* (see Health Technical Memorandum 04-01).

3.48 Taps can be lever- or sensor-operated and should be easy to turn on and off without contaminating the hands.

3.49 Taps discharging directly into a drain hole can cause splashing, which could disperse contaminated droplets. The tap outlet flow should not discharge directly into the waste aperture.

3.50 Non-TMV taps (commonly used in kitchens and on sinks in cleaners' rooms/dirty utilities) allow the user free rein to determine the temperature of the water delivered at the point of use; however, a risk assessment should be undertaken first.

3.51 Swan-neck tap outlets are not recommended, as they do not empty after use. Similarly, strainers, aerators and flow restrictors should not be used as they become colonised with bacteria.

Taps in augmented care settings

3.52 For the augmented care setting, the choice and type of water outlets is important and should be based on a risk assessment of infection-control and scalding issues. There is some evidence that the more complex the design of the outlet assembly (for example, some sensor-operated taps), the more prone to *P. aeruginosa* colonisation the outlet may be (see Berthelot et al. 2006).

3.53 In intensive care and other critical care areas, where patients are unlikely to be able to use the wash-hand basins, the installation of non-TMV mixing taps may be the preferred control option following a risk assessment (see Health Technical Memorandum 04-01 'Addendum – *Pseudomonas aeruginosa*: advice for augmented care units').

Soap dispensers

3.54 Liquid soap dispensers should be wall-mounted at all wash-hand basins and be designed to be operated without contamination from the user's hands coming into direct contact with the dispensing mechanism.

3.55 Dispensers should not be refillable but be of a disposable single-cartridge design (see also Appendix 1 for guidance on mental health units).

3.56 Antimicrobial hand-rub dispensers should be available at the point of patient care, subject to local risk assessment. Users and IPC teams should liaise and advise on the position of these units in clinical areas.

Hand drying

3.57 Paper hand-towel dispensers should be conveniently placed by all wash-hand basins (clinical and non-clinical).

3.58 The use of paper towels in rolls should be discouraged; they are difficult to tear off without contaminating the remaining roll.

3.59 Fabric towels are a source of cross-contamination and are not recommended in clinical areas.

3.60 Hot-air hand dryers reduce paper waste and may be considered for use in public areas of healthcare facilities, but should not be installed in clinical areas as they are noisy and could disturb patients.

3.61 Hands-free waste bins, with appropriate colour-coded waste bags, should be provided by each wash-hand basin.

Sinks and disposal facilities

3.62 Using sinks for both hand-washing and the cleaning of equipment should be discouraged as this will significantly increase the risk of hand and environmental contamination. Dirty utility rooms should contain a:

- sluice for disposing of body fluids and patients' wash-water;
- separate sink for cleaning equipment;
- clinical wash-hand basin.

3.63 Contaminated fluids such as patients' wash-water should not be emptied down clinical wash-hand basins in adjacent ward areas.

3.64 Disposal facilities should be provided in areas where dirty wastewater is disposed (for example, dirty utility rooms and cleaners' rooms/areas for cleaning equipment). See Health Building Note 00-10 Part C – 'Sanitary assemblies' for further guidance.

Recommendations

- In each single-bed room, a minimum of one clinical wash-hand basin should be available. En-suite single-bed rooms should have a separate general wash-hand basin for patients and visitors in the en-suite facility.
- In critical care areas, one clinical wash-hand basin should be available by each bed space.
- In multi-bed rooms, two clinical wash-hand basins should be provided.
- In primary care and out-patient settings, where clinical procedures or examination of patients/clients is undertaken, a clinical wash-hand basin should be close to where the procedure is carried out.
- All clinical wash-hand basins should be accessible and should not be situated behind curtain rails.
- All en-suite facilities should have a wash-hand basin for use by patients and their visitors.
- Clinical wash-hand basins should not have an overflow or be capable of taking a plug.
- All wash-hand basins should be sealed to a waterproof splash-back.
- Wall-mounted liquid soap and paper-towel dispensers should be available at each wash-hand basin.
- Antimicrobial hand-rub dispensers should be available at the point of patient care.
- Space should be allowed at the design stage for the placement of hands-free waste bins next to each wash-hand basin.
- Hands-free operated taps are recommended for clinical wash-hand basins.
- Taps should not be aligned to discharge directly into the waste aperture.
- The alignment of tap and basin should be such that staff can wash their hands without excessive splashing to their bodies.
- For decontamination, two sinks will be needed – one for decontamination/washing and one for rinsing, plus a clinical wash-hand basin for staff use.

For guidance on mental health units, see Appendix 1.

Ancillary areas

3.65 It is important that ancillary areas are of an acceptable standard to support effective infection prevention. Clean and dirty areas should be kept separate and the workflow patterns of each area should be clearly defined.

3.66 The design and finish of ancillary areas should facilitate good cleaning. These areas should have facilities for hand-hygiene and sufficient storage for supplies and equipment.

3.67 IPC issues are determined on:

- the use of the ancillary area;
- who will have access; and
- what type of activity will be carried out there.

3.68 Ancillary areas include:

- dirty utility;
- clean utility;
- clean linen store;
- decontamination room;
- disposal room;
- day room/patient waiting areas;
- play areas;
- nappy-changing area;
- visitors' toilets;
- personal laundries in mental health and learning disability settings (but not domiciliary care settings);
- treatment room.

Dirty utility room

3.69 A dirty utility room should include facilities for:

- cleaning items of equipment;
- testing urine;
- the disposal of body fluids including water contaminated with body fluids, exudate etc;

- the decontamination of commodes;
- temporarily holding items requiring reprocessing;
- clinical washing of hands after activity in the dirty utility room.

3.70 Space and facilities for the holding, reprocessing or disposing of bedpans, urinals and vomit bowls are required. Unused bedpans and linen-bag carriers can also be stored in this area. Apron and glove dispensers should be provided for ease of access to PPE.

3.71 Where commodes are to be used, there should be sufficient space allowed for their decontamination and storage.

3.72 A clinical wash-hand basin is necessary plus a slop-hopper for disposal of body fluids and a separate sink for decontaminating equipment.

3.73 There needs to be a clear demarcation between clean/unused equipment and soiled/dirty equipment. Clean and dirty areas should be kept separate and the workflow patterns of each area should be clearly defined.

Clean utility room

3.74 A clean utility room is required where drugs and lotions may be stored and prepared, a supply of clean and sterile supplies may be held and dressing trolleys prepared. Clinical hand-hygiene facilities are required.

3.75 The room should be located adjacent to the treatment area.

3.76 It is important that planners/design teams think about the type of storage facilities provided. There should be enough storage area for sterile supplies equipment and other clean supplies to keep supplies off the floor with sufficient space under the lowest shelf to permit cleaning the floor underneath.

3.77 It is important that sufficient worktop area is provided to enable aseptic preparation to be carried out (for example, preparation of intravenous infusion).

3.78 Storage facilities should be able to be cleaned easily and quickly while protecting clean stores and equipment from dust and contamination.

Clean linen store

3.79 Clinical areas should have designated areas for the storage of clean linen to maintain the cleanliness of the linen and allow easy access. Storage should be on slatted shelving or racking and be off the floor, with sufficient space under the lowest shelf to permit cleaning the floor underneath.

Treatment room

3.80 A treatment room may be required for in-patient examination or investigations. In primary care settings, it will require different design features according to its planned use, for example immunisation or wound dressing (see Health Building Note 11-01).

3.81 A clinical wash-hand basin should be provided (see Health Building Note 00-03).

3.82 Carpets should not be used as this area has a high probability of body fluid contamination.

3.83 Space should be available to allow for the storage of equipment and sterile supplies.

Equipment decontamination room

3.84 Local decontamination (that is, the decontamination of reusable medical devices undertaken at the point of use) is associated with large items of equipment that are not amenable to steam sterilization such as infant incubators in neonatal intensive care units. This room should facilitate a defined dirty-to-clean flow throughout the decontamination process and have sufficient work surfaces and sinks to allow effective reprocessing.

Disposal room

3.85 The disposal room is for temporary storage of supplies and equipment that have to be removed for cleaning, reprocessing or disposal (for example, used linen, items to be returned to the sterile services department (SSD), waste bags and sharps bins).

3.86 The sizing of disposal rooms should be considered at the design stage, taking into account the predicted levels and types of waste to be generated and the planned operational policies relating to frequency of waste and linen collection.

3.87 This area should be secure and not accessible to the public.

Cleaners' room

3.88 This room is used to deliver day-to-day cleaning services for a defined area. Cleaning materials and equipment in daily use should be stored in this room.

3.89 The room should be provided with a sink and slop-hopper or janitorial unit as well as a wash-hand basin. There should be unrestricted access to the sink and slop-hopper/janitorial unit (see Health Building Note 00-10 Part C for more information on these sanitary assemblies).

3.90 Space should be provided for mops, buckets, a vacuum cleaner, scrubbing/polishing machine (for hard floors) and other appropriate cleaning equipment.

Day room/patient waiting areas

3.91 There is often conflict between the aesthetics of these areas and the prevention of contamination of the environment or furnishings and ease of cleaning/disinfection. This is especially the case in waiting areas such as in accident & emergency departments, primary care and minor injury units.

3.92 It is important that where blood and body-fluid spillages may occur, the environment should be able to be cleaned effectively. Carpets should not be used in areas where body-fluid spillage is anticipated.

Play area

3.93 All equipment, finishes and furnishings should be fluid-resistant and be able to withstand cleaning and disinfection. This is particularly important for play mats and soft floor coverings.

Nappy-changing area

3.94 Facilities for the disposal of soiled nappies and for hand-washing in the immediate environment are required along with a regular cleaning programme of equipment used.

3.95 The area used for nappy-changing should have a surface that can be easily cleaned and disinfected.

Visitors' toilets

3.96 Visitors' toilets are heavily used and should provide enough space and have a high grade of finishes to maintain a high standard of cleanliness.

3.97 There should be provision of disposal facilities for sanitary waste in women's, accessible and unisex toilets.

3.98 The number of toilets, wash-hand basins and hand-drying facilities provided should be sufficient for the size of the facility (see Health Building Note 00-02).

3.99 Hand-drying should be by single-use paper hand towels or hot-air hand dryers. If a facility is in, or closely adjacent to, areas where patients may be sleeping, hot-air hand dryers should be avoided due to the noise they create.

Recommendations

- Clean and dirty areas should be kept separate and the workflow patterns of each area should be clearly defined.
- The design and finish of ancillary areas should facilitate good cleaning. They should have facilities for hand-hygiene and sufficient storage for supplies and equipment.

Storage

3.100 Storage areas need to be appropriate for the operational requirements of each clinical area.

3.101 The need for sufficient secure storage should not be underestimated. Many plans start with sufficient storage, but this space is often lost to other areas during the design process. This can have implications for both clinical practice and infection control.

3.102 Storage away from areas of clinical activity is required for both small and bulky items of equipment to minimise clutter, enabling efficient environmental cleaning.

3.103 All healthcare premises need a storage area for large pieces of equipment such as beds, mattresses, hoists, wheelchairs and trolleys that are not currently in use. The use of equipment libraries can be an effective way of storing, maintaining and decontaminating large or electrical equipment.

3.104 Cleaning equipment, laundry and clinical waste need to be stored in separate purpose-built areas to prevent cross-contamination.

3.105 Sufficient and appropriate storage will protect equipment from damage, contamination and dust (which may potentially carry microorganisms), but should also allow free access to floors and shelves for cleaning.

Storage for patients' possessions

3.106 Adequate space should be allocated for the storage of patients' possessions. Wardrobes and lockers used for storage of patients' possessions should be selected to be easily and efficiently cleaned. Louvre doors should not be fitted, as they are difficult to keep clean.

3.107 In mental health settings, risk assessment should inform the choice of furniture (see Appendix 1).

Recommendations

- Wardrobes and lockers used for storage of patients' possessions should be selected to be easily and efficiently cleaned.
- Cleaning equipment, laundry and clinical waste need to be stored in separate purpose-built areas to prevent cross-contamination.
- All healthcare premises need a storage area for large pieces of equipment such as beds, mattresses, hoists, wheelchairs and trolleys that are not currently in use.
- Sufficient and appropriate storage will protect equipment from damage, contamination and dust (which may potentially carry microorganisms), but should also allow free access to floors and shelves for cleaning.

Interior finishes/fixtures and fittings

Note:

Although a range of antimicrobial-impregnated products (such as surface coatings, paints and curtains) is available, there are, at present, no definitive data to support their efficacy in reducing HCAIs.

3.108 The quality of finishes in all clinical areas should be readily cleaned and resilient. It is important that the healthcare environment is aesthetically pleasing but takes into account the clinical nature of the intended purpose suited to its function.

Flooring

For guidance on flooring in healthcare facilities, see Health Building Note 00-10 Part A – 'Flooring'.

For guidance on flooring in mental health settings, see Appendix 1.

Flooring in clinical areas

3.109 Flooring should be seamless and smooth, slip-resistant, easily cleaned and appropriately wear-resistant.

3.110 There should be coving between the floor and the wall to prevent accumulation of dust and dirt in corners and crevices.

3.111 Any joints should be welded or sealed to prevent accumulation of dirt and damage due to water ingress.

3.112 Wood and flooring with unsealed joints are difficult to keep clean and should be avoided.

3.113 In areas where frequent wet cleaning methods are employed (for example, clinical areas and theatres), floors should be of a material that is unaffected by the agents likely to be used.

3.114 Floors that are particularly subject to traffic when wet (bathrooms, kitchens) should have a slip-resistant surface, but be easily cleaned.

Carpets

3.115 Carpets should not be used in clinical areas. This includes all areas where frequent spillage is anticipated. Spillage can occur in all clinical areas, corridors and entrances. Aesthetic considerations and noise reduction are most often cited as the reason for using carpets; yet in areas of frequent spillage or heavy traffic, they can quickly become unsightly. Smell and staining have been responsible for the removal of carpets in many clinical areas (see Appendix 1 for flooring in mental health settings).

3.116 If carpets are to be considered for non-clinical areas (for example, interview rooms, counselling suites, consulting rooms), it is essential that a

documented local risk assessment is carried out with IPC involvement and a clearly defined pre-planned preventative maintenance and cleaning programme is put in place.

3.117 Where the care environment is also a person's home, such as a residential setting for people with a learning disability, carpets may be acceptable. The use of carpets may be appropriate in such facilities but the need for frequent cleaning should be considered in the design stage, both in the choice of carpet and its continued maintenance.

3.118 Facilities should also be available for the prompt and effective removal of any spillage.

Walls

3.119 Smooth cleanable impervious surfaces are recommended in clinical areas. Design should ensure that surfaces are easily accessed, will not be physically affected by detergents and disinfectants, and will dry quickly. Additional protection to the walls should be considered to guard against gouging/impacts with bedheads and trolleys. Wall surfaces should be maintained so that they are free from fissures and crevices (see also Health Building Note 00-10 Part B – 'Walls and ceilings').

Ceilings

3.120 Smooth jointless impervious ceilings should be used in operating theatres and special ventilated isolation rooms.

3.121 Suspended ceilings may be installed in general clinical areas and other areas in the healthcare facility (see Health Building Note 00-10 Part B). Dust and fungal spores may accumulate on the upper surface of ceiling tiles over time, and their dispersal on tile removal or manipulation may pose an inhalation risk to highly immunocompromised patients. A risk assessment should always be done before such work is carried out (see Appendix 3).

Lighting

3.122 Efficient lighting in all areas of wards or departments enables cleaning staff to undertake cleaning more effectively. CIBSE's Lighting Guide 2 – 'Hospitals and healthcare buildings' gives guidance on lighting levels in healthcare facilities.

3.123 Light fittings that are easy to clean and unlikely to accumulate dust should be chosen for clinical areas. For example, flush ceiling fittings are acceptable, but not open up-lights.

3.124 The location and design of luminaires should permit easy changing of lamps and frequent cleaning. They should be designed so that there are no ledges or ridges and they allow ease of access for cleaning. If skylights or light tubes are to be installed, ease of cleaning and maintenance should be the key considerations.

Doors

3.125 Doors should be cleanable, that is, smooth, non-porous and fluid-resistant, especially where contamination with blood or body fluid is a possibility.

3.126 Doors should have smooth handles that can be easily cleaned and dried. Additional protection to the doors should be considered to guard against gouging/impacts with bedheads and trolleys.

3.127 In mental health settings, risk assessment should inform the choice of door furniture (see also Appendix 1).

Windows

3.128 Windows should be sealed and unopenable in operating theatres and special ventilated isolation rooms.

3.129 Internal ledges in all windows should be avoided as this will allow dust and clutter to accumulate. Sloping ledges should be considered.

Finishes

3.130 Floors or walls penetrated by pipes, ducts and conduits should be sealed to stop entry of pests.

Fixtures and fittings

3.131 Design should ensure that surfaces are easily accessed, will not be physically affected by detergents and disinfectants, and will dry quickly.

Work surfaces

3.132 All work surfaces should be impervious, designed for easy cleaning and be free of fissures and unsealed joints. They should be able to withstand the

effects of regular cleaning with both detergents and disinfectants.

Soft furnishings

3.133 Soft furnishings (for example, seating) used within all patient areas should be chosen for ease of cleaning and compatibility with detergents and disinfectants. They should be covered in a material that is impermeable, preferably seam-free or heat-sealed.

3.134 Fabric that becomes soiled and stained cannot be adequately cleaned and will require replacement.

Curtains and blinds

3.135 Privacy curtains become contaminated with microorganisms, which can then be transmitted to staff hands. Where patients may be particularly susceptible to infection, curtains should have fittings that make them quick and convenient to replace; such fittings are common in disposable curtains.

3.136 In new-build or refurbished augmented care units, consideration should be given to having separate curtains for each bed space, sufficiently separated such that staff can easily and correctly identify which curtain belongs to which bed space.

3.137 Reusable curtains should be able to withstand decontamination in healthcare laundering processes (see Choice Framework for local Policy and Procedures 01-04 – 'Decontamination of linen for health and social care').

3.138 There should be a local policy on the changing of privacy curtains, both for routine changing when the curtains become soiled and after the discharge of a patient with a known/or suspected infection.

3.139 Window blinds that are not readily amenable to cleaning are not recommended. Double-glazed room vision panels with integral blinds are easy to clean.

3.140 Impervious dividers, screens that can be manoeuvred on wheels or retractable fixed screens between bed spaces can be of benefit in certain clinical areas. The use of these dividers requires consideration at the planning stages as extra space is required either for their use between beds or for storage. It is important that they are easily cleaned, are non-fabric and can withstand the effects of disinfectants.

Radiators

3.141 Wherever possible, radiators should be accessible and cleanable. In clinical areas, supply pipework should always be concealed. In all cases, the objectives of design and specification should be an installation that is neat, easy to clean and maintain, and durable.

3.142 Underfloor heating should be considered in mental health and in-patient learning disability settings.

Recommendations

- The quality of finishes in all clinical areas should be readily cleaned and resilient.
- **Carpets should not be used in clinical areas.**
- Flooring should be seamless and smooth, slip-resistant, easily cleaned and appropriately wear-resistant.
- Design should ensure that surfaces are easily accessed, will not be physically affected by detergents and disinfectants, and will dry quickly.
- Avoid internal ledges in all windows as this will allow dust and clutter to accumulate. Consider the use of sloping ledges.
- All work surfaces should be impervious, designed for easy cleaning and be free of fissures and unsealed joints.
- In all cases, the objectives of design and specification should be an installation that is neat, easy to clean and maintain, and durable.

Changing facilities

Out-patient and day surgery changing facilities

3.143 In areas such as out-patients, day surgery, imaging and minor injuries units, it will be necessary to provide sufficient changing/storage facilities if clothing has to be removed and kept safe. These facilities should be included at the planning stage and should be able to be cleaned easily.

Clinical staff changing facilities

3.144 By providing staff changing facilities, sanitary facilities, showers and sufficient locker space for outdoor clothing, staff will be able to change out of their uniform on-site. Wash-hand basins and shower facilities for staff should be available and easily accessible in case of substantial blood or body-fluid contamination. There needs to be sufficient storage for clean scrub suits and footwear.

Maintenance staff

3.145 Changing facilities should be provided for maintenance staff who undertake activities that could expose them to contamination. There should also be access to showers in case of significant contamination.

Recommendations

- Appropriately sized changing facilities should be provided for staff to encourage them to change out of their uniform on-site.
- Wash-hand basins and sanitary facilities should be included, and showers should be provided in the event of contamination by blood or body fluid.

Laundry and linen services

3.146 See Choice Framework for local Policy and Procedures 01-04.

Catering/food hygiene

3.147 Hand-hygiene facilities should be provided for staff who prepare and serve food. Ward kitchens should have a separate staff wash-hand basin with non-touch taps, liquid soap and paper towels.

3.148 Hand-washing facilities should ideally be located between raw and cooked-food preparation areas.

Healthcare waste

3.149 Guidance on healthcare waste management is outlined in Health Technical Memorandum 07-01 – 'Safe management of healthcare waste'.

Responsibilities under "duty of care"

3.150 The "duty of care" is a law (as set out in section 34 of the Environmental Protection Act 1990 and associated regulations) decreeing that anyone who manages waste and/or has responsibility for the management of waste must take all reasonable steps to keep that waste safe.

3.151 One of the main responsibilities under duty-of-care, which has major implications for IPC and the built environment, is to ensure that waste is stored safely on-site. Essentially:

- storage areas at ward and unit level should be secure and located away from public areas;
- storage areas should be sufficient in size to allow packaged waste to be segregated and so as to avoid waste of different classifications being stored together in the same area.

Waste segregation and storage

3.152 Any new capital developments should have enough space for waste receptacles to be located close to the point of waste production to avoid unnecessary handling of waste.

3.153 Waste segregation entails providing sufficient space for recycling, reuse and recovery to minimise waste and reduce costs.

3.154 Space at the ward/unit level is needed for suitable waste receptacles to segregate the waste in line with the approach described in Health Technical Memorandum 07-01. The storage should be sufficient for different waste streams to be segregated pending collection; that is, domestic waste should be separate from clinical waste, and clinical waste with different disposal routes should not be mixed (for example, sharps waste not mixed with orange-bagged waste). There should be no public access to this area.

3.155 Adequate secure storage areas for waste are best located at entrances to wards or departments, preferably with access from both ward and hospital corridor to facilitate collection by authorised personnel only. Waste can then be stored in these areas – instead of taking up valuable space in dirty utility rooms.

3.156 Storage for used linen should be in a clearly designated area separate from waste. This should minimise any risks of used linen being accidentally taken for disposal, or of waste being taken to the laundry.

3.157 The waste and used linen storage areas should be able to be cleaned easily and efficiently. The holding area should be large enough to hold a wheeled-bin, which in turn will reduce handling and the subsequent risks to porters.

3.158 A designated secure area is also necessary to hold receptacles from the whole site for collection for disposal and should be provided with good access routes away from public areas. This area should also be washable and animal-proof.

Waste receptacles

3.159 The size of waste receptacles required needs to be in line with the quantity of waste generated in a particular area by waste stream (that is, clinical or domestic waste).

3.160 Waste receptacles should be foot-operated only (that is, it should not be possible to open them by hand in normal use) and should be easy to clean. The foot pedal should be sturdy and durable. Staff training and awareness-raising on the risks of cross-infection will be key to understanding the importance of the receptacle's hands-free operation and design.

3.161 The lids of clinical waste receptacles need to be capable of being cleaned and disinfected. Temporary labels should not be attached to receptacles as they inhibit effective cleaning.

Clinical waste generated in primary care and community settings

3.162 In healthcare facilities such as care homes and primary care settings, all waste should be contained appropriately and kept secure at all times.

3.163 The system and frequency of waste collection needs to be taken into account when planning facilities needed for temporary holding bays etc. If located externally, the holding bay or receptacle should be washable, secure and animal-proof. Only rigid lockable receptacles should be stored in external areas.

3.164 There should be a strict routine for removing waste to ensure it does not remain uncollected for extended periods.

Storage capacity

3.165 Storage areas need to be of a sufficient size to meet the needs of the number of different waste streams likely to be generated.

3.166 Storage capacity needs to match the proposed frequency of collection by a waste disposal contractor. The design of the facility should also take account of accessibility and space needed for vehicles collecting the waste.

Recommendations

- Refer to Health Technical Memorandum 07-01 – 'Safe management of healthcare waste'.
- Waste receptacles should be foot-operated only (that is, it should not be possible to open them by hand in normal use) and should be easy to clean.
- The lids of clinical waste receptacles need to be capable of being cleaned and disinfected.
- Storage areas need to be of a sufficient size to meet the needs of the number of different waste streams likely to be generated in the healthcare facility.

Engineering services

3.167 This section discusses various aspects of engineering services and the IPC implications of each.

Planned preventative maintenance

3.168 In accordance with the HCAI Code of Practice, local policies should be in place for planned preventative maintenance to ensure safety and efficiency of the engineering services provided.

Heating/temperature control

General

3.169 Covered heat emitters allow dust to build up beneath and inside the heat emitter grille. Where heat-emitter covers are used, regular planned cleaning should be undertaken to prevent dust

accumulation. When installing heat emitters, it is recommended that there be sufficient space underneath the heat emitter to allow cleaning machinery to be used.

Pipework siting and access

3.170 Pipework should be contained in a smooth-surfaced box that is easy to clean; pipework sited along a wall can become a dust trap and be impossible to clean.

3.171 Pipes and cables running through walls above suspended ceilings should be sealed as far as is practicable.

Heating and general ventilation grilles

3.172 Ventilation grilles need to be accessed easily for inclusion in cleaning programmes by cleaning and estates staff.

Ventilation ductwork

3.173 Ventilation ductwork should be installed in such a way that it can be accessed for cleaning. Extract ductwork accumulates large amounts of dust, particularly where heat reclamation systems are used.

See Health Technical Memorandum 03-01 – 'Specialised ventilation for healthcare premises' for comprehensive guidance on the design, installation and operational management of ventilation systems in healthcare premises.

Specialised ventilation

3.174 In healthcare premises, certain activities will necessitate the provision of ventilation equipment with additional special features in order to achieve and maintain specific conditions. For infection prevention in specialist areas such as operating theatres, to prevent contaminated air from entering designated clean areas, it should be ensured that air flows from the cleanest to sequentially less clean areas. This direction of airflow prevents contaminated air passing in the opposite direction.

3.175 The following areas usually have specialised ventilation requirements for infection prevention:

a. operating departments;

b. airborne infectious diseases isolation;

c. bronchoscopy and sputum induction rooms where a risk assessment has indicated a tuberculosis risk;

d. accommodation for highly immunocompromised patients;

e. cardiac catheterisation/interventional radiology units;

f. microbiology containment laboratories;

g. mortuaries.

Split and cassette air-cooling units

3.176 Only units that are readily amenable to regular cleaning should be used. If installed, they should be cleaned as part of a regular planned maintenance scheme. Particular attention should be paid to the accessibility of the condensate drip-tray for cleaning.

Chilled beam units

3.177 These comprise heat-exchange beams in a ceiling through which water is passed to cool or heat air that passes across them. They can be used as terminal devices on a mechanical ventilation system to cool or heat fresh air as it enters a room. If needed, they should be installed so that they can operate without generating condensate. They should be accessible for regular cleaning and maintenance.

Hot and cold water systems

See Health Technical Memorandum 04-01 Parts A and B for comprehensive guidance on the design, installation and operational management of water systems in healthcare premises.

3.178 The Water Supply (Water Quality) Regulations 2000 contain provisions to ensure that the drinking water supply within buildings to which the public has access remains wholesome and is not adversely affected by the local distribution system.

3.179 Immunocompromised patients are at particular risk from cryptosporidium. Very low numbers of cryptosporidium cysts can occasionally occur in mains potable water. A local risk assessment could be used to establish the need for filtration of drinking water to remove these cysts. For guidance

on separate cold water services for drinking water, see Health Technical Memorandum 04-01 Part A.

Storage and distribution of water

3.180 Many organisms capable of causing disease, particularly in highly susceptible patients (such as *Pseudomonas aeruginosa* and *Legionella* spp.), have been isolated from healthcare water systems. Preventative measures include:

- routine inspections of water storage tanks with cleaning as required;
- identifying and removing dead-legs and blind ends;
- keeping cold water systems cold and hot water systems hot; and
- ensuring rapid turnover in water storage.

3.181 Temperature control is the traditional strategy for reducing the risk from *Legionella* spp. in water systems. This will require temperature monitoring on a regular basis. The recommended test frequencies are given in Health Technical Memorandum 04-01 Part B. It is good practice to ensure that hot- and cold-water pipework is separated, insulated and preferably not in the same ducting to avoid heat transfer to the cold water supply.

3.182 Chemical and other water treatments that have been shown to be capable of controlling *Legionella* spp. to some extent may also be considered. They will only work in systems that are amenable to their use (for example, those that do not have dead-legs and blind ends).

For guidance on control of *Legionella* in water systems, see the Health & Safety Executive's (2000) 'Legionnaire's disease: the control of *Legionella* bacteria in water systems – Approved Code of Practice and guidance'.

Health Technical Memorandum 04-01 Part B provides guidance on the monitoring and maintenance of water systems (including water storage).

See also Health Technical Memorandum 04-01 – 'Addendum: *Pseudomonas aeruginosa* – advice for augmented care units'.

Sanitary facilities

3.183 WCs, bathrooms and showers should be designed to be easily cleaned and maintained. Wash-hand basins should be provided in or adjacent to WCs.

3.184 Showers are generally more practical than baths in connection with clinical procedures and are easier to keep clean. Any fixture with a shower such as a seat should be readily amenable to cleaning.

3.185 To minimise the possibility of bacterial colonisation of showerheads, they should be regularly cleaned and descaled.

3.186 Bidets may present infection risks, depending on design and patient group (although they are most commonly installed in maternity units). The appliance should be rimless with an over-rim water supply and conform to the specifications given in Health Building Note 00-10 Part C.

3.187 Baths should be easy to clean. Recirculating spa pools are not recommended (see Health Building Note 00-10 Part C).

3.188 In wet rooms, high quality water-resistant cladding should be used on the walls to prevent mould.

Health Building Note 00-10 Part C contains guidance to assist the design team in the selection, specification and application of sanitary assemblies in healthcare buildings. It also gives guidance on the appropriate cleaning and maintenance regimes.

Health Building Note 00-02 gives detailed guidance on the design of sanitary facilities.

Water fittings

3.189 Water fittings (washers etc) should not support microbiological growth. All fittings should satisfy the requirements of the Water Supply (Water Fittings) Regulations 1999. Even if WRAS-approved, the unnecessary use of flexible hoses should be avoided.

3.190 Where flexible hoses must be used (for example, on essential equipment such as hi-lo baths), they must be lined with a suitable alternative to EPDM (ethylene propylene diene monomer) as well as being WRAS-approved. Care should be taken to

avoid kinking or distorting them during installation (see DH Estates & Facilities Alert DH (2010) 03 – 'Flexible water supply hoses').

Ice for patient consumption

3.191 Ice machines should be of a type that dispenses ice by a non-touch nozzle.

3.192 Ice should be made directly from water that is of drinking quality. Ice for the immunocompromised should be made by putting drinking water into single-use ice-making bags, then into a conventional freezer.

Bedhead services

3.193 Bedhead services should be smooth, accessible and easy to wipe clean.

3.194 Sufficient dedicated 13-amp socket outlets should be provided in corridors and in individual rooms to enable cleaning appliances with 9m long leads to operate over the whole department.

3.195 Where possible, socket outlets should be provided flush-mounted or in trunking systems to enable easy cleaning and prevent the build up of dust.

Patient entertainment systems

3.196 Radio and television headsets should be capable of being cleaned or disinfected between patient use or should be single use, whichever is the most economical method to adopt.

See Health Technical Memorandum 08-03 – 'Bedhead services' for further guidance.

Wastewater and sanitation

3.197 Wastewater is generated from a huge number of tasks carried out in healthcare buildings, which range from cleaning, hand-washing, specialist laundries, surgical operations and areas such as renal dialysis units. Most of this wastewater contains pathogenic microorganisms and must be disposed of via a safely contained internal drainage system into the external wastewater sewerage system.

Internal drainage system

3.198 An internal drainage system should use the minimum amount of pipework, retain water and be airtight at joints and connectors. It should be sufficiently ventilated to retain the integrity of water seals.

3.199 The design should comply with the relevant British Standards and Codes of Practice, including BS EN 12056 and Approved Document H of the Building Regulations – 'Drainage and waste disposal'. Recommendations for spatial and access requirements for public health engineering services are contained in CIBSE's (2004) Guide G – 'Public health engineering'.

3.200 Provision for inspection, rodding and maintenance should be located to minimise disruption or possible contamination, and access points should not be sited in clinical areas.

Bedpan washer-disinfectors/macerators

3.201 Where reusable bedpans are used, ward areas require adequate and suitable bedpan washer-disinfectors that comply with Choice Framework for local Policy and Procedures 01-01 Part D – 'Management and decontamination of surgical instruments: washer-disinfectors'. Hands-free door-opening machines are recommended.

3.202 Where fitted, bedpan washer-disinfectors should be installed according to the Water Supply (Water Fittings) Regulations 1999 to prevent backflow and contamination. Easy access is essential.

3.203 When considering installation of bedpan macerators, it should be established that internal drains and the external sewerage system can cope with the resultant slurry.

3.204 Where reusable supports are used with maceratable bedpans, there should be adequate facilities for their cleaning and disinfection between uses.

See also Appendix 1 on mental health settings.

Medical gas vacuum systems

3.205 Health Technical Memorandum 02-01 – 'Medical gas pipeline systems' gives guidance regarding piped medical gases and vacuum systems and includes recommendations on emergency procedures; power failure; access for cleaning contaminated vacuum systems; training and communication; maintenance and infection risk.

Pneumatic-air tube transport systems

3.206 Guidance for the design and management of pneumatic transport systems can be found in Health Technical Memorandum 2009 – 'Pneumatic air tube transport systems'.

3.207 The carrier for specimens should be transparent, able to be autoclaved and incorporate a leak-proof seal.

3.208 If leaking samples are allowed to enter the tube system or station, the station should be isolated and dealt with following advice from the IPC team. The disinfection procedure or cleaning will depend on the nature and level of risk imposed by the contaminant. Each incident will need to be assessed separately.

3.209 If clinical samples leak on entering or during transportation, the station and/or system should be isolated and dealt with following advice from the IPC team. Each incident will need to be assessed separately.

3.210 Major policy decisions with reference to the system should be made through the director of infection prevention and control (DIPC) and/or the IPC team.

Recommendations

- Refer to Health Technical Memorandum 04-01 Parts A and B for comprehensive guidance on the design, installation and operational management of water systems in healthcare premises.
- Heat emitters should be designed and installed in a manner that prevents build-up of dust and contaminants.
- Heat emitters, heating and general ventilation grilles should be easily accessible for cleaning.
- WCs, bathrooms and showers should be designed to be easily cleaned and maintained. Wash-hand basins should be provided in or adjacent to WCs.
- To minimise the possibility of bacterial colonisation of showerheads, they should be regularly cleaned and descaled.
- Lighting should be planned so that units can be easily cleaned, with no ledges or ridges where dust can gather.
- Contamination of the water supply can occur due to poor design of pipework, inappropriate storage or during renovation and refurbishment work (see Health Technical Memorandum 04-01).
- Ice-making machines should not be installed in immunocompromised patient facilities. Ice for the immunocompromised should be made by putting drinking water into single-use ice-makers, then into a conventional freezer.
- With regard to pneumatic-air tube transport systems, the carrier for specimens should be transparent, able to be autoclaved and incorporate a leak-proof seal.

Appendix 1 – Mental health and learning disability settings

Note:

1. This appendix should be read in conjunction with the rest of the document.
2. With regard to learning disability settings, this guidance applies to in-patient units only and not to domiciliary care services that provide support in people's own homes.

1. The need to minimise the risk of cross-infection is important in mental health settings, but other factors such as ligature risk and the creation of a positive therapeutic environment will need to be taken into consideration when providing advice to these areas.

2. The IPC requirements for those using mental health and learning disability environments must be made in conjunction with health and safety teams, risk management teams and clinicians when advising on the built environment. Specific design guidance for mental health units (Health Building Note 03-01 – 'Adult acute mental health units') and medium secure services (DH's 'Environmental design guide: adult medium secure services') should also be consulted. For dementia settings, additional considerations are discussed in the 'Dementia Design Checklist' (Health Facilities Scotland, 2007).

Recommendations:

- Creating/maintaining a non-clinical feel can be achieved by using furnishings/fittings that are manufactured especially for this setting and are easy to clean and maintain. For example, wood-effect vinyl can be used to create a less clinical environment, but cleanliness can be maintained. Vinyl is easy to maintain and requires less frequent replacement.
- In some specialties within mental health bedroom areas, porcelain basins and toilets would present a risk; alternatives such as resin or stainless steel should be considered. Cleaning of these materials should, however, be considered carefully.
- There is no requirement for a clinical wash-hand basin in an en-suite bedroom. Alternative arrangements to provide healthcare staff with access to hand hygiene should be made.
- There should be sufficient access to hand-hygiene facilities for staff. Clinical wash-hand basins should be sited only in supervised areas such as the clean utility room, treatment rooms and dirty utility room. Antimicrobial hand-rub should be provided. Where necessary, the use of patient wash-hand basins in en-suite rooms can be used with care to avoid recontamination of hands.
- In secure mental health units, hand dryers or vandal-proof integral hand-wash dryers in communal toilets may provide a safer option for hand hygiene while encouraging those in the service to clean hands.
- Single rooms can be used for source isolation.
- Risk assessment should inform the storage of protective clothing, soap and paper towels, clinical waste receptacles etc. All fixtures and fittings should be anti-ligature (see Health Building Note 03-01 – 'Adult acute mental health units').
- Assessment of the need for a macerator or bedpan washer-disinfector should be undertaken. If a specific dirty utility room is not required, alternative procedures should be in place for the disposal of body fluids and urine testing.
- DH's 'Environmental design guide: adult medium secure services' advises on appropriate floor coverings to reduce risk of harm.

Appendix 2 – Example of a typical IPC checklist

Business case review	
For non-clinical issues related to the design, construction and fitting out of multi-bed rooms and associated areas	Date:
To be completed by the healthcare provider	
Healthcare provider	
Site	
Project/scheme	
Building/ward	
Project manager for the healthcare provider	
Business case or design stage to which this checklist/review applies	
Completed by (for healthcare provider)	Date:
Reviewed by	Date:
General notes	

Part 1. Sign-off

The infection prevention and control checklist/review should be signed off by the relevant parties before the scheme proceeds. Some of the roles below (not chief executive officer) may be covered by a relevant director in the healthcare provider organisation. If appropriate, a single sign-off, clearly stating which areas of responsibility are covered, may suffice.

	Check	Reason	Involvement	Design signed-off by:
	Chief executive officer	With regard to control and prevention of infection and privacy and dignity issues of the facilities to be provided by his/her organisation to patients, staff and visitors.	To ensure that all departments/commissioners are satisfied with the IPC issues for the facilities proposed. The person ultimately responsible.	
	Director of infection prevention and control (DIPC)	With regard to IPC of the facilities and resources to be provided by his/her organisation to patients, staff and visitors.	The provision of coordination, advice and management across clinical boundaries and to inform the trust board/management team.	
	Director of Estates & Facilities	With regard to design, operation and maintenance of the buildings and resources to be provided by his/her organisation in order to ensure a safe estate is provided for patients, staff and visitors.	The provision of coordination, advice and management across the estates and facilities team and to inform the trust board/ management team	
	IPC team manager	To ensure involvement in the design and signing-off process and that the design is to their satisfaction for IPC purposes.	To provide specialist input into the design and management process to facilitate effective IPC performance.	
	Facilities manager	To ensure that the design and detailing is approved with respect to the potential for effective and efficient cleaning and that sufficient resources are/will be available.	Working with the maintenance manager, current and anticipated problems should be designed out of the new/refurbished facility.	
	Maintenance manager	To ensure that the design and detailing is approved with respect to the potential for effective and efficient maintenance to promote and maintain effective and efficient cleaning.	As above.	
	Ward/nurse manager/ matron	To ensure that the physical design and the operation of the facility or ward can be run and managed in an efficient and hygienic manner.	Nursing/local input is essential as the nursing staff are ultimately those using the facility. Their buy-in as a stakeholder in direct patient care is very important.	
	Equipping manager	To ensure that storage facilities and space provided for equipment is adequate and is suitable.	One of the prime causes of poor cleaning is clutter and poor storage facilities.	

Part 2. Design

	Check	Reason	Possible issues to consider	Y/N	Comments on scheme
1	Has an infection prevention and control risk assessment been completed in relation to the completed facility as proposed?	To assist in designing-out all IPC-related risks.	See issues below.		
2	Isolation facilites	The primary aim of IPC is to prevent the spread of infection between patients, visitors and staff by cont ontainment of pote	A sessment should be used to inform garding which patients to nurse in ms. Healthcare providers should -suite single-bed rooms to er local requiremen		

Healthcare organisations will each have their own specific design and build issues to consider. They should use the guidance in this document to develop bespoke IPC checklists for sign-off by the relevant parties.

Part 3. Management of the construction of the new facility (including demolition and enabling works)

	Check	Reason	Possible issues to consider	Y/N	Comments on scheme
66	Has an infection prevention and control risk assessment been completed in relation to the construction refurbishment of the healthcare facility?	To minimise and manage risk.	See issues below.		
67	Will the new facili e constructed in of existing staff su exis	Has the design and project planning taken into account the implications on existing patients and staff? IPC is area that may not fe the usual risk ass ertaken.	Pr ting immunocompromised patients from fungal infection. ence with specialist ventilation k is adjacent to an operati m.		

Appendix 3 – IPC risk assessment during construction/refurbishment of a healthcare facility

1. Quality assurance in IPC associated with building work, fungal spore generation and susceptible patients should be centred on the three principles of:

a. identifying susceptible patient groups;

b. where necessary, using methods of work that reduce the dissemination of airborne fungal spores; and

c. protecting susceptible patients from those airborne fungal spores that will be generated.

2. The first principle is one of clinical risk assessment. The second and third are deciding on actions and ensuring those actions are constantly applied for the duration of the risk. This could be achieved by:

- instruction of those working on the project, those in the estates team and clinical staff in affected areas;
- routine monitoring of actions and precautions; and
- an efficient reporting and reaction system (should deficiencies be identified).

3. Patients who are highly immunocompromised are thought to be a particular risk from infection by inhalation of fungal spores whose airborne concentrations are thought to increase in association with demolition, construction, maintenance and refurbishment (that is, building) works. The occurrence of clusters of fungal infection associated with building works has been observed on a number of occasions, which suggests the need to minimise the risk of spore dispersal during this time. Many of the recommendations in this appendix are based on consensus rather than scientific observation. The following measures are thought to reduce the dissemination of spores, including aspergillus.

Help to reduce specific infection problems during construction

4. A planned contamination-control programme is essential when building work of any nature is planned.

5. Early and sustained involvement of the IPC team in the planning process is essential and will lead to minimising of potential infection risks. Building dust control measures may not be sufficient for the control of fungal spore release; therefore, the following should be considered:

- Use floor-to-ceiling barriers that completely enclose the work area.
- Seal windows in areas accommodating patients assessed as susceptible to minimise ingress of fungal spores generated by nearby building work.
- If vacuum cleaners are used, ensure they have high efficiency filters on exhausted air.
- Use a vacuum cleaner with a HEPA filter to clean areas daily or more often if necessary.
- Transport debris in sealed bags or containers with tightly fitting lids, or cover debris with a wet sheet.
- The removal of debris by chutes is liable to produce airborne fungal spores. The use and positioning of chutes should be carefully considered.
- Do not haul debris through patient-care areas but through an exit restricted to the construction crew.

- Commission additional hotel services with regard to cleaning during construction projects.
- Temporary storage for clinical equipment and clean linen should be clean and free of pests.

Monitoring

6. Demonstration that measures have reduced ingress of fungal spores into protected areas can be demonstrated by exposing settle plates in protected areas and comparing fungal deposition on these with equivalent settle plates exposed outside protected areas at the same time and for the same duration.

7. There is limited evidence that occasional active sampling for fungal spores demonstrates that protective measures are effective.

1. First, identify **construction activity type** from the table below.

Type A	Inspection and non-invasive activities, includes, but not limited to: • removal of ceiling tiles for visual inspection on corridors and non-clinical areas; • painting and minimum preparation in corridors and non-clinical areas; • electrical trim work (all plugs, switches, light fixtures, smoke detectors, ventilation fans); • minor plumbing and activities that do not generate dust or require cutting of walls or access to ceilings other than for visual inspection.
Type B	Small scale, short duration activities that create minimal dust. Includes: • removal of a limited number of ceiling tiles in low risk clinical areas for inspection only; • installation of telephone and computer cabling; • access to chase spaces; • cutting of walls or ceiling where dust migration can be controlled in non-clinical areas.
Type C	Any work of long/short duration which generates a moderate-to-high level of dust or requires minor building works, demolition or removal of any fixed building components or assemblies. Includes, but is not limited to: • sanding of walls for painting or wall covering; • removal of floor coverings, ceiling tiles, panelling, and wall-mounted shelving and cabinets; • new wall construction; • minor duct work or electrical work above ceilings; • major cabling activities.
Type D	Major demolition and construction projects. Includes, but is not limited to new construction/machinery and equipment installations, rectifications and modifications

2. Then identify the **infection control risk group** by area.

Group 1 (low risk)	Group 2 (medium risk)	Group 3 (high risk)
Office areas/corridors plant rooms/ service ducts Primary care/community treatment rooms	A&E clinical rooms Radiology/magnetic resonance imaging General surgery recovery units Wards Nuclear medicine Admissions/discharge units Echocardiography Other departmental clinical areas Out-patient department Pharmacy (general) Laboratories Endoscopy clinics Examination rooms	Day surgery rooms All intensive care units All operating suites All high dependency units Dialysis & transplant units Oncology Cardiology Cardiac catheterisation suite Pharmacy clean rooms Sterile services departments Bone marrow transplant units

3. Now identify the "risk class" by correlating "construction type" with "risk group" (from 1 and 2 above) in the matrix below.

	Construction activity type			
Risk group	**Type A**	**Type B**	**Type C**	**Type D**
Group 1	Class 1	Class 2	Class 2	Class 3
Group 2	Class 1	Class 2	Class 3	Class 3
Group 3	Class 2	Class 3	Class 3	Class 4

4. After identifying the risk class from 3 above, follow the risk measures advised for each class.

Class 1	• Execute work by methods to minimise dust from construction • Immediately replace any ceiling tile displaced for visual inspection
Class 2	• Where appropriate, isolate HVAC (heating, ventilating, and air conditioning) system in areas where work is being performed • Provide active means to prevent airborne dust from dispersing into atmosphere if practicable, i.e. dust bag to machine • Water-mist work surfaces to control dust while cutting • Avoid pooling of water which may be prolonged • Seal unused doors with duct-tape • Block off and seal air-vents • Wipe work surfaces with detergent • Contain construction waste before transport in tightly covered containers • Wet-mop and vacuum with filtered vacuum cleaner before leaving work area • Place dust-attracting mat at entrance and exit of work area (tacky mat) • Remove isolation of HVAC system
Class 3	• Where appropriate, isolate HVAC system in area where work is being done to prevent contamination of duct system • Complete all critical barriers and implement dust control methods before construction begins • Maintain negative air pressure within work site. Use HEPA (high efficiency particulate air)-equipped air filtration unit if there be a risk that air will enter building • Do not remove barriers from work area until complete project is clinically clean • Vacuum with filtered vacuum cleaner during works • Wet-mop area during works • Remove barrier materials carefully to minimise spreading of dust and debris associated with construction • Contain construction waste before transport in tightly covered containers • Remove isolation of HVAC system in areas where work has been done and appropriate checks performed
Class 4	• Isolate HVAC system in area where work is being done to prevent contamination of duct system • Complete all critical barriers and implement dust control methods before construction begins • Maintain negative air pressure within work site using HEPA-equipped air filtration unit • Seal holes, pipes, conduits and punctures appropriately • Construct airlock and require all personnel to remove dirty apparel and clean down before leaving the work site. The use of cloth/paper disposable overalls/shoes, etc., may be required • Do not remove barriers from work area until completed project is thoroughly cleaned (as before) and repeat clinical clean after barrier removed • Vacuum work area with filtered vacuum cleaner • Wet-mop area with detergent during works • Remove barrier materials carefully to minimise spreading of dust and debris associated with construction • Contain construction waste before transport in tightly covered and sealed containers • Remove isolation of HVAC system in areas where work has been done and appropriate checks performed

Appendix 4 – Microorganisms and infections: a guide for designers

1. Microorganisms are classified into bacteria, viruses, fungi and parasites. A human body has probably more bacteria in or on it than it has cells. The vast majority of microorganisms that people encounter will, for most of their lives, do no harm. However, some of them can take advantage of susceptible individuals and cause infections. Many patients in hospitals are unusually susceptible to infection and it is this, rather than the pathogenicity (disease-causing ability) of the microorganisms, that is responsible for most infection in hospitals.

What is an infection?

2. An infection occurs when microorganisms on or in a person's body cause them harm. In order to do this, the microorganisms will have to combat the person's defences against infection (immunity); in doing this, they can invade the tissues and produce harmful substances (toxins) that cause damage either locally or systemically.

3. To produce an infection, a sufficient number of a suitably virulent microorganism have to be introduced into a suitably susceptible site on a suitably susceptible individual. The point most amenable to control is that of reducing the numbers of microorganisms that are transferred between patients –this is the most valuable control point in IPC.

4. Microorganisms that can cause infection sometimes exist in an individual without causing disease. This is termed colonisation or carriage. However, they can cause infection if transferred to another, more susceptible, person. As there is no obvious disease when an individual is colonised, it may not be recognised that they are a source of potentially dangerous microorganisms. These microorganisms can also cause disease in the person originally colonised if they become more susceptible, either due to another disease process or as a complication of their treatment.

5. A patient can also be infected by microorganisms that have been harmlessly living on or in them for years. This change in interrelationship can be as a result of increased patient susceptibility to infection. Infection with one's own resident microorganisms is termed endogenous, as opposed to infection with microorganisms from elsewhere, which is termed exogenous.

6. Patients can acquire infections as a consequence of their treatment in a healthcare facility (HCAI). They can acquire an infection outside hospital and bring that infection into hospital (community-acquired infections). Sometimes the community-acquired infection will be the reason a patient is admitted into hospital, and so the infection should be obvious, but other times it may not be (for example, a patient with hepatitis B who has been admitted hospital for an unrelated surgical procedure). At any one time in a hospital, about half of the infections are HCAIs and half are community-acquired, but both can be a risk of transmission to other patients.

Appendix 5 – Glossary

Airborne transmission: A mechanism of transmission of an infectious agent by aerosols – that is, microbes in very small particles that can travel long distances but are usually relatively inefficient at transmitting infection. This route is only relevant for a small number of infections, principally tuberculosis.

Cohorting: Placing patients infected or colonised with the same infection (but with no other infection) in a discrete clinical area where they are cared for by staff that are restricted to these patients.

Contact: Association with an infected person or animal or a contaminated environment such that there is an opportunity to acquire the infection.

Cross-infection: An infection either due to a microbe that came from another patient, member of staff or visitor in a healthcare establishment, or due to a microbe that originated in the inanimate environment of the patient.

Dead-legs: In a water supply and distribution system, pipes that are capped off (blind ends) or rarely used (dead-legs) or not part of a main circulation system (for example, a branch off the main system).

Direct contact: Refers to a mode of transmission of infection between a colonised/infected host and a susceptible host. Direct contact occurs when skin or mucous surfaces touch (for example, via hand contact).

En-suite: a room attached to a single room or multi-bed room that has a shower, rimless WC and wash-hand basin (with extract ventilation).

Healthcare-associated infections (HCAI): encompasses any infection by any infectious agent acquired as a consequence of a person's treatment or which is acquired by a healthcare worker in the course of their duties.

Immunocompromised patient: A patient whose immune response is deficient because of an impaired immune system.

Mode of transmission: see **Transmission**

Non-touch (taps): Includes foot-operated, knee-operated, elbow-operated and sensor taps.

Pathogen: A bacterium, virus or other microorganism that can cause disease.

Scale: a ratio representing the relationship between a specified distance on a sketch plan and the actual distance on the ground. For example, at the scale of 1:50, 1 unit of measurement on the plan equals 50 units of the same measurement on the ground.

Slop-hopper: A disposal unit used for the disposal of liquid or solid waste.

Spore: Some species of bacteria, particularly those of the genera Bacillus and Clostridium, which are a significant cause of infection in humans, develop highly resistant structures called spores. They may remain viable for many years but when the environment conditions improve the spores germinate and the bacterial cell inside starts to multiply again.

Thermostatic mixing valves (TMVs): Valves that mix the hot and cold water in the system to provide water at a predetermined safe temperature.

Transmission: Any mechanism by which an infectious agent is spread from a source or reservoir to a person. Modes of transmission of infection include direct transmission involving direct transfer of microorganisms to the skin or mucous membranes by direct contact; indirect transmission involves an intermediate stage between the source of infection and the individual (for example, infected food, water or vector-borne transmission by insects); airborne transmission involves inhaling aerosols containing microorganisms (as is the case with diseases such as legionnaires' disease and tuberculosis).

References

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Water Supply (Water Quality) Regulations 2000 (as amended).
http://www.legislation.gov.uk/uksi/2000/3184/contents/made

Workplace (Health, Safety and Welfare) Regulations 1992.
http://www.legislation.gov.uk/uksi/1992/3004/contents/made

British Standards

BS EN 12056-3:2000. Gravity drainage systems inside buildings. Roof drainage, layout and calculation. British Standards Institution, 2000.
http://shop.bsigroup.com/en/ProductDetail/?pid=000000000030162802

DH estates and facilities guidance

Note:

The Space for Health website is closing. From April 2013, all DH estates guidance and other materials normally accessed via Space for Health will be available from the individual websites of England, Wales, Scotland and Northern Ireland.

As the details of these individual websites are not currently available, any queries about the status of, and access to, the following DH estates guidance documents should be addressed to help@spaceforhealth.net

This reference list will be updated once the full access details of the migrated guidance documents are established.

Choice Framework for local Policy and Procedures

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Research-based commentary

Journal of Infection Prevention

Aspects and problems associated with the water services to be considered in intensive care units

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Abstract

Background: Water is a product taken for granted and assumed to be a safe commodity in intensive care units (ICU). Biofilm readily becomes established in complex water services presenting a risk to vulnerable patients. Harboured within biofilms are opportunistic pathogens which can be transmitted via hand contact, splashing, aerosol and indirect contact through medical equipment. Evidence linking the role of water services in transmission of infection to patients in ICUs has increased in recent years.

Aims: This research based commentary set out to identify current problems with water and wastewater systems in ICU settings.

Methods: Databases and open source information was used to obtain data on current water and wastewater-related issues in ICU settings. This and the authors experiences have been used to describe current challenges.

Findings: the authors found a number of problems with water systems in ICU to which there has not been a cohesive response in terms of guidance to support users and designers. The resultant void permits new projects to proceed with suboptimal and designs which place patients and staff at risk.

Discussion: Hand hygiene stations are frequently misused or close enough to patients such that splashing poses a transmission risk. The wastewater system (drain) also presents a risk, from where Gram-negative antibiotic resistant organisms may be dispersed resulting in untreatable patient infections. The water and wastewater system provide a superhighway for the movement of pathogenic microorganisms and these risks need to be addressed if we are to safeguard vulnerable users in ICU.

Keywords

Water-systems, waste water, waterborne pathogens, antibiotic resistant microorganisms, hand hygiene, biofilms, splashing

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Introduction to water and associated problems in ICU

Whilst water is essential to life, in healthcare the lack of training, education and familiarisation with current guidance means that water and waste services are dispersing micro-organisms including those that are antimicrobial resistant and resulting in infections (Mogasale et al., 2018) Water-borne infections are common even in well controlled healthcare systems and equally concerning is the recognition that wastewater organisms are infecting patients. (Parra et al., 2020) These infections are reminiscent of the 19th century when faecal contamination of water supplies caused disease, only now water contaminated with faecal organisms is infecting critical care patients in the most sophisticated healthcare systems (Jung et al., 2020).

Failure to address these issues not only puts the individual vulnerable patient at risk but threatens the wider population due to the dispersal of highly antibiotic resistant organisms (Ahmad and Khan, 2019).

Consequently some critical care units have reduced the number of water services including hand hygiene stations to

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prevent the of dispersal of organisms. (Hopman et al., 2017) Whilst these units are considered to provide "water free" patient care, a limited number of water services are still provided for hand hygiene purposes. The reduction of water services simultaneously removes the risk from both the outlet and from the wastewater (drain) related to hand the wash station.

Methodology

A narrative review was performed using relevant search terms: intensive care unit OR critical care unit AND design OR design guidelines OR design criteria OR water outbreaks OR water system design OR water free patient care, OR sinks/water/drainage OR wastewater. Pubmed was searched for guidelines, reviews and original articles detailing recommendations for intensive care patients. Published data were checked for additional references and duplicate publication.

What are the risk from water services?

Incoming mains water contains Opportunistic Premise Plumbing Pathogens "OPPPs", naturally found in the aquatic environment which resist low level chlorination in water treatment plants, survive in low nutrient conditions and form biofilms. (Falkinham et al., 2015) These organisms invariably enter healthcare water systems in small numbers in the incoming mains water and water system should be designed and maintained to minimise the risk of microbial growth and biofilm formation (DHSC, 2016; HSE, 2014).

However, the periphery of the system (last 2 m) is much more difficult to maintain biofilm free as maintaining conditions which preclude biofilm formation are challenging as is the control in medical equipment that requires water.

Failure to comprehend the inherent water risks resulted in a global outbreak with *Mycobacterium chimera* from cardiac bypass heater water coolers which were initially contaminated during the manufacturing process (Sax et al., 2015).

Regulations require that water should be safe for immunocompromised patients and the microorganisms should be controlled in the water such that they do not multiply and cause disease. (UK Govenrment, 2007) What may be seen as safe practices in a home environment are not the case in a clinical setting, but this distinction may not be obvious to staff. Therefore, we must train and educate staff, so they understand the risks of water and the consequences of their actions if transmission of infection through water is to be controlled.

What are the routes of transmission?

Water by its very nature aids dispersal of organisms. Water carries microorganisms over vast distances from reservoirs to buildings where biofilms grow and disperse their progeny. (Capelletti and Moraes, 2016) Outside of water systems, the ability of water to conform to any shape allows it to flow into crevices where biofilm forms. Just like in our homes, the presence of sealant around a sink or a wet room will eventually allow ingress of water and retention of moisture and microorganisms will grow on the nutrients hat are supplied and will be transmitted to patients (Seiler et al., 2020).

Splashing will disperse water droplets containing microorganisms at least 2 m from the outlet or surface of the sink/drain and patients and medical equipment are frequently located within this 2 m splash zone (Inkster et al., 2021).

Aerosolisation causes the bacteria within water to become airborne and Legionella plumes from cooling towers have infected individuals 10 km away. (Fennelly, 2020; Nguyen et al., 2006) Ward showers are a significant risk for aerosolization and other sources such as hand wash basins or flushing toilets cannot be excluded. (Bollin et al., 1985) Small leaks from cardiac bypass heater coolers were sufficient to cause aerosolization of mycobacteria which became a worldwide problem (Walker et al., 2017).

Contact transmission?

Direct and indirect contact can complete the journey of organisms from the hand wash station to the patient. The sole purpose of a clinical hand wash station should be for hand hygiene and nothing else. However, Grabowski et al., found that hand washing accounted for only 4% of behaviours i.e. 96% of visits were for the wrong purpose. (Grabowski et al., 2018) This included using the hand wash basin as a shelf, washing equipment and disposal of fluids. Washing trays in tap water resulted in contamination with *Stenotrophomonas maltophilia* (Figure 1). When the tray was used for drug preparation either staff hands or equipment transferred the organism into a Hickman line resulting in a line infection. Controlling human behaviour is a difficult endeavour, but without the necessary training the findings of Grabowski et al., and others should not come as a surprise. (Grabowski et al., 2018) A hand wash station is often seen as a place of safety as it is linked to hand washing, a procedure which healthcare staff (as well as patients and the public) view as being the most effective means of preventing cross infection.

Re-fillable spray cleaning bottles represent another example of risk, becoming an extension of the water system. (Figure 2). In this case filling the bottle with tap water led to the fluid being contaminated with *P. aeruginosa* (>10^8 organisms/L) (Weinbren, 2018) From a staff perspective filling a spray cleaning bottle in the home environment is not perceived as a risk and neither is washing an item at the sink. However, in a healthcare environment the consequences can be fatal, hence the requirement for more training and education.

Figure 1. Placement of materials on the hand wash basin surface that will not only lead to contamination but also lead to hand hygiene not being performed.

Figure 2. Spray cleaning bottle and microbial growth on the agar plates following culture.

What is the role of the wastewater system?

It is a daily occurrence to dispose of liquids in hand wash basins. (Feng et al., 2020) However, wastewater systems provide a superhighway for microorganisms to travel within the building resulting in patient infections. (Smismans et al., 2019) Carbapenemase producing *Enterobacteriaceae* in wastewater systems are increasingly recognised as a major risk factor in the propagation of antibiotic resistance (Breathnach et al., 2012).

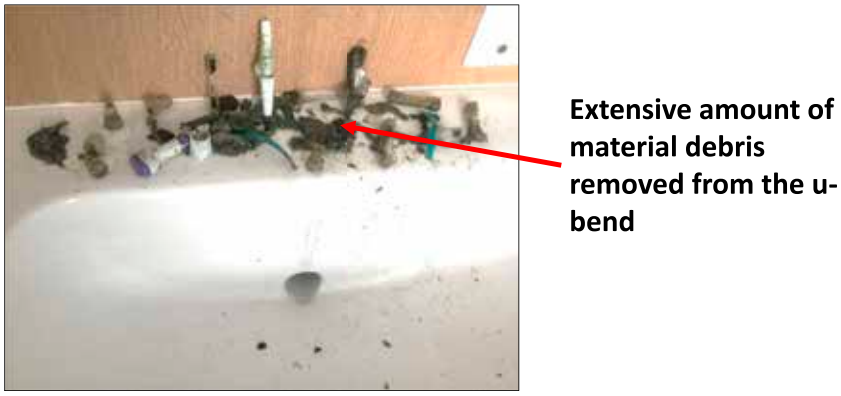
The combination of several mechanisms facilitates this situation including;

1. When a toilet is flushed and water and faecal material enter the main sewage stack, gravity causes the water and faecal material to drop down the pipe. Simultaneously air is forced to escape upwards, creating a flow of water particles including faecal organisms to travel up several floors in the building to contaminate other parts of the hospital wastewater system (Wong et al., 2021).
2. Blockage of drainage systems in hospitals is common and creates a route of transmission of microorganisms across the drainage network (Vardoulakis et al., 2022).
3. Experimental models have shown that if the waste trap of one sink (connected via the drainage system to a gallery of sinks) is inoculated with a tracer organism, the same organism can be found in most other waste traps within a week (Mathers et al., 2018).
4. Disposing of carbon sources down a sink drain, will stimulate the growth of biofilm up the vertical section of the drain at a rate of 1 mm/hour (Kotay et al., 2020).

How do microorganisms escape from the drainage system and find their way to a patient?

The purpose of a waste traps is to provide a water seal to prevent escape of sewer gases, however the traps contain bacteria. (Aranega-Bou et al., 2018) In a drain located directly below an outlet bacteria grow up the trap to reach the sieve at the top of the drain. When water directly hits the drain organisms will be dispersed up to 2 m into the environment. Even when the drain is placed at the bottom of the sink but offset, dispersal of organisms still takes place. In the UK, the recommended design is for the drain to be located at the rear of the basin. Work has shown that a

Figure 3. Example of debris removed from the u bend.



rear drain is effective at preventing dispersal of drain organisms providing drainage is not impaired. (Aranega-Bou et al., 2021) But impaired drainage with rear drains is common, as they usually lack a sieve. Items removed from waste traps include end caps from giving sets, razor blade covers, capillary sampling devices and intravenous connecting devices. (Figure 3) Drain hole sieves are available, but can become heavily colonised with biofilm, and therefore create their own transmission risk. (Walker et al., 2014) Clinical staff have not been taught the importance of reporting poorly draining sinks, so in practice blockages only tend to be reported when they have become so bad that no drainage occurs.

Whilst disposal of fluids, including patient fluids/secretions, should not occur in hand wash stations it does happen. The design of intensive care units makes appropriate disposal of fluids more difficult as side rooms tend to lack ensuite facilities (as would be found inside rooms on a general ward). Instead, staff are required to take the most heavily contaminated fluids out of an isolation room, possibly contaminating the surrounding environment (through spillages and hand contact points eg door handles) then traverse a considerable distance before entering the dirty sluice. In the dirty sluice secretions may be dropped down the sluice hopper, generating splashing which can contaminate items incorrectly stored within the vicinity. Many sluices lack appropriate infection control governance including a flow from dirty to clean and appropriate storage facilities (Breathnach et al., 2012).

In general, anything which impairs wastewater drainage increases risk of dispersal of organisms. Non-biodegradable wipes frequently cause blockages of waste pipes in healthcare facilities. Incorrect disposal of items is further hindered by poor design/engineering practices such as incorporating 90° bends in the waste pipes from macerators (Weinbren, 2020).

Conclusions

Water services in intensive care units represent a risk to patients both from water quality arising from the outlet and the risk of dispersal of wastewater organisms. Intractable outbreaks with highly resistant organisms emanating from wastewater systems have been a driver for water free patient care. New guidance is urgently required to inform design in order to mitigate against these increasingly commonly identified risks.

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Research-based commentary

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Factors to consider in the safe design of intensive care units – Part 1: historical aspects and ventilation systems

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Abstract

Background: Evidence linking the role of ventilation systems in transmission of infection to patients in intensive care units has increased in recent years.

Aims: This research-based commentary set out to identify the historical aspect of intensive care unit design, current problems and some potential solutions with respect to ventilation systems.

Methods: Databases and open source information was used to obtain data on the historical aspects and current guidance in ICU, and the authors experiences have been used to suggest potential solutions to ventilation problems in ICU.

Findings: The authors found a number of problems with ventilation in ICU to which there has not been a cohesive response in terms of guidance to support users and designers. The resultant void permits new projects to proceed with suboptimal and designs which place patients and staff at risk.

Discussion: The NHS is now at the start of major new investments in healthcare facilities in England and this together with the end of the antibiotic era mandates new guidance to address these major concerns.

Keywords

Intensive care unit design, intensive care unit ventilation, healthcare ventilation

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Introduction

Historical and evolution of ICU design to control microbial transmission

The origins of the Intensive Care Unit (ICU) come from the concept of progressive patient care (Thoms, 1962). Clinicians in the 1950s described five basic elements of care, the first of which was the specialised intensive treatment for the critically ill (Thoms, 1962). Care for these patients had traditionally taken place in a small number of beds within an existing ward (Robinson, 1966). Early ICU's consisted of six beds surrounded by a centralised nursing area where equipment and drugs were stored with some units having single bed cubicles (Hamilton, WK, n.d.). Each hospital had to work out its own plan in relation to its own needs and the patient population served was emphasised (Thoms, 1962). Workshops developed the concept further and focused on cross infection, with every patient described as 'an exercise in bacteriologic control' (Hamilton, WK, n.d.). Routes of transmission including airborne were discussed, and removal of pathogens by an ultraviolet source or by ventilation systems was proposed. Air changes were cited as a requirement not just for comfort but for dilution of pathogens with 10 ACH/hr described as optimal (Hamilton, WK, n.d.).

Some of the earliest UK ICUs were constructed in the 1960s (Robinson, 1966). Early infection control measures included single rooms, designated nurses for each patient and removal of jackets and white coats on entry with gowns and footwear for each room. Rooms contained the

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required instruments, drugs and solutions and movement between rooms was minimised and ethylene oxide sterilisation of ventilators was undertaken with a positive pressure air gradient from the rooms to the corridor to reduce infection risk (Robinson, 1966). Two options were proposed 1) a normal ward type accommodation was provided over a large area with a limited number of isolation rooms and in the second, the design was based almost on single room accommodation with a stepdown area for patients whose nursing requirements were less (Robinson, 1966).

Over time, seven types of ICU layout were described, including the racetrack variety (in 12/19 ICUs) where the services were in the centre and patient beds in the perimeter (James and Tatton-Brown, 1986; Rashid, 2006). Advantages to the racetrack layout included maximisation of perimeter walls, natural light in patient rooms and reduced walking distances for staff. In one study, 32% (six of 19) had no isolation rooms (Rashid, 2006); and in another, 85% of ICUs (33 units) did not have a single room for isolation with 60 % having fewer than one washbasin per bed space, and the authors called for alterations to enable adequate hand washing to be carried out and for source isolation of infected patients (Inglis et al., 1992).

A task force published recommendations on minimal requirements for ICUs including an essential ratio of isolation rooms to common rooms of 1–2/10, two sinks in each room, elbow or foot operated taps and self-sterilising heat traps with storage areas 30m (max) away from the patient area and 5 m^2 per bed for consumables and equipment (Ferdinande, 1997). Recommendations were updated in 2011, with single rooms to reduce cross contamination and minimise stress from noise and activities, with some to be equipped as isolation rooms (Valentin et al., 2011). A separate circuit for evacuation of contaminated material in the room was also recommended as well as more detailed recommendations for waste disposal including a fluid disposal or bedpan flushing device available in each patient room or as part of an adjacent toilet (Thompson et al., 2012). However, bedpan washers may generate infectious aerosols so barriers or sealed models should be used to protect staff from exposure. Where fluid disposal was not available in the room, it should be provided in close proximity in the corridor (Thompson et al., 2012).

Methodology

A narrative review was performed using relevant search terms: intensive care unit OR critical care unit AND design OR design guidelines OR design criteria OR ventilation OR ventilation specification OR ventilation systems. The databases employed were PubMed, CINAHL, CDSR, DARE and EMBASE from ‘Jan 2000 to April 2022’ for guidelines, reviews and original articles detailing recommendations for intensive care settings. Published data were checked for additional references and duplicate publication.

Ventilation aspects of ICU design

Ventilation specification (HBN 04–02) guidance is available for ICUs (NHS England, 2021a); however, ventilation specification details are contained within an appendix (S) HTM 0301. Recommendations have evolved from specifications comprising 10 ACH/hr, a positive pressure of 15 pascals relative to the corridor and high hygienic demand SUP (Supply air category) 1 filtration (National Services Scotland, 2011). ICUs housing immunosuppressed patients require HEPA filtration in the isolation rooms. Clean and dirty utility areas should be designed with 6 ACH/hr. The dirty utility should be extract only and at a negative pressure to the corridor with the clean utility at positive pressure to the corridor and supply air.

ICU’s should be at a positive pressure relative to the external corridor to protect against contamination, especially due to *Aspergillus* spp. *Acinetobacter* spp and MRSA (Baddley et al., 2013; Ichai et al., 2020).

ICU ventilation is classed as critical and following initial commissioning and validation should be subject to annual verification(National Services Scotland, 2011). HTM 0301 introduces the Ventilation Safety Group whose remit is the operational management and maintenance of ventilation systems in addition to annual verification and performance testing (NHS England, 2021b). Saran et al., advocated six monthly checks on indoor air quality quoting an acceptable Index of Microbial air contamination (IMA) of up to 25 (10–39 cfu/dm^3/h) in ICU (Saran et al., 2020). This is based on the use of settle plates (1 hour) 1m from the floor and 1m away from walls/obstacles. The microbial count (cfu) is converted to an IMA value. For passive air sampling, five classes of IMA have been defined, representing an increasing level of contamination (Viani et al., 2020). Air quality checks are not current practice in UK units. The same review article found variation in international guidance regarding HVAC standards in ICU. With regards to filtration, only the Dubai Health Authority recommends the use of HEPA filtration in ICUs (Ichai et al., 2020).

Isolation rooms

HBN 04-02 specifies that no unit should have less than 20% of their beds as isolation rooms and ICUs in hospitals with neutropenic haematology patients may require up to 50%. Clinical input is essential in planning the number and type of isolation rooms. Final specification will depend on the patient population, demographics of the catchment area and

any specialist services (IHFG, 2017). HBN 04–02 is vague when describing the ventilation requirements for isolation rooms. It specifies single rooms should be provided with a system that can provide source and protective isolation with lobbies present (NHS England, 2021a). It proposes a balanced supply and extract ventilation to each isolation room and gowning lobby with the lobby functioning as an airlock. It recommends the lobby should have a high and balanced supply and extract air change rate to be effective against airborne organisms. HTM 03–01 provides information on the specification for negative and positive pressure rooms with regards to ACH/hr, pressure differentials and filtration in an appendix table. Other features include self-closing entryway with adequate seal, sealed floors ceiling walls and windows and a monitoring system (Al-Benna, 2021; NHS England, 2021b).

CDC guidance contains more specification for different isolation facilities with anterooms to accommodate immunosuppressed patients, airborne infections and those with requirements for both protective and source isolation utilising pressurised anterooms (CDC, 2019). HBN04-01 Supplement 1 describes detailed specification for negative pressure room facilities and positive pressure ventilated lobby (PPVL) rooms but cites critical care units as an exclusion for PPVLs (NHS England, 2013). Despite this, PPVL rooms are listed in the HTM 0301-part A as an option for isolation facilities in critical care areas (NHS England, 2021b). This appears contradictory and can cause confusion. Poovelikunnel et al. found evidence of efficacy of PPVL rooms for protecting at-risk patients from airborne infection as well as source isolation of those with airborne infections. However, this study evaluated just two rooms over a period of eight weeks and it is not clear if these rooms were within an ICU (Poovelikunnel et al., 2020). The authors highlight concerns regarding the reliability of negative pressure rooms based on the findings of a study undertaken during SARS-1 in Hong Kong where it was found that 60 % of ensuite facilities were operating at positive pressure and > 90% of the corridor-anteroom or anteroom-patient room doors had a bidirectional flow (Li et al., 2007). In an assessment of rooms designed to be negative pressure in the US, it was found that the direction of airflow in the negative pressure rooms was not always correct. In the seven hospitals assessed none had routinely assessed the efficacy of negative pressure rooms, this points to issues with validation and maintenance. 52/115 (45%) designated negative pressure rooms had positive airflow to the corridor. High-risk areas including ICU and emergency rooms were not equipped to provide respiratory isolation (Fraser et al., 1993). Due to ICU rooms electrical and medical gas requirements, isolation rooms can be difficult to seal resulting in the inability to control airflow and placing the patient or staff at risk. Isolation rooms within ICU should be subject to regular maintenance in the same manner as the unit as a whole, including permeability tests (Bartley and Streifel, 2010).

Future ventilation considerations

General specification and isolation rooms

ICUs would benefit from more bespoke and detailed guidance discussing the basic specification but also incorporating advice and specification of isolation rooms and how these should be incorporated into the design. Some background to formulation of the guidance for design teams, detailing how the specification arose and the patient risks would be beneficial. At present, it is not clear to the reader why there is a need for the higher air change rates and positive pressure compared to general hospital wards.

Clarity is required on the proportion and types of isolation rooms to be installed in ICU settings, and the role if any for positive pressure ventilated lobbied (PPVL) rooms in this setting. An understanding of the patient population is essential to determine types of rooms required. Whilst PPVL rooms provide both source and protective isolation, there are exclusions in guidance to their use in critical care areas including airborne infections and severe immunosuppression. The current PPVL with ensuite constitutes a risk in terms of little used water outlets as such facilities are rarely used by the patient. It is worth considering whether the PPVL design could be modified and used to advantage in an ICU setting by allocating the ensuite space for waste disposal, completely separating waste and macerators from the patient room.

Any isolation facility in ICU must be subject to regular maintenance and undergo annual verification including permeability testing (NHS England, 2021b). As such, ventilation safety groups should include all ICU settings on their verification programme. For isolation facilities, there should be visual displays of pressure and alarms for pressure failure with advice for staff on appropriate action should failures occur. Staff education regarding the different types of side room ventilation facility available and appropriate patient placement, is advised, particularly in units where there are different types of isolation rooms. Signage on isolation room doors might be useful in this regard.

Given the risk to ICU patients from fungal infections including *Aspergillus* spp (7% of cases) and Mucor, HEPA filtration of the unit is worth considering for future design as the incidence is likely to be higher (Baddley et al., 2013; Machado, 2021). Aspergillosis as a complication of influenza is well described in ICU patients and has been reported in association with COVID-19 (Montrucchio et al., 2021). In a recent Italian study of 12 ICU's, 12% of environmental samples (infusion pumps and patient tables) testing positive with *A. fumigatus* and the authors suggest surface sampling in preventing fungal infection as knowledge of fungi in the environment can guide prophylaxis treatment regimes (Prigitano et al., 2022). These findings support HEPA filtration as an additional prevention strategy and should be included in future guidance. Key considerations for ventilation in ICU are listed in Table 1.

Table 1. Key ventilation considerations for ICU settings.

Involvement of clinical teams from outset of design and consideration given to patient population and any specialist units
Air changes of 10/hour
Unit positively pressurised to the corridor (+ 10 pascals)
Filtration – SUP 1 but consider HEPA for the entire unit
Number of isolation rooms, type and proportion of isolation facility required, for example, positive or negative pressure rooms required
Dirty utility at negative pressure, extract only and 6 ACH/hour
Clean utility, positive pressure, supply only and 6 ACH/hour
ICU unit as a whole and each isolation room should be listed as a critical ventilation system and following initial commissioning and validation should be subject to annual verification
Hospital ventilation safety group to be involved in annual verification and any planned upgrades/refurbishments
Education of staff on type of isolation rooms available, consider signage where there are mixed facilities
Installation of visual pressure indicators for isolation rooms and an alarm system to alert to pressure failure

Challenges of COVID and future planning for pandemics

The COVID-19 pandemic highlighted the importance of ventilation in NHS estates. Many hospitals are equipped to deal with new and emerging airborne threats in having some negative pressure rooms, to deal with small case numbers, however, once epidemic/pandemic levels are reached, they are quickly overwhelmed.

Challenges emerge for ICUs admitting both COVID positive and negative requiring ICU care. Larger facilities with multiple ICU/HDU units may be able to dedicate one or more for COVID-19 patients. In a South Korean hospital, one of two ICUs was remodelled due to lack of capacity for isolation of COVID-19 patients (Lee et al., 2020). The unit was divided into a space with 1) isolation room plus anteroom accommodating three beds and 2) two pre-existing airborne isolation rooms. Negative pressure was created in the anteroom by adding temporary duct systems which were connected to a pre-existing exhaust system. The isolation zone had five mobile negative pressure air machines generating a negative pressure relative to the anteroom. A negative pressure gradient was maintained between the existing airborne isolation rooms and the anteroom using an air volume control damper.

For smaller hospitals with one ICU, a conversion of this sort may not be possible and thought needs to be given to conversion of an HDU or general ward to a temporary ICU which may make it difficult to meet ventilation specifications (Peng et al., 2020). Miller et al. described conversion of a ward to a negative pressure facility (Miller et al., 2021). A temporary anteroom was set up in one hallway and the other was sealed off from the rest of the hospital by closing fire doors. Adjustments to the HVAC system were made to create negative pressure (−29 pascal) across the closed fire doors using two HEPA filtered negative air machines. This setup was achievable because the ward had its own dedicated AHU, bathroom exhaust system and a firewall separating it from the rest of the hospital. Negative pressure was sustained for a period of 24 hours. Whilst achievable it is not transferable to all settings and in a pandemic situation there is a need for prolonged and sustained negative pressure.

Conversion of ICU facilities to negative pressure throughout is not without risk. In one ICU hospital, previous air sampling had not shown any evidence of fungi and the annual incidence of Aspergillus cases was low (< 2%). Two months after converting rooms to negative pressure, 6 of 26 patients developed probable or proven pulmonary aspergillosis and air sampling from rooms of the first four patient cases recovered *A. fumigatus* (National Services Scotland, 2011). Increasing the pressure to 1.2 +/− 1.5pa resulted in a reduction in the recovery of the *A. Fumigatus* (0–2 CFU/m^3) and the authors concluded that converting to negative pressure could have had unintended consequences and dispersed Aspergillus in dust from the false ceilings in the plenum spaces (National Services Scotland, 2011).

Consideration must be given to design of future ICUs with respect to pandemic preparedness. Units with 100% single rooms incorporating a PPVL design which would enable both protective and source isolation is an attractive option. Regardless, in a pandemic situation, surge capacity will also be required and consideration as to how this can be achieved without unintended consequences. A number of solutions for temporary isolation have been proposed. These include models that rely on air filtration/dilution, and those that rely on local exhaust ventilation (ASHE, 2020). These temporary facilities are unlikely to comply with guidance documents and may lead to contamination of clean areas and

compromise fire safety (ASHE, 2020). As such, these proposals should be risk assessed by the ventilation safety group prior to implementation.

Conclusion

We have discussed ventilation aspects of ICU design including future preparedness for pandemics. Despite ICUs serving different patient populations, there are many design features that remain common to all, particularly with respect to ventilation systems and isolation rooms. Present guidance is piecemeal, and conflicting, and more bespoke guidance would be beneficial.

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Research-based commentary

Journal of Infection Prevention

Implementing changes to reduce infections in ICU patients. Water services and waste systems

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Abstract

Background: Evidence linking the role of water services in transmission of infection to patients in ICUs has increased in recent years.

Aims: This research based commentary set out to identify potential solutions for water and wastewater systems in ICU settings.

Methods: Databases and open source information was used to obtain data on approaches to water and wastewater-related issues in ICU settings. This and the authors experiences have been used to describe approaches to these problems.

Findings: The lack of updated guidance has required some ICUs to develop unique responses, including 'water free' patient care combined with reduction in water services. The options consider guidance, compliance, training and education as key factors to successful outcomes and protecting vulnerable patients in ICU.

Discussion: The authors found a number of problems with water and wastewater systems in ICU to which there has not been a cohesive response in terms of guidance to support users and designers. The resultant void permits new projects to proceed with suboptimal and designs which place patients and staff at risk. As an interim measure a series of solutions suitable for existing units and new builds need to be considered.

Keywords

water systems, waste water, waterborne pathogens, biofilms, splashing

Introduction

Water-related healthcare acquired infections (HCAI) represent 22% of CDC investigations in the USA and *Pseudomonas aeruginosa* accounts for 1400 deaths per year in France. (Anaissie et al., 2002; Perkins et al., 2019) Extrapolating the USA data in Europe would equate to 8140 deaths every year as a result of waterborne HCAI in ICUs. The lack of sensitivity surveillance methods for environmental source infections (especially antibiotic sensitive strains) means that the link to water services often goes unrecognised. The upsurge in reported outbreaks with multidrug resistant organisms originating from wastewater in augmented care areas in recent years is a disturbing development. Yet, multidrug resistant organisms are not thought to possess any special adaptation to dispersal from wastewater systems and sensitive organisms have spread via this route undetected for years and HBN 04–02, critical care units has not been updated since 2013.

A study of ICU ward design and nosocomial infection rates in Germany did not include water or wastewater services and focussed instead on ventilation (Stiller et al., 2017). The substantial body of evidence of risk from water and wastewater services has failed to result in the publication of new guidance to challenge the enthusiasm for installing hand wash stations (HWS).

The assumption that change is not required in an ICU because there is no perceived transmission from water/wastewater is extremely dangerous.

New investments in healthcare facilities in England combined with the threat of AMR require urgent new

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guidance to influence future hospital design. This publication is designed to fill the hiatus and help stimulate and point.

Methodology

A narrative review was performed using relevant search terms: intensive care unit OR critical care unit AND design OR design guidelines OR design criteria OR water outbreaks OR water system design OR water free patient care, OR sinks/water/drainage OR wastewater. Pubmed was searched for guidelines, reviews and original articles detailing recommendations for intensive care patients. Published data were checked for additional references and duplicate publication.

Design teams, architects, engineers and clinical and infection control teams need to:

- Review of existing water/drainage services and implement change
- Review specialised water services and implement change.
- Reduce risk in the new build/major refurbishment projects (specifically advice for new projects).

All units should therefore carry out the following:

- **Gap analysis**
- **Evaluate interventions**
- **Assess and understand interdependencies**
- **Select preferred options**
- **Address guidance weaknesses**
- **Implement change**

Review of existing water/drainage services and implement change

Reducing microbial transmissions is very much dependent upon senior ICU staff taking ownership of the process, understanding the risks from water and wastewater, believing in the necessity for change and using their skills to empower and educate staff through the process.

Moving to a 'waterless patient care and reduced drainage unit' appears daunting. However, units can trial the concept prior to committing to removal of water/drainage services. For potential new builds, it is recommended they test waterless patient care in the existing unit and utilise their findings to influence the future design.

- Design issues with clinical hand wash station include pedestal mounted outlets, lack of hand free operation, insufficient activity space and water from outlet hitting drain.
- Location issues include oversupply (ie not used frequently), inappropriate placement, within 2 m of vulnerable patients or medical equipment.

Gap analysis

A multidisciplinary group (medical, nursing, infection control, estates, domestic services) is required to undertake a gap analysis including review of guidance and standards (BSI, 2022; DHSC, 2016). The gap analysis must include all water and drainage services including drug preparation areas, dirty sluice, work surfaces, storage of equipment within 2 m of any HWS and all routes by which water may reach the patient or their environment as well as staff training.

The gap analysis informs what changes are necessary to bring the unit in line with current guidance and needs to identify high risk findings relating to clinical HWSs, requiring immediate action/removal/replacement or mitigating factors such removal or insertion of splash screens.

Evaluate interventions

Key to implementing change beyond current guidance is recognising that clinical HWSs (or any water service), even when installed and set up correctly represents a significant risk to patient care. This is primarily due to staff interact with these services. Once this is appreciated the dialogue can move from 'we have to have a clinical HWS' to 'why do we need a HWS as the risk is too high?'

Kearney et al. ranked the effectiveness of interventions (Kearney et al., 2021). The most effective was to eliminate the hazard, that is, removal of the HWS and associated pipework followed by isolating or separating the hazard i.e. installation of physical barriers between patients and sinks or no sink proximity to patients. The second least effective was engineering solutions to prevent dispersal of contamination from drains which included sink design and disinfectant regimens. The least effective administrative control was policy guidelines and education, which is of concern as much practice is delivered by this route.

Grabowski's demonstrated that hand washing accounting for only 4% of activities at an ICU HWS, that is, 96 out of every 100 activities were for an inappropriate purpose, almost all of which place the patient at risk. New designs of HWS are available which offer to mitigate against many of the risks, but there is limited research as to their effectiveness. (Baillie, 2020)

Lowe et al. described an ICU outbreak caused by disposal of body fluids down HWS. (Lowe et al., 2012) However, the nurses in the ICU were required to walk past several rooms (and out of isolation rooms) to reach the dirty utility room which is clearly a risk in itself. As such the design of ICUs becomes critical for protecting patients from these risks. Poor design is a factor in non-compliance and needs to be reflected in guidance.

Is it realistic to expect that clinical and domestic staff will never contaminate the end of a water outlet? Once an outlet becomes contaminated there may be a direct route of transmission to patients. Even water testing of outlets is

subject to poor compliance, as the collection a true pre-flush sample, without which a false negative water sample is likely to be obtained is poorly understood.

The combination of the above with an insensitive surveillance system favours elimination of the hazard including clinical HWSs.

With emphasis on increasing numbers of clinical HWSs (over supply) and failure to identify the risks arising from them, staff require reassurance that their removal is safe. Institutes that have removed clinical HWSs have not reported any adverse outcome; in fact, some have shown reduced transmission events to patients (Hopman et al., 2017). Studies consistently show compliance with hand washing to be disappointingly low. Failure to comply with hand decontamination is complex but rarely to do with lack of availability of clinical HWSs. Alcohol gel is the preferred method of hand decontamination in the absence of visibly soiled hands or an organism resistant to alcohol.

Understanding interrelationships

The term 'water free patient care' is somewhat of a misnomer as it suggests that the quality of water from the outlet is the motivation for removing water services. The change has been driven by intractable outbreaks of highly antibiotic resistant organisms arising from wastewater systems (Carling, 2018; Eveillard et al., 2019; Feng et al., 2020; Kearney et al., 2021) necessitating removal of water and drainage services.

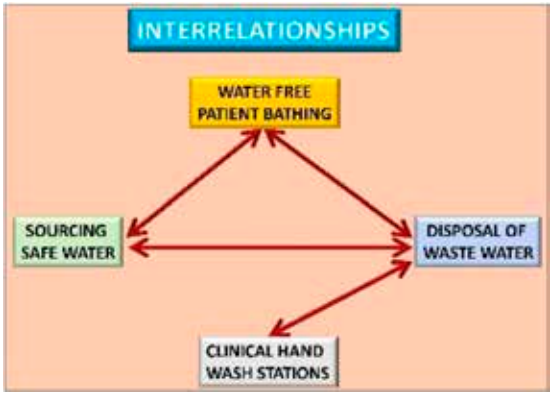
This then moves the focus on how to dispose of wastewater safely in the ICU. This is complicated by isolation room design lacking facilities for disposal of wastewater. Staff are required to walk the length of the unit to the dirty sluice (leading to poor compliance) in contrast to isolation rooms in medical wards which have ensuite facilities allowing disposal in the toilet.

The number of clinical HWSs, water free patient bathing, the need for sourcing safe water, disposal of wastewater/other fluids in patient room, and the requirement to walk to the dirty sluice are interrelated (Figure 1). Understanding the interrelationships is key as altering one component is likely to have a knock-on effect on other areas. For example, moving to water free patient bathing lessens the risk of disposing wastewater down the HWS and obviates having to source safe water for this purpose. (Groven et al., 2017; Veje et al., 2019, 2020)

Incorrect disposal of wastewater

Despite guidance, disposal of wastewater in HWSs on ICUs continues, is a common cause of outbreaks. (DHSC, 2016) In France ICU isolation rooms may contain two sinks, one for hand washing the other for disposal of fluids and has

Figure 1. Inter- relationships.



successfully reduced the level of HWS contamination. (Weinbren et al., 2021)

An alternative is to install small macerators in patient rooms or creating mini sluices within the isolation room which has allows disposal of all wastewater/waste within the room, obviating the need for staff to leave the patient room to walk to the dirty sluice.

Sourcing safe water for patient care

An unrecognised risk when collecting water for patient care, is when the receptacle contacts the drain thereby becoming a vehicle for transmission of wastewater organisms (Figure 2) as filling patient water jugs in a kitchen sink has caused CPE outbreaks (Decraene et al., 2018).

One hospital devised a support arm that could be raised or lowered to position bowls for filling so minimising risk of contact with the drain. (Figure 3)

Select preferred option

A systematic review concluded that there was limited moderate to high quality evidence that washing without water is not inferior to the traditional bed bath (Groven et al., 2017).

Various options of interdependencies and likely compliance are provided in Table 1.

The minimum of HWSs on an ICU will depend upon size of unit and preferred option adopted. In the first water free care ITU, a single surgical scrub sink was present in the main open part of the unit and a HWS in the dirty sluice (Hopman et al., 2017). A mobile HWS was available (requires effective decontamination) where alcohol resistant organisms were a concern.

For isolation rooms with a built-in lobby a single HWS in the lobby (none in room) should suffice.

Figure 2. Risk when collecting water for patient care.

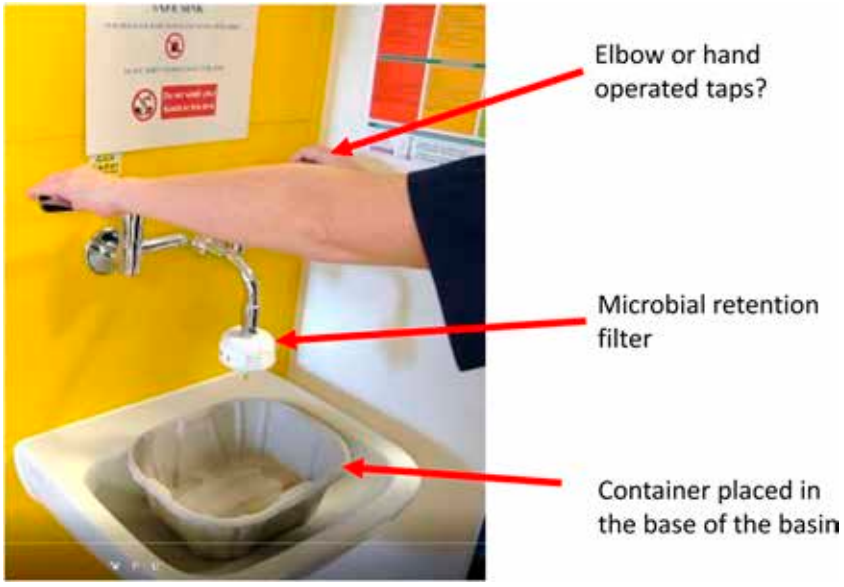


Figure 3. Use of a support arm. Note: This innovative design was developed at the Norfolk and Norwich University Hospital NHS foundation Trust by Sarah Morter and MarcLillystone

Address weakness in existing guidance and implement change

- Since HTM 04-01 was published where HWS are retained knowledge on reducing risk has increased and includes:
- Improving outlet cleaning compliance through engagement with cleaners so that they are aware of their work on patient safety and undertake audits.
- Consider drain enhanced decontamination through chemical or thermal disinfection.
- Prevent items from being thrown in to the HWS and empty waste-trap regularly.
- Reducing contamination of outlets;
- Consider regular in line thermal disinfection and outlet replacement as a preventative measure to combat local biofilm formation water outlet.
- Enhance water sampling regimen and ensure that true pre-flush samples are collected.
- Ensure infection control database includes full list of alert organisms.

B. High risk/specialised areas

Drug preparation requires full assessment and pill crushing devices, unless single use, should not be washed in tap water.

Table 1. Possible options with likely compliance, grey areas highlight risk of poor compliance.

Hand wash stations	Water free patient bathing	Requirement to access safe water safely***	Facility to dispose of wastewater in patient room **	Requirement to walk to dirty sluice*
HWS in bed space	NO	YES	NO	YES
			Provide extra sink for wastewater disposal	YES
			Install small macerator in the vicinity**	NO
HWS in bed space	YES	Minimal/no	NO	YES
			Small volumes may be disposed of in a container filled with absorptive granules	YES
			Install small macerator in the vicinity**	NO
HWS removed from area	NO	YES	NO	YES
			Provide extra sink for wastewater disposal	YES
			Install small macerator in the vicinity**	NO
HWS removed from area	YES	Minimal/no	NO	YES
			Small volumes may be disposed of in a container filled with absorptive granules	YES
			Install small macerator in the vicinity**	NO

*Requirement to walk to dirty sluice is for disposal of faeces/urine and other body fluids.
**Preferred option. (Ensure noise when in use not interfering with patient care. However, cycles are short and there should not be a requirement for frequent use. This could be overcome by having a small annex within room to house macerator. This area may also be fitted with ventilation extract as for PPVL rooms (see ventilation section).
***Requirement for collecting water without risk of receptacle making contact with drain and wastewater organisms.

The dirty sluice needs to be addressed as an area of concern and is covered in the gap analysis.

Other areas of concern include venous extracorporeal membrane oxygenation (ECMO), renal support in critical care, bottled water and plumbed in chilled water units, ice making machines (industrial ice making machines recommended in the HBN as opposed to HTM 04-01 which prohibits their use) and Blanketrol are not covered in this article but these risks must be addressed by the WSG.

c. Designing and constructing new units or installing new water or wastewater services

Ensure engagement and appointment of relevant staff to the water safety group with the necessary skills at inception of the project.

In a new unit it would make sense to keep waste drainage separate from drainage from HWSs and the kitchen area. For drainage to be effective, it requires adequate camber which should be checked during construction. Measures to prevent builders placing rubble down drains should be built into the construction programme. There should be adequate and easy access for rodding drains in the event of a blockage and this rodding equipment should be effectively decontaminated prior to being used elsewhere in the hospital.

Conclusion

There is now irrefutable evidence linking water and wastewater services to infections in vulnerable ICU patients. Government guidance is no longer up to date and healthcare institutions are implementing novel ways to control transmission of water and waste waterborne pathogens to vulnerable patients including 'water free patient care'. Water safety groups and senior management have a duty of care to safeguard patients by reviewing existing water/waste-water services and implement change and to reduce the risk in new build/major refurbishment projects.

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Bundle of documents for Oral hearings commencing from 19 August 2024 in relation to the Queen Elizabeth University Hospital and the Royal Hospital for Children, Glasgow

Bundle 18 – Documents referred to in the expert report of Dr J.T. Walker - Volume 2 (of 2)

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