HOW REAL TIME CONTINUOUS MONITORING OF TEMPERATURE AND FLOW EVENTS PRESENTS A NOVEL APPROACH TO ASSIST WITH WATER QUALITY RISK MANAGEMENT (WQRM)

Harriet Whiley, Jason Hinds, James Xi and Richard Bentham

1. Introduction

Opportunistic premise plumbing pathogens (OPPPs) are an increasingly significant public health issue [1-3]. In hospitals, it is argued that water distribution systems are the most important but overlooked source of hospital acquired infections [3]. Faucets and water distribution systems have been recognised as reservoirs and sources of infection for a wide range of pathogens including *Legionella* spp., *Pseudomonas aeruginosa, Aeromonas* spp.*, Acinetobacter* spp.*, Burkholderia* spp.*, Enterobacter* spp, *Flavobacterium* spp., *Serratia marcescens, Stenotrophomonas maltophilia* and non tuberculous mycobacteria (NTM) [3-5]. Extended hospitalization and even death are real outcomes of waterborne bacterial infection which pose significant risk to immune-compromised patients and increase the financial strain on our health systems. Therefore, it is imperative to consider how technology and data can reduce this burden through greater visibility of unseen risks and improve operational compliance to provide real time management of heath care facilities to prevent infections.

An established source of OPPPs in hospital and healthcare water distribution systems is the municipal potable water supplies [6, 7]. Once microorganisms enter a system they form, or are incorporated into, biofilm, a slimy matrix consisting of microorganisms, extracellular organic polymers and inorganic particles [4]. Biofilm build-up is a primary cause of decreased water quality [8] as it provides a nutrient source to support microorganism growth and protects them from disinfection strategies [9].

Biofilm formation is influenced by a range of environmental conditions including water temperature, disinfection type and residual, pipe materials and sizes, as well as temporal changes in water hydraulics and chemistries [2]. One of the most important factors promoting biofilm formation is stagnation arising from fluctuating water usage [10-12][9]. A previous study of residential properties found that microbial concentrations in the drinking water increase 2-3 times as a consequence of sitting stagnant in the pipes overnight [11].

Preventing stagnation in in premise plumbing water systems is arguably the most effective operational control and is widely recognised to reduce the risk of *Legionella pneumophil*a in potable water distribution systems [8].

Furthermore, a global recognised strategy in controlling the risk of *Legionella* is to frequently flush outlets to remove biofilm debris and introduce residual disinfection [13]. This view is supported within enHealth's 'Guidelines for *Legionella* control in the operation and maintenance of water distribution systems in health and aged care facilities' where it states '*low flow or stagnant water can provide conditions that contribute to the growth of Legionella*'[14]. Apart from improper plumbing installation and capping of pipework to form dead end and dead legs, another major contributing factor to water stagnation in premise plumbing systems is idle legs of pipe that are not regularly flushed due to unused taps and outlets. This concern has initiated the need for 'operational infrastructure controls' such as weekly flushing of all unused outlets to manage this risk.

Further to these guidelines, current regulations require 'verification monitoring' through regular microbial water

*Correspondence: Harriet.Whiley@flinders.edu.au ; Tel.: +61-8-7221 8580

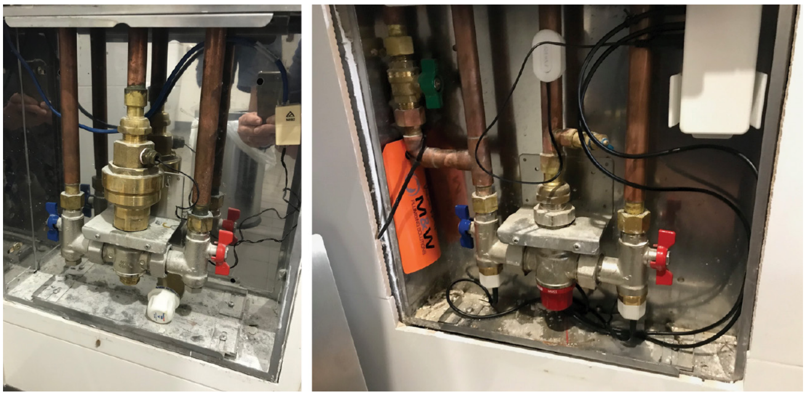

Figure 1: Images depict typical Aquablend TMVs with Smart Flow Monitoring system used within the study.

Figure 2 Monthly Ave 7 days consecutive of no/low flow + Monthly Ave 21 days + consecutive of no/low flow

testing to inform the management and treatment of warm water systems. However, there are many limitations associated with the standard culture method of detection, including the underestimation of viable but non culturable (VBNC) bacteria that exist undetected in the potable water system just waiting for favourable conditions to commence proliferation and the time delay from sampling to results. Current operational practices rely heavily on water sampling results to instigate any water quality rectification initiatives which are reactive and may underestimate potential risks [15].

As such, there is a need for novel approaches to better inform Water Quality Risk Management (WQRM) protocols and the use of water use monitoring technology and data to reduce operational costs and risks [6]. A case study investigating one such novel approach which utilised real time monitoring of temperature fluctuations in TMVs located in an Australian hospital to identify flow events was conducted by enware and has been published in the International Journal of Environmental Research and Public Health [16]. By investigating the associations with flow, temperature and microbial water quality, WQRM control interventions associated to stagnation and bacterial growth management were identified.

The study was conducted over 5 years within an old busy metropolitan hospital located in Sydney NSW containing 125 inpatient rooms spread over 12 floors. This study site had Enware's Smart Flow TMV monitoring system (Figure 1) installed that provided continuous monitoring of 220 TMVs (that supply 918 outlets) between 12/08/2013 until 22/05/2017, where the temperature of water output was collected and analysed. All temperature change events were monitored continuously at each fixture within the study at an accuracy of 0.5°C and a computer modelling algorithm was used to identify and separate flow events based on changes in temperature over time.

Initial analysis focused on determining the level of system stagnation that occurs naturally due to standard operational use. Using enHealth guidance associated to the flushing all outlets that remain unused for 7 consecutive days, our analysis determined that over a 3 year period, the rolling monthly average of stagnant fixture outlets was 33%. Further investigation proved that of these 33%, another 30% of these fixture outlets remained stagnant for 21 days or more (Figure 2). The identification of stagnant fixtures, including their location and functional application, was analysed further across all TMVs monitored, and provided inconsistent results suggesting fixture usage are not typical and are dependent upon variants in human behaviour. This identified a number of challenges. Within a large operational hospital, how do you determine what outlets remain unused and which ones to flush? Do we just make a blanket rule and flush every tap once a week? Is this a sustainable solution, it must waste huge amounts of time, water and energy? Who has the time and resources to ensure every tap gets flushed weekly?

An effective solution to these challenges is to use technology to collect the data needed to inform more sustainable and cost effective operational management. For example, if we compare a standard operational practise known as 'flushing Fridays' with flushing only unused outlets then we can calculate the potential saving in time, water and energy across that facility. If we assume the weekly flushing of 918 fixture outlets for 60 seconds can be reduced by 30% by only flushing the unused fixture outlets, then there is a reduction in approx. $40,000 in operational costs per year plus approx. 4000 litres of cold and heated water which has a significant impact of the facilities sustainability.

Following the system stagnation study, the TMVs monitoring data was analysed and broken into flow/flushing events greater or less than 15 second duration. The analysed data was separated into different categories according the flow (flushing) frequency:

- Total flushing events on day of sampling
- Total flushing events less than 15 seconds duration on day of sampling
- Total flushing events longer than 15 seconds on day of sampling
- Total flushing events during the 3 days prior to sampling
- Total flushing events during the 7 days prior to sampling

The total flow (flushing) data was compared against 865 water samples were collected from faucets attached to TMV during the study period, as part of hospitals mandatory verification monitoring program in accordance with NSW Code of Practice for the Control of Legionnaires' Disease (2004). Of the water samples collects, there was a total of 629 (73%) positive for total heterotrophic bacteria at a range of 1-52000. Further to this, there was only 4 (0.5%) samples positive (limit of detection 10 CFU/mL) for *L. pneumophila* and all four were serogroup 1. No samples were positive for *Legionella* spp other than *L. pneumophila*. All four water samples were also positive for total heterotrophic bacteria and concentrations ranged from 690 CFU/mL to 14000 CFU/mL.

The comparative analysis results demonstrated that the temperature of the water at the sampling locations ranged from 25.0°C to 89.0°C; however, the median temperature was 25.7. There were a total of 1369 flow/flushing events on the days of sampling in which 730 were less than 15 second in duration, while 639 greater than 15 second in duration.

As the number of flushing/flow events on the day of sampling increased there was an initial increase in total heterotrophic bacteria observed. This possibly could be attributed to biofilm detachment caused by sheering [17]. However, after 5 flushing events there is a decline in total heterotrophic bacteria which plateau after around 10 flushing events. Further data analysis revealed a significant correlating relationship between the total number of flushing event greater than 15 seconds and total heterotrophic bacteria. Statistically the data also demonstrated a significant relationship between the concentration of total heterotrophic bacteria and number of flushing events seven days prior to sampling, with increased flow events associated with decreased concentrations of heterotrophic bacteria.The data also revealed a close relationship between temperature and the total heterotrophic bacteria with lower temperatures associated with higher heterotrophic bacteria).

This case study demonstrates the effectiveness of this novel approach for monitoring building water quality using real time surveillance of temperature and flow events to assist with WQRM [16]. This real time monitoring approach was validated by the statistically significant association of

Unused Fixture Outlets Flush Requirement

Activity	Description	Unit	Frequency Manual Best Practise	Rate	Process	Manual Flushing Friday Practice	Smart Flow^{TM} enabled system
Weekly Flushing of Outlets in accordance with your Water Risk Management Plan (including administration)	No. of Fixture outlets x 1 minutes per outlet @ $70/hr.	0.0168	52	$70.00	Smart FlowTM records flow automatically. (On Average 70% of valves do not require flushing)	$56,138	$16,841
Energy Savings	Taking 0.195Kwh to heat 3 litres of heated water per fixture outlet per week @ $0.33 per Kwh.	0.195	52	$0.33	70 % reduction in Heated Water usage.	$3,072	$922
Monetary Water Savings	6 litres per Unused fixture outlet weekly flush @ $2.35 per Kl water Cost.	6	52	$0.0024	70 % reduction water usage.	$673	$202
				Total Annual Flushing Compliance cost:		$59,882	$17,965

increased heterotrophic bacteria observed at sampling point with few flushing events and low temperatures. This would enable corrective action to be taken much quicker compared with waiting for the microbial water quality test results to be received, reducing the risk to patients.

Although, in this study there were not enough *Legionella* positive samples for statistical analysis, previous studies have demonstrated *Legionella* concentrations to be positively associated with total heterotrophic bacteria at 22°C and 37°C, but not at temperatures above 55°C [18].

This study also found the increased flushing events was associated with increased water temperatures and increased bacteria concentrations were associated with lower water temperatures. There is an observed relationship between the influences of flushing events and temperature at faucets on microbial water quality. This study validated a remote monitoring strategy that can be used to ensure good thermal control and minimise stagnation occurring at outlets within potable water systems. The biggest advantage with the real time monitoring strategy is that it can be used to inform WQRM operational controls and significantly reducing operational costs associated with flushing of unused outlets. The study has demonstrated use of technology and data is an efficient means of identifying high risk areas within the water distribution system in real time and ensure system stagnation is avoided. It has the real opportunity to complement, and reduce the reliance, on microbial testing, which has limitations due to cost, is time consuming and the detection methodology increases the risk of cross-contamination or loss of culturability [21, 22].

The full article presenting this study can be found: https://www.mdpi.com/1660-4601/16/8/1332
Whiley, H.; Hinds, J.; Xi, J.; Bentham, R. Real-time continuous surveillance of temperature and flow events presents a novel monitoring approach for hospital and healthcare water distribution systems. International Journal of Environmental Research Public Health 2019, 16, 1332.

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