



¹Aquatools Inc. - 233 S. Wacker Drive, Chicago IL 60606, USA
Call us: +1 872 261 1554 – sales@aquatools.us

²Pace Analytical - 1401 Forbes Ave # 401, Pittsburgh, PA 15219, USA

³AQUATOOLS - 18, rue du Maréchal Foch – 80130 Friville – France



A Multi-Barrier Approach to Waterborne Pathogen Control in Healthcare Facilities

Authors: Pascal Bru¹, Abraham C. Cullom², Ashley King², Delphine Bussiere³

Introduction

Every day, modern healthcare facilities wage a silent war against an invisible enemy hiding inside their own walls. While medical teams focus on clinical care, Opportunistic Waterborne Pathogens (OWPs) thrive within complex premise plumbing networks. Protected by biofilms, these pathogens can resist municipal treatment and chemical disinfectants. For vulnerable, immune-compromised patients, a simple exposure to tap water or medical aerosols can transform a place of healing into a source of severe, high-mortality healthcare-acquired infections. Relying on a single line of defense, like routine flushing or basic temperature control, is an invitation for systemic failure because any interruption in that measure leaves the system vulnerable to pathogen growth and exposure, especially in complex healthcare water systems. Managing this threat demands a «defense-in-depth» approach, combining multiple complementary measures to reduce pathogen growth and exposure throughout the entire water system, from design to point-of-use.

This article examines the strengths and limitations of common water management strategies, including flushing, temperature control, secondary disinfection, and point-of-use filtration. Because each control has inherent limitations, effective risk reduction requires a multi-barrier approach that combines multiple complementary strategies to minimize patient exposure to waterborne pathogens.

Common Opportunistic Waterborne Pathogens

Healthcare-acquired infections (HAIs) are a continuing public health concern. One source of HAIs is opportunistic pathogens, which most commonly infect those with underlying illnesses or a weakened immune system. Though less conventional monitoring targets in water systems, they represent a much larger disease burden than traditional enteric pathogens (Figure 1). Numerous waterborne bacteria that reside within the potable cold and hot water networks in buildings are opportunistic waterborne pathogens. Some common OWPs include *Legionella pneumophila*, *Pseudomonas aeruginosa*, Nontuberculous Mycobacteria (NTM), *Acinetobacter spp.*, and *Stenotrophomonas spp.* These organisms are well documented in healthcare plumbing systems and HAIs. For these reasons, control of OWPs in healthcare building plumbing is an area of growing concern.

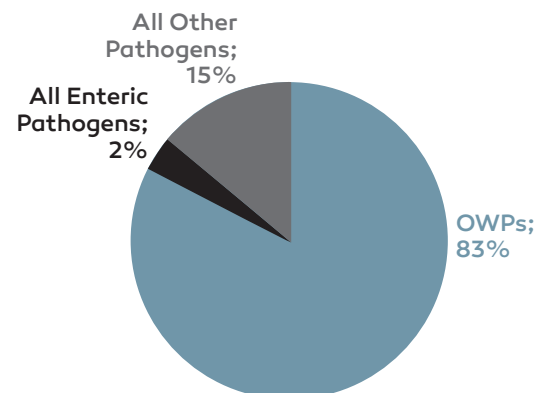


Figure 1. Share of Waterborne Deaths Associated with Pathogen Classifications in the US. Source: Collier et al., 2021.

The cost burden and mortality rate associated with OWPs are substantial. In the United States, Legionella alone is estimated to account for 11,400 hospitalizations and \$400 million per year in direct healthcare costs. Healthcare-acquired Legionnaires’ disease has a mortality rate as high as 20-30%. For other OWPs, the burden of infection is surprisingly similar to or even greater than that of Legionella, as reflected in Table A. For example, 2014 CDC estimates attributed approximately 51,400 annual U.S. waterborne hospitalizations and \$1.53 billion in direct healthcare costs to NTM infections, compared with 10,800 hospitalizations and \$402 million for Legionnaires’ disease and 15,500 hospitalizations and \$453 million for Pseudomonas pneumonia.

Most OWPs persist within biofilms and free-living amoebae, which provide nutrients and protection from disinfectants and environmental stressors. Approximately 90% of bacteria in water systems exist within biofilms rather than the bulk water. OWPs often persist despite flushing, disinfection, temperature control, and fixture sanitization, requiring ongoing control measures. Many are resistant to one or more chemical disinfectants. Some OWPs, such as NTM and P. aeruginosa are especially resistant due to their propensity to form complex biofilm structures and their environmental adaptability. Both groups also feature prominent antibiotic-resistant strains, greatly complicating treatment.

Table A. Comparative Analysis of OWP Estimated Annual Disease Burden in the United States. Source: Collier et al., 2021.

Disease or syndrome	Estimated total cases	% Waterborne Infections	Domestic waterborne hospitalizations	Direct healthcare cost, millions
Legionnaires’ disease	11,400	97%	10,800	\$402
Pseudomonas pneumonia	31,700	51%	15,500	\$453
Nontuberculous mycobacteria infection	97,000	72%	51,400	\$1,530

Estimates represent annual disease burden in the United States attributable to waterborne transmission and were adapted from Collier et al. (2021). Hospitalizations represent estimated cases associated with waterborne transmission rather than total hospital admissions.

Building Factors Promoting Pathogen Growth

The environmental success of OWPs is due to multiple building factors, including building size, age, and the presence of green building features or water saving devices (Figure 2). Oversized plumbing systems, reactive pipe materials, low disinfectant residuals, sediment accumulation, and stagnation all promote biofilm growth and OWP persistence. While high velocity helps maintain clear pipes, low pressure encourages sediment accumulation and biofilm growth. These conditions can be worsened by green design components such as low-flow and automatic sensor fixtures, which further reduce hydraulic pressure and water usage.

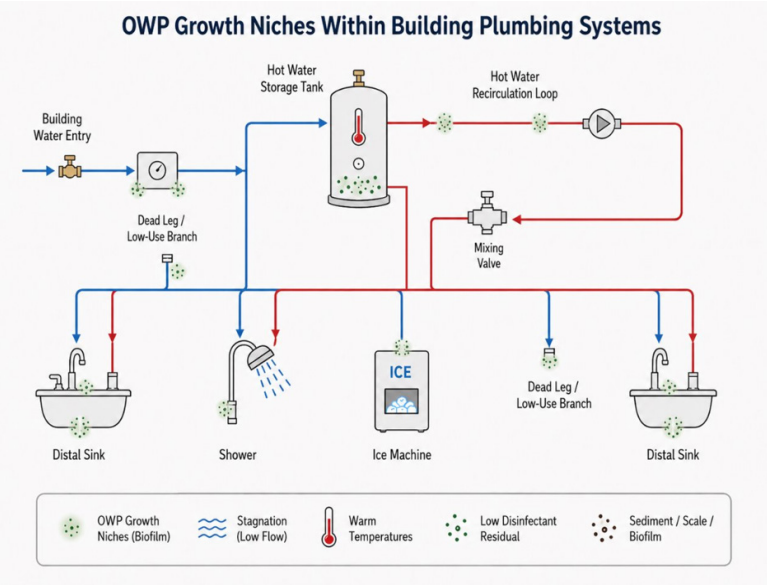


Figure 2. Opportunistic waterborne pathogen growth niches within building plumbing systems

Pipe materials can limit or increase pathogen growth through complex interactions with the incoming water chemistry. For example, plastic pipes have a relatively low disinfectant demand but can contribute nutrients by leaching organic carbon. Both copper and iron provide key micronutrients, but many studies show copper as having antimicrobial properties, though perhaps dependent on specific water quality criteria. Iron, unlike plastic, has a high disinfectant demand and degrades chlorine and monochloramine. Iron also contributes to scale formation, particularly in aging pipes, on which biofilms thrive.

Construction and renovation can increase exposure to OWPs. These activities are often associated with periods of low or intermittent water use, resulting in further stagnation. Cutting into pipes or causing vibrations can disturb sediment and biofilm. Biofilm shedding can occur, releasing bacteria into the water. Even limited activities such as replacing or adding new pipes, fittings, and storage tanks can introduce

contaminants, including dust and debris from building construction. After renovation, waterborne pathogens can colonize stagnant water in abandoned piping and further contaminate the water system.

In addition to building conditions, biological factors within the premise plumbing system can influence pathogen growth as microbial organisms compete for nutrients and amoeba hosts and engage in predatory behavior. Many OWPs thrive in niche microbiomes, preferring specific temperature ranges and amoeba species as hosts. The interactions between pathogens, plumbing materials, and water chemistry create a unique challenge for facility managers.

Water Management Programs as a Risk Framework

Water management programs provide an individualized framework for minimizing the risk associated with OWPs in building water systems. ASHRAE, CDC, CMS, and the Joint Commission have established a set of standards, tools, and requirements to ensure facilities implement effective water management programs. These documents seek to help facilities understand and assess building risk factors to develop a tailored strategy for minimizing pathogen growth.

ASHRAE Standard 188 Legionellosis: Risk Management for Building Water Systems defines the minimum requirements for a water management program, while ASHRAE Guideline 12 provides detailed information on how best to implement these requirements. The CDC Toolkit, *Developing a Water Management Program to Reduce Legionella Growth and Spread in Buildings*, along with associated CDC Checklist for healthcare water management programs includes additional guidance for implementing an effective and compliant program.

More recently, CMS and the Joint Commission have introduced their own documentation. CMS requires healthcare facilities to conduct a risk assessment to determine where OWPs can grow and spread in the water systems and to implement a water management program which considers the ASHRAE standard and CDC Toolkit. The Joint Commission standard, which took effect in 2022, similarly requires healthcare facilities, specifically hospitals, critical access hospitals, and nursing care centers, to develop a water management plan which addresses Legionella and waterborne pathogens.

While the guidelines provide a general structure, many solutions exist. Implementation is contingent on numerous factors, including building size, use, occupancy, and budget. Since all buildings are unique in their design and risk factors, an effective water management program begins with a water system and building occupant survey to identify opportunities for pathogen growth and infection risk. The water management program should include both verification monitoring procedures to ensure control limits (e.g. temperature monitoring) to minimize pathogen growth are met, and validation monitoring (e.g. microbial testing) procedures which confirm the program is working as intended.

Water management plans are a living document. Ongoing program validation should be used to evaluate program effectiveness, guide updates to procedures, and communicate necessary changes to water management stakeholders.

Why Single Interventions Often Fail

The primary barriers utilized in water management include routine flushing, temperature regulation, secondary disinfection and filtration. Each method, while offering some degree of control, has advantages and disadvantages (*Figure 3*). Buildings might also face operational challenges due to building hydraulics, system components, and staffing.

Flushing and temperature control require the least additional equipment. Flushing, while simple, is tedious to implement and provides only a temporary solution. Temperature control is an important barrier but maintaining target temperatures throughout large and complex plumbing systems can be challenging. Secondary disinfection can be highly effective, but its performance is influenced by system hydraulics, water chemistry, and pathogen-specific susceptibility. Point-of-use filtration provides a highly effective final barrier but only protects the fixtures where it is installed and does not directly address the conditions contributing to OWP growth.

Implementing single interventions to minimize waterborne pathogens in premise plumbing systems often fails, requiring a more robust approach to control growth. Reducing stagnation and water age is crucial to minimizing microbial growth, but flushing alone might not be enough long-term in the absence of sufficient disinfectant residual or temperature control. Likewise, secondary disinfection and temperature control measures are ineffective without movement of fresh water through the system. Ideally, a water management program ensures movement of fresh water through the system, adequate disinfection residual, and appropriate water temperatures.

The Multi-Barrier Approach

System Design and Commissioning

OWP control begins well before patients step into a building, or ideally before the building even exists. Effective mitigation requires a fundamental design philosophy of system minimization and material optimization. Historically, commercial plumbing systems were oversized to accommodate unrealistic peak demands, resulting in excessive water age, low flow velocities, and rapid disinfectant decay. Modern OWP-conscious design mandates “right-sizing” the entire piping network to maximize water velocity and ensure rapid turnover. Furthermore, engineers must specify plumbing materials that mitigate biofilm adhesion and withstand high-temperature or chemical disinfection protocols.

Dead legs are stagnant sections of pipe where water does not flow, creating a severe hazard. Stagnant water quickly loses its disinfectant residual and shifts toward ambient temperatures, creating an ideal breeding ground for biofilm and dangerous pathogens like Legionella. To eliminate this risk during the design phase, engineers must eliminate capped mains, long runouts to low-use fixtures, and unnecessary bypass lines. During commissioning, teams must verify that all temporary construction caps are removed and that all fixtures are aggressively flushed before building occupancy.

Physical accessibility dictates whether an OWP management plan succeeds or fails over time. If crucial components like valves, sensors, and sampling ports are hidden behind permanent drywall, issues remain hidden, maintenance teams will skip routine testing and remediation. Designing for safety means installing dedicated, clearly labeled access panels for all thermostatic mixing valves, balancing valves, and digital sensors.

Hydronic balancing ensures uniform water temperature and pressure throughout the entire building infrastructure. Unbalanced loops create low-flow or stagnant zones where hot water cools down directly into the OWP proliferation range of 68°F to 122°F. Engineers mitigate this by specifying self-balancing, thermally actuated valves that automatically adjust flow based on real-time return temperatures. Commissioning agents must then perform rigorous temperature mapping across all risers to confirm that the hot water return loop consistently maintains its target temperature.

Construction staging and commissioning are critical to preventing OWP colonization before occupancy. During construction, stagnant water in unfinished piping poses severe biological risks. Implementing periodic biological testing, such as Heterotrophic Plate Counts (HPC) or targeted OWP assays, establishes baseline water safety and identifies early contamination. To maintain water velocity and disinfectant levels, teams must execute structured, documented flushing practices across all outlets. Finally, prior to handover, the entire plumbing system requires effective chemical disinfection—typically through hyperchlorination—followed by rigorous confirmatory testing to verify pathogen control before the building opens to the public.

Figure 3. Coverage of Common Risk Management Strategies for OWP-Growth Risk Factors

Barrier	Water Age	Biofilm	Temperature	Absence of disinfectant	Exposure
Flushing	High	Low	Moderate	Moderate	None
Temperature	None	Low	High	None	None
Secondary Disinfection	None	Moderate	None	High	None
Point-of-use (POU) Filtration	None	None	None	None	High
Validation Testing					

Flow and Stagnation Management

Stagnation and low-flow conditions typically increase OWP numbers through multiplication and migration from the biofilm once nutrients are depleted or the local carrying capacity is reached. Thus, a necessary condition of nearly any OWP control plan is sufficient water flow. Unfortunately, there is no consensus definition of 'sufficient' here. A minimum weekly flow is commonly stipulated, but the utility of this has been disputed. Additional flow varies in the shear stress it applies, nutrients it delivers, or disinfectant it applies from building to building and pipe to pipe. Thus, sufficient flow should be operationally defined by direct observation of the target organism within each area of a water system.

Commonly, flow intervention means manual, routine flushing performed by housekeeping or facility staff. While straightforward, this is labor intensive to scale in response to increased OWP presence or reduced occupancy. Engineering interventions can lighten this load. Centralized auto-purge valves on return lines, risers, or even water entry can reduce the average water age in a system and increase the efficacy of downstream flushing. To limit water age at outlets, though, specialized outlets must be installed. These may be programmed to flush after a fixed time or after an amount of time without use. Whichever approach is selected, it is important to consider how it will interact with the other barriers considered below.

In water-stressed regions, there is a reasonable objection to additional water used for flushing. Here, additional interventions like secondary disinfection and higher temperatures can increase the efficacy of each individual flushing event and may reduce the overall water need. However, it is important to consider that water used to safeguard the patient environment is not wasted.

Temperature Control

Legionella is capable of growth between 68°F and 120°F, with optimal growth between 77° and 113°F. Maintaining potable water temperatures outside of this range, where possible, is central to Legionella control. For cold water systems, this principally means avoiding or identifying cross connections. However, in areas with warm source waters and/or warm climates with shallow main installation depths, cold water may still enter this range. These conditions should be identified so that these systems can be appropriately targeted for monitoring and control measures. Legionella growth is much more common in hot water systems where water is either not heated sufficiently or allowed to cool into this tepid range during distribution. To mitigate risk, water should be heated to ≥140°F and distributed at ≥120°F. Ensuring hot water delivery is a continuous process involving routine temperature monitoring and adjustments to equipment set points, circulation, and/or routine flushing measures in response to that monitoring. Where codes or regulations prohibit such hot water temperatures, other measures should be considered in lieu of temperature control. Since water temperatures can fluctuate over time, maintaining the required temperatures in distal piping and fixtures can be challenging.

Secondary Disinfection

Secondary, or supplemental, disinfection systems apply a chemical to a central water line so that it may be carried to all outlets served by that line. Depending on the risk profile of the facility and chemical, these systems may be applied to the hot or cold water side, and to the entire water system or only a portion of it. The effectiveness of these systems for OWP control is supported both by peer-reviewed literature and field experience.

Common choices of secondary chemical disinfectants include chlorine, chlorine dioxide, monochloramine and copper-silver ionization. Chlorine, while most affordable, is effective only within a specific pH range and achieves limited biofilm penetration. Additionally, chlorine degrades quickly in hot water and can corrode piping. Chlorine dioxide, though more effective than chlorine at penetrating biofilm, has similar drawbacks: It is not universally pipe-friendly and degrades rapidly in hot water. Monochloramine is stable, effective at penetrating biofilm, and holds up in high water temperatures. However, it is also less effective against certain pathogens, such as NTM. Copper-silver ionization (CSI) releases antimicrobial copper and silver ions into the water system. While CSI can be effective for *Legionella* control, performance strongly depends on water chemistry, such as pH. Water flow conditions and interactions with pipe materials and sediment must be evaluated. Facilities must consider budgetary constraints, pathogens of concern, and how disinfectants interact with water chemistry and system materials.

All of the above treatment approaches have practical and regulatory limitations. Chemical disinfectants are subject to regulatory limits governed by the EPA and Safe Drinking Water Act, and the chlorine-based disinfectants will generate regulated disinfection byproducts, though not necessarily to harmful levels. Some disinfectants may also accelerate corrosion or material degradation, increasing sediment accumulation, disinfectant demand, and biofilm habitat within the piping system. Moreover, a protective residual at the point of application does not guarantee patient safety. The activity of these chemicals is not conservative, so low flow or stagnant conditions may limit disinfection activity. Thus, these systems require adequate water flow and monitoring, which can be done in conjunction with stagnation mitigation and temperature monitoring activities. Also, water treatment equipment, like softeners, can reduce the effectiveness of secondary disinfectants if interactions between the two are not properly considered. Finally, these systems do not eliminate the need for target monitoring, especially because any given disinfectant will have differing efficacy for different OWPs. Active maintenance and rapid response to failures are essential parts of using these systems. In our experience, the reliability of the water treatment partner is as important to the success of this barrier as the individual choice of chemicals or equipment.

Point-of-use filtration

Point-of-use (POU) filters, particularly microbial exclusion filters with a pore size of 0.2 microns or smaller, physically exclude harmful bacteria from the water stream at sinks and showers, significantly reducing microbial exposure from that outlet when properly selected, installed, and maintained.

Point-of-use filtration is especially valuable because it provides an immediate, effective barrier exactly where water is used, making it an essential control for outbreak response and a proactive safeguard for immunocompromised patients. As shown in the publication *Point-of-use filters for prevention of health care-acquired Legionnaires' disease: Field evaluation of a new filter product and literature review* (Parkinson et al., 2020), POU filters are well suited for temporary use during outbreak investigations or when additional protection is required. For example, POU filters may also be used where the susceptibility of the population or risk of contamination is especially high (e.g., burn units, oncology wards, transplant units, NICU) or greater than that found in the rest of the water system (e.g., mixed-use facilities where healthcare services are only provided in a small part of the water system).

Careful monitoring and maintenance, too, are central to successful applications of this barrier, which includes tracking, inspecting, and changing filters according to the filter life span. Water quality may influence how frequently the filters must be replaced, and excessive sediment can clog membranes. Choosing the correct filters and where to implement them is essential. It should be noted that their predominant failure method (clogging) is fail-secure rather than fail-safe, because clogging generally reduces flow rather than allowing unfiltered water to pass, depending on product design. This makes POU filters distinct from all other control methods discussed above. Filter fouling can also affect usability and flushing practices, so POU filtration should be implemented in coordination with broader flow management and water management program activities.

Point-of-use filtration provides a highly effective final barrier, and its performance depends on selecting the appropriate filtration technology for the application. Facilities should consider factors such as membrane design, bacterial retention capability, flow performance, and resistance to clogging or retrograde. Advances in membrane design, including hollow fiber membrane technology, and retrograde contamination control have significantly enhanced the reliability and performance of point-of-use filters.

Validation Testing

Most hospital buildings are comprised of thousands of feet of pipe, occupied by perhaps hundreds of millions of OWP cells. Even the most active, robust water management team is dwarfed in scale. Thus, all of these defenses should be validated through environmental sampling for OWP. The true objective of this is to test whether or not our beliefs about the water system and our chosen interventions are correct, something we can never be sure of a priori, in the face of such complexity.

Environmental testing serves as a proactive defense mechanism, evaluating water safety before pathogens reach vulnerable patients, whereas clinical testing only identifies system failures after an outbreak has already occurred. However, relying on a single target screening, such as testing exclusively for *Legionella pneumophila*, fails to validate the control of multiple OWPs. Different OWPs thrive in distinct niches and possess varying resistance to disinfectants, meaning a system clear of one may still harbor another.

Compounding this challenge is the fact that regulatory guidance on monitoring OWPs other than *Legionella* is sorely lacking, leaving infection preventionists with few standardized protocols for emerging waterborne threats.

To overcome this gap, hospitals should transition from a broad, non-specific screening approach to a targeted, routine monitoring program. By identifying the specific baseline pathogens native to the facility's local water supply, teams can establish actionable triggers and tailor their ongoing validation efforts to the highest-risk organisms.

Conclusions

A single broken link in a building's plumbing system can compromise patient safety, highlighting why isolated engineering interventions routinely fail. Safeguarding a healthcare facility from OWPs requires a coordinated, multi-barrier strategy where no single control stands alone. Within that framework, basic controls such as water movement and temperature management are essential, secondary disinfection provides additional treatment benefits, and point-of-use filtration acts as the final protective barrier to help ensure water safety at the point of use. By stacking defensive layers, facilities can create an unforgiving environment for biofilm and bacterial colonization. This defense-in-depth framework must be actively verified and validated through targeted environmental monitoring to ensure every barrier holds firm over time.

Take Action Now: Do not wait for a positive clinical culture to reveal a systemic vulnerability. Convene your multi-disciplinary water management team today to execute a comprehensive building and occupant risk survey. Audit your current flushing schedules, test your residual disinfectant levels, and establish automated validation protocols. Transition your facility from reactive remediation to proactive, multi-layered defense to neutralize waterborne threats before they ever reach a vulnerable patient.

About AQUATOOLS: *AQUATOOLS is a manufacturer and supplier specializing in advanced water filtration solutions, including medical-grade point-of-use and inline filters designed to control waterborne pathogens in healthcare and other high-risk environments. Their products are used globally to help reduce the risk of healthcare-associated infections by providing a final barrier against bacteria at the point of use.*

About PACE ANALYTICAL: *PACE (Pace® Analytical Services) is a leading provider of environmental and water safety services, including water management planning, risk assessments, and laboratory analysis for waterborne pathogens such as *Legionella* and nontuberculous mycobacteria. PACE supports healthcare and other organizations in developing and implementing water safety and management plans, ensuring compliance with industry standards and regulations, and providing expertise in infection control risk assessment and emergency response.*

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About the Authors

Pascal BRU is the Vice President of Operations at Aquatools Inc., a company specializing in water hygiene solutions for healthcare facilities and public buildings. Based in Chicago, Illinois, he has held this position since September 2023. Before joining Aquatools, he held several roles in business development and served as an International Sales and Marketing Director, with a focus on scientific equipment for the healthcare and chemistry markets.

Dr. Abraham Cullom (abe.cullom@pacelabs.com) is the Director of Water Safety and Management at Pace Analytical. His peer-reviewed research has elucidated the impact of the in-building plumbing environment on opportunistic pathogens, antibiotic resistance, and microbial ecology. His work translates insights from engineering, microbiology, and chemistry into practical solutions to end Legionnaire's disease.

Ashley King is a Water Management Specialist for Pace Analytical, where she helps clients understand and mitigate risks associated with Legionella and other waterborne pathogens. She supports building water system assessments, water management program development, and implementation of practical control measures to improve facility water safety. Ashley earned a Bachelor of Science in Environmental Studies from Portland State University.

Delphine Bussiere is the Marketing and Communication Director at AQUATOOLS, where she has held this role since July 2019. In this position, she supports the communication of water hygiene solutions for healthcare and other sensitive environments, and she is committed to providing technical and scientific support to promote best practices in infection control and water safety.