Industrial Revolution

Every home that is built is a representation of compromises made between different and often competing goals: comfort, convenience, durability, energy consumption, maintenance, construction costs, appearance, strength, community acceptance, and resale value. Consumers and developers tend to make tradeoffs among these goals with incomplete information which increases risks and slows the process of innovation in the housing industry. The slowing of innovation, in turn, negatively affects productivity, quality, performance, and value. This department piece features a few promising improvements to the U.S. housing stock, illustrating how advancements in housing technologies can play a vital role in transforming the industry in important ways.

Premise Plumbing Decontamination Research in EPA's Homeland Security Research Program

Jeff Szabo
U.S. Environmental Protection Agency

Introduction

The U.S. Environmental Protection Agency's (EPA's) Homeland Security Research Program (HSRP) conducts research to detect, respond to, and recover from the impacts of terrorist attacks, accidental contamination, and natural disasters on the nation's water and wastewater infrastructure. For many years, the HSRP has worked with the water sector on research to address high-priority needs, such as decontamination of drinking water distribution systems, after an intentional or unintentional contamination event. Decontamination research in the HSRP has historically focused on the water distribution infrastructure owned by water utilities, such as the large-diameter pipes that convey water from the treatment plant to communities and above-ground water storage tanks.

However, if a water distribution system is contaminated, that contamination can easily enter a home or building (premise) plumbing system. Because of that threat, experts in the water sector increasingly believe that information on premise plumbing decontamination is needed to help home and building owners make remediation decisions. The issue has come into clear focus in recent years as premise plumbing system contamination events have occurred. For example, *Legionella* bacteria can grow in premise plumbing systems in nursing facilities and hospitals and sicken immunocompromised people. In areas affected by wildfires, volatile organic compounds have been found in distribution systems and home plumbing systems. Accidental contamination events, such as backflushing of per- and polyfluoroalkyl substances (PFAS) from aqueous film forming foam (AFFF) during firefighting events, have also occurred.

Premise plumbing systems belong to home and building owners, and those owners—not the local water utility—are responsible for remediating their plumbing. Removing a premise plumbing system and replacing it is expensive and unrealistic for most home and building owners. Therefore, tools and information are needed to help home and building owners make decisions about remediating their home plumbing so that it can be brought back online. Every water system contamination event is different, and local conditions will determine which decontamination or remediation approach is appropriate. Even though a local water utility is not responsible for remediation of plumbing in a private building, home and building owners should look to the utility for advice and guidance. Information developed through research on plumbing decontamination can help inform the decisionmaking process.

Full-Scale Decontamination Test Systems

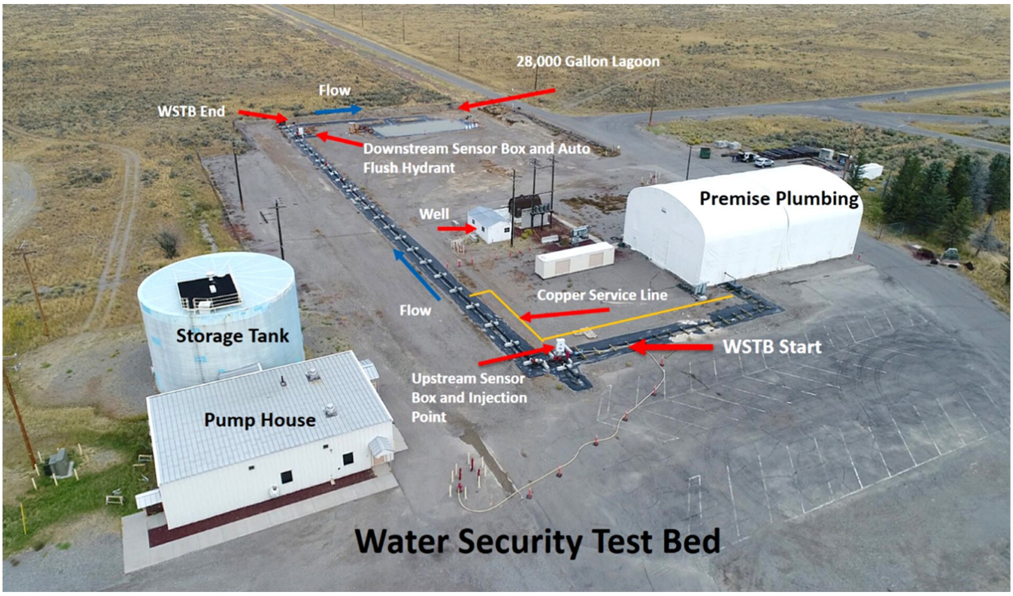
Research on decontamination of water infrastructure can be informed by small, bench-scale experiments. However, contaminant persistence in water systems and the effectiveness of decontamination methods are best demonstrated on a full scale that reflects how the infrastructure operates in real life. Given the importance of premise plumbing to future research initiatives at the HSRP, EPA has constructed full-scale premise plumbing setups at its Water Security Test Bed (WSTB) and Test and Evaluation (T&E) facility. The following section describes premise plumbing setups, along with past and future research.

WSTB Premise Plumbing System

EPA's WSTB is located at the Idaho National Lab (exhibit 1). Its main feature is a 450-foot stretch of 8-inch-diameter water distribution pipe that can be contaminated and decontaminated under real-world conditions. A full description of the WSTB and the experiments conducted there can be found on the EPA WSTB website.

Exhibit 1

EPA's Water Security Test Bed (WSTB) at the Idaho National Lab



Source: U.S. Environmental Protection Agency—https://www.epa.gov/emergency-response-research/water-security-test-bed

The WSTB also features a premise plumbing system (exhibit 2). A copper service line feeds water from the 450-foot distribution main into a building next door. From there, water flows through a water meter and then into copper plumbing that splits into three branches containing removable pieces of pipe; the removable pieces allow researchers to sample the interior pipe surface. Water then flows into a hot water heater, refrigerator water dispenser, washing machine, dishwasher, and sink. Water flow can be controlled with adjustable flow meters attached to the sink faucets via tubes. All water from the system then empties into an outdoor tank.

In recent years, the premise plumbing system has been contaminated (on separate occasions) with the following:

- Non-pathogenic *Bacillus* spores, which are a model microorganism for pathogenic spores that could be used in a high-consequence intentional contamination event
- Soluble components of Bakken crude oil, which could enter a water system after an oil spill
- AFFF containing PFAS, which is used to put out petroleum-based fires
- Untreated water, which could enter a water system after a water treatment plant failure

Exhibit 2

WSTB Premise Plumbing System

Note: Shown clockwise from the upper left are the water meter, removable pipe sections, hot water heater, appliances, sink, and tank that collects water from the system.
Source: U.S. Environmental Protection Agency—https://www.epa.gov/emergency-response-research/water-security-test-bed

Decontamination methods include flushing the water pipes for extended periods, running the appliances multiple times, and draining and refilling the hot water heater while adding a disinfectant, such as chlorine. The effectiveness of running the dishwasher and washing machine with and without detergent was also tested. An overview of the WSTB and links to key reports can be found on the EPA WSTB website.

T&E Facility Premise Plumbing System

The importance of premise plumbing to the HSRP's research priorities led to the development of a full-scale premise plumbing test bed in EPA's facilities (exhibit 3). Local chlorinated tap water flows into the system and supplies six hot water tanks. Three tanks have a gas heating source and three have an electric heating source. The electric and gas water heaters are each represented by two common 40-gallon tank models and one on-demand model. Hot water from each tank flows into a dedicated utility sink along with a parallel stream of cold water. In an adjacent room, the hot water tanks supply a shower, and cold water is supplied to three toilets. Throughout the setup, three common types of plumbing pipe are installed: copper, polyvinyl chloride, and cross-linked polyethylene. Flow through the system is controlled by programmable solenoid valves that periodically allow flow at set times throughout the day. Water sits stagnant in the pipes overnight. This flow pattern is meant to simulate use in a home or building in which flow is present when fixtures are turned on or a toilet flushes but is otherwise stagnant.

The research focus will be on how to effectively decontaminate hot water heaters, plumbing pipes, and fixtures. The primary decontamination approaches will be flushing, filling, and emptying the hot water heaters and adding a disinfectant if necessary. Researchers will monitor aerosolization of contamination from the taps, toilets, and hot water heaters and explore strategies for minimizing exposure to aerosolized contaminants.

Exhibit 3

Full-Scale Premise Plumbing at the T&E Facility (1 of 2)

Exhibit 3

Full-Scale Premise Plumbing at the T&E Facility (2 of 2)

Note: Shown clockwise from the top are an overview of the plumbing system, pipes and sinks with controllable solenoid valves, a shower, toilets, and a close-up of the hot water heaters.

Source: U.S. Environmental Protection Agency—https://www.epa.gov/emergency-response-research/premise-plumbing-decontamination

Wildfire Research

In recent years, benzene and other volatile organic compounds (VOCs) have been detected in tap water in wildfire-affected areas. Benzene contamination persisted for months after two wildfires in California. The cause of VOC contamination is not certain but could come from heat damage to plastic (e.g., high-density polyethylene) distribution pipes or the entry of VOC-containing wildfire smoke into distribution systems after pressure loss. Polyethylene pipes are vulnerable to permeation by benzene, which is a common industrial chemical and a known human carcinogen. Polyethylene is commonly used in home plumbing in addition to water distribution pipes.

The permeability of polyethylene to benzene and other VOCs has important implications for the recovery of drinking water systems from wildfires and other contamination events. Contaminated water can sit in vacant homes for months while remediation and re-habitation decisions are being made. Flushing water systems is a common decontamination and remediation method. However, VOCs that have permeated deep in the pipe wall during stagnant periods can resist decontamination by conventional flushing. Likewise, if water from such badly permeated pipes is sampled immediately after flushing, benzene may not be detected, but the pipe may still have the capacity to contaminate water under stagnant conditions after the benzene has had time to diffuse out of the pipe and into the water.

To address this issue, the HSRP has undertaken research on two fronts. First, researchers aim to measure the rates and amounts of uptake and release of VOCs in contact with polyethylene pipes of several sizes, materials, and manufacturers—including unused, off-the-shelf pipes and samples taken from the field. Second, a numerical model that was developed using these data for the rate of uptake and release of organic contaminants from polyethylene pipes can be used to assist decision makers in implementing recovery strategies. For instance, the model can estimate the effectiveness of flushing programs and help interpret sampling results. This information can inform cost-benefit analysis between flushing and other remediation options, such as pipe replacement.

Copper-Silver Ionization

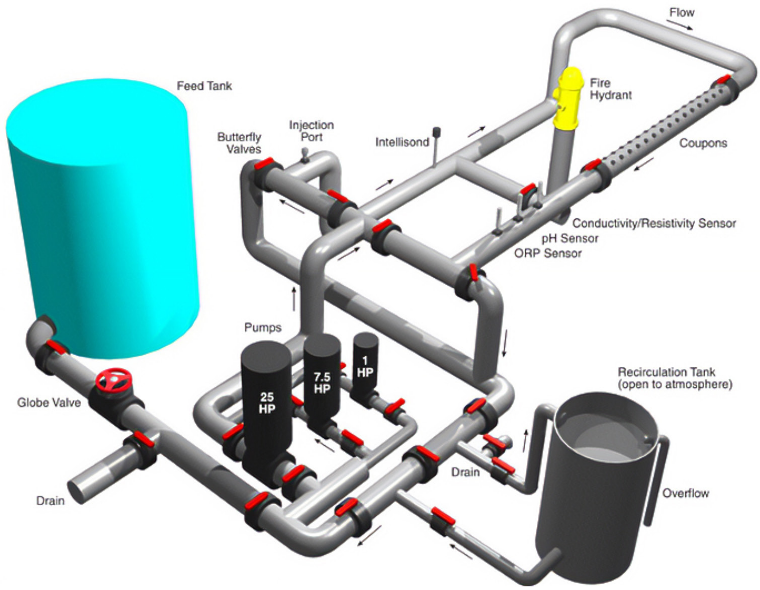
Legionella pneumophila (Lp) is used in premise plumbing research because it is an opportunistic drinking water pathogen and acts as a model microorganism for other vegetative bacteria of homeland security concern. Lp can cause bacterial infections ranging from mild flu-like illness to more serious pneumonia (specifically, Legionnaires' disease). The growth and persistence of Lp have been linked to premise plumbing systems. Copper-silver ionization (CSI) systems generate copper (Cu) and silver (Ag) ions, which are added to the water in premise plumbing systems (particularly hot water loops) in an effort to inactivate (or kill) Lp. These systems are commonly used in healthcare settings because immunocompromised individuals are more susceptible to infections from Lp, but the data on the effectiveness of CSI are limited.

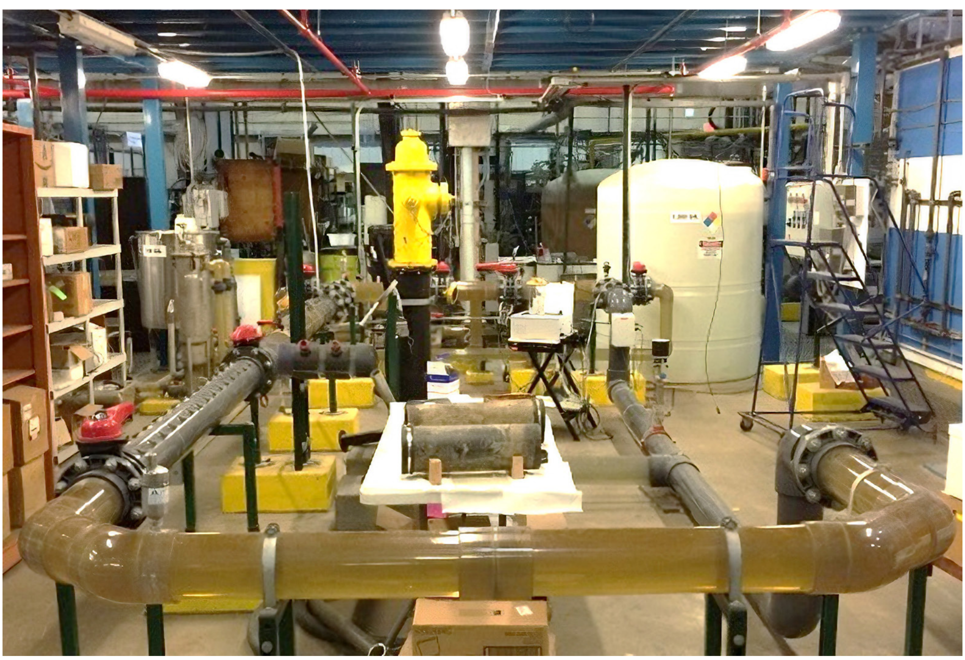
Disinfection efficacy has been tested in both laboratory settings and hospital systems. The effectiveness of CSI has been mixed, and effective levels of Cu and Ag ions are hard to determine from past studies. In addition, water quality parameters (particularly pH and total organic carbon) have been shown to influence the effectiveness of CSI.

This study aimed to identify individual concentrations of Cu and Ag that were effective in inactivating Lp using bench- and pilot-scale experiments. The study was conducted in a drinking water distribution system simulator, which is shown in exhibit 4. Two evaluations were conducted: one with a commercially available Cu-Ag system installed in line with the pipe and one for which Cu and Ag ions were dissolved into the water to achieve the desired biocidal concentration. Naturally occurring *Legionella* in the influent tap water were used to colonize the system.

Exhibit 4

Drinking Water Distribution System Simulator Used to Conduct CSI Experiments





Source: U.S. Environmental Protection Agency—https://nepis.epa.gov/Exe/ZyPDF.cgi/P100SUBR.PDF?Dockey=P100SUBR.PDF

Thus far, results have shown that a commercially available CSI unit was unable to achieve target levels of Cu and Ag after several weeks of testing and troubleshooting with the company's engineering team. Although using dissolution of salts achieved target concentrations of Cu (0.3 parts per million) and Ag (30 parts per billion), the process took several weeks. In the presence of Cu and Ag target levels, decreases in Lp were not observed during 10 weeks of observation. In the future, the researchers will assess the impact of Cu and Ag on colonized Lp.

Ultraviolet Light-Emitting Diode Disinfection

Ultraviolet-C light-emitting diodes (UV-C LEDs) are an emerging water treatment technology and have been shown to effectively inactivate waterborne pathogens. The UV spectrum consists of four regions: UV-A (315 to 400 nanometers [nm]), UV-B (280 to 315 nm), UV-C (200 to 280 nm), and vacuum UV (100 to 200 nm). UV-C light is considered the most germicidal because UV light absorption for DNA, RNA (200 to 300 nm), and proteins (185 to 320 nm) falls primarily in that range. The principle behind UV disinfection of microorganisms is that UV disinfection causes damage to DNA, RNA, and proteins, resulting in cell death or inability to reproduce. Laser-emitting diodes are becoming more common in UV disinfection systems. Although not as common now as traditional UV mercury lamps, LEDs have considerable benefits compared with mercury lamps—LEDs can emit UV light at specific wavelengths, do not contain toxic materials or require a warmup time, are more compact and durable, and require less energy.

The goal of this research is to demonstrate that UV-C LED systems can effectively inactivate pathogens at the point of use (POU) in a premise plumbing system. In premise plumbing, examples of the POU are water taps, shower heads, and hose bibs. To accomplish this task, the researchers performed bench-scale work to determine the most effective disinfection wavelength and UV fluence rate (total radiant energy incident on a fixed area). Four Lp strains were introduced (in separate experiments) into flowing tap water and allowed to flow through the UV-C device and then out of a tap into a waste container. The setup simulated flow through a UV-C disinfection device attached to a water tap.

Experimental results showed that the efficacy of UV-C LED inactivation can differ between strains of the same Lp species. Understanding how strain-specific Lp characteristics, such as outer membrane properties, could influence inactivation efficacy is important for effective remediation. Still, a 3-log to 5-log reduction of *Legionella pneumophila* was observed across all strains, which was an important finding considering the elevated initial Lp concentration used in the experiments (6- to 7-log).

Summary

EPA's HSRP current and future research focuses on the following high-priority research topics in the premise plumbing area:

- Decontamination of priority contaminants using full-scale test systems with flushing and disinfection for various chemical and biological contaminants

- Research on the impacts of wildfire on plastic pipes used in home plumbing (and distribution systems)
- Inactivation of water-based opportunistic pathogens in premise plumbing using ultraviolet (UV) and copper-silver (Cu-Ag) disinfection systems.

As noted previously, all contamination incidents in premise plumbing are different, and the response actions depend on many local factors. However, results from the research here can inform decisionmaking on topics such as the following:

- Whether flushing is appropriate for a certain contaminant
- How long to flush plumbing if flushing must occur more than once
- Which disinfectants are effective for different microorganisms and how long to disinfect
- If point-of-use technologies are appropriate for disinfection at a water fixture

Most importantly, these data can help inform decisionmaking about partial or full replacement of a plumbing system if no effective decontamination methods exist.

Further Reading

EPA Water Infrastructure Decontamination: https://www.epa.gov/emergency-response-research/water-infrastructure-decontamination

EPA Premise Plumbing Decontamination: https://www.epa.gov/emergency-response-research/premise-plumbing-decontamination

EPA Water Security Test Bed: https://www.epa.gov/emergency-response-research/water-security-test-bed

EPA Test and Evaluation Facility: https://nepis.epa.gov/Exe/ZyPDF.cgi/P100SUBR.PDF?Dockey=P100SUBR.PDF

EPA Strategic Research Action Plans: https://www.epa.gov/research/strategic-research-action-plans-fiscal-years-2023-2026#hs

Author

Jeff Szabo is a scientist at the U.S. Environmental Protection Agency, Office of Research and Development. He conducts and manages water security research projects at EPA's Test and Evaluation facility and Water Security Test Bed.