Some Unintended Consequences of Water Conservation/Efficiency

Threats to human health and safety

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As hot water flow rates are lowered in order to achieve water and energy use reductions, unintended consequences can occur. A significant part of these potential consequences fall into the category of threats to health and safety. This is due, in part, to (1) the inability of (some) plumbing system components to protect against scalding and thermal shock, and (2) longer water residence times. A related consequence of these reductions is the hot water 'wait times' associated with lower flows, inconveniencing some users.

<u>Threats of scalding and thermal shock</u>

It is widely understood by plumbing professionals that exposure to hot water or a sudden unanticipated change in water temperature in the shower can present a hazard to the user. The hazards generally fall into two distinct categories: thermal shock and scalding.

Thermal shock is a sudden and unanticipated change in shower water temperature that can cause an abrupt physical reaction in the user, resulting in a serious injury from a slip and fall. The rapid temperature changes can be either toward colder or hotter water. In the latter case, scalding can also result. These temperature changes are caused by simultaneous usage of other fixtures or appliance on the same premise plumbing distribution system, such as a toilet, or an appliance such as a dishwasher or clothes washing machine. Each of those devices can demand a large quantity of water, quickly.

One example that many are familiar with occurs in buildings built before the mid-1980s when pressure-balanced shower valves became common in the United States. Older shower systems had separate valves for the hot and cold supplies. When someone flushed a toilet, rapidly lowering the pressure in the cold-water piping, the amount of cold water going through to the showerhead was reduced. This pressure imbalance changed the ratio of hot and cold water, which led to a change in the outlet temperature, in this case making it hotter. Since this change happened rapidly, there was no way to respond quickly enough to adjust the hot water valve and rebalance the temperature delivered through the showerhead. A common reaction was for the person in the shower to "do the shower dance". Getting out of the way of the shower stream as quickly as possible was a risky proposition since there isn't a great deal of room in the shower stall (or tub) and the floor and their feet were slippery.

Much of this problem was dramatically reduced with the introduction of pressure-balanced shower valves in the 1980s. While these valves respond very quickly to the pressure imbalances described above, they require a minimum operating pressure at the valve to operate properly. Most of the shower valves in the United States are designed to operate at a pressure of at least 20 pounds per square inch (psi). This means that from the water main, though the meter, through the backflow prevention devices and water heater, through the distribution pipe and fittings, and then through to the shower, the pressure remaining (residual) after all of the losses must be at least 20 psi. In a design case, if the difference between the available pressure at the showerhead is less than this minimum residual pressure, the plumbing engineer may increase the diameter of the piping since there is less pressure drop at the same velocity through larger diameter piping.

Scalding from tap water occurs most often in the residential bathroom, both in the shower and bathtub as well as at the lavatory basin. As noted above, the shower is a prime location for scald burns in older homes. Showers in newer homes, equipped with the required pressure-balancing shower valves, possess less of a risk, but only if the shower valve is rated to perform satisfactorily at the flow rates of the companion showerhead.

Tap water scalds are almost completely preventable, through a combination of behavioral and environmental changes. Scalds from tap water are more common among young children, older adults, and people with disabilities. These burns tend to be more severe and cover a larger portion of the body than other scald burns[1] (e.g., cooking-related scalds in the kitchen). For these high-risk groups, hospitalization is longer and recovery more difficult.[2]

Tap water scalds to older adults or someone with a disability usually happen when they slip or fall in the tub or shower, when a caregiver fails to recognize that the water is too hot, when water temperature fluctuates due to running water in other parts of the home (as noted above), or when a faucet or plumbing fixture malfunctions and the person is unable to escape a sudden burst of scalding water.[3]

In March 2012, the American Society of Sanitary Engineering (ASSE) Scald Awareness Task Group released a white paper to address scald hazards associated with low-flow showerheads and taps.[4] That paper noted the following recommendation related to showers:

> *"The installer should check the manufacturer's recommended minimum flow rate for the shower or tub/ shower valve when installing only a new water saver showerhead. If the recommended minimum flow rate of the shower or tub/shower valve is greater than the flow rate of the new water saver showerhead, replace the valve with one that matches the flow rate of the showerhead."* (underlining added)

As noted elsewhere in this report, changes in pipe sizes, water velocity, water volume, and distribution distances could occur as structured plumbing design practices are implemented in new construction. This could amplify or mitigate some or all of the health and safety threats noted above.

Effects of longer water residence times

When high-efficiency fixtures and appliances, coupled with aggressive water conservation programs, are introduced into the built environment, the flow of water in municipal and building supply lines is reduced. However, the water mains must still be sized to handle fire flows. The reduction in flow causes the water to remain in the municipal and building piping systems three to four times longer than prior to 1992, when the EPAct 92 was enacted. This slower water flow allows water treatment chemicals to dissipate to lower levels[5] by the time the water gets to the remote portions of the water distribution systems. This water, dissipated of chlorine, is also

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[1] Safe Kids Worldwide, 2015. *Safekids_Burn_Fact_Sheet* https://www.safekids.org/sites/default/files/documents/skw_burns_fact_sheet_feb_2015.pdf

[2] American Burn Association, *Scald Injury Prevention – Educator's Guide, 2007*. http://ameriburn.org/wp-content/uploads/2017/04/scaldinjuryeducatorsguide.pdf

[3] ibid

[4] ASSE, 2012. *Scald Hazards Associated with Low-Flow Showerheads, A White Paper* http://www.asse-plumbing.org/ScaldHazards.pdf

[5] Prior to the significant water conservation efforts in the 1990s and 2000s (see Table X), the rate of dissipation from 4 ppm to 0.5 ppm could occur as quickly as 1-½ days in galvanized piping systems. The rate of dissipation from 4 ppm to 0.5 ppm could take 10 to 12 days in PVC or lined cast iron piping systems. For unlined cast iron piping systems, it would take about 4-½ days for the chlorine to dissipate from 4 ppm down to 0.5 parts per million. Previously, water would take about three to four days to flow from the water treatment plant to the farthest outlet and, thus, disinfection was maintained. Today, however, on average it takes about 12 to 16 days. Given the 30-year history of water flow rate reductions and the fact that water mains must accommodate periodic fire flow rates from fire hydrants, this extended amount of time water is held in the water mains and distribution piping is exceeding the time required to maintain water treatment chemical levels that will be effective at fighting off contaminants like Legionella, Cryptosporidium, E.coli and many other organic contaminants.
Source: Plumbing Engineer Magazine, 2015. *Legionella, low flow fixtures and Chlorine dissipation,* November 2015 https://www.phcppros.com/articles/2308-legionella-low-flow-fixtures-and-chlorine-dissipation

generally referred to as "aged water" or "stagnant water."[6] This phenomena, in turn, can increase the chance of microbial re-growth, disinfectant decay, and corrosion (or related) problems in distribution and premise plumbing systems.[7]

Water conservation and water use efficiency programs, equipment advances, and drought response messages over the past 30 years have led to large reductions in water and energy consumption. (see Table 1)

Table 1. Water Consumption by Water-Using Plumbing Products and Appliances (1980 to 2017)

Water-using Fixture or Appliance	1980s Water Use (typical)	1990 Requirement (maximum)	EPAct 1992 Requirement (maximum)	2009 Baseline Plumbing Code (maximum)	"Green Code" Maximums (2017 CALGreen)	% Reduction in avg water use since 1980s
Residential Bathroom Lavatory Faucet	3.5+ gpm	2.5 gpm	2.2 gpm	2.2 gpm	1.2 gpm	66%
Showerhead	3.5+ gpm	3.5 gpm	2.5 gpm	2.5 gpm	1.8 gpm	49%
Residential ("private") Toilet	5.0+ gpf	3.5 gpf	1.6 gpf	1.6 gpf	1.28 gpf	74%
Commercial ("public") Toilet	5.0+ gpf	3.5 gpf	1.6 gpf	1.6 gpf	1.28 gpf	74%
Urinal	1.5 to 3.0+ gpf	1.5 to 3.0+ gpf	1.0 gpf	1.0 gpf	0.125 gpf	96%
Commercial Lavatory Faucet	3.5+ gpm	2.5 gpm	2.2 gpm	0.5 gpm	0.5 gpm	86%
Food Service Pre-Rinse Spray Valve	5.0+ gpm	No requirement	1.6 gpm *(EPAct 2005)*	No requirement	1.3 gpm	74%
Residential Clothes Washing Machine	51 gallons per load	No requirement	26 gallons per load *(2012 std)*	No requirement	12.6 gallons per load *(Energy Star)*	75%
Residential Dishwasher	14 gallons per cycle	No requirement	6.5 gallons per cycle *(2012 std)*	No requirement	3.5 gallons per cycle *(Energy Star)*	75%

[6] Ibid

[7] Water Research Foundation, 2015. *Green Building Design: Water Quality Considerations - Project 4383* http://www.waterrf.org/ExecutiveSummaryLibrary/4383_ProjectSummary.pdf

The advances of significantly decreased treated water consumption have been achieved in spite of increasing populations in the served communities. As noted earlier, reduced water consumption, coupled with the same volumetric capacity of the piping created longer water travel times through both the water distribution network and the building (premise) plumbing network.

Additionally, some studies have linked these lower flows to a number of problems affecting water quality and availability. A National Research Council (NRC) report[8] cited the impact of lower flows and lower temperatures (to address scalding and energy efficiency), on greater loss of residual disinfectants and increased formation of sediment and biofilms, creating more conducive environments for opportunistic premise plumbing pathogens (OPPPs) such as ***Legionella pneumophila*** and ***Mycobacteria*** species[9] as well as corrosion and deposition issues. At low velocities, sediment in suspension will more likely drop out of solution and form deposits in the piping. These deposits can create corrosion cells and provide greater media for bacteria growth.

Legionella are naturally occurring bacteria found in freshwater sources, such as rivers and lakes, where the bacteria generally are present in low amounts and do not lead to disease.

However, Legionella can multiply to dangerous levels under certain conditions and potentially cause Legionnaires' disease, or Legionellosis. People contract this disease by inhaling small droplets of the contaminated water through mist or vapor.[10] Premise plumbing systems can be colonized with *Legionella* and transmit the bacteria through aerosols generated from showers, humidifiers and spas associated with hot water distribution systems, as well as from respiratory therapy devices, ultrasonic mist machines, decorative fountains and industrial-use water.[11]

It is well established that high water age is problematic in main distribution systems, contributing to problems with corrosion, taste and odors, and microbial regrowth.[12] High water age in premise plumbing can further amplify such problems and also instigate proliferation of human pathogens. Synergistic effects can be incurred when both distribution and premise plumbing system water ages are high.[13]

Water age is increasing in both distribution and premise plumbing systems as water conservation practices and water use efficiency mandates are adopted at the community level. These trends have given rise to concerns that widespread adoption of green building practices will further detract from potable water quality in buildings.[14]

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[8] National Research Council (NRC), 2005. *Public Water Supply Distribution Systems: Assessing and Reducing Risks: First Report*, http://nap.edu/11262

[9] U.S. EPA, 2016. *National Priorities: Impacts of Water Conservation on Water Quality in Premise Plumbing and Water Distribution Systems* https://www.epa.gov/research-grants/national-priorities-impacts-water-conservation-water-quality-premise-plumbing-and

[10] Plumbing Manufacturers International, *Just the Facts: Legionella and Water Supply Systems* https://www.safeplumbing.org/advocacy/health-safety/legionella

[11] U.S. EPA, 2016. *Technologies for Legionella Control in Premise Plumbing Systems: Scientific Literature Review* https://www.epa.gov/sites/production/files/2016-09/documents/legionella_document_master_september_2016_final.pdf

[12] U.S. EPA, 2002. *Effects of Water Age on Distribution System Water Quality.* Office of Ground Water and Drinking Water: Cincinnati, OH, 2002, http://www.epa.gov/ogwdw/disinfection/tcr/pdfs/whitepaper_tcr_waterdistribution.pdf

[13] 2016, Environmental Science, Water Research & Technology - Royal Society of Chemistry. *Survey of green building water systems reveals elevated water age and water quality concerns,* by William J. Rhoads, et. Al. https://vtechworks.lib.vt.edu/bitstream/handle/10919/64962/2016_Rhoads_Survey_of_green_building_water_sys.pdf

[14] Ibid.

Higher water age also has possible implications for OPPPs, including Legionella spp. (especially L. pneumophila), Mycobacterium avium complex (non-tuberculosis mycobacteria), Pseudomonas aeruginosa, Acanthamoeba spp., and Naegleria fowleri, which are now the waterborne pathogens of highest concern in the U.S. OPPPs can thrive under conditions created by premise plumbing, including the presence of materials that rapidly react with disinfectants or leach nutrients to water, inherently high plumbing surface area to volume ratios, widely variable flow conditions, numerous dead ends, impaired ability to achieve and maintain thermal targets that discourage microbial growth, and high water age. OPPPs are integral members of potable water microbial communities and have complex life cycles, including amplification and enhanced virulence when hosted by free-living amoebae such as Vermamoeba vermiformis. L. pneumophila causes about 90% of reported premise plumbing related disease outbreaks, with other ecologically related Legionella spp. also a cause for health concern.[15]

Temperature profiling of the green buildings in the Rhoads study generally revealed the need for very extensive flushing to draw fresh distribution system water to the point of use. In general, temperatures were in the ideal growth range for OPPPs (35–42 °C).[16]

Other key problems associated with health or aesthetics within premise plumbing water systems include loss of disinfectant stability, corrosion of premise plumbing components, scaling, development of taste/odor causing compounds, and microbial (re)growth. High water age can exacerbate many of these problems. While there are several ways to reduce the water age within buildings, such as limiting the overall volume of the system or regularly flushing the pipes, there are potential disadvantages to each strategy. As noted earlier, pipe size is often constrained by water demand needed for fire protection systems or by the original plumbing design in retrofitted green buildings. It is also unclear whether decreasing the pipe size will solve these problems, since smaller pipes increase the surface area-to-volume ratio and the water velocity within pipes. Although reducing pipe size will likely reduce water age, the higher surface area-to-volume ratio that results might increase problems with microbial growth and disinfectant decay, and the higher velocities might cause corrosion problems or increase detachment of biofilms.[17]

Factors that increase the likelihood of biofilm formation include the presence of nutrients, scale and corrosion, warm water temperatures and long water residence time as occurs in the dead ends of distribution systems and in storage tanks[18] When biofilm, a sticky substance created by bacteria, forms on the inside wall of water supply piping, it protects Legionella from heat and disinfectant.[19]

Although this practice may seem counterintuitive with respect to water conservation, regularly flushing water at the end of the existing plumbing system[20] is probably the simplest solution to

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[15] Ibid
[16] Ibid
[17] [17] Water Research Foundation, 2015. *Green Building Design: Water Quality Considerations - Project 4383* http://www.waterrf.org/ExecutiveSummaryLibrary/4383_ProjectSummary.pdf
[18] U.S. EPA, 2016. *Technologies for Legionella Control in Premise Plumbing Systems: Scientific Literature Review* https://www.epa.gov/sites/production/files/2016-09/documents/legionella_document_master_september_2016_final.pdf
[19] Plumbing Manufacturers International, *Just the Facts: Legionella and Water Supply Systems* https://www.safeplumbing.org/advocacy/health-safety/legionella
[20] Water utility employees typically go to hydrants at the ends of the system and open those hydrants and flush water from them at a flow rate in excess of 2,000 gallons per minute for 15 to 30 minutes until the chlorine test strips showed adequate chlorine levels.
Source: 2018, Plumbing Engineer Magazine. *Legionellosis: An Inconvenient Disease,* February 2018. *https://www.phcppros.com/articles/6998-legionellosis-an-inconvenient-disease*

reduce water age, help maintain disinfectant residuals, and prevent microbial growth.[21] *(underlining added)*

For example, the current consensus is that stagnant waters are more likely to promote the growth of microorganisms. While this may be true for overall microbial populations, one direct test indicated that continuous flow actually facilitates amplification of Legionella.[22] *(underlining added)*

If it is not possible to reduce water age by implementing design changes or altering water use so that effective disinfectant residuals are maintained and microbial growth is limited, then water flushing is likely to be an effective temporary solution for buildings being supplied with water that has a disinfectant residual. An advantage to this strategy is that it can be implemented anytime, and the "wasted" water can potentially be recovered and used for non-potable applications.[23]

On the water utility side, older water infrastructure can be more vulnerable to contamination through leaks and breaks. When a leak or break occurs, it increases the possibility of OPPPs like Legionella entering the infrastructure, forming in biofilms, and then being released into the water supply. Approximately 240,000 water main breaks occur annually in the U.S., wasting more than 2 trillion gallons of treated drinking water, according to the 2017 Infrastructure Report Card by the American Society of Civil Engineers. In addition, the report card noted that many of the 1 million miles of pipes delivering drinking water across the country have either reached – or are fast approaching – the end of their lifespans. In addition, maintenance, repair and replacement of water mains have been associated with multiple large outbreaks of Legionella.[24]

Current water treatment dogma is based upon the epic battles of the 20th century, when waterborne pathogens (e.g., Salmonella, Vibrio) primarily originated from fecal contamination of water supplies. Those pathogens are naturally attenuated over the time of exposure to drinking water and by treatment steps including disinfection, because **they do not multiply outside of their mammalian host. In contrast, OPPP numbers increase with distance from the treatment plant as they multiply in the distribution system.** OPPPs are not merely transported through pipes, but are actually adapted to growth and persistence in drinking water, especially in building plumbing systems, presenting three challenges to the current paradigm for water treatment[25]:

- First, source tracking within a water distribution system is meaningless, as the likelihood of amplification and detection increases in the more distal parts of the system.
- Second, disinfection using the guidance developed for E. coli, rather than based on susceptibility of these disinfectant-resistant opportunistic pathogens, can actually select for their predominance.
- Third, the current location for regulatory compliance sampling, at the treatment plant effluent, is actually where the opportunistic premise plumbing pathogens are least likely to be detected, and utilities do not sample stagnant water in buildings where they are most likely to be detected.

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[21] Water Research Foundation, 2015. *Green Building Design: Water Quality Considerations - Project 4383* http://www.waterrf.org/ExecutiveSummaryLibrary/4383_ProjectSummary.pdf
[22] Ibid
[23] Ibid
[24] Plumbing Manufacturers International, *Just the Facts: Legionella and Water Supply Systems* https://www.safeplumbing.org/advocacy/health-safety/legionella
[25] Virginia Tech, 2015. *Opportunistic Premise Plumbing Pathogens: Increasingly Important Pathogens in Drinking Water* http://www.mdpi.com/2076-0817/4/2/373