

Analysis of building plumbing system flushing practices and communications

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ABSTRACT

Drinking water distribution system contamination incidents can prompt public agencies and drinking water utilities to issue do-not-drink and do-not-use advisories. After the contaminant is cleared from distribution mains, consumers are often directed to flush their plumbing. However, little validated guidance and few evaluated communications strategies are available on using flushing to decontaminate building water systems. Additionally, limited data support the effectiveness of current practices and recommendations. In this study, expert elicitation was used to assess existing flushing guidance and develop validated flushing guidance and communications for single-family residences. The resulting guidance recommends progressively opening all cold-water taps from the closest to point of entry to the furthest and allowing the water to run for at least 20 minutes. Hot-water taps should be opened progressively and run for at least 75 minutes. The guidance language and format conformed to grade-level and readability scores within recommended health communication ranges. The readability of eight other flushing guidance documents was also evaluated for contamination incidents from 2008–2015. Seven were written at a 10th–12th grade level, above the 6th–7th grade level recommended for health communications.

Key words | drinking water, flushing, guidance, readability

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INTRODUCTION

In the USA and Canada, water chemical contamination incidents that occurred between early 2014 and mid-2015 affected more than 1 million people and resulted in more than 150,000 building water systems being contaminated by a variety of organic contaminants (Casteloes *et al.* 2015). Contaminant fate and transport in building plumbing can differ widely based on the plumbing system material, plumbing system configuration and contaminant, with some contaminants posing risks to building water systems (BWS) or the

health of those conducting flushing or living in the building (Moya *et al.* 1999; US EPA 2012a, 2012b; Happo *et al.* 2014). Adding to the complexity, building plumbing and the distribution system supplying water to BWS comprise a connected network that is a shared responsibility between the water utility and building owner to flush out contaminants (National Research Council 2006). The Safe Drinking Water Act regulatory authority extends from the source water and intake, in the water treatment plant, through the distribution system and to the service line or meter on a given property (US EPA 1973). After that point, ownership of and management of water quality and delivery become the responsibility of the property owner (National Research

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Council 2006). Therefore, most drinking water utilities and regulatory agencies only have responsibility for water quality as it is delivered to the property line (National Research Council 2006). In most cases, state drinking water regulatory, or primacy, agencies have no role in building water quality or plumbing, nor do drinking water utilities, with the exception of backflow prevention, cross connection control and the Lead and Copper Rule (LCR) (Triantafyllidou 2017). Due to this governance construct, utilities are expected to recommend and communicate the need to take protective action to customers (National Research Council 2006).

The flushing protocol from the 2014 West Virginia chemical spill illustrates the complex coordination between the BWS and distribution systems during a contamination incident. The water utility flushed the distribution system in specific pressure zones sequentially. Residents and owners then flushed their BWS in the cleared pressure zone. This necessitated close coordination between the water utility and incident responders as well as residents and property owners (Rosen *et al.* 2014; Whelton *et al.* 2014, 2017; Casteloes *et al.* 2015). The complex logistics and compliance with guidance associated with staging was a factor that extended the incident for weeks (Schade *et al.* 2015). However, staging distribution system and BWS flushing has the advantage of preventing entrainment of contaminated distribution system water into BWS. Another benefit of deliberate staged pressure zone flushing is that it prevents excessive water demand, low water pressure, and the draining of certain sections of the distribution system (AMWA 2011).

Flushing as a public health intervention

For this study, flushing is defined as running water through components to turn over water in BWS to remove a contamination and prevent exposure to contaminated drinking water. Flushing is a de facto public health intervention wherein individuals choose to take an action to prevent exposure and consequential health effects. Alternatives to flushing, such as boil water advisories, have disadvantages, including potential injury, economic disruption, energy consumption, and low levels of compliance (Raucher *et al.* 2014; Lindell *et al.* 2015; Savoia *et al.* 2015). Compared to other interventions such as booster disinfection or drinking water advisories, flushing also has advantages as a protective

action to manage potential or known contamination. This approach could limit some health exposures and may be less disruptive to consumers, critical infrastructure, and the economy (McCarty 2016; Hsu *et al.* 2017). Despite the advantages of flushing, there are no evidence-based protocols available for flushing BWS or evaluated communication strategies and messages for consumers. Additionally, limited data are available to establish the effectiveness of current utility practices and recommendations for either.

Table 1 presents types of incidents that may prompt flushing BWS and lists contaminant types and properties for consideration when recommending flushing. Among the classes of contaminants, unknown contaminants pose the greatest challenge because limited information is available about toxicity, dose response, and potential health effects to inform the public about effective and safe flushing (Villanueva *et al.* 2014; Sain *et al.* 2015; Huang *et al.* 2017; Gallagher *et al.* 2018). Decision-makers opting to recommend flushing must recognize that the procedure may have human health and infrastructure consequences. Although water professionals are typically integrated into contamination incident response, in some circumstances the decision-makers are emergency response or public health officials with limited knowledge of water systems,

Table 1 | Examples of scenarios, contaminant classes, and contaminant properties that can influence flushing procedures

Scenarios	Contaminant classes	Contaminant properties
Contamination incident	Susceptible pathogens	Volatility
Distribution system low pressure transient	Resistant pathogens	Miscibility
Overfeed	Sediments, particles	Toxicity (oral, inhalation, dermal)
Free chlorine burns	Chemical compounds	Reactivity
Aesthetic concerns	Radioactive elements	Retention on plumbing surfaces
Distribution system maintenance or failure	Disinfection byproducts	Odor threshold
Backflow	Unknown contaminants	Appearance/color
Plumbing contamination		
Plumbing disinfection		

possible exposures, or other factors (Zhou *et al.* 2007; Phetxumphou *et al.* 2016; Whelton *et al.* 2017).

Previous work by the Centers for Disease Control and Prevention (CDC) on the *Drinking Water Advisory Communication Toolbox* identified two needs directly related to this study: improved language for communication tools providing flushing guidance and evidence to support flushing guidance content or recommendations (CDC 2016a, 2016b). Prior studies found that the language in drinking water public notification and advisory communications was arcane and difficult for consumers to understand, and it hindered consumers from taking protective action (Rundblad *et al.* 2010, 2014; Bradford *et al.* 2017; Lindell 2018). Health communications for a general audience should read at a 6th–7th grade level and score between 65 and 80 on the Flesch–Kincaid scale (National Institutes of Health 2013). This readability formula is used extensively in the health and education fields to assess how understandable the materials are (DuBay 2004; Friedman & Hoffman-Goetz 2006; Daraz *et al.* 2018). The tests consist of two inversely related components: the Flesch reading ease and the Flesch–Kincaid grade level (Kincaid *et al.* 1975). A high Flesch reading ease score (scaled from 0 to 100) suggests better comprehension, while the Flesch–Kincaid grade level is equivalent to the US school grade level. Although several readability scales exist, we selected the Flesch–Kincaid for its accessibility and ease of use for water systems, primacy agencies, and health departments to incorporate into practice (Benjamin 2012). In drinking water notifications and advisories, the language is consistently assessed at a 11th–14th grade level and 26–44 on the Flesch–Kincaid scale (Roy *et al.* 2015). Challenges to improving the status quo include the Public Notification Rule and other regulatory requirements for specific language and topics in drinking water advisories. To address the lack of evidence for both flushing guidance and effective communications strategies, our goal was to (1) use available resources to develop a guidance for flushing building plumbing and service lines and (2) develop a communications strategy to deliver the guidance to audiences consisting of home owners, building managers, and others with control over building plumbing. The result is clear guidance for consumers to use to flush and clear contaminants in a building water system.

MATERIALS AND METHODS

Development of flushing protocols

Expert elicitation was used to assess current and prior protocols and to generate a new guidance based on the deliberation and professional experience. This method is a structured consultation approach to systematically assess expert opinion for topics with uncertainty (Knol *et al.* 2010). A workshop was convened to establish a baseline flushing guidance and assess related water community communication needs. The workshop format, list of experts, and approach for developing a consensus are detailed in Bartrand *et al.* (2018). The 2-day session included representatives from government agencies, utilities, academia, and advocacy organizations (see Supplementary materials, available with the online version of this paper). The primary goal was to review and improve current flushing practices following contamination incidents and identify an agreed upon process to validate. The workshop focused on developing the technical guidance. A communications session was conducted and integrated into the full workshop and findings. The final session incorporated the guidance and flushing recommendations. The assumptions used to develop the flushing guidance are summarized in Table 2. Assumptions were chosen to be conservative, that is, to overestimate the required flushing time per faucet/tap. Flushing activities were staged to minimize entrainment of contaminants into the BWS and, for the hot water plumbing, to achieve greater than 1-log reduction in the contaminant concentration.

The minimum time for flushing cold water lines was determined by the time required to transport clean water from the distribution main to faucets in the building. Assuming four faucets in the building, a flow rate of 0.8 gpm for each faucet, a service line length of 150 ft, and a pipe diameter of 1 inch, the minimum flushing time can be calculated using the approach outlined by Burlingame *et al.* (2012):

Flushing time

$$= \frac{7.48 \text{ gal}}{1 \text{ ft}^3} \times \frac{3.142 \times (\text{Service line diameter (ft)/2})^2 \times \text{Length (ft)}}{\text{Number of faucet} \times \text{Flow rate (gpm)}}$$

The minimum flushing time to clear the service line is 2 minutes. Because contaminant properties, building materials,

Table 2 | Protocol assumptions

Factors that were considered	Assumptions that were made
Assumed properties of the contaminant to be flushed	Non-reactive and non-sorbing Dissolved or suspended in water Does not have a strong objectionable odor Does not leave a stain or deposit or residue No harmful effects from inhalation or dermal exposure during flushing Safe for disposal down residential drains Safe for discharge to the outdoor environment
Goal of flushing	The fresh water from the water supply is free of the contaminant Target concentration after flushing is of 1-log reduction; 90% reduction in water heater
Tap flow	0.8 gpm (EPA mandated minimum flow for low-flow faucets)
Plumbing components	Internal plumbing pipe diameter is 1-inch id Service line diameter is 1-inch id and 150 ft long 80-gallon water which acts as a continuously stirred tank reactor No point of use or point of entry filters

and plumbing configurations vary widely, safety factors of 10 and 5 are used for indoor faucets and outside spigots, respectively. Therefore, flushing times of 20 minutes and 10 minutes are recommended for indoor faucets and outside spigots, respectively. The safety factor for the outside spigots is less than that for indoor faucets because we assumed that the spigots are closer to the service line and will require less flushing time. Assuming that the water heater hydraulics are similar to a continuously stirred tank reactor, we then calculated the minimum flushing time required to reduce the concentration of a given contaminant in a water heater by 90% (Casteloës *et al.* 2015; Hawes *et al.* 2017):

$$\frac{C}{C_0} = e^{(nQ/V)t}$$

where C = final concentration, C_0 = initial concentration in the tank, n = number of faucets, Q = flow rate = 0.8 gpm, including aerator restricted flow, V = tank volume = 80 gallons, t = flushing time, minutes.

The minimum flushing time for an 80-gallon tank is estimated to be 58 minutes. A safety factor of 1.3 is applied

to account for the volume of water sitting in hot water pipes and the water tank. Therefore, the recommended flushing time is 75 minutes.

Selection and evaluation of flushing protocols

Readability of prior flushing protocols was evaluated because, to be effective, guidances must be both evidence based and understandable. Flushing guidance for evaluation was selected using the following criteria: publicly accessible documents used for verified incidents that occurred after 2008 in North America. We evaluated the readability of eight past flushing protocols to identify effective messages that could be used in our guidance. Six of these eight guidance documents for which copyright permission was obtained are provided in the Supplementary material, and each was evaluated for readability using the Flesch–Kincaid readability tests. The flushing protocols were downloaded in portable document format (PDF) and converted to Microsoft® Word (.docx) files. Similar to the method used by Roy *et al.* (2015), the documents were inspected to ensure the continuity of all paragraphs and text blocks were intact before performing the Flesch–Kincaid tests using readability statistics in Microsoft® Word 2013.

RESULTS AND DISCUSSION

Flushing single-family household building plumbing

Workshop experts acknowledged that there are limited studies and data to provide a foundation for specific flushing guidance for all of the possible contaminant-plumbing material combinations and all the possible plumbing system layouts. Yet utilities must frequently issue flushing advisories and provide guidance. To address the need for a basic response to building water system contamination, we developed flushing guidance for the simplest possible scenario – turnover of water in a single-family residence (SFR) BWS contaminated with a non-volatile, soluble, and low toxicity contaminant. The resulting flushing guidance provides the minimum requirements for flushing BWS. More complex scenarios can be adapted by adding safety factors or precautions or the use of personal protective

equipment to the guidance for a specific contaminant. For example, a water contamination incident with a volatile compound could create a health hazard for those engaged with the flushing protocol. The following flushing guidance was developed for a simple contaminant non-volatile, non-reactive, conservative contaminant in an SFR plumbing and is based on a review of protocols, the expert elicitation, and our best engineering judgment. As such, more research is needed to develop evidence-based guidance. The following is draft language of the step-by-step procedures for customers to use to flush their building plumbing applying the flushing times and strategies.

How to flush your plumbing system

For the cold-water system, the following step-by-step actions are needed.

1. Begin by running the cold water faucet closest to where water enters the house. Starting from the point closest to where water enters the house, open all the other cold water taps sequentially and allow the water to run for 20 minutes.
2. Next, flush each toilet at least once.
3. If a bathtub has a spout and shower head, direct flow through the spout.
4. Flush all outside spigots for 10 minutes.
5. After flushing all cold taps, direct the flow from the bathtub spout to the shower head, if applicable.

For the hot water system, the following step-by-step actions are needed.

1. Run the hot water tap closest to the water heater.
2. Open all hot water taps.
3. If a bathtub has a spout and shower head, direct flow through the shower head first.
4. Allow the water to run for at least 75 minutes and then turn off the faucets.
5. If applicable, direct shower head flow to the bathtub tap for 2 minutes.

For appliances, the following step-by-step actions are needed.

1. Run empty dishwasher and washing machine once on rinse cycle.

2. Replace all water filters (e.g., whole-house filter, refrigerator filter) and empty ice from ice maker bin; run ice maker and discard two additional batches of ice.

Comparison of flushing guidance readability

The average American reads at a 7th–8th grade level (Kutner *et al.* 2006), and the National Institutes of Health recommended in 2013 that health communications materials be written at a 6th–7th grade level (National Institutes of Health 2013). However, previous studies analyzing drinking water communications indicated that the language used was at an 11th–14th grade level, which is well above the grade level recommended for public health communications (Roy *et al.* 2015). Furthermore, the ease of reading ranged from 26.3 to 43.8 on the Flesch–Kincaid readability scale, which is similar to the Harvard Law Review, which has a reading ease in the low 30 s (Kunz & Osborne 2010; Roy *et al.* 2015). Water system flushing guidance issued in response to prior contamination incidents and the flushing guidance developed based on the experts' workshop protocol were evaluated to determine their Flesch reading ease and the Flesch–Kincaid grade level (Table 3). To our knowledge, this is the first study to evaluate the readability of flushing guidance. Seven of the eight flushing protocols evaluated in this study had reading grade levels above the recommendation for public health communications (9.5–12), with the reading ease ranging between 41.2 and 54.5 (Table 3). Only the protocol used after the Glendive, MT, benzene contamination incident and the experts' workshop guidance met the criteria for public health communications readability. In general, this protocol had clear, short sentences and paragraphs and simpler language. Similarly, the flushing protocol developed in the experts' workshop was written to ensure that the Flesch–Kincaid grade level and Flesch readability were within the ranges recommended for public health communications. As such, the protocol readability score is 65.5, and the grade level is 7.2.

CONCLUSION

To our knowledge, this is the first study to use expert elicitation to develop a building flushing protocol and to evaluate

Table 3 | Analysis of readability of building plumbing flushing guidance

Flushing guidance	Incident	Date	Reading ease	Grade level
Expert panel guidance	General advice	Not applicable	65.5	7.2
Middleton, WI	Discolored water	Not available	54	9.6
Walkersville, MD	Boil water advisory	January 2008	43.8	12
Prince Albert, Saskatchewan	Boil water advisory	March 2012	54	9.8
Charleston, WV ^a	MCHM chemical spill	January 2014	54	9.6
Toledo-Lucas County, OH	Microcystin	August 2014	54.5	9.5
Washington DC	Petroleum smell	December 2014	46.5	10.5
Syracuse City, UT	Boil water advisory	June 2015	41.2	10.6
Glendive, MT	Crude oil	January 2015	70.9	6.6

^aThis flushing guidance is specific to West Virginia American Water. Other flushing procedures were issued by the State of West Virginia and a nonprofit organization.

the readability of flushing protocols. The flushing protocol and the guidance language provided in this study are a starting point until other studies can be conducted to develop evidence. The protocol is based on the best current knowledge and can be used as a resource when water providers must respond to a contamination incident. As is, this guidance is appropriate for flushing when the contaminant acts as a non-reactive tracer and poses no known significant health risks to those conducting the flushing or in the building during flushing. Additional actions depend upon the incident category, the building type, the audience, the information needed to prompt action, and the actions that consumers should take. Significant research and assessment are required to refine the protocol and guidance and make them the evidence-based, tested materials that would best serve the water community. Particular attention should be given to complex scenarios ranging from volatile contaminants associated with health hazards to certain types of plumbing materials. Safety factors or precautions, such as personal protective equipment, can be added to the guidance for specific contaminant characteristics.

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