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Considerations for Large Building Water Quality after Extended Stagnation

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Abstract

The coronavirus (COVID-19) pandemic prompted the closure and reopening of previously shutdown large buildings globally. Building water stagnation has been identified as a potentially serious chemical and microbiological health concern for occupants. Health officials, building owners, utilities, and other entities are rapidly developing guidance. A synthesis of peer-reviewed, government, industry, and nonprofit literature relevant to the implications of water stagnation in plumbing systems and decontamination practices for water quality and health was conducted. A primer of large building plumbing preventative and remedial strategies is provided to inform ongoing efforts to develop recommissioning guidance. Preventative practices to help avoid the need for recommissioning and specific actions, challenges, and limitations associated with recommissioning were identified and characterized. Considerations for worker and occupant safety were also indicated. The responsibility for building water safety was identified to be shared between the building owner, drinking water provider, and local and state public health authorities.

Potential Keywords

COVID-19; Stagnation; Recommissioning; Flushing; Water quality; Plumbing; Customer; Advisory, Disinfection; Coronavirus; Health risk; Building; SARS; SARS-CoV-2; Disaster

1. Introduction

Starting in late 2019, the global onset of novel coronavirus SARS-CoV-2 disease (COVID-19) prompted "stay-at-home" advisories and orders in the U.S. These government actions addressed closing non-essential businesses and other organizations (e.g., education, event, worship, recreation, office, and retail buildings) [1,2]. With more than 5.6 million commercial buildings in the U.S.[3], the shutdowns significantly altered drinking water demand patterns at both the water distribution and building system levels. Specifically, many buildings experienced reduced water use and increased water stagnation time (i.e., water age). This is problematic as stagnation has been associated with development of water quality issues in routine settings (on a time scale of hours to days) at the building [4–12] and water distribution system level [13–18]. However, the impact of such prolonged stagnation (weeks to months) has not yet been fully quantified.

Prolonged stagnation periods associated with building closures, and partial occupancy due to seasonal use, construction, or during response to natural disasters are not unprecedented. These closure events have been associated with Legionnaires disease outbreaks [19–24] and other water quality issues [25,26]. The unprecedented number of building closures related to the COVID-19 pandemic is concerning because many impacted buildings likely do not have a water management plan in place to preemptively or retroactively deal with water quality problems when COVID-19 social-distancing practices are discontinued [27].

A process referred to as "recommissioning" may be necessary to mitigate public health risks that develop during prolonged stagnation. This is distinct from commissioning, which is required for new buildings or new additions to existing buildings. While recommissioning guidance exists for seasonal public water supplies (startup [28,29]) or after plumbing system construction [30–32], these documents do not explicitly pertain to prolonged stagnation in low-occupancy buildings. Many of the existing protocols that may be adapted to recommissioning do not address water quality issues that can develop in building plumbing systems, including increased presence of opportunistic pathogens. To fill this gap, many entities are rapidly developing and releasing public guidance that may present conflicting recommendations [33–35]. It is critical that guidance addresses the diverse and complicated nature of building plumbing in large buildings and the water quality issues that may develop within them.

At this point, it appears unclear (1) to what extent will water quality degrade during extended closures or partial-closures, and (2) to what extent are remediation activities (e.g., flushing, disinfection) will be effective or necessary. The purpose of this study was to provide a better understanding of challenges, current practices, and knowledge-gaps for restoring plumbing to prior conditions after extended periods of limited water use. Several guidelines discussed in this paper may be directly and tangentially useful in considering the current COVID-19 situation. While this review is not meant to explicitly serve as a step-by-step recommissioning procedure for buildings, it (1) raises several concerns for water quality relevant to stagnation surrounding the COVID-19 response based on literature and experience; (2) highlights building water management practices which could reduce the impact of building closure or low occupancy; (3) summarizes recommissioning actions from various potentially relevant guidance documents; (4) highlights potential challenges for writing general guidance for large buildings; and (5) identifies questions over responsibility and implementation of recommissioning actions. Results of this study can serve as a foundation for the development of step-by-step guidance.

2. Methods

Approach. To document concerns regarding water quality deterioration that may occur during prolonged building closures or partial-closures, the authors reviewed literature regarding (1) water quality deterioration associated with shorter stagnation periods (days) and parallel situations; (2) water quality in large buildings; (3) disease outbreaks associated with plumbing; (4) issues associated with stagnant municipal water; and (4) plumbing decontamination practices.

The authors also referenced guidance documents that may inform building owner responses to this unprecedented event (**Table S1**) including plumbing standards, guidance documents from U.S. or world authorities, and recommendations from related professional organizations [28–44]. Specific parallel situations included seasonal public water systems (e.g., campgrounds, fair grounds); ski resort/snowbird communities with 80% reduction in water use in off-season [45]; athletic or other event centers, schools, and dormitories that have lower than design capacity water use seasonally; and water disconnections due to non-payment that last weeks to months [46–48]. Finally, the authors' own firsthand experiences assisting building owners decontaminate and restart plumbing after nonuse, conducting plumbing related disease outbreak investigations, and answering questions received from local, state, federal agencies and nonprofit organizations about policy were considered.

<u>Scope.</u> In this paper, the term building 'recommissioning' refers to the reopening of buildings after extended closures and focuses on restoring water quality to baseline conditions. The process should not be confused with the recommissioning process featuring water audits and subsequent changes made to increase water and energy efficiency in buildings (e.g., changing toilets and fixtures to low-flow) [49]. This paper focuses on large buildings closed in spring 2020 to promote social distancing. Other recommissioning actions unrelated to water quality (e.g., air quality, heating systems) or for other building water systems (e.g., cooling towers) were not considered. The focus of this paper is the hot and cold water systems. Other considerations will need to be taken for alternative building types (e.g., water shut-offs impacting 15M people due to non-payment [46]).

The intended audience of this review includes public health officials and water officials who may be developing guidance or are responsible to investigating disease outbreaks. This may also be of interest to plumbing engineers and building owners who must consider these potential issues when implementing guidance. Utilities may also be interested to help coordinate their efforts with their customers.

3.0 Results and Discussion

3.1 Defining building plumbing

Building plumbing is all the piping, equipment, treatment devices, fixtures, and appliances associated with providing water from the water source to the point of use for both cold and hot systems. There is high variability in the number and type of plumbing components in a building (**Table 1**), which will depend on the building's water source, design (**Figure 1 & S1**), and water use applications. Service lines convey water to the building from a public water supplier's water main or an onsite water source (e.g., well, surface water). In-building treatment may be present at the point-of-entry (POE) (i.e., where water pipes enter the building) and point-of-use (POU) locations, ranging from a cartridge filter to multi-stage filtration or chemical addition. Multiple piping systems can convey water to taps, with separate hot and cold water pipes, as well as different systems for level of treatment (e.g., softened for drinking fountains, but untreated for bathroom sinks) or multiple temperatures [51]. Hot water systems might include multiple recirculation loops that circulate water back to an array of heaters to maintain high temperatures or on demand water heaters at the POU (**Figure 1 & S1**). As water is stored in and travels through the plumbing, it may contact ceramic, metal, plastic, and glass materials. Large buildings sometimes have multiple pressure zones because the supplied water pressure to the building is inadequate for the distal locations in the building (i.e., multi-story buildings, sprawling buildings like shopping malls). Given the variability and complexity of plumbing, it is difficult to make generalizations. The rapidly developing guidance surrounding COVID-19 responses (**Table 2**) should address the practical water quality and implementation this paper raises.

3.2 Concerns for water quality during prolonged stagnation

The unprecedented amount of stagnation that is likely occurring due to COVID-19 stay-at-home orders has never been adequately studied. As such, it is critical to understand the inter-related factors that influence water quality deterioration during stagnation that are common in large building systems (**Figure 2**). Discussion of recommissioning must consider the known science on drinking water deterioration in plumbing and water management interventions before developing new or adapted response recommendations for building owners.

<u>Disinfectant residual stability.</u> Disinfectant residuals are used in U.S. drinking water to maintain microbial stability and prevent the microorganism proliferation. For buildings that rely on a public water system, the level and stability of disinfectant residual in water delivered to the POE can be highly variable. This is based on a multitude of factors, including type of disinfectant (free chorine or monochloramine), amount of disinfectant typically maintained in municipal distribution system, the location within the distribution system, pipe materials used, and corrosivity of the water, among others [15,52–57]. During normal building operation, disinfectant residual is not always detectable at the building POE: It was present in only 10% of 58 discrete sampling events in a year [6]. Disinfectant residuals can dissipate rapidly within the plumbing system, especially in hot water systems [4,6,58,59]. Residual was found to decay at highly stagnant taps >140 times faster than in corresponding municipal water [10]. These problems may be exacerbated in green buildings that have low water use by design [6,9,10].

<u>Decreased effectiveness of corrosion control.</u> Plumbing material corrosion is dependent on water chemistry (e.g., dissolved oxygen, pH, disinfection), pipe characteristics (e.g., material, diameters, lengths), temperature, and water flow [60]. Corrosion control treatment aims to reduce the presence of soluble and particulate metals in water primarily by addition of corrosion inhibitors (e.g., phosphates or silicates) and water pH/alkalinity adjustments to promote formation of stable scales. During periods of stagnation, lead and other heavy metals can leach from plumbing materials, and issues are common in homes, schools, and buildings with lead-bearing plumbing (e.g., service line, brass, pre-1986 lead-tin solder). While lead equilibrium is reached fairly rapidly (e.g., ½-¾ inch diameter lead pipes within 24 hrs [61]), redox gradients will develop as a function of water age and can create corrosion “hot spots” [62]. During stagnation, corrosion scales can become destabilized and/or modified, but there has been limited research on prolonged

stagnation. Moreover, researchers have highlighted the dynamic relationship between corrosion and disinfection [63,64].

Microbial issues. Microbial growth during water stagnation is well documented [4,65,66], and may result in nitrification, growth of opportunistic pathogens, and community shifts. Nitrifying bacteria, which oxidize ammonia-nitrogen and catalyze residual destruction [67–69] may become more prevalent in distributed and building water due to stagnation, particularly in summer months (i.e., temperature >15 °C, 68 °F). Nitrification can also produce nitrate, a contaminant with a regulated drinking water limit of 10 mg/L (measured as N) [70] due to its linkage to methemoglobinemia or "blue-baby syndrome". Some utilities may temporarily convert to a free chlorine residual to remove nitrogen-containing ammonia nutrients and starve nitrifying bacteria [71], which has implication for water corrosivity and measurements taken at the building level to confirm disinfectant is present (i.e., free vs total chlorine (Cl_2)).

Opportunistic pathogens are a significant health concern in building water systems, especially where water can produce aerosols. These organisms cause infections primarily in immunocompromised persons after inhalation, aspiration, and/or dermal exposure. *Legionella pneumophila* is linked to issues with inadequate control measures (e.g., temperature too low) in hot water systems, decreased effectiveness of corrosion control, and uncontrolled external events in the public water distribution systems and building plumbing [72], which are anticipated to become worse during stagnation. Other opportunistic pathogens, including non-tuberculous mycobacteria (e.g., *Mycobacterium avium* complex), *Pseudomonas aeruginosa*, and free-living amoeba (e.g., *Acanthomoeba*, *Vermamoeba*) have unique ecology (e.g., responsiveness to chlorine vs. chloramine) [73], but are also likely to grow during stagnation [74–76]. To minimize risk of pathogen growth in plumbing, healthcare facilities routinely flush outlets and POU devices [24,77–79], maintain growth-deterrents (i.e., hot water; disinfectant residual), and hydraulically balance systems to minimize stagnation [80–84]. For those buildings that receive water from public water systems, stagnation may pose an additional risk [85–87].

The impact of prolonged stagnation on microbial ecology changes are unclear, but significant microbial community shifts have been observed in stagnant water and stagnant distal ends on short time scales [4,65,66,88–91]. In particular, biofilm structure is influenced by flow regime [92–94], which changes during stagnation and may have implications for biofilm mobilization, including pathogens, when water use is resumed. Nutrients to sustain growth could be introduced through leaks, nutrient cycling within biofilms [95], and necrotrophic growth [96].

Other issues. A number of other water quality issues have been documented with stagnation. The concentration of some disinfectant byproducts may increase to unacceptable levels as disinfectant residual decays during stagnation time (over several hours), especially with high temperatures [97,98]. As these reactions may occur quickly, the significance of disinfectant byproduct formation during prolonged stagnation is unclear. While many plumbing designs avoid cold water heat gain from hot water pipes via spacing and insulation, heat gain in cold water systems and heat loss in hot water systems are inevitable [80]. Ambient indoor temperatures that control temperature in stagnant pipes [5,99,100] will be dependent on climate and indoor temperature: During closures, these may change relative to normal building operation and may influence corrosion reaction rates and growth conditions.

3.3 Water management practices to reduce the impact of prolonged stagnation on water quality

Building water management plans. Water management plans are required for some buildings [30,101,102] to help guide prevention and response to water quality issues, especially opportunistic pathogen growth. Resources are readily available to aid in the development of the plans [30,43,103]. While every plan should reflect the building's unique characteristics, common elements include regular flushing and thermal regulation. Development of water management plans may also be considered in response to COVID-19 related stagnation [34,35].

Periodic flushing. Periodically flushing a building's plumbing by replacing stagnant water within the system with "fresh" water may help prevent water quality deterioration associated with stagnant water. Although flushing is often recommended in guidance as a preventive measure, the efficacy of flushing has not been thoroughly documented and validation of recommendations for how long, how often, or where to perform flushing are lacking. At a minimum, water used for flushing should have a growth deterrent (high temperatures or disinfectant) and corrosion control component.

Defining flushing criteria to reduce chemical and microbial contaminant exposure is challenging, as recommendations vary based a number of parameters not always accounted for in peer-reviewed literature. For instance, in one hospital, a flushing frequency of every two hours was required to reduce culturable *Legionella* numbers to acceptable levels [104]. Yet building water management plans often contain provisions for flushing "unused" or "unoccupied" outlets weekly as a practical recommendation that can be implemented by building personnel [75]. There are several variables that make weekly flushing insufficient for effective *Legionella* control: (1) plumbing design and hydraulic balancing issues; (2) complexity of components such as electronic faucets and thermal mixing valves; and (3) stored volume of water relative to water use. To increase the chance that flushing draws fresh water into and through the plumbing, generalized flushing protocols should include guidance on how to select a flushing frequency and duration, as well as how to account for site-specific variability (section 3.5).

Full closures. More significant actions might be considered for full building closures, but these require serious consideration. Users may choose to change the operation of their water heaters during periods of non-use. *Legionella* management in large buildings typically relies on thermal control or on-site disinfection [75,80,105]. For such controls to remain efficient, hot water systems should continue to be operated in a way to minimize the potential for *Legionella* growth (i.e., maintaining hot water generation and return temperatures combined with regular flushing of stagnant pipes). If water heaters or recirculation pumps are completely shut down to save energy, these controls will no longer be effective, but systems may cool to completely sub-optimal growth ranges. This has never been studied. In both cases, regular flushing should be considered, and if feasible, implemented.

Draining plumbing may prevent growth in water but can introduce other issues. As plumbing is designed to maintain pressure, drainage may introduce backflows and contamination from other water systems such as cooling towers and fire protection systems if efficient backflow prevention is not in place. Challenges associated with draining water from plumbing include the destabilization of sediments and biofilms when refilled and introduction of external contaminants to the pipes. Microbial community changes may also occur in biofilms over time. Shock disinfection may be necessary at startup after depressurization: If depressurization is thought to have occurred in seasonal potable water systems, additional shock disinfection is recommended [28]. While one guidance released regarding COVID-19 building closures advised for draining plumbing [41], another guidance explicitly advises against it due to the pockets of water likely to remain in plumbing [42].

Water utility distribution network. Building flushing protocols should consider water quality supplied by the water utility. A disinfectant residual should be present but may be harder to achieve with reduced system demand. Utilities may increase the concentration of disinfectant residual in their distribution system, which has precedent in this and other emergency situations [106,107]. This action must be weighed against disinfection byproduct production. Utilities may also more closely review routine water quality monitoring data for affected areas to focus flushing efforts, install auto-flushers, or generally increase frequency of hydrant flushing to increase delivery of residual.

3.4 Recommissioning considerations

There are several considerations when determining whether plumbing should be recommissioned (**Figure 3**). The materials reviewed (**Table 3**) are not all directly applicable

(**Table S1**), as they apply to (1) initial building commissioning, (2) seasonal potable water systems that adhere to specific regulatory requirements, or (3) the start-up of drained or purposefully shutoff systems. Specific care must be taken in adapting these documents, as the complexities and variability of large building plumbing may not be considered.

System integrity. Before taking any preventive or remedial actions, it is critical to ensure that the building water system is working properly. This is standard practice for seasonal public water systems. For buildings, this could involve inspection of mechanical and plumbing components to identify leaks, depressurization, adequate backflow prevention, and assess functionality (e.g., hot water supply and return temperatures, on-site disinfection dosing correctly). The performance of routine maintenance or start-up procedures if equipment was taken offline can also be considered. Specific mechanical systems to consider are listed in Section 3.5 (Equipment; Appliances).

Recommissioning necessity. The decision regarding what actions are needed, if any, before resuming building water use should be determined in consultation with relevant public health authorities who oversee building water safety. The main concern is whether water poses unacceptable chemical and microbial health risks to building occupants, which can differ drastically in terms of building size and complexity, length of shutdown, likely integrity of the system, type of occupants, and water uses. There is precedent for regulated seasonal public water systems that some requirements may be waived or reduced if the buried water infrastructure maintained pressure (**Table 3**). Preventative actions taken during closure (Section 3.3) may influence which recommissioning actions may be needed at building reopening (Section 3.4).

No consensus was found for the length of time a building can remain unoccupied or with extremely low occupancy before it should be formally recommissioned. The American Society of Heating Refrigeration and Air-conditioning Engineers Standard 188 (ASHRAE 188 [30]) outlines that shock disinfection should occur within three weeks of planned occupancy. If occupancy is delayed more than four weeks, another shock disinfection is required prior to occupancy. It is unclear how this would differ for existing buildings because ASHRAE applies to new or recently renovated buildings. Due to the lack of guidelines and scientific data to support specific recommendations for the unprecedented COVID-19 situation, building owners and operators should consult local public health officials, onsite personnel (e.g., building manager), and mechanical/plumbing engineers in deciding what recommissioning actions to take and acceptable water uses (e.g., toilet flushing and handwashing vs. consumption).

Informing occupants. Communication plans to notify building occupants of potential water quality vary depending on the issuing organization, intended audience, and content. Notifications regarding water quality are considered separate from notifications of outbreaks if an issue has occurred. Communication regarding risks to *Legionella* exposure has been developed [103], but has not been developed for the current situation. Building owners with concern may consider contacting public health authorities and distributing information to their occupants. A proactive approach to addressing and communicating water quality issues in buildings is generally recommended at both the utility and facility level [108]. Further considerations for facility and utility level communication are included in Section 3.6.

While communication typically follows specific pathways, communication to occupants should be tailored to individual situations to (1) address specific concerns; (2) identify particular risk factors; (3) be accessible to all building occupants (i.e., simple language, multiple translations);, and (4) communicate specific risk factors to allow occupants to assess and limit their risk. For example, after the discovery of volatile organic compounds in drinking water, the town of Paradise, CA issued water orders specifically allowing only certain water uses to minimize public health impacts [109]. When *Legionella* growth is suspected, aerosol-producing activities might be discouraged. For opportunistic pathogens, a variety of individuals are at higher risk, including critically ill or highly immunocompromised individuals (neonates, chronic obstructive pulmonary disease (COPD) or chronic lung disease, cancer patients), as well as a large fraction of the U.S. population (>60 years old, smokers, diabetics), and potentially persons who are recovering from COVID-19. Communication can also inform whether actions taken are preventative or curative.

Flushing considerations. There is precedent for using flushing alone to restart seasonal drinking water systems that have experienced extended stagnation but maintained pressure [28,29]. However, this strategy is targeted at complying with state and federal drinking water regulations (e.g., Total Coliform Rule [110]) with large diameter pipes and tanks, and does not necessarily address opportunistic pathogens or metals discussed in Section 3.2. While some public health agencies may recommend flushing as the primary building water system recommissioning action, site-specific variables should be considered to ensure that the entire volume of hot and cold water is flushed and that any dislodged sediment or biofilm is removed (see Section 3.5 for detailed considerations). Due to non-ideal and non-plug flows in pipes and appliances, replenishing volume will require flushing more volume than is present in the system [111]. Thus, widely issued time-based flushing protocols will be ineffective for some buildings. For example, flushing a distal tap for 10 minutes and any other water outlet for 5 minutes as recommended in response to COVID-19 building water quality problems [33] would not suffice for removing 'dead volume' from an out-patient healthcare facility, green office building, or a school in which the authors have worked [10,112,113].

Shock disinfection considerations. Shock disinfection for plumbing introduces a high concentration of disinfectant or high temperature for a relatively short period of time to reduce the presence of waterborne pathogens that pose a human health risk. Disinfection practices for commissioning new or recently renovated buildings are stipulated in Universal Plumbing Code (UPC) and International Plumbing Code (IPC) adopted by local jurisdictions, or reference American Water Works Association (AWWA) standards for disinfecting water mains and their associated storage facilities (**Table 4**). There is also a body of literature specific to remediating *Legionella* colonization in the aftermath of cases or outbreaks of Legionnaires' disease that would also be applicable to disinfecting plumbing. Free chlorine, chlorine dioxide, chloramines, and thermal shock have been used successfully for remediating *Legionella* growth [75,114]. While partial system disinfection is less ideal, targeted approaches for high-exposure activities for inhalation of aerosols (e.g., showering, Jacuzzis) have been used in the past, and is suggested by the CDC regarding the COVID situation [34]. Disinfection may be paired with cleaning, which is discussed in section 3.5.

The efficacy of any shock disinfection procedure can be increased by taking several actions. An important consideration is to ensure that the procedure is completed so that water at an inhibitory temperature or with disinfectants is distributed throughout the building so that all parts of the systems are exposed for recommended durations. It is also important to thoroughly flush the system before and after the procedure is performed to remove loose deposits and shock chemical disinfectants. The procedure should be conducted in conjunction with a building water system risk assessment to identify and correct secondary issues with water system operation (e.g., unbalanced hot water system [75,80,84,105]). Water quality validation testing, which includes confirmation of delivery of the disinfectant or high temperatures to outlets, and, when justified, microbial growth (see Section 3.6), should be considered. The procedure should be performed by an experienced professional. It should be noted that most required validation testing for initial commissioning or seasonal public water system startup is aimed at total bacteria (heterotrophic plate count) or fecal coliform, rather than specific pathogens which are the source of waterborne disease outbreaks in plumbing.

<u>Readiness for use.</u> In normal operation, maintaining adequate disinfectant residual and/or sufficiently high water temperatures, can limit stagnation related water quality issues. Confirmation that these are present throughout plumbing may be appropriate. While a surrogate measure of temperature can help determine flushing completeness (see Section 3.6), the most definitive way to ensure that water quality is restored is to test relevant water quality parameters [115]. While testing water routinely in large commercial buildings is typically not required, testing

for recommissioning may be desired. Requiring testing in buildings is not unprecedented: when volatile organic carbons were discovered after a wildfire in Paradise, CA, the local health authority required plumbing testing of large buildings prior to occupancy [116]. Moreover, some states require testing of lead and copper in schools [117,118].

If conducted, testing should be tailored to specific water quality issues described in Section 3.2 (e.g., disinfectant residual, lead, copper, opportunistic pathogens), and specific systems (e.g., testing for chloramine rather than total chlorine if chloramines are used). Considerations for testing are expanded in Section 3.6. A challenge may be that full-occupancy may not occur immediately after the plumbing is determined acceptable, or that testing requires time and planning before occupancy. As such, building owners will need to consider and minimize pathogen growth risks [103] and metals during this low occupancy period (see Section 3.3). This may precipitate the need for additional flushing, testing, or more significant actions over time.

3.5 Potential challenges in writing guidance for large buildings

Recommissioning guidance must account for site-specific variability in plumbing design, mechanical/plumbing equipment, specific appliances, and end-use devices. The amount of water to be flushed should be based on the overall plumbing configuration and design (e.g., adequate to turn over full water volume within all system components). Estimating the total volume of all system components, including service lines, may be helpful to know how much water to flush at each location. Alternatively, or in addition to volume estimation, the presence of disinfectant residuals at levels representative of “fresh” water and/or steady-state temperature can also be iteratively evaluated to determine the appropriate amount of water to flush. After a site-specific approach is developed, flushing should begin by establishing fresh water at the POE to avoid contaminated water entering the building (this may need to consider multiple POEs) and then progress through the rest of the system in a “downstream” fashion, as described below.

Service line. The service line provides water to the building for cold and hot systems as well other property water systems (e.g., sprinkler systems [119], cooling towers). The water volume stored in a commercial building water service line can range from 10s of gallons to more than 1000s of gallons depending on the property design (**Figure 4**). It is critical that water is flushed at the building POE prior to starting the recommissioning process to avoid drawing stagnant or potentially contaminated water into the building plumbing. Flushing privately owned fire hydrants (e.g., on campuses) may be considered to clear service lines [113]. Even with volume calculations, it is advisable to confirm the presence of disinfectant residual at the POE, as distribution system water quality may be degraded due to widespread stagnation in the area.

Equipment. An effective flushing or disinfection protocol should consider the mechanical plumbing equipment that are typically located in mechanical spaces and "upstream" of the main building piping network, listed in **Table 1.** Bacterial growth, including pathogen growth, has been associated with this equipment and associated with subsequent disease cases [120,121]. These devices may warrant specific and targeted recommissioning procedures in addition to replacing the stored volume associated with them.

The routine cleaning and maintenance procedures of these devices are a starting place for recommissioning these devices, but in the authors' experience manufacturer guidance does not typically cover prolonged stagnation events. Volume-based flushing may be inadequate due to nonideal flow through devices (e.g., water heaters [111]). Supplemental commissioning procedures should seek approaches for these devices and equipment to fully replace water volumes, remove sediment that may have accumulated, and be cognizant of negative effects of exposure to recommissioning conditions (e.g., if certain pieces of equipment should be bypassed, filters replaced, or not exposed to high chemical concentrations) [122,123]. As devices can reduce water flowrate (e.g., filters, softeners) [124], bypassing devices may be beneficial for downstream flushing, but should still be flushed separately. Routine maintenance, (e.g., softener resin cleaning and disinfection; tank draining and cleaning), which may be done every year should be considered prior to or immediately following (e.g., filter replacement) whole building flushing. Finally, since buildings have a wide variety of devices, general guidance should require inventorying devices. Several guidance documents recently released for homes [125,126] and buildings [33,34,127] addressing stagnation or shutoff building water systems fail to account for all of these devices.

Plumbing configuration. Pipe length, diameter, and layout can vary greatly (**Figure 1**). Thus, estimating water volume or designing sequential flushing plans can be challenging. Typical non-residential plumbing systems in large buildings have been designed as trunk-and-branch systems with one or more risers and headers with branches to individual outlets, but may have much more complexity (Section 3.1). Smaller systems may also be designed as manifold systems. Site-specific configurations will affect the water volume (and time) needed to flush each tap and the order in which outlets should be flushed. Thus, implementing effective protocols may require access to plumbing plans (or as-built drawings, if available) and/or building personnel knowledge of system design and operation. Such drawings may also be useful in inventorying every water outlet (e.g., outdoor spigots, forgotten taps) so that every pipe and location is flushed. Deadends (pipes that lead to nowhere) can also exist in buildings, especially if buildings have been remodeled or had a change in use. Deadend pipes cannot be flushed without more extreme actions, like depressurization, and capping them or installing ball-valves as close to the beginning of deadend lines as practical may be preferred.

Appliances. End use devices (**Table 1**) also have small amounts of water storage. As pathogen issues have been associated with many of these devices [128–133], their operation must be taken into account for recommissioning. Yet, the authors have noted the absence of some (or any) of these devices from some COVID-19 inspired flushing guidance for buildings [33] (further details of several guidance documents, including more comprehensive ones in **Table 2**). These distal end volumes can be replenished by running them or manual action (e.g., removing ice and the first few batches of new ice). Routine maintenance of all devices (e.g., replacement of filters) should also be considered at the time of recommissioning. Medical and dental facilities with specific sterile water appliances must be particularly careful of appliance maintenance. In particular, the use of sterile water only for medical or dental devices such as heater-coolers in operating rooms, is always recommended [129,134–136]. Recent outbreaks have resulted from exposures both via aerosols and medical equipment contamination from sink drain splashes/aerosol deposition [137]. Special care should be taken with cleaning these devices during building reoccupancy.

<u>Fixtures</u>. Unlike most plumbing components, fixtures such as faucets, aerators, fountains, thermostatic mixing valves, showerheads, and shower wands can be relatively easily removed, cleaned, and/or replaced, though it is time and labor intensive. Pathogen growth and heavy metal accumulation (e.g., particles of copper, iron, lead) has been associated with these plumbing components [58,91,138–147]. Thermostatic mixing valves, used in showers and faucets to mix hot and cold water to prevent scalding, have been identified as particularly problematic for growth of *Legionella* [148–150]. Cleaning such devices is recommended for normal maintenance, particularly thermostatic mixing valves [75,123,151,152], and recommissioning may be an opportune time for these practices. While not directly part of water delivery, sink drains can be a source of pathogens, contaminating faucet aerators in hospitals [137], and thus cleaning and disinfection should be considered.

<u>Flushing issues</u>. By flushing at high flowrates, loose deposits and biofilm may be mobilized from pipe walls. For water mains (4 to 16 inch diameter), a water velocity of 3 ft/s for at least 30 minutes was found to achieve 2.5-log removal of sand particles [153]. To achieve a similar water velocity in plumbing, very high flowrates would potentially be needed: 2 inch (34 gpm), 1 1/2 inch (19 gpm), 1 inch (9 gpm), ¾ inch (5 gpm), ⅝ inch (3 gpm). Some of these flowrates may be achievable in the service line, plumbing trunk lines or branches by removing aerators or low flow showerheads. Removing aerators increased flowrates by 20-80% in a hospital [111], but these devices can also be difficult to remove with scale build-up or require special tools. At the same time, water velocity below 10 ft/s is recommended to minimize the water hammer effect [154].

In order to achieve a high flowrate in a pipe, guidance documents often recommend opening all faucets at once (i.e., lead service line flushing guidance, designed to maximize flowrate in a service line after disturbance during construction [155]). In the large buildings addressed here, removing water and sediment from plumbing branches is a concern and requires several considerations. Opening only a subset of faucets (i.e., by pressure zones) can be considered, as opening all faucets can be logistically challenging, and have drawbacks if pressure cannot be maintained. Pressure may be particularly problematic in large buildings with improper design or plumbing corrosion. If pressure is not sustained, then the resulting reduced flow (velocity) in individual distal plumbing pipes could result in the deposition of particles (i.e., lead) that were dislodged from trunks or service lines. To avoid sediment deposition, the service line can be flushed first at the POE, without drawing water through plumbing. Pressure drops can also lower water velocity in the building pipes, such that flushing is ineffective. Depressurization, which could trigger a need for disinfection, and back-siphonage, the reversal of flow direction [111] can also occur.

Flowrates are likely to vary, even within a building, for cold and hot systems, particularly if many fixtures are opened one at a time. Pressure delivered by the water utility or onsite pump may not be consistent, especially if many local buildings are engaging in simultaneous flushing. The flow obstruction caused by scale and plumbing fittings like elbows, irremovable aerators, tees, elbows, valves, faucets and showerheads could also cause variability within a building. Understanding building pressure is critical to designing effective flushing guidance compatible with the buildings' specifications.

<u>Ensuring complete flushing</u>. Incomplete flushing could result in contaminated water remaining in the system or not deliver the intended benefits (i.e., growth deterrent doesn't reach all taps, dirty water moved through building). Even under normal scenarios, residuals can be difficult to achieve at the POU even if present at the POE to the building. For example, >80 minutes of flushing was needed to obtain a residual at distal outlets in one green outpatient

healthcare building [10]. To understand where water is originating from during flushing, the EPA measures water quality parameters such as turbidity, pH, temperature, specific conductance, disinfectant residual [156]. Temperature stabilization (<0.1 °C or <0.2 °F change in temperature) may be used as a criterion in cold water systems, but local climate considerations should be taken into account.

Using flushing diagnostics for hot water systems is much more difficult, but has been successful [80,84]. If hot water systems are properly balanced, steady state temperatures will remain at setpoint and recirculation temperatures, depending on the heating capacity of the water heater(s) and number of outlets flushing simultaneously. For example, a high stable temperature (i.e., 55° C, recirculating temperature) may be reached for several minutes without drawing significantly from the water heater (i.e., 60° C, heater set point). If the system is not properly balanced, steady-state temperatures can vary substantially throughout the building. Change in operation of building heating and cooling during shutdown may also affect flushing temperature profiles.

<u>Pipe material</u>. Piping material can vary widely within a building, and service line materials may differ from plumbing materials in the building (e.g., copper service line and plastic plumbing). These materials can contribute changes in water quality that has implications for public health (e.g., copper and lead concentrations [5]) as well as biofilm structure and composition (e.g., iron as a nutrient) [89,157,158]. Thus, initial stagnation and recommissioning procedures will vary from building to building. Material compatibility must also be considered when selecting recommissioning processes, as damage can be caused to plumbing materials. Shock disinfection with chemicals or heat is often used without issue, but sometimes can be potentially problematic. For example, free chlorine shock disinfection has previously been associated with hospital plumbing leaks [159], chloramines are known to accelerate gasket mechanical degradation resulting in leaking toilets, faucets, and other fixtures [160], and high temperatures can damage certain plastics. Copper pipes, metal connections, and lead bearing plumbing fittings may also be

damaged by shock disinfection practices [161,162]. Comprehensive resources about this are not readily available but building owners may need professional help or further advice (i.e., lower dosage limits combined with increased contact time) if shock disinfection becomes required.

3.6 Responsibility, implementation, and care

Responsibility. From existing guidance, the responsibility for building water quality and safety is largely the responsibility of the building owner. Codes require that the local health authority (generally referred to in the UPC and IPC [31,32]) make decisions about plumbing commissioning. However, given that (1) COVID-19 building closures can affect water main water quality (Section 3.2), and (2) many buildings may be flushing in similar time-frames, it may be necessary to coordinate actions with the local water utility. Building owners may benefit from utilities temporarily and locally providing higher levels of disinfectants than normal. Building owners may also avoid low pressure or depressurization by staggering flushing activities in the area. If water quality in water mains is of low quality due to stagnation, drawing this low-quality water into the plumbing may initiate new problems or exacerbate ongoing issues. Thus, the building owner and health authority will want to communicate with the water authority regarding distribution water quality.

Resources. Building owners will be responsible for the cost of recommissioning: the volume needed for flushing and cost associated with that water (i.e. local municipal water rates [117]) will vary considerably. Inexpensive hand-held disinfectant residual monitors or temperature probes could enable building managers to quickly begin better understanding their building water. Testing, treatment, and other costs may also be necessary based on the health authority's guidance to better ensure safe water delivery to occupants.

Flushing implementation issues. Worker safety while flushing may need to be considered. Initial flushes of stagnant water and associated transient pressure events can release high concentrations of chemical and microbiological contaminants due to high shear stress associated with flushing protocols, combined with in-situ reactions (Section 3.2). One study reported increases in iron, copper, particles, and turbidity, and bacteria (as much as 19X) following a pressure shock [163]. To reduce exposure risk during flushing water with chemical and microbial contaminants, workers can be screened for preexisting conditions that may make them vulnerable (e.g., to opportunistic pathogens), and/or use personal protective equipment (PPE) (**Table 2**). The Occupational Safety and Health Administration (OSHA) recommends that "if *Legionella* contamination is possible, but a Legionellosis outbreak is not necessarily known or suspected, consider encouraging voluntary use of respirators in accordance with" their criteria [44]. Both N95 and N100 respirators are mentioned, but OSHA requires that workers wear respirators with an N100 cartridge in the event of a known or suspected *Legionella* contamination with aerosolization is possible [44]. In response to building water stagnation prompted by the COVID-19 outbreak, the American Industrial Hygiene Association recommends a higher level of respiratory protection with P100 HEPA filters when sampling building water and *Legionella* may be present [36]). On April 1, 2020, the CDC explained to the authors that local health authorities should determine appropriate personal protective equipment [164]. However, during the COVID-19 outbreak, there are global shortages in critical PPE (e.g., gloves, masks) [165]. PPE supply chains may improve once reoccupancy is being explored. To further reduce exposure, flushing should be conducted in a manner that reduces water splashing and aerosolization [166] (e.g., use of hoses to connect difficult spigots directly to drains).

Building owners should also consider waste during flushing. If the building utilizes an onsite septic system, special care must be taken not to overload and flood the system with water. Such an action can permanently damage the tank and leaching field. To accomplish the building recommissioning tasks, the building owner may consider enlisting building water system experts such as a plumber or an engineer to design or complete flushing plans, in addition to requesting advice from the local health authority.

Shock disinfection implementation issues. Shock disinfection, if performed, likely requires the assistance of professionals. Extra caution is needed to avoid dermal and inhalation exposure. Warnings and signage during shock chlorination or temperature shock can warn occupants against water use; these practices are easier to perform while the building is unoccupied and entrance is barred. Given the vulnerability of some materials to high concentrations of chemicals, systems should be inspected for loose or cracked joints, fittings, and leaks after shock chlorination. Disposal of water with high chemical concentrations may require pretreatment or coordination with local wastewater authorities.

Testing. Water testing is required in some guidance documents after disinfection to confirm the efficacy of disinfection and subsequent flushing (**Table 3**). Regulated seasonal public water systems, for example, must test for fecal coliform and disinfectant residual to confirm system integrity. Disinfectant residual testing is relatively easy to conduct to confirm delivery of disinfectants during flushing, even when shock disinfection is not performed. However, the specific tests to be conducted should be determined after consultation with the water supplier as they use different disinfectants (i.e., chlorine vs. chloramine).

The relevance of fecal coliform testing in buildings is relatively low, as fecal pathogens are not thought to grow readily in building water systems and plumbing integrity should be high if depressurization was avoided. General bacteria testing (e.g., heterotrophic plate count) may be more relevant to determine the success of shock disinfection, but (1) heterotrophic plate count data from buildings may be difficult to interpret, since normal use results in high and variable counts in buildings [5,11,66,167–169] and (2) heterotrophic plate counts levels have no known health impact. As the growth of opportunistic pathogens is of highest concern with extended stagnation, water testing for opportunistic pathogens may be most relevant in some circumstances. However, choosing which one(s) to test for can be difficult, testing can be expensive, and analysis results are not available for more than 7 days.

Guidance for building commissioning after construction does not give advice for determining where, how, or how often to sample water. This gap is problematic in that variability in water quality within a building is well-documented [4,6,169]. The different pipe lengths, legs, and materials make deciding how to design a testing plan challenging. Advice for regular *Legionella* sampling in other countries may be a useful start point [75].

Communicating risk. No explicit regulatory requirements were found that required building owners to notify building occupants about building water quality. Communications about building water health risk should be coordinated with the public health authority. A temporary restriction on some uses to either all, or just showers and other aerosol producing devices could be considered. In extreme contamination situations, building owners could perform a "lockout and tagout" of the affected water fixture or building area [170]. Progressive re-occupation of buildings raises a special challenge as it could mean multiple corrective actions and notices to building occupants may be needed.

There is a lack of instructional material available for building owners to communicate building water health risk to occupants, but some information has been developed for utilities. There is precedent that public water systems must notify building owners about the quality of water they are delivering and issue do not drink and do not use orders [171]. Available materials for utilities are focused on communicating by utilities to building owners regarding the presence and detection of legionella, lead, disinfection byproducts, and total coliforms [30,123,172–178]. Guidance on utility issued boil water notices, as well as do not drink, and do not use notices in escalating order of severity [176] is available. Prior research has revealed key aspects of messaging and communication. Public health communications are best tailored at the 6-7th grade reading level [123,176,179,180]. Consideration is needed for populations including those with limited English proficiency, the blind or visually impaired, persons who are deaf or hard of hearing, older adults and frail elderly, children, pregnant women, physically and mentally impaired, and/or people with compromised immune systems [123,176]. Example communications messages for building owners, public health authorities, and water utilities related to building water can be found in the SI section (**SI-1**).

4.0 Conclusions

This study was conducted to inform guidance documents that are rapidly being developed to address COVID-19-related water quality concerns regarding full or partial building shutdowns, or reopening/repurposing other buildings for expanded local medical capacity. Reduced or no water use in buildings during COVID-19 responses may present both chemical (in particular, lead) and microbiological (in particular, opportunistic pathogens) health risks. However, the unprecedented nature of widespread, long-term building closures has never been studied. While some resources exist, none apply directly to the current situation and have limitations in their application or adaption to COVID-19 recommendations. This paper provides an overview of the challenges, current practices, and knowledge-gaps for maintaining stable water quality during and after extended periods of limited or no water use. The intended audiences of this review were public health officials, building owners, and water utilities who may seek to avoid or reduce public exposure to chemically and microbiologically degraded water.

Until more information is available, building owners and health officials should consider all of the actions identified. Several efforts were recognized as requiring future investigations:

- Evaluate the effectiveness of specific recommissioning actions or series of actions in reducing health risks across plumbing types, configurations, and in the context to types of occupants and building use. Documenting success or failure of guidance will allow for improved guidance that minimizes risks and costs.
- Develop methods for determining the frequency, number, and location of representative water samples for a building and the necessary chemical and microbiological analyses needed to adequately asses health risks.

- Investigate the factors that control chemical and microbiological water quality characteristics under prolonged stagnation (i.e., months).

The COVID-19 response provides an opportunity for health officials, building owners, and utilities to proactively reduce health risks building occupants may encounter. Evidence-based standards are needed to address routine plumbing maintenance (e.g., flushing) and recommissioning procedures. In absence of those standards, information contained in this review can help inform and guide health authorities and building officials make those decisions.

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Conflicts of Interest

The authors declare no competing interest.

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Figures and Tables

Figure 1. Building plumbing schematic. Top: what occupants can see; Option 1: Traditional trunk-and-branch; Option 2: Trunk-and-branch with headers for every flow; Option 3: Trunk-and-branch with multiple risers.

Figure 2: Potential chemical and microbial water quality impacts associated with prolonged stagnation in chlorine (Cl_2) and chloramine-based (NH_2Cl) disinfectant drinking water systems.

Figure 3: Considerations for recommissioning guidance in six major categories: system integrity, recommissioning necessity, informing occupants, flushing considerations, disinfection considerations, and finally, readiness of water for use. [1]ASHRAE 188 is an adoptable standard focused on *Legionella* contamination and is the only guidance regarding length of closure that may prompt the recommendation for recommissioning actions; it may not apply to all contaminants discussed; [2]multifamily residential, >10 stories tall, healthcare facility, patient stays >24 hours, housing or treating immunocompromised individuals, housing >65 years old occupants.

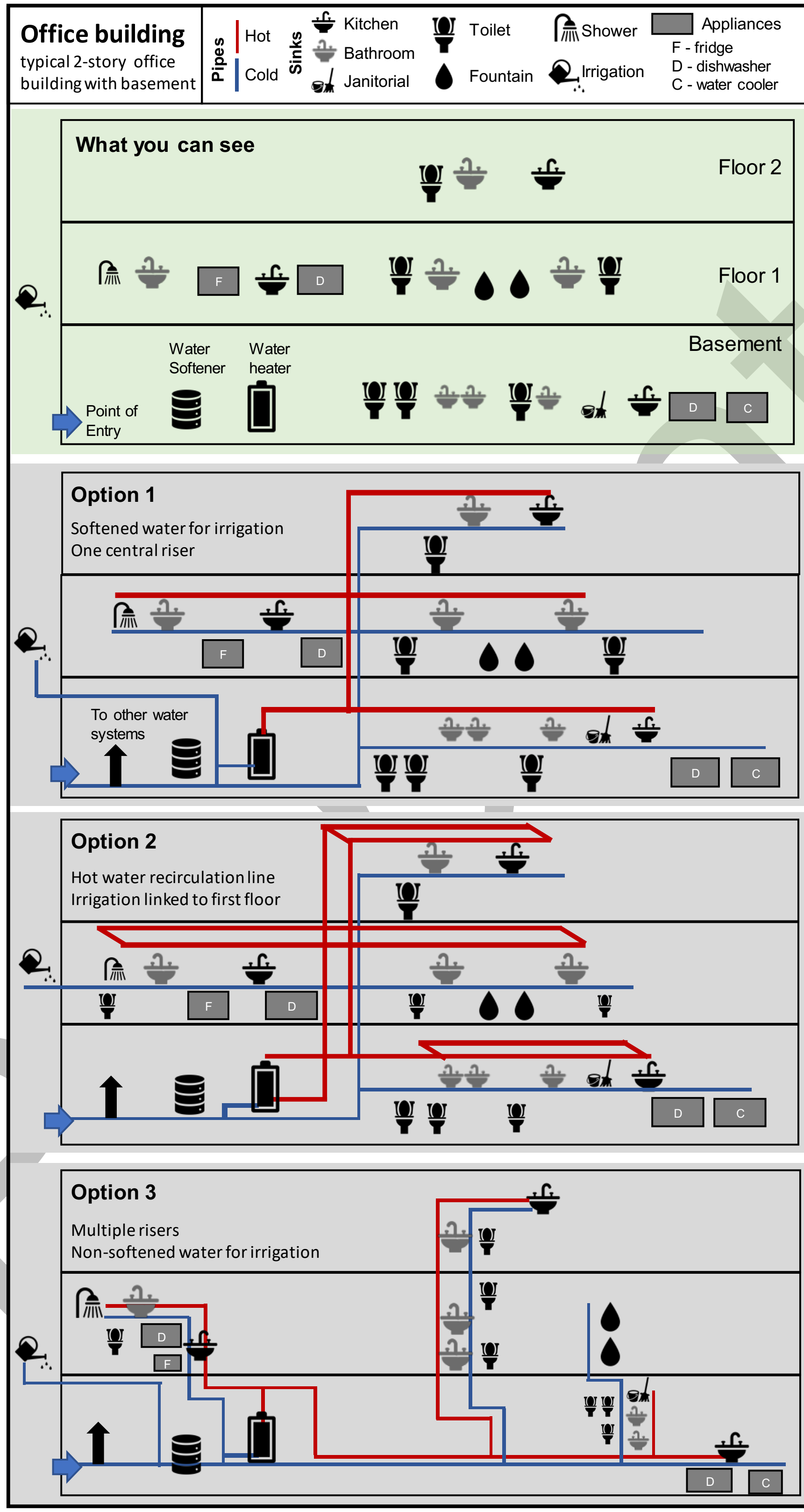
Figure 4. Example variation in the length of an actual service line from water main to an actual building water system

Table 1. Types of building plumbing components

Table 2. Comparison of disinfection methods from plumbing codes, AWWA standards for water utility infrastructure, and ASHRAE guideline 12-2000[1]

Table 3: Attributes of actions suggested or required for building start-up, commissioning, and recommissioning in referenced documents, codes, and standards

Table 4. Comparison of disinfection methods from plumbing codes, AWWA standards for water utility infrastructure, and ASHRAE guideline 12-2000[1]



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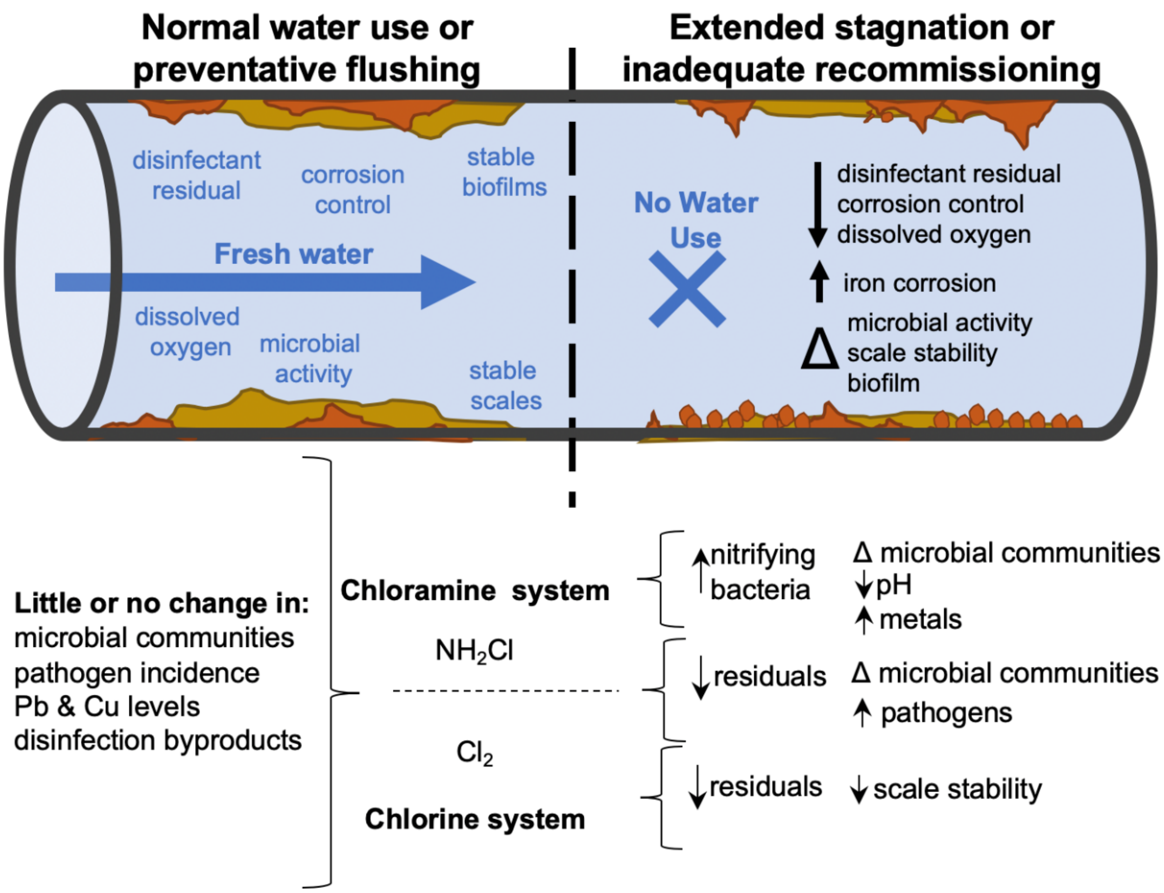
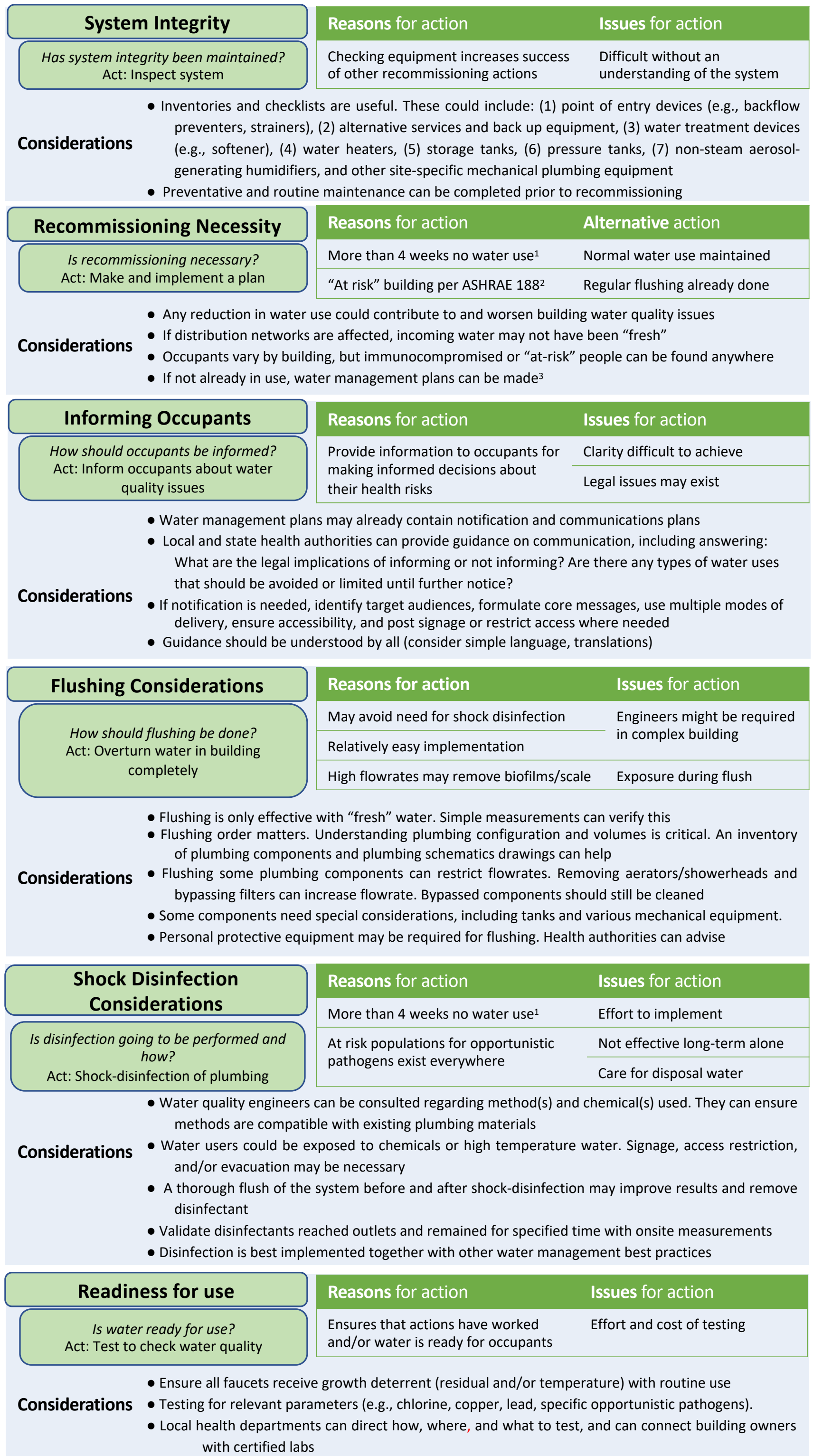


Potential Water Quality Impacts Associated with Water Use Patterns

Figure 2: Potential chemical and microbial water quality impacts associated with prolonged stagnation in chlorine (Cl_2) and chloramine-based (NH_2Cl) disinfectant drinking water systems.



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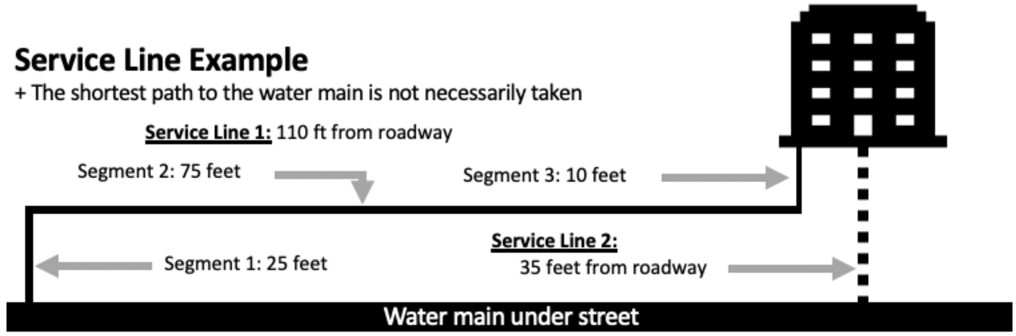

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2 **Figure 4.** Example variation in the length of an actual service line from water main to an actual
3 building water system

Table 1. Types of building plumbing components

Components	Description
Water source	Municipal water, onsite well, surface water, rainwater.
Service line	Pipe system that carries water from the source to the building water system. Service line materials are variable and may or may not be the same as indoor pipes.
Safety devices including valves	Pressure relief valve, pressure reduction value, isolation valve, mixing valve, thermostatic device, backflow prevention device, water hammer arrestors. Materials can include aluminum, brass, copper, lead, plastic, and stainless steel.
Water treatment devices	Filter, strainer, water softener, chemical addition equipment for disinfection and corrosion control.
Water service and distribution piping and faucet connectors	Various material types have been used to include acrylonitrile butadiene styrene (ABS), brass, cast iron (CI), chlorinated polyvinyl chloride (CPVC), copper, crosslinked polyethylene (PEX), ductile iron (DI), high density polyethylene (HDPE), lead, lead lined steel, multilayer pipes, polyethylene raised temperature (PERT), polypropylene (PP), unplasticized polyvinyl chloride (uPVC), polyvinylidene fluoride (PVDF), black steel, stainless steel.
Hot water recirculation system	Primary and secondary water heater loops, which serve different building zones with different temperatures and have to be hydraulically balanced. Equipment includes master mixing valves, local mixing valves, flow balancing valves, pressure reducing valves. Hot water return pumps and water heaters.
Fixtures and fixture fittings	Aerator, air washers, atomizers, bathtub, bidet, decorative fountains, dishwasher, drinking fountain, eyewash stations, manual faucet, electronic faucet, faucet flow restrictors, hoses, point of use mixing valves, hot tubs, humidifiers, ice machines, misters, shower head, shower wand, sink, tub spout, toilet, urinal, washbasin, thermostatic mixing valves
Pumps	Pumps are often used for pressure boosting within the building (i.e., for multi-story buildings) where water pressure entering the building is not adequate for water use at distal locations. Pumps are also used for hot water recirculation systems.
Tanks	Stand water heater, on-demand water heater, hydropneumatic tanks, cold water supply storage tank. Water heaters can contain Mg or Al sacrificial anodes and plastic dip tubes.
Point-of-use devices	On-faucet treatment system, under sink treatment system.

* ASHRAE 188 defines the delivery system for hot and cold water as the “potable” water system [50], and it is sometimes referred to as “domestic” water. Some of the components contain both metal and plastic subparts. These include gaskets, polysulfone or PEX dip tubes, liners and coatings such as glass, ceramic, epoxy, polyurethane, polyurea, and fiberglass. Gaskets may be ethylene propylene diene monomer (EPDM) (sulfur or peroxide crosslinked), butyl rubber (BR), natural rubber (NBR), neoprene, styrene butadiene rubber (SBR), synthetic rubber.

Table 2: Guidance developed since COVID-19 for building water management

Documents Listed in Order of Most Recent Date Issued	**Specific health risks explicitly identified**	**Action during building closures**	**Actions Suggested Prior to Building Use**						
			Inspection	Flushing (amount, speed)	Other cleaning	Shock disinfection	Other step	Worker safety mentioned	Testing
Expert Report (This Study) & Key Messages In SI Section	*Legionella, mycobacteria, Pseudomonas aeruginosa, and free-living amoeba; high lead and copper concentrations; disinfectant byproducts.*	Flush hot and cold water outlets at least weekly; Consult public health authority	Consult public health authority	Consult public health authority	Consult public health authority	Consult public health authority	Consult public health authority	Workers and building occupants must be protected from exposure to contaminated water, aerosols with pathogens, shock disinfection water, and scalding.	Consult public health authority
PHE (2020): COVID-19 and Food Water and Environmental Microbiology Services [41]	*Legionella*	Hot and cold water system outlets should be used at least weekly to maintain a degree of water flow and to minimize stagnation. Consider implementing a flushing regime or other measures such as draining the system if it is to remain vacant for long periods.	Recommends reviewing ESGLI (2020)	Recommends reviewing ESGLI (2020)	Recommends reviewing ESGLI (2020)	Recommends reviewing ESGLI (2020)	Recommends reviewing ESGLI (2020)	Recommends reviewing ESGLI (2020)	Recommends reviewing ESGLI (2020)
CDC (2020): Guidance for Building Water Systems [34]	*Legionella* and other biofilm-associated bacteria. Minimize the risk of Legionnaires' disease and other diseases associated with water.	Develop a comprehensive water management plan and perform manufacturer maintenance on equipment	Identify slime on decorative water features, hot tubs/spas, cooling towers; Ensure water heater working	Flush hot and cold water through all points of use. Flushing may need to occur in segments. The purpose of building flushing is to replace all water inside building piping with fresh water. Flush until the hot water reaches its maximum temperature.	Follow manufacturer recommendations for draining the water heater after a prolonged period of disuse. Clean all decorative water features. clean fire sprinkler systems, eye wash stations, and safety showers.	Recommended for hot tubs/spas	Regularly check water parameters. Follow water management plan. Contact local water authority.	No warning about exposure and health risks during flushing.	Measure disinfectant levels in refilled water features. Request that disinfectant residual entering the building meets expected standards.
ESPRI (2020) v1: Coronavirus Building Flushing Guidance [no differences found in version 2] [35]	Disease causing (specifically *L. pneumophila*) microorganisms Toxic metals such as lead. Harmful substances such as disinfection byproducts.	Do not turn off water heaters. On-going flushing (see flushing). Create water management plan. Shock disinfection can be considered.	Inspect mechanical equipment and examine function.	Flush from building entry to periphery of building. Identify all places water is stored in the building. Sketch building design. Flush zone by zone according to design (start with zone nearest the building entry and then move outward). Open faucets in the zone from nearest to entry to furthest and flush for 5 minutes AND cold water temperature at final tap is steady. Do cold water and then hot water. [Other suggestions for homes]	Flush, clean and maintain treatment systems. Clean showerheads, faucets and other fixtures. Flush and clean any water systems that store water. Replace/ maintain POU filters. Aerators and other flow restrictors removed.	Disinfect building water systems with concentrated chlorine If building is occupied by people more susceptible to infections like legionnaires' disease.	Conduct on going flushing for 12 weeks to stabilize lead scales. Once per week.	Concentrated chlorine could be dangerous to handle.	Collect water samples for analysis at a qualified laboratory (only recommended for buildings with specific at-risk populations like children in childcare and elderly people) Ongoing testing when flushing. Measure concentration of disinfectant at point of entry and the furthest tap of the cold water system. Recommend against any measurements, other than for chlorine, unless there is a compelling reason and the owner can understand what the results mean and what to do about them.
ESGLI (2020): Guidance for Managing *Legionella* in Building Water Systems during the COVID-19 Pandemic [42]	*Legionella*	Building closed for <1 month: Inspect the system. Maintain hot water temperatures. Flush hot and cold water weekly. Monitor in-building disinfectant residual levels.	Not mentioned	Flushing to remove biocide from shock disinfection	Follow advice for other additional water systems and equipment.	Carry out a full system disinfection of the cold water system in accordance with their guidance. Provide hot water to hot water tanks and plumbing	Flush cold water through every outlet. Refill and reheat water heater, then flush outlets.	Take care to avoid scalding risk..	Monitor temperature and biocide levels for at least 48 hr. Collect Legionella samples from the sentinel outlets (microbiological samples collected before 48 hr may give false negative results)
IAPMO (2020): Rehabilitating Stagnant Building Water Systems [33]	*Legionella* and other pathogens	Building closed >1 month: close down with or without draining	Not mentioned	See instructions for a building being closed for < 1 month	See instructions for a building being closed for < 1 month	Carry out a full system disinfection	Before reopening follow the procedures recommended if the building had been closed for <1 month.	Take care to avoid scalding risk..	Monitor temperature and biocide levels for at least 48 hr. Collect Legionella samples from the sentinel outlets (microbiological samples collected before 48 hr may give false negative results)

Table 3: Attributes of actions suggested or required for building start-up, commissioning, and recommissioning in referenced documents, codes, and standards

Documents, standards, and codes	Startup/Commissioning/Recommissioning actions suggested/Required				
	Inspection	**Flushing and cleaning**	**Shock disinfection**	**Safety explicitly mentioned**	**Testing**
UPC (2018): Chapter 6 Water Supply and Distribution [31]	Prescriptive actions for each installation step	The system shall be flushed with clean, potable water until potable water appears at the points of the outlets.	The system must be disinfected with specific methods after flushing potable water appears at the points of the outlet.	Not mentioned	Upon completion, the system should be tested with water or air. Test pressures are mentioned.
IPC (2018): Chapter 6 Water Supply and Distribution [32]	Prescriptive actions for each installation step	After construction, the system should be purged of deleterious material	The system must be disinfected with specific methods after flushing potable water appears at the points of the outlet.	Not mentioned	"Bacteriological examination" after disinfection
Revised Total Coliform Rule Checklist (2016) [28,29,40]	Inspection of source, storage, and pipes	Flushing stagnant volume required even if system remains pressurized. Flushing recommended after disinfection. Clean/Flush out tanks.	Add disinfectant w/ directed dosage, details provided vary across states. Fill system with chlorinated water completely. Let sit 24 hours. Flush. Keep chlorinated water away from septic tanks and surface water.	Not mentioned	Coliform bacteria sample
AWWA 651: Disinfecting Water Mains [38]	Recommended	Recommended	Required. See Table 2	Concerns for the safety of workers and the public is mentioned.	Coliform bacteria sample
AWWA 652: Disinfecting Water Storage Facilities [37]	Recommended	Not mentioned. High-pressure water jet, sweeping, scrubbing, or equally effective means.	Required. See Table 2	Concerns for the safety of workers is mentioned.	Coliform bacteria sample
WHO (2011): Water Safety in Buildings[1] [39]	Recommended	Recommended for routine use	Adding chlorine compound to the storage tank to have 20–50 mg/L free residual chlorine concentration. Run all taps to smell the chlorine at all fixtures, then close all taps and allow the system to be stagnant at least 1 hr for 50 mg/L and 2 hr 50 mg/L. Then flush the taps to obtain the normal free chlorine level.	Concerns for the safety of building occupants	Free chlorine measurement to make sure super-chlorinated water if flushed out of the system.

[1] Additional relevant consideration of WHO (2010) guidance: It is important to keep all finished parts of the water installation dry until the whole system is commissioned for routine operation. If this is not possible, sections that remain stagnant for extended periods should be thoroughly drained and disinfected prior to the system being commissioned; keep all finished parts of the water installation dry; Water-using devices, end of plumbing devices and point of-use devices should be maintained to minimize microbial growth. These devices should be decommissioned when not in use and where possible drained. Water-using devices will often require decontamination prior to being returned to service; As part of remediation contaminated drinking water will need to be flushed from the entire distribution system including water-using devices, POU and end of pipe devices. Treatment systems such as water softeners and filtration systems will need to be regenerated, backwashed or re-commissioned before being returned to service. Small filters at PoU could harbor contamination and may need replacing.; At the time of commissioning, water quality should be documented by hygienic testing of microbial and chemical quality in an adequate set of drinking water samples. Initial higher intensity monitoring (additional samples and parameters) might be necessary depending on intended use of the facility, outcomes of inspection, any irregularities during construction or commissioning and delays in beginning of regular use. In these cases, a water quality expert should be consulted.

Table 4. Comparison of disinfection methods from plumbing codes, AWWA standards for water utility infrastructure, and ASHRAE guideline 12-2000[1]

Method name	Initial chlorine level / Temperature to be maintained	Minimum contact time	Required level after contact
Uniform Plumbing Code (2018) [31]; *International Plumbing Code (2018)* [32]			
Option 1	50 mg/L	24 hr	No level reported
Option 2	200 mg/L	3 hr	No level reported
AWWA Standard C651-14, Disinfecting Water Mains (2014)[2] [38]			
Tablet	25 mg/L	24 hr	0.2 mg/L after 24 hr
Continuous Feed	25 mg/L	24 hr	10 mg/L after 24 hr
Slug	100 mg/L	3 hr	Not applicable
Spray	200 mg/L	Not applicable	Not applicable
AWWA Standard C652-92, Storage Facility Disinfection (1992) [37]			
Method 1 (Full storage)	Achieve 10 mg/L after the appropriate 6 hr or 24 hr period.	6 hr if gaseous chlorine feed used; 24 hr if calcium or sodium hypo used	10 mg/L
Method 2 (Spray or painting)	200 mg/L	0.5 hr	Not applicable
Method 3 (Full storage)	50 mg/L	24 hr	2 mg/L
ASHRAE Guideline 12-2000[1] [43]			
Chemical shock	To discretion of building owner; Indicates that AWWA C651-14 should not be used (5.5.1)		
Thermal shock	≥70 °C	20 minutes at all outlets[3]	During flushing

[1]based on public draft review February 2018; [2]These guidelines are not intended for building use. [3]use with caution; thermal capacity of heaters may not be capable of supplying this temperature given flushing demand. Performing shock treatment in phases to allow water heater recovery may decrease efficacy.