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RESEARCH ARTICLE

Investigating water safety in multi-purpose buildings used as an elementary school and plumbing remediation effectiveness

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Abstract

Three buildings that were repurposed for use as an elementary school were shutdown for three months in response to the pandemic. Building cold and hot water quality was monitored before reopening to detect and resolve chemical and microbiological problems. The authors collected first draw pre-flush and post-flush water samples. First draw water samples did not contain detectable disinfectant residual, but nickel and lead sometimes exceeded the health-based action limits for cold water (max. 144 μg Ni/L, 3.4 μg Pb/L). Stagnant cold water at a bathroom sink (188 MPN/100 mL) and drinking water fountain (141.6 MPN/100 mL), in the same building, exceeded the *L*. *pneumophila* thresholds advised by the World Health Organization (WHO) (10 CFU/mL) and American Industrial Hygiene Association (AIHA) (100 CFU/mL). Fixture flushing was conducted to remove cold and hot stagnant water and no *L*. *pneumophila* was detected immediately after flushing. Two weeks after no subsequent building water use, chemical and microbiological contaminant levels were found to be similar to levels prior to flushing with one exception. The maximum *L*. *pneumophila* level (kitchen sink, hot water: 61.1 MPN/100 mL) was found in a different building than the prior maximum detections. No repeat positive locations for *L*. *pneumophila* were found during the second visit, but new fixtures were positive the organism. When this study was conducted no evidence-based guidelines for plumbing recommissioning were available. A single plumbing flush reduced heavy metal and *L*. *pneumophila* levels below WHO and AIHA thresholds in all three buildings. Additional work is needed to examine the role of building size, type and plumbing design on fixture water quality in shutdown buildings.

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Introduction

Water at schools can pose health risks to children, and U.S. schools have historically not been a focus of routine drinking water testing. School buildings also lack formal water management programs [1], and are not specifically regulated under the *Safe Drinking Water Act* (SDWA) [2]. Only about seven states and the District of Columbia require school water testing. Therefore, the act, type, and frequency of school water testing is primarily at the discretion of the building owners [2]. A 2019 U.S. study revealed that less than half of the schools surveyed conducted water quality testing (n = 514), 46% flushed drinking water outlets after periods of non-use, and even fewer (25%) required staff training on water quality maintenance (n = 520) [3]. Another 2019 survey found that for 25 states, uniformity of school water quality testing programs was lacking [4]. During the pandemic, school water safety concerns were raised due to the presence of stagnant water [5]. In Ohio, school custodians contracted Legionnaires Disease and one fatality occurred [6]. Elevated drinking water lead, copper and manganese levels are also known to pose health risks to children [7–9]. Because there were more than 124,000 U.S public and private schools shutdown in response to the pandemic [10], school water safety concerns became nationally important. During the pandemic, a federal watchdog agency warned that government building operators were not adequately testing water safety before reopening schools [11].

Prior to the pandemic it was well-known that stagnation could cause water quality deterioration in large buildings, and many studies were conducted during the pandemic to explore this phenomenon [11–23]. Disinfectant residual, such as free chlorine, in drinking water delivered to buildings is meant to help minimize microbiological growth. Within plumbing, disinfectant concentration decreases due to temperature, as well as reactions with bulk water constituents and plumbing surfaces. Chemical and microbiological quality can change in water heaters and water softeners within hours. Prior studies have shown that low water use can prompt greater cold and hot water copper and bacteria levels (*Mycobacterium avium*, *Mycobacterium spp*. *Legionella spp*., and total cell count [TCC]) [16, 23]. Leaching of metal contaminants like copper, lead, and zinc from plumbing is a known children's health risk in drinking water [24–27]. Weekend stagnation can sometimes cause heavy metal concentrations to exceed health-based limits [28]. Stagnant cold and hot water can contain *Legionella* spp. and *Mycobacterium avium* [22]. Stagnant water has been found to contain greater concentrations of *Legionella spp*., *Mycobacteria*, heterotrophic plate counts [HPC], and TCC in building plumbing compared to flushed water samples [28–32].

At the time this study was initiated, there was no agreement on the actions needed to find and reduce chemical and microbiological health risks in school plumbing. During the pandemic, many guidelines were issued by local, state, federal agencies as well as trade associations and companies [33–39]. Instructions were often vague, different organizations contradicted other organizations, and guidance rarely recommended water testing [33]. Generally, removing stagnant water by flushing plumbing was recommended [34, 38, 39], though some organizations recommended shock disinfection [40–42]. Studies of buildings during the pandemic found that heavy metal and microbial contaminant concentrations were not reduced completely or the levels increased. In one study, flushing decreased lead concentration but 28 μg/L remained which is still above the American Academy of Pediatrics recommended limit of 1 μg/L [24]. In another study, copper and lead concentration significantly decreased after flushing but iron levels increased by 200% possibly due to scale destabilization [25]. In some studies most flushed water samples had lower *Legionella spp*. levels [27, 30], but sometimes these levels were greater after flushing [24]. Also reported was that *Legionella spp*. was not detected immediately after flushing, but was detected again two to four days later. For reference, the World Health Organization (WHO) and American Industrial Hygiene Association (AIHA) recommend shock disinfection when Legionella levels are greater than 10 CFU/mL [43] and 100 CFU/mL [40]. Specifically, AIHA [40] has recommends that when greater than 100 CFU/mL is found, "immediate steps to clean and disinfect the system" are required. Though, one study indicated "a gradual increase in water demand was more sufficient in changing waterborne microbial loads than a short-term fixture flushing for remediation" [44]. Another study also found that "regular flushing in low-use or low-flow [systems] is inefficient to control waterborne pathogen" [45]. The lack of specificity on school water sampling and plumbing remediation actions during low water use and building reopening is a gap in knowledge.

The study goal was to better understand water quality in the shutdown buildings and the effectiveness of flushing to reducing chemical and microorganism levels at the fixtures. Specific research objectives were to (1) document chemical and microbiological first draw water quality after three months of stagnation in three separate school buildings in one property, (2) conduct flushing of each building water system and monitor flushing effectiveness, and (3) determine the limitations of flushing.

Materials and methods

Water supply and site inspection

The study site was an elementary school campus in Indiana with three detached buildings (**Fig 1**). The campus was served by a single public water system through two different service lines, each with a water meter. The public water system utilized eight groundwater wells and served water to about 35,000 people. Free chlorine disinfectant and a polyphosphate-orthophosphate blend of corrosion inhibitor were added to the water before water entered the water distribution system. In a separate study, service line water quality monitoring for one year was conducted in the same water distribution system 2.6 miles (4.2 km) away from the campus and the following water quality characteristics were reported (pH: 7.22 to 7.81; total Cl_2: 0 to 2.10 mg/L; free Cl_2: 0 to 1.40 mg/L; Dissolved oxygen [DO]: 4.50 to 11.12 mg/L) [18].

None of the campus buildings were originally designed to be school buildings (**Fig 1**). Buildings A (2 floors, 2,423 m^2) and B (1 floor, 1,024 m^2) were constructed in 1966 as multipurpose buildings on the property. In 2001, the property changed owners, buildings were renovated to be used as an elementary school, but the plumbing was not modified. In 2006, another building was constructed on the property (building C, 114 m^2). Buildings A and B were served by a single service line entering the West side of the property with a water meter while building C was served by a service line on the North side of the property with a separate water meter. The estimated distance from the water meter to the building B was about 78 meters, and to building C was eight meters.

Plumbing designs and components were relatively similar across buildings. Domestic water plumbing was soldered copper pipe with crosslinked polyethylene (PEX) faucet connectors and Elkay[1] drinking water fountains. Each building had a different volume water heater (A: 151 L, B: 113 L, C: 189 L). In building A there were two pressure tanks (179.8 L each) and single water softener. Buildings B and C did not have water softeners. In buildings A and B, each classroom had one sink, one mini- or typical size refrigerator, and dishwasher. In building A, the main faculty/staff break room had one refrigerator with an icemaker and coffee maker appliance connected to the plumbing. Building A had one classroom on the first floor, three classrooms on the second floor; building B had two classrooms, building C had two classrooms. At the playground, two outdoor drinking water fountains connected to building B's plumbing.

Fig 1. (a) Site property with building A, B and C with estimated location of public water supply pipe (blue), two water meters (sky blue circle) and service line to each building (sky blue) and where splits to deliver to building A (dotted sky blue), (b) Elkay drinking water fountains installed for kids' height, (c) all classrooms had their own sinks, drinking water fountain, and appliances, (d) coffee maker connected to the plumbing in building A, and (e) particulates in the aerator before removal.

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In mid-March 2020 the school shutdown for Spring Break, but then switched to online learning due to the pandemic. During the online learning period, students did not return to campus until mid-August 2020. The authors visited the site on June 19, 2020 for an initial inspection. During the initial inspection visit, the authors learned that even though the campus was closed from March to August, the building owner was using water from building C (hose spigot) to water the grass. Water used for irrigation occurred weekly starting in June. Through discussions, the authors learned that the building owner also flushed water from select fixtures on a few days in response to hearing that government agencies recommended schools flush fixtures in response to low occupancy. The school planned to reopen for in-person learning on July 1, 2020, but after authors' initial investigation, the school did not reopen until mid-August. The building owner did not have as-built plumbing drawings or understand their buildings' plumbing design or components. Prior to the author's study, the building owner had never tested water from the plumbing except for drinking water lead samples collected a few years prior by a consultant.

Water sampling and analysis approach

The study period included mid-March 2020 to July 2020 (**Fig 2**). On June 26, 2020, the authors visited the property to collect samples at 9:00 am. First draw samples were collected, followed by samples collected during and after flushing. The authors returned to the buildings two weeks later and also collected first draw samples. At each building, cold water samples were collected first followed by hot water samples. Samples were collected from kitchen sinks, bathroom sinks, and drinking water fountains (**S1 Table**). The authors first sampled water in building C, followed by building B and then building A. From each fixture about 150 mL was first collected in a beaker for total chlorine, pH, temperature, and dissolved oxygen (DO) concentration followed by samples for [total or dissolved] metal concentration (125 mL for each), *L. pneumophila* by Legiolert (125 mL), total cell counts [TCC] (Two 15 mL), total organic

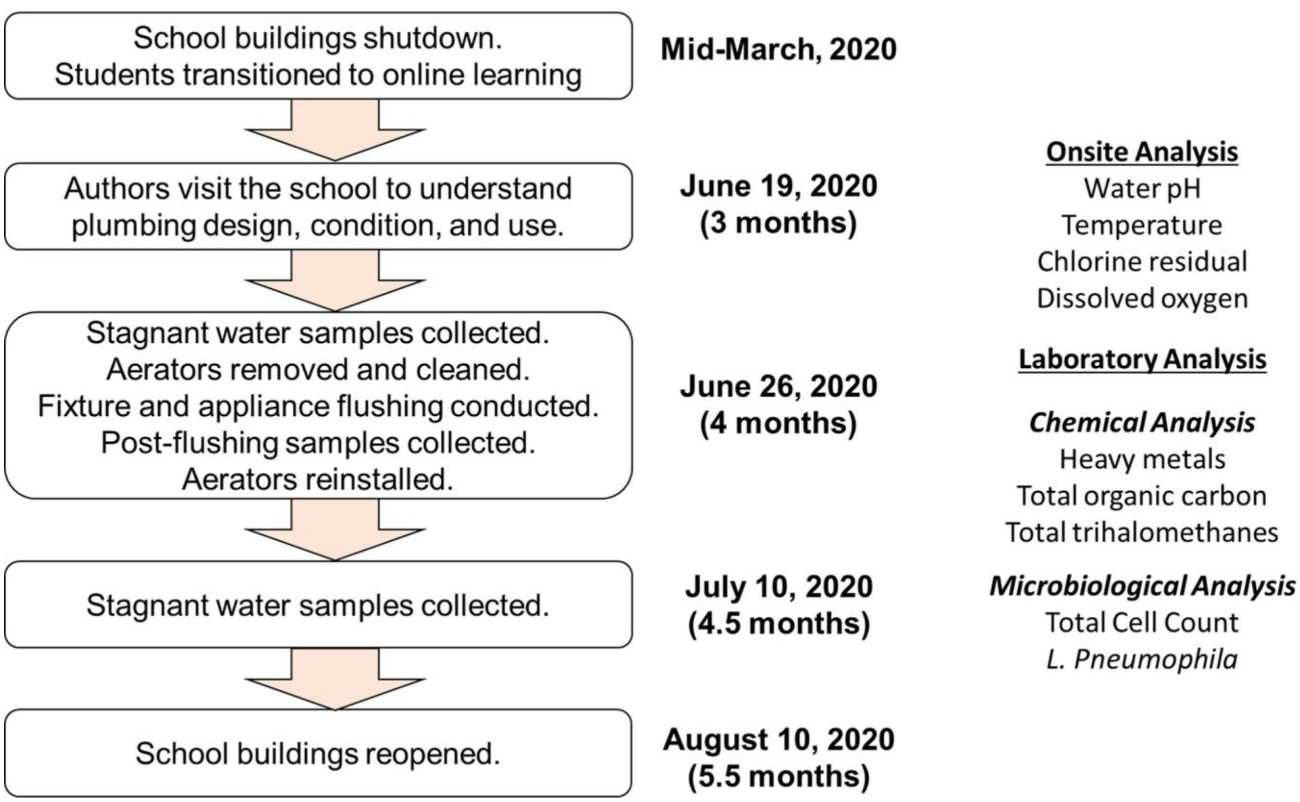

Fig 2. Flowchart of the research methodology. Building water use and water sampling activities ranged from March 2020 to July 2020.

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carbon [TOC] concentration (125 mL). Approximately 1,000 mL was then flushed from each fixture followed by a sample collected for measuring total trihalomethanes concentration [TTHMs] (10 mL). Hot water samples were collected in the same order. All stagnant water samples were collected at a slow flow rate. For metal samples, 3N HCl was added to each bottle and for TOC samples, Na_2SO_4 was added glass bottles. All samples were stored at 4˚C until analysis.

Onsite analysis for chlorine measurement was conducted using a HACH® DR300 Pocket Colorimeter with DPD total chlorine (detection limit = 0.02 mg/L as Cl_2). Water pH, temperature, and DO concentration were measured using HACH® SL1000 PPA Portable Parallel Analyzer. For heavy metals analysis, an iCAP ™ 7400 ICP-OES with autosampler (ASX-280, CETAC Teledyne) was used. A 0.45 μm nylon filter was used to prepare water samples for dissolved metal analysis. An IDEXX® Legiolert with quanti-tray system was used to determine *L. pneumophila*, and trays were incubated for a week at 39˚C. Locations that had less than 1 MPN/100 mL were not counted as detected. A cytoflex flow cytometer (Beckman-Coulter, Inc.) was used to determine total cell counts with method 366.1 [46]. TOC concentration was measured using Shimadzu TOC-L CPH/CPN with EPA method 415.1 [47]. A gas chromatograph/mass spectrometer system that is Agilent GC-7890B coupled with an Agilent TQ 7000C triple quadrupole MS was used to determine TTHM levels.

Flushing

After first draw stagnant water samples from all buildings were collected, the authors removed all water from the plumbing by first running cold water from the janitor sinks with highest flowrate. Flushing also started in the order of building C, B, and then A. Flushing was not halted until a chlorine residual concentration of 0.2 mg/L as Cl_2 was detected. While flushing, water samples were collected for chlorine and temperature analysis every minute. After flushing stopped, the authors removed and cleaned all aerators by scrubbing them with a new toothbrush and soaked them in food grade vinegar for 30 minutes. Toilets were flushed three times. All toilets near the classroom were child sized toilets (about 4.84 L per flush). After all fixtures were flushed, the authors returned to the janitor sink and flushed building hot water. Gas water heaters were subsequently drained by plumbers hired by the building owner after the authors left. The building owner also followed the author's recommendation to operate dishwashers three times, and discard three batches of ice from the icemaker. Two weeks after the flushing (July 10th), the authors revisited the school to again collect first draw water samples. The sampling and analysis approach then was similar to the first visit except aerators were not removed or cleaned and flushing was not conducted. When the authors returned, they were informed that irrigation had continued to be conducted using an outdoor spigot from building B.

Results and discussion

Observations of the closed buildings

While in-person learning at the campus stopped in mid-March, from April to June 2020 building C water usage was nondetectable (**S1 Fig**). During this same period, buildings A and B had detectable water use in April (3,785 L) but not through June. Prior to building mid-March, building C's 2019 average monthly water use was 4,967 L and the daily water use was 170 L. For buildings A and B, the 2019 average water monthly usage was 15,431 L and daily average was 510 L. Even though the building owner began using water for irrigation in June, once per week, the public utility had no record of customer water usage. During the first visit the authors also found that the building owner shutoff air conditioning in all three buildings. This shutoff saved the school about $6,000 of their typical $12,000 annual electric utility bill. Maximum outdoor air temperatures during the building closure period ranged from 25 ˚C to 35 ˚C (S2 Fig).

First draw cold water contained the highest levels of heavy metals and Legionella

Like other buildings studied by the authors elsewhere and by other investigators, no chlorine residual was detected in the stagnant water in the present study (Fig 3) [27, 33, 48–50]. Typically, the water supplier reported chlorine residual values of 1.3 mg/L as Cl_2 leaving the treatment plant and 0.94 to 1.48 mg/L as Cl_2 in the distribution system [51]. High frequency water sampling a residential service line on the same water distribution system (in another study) revealed that 25% of the time, the water entering that building did not have detectable chlorine residual concentration and varied seasonally (0 to 2.1 mg/L as Cl_2) [18]. Therefore, it is unknown if the water sampled from the campus buildings in the present study contained a detectable chlorine residual when it was delivered to the water meter. TTHM levels in the school buildings (0.5 to 7.3 μg/L) were often much lower than the levels reported by the water supplier (9.2 to 9.8 μg/L) and a service line of the nearby home (0 to 10.18 μg/L) [18]. The authors expected TTHM levels would have increased inside plumbing (max. 40.83 μg/L) like

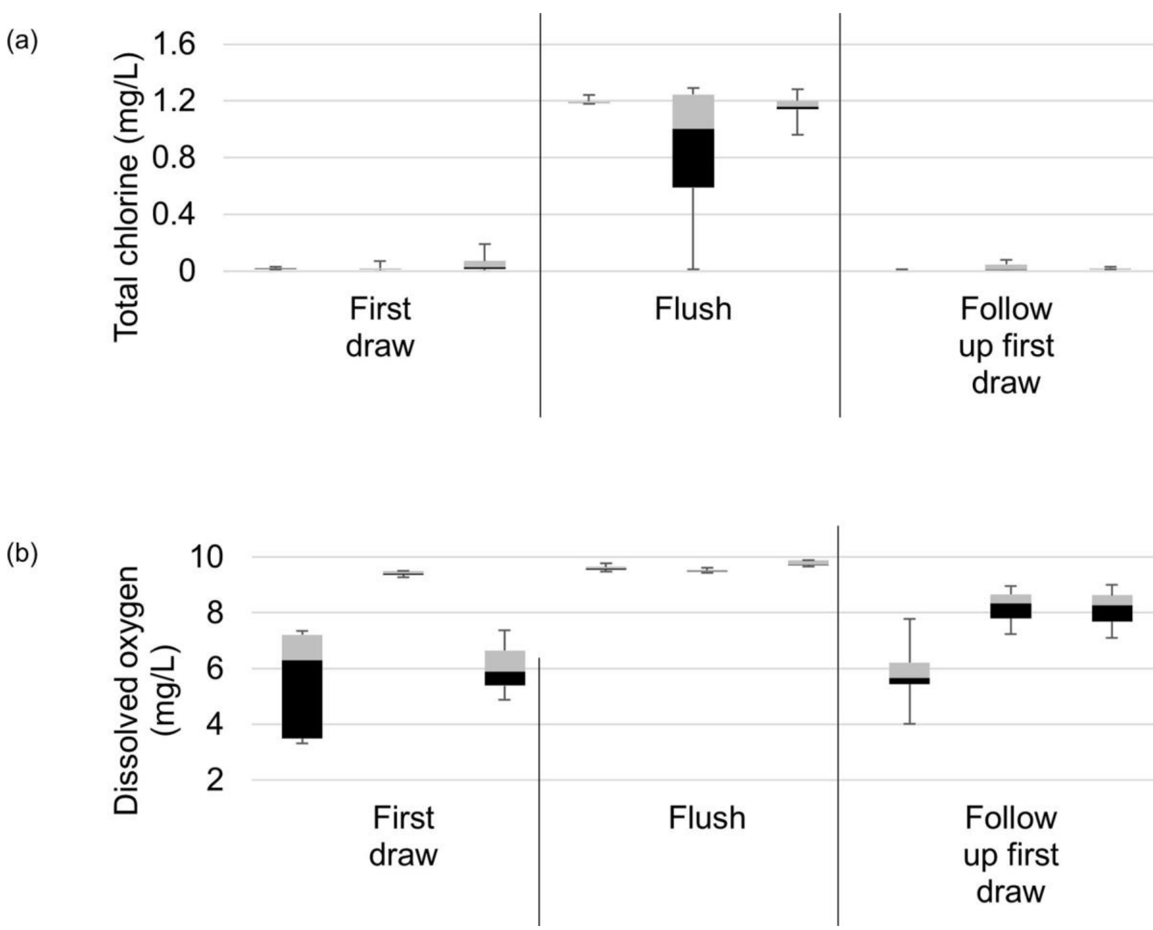

Fig 3. Water quality measurements for buildings A, B, and C for (a) total chlorine residual, and (b) dissolved oxygen. For flush graphs, last recording data after flush was reported.

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seen elsewhere in the water distribution system, but levels found in school plumbing were low. The low TTHM concentrations may be due to the absence of chlorine residual, though plumbing may have also influenced these levels [52]. Cold water temperatures were relatively consistent (20˚C to 23˚C) and drinking water fountains had the coldest water (12˚C to 22˚C).

Except for nickel and lead, no heavy metals exceeded health or aesthetic based drinking water thresholds. Two cold water fixtures had a noticeably higher nickel level than the average level (18.8 μg Ni/L) found at fixtures: building B (144 μg Ni/L), building C (75.7 μg Ni/L). Nickel's health-based drinking water threshold is 100 μg/L [53]. Lead was detected in cold water (12/15) including at drinking water fountains (2/4) at a maximum of 3.3 μg/L. The health-based drinking water lead threshold, the maximum contaminant level goal, is 0 μg/L [54], and the American Academy of Pediatrics recommends that school water fountains should not exceed 1 μg Pb/L [55]. The maximum copper concentration found was 0.6 mg/L, while iron and manganese levels were less than the minimum concentrations reported by the supplier (<0.01 mg Fe/L, <0.007 mg Mn/L).

Total cell count and *L. pneumophila* levels were similar to those reported by others for school and office buildings under stagnant and non-stagnant scenarios [12, 28, 32, 56, 57]. These contaminant concentrations differed across the three buildings, between cold and hot water, and locations. Drinking water fountains generally had higher TCC levels (5.02 to 5.64 log cells/mL) than the other cold water fixtures (3.00 to 5.05 log cells/mL), and this was consistent across all three buildings. The highest *L. pneumophila* level was detected at the building C bathroom sink cold water (188.2 MPN/100 mL) and a drinking water fountain (141.6 MPN/100 mL). At building A, only a single kitchen sink cold water sample was positive (1.1 MPN/100 mL). *L. pneumophila* was not detected at any cold or drinking water fixture in building B. Of 25 cold water samples from buildings A, B and C, two samples from building C exceeded the WHO limit (10 CFU/mL) and the AIHA (100 CFU/mL) thresholds (**Table 1**). Although, 1 CFU is not same as 1 MPN (approximately 1.2 CFU = 1 MPN) [58], few samples still exceeded the WHO (8.3 MPN/mL) and AIHA (83 MPN/mL) thresholds. One other location at building A also detected *L. pneumophila* but did not exceed the WHO limit. No *L. pneumophila* detections were found at building B.

Table 1. Number of locations where *L. Pneumophila* was detected and its concentration.

Fixture		Building A			Building B			Building C		
		Stagnant	Post flush	Stagnant 2 weeks later	Stagnant	Post flush	Stagnant 2 weeks later	Stagnant	Post flush	Stagnant 2 weeks later
Cold	Bathroom sink	0/3	-	0/2	0/2	-	-	1/1 (188.2)	-	0/2
	Kitchen classroom sink	1/2 (1.1)	0/4	0/3	0/2	-	0/2	0/1	-	-
	Water fountains	0/2	-	1/2 (5.8)	0/1	-	0/1	1/1 (141.6)	-	0/1
	Janitor sink	-	-	-	0/6	-	-	0/4	-	-
Hot	Bathroom sink	0/3	-	2/2 (1.1, 2.3)	0/1	-	0/1	0/1	-	0/1
	Kitchen classroom sink	0/5	0/4	3/3 (2.2, 15.5, 61.1)	0/2	-	1/2 (2.3)	0/1	-	0/1
	Janitor sink	-	-	-	1/4 (2)	-	0/1	0/4	-	-

Units are MPN/100 mL; Locations that had less than 1 MPN/100 mL were not counted as detected, and no repeat positive locations were found on follow-up visit first draw water samples

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First draw hot water contained lower Legionella concentrations than cold water

Hot water sample temperatures never exceeded 41˚C, and to reduce *L*. *pneumophila* potential water heater settings of 60˚C are recommended [41, 59–62]. *L*. *pneumophila* growth can occur at temperatures as low as 20˚C [41]. Interestingly, the International Plumbing Code defines hot water as having a "water temperature greater than or equal to 43 ˚C [63]. Thermostatic mixing valves (TMV) are usually present at bathroom fixtures to prevent children from being exposed to hot water; though, TMVs were not present at the study site. Chemically, the hot water was similar to cold water (**S2 Table**), but microbiological differences were apparent. TCC levels were (4.8 to 6.2 log cells/mL) and were greater than TCC levels in the cold water (non-drinking water fountain fixtures). *L*. *pneumophila* was found at a janitor sink fixture at building B at 2 MPN/100 mL. While 1 MPN was equivalent to 1.2 CFU, building C had a greater level of TCC than the other two buildings. Interestingly, building C had less water use than both buildings A and B. Of 21 first draw hot water samples from the buildings, *L*. *pneumophila* was only detected in one sample at building B and its concentration was less than the WHO and AIHA thresholds (**Table 1**).

Flushing did not improve all water quality characteristics

Total chlorine residual and DO concentration had the greatest magnitude increase after flushing, and pH ranged from 7.1 to 8.2 (**Fig 3**, **S2 Table**). For two locations however detectable chlorine was found during flushing but was not detected after 10 minutes of fixture flushing (**Fig 4**). It is unclear why this phenomenon was observed. Buildings B and C were located closer to the water main and should have theoretically had a greater starting chlorine residual concentration, than building A. Based on water distribution system sampling in the service area by others, however, water without a detectable amount of chlorine disinfectant could have been delivered to the buildings [18, 23]. Heavy metal concentrations were lower after flushing; Nickel and lead levels were reduced below their drinking water thresholds ($p<0.05$) (**S3 Fig**).

Post-flush TCC levels were slightly less than stagnant water levels for cold and hot water. Mean cold water TCC levels reduced from 4.34 to 3.59 log cells/mL and for hot water reduced from 5.48 to 4.13 log cells/mL. TCC levels in the present study before and after flushing were slightly lower than the other studies, and post-flush TCC levels were lower than levels found in stagnant water [28, 31]. Building A, the site of the main school office, faculty/staff kitchen, and was the only two-story building, was targeted for *L*. *pneumophila* sampling post-flush. *L*. *pneumophila* was not detected at either cold (4) or hot (4) water locations sampled.

Generally, water quality after two weeks of stagnation was similar to the 3-month stagnant water quality

Similar to the prior visit, first draw chemical and microbiological water quality characteristics were similar except that *L*. *pneumophila* concentration was lower than concentrations in the stagnant water (**S3 Table**). No cold water including drinking water fountains had a detectable chlorine concentration. No heavy metals exceeded their drinking water thresholds (**S4 Table**). TCC levels at drinking water fountains (4.70 to 5.26 log cells/mL) were again generally greater than levels in other cold water samples (3.53 to 4.84 log cells/mL). The range of TCC values detected was similar for the three month stagnated water. For *L*. *pneumophila*, no previously positive locations were found on this follow-up visit, but the organism was detected at new, previously negative, locations. Of the 12 samples collected in building A, *L*. *pneumophila* was detected at one drinking water fountain (5.8 MPN/100 mL), as hot water from three kitchen

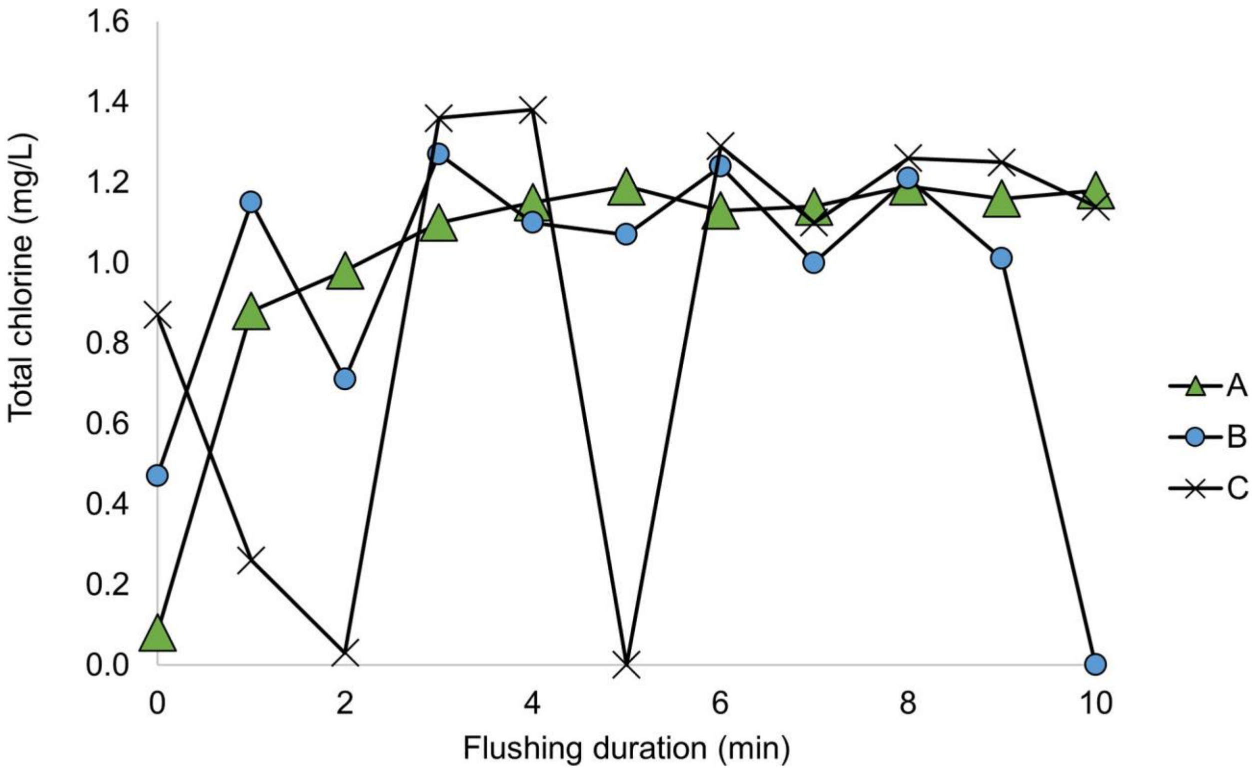

Fig 4. Chlorine residual concentration fluctuated during the 10-minute cold water at the kitchen sink in building A and the janitor sinks in buildings B and C.

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sinks (max. 61.1 MPN/100 mL), and from two bathroom sinks (max. 2.3 MPN/100 mL). These values exceeded the maximum concentration in the building previously of 1.1 MPN/100 mL (cold water stagnant). Of the seven samples collected in building B, no cold water samples were positive for the organism, but one hot water kitchen sink sample was positive (max. 2.3 MPN/100 mL). Building C had no detections of *L. pneumophila* unlike the prior visit where this building had the greatest concentrations detected (**S4 Fig**). Of 13 cold water samples, only one sample at building A had detectable *L. pneumophila* but the concentration was less than the WHO threshold (**Table 1**). Six of 11 hot water samples (five from building A and one from building B) detected *L. pneumophila*, and two samples exceeded the WHO threshold but did not exceed the AIHA threshold.

Implications and recommendations

This study was conducted to better understand water quality in buildings that had been stagnated for three months and the effectiveness of flushing to improve water quality. The buildings were not initially designed for use as an elementary school and the owner (second owner of the property) did not have drawings that outlined the plumbing components (i.e., location, types, sizes, lengths, etc.). During the pandemic, the public water supplier and state health department specifically advised school building owners to flush out stagnant water [29, 64].

After three months of stagnation, first draw water samples had no detectable chlorine residual concentration and nickel and lead exceeded health-based drinking water thresholds. *L. pneumophila* was found at its greatest concentration in the three month stagnated cold water (188 MPN 100 mL). Fixture flushing reduced heavy metal levels below health-based drinking water limits. Flushing sometimes, but not always, resulted in water with a chlorine residual being detected at fixtures. *L. pneumophila* concentrations were reduced due to flushing. Though, *L. pneumophila* was detected at different fixture locations and lower concentrations two weeks later after the stagnant cold water flush (max. 61 MPN/100 mL). Because *L. pneumophila* resides in biofilms it was not surprising this organism was found in the plumbing after flushing [65–67]. Results from the present study indicate that flushing reduced *L. pneumophila* levels below 100 CFU/mL. This finding indicated that shock disinfection [40–42] was not needed, which the AIHA recommends when 100 CFU/mL is detected. For context, Hamilton et al. [68] recommends faucet activities present a risk at a concentration of 102 CFU/mL using annual infection risk metric for a scenario when the faucet is used 20 times per day and 30 seconds per use.

Results of the present study agree with some of the existing literature but underscore several knowledge-gaps. Flushing did not always prompt disinfectant levels to be found at faucets and this may be because unchlorinated water was delivered to the building and chlorine residual decayed as water was drawn to the faucet. Better understanding the chemical and microbiological variability of water delivered to service lines is needed. Here, *L. pneumophila* concentrations were reduced by flushing found like others [27, 30, 32]. In contrast, others have found *L. pneumophila* concentrations increased after flushing [24, 32]. Flushing has previously demonstrated short-term (24 hour) benefits by reducing microbial levels at fixtures within large buildings [68]. Bench- and pilot-studies are needed to examine the impact of flushing frequency on fixture water quality. Future work should also focus on understanding the sources of *L. pneumophila* and conditions that cause greater *L. pneumophila* levels post-flushing. This will require better understanding plumbing complexity and monitoring. Culture, and qPCR methods for *L. pneumophila* and other organisms may provide greater insights [45]. Specificity in routine sampling and testing for metal contaminants and microorganisms for building plumbing should be developed as only general recommendations exist [69, 70].

While the present study was focused on buildings being used as an elementary school, none of the buildings were initially designed to be school buildings. Stagnation caused water quality problems are not unique to school buildings, which can be impacted by plumbing design, and low to no water use during weekends, as well as summer and winter vacations. To help lessen water quality variability at fixtures, it is recommended that each building owner create and execute a building water quality maintenance program. Here, such a program can instill the importance of plumbing safety and maintenance on building inhabitant health. This program should also including a flushing plan created using as-built drawings. The U.S. Department of Education, state regulators, and health departments could require schools include this information in their formal health and safety plans. Schools should also consider: (1) that before buildings are reopened flush water outlets to remove water with higher metal and microorganism contaminant concentrations, (2) to strive to maintain chlorine residual at fixtures to minimize biofilm growth similar to goals worked towards by public water suppliers for systems where chlorine residual is used, and (3) maintaining the water heater temperature at the highest temperature allowable by state regulation and code as well as the hot water recirculation loops, if any. A single plumbing flush was effective at reducing heavy metal concentrations, bringing in disinfected water, and reducing *L. pneumophila* levels to all fixtures.

Supporting information

S1 Table. Sample location and description.
(DOCX)

S2 Table. Water quality measurements before and after flushing.
(DOCX)

S3 Table. First draw water quality measurement after 2 weeks.
(DOCX)

S4 Table. Comparison on average heavy metal concentrations for buildings A, B, C combined.
(DOCX)

S1 Fig. Water usage in (a) building A and B, and (b) building C. Only average water use in building C from Dec. 2018 to beginning of Feb. 2020 was reported by the utility (71,915 L). Red arrows are when the building was closed (May to June for building A and B, April to June for building C).
(TIFF)

S2 Fig. Outside temperature of June and July 2020.
(TIFF)

S3 Fig. Average heavy metal concentration for before and after flushing at (a) cold and (b) hot fixtures.
(TIFF)

S4 Fig. Example of quanti-tray by IDEXX Legiolert for field blank, A-10, and A-18.
(DOCX)

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