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ORIGINAL RESEARCH

AWWA WATER SCIENCE

Pre- and post-flushing of three schools in Arizona due to COVID-19 shutdown

Rain Richard[1,2] | **Treavor H. Boyer**[1,2]

[1]School of Sustainable Engineering and the Built Environment (SSEBE), Arizona State University, Tempe, Arizona, USA
[2]Biodesign Swette Center for Environmental Biotechnology, Arizona State University, Tempe, Arizona, USA

Correspondence
Treavor H. Boyer and Rain Richard, School of Sustainable Engineering and the Built Environment (SSEBE), Arizona State University, PO Box 873005, Tempe, AZ 85287-3005, USA.
Email: thboyer@asu.edu and rain.richard@asu.edu

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Abstract
A one-day water sampling and flushing study was conducted for three schools in Maricopa County that experienced prolonged building inactivity due to the COVID-19 pandemic: an elementary school, middle school, and high school. Grab samples were taken at hand washing sinks, water fountains, and hose bibbs before and after flushing. Samples were analyzed for free chlorine, UVA254, copper, lead, total trihalomethanes, pH, conductivity, temperature, and *Legionella* species. All three schools experienced an increase in free chlorine post-flush. Copper concentrations were higher for first draw samples than post-flush samples for all schools. Conductivity, temperature, and pH did not see a major change after flushing. UVA254 values decreased after flushing. Bromoform species saw a 20% increase after flushing at the elementary school. *Legionella* spp. did not decrease post-flush at the elementary school. Overall, flushing changed the water quality at the schools. However, equipment flushing may be necessary to fully remediate *Legionella* spp.

KEYWORDS
building, chlorine residual, copper, COVID-19 shutdown, flushing, *Legionella*, mixing valves, schools, tempered water, trihalomethanes, UVA254

1 | INTRODUCTION

Flushing building water systems due to prolonged inactivity, in this case due to stay at home orders because of COVID-19, is an important area of research and practice. For example, research on flushing building water systems aims to determine if disinfectant residual can be reestablished due to long-term inactivity, especially when the building does not have an established water management plan. The literature in this area is mostly limited to guidance documents such as but not limited to the American Water Works Association (AWWA), The United States Centers for Disease Control and Prevention (CDC), and the United States Environmental Protection Agency (U.S. EPA) (AWWA, 2020; Centers for Disease Control and Prevention, 2021, 2021a, 2021b; Department of Veterans Affairs, 2014; Proctor et al., 2020; U.S. Environmental Protection Agency, 2020a). The known issues with stagnant water in premise plumbing include loss of disinfectant residual, biofilm growth including spread and proliferation of opportunistic premise plumbing pathogens (OPPP), leaching of metals (especially lead (Pb) and copper (Cu)) and plasticizers, disinfectant by-product (DBP) formation, and taste and odor issues. Of these listed issues, disinfectant residual, DPBs, lead and copper, and *Legionella* are significant because they are regulated by Primary Drinking Water Standards set forth by the U.S. EPA due to their effects on human health (U.S. Environmental Protection Agency, 2020b).

The most important chemistry factors for degraded water quality are absence of disinfectant, DBP formation such as THMs, and metals leaching from pipes and other materials. Zheng et al. (2015) showed that the three material types tested, copper, galvanized iron, and polyvinyl chloride (PVC), showed chlorine decay due to stagnation (Zheng et al., 2015). Other authors have also shown that disinfectant decay in pipe is unavoidable save for glass pipes which is not a suitable premise plumbing material (Nguyen et al., 2012; Tolofari et al., 2020; Zhang et al., 2017). Studies have also shown an increase in THM formation in buildings due to stagnation (Dion-Fortier et al., 2009; Salehi et al., 2020) or equipment such as hot water tanks (Dion-Fortier et al., 2009) and water softeners (Richard et al., 2021). Leaching of copper into water is undesirable as high levels of copper during short-term exposure can cause stomach issues while long-term exposure can cause neurological issues and liver and kidney damage (U.S. Environmental Protection Agency, 2020b). Furthermore, organic leaching of cross-linked polyethylene or other organic chemicals has been shown to cause taste and odor issues which is a dissatisfying characteristic of drinking water (Kelley et al., 2014).

Ling et al. (2018) showed that stagnation not only increased microorganism growth, but biodiversity of the microorganisms changed dramatically from fresh water to stagnant water conditions and small-diameter pipes allow for re-growth of microorganisms, an undesirable outcome for premise plumbing (Ling et al., 2018). The biofilm of premise plumbing materials has been shown to be a reservoir for *L. pneumophila* and *Pseudomonas aeruginosa*, two common OPPPs (Moritz et al., 2010). And building equipment, such as water softeners (Richard et al., 2021) and hot water tanks (Rhoads et al., 2015) can also promote microorganism growth. Lautenschlager et al. (2010) and Bédard et al. (2018) were able to demonstrate that flushing showed a decrease in viable cell count for cold water after varying stagnation events (1 h to 10 days) (Bédard et al., 2018; Lautenschlager et al., 2010). However, this decrease was not seen when flushing hot water, due to the fact hot water is supplied by recirculation loops inside buildings. The recirculation of hot water along with minimal dilution (or addition of fresh water) facilitates the spread of microorganisms throughout the hot water distribution system (Bédard et al., 2018). Therefore, when hot and cold water are blended at sink faucets, as often they are with point of use mixing valves or with master mixing valves, microbial growth, and contamination due to stagnation events become more difficult to assess because the cold is not recirculated while hot water is. As a result, the impact of flushing on water quality can be varied.

The U.S. EPA has two flushing protocols. One protocol is to help schools and childcare facilities mitigate lead in their drinking water (U.S. Environmental Protection Agency, 2018). The other protocol is for the reopening of buildings after prolonged inactivity or low use (U.S. Environmental Protection Agency, 2020a). The CDC also has guidance documents for reopening buildings after low or no use (Centers for Disease Control and Prevention, 2021b) as well as guidance documents on a water management plan, especially for the mitigation of *Legionella* (Centers for Disease Control and Prevention, 2021). The AWWA has a guidance document for reopening after long periods of low or no use with a decision tree and strategies for flushing, such as remedial, one-time flushing versus routine flushing (AWWA, 2020). Other guidance on building flushing is also available (Keane, 2020). Aside from the recent guidance documents for reopening after prolonged inactivity, there are also several guidance documents detailing the importance of flushing or a building water management plan as a control measure specifically for *Legionella* (Bartram et al., 2007; Centers for Disease Control and Prevention, 2021a; Centers for Medicare and Medicaid Services, 2017; Department of Veterans Affairs, 2014; European Guidelines Working Group, 2019). Considering the guidance documents and published research available (Dore et al., 2018; Hozalski et al., 2020; Lipphaus et al., 2014; Ra et al., 2020; Singh et al., 2020; Whiley et al., 2019; Zhu et al., 2014), it is still difficult to assess if remedial flushing is successful for buildings that have sustained long terms of inactivity or prolonged shutdown because of the gap in knowledge to test effectiveness.

Article Impact Statement
Prolonged closure of buildings causes water quality issues such as lack of disinfectant and *Legionella*. Flushing can restore water quality.

The goal of this research was to evaluate whether the one-time flushing of a building water system at fixtures could make short-term improvements in the chemical and microbial composition of tap water. The specific objectives of the research were to evaluate the impact of (1) initial water quality and (2) plumbing design/configuration on the efficacy of flushing.

2 | EXPERIMENTAL

2.1 | Description of schools

Three schools of increasing size and occupancy were selected for this study: an elementary school (ES), middle school (MS), and high school (HS), all served by the same public water system. All three schools transitioned to virtual learning in March 2020 and did not return to inperson classes until after this study was completed. As a result, the three schools had minimal occupancy for over 6 months. Water sampling and flushing was conducted on one day for each school starting at 6:30 AM local time. The study was conducted between September 16 and October 2, 2020.

Prior to flushing, a walkthrough of each school was conducted to understand building layout and determine grab sample locations. Sampling location criteria were based on fixtures that would be used by students and included water fountains, hand washing sinks, and one shower location. The water fountains were traditional push button with and without chillers, not water bottle refill stations. Some hose bibbs inside the bathrooms and inside the campus were tested as well as the hose bibb closest to the point of entry (POE). The point of entry is near the meter where the city water enters the building. Hose bibbs inside the building and within the campus were fed by domestic cold water (DCW) only with no mixing valves or other equipment that could alter water quality, so these hose bibbs represented water from the building main. The elementary school had 47 sampling locations, the middle school had 24 sampling locations including one shower head, and the high school had 18 sampling locations. Schematics of each school (Figures S1–S3) with tables of sampling locations for each school (Tables S1–S3) are listed in the supplementary information. The age of each school building was at least 20 years or older.

The elementary school was single story, fed by one building water main which tied to the city and this single main snaked through seven building sections laid out in a square pattern. The middle school was two stories with one building water main, which was tied to the city that snaked through seven building sections. For two story locations, the building water main would start at the second floor and drop down to the first floor. The high school was two stories with three building water mains which tied to the city at three separate locations: one on either end and the other feeding the school through the middle of campus. The building water mains in the high school started on the first floor and then moved to the second floor. Hot water heaters were located in the bathrooms or within a few feet of the bathrooms. There were no fixtures at any schools in which hot and cold water had separate lines and could be measured independently. All schools had tempered, mixed hot and cold water at the sinks or shower. Only the hose bibbs and water fountains had domestic cold water. The plumbing code for Arizona considers hot water potable for schools (Maricopa County Environmental Services Department, 2015; State of Arizona, 2009). However, there is concern that hot water should not be considered potable (Contractor Talk, n.d.; Denver Water, n.d.; The New York Times, n.d.). For this research, the tempered water is considered potable because practicing hygiene such as brushing teeth, showering, and washing hands could only occur with tempered water.

The elementary school had hand washing sinks and water fountains inside each classroom and used a master mixing valve at the hot water heaters (anti-scalding measure) to supply tempered water to a dedicated tempered water line of copper material for the hand washing sinks in classrooms. The water fountains inside each classroom did not have chillers. In the restrooms, a point-of-use mixing valve under the sinks was used which was separate from the tempered water line. The middle school had bathrooms and two water fountains at the east end of each building on each floor with master mixing valves at the hot water heaters to supply tempered water to a dedicated tempered water line of copper material to feed warm water to the hand washing sinks. It was not possible to determine if there was also a point of use mixing valve under the hand washing sinks in the bathrooms. The elementary school and high school used point of use mixing valves for the bathroom hand washing sinks. The plumbing drawings were not always clear and removing covers or dismantling fixtures was not an option for this research effort. One shower was tested at the middle school which was serviced by a tempered water line attached to a master mixing valve. All water fountains at the middle school had chillers. Only one water fountain was also a water bottle refill station with a granular activated carbon (GAC) filter located in the cafeteria. The high school had bathrooms and two water fountains on the south side of each building section with point of use mixing valves under restroom sinks to mix cold and hot water to provide the tempered water for the sinks. The high school also had water fountains placed in high traffic locations not near restrooms. All water fountains at the high school had chillers. One water fountain was a water bottle refill station with GAC filter. To note, water bottle refill stations were not analyzed for free Cl_2 for this study as the refill stations had granular activated carbon filters which removes chlorine. Table 1 provides a basic summary of each school as building drawings are not possible due to confidentiality purposes.

2.2 | Water sampling and flushing

Each location had a first draw grab sample and a post-flush grab sample. Of these locations, some were selected for water microbiology, namely, *L. pneumophila* (serotype 1 and serotypes 2–15) and other *Legionella* species (termed collectively as *Legionella* spp), and advanced water chemistry, specifically dissolved lead (Pb), and the

TABLE 1 Summary of building layout and flushing for each school

	Elementary school	Middle school	High school
Building section	7	7	4
Stories	1	2	2
Premise plumbing material	Copper	Copper	Copper
Service line material	Copper	Copper	Copper
Mains	1	1	3
Manual sinks	Yes	No	No
Water fountains (no chiller)	Yes	No	No
Water fountains (with chillers)	No	Yes	Yes
Sinks with sensors	Yes	Yes	Yes
Master mixing valve	Yes	Yes	No
Point of use mixing valve	Yes	Yes	Yes
Hot water heaters	Yes	Yes	Yes
Flushing zones	2	3	3
Fixtures flushed	Yes	Yes	No
Hose bibbs flushed	Yes	Yes	Yes

four regulated trihalomethanes (THM4) chloroform (CF), bromoform (BF), dibromochloroform (DBCM), and dichlorobromoform (DCBM). Location selection method for water microbiology and advanced water chemistry was random to provide indiscriminate sampling but was loosely based on distance from hot water tanks, use or lack of use of fixture by students, and distance from building inlet. All samples were measured for UVA254, dissolved, unfiltered copper (Cu), free chlorine (Cl_2), pH, temperature, and conductivity. For this study, free Cl_2 is the residual chlorine concentration. The first draw was either an immediate 250 ml draw for microbiology or 250 ml to replicate the volume collected for microbiology but was not analyzed for any purpose. Aerators were not allowed to be removed. If a sample location was selected for water microbiology, the lab-provided *Legionella* collection bottle was used. This bottle required 250 ml of water and was put on ice immediately after collection. After the 250 ml volume of water was collected, a 1 L wide mouth polypropylene bottle (US Plastics product code 76632) was used to collect the rest of the first draw. Time was recorded for the first draw. Temperature was measured from the 1 L plastic bottle. For first draw locations that were not selected for microbiology or advanced chemistry, an initial 250 ml of water was collected in a separate container and immediately after a 1 L plastic bottle was used to collect the remaining 1 L water sample. Temperature and time were recorded. After collection, all 1 L wide mouth polypropylene bottles were placed in boxes and covered to reduce free Cl_2 loss due to exposure to light as they were transferred to the onsite analysis station.

After all first draw grab samples were collected, pH, conductivity, and free Cl_2 were measured using a Hach handheld portable parallel analyzer (SL1000) kit. Free Cl_2 was measured with a chemkey (Hach product code 9429000) and chemkey for chlorine standard (Hach product code 9427900) was used randomly throughout the day to confirm the free Cl_2 chemkeys and Hach handheld analyzer were functioning properly. The method detection limit (MDL) for the free Cl_2 chemkeys is 0.04 mg/L. Standards were also used for the pH probe for calibration throughout the day to confirm measurements were correct. After onsite analysis was conducted, analysis of UVA254 and dissolved, unfiltered Cu occurred at Arizona State University. UVA254 was measured with a UV–vis spectrophotometer (Orion AquaMate 8000). Dissolved, unfiltered Cu was measured by a bicinchoninate method (reagent #AC4P29, range 0.05–5 mg/L). Third-party water microbiology for *Legionella* spp. used approved CDC method EM-BT-S-1687 which is a culture-based method followed by serotyping. To note, *L. pneumophila* serotype 1 was not found for any samples. All *Legionella* values reported in this research paper are of serotypes 2–15 or other *Legionella* species (*Legionella anisa, Legionella bozemanii, Legionella gormanii, Legionella jordanis, Legionella longbeachae 1 and 2, and Legionella micdadei*) as these are serotypes and species that have been shown to cause illness (Legionella Control, 2021). Dissolved Pb was measured by inductively coupled plasma mass spectrometer (ICP/MS) U.S. EPA method 200.8, reporting limit 0.50 μg/L. Trihalomethane analysis was conducted by gas chromatography-mass spectrometer (GC/MS) U.S. EPA method 524.2, reporting limit 0.50 μg/L.

After all first draw grab samples were collected, the building water system was flushed. Flushing time was calculated based on service line diameter, length of pipe, number of faucets, and flow rate of the fixtures (WRF, 2018). For this study, the service line diameter was considered the size of the main servicing the building plus the length from the meter where the city tied to the building. The entire building length of pipe was found from the "Water Calculations Table" listed in the *Plumbing Calculation and Fixture Calculations* section in the drawings provided by the school. The "Fixture Connection Schedule" was used to determine the fixture flow rate which was also in the *Plumbing Calculation and Fixture Calculations* section of the drawings. This method was used as a way to standardize the flow rates of the fixtures due to the fact that fixture flow rate can change over time because of aerators being removed, breaking, or clogging as well as fixtures being replaced. Furthermore, the complexity of the study as well as the limited time permitted on the campuses did now allow for measuring the flow rates of every fixture sampled. The schools were partitioned into zones to manage the ease of flushing the campus, as well as maintain water pressure throughout the lines. Each zone was flushed for the calculated flushing time based on the entire building length of pipe, not for the length of pipe of the zone. At each zone, all fixtures were open simultaneously. The elementary school and middle school were flushed moving in the direction closest to POE to farthest from POE. The high school had three mains, so flushing zones were from west to east, instead of POE since there were three POE.

The elementary school was divided into two flushing zones and each zone flushed for 10 min by opening all manual sinks and exterior hose bibbs, especially the hose bibb closest to POE as well as the most distal hose bibb. Water fountains could not be flushed. The middle school was divided into three flushing zones. The first two zones were flushed for 10 min. The last zone was flushed for 20 min. Because the sinks had sensors, an object was placed in front of the sensor to induce the flow of water. Water fountains could not be flushed. Hose bibbs inside the bathrooms were flushed as well as the hose bibb closest to POE and most distal to building inlet. All interior hose bibbs had a short hose attachment positioned by a floor drain so water would not pool in the bathroom. This was not necessary for exterior hose bibbs. The high school had a more rigorous flushing procedure due to the size of the building and the fact that multiple mains fed the building. The school was sectioned into three flushing zones. All exterior hose bibbs were flushed at one time for 45 min. Prior to the hose bibbs inside the bathrooms being flushed by zone. This exterior flushing time was conducted in case no fixtures inside the school could be flushed. Two exterior hose bibbs remained running for the entire flushing sequence to confirm fresh water was being introduced into the school because of the size of the campus. Placing an object in front of the sink sensor had marginal success at the middle school, therefore hand washing sinks were not flushed. Drinking fountains could not be flushed. Therefore, zone flushing only occurred at hose bibbs inside the bathrooms and were flushed with short hose attachment like the middle school. Each of the three zones were flushed for 30 min after which a post-flush sample was collected in the same manner and at the same location of the first draw samples.

2.3 | Data analysis

JMP version 15 was used for statistical analysis. A 95% confidence interval was used for the statistical analyses. The criteria of 10% of the absolute value of the relative difference between mean 1st draw and post-flush values between schools and within schools were used to determine whether water quality values were the same or changed. Shapiro–Wilk test was used to test for normality of the data. The Pearson correlation coefficient was calculated for residuals with normal distribution and Spearman's rho correlation coefficient was calculated for nonparametric data. The list of water parameters used to determine correlations were free Cl_2, Cu, Pb, THM4, *Legionella* spp., temperature, pH, conductivity, UVA254, and distance. For the criteria "distance" for the elementary school and middle school, a numeric value was given for each section of building. A numeric value of 1 was closest to the building inlet while a numeric value of 7 was farthest from building inlet. The high school had three mains serving the campus so providing a numeric value for distance was not possible. But occupancy movement and activity were in one direction, moving from west to east. Therefore, occupancy activity was greatest at the east side of campus. This occupancy activity and movement was based on what a typical school day would look like as well as the foot traffic of the few staff on hand at the high school the day sampling took place. Therefore, each section of the campus was assigned a number based on distance from the east side of campus. As an example, section A was given a value of 4 as this was the most east side of campus while section D was given a value of 1, the most west portion of campus. A simple method to evaluate the effectiveness of remedial flushing was to discretize each sample value for THM4, Cu, Pb, free Cl_2, and *Legionella* spp. for each school and each draw. For THM4, Cu, and Pb, the primary maximum contaminant level (MCL) or action level was used for scoring. For example, a grab sample measuring greater than or equal to 80 μg/L for THM4 received a 0, while a value less than this received a score of 1. For Cu, a value equal to or greater than 1.3 mg/L received a score of 0, values less than 1.3 mg/L received a score of 1. For Pb, a grab sample value greater than or equal to a value of 15 μg/L received a score of 0, with samples measuring below this value received a score of 1. For *Legionella* spp., the scores were based on a value of 1 cfu/ml or less. A grab sample greater than 1 cfu/ml received a score of 0 and grab samples less than 1 cfu/ml received a score of 1. Free Cl_2 values were scored based on a minimum value of 0.2 mg/L. Grab samples equal to or greater than 0.2 mg/L were given a score of 1, less than 0.2 mg/L were given a score of 0. Scores were added up for each parameter and for each school, respectively, then divided by the total number of fixtures sampled at the school to provide the percent "grade" for the specific water quality parameter. This was done for first draw and for post-flush samples. Next, each parameter was summed to provide one aggregated value by draw. Then, each parameter was weighted equally with a value of 1. Therefore, a max value of 5 was possible. The aggregated value by draw was then divided by 5 to give the percentage of overall water quality value or "grade".

3 | RESULTS AND DISCUSSION

Figure 1 shows box and whisker plots of each water quality parameter, separated by school, and shows results for first draw and post-flush. Free Cl_2 was not detected in most first draw samples from the elementary school and middle school. After flushing, chlorine concentrations were greater at the middle school than at the elementary school. Overall, the median chlorine concentration increased after flushing for the three schools and is shown in further detail in Figure 2. Copper concentrations were higher in first draw samples than post-flush samples, especially for the elementary school and middle school. Flushing decreased the median Cu concentration at the elementary and middle schools with the high school median Cu concentration showing no change. The median concentration of Pb was low (< 1.7 μg/L) and similar range at the three schools. There was an increase in median Pb post-flush at the elementary school from 0.75 μg/L for first draw to 3 μg/L post-flush. The one shower at the middle school was not considered in this range as the fixture was considered an outlier due to the fact that the elementary school did not have shower nozzles and the showers at the high school were not accessible to the research team. Furthermore, the showers at the middle school were no longer in use, but still operational. But it is important to know that the first draw Pb value for the shower was 55 μg/L and the post-flush value was 28 μg/L. The median THM4 was similar at the three schools (<55 μg/L) and showed minimal change after flushing. *Legionella* spp. results varied by school. The median *Legionella* spp. values for the elementary school for first draw was 15.0 cfu/ml and post-flush median value increased to 16.5 cfu/ml. The middle school first draw median value was 13.5 cfu/ml for *Legionella* spp. and decreased to 0.1 cfu.ml post-flush. The high school median value for Legionella spp. was 2.7 cfu/ml for first draw and 0.4 cfu/ml post-flush. Median water temperatures were similar at all three schools (26.2–27.6°C) with no major change after flushing at any school. First draw and post-flush median pH was similar at all three schools (median < 7.7). There was no change in conductivity in first draw samples or post-flush samples between schools or within schools. UVA254 decreased after flushing at all three schools with the elementary school having higher UVA254 in first draw (max value $= 0.10\ cm^{-1}$, median $= 0.03\ cm^{-1}$) and post-flush samples (max $= 0.06\ cm^{-1}$, median $= 0.02\ cm^{-1}$) than the other schools (max $\leq 0.03\ cm^{-1}$, median $\leq 0.02\ cm^{-1}$).

The parameters in Figure 1 were compared with the same parameters found in the Consumer Confidence Report (CCR) for the city (which cannot be referenced for anonymity purposes) to show a general relationship between city distribution and building water quality. The max Cl_2 values at any school were below the CCR values. Lead and Cu values at the schools were greater than the 90th percentile reported in the CCR. However, the CCR reports for homes, not for large buildings. Total trihalomethanes, temperature, and pH were within the range of the CCR. There were no values for *Legionella*, conductivity, or UVA254. While this study did not measure alkalinity, the CCR showed a range of 100–300 mg/L for alkalinity. A reason why the Cl_2 values for all schools were below the CCR values could most likely be due to the fact the schools had very low occupancy because of the shutdown causing a drastic reduction in building water use. Regardless of the distribution system Cl_2 levels, if water is not present inside a building, then Cl_2 will decay. The metals concentrations observed at the schools could be due to building water system response. The premise plumbing material is copper. Therefore, it makes sense copper would leach into the water supply. As such, the fixtures most likely had some lead parts. Therefore, if the fixtures went unused for a prolonged period of time, lead could also leach into the water. The elevated *Legionella* spp. values show in general that disinfectant is critical for pathogen control. Without water flow to promote fresh water to the building, Cl_2 decays

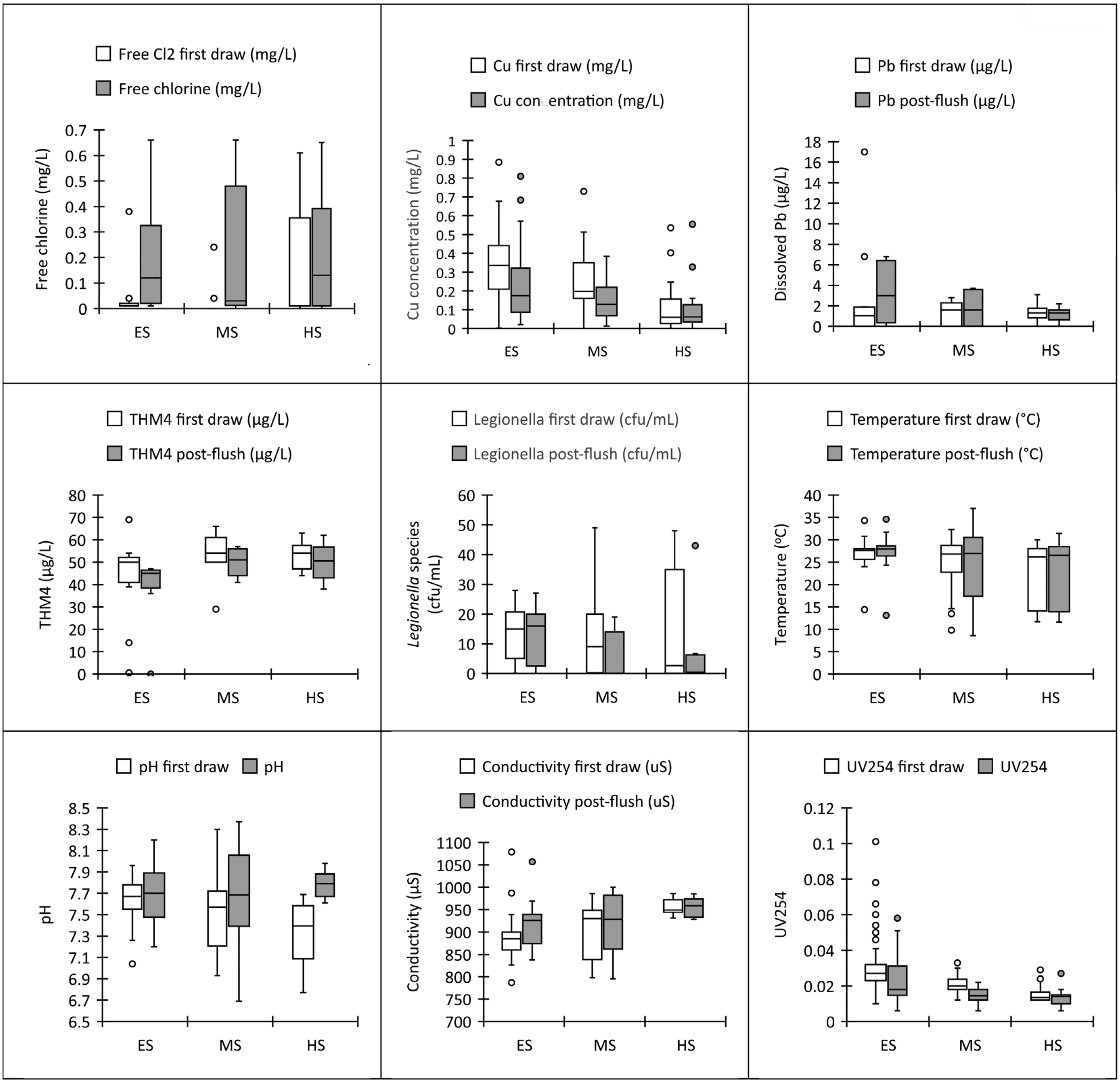
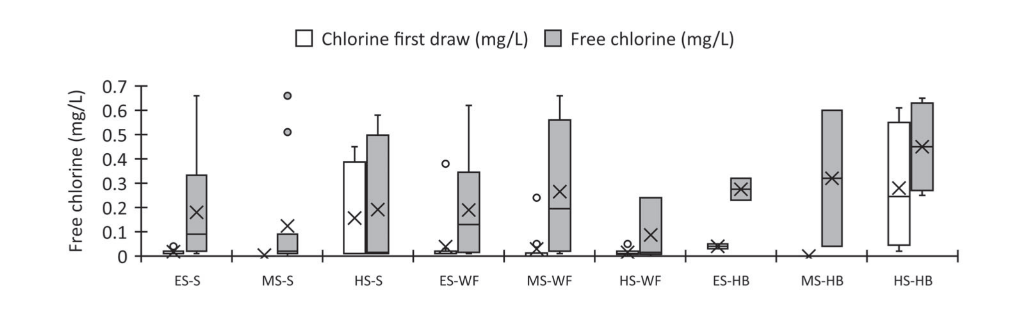


FIGURE 1 Box and whisker plots for key water quality parameters measured separated by school and by draw where ES = elementary school, MS = middle school, and HS = high school; the ES has three unpaired data points for THM4 and 2 unpaired data points for *legionella*, spp. and Pb. Box and whisker plots show the minimum, first quartile, median, third quartile, and maximum

causing an increase in microorganism and potentially pathogen growth.

Comparing only free Cl_2 by fixture and draw at each school (Figure 2, where n = number of fixtures), the free Cl_2 concentrations increased post-flush for all three schools at the sinks. The high school was the only school with measurable free Cl_2 for first draw grab samples at the sinks. While the high school had higher maximum free Cl_2 values for first draw, there was no change in the percent of sinks that measured at or above the MDL from first draw to post-flush. At the high school, the sinks that had measurable free Cl_2 for the first draw were the same sinks that had measurable chlorine post-flush. The elementary school had the greatest range in free Cl_2 measurements while the middle school had the least variability in free Cl_2 measurements. The elementary and middle school had nearly the same percentage of sinks with measurable free Cl_2 for first draw, 8% and 9%, respectively. However, post-flush resulted in 62% of the sinks at the elementary school with measurable free Cl_2



	ES-S		MS-S		HS-S	
	1st draw	post-flush	1st draw	post-flush	1st draw	post-flush
minimum	0.00	0.00	0.00	0.00	0.00	0.00
1st quartile	0.00	0.00	0.00	0.00	0.00	0.00
median	0.00	0.09	0.00	0.00	0.00	0.00
3rd quartile	0.00	0.33	0.00	0.05	0.36	0.39
max	0.04	0.66	0.04	0.66	0.45	0.58
mean	0.02	0.18	0.00	0.12	0.16	0.19
n	26	26	11	11	8	8
% equal or greater than MDL	8%	62%	9%	27%	38%	38%
	ES-WF		MS-WF		HS-WF	
	1st draw	post-flush	1st draw	post-flush	1st draw	post-flush
minimum	0.01	0.01	0.00	0.02	0.00	0.01
1st quartile	0.01	0.02	0.00	0.02	0.01	0.01
median	0.02	0.15	0.00	0.30	0.01	0.02
3rd quartile	0.02	0.32	0.00	0.55	0.01	0.24
max	0.38	0.62	0.24	0.66	0.05	0.24
mean	0.04	0.20	0.03	0.29	0.02	0.10
n	16	16	9	9	5	5
% equal or greater than MDL	6%	56%	22%	67%	20%	40%
	ES-HB		MS-HB		HS-HB	
	1st draw	post-flush	1st draw	post-flush	1st draw	post-flush
minimum	0.04	0.23	0.00	0.04	0.02	0.25
1st quartile	0.04	0.23	0.00	0.18	0.10	0.31
median	0.05	0.23	0.00	0.32	0.25	0.45
3rd quartile	0.05	0.23	0.00	0.46	0.43	0.59
max	0.05	0.23	0.00	0.60	0.61	0.65
mean	0.05	0.23	0.00	0.32	0.28	0.45
n	2	1	2	2	4	4
% equal or greater than MDL	100%	100%	0%	100%	75%	100%

FIGURE 2 Box and whisker plots of free Cl_2 values measured at fixtures for first draw and post-flush at all schools with the simple statistics reported as well. The naming convention is ES = elementary school, MS = middle school, HS = high school, S = sink, WF = water fountain, HB = hose bibb. Box and whisker plots show the minimum, first quartile, median, third quartile, and maximum

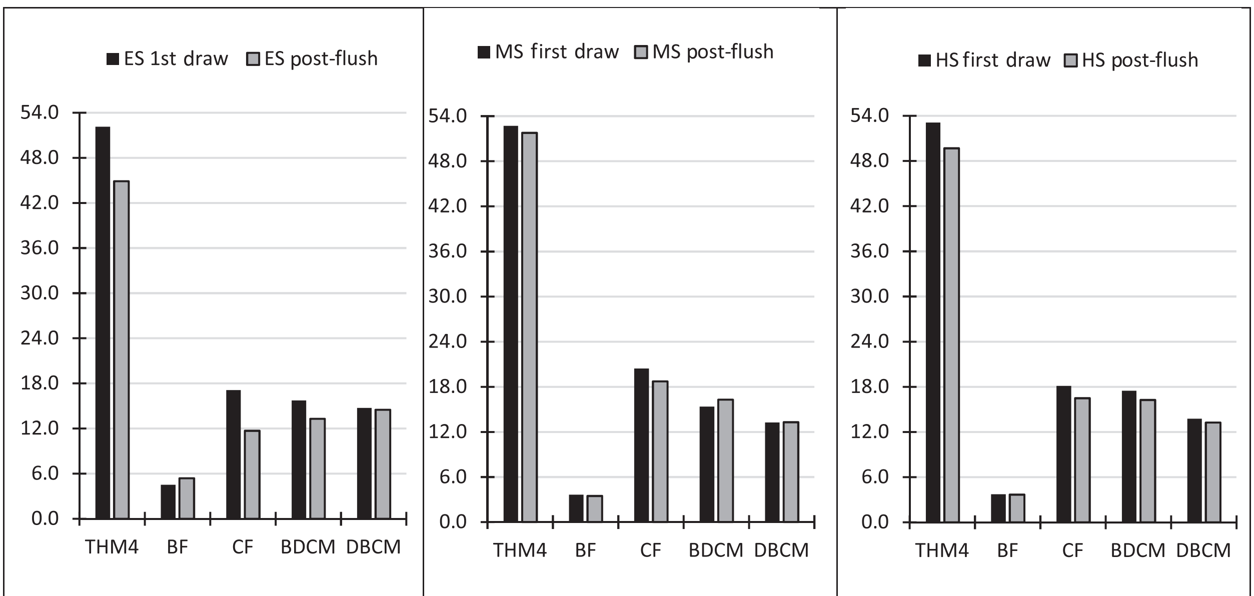
while 27% of the sinks at the middle school with measurable free Cl_2.

First draw grab samples measured minimal free Cl_2 at the water fountains for all three schools. However, post-flush, free Cl_2 concentrations increased for all three schools. The elementary school and middle school showed a similar range for free Cl_2 post-flush while the high school showed the least variability and range. The greatest maximum value for first draw free Cl_2 was measured at the elementary school which was 0.38 mg/L and the lowest maximum value was reported at the high school which was 0.05 mg/L. The elementary school only had 6% of the water fountains measured at or greater than the MDL for first draw, while 22% of the water fountains measured equal to or greater than the MDL at the middle school and 20% for the high school. Post-flush values at the elementary school showed 56% of water fountains measured equal to or greater than the MDL, 67% of water fountains at the middle school measured equal to or greater than the MDL post-flush, and 40% of the water fountains at the high school measured equal to or above the MDL post-flush. The post-flush median value at the water fountains for the elementary school was 0.15 mg/L and the median value at the hose bibb post-flush was 0.23 mg/L. The middle school post-flush median value at the water fountains was 0.30 mg/L and the post-flush median value at the hose bibbs was 0.32 mg/L. The post-flush median value for water fountains at the high school was 0.02 mg/L and the hose bibb median value for post-flush was 0.45 mg/L. All hose bibb values were higher than water fountain values. The importance of this finding is that water fountains are not attached to mixing valves and no water fountains reported had granular activated carbon cartridges. Therefore, the water analyzed from the water fountains was strictly potable water, the same water as analyzed at the hose bibbs.

There was no measurable free Cl_2 at the hose bibbs at the middle school for first draw samples. But there was measurable free Cl_2 for first draw samples for the elementary school and high school at the hose bibbs. And post-flush free Cl_2 values at all three schools were greater than first draw values. The minimum post-flush value at the hose bibbs for the middle school was the least, 0.04 mg/L, in comparison to the elementary school and high school: 0.23 and 0.25 mg/L respectively. The median values measured at the hose bibb were the greatest for first draw and post-flush at the high school in comparison to the elementary school and middle school. To note, there were data for only one hose bibb post-flush for the elementary school.

Figure 3 shows the average THM4 values by school and by draw. There was a 14% decrease in THM4 concentrations from first draw to post-flush for the elementary school (n = 8), 6% decrease for the high school (n = 8), while the middle school (n = 7) saw a 2% decrease. In some instances, there was a more noticeable change in species concentrations also shown in Figure 3. The elementary school BF species increased by 20% while all other species decreased; CF (−32%), DBCM (−16%), DBCM (−2%). The middle school BDCM species increased by 6% while BF and CF decreased by 5% and 8%, respectively, and DBCM did not change. All 4 THM species for the high school decreased, −2% (BF), −9% (CF), −7% (BDCM), −4% (DBCM). However, these data show overall there was minimum change in THM4 pre- and post-flush.

Correlations between parameters were quickly investigated to determine if any correlations existed before and after flushing the buildings. The statistically significant correlations are shown in Table S4. In general, not all first draw correlations showed a correlation post-flush



% delta	THM4	BF	CF	BDCM	DBCM	THM4	BF	CF	BDCM	DBCM	THM4	BF	CF	BDCM	DBCM
	-14%	20%	-32%	-16%	-2%	-2%	-5%	-8%	6%	0%	-6%	-2%	-9%	-7%	-4%

FIGURE 3 THM species for each school first draw versus post-flush with the percent change in species as % delta for each species from first draw to post-flush. BF, bromoform; BDCM, bromodichloromethane; CF, chloroform; DBCM, dibromochloromethane

and some post-flush correlations did not show a correlation for first draw. In some instances, correlations for first draw that also existed post-flush changed from a positive to an inverse relationship or from one school to another, the relationship would change from positive to inverse. For example, all three schools reported a correlation between distance and pH; elementary school, first draw moderate-to-strong (0.49, p = .010), middle school, post-flush moderate-to-strong (0.64, p = .010), high school, first draw strong-to-very strong (−0.80, $p < .0001$). UVA254 and Cl_2 showed a moderate-to-strong correlation (0.52, p = .0002) at the elementary school first draw and at the middle school first draw the correlation was a moderate-to-strong relationship (−0.51, p = .011) as well. In other instances, the correlations were similar at the schools. For example, the correlation between UVA254 and Cu remained moderate-to-strong for first draw (0.59, $p < .0001$) at the elementary school as well as post-flush (0.58, $p < .0001$) and at the middle school, first draw (0.41, p = .046) and post-flush (0.53, p = .008). The middle school, first draw correlation between temperature and Cu was moderate-to-strong (−0.64, p = .0008) and high school, post-flush correlation was also moderate-to-strong (−0.63, p = .005). The middle school post-flush correlation between distance and Cl_2 was moderate-to-strong (−0.52, p = .010) and the high school, post-flush also resulted a similar moderate-to-strong relationship (−0.56, p = .017). The middle school and high school also showed a correlation with conductivity and pH; strong-to-very strong for the middle school (−0.81, $p < .0001$) and high school was moderate-to-strong (−0.63, p = .005). Yet, the correlation between Cu and Cl_2 was only seen at the elementary school, first draw was moderate-to-strong (0.41, p = .004), and post-flush was weak-to-moderate (−0.32, p = .035). The correlation between THM4 and Cl_2 was only observed at the high school for both draws; first draw was strong-to-very strong (−0.79, p = .0206) and post-flush was also strong-to-very strong (−0.88, p = .004). But there was no correlation between THM4 and distance for the elementary school or middle school and no correlation between THM4 and increase in occupancy activity for the high school. The correlation between conductivity and Cl_2 was also only observed at the high school for both draws as well. The first draw correlation was moderate-to-strong (0.59, p = .0.010) as well as the post-flush correlation (0.58, p = .012).

These correlations bring forth important insights. For example, the fact that pH increased farther from POE for the elementary school and middle school and decreased at the high school (occupancy activity was used as a surrogate for distance) show potentially that changes in pH can occur due to longer residence time within premise plumbing. However, why UVA254 and Cl_2 would show a positive relationship at one school and an inverse relationship at another school is not clear. The assumption would be that this relationship should be inverse as UVA254 is a surrogate for organic matter so the more organic matter present, the less Cl_2 would be measurable due to the interaction with the organic matter in the water. However, neither school showed measurable Cl_2 until after the flush. Therefore, further investigation would be necessary to determine what type of considerations and limitations should be given to correlating data between first draw and post-flush samples for in-field analysis such as this study. It could be that even if a correlation exists, the correlation may be due to other circumstances that were not captured. Finally, some expected or known correlations were observed, such as UVA254 and Cu, temperature and Cu, and THM4 and Cl_2. The importance for observing known correlations further strengthens the expected outcomes flushing has on building water quality.

Table S5 shows the calculated results of effectiveness of remedial flushing. Copper and THM4 were not issues for any school for either draw, meaning Cu and THM4 values for all samples remained below the MCL. Remedial flushing overall showed a positive percent change for free Cl_2, Pb, and *Legionella* spp. meaning less grab samples were equal to or greater than the MCL post-flush for Pb and *Legionella* spp. and more samples measured equal to or greater than 0.2 mg/L for free chlorine. More scrutiny reveals the elementary school had only 2% of all samples measured equal to or greater than 0.2 mg/L for free Cl_2 for first draw, while 38% of grab samples satisfied this criterion post-flush. The performance of remedial flushing at the middle school was similar (first draw 4%, post-flush 33%) while the performance at the high school was better (first draw 28%, post-flush 50%). The middle school rated a 96% for first draw and post-flush for Pb. This is undesirable as no grab sample should exceed the Pb action level. The cause for the exceedance was a bank of showers that were not used but were still operational. One shower nozzle from this bank of showers was tested and both first draw and post-flush grab samples measured above 15, 55 and 28 μg/L, respectively. *Legionella* spp. was also never fully remediated post-flush for any school, but a decrease was seen at the middle school and high school. The overall evaluation score for each school first draw to post-flush increased, however no school scored 90% or greater. The highest score was at the high school which was 87% post-flush. And the increase in score from first draw to post-flush at each school was 9% point increase at the elementary school, 7% point increase at the middle school, and 6% point increase at the high school. In general, the data show that a one-time flushing event for three school buildings which experienced prolong inactivity for at least 6 months was able to increase the free Cl_2 in the potable water (tempered or cold water that meets drinking water criteria) as well as decrease *Legionella* spp. (at two schools) and Pb. Problem fixtures could not be flushed individually due to time constraints and hot water heaters were not flushed.

Remedial flushing is a basic mitigation strategy for complex water systems inside buildings that are composed of elements such as master mixing valves, point of use mixing valves, tempered water lines, and water heaters. This flushing study was able to promote fresh water throughout the schools as can be seen by the presence of free Cl_2 post-flush at all hose bibbs and some sinks and water fountains. However, the effect is likely momentary unless routine flushing is maintained or the building resumes normal activity. *Legionella* spp. was still an issue at some fixture locations after flushing, Pb was definitely an issue at the middle school due to the one shower nozzle, and not all fixtures measured for free Cl_2 post-flush. Please note, the district enacted mitigation strategies for *Legionella* and Pb after this study. The change in THM species at the elementary school requires further investigation to determine whether analytical variability or the building response to flushing altered the THM speciation. Brominated THM species have been shown to be more toxic to humans (Echigo et al., 2004; Organization, 2009) and brominated species have been shown to behave differently in premise plumbing during stagnant conditions (Dion-Fortier et al., 2009). Therefore, additional research is necessary to determine if remedial flushing caused this change in species due to prolonged stagnation of water inside the water heaters, if the distribution system was the cause for increase in brominated THM species, and if routine flushing would have prevented an increase in brominated THM species. However, what this study did show was that even though remedial flushing is a basic mitigation strategy, all three schools were able to show a desirable response with basic flushing regardless of building size. Had there been enough time to flush fixtures independently or to flush the hot water heater, more locations may have corrected to show a chlorine concentration of 0.2 mg/L or greater and possibly no detectable *Legionella* spp. This positive response means that flushing in general is effective and definitely more desirable than recommissioning as recommissioning can be tedious and expensive.

4 | CONCLUSION

The goal of this research was to evaluate whether the one-time flushing of a building water system at fixtures could improve the chemical and microbial composition of the tap water. The specific objectives of the research were to evaluate the impact of (1) initial water quality and (2) plumbing design/configuration on the efficacy of flushing. Flushing fixtures as part of a remedial flushing plan is a basic strategy to promote fresh water into a building that has degraded water due to prolonged occupant inactivity and low to no water use. Hose bibbs are not attached to master mixing valves or point of use mixing valves, so the hose bibbs are supplied with only domestic cold water allowing for an easy method of detecting whether or not fresh water has been provided to premise plumbing. However, in schools, hand washing sinks typically have point-of-use mixing valves or master mixing valves supplying water to tempered lines as an anti-scalding measure. The hot water supplied for mixing is stored in a hot water heater. Remedial flushing at sinks is either not possible due to sensors or will most likely not drain the hot water heater and flushing hose bibbs will not affect the hot water heater. Stagnant, hot water with no or low disinfectant promotes *Legionella* growth. Therefore, flushing regimes should consider flushing hot water heaters separately. Furthermore, if showers are not being used, but are required due to state codes, then all shower head nozzles should be flushed routinely. Lastly, fixture location in relation to the mains and risers is important as well as the fact that fixtures are not designed for flushing, especially when they have sensors. For example, the water fountains at the middle school were plumbed next to the risers while the high school water fountains were not located near the risers. Therefore, the high school saw the least measurable free Cl_2 post-flush for water fountains in relation to the middle school. Yet, flushing individual water fountains is not feasible as this is a manual effort. Hand washing sinks with sensors cannot be flushed either but could benefit greatly from individual fixture flushing. While water conservation is an important consideration, the overall building water quality should also be considered when designing or installing fixtures with the possibility of a design option that allows maintenance personnel to easily flush fixtures such as hand washing sinks and water fountains or maybe creating smart fixtures that can automate a flushing sequence built into the fixture itself. Lastly, an unexpected outcome of this research revealed the definition of hot water is ambiguous. Some agencies consider hot water potable while other agencies do not consider hot water as drinking water. Further review and conclusive agreement by agencies and organizations regarding the definition of hot water is necessary, especially when there is no option for cold water at a sink, only tempered water.

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CONFLICT OF INTEREST

The authors declare no conflict of interest.

AUTHOR CONTRIBUTIONS

Rain Richard: Conceptualization; formal analysis; investigation; methodology; writing - original draft; writing-review & editing. **Treavor H. Boyer:** Conceptualization; formal analysis; supervision; funding acquisition; investigation; methodology; writing - original draft; writing-review & editing.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available on request from the corresponding author. The data are not publicly available due to privacy or ethical restrictions.

ORCID

Rain Richard https://orcid.org/0000-0002-3739-2998
Treavor H. Boyer https://orcid.org/0000-0003-0818-5604

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SUPPORTING INFORMATION

Additional supporting information may be found in the online version of the article at the publisher's website.

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