SUPPLEMENTARY INFORMATION

Finding Building Water Quality Challenges in a 7-Year Old Green School: Implications for Building Design, Sampling, and Remediation

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Tables and Figures

1. Materials and methods

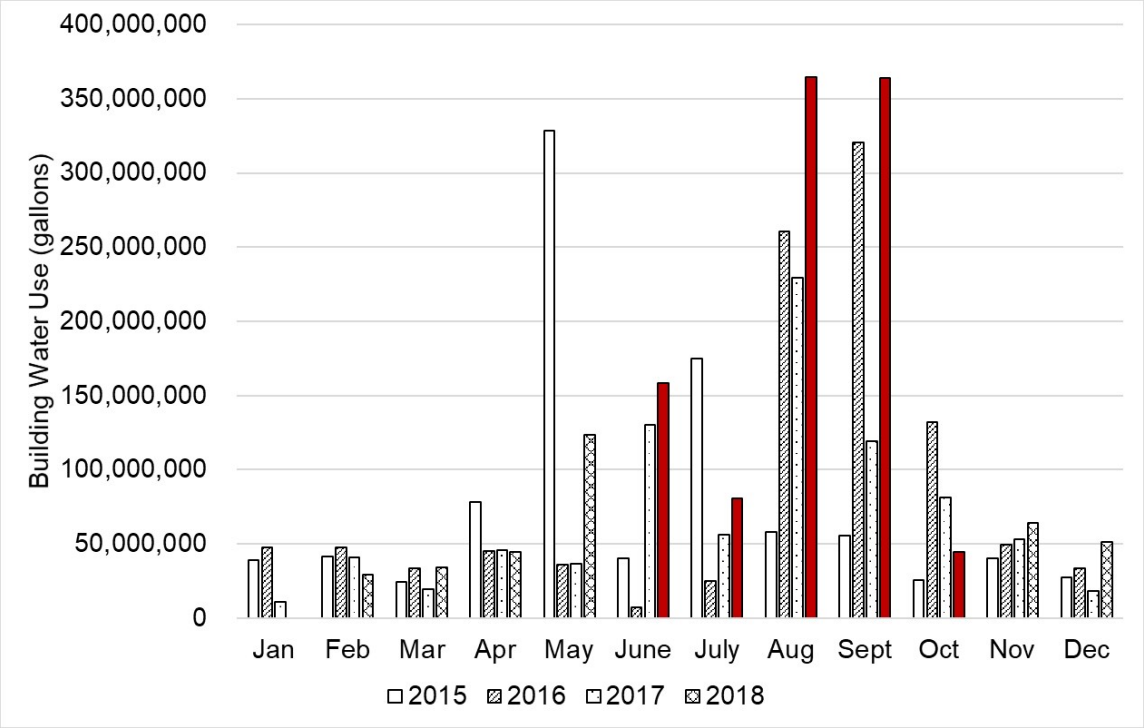

Figure SI-1. School water usage for last four years. Red colored bars are when the water sampling event was conducted (June 22, July 20, July 27, August 3, September 7, October 12).

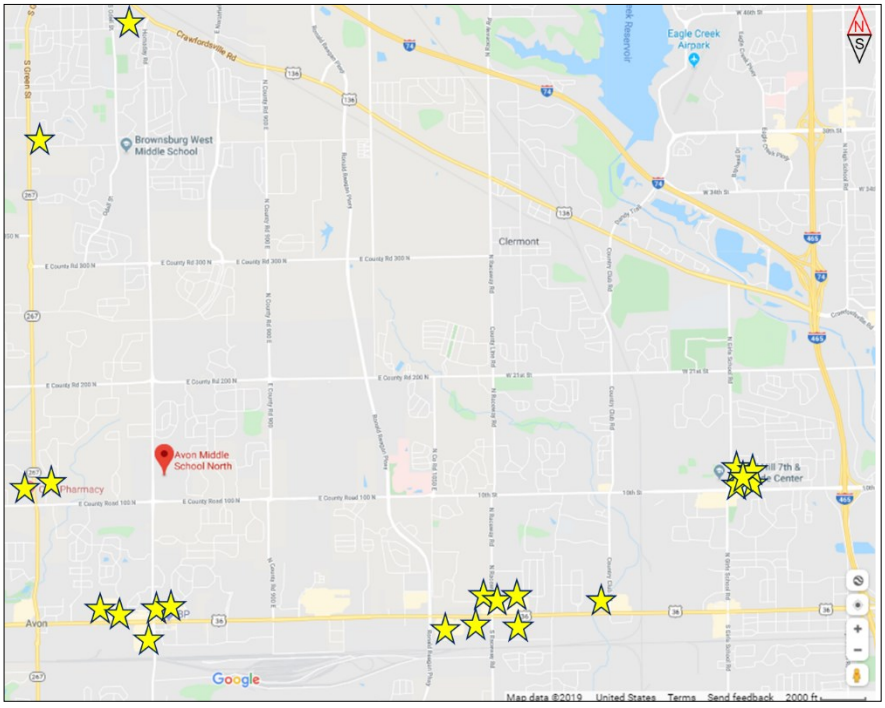

Figure SI-2. Location of water sample collection outside the school campus. Yellow stars indicate the approximate location of the commercial building water samples (21 locations). Scale and compass are on the right corner.

1.1 Water Quality Analysis

1.1.1 Onsite Water Quality Analysis

Total chlorine, free chlorine, monochloramine and free ammonia were analyzed onsite using HACH® 131 pocket colorimeter (DPD method). Water pH, DO, and temperature was measured using an Orion Star A329 portable pH meter (Thermo Scientific). Method detection limit (MDL) for total chlorine was 0.05 mg/L, free ammonia was 0.02 mg/L, and monochloramine was 0.04 mg/L.

1.1.2 TOC and DOC Quantifications

A Shimadzu TOC-L CPH/CPN was used to analyze TOC and DOC concentration. To get DOC samples, 50 mL of water sample was filtered through 0.5 μm glass fiber filter. The instrument was calibrated at 0.25 mg/L, 0.5 mg/L, 1 mg/L, 2 mg/L, 5 mg/L, 10 mg/L, and 50 mg/L TOC using $HOOCC_6H4COOK$ (r^2>0.99).

1.1.3 Total and Dissolved Heavy Metals Quantifications

To get dissolved metal samples, 30 mL of water sample was filtered through 0.45 μm nylon filter. Total and dissolved metal samples were analyzed by iCAP 7400 Duo ICP-OES (Thermo Scientific), and autosampler ASX-280 (CETAC Teledyne). Mixture of metals including Al, As, Be, Cd, Co, Cr, Cu, Fe, Hg, Mn, Ni, Pb, Se, and Zn was analyzed. The instrument was calibrated at 1 μg/L, 2 μg/L, 5 μg/L, 10 μg/L, 25 μg/L, 50 μg/L, 100 μg/L and 250 μg/L (r^2>0.99).

1.1.4 Ion Chromatography

An Metrohm 940 Professional IC Vario with a 850 Professional Sample Processor was used to analyze ion chromatography. The anions including bromide, chloride, fluoride, nitrate, nitrite, phosphate, and sulfate, and the cations including ammonium, calcium, lithium, magnesium, potassium, and sodium were analyzed. A mixture of 3.2mM sodium carbonate and 1mM sodium bicarbonate was used for the anion eluent, and a 3.5mM oxalic acid was used for the cation eluent. Custom anion mix 3 (Metrohm Cat No. REAIC1230), and custom cation mix 2 (Metrohm Cat no. REAIC1035) were used. The instrument was calibrated at 0.2 mg/L to 100 mg/L (r^2>0.99).

1.1.5 TTHM Analysis

An Agilent Technologies 7890B Gas Chromatography was used to analyze TTHMs. From collected water samples, only 5 mL water sample was transferred to headspace vials to extract TTHMs. 1 mL sample extracted by sampler was heated in an agitator for 15 min at 80°C. Then the gas phase sample was injected to 1:10 to 1:50 split ration column for analysis. The program was set for 5 min at 40°C, ramped to 240°C at 20°C/min, and then held at 240°C for 5 min. The analytical standard mix including $CHCl_3$, $CHBrCl_2$, $CHBr_2Cl$, and $CHBr_3$

purchased from Supelco™ was used.

1.1.6 HPC Analysis

The water samples in the field were collected in 1L HDPE bottles and transferred to the laboratory. Sterilized water was filtered first using a PALL® 47mm magnetic filter funnels, and Advantec® sterilized MCE filters with pore size 0.45 μm was used. Each sample was filtered at least 300 mL volume three times, and filters were placed on agar plates. Agar plates were incubated at 35˚C for 48 hours before colonies were counted.

1.1.7 TCC Analysis

FCM analysis was conducted to quantify the total number of microbial cells in each water sample using SYBR Green I dye which binds specifically to nucleic acid (Swiss Research method 366.1). Each water sample was stained 1:100 with SYBR-Green I nucleic acid gel stain diluted in filtered dimethylsulfoxide (DMSO). The samples were incubated in a 96-well plate in the dark at 37℃ for 13 minutes. Triplicate samples from each fixture were analyzed using FCM (CytoFLEX, Beckman-Coulter Inc., Brea, CA, USA). A constant and uniform gating strategy was applied to all samples.

1.1.8 Nitrification/Denitrification Analysis

Nitrifying and denitrifying bacteria were measured using BART™ test. For both tests, water samples were collected in the provided tubes. For nitrification, the cap was replaced with a reactor cap after 5 days. Reaction was observed after the tube was rest for 3 hours. For denitrification, tubes were incubated at room temperature for 4 days to observe any bacteria growth each day.

2. Results and discussion

Table SI-1. A comparison of water quality entering the building to the public water supplier's annual report

Measurement	Drinking water standard	2018 system range reported by the public water supplier	School sampling results from June - October
pH	6.5 – 8.5	7.00 – 8.48	7.62 – 7.87
Chlorine as Cl_2	4 ppm	0.02 – 2.9 ppm	BDL – 0.43 ppm
E. coli	1	0	-
Giardia (org/10L)	0 org/10L	ND	-
Hardness (ppm)	-	138 – 453 ppm	286 – 358 ppm
Total Coliforms	-	0 – 2.4%	-
Turbidity	-	0.075 – 0.19 NTU	-
2,4-D	70 ppb	ND	-
Aluminum	200 ppb	ND – 175 ppb	0 ppb
Ammonium nitrogen	-	-	0.37 – 1.34 ppm
Antimony	6 ppb	ND	-
Arsenic	10 ppb	ND – 1.9 ppb	-
Atrazine	3 ppb	ND- 1.8 ppb	-
Barium	2 ppm	0.037 – 0.29 ppm	-
Benzo[a]pyrene	0 ppb	ND	-
Bromide	0.5 ppm	N/A	0.32 – 0.46 ppm
Chloride	250 ppm	25 – 139 ppm	65.6 – 101.9 ppm
Chromium	100 ppb	ND – 3.2 ppm	-
Copper	1.3 ppm health-based limit	0.27 (90^{th} percentile) – 0.43 ppm	0 – 2.7 ppm
Fluoride	4 ppm	0.24 – 1.2 ppm	0.68 – 0.83 ppm
Haloacetic acids (HAA5)	-	8.9 – 90 ppb	-
Iron	0.3 ppm	ND – 0.21 ppm	0 – 0.038 ppm
Lead	15 ppb for corrosion control	8.2 (90^{th} percentile) – 36 ppb	0 – 40.9 ppb
Manganese	0.05 ppm	ND	0 – 0.00176 ppm
Nitrate	10 ppm	ND – 4.8 ppm	0.82 – 2.78 ppm
Nitrite	3 ppm	N/A	ND – 0.06 ppm
Nickel	-	ND – 2.3 ppb	0 – 3.18 ppb
Phosphate	-	N/A	ND – 0.04 ppm
Potassium	-	N/A	0.68 – 3.69 ppm
Simazine	4 ppb	ND – 1.2 ppb	-
Sodium	-	14 – 86 ppm	0 – 65.92 ppm
Sulfate	250 ppm	8.8 – 165 ppm	44.61 – 63.03 ppm
Toluene	1,000 ppb	ND – 1.5 ppb	-
Total Xylenes	10,000 ppb	ND	-
Total Trihalomethanes (TTHMs)	80 ppb	18 – 82 ppb	13.65 – 26.86 ppb

Table SI-2. 2018 Total water use at the school campus

Month	Total Gallons/Month	Gallons per day
Jan	0	0
Feb	29,174,028	1,458,701
Mar	33,942,859.5	1,697,143
Apr	44,434,288.8	2,221,714
May	123,709,100	6,185,455
Jun	158,493,518	7,924,676
Jul	80,621,304.3	4,031,065
Aug	364,843,662	18,242,183
Sept	364,114,311	18,205,716
Oct	44,378,184.9	2,218,909
Nov	64,238,965.5	3,211,948
Dec	51,278,964.6	2,563,948
Total	*44,434,288.8*	*67,961,459*

School water use (GPD) was calculated with assumtion of 20 days of water use per month.

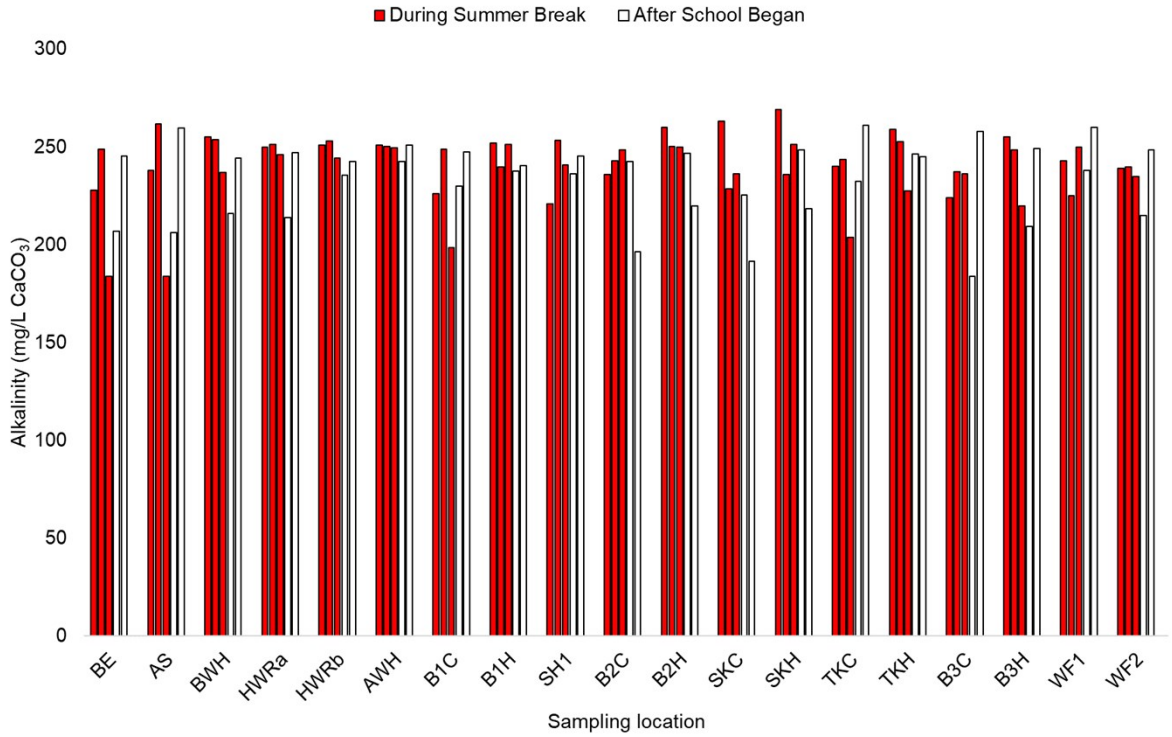

Figure SI-3. Alkalinity concentration as $CaCO_3$ at routine sampling locations

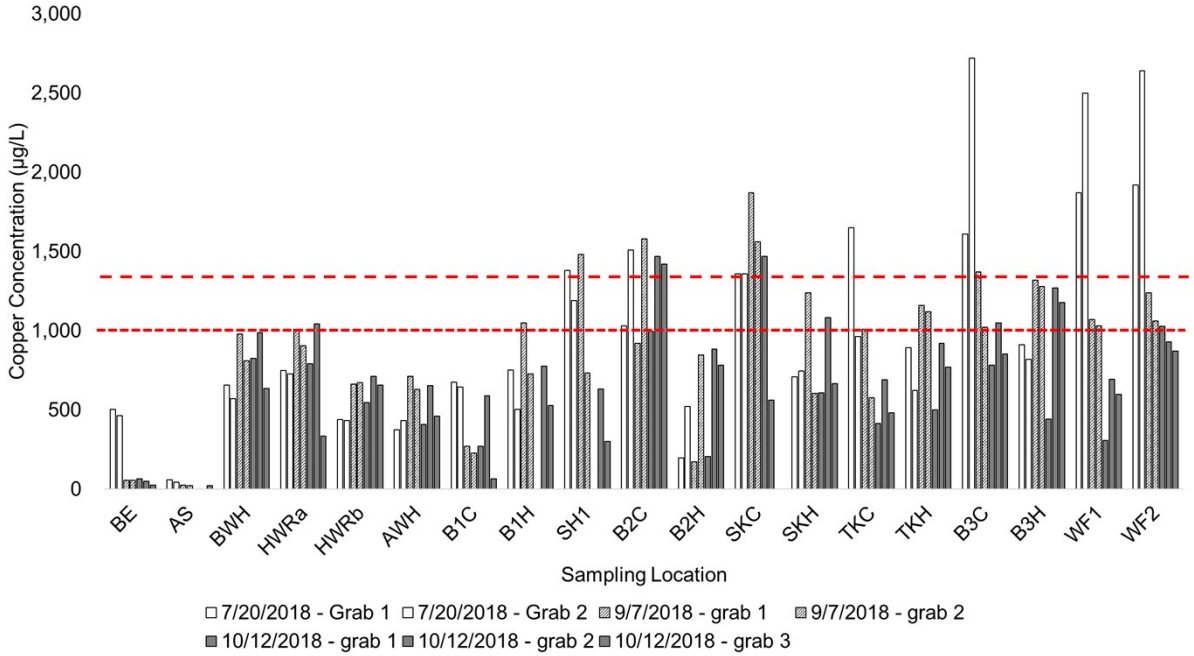

Figure SI-4. Copper concentration of multiple grabs from routine sampling locations. The 1.0 mg/L SMCL and 1.3 mg/L MCL are shown.

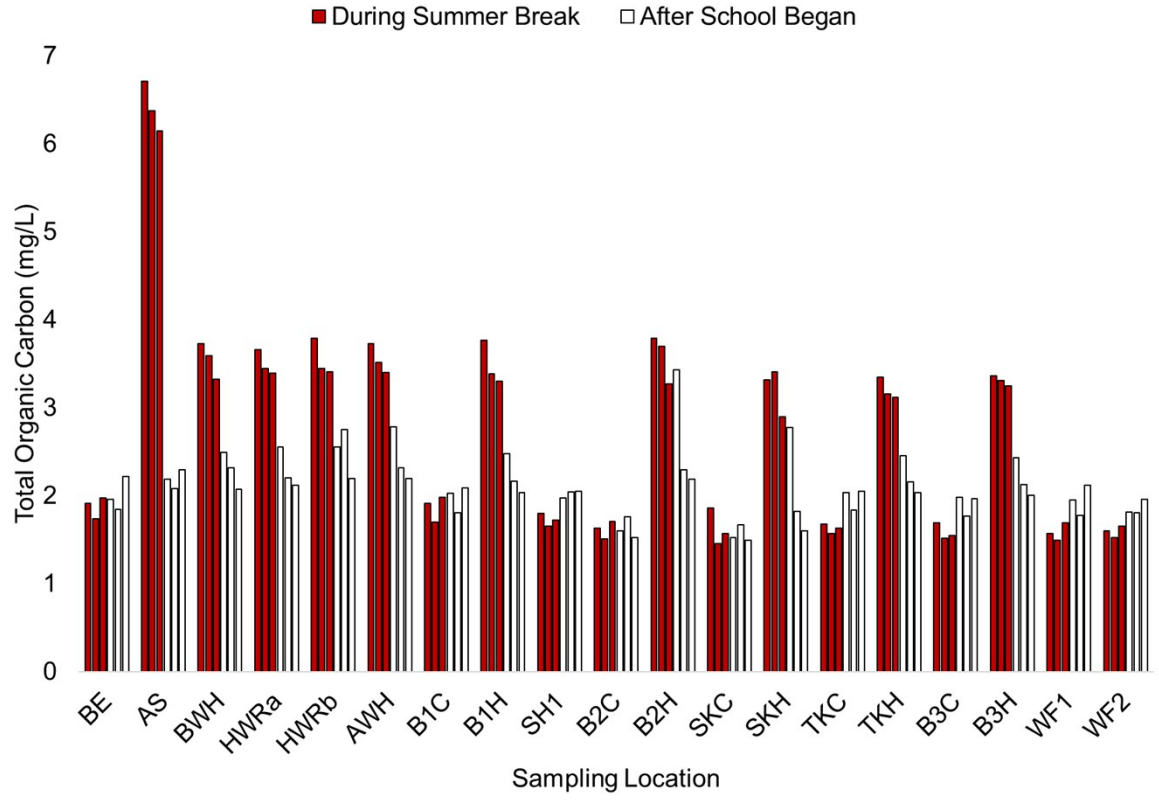

Figure SI-5. Total organic carbon concentration of first draw water samples

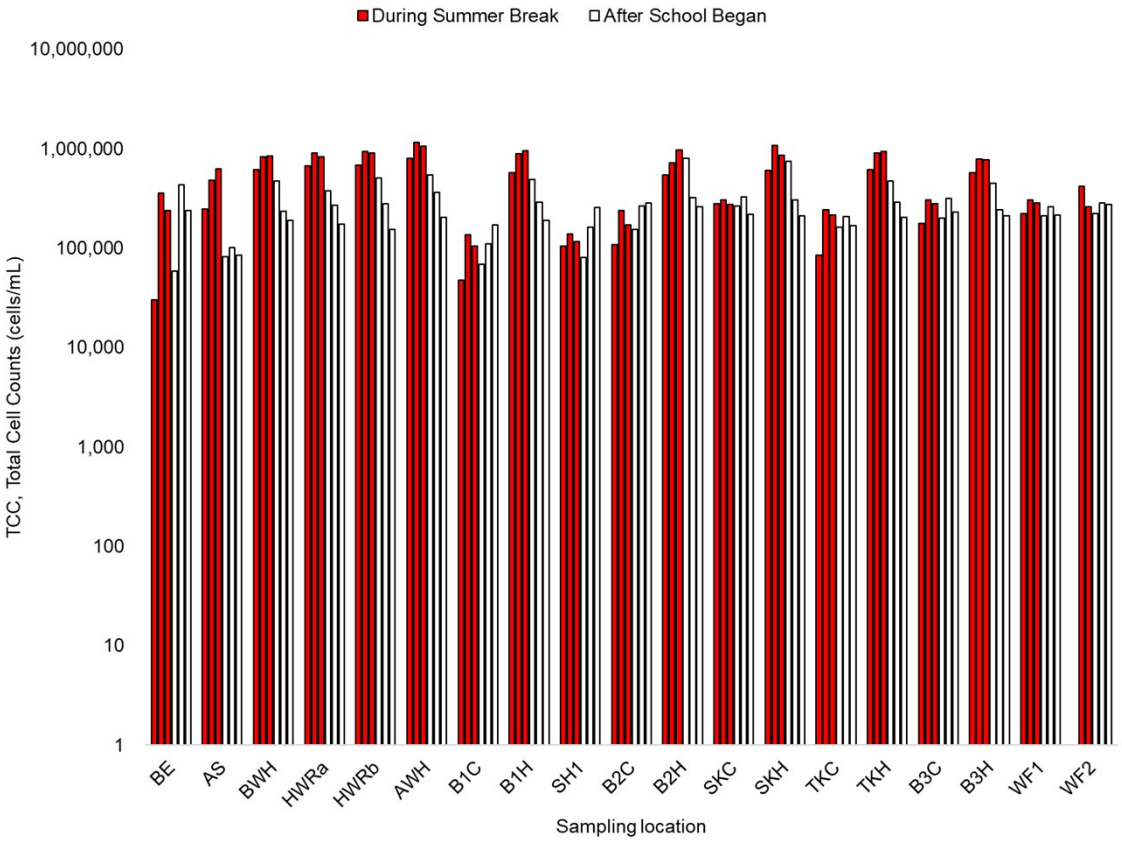

Figure SI-6. Total cell count concentration at routine sampling locations

Table SI-3. Water quality test results for water sampling outside the school campus

Location	Temp. (˚C)	pH	DO (mg/L)	Total Cl_2 (mg/L)	Free Cl_2 (mg/L)	NH_2Cl (mg/L)	NH_3-N (mg/L)	Copper (µg/L)
1	27.3	7.85	7.95	0.57	0.52	1.39	0.12	91.4
2	25.1	7.8	7.62	0.54	0.45	1.16	0.14	137
3	25.8	7.86	7.91	0.44	0.39	0.97	0.16	76.9
4	30.7	7.75	7.24	0.61	0.51	1.33	0.14	26.1
5	25.7	7.88	7.94	0.25	0.2	0.56	0.18	163
6	23.7	7.77	7.44	0.58	0.52	1.29	0.17	69.6
7	28.2	7.77	7.75	0.28	0.26	0.12	0.15	764
8	26.1	7.68	7.69	0.44	0.33	1.05	0.16	46.9
9	27.4	7.56	7.03	0.05	0.03	0.09	0.17	1,140
10	25.6	7.87	8.46	0.54	0.5	1.3	0.14	149
11	30.6	7.78	7.41	0.3	0.28	0.68	0.1	89.6
12	26.8	7.81	8.2	0.67	0.61	1.53	0.07	17.1
13	22.8	7.76	7.64	0.14	0.11	0.27	0.08	861
14	23.1	7.56	8.22	0.03	0.02	0.08	0.03	147
15	20.8	7.84	8.08	0.04	0.01	0	0.17	1,620
16	26.9	7.86	8.38	0.54	0.49	1.31	0.11	46.9
17	27.4	7.77	7.85	0.22	0.2	0.45	0.19	548
18	27.7	7.7	7.81	0.32	0.26	0.78	0.16	232
19	18.9	7.75	8.03	0.03	0.01	0	0.03	1,590
20	27.3	7.73	7.51	0.04	0.03	0.1	0.13	725
21	16.2	7.6	3.63	0.04	0.03	0.01	0.17	999

2.1 Other Heavy Metals Found and Water Corrosivity

Other heavy metals associated with metal plumbing component corrosion were detected throughout the building but below MCL and SMCLs (**TABLE SI-4**). Nickel and zinc were found at a much greater concentration outside the utility room (max. 20.4 µg/L for nickel, max. 1,180 µg/L for zinc) compared to inside the utility room (0 to 3.2 µg/L for nickel, 7.9 to 177 µg/L for zinc). Lead was only detected at the shower head location (3 of 6 first grab samples), and all first three grabs exceeded the action level of 15 µg/L (**Table 2**). Corrosivity estimated using school water quality data does not seem helpful to predict none of copper or lead leaching. Although hot water was predicted to be slightly more corrosive than other cold locations (Langelier Index from -0.56 to -0.05), more aggressively corrosive locations did not always have high heavy metal concentrations.

Table SI-4. Other heavy metal water sampling results from the school

Heavy metal	MCL and SMCL (mg/L)	School water entering point (mg/L)	School sampling range in cold (mg/L)	School sampling range in hot (µg/L)
Aluminum	0.05, 0.2	0	0 – 0.087	0 – 0.039
Copper	1.3, 1.0	0.026 – 0.50	0 – 2.72	0 – 1.32
Iron	10, 0.3	0 – 0.0104	0 – 0.062	0 – 0.026
Manganese	0.05	0 – 0.00112	0 – 0.0052	0 – 0.0011
Nickel	0.1	0 – 0.0032	0 – 0.056	0 – 0.093
Lead	0.0015, 0	0	0 – 0.041	0
Zinc	5	0 – 0.18	0 – 11.8	0 – 10.2

2.2 Other Contaminants

No specific trend or statistically significant found for TTHM, but the biggest difference found in the utility room. TTHM was similar for all six visits for the water entering the building but decreased after softener (**Figure SI-7**). TTHM levels entering the building were 13.6 to 26.4 µg/L while the water supplier reported a water distribution system annual average TTHM concentration of 18 to 82 µg/L (Citizens Energy Group, 2018) (**Table 2**). Other organic (TTHM) and inorganic contaminants were also found entering the building but within levels reported by the water supplier (Al, Cl-, Cr, F-, Fe, Mn, Na, Ni, Zn, NO3-, NO2-, SO4-2, hardness) (**Table SI-1**). Distance from the entry point to location was correlated with TTHM concentration (p=0.03), but no difference between before and after students returned to school. None of the locations exceeded the TTHM limit of 80 µg/L (EPA, 2002).

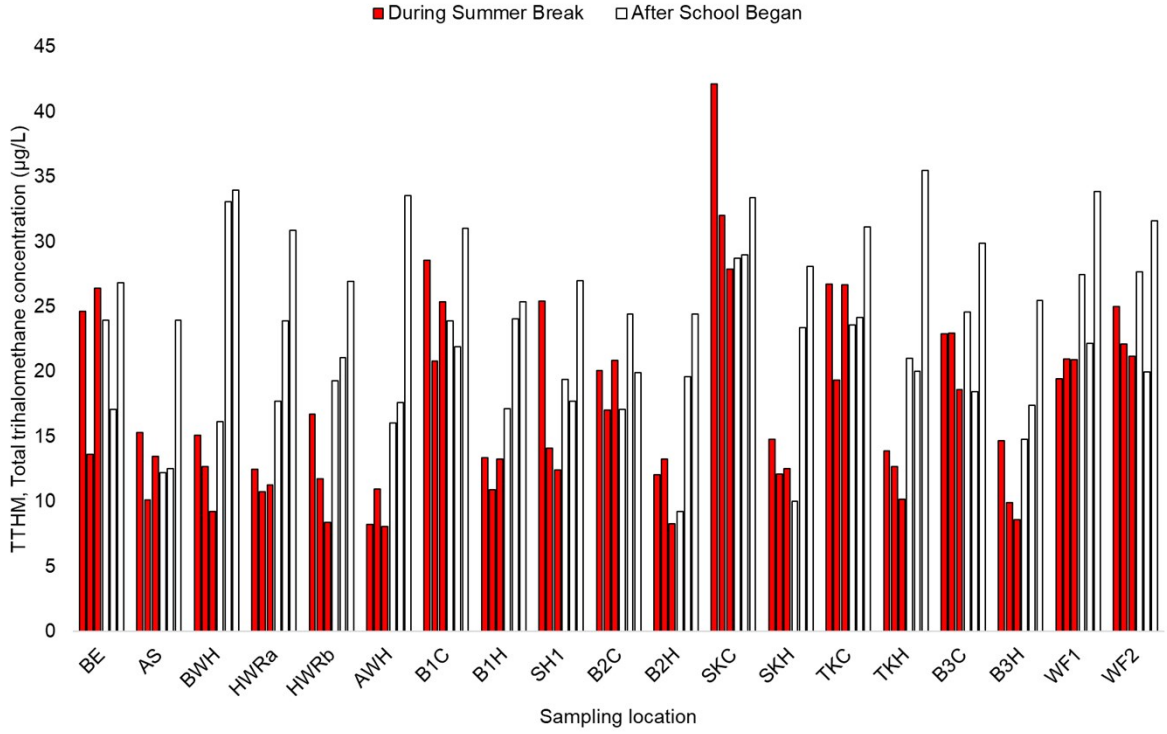

Figure SI-7. Total trihalomethane concentration at routine water sampling locations

2.3 Water Temperature Monitoring

Hot water recirculation lines should be prevented from getting below 55˚C but 60˚C line returned at 48˚C and the other lines returned at 35˚C (according to in-line sensors). Because authors concerned about some locations may not get the hot water, temperature monitoring at 3 distal fixtures was conducted for 5 minutes (**Figure SI-8, Table SI-5**). No location reached the hot water recirculation line temperature threshold (48.8˚C). SKH had shorter distance from BE increased temperature much faster, but still did not reach the threshold. B3H had longest distance from BE never reached above 28˚C within 5 minutes. Although only three locations were monitored for temperature, a possible problem that may have with the recirculation system with large dead ends in certain parts of the school was noticed. This may mean that many locations do not reach certain temperature that are in a perfect temperature zone for microbial growth.

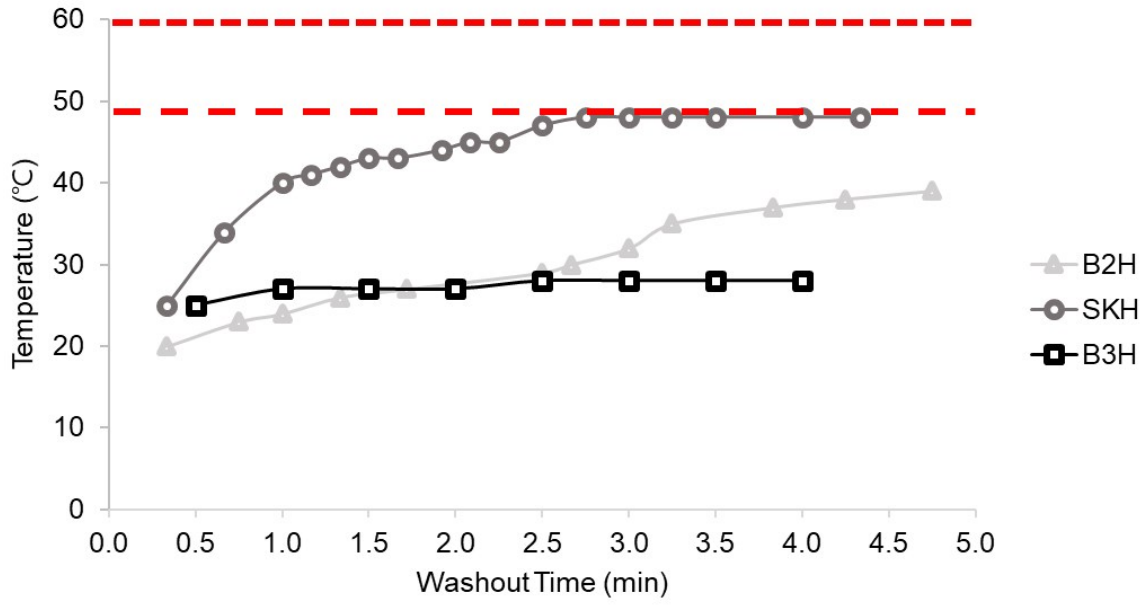

Figure SI-8. Temperature washout curves for hot water. Red lines are the temperature threshold (60˚C and 48.8˚C) that are supposed to be achieved based on the water heating equipment set points.

Table SI-5. Estimated delivery and return pipe length for the water temperature monitoring

Water deliver	Delivery length	Water returns	Return length	Total length
BE to B3H	509.97 ft	B3H to HWRC	496.75 ft	1006.72 ft
BE to B2H	252.002 ft	B2H to HWRC	215.49 ft	467.492 ft
BE to SKH	267.75 ft	SKH to HWRC	282.3 ft	550.05 ft