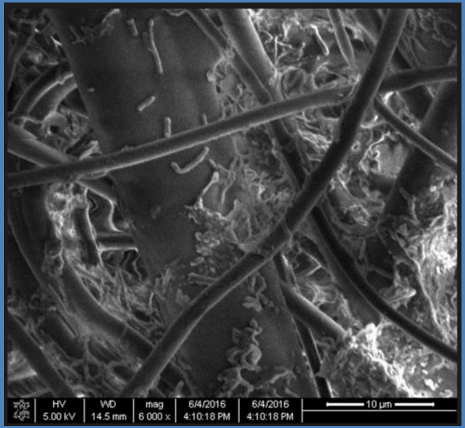
Right Sizing Tomorrow's Water Systems for Efficiency, Sustainability, & Public Health



Overview, status, and projected timeline

November 2020

Andrew Whelton, Jade Mitchell, Joan Rose, Juneseok Lee, Pouyan Nejadhashemi, Erin Dreelin, Tiong Gim Aw, Amisha Shah, Matt Syal, Maryam Salehi

PURDUE UNIVERSITY | MICHIGAN STATE UNIVERSITY | SJSU SAN JOSÉ STATE UNIVERSITY | MANHATTAN COLLEGE | Tulane University | THE UNIVERSITY OF MEMPHIS

awhelton@purdue.edu

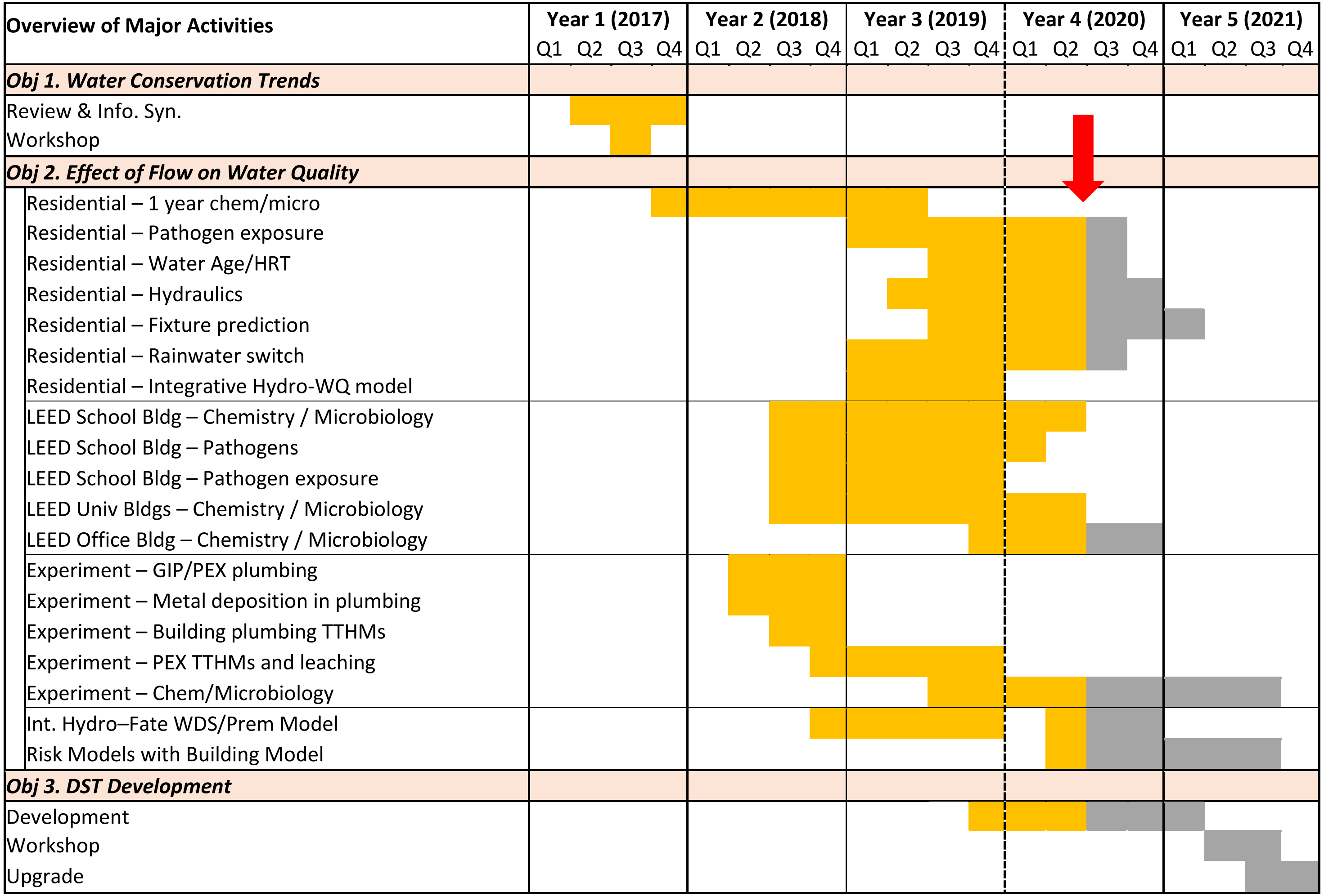
Goal and Objectives

To better understand and predict water quality and health risks posed by declining water usage and low flows

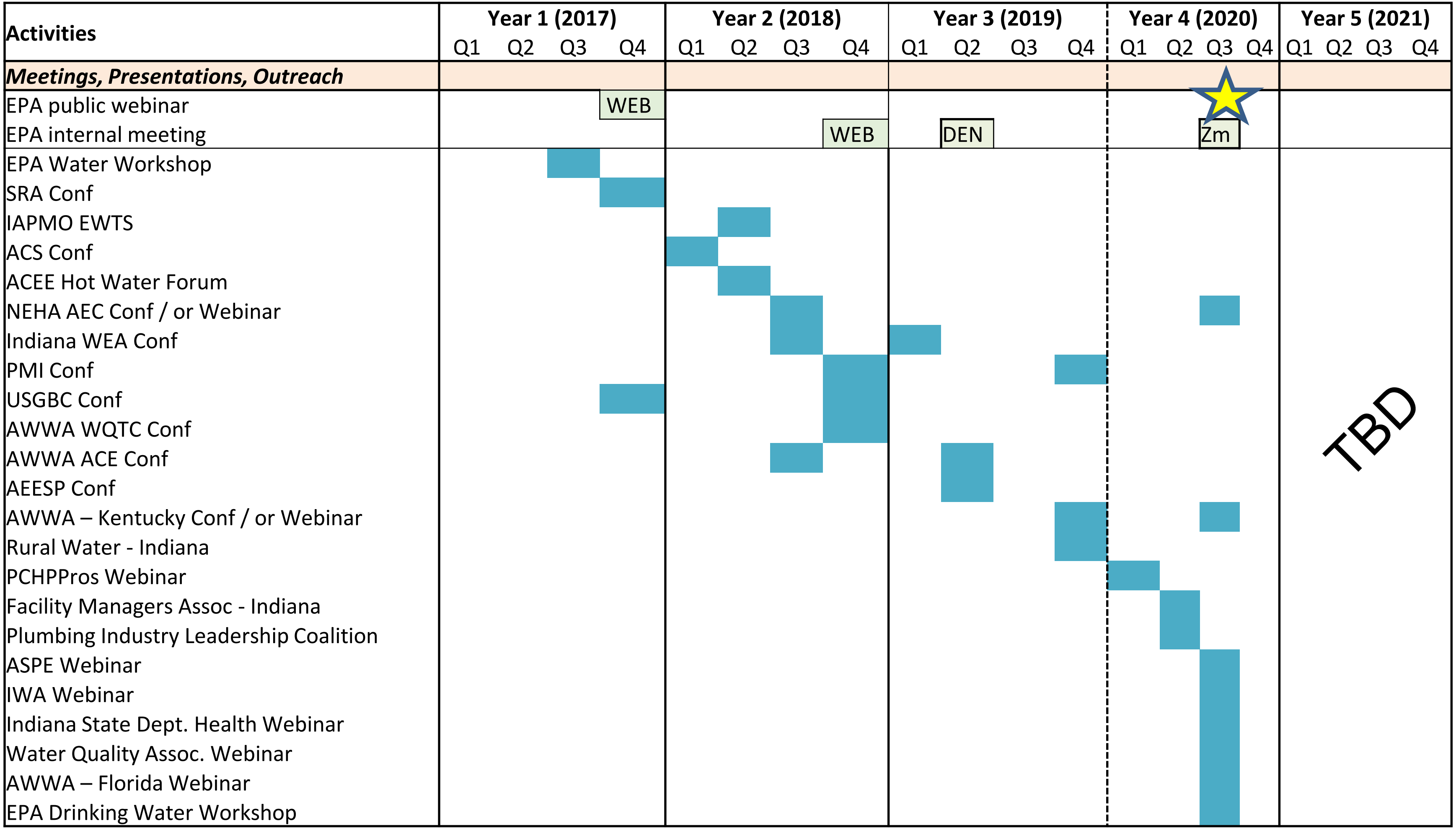
1. **Improve the public's understanding of decreased flow** and establish a range of theoretical premise plumbing flow demands from the scientific literature and expert elicitation with our strategic partners

2. **Elucidate the factors and their interactions that affect drinking water quality** through fate and transport simulation models for residential and commercial buildings

3. **Create a risk-based decision support tool** to help guide decision makers through the identification of premise plumbing characteristics, operations and maintenance practices that minimize health risks to building inhabitants.


Overview of Major Activities
Year 1 (2017)
Year 2 (2018)
Year 3 (2019)
Year 4 (2020)
Year 5 (2021)
Q1 Q2 Q3 Q4
Obj 1. Water Conservation Trends
Review & Info. Syn.
Workshop
Obj 2. Effect of Flow on Water Quality
Residential – 1 year chem/micro
Residential – Pathogen exposure
Residential – Water Age/HRT
Residential – Hydraulics
Residential – Fixture prediction
Residential – Rainwater switch
Residential – Integrative Hydro-WQ model
LEED School Bldg – Chemistry / Microbiology
LEED School Bldg – Pathogens
LEED School Bldg – Pathogen exposure
LEED Univ Bldgs – Chemistry / Microbiology
LEED Office Bldg – Chemistry / Microbiology
Experiment – GIP/PEX plumbing
Experiment – Metal deposition in plumbing
Experiment – Building plumbing TTHMs
Experiment – PEX TTHMs and leaching
Experiment – Chem/Microbiology
Int. Hydro–Fate WDS/Prem Model
Risk Models with Building Model
Obj 3. DST Development
Development
Workshop
Upgrade

OBJECTIVE 1. Improve the public's understanding of decreased flow and establish a range of theoretical premise plumbing flow demands from the scientific literature and expert elicitation with our strategic partners


Activities
Year 1 (2017)
Year 2 (2018)
Year 3 (2019)
Year 4 (2020)
Year 5 (2021)
Q1 Q2 Q3 Q4
Meetings, Presentations, Outreach
EPA public webinar
EPA internal meeting
WEB
WEB
DEN
Zm
EPA Water Workshop
SRA Conf
IAPMO EWTS
ACS Conf
ACEE Hot Water Forum
NEHA AEC Conf / or Webinar
Indiana WEA Conf
PMI Conf
USGBC Conf
AWWA WQTC Conf
AWWA ACE Conf
AEESP Conf
AWWA – Kentucky Conf / or Webinar
Rural Water - Indiana
PCHPPros Webinar
Facility Managers Assoc - Indiana
Plumbing Industry Leadership Coalition
ASPE Webinar
IWA Webinar
Indiana State Dept. Health Webinar
Water Quality Assoc. Webinar
AWWA – Florida Webinar
EPA Drinking Water Workshop
TBD

PURDUE UNIVERSITY | Center for Plumbing Safety

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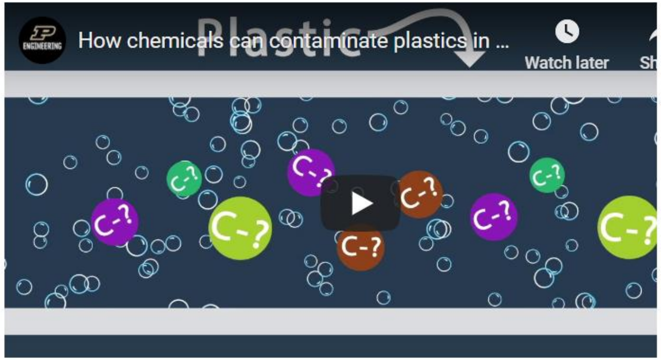


News

- 'It's gone to the ground': Big Basin Water Co. struggles to recover from fire (Santa Cruz Sentinel)
- Wildfires can spark widespread contamination of public water supplies (NRDC)
- Biggest risk to surface water after a wildfire? It's complicated (Eos)
- As wildfires ravage the West, contaminated water raises health concerns (STAT)
- Unsafe to drink: Wildfires threaten rural towns with tainted water (Cal Matters)
- How wildfires are contaminating the water supply with benzene, other hazardous chemicals (WBUR)

COVID-19 Response

Thank you for visiting. This website is designed to provide information to persons who drink water in buildings, as well as building construction, plumbing, water utility, education, and public health sectors. Together, we are working to understand how to make certain the water you use at home, at work, and at schools is safe. Please contact us if you have any questions at awhelton@purdue.edu.

Partner Institutions:

Manhattan College | Michigan State University | SJSU San José State University | Tulane University | The University of Memphis

2017: 1,790 views
2018: 3,327 views
2019: 6,411 views
2020: 27,830 views

OBJECTIVE 2. Elucidate the factors and their interactions that affect drinking water quality through fate and transport simulation models for residential and commercial buildings

Published… so far

Initiative	Lead	Stage
Residential Building City Water Chemistry and Microbiology 4 month startup: https://doi.org/10.1016/j.chemosphere.2017.11.070	Purdue-MSU	Published
Residential Building City Water Chemistry 1 Year Study: https://doi.org/10.1039/D0EW00334D	Purdue-Memphis-MSU	Published
Residential Building City Water Microbiology 1 Year Study: https://doi.org/10.1039/D0EW00334D	Tulane-Purdue-MSU	Published
Residential Building Reverse QMRA for *P. aerugi*nosa Exposure: https://doi.org/10.1061/(ASCE)EE.1943-7870.0001641	MSU	Published
Residential Building Rainwater Chemical/Micro Transition Study: https://10.1021/acs.est.0c03641	Purdue-Tulane-MSU	Published
Dose Response *Naegleria fowleri*: https://doi.org/10.2166/wh.2018.181	MSU	Published
LEED School Green Building Chemistry Study: https://doi.org/10.1039/D0EW00520G	Purdue-Tulane	Published
Dose Response *P. aeruginosa*: https://doi.org/10.1016/j.mran.2020.100115	MSU	Published
Synthesis Study: Plumbing Research Needs: https://doi.org/10.1002/aws2.1177	MSU-Purdue-Manhattan	Published
Heavy Metal Accumulation on Plastic Plumbing, Field Study: https://doi.org/10.5942/jawwa.2017.109.0117	Purdue	Published
Water Quality in Mixed GIP-PEX Plumbing: https://doi.org/10.1016/j.jhazmat.2019.121585	Purdue	Published
Heavy Metal Degradation of Downstream PEX Plumbing: https://doi.org/10.1016/j.chemosphere.2019.07.060	Purdue	Published
TTHM Generation and Fate in PEX Plumbing: https://doi.org/10.1039/D0EW00262C	Purdue	Published
Synthesis Study: Stagnation Water Quality Impact Review: https://doi.org/10.1002/aws2.1186	Purdue	Published
Dose Response *Acanthamoeba*: https://doi.org/10.1111/risa.13603	MSU	Accepted

In review, undergoing data analysis, planning, and more…

Initiative	Lead	Stage
LEED Institutional Buildings Chemistry and Microbiology Study (Gim Aw et al.)	MSU	In peer-review
ID variables that influence legionella in building plumbing (Julien et al.)	MSU-Purdue	In peer-review
Enumeration and Characterization of Five pathogenic Legionella species from Large Research and Educational Buildings (Logan et al.)	MSU	In peer-review
The Occurrence of 5 Pathogenic Legionella species from Source (Groundwater) to Exposure (Taps and Cooling Towers) In a Complex Water System (Logan et al.)	MSU	In peer-review
Residential Building Upstream Fixture Water Use Prediction Study (Kropp et al.)	MSU-Manhattan-Purdue	In peer-review
Influence of thermal gradients on legionella in residential plumbing (Julien et al.)	MSU	Data analysis
Residential Building Water Age/HRT Modeling (Julien et al.)	MSU-Purdue	Data analysis
LEED Office Green Building Chemistry and Microbiology Study (Montagnino et al.)	Purdue-Tulane	Data analysis
Residential Building City Water Hydraulic Plumbing Study (Palmegiani et al.)	Manhattan-Purdue	Data analysis
Residential Building City Water Integrative Hydro-Water Quality Study (Lee et al.)	Manhattan-Purdue	Data analysis
LEED School Green Building Opportunistic Pathogen Study (Gim Aw et al.)	Tulane-Purdue	Data analysis
Legionella and amoeba in cooling towers and building water systems (Logan et al.)	MSU	Data analysis
Synthesis Study: Copper in Schools (Montagnino et al.)	Purdue-MSU	Data analysis
Risk Based Decision Support Tool (Nedjashimi et al.)	MSU-Manhattan-Purdue	Planning
Synthesis Study: Plumbing Safety of the Future	Purdue-MSU-UM-Manhattan-Tulane	Planning
And more….		

The Most Monitored Home in America

West Lafayette, Indiana
Less than 100 yards from Purdue
3 Bedroom, 1.5 baths
Water saving fixtures
Trunk-and-Branch design
PEX piping
Renovated in 2014

October 2017-October 2018

30,000+ individual water quality measurements completed - does not include flow monitoring, pressure monitoring, or qPCR

2.64 billion online plumbing related measurements

Thermocouples throughout piping, 1x /sec
Indoor air temperature, 1x /sec
Flowrates at every fixture, 1x /sec
Energy use per device, 1x /sec

www.ReNEWWHouse.com

Today, we'll share some emerging results

1:50 to 3:00 pm … Please post questions in the chat box during the presentations.
Andrew Whelton will compile them and during his talk ask each speaker to explain and/or follow-up after the meeting.

Andrew Whelton/Purdue	Project overview, status, and timeline
Liz Montagnino/Purdue	Office building water safety: The role of weekend stagnation
Tiong Gim Aw/Tulane	Microbiology of a school during Summer and Fall seasons
Alshae Logan/MSU	Microbiology of large institutional buildings
Ryan Julien/MSU	Identifying variables that influence Legionella concentrations
Ian Kropp/MSU	Bootstrap Aggregated Decision Tree Classification of End-use Events Through Upstream Features
Maria Palmegiani/Manhattan-Purdue	Development of the integrative hydraulic and water quality model
Ryan Julien/MSU (w/ Drexel)	Comparing risks across building water use types with QMRA
Andrew Whelton/Purdue	Next steps

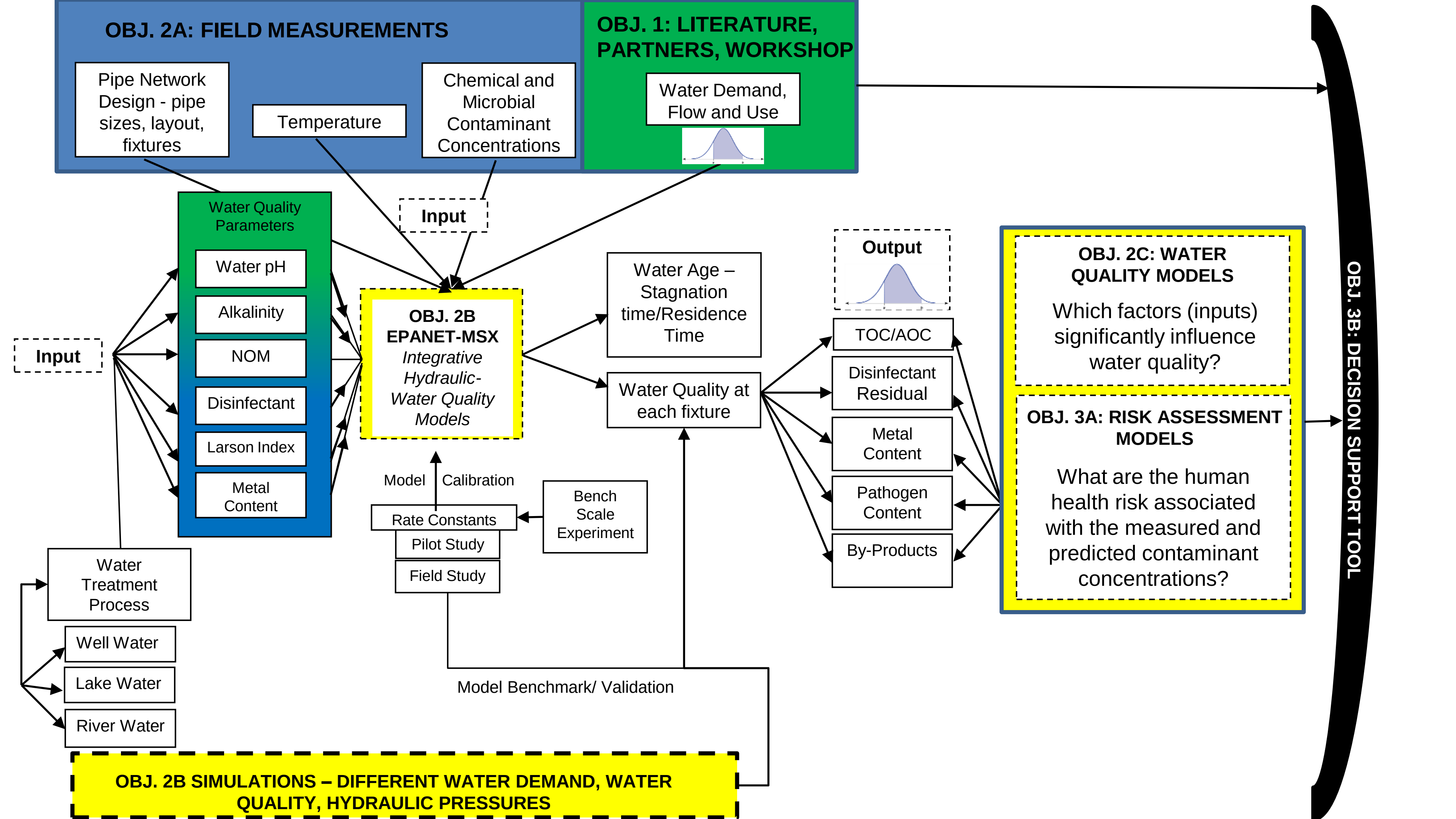
Extra Slides

This will be the integrative water quality-hydraulic model for a single-family home

2014, building plumbing renovated with new PEX, trunk and branch design; low flow fixtures

Drinking water source:
Public water system: Groundwater, treated with free chlorine residual and a corrosion inhibitor, PVC and Iron water mains

- October 2017-November 2018
- Continuous monitoring of water flow, air and water temperature at service line and all plumbing components
  = 2.64 billion data points
- Pressure monitoring continuous during water sampling, 2-3 week periods
- **More than 222,223 labor hours** for water sampling and analysis (**does not include data interpretation, reporting and other activities**)
  - 58 sampling events, 5 locations, hot and cold water, 7am, 12pm, 3pm


OBJ. 2A: FIELD MEASUREMENTS
Pipe Network Design - pipe sizes, layout, fixtures
Temperature
Chemical and Microbial Contaminant Concentrations
OBJ. 1: LITERATURE, PARTNERS, WORKSHOP
Water Demand, Flow and Use
Input
Water Quality Parameters
Water pH
Alkalinity
NOM
Disinfectant
Larson Index
Metal Content
Input
OBJ. 2B EPANET-MSX
Integrative Hydraulic-Water Quality Models
Water Age – Stagnation time/Residence Time
Water Quality at each fixture
Output
TOC/AOC
Disinfectant Residual
Metal Content
Pathogen Content
By-Products
OBJ. 2C: WATER QUALITY MODELS
Which factors (inputs) significantly influence water quality?
OBJ. 3A: RISK ASSESSMENT MODELS
What are the human health risk associated with the measured and predicted contaminant concentrations?
OBJ. 3B: DECISION SUPPORT TOOL
Model
Calibration
Rate Constants
Pilot Study
Field Study
Bench Scale Experiment
Water Treatment Process
Well Water
Lake Water
River Water
Model Benchmark/ Validation
OBJ. 2B SIMULATIONS – DIFFERENT WATER DEMAND, WATER QUALITY, HYDRAULIC PRESSURES

Office Building Water Safety:

The Role of Weekend Stagnation

ELIZABETH MONTAGNINO

NOVEMBER 12, 2020

Stagnation of water in office buildings

Friday → **Saturday** → **Sunday** → **Monday**: Low to no water use

Stagnation can induce:

disinfectant decay[1,2,3]
metal leaching from plumbing and scales[4,5,6]
bacterial growth and emergence of pathogens into bulk water[3,7,8]

Flushing has been previously assumed to be adequate for remediating water quality problems.

[1]Biswas, P., Lu, C., & Clark, R. M. (1993). A model for chlorine concentration decay in pipes. Water Research, 27(12), 1715-1724.
[2]Hallam, N. B., West, J. R., Forster, C. F., & Simms, J. (2001). The potential for biofilm growth in water distribution systems. Water Research, 35(17), 4063-4071.
[3]Nguyen, C., Elfland, C., & Edwards, M. (2012). Impact of advanced water conservation features and new copper pipe on rapid chloramine decay and microbial regrowth. Water research, 46(3), 611-621.
[4]Lytle, D. A., & Schock, M. R. (2000). Impact of stagnation time on metal dissolution from plumbing materials in drinking water. Journal of Water Supply: Research and Technology—AQUA, 49(5), 243-257.
[5]Ra, K., Odimayomi, T., Ley, C., Aw, T. G., Rose, J. B., & Whelton, A. J. (2020). Finding building water quality challenges in a 7 year old green school: implications for building design, sampling, and remediation. Environmental Science: Water Research & Technology.
[6]Richard, R., Hamilton, K. A., & Boyer, T. (2020). Tracking copper, chlorine, and occupancy in a multi-story, new, institutional green building. Environmental Science: Water Research & Technology.
[7]Lautenschlager, K., Boon, N., Wang, Y., Egli, T., & Hammes, F. (2010). Overnight stagnation of drinking water in household taps induces microbial growth and changes in community composition. Water research, 44(17), 4868-4877.
[8]Lipphaus, P., Hammes, F., Kötzsch, S., Green, J., Gillespie, S., & Nocker, A. (2014). Microbiological tap water profile of a medium-sized building and effect of water stagnation. Environmental Technology, 35(5), 620-628.

Technical approach: Fixture use, water sampling, and analysis

3 weekends in Winter 2020

Friday @ 5:30 pm

Monday @ 6:30 am

Daily fixture use recorded by building inhabitants

Collected water samples at the point-at-entry and worked our way from the basement to the top floor

On-Site

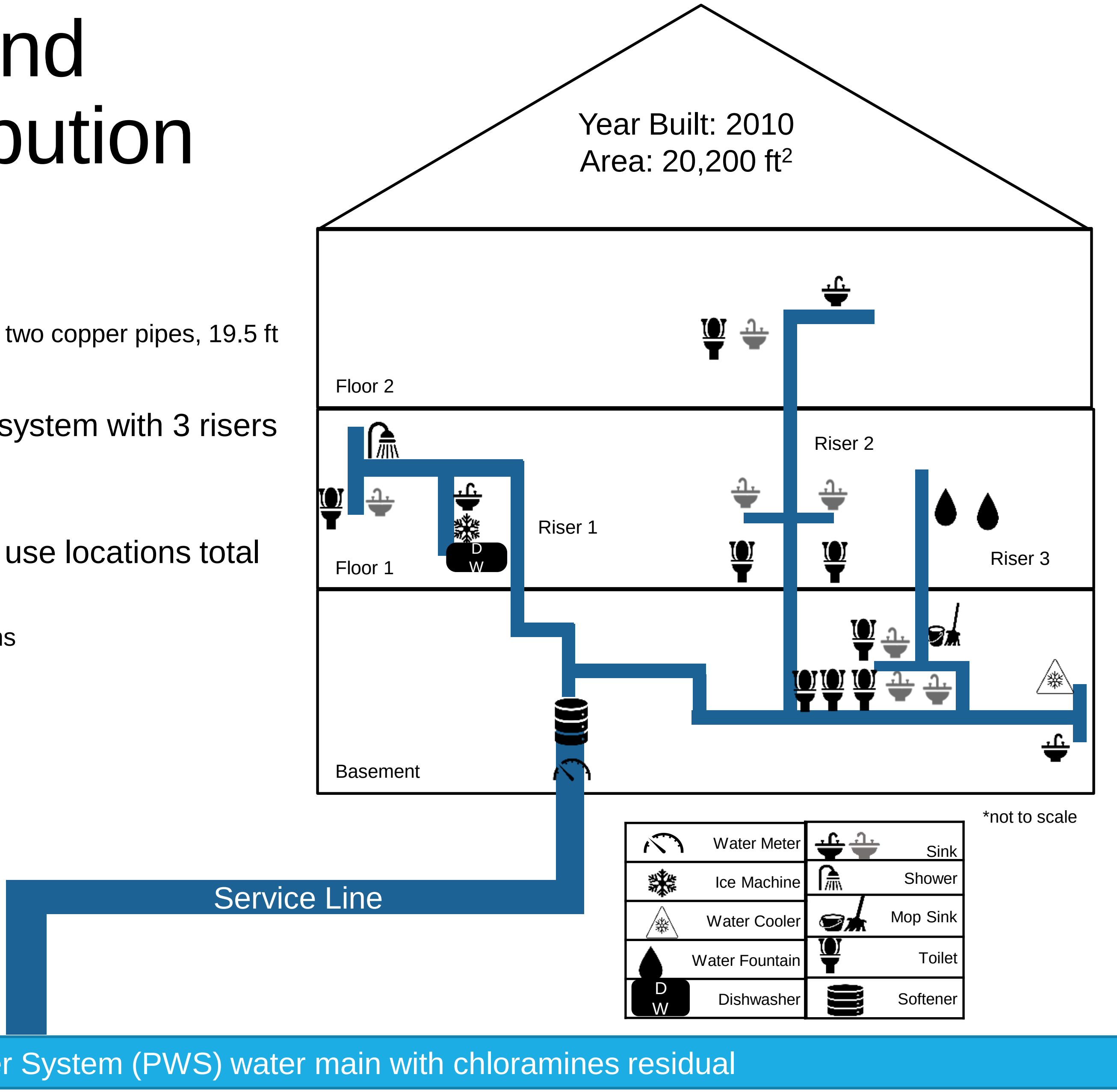
pH
Temperature
Total chlorine

Lab Analysis

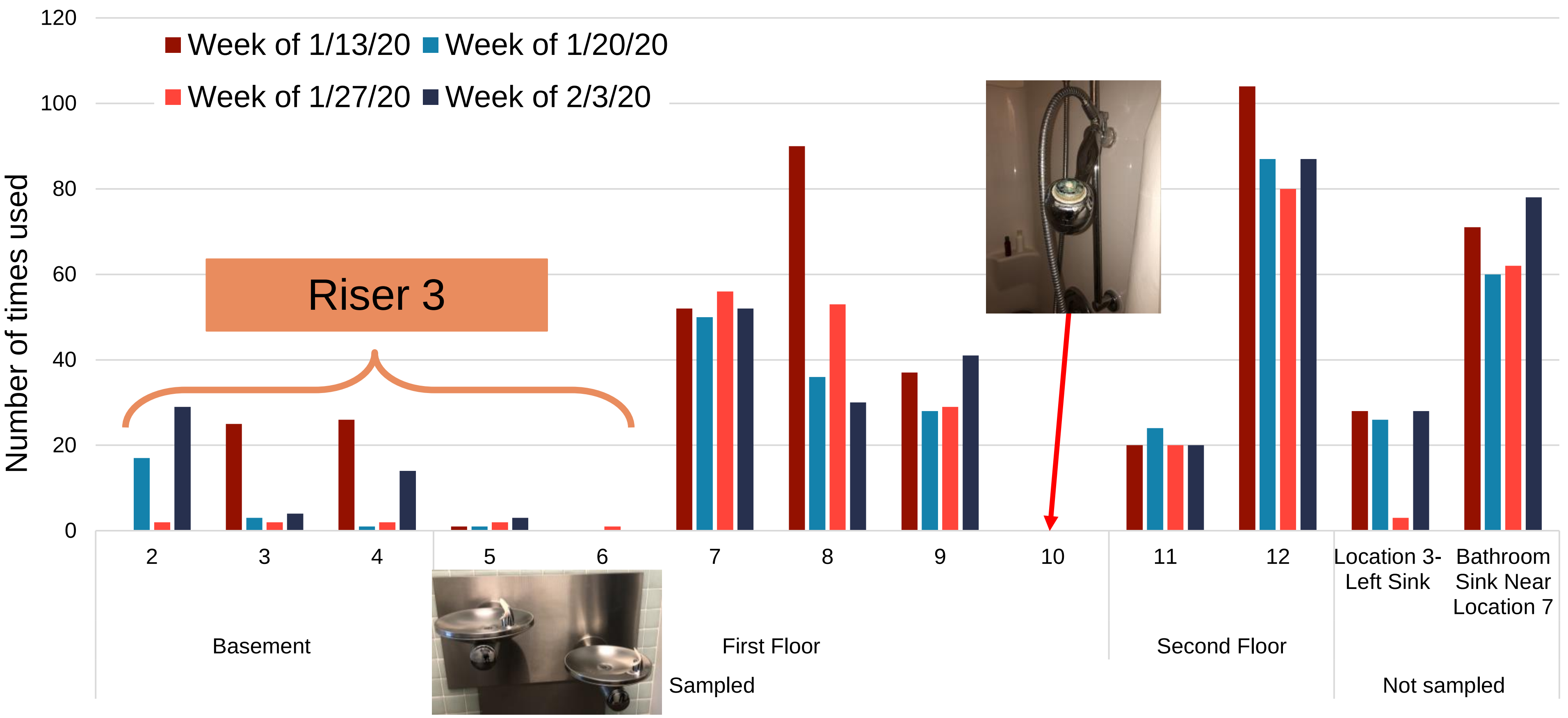
Alkalinity
ICP-OES
Ion chromatography (IC)
Flow cytometry for TCC
Organic carbon: TOC and DOC
qPCR at Tulane

Service Line and Building Distribution

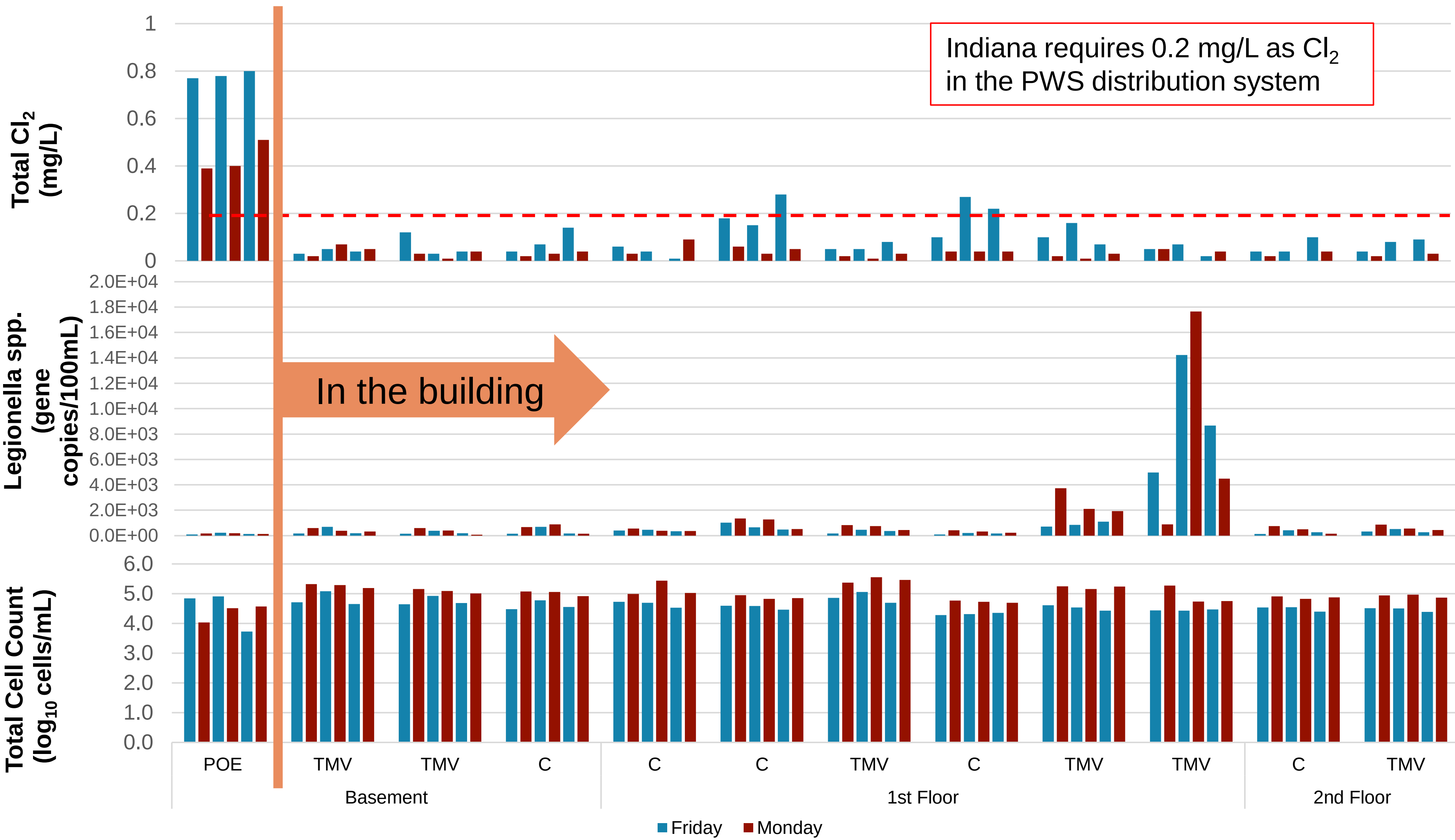
- Service line: 31.5 G (118.5 L)
  - 3 pipe segments: 25 ft galvanized pipe + two copper pipes, 19.5 ft and 72.5 ft
- A 3- story copper pipe distribution system with 3 risers
- Water softener: 16 G (59.7 L)
- 1 Point of Entry (POE) + 17 Water use locations total
  - 11 sample locations + 1 sample at POE
  - 5 potable cold (C) water sample locations
  - 6 thermal mixing valve (TMV) fixtures
- Appliances
  - On demand water heaters
  - Dishwasher, ice machine, refrigerator
  - Water cooler



Results: Fixture use



Disinfectant levels were always lower on Monday; bacteria levels always higher



Copper consistently exceeded the health-based 1.3 mg/L limit at select locations

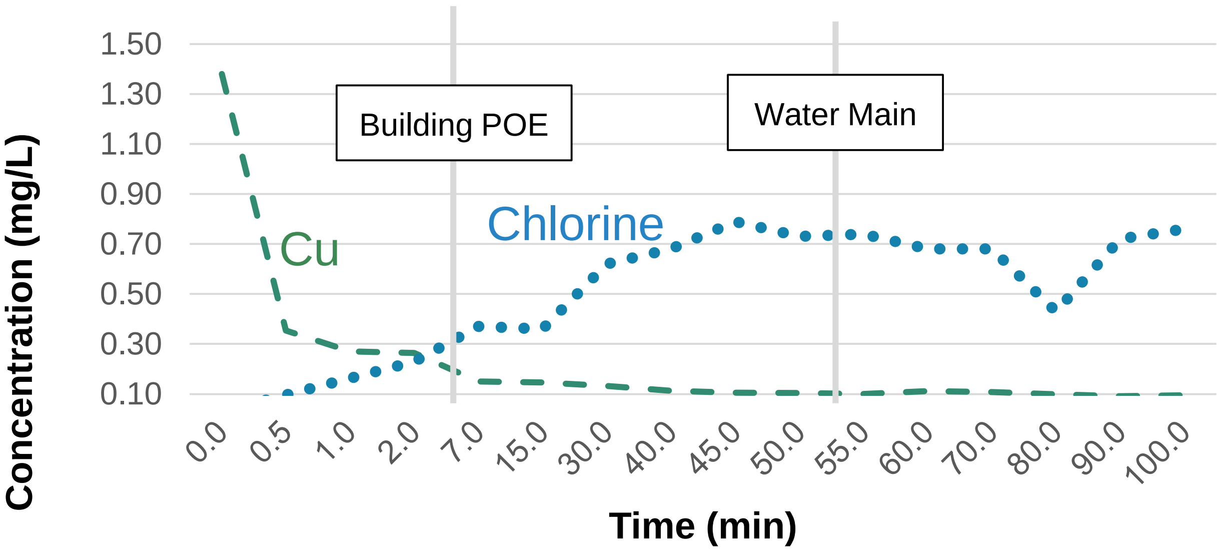
Location Description		Cu, mg/L		Pb, µg/L	
		Friday	Monday	Friday	Monday
POE	1	0.05 - 0.96	0.19 - 0.29	2.4 - 4.4	3.1 - 4.1
Basement	2	0.87 - 1.5	1.1 - 1.4	3.6 - 6.8	4.1 - 5.0
	3	0.80 - 1.6	1.1 - 1.3	3.8 - 5.8	3.4 - 5.0
	4	0.74 - 1.9	1.4 - 1.7	3.1 - 5.4	3.1 - 4.5
First Floor	5	0.39 - 0.87	0.68 - 0.78	2.5 - 4.2	3.2 - 4.9
	6	0.49 - 0.69	1.3 - 1.4	2.3 - 5.2	3.4 - 4.0
	7	0.37 - 0.96	0.86 - 1.0	2.7 - 5.5	4.6 - 5.6
	8	0.26 - 0.49	0.38 - 0.47	3.6 - 5.4	2.8 - 3.0
	9	0.43 - 0.47	0.41 - 0.44	4.5 - 6.7	4.0 - 4.6
	10	0.33 - 0.55	0.43 - 0.49	3.7 - 7.6	3.2 - 4.3
Second Floor	11	0.53 - 0.93	0.74 - 0.92	3.3 - 4.3	3.4 - 3.9
	12	0.04 - 0.87	0.68 - 0.77	1.8 - 4.2	3.7 - 3.8

Exceedances found every week at Riser 3

Overall, greater amounts of Cu and Pb were found on Monday morning ($p<0.05$)

Pb always >1

Flushing reduced copper levels and increased disinfectant levels, BUT rebounded quickly

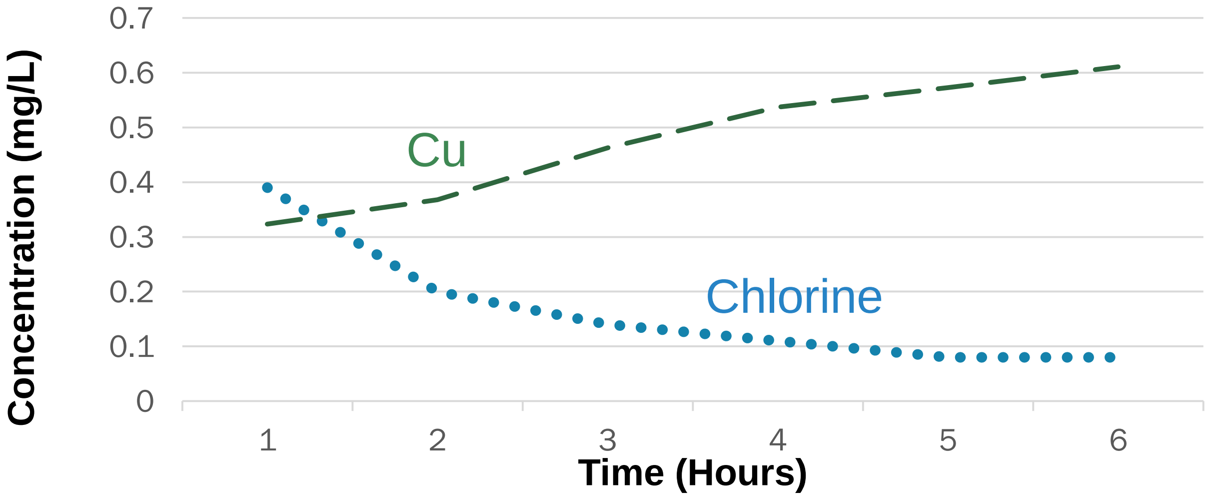


Location 4-
Basement Kitchen (Riser 3)

Flushing Time:

9 min. to reach the point-of-entry (POE), Q = 2.18 L/min

54 min. to reach the water main



Copper rebounded at
0.06 mg/L-hr
Time for copper to exceed 1.3 mg/L:
initial conc. 0.09 mg/L… 19 hours

Chlorine decayed at
0.31 mg/L-hr
Time for chlorine to be <0.2 mg/L:
initial conc. 0.4 mg/L… 1 hour
Time for chlorine to be <0.01 mg/L:
initial conc. 0.4 mg/L… 31 hours

Discussion and Recommendations

PWS water met federal and state drinking water standards

10 years after the green building was placed into service, Cu problems were consistently found at 1 of 3 risers due to weekend stagnation

Monday AM had higher TCC, Cu, and Pb levels compared to Friday PM

Cu levels rebounded quickly after fixture flushing. Est. within 21 hours, >1.3 mg/L

Total Cl_2 residual decays to below state regulated levels (0.2 mg/L) within Est. 1 hour

Recommendations

As part of a new building's certificate of occupancy attainment….

Water safety testing for copper, lead, and chlorine should be required to identify conditions where unsafe water may exist in buildings. Weekend stagnation is recommended before sampling.

A plumbing flushing plan and as-built plumbing drawing should be present. This can help the health department, building officials, and building owners understand how the system is designed and may operate.

Thank you.

Elizabeth Montagnino
Purdue University
Lyles School of Civil Engineering

Contact:
emontagn@purdue.edu

Contributions by

Graduate Students
Kyungyeon Ra
Yoorae Noh
Tolulope Odimayomi
Christian Ley
Sruthi Dasika

Undergraduate Research Assistants
Ethan Edwards
Danielle Angert
Conner Poort
Garrett Bryak
Yifei Bi

Caitlin Proctor, Ph.D.
Andrew Whelton, Ph.D.
Tiong Gim Aw, Ph.D. (Tulane University)

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Water microbiology of a school building during Summer and Fall seasons

Tiong Aw, PhD
Assistant Professor
Department of Environmental Health Sciences
School of Public Health and Tropical Medicine
Tulane University
taw@tulane.edu

Kathryn Jordan, Laura Scott (Tulane University), Kyungyeon Ra, Christian Ley (Purdue University), Rebecca Ives, Matthew Flood (MSU)

Study objectives

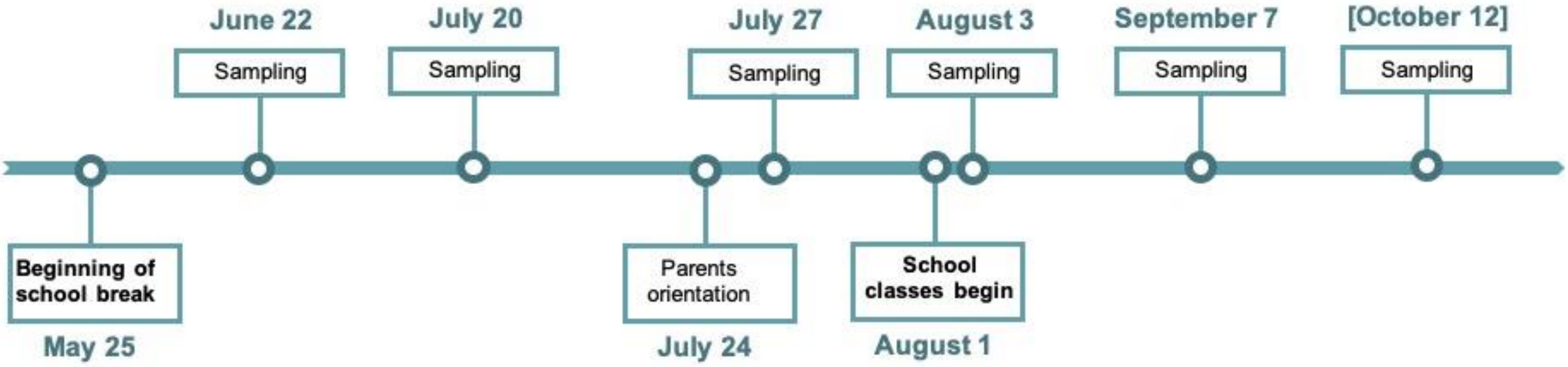
- This study was conducted to better understand microbial water quality changes in a LEED-certified school building (Green building) during low water use (Summer) and normal water use (Autumn).

Objectives:

- Determine chemical and microbiological water quality at 20 cold and hot water locations in a building;
- Examine occurrence and density of four opportunistic pathogens (*Legionella*, *Mycobacterium*, *Naegleria fowleri*, *Acanthamoeba*) in plumbing of a green school building; and
- Determine if water quality differed between low water use and normal water use conditions.

Field Study: LEED Middle School

- LEED middle school receives chloraminated water from a public water system; Copper plumbing, water softener, hot water recirculation system.
- School water source: blending waters that originate from two different treatment plants (on average, 75% of groundwater source and 25% of surface water source)
- Water samples were collected from 20 different locations. Water sampling schedule:



11,12. **B2C, B2H**: E207J [H119] P-6 Farthest bathroom sink to utility room (cold and hot)

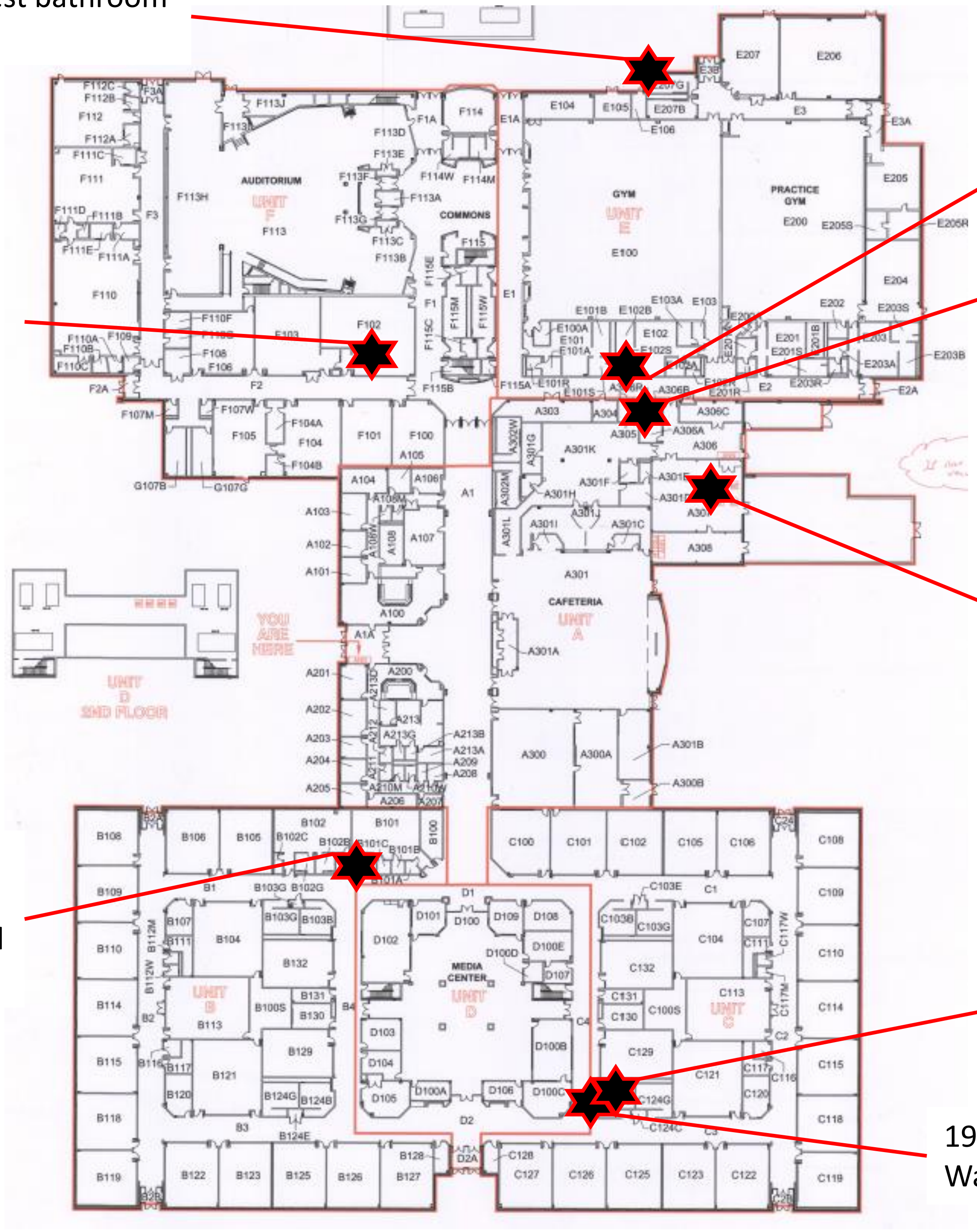
13,14. **SKC, SKH**: F102 [G102] Students' kitchen (cold and hot)

Most used Bldg portion

Least used Bldg portion

15,16. **TKC, TKH**: B102A [D110] P-10 Teachers' Kitchen sink (cold and hot)

NOT SHOWN
21,22. Trip Blank, Field Blank



9,10. **SH1, SH2**: P-14, P-13 disabled, combined stand Showers (cold)

7,8. **B1C, B1H**: A306R [L123] Closest bathroom sink to utility room (cold and hot)

UTILITY ROOM

1. **SL**: Service line (cold)
2. **AS**: After softener (cold)
3. **BWH**: Before water heater (warm?)

4,5. **HWRa, HWRb**: Hot Water Recirculation (120, 140)

6. **AWH**: After water heater (hot)

17,18. **B3C, B3H**: C124B [A132] P-6 bathroom sink (cold and hot)

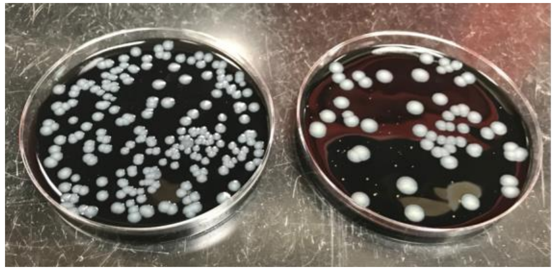
19,20. **WF1, WF2**: C124B [A132] P-11, P-12 Water Fountains higher, lower (cold)

Methods for the pathogen detection

1 liter of tap water was collected (first-draw)

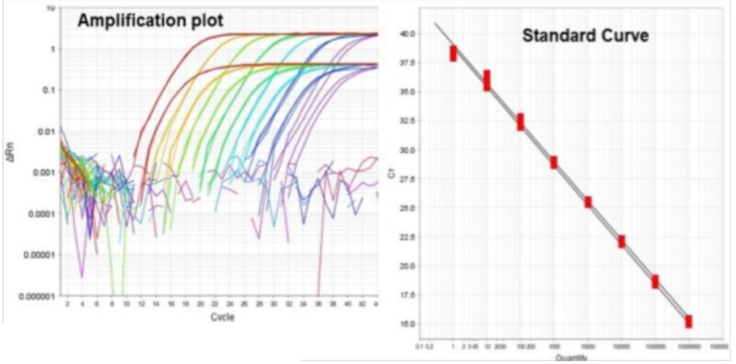
Membrane filtration

Culture (ISO 11731-2. Water quality – Detection and enumeration of *Legionella* – Part 2: Direct membrane filtration method for waters with low bacterial counts)



Quantitative PCR –

- *Legionella* spp. (23S rRNA)
- *Legionella pneumophila* (*mip* gene)
- *Mycobacterium* spp. (the internal transcribed spacer sequence)
- *Mycobacterium avium* (16S rRNA)
- *Naegleria fowleri*
- *Acanthamoeba* spp.



Water quality measurement of first draw samples

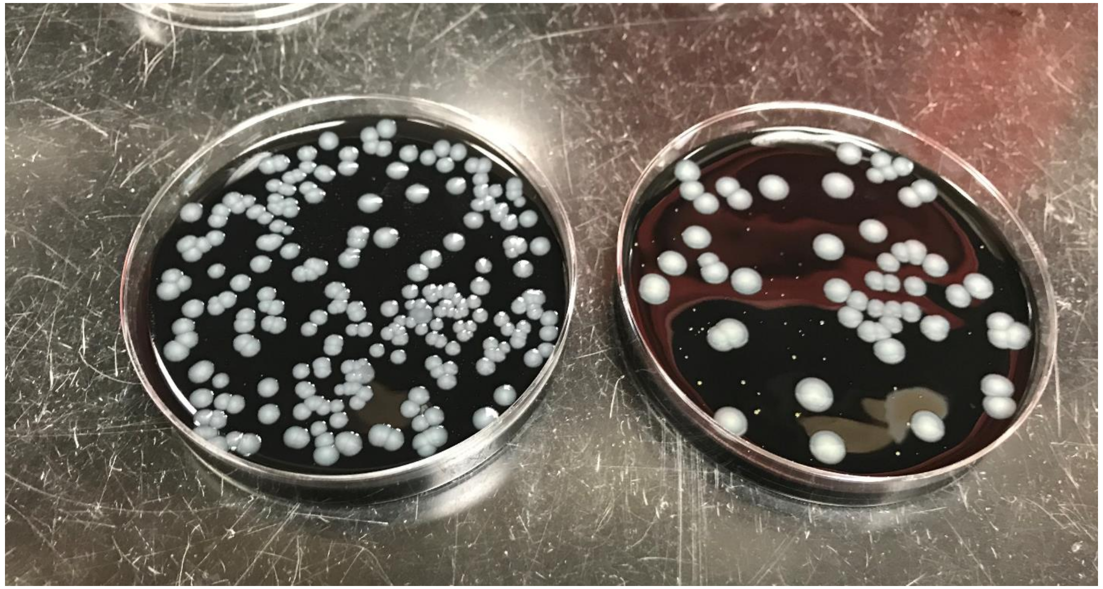
Parameter		Summer									Fall								
		After meter (n = 3)			Cold lines (n = 27)			Hot lines (n = 27)			After meter (n = 3)			Cold lines (n = 27)			Hot lines (n = 27)		
		Min	$\bar{x}$	Max	Min	$\bar{x}$	Max	Min	$\bar{x}$	Max	Min	$\bar{x}$	Max	Min	$\bar{x}$	Max	Min	$\bar{x}$	Max
General	Temp, °C	25.2	26.1	27.3	15.8	21.9	26.4	21.5	29.3	47.3	20.4	24.2	27.1	14.5	21.8	30.2	19.7	29.8	46.3
	pH	7.6	7.8	7.9	7.2	7.8	8.5	7.7	8	8.2	7.7	7.8	7.9	7.6	7.9	8.2	7.7	8	8.2
	DO, mg L^{-1}	8.9	9	9.1	2.6	6.9	10.2	3.1	5.6	8.9	7.4	8.4	9.2	4.4	7.4	9.2	3.2	6.6	9
	Total Cl_2, mg L^{-1}	0.1	0.2	0.2	0	0.1	1.4	0	0.1	1	0	0.2	0.2	0	0.03	0.3	0.01	0.03	0.13
	NH_2Cl, mg L^{-1}	0.1	0.2	0.3	0	0.08	0.5	0	0.04	0.1	0.07	0.5	0.94	0	0.07	0.41	0	0.1	0.7
	Free NH_3, mg L^{-1}	0	0.2	0.48	0	0.1	0.41	0.01	0.2	0.84	0	0.06	0.13	0	0.08	0.21	0.01	0.06	0.16
Organics	TOC, mg L^{-1}	1.7	1.9	2	1.5	2.2	6.7	2.9	3.4	3.8	1.8	2	2.2	1.5	1.9	2.3	1.6	2.3	3.4
	DOC, mg L^{-1}	1.7	1.9	2	1	2.1	6.5	2.6	3.3	3.6	1.8	2	2.1	1.4	1.9	2.2	1.7	2.2	3.3
Microbiology	HPC, CFU/100 mL	11	148	400	13	12 614	214 000	0	1284	12 667	18	114	245	0.667	7489	117 670	0	720 894	19 430 000
	TCC, cell per mL × 10^4	3.02	20.9	35.6	4.79	23.8	62.8	54.8	81.6	116.1	5.89	80.5	43.4	6.86	19.9	32.8	15.4	34.2	79.8
Nitrogen	NH_4–N, mg L^{-1}	0.4	0.7	1.3	0.1	0.3	0.5	0.1	0.1	0.2	0.4	0.6	0.8	0.1	0.4	3.2	0.0	0.1	0.2
	NO_2–N, mg L^{-1}	—	—	—	—	—	—	0.0	0.1	0.3	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
	NO_3–N, mg L^{-1}	0.8	1.5	2.8	0.8	1.9	3.0	0.9	1.3	1.7	1.2	1.4	1.5	1.0	1.5	2.6	1.0	1.3	2.2
Metal	Cu, µg L^{-1}	347	415	503	55	1356	2440	196	689	1320	57	68	81	0	980	2290	0	693	1320
	Pb, µg L^{-1}	0	0	0	18.5	2.2	40.9	0	0	0	0	0	0	0	1.3	35.1	0	0	0

x = mean; lead was only detected in shower cold water, also detected for second draw (7.79 µg L^{-1}) but not for third draw on the last sampling event.

Ra K., Odimayomi T., Ley C.J., Aw T.G., Rose J.B., Whelton A.J. Finding building water quality challenges in a 7-year old LEED school: implications for building design, sampling and remediation. Environmental Science: Water Research and Technology. 6: 2691-2703.
https://doi.org/10.1039/D0EW00520G

The detection of *Legionella* using cell culture

- Water samples collected on July 20 and Oct 12 were also analyzed for *Legionella* using culture-based method.
- **July 20** - Colonies of *Legionella* species, as confirmed by qPCR, were recovered from **5 of 20** water samples **(25%)**. The *Legionella pneumophila* specific test for these colonies showed negative. This means that other cultivable *Legionella* species were present in the water systems.
- All isolates were identified as most closely related to *Legionella donaldsonii*.
- **Oct 12** – Cultivable Legionella were not detected in water samples.



The detection of *Legionella* species in water samples using cell culture. Left, water sample AS (After softener); right, water sample HWRa (Hot water recirculation).

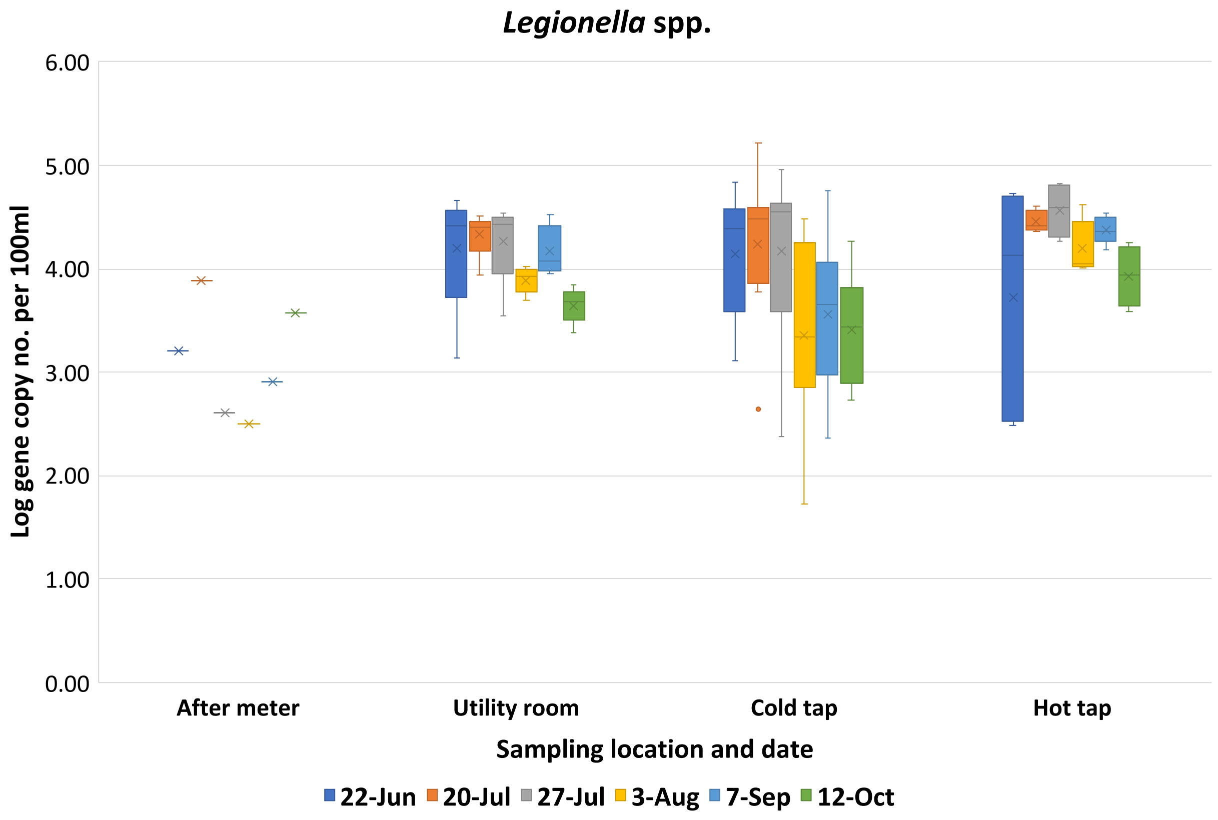
Concentration of *Legionella* species by cell culture (Sampling: July 20)

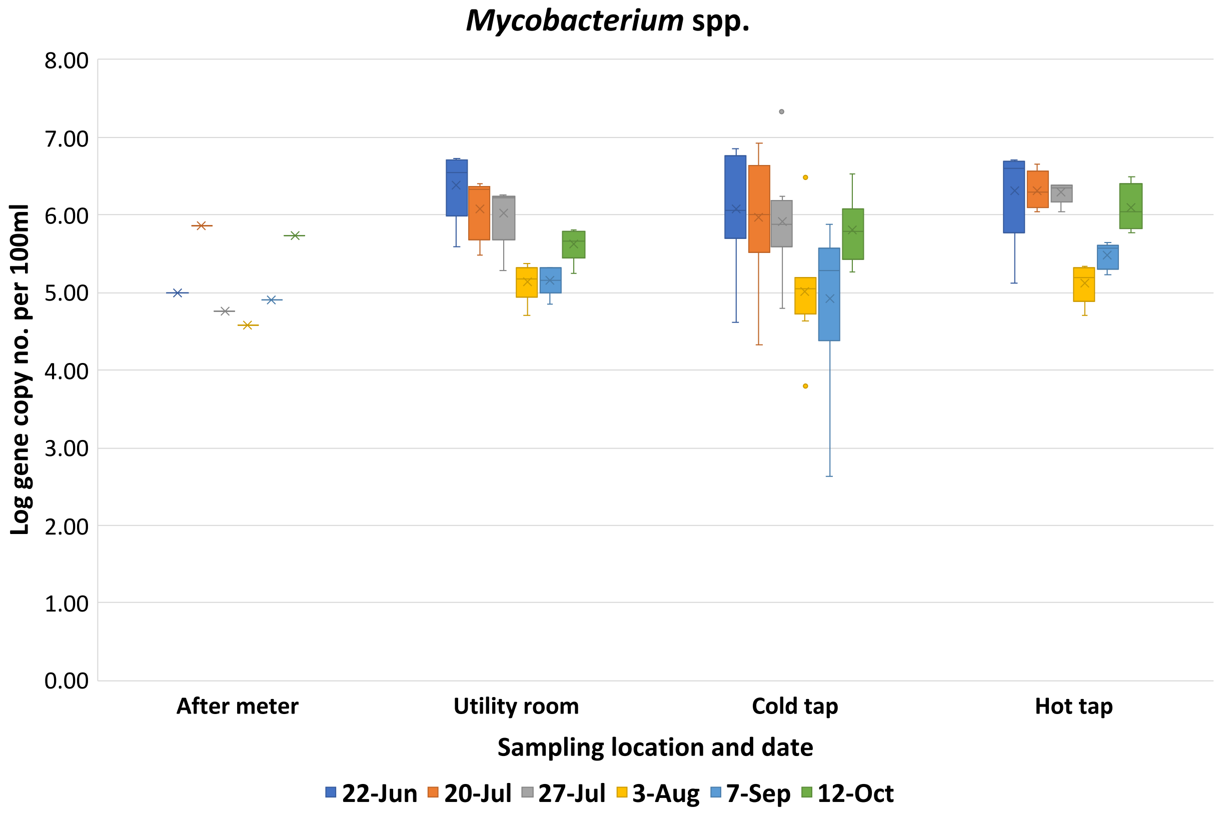
Sampling site	Site ID	*Legionella* species concentration by culture (CFU/100ml)
After softener	AS	5,720
Before water heater	BWH	4,810
Hot water recirculation	HWRa	970
Bathroom hot water	B1H	1,040
		Legionella species concentration by culture (CFU/swab)
Bathroom shower	SH2 (swab)	7

Opportunistic pathogen survey of school water systems using qPCR

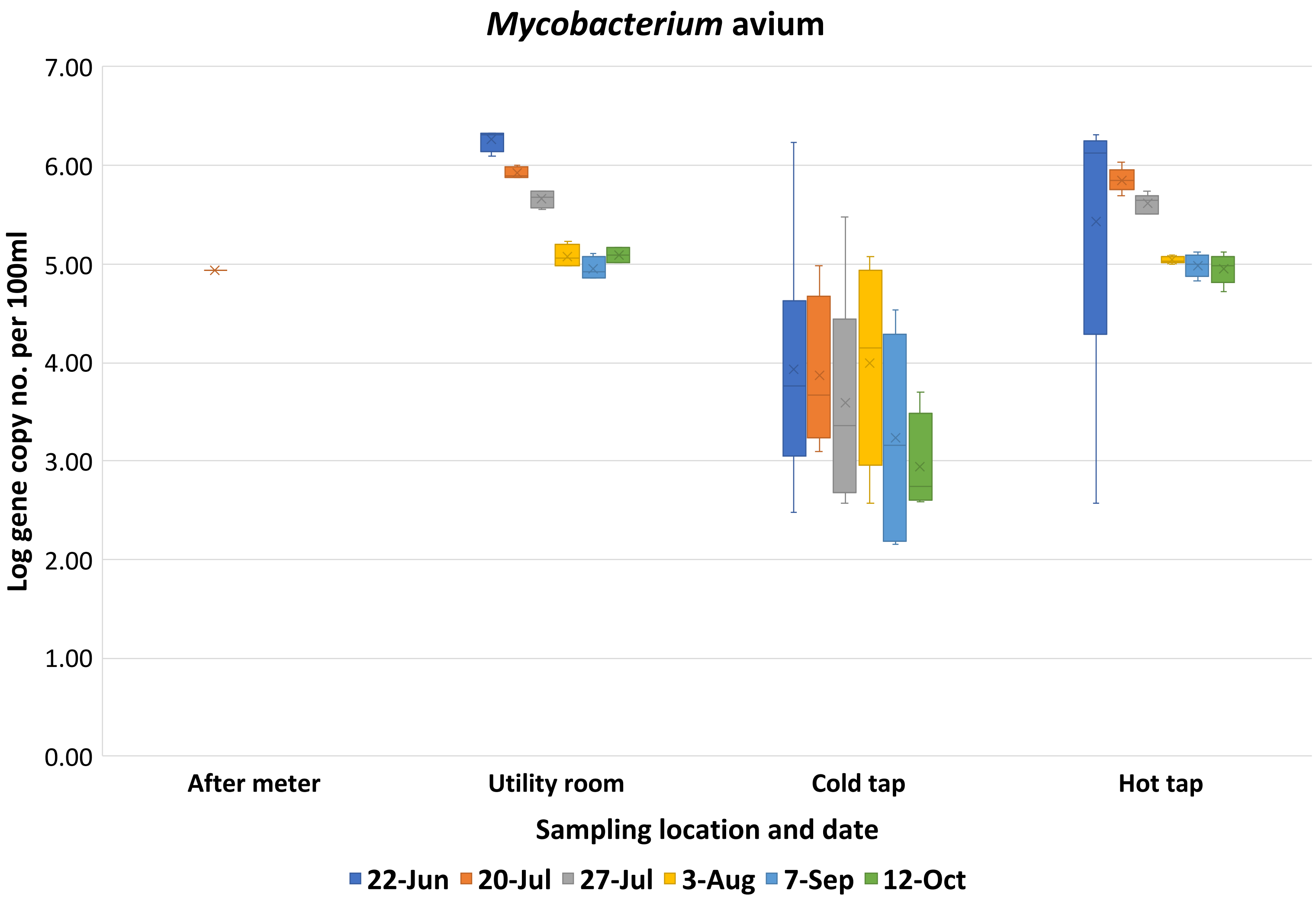
Target organism	Occurrence rate (%)		Concentration (gene copy no. per 100ml)	
	Sites (n = 20)	Water samples (n = 120)	Highest	Average for positive samples
Legionella spp.	100	100	1.7×10^5	9.0×10^3
Legionella pneumophila	0	0	N/A	N/A
Mycobacterium spp.	100	100	2.2×10^7	5.0×10^5
Mycobacterium avium	95	75	2.1×10^6	4.9×10^4
Naegleria fowleri	0	0	N/A	N/A
Acanthamoeba spp.	70	17.5	6.0×10^5	6.3×10^2

Spatial and temporal distribution of *Legionella* spp., *Mycobacterium* spp. in plumbing of a green school building as determined by qPCR

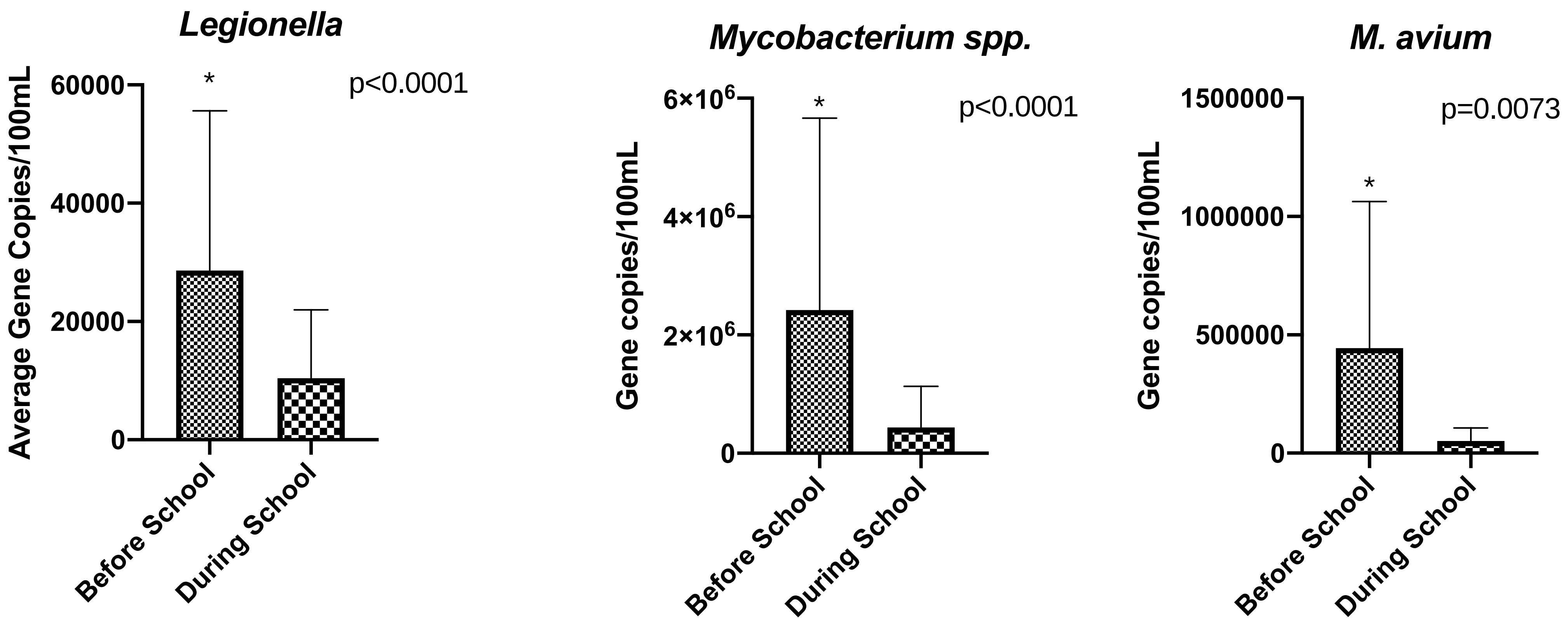




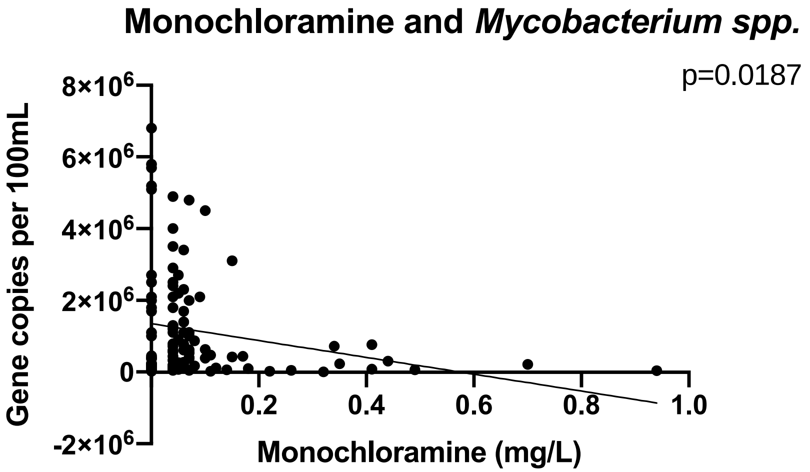
Spatial and temporal distribution of *Mycobacterium avium* in plumbing of a green school building as determined by qPCR

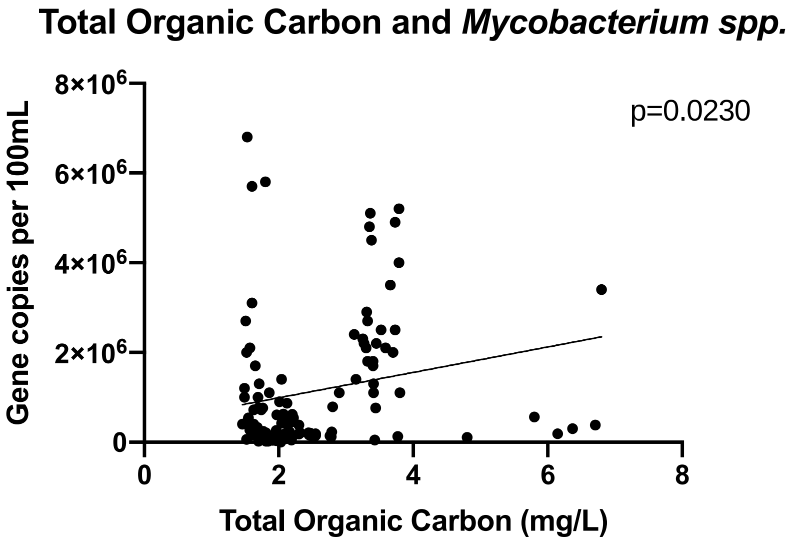


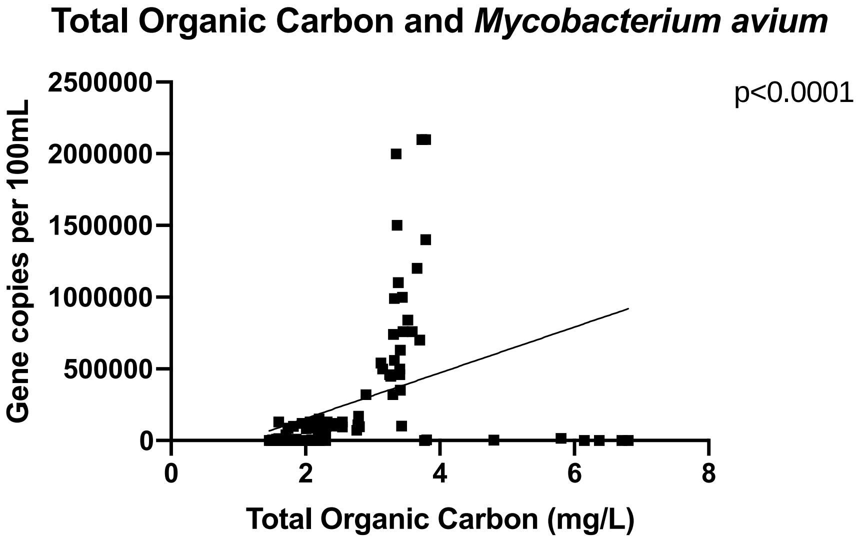
Comparison of average concentrations of pathogen genetic markers in water systems under low vs. normal water use conditions

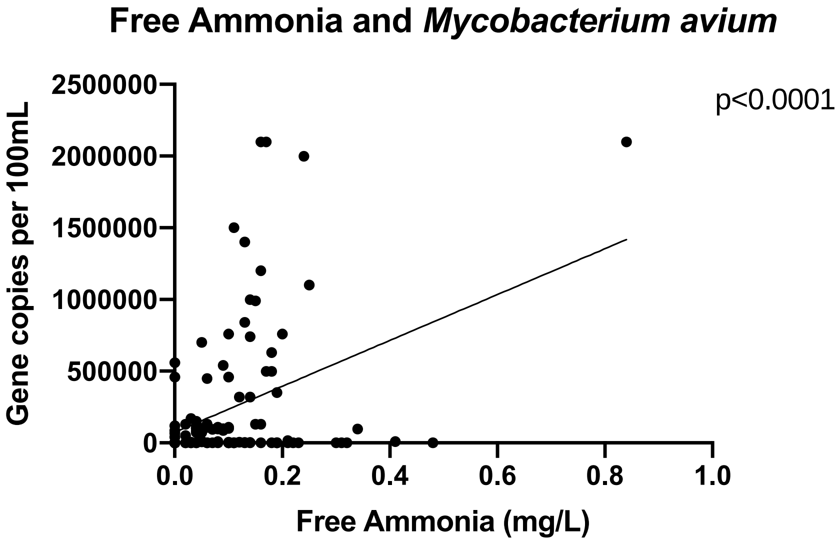


Significant association between physiochemical properties and opportunistic pathogen genetic markers









Conclusions

- The presence of opportunistic pathogens in premise plumbing can be affected by the frequency of water use in a building.
- The rapid rate of disinfectant loss in green buildings due to high water stagnation needs to be better understood and addressed.
- This study demonstrates the importance of considering potential public health impacts in the design of sustainable water systems in green buildings.

Occurrence of Pathogenic *Legionella* and Amoebae spp. from Source (Groundwater) to Exposure Sites (Taps And Cooling Towers) In a Complex Water System

Alshae' Logan-Jackson
Advisor: Joan B. Rose
Departments of Microbiology and Molecular Genetics; Fisheries and Wildlife
Michigan State University
November 12th, 2020

The Research Project Has 3 Main Objectives

- Objective 1: Examine pathogenic *Legionella* species in different types of buildings in two different seasons

- Objective 2: Examine pathogenic *Legionella* species on MSU campus groundwater source to distributed water to cooling towers, a wholistic view of the water system

- Objective 3: Examine the co-occurrence between *Naegleria fowleri, Acanthamoeba* spp. and *Legionella* spp.

Sampling Sites and Dates for Objective 1

F August 13th, 2018
and January 15th, 2019

BPS: August 13th, 2018
and January 7th, 2019

M August 13th , 2018
and January 8th,2019

Sampling Sites and Dates for Objective 1

FH: September 4^{th}, 2018
and January 14^{th}, 2019

ERC: August 27^{th}, 2018
and January 9^{th}, 2019

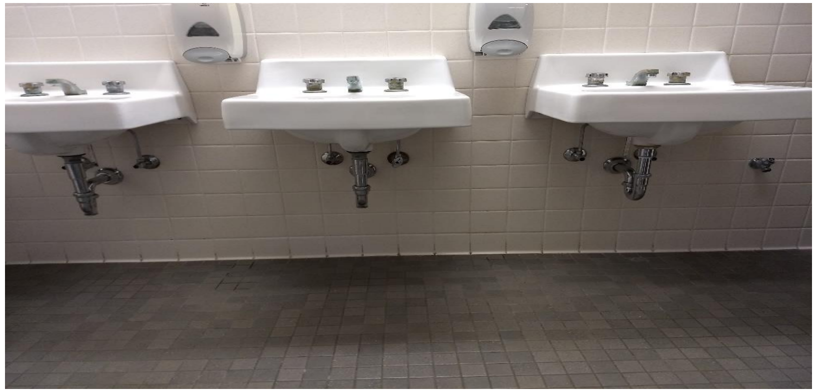
Sampling sites and Dates for Objectives 2 & 3: Variability from Source to Tap, and Cooling Towers

Reservoir
Influent: N= 6
Effluent: N= 6

July 15th, 23, & 29th
and August 6th , 13th, & 20th

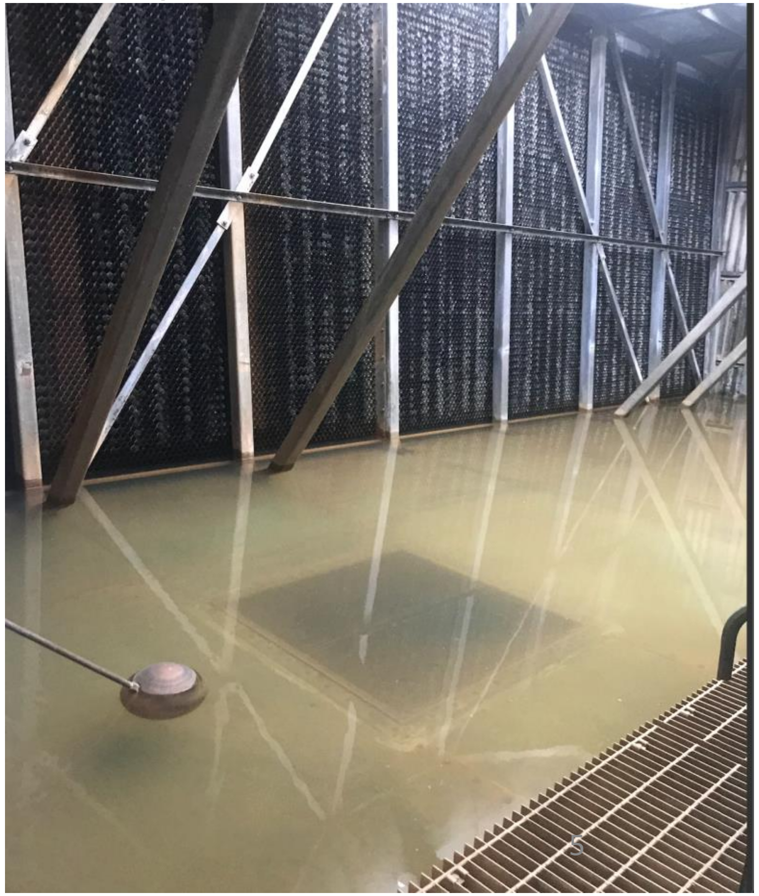
F: N= 15
ERC: N= 9

August 12th & 19th
and September 3rd, 9th, 16th and 23rd



Cooling tower: N = 6

July 25th & 31st
and August 7th, 14th & 21st



Monitoring: Water Diagnostics using Droplet Digital Polymerase Chain Reaction (ddPCR)

Bacteria species

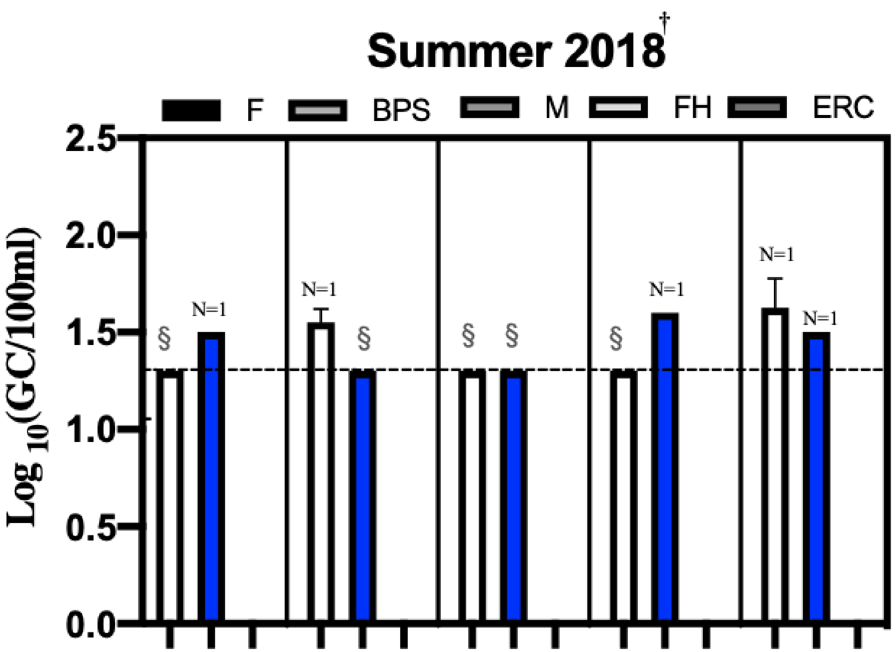
Target Species	Primer/Probe name	Primer/Probe Sequence	Reference
Legionella species	23SF 23SR 23SP probe	5'-CCCATGAAGCCCGTTGAA-3' 5'-ACAATCAGCCAATTAGTACGAGTTAGC-3' 5'-HEX-TCCACACCTCGCCTATCAACGTCGTAGT-BHQ1-3'	Nazarian et al., 2008
L. pneumophila (*mip* gene)	mipF mipR LmipP	5'-AAAGGCATGCAAGACGCTATG-3' 5'- GAAACTTGTTAAGAACGTCTTTCATTTG-3' 5'-FAM- TGGCGCTCAATTGGCTTTAACCGA-BHQ1-3'	
L. micdadei *L. anisa* *L. bozemanii* *L. longbeachae*	Pan-*Legionella* F Pan-*Legionella* R LmicdadeiP LanisaP LbozemaniiP LlongbeachaeP	5'- GTACTAATTGGCTGATTGTCTTG-3' 5'- TTCACTTCTGAGTTCGAGATGG-3' 5'-FAM- AGCTGATTGGTTAATAGCCCAATCGG-BHQ1-3' 5'-HEX-CTCAACCTACGCAGAACTACTTGAGG-BHQ1-3' 5'-FAM-TACGCCCATTCATCATGCAAACCAGnT-BHQ1-3' 5'-HEX-CTGAGTATCATGCCAATAATGCGCGC-BHQ1-3'	Cross et al., 2016
Acanthamoeba spp.	18S rRNAF 18S rRNAR 18S rRNAP	5'-CGACCAGCGATTAGGAGACG-3' 5'-CCGACGCCAAGGACGAC-3' 5'-FAM-TGAATACAAAACACCACCATCGGCGC-BHQ1-3'	Riviere et al., 2006;
Naegleri fowleri	ITSF ITSR ITSP	5'-GTGAAAACCTTTTTTCCATTTACA-3' 5'-AAATAAAAGATTGACCATTTGAAA-3' 5′-HEX-GTG GCC CAC GAC AGC TTT-BHQ1-3′	Pélandakis et al., 2000

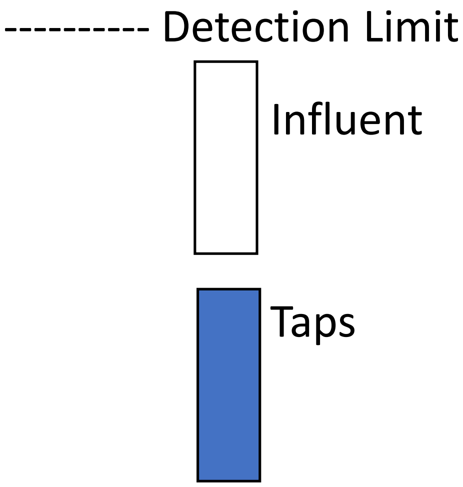
Amoebae species

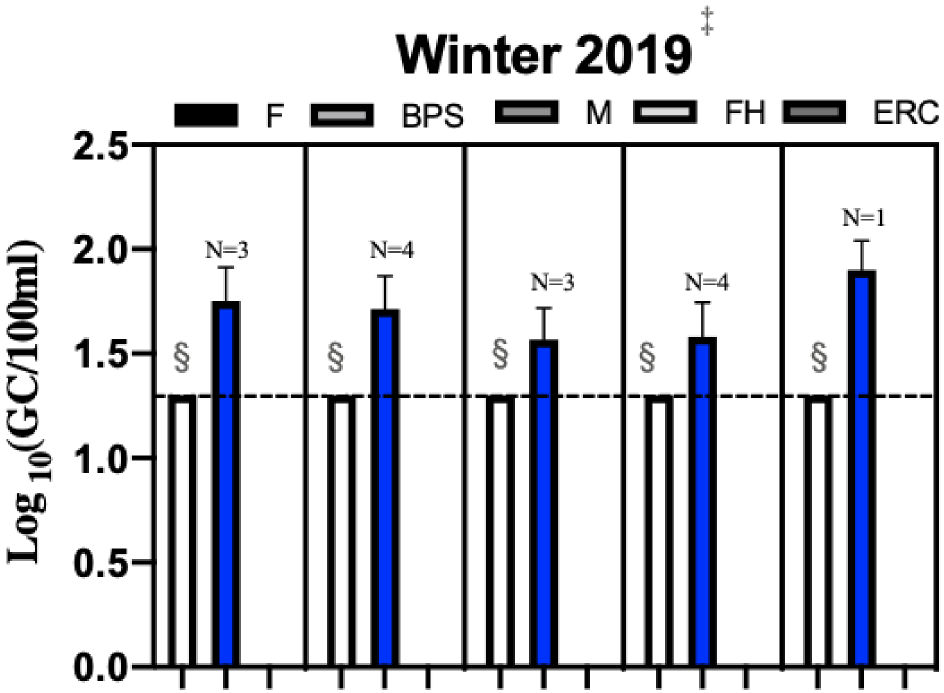
Source: BioRAD

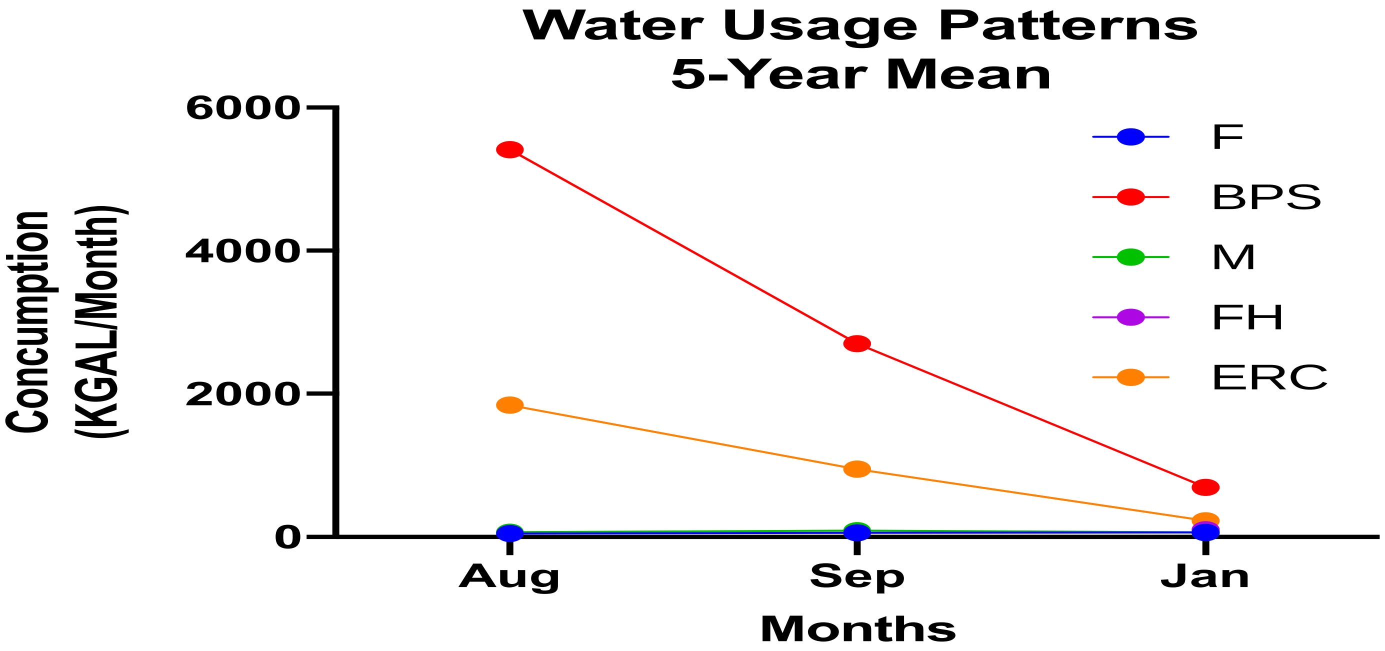
Legionella spp.

- Total samples collected: 37
- *Legionella* species (23S rRNA) in all water samples was 100% positive
  - 2 out of 5 buildings potentially amplified at the points of use
    - 1.8 to 3.5 Log_{10} GC/100 mL on influent vs points of use (Winter 2019)





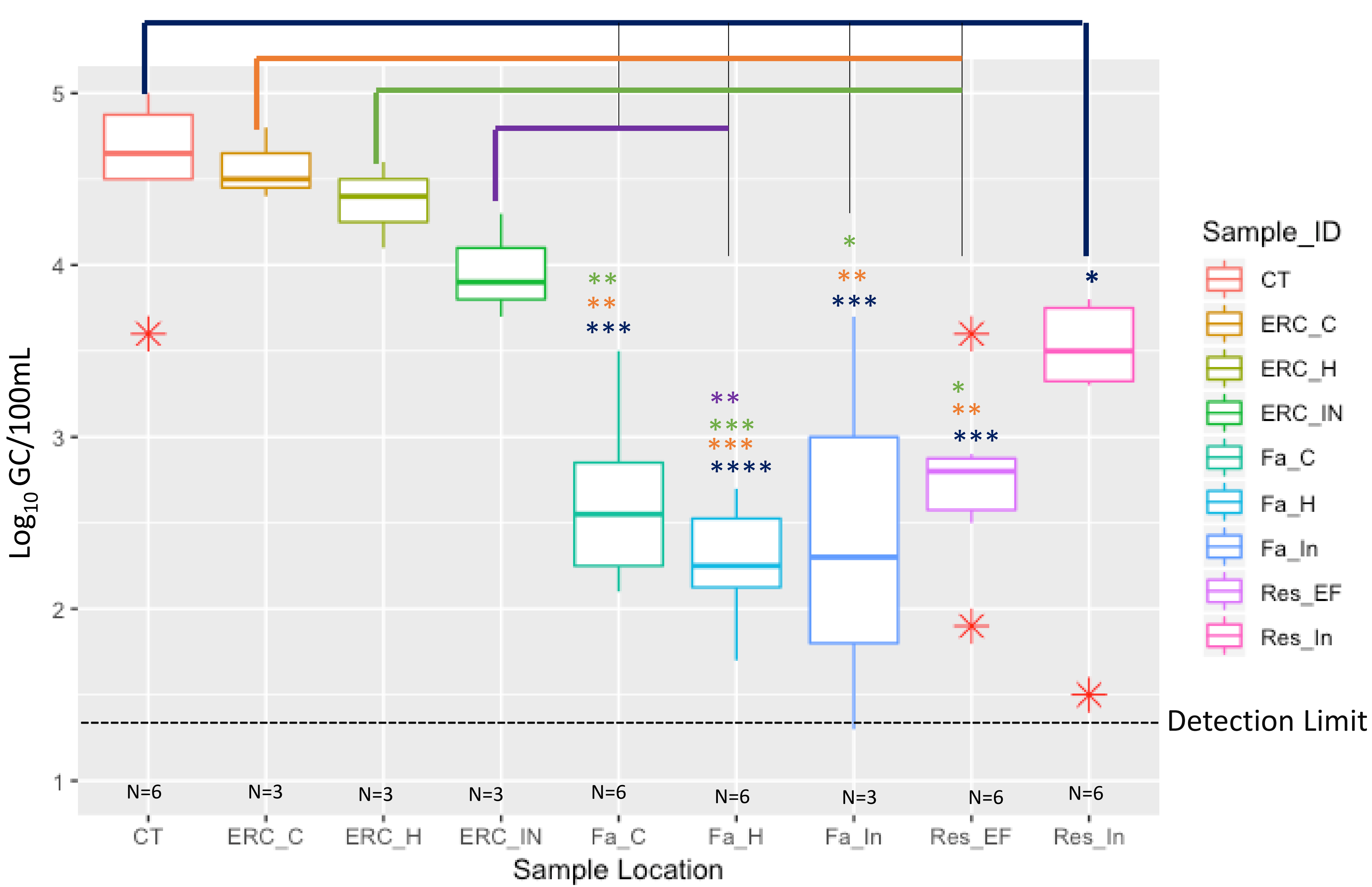




Presence of pathogenic *Legionella* species at the taps & water usage patterns

*Water usage for FH was only available for January

Legionella species (23S rRNA) in the Cooling Towers, Buildings (ERC & F), and the Reservoir (In. & Ef.)



One-Way ANOVA

CT vs Res_In, Res_EF, Fa_In, Fa_H, Fa_C (p= 0.0156, 0.0003, 0.0006, <0.0001, 0.0001)

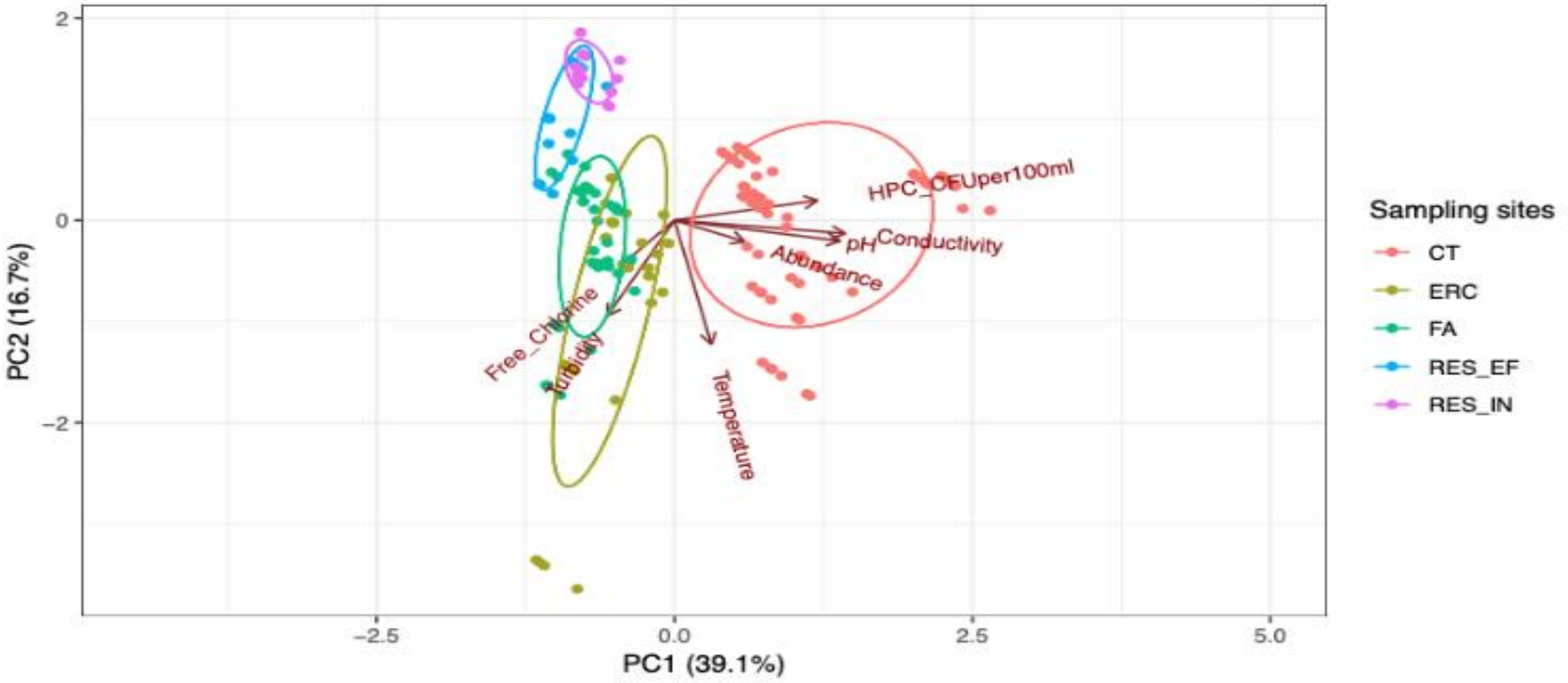
ERC_C vs Res_EF, Fa_In, Fa_H, Fa_C (p= 0.0043, 0.0036, 0.0002, 0.0020)

ERC_H vs Res_EF, Fa_In, Fa_H, Fa_C (p= 0.0152, 0.0107, 0.0007, 0.0074)

ERC_In vs Fa_H (p = 0.0091)

*** (Outliers)**

Principal Component Analysis biplot showing the clustering of the data according to the water sampling sites



[a]Abundance represents free-living amoebae and *Legionella* species

Legionella spp.

- Total samples collected: 42

- *Acanthamoeba* spp. (%+)
  - 8/42 (19%)

- *Naegleria fowleri* (%+)
  - 17/42 (40%)

- *Naegleria fowleri* correlates with *L. micdadei,* and *L. bozemanii* (p= 0.002**, 0.002**) in the BWS

Conclusion

- *Legionella* spp. (23S) and pathogenic *Legionella* related to water usage patterns
- Water age may play a role on the occurrence and concentration of *Legionella* spp. (23S) in the distribution system, premise plumbing, and the cooling towers
- A separation was between water samples collected from the cooling towers (CT) and those collected from the drinking water system (Fa, ERC, and RES_IN, and RES_EF)
- *Legionella micdadei* and *L. bozemanii* were more often related to *Naegleria* than *Acanthamoeba* spp.

Discussion

- Large volume composite sampling was successful in the study of *Legionella* specific species in a complex water system.

- Should compare pathogenic *Legionella* species in the influent vs the points of use.

- More studies are needed to understand the microbial ecology and water chemistry that affects the amplification of *Legionella* and amoebae species.

Building Water Quality Relationships

Ryan Julien*, Jade Mitchell,
Pouyan Nejadhashemi, Babak Saravi, Ian Kropp

November 12, 2020

Introduction

- Water quality in premise plumbing is highly variable
- Goal: Reduce the number of input variables required to identify elevated Legionella risks

Data Utilized – Analytical Data

- Analytical results
  - 59 sampling events from 8/17/17 through 10/9/2018
  - Seven fixtures
  - 12 variables including pH, residual chlorine, HPC, and qPCR for Legionella

Variable Name	Variable Description	Units	Percentile 2.5%	Percentile 50.0%	Percentile 97.5%
pH	pH	NA	7.36	8.00	9.04
Temp	Temperature	C	15.63	22.90	26.30
DO	Dissolved oxygen	mg/L	4.30	8.40	10.56
Total.Cl	Total Chlorine	mg/L	BDL	0.10	1.00
Free.Cl	Free Chlorine	mg/L	BDL	0.01	0.75
TOC	Total Organic Carbon	mg/L	0.42	0.81	15.36
DOC	Dissolved Organic Carbon	mg/L	0.42	0.73	18.97
Alka	Alkalinity	mg/L as $CaCO_3$	264.15	287.25	332.65
TTHM	Total Trihalomethanes	mg/L	0.05	15.57	31.55
TCC	Total Cell Count	#cells/mL	1.54E+03	3.77E+04	1.56E+06
HPC	Heterotrophic Plate Count (by culture)	CFU/100mL	4.03E+00	1.01E+04	3.60E+07
Leg.sp	Legionella spp. (by qPCR)	# gene copies /100mL	2.29E+01	4.02E+03	1.78E+05

Data Utilized – Water Use Metrics

- Water use records (two-week span prior to sample collection)
  - Mean time since last event (meanTSL)
  - Maximum time since last event (maxTSL)
  - Number of events (num.events)
  - Event volume (vol.events)

Fixture Name	ID tag	Design Flowrate (LPM)	Total Volume Consumed (m^3)	Percent of Cumulative Total
Service Line	SL	NA	130.7	100%
Kitchen Sink - Cold	CKS	6.8	5.9	4%
Bathroom Sink - Cold	CBS	4.5	2.0	2%
Water Heater	WH	NA	40.6	31%
Kitchen Sink - Hot	HKS	6.8	5.2	4%
Bathroom Sink - Hot	HBS	4.5	16.2	12%
Bathroom Shower - Mixed	MBS	7.6	36.6	28%

Analyses Conducted

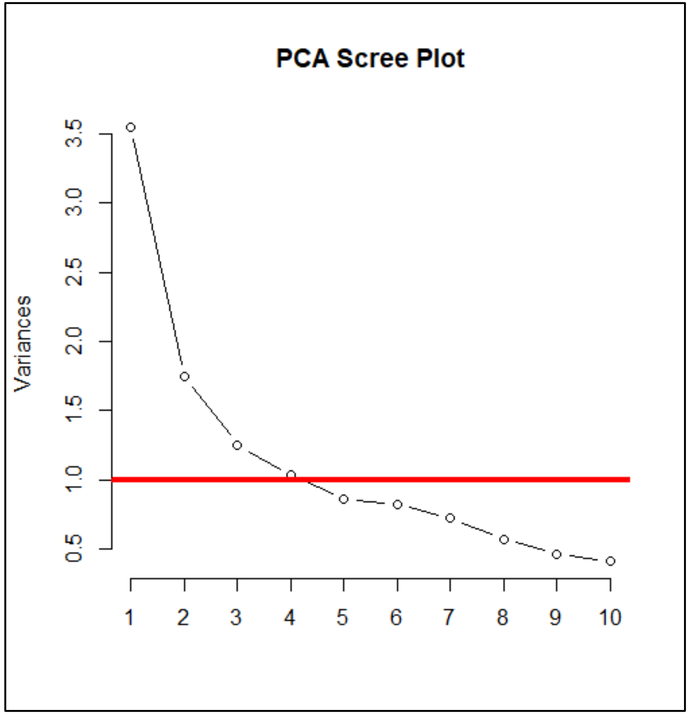
- Correlation Analysis
  - Spearman correlation coefficients (non-parametric)
- Principal Component Analysis (PCA)
- Generalized Linear Model (GLM)
  - Linear modeling to predict Legionella concentrations
  - Multiple iterations considered to account for missing observations
- Bayesian Variable Selection

Spearman Correlation Coefficients

	pH	Temp	DO	Total.Cl	Free.Cl	TOC	DOC	Alka	TTHM	TCC	HPC	Leg.sp	vol.events	num.events	meanTSL	maxTSL
pH	1.00															
Temp	0.09	1.00														
DO	-0.30	-0.40	1.00													
Total.Cl	-0.20	-0.51	0.27	1.00												
Free.Cl	-0.19	-0.41	0.22	0.79	1.00											
TOC	0.19	0.49	-0.42	-0.35	-0.25	1.00										
DOC	0.17	0.53	-0.45	-0.42	-0.27	0.97	1.00									
Alka	0.07	0.31	-0.14	-0.21	-0.12	0.36	0.36	1.00								
TTHM	0.24	0.20	-0.34	-0.29	-0.33	0.65	0.62	0.32	1.00							
TCC	-0.06	0.48	-0.23	-0.28	-0.14	0.53	0.56	0.56	0.26	1.00						
HPC	0.19	0.46	-0.35	-0.30	-0.16	0.61	0.60	0.50	0.37	0.70	1.00					
Leg.sp	0.15	0.35	0.08	-0.48	-0.32	0.53	0.52	0.54	0.33	0.54	0.62	1.00				
vol.events	-0.11	-0.27	0.34	0.19	0.15	-0.57	-0.57	-0.17	-0.47	-0.16	-0.24	-0.22	1.00			
num.events	-0.19	-0.29	0.38	0.16	0.04	-0.53	-0.53	-0.12	-0.31	-0.19	-0.40	-0.35	0.75	1.00		
meanTSL	0.18	0.34	-0.39	-0.21	-0.07	0.53	0.54	0.14	0.30	0.23	0.42	0.39	-0.74	-0.99	1.00	
maxTSL	0.14	0.47	-0.50	-0.26	-0.12	0.61	0.63	0.29	0.38	0.38	0.49	0.22	-0.72	-0.79	0.79	1.00

Principal Component Analysis

- Twelve variables
  - Free.Cl and DOC not considered due to strong correlations with other variables
- Principal Components
  - PC1 – Water age
    - 39% of variance
  - PC2 – Biofilm detachment
    - 14% of variance
  - PC3 – Biofilm development/age
    - 9 % of variance



Generalized Linear Model

- Preliminary GLM
  - Eliminated alkalinity, allowed more data to be considered
- GLM with all variables
  - All combinations of main-effects evaluated with AIC_C
- Two models evaluated
  - m.top <- top performing model
  - m.comp <- Uses all variables found in models with < 2.0 Δ AIC_C
  - Random effect included for sample location

- m.top
  - DO, HPC, maxTSL, meanTSL, num.events, pH, TCC, TOC, Total.Cl, and Location
- m.comp
  - DO, HPC, maxTSL, meanTSL, num.events, pH, TCC, TOC, Total.Cl, Location, and **TTHM**

GLM Results

Variable	m.top			m.comp		
	Estimate	Std. Error	Signif.	Estimate	Std. Error	Signif.
Intercept	-5.14E+00	1.46E+00	***	-5.34E+00	1.49E+00	***
DO	3.03E-01	4.99E-02	***	3.05E-01	5.00E-02	***
HPC	2.64E-01	5.39E-02	***	2.70E-01	5.44E-02	***
maxTSL	-1.21E-06	7.09E-07		-1.15E-06	7.13E-07	
meanTSL	6.76E-06	2.93E-06	*	6.66E-06	2.94E-06	*
num.events	3.37E-07	7.92E-05		7.02E-08	7.90E-05	
pH	3.34E-01	1.53E-01	*	3.47E-01	1.55E-01	*
TCC	3.26E-01	1.04E-01	***	3.18E-01	1.04E-01	***
TOC	7.17E-01	2.14E-01	***	6.52E-01	2.34E-01	**
Total.Cl	-3.12E-01	1.26E-01	*	-2.95E-01	1.28E-01	*
TTHM	NA			6.49E-03	9.53E-03	

Significance:
*** < 0.005
** < 0.01
* < 0.05

- Models exhibited similar performance
  - Only difference is TTHM
- Variable significance
  - DO, HPC, TCC (***) in both
  - TOC (***) in m.top, (**) in m.comp
- Water age metrics
  - Only meanTSL significant (*)
  - Demonstrates need for accurate water age measurement

Bayesian Generalized Linear Model

- Employed BGLR library in R
  - Relies on Gibbs sampling with scalar updates
  - Assumes priors based on Gaussian “point and slab” mixtures
  - BGLR used for variable selection in high-dimensional data sets

- Results
  - High probability (98%-100%) of non-zero parameter estimate for meanTSL (stagnation)
  - Low probability (14%-38%) of non-zero maxTSL parameter
  - All others 52%-57%
- Data appear too correlated to overcome point mass in prior
  - However, water age/stagnation highlighted as important

Conclusions

- Results agree with published literature
  - Confirms these phenomena occur at full-scale
  - Legionella more prevalent with elevated DO, HPC, TCC, TOC, and water age
- Additional research is needed
  - Developing water age model for premise plumbing

Thank You
&
Questions

Contact us:

Jade Mitchell, PhD jade@msu.edu
Ryan Julien, PE julienry@msu.edu

MICHIGAN STATE UNIVERSITY

Computational Ecohydrology Group

BOOTSTRAP AGGREGATED DECISION TREE CLASSIFICATION OF END-USE EVENTS THROUGH UPSTREAM FEATURES

Ian Kropp [a, b], A. Pouyan Nejadhashemi [a, *], Ryan Julien [a], Jade Mitchell [a], Andrew J. Whelton [c]

[a] Department of Biosystems and Agricultural Engineering, Michigan State University, East Lansing, Michigan, United States

[b] Department of Computer Science and Engineering, Michigan State University, East Lansing, Michigan, United States

[c] DLyles School of Civl Engineering, epartmentivison of Environmental and Ecological Engineering, Purdue University, West Lafayette, Indiana, United States

BACKGROUND

- Understanding water end-use is critical to:
  - designing premise plumbing guidelines
  - forecasting water demand
  - projecting the impacts of water saving practices and devices
  - determining water age
- However, end-use sensor systems are costly (on the order of $100K) to install for a single home.

JUSTIFICATION

- Reducing the cost of analyzing house end-use events would open end-use research to a wider group of practitioners
- Machine learning is an effective way to classify end-use events with an affordable number of sensors

RESEARCH QUESTIONS

- Can end-use events be categorized by a few upstream sensors in a system?
- What upstream sensors and preprocessing methods are optimal for use in a machine learning system?

Hypotheses

We hypothesized that an affordably small number sensors will be sufficient to predicting end-use events via a machine learning model

METHODOLOGY

We exhaustively trained and tested a machine learning algorithm (bootstrap aggregated decision trees) to classify…

- sink, shower, dishwasher, and washing machine events

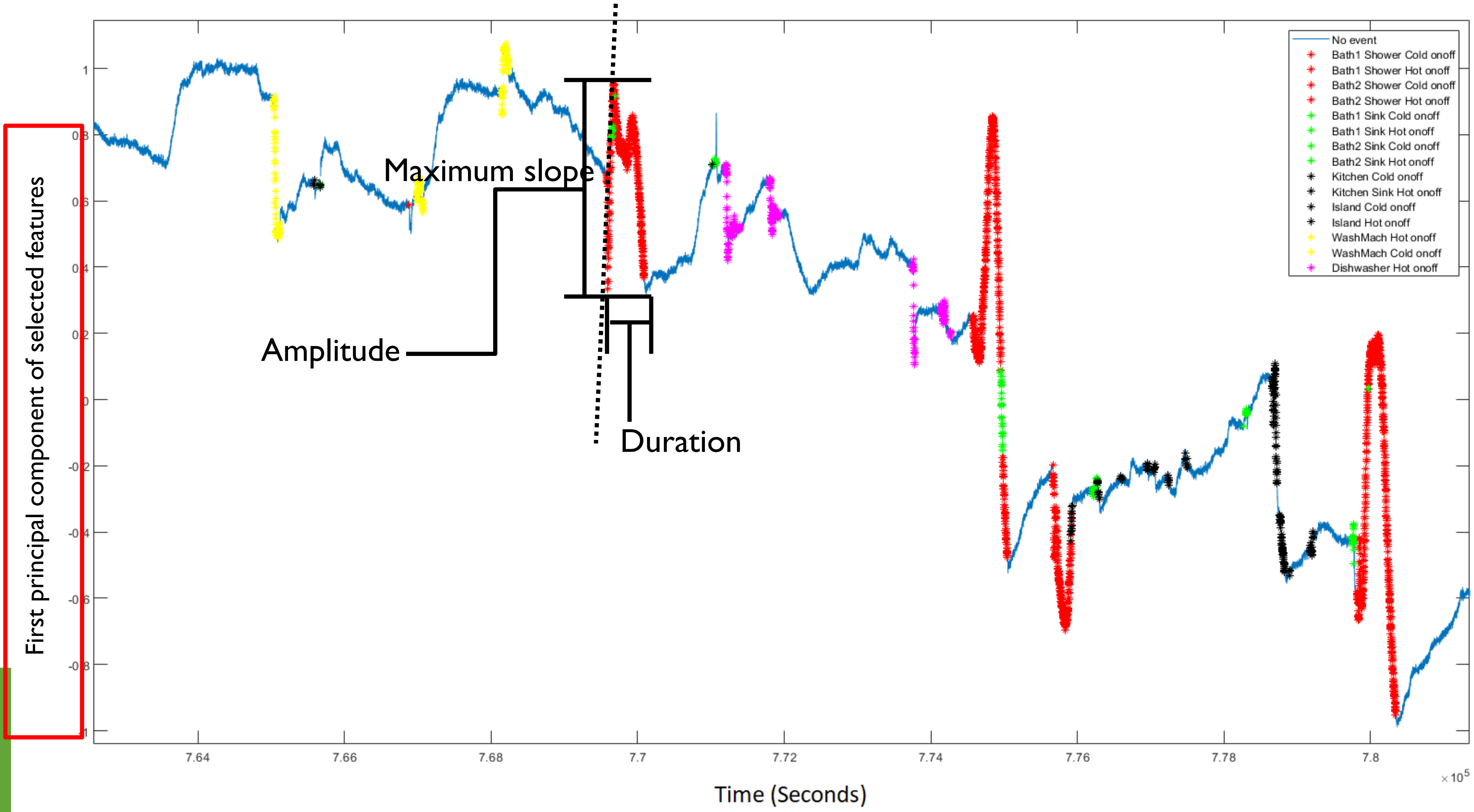
… for all combinations of …

- upstream sensors
- preprocessing methods

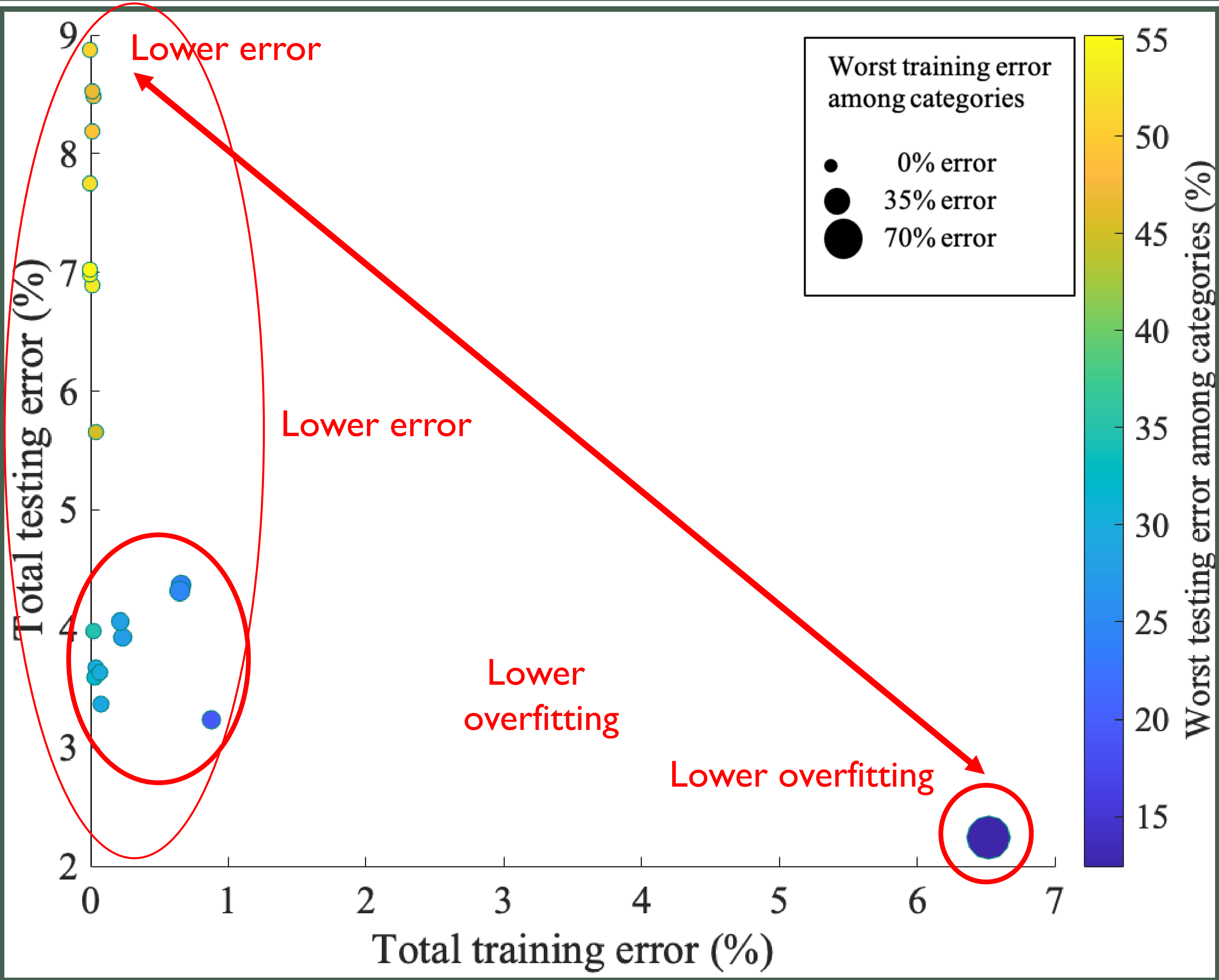
… using real world data from the ReNEWW house.

We then analyzed the best of these above configurations, and analyzed the best sensors and preprocessing methods with respects to:

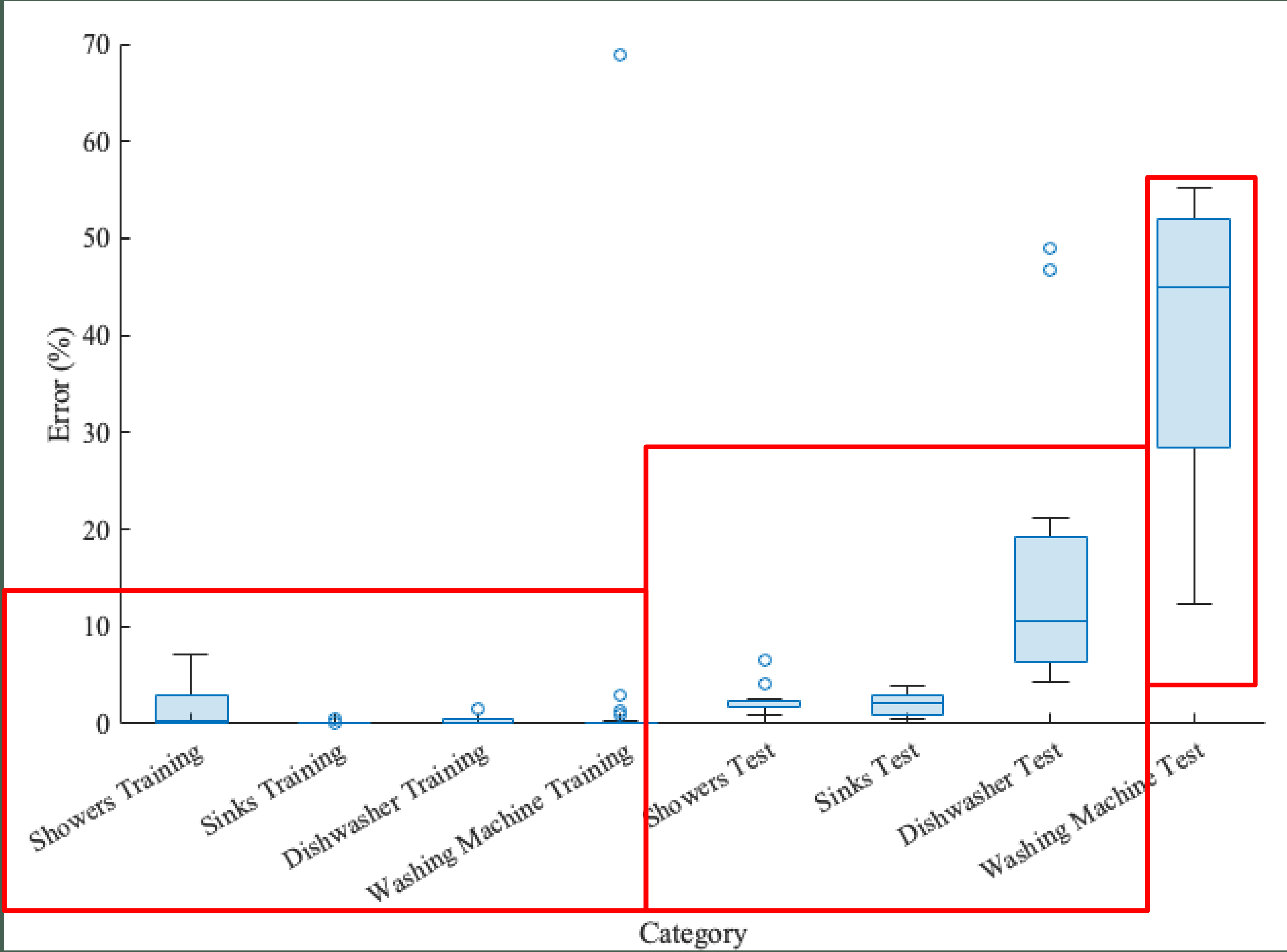
- accuracy
- overfitting


No event
Bath1 Shower Cold onoff
Bath1 Shower Hot onoff
Bath2 Shower Cold onoff
Bath2 Shower Hot onoff
Bath1 Sink Cold onoff
Bath1 Sink Hot onoff
Bath2 Sink Cold onoff
Bath2 Sink Hot onoff
Kitchen Cold onoff
Kitchen Sink Hot onoff
Island Cold onoff
Island Hot onoff
WashMach Hot onoff
WashMach Cold onoff
Dishwasher Hot onoff
Maximum slope
Amplitude
Duration
First principal component of selected features
Time (Seconds)
1
0.8
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
-0.8
-1
7.64
7.66
7.68
7.7
7.72
7.74
7.76
7.78
7.8
× 10^5

MAIN FINDINGS



MAIN FINDINGS: PERFORMANCE AMONG CATEGORIES



DISCUSSION

- Our algorithm was able to accurately predict all categories, though washing machine was moderately overfitted
- Best sensors for machine learning:
  - The city main volumetric flow sensor
  - The city hot water inlet volumetric flow sensor
- The best preprocessing methods for machine learning were:
  - Event duration
  - Maximum slope of event hydrograph

RECOMMENDATIONS

- Two to four sensors were optimal for minimizing error and overfitting
- The methodology is expandable to other:
  - premise plumbing systems
  - available sensors
  - preprocess methods
  - machine learning algorithm

QUESTIONS

Development of Integrated Hydraulic Water Quality Models

Maria Palmegiani, Juneseok Lee,
Jade Mitchell, Amirpouyan Nejadhashemi,
Andrew J. Whelton

PURDUE UNIVERSITY
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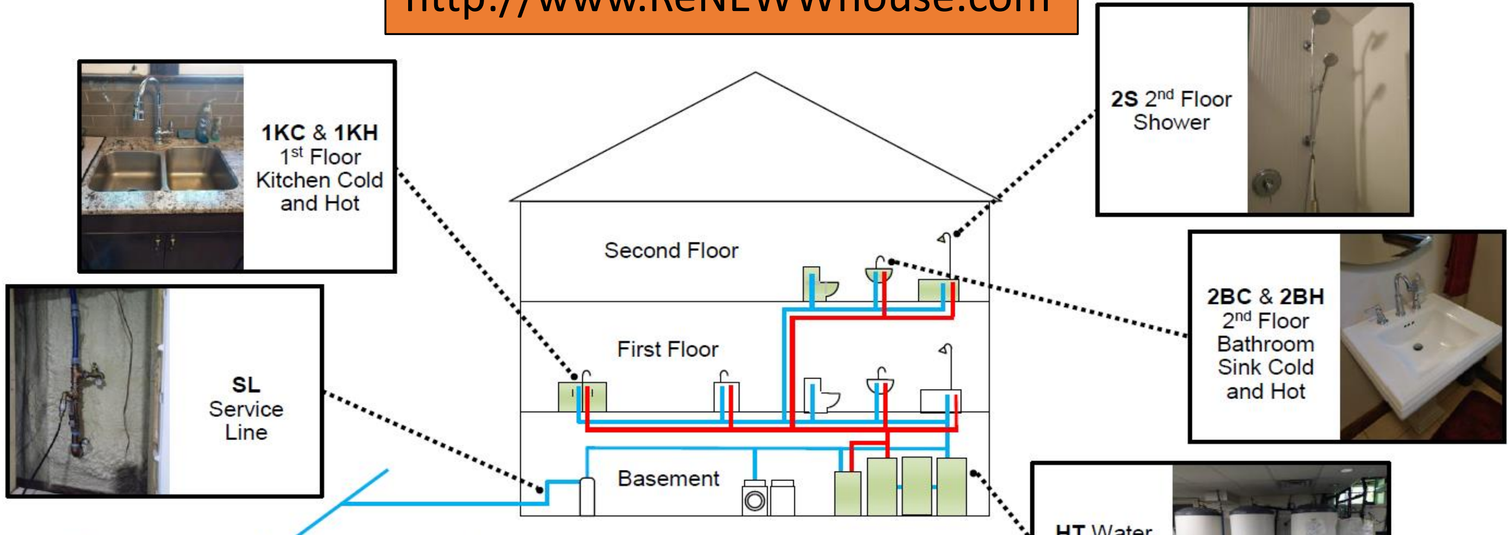
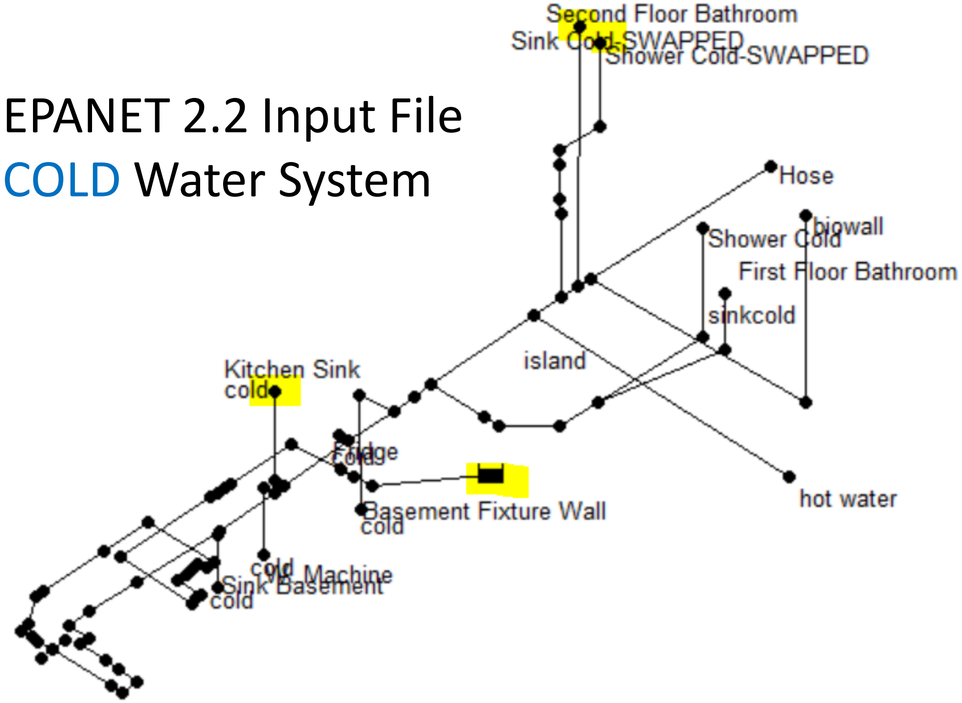
Retrofitted Net-Zero Energy, Water and Waste House

http://www.ReNEWWhouse.com



Service line (SL) pressure monitoring
Plumbing: Flow meters, temperature
Indoor air temperature

EPANET 2.2 Input File
COLD Water System

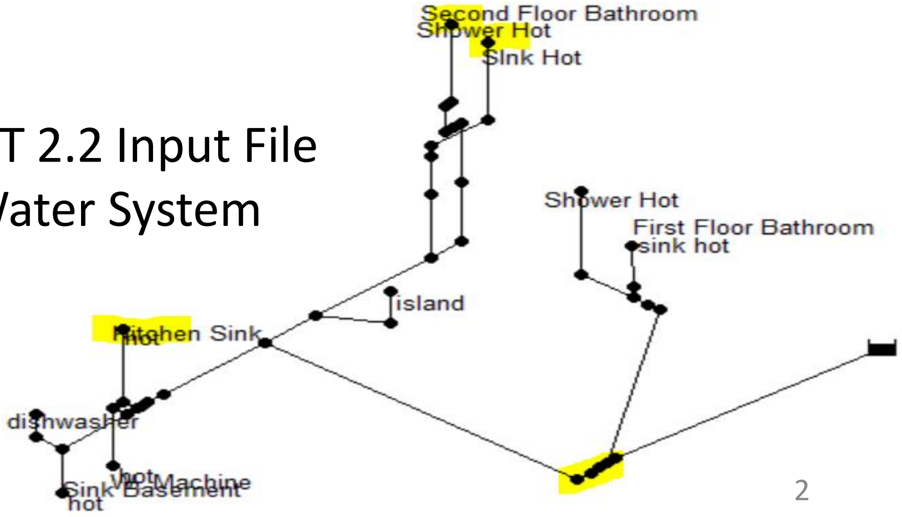


Area: 266 m^2, 4 bedrooms, 1.5 baths
Study Period: Oct. 2017-Oct. 2018
30, 000+ water quality measurements
2.64 billion online plumbing measurements

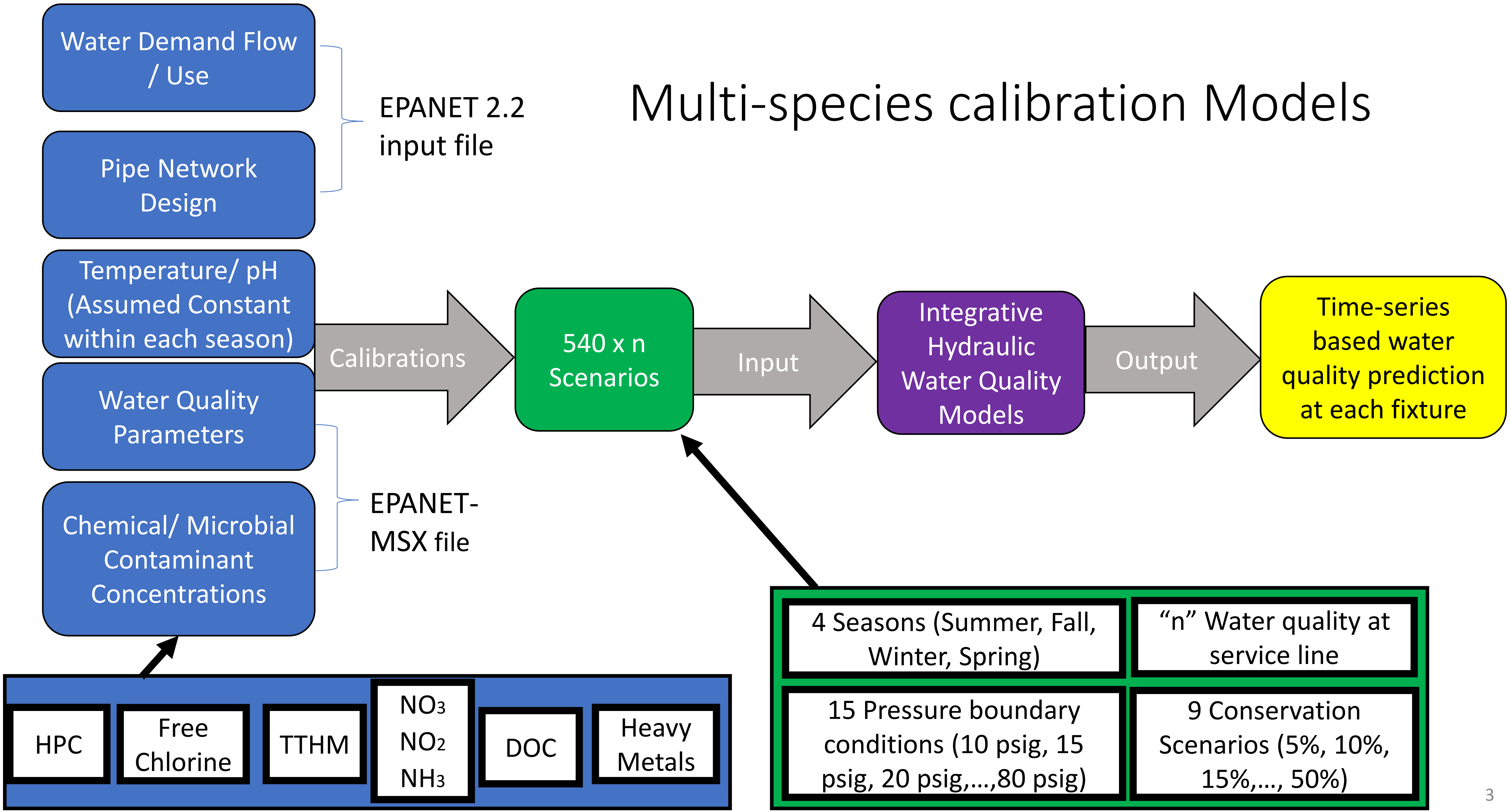
- Thermocouples
- Indoor air temperature
- Flowrates/ fixture
- Energy use/ device

} 1x/second

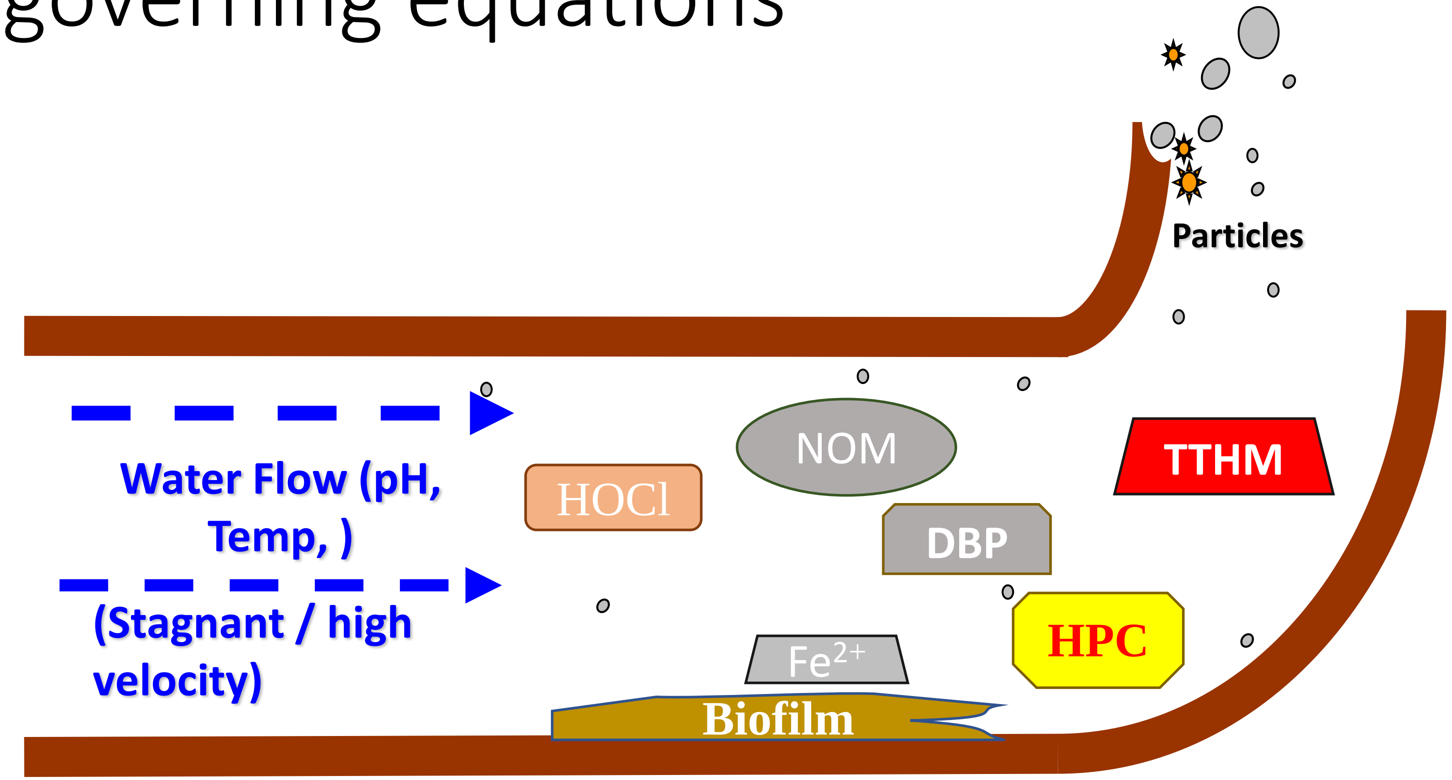
EPANET 2.2 Input File
HOT Water System



Multi-species calibration Models



Multi-species calibration models-governing equations



$$\frac{dC}{dt} = -KC$$

Where,

k= Free Chlorine reaction rate constant

C=Chlorine concentration

HOCl

$$\frac{\partial C_{TTHM}}{\partial t} = k(C_{TTHMMAX} - C_{TTHM})$$

Where,

k= TTHM reaction rate constant

$C_{TTTHMMAX}$=Maximum TTHM concentration

C_{TTTHM}=TTHM concentration

TTHM

$$\frac{dX_h}{dt} = Y_h\left(q_m\left[\frac{BOM}{k_s + BOM}\right]\right)X_h - k_d[HOCL]$$

Where,

X_h= heterotrophic biomass concentration

BOM= biodegradable organic matter

K_s= half maximum rate concentration

y_h= synthesis yield

q_m= max specific rate of utilization

HPC

Woolschlager et al., 2007

Seyoum & Tanyimboh, 2017

Tiruneh et al., 2016

Multi-species calibration models

1. Kitchen Sink
2. Bath 2 Sink
3. Bath 2 Shower

1. Cold Water System
2. Hot Water System

1. Fall 1 (10/10/2017-10/16/2017)
2. Winter 1-2 (1/22/2018-3/7/2018)
3. Spring 1-2 (5/13/2018-6/4/2018)
4. Summer 1-2 (6/25/2018-7/25/2-18)
5. Fall 2 (9/20/2018-10/9/2018) (VAL)

1-minute timestep≈ 53, 000 data points/ Month

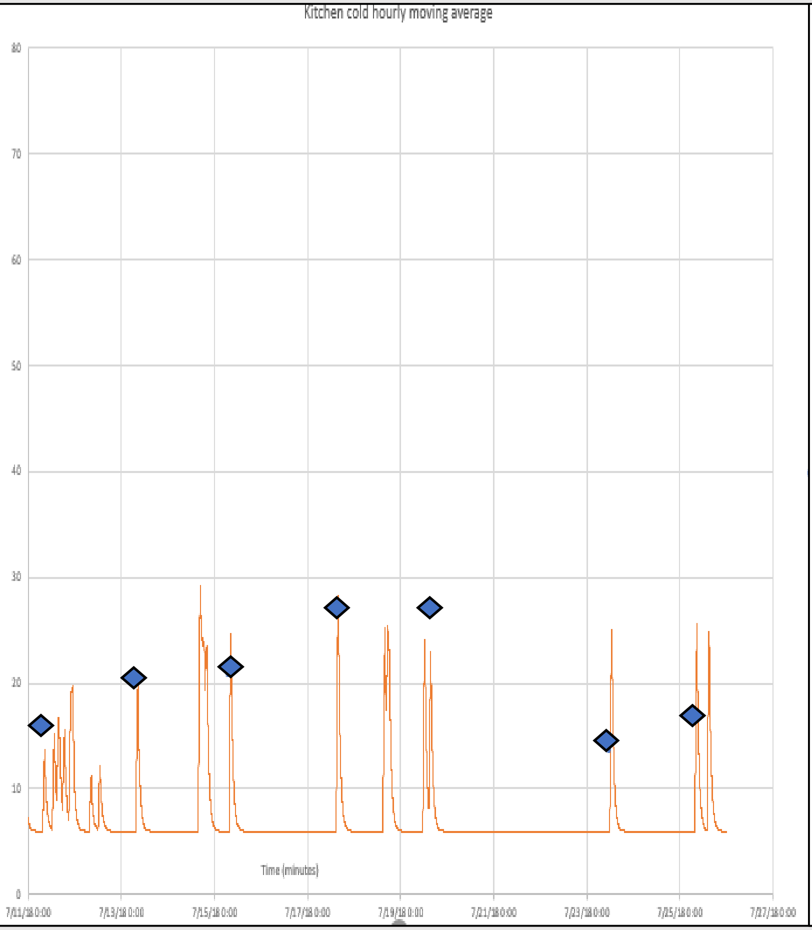
Accounts for temperature/ pH variations by assuming constant/ season

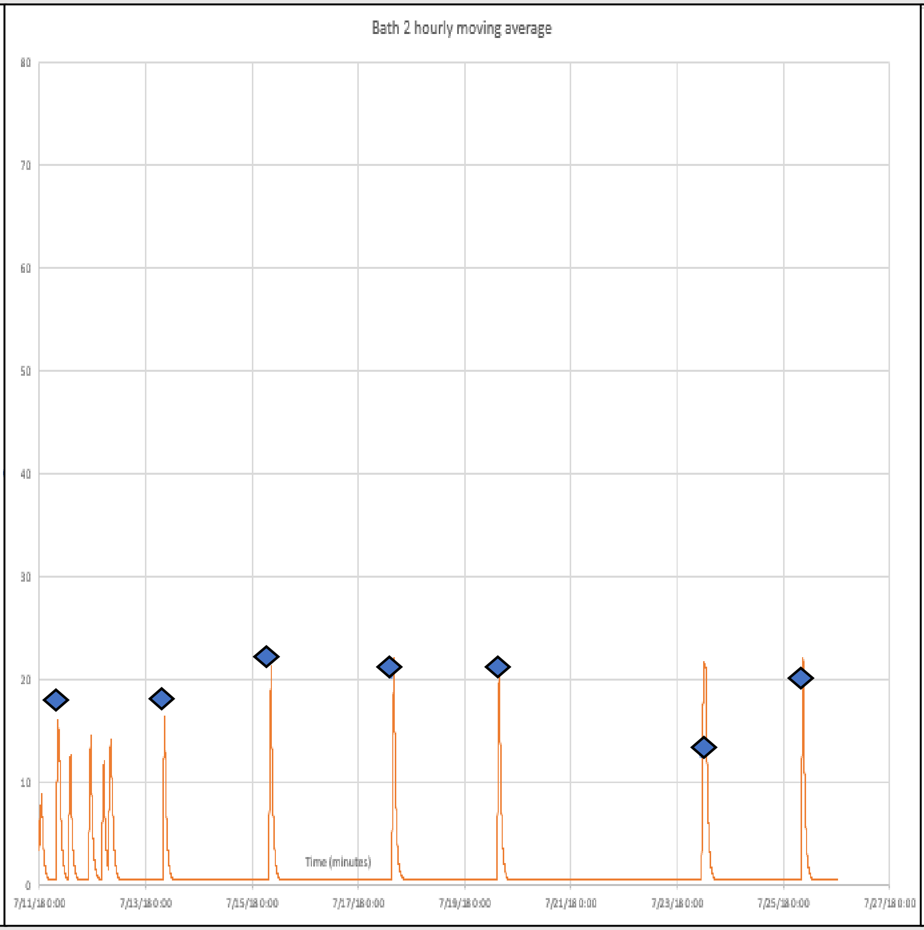
Split into smaller clusters to match the water sampling trip dates

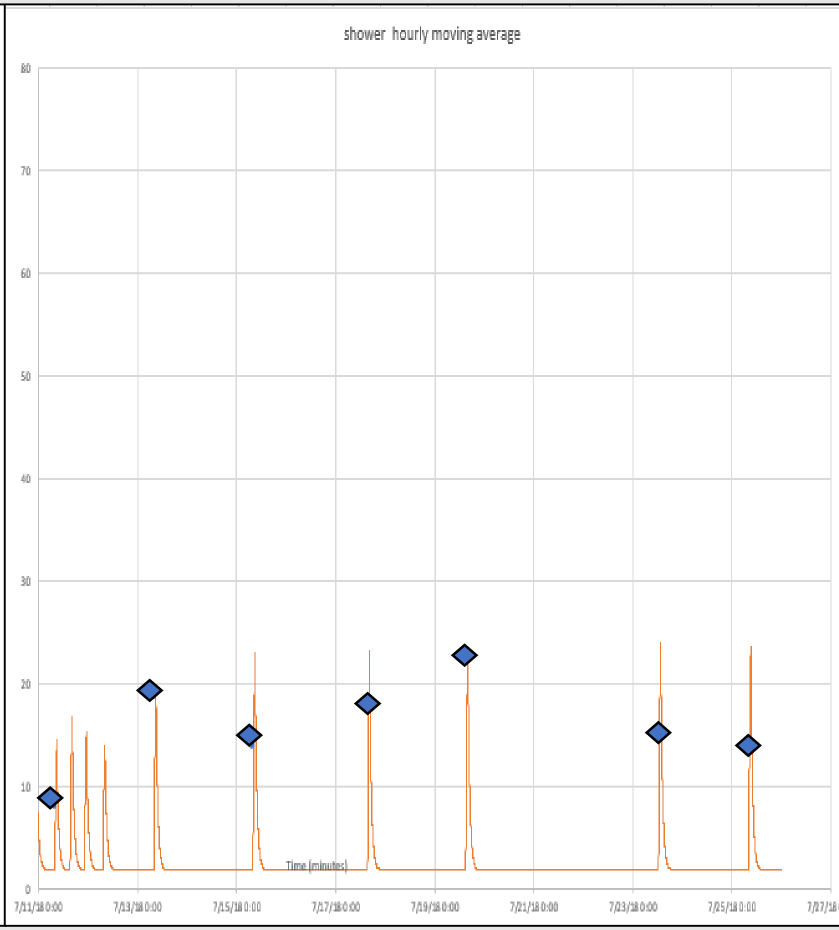
TTHM (ug/L)

TTHM

$$\frac{\partial C_{TTHM}}{\partial t} = K_{TTHM1} - K_{TTHM2} \cdot TTHM \qquad K_{Universal1} = 1.5 \qquad K_{Universal2} = 0.04$$







Kitchen Sink

K_1=6.0
K_2=1.0

Bath 2 Sink

K_1=0.6
K_2=1.2

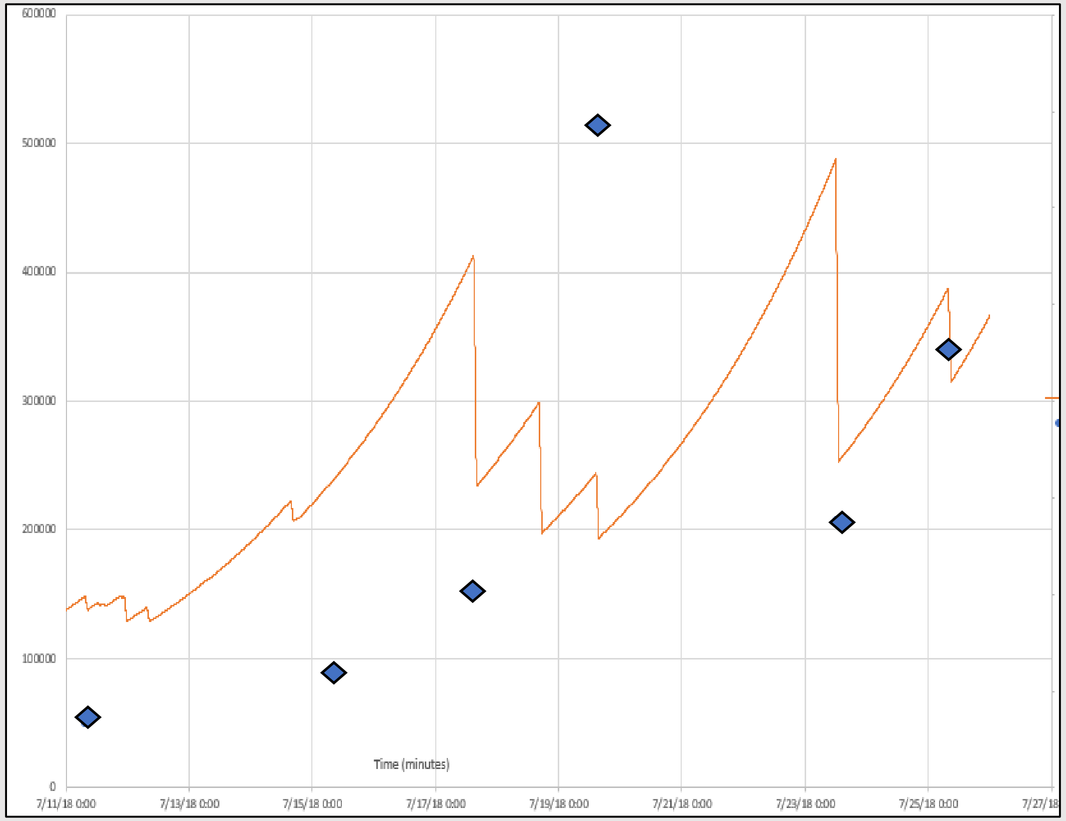
Bath 2 Shower

K_1=2.0
K_2=1.1

HPC

HPC (CFU/L)

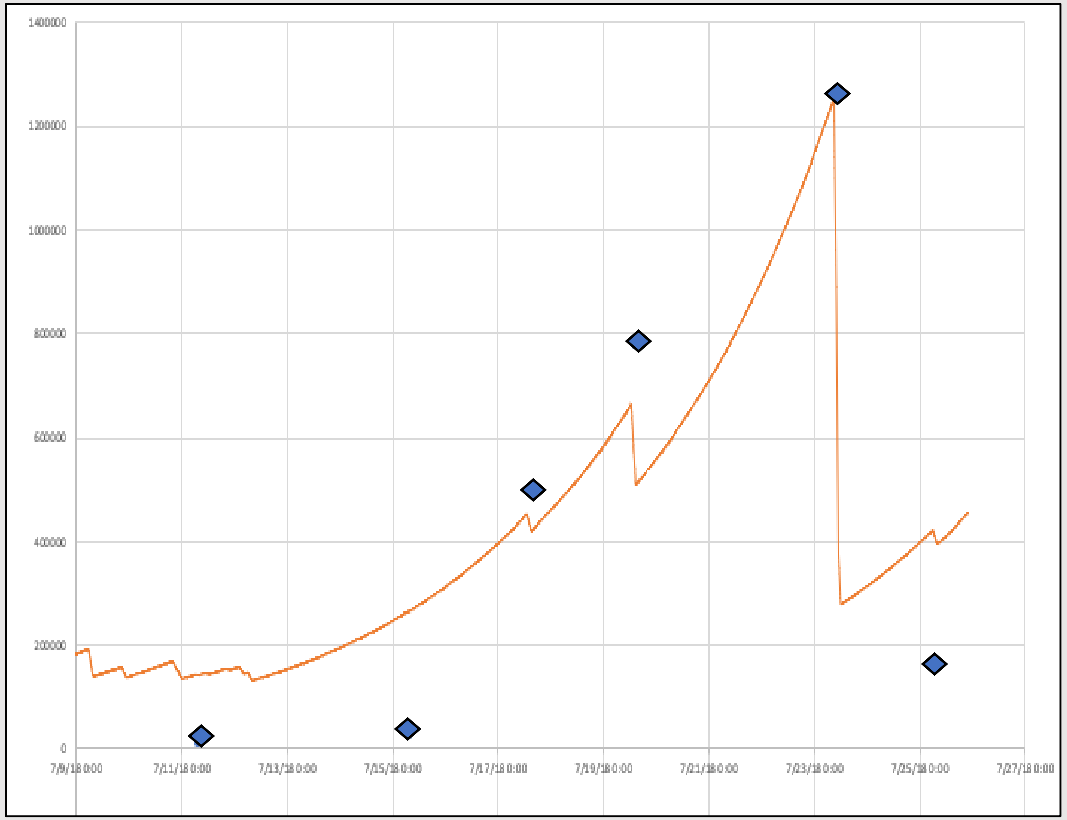
$$\frac{d\mathrm{HPC}}{dt} = K_{HPC1} \cdot HPC - K_{HPC2} \cdot \mathrm{FCL} \qquad K_{Universal1} = 0.01 \qquad K_{Universal2} = 0.01$$



Kitchen Sink

$K_1 = 0.01$

$K_2 = 0.01$



Bath 2 Sink

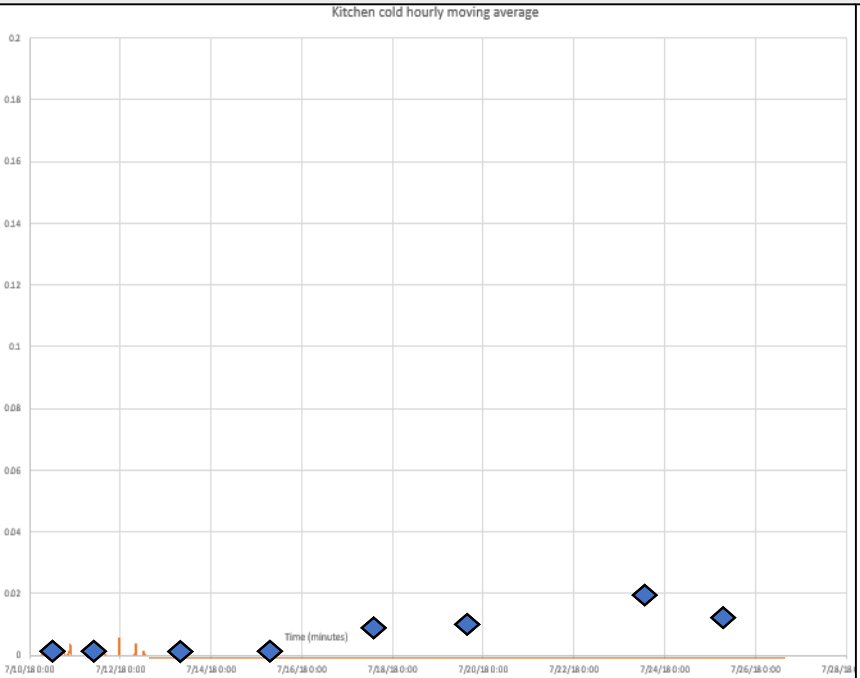
$K_1 = 0.001$

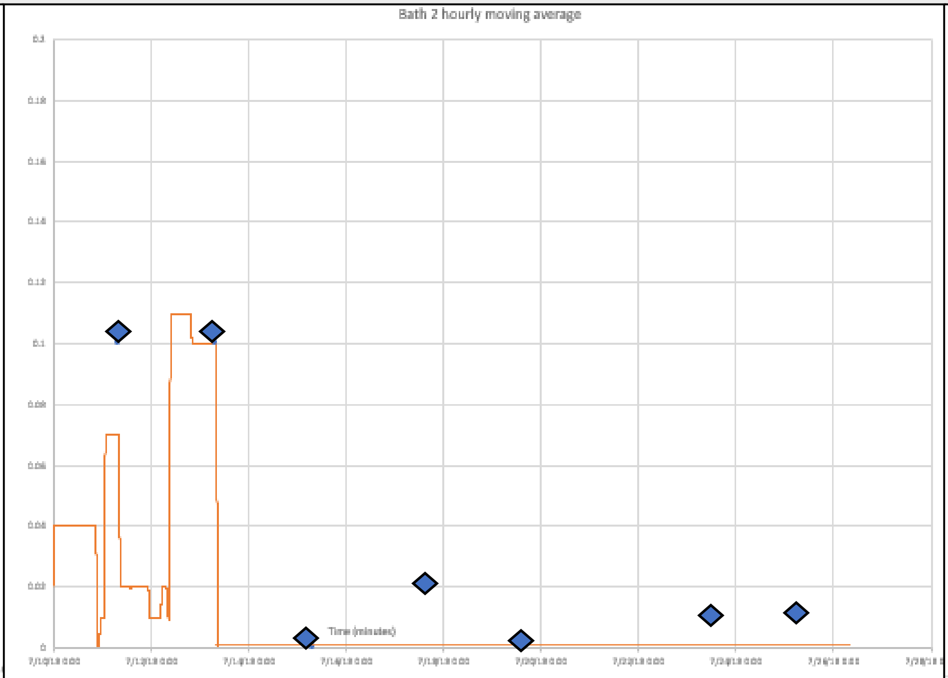
$K_2 = 0.09$

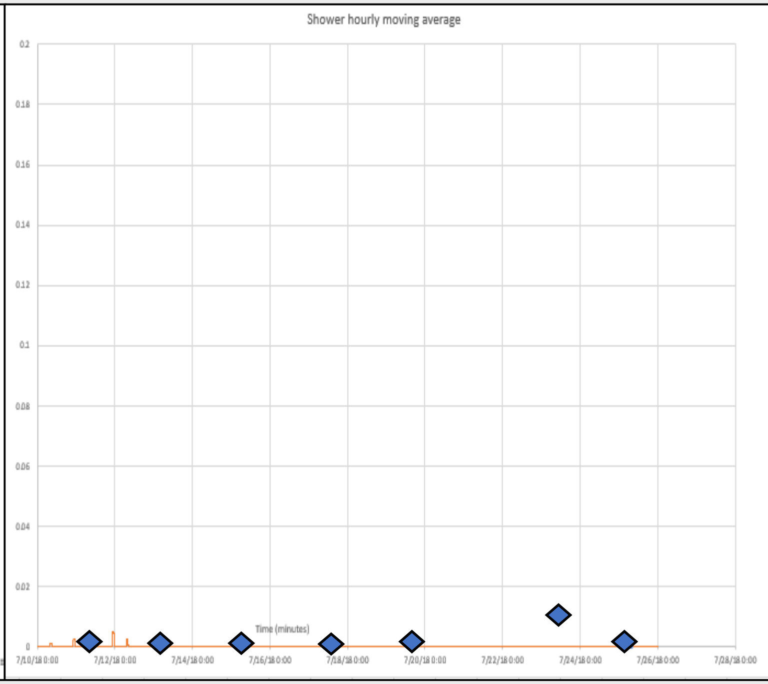
Free Chlorine (mg/L)

HOCl

$$\frac{dC}{dt} = K_{FCL} \cdot FCL \qquad K_{Universal} = 0.2$$







Kitchen Sink

K=35

Bath 2 Sink

K=0.008

Bath 2 Shower

K=18

Limitations

Better sensors needed
Availability of governing equations
Grab vs.online sensors

Thank you & Questions?

- Maria Palmegiani, mpalmegi@purdue.edu
- Juneseok Lee, Juneseok.Lee@manhattan.edu

MICHIGAN STATE UNIVERSITY

Comparing Risks Across Building Water Use Types with QMRA

Ryan Julien*, Jade Mitchell,
Md. Rasheduzzaman, Wanyu Huang, Yolanda Brooks,
Patrick Gurian, & Mark Weir

November 12, 2020

MICHIGAN STATE UNIVERSITY

Outline

- Introduction
- Model
- Results
- Conclusions

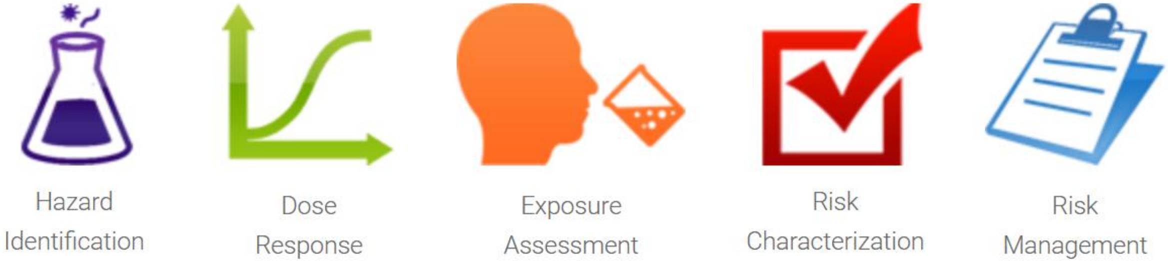


Image: QMRA Wiki (qmrawiki.canr.msu.edu/)

Introduction

- Goal: Assess differences in pathogen health risk across common water use types
- Pathogens
  - Mycobacterium Avium complex (MAC)
  - Legionella spp.
- Hospital/group home setting
  - Higher-risk population
  - Pathogen concentrations from studies in these homes

- QMRA Framework
- Water uses considered:
  - Showering
    - Conventional (13 LPM)
    - Low-flow (7 LPM)
  - Toilet Flushing
    - Flushometer (FOM)
    - Pressure-assisted (PAT)
    - High-efficiency (HET)

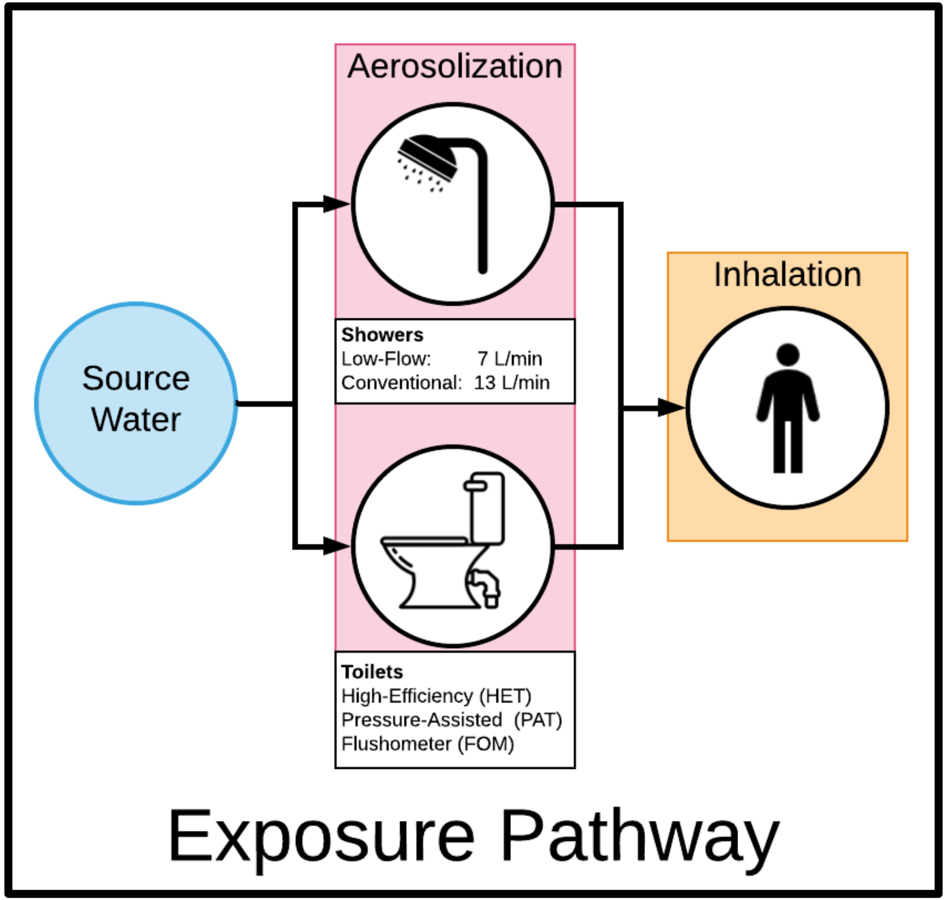
Model Form

- D_P – Exposure dose of each pathogen, P
- R – Recovery efficiency
  - 0.84 (Hamilton, 2019)
- C_P – Concentration of pathogen P
  - MAC - Triangular dist. (de Moulin 1988)
  - Legionella - Lognormal dist. (Fillipis 2018)
- R_B – Breathing rate
  - Normal dist. (USEPA, 2011)
- t – Exposure duration
  - Shower = 15 min
  - Toilet = 30 min (reflects sampling methods)
- $C_{aer,\,d}$ – Concentration of aerosolized droplets of diameter d (in microns)
- V_d – Volume of each aerosol of diameter d
- $\eta_{D,d}$ - Deposition efficiency for aerosols of diameter d

$$D_P = \frac{1}{R}\, C_P\, R_B\, t \sum_d C_{aer,d}\, V_d\, \eta_{D,d}$$

$$R_P = 1 - e^{-k_P D_P / C}$$

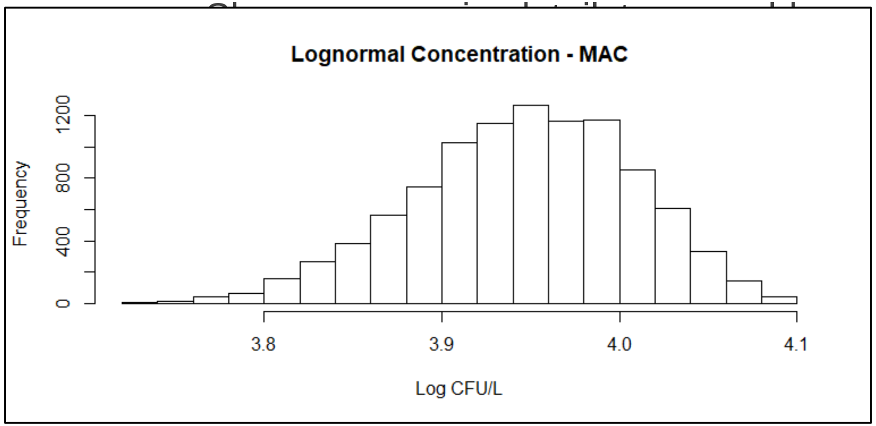
- R_P – Risk of infection for each pathogen, P
- k_P – Dose-Response parameter
  - (Hamilton et al. 2017)
- C – Exposure route conversion factor
  - (Hamilton et al. 2017)

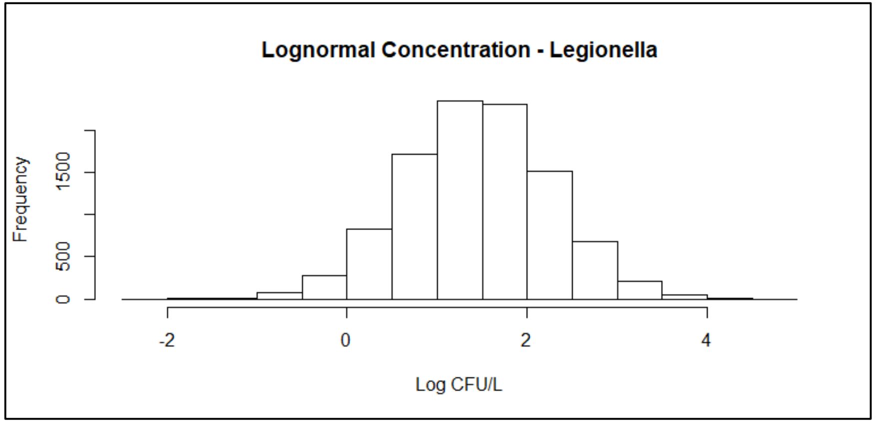

Aerosolization
Source Water
Showers
Low-Flow: 7 L/min
Conventional: 13 L/min
Toilets
High-Efficiency (HET)
Pressure-Assisted (PAT)
Flushometer (FOM)
Inhalation
Exposure Pathway

Pathogen Input Concentrations

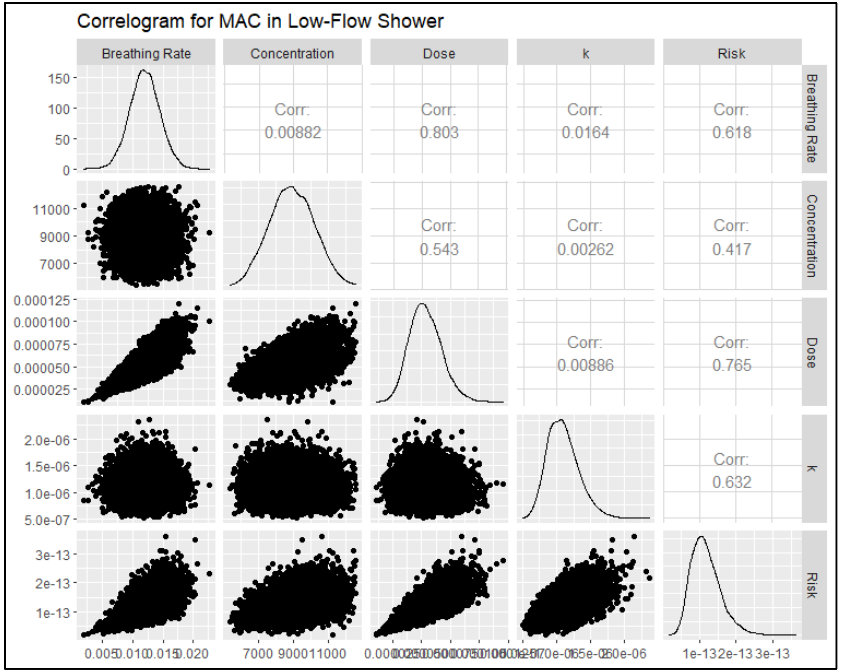
- MAC
  - Data: de Moulin et al. 1988
  - Triangular distribution based on minimum, median, maximum
  - Hot/cold water simulated separately

- Legionella
  - Data: Filipis et al. 2018
  - Fit a log-normal distribution
    - Raw data available
  - Hot and cold water assumed to contain same concentration





Common Correlations within Model

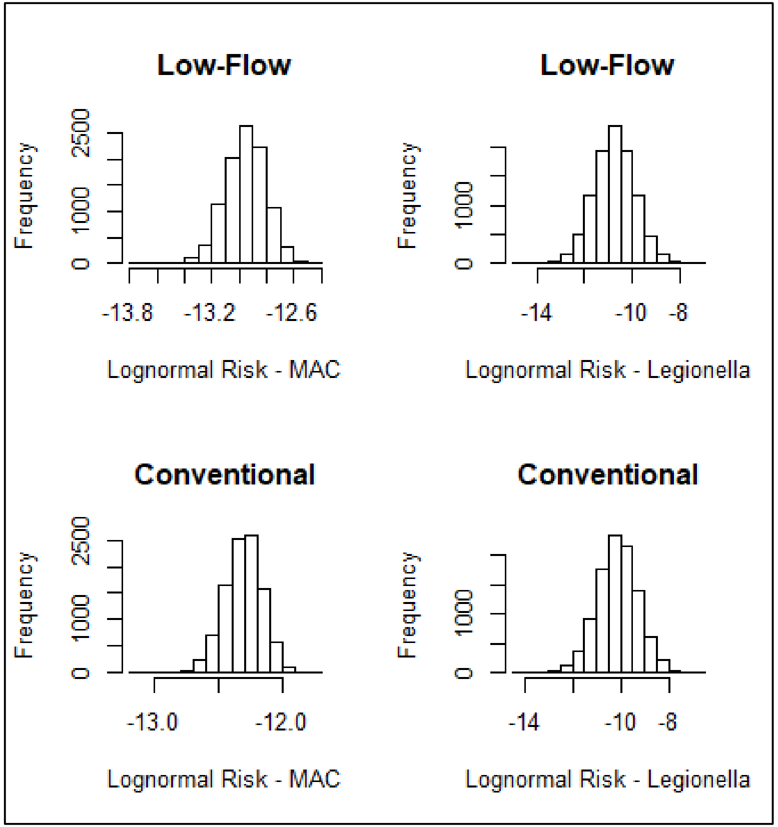


MAC in Low-Flow Shower

- Breathing Rate
  - Correlated with dose (0.80) and risk (0.62)
- Concentration
  - With dose (0.54) and risk (0.42)
- Risk
  - With dose (0.77) and k (0.63)

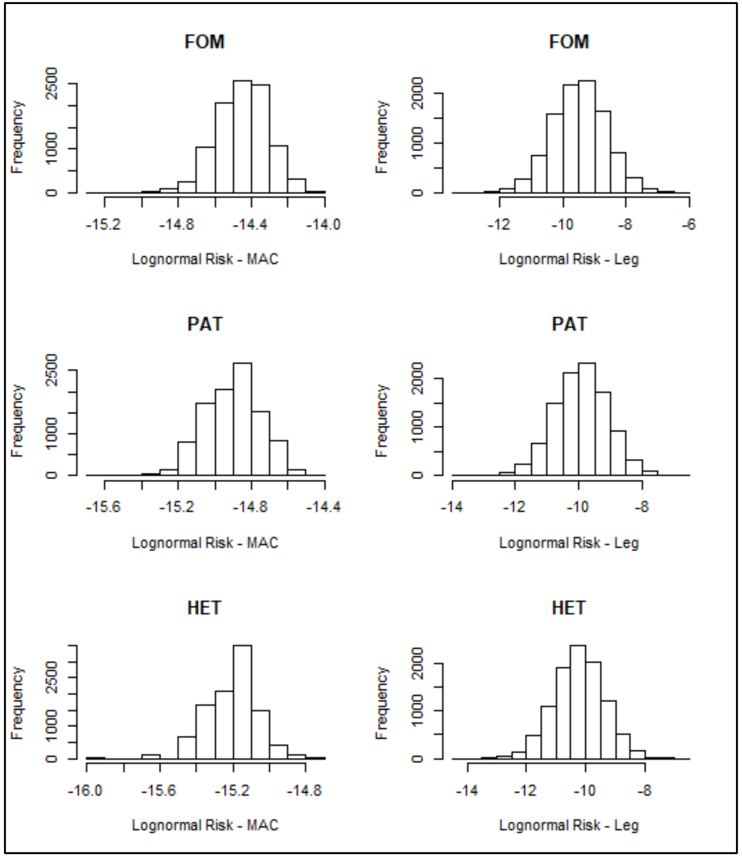
Results – Showering

- Low-flow showers exhibited slightly lower risk
  - True for both MAC and Legionella
    - Higher flowrate ⇒ more aerosols
  - This analysis does not consider the effects of stagnation



Results – Toilet Flushing

- Risks for toilets
  - FOM > PAT > HET
  - True for both pathogens
  - Differences more pronounced for MAC



Conclusions

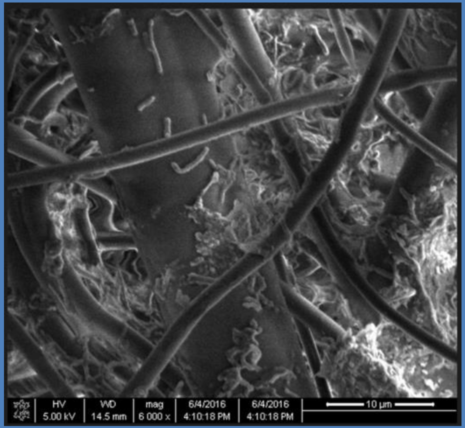
- Risks across all water use are low
  - Used dose-response factor for general population
- Additional water use appears to increase risk
  - Effect of stagnation not considered
- Pathogen concentrations highly variable

- Potential improvements
  - Additional data for pathogen concentration estimates
  - Consider water age/stagnation
  - Incorporate dose-response for vulnerable populations

Thank You
&
Questions

Contact us:
Jade Mitchell, PhD jade@msu.edu
Ryan Julien, PE julienry@msu.edu

Right Sizing Tomorrow's Water Systems for Efficiency, Sustainability, & Public Health


NEXT STEPS

PURDUE UNIVERSITY

MICHIGAN STATE UNIVERSITY

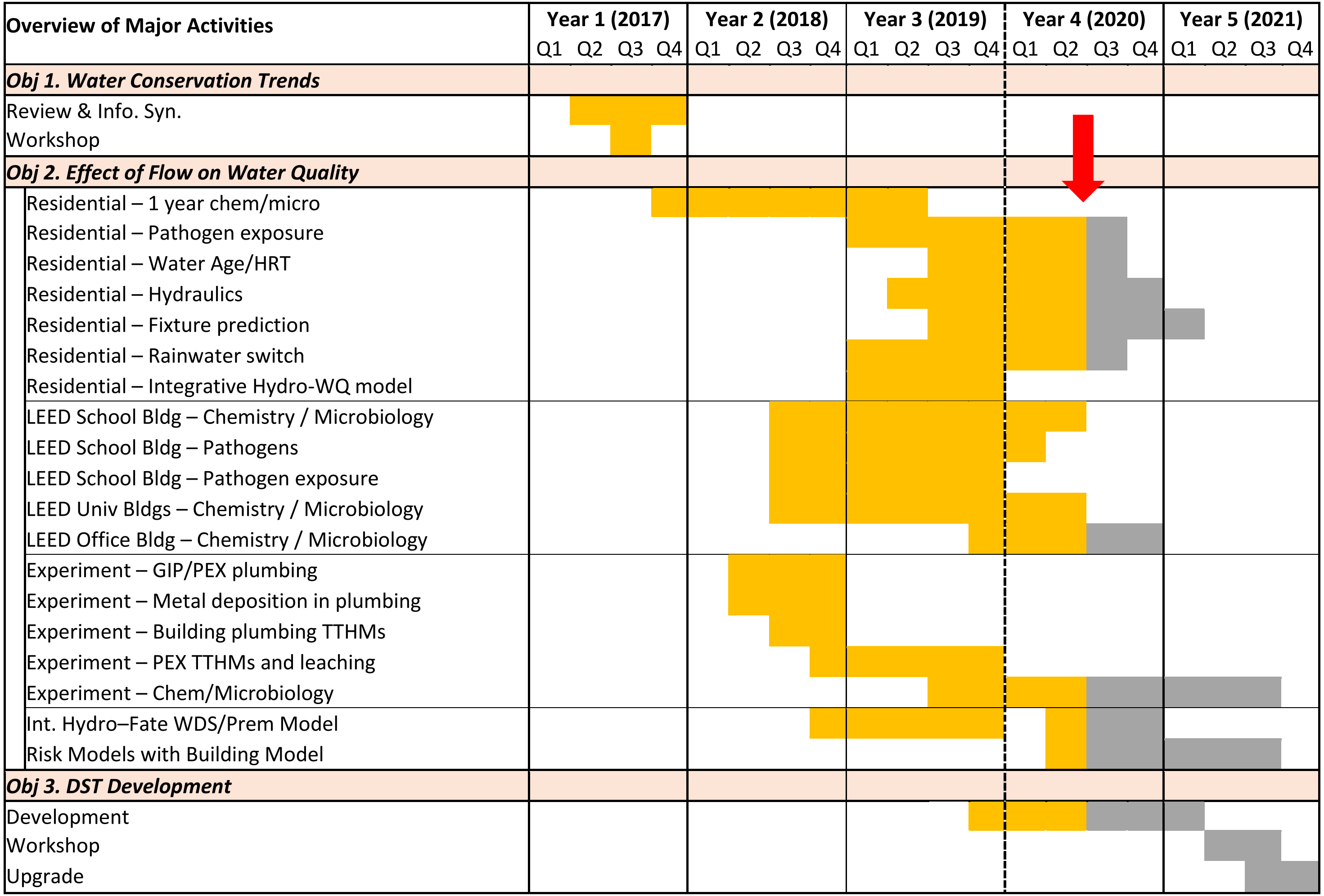
SJSU SAN JOSÉ STATE UNIVERSITY

MANHATTAN COLLEGE

Tulane University

THE UNIVERSITY OF MEMPHIS

awhelton@purdue.edu


Overview of Major Activities
Year 1 (2017)
Year 2 (2018)
Year 3 (2019)
Year 4 (2020)
Year 5 (2021)
Q1 Q2 Q3 Q4
Obj 1. Water Conservation Trends
Review & Info. Syn.
Workshop
Obj 2. Effect of Flow on Water Quality
Residential – 1 year chem/micro
Residential – Pathogen exposure
Residential – Water Age/HRT
Residential – Hydraulics
Residential – Fixture prediction
Residential – Rainwater switch
Residential – Integrative Hydro-WQ model
LEED School Bldg – Chemistry / Microbiology
LEED School Bldg – Pathogens
LEED School Bldg – Pathogen exposure
LEED Univ Bldgs – Chemistry / Microbiology
LEED Office Bldg – Chemistry / Microbiology
Experiment – GIP/PEX plumbing
Experiment – Metal deposition in plumbing
Experiment – Building plumbing TTHMs
Experiment – PEX TTHMs and leaching
Experiment – Chem/Microbiology
Int. Hydro–Fate WDS/Prem Model
Risk Models with Building Model
Obj 3. DST Development
Development
Workshop
Upgrade

Remaining Efforts

Integrative Hydraulic Water Quality Model for the Residential Home (EPANET)

↓

Conduct Water Quality Modeling and Risk Analysis

↓

Develop Decision Support Tool (DST)

Finish Studies

Pathogens in Schools
Office Building Water Quality
Copper in Schools
Institutional Building Microbiology
Downstream fixture prediction

Inform and Receive Feedback from Partners

Consider Feedback in DST and Deploy

↓

Deliver

The Pending Decision Support Tool

Development of Decision Support Tool (DST) will be performed by the Decision Support and Informatics (DSI) Unit at Michigan State University.

We draw from multiple data sources including:

- Water distribution (**Partners-Whelton**)
- Premise plumbing modeling (**Obj. 2b-Lee**)
- Water quality modeling (**Obj. 2c- Mitchell**)
- Risk assessment (**Obj. 3a-Micthell**)

To address different issues such as:

- Right-sizing (**Lee/Palmegiani**)
- The effect of plumbing designs (**Lee/Palmegiani**)
- Stagnation times (**Mitchell/Julien**)

on water quality and human health risks within a robust information platform

Status on the Decision Support Tool

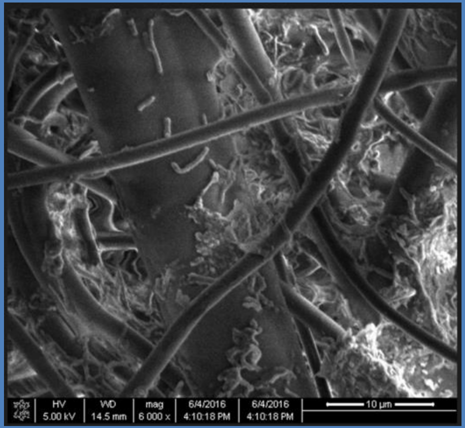
- A private and secure data repository is established for all collaborators
- Created wireframes for a future decision support tool
- A SQL database was established which hosts the results from different sources, including:
  - Modeling exercises
  - Partner inputs
- We have designed and implemented a powerful API to interface between the database and the decision support tool

Initial Plan for Disseminating the Results to Public after the Grants End

The DST website will be published in the Decision Support and Informatics website (dsiweb.cse.msu.edu) and advertised through different means such as:

- University newsletters
- Conference presentations
- The Whirlpool ReNEWW house website
- Trade conferences and associations
- Standard and trade organizations (e.g., NIST, IAPMO, ASPE)

Right Sizing Tomorrow's Water Systems for Efficiency, Sustainability, & Public Health



Next Steps November 2020

Andrew Whelton, Jade Mitchell, Joan Rose, Juneseok Lee, Pouyan Nejadhashemi, Erin Dreelin, Tiong Gim Aw, Amisha Shah, Matt Syal, Maryam Salehi

Purdue University
Michigan State University
SJSU San José State University
Manhattan College
Tulane University
The University of Memphis

awhelton@purdue.edu