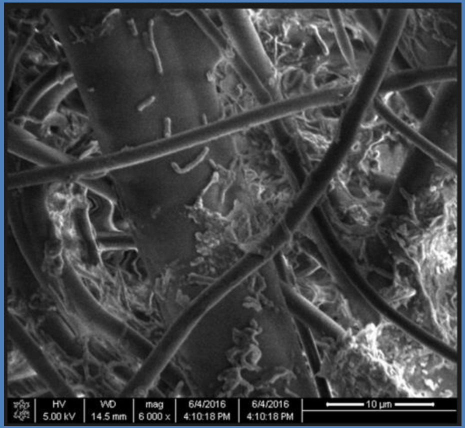
The Most Monitored Home in America: Plumbing for Innovation and Prosperity



November, 2018

Andrew J. Whelton, Ph.D.

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

plumb·ing

[ˈpləmiNG] ***NOUN***

the system of pipes, tanks, fittings, and other apparatus required for the drinking water supply, heating, and sanitation in a building

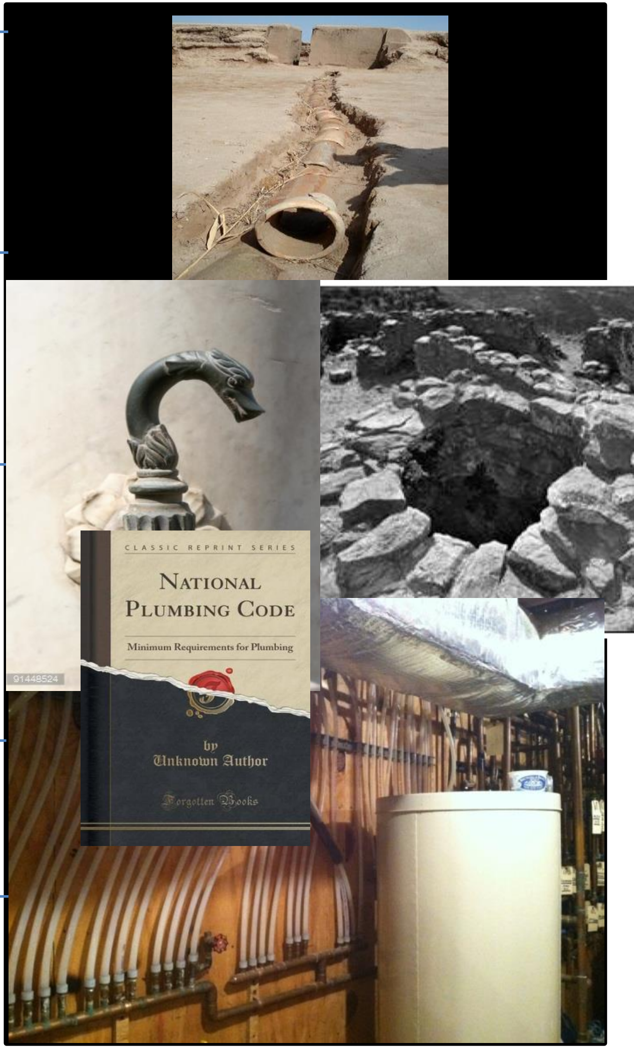
4000-3000 BCE
Copper water pipes in buildings (India)

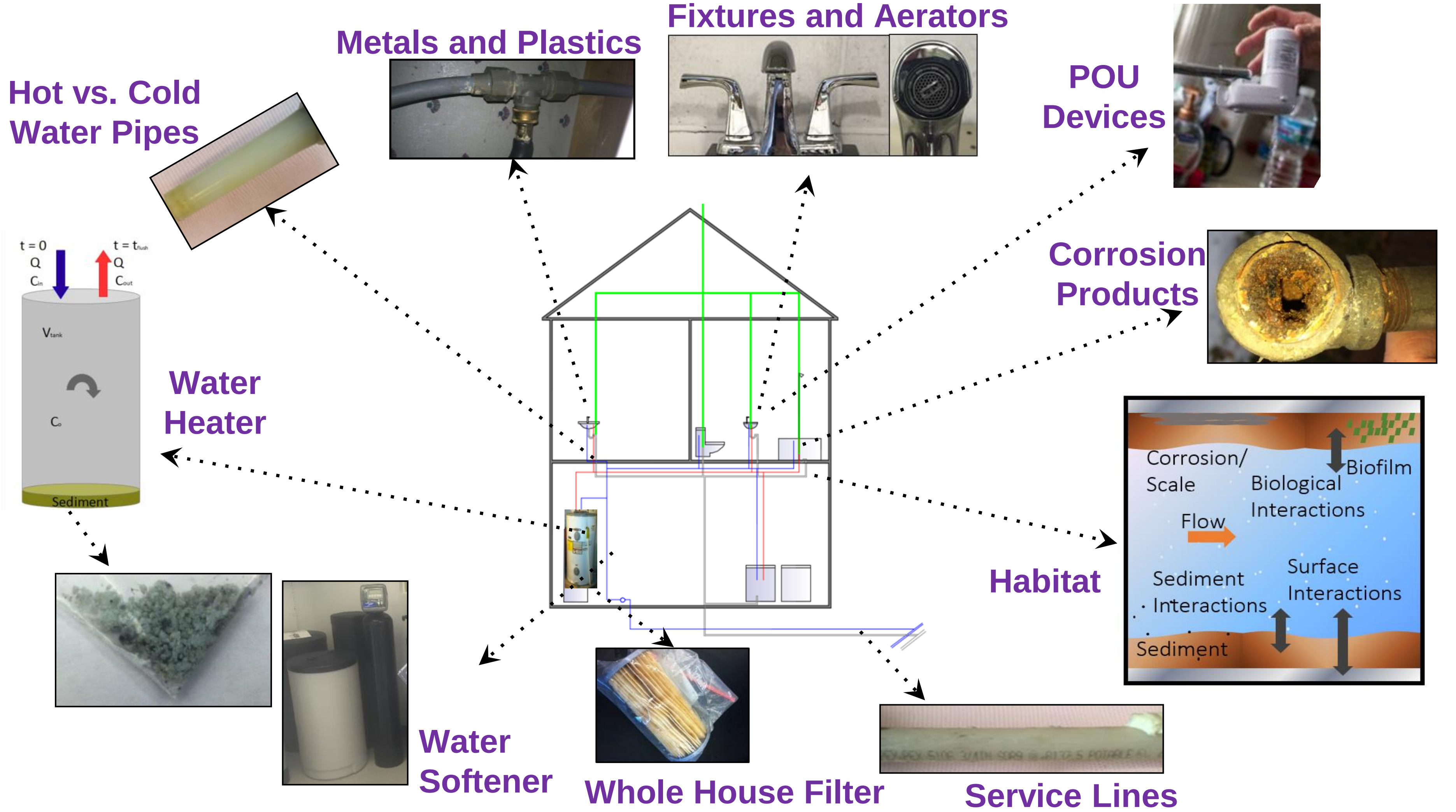
1500 BCE
Rainwater cisterns (Greece)

500 BCE- 250 AD
Lead & bronze pipes, marble fixtures, gold & silver fittings (Egypt)

1928
First US plumbing code

1966
Copper shortage enabled plastics entry





Fixtures and Aerators
Metals and Plastics
POU
Devices
Hot vs. Cold
Water Pipes
Corrosion
Products
t = 0
Q
Cin
t = tflush
Q
Cout
Vtank
Co
Sediment
Water
Heater
Corrosion/
Scale
Biofilm
Biological
Interactions
Flow
Surface
Interactions
Sediment
Interactions
Sediment
Habitat
Water
Softener
Whole House Filter
Service Lines

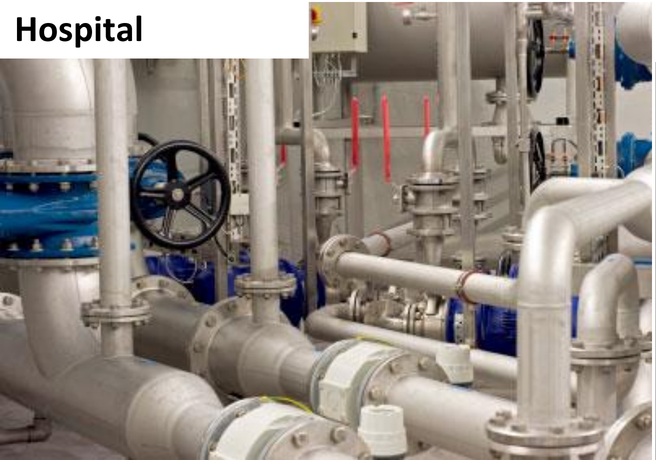
Building plumbing is complex

Food Prep Facility

Domestic Hot Water

PEX pipe with copper manifold

Hospital



Cartridge Filters

Copper pipe to cPVC pipe

Some images courtesy of: Gordon & Rosenblatt, LLC

Building Water Use has Been Declining

Energy Policy Act of 1992

Water Use has Decreased From Lower-Flow Faucets

Pre-1994 (4^+ gpm)

1994 (2.5 gpm)

2015 (0.5 gpm)

2016? (0.01 gpm)

How old is your water before reaching the faucet?

$$\frac{\text{Volume of water stored in pipes}}{\text{Flowrate of water exiting the Faucet}}$$

…our water systems are not designed to handle lower use

PURDUE UNIVERSITY

THE UNIVERSITY OF MEMPHIS

Rebecca Ives, Kyungyeon Ra, Christian Ley, Tolu Odimayomi, Sruthi Dasika, John Mayo, Xianzhen Li, Xiangning Huang, Kara Dean, Ryan Julien, Erica Wang, Miriam Tariq, Emerson Ringger, Bill Schmidt, Kim Petersen, Caitlin Proctor, Mohammad Abouali, Paul Robinson, Jennifer Sturgis

MANHATTAN COLLEGE

Tulane University

MICHIGAN STATE UNIVERSITY

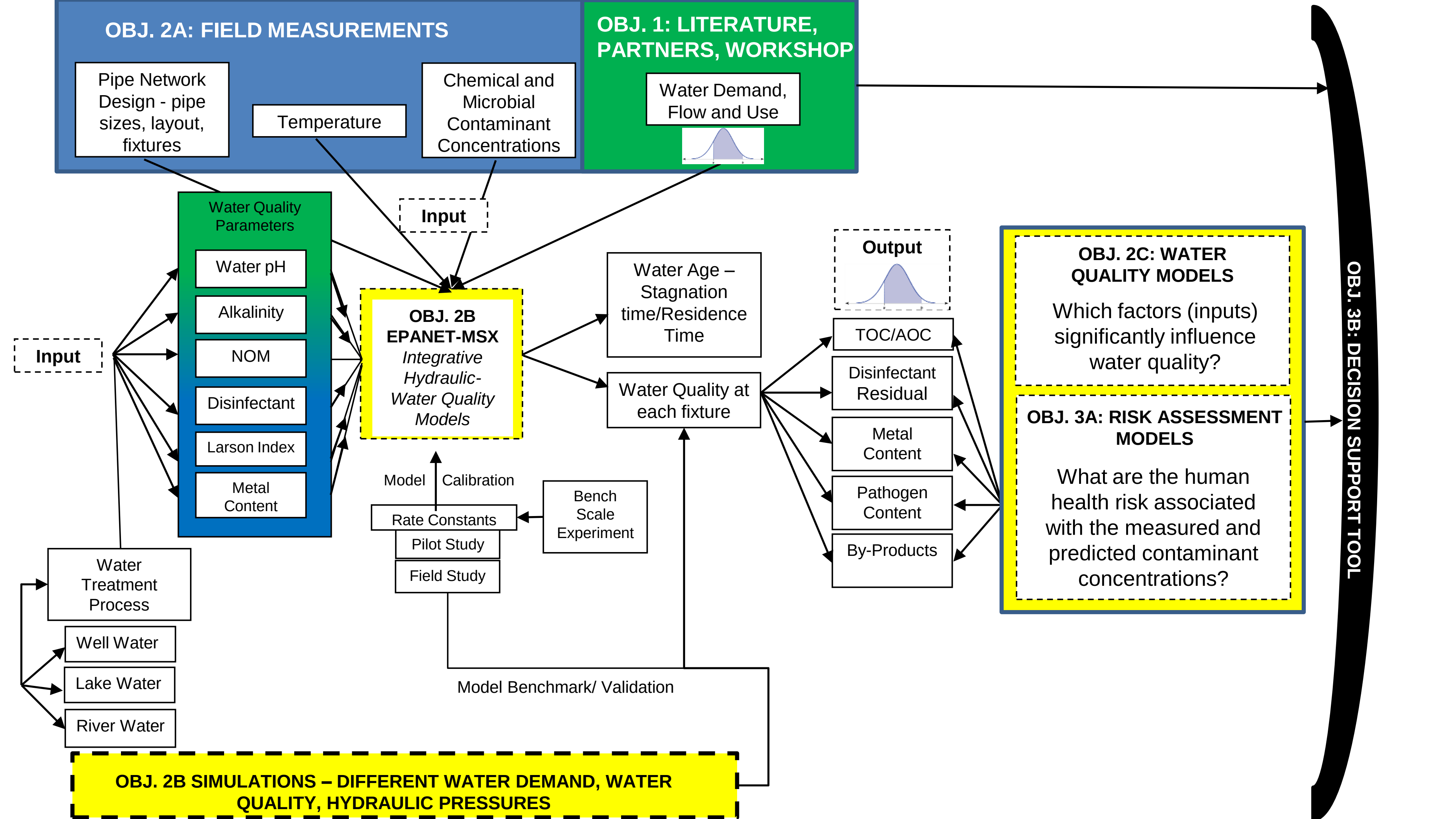
Project Goal and Objectives

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.


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
Model
Calibration
Rate Constants
Pilot Study
Field Study
Bench Scale Experiment
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
Water Treatment Process
Well Water
Lake Water
River Water
Model Benchmark/ Validation
OBJ. 2B SIMULATIONS – DIFFERENT WATER DEMAND, WATER QUALITY, HYDRAULIC PRESSURES

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TAPPED INTO PLUMBING

Issue September 2018

Reflecting on Year 2

By Andrew Whelton, PhD
Purdue University

Greetings !

Two years ago the US Environmental Protection Agency provided our team a grant to address a National Priority problem: Drinking Water Safety in Building Plumbing. Since then, we have accomplished a lot working with our 31 Partners. We have been testing drinking water safety in homes, schools, and other buildings and also conducting pilot and bench-scale tests. In 2019 you can learn more about this study and it's results through our website www.PlumbingSafety.org, meetings, and webinars.

It is mind-blowing to think about the sheer scope of what we are working on. This project would not have been possible without the tremendously talented cadre of students, postdoctoral associates, staff, and faculty in Indiana, Louisiana, New York, Michigan, and Tennessee. A special thanks is extended to our project partners shown on the next page! Here's a taste of what we've done:

- More than 300 million plumbing related measurements have been conducted at a single home alone. More than 15,000 drinking water quality sampling results have been obtained for that same building—and testing is not yet complete.
- Researchers have identified new exposure thresholds for some emerging disease causing organisms sometimes found in building drinking water.
- Students, postdoctoral associates, and staff have run thousands (possibly tens of thousands) of laboratory tests to better understand how plumbing can affect drinking water in plumbing rigs and at real buildings.
- Our team members have shared results with the public health and utility sectors along with regulators in California, Indiana, Louisiana, Nevada, Oregon, and Washington, DC.

Stay tuned and check our website for coming results. 2019 is going to be an amazing year. And, we hope you join us on this journey of discovery.

HEALTHY HOMES

By Andrew Whelton, PhD, Purdue University

While more than 136 million homes exist in the US, validated models for predicting water safety in homes are lacking. Through this project, we are addressing that problem head-on. Almost 1 year into our intensive drinking water testing study at a single-family home, we have an amazing series of discoveries. More than 300 million online water measurements and 15,000 water sample results have been collected—so far. Results will begin to be released in 2018 and 2019.

SCHOOLS AND OTHER LARGE BUILDINGS

By Tiong Gim Aw, PhD, Tulane University

For large buildings like schools, "Are chemical and microbiological characteristics of water the same during low water use Summer months compared to when school is back in session?" Our drinking water study of large buildings is addressing this question.

PLUMBING AT SCALE

Our state-of-the-art Plumbing Testing & Evaluation (T&E) Facility is up and running thanks to amazing and herculean efforts by students and staff. We now can test at-scale different plumbing components and designs. Online water quality monitoring, temperatures, flows, water heaters, pipes, faucets, home treatment equipment, chemistry and microbiology, and more. In 2019 we expect to initiate tests to better answer questions generated from our testing from real buildings. We are also on the lookout for collaborators. If you would like to work with us, have ideas, or wish to help, please contact us.

CONTACT US www.PlumbingSafety.org awhelton@purdue.edu

Partners, Supporters, and Participants

Whirlpool Corporation
Gordon & Rosenblatt
hbn Healthy Building Network
IDEM
Watershed, LLC
Indiana State Department of Health
HRC
Community Engineering Services, PLLC
U.S. Green Building Council LEED USGBC
The Nature Conservancy
Genesee County Health Department
citizens energy group
Avon Community School Corporation
NEHA National Environmental Health Association
DeKalb County Georgia
IRWA
IAPMO
NIST National Institute of Standards and Technology U.S. Department of Commerce
Science Interactive
ASPE American Society of Plumbing Engineers
Naval Hospital Jacksonville, Florida
InspectAPedia
Université Laval
Technion Israel Institute of Technology
University of Cincinnati

Visit www.PlumbingSafety.org

Obj 1. Our Industrial Stakeholders Workshop, 2017

Stakeholder Questions from the Workshop

Research Theme	Priority Research Questions
Stagnation	How does stagnation affect water quality? How does stagnation affect microbial growth? How can microbial growth in the plumbing system be minimized? How can a simple experimental setup be used to study all the effects that could affect water quality in general?
Water use	How does water use vary by building type, within buildings, and with season? How is water use related to water quality? What are effective protocol(s) for collecting water use and quality data that capture variability? Do certain patterns of use or plumbing systems, such as recirculating hot water systems, pose an increased health risk?
Standards	What are the hazardous conditions in the plumbing system? What control measures are needed to address the hazardous conditions? What is the limit of acceptance? How will the system be monitored?
Risk & Disease Modeling	Do the pathogens of interest have good dose response models? What are the thresholds of safe conditions to be used for the models? How should variability and risk across different communities, such as competent versus immunocompromised, be addressed? What number of each building or community type should be investigated before we have statistical confidence that we can model risk?
Safety & Sustainability	How does water quality degrade in standard vs water-efficient buildings problems are created for different building types when low-flow fixtures are installed? What changes to standards are required to increase water use efficiency while maintaining effective sanitation and supply? When and where is it safe and practical to use reclaimed water?

To view these download our newsletter at www.PlumbingSafety.org

What is the Most Monitored Home in America?

Solar panels
Net-zero waste
Energy efficient appliances
Rainwater catchment
Greywater recycling
Online monitors throughout bldg

ReNEWW House = Retrofit Net Zero Energy, Water, and Waste

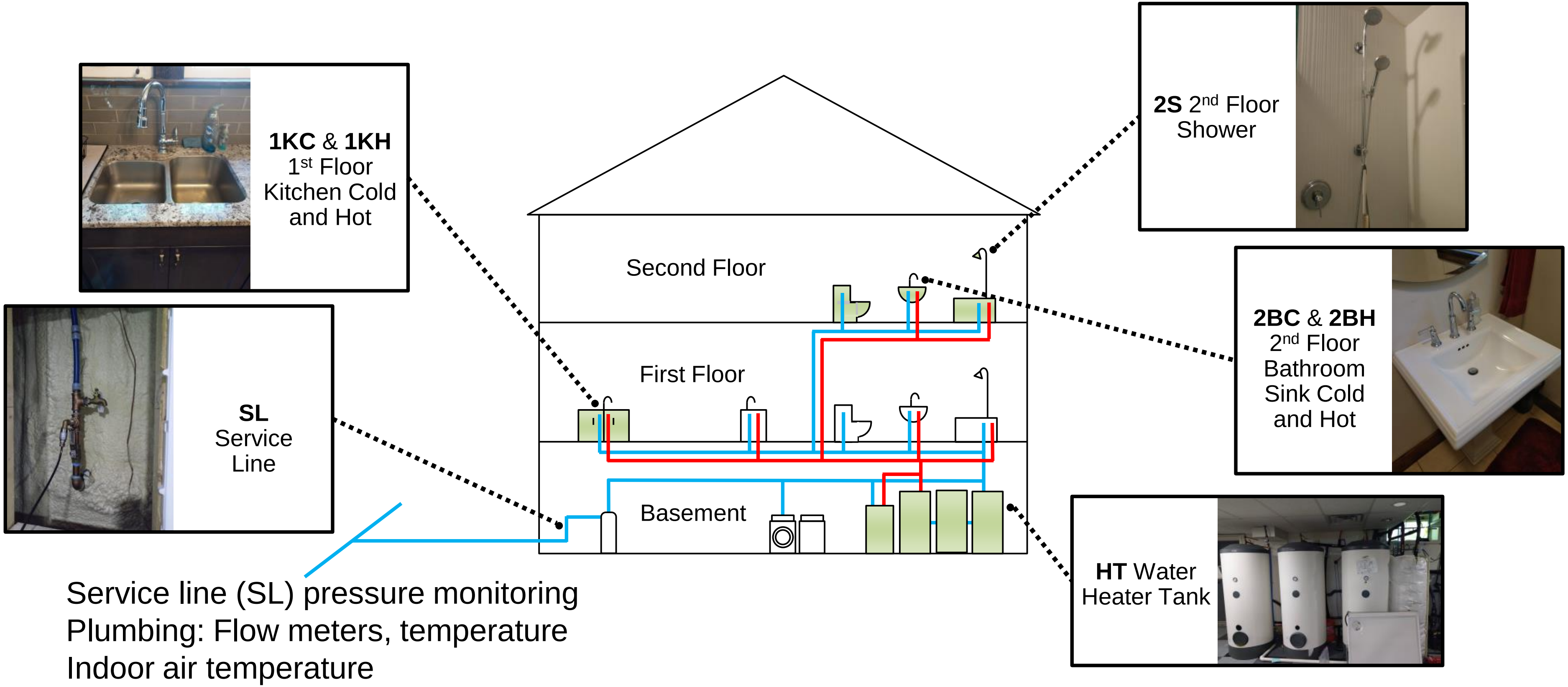
West Lafayette, Indiana
Less than 100 yards from lab
3 Bedroom, 1.5 baths
Water saving fixtures
Trunk-and-Branch design
PEX piping
Renovated in 2014

October 2017 to October 2018

Continuous monitoring of water flow, air and water temperature at service line and all plumbing components

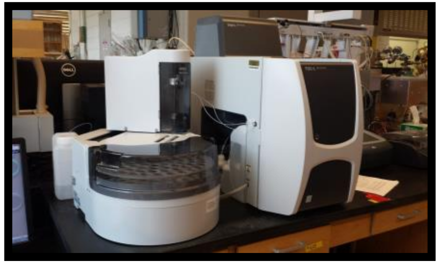
Pressure monitoring

[Online water quality monitoring at service line]



Sampling locations
50x, hot & cold water, 7am, 12pm, 3pm

Drinking Water Quality Monitoring



Chemical

Chlorine residual, pH, temperature,
Dissolved oxygen (DO)
Total and dissolved organic carbon (TOC, DOC)
Total and dissolved metals
Ions
Total trihalomethanes (TTHM)

Microbial

Culture-based heterotrophic Plate Count (HPC)
Assimilable Organic Carbon (AOC)
Quantitative Polymerase Chain Reaction (qPCR)

ReNEWW Home Preliminary Results

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

600+ million online plumbing related measurements

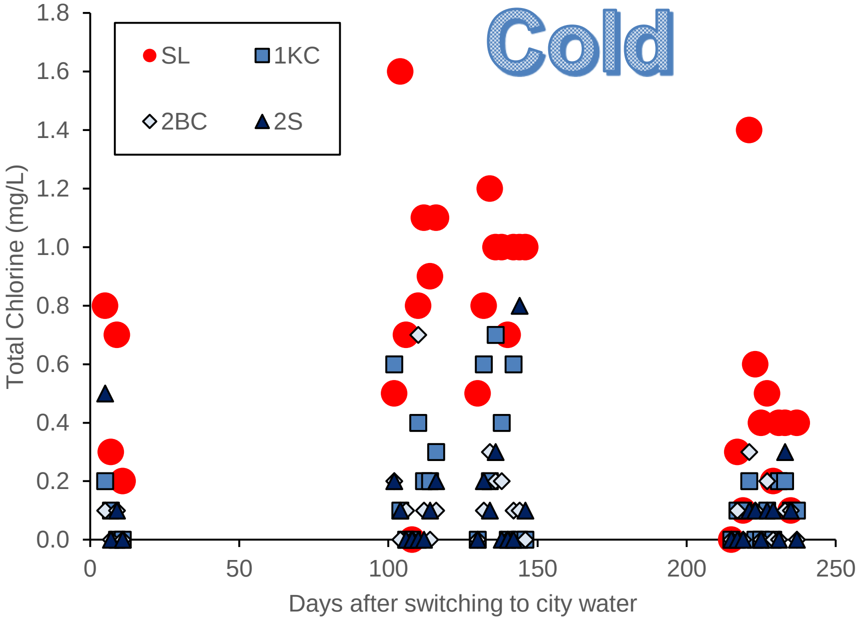
Water in pipes equilibrates to ambient temperature quickly (<4 hours)

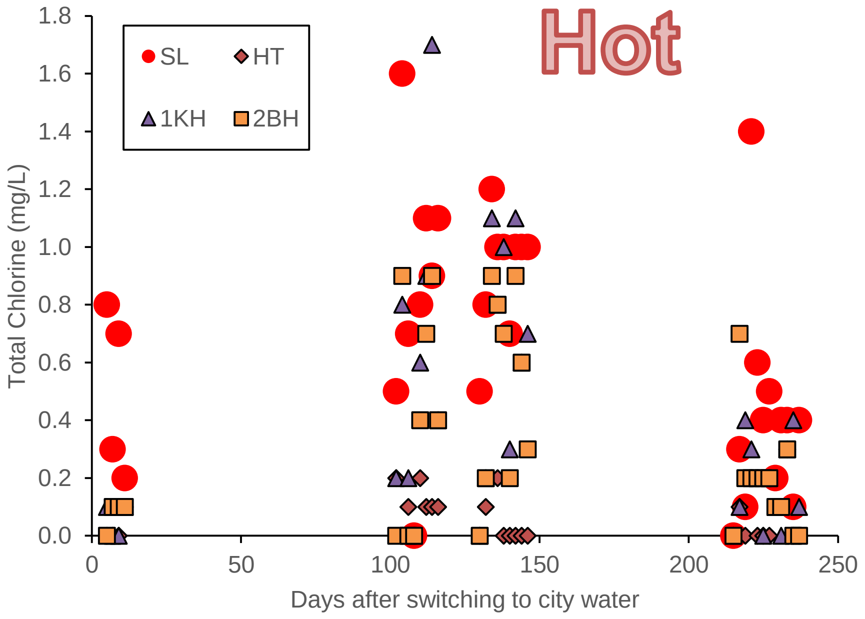
Usage events are short; ~70% of events are less than 5 seconds

Snapshot of Preliminary Total Chlorine Results

(Service line = **red**)

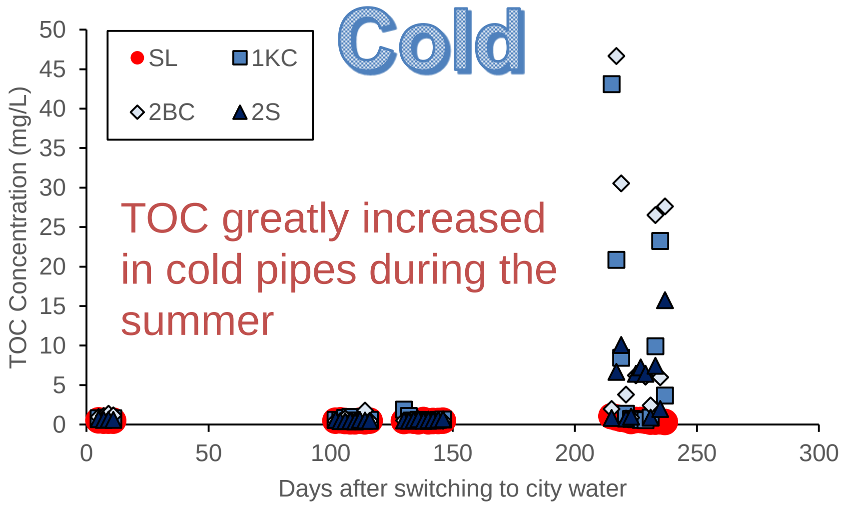
not found in more than 50% of water samples exiting the water heater, at the 1st floor kitchen sink cold, 2nd floor bathroom sink cold, and 2nd floor shower

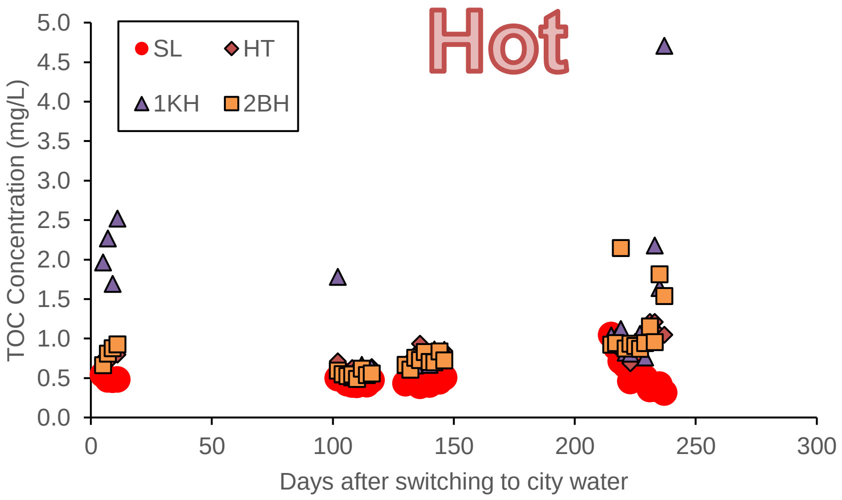




Snapshot of Preliminary Organic Carbon Results

(Service line = red)





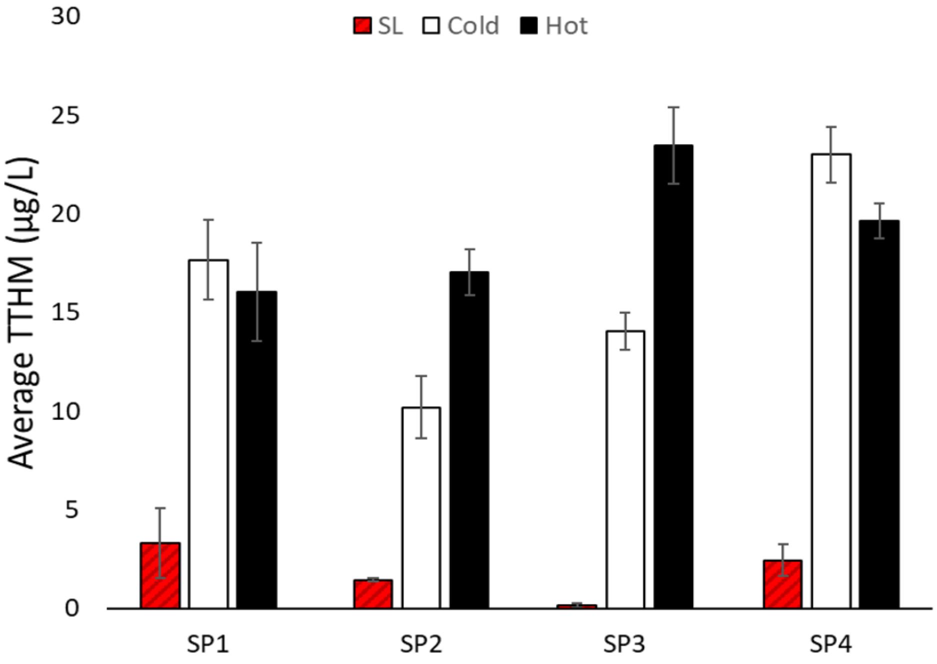
Often >70% organic carbon was dissolved

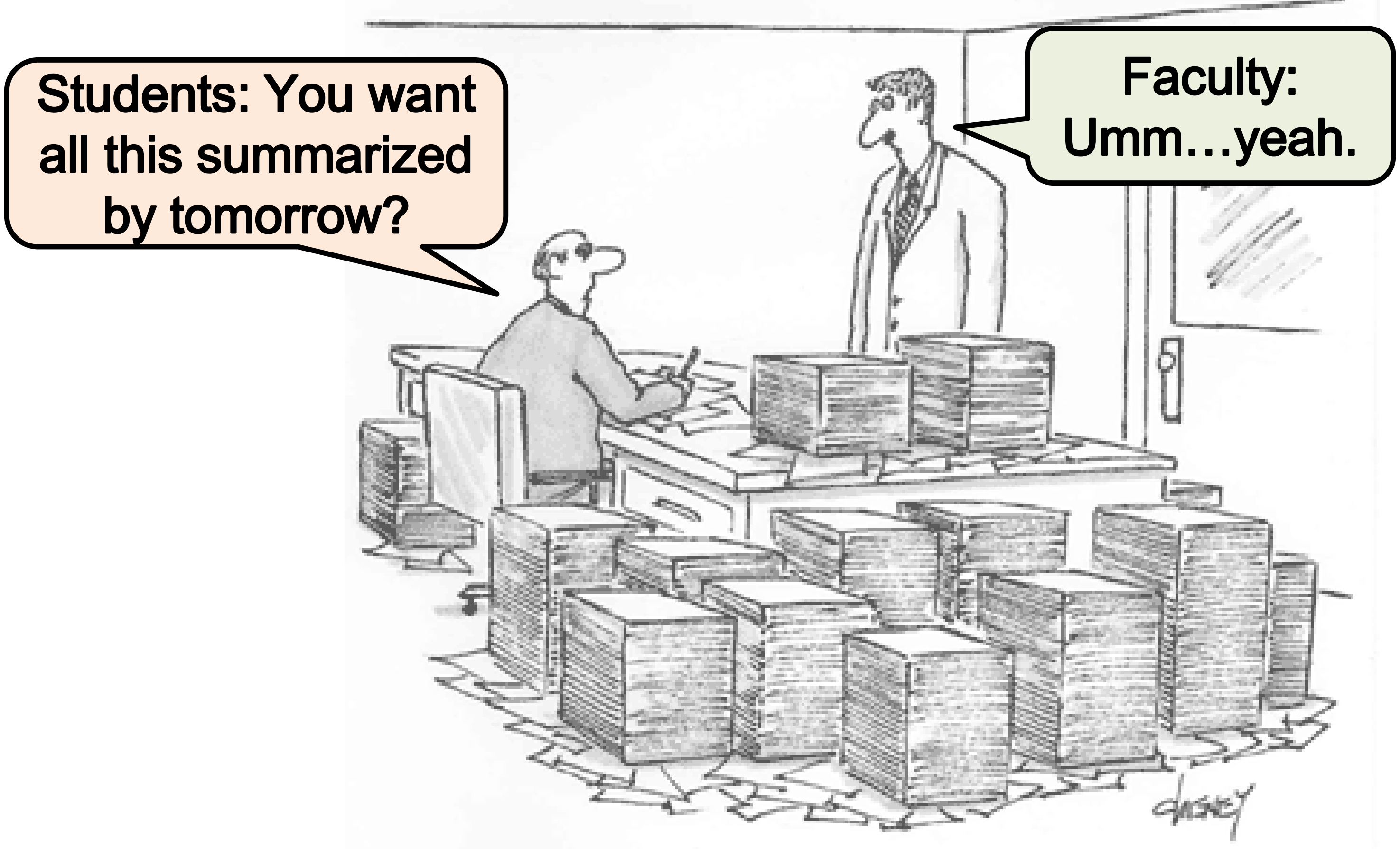
Snapshot of Disinfectant Byproduct (DBP) Results

Total Trihalomethane (TTHM) levels were consistently greater within the house when compared to city water entering the house

The concentration of TTHMs was greater in cold pipes during warmer months and in hot pipes during cooler months

98.5% of TTHMs were generated within the house





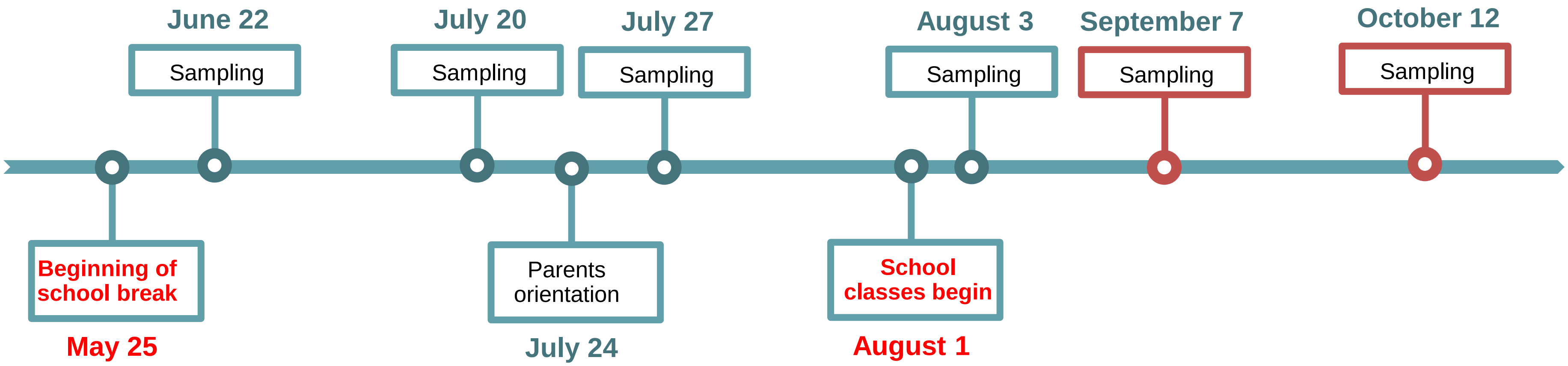
30,000+ individual water quality measurements completed
600+ million online plumbing related measurements

Field Study School

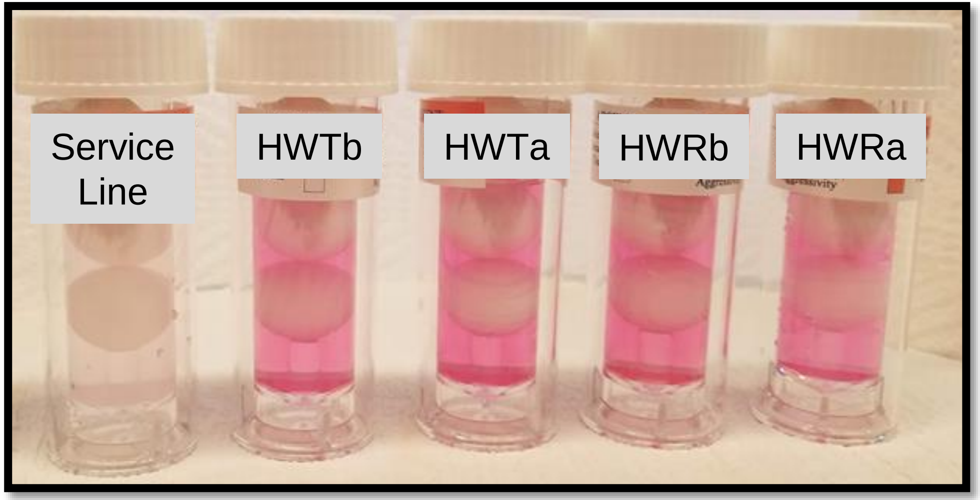
7 year old LEED middle school receives chloraminated water from a public water system; Copper plumbing, water softener, hot water recirculation system - 4 zones.

Study Goal: Understand how drinking water chemical and microbial parameters change during the ***transition from Summer to Fall***

- Service line, staff kitchens, bathrooms, showers, classroom, water bubblers



Preliminary Analysis: More than 4,500 Tests

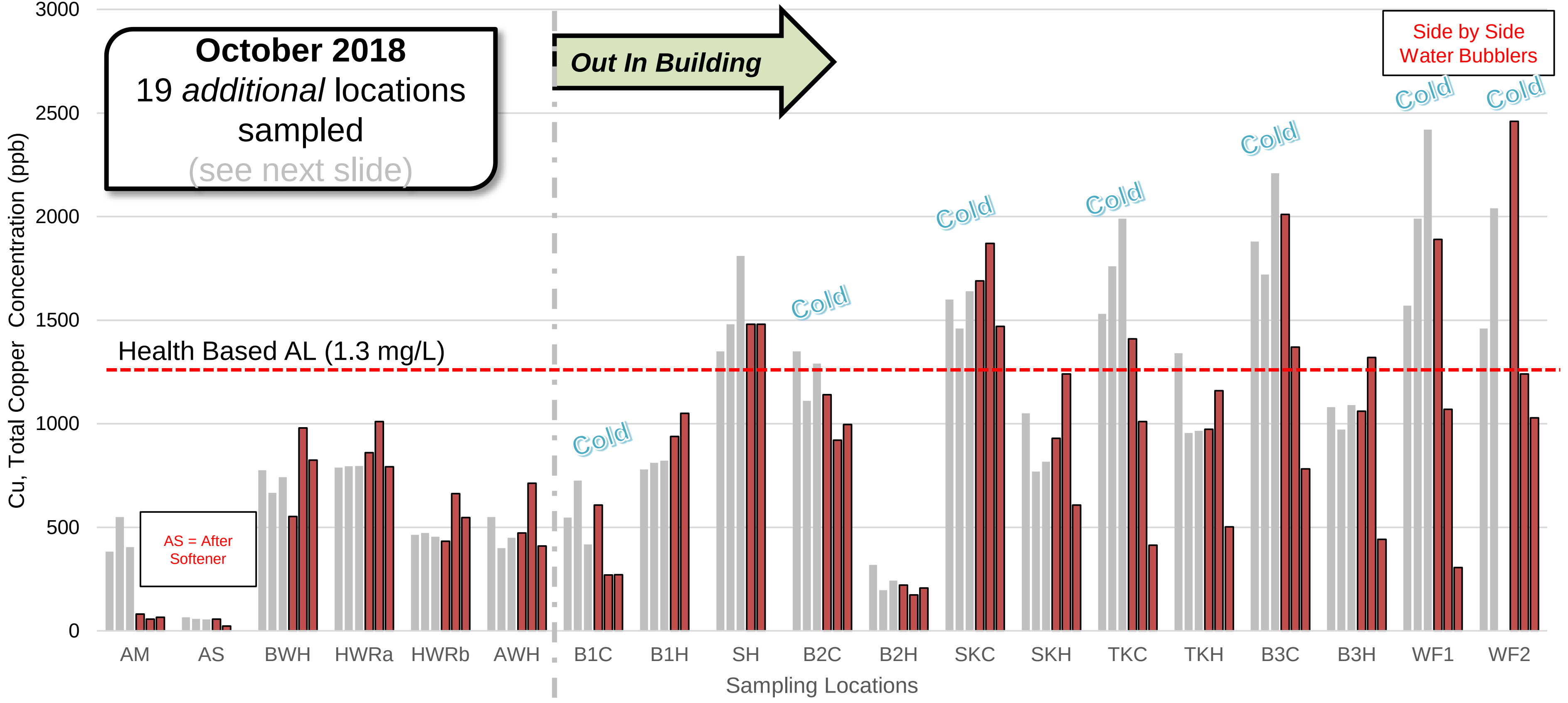


Nitrifying bacteria detected in hot water system
Free ammonia detected
Total chlorine$_{\text{service line}}$ > Total chlorine $_{\text{In-building}}$
Hot water organic carbon > Cold water

So far….Quick Estimate Values

- *In-building water pH: 7.2 to 8.4*
- *AOC <20 µg/L to about 200 µg/L*
- *Many more chemical, physical, & microbial parameters*

Copper drinking water action level was exceeded June 2018 to October 2018



Routine Sampling Locations in October	1st grab (mg/L)	2nd grab (mg/L)	Our Experience with Locations
B2C	0.996	1.470	3 of 7 prior samples exceeded the AL
SKC	1.470	0.561	7 of 7 prior samples exceeded the AL
None of our other routine locations exceeded the copper AL during the October sampling event			

of 19 Routine Sampling Locations

In October we added 19 new cold water sampling locations

New Sampling Locations in October	1st grab (mg/L)	2nd grab (mg/L)
SRS - shower room right sink	0.123	0.149
SLS - shower room left sink	0.479	0.164
B2CR - bathroom 2 cold right	0.949	1.403
B2CL - bathroom 2 cold left	1.164	1.452
SKD - student kitchen sink D	1.32	0.832
SKF - student kitchen sink F	1.58	0.529
FK - faculty kitchen - A108	0.831	0.120
ARRS - art room right sink - F105	0.424	0.638
WF3 - water fountain 3 - F112 (choral room)	1.773	1.360
WF4 - water fountain 4 - F115W	1.047	0.902
WF5 - water fountain 5 - B103B	0.945	0.374
ABS - auditorium back sink	1.141	1.314
B3LS - bathroom 3 left sink	0.898	0.866
B4 - bathroom 4 - C124G - next to sink 2	1.141	0.868
B5 - bathroom 5 - B103B	0.275	0.216
B6 - bathroom 6 - B124B	1.097	0.819
B7 - bathroom 7 - B112W - staff bathroom	0.649	0.618
B8 - bathroom 8 - C112W - staff bathroom	0.697	0.646
B9 - bathroom 9 - A108M - in office	0.142	0.105

- ✓ **You cannot flush away this problem. It exists other places too.**
  - Discarding first 250 mL of water did not consistently reduce copper levels
  - Flushing 1.5 Liters of water at each location (3-5 minutes) did not consistently reduce copper levels
  - Flushing can remove large volumes of stagnant water, but rebound likely
- ✓ POU devices likely needed and/or in-building treatment
- ✓ Additional water testing needed

Summer water quality was more degraded than fall drinking water quality after students returned

Where we are headed: Anticipate this situation through building design to avoid contaminated water

Our Plumbing Testing Facility is Ready: Plumbing, Water Use, and Water Quality Relationships

Full-Scale Testing

Plumbing Testing Facility @ Purdue

Other Field/Bench-scale tests

This is an opportunity.

NOW LIVE:

Pilot scale testing facilities for water quality testing in premise plumbing.

Plumbing for Innovation and Prosperity

Questions: Andy Whelton, awhelton@purdue.edu

Learn more at www.PlumbingSafety.org

Follow us on Twitter @PlumbingSafety

Funding: Environmental Protection Agency grant R836890

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