Development of Premise Plumbing Hydraulics-Water Quality Models

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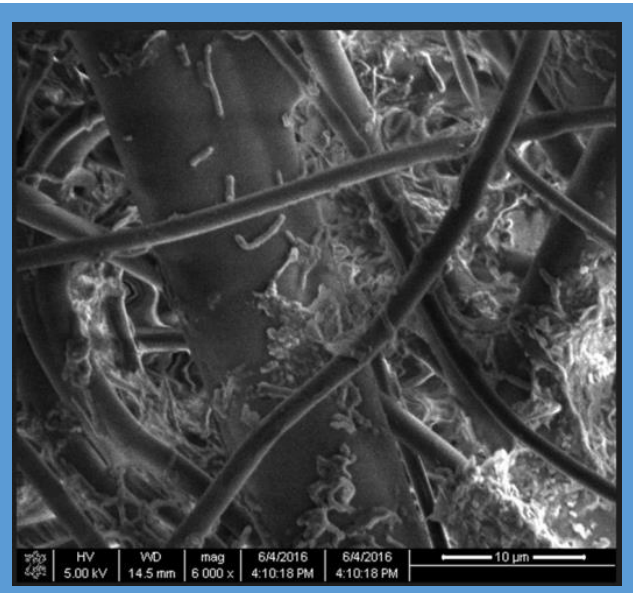
Building Plumbing Safety: Right Sizing Tomorrow's Water Systems for Efficiency, Sustainability, & Public Health


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

ACS Spring Meeting 2018

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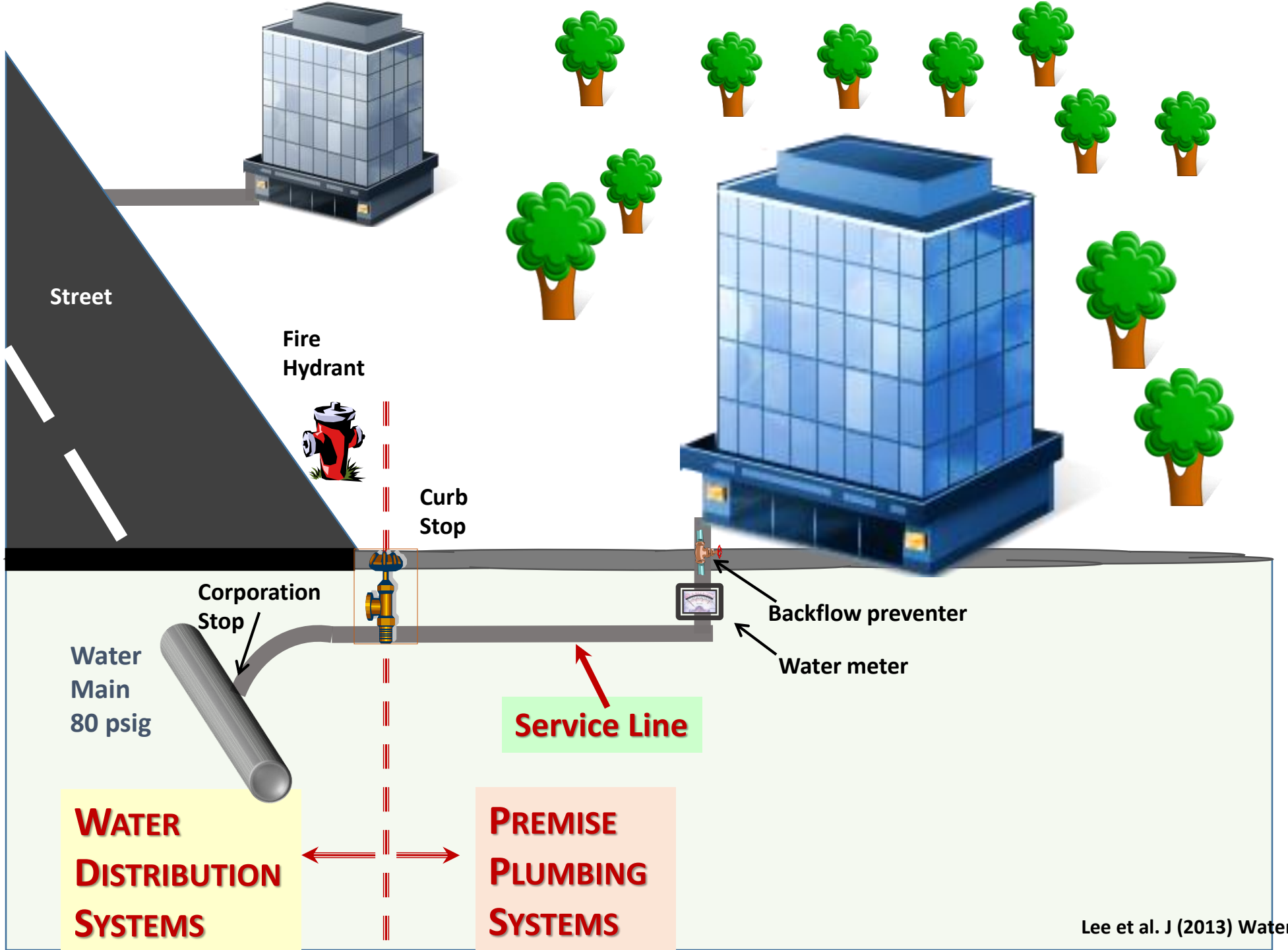
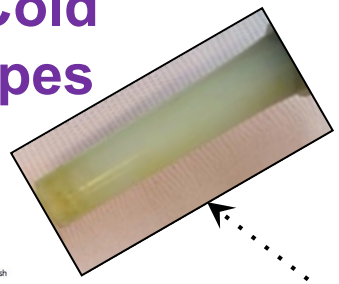


Lee et al. J (2013) Water Supply AQUA 64(2)

Hot vs. Cold Water Pipes

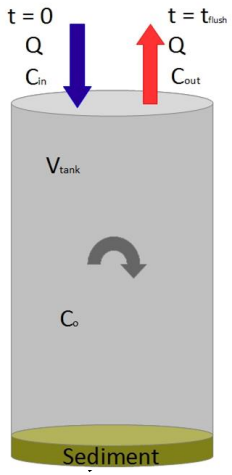


Metals and Plastics

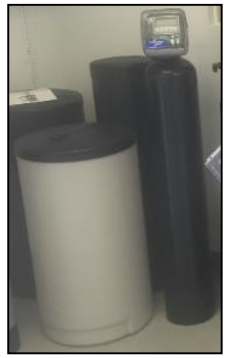
Fixtures and Aerators

POU Devices

Corrosion Products

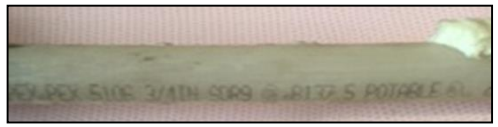


Water Heater



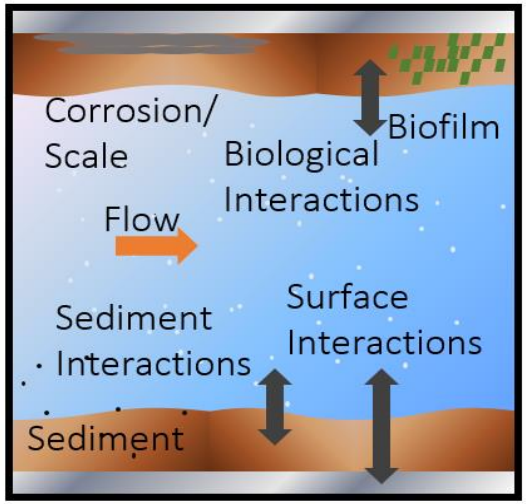
Water Softener

Whole House Filter



Service Lines

Habitat



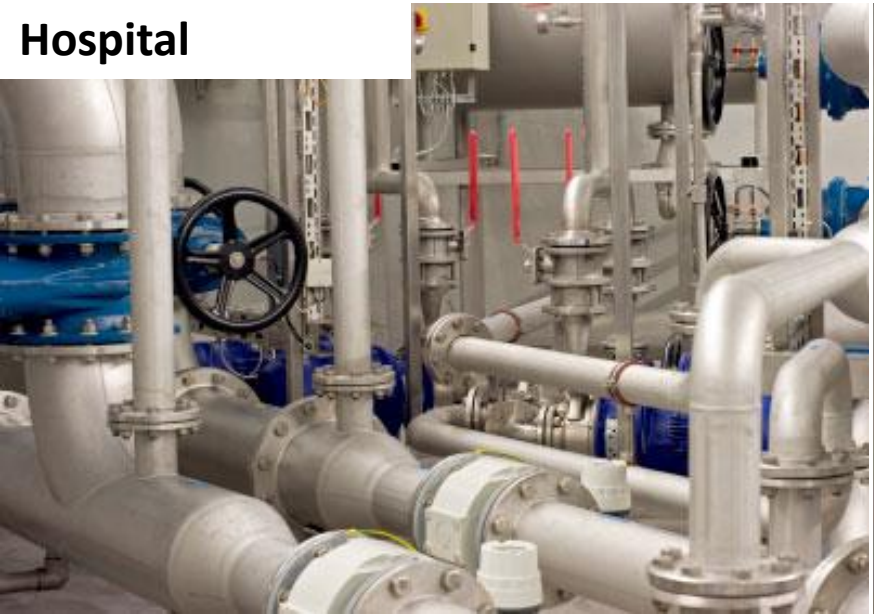
Premise plumbing is complex

Food Prep Facility

Domestic Hot Water

PEX pipe with copper manifold

Hospital



Cartridge Filters

Some images courtesy of: Gordon & Rosenblatt, LLC

Copper pipe to cPVC pipe

Building Water Use has Been Declining

Water Use Energy Policy Act of 1992

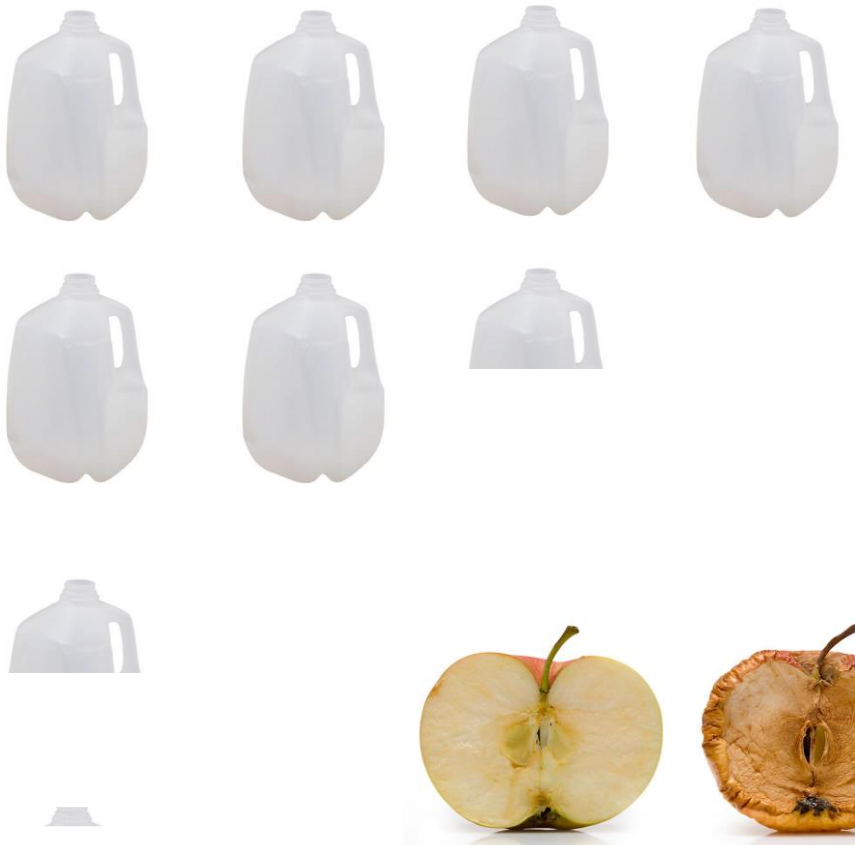
Water Use has Decreased From Lower-Flow Faucets

Pre-1994 (4^+ gpm)

1994 (2.5 gpm)

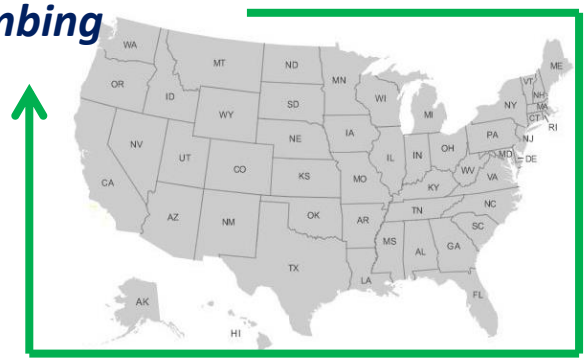
2015 (0.5 gpm)

2016? (0.01 gpm)



Residential plumbing is critical for the health and safety of populations worldwide.

5-10 million miles of plumbing



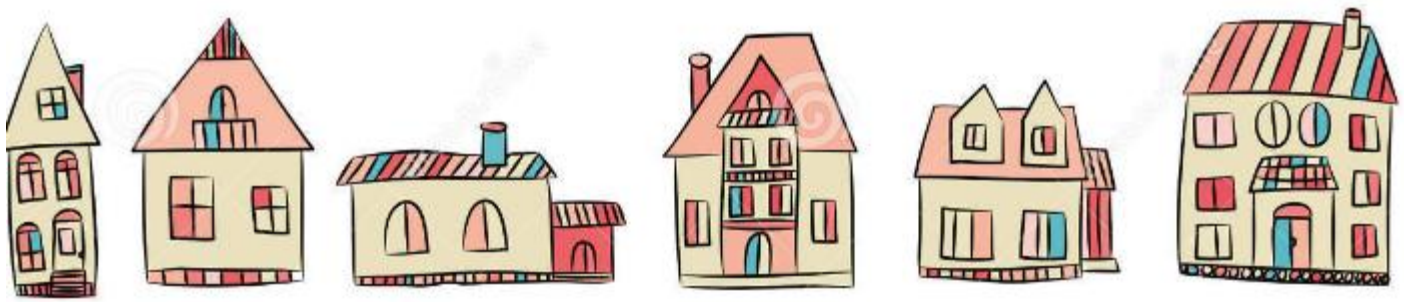
Water saving & Low-flow devices

Increased water age

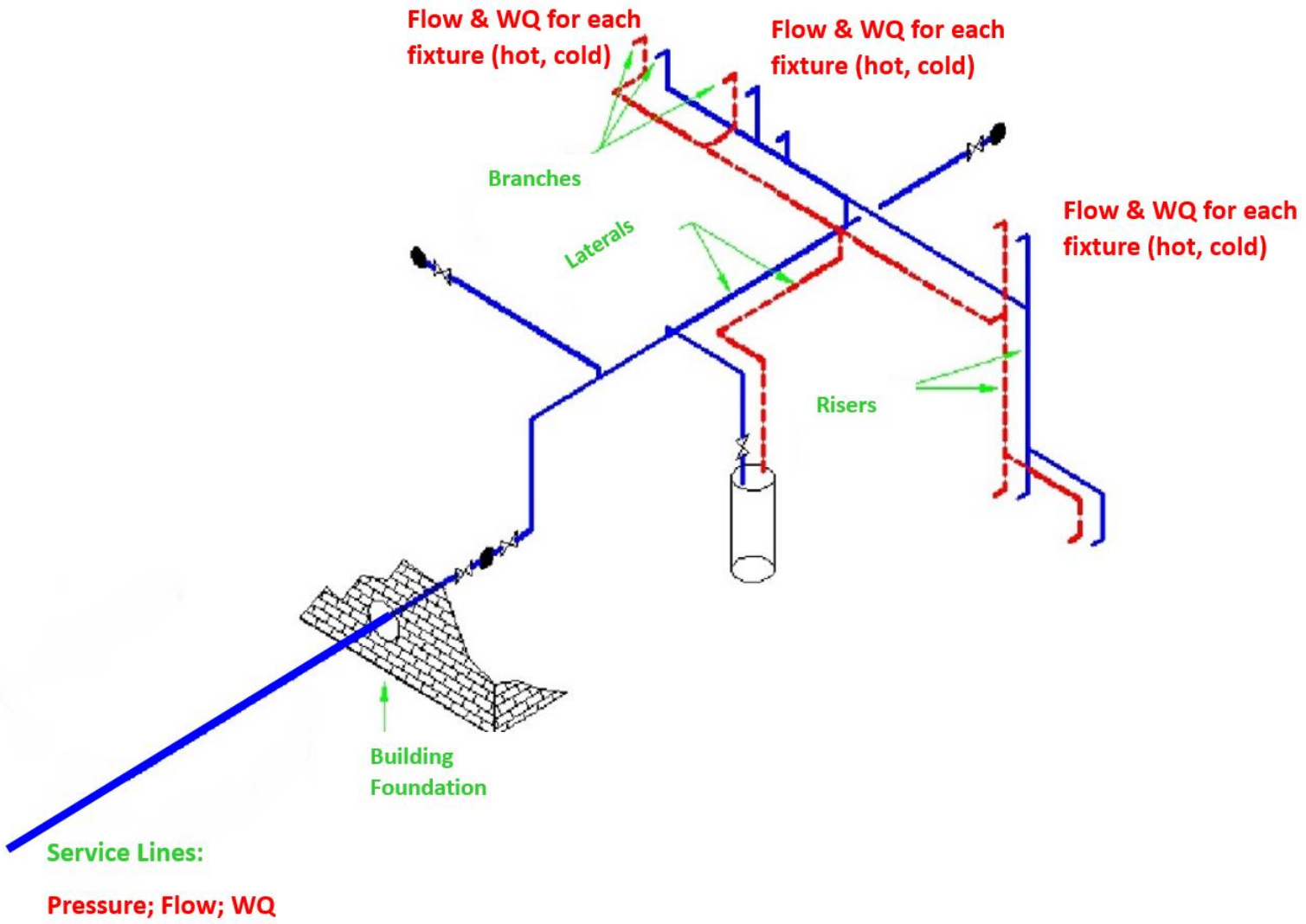
Disinfectant residual loss

Microorganism proliferation

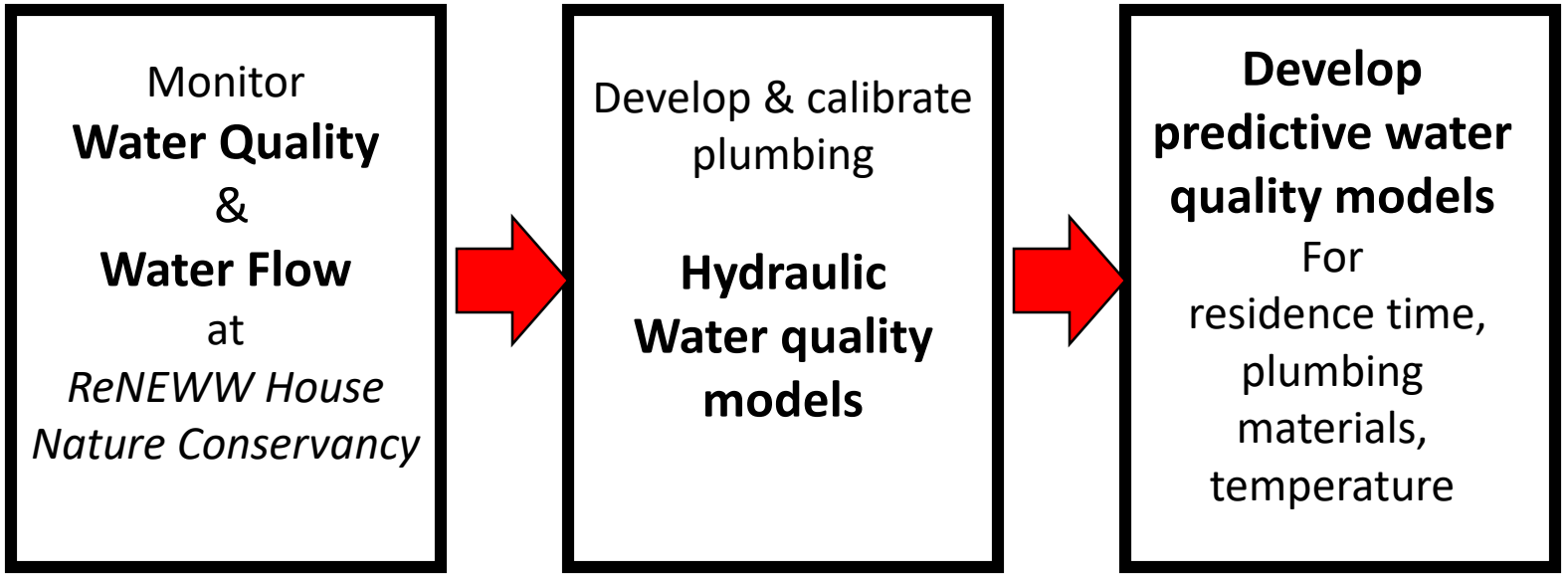
Enable contaminant leaching



Integrative Hydraulic – WQ Modeling:



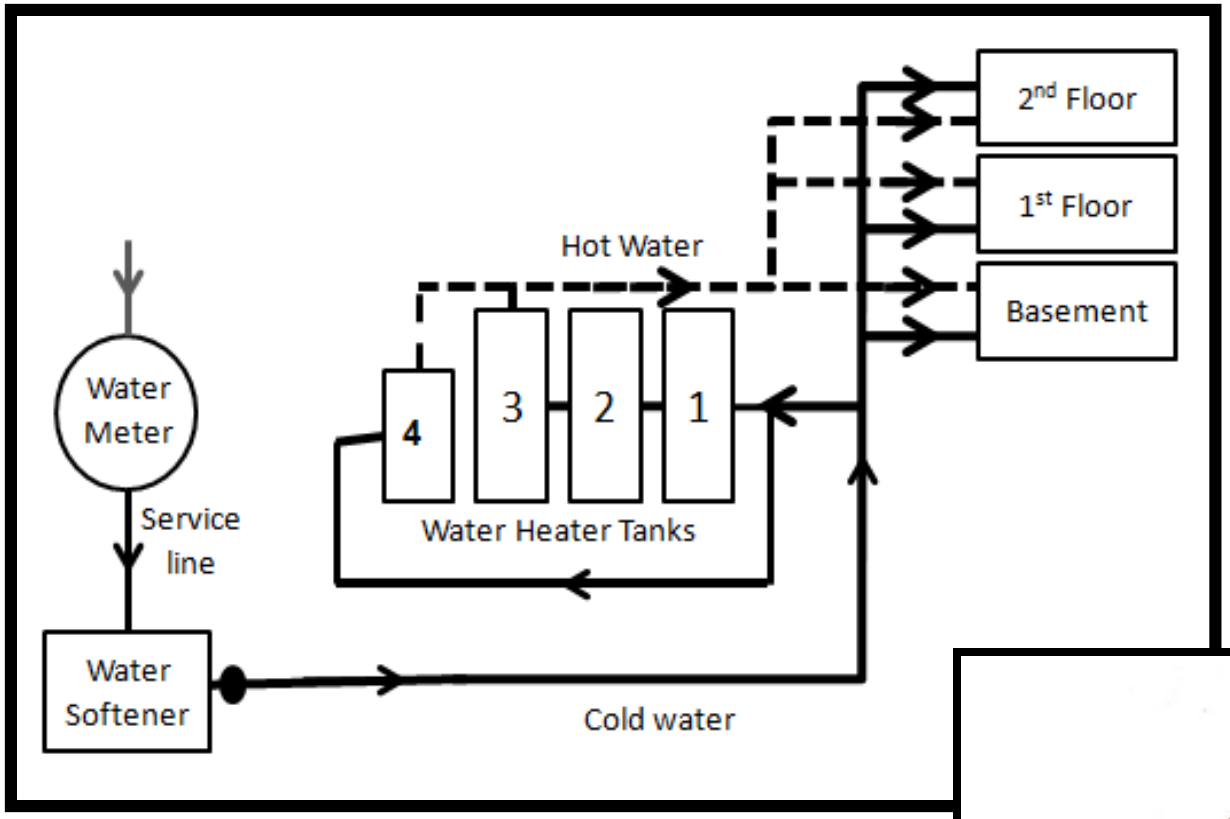
Goal: *Elucidate the factors & their interactions that affect water quality through integrative water distribution system-premise plumbing models.*



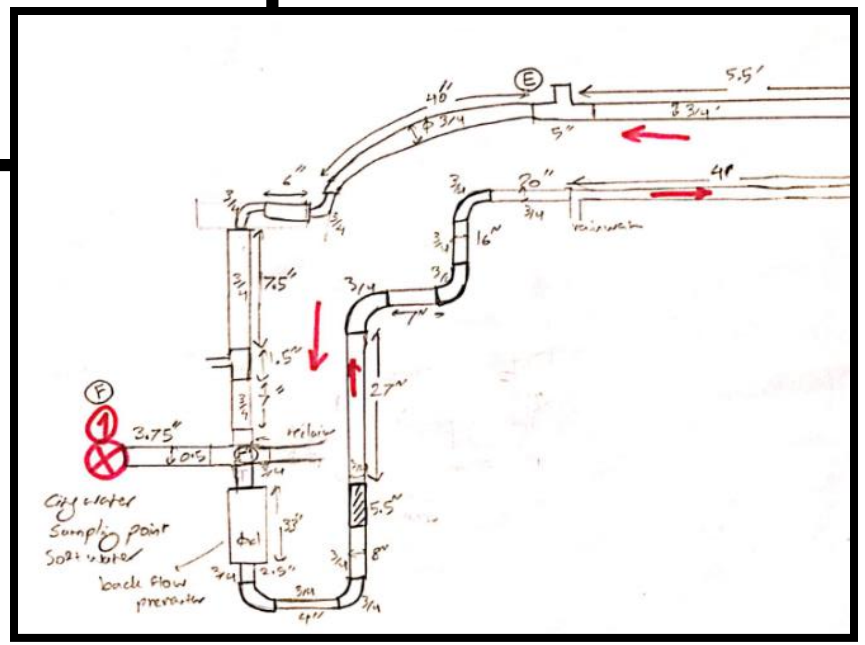
Retrofitted Net-Zero Energy, Water and Waste

http://www.ReNEWWhouse.com

2015: PEX plumbing removed, new PEX plumbing installed, city and rainwater use;
City water: Groundwater, treated with $KMnO_4$, free chlorine residual, PVC and Iron water mains



PEX-A pipe



Pipe Type	Diameter (ID), cm	Length, m	Total Internal Surface Area, m^2
Cold	1.2	41.9	0.3
Hot		40.9	0.3
Cold	1.7	35.8	0.3
Hot		38.3	0.4

Chemosphere

Available online 30 November 2017

In Press, Accepted Manuscript — Note to users

Case study: Fixture water use and drinking water quality in a new residential green building

Maryam Salehi[a], Mohammad Abouali[b], Mian Wang[a], Zhi Zhou[a, c], Amir Pouyan Nejadhashemi[a, d], Jade Mitchell[b], Stephen Caskey[e], Andrew J. Whelton[a, c]

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https://doi-org.ezproxy.lib.purdue.edu/10.1016/j.chemosphere.2017.11.070

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Goal: To better understand link between water use & drinking water quality.

Hypotheses:

1. Water quality inside the building influenced by chemical leached by PEX pipes.
2. Fixture usage pattern & water temperature influence organic & bacteria levels in water.
3. Less frequent used fixtures have lower water quality.

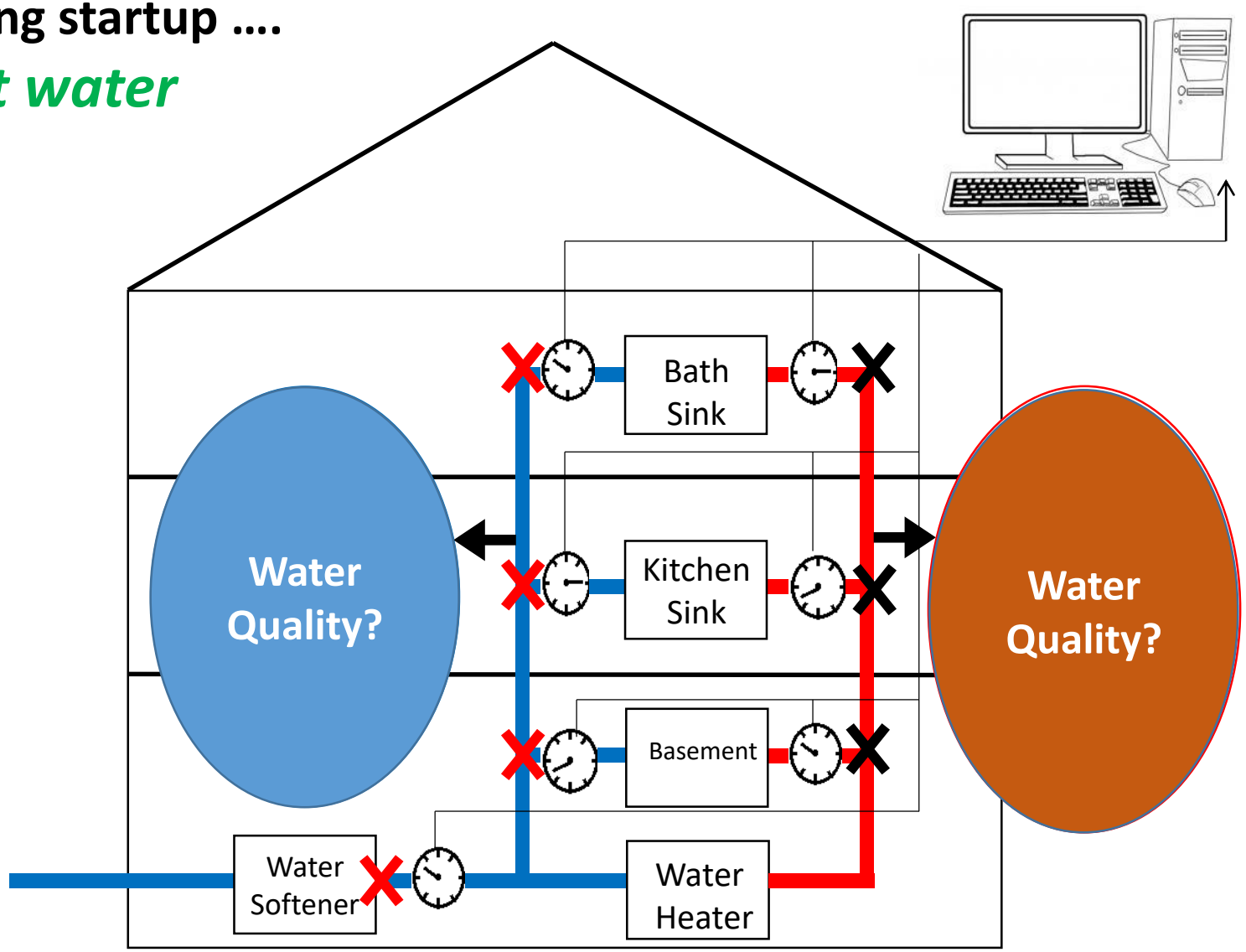
During the 4 month building startup ….

How does cold and hot water quality change?

<u>Monitoring</u>
After softener
Basement (cold/hot)
Kitchen sink (cold/hot)
Bathroom sink (cold/hot)

Online flow
Online fixture temp
Grab water sampling

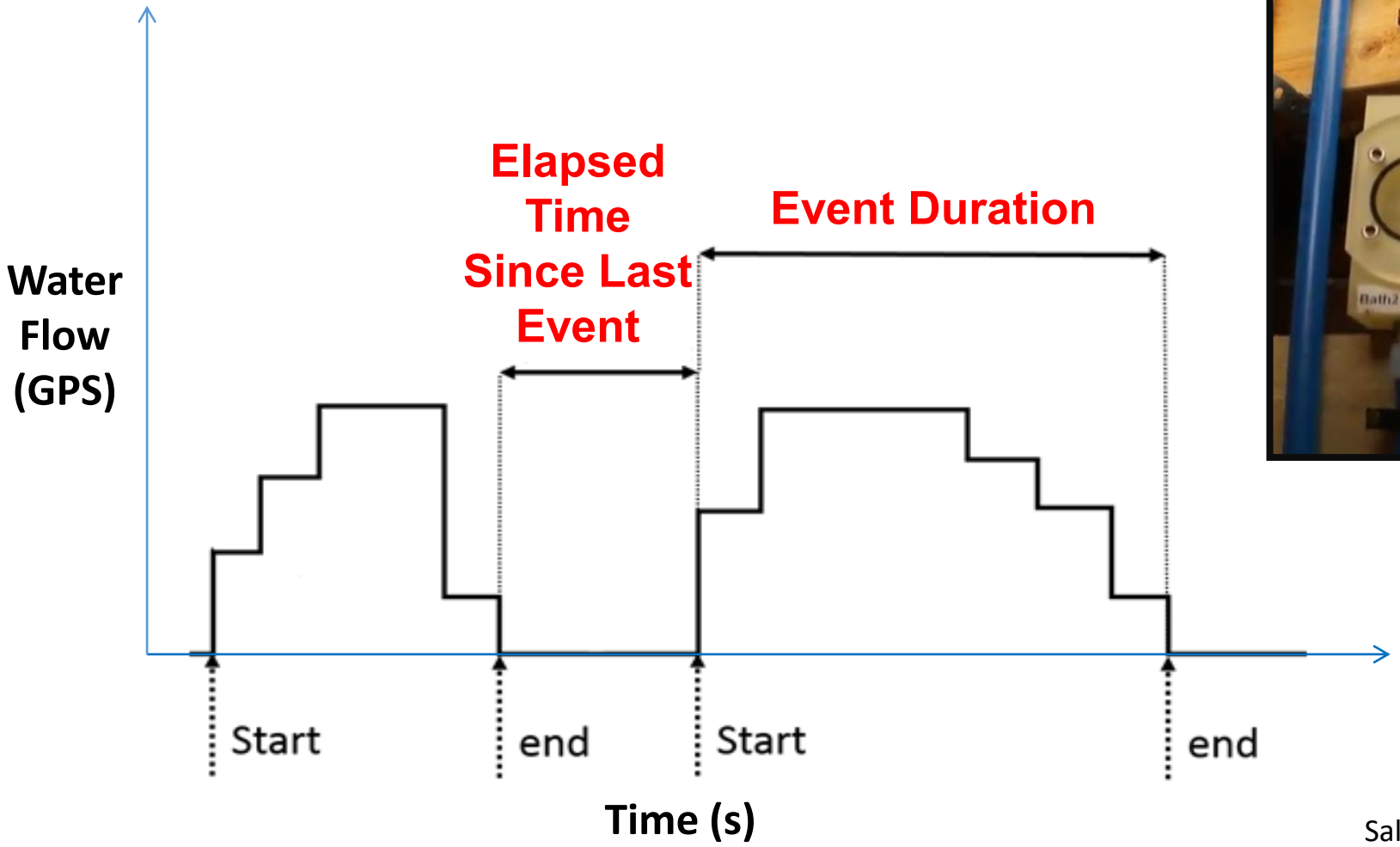
- Day 3, 15, 30, 60 & 90
- Onsite: pH, chlorine residual, temp
- Lab: TOC, total metals, HPC, gene copies



Salehi et al. (2018). *Chemosphere.* https://doi.org/10.1016/j.chemosphere.2017.11.070

Water Usage Monitoring & Analysis

4 months = 64,891,484 *data points*



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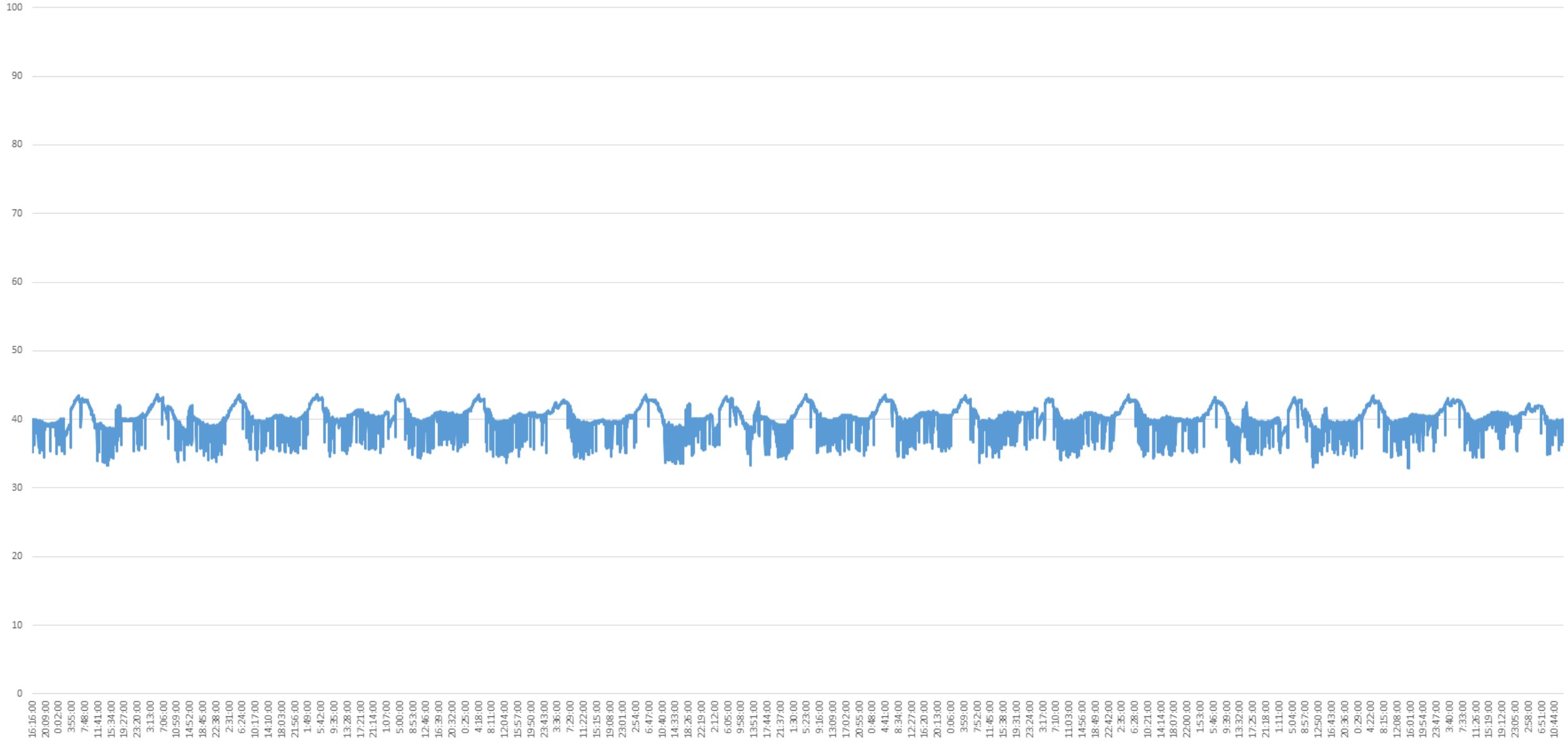
Water Usage Patterns for a Few Fixtures Monitored in December 2015

Parameter / Fixture	Total Volume Used (m^3)	Number of Events	Average Elapsed Time (hr)	Maximum Elapsed Time (hr)
Service Line	5.2	3535	0.1	72
Basement-Cold	0.4	60	0.5	72
Basement-Hot	0.04	21	0.7	72
1st Floor-Cold	0.3	619	0.6	72
1st Floor-Hot	0.2	389	0.9	72
2nd Floor-Cold	0.1	145	2.0	72
2nd Floor-Hot	1.0	825	0.5	72

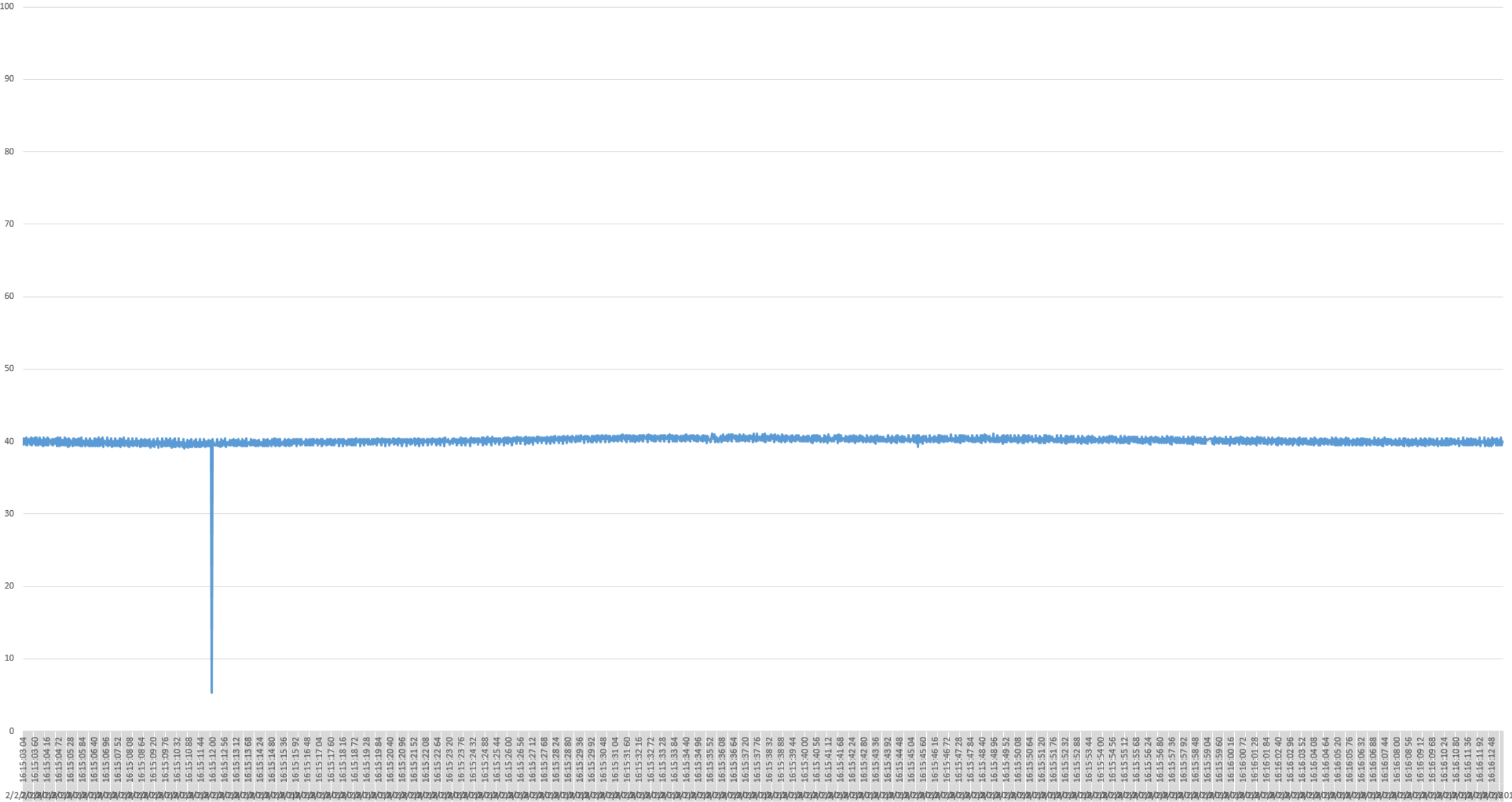
Water Usage Patterns

- During October to December the daily water usage varied between **0.169-0.245** m^3/d.
- **Basement fixture** was the least used (number of events at cold: 60-105, hot: 21-69) compared to the other fixtures in the building (number of events at cold: 145-856, hot: 326-2,230).
- During October to December the most frequently used fixture was the **2nd floor hot water** (bathroom sink, number of events per month 2,230).

1/19/2018-2/7/2018
Pressure @Service Line

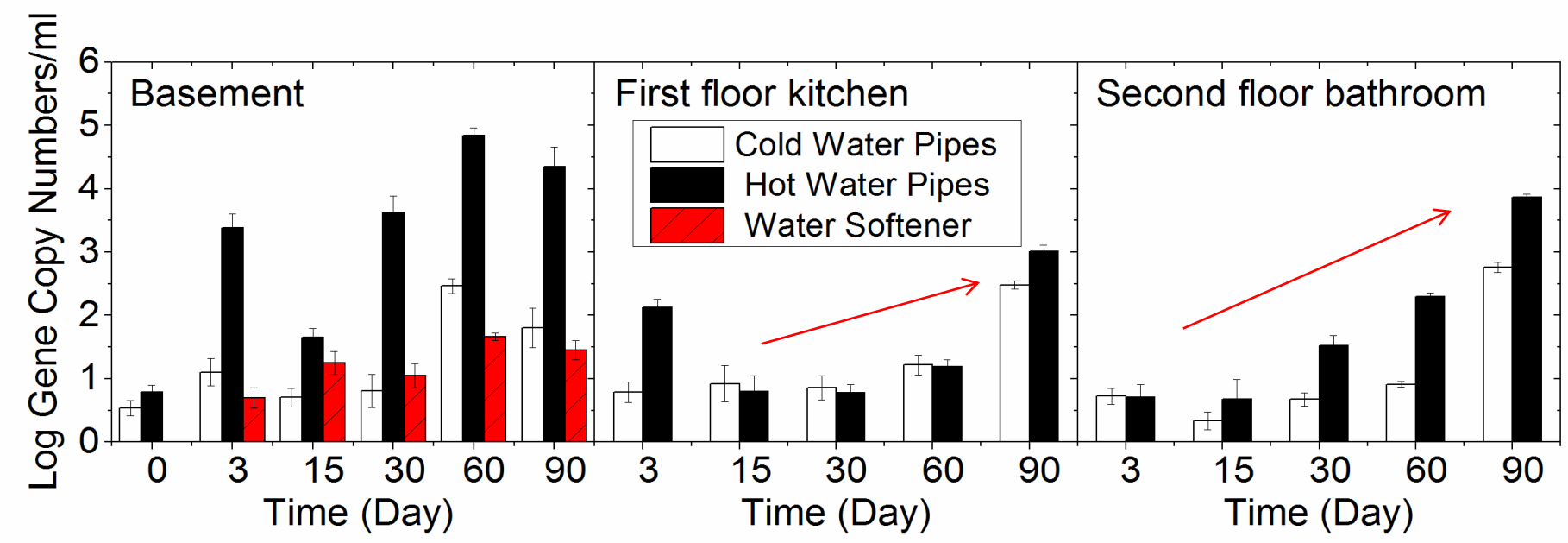


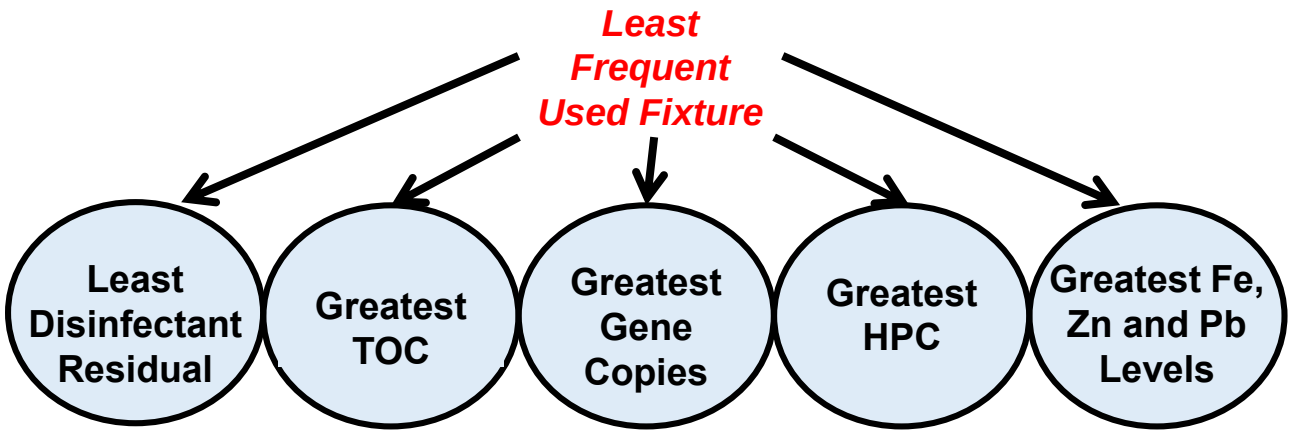
2/2 Pressure



2/3 Pressure

During the 4 month startup, bacteria levels increased with time and bacteria were more numerous in hot water vs. cold water





Basement: Pb AL exceeded
Basement: Zn SMCL exceeded
All locations: Odor SMCL exceeded

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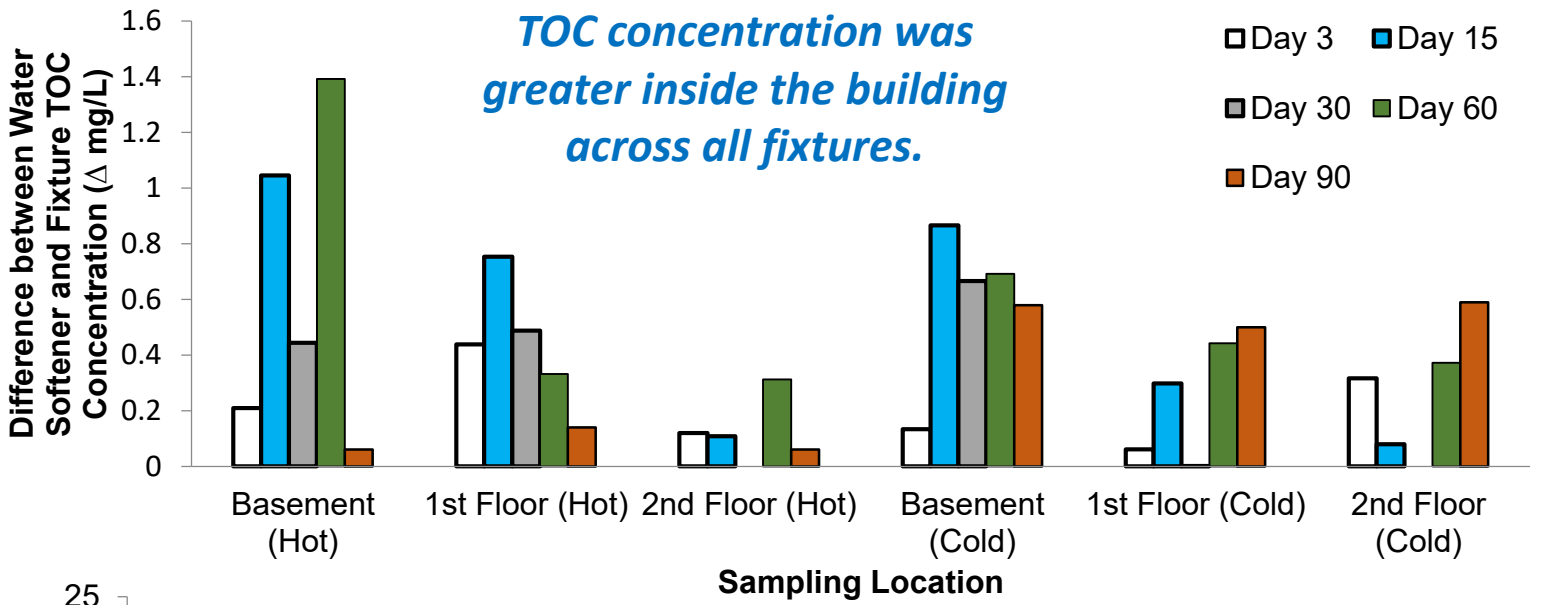
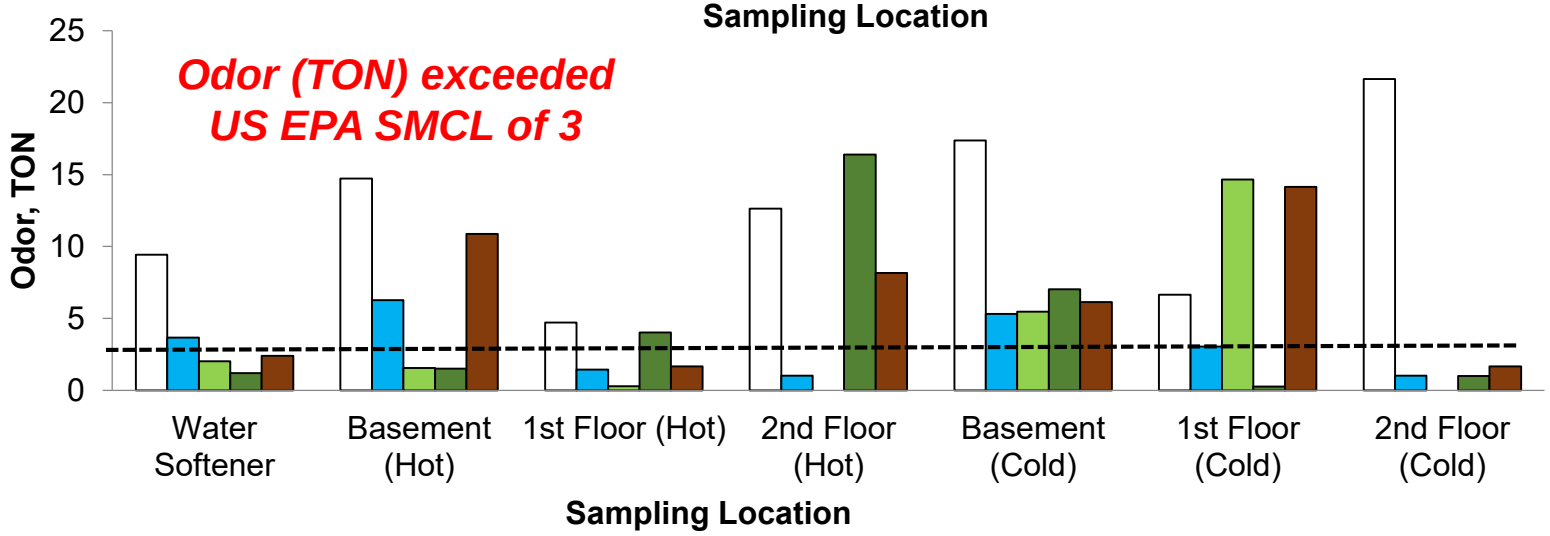
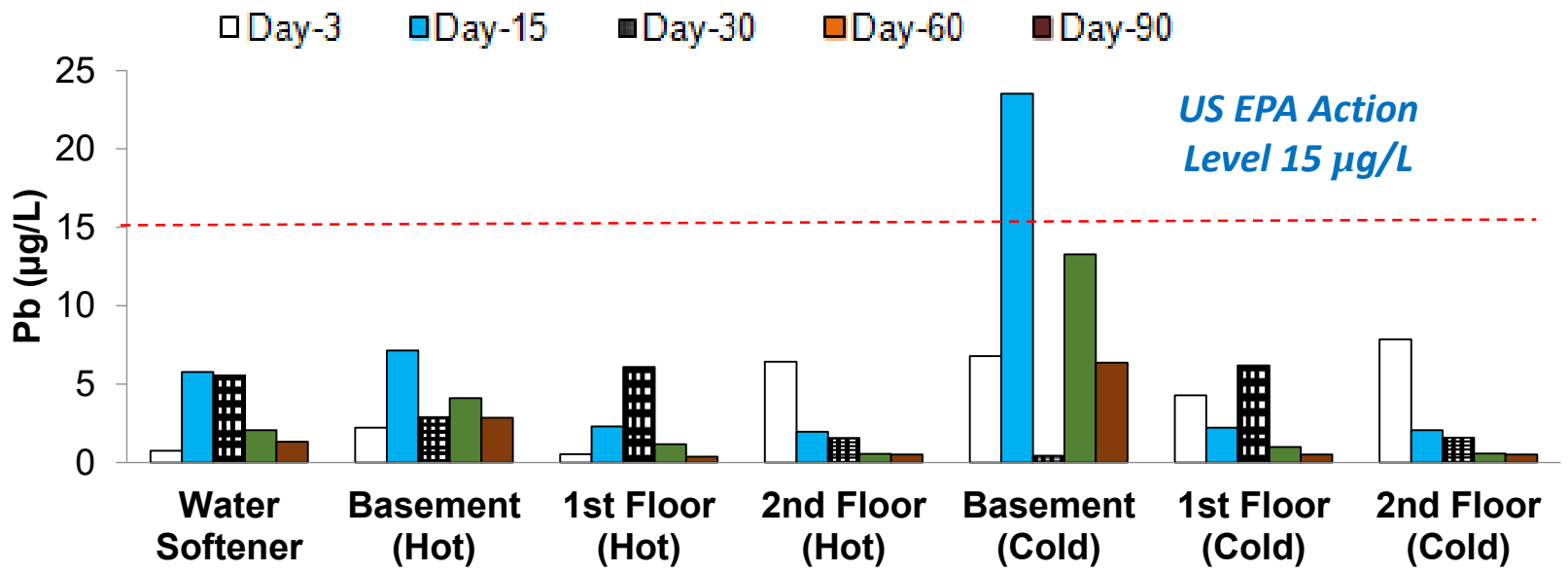
TOC Concentration Increased Inside the Building



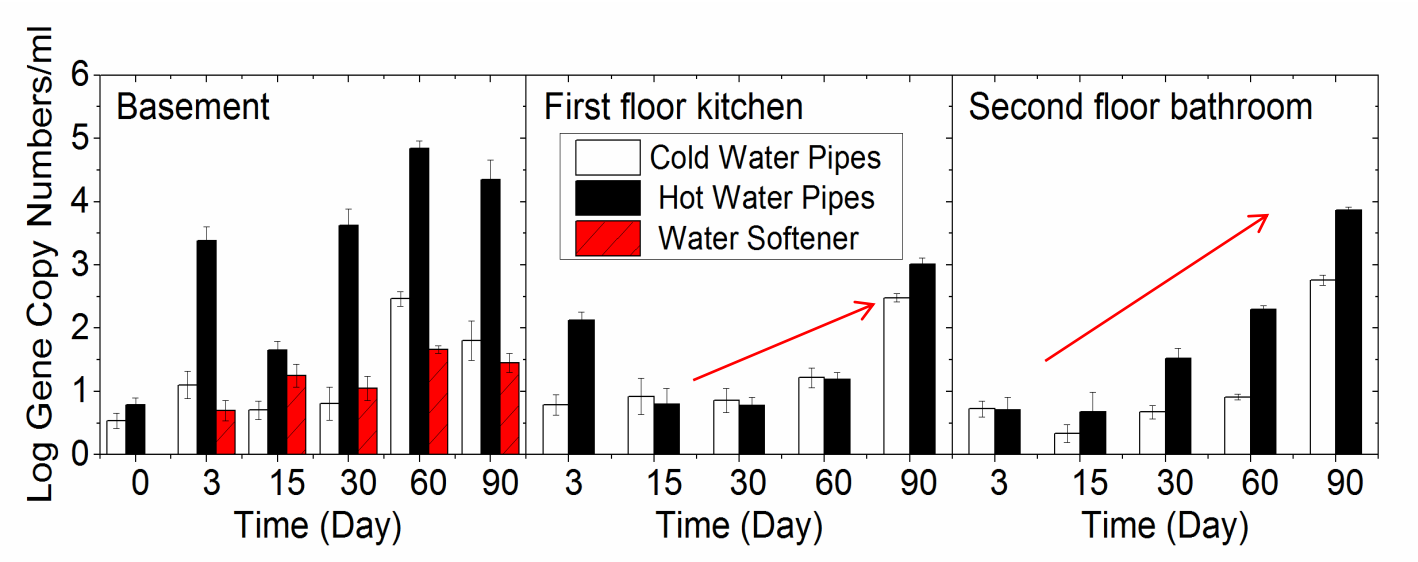


Several Heavy Metals with Health & Aesthetic Limits were Detected



The **basement fixture brass needle valve** may have caused maximum Zn (5.9 mg/L), Fe (4.1 mg/L), and Pb (23 µg/L) levels compared to other fixture water samples.

Both HPC & Gene Copy Number Increased at 1st & 2nd Floor



Greatest HPC level (856.7 CFU/mL) at day 90 basement hot water.

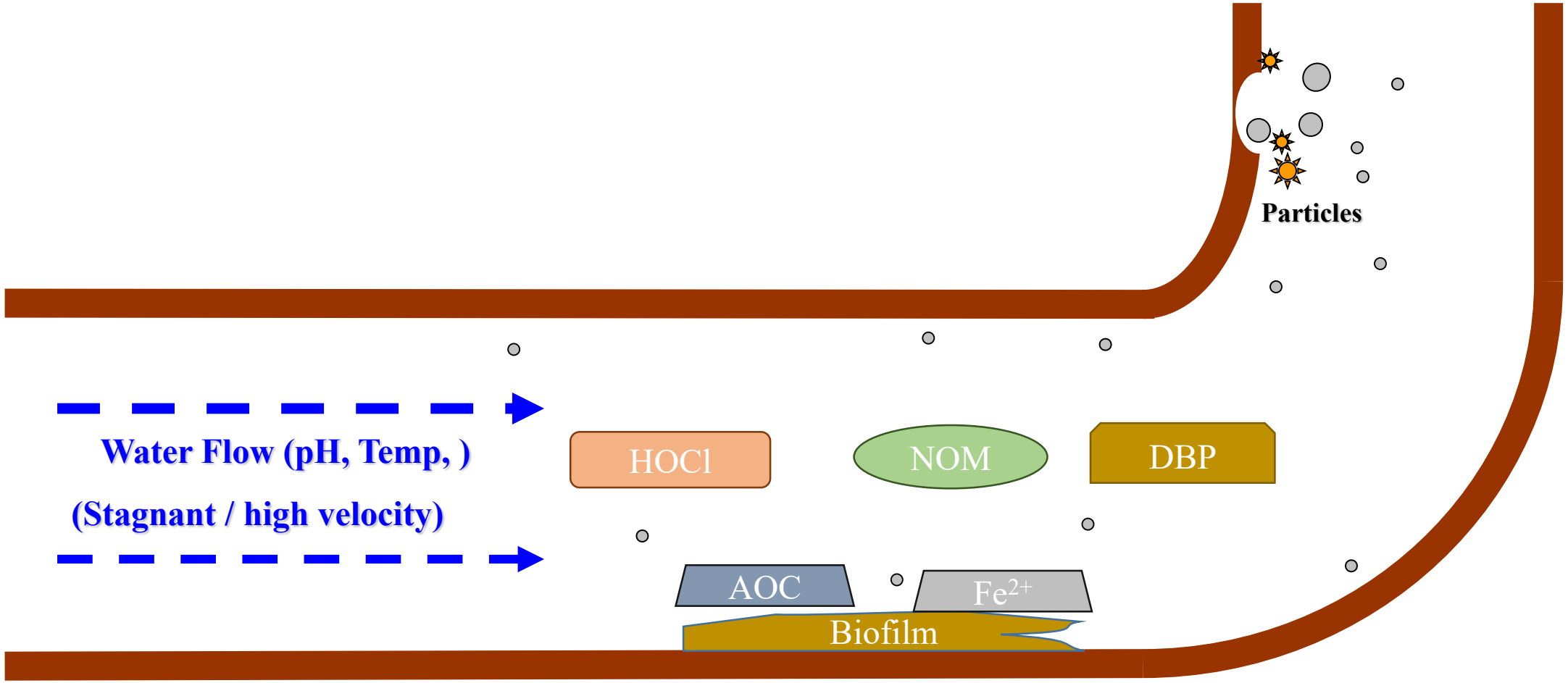
Positive correlations between TOC levels & bacterial gene copy numbers at water softener, 1st floor (cold), 2nd floor (cold/hot).

Water Quality Summary

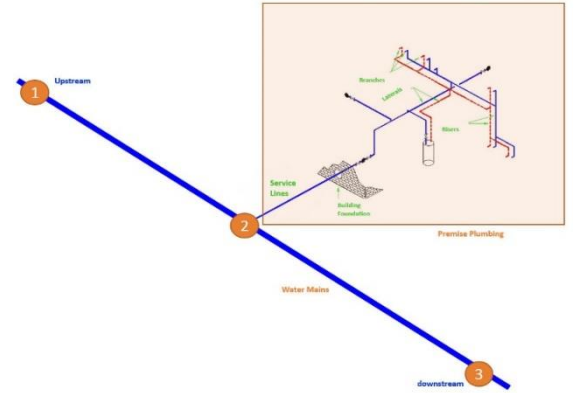
- ❑ The maximum water stagnation time was 72.0 hr.
- ❑ Bacteria & organic carbon levels increased inside the plumbing system compared to the municipal tap water entering the building.
- ❑ A greater amount of bacteria was detected in hot water samples compared to cold water samples.
- ❑ At the basement fixture, where the least amount of water use events occurred, greater organic carbon, bacteria, and heavy metal levels were detected.

Premise Plumbing Hybrid Model

Pipe Inside Phenomenon



Integrative Hydraulics – WQ models

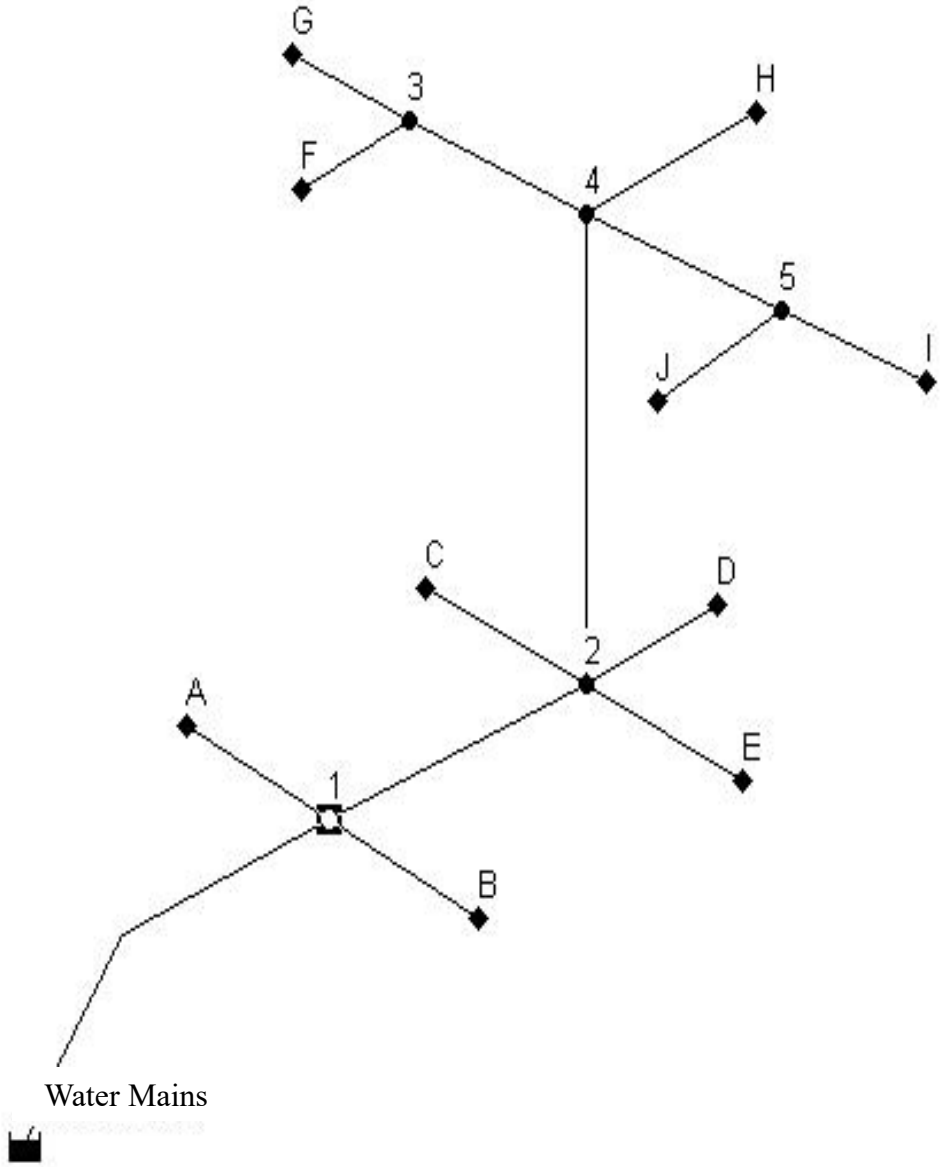


- Predict drinking water disinfectant residual and microbial quality at each fixture.
  - framework of EPANET-MSX using the EPANET programmer's toolkit
  - parameters: disinfectant concentrations, DBP, THMs, water age, temperature, pH, TOC, heavy metal concentration, bulk decay rate constant, wall chlorine demand (wall reaction coefficients), microbiological quality, and turbidity.

- Stochastic nature of water demand: Poisson Rectangular Pulse models and SIMDEUM model.

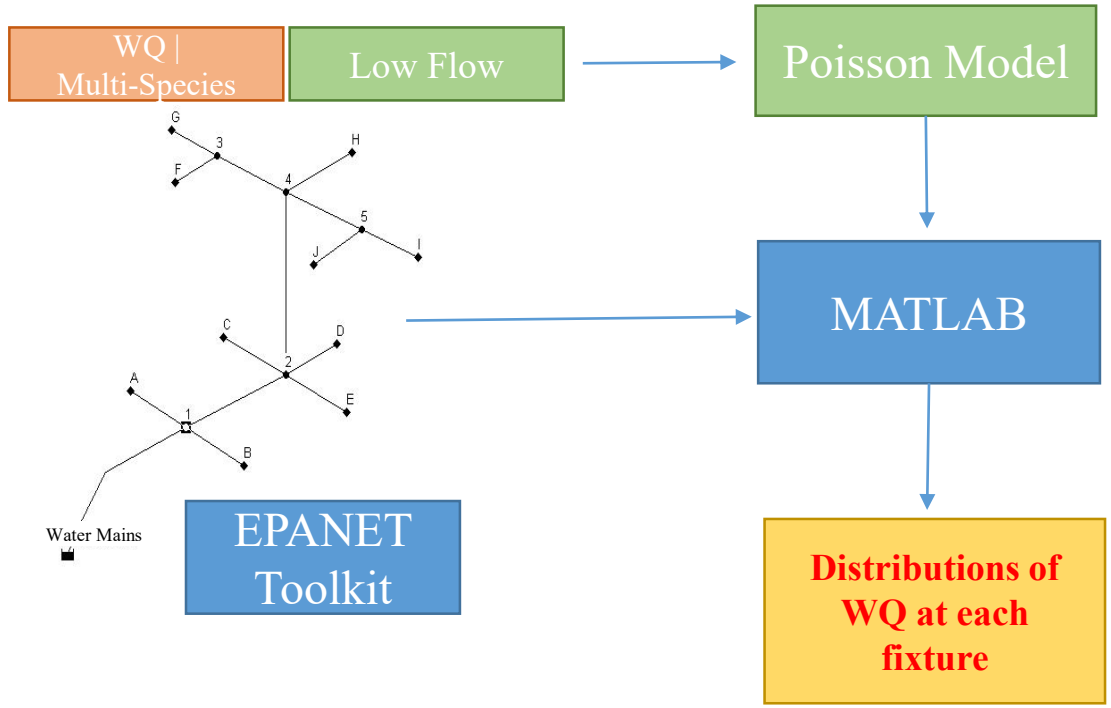
At time = t
& Extended period

- Hydraulic flow and Water quality simulation which involve multi-species.
- Pressure at service line
  - Mostly steady state except extreme low/ high pressures
- Stochastic demand at each fixture
- Calibration of parameters for each season’s data



Simulation for low flows

- Call EPANET Toolkit from MATLAB;
- Change water demand values based on low demand – Poisson Model Development
- This is iterated many times.
- Produce distributions of WQ parameters – Fe, AOC, Chlorine, etc.



1. Hydraulics - Water demand/ pressure

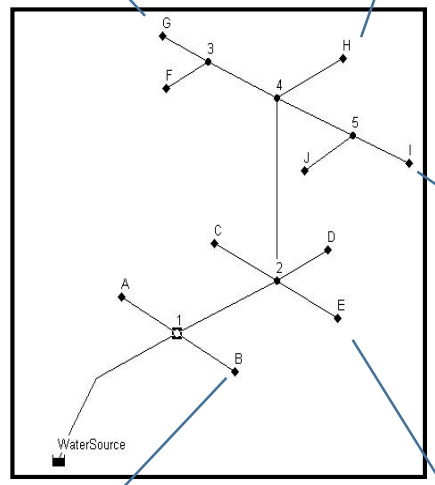
2. Water quality - pH, temp, NOM, disinfectant, metal, etc.

3. Microbiology - pathogen, legionella, etc.

Low flow simulations

Premise Plumbing Hybrid Model with EPANET-MSX

Plumbing systems Design (layouts, sizes, fixtures, etc)



AOC, Disinfectant, Pathogen, by - product

AOC, Disinfectant, Pathogen, by - product

AOC, Disinfectant, Pathogen, by - product

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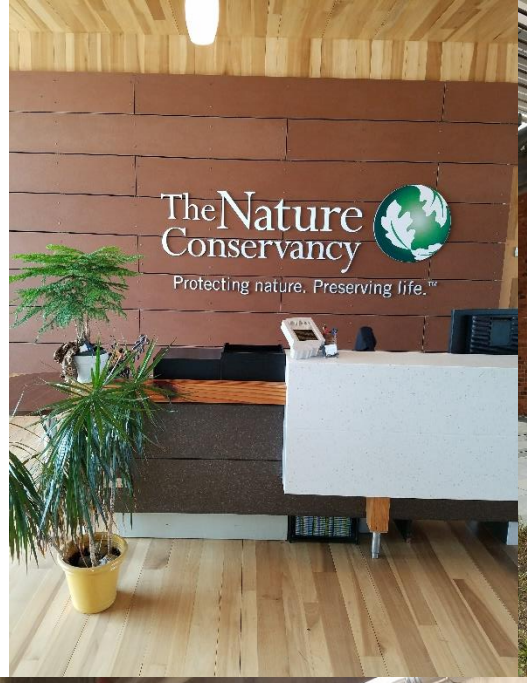
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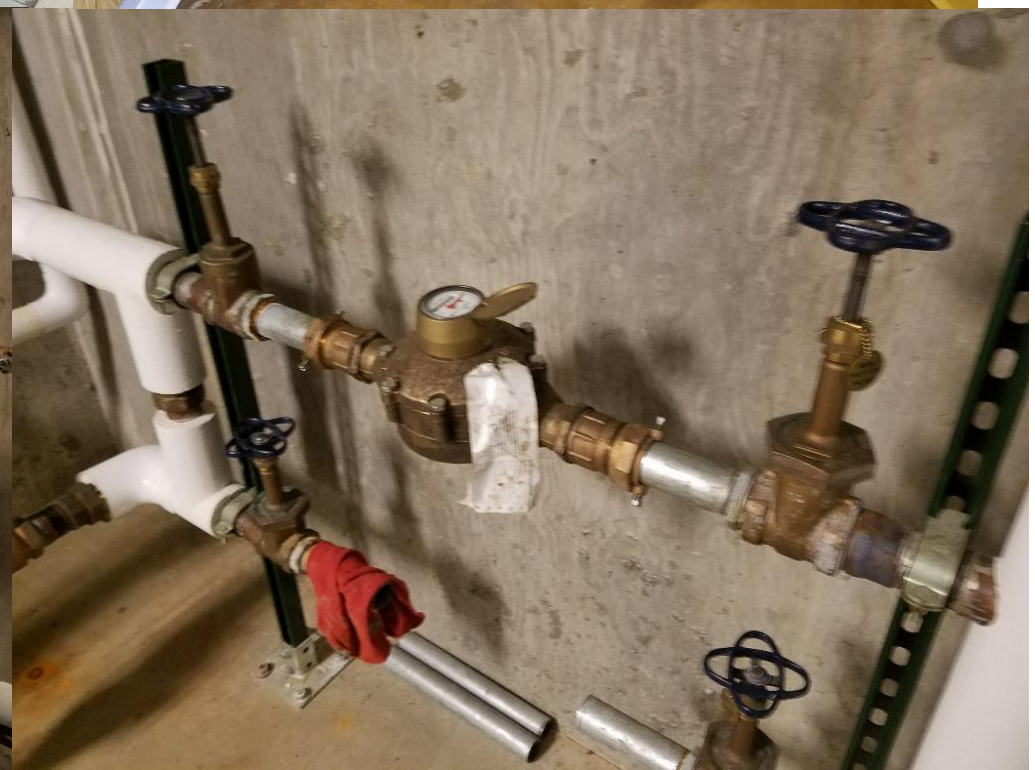
Protecting nature. Preserving life.™


DOMESTIC COLD WATER
WATTS
OneFlow



ACKNOWLEDGEMENT

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Building Plumbing Safety: Right Sizing Tomorrow's Water Systems for Efficiency, Sustainability, & Public Health

www.PlumbingSafety.org

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