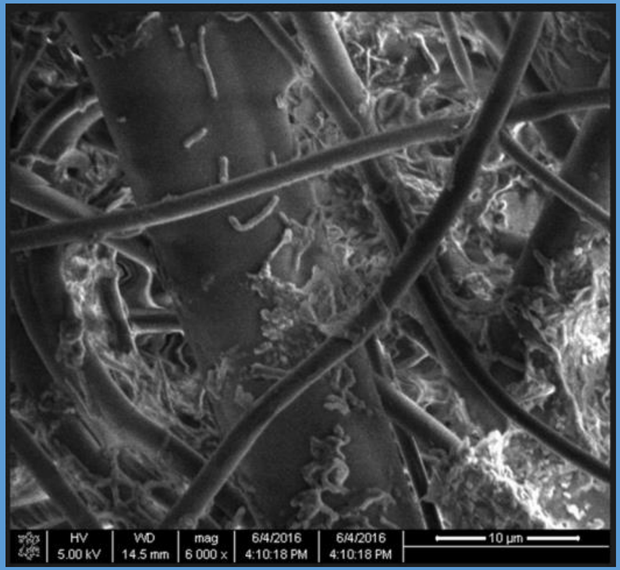
Building Plumbing Safety: Right Sizing Tomorrow's Water Systems for Efficiency, Sustainability, & Public Health



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

PURDUE UNIVERSITY
MICHIGAN STATE UNIVERSITY
SJSU SAN JOSÉ STATE UNIVERSITY
Tulane University

Partners, Supporters, and Participants

Whirlpool Corporation

Gordon & Rosenblatt

Indiana State Department of Health

HRC

Community Engineering Services, PLLC

hbn Healthy Building Network

IDEM

Watershed, LLC

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

Naval Hospital Jacksonville, Florida

Technion Israel Institute of Technology

University of Cincinnati

ASPE American Society of Plumbing Engineers

Université Laval

InspectAPedia

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***

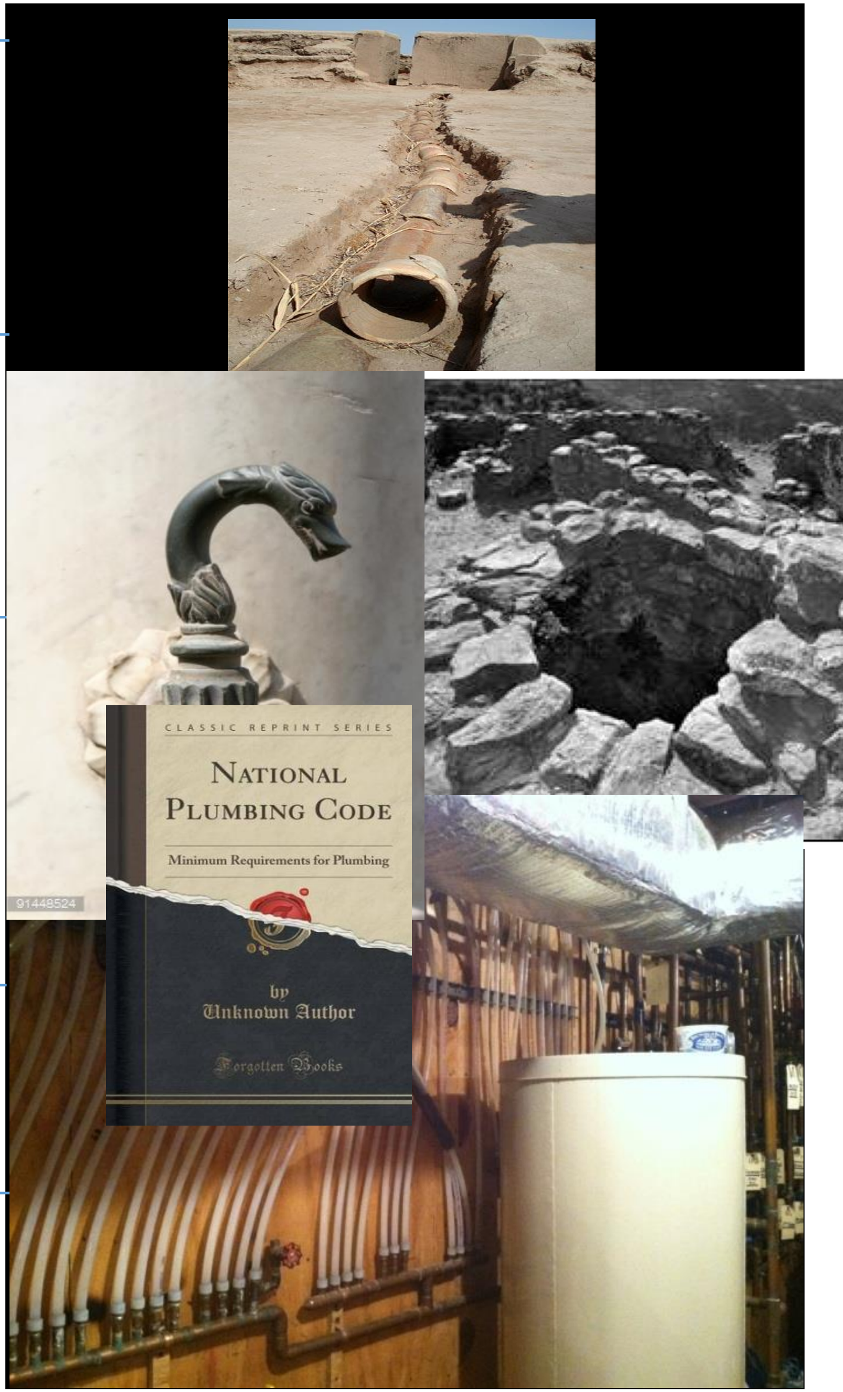
4000-3000 BCE
Copper water pipes in buildings (India)

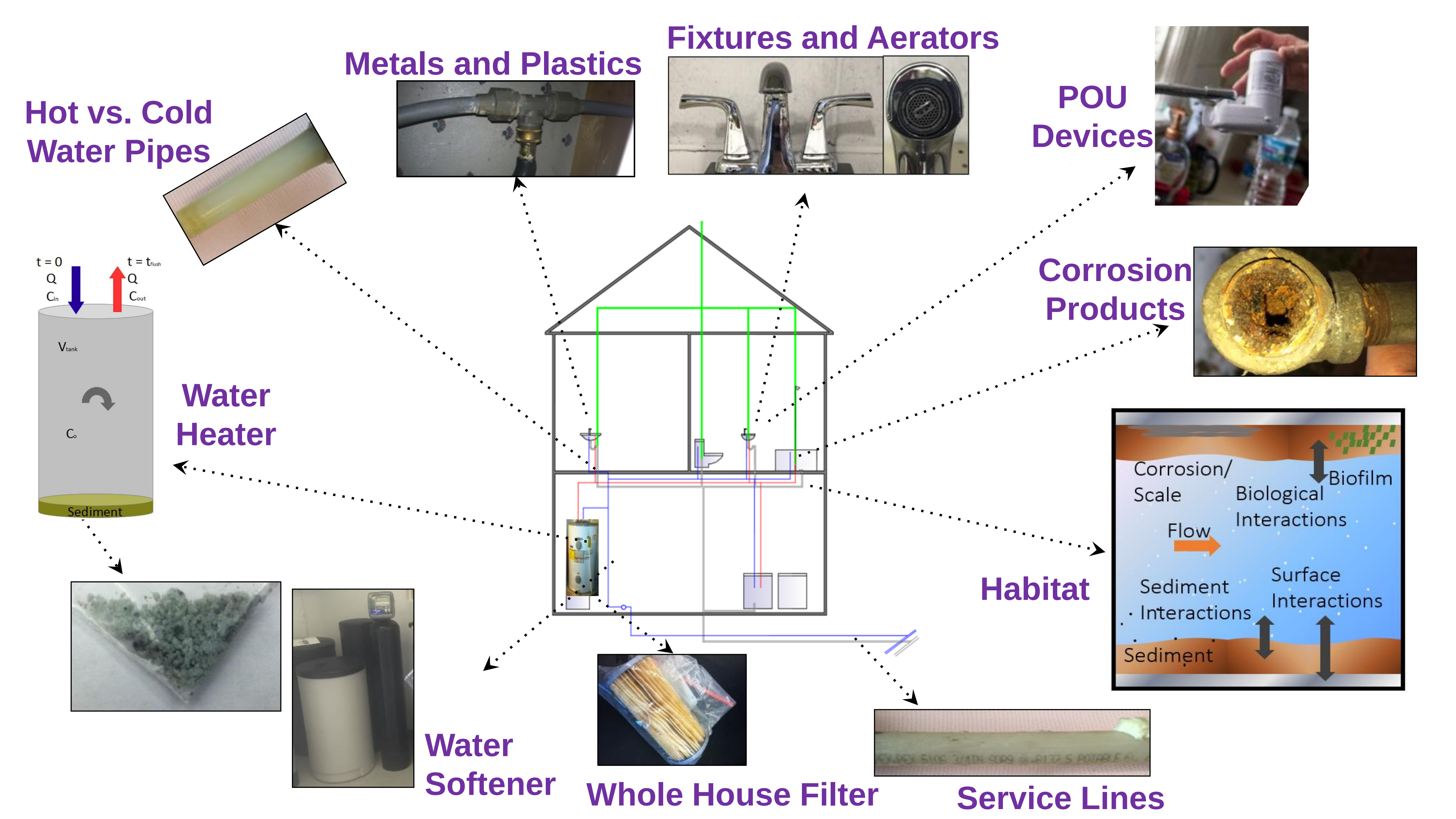
1500 BCE
Rainwater cisterns (Greece)

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

1928
First US plumbing code

1966
Copper shortage enabled plastics entry




Hot vs. Cold Water Pipes
Metals and Plastics
Fixtures and Aerators
POU Devices
Corrosion Products
t = 0
Q
C_in
t = t_flush
Q
C_out
V_tank
C_o
Sediment
Water Heater
Corrosion/ Scale
Biofilm
Biological Interactions
Flow
Sediment Interactions
Surface Interactions
Sediment
Habitat
Water Softener
Whole House Filter
Service Lines

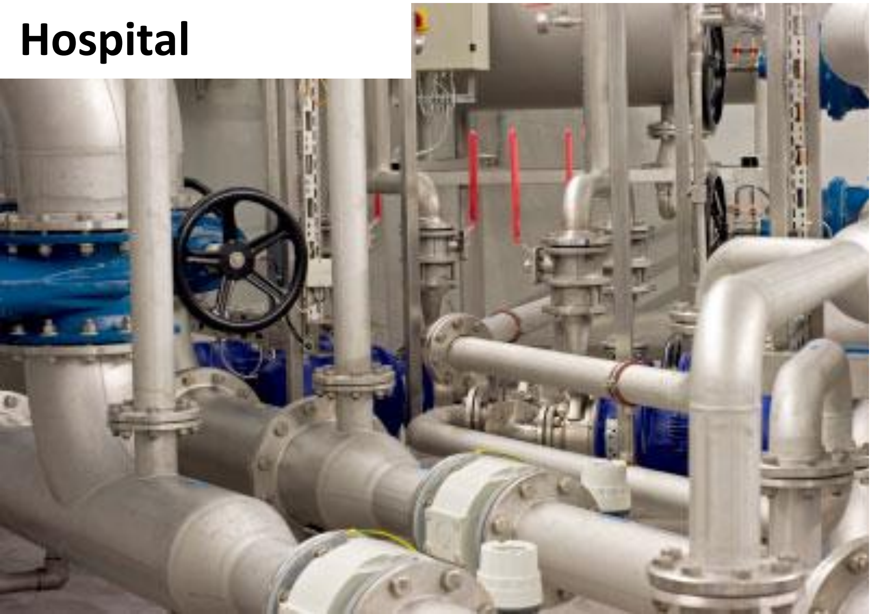
Premise plumbing is complex

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

Water Use Energy Policy Act of 1992

Water Use has Decreased From Lower-Flow Faucets

Pre-1994 (4^{+} gpm)

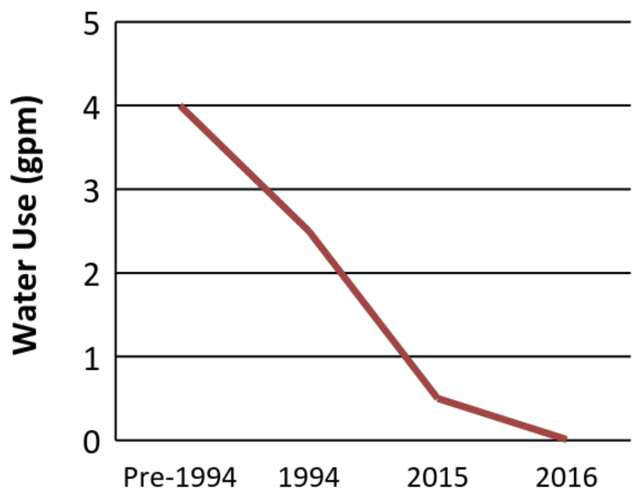
1994 (2.5 gpm)

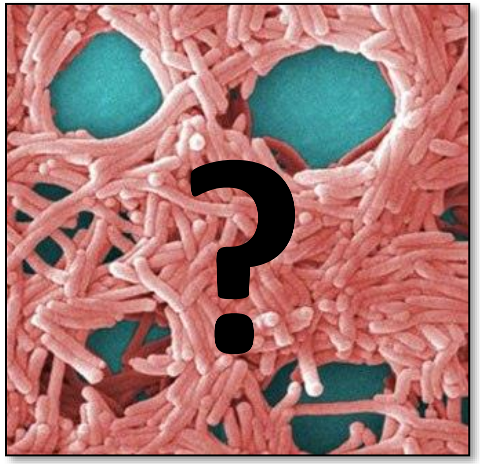
2015 (0.5 gpm)

2016? (0.01 gpm)

Our EPA Project Goal

To better understand and predict water quality and health risks posed by declining water usage and low flows, 2017-2020



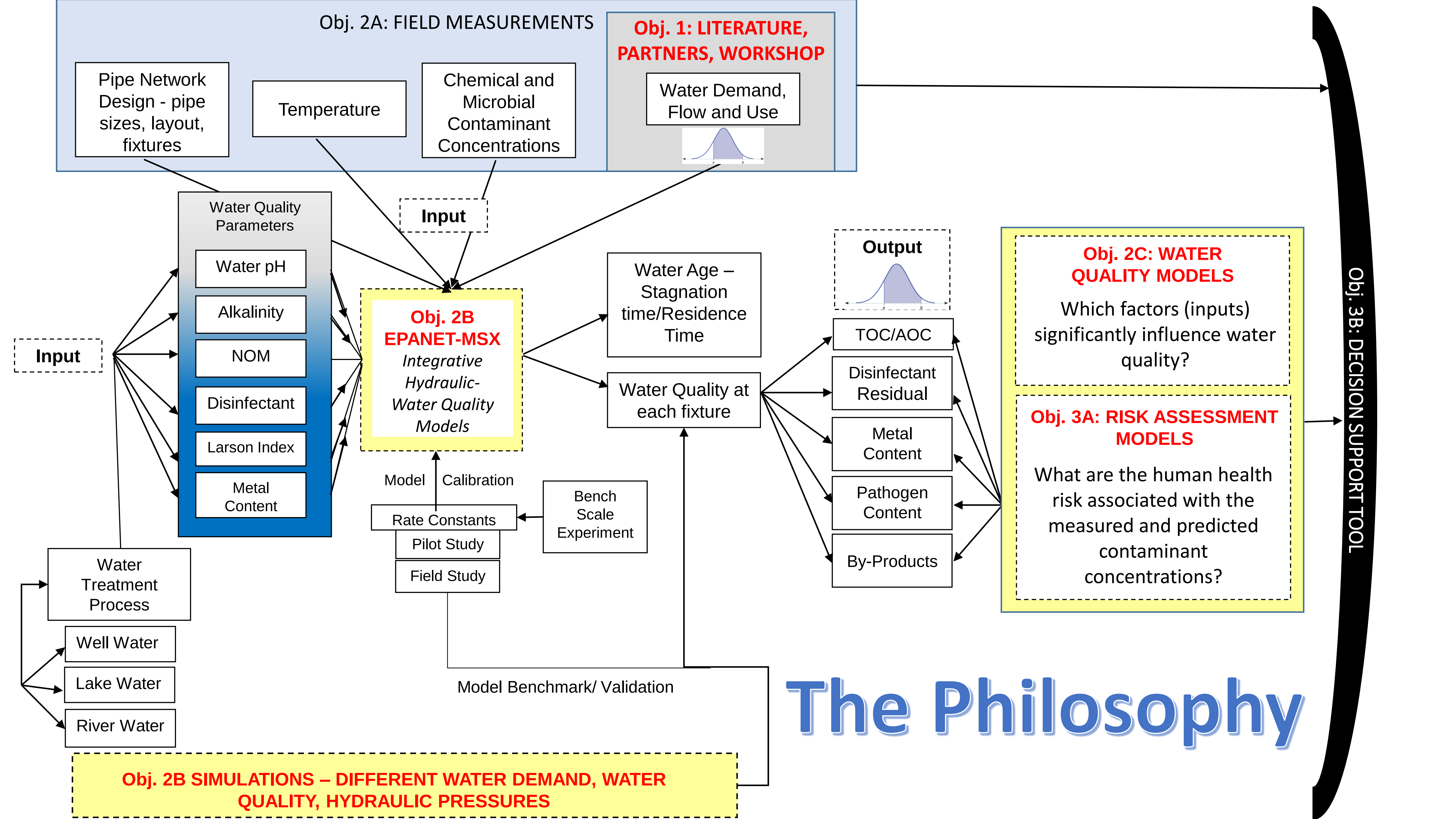


Our EPA Project Objectives

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
The Philosophy

Retrofitted Net-Zero Energy, Water and Waste

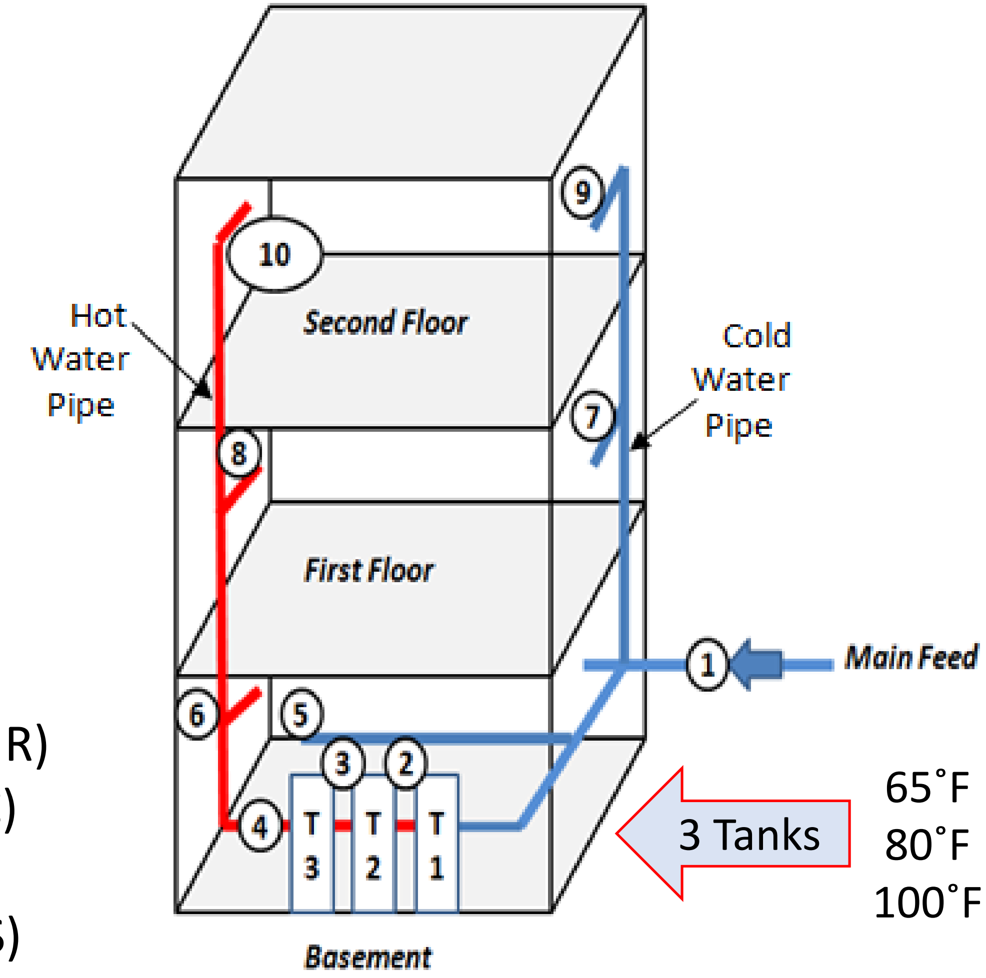
2014: Renovation of single-family building, new PEX plumbing installed, city water use only

2015: PEX plumbing removed, new PEX plumbing installed, city and rainwater use

- *J. AWWA, J. HAZMAT:* Plumbing pipes analyzed, funded by NSF
- *Chemosphere:* Monitored flow and water quality during inhabitance (flow, chemistry, microbiology) , funded by NSF
- Ongoing: Integrative hydraulic-water quality models, EPA funded

City water: Groundwater, treated with $KMnO_4$, free chlorine residual, PVC and Iron water mains

The entire 1 year old PEX pipe plumbing system exhumed and 10 pipe sections were examined

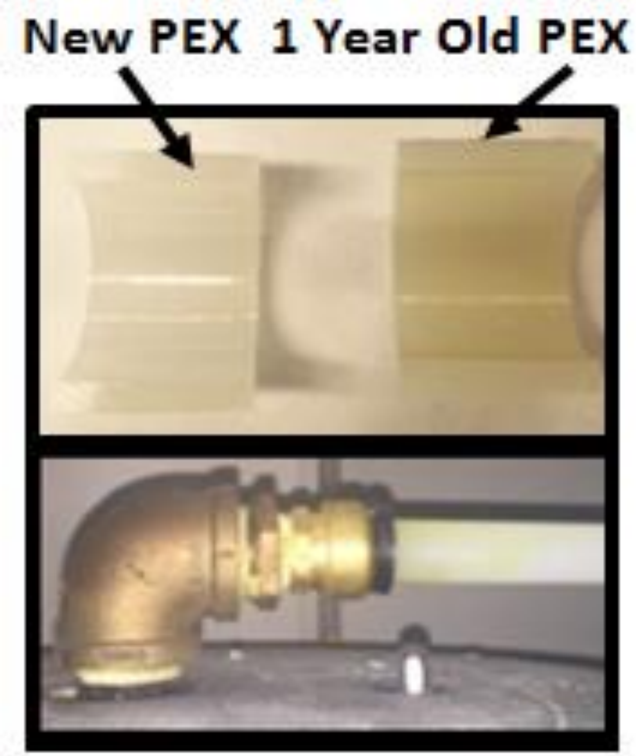


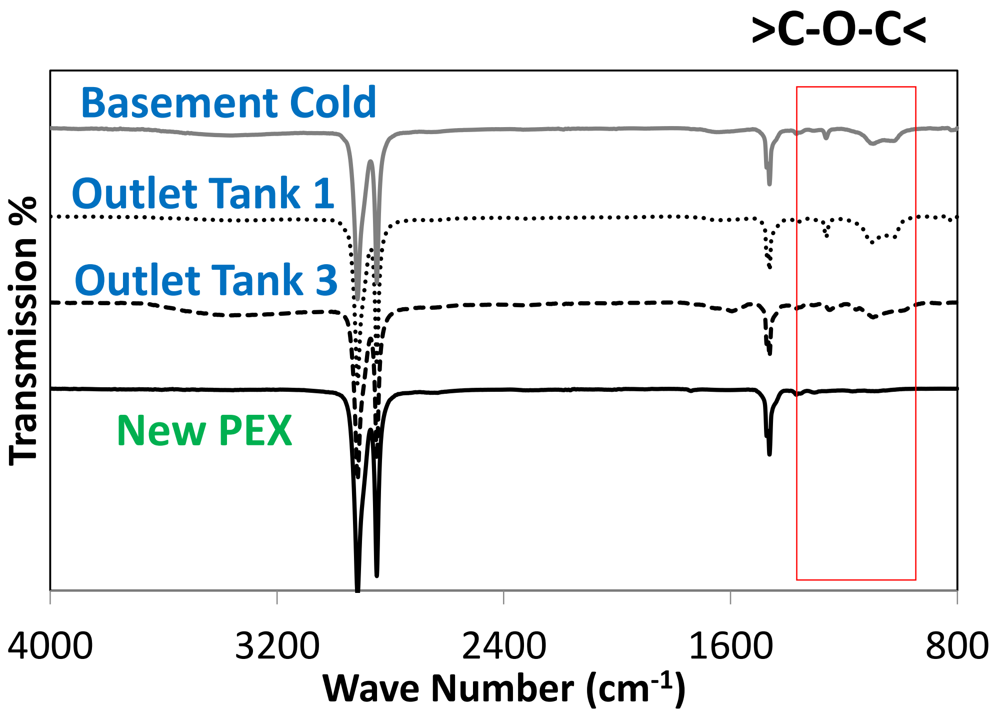
Techniques

Surface chemistry (ATR-FTIR)
Antioxidant content (DSC)
Surface characteristics
(ICP-MS, FESEM-EDX, XPS)

Salehi et al. (2017). *Journal AWWA.*
https://doi.org/10.5942/jawwa.2017.109.0117

Pipes located throughout the home had different age characteristics





Oxidative resistance varied between exhumed pipe samples

Salehi et al. (2017). *Journal AWWA.*
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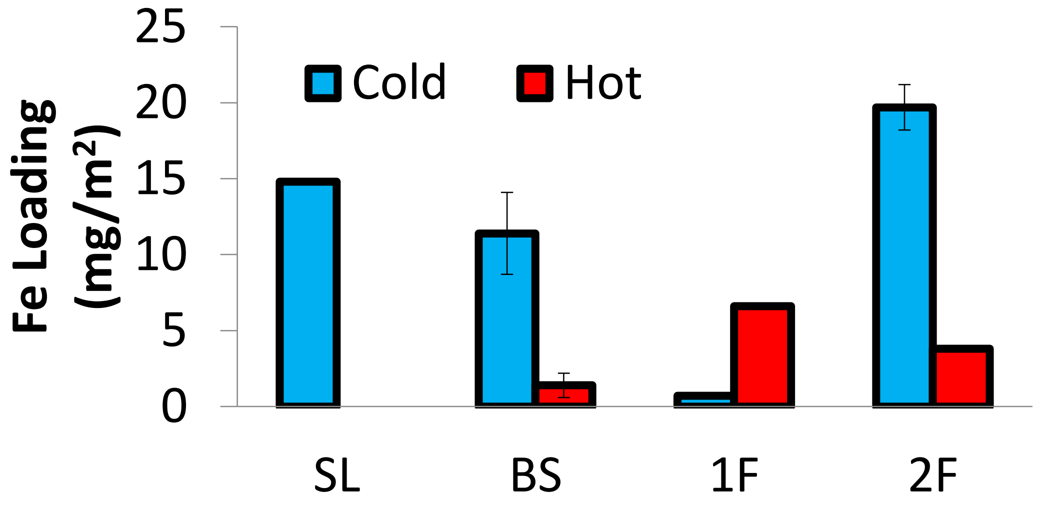
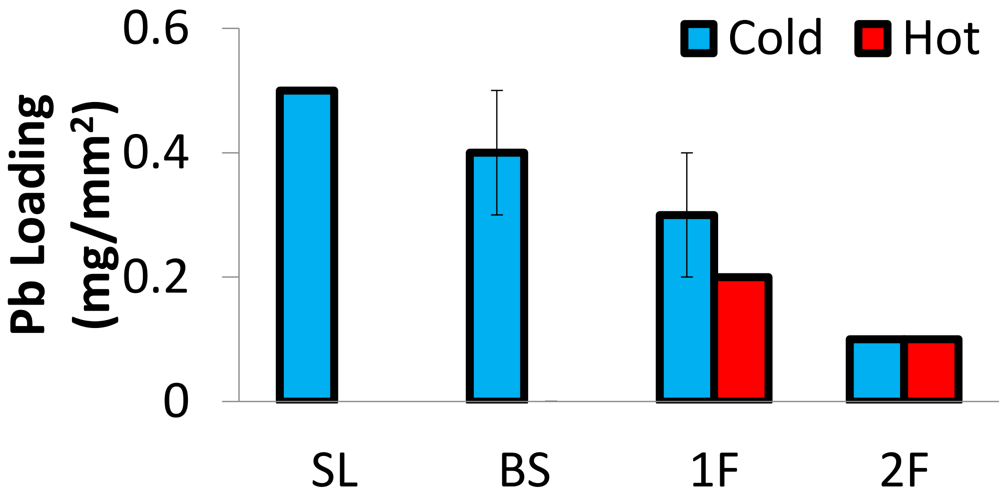
Fe was the Most Abundant Metal Found on the Exhumed Pipes



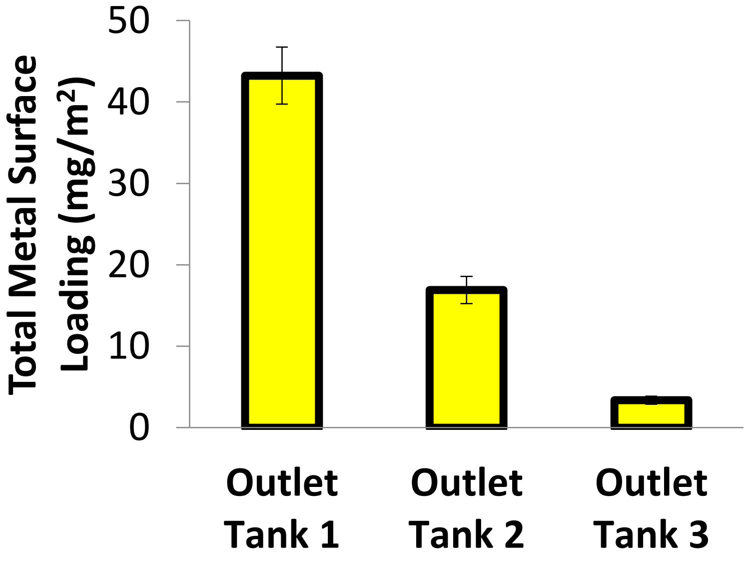


SL: Service Line, BS: Basement, 1F: 1st Floor, 2F: 2nd Floor

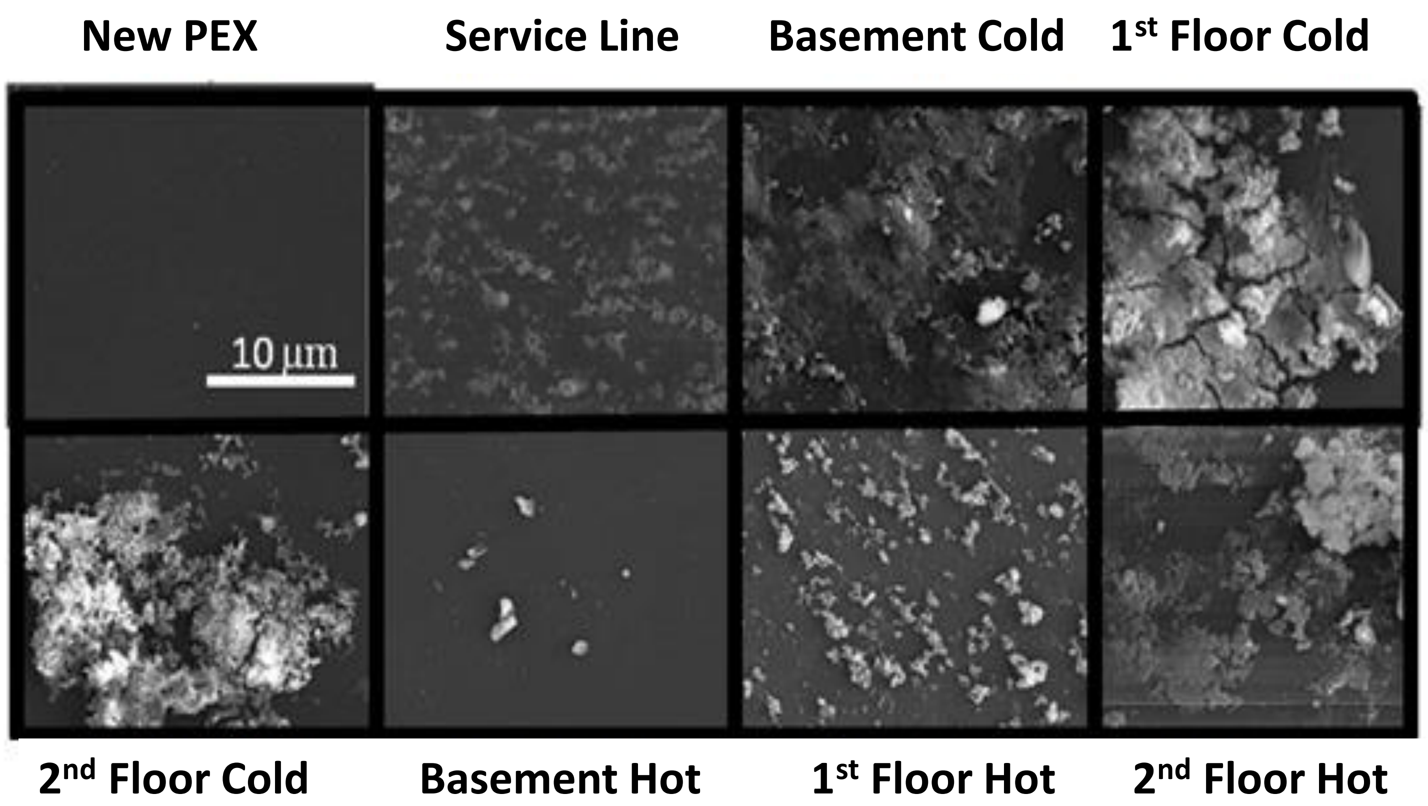
Fe, Mn, Na, Ca, Zn, Cu, Al, Mg mg/m^2

Co, Ni, Pb, Se $\mu g/m^2$

Greatest total metal loading was found on the pipe exiting tank 1 (43 mg/m^2)



Plastic pipe scale morphology varied based on water temperature



EDX Analysis: Fe was most frequent found metal on pipe surface. Oxygen also found on pipe surface.

Salehi et al. (2017). *Journal AWWA.*
https://doi.org/10.5942/jawwa.2017.109.0117

ELSEVIER

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]

Show more

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

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.

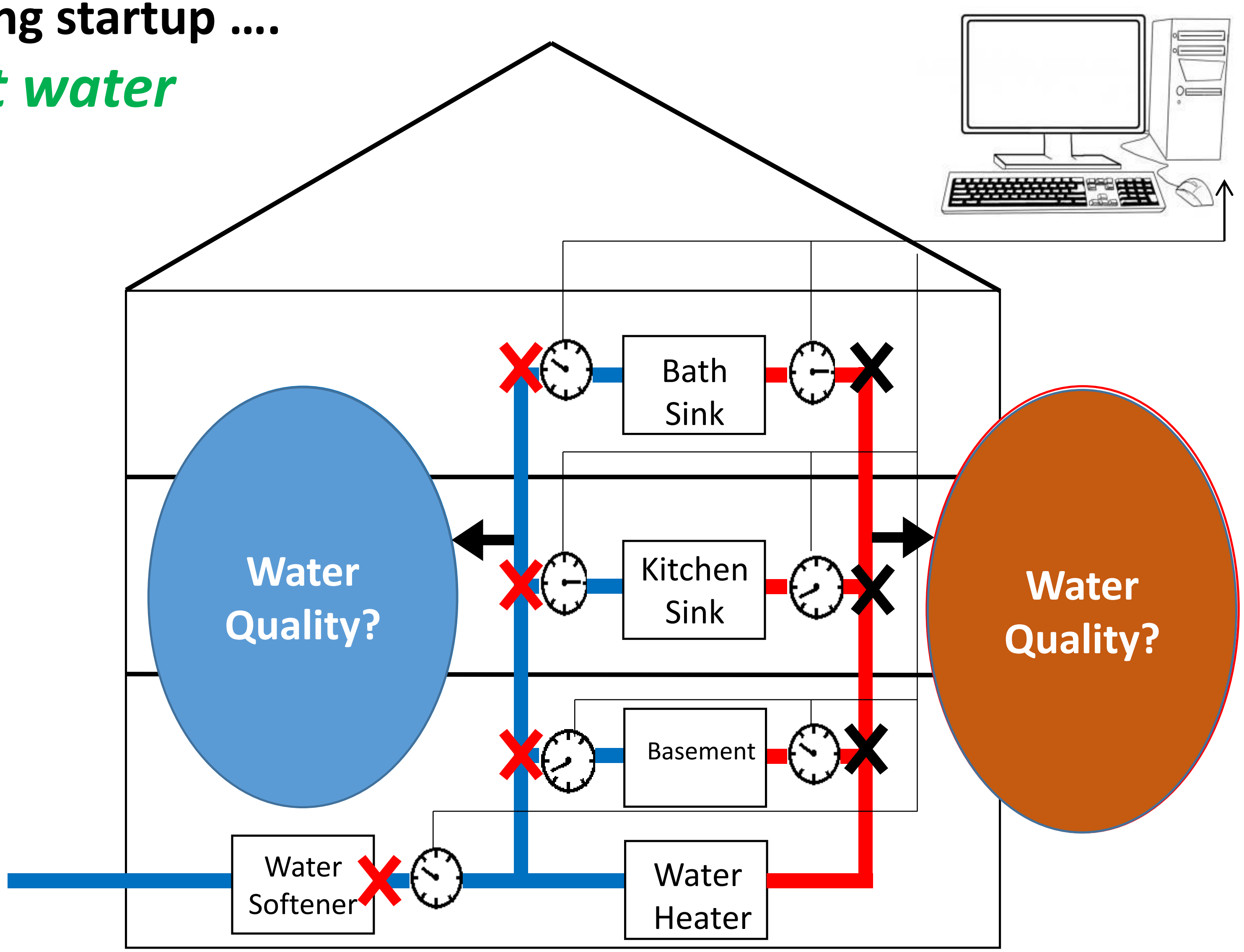
During the 4 month building startup ….

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



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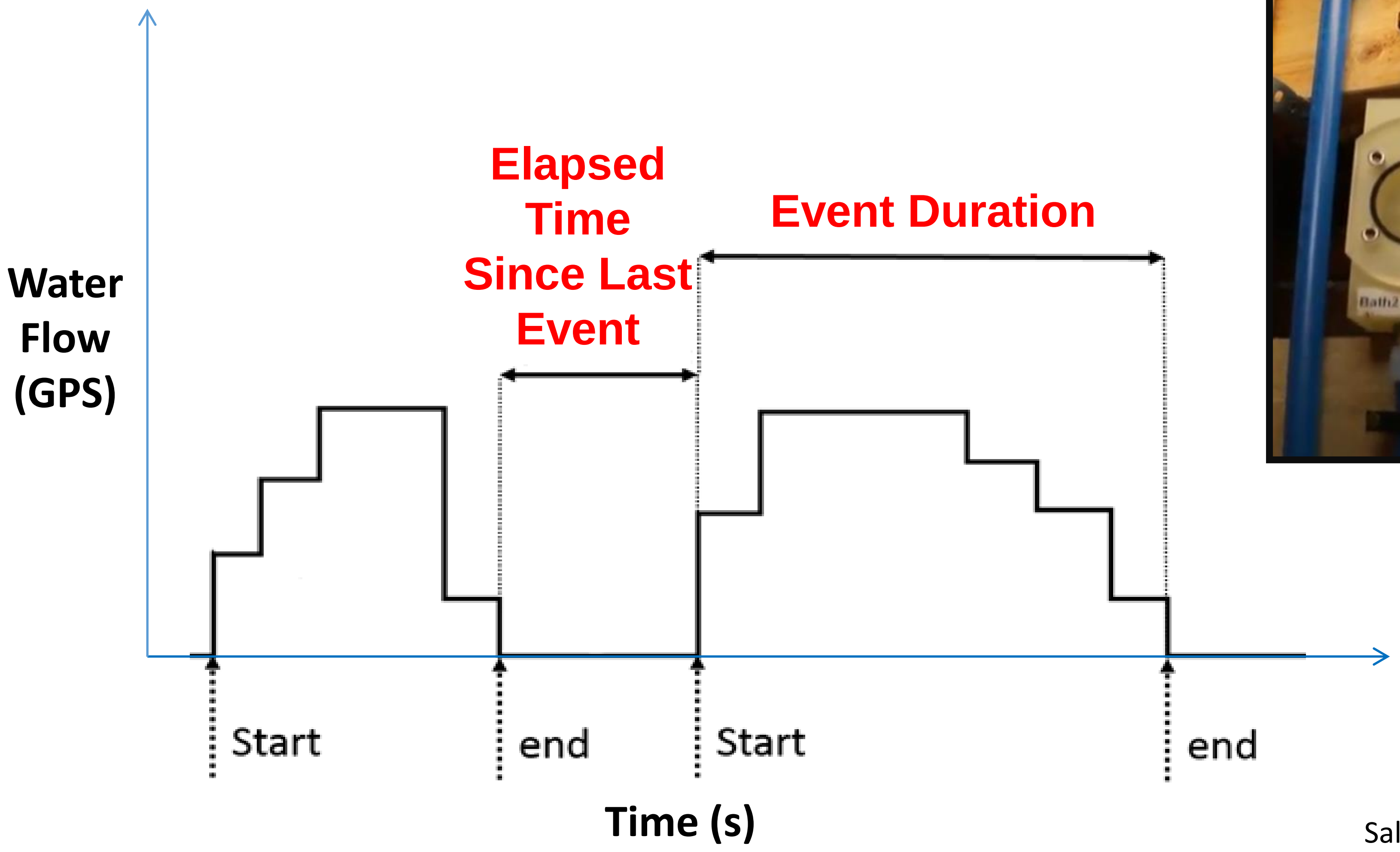
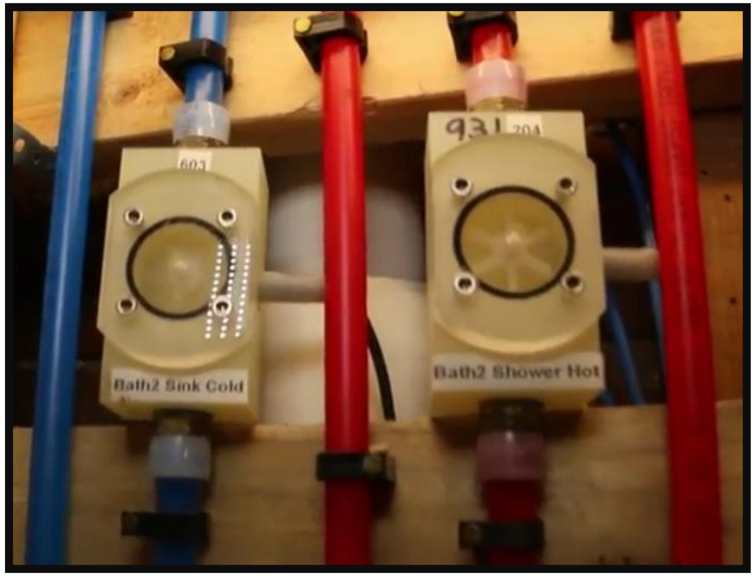
Water Usage Monitoring & Analysis

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





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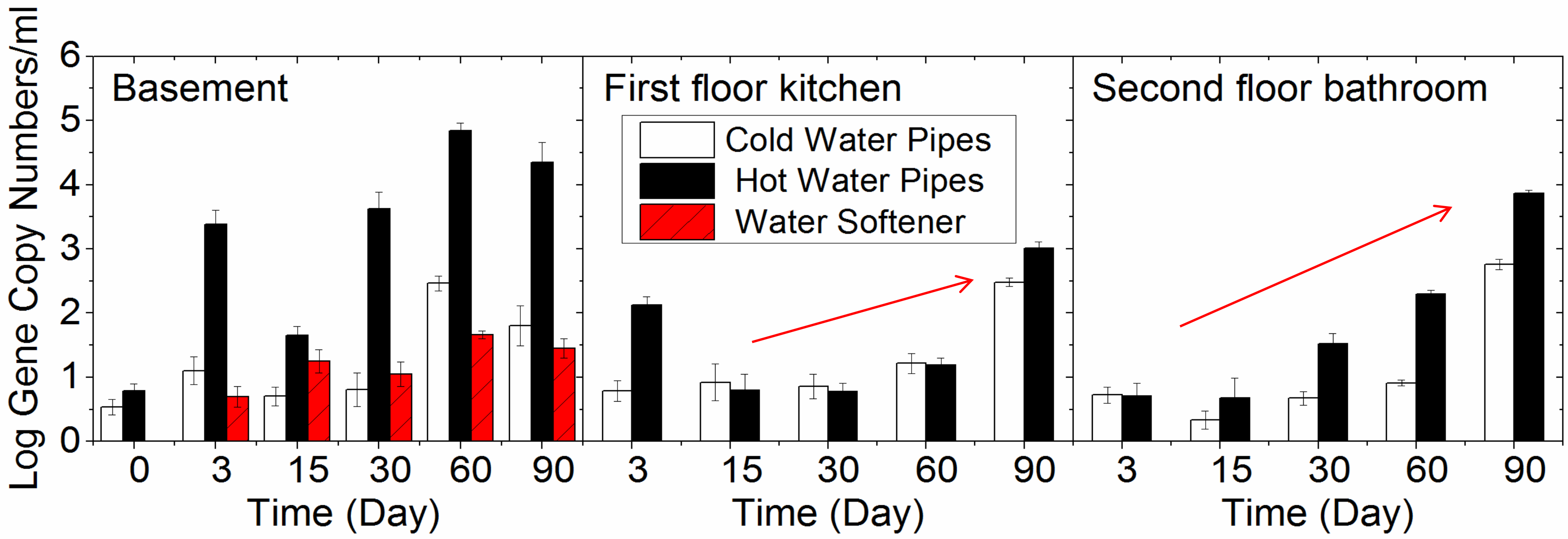
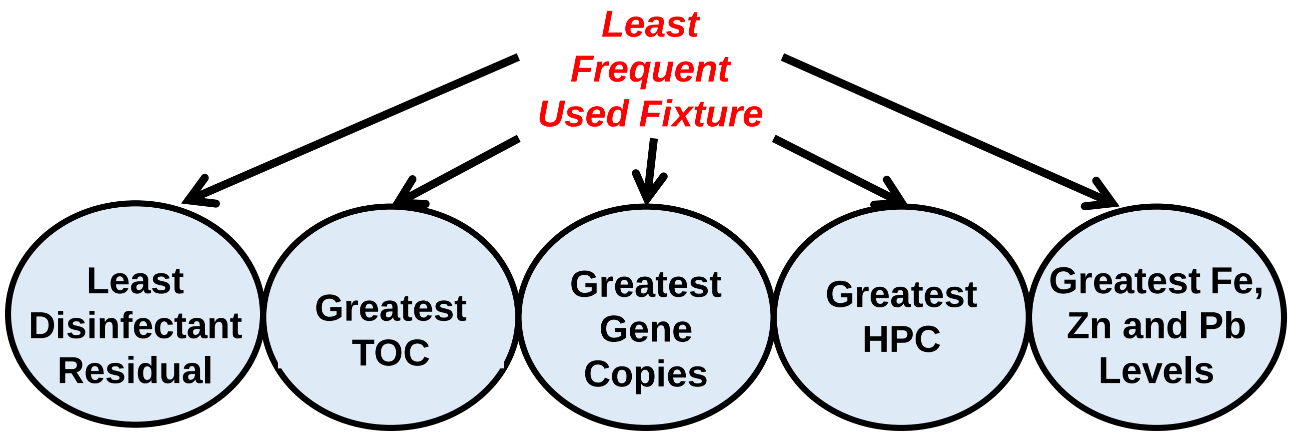
Water Usage Patterns for a Few Fixtures Monitored in December 2015

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

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

Salehi et al. (2018). *Chemosphere.*
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EPA Funded Plumbing Research

Microbiology

- *Legionella spp.*
- *L. pneumophila*
- *P. aeruginosa*
- *Mycobacterium*
- *E. Coli*
- *Total coliforms*
- *HPC*

Chemistry

- Temperature
- pH
- Disinfectant residual
- DO
- Metals
- TOC/DOC
- AOC
- Alkalinity
- Ions
- TTHMs

Online – Physical

(All fixtures every 1 s)

- Pressure (service line)
- Fixture temperature
- Indoor air temperature
- Flow rate
- # of events
- Event duration

And more…

Preliminary Results - ReNEWW Home Testing

- 1 Sample Period
  - Every other day for 8 trips in Jan-Feb
  - About 2,000 analyses handled
- Grab water samples
  1. City water service line (before water softener)
  2. 1st floor – Kitchen sink (cold/hot)
  3. 2nd floor – Bath sink cold (cold/hot)
  4. Basement – Water heater tank
  5. 2nd floor – shower standpipe

  Field and trip blanks used for controls
- No aerators removed, real fixture use

Onsite analysis

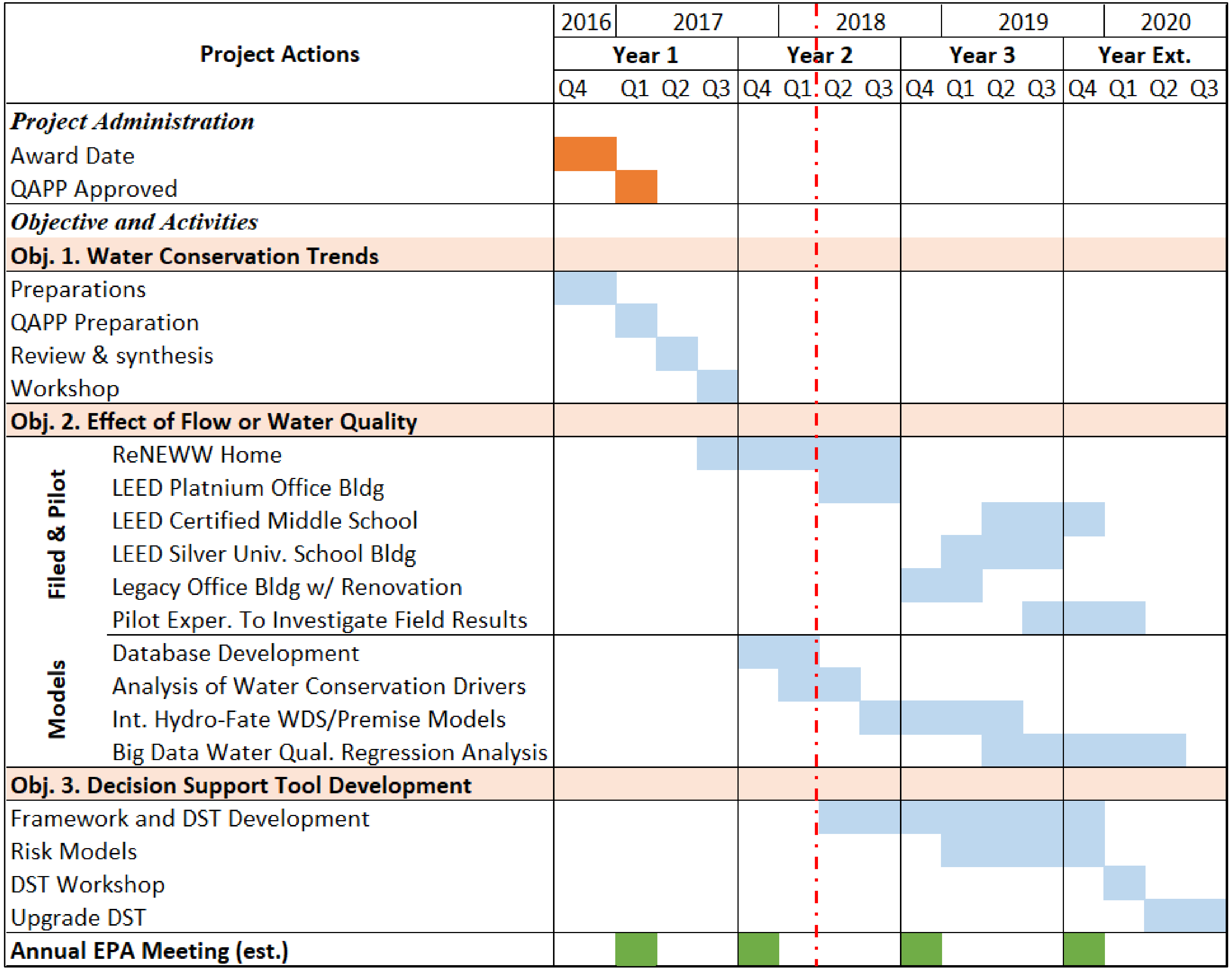
1. Water temp
2. Water pH
3. Total chlorine
4. DO

Lab analysis

1. Total metals
2. Dissolved metals
3. Ions by IC
4. TTHM
5. TOC
6. DOC
7. AOC
8. HPC
9. Pathogens

Preliminary Observations

- Service line
  - Pressure typically 40 psi, but max about 90 psi to less than 0 psi
  - Chlorine residual fluctuated significantly (0-1.6 mg/L), 1 day no residual in home including service line, another day 1.7 mg/L at fixture
  - Water softener working! City water higher Ca^{+2}, Mg^{+2}, K^{+}, lower in rest of building with higher Na+ levels
- Fixture pH (up to 8.4) > Service line (7.6-7.8)
- Fixture TTHM > Service line
- Fixture (hot water) Al, Co > Service line
- Fixture Pb, Cu, Zn > Service line
- Mn service line > Fixtures
- Reviewing Others: DO, alkalinity, dissolved metals, ions, DOC, HPC, TOC, AOC, others



Project Schedule

Looking Ahead

EPA Funded Project

- Report: Identified data gaps in building types from stakeholders
- Field work
  - ReNEWW single-family home
  - LEED commercial buildings
  - LEED school
  - University buildings
- Bench- and pilot-scale studies
  - Answer field generated questions
- Risk models for fixture use in standard residential building

Some Identified Needs

- Integration of standards and codes
- Integrated hydraulic-WQ models
- Water quality in commercial buildings (designs differ a lot)
- Online water quality sensors
- Role of plastics and scales on influencing the microbiome and water quality
- Plastics: New vs. aged, Across vs. within brands
- Predicting plumbing scales
- Role of different components on water quality (treatment, filters, pipe surfaces, scales, heaters, aerators)

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

www.PlumbingSafety.org

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