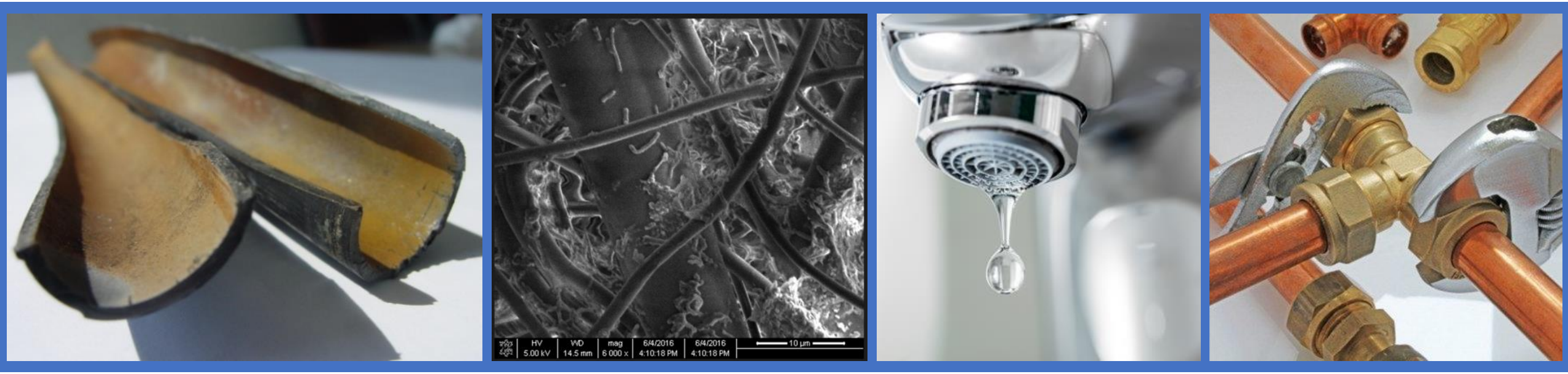
Right Sizing Tomorrow's Water Systems for Efficiency, Sustainability, & Public Health



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

December 14, 2017

PURDUE UNIVERSITY

MICHIGAN STATE UNIVERSITY

SJSU SAN JOSÉ STATE UNIVERSITY

Tulane University

The goals of this project are to…

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.

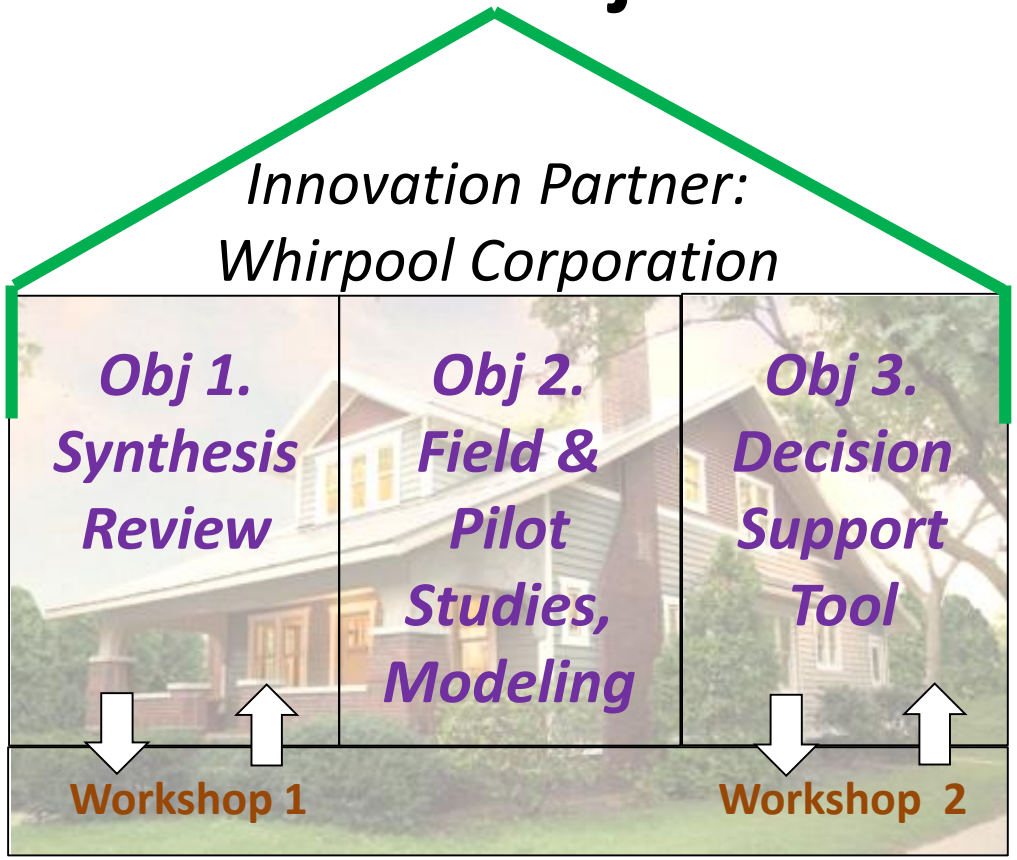
Main Objectives

Full-Scale Test Sites

ReNEWW Home
LEED Platinum Office Bldg
LEED cert. Middle School
LEED Silver Office Bldg
Renovated Office Bldg

Academic Partners

Univ. Cincinnati, USA
Univ. Laval, CAN
Israel Technol. Inst., ISR
Denmark Tech. U, DEN



Government Collaborators

Genesee Co. Health Dept.
NIST
NAVFAC
Army PHC

Utility Collaborators

Dekalb County, GA
Desoto Public Utilities, TX
Jacksonville Naval Hospital
Citizens Energy
Purdue Utilities
Michigan State Utilities

Association Partners

US Green Building Council
American Society of Plumbing Engrs.
National Environmental Health Assoc.
American Water Works Association
Indiana Rural Water Assoc.
Healthy Building Network

Design & Consulting Firms

Gordon & Rosenblatt, LLC
Watershed, LLC
CoEngineers, LLC
HRC, Inc.
Inspectapedia
Science Interactive

Several full-scale buildings are being studied

Characteristics	ReNEWW Net-Zero Energy Home, IN	LEED Platinum Office Bldg, IN	LEED Silver Lab/Office Bldg, MI	LEED Middle School, IN	Legacy Renovated Office Bldg, MI
Area, square feet	3,000	22,500	30,000	220,000	156,752
Number of Floors	2	3	5	1	16
Potable water pipe type	PEX-a plastic	Cu	Cu & Galv. Steel	Cu	Brass (hot) & galvanized Fe (cold)
Water heaters, gal	Two: 300 & 50	On-demand	Continuous recirculation	Five: 300 each	Two: 75 & 115
Sample points	SL; 1Flr Kitchen sink; 1Flr Island sink; 1Flr, 2Flr Bath sink	SL; 1Flr, 2Flr, 3Flr Kitchen sink	SL; 1Flr to 5Flr Bath sink	SL; 1Flr Kitchen sink; 1Flr Class Rm	Basement, 2, 6, 14, 16 Flr Bath sink
Sampling approach	For 1 wk period every day, 1x/season; then 1x/mo. for 6 mo.	For 1 wk period every day, 1x/season; then 1x/mo. for 6 mo.	School start; Aug-Dec 1x/mo.	School start; Aug-Dec 1x/mo.	Apr-Sept 1x/mo.
Other building characteristics*	SW, SL, FF, IBT, HWS, LOW	SL, FF, PT, HWS, LOW	SL, FF, LOW, HWS	HWS, VP, LOW	HWS

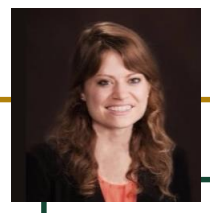
Core Team

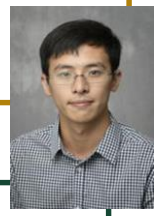

PI Whelton


Shah


Salehi

PURDUE UNIVERSITY






Lee

SJSU SAN JOSÉ STATE UNIVERSITY


Aw

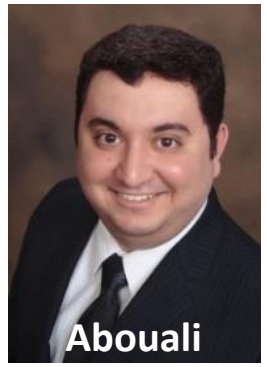
Tulane University


Mitchell

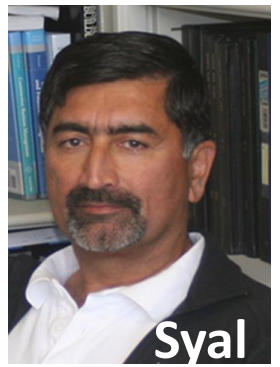

Rose


Beecher


Nejadhashemi


Abouali


Dreelin


Syal

MICHIGAN STATE UNIVERSITY

Our Partners, Supporters, and Participants

GORDON & ROSENBLATT

HRC

Watershed, LLC

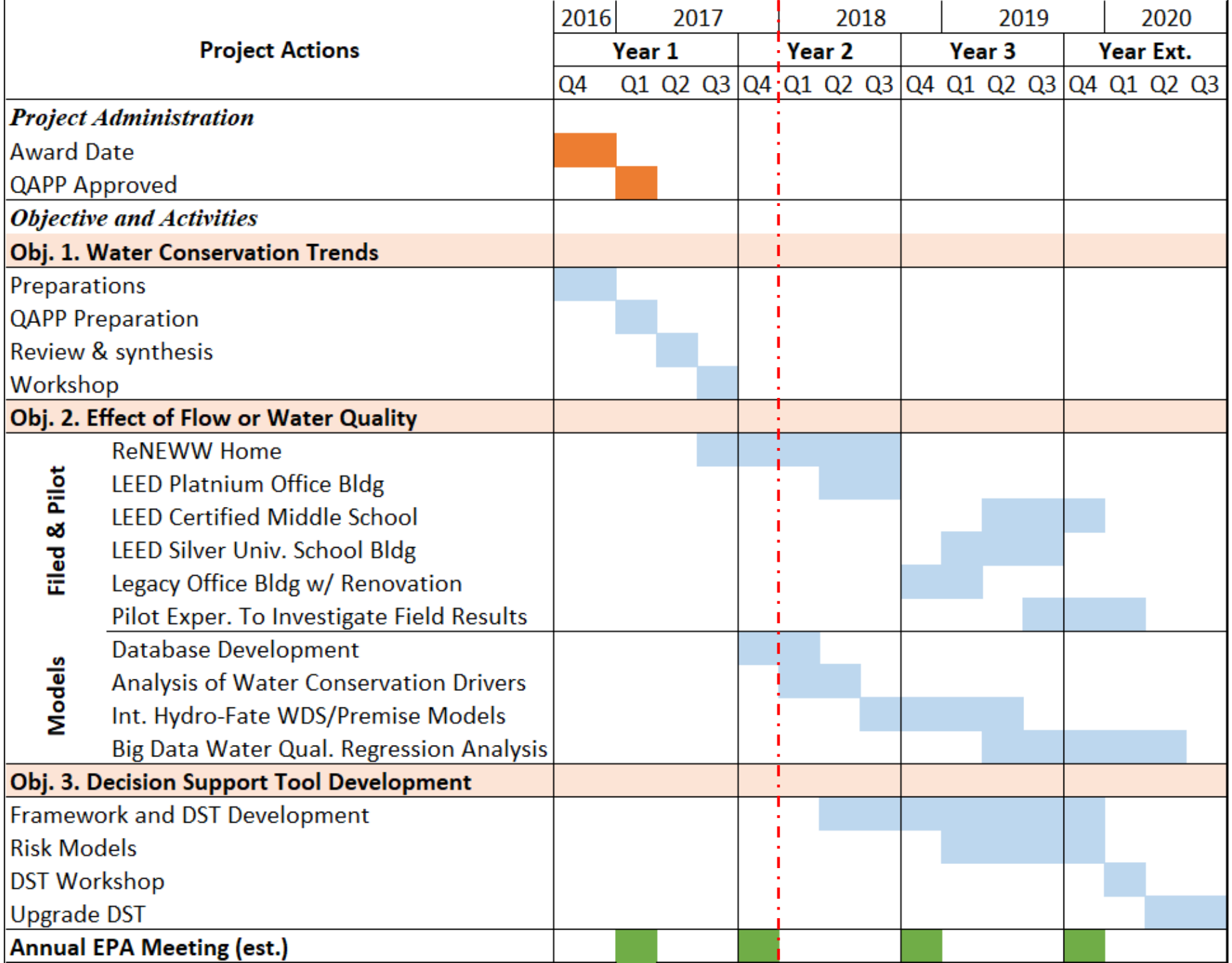
Science Interactive

InspectAPedia

Proposed Schedule of Major Activities

Objectives and Activities		Year 1 Q1	Q2	Q3	Q4	Year 2 Q1	Q2	Q3	Q4	Year 3 Q1	Q2	Q3	Q4
Obj. 1. Water Conservation Trends													
Review & Information Synthesis													
Workshop													
Obj. 2. Effect of Flow or Water Quality													
Field & Pilot	ReNEWW Home												
	LEED Platnium Office Bldg												
	LEED Certified Middle School												
	LEED Silver Univ. School Bldg												
	Legacy Office Bldg w/ Renovation												
	Pilot Exper. to Investigate Field Results												
Models	Database Development												
	Analysis of Water Conservation Drivers												
	Int. Hydraulic-Fate WDS/Premise Models												
	Big Data Water Qual. Regression Analysis												
Obj. 3. Decision Support Tool Development													
Risk Models													
Development													
Workshop													
Upgrade													
Annual EPA Meeting (est.)													

Project awarded Q4 2016
QAPP approved Q2 2017



Current Status

Year 1 Overview

1. *Bibliography (in annual report)*
2. **Plumbing safety workshop**
3. **Field and laboratory work**
4. **Next steps**

Plumbing Safety Research Workshop

Aug 23-24, 2017

Investigate Plumbing Safety with a skilled team of microbiologists, risk assessors, data scientists, civil, environmental, and ecological engineers, ecologists, and political scientists. Whirlpool Corporation is our team's innovation partner. Our research partners represent plumbing and architectural design companies, nonprofit organizations, trade industry associations, water providers, and health agencies.

Agenda

Day 1, Time	Activity
8:00-8:30	Sign-in
8:30-9:15	Welcome and opening remarks
9:15-10:00	Project overview
9:45-10:45	Identifying challenges: Premise plumbing and water safety
10:45-11:00	Break
11:00-12:00	Identifying challenges: Greatest difference to the future
12:00-1:00	Lunch
1:00-2:15	Prioritizing challenges: Highest priority for action
2:15-2:30	Break
2:30-3:45	Data and Information Needs: Water quality
4:00-4:30	Synthesis
4:30-5:00	Wrap up and next steps

Day 2, Time	Activity
8:00-8:30	Sign-in
8:30-9:50	Decision Support Tool
9:50-10:05	Break
10:05-11:30	Data and Information Needs: Water Use
11:30-12:00	Next steps

Key Contributions to the Project and Findings

Reviewed and compiled sources of water usage data

Identified data gaps in building types

Received feedback

- Need for integration of standards and codes
- Need for software development

More….

Workshop synthesis document (in preparation)

Better understand technology and information limitations

Exposure variability across building types

Positioned to better interpret results and setup for standards and codes

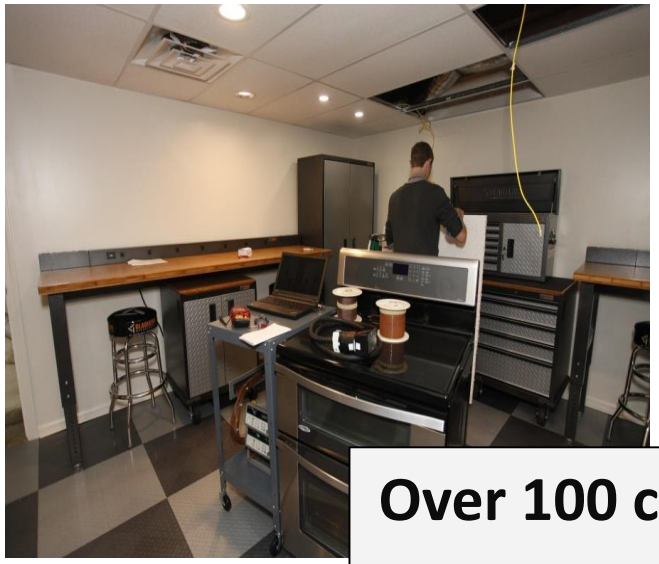
The ReNEWW House, West Lafayette, Indiana

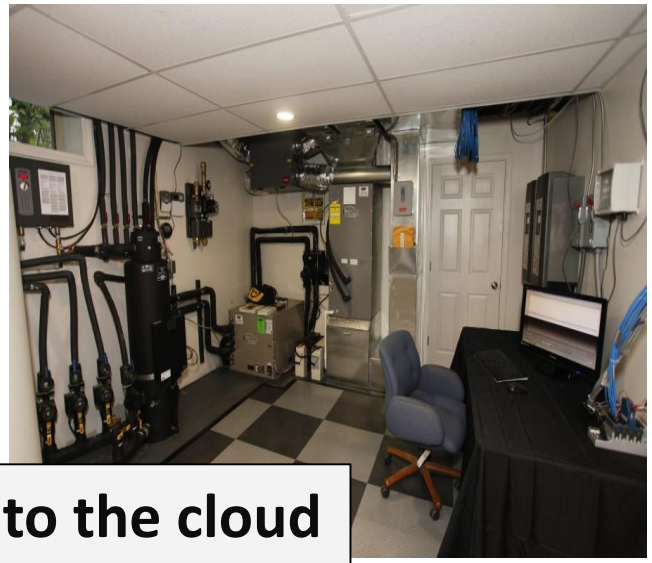
- Called the ReNEWW House for **Re**trofitted **N**et-Zero **E**nergy, **W**ater and **W**aste

- Whirlpool / Purdue University partnership to retrofit a 1920s vintage home into a net-zero energy, water and zero-waste-to-landfill structure
  - Year 1 - Energy Retrofit
  - Year 2 - Water Retrofit
  - Year 3 (now) - Zero Waste-to-landfill

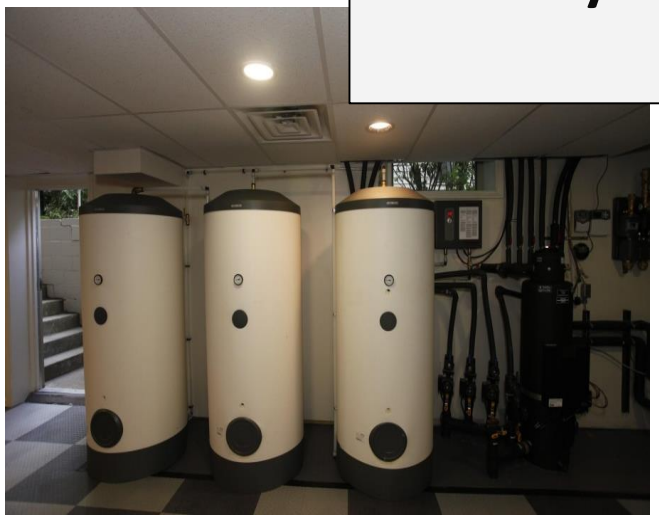
Courtesy: Whirlpool

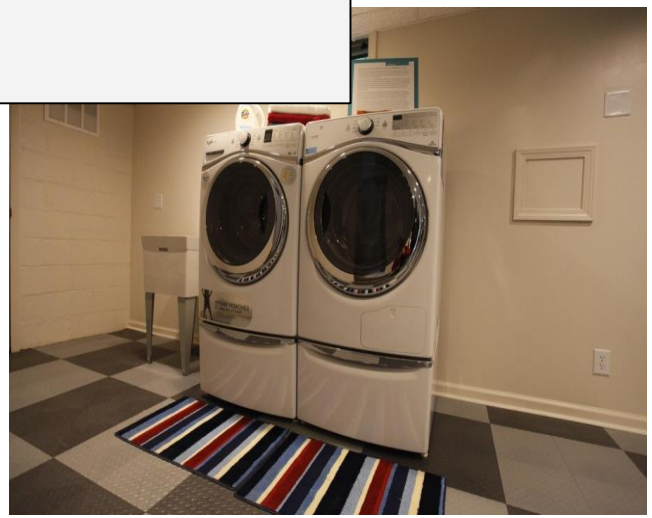
The ReNEWW House - Real-World Data





Over 100 channels of Data to the cloud every second = +20 BILLION data points/yr





Courtesy: Whirlpool

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

ReNNEW House
Net Zero Energy
Low-flow fixtures
3 Bedroom 2.5 bath
PEX plumbing

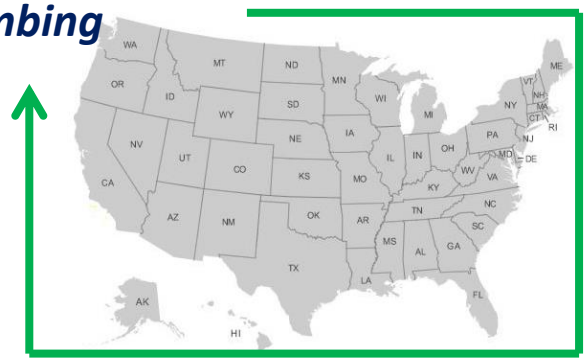
Goal: To better understand link between water use & drinking water quality.

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.

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

5-10 million miles of plumbing



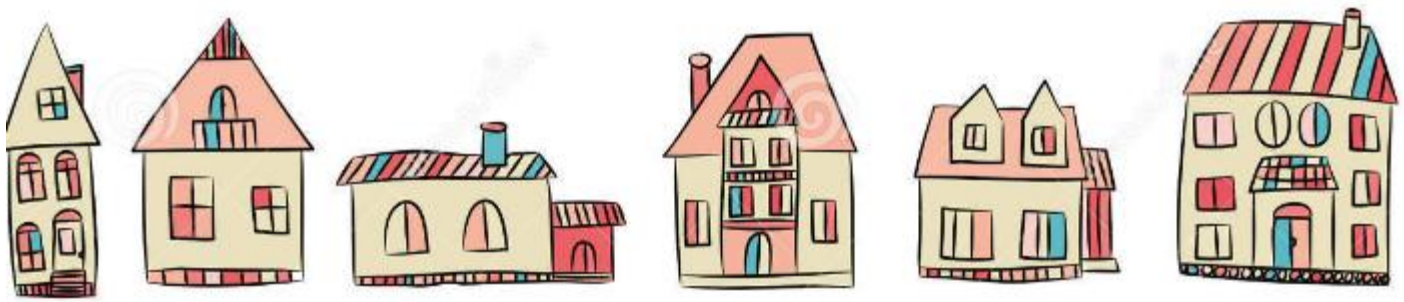
Water saving & Low-flow devices

Increased Water Age

Disinfectant residual loss

Microorganism proliferation

Enable contaminant leaching



Literature Review: Many residential building water quality studies conducted

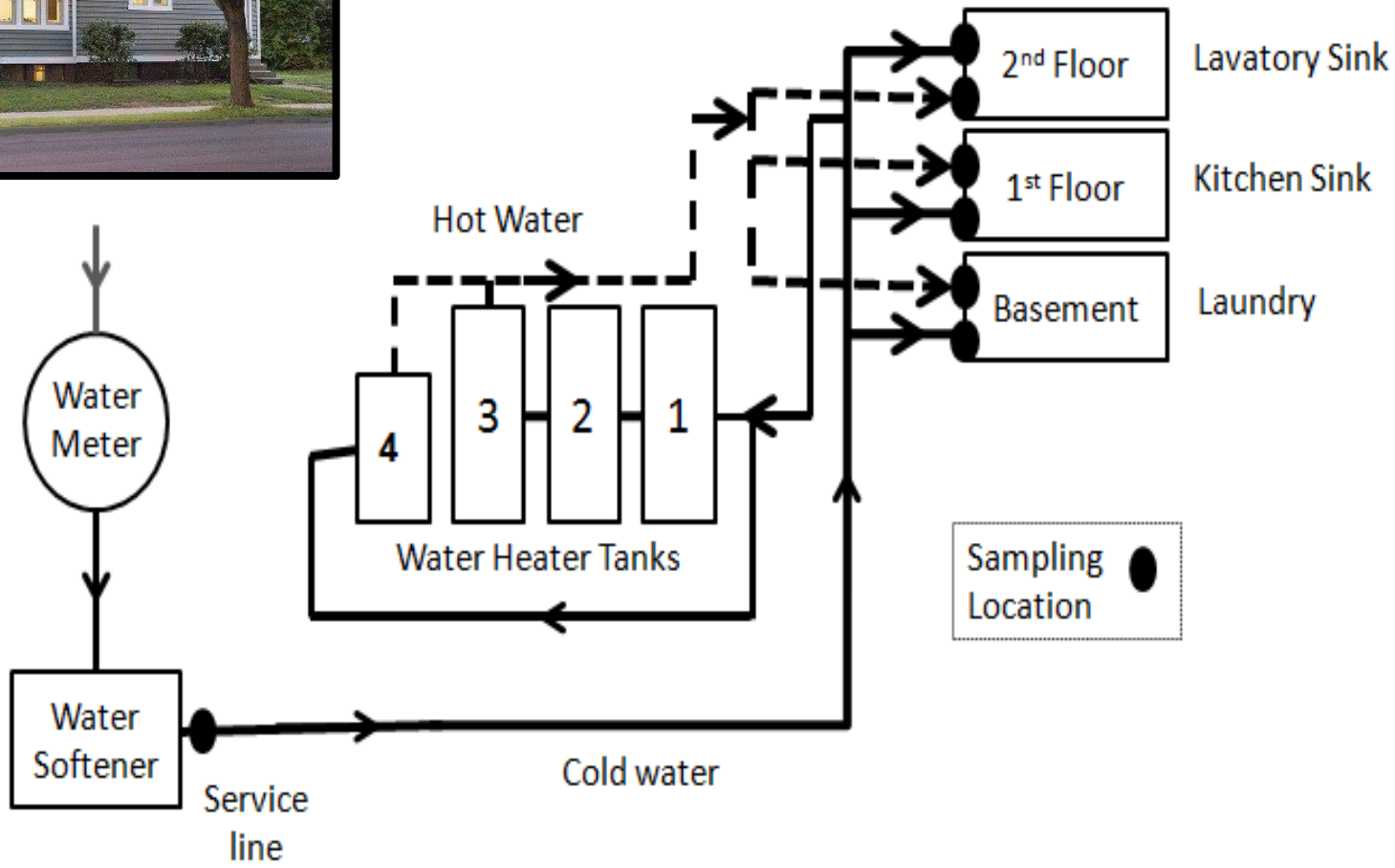
Country and Type of Buildings (Number)		Pipe Type / Plumbing Age (years)
USA	SFRBs (18)	nr/nr
	NZE SFRB (1)	PEX-a/ 0.5
	NZE SFRB & SFRB (2)	Cu, PEX/nr
	SFRB (3)	PEX-a, PEX-b/0.5-2
	Households (nr)	Cu, plastic/nr
CAN	SFRBs & Apartments (nr)	Cu, plastic/ <5, >10, >40
	SFRBs (6)	nr/nr
IT	SFRBs (nr)	Metal, plastic/nr
SWZ	Households (10)	nr/nr
DE	Households (1,674)	Cu/0.5-5
	Households (1,485)	nr
	SFRBs (nr)	Cu, plastic, galvanized steel/nr
	SFRBs (4)	Cu/nr

<u>But Data are Lacking</u>

1. Different sampling methods
2. Different plumbing characteristics
3. Lack of information

Water Sampling

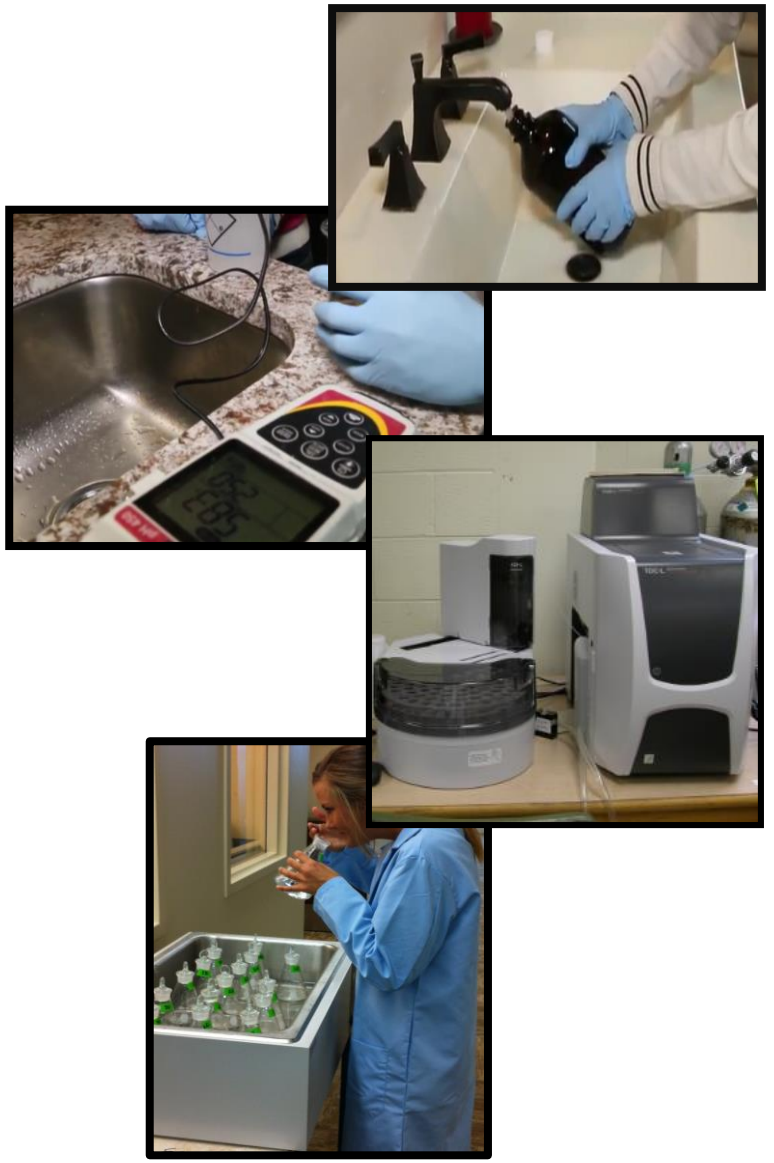
Water sampling (cold/hot)
on day 3, 15, 30, 60 & 90



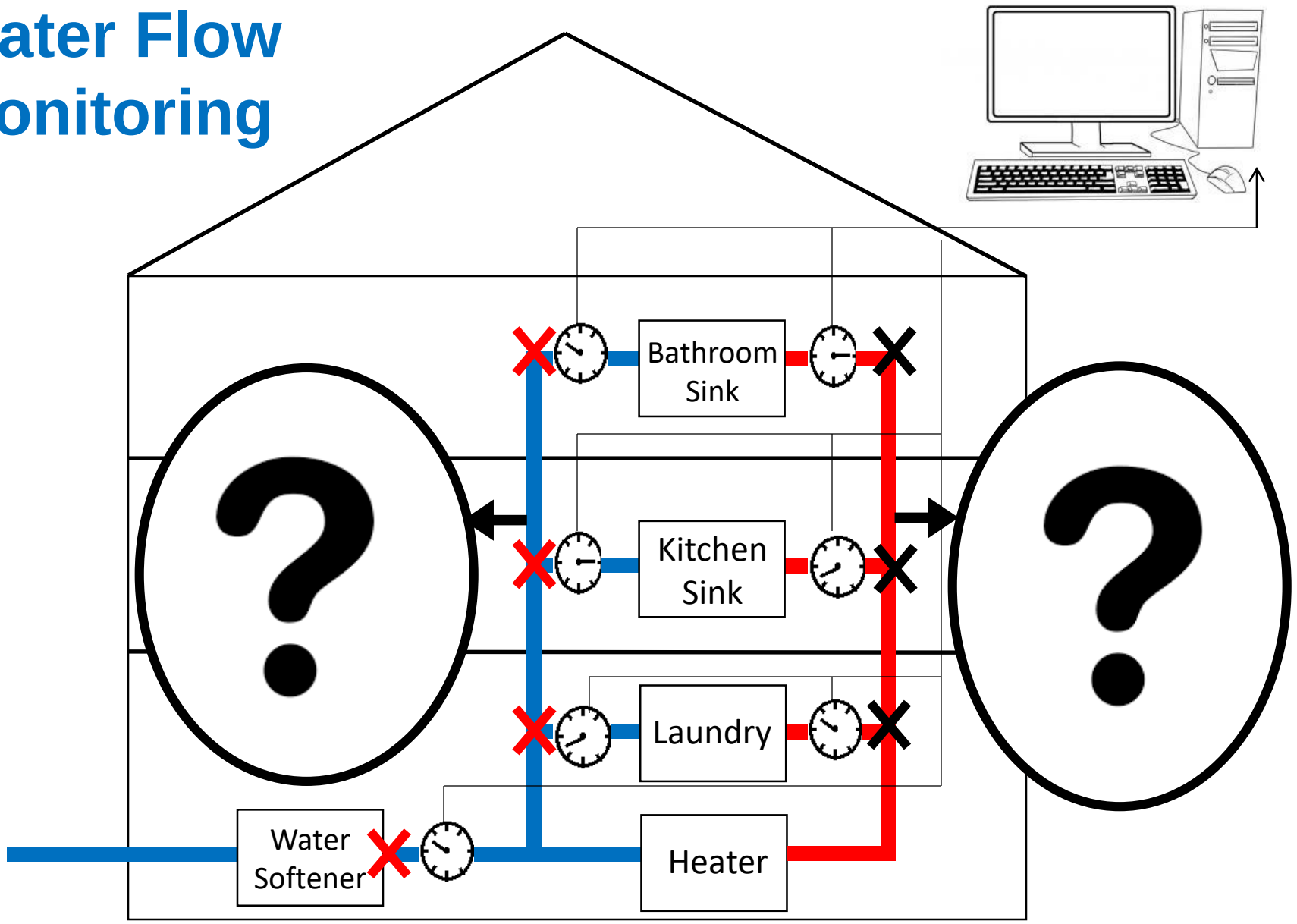
Water Quality Monitoring

Chemical Quality: Free chlorine, pH, Alkalinity, Total Organic Carbon (TOC),UV_{254} absorbance, Metals, Threshold Odor Number (TON)

Bacterial Quality: Culture-based HPC & Culture-independent quantitative real-time PCR (qPCR)

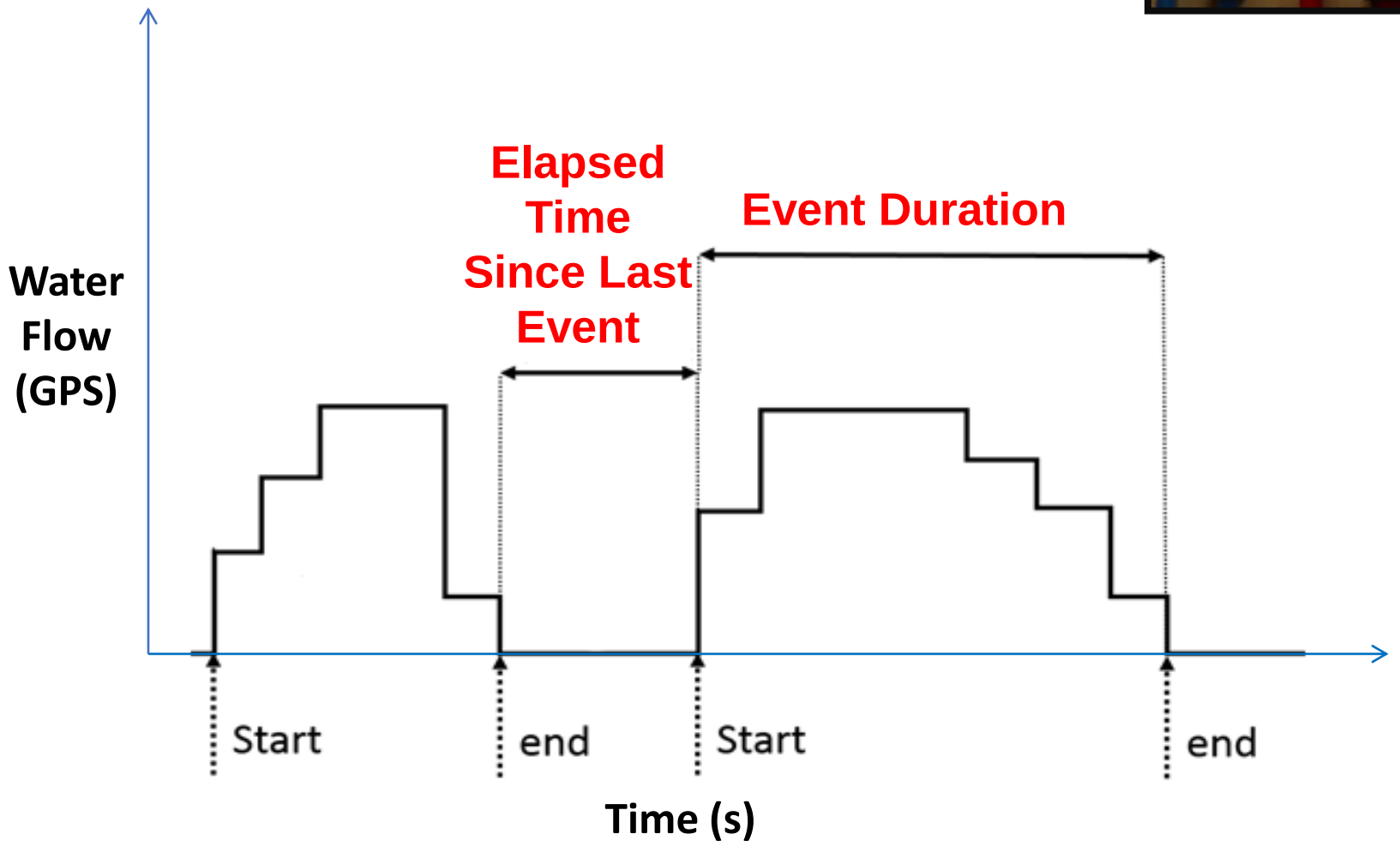


Water Flow Monitoring



Water Usage Analysis

64,891,484 *data points*



December Water Use, Month 3				
Water Sampling Location	Total Volume of Water Used, m^3	Number of Events	Average Stagnation Time, hr	Maximum Stagnation 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

Fixture Use: We monitored water use at 4 locations in a new green building during a 3 month period

Salehi et al. 2017.

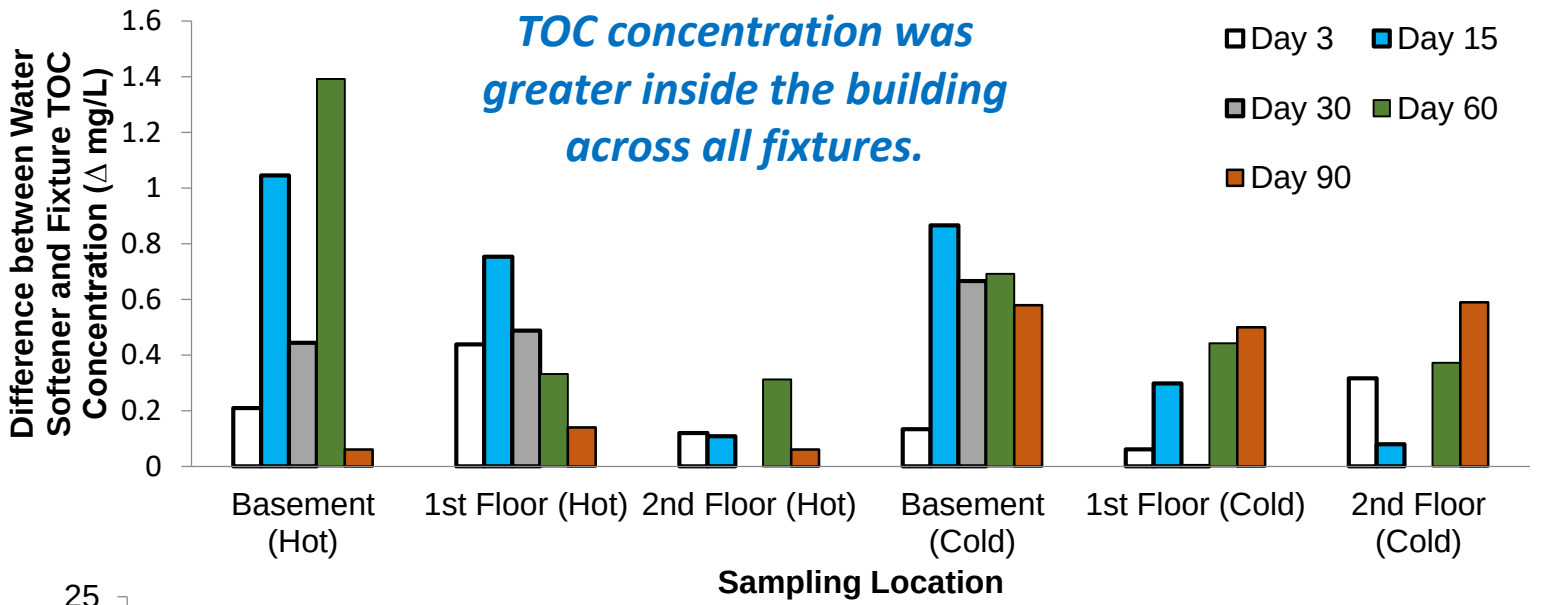
Water Usage Patterns

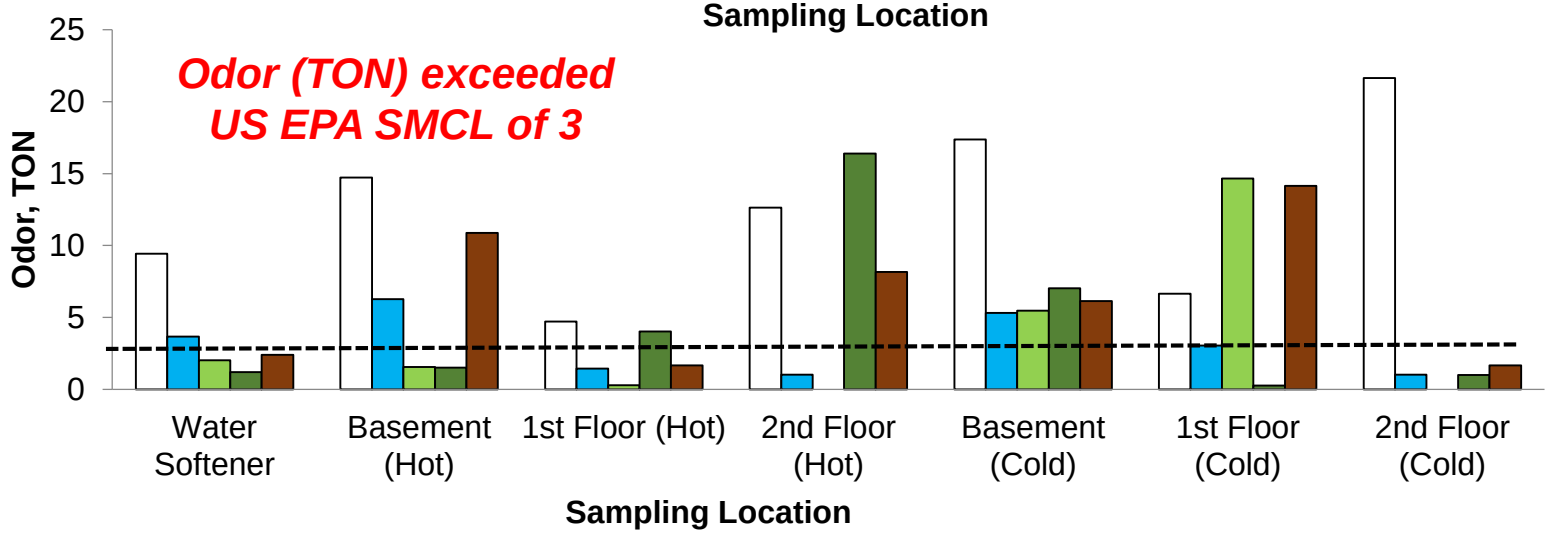
- During October to December the daily water usage varied between **0.169-0.245** m^3/d.

- **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).

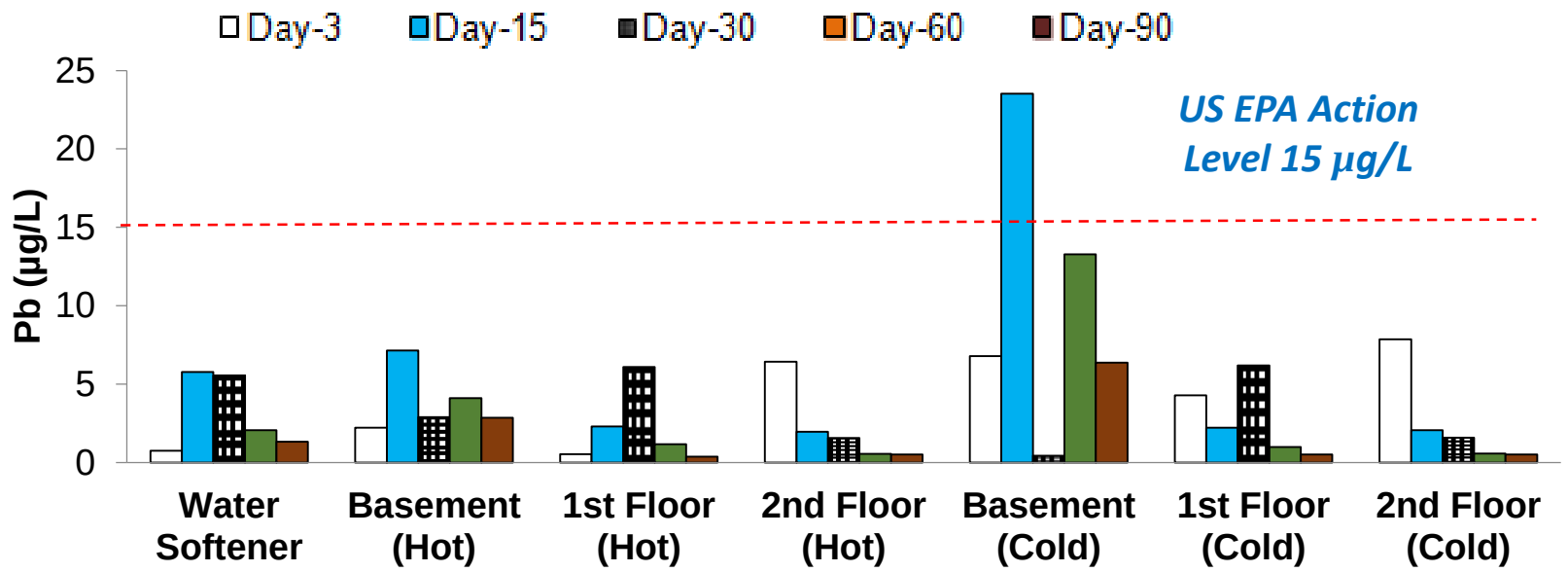
- During October to December the most frequently used fixture was the **2nd floor hot water** (bathroom sink, number of events per month 2,230).

TOC Concentration Increased Inside the Building



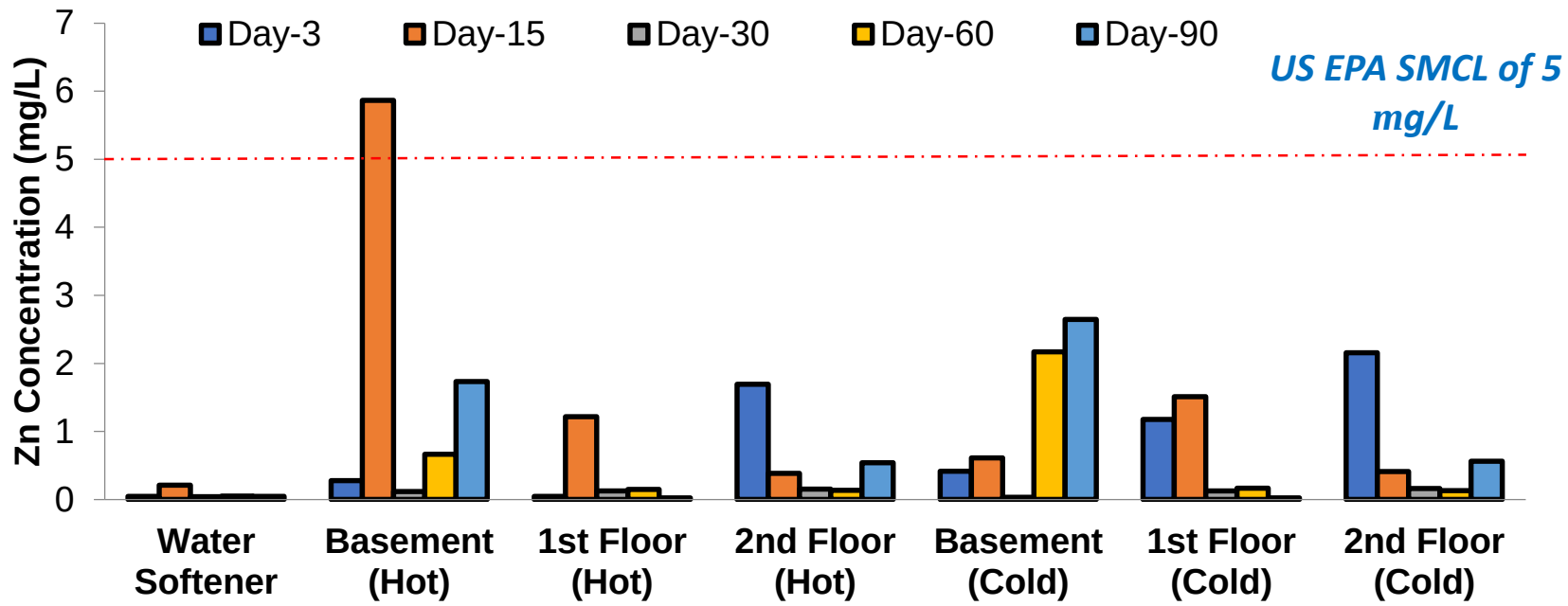


Several Heavy Metals with Health & Aesthetic Limits were Detected



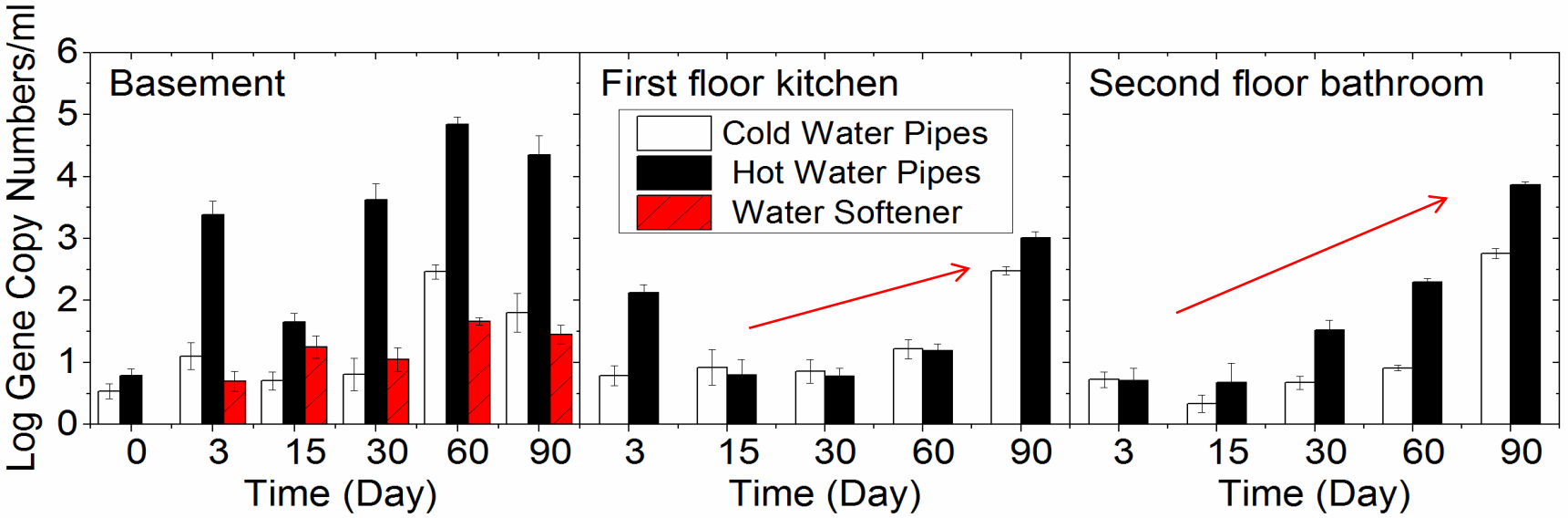
Fe concentration exceeded US EPA SMCL of **300 µg/L** at **Basement Hot (Day 15).**

Mn exceeded its 50 µg/L USEPA SMCL in the **basement hot water on day 15**.

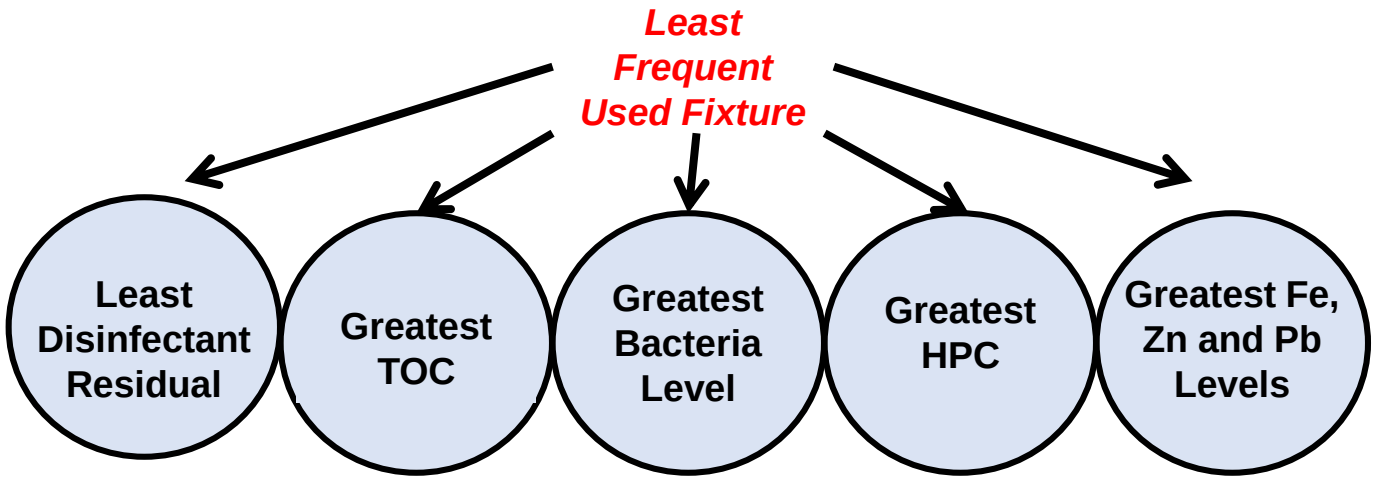


The **basement fixture brass needle valve** may have caused maximum Zn (5.9 mg/L), Fe (4.1 mg/L), and Pb (23 µg/L) levels compared to other fixture water samples.

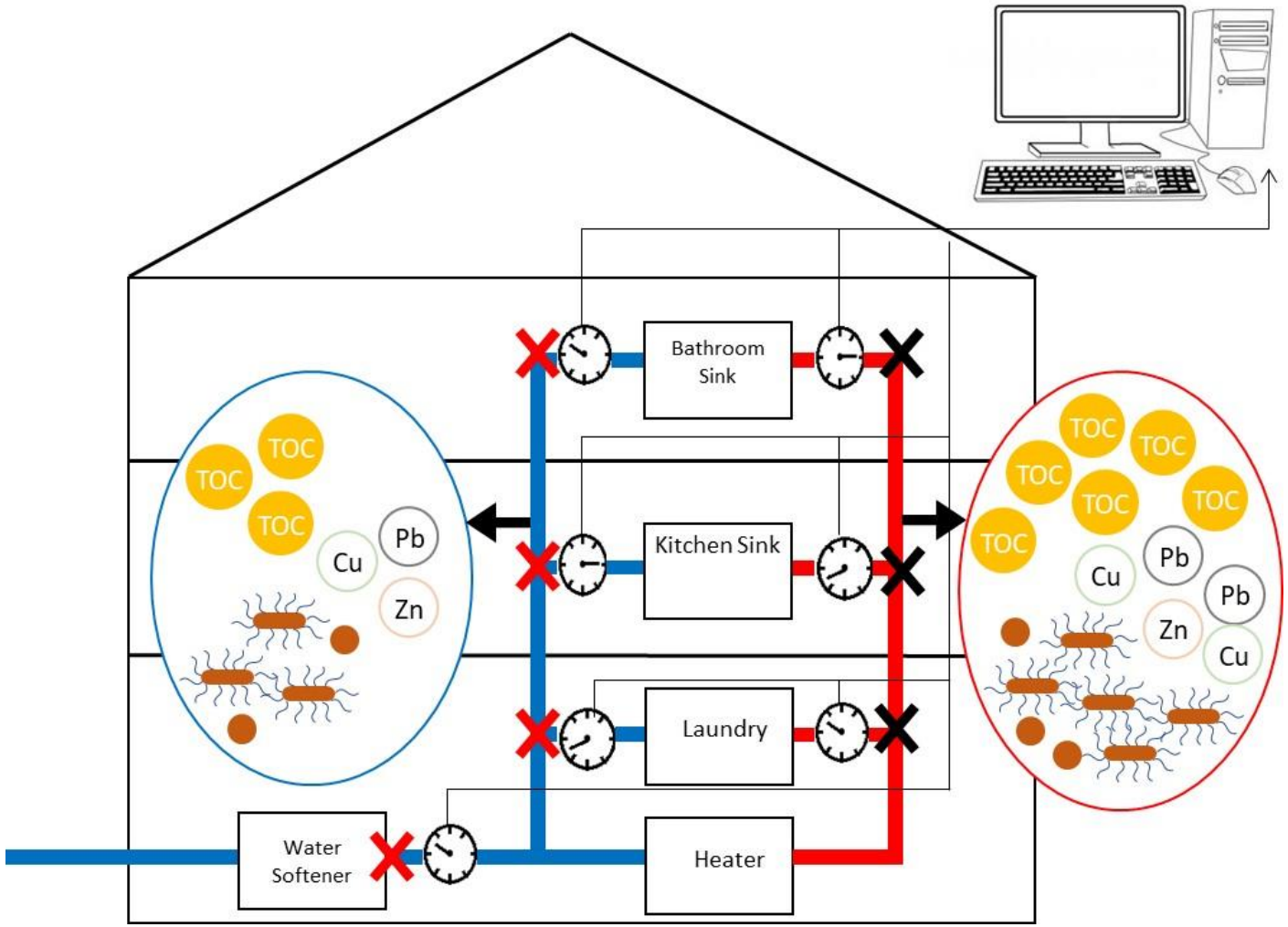
During the same period, bacteria levels increased with time and bacteria were more numerous in hot water vs. cold water



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



Salehi et al. 2017.

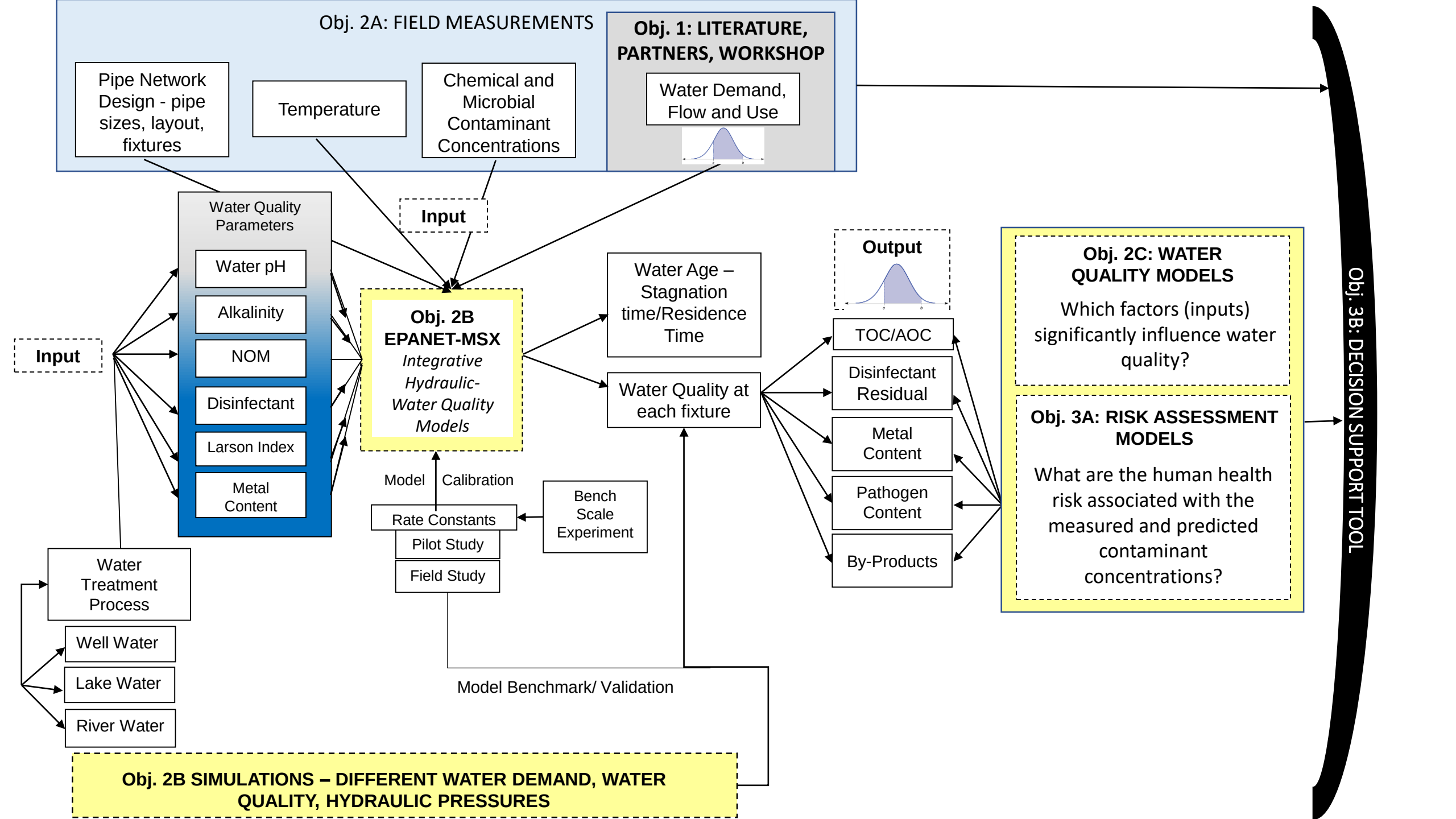


Highlights

1. A new residential green building was studied for its first 4 months.
2. Fixture use and water quality were monitored at four in-building locations.
3. The maximum fixture water stagnation time was 72 h.
4. Hot water contained greater bacteria and organic carbon levels than cold water.
5. Chemical and bacteria levels varied across fixtures within the building.

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.
- Hot water plumbing promoted greater microbial growth.
- At the basement fixture, where the least amount of water use events occurred, greater organic carbon, bacteria, and heavy metal levels were detected.


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 Treatment Process
Well Water
Lake Water
River Water
Model Benchmark/ Validation
Obj. 2B SIMULATIONS – DIFFERENT WATER DEMAND, WATER QUALITY, HYDRAULIC PRESSURES
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

Testing at ReNEWW House

Microbiology

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

Chemistry

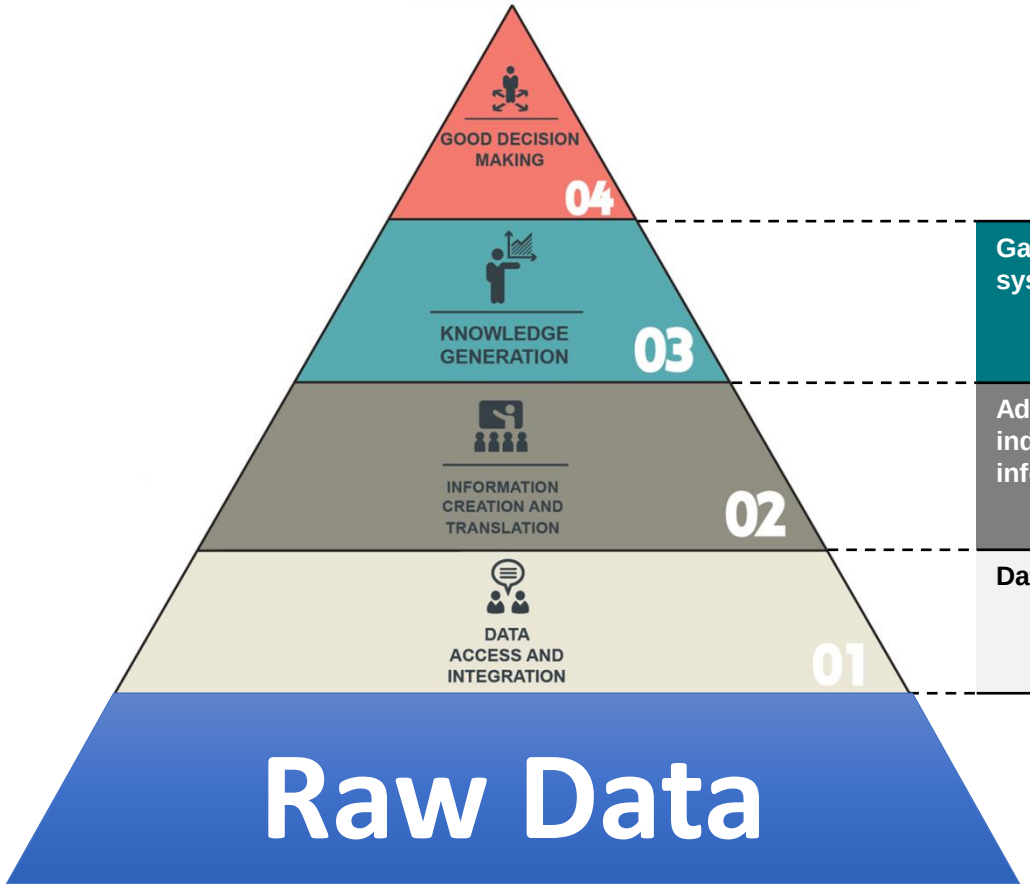
- Temperature
- pH
- Disinfectant residual
- DO
- Metals
- TOC/DOC
- AOC
- Alkalinity
- Ions
- DBPs

Physical

- Pressure
- Fixture temperature
- Indoor air temperature
- Flow rate
- # of events
- Event duration

And more…

Knowledge Hierarchy



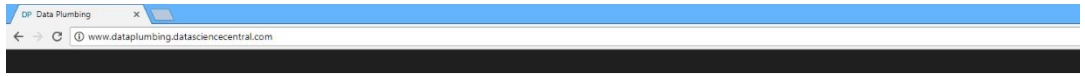
DST Functions

Gateway to more advanced research related to complex systems or new knowledge

Advanced analytics, including custom mapping, integrated index creation, raster calculations, relational mapping, information communication, basic statistical analysis

Data gathering, integration, and delivery

DSTshortens data development time, answers critical questions, and discovers new relationships



Data Plumbing

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DSC Community created

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Specifically differenti
industry event, the St
is targeted for "hardc
configuring, integratir
"storage plumbing."

Sessions planned suc
systems, IO, storage s
house software and a
submissions coverin
deployment cycle of

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Select a state to search by clicking on the map or on the text links below.

May 10, 2016

Data standards and plumbing

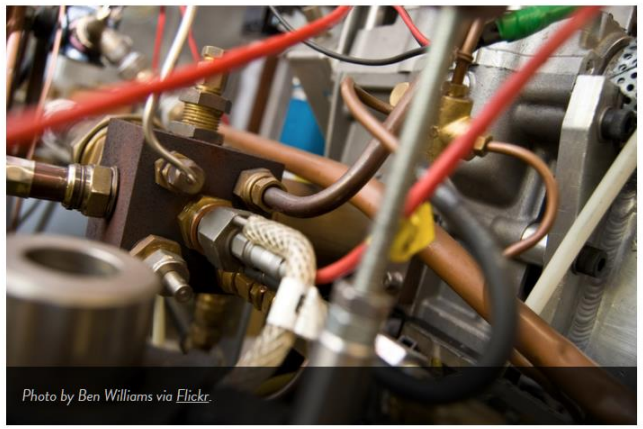

Photo by Ben Williams via Flickr.

The Canadian government is running an online consultation on its open government plan. We've submitted a proposal: to implement a new open data standard for federal grants and contributions.

Data standards are like plumbing: they're not the most exciting thing to talk about, but when they're working properly it makes all the difference.

There are plenty of simple questions — for example, how much federal funding goes to youth programs in Toronto? — that are very difficult to answer right now. The information needed to do so is scattered across a dozen locations in many different formats.

striving to improve standards of service delivery and increase customer satisfaction, there is a need to shift from this reactive approach to a more proactive management strategy. One of the tools that can be used to help accomplish this shift is an online hydraulic network simulation model.

the inclusion of pressure-controlling elements without specifying the operational state of the network (Andersen and Powell, 1999).

Drinking Water
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Jun 14, 2017

We are honoured to have been awarded the Open Data Accessibility Award during the Canadian Open Data Awards annual ceremony on June 13th, 2017 in Edmonton, Alberta.

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on Master Plan

Burns & McDonnell to perform a plan. Burns & McDonnell developed ties to an ESRI geodatabase

isting information management op a fully geographic information system (GIS) integrated water distribution master plan. A combination of an AutoCAD distribution system mapping and a Microsoft SQL Server 2000 geodatabase GIS was used to develop the

Looking Ahead, Year 2 (Oct 1, 2017-Sept 30, 2018)

- Prepare summary of 2017 stakeholders workshop
- Complete water quality monitoring of ReNEWW house
- Develop integrated water quality-hydraulic model for residential plumbing (trunk-and-branch)
  - Evaluate temperature and pressure profiles
- Analyze water quality data from ReNEWW house with respect to usage, flow, temperature and source through regression modeling
- Develop risk models for opportunistic pathogens
- Begin water sampling of a few commercial buildings we have identified (schools, offices, institutions)

Looking Ahead, Year 2 (Oct 1, 2017-Sept 30, 2018)

- Disseminate results to the public and stakeholders
  - ✓Society of Risk Analysis Annual Meeting
  - ✓Expert drinking water safety panel at the U.S. Green Building Council (USGBC) GreenBuild Conference

  - American Chemical Society Annual Conference, March 2018, Louisiana
  - American Water Works Association Annual Conference and Exposition
  - National Environmental Health Association Annual Educational Conference & Exhibition and HUD Healthy Homes Conference
  - Emerging Water Technology Symposium sponsored by American Society of Plumbing Engineers (ASPE), Alliance for Water Efficiency (AWE), International Association of Plumbing and Mechanical Officials (IAPMO), Plumbing Manufacturers International (PMI), and World Plumbing Council (WPC)

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