PREDICTING DRINKING WATER SAFETY INSIDE BUILDINGS IN A TECHNOLOGY CHANGING WORLD

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

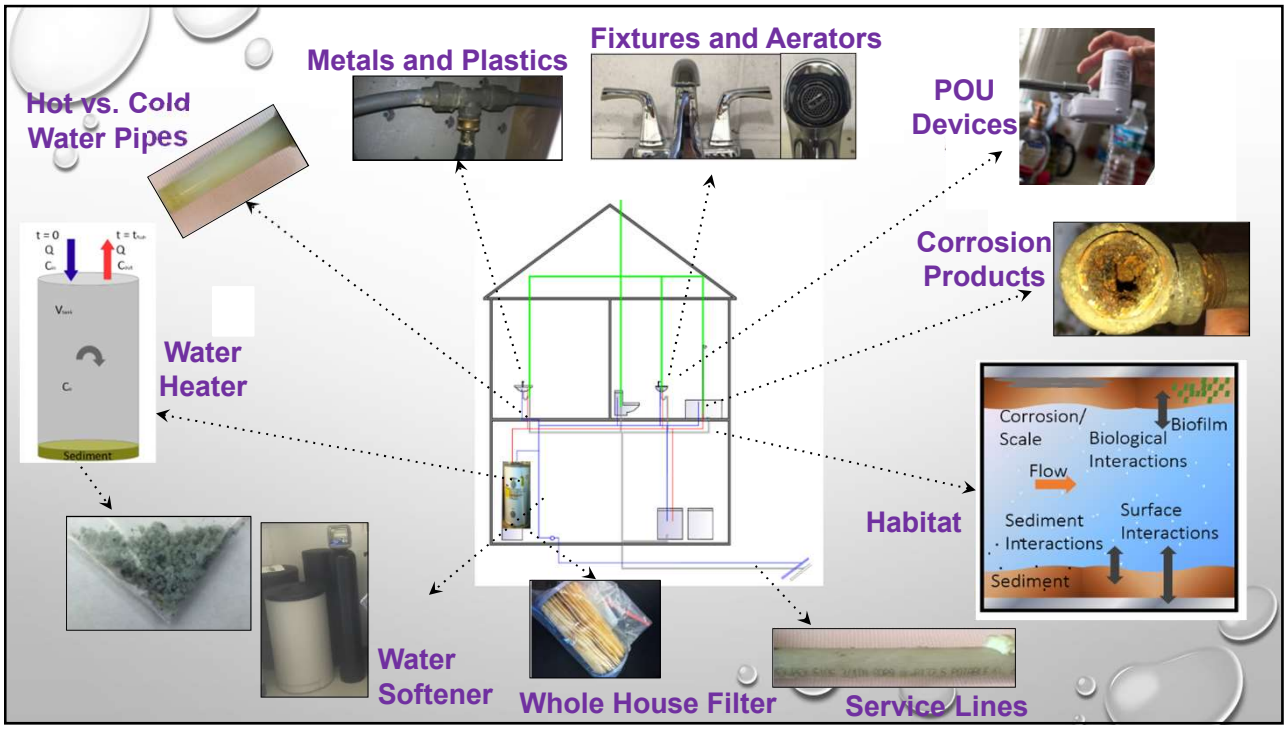
National Environmental Health Association (NEHA) 2018 AEC and HUD Healthy Homes Conference

ACKNOWLEDGMENTS

THANKS TO THE **ENVIRONMENTAL PROTECTION AGENCY NATIONAL PRIORITIES GRANT (#R836890)** FOR FUNDING.

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

SPECIAL THANKS TO WHIRLPOOL CORPORATION INCLUDING ERIC BOWLER, JASON SCHNEEMANN AND RONALD VOGELWEDE FOR PROVIDING TECHNICAL ASSISTANCE AND HOSTING THE TEST-SITE AT THE RENEWW HOUSE PROJECT.



BUILDING WATER USE HAS BEEN DECLINING

Water Use Energy Policy Act of 1992

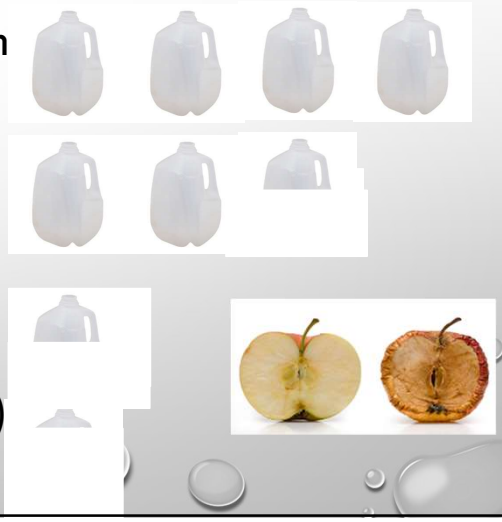
Water Use has Decreased From Lower-Flow Faucets

Pre-1994 (4^{+} gpm)

1994 (2.5 gpm)

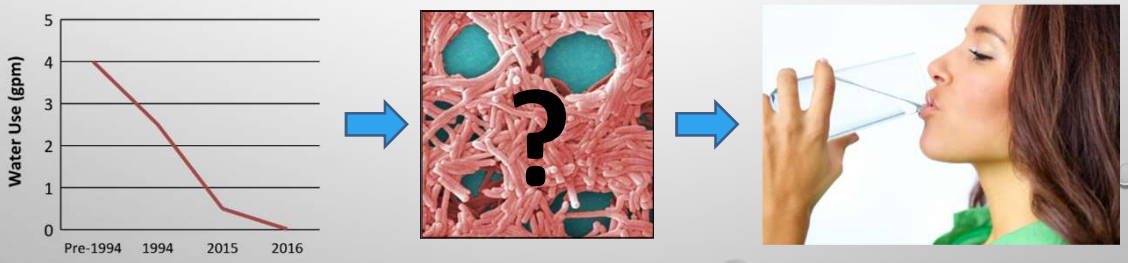
2015 (0.5 gpm)

2016? (0.01 gpm)



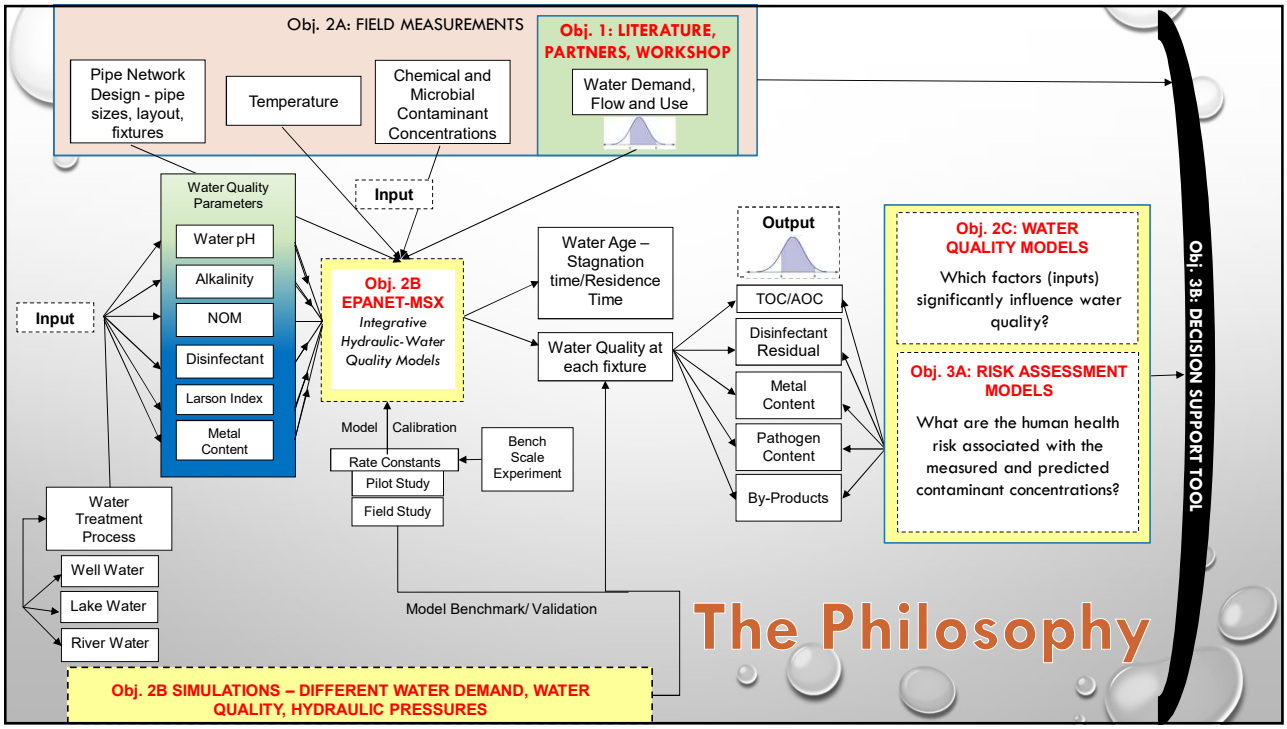
OUR EPA PROJECT GOAL

TO BETTER UNDERSTAND AND PREDICT WATER QUALITY AND HEALTH RISKS POSED BY DECLINING WATER USAGE AND LOW FLOWS, 2017-2020



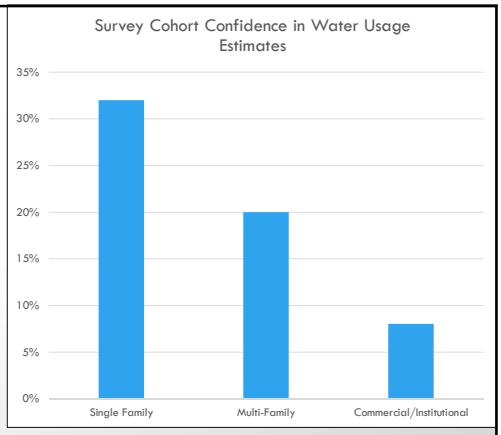
OUR EPA PROJECT OBJECTIVES

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


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
Science Interactive
NIST National Institute of Standards and Technology U.S. Department of Commerce
NAVAL HOSPITAL JACKSONVILLE, FLORIDA
Technion Israel Institute of Technology
UNIVERSITY OF Cincinnati
ASPE American Society of Plumbing Engineers
UNIVERSITÉ LAVAL
InspectAPedia

SURVEY RESULTS



- WATER CONSERVATION ISSUES
  1. PATHOGEN GROWTH
  2. SOURCE WATER QUALITY
  3. METAL LEACHING
  4. TASTE/ODOR
- HIGH PARTICIPANT CONFIDENCE
  - WATER USAGE WILL CONTINUE TO DECLINE (56%)
  - AWWA IS THE MOST RELIABLE SOURCE OF USAGE INFORMATION (42%)
  - RESIDENTIAL END-USE RATES FROM REU2016 ARE ACCURATE (32%)
- LOW PARTICIPANT CONFIDENCE
  - COMMERCIAL/INSTITUTIONAL USAGE RATES (WRF) ARE ACCURATE (8%)
  - WHEN ASKED TO QUANTIFY RECIRCULATION RATES IN BUILDINGS (8%)

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

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.

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?

Monitoring

After softener

Basement (cold/hot)

Kitchen sink (cold/hot)

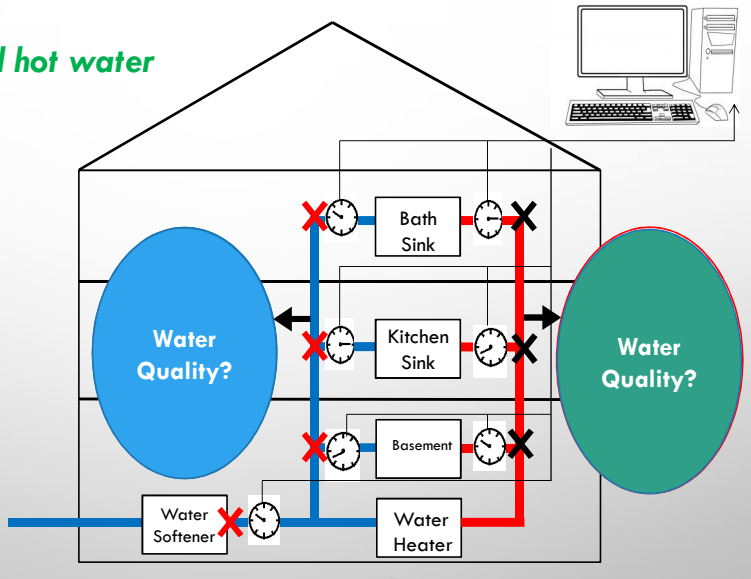
Bathroom sink (cold/hot)

Online flow

Online fixture temp

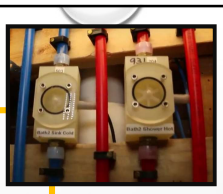
Grab water sampling

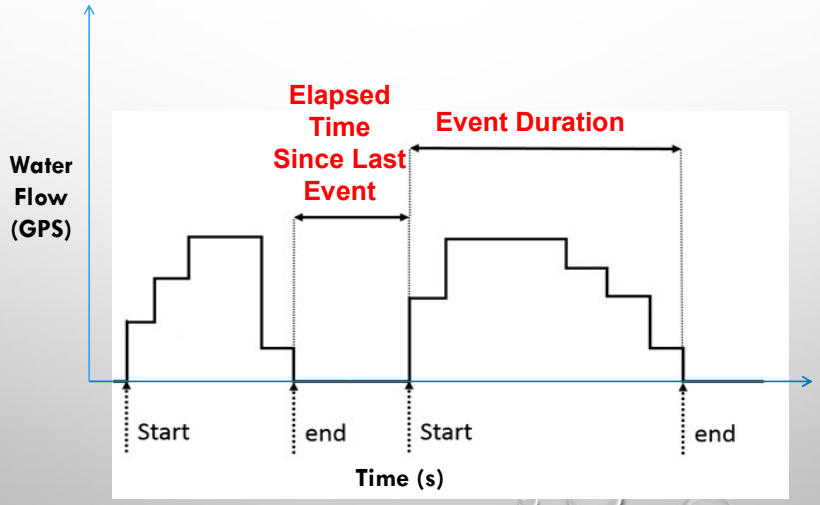
- Day 3, 15, 30, 60 & 90
- Onsite: pH, chlorine residual, temp
- Lab: TOC, total metals, HPC, gene copies



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

Water Usage Analysis

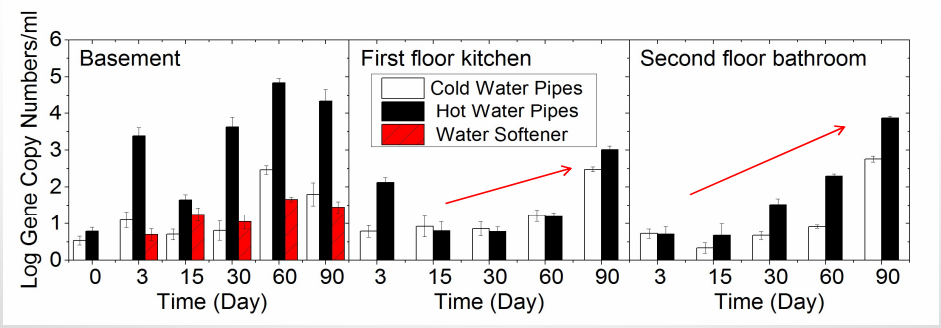


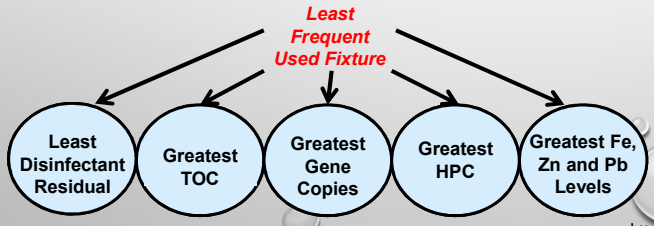


Water Usage Patterns for a Few Fixtures Monitored in December 2015

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*. https://doi.org/10.1016/j.chemosphere.2017.11.070

MEASUREMENTS

MICROBIOLOGY

- *LEGIONELLA SPP.* **-LEG23S RRNA**
- *L. PNEUMOPHILA*
- *P. AERUGINOSA*
- *MYCOBACTERIUM SPP.*
  - **- 23S RRNA AND ITS REGION**
- *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

- 3 SAMPLE PERIODS
  - AUGUST 2017 ON RAINWATER
  - OCTOBER 2017 AND JAN. - FEB. 2018 ON MUNICIPAL WATER
  - EVERY OTHER DAY FOR ONE WEEK IN OCT. & 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

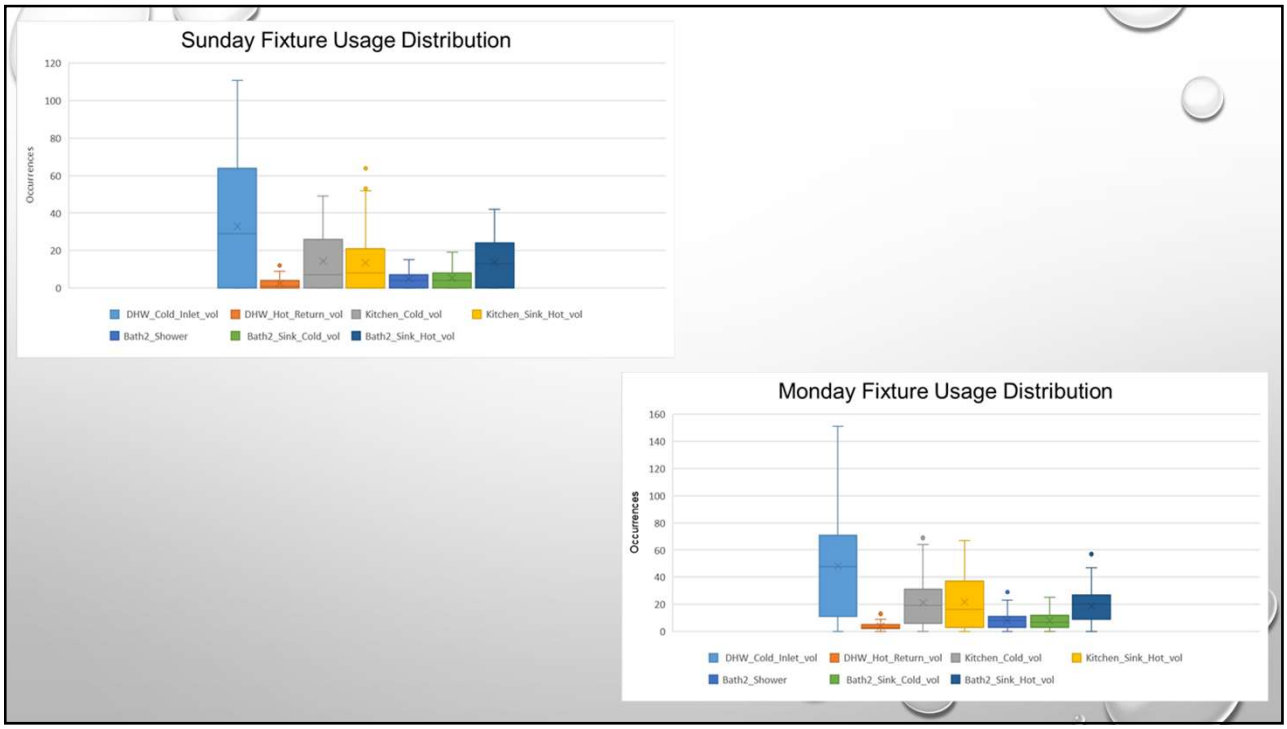
WATER USAGE ?

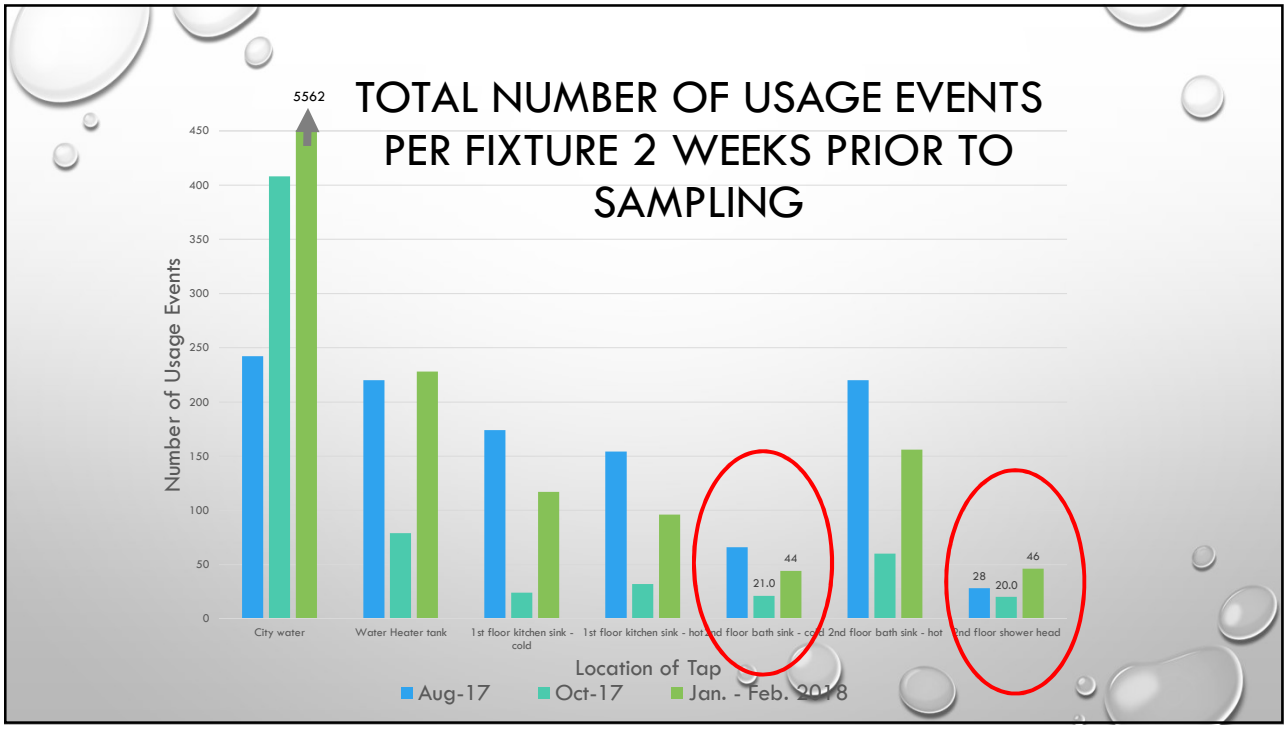
- WHAT TIME PERIOD BEFORE SAMPLING SHOULD BE CONSIDERED?
  - 1 WEEK, **2 WEEKS**, 30 DAYS, 60 DAYS
- WHAT METRICS SHOULD BE CONSIDERED TO DEFINE USAGE?

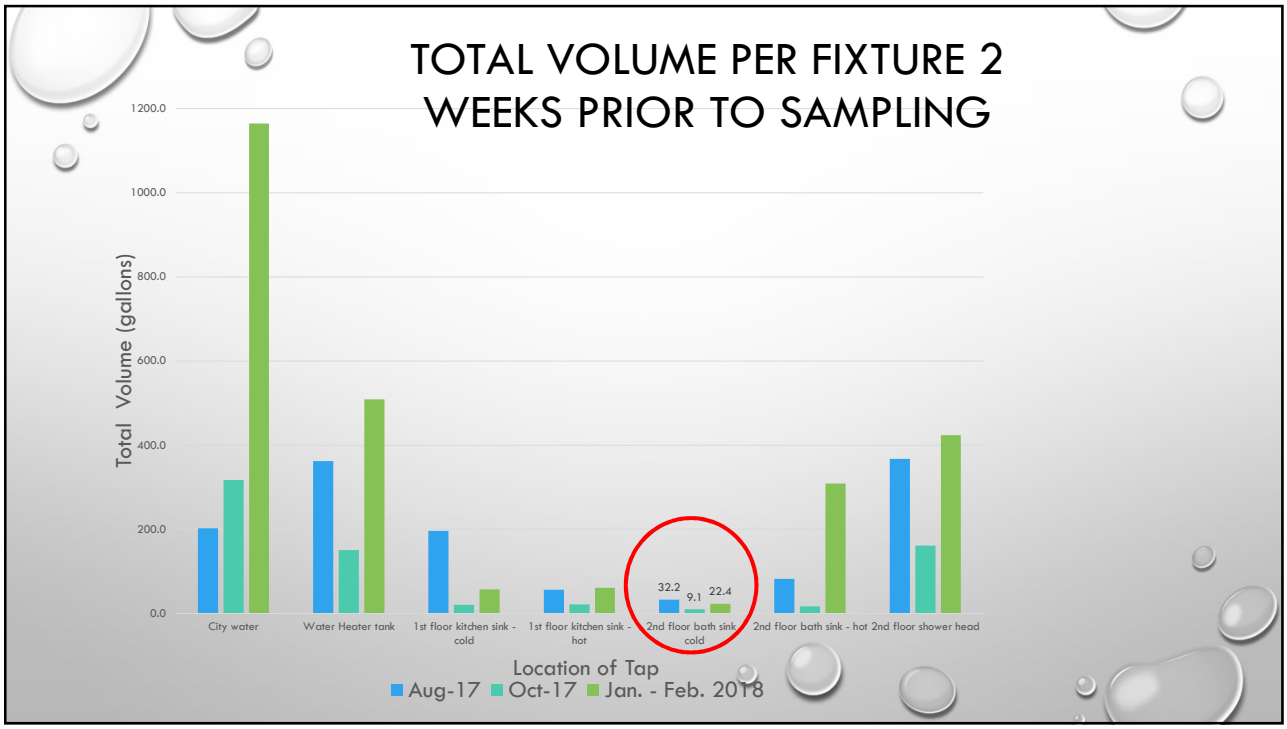
Exposure

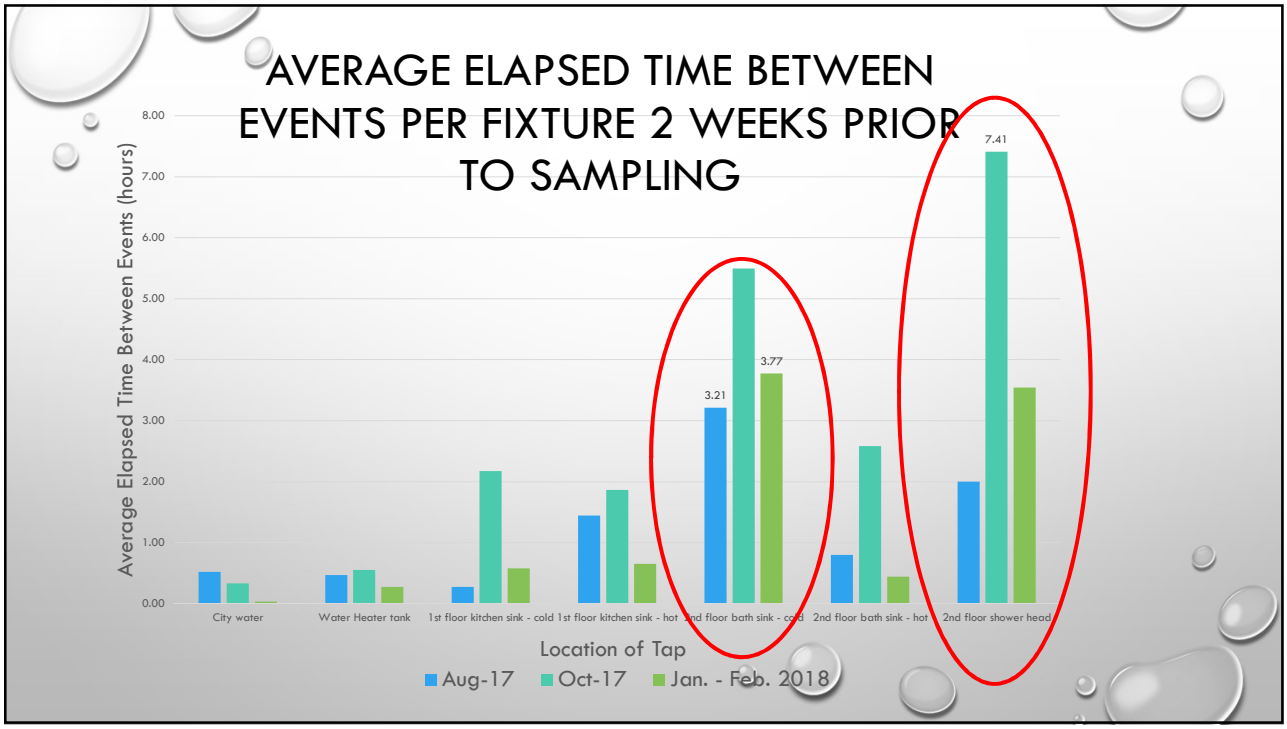
- NUMBER OF EVENTS
- TOTAL VOLUME PER FIXTURE
- AVERAGE OR MAXIMUM FLOW RATE PER FIXTURE
- AVERAGE OR MAXIMUM ELAPSED TIME BETWEEN EVENTS (~STAGNATION)

Physical
Chemical
Biological changes


Sunday Fixture Usage Distribution
Occurrences
120
100
80
60
40
20
0
DHW_Cold_Inlet_vol
DHW_Hot_Return_vol
Kitchen_Cold_vol
Kitchen_Sink_Hot_vol
Bath2_Shower
Bath2_Sink_Cold_vol
Bath2_Sink_Hot_vol
Monday Fixture Usage Distribution
Occurrences
160
140
120
100
80
60
40
20
0
DHW_Cold_Inlet_vol
DHW_Hot_Return_vol
Kitchen_Cold_vol
Kitchen_Sink_Hot_vol
Bath2_Shower
Bath2_Sink_Cold_vol
Bath2_Sink_Hot_vol


TOTAL NUMBER OF USAGE EVENTS PER FIXTURE 2 WEEKS PRIOR TO SAMPLING
5562
Number of Usage Events
450
400
350
300
250
200
150
100
50
0
44
21.0
46
28
20.0
City water
Water Heater tank
1st floor kitchen sink - cold
1st floor kitchen sink - hot
2nd floor bath sink - cold
2nd floor bath sink - hot
2nd floor shower head
Location of Tap
Aug-17
Oct-17
Jan. - Feb. 2018


TOTAL VOLUME PER FIXTURE 2 WEEKS PRIOR TO SAMPLING
Total Volume (gallons)
1200.0
1000.0
800.0
600.0
400.0
200.0
0.0
32.2
9.1
22.4
City water
Water Heater tank
1st floor kitchen sink - cold
1st floor kitchen sink - hot
2nd floor bath sink - cold
2nd floor bath sink - hot
2nd floor shower head
Location of Tap
Aug-17
Oct-17
Jan. - Feb. 2018


AVERAGE ELAPSED TIME BETWEEN EVENTS PER FIXTURE 2 WEEKS PRIOR TO SAMPLING
Average Elapsed Time Between Events (hours)
8.00
7.00
6.00
5.00
4.00
3.00
2.00
1.00
0.00
3.21
3.77
7.41
City water
Water Heater tank
1st floor kitchen sink - cold
1st floor kitchen sink - hot
2nd floor bath sink - cold
2nd floor bath sink - hot
2nd floor shower head
Location of Tap
Aug-17
Oct-17
Jan. - Feb. 2018

CORRELATION ANALYSIS

- CORRELATION BETWEEN WATER USAGE PARAMETERS AND PATHOGEN WAS CONDUCTED AT:

Water Heater tank
1st floor kitchen sink - cold
1st floor kitchen sink - hot
2nd floor bath sink - cold
2nd floor bath sink - hot
2nd floor shower head

- CITY WATER MAIN /SERVICE LINE WAS EXCLUDED
  - **LEGIONELLA** AND **MYCOBACTERIUM SPP.** WERE DETECTED BY QPCR ONLY DURING THE JAN./FEB. 2018 SAMPLING PERIOD
- CHEMICAL DATA AND HPCS WERE NOT COLLECTED DURING THE AUGUST 2017 SAMPLING PERIOD SO ONLY TWO TIME POINTS ARE CURRENTLY AVAILABLE

RESULTS

2ND FLOOR BATH SINK COLD

Bath2_Sink_Cold_vol	pH	Temp (C)	DO (mg/L)	Total Cl (mg/L)	Mean AOC (ug/L)	HPC (CFU/100 mL)	Leg23s rRNA	23s rRNA and ITS region	nEvents (>1 sec)	fixVol	timeSinceLast
pH	1.00										
Temp (C)	-0.73	1.00									
DO (mg/L)	0.98	-0.86	1.00								
Total Cl (mg/L)	0.47	-0.94	0.64	1.00							
Mean AOC (ug/L)	-0.36	0.90	-0.54	-0.99	1.00						
HPC (CFU/100 mL)	-0.77	1.00	-0.88	-0.93	0.87	1.00					
Leg23s rRNA	0.94	-0.45	0.85	0.13	-0.01	-0.49	1.00				
23s rRNA and ITS region	0.94	-0.45	0.85	0.13	-0.01	-0.49	1.00	1.00			
nEvents (>1 sec)	-0.61	0.99	-0.76	-0.99	0.96	0.98	-0.30	-0.30	1.00		
fixVol	-0.59	0.98	-0.74	-0.99	0.97	0.97	-0.27	-0.27	1.00	1.00	
timeSinceLast	0.85	-0.98	0.94	0.86	-0.80	-0.99	0.61	0.61	-0.94	-0.93	1.00

RESULTS

2ND FLOOR BATH SHOWER HEAD

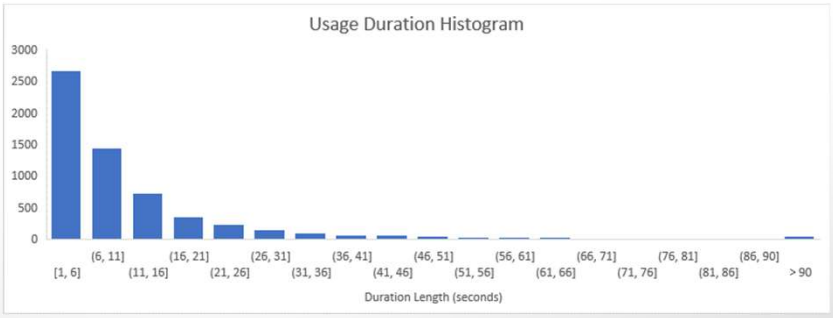
Bath2_Shower	pH	Temp (C)	DO (mg/L)	Total Cl (mg/L)	Mean AOC (ug/L)	HPC (CFU/100 mL)	Leg23s rRNA	23s rRNA and ITS region	nEvents (>1 sec)	fixVol	timeSinceLast
pH	1.00										
Temp (C)	-0.97	1.00									
DO (mg/L)	1.00	-0.98	1.00								
Total Cl (mg/L)	0.15	0.09	0.13	1.00							
Mean AOC (ug/L)	0.98	-0.92	0.98	0.32	1.00						
HPC (CFU/100 mL)	0.98	-0.90	0.97	0.35	1.00	1.00					
Leg23s rRNA	0.94	-0.84	0.94	0.46	0.99	0.99	1.00				
23s rRNA and ITS region	0.90	-0.78	0.89	0.56	0.97	0.97	0.99	1.00			
nEvents (>1 sec)	-0.40	0.60	-0.42	0.85	-0.23	-0.20	-0.08	0.03	1.00		
fixVol	0.08	0.15	0.06	1.00	0.26	0.29	0.41	0.50	0.88	1.00	
timeSinceLast	-1.00	0.98	-1.00	-0.13	-0.98	-0.98	-0.94	-0.90	0.41	-0.07	1.00

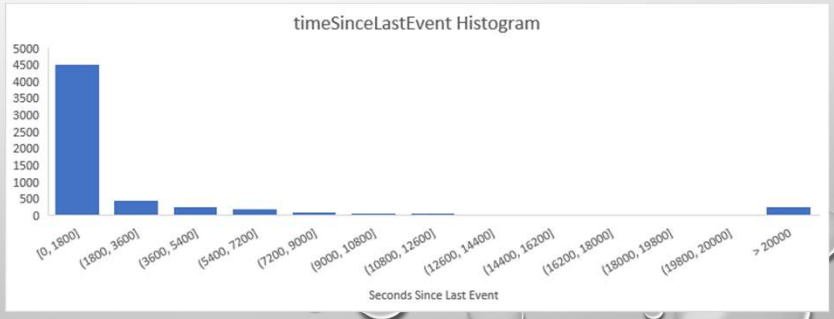
GENERAL RESULTS FOR ALL FIXTURES

- LEGIONELLA PRESENCE IS **STRONGLY POSITIVELY** CORRELATED WITH MYCOBACTERIUM PRESENCE AT ALL FIXTURES
  - THIS SUPPORTS LITERATURE INDICATING THESE PATHOGENS ARE LIKELY TO OCCUR TOGETHER
- LEGIONELLA/MYCOBACTERIUM PRESENCE ARE **WEAKLY POSITIVELY** CORRELATED WITH THE NUMBER OF EVENTS AND THE FIXTURE VOLUME.
- LEGIONELLA/MYCOBACTERIUM ARE **WEAKLY NEGATIVELY** CORRELATED WITH TIME SINCE LAST FIXTURE USE.
  - IMPLIES THAT PATHOGEN PREVALENCE **INCREASES** WITH MORE FREQUENT AND HIGHER VOLUME USAGE, AND **DECREASES** WITH LONGER STAGNATION TIMES

COUNTERINTUITIVE RESULTS ?

- Effects of frequent/high volume use sloughing biofilm
- Stagnation period is almost always less than 30 minutes
- May see a stronger relationship develop if we had longer stagnation times





CONCLUSIONS AND FUTURE GOALS

- COMPLETE SAMPLING IN RENEWW HOME FOR STRONGER CORRELATION ANALYSIS
- BUILD AND CALIBRATE A HYDRAULIC WATER QUALITY MODEL FOR SIMULATION
- INVESTIGATE AT PILOT SCALE THE WATER USAGE AND PHYSICAL FACTORS CONTRIBUTING TO OUR OBSERVATIONS

LOOKING AHEAD

EPA FUNDED PROJECT

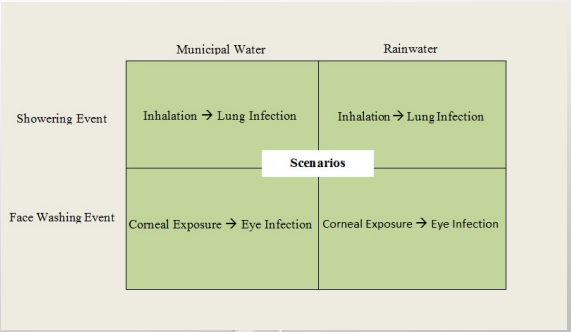
- Report: Identified data gaps in building types from stakeholders
- Field work
  - ReNEWW single-family home
  - LEED commercial buildings
  - LEED school
  - University buildings
- Bench- and pilot-scale studies
  - Answer field generated questions
- Risk models for fixture use in standard residential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

QUANTITATIVE MICROBIAL RISK ASSESSMENT (QMRA) FRAMEWORK

1. HAZARD IDENTIFICATION
2. DOSE RESPONSE
3. EXPOSURE ASSESSMENT
4. RISK ASSESSMENT
5. RISK MANAGEMENT



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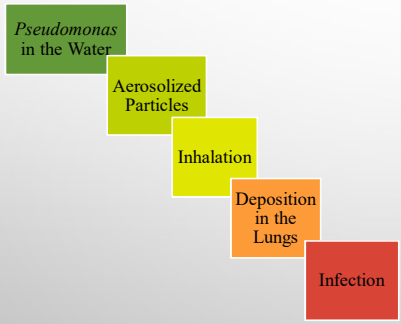
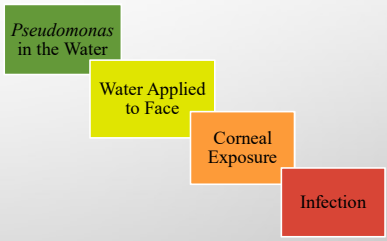
EXPOSURE PATHWAYS FOR *PSEUDOMONAS AERUGINOSA* IN THE RENEWW HOUSE

Showering: Showerhead → Lungs



FACE WASHING: FAUCET → CORNEA



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PROJECT SCHEDULE

Project Actions	2016	2017			2018				2019				2020			
	Year 1				Year 2				Year 3				Year Ext.			
	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3
Project Administration																
Award Date																
QAPP Approved																
Objective and Activities																
Obj. 1. Water Conservation Trends																
Preparations																
QAPP Preparation																
Review & synthesis																
Workshop																
Obj. 2. Effect of Flow or Water Quality																
Filed & 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. Hydro-Fate WDS/Premise Models																
Big Data Water Qual. Regression Analysis																
Obj. 3. Decision Support Tool Development																
Framework and DST Development																
Risk Models																
DST Workshop																
Upgrade DST																
Annual EPA Meeting (est.)																

RIGHT SIZING TOMORROW'S WATER SYSTEMS FOR EFFICIENCY, SUSTAINABILITY, & PUBLIC HEALTH

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