Legionella management in potable water systems, especially low flow systems

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Legionella and Its Impacts on Public and Occupational Health:
Why the Water Sector Should Care
WEF Webinar, April 28, 2022

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Our Focus

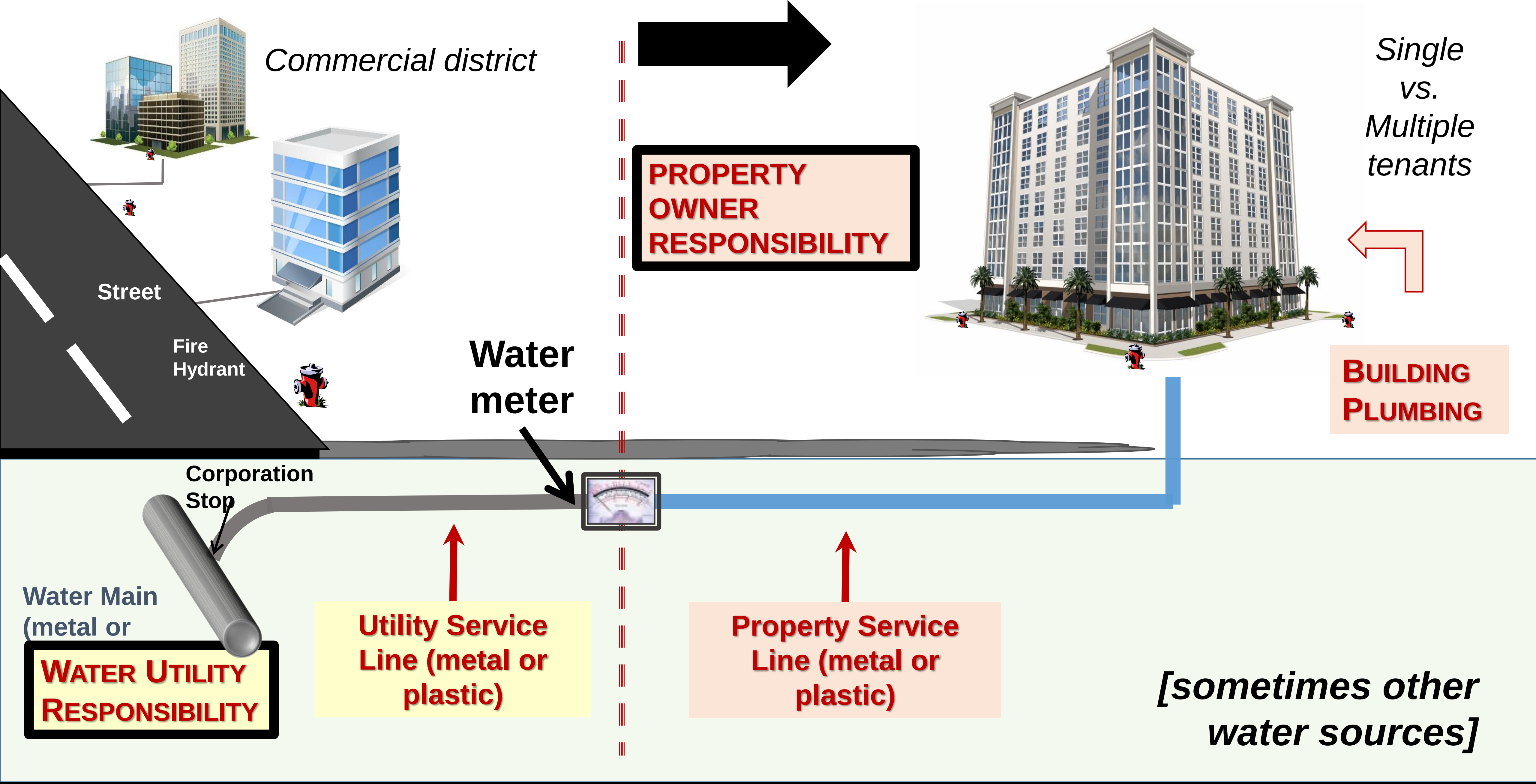
Water Safety and Disasters



Infrastructure Construction and Repair Technologies


Waste Materials and Management Solutions



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System Basics

Building water system public health **risks**

Exposure Routes of Concern: Ingestion, Dermal, Inhalation

Routine Operations

Disinfectant residual may not be replenished

Heavy metals can leach (Cu, Mn, Ni, Pb, Zn..)

Organics can leach/form (VOCs, SVOCs, DBPs)

Scale can destabilize and suspend

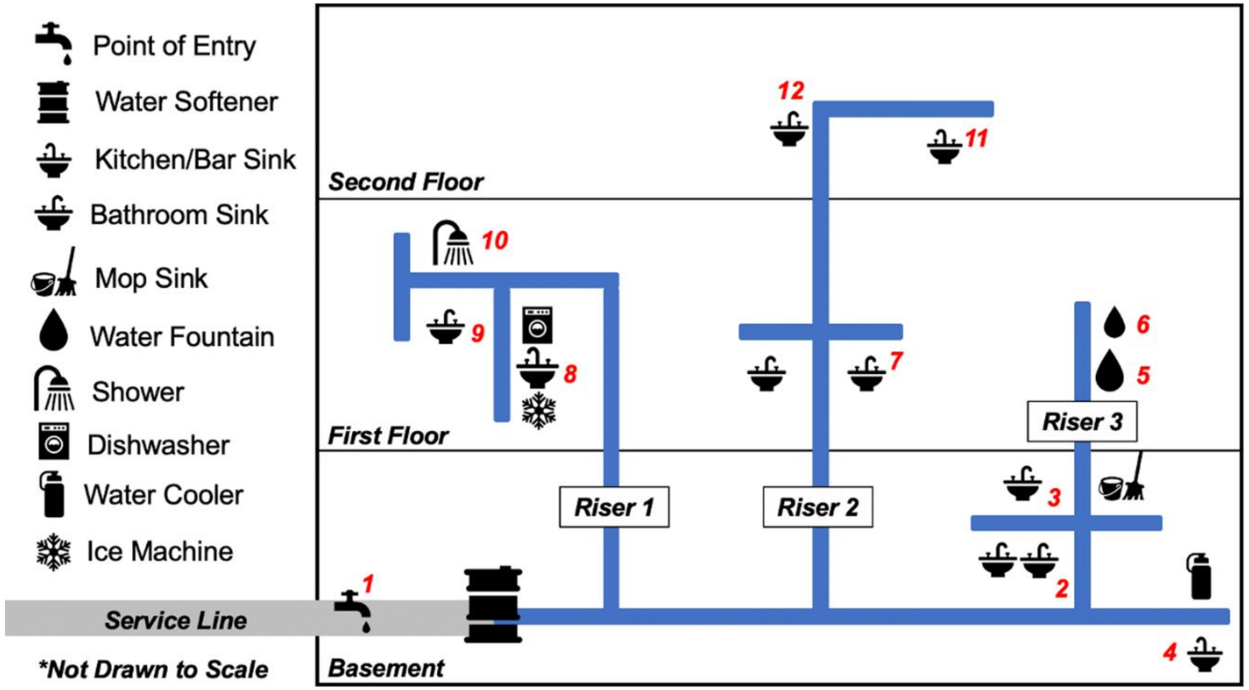
Harmful organisms can grow (e.g., *L. pneumophila, MAC, P. aeruginosa …*)

Accident and Post-Disasters

Pressure loss, backflow, chemical spill, hurricane, flooding, wildfire, intentional attack, and more

Legionella Management:
Temperature, Food, Flow

Many office buildings routinely are subjected to weekend stagnation



Indiana, USA

10 year old LEED certified

Chloramine disinfectant, Cu plumbing

Weekend, not used

Sampling: Friday PM, Monday AM

3 sampling events Winter 2020

Montagnino et al. 2022. Over the weekend: Water stagnation and contaminant exceedances in a green office building. *PLOS Water.* https://doi.org/10.1371/journal.pwat.0000006

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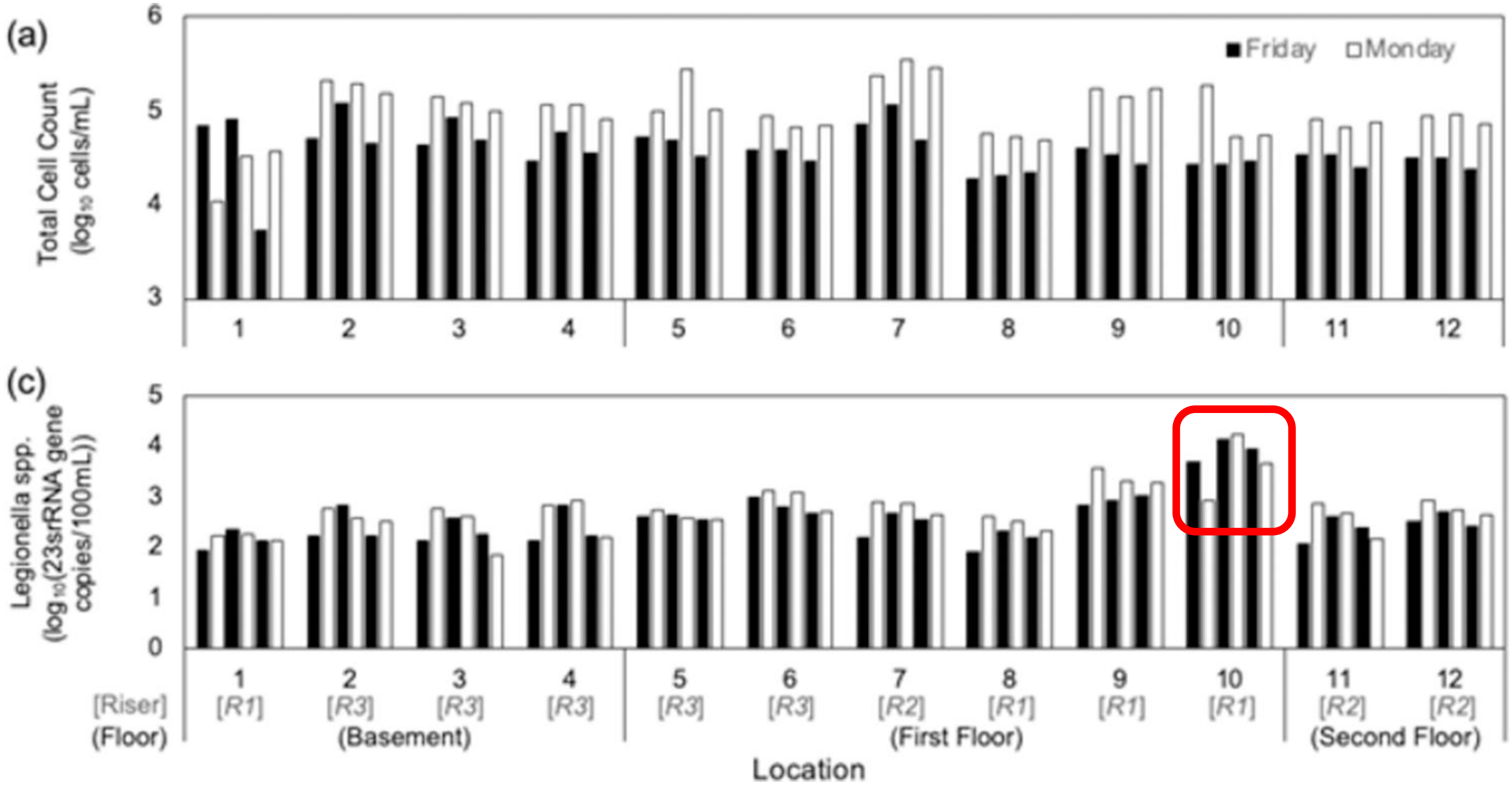
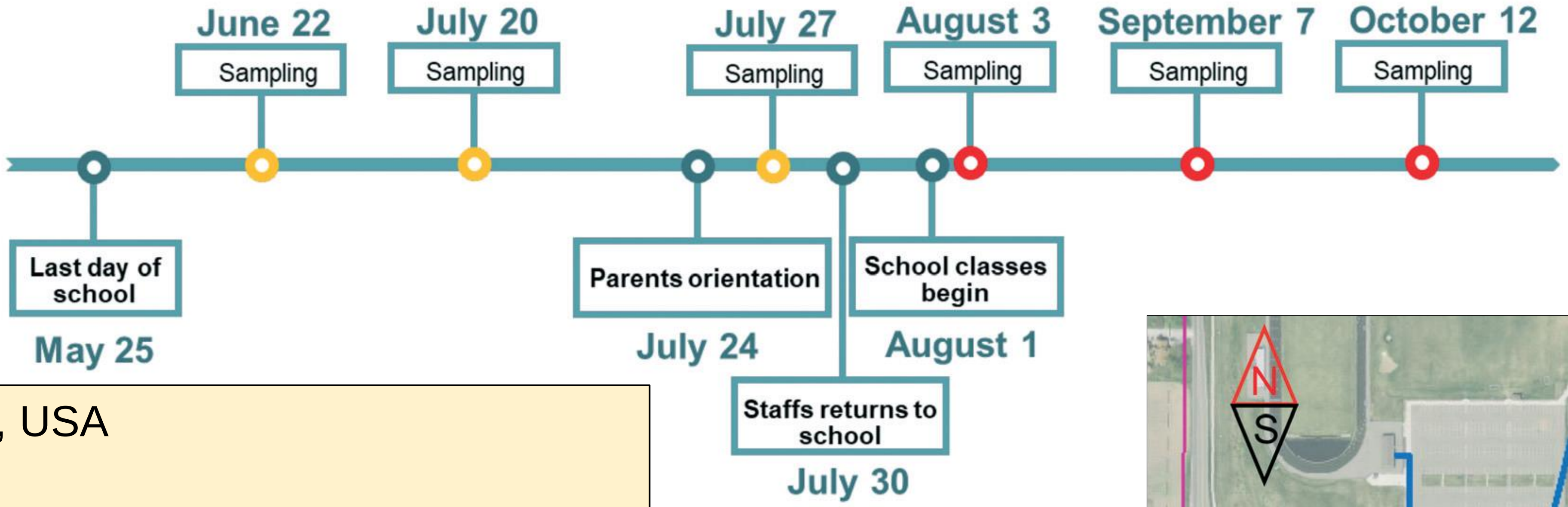


L. pneumophila was not detected in any water samples.

As expected, TCC and Legionella spp. levels were greater on Monday morning compared to Friday afternoon.

Elevated *Legionella* spp. concentrations were at the seasonally used shower

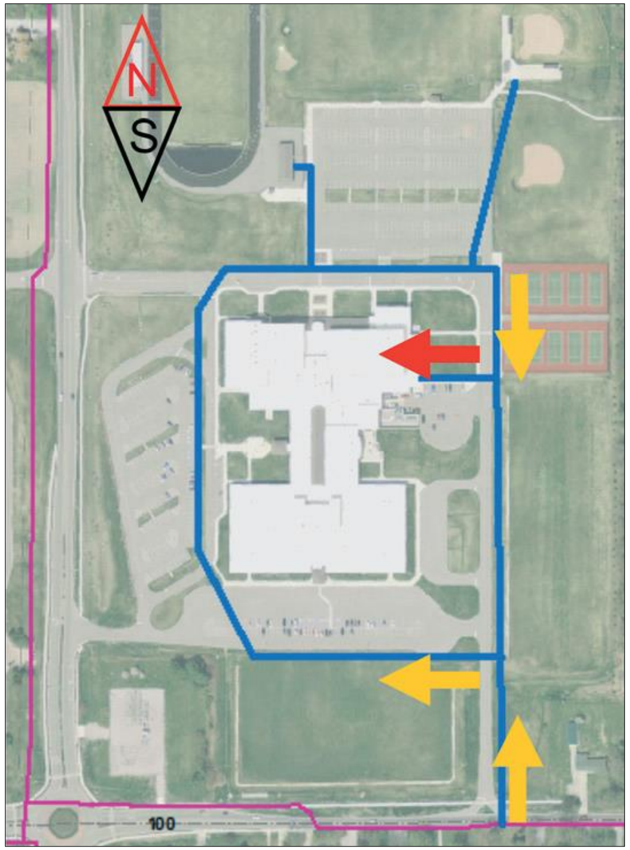


Indiana, USA

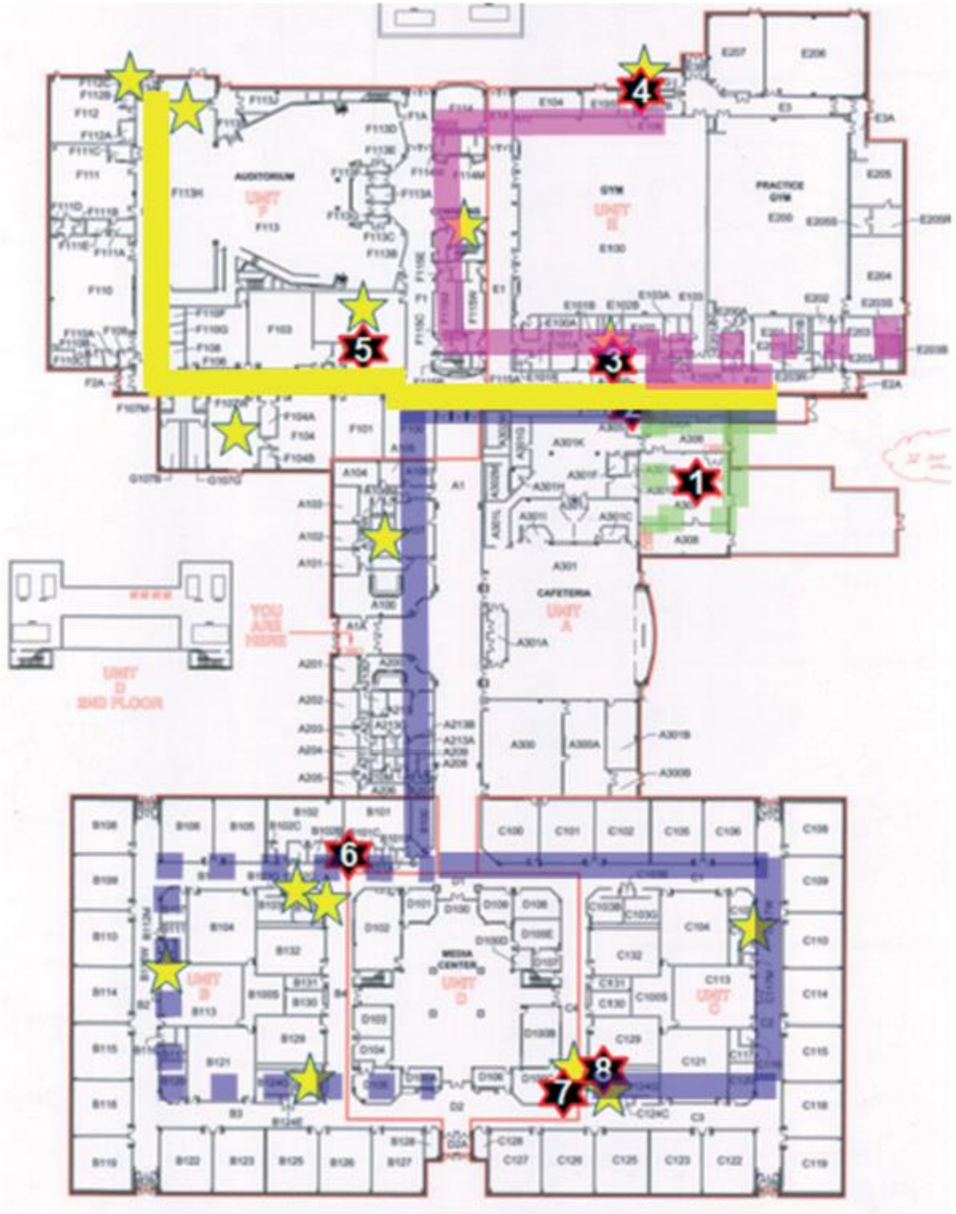
7 year old LEED certified school
(same distribution system)

Chloramine disinfectant, Cu plumbing, 250+ fixtures, 3 recirc loops, numerous legs

Summer 2019 ➔ Fall 2019



Ra et al. 2020. Finding building water quality challenges in a 7 year old green school: implications for building design, sampling, and remediation. *ES: WR&T.* https://doi.org/10.1039/D0EW00520G



Detected:

Legionella spp. 100%; _Mycobacterium spp._ 99%
M. avium 75%; _Acanthamoeba spp._ 17.5%

Cultivable _Legionella_ during low water use.

NOT detected:

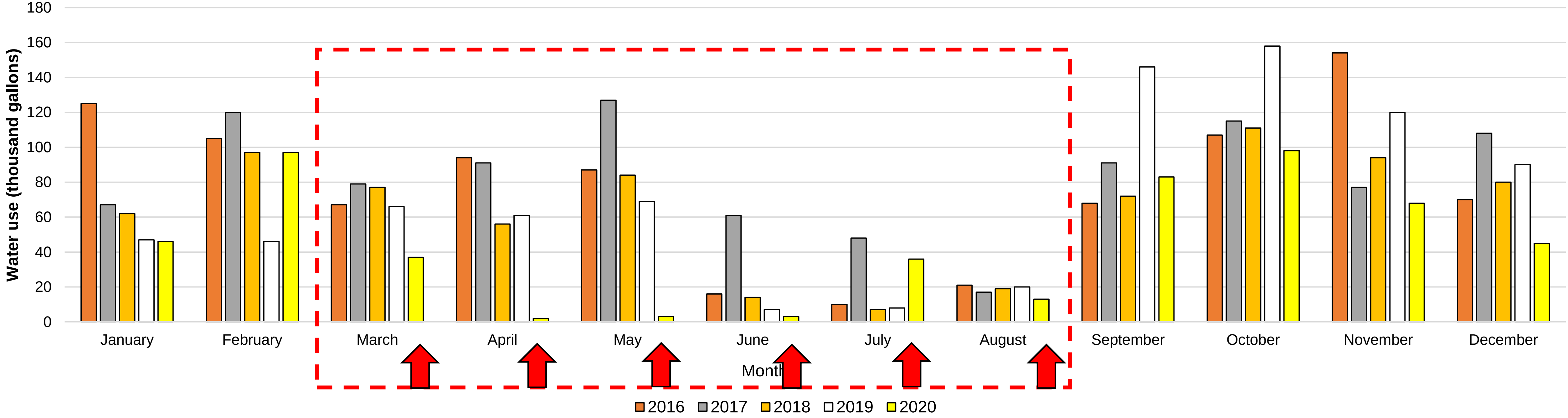
L. pneumophila, _Naegleria fowleri_

Summer ➔ Fall: Levels statistically ↓↓↓
Legionella spp., _Mycobacterium spp., M. avium_

The water softener was an incubator for growth

Aw et al. 2022. Prevalence of opportunistic pathogens in a school building plumbing during periods of low water use and a transition to normal use. _IJHEH._ https://doi.org/10.1016/j.ijheh.2022.113945

The COVID-19 pandemic response prompted reduced water use at schools and building water safety concerns



In March 2020 when the school switched to online learning, a **48.8% reduction in water use occurred** compared to the previous 4-year average for the month of March (2016-2019).

In the following months, water use was reduced even further by **97.4% in April, 96.7% in May, and 87.8% in June,** compared to the previous monthly averages for the previous 4 years.

Ley et al. *In Prep*. Water quality and shock chlorination impacts on chemistry and microbiology after 6 months of low water use.

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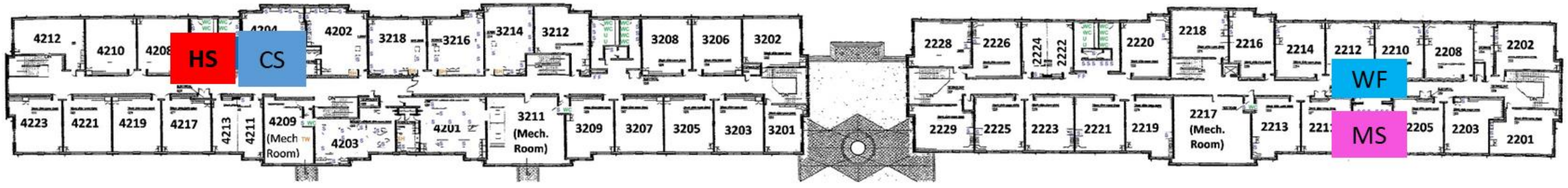
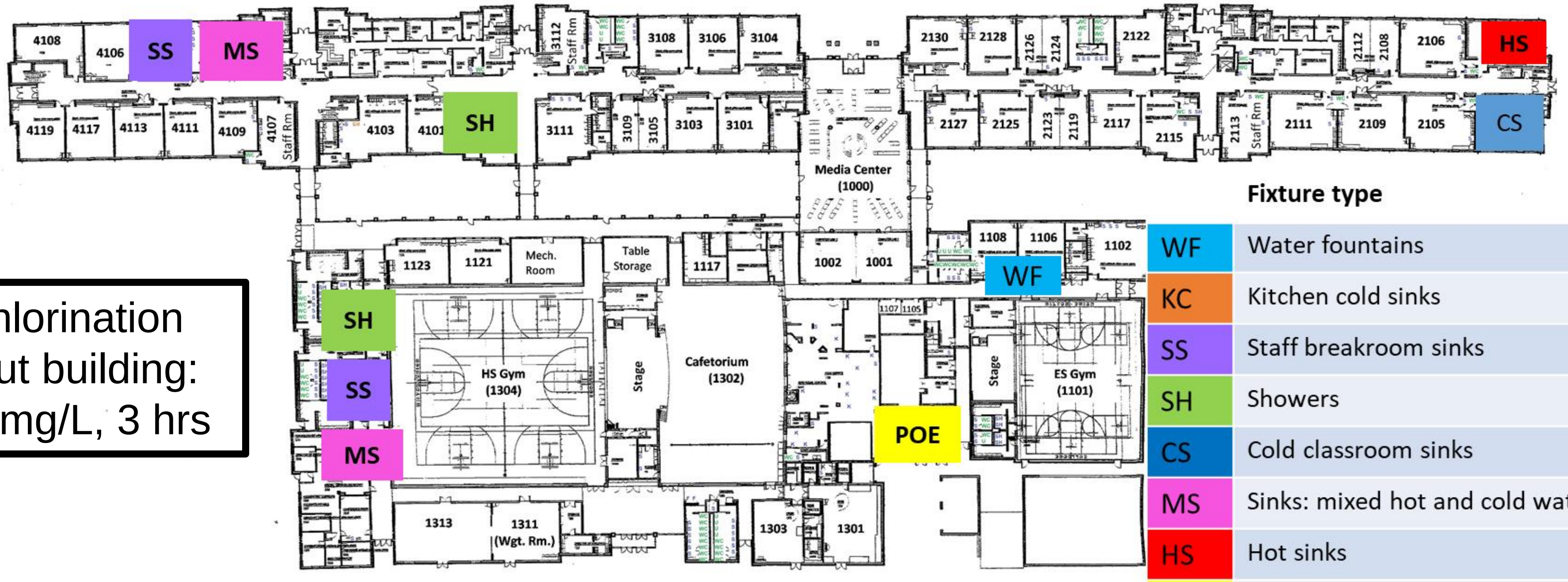
L. pnemophila was detected in the school and prompted officials to seek shock chlorination

400⁺ fixtures



2nd floor



1st floor

Super chlorination throughout building: 160-340⁺ mg/L, 3 hrs

	Fixture type	# Type*
WF	Water fountains	2
KC	Kitchen cold sinks	1
SS	Staff breakroom sinks	2
SH	Showers	2
CS	Cold classroom sinks	2
MS	Sinks: mixed hot and cold water	3
HS	Hot sinks	2
POE	Point of entry – service line	1

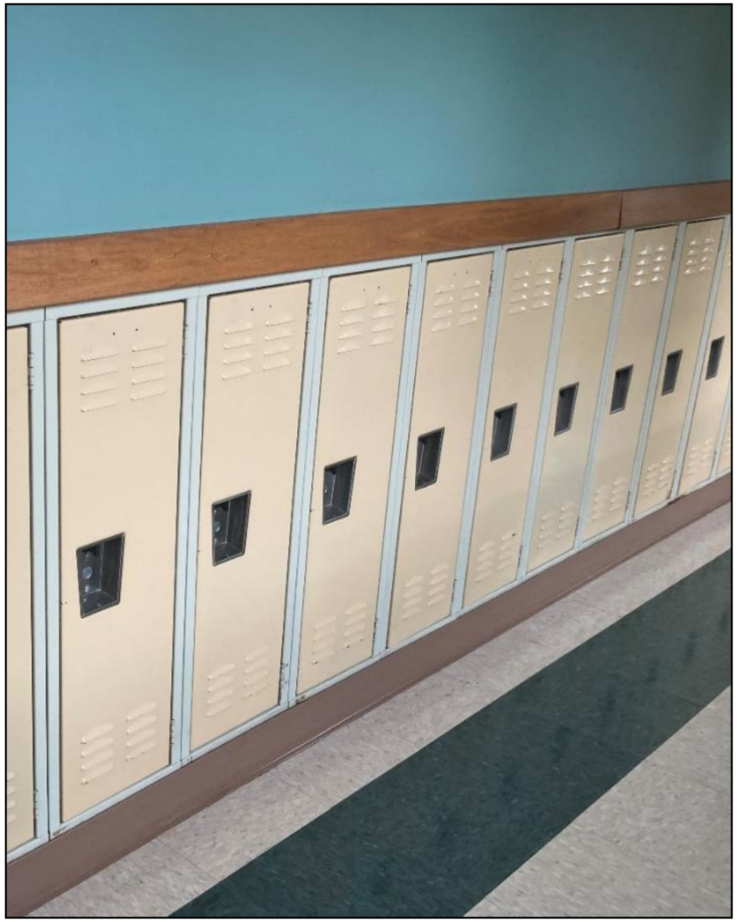
Sample type	Fixture type	*L. pneumophila* Concentration (MPN/100 mL)	Suggested *L. pneumophila* Limit (CFU/mL)
Initial stagnation	Water fountain (cold)	239.6	106
	Staff sink (cold)	1,289.6	106
	Cafeteria sink (cold)	3.5	106
	Cold faucet (distal end)	1	106
	Cold faucet (central)	1.1	106
Pre-shock chlorination	Various	0	106
Immediately after shock chlorination	Various	0	106
Immediately after shock chlorination	Fountain (cold) Bathroom sink (cold)	3.9 7.9	106 106
72 hours post-shock	Various	0	NA
1 month post-shock chlorination	Various	0	NA

Stagnation:
Approximately 5.3% (5/94) of fixtures positive for *L. pneumophila*

Right after shock:
L. pneumophila was detected in two fixtures (drinking fountain and TMV sink)

1 month after shock:
No *L. pneumophila* was detected

A small school in Indiana…



3 buildings, built in the 1960s

3 months of **low/no** water use

Characteristics

- POE free chlorine residual <0.2 to 1.3 mg/L
- Per building: 1 service line, 1 heater, Cu plumbing
- *No recirc loops, no showers, no cooling towers*

Stagnant water: 1-2 *L. pnemophila* detects/building (<188 MPN/ 100mL); Cold (4 of 25 locations), Hot (1 of 21 locations)

Flushed water: No detects

2 weeks later: Several detects at *new* locations (<61 MPN/ 100mL); 5 of 7 detects were hot water

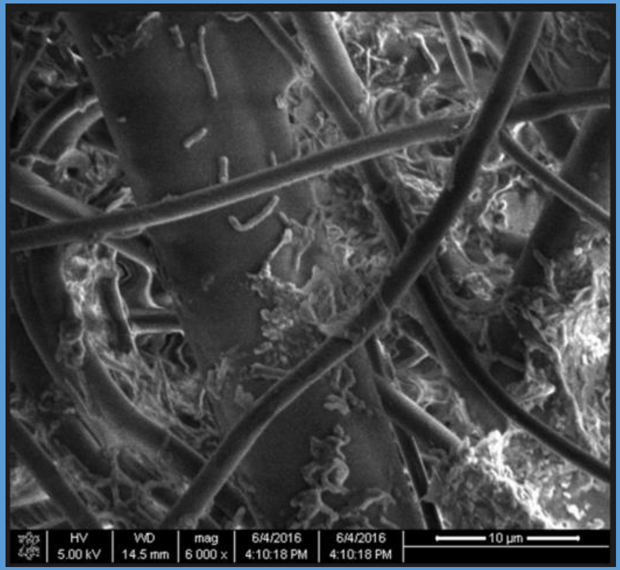
Ra et al. *In Prep*. The role of flushing on reducing low levels of L. pneumophila from a stagnant school building water system

None of the commercial buildings we visited had a water management program.

Commercial plumbing design, operation, and water quality is complex.

Can we simplify things?

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

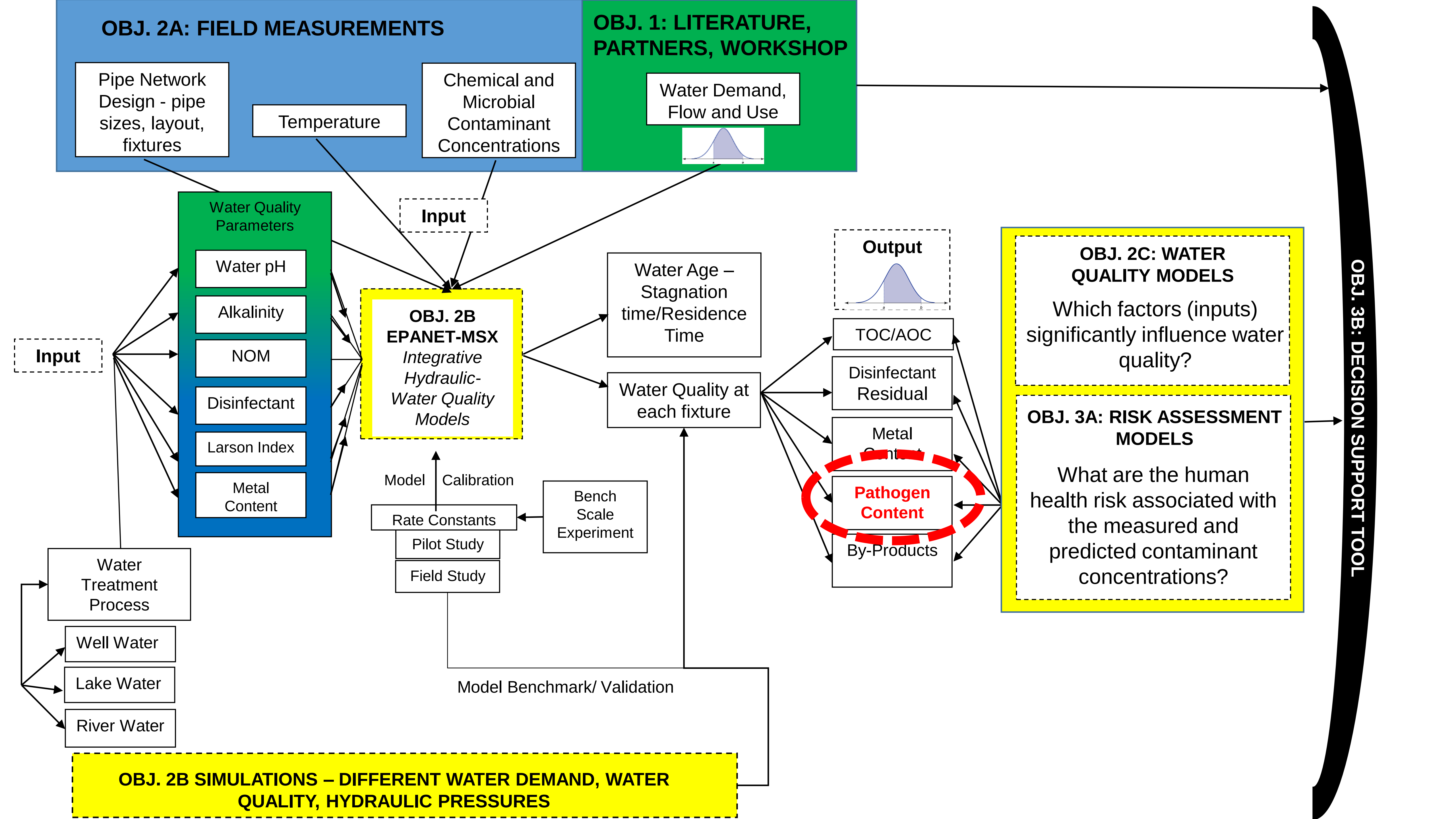


Completed: 2017-2021

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

Funded by: United States Environmental Protection Agency

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



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
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
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

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Water saving fixtures
Trunk-and-Branch design
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Renovated in 2014

Thermocouples throughout piping, 1x /sec
Indoor air temperature, 1x /sec
Flowrates at every fixture, 1x /sec
Energy use per device, 1x /sec

www.ReNEWWHouse.com

October 2017-October 2018

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

2.64 billion online plumbing related measurements

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Water microbiology varied seasonally and spatially through the low-flow residential building

Legionella spp. and *Mycobacterium spp.* were highest during summer months.

Fixture	*Legionella spp.* % pos			*Mycobacterium spp.* % pos		
	Sum	Fall	Winter	Sum	Fall	Winter
SL	12.5	30.8	14.3	87.5	38.5	37.5
KC	100	61.5	62.5	100	69.2	87.5
BC	100	69.2	50	100	69.2	75
WH	100	100	50	100	92.3	87.5
KH	100	84.6	75	85.7	76.9	75
BH	100	92.3	87.5	100	69.2	87.5
SH	100	92.3	100	100	76.9	100

HPC were correlated with TCC, *Legionella spp.*, *Mycobacterium spp.*

Reduced water use weakly correlated with TCC, *Legionella spp.*, and *Mycobacterium spp.*

Ley et al. 2020. Drinking water microbiology in a water-efficient building: stagnation, seasonality, and physicochemical effects on opportunistic pathogen and total bacteria proliferation. *ES:WR&T*. https://www.doi.org/10.1039/d0ew00334d

Using advanced statistical approaches, relationships between plumbing use and water quality were investigated

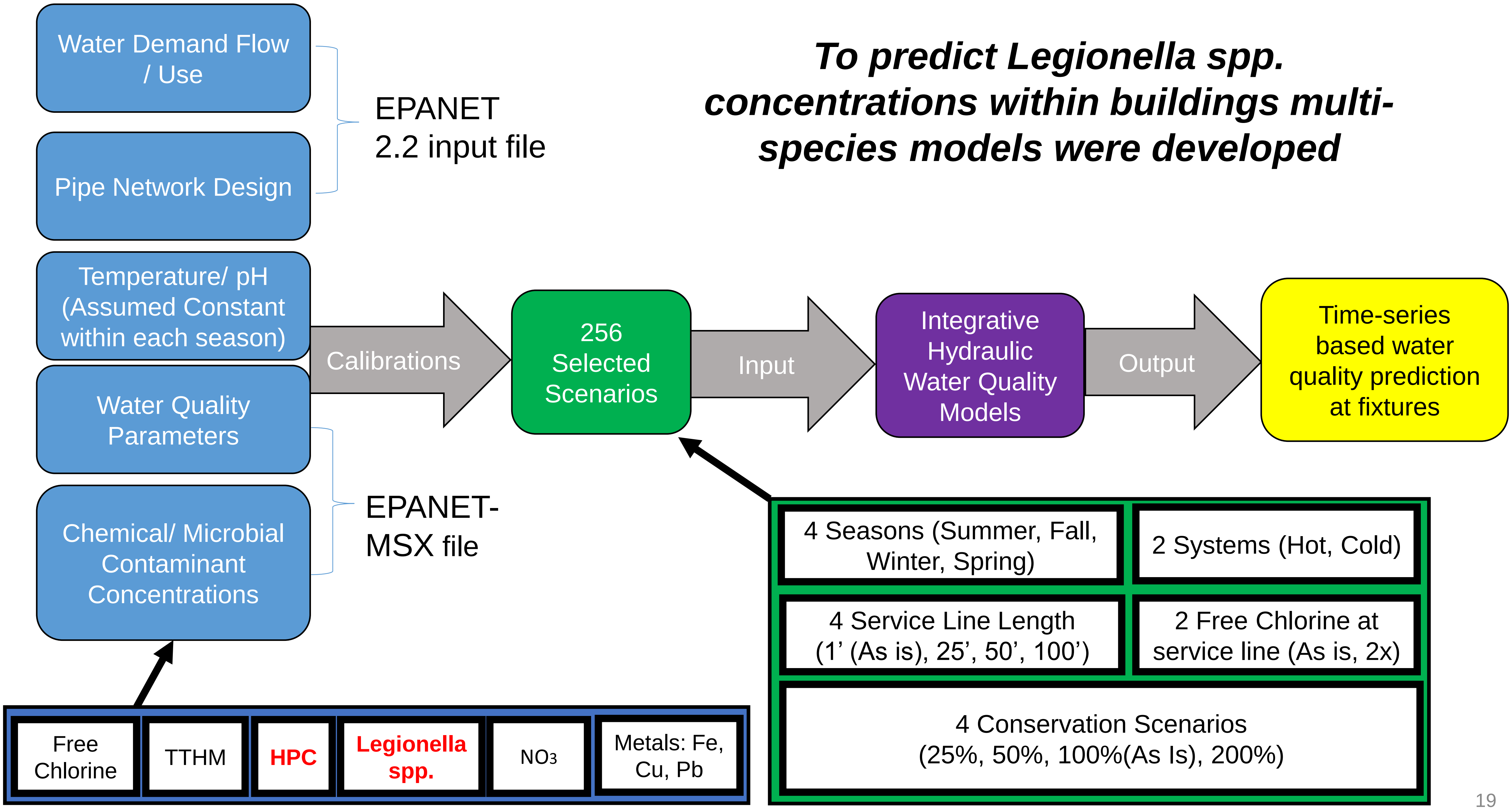
Variable name	Variable description	Units	Log transformed	Percentile (natural scale) 2.5%	50.0%	97.5%	Number of observations
pH	pH	NA	No	7.36	8.00	9.04	406
Temp	Temperature	C	No	15.63	22.90	26.30	406
DO	Dissolved oxygen	mg/L	No	4.30	8.40	10.56	406
Total.Cl	Total chlorine	mg/L	Yes	BDL	0.10	1.00	406
Free.Cl	Free chlorine	mg/L	Yes	BDL	0.01	0.75	259
TOC	Total organic carbon	mg/L	Yes	0.42	0.81	15.36	406
DOC	Dissolved organic carbon	mg/L	Yes	0.42	0.73	18.97	371
Alka	Alkalinity	mg/L as $CaCO_3$	Yes	264.15	287.25	332.65	377
TTHM	Total trihalomethanes	mg/L	No	0.05	15.57	31.55	399
TCC	Total cell count	#cells/ml	Yes	1.54E+03	3.77E+04	1.56E+06	406
HPC	Heterotrophic plate count (by culture)	CFU/100 ml	Yes	4.03E+00	1.01E+04	3.60E+07	390
Leg.sp	*Legionella* spp. (by qPCR)	Gene copies/100 ml	Yes	2.29E+01	4.02E+03	1.78E+05	258

Increased water age prompted:
↓↓ DO, FAC
↑↑Temp, TOC, TTHM, TCC, HPC….

Legionella spp. concentration primarily driven by water age

Julien et al. 2022. Identifying water quality variables most strongly influencing Legionella concentrations in building plumbing. AWWA Water Science. https://www.doi.org/10.1002/aws2.1267

To predict Legionella spp. concentrations within buildings multi-species models were developed



8 Integrated hydraulic-water quality models were created to predict fixture water quality

For microbiology, the models revealed …

- Water use reduction by 25% **increased HPC and *Legionella spp.* by a factor of 100,000**
- As service line length increased, ***Legionella* spp. concentrations increased by 1,000,000 GNC/L** (in the Summer).

Limitations

- No other full-scale models are available for predictions
- Carrying capacity of *Legionella spp.* (and other organisms) in other buildings unknown
- This study was extremely labor intensive, technology innovations needed

Palmegiani et al. 2022. New integrative hydraulic-water quality models can predict Legionella spp. concentrations at fixtures. https://doi.org/10.1002/aws2.1280

Plumbing water quality tool

Tool 1

Scenario 1 | Scenario 2

1. Contaminant identification 2. Fixture location 3. Season selection 4. Plumbing conditions

Step 1: Contaminant selection

Explore different contaminants. Each chemical or microbial contaminants have unique behaviors and hazardous outcomes. All these species are regulated by US EPA.

Choose a chemical or microbial contaminant for this scenario

Choose contaminant...

→ Click Here ←

Next step

Run default simulation

This tool was funded by US Environmental Protection Agency grant R836890, and was designed and developed by the Decision Support and Informatic Lab (DSI) of Michigan State University (Ian Kropp, Josué Kpodo, Shashank Mohan, and Dr. Pouyan Nejadhashemi). We also acknowledge the contribution of the labs of Dr. Juneseok Lee of (Manhattan College), Dr. Andrew Whelton (Perdue University), and Dr. Jade Mitchell (Michigan State University). Neither the U.S. Environmental Protection Agency nor the system authors can assume responsibility for system operation, output, interpretation, or use.

QMRA Decision Support Tool

Tool 2

Scenario 1 | Scenario 2

Step 1: Hazard Identification Step 2: Exposure Assessment Step 3: Dose-response

Step 1: Hazard Identification

To determine the risk of this scenario, the microbial hazard must be defined to focus the subsequent steps in the QMRA. Explore different plumbing-based microbes, and choose the one you're interested in measuring.

Choose a hazard for this scenario

Choose...

→ Click Here ←

Next step

Run default simulation

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Online and FREE Building Water Quality Tools Now Available

Usefulness

Multiple contaminants: *Legionella spp.*, HPC, Cl_2, Cu, Fe, Pb, NO_3^-, TTHM

Compare exposure scenarios

Examine plumbing design impacts

Examine water use impacts

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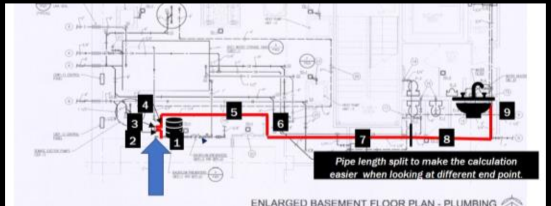

If interested e-mail awhelton@purdue.edu

Info and registration: https://cutt.ly/Sg4RXJv

The Center for Plumbing Safety at Purdue

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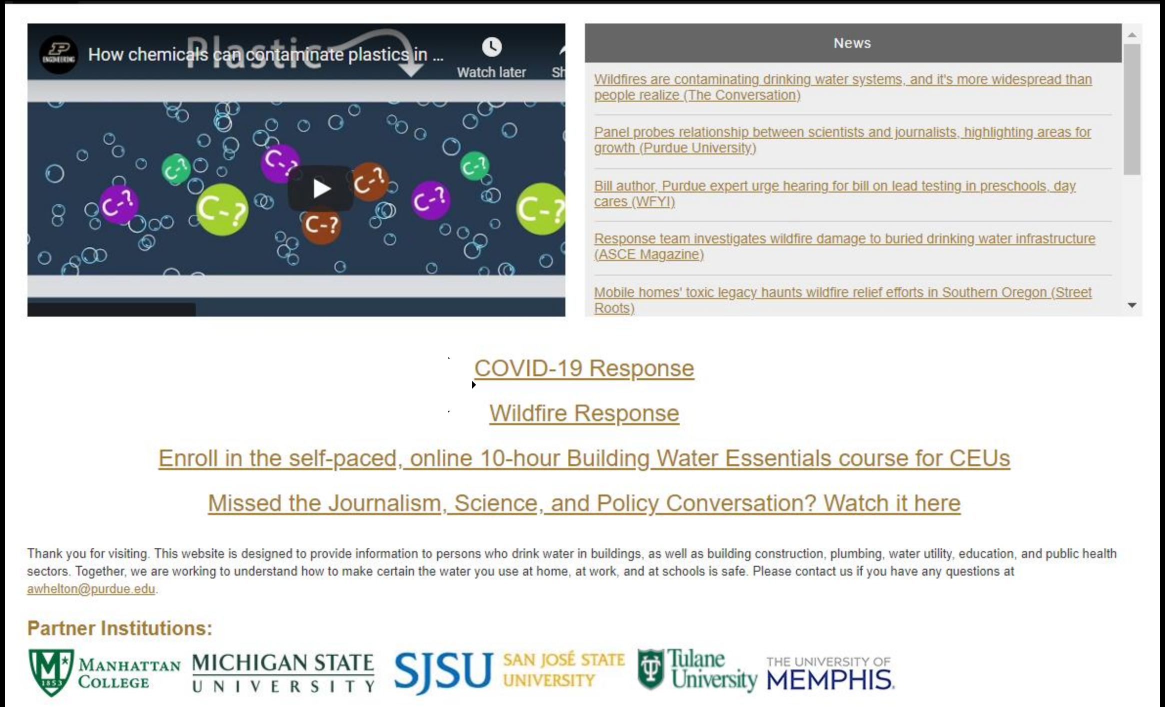

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