A 5 Year USEPA Backed Program: Finding, predicting, and resolving building water system chemical and microbiological contamination

APHA Annual Meeting
Boston, Massachusetts

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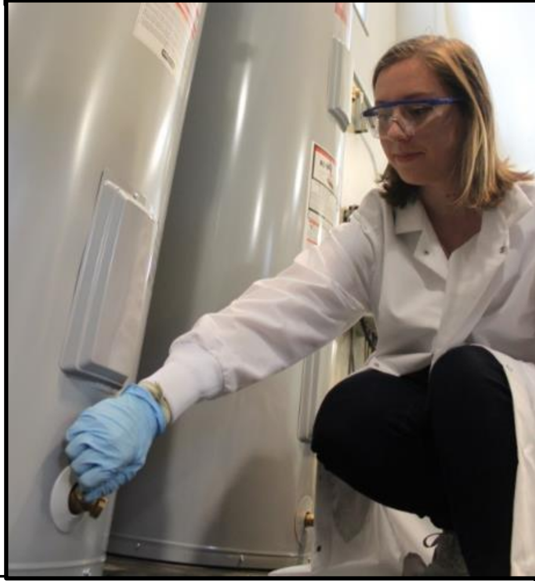
Biosystems and Agricultural Engineering

www.PlumbingSafety.org



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November 2022

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

Right Sizing Tomorrow's Water Systems for Efficiency, Sustainability, & Public Health, 2017-2022

To better understand and predict water quality and health risks posed by declining water usage and low flows

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.

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

FINAL REPORT: To be posted at www.PlumbingSafety.org
December 2022

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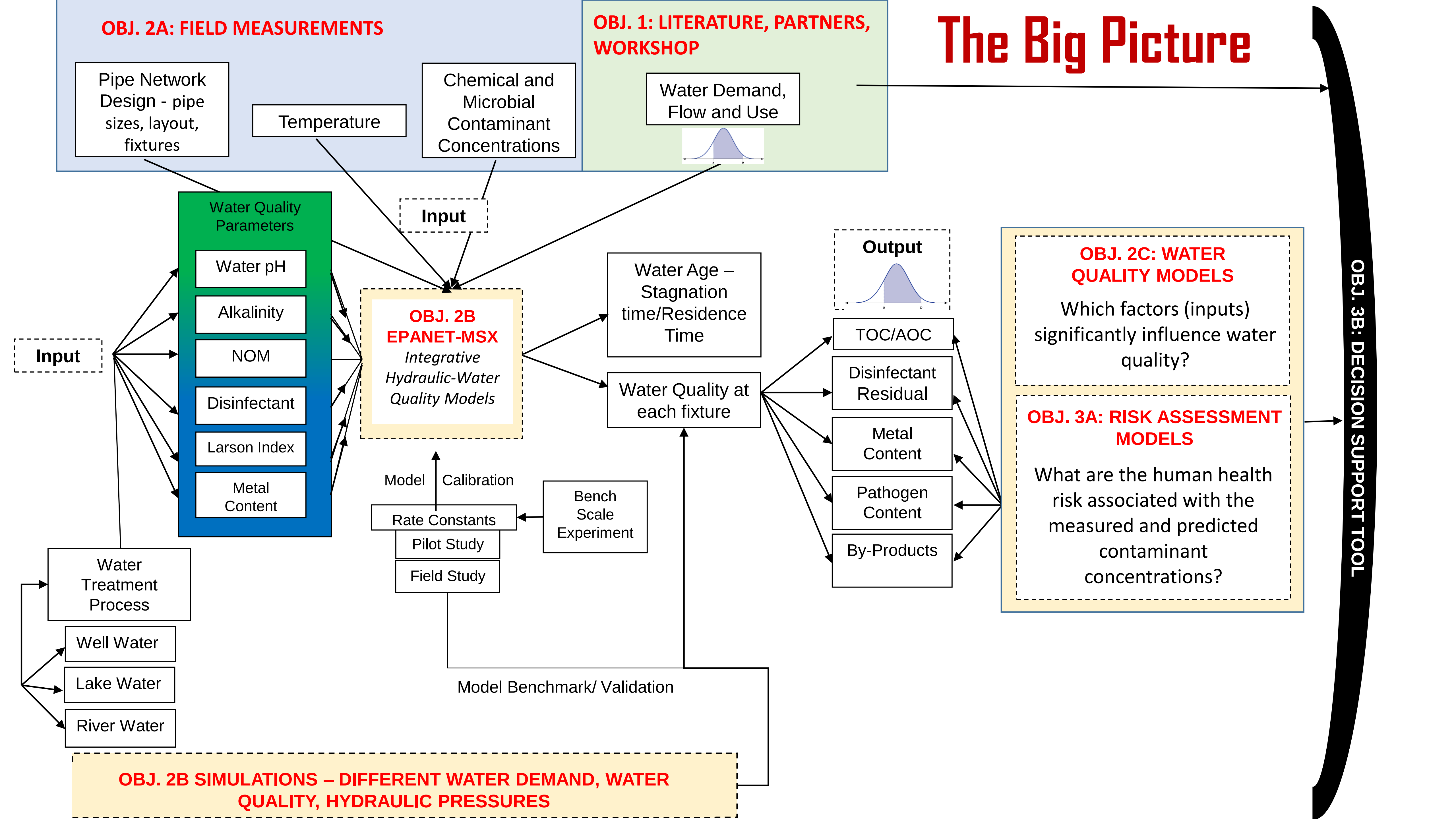
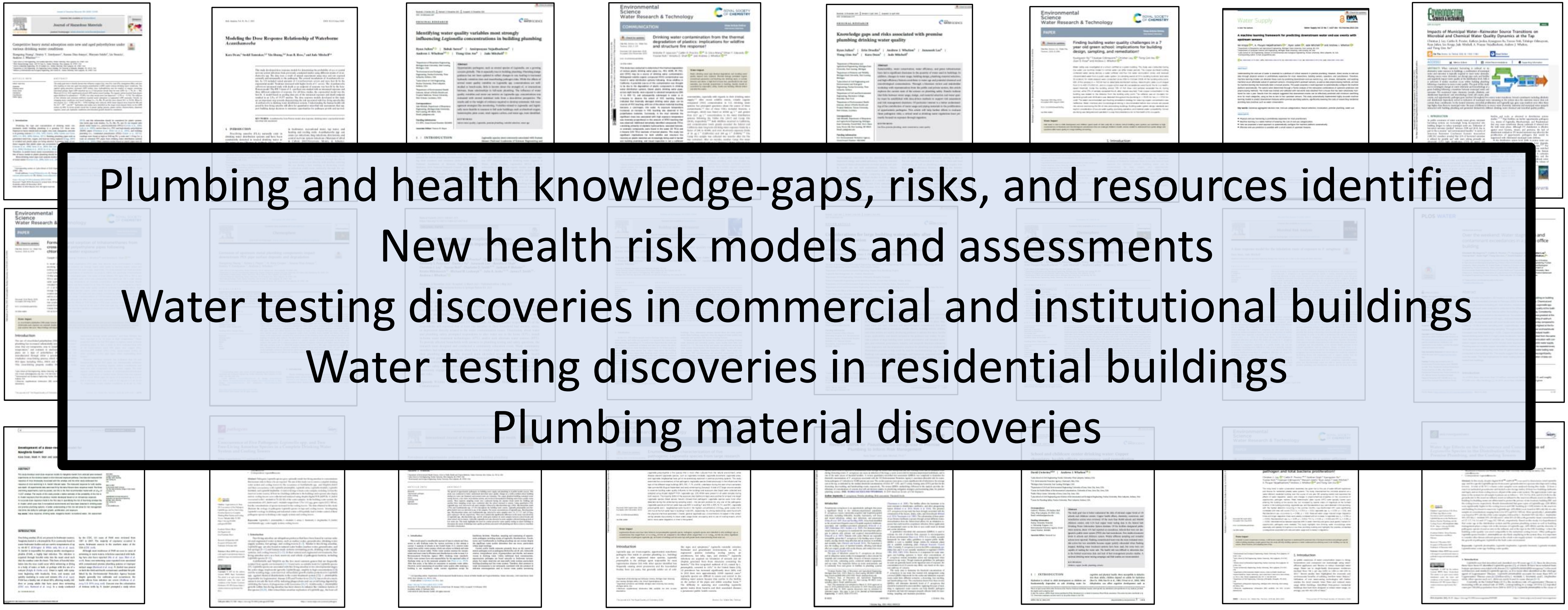


The Big Picture
OBJ. 2A: FIELD MEASUREMENTS
Pipe Network Design - pipe sizes, layout, fixtures
Temperature
Chemical and Microbial Contaminant Concentrations
OBJ. 1: LITERATURE, PARTNERS, WORKSHOP
Water Demand, Flow and Use
Input
Water Quality Parameters
Water pH
Alkalinity
NOM
Disinfectant
Larson Index
Metal Content
Input
OBJ. 2B EPANET-MSX
Integrative Hydraulic-Water Quality Models
Water Age – Stagnation time/Residence Time
Water Quality at each fixture
Model
Calibration
Rate Constants
Pilot Study
Field Study
Bench Scale Experiment
Water Treatment Process
Well Water
Lake Water
River Water
Model Benchmark/ Validation
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
OBJ. 2B SIMULATIONS – DIFFERENT WATER DEMAND, WATER QUALITY, HYDRAULIC PRESSURES

OBJECTIVE 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 partners (Ind., Gov.)

- The www.PlumbingSafety.org website had 10,000s page views. Educational YouTube videos as well as lists of resources, and FAQs were created.
- **70+ presentations** for multiple sectors (public health, water utility, manufacturer, building design) in the U.S., Canada, the U.K., and also an international water association webinar.
- Supported homeowners about water testing, materials, and also wildfires.
- Helped develop the AWWA COVID-19 building water system guidance.
- Established a range of theoretical plumbing flow demands.

OBJECTIVE 2. Elucidate the factors and their interactions that affect drinking water quality through fate and transport simulation models for residential and commercial buildings



Plumbing and health knowledge-gaps, risks, and resources identified

New health risk models and assessments

Water testing discoveries in commercial and institutional buildings

Water testing discoveries in residential buildings

Plumbing material discoveries

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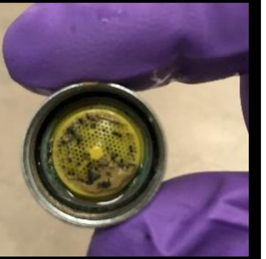


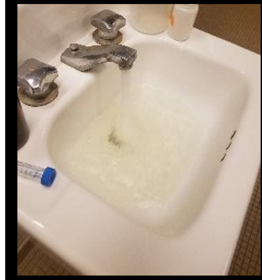

25+ Studies: Some Discoveries

New health risk models for *Pseudomonas aeruginosa*, *Acanthamoeba,* and *Naegleria fowleri.*

Microbiological testing of cooling towers revealed new water quality-plumbing interaction discoveries and sampling methods.

In schools and other commercial buildings

- … A water softener was an incubator for *Legionella spp.* growth and nitrification
- … Excessive copper leaching (>2.7 mg/L) found throughout school building "built to code" and flushing didn't remediate.
- … High alkalinity and neutral pH enabled excessive copper leaching
- … Nearly all U.S. school and childcare centers (99.8% of 598,000) lack copper testing data. Faucet flushing doesn't work.
- … Vacation stagnation prompted school copper levels of >1.3 mg/L
- … Weekend office stagnation prompted copper levels of >1.3 mg/L. Flushing was not effective.





...More Discoveries

Plastic pipes

... on the inside are sometimes coated by heavy metals (Pb, Cu, Fe, Mn)

… leach poorly characterized organic carbon

… carbon leaching can prevent some heavy metal deposition

… carbon leaching can react with free chlorine and create THMs

… THMs can sorb into some plastic pipes

… carbon leaching varies across and even within the same brand, 30 days later 20 mg/L TOC still leaching

… letting pipes sit on the shelf before use prompted lesser carbon leaching

… thermally damaged pipes can leach VOCs and SVOCs (carbon!)

New water softeners release bacteria, TOC (~1000 mg/L), sulfur (~1200 mg/L), and 7 days later TOC levels remained elevated




The Most Monitored Home in America

West Lafayette, Indiana
Less than 100 yards from Purdue
3 Bedroom, 1.5 baths
Water saving fixtures
Trunk-and-Branch design
PEX piping
Renovated in 2014

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

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

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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

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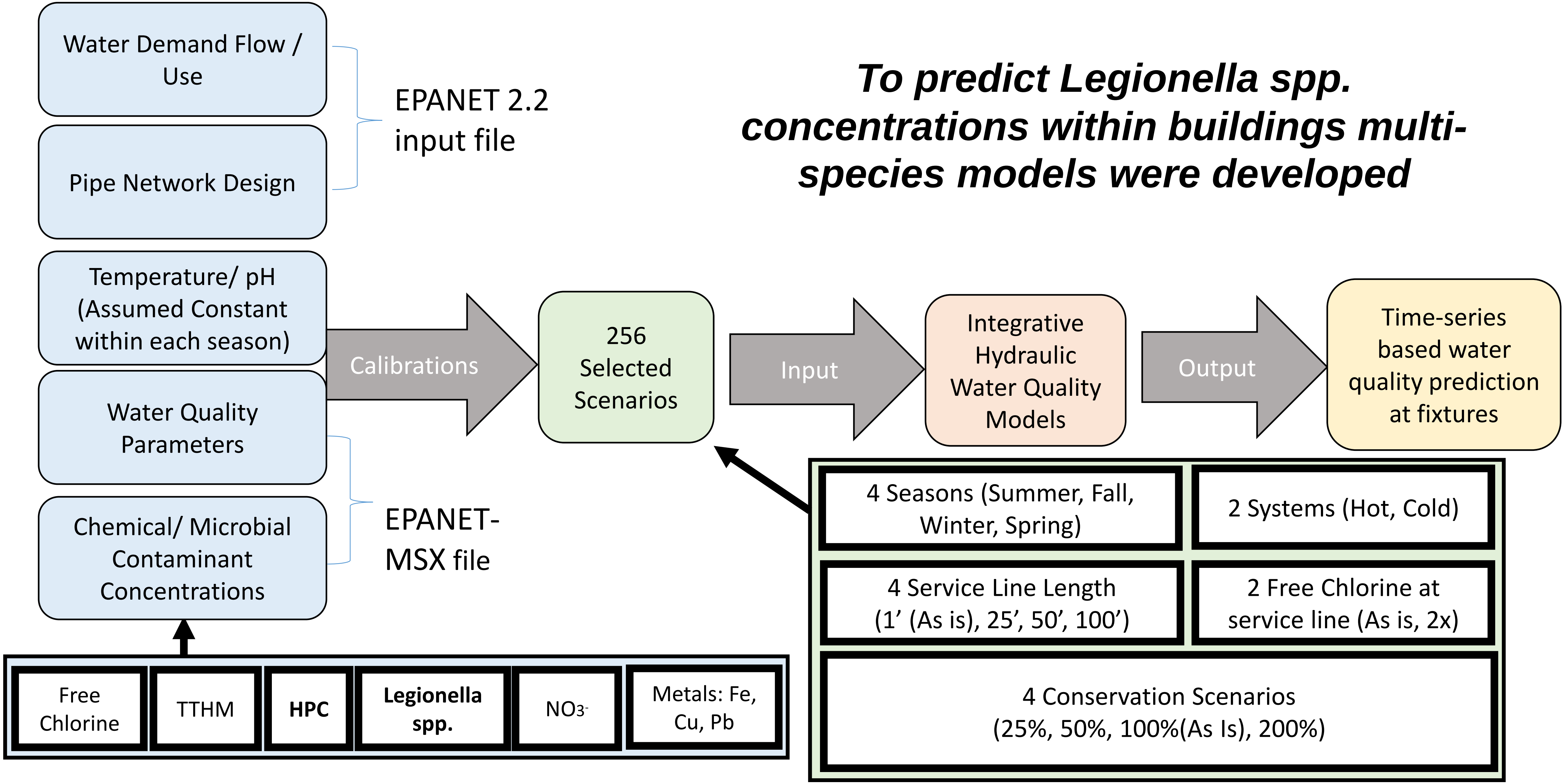
To predict Legionella spp. concentrations within buildings multi-species models were developed



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

They're free to use online!

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. This is a first.

Carrying capacity of *Legionella spp.* (and other organisms) in other buildings is unknown

This home 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. *AWWA Water Science.* https://doi.org/10.1002/aws2.1280

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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

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.

Online and FREE Building Water Quality Tools Now Available

Usefulness

Examine plumbing design impacts

(pipe length, cold vs. hot, conservation)

Evaluate water use impacts

(fixture type, seasons)

Compare exposure scenarios

(Legionella spp., MAC, HPC, Cl_2, Cu, Fe, Pb, NO_3^-, TTHM)

Building Water Essentials
10 Hour, Online Short-Course

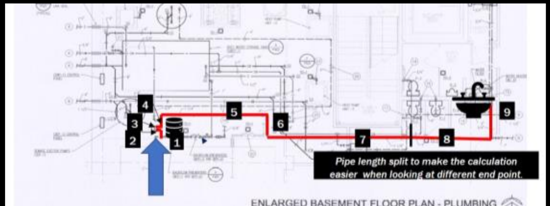





Audience: Public health, code officials, utility staff, manufacturers, architects, engineers

Learn the basics:
8 modules do not have to be taken in sequence.

A training tool, an encyclopedia, and an extensive FAQ, designed to be immediately applicable in the field.

If interested e-mail awhelton@purdue.edu

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

Thank you. Final report on website in December 2022

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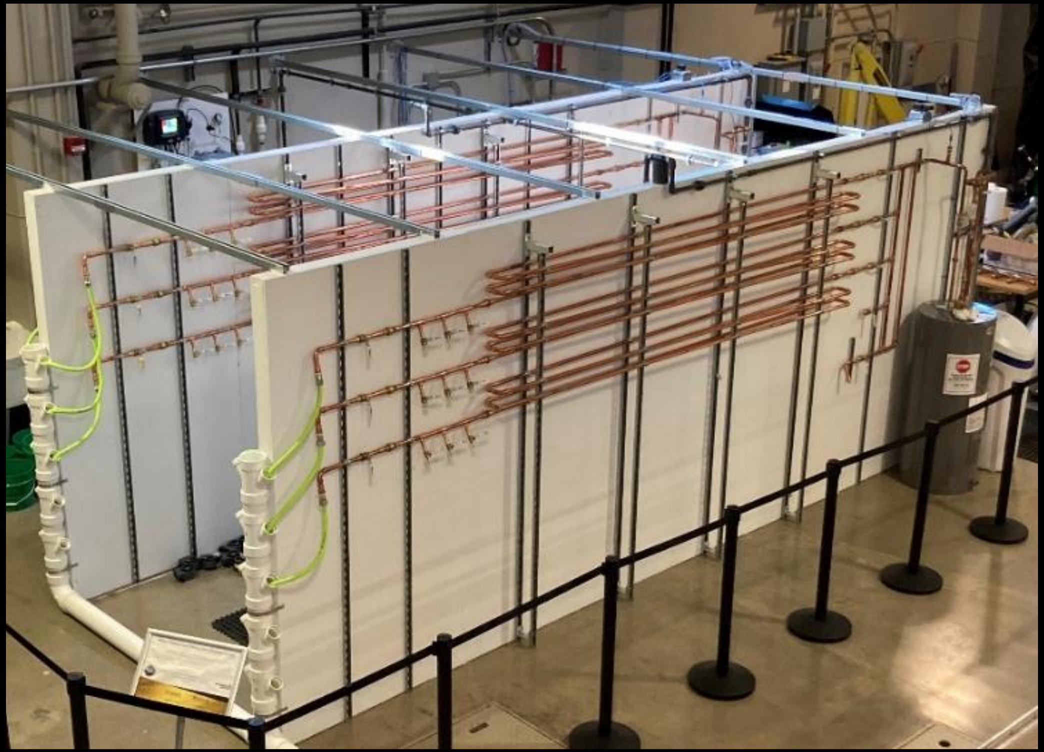

www.PlumbingSafety.org

- ✓ Online short-course
- ✓ Plumbing education videos
- ✓ Flushing plans
- ✓ Plumbing explainers
- ✓ List of projects
- ✓ Scientific opinions
- ✓ Resources ➔ presentations
- ✓ Scientific reports
- ✓ External plumbing docs
- ✓ YouTube Channel

10 hr, 1 CEU, Self-paced, Online
Building Water Essentials Short-Course:
https://engineering.purdue.edu/online/certifications/building-water-essentials

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Additional slides

Published Studies

Knowledge-Gap and Synthesis Investigations and New Health Risk Assessments

Initiative	Lead
Knowledge gaps and risks associated with premise plumbing drinking water quality: https://doi.org/10.1002/aws2.1177	MSU-PU-MC
Considerations for large building water quality after extended stagnation: https://doi.org/10.1002/aws2.1186	PU-UM-MP-VT-NU-UI-AZU
Development of a dose–response model for Naegleria fowleri: https://doi.org/10.2166/wh.2018.181	MSU
A dose response model for the inhalation route of exposure to P. aeruginosa: https://doi.org/10.1016/j.mran.2020.100115	MSU
Reverse QMRA for Pseudomonas aeruginosa in Premise Plumbing to Inform Risk Management: https://doi.org/10.1061/(ASCE)EE.1943-7870.0001641	MSU
Modeling the dose response relationship of waterborne Acanthamoeba: https://doi.org/10.1111/risa.13603	MSU

New Commercial and Institutional Building Investigations

Initiative	Lead
Finding building water quality challenges in a 7 year old green school: implications for building design, sampling, and remediation: https://doi.org/10.1039/D0EW00520G	PU -TU
The Occurrence of 5 Pathogenic Legionella species from Source (Groundwater) to Exposure (Taps and Cooling Towers) In a Complex Water System: https://doi.org/10.1039/D0EW00893A	MSU
Cooccurrence of Five Pathogenic Legionella spp. and Two Free-Living Amoebae Species in a Complete Drinking Water System and Cooling Towers: https://doi.org/10.3390/pathogens10111407	MSU
Over the weekend: Water stagnation and contaminant exceedances in a green office building: https://doi.org/10.1371/journal.pwat.0000006	PU-TU
Water Age Effects on the Occurrence and Concentration of Legionella Species in the Distribution System, Premise Plumbing, and the Cooling Towers: https://doi.org/10.3390/microorganisms10010081	MSU
Prevalence of opportunistic pathogens in a school building plumbing during periods of low water use and a transition to normal use: https://doi.org/10.1016/j.ijheh.2022.113945	TU-PU
School and childcare center drinking water: copper chemistry, health effects, occurrence, and remediation: https://doi.org/10.1002/aws2.1270	PU-MSU-UI-EPA

New Residential Building Investigations

Initiative	Lead
Case study: Fixture water use and drinking water quality in a new residential green building: https://doi.org/10.1016/j.chemosphere.2017.11.070	PU-MSU
An investigation of spatial and temporal drinking water quality variation in green residential plumbing: https://doi.org/10.1016/j.buildenv.2019.106566	PU-MSU-UM
Drinking water microbiology in a water-efficient building: stagnation, seasonality, and physicochemical effects on opportunistic pathogen and total bacteria proliferation: https://doi.org/10.1039/D0EW00334D	TU-PU-MSU
Impacts of Municipal Water–Rainwater Source Transitions on Microbial and Chemical Water Quality Dynamics at the Tap: https://10.1021/acs.est.0c03641	PU-TU-MSU
Water safety attitudes, risk perception, experiences, and education for households impacted by the 2018 Camp Fire, California: https://doi.org/10.1007/s11069-021-04714-9	PU-UCB-BC-CSUS

New Plumbing Material Discoveries and Decision Support Tools

Initiative	Lead
Metal Accumulation in Representative Plastic Drinking Water Plumbing Systems: https://doi.org/10.5942/jawwa.2017.109.0117	PU
Competitive heavy metal adsorption onto new and aged polyethylene under various drinking water conditions: https://doi.org/10.1016/j.jhazmat.2019.121585	PU
Corrosion of upstream metal plumbing components impact downstream PEX pipe surface deposits and degradation: https://doi.org/10.1016/j.chemosphere.2019.07.060	PU
Formation and sorption of trihalomethanes from cross-linked polyethylene pipes following chlorinated water exposure: https://doi.org/10.1039/D0EW00262C	PU
Drinking water contamination from the thermal degradation of plastics: implications for wildfire and structure fire response: https://doi.org/10.1039/D0EW00836B	PU
Identifying water quality variables most strongly influencing Legionella concentrations in building plumbing: https://doi-org.proxy1.cl.msu.edu/10.1002/aws2.1267)	MSU-PU-TU
New models for predicting chemical and biological quality at residential fixtures https://doi.org/10.1002/aws2.1280	MC-PU-MSU
Machine learning framework for predicting downstream fixture use events: https://doi.org/10.2166/ws.2022.226	MSU-PU

The Healthy Plumbing Consortium (2021 – Pres)

Mission: To advance health and quality of life by innovating new and existing technologies and providing transformative education.

DELTA FAUCET COMPANY

Intellihot

Copper Development Association Inc.
Copper Alliance

1. Technological and operational approaches for maximizing building water health
2. Smart technology for improved building water health
3. Education of systems and technology

PURDUE UNIVERSITY

School and childcare center drinking water: Copper chemistry, health effects, occurrence, and remediation

1. Only 0.2% of 598,000 schools and childcare centers had copper testing data
2. Where present, widely different sampling and remedial actions were reported
3. Plumbing and fixture flushing was unreliable, copper quickly rebounded
4. Building treatment systems have been used, but some were not effective
5. A national drinking water testing campaign and field studies are recommended

Watch out for elevated alkalinity levels with near neutral pH!

Montagnino et al. 2022. School and childcare center drinking water: Copper chemistry, health effects, occurrence, and remediation. *AWWA Water Science.* https://doi.org/10.1002/aws2.1270

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A 7 year old LEED School in Indiana
(250+ outlets, 1 floor, 3 recirc loops, chloramines)

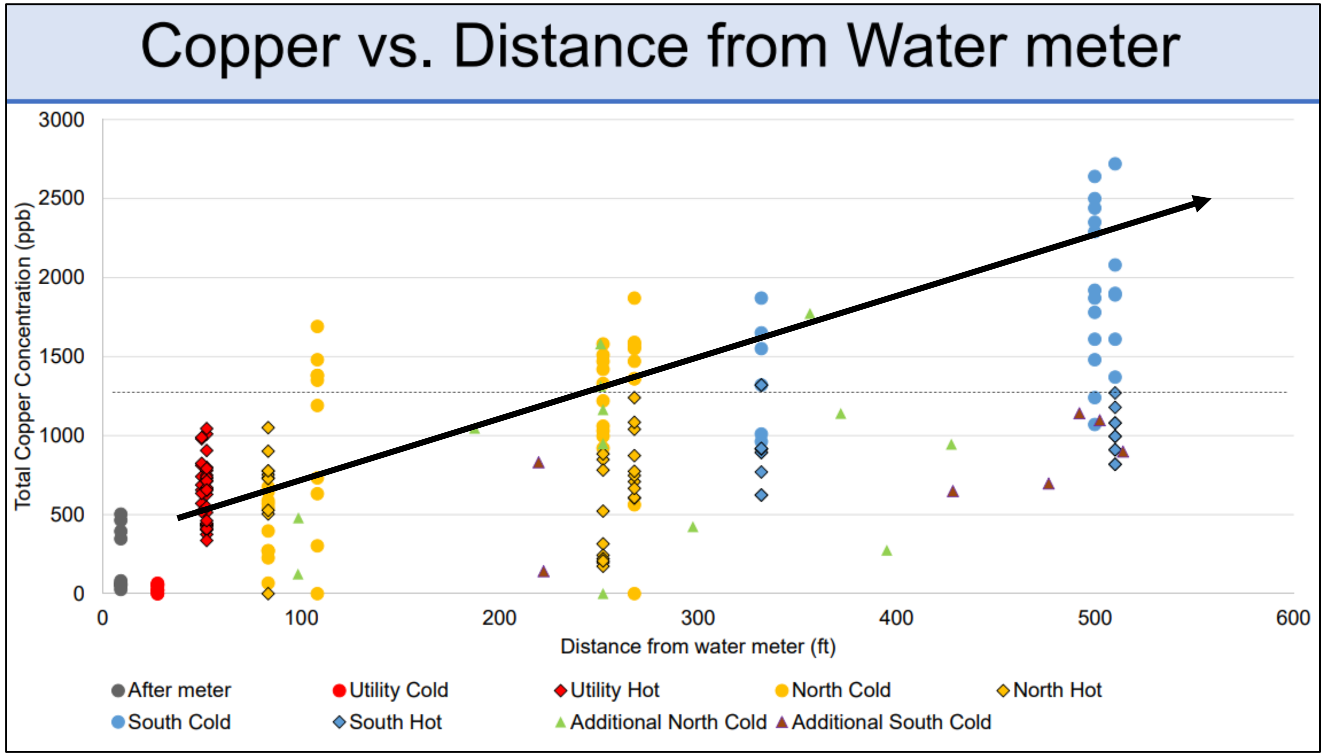
Summer 2019

↓

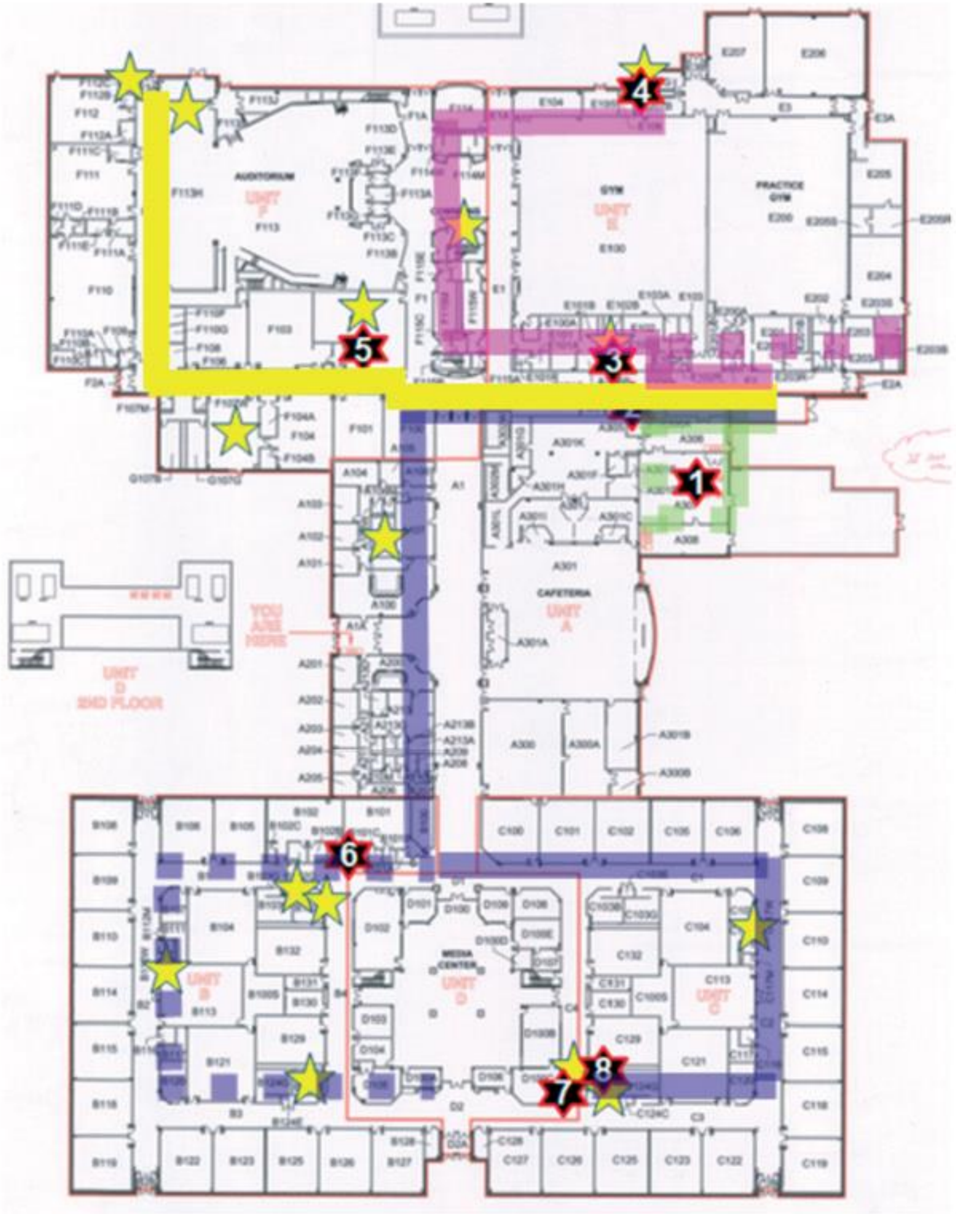
Fall 2019

Prior testing:

Lead only



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

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A Large School in Ohio (450+ outlets, 2 floors, no recirc loops, yes showers)

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

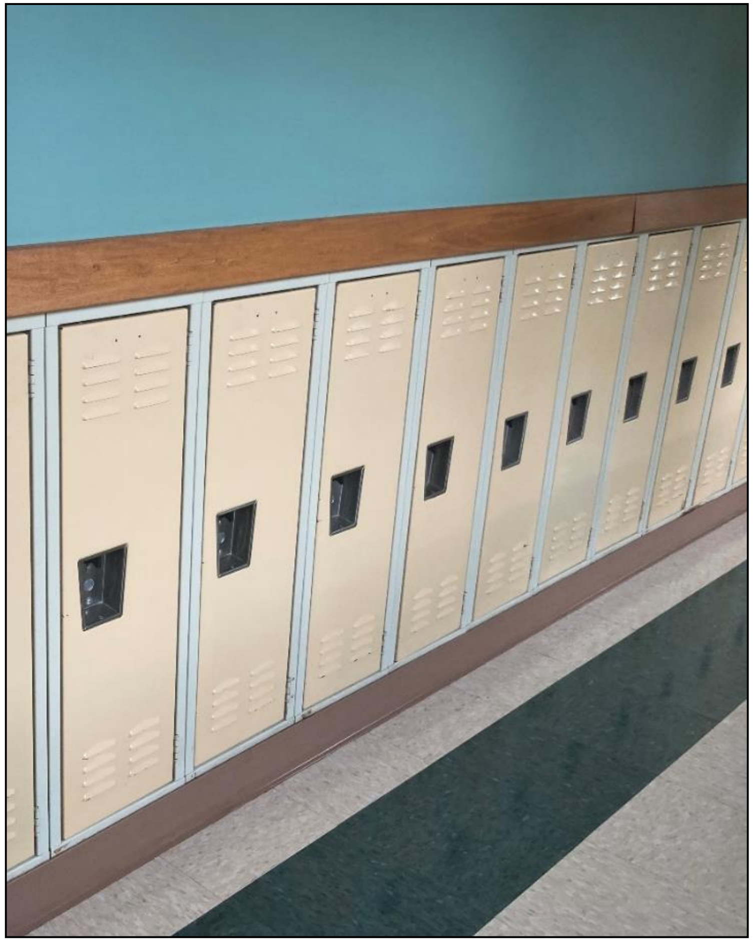
Stagnation:
Approximately 5.3% (5/94) of fixtures positive for *L. pneumophila*

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

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

Nickel exceeded health based limits in kitchen

A small school in Indiana…multiple buildings



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*

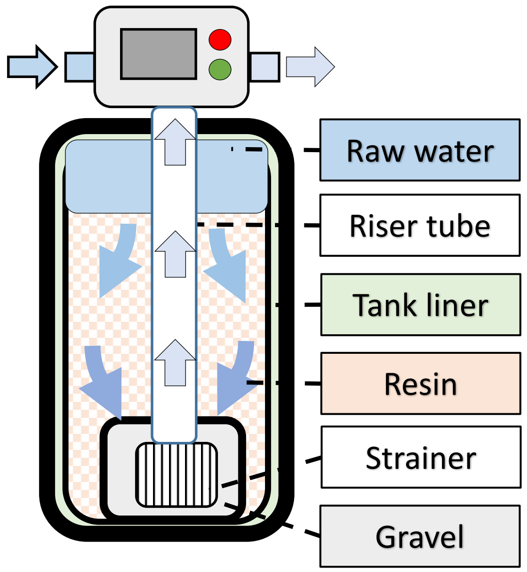
Stagnant water: 1-2 *L. pneumophila* detects/building (<188 MPN/ 100mL). Total cold (4 of 25 locations), Hot (1 of 21 locations)

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

Hydrocarbon Contamination and Decontamination of Water Softeners

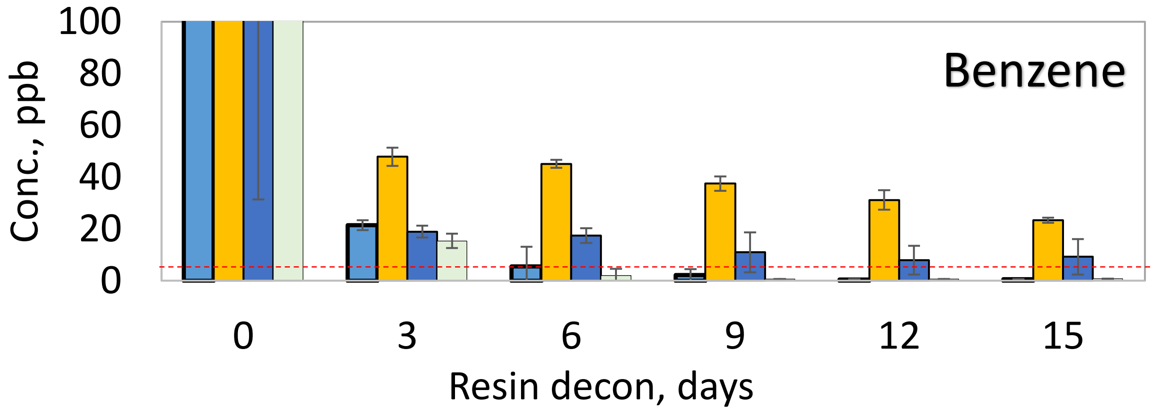


Surface area

Resin: 2,800,000+ cm^2

Liner: 9,300 cm^2

Gaskets: 32 cm^2



…. of Water Supply Connectors

After the 2014 West Va. chemical spill, the Health Department recommended discarding tubing at restaurants

Dishwasher connector – PVC

Softener connector – PVC

Ice-maker tubing – PE

Multipurpose tubing – PVC

Faucet supply line – PVC

Ice-maker tubing – PEX

All plastics sorbed 93-100% of the BTEX in 24 hr

9 of 11 materials still exceeded the benzene MCL after 9 days of decon

Washing machine hose – EPDM

Jankowski, Le et al. *In Prep.*

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Download information here
www.PlumbingSafety.org

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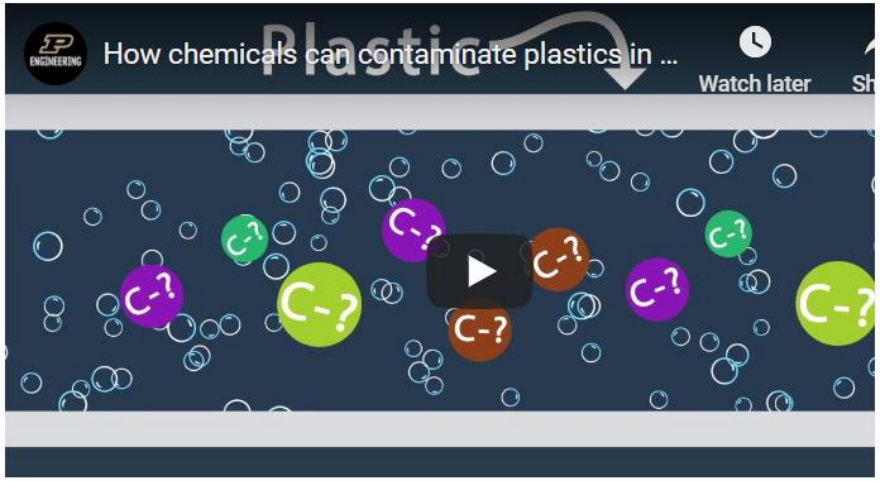

News

- 'It's gone to the ground': Big Basin Water Co. struggles to recover from fire (Santa Cruz Sentinel)
- Wildfires can spark widespread contamination of public water supplies (NRDC)
- Biggest risk to surface water after a wildfire? It's complicated (Eos)
- As wildfires ravage the West, contaminated water raises health concerns (STAT)
- Unsafe to drink: Wildfires threaten rural towns with tainted water (Cal Matters)
- How wildfires are contaminating the water supply with benzene, other hazardous chemicals (WBUR)

COVID-19 Response

Thank you for visiting. This website is designed to provide information to persons who drink water in buildings, as well as building construction, plumbing, water utility, education, and public health sectors. Together, we are working to understand how to make certain the water you use at home, at work, and at schools is safe. Please contact us if you have any questions at awhelton@purdue.edu.

Partner Institutions:

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

BUILDING WATER ESSENTIALS: CERTIFICATE PROGRAM

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