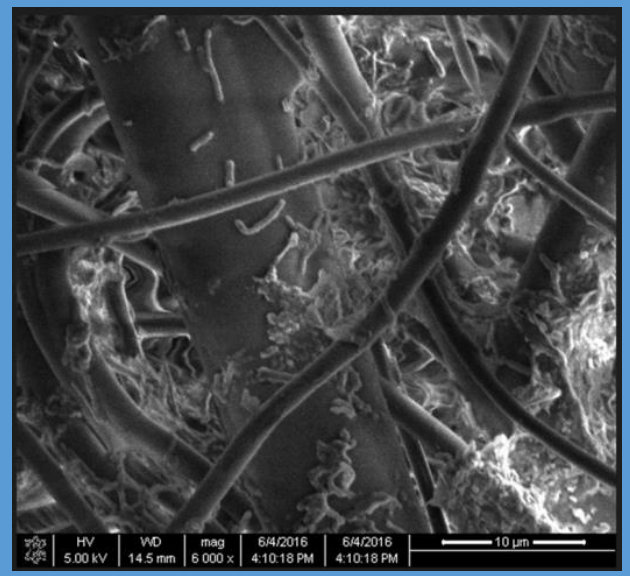
Right Sizing Tomorrow's Water Systems for Efficiency, Sustainability, & Public Health



Completed: 2016-2022

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

NIST Premise Plumbing Research Workshop
November 15, 2022

Final Report: Now available at www.PlumbingSafety.org

PURDUE UNIVERSITY | MICHIGAN STATE UNIVERSITY | SJSU SAN JOSÉ STATE UNIVERSITY | MANHATTAN COLLEGE | Tulane University | THE UNIVERSITY OF MEMPHIS

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 posted at www.PlumbingSafety.org
December 2022

PURDUE UNIVERSITY · MICHIGAN STATE UNIVERSITY · SJSU SAN JOSÉ STATE UNIVERSITY · MANHATTAN COLLEGE · Tulane University · THE UNIVERSITY OF MEMPHIS

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

Model Calibration

Rate Constants

Bench Scale Experiment

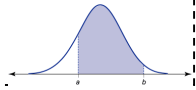
Pilot Study

Field Study

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?

Water Treatment Process

- Well Water
- Lake Water
- River Water

Model Benchmark/ Validation

OBJ. 2B SIMULATIONS – DIFFERENT WATER DEMAND, WATER QUALITY, HYDRAULIC PRESSURES

OBJ. 3B: DECISION SUPPORT TOOL

OBJECTIVE 1. Improve the understanding of decreased flow and establish a range of theoretical 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 in the peer-review literature.

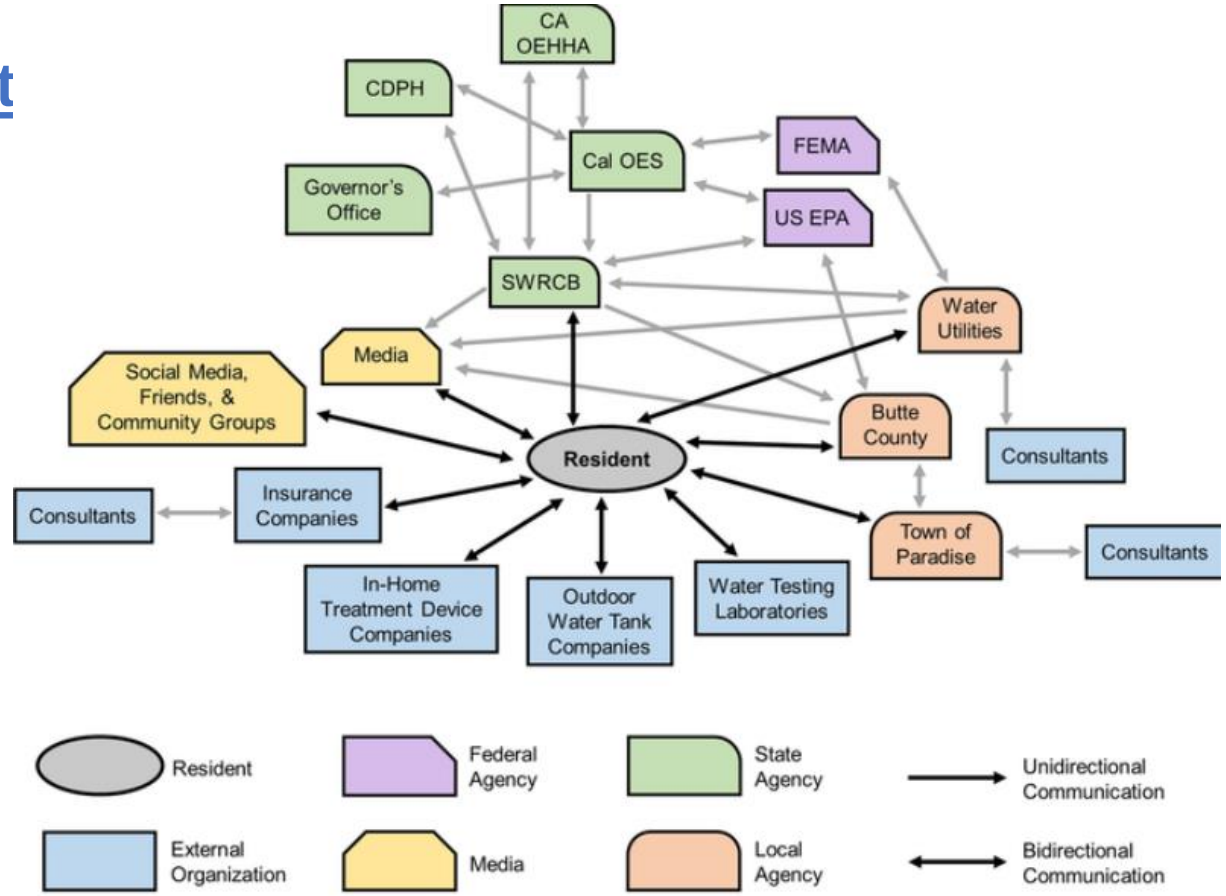
Water safety attitudes, risk perception, experiences, and education for households impacted by the 2018 Camp Fire

Natural Hazards, Published May 2021 https://doi.org/10.1007/s11069-021-04714-9

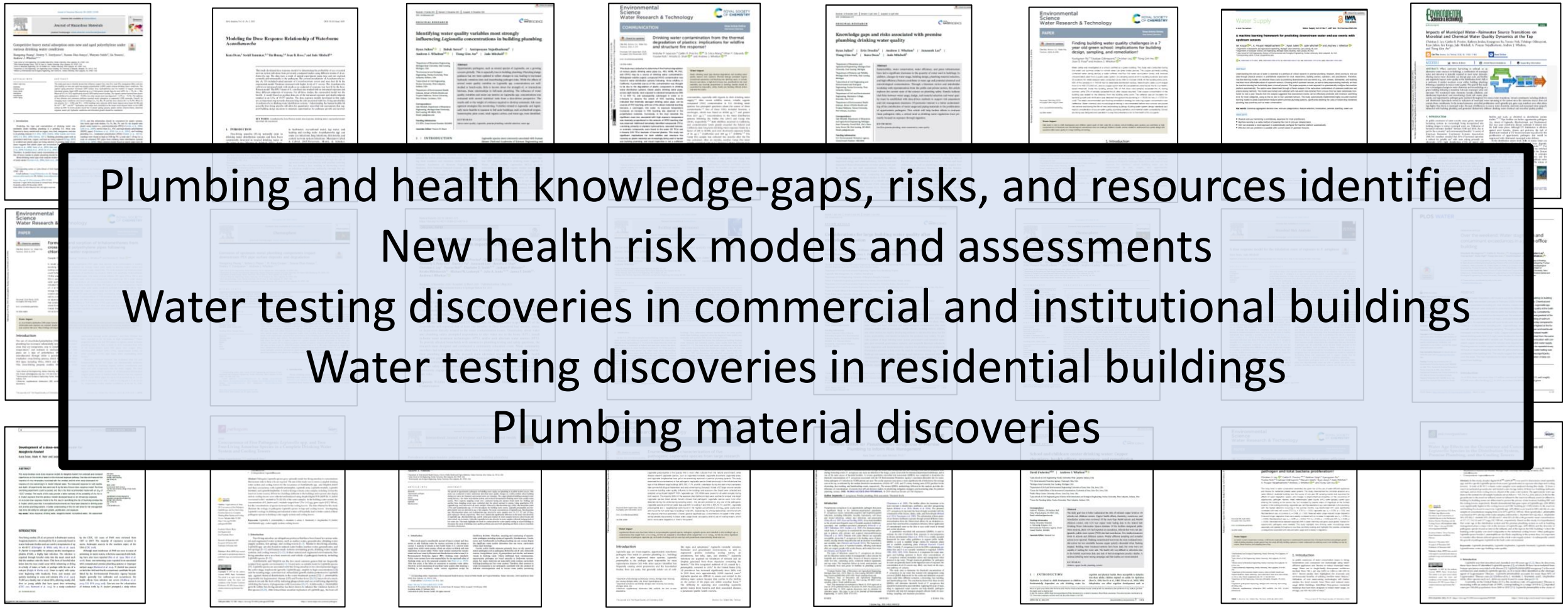
Household Public Health Support Not (yet) Based on Science

1) Water use restrictions
2) Plumbing sampling and testing
3) Plumbing decon and validation
4) Water tank selection and maintenance
5) In-home treatment device selection and maintenance

Rural communities are especially impacted



OBJECTIVE 2. Elucidate the factors and their interactions that affect drinking water quality through fate and transport simulation models for residential and commercial buildings (25+ more peer-reviewed publications)



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

PURDUE UNIVERSITY

MICHIGAN STATE UNIVERSITY

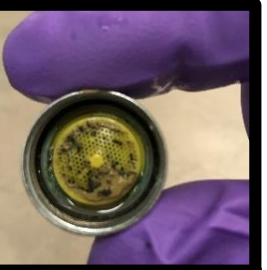
SJSU SAN JOSÉ STATE UNIVERSITY

MANHATTAN COLLEGE

Tulane University

THE UNIVERSITY OF MEMPHIS





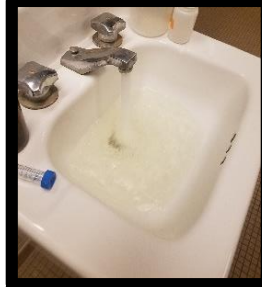

25+ Studies: Some Discoveries

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.

PURDUE UNIVERSITY · MICHIGAN STATE UNIVERSITY · SJSU SAN JOSÉ STATE UNIVERSITY · MANHATTAN COLLEGE · Tulane University · THE UNIVERSITY OF MEMPHIS





…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 (~1,000 mg/L), sulfur (~1,200 mg/L), and 7 days later TOC levels remained elevated




PURDUE UNIVERSITY · MICHIGAN STATE UNIVERSITY · SJSU SAN JOSÉ STATE UNIVERSITY · MANHATTAN COLLEGE · Tulane University · THE UNIVERSITY OF MEMPHIS

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

PURDUE UNIVERSITY · MICHIGAN STATE UNIVERSITY · SJSU SAN JOSÉ STATE UNIVERSITY · MANHATTAN COLLEGE · Tulane University · THE UNIVERSITY OF MEMPHIS

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

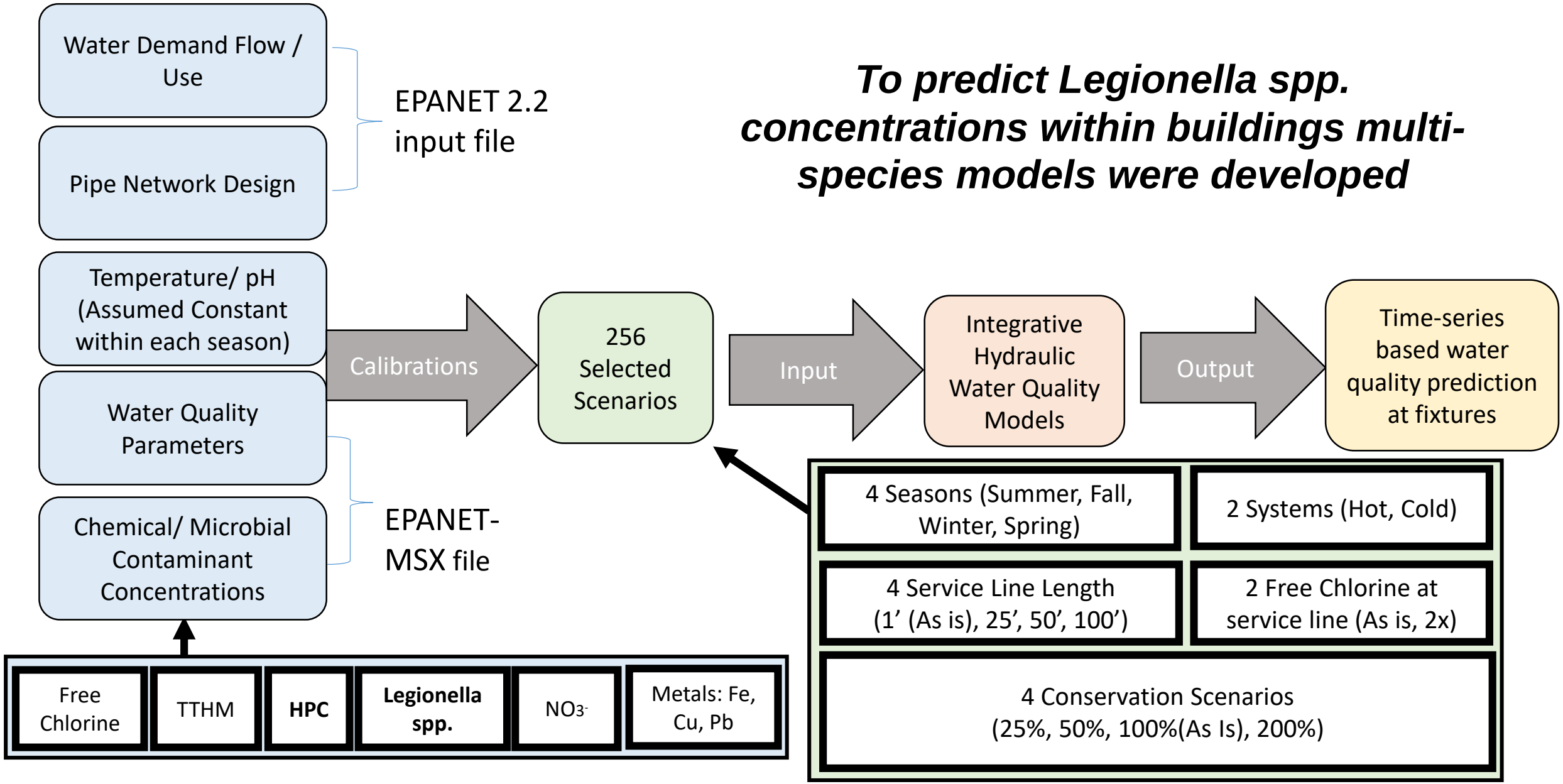
Variable name	Variable description	Units	Log transformed	Percentile (natural scale) 2.5%	50.0%	97.5%	Number of observations
pH	pH	NA	No	7.36	8.00	9.04	406
Temp	Temperature	C	No	15.63	22.90	26.30	406
DO	Dissolved oxygen	mg/L	No	4.30	8.40	10.56	406
Total.Cl	Total chlorine	mg/L	Yes	BDL	0.10	1.00	406
Free.Cl	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

PURDUE UNIVERSITY MICHIGAN STATE UNIVERSITY SJSU SAN JOSÉ STATE UNIVERSITY MANHATTAN COLLEGE Tulane University THE UNIVERSITY OF MEMPHIS



PURDUE UNIVERSITY · MICHIGAN STATE UNIVERSITY · SJSU SAN JOSÉ STATE UNIVERSITY · MANHATTAN COLLEGE · Tulane University · THE UNIVERSITY OF MEMPHIS

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

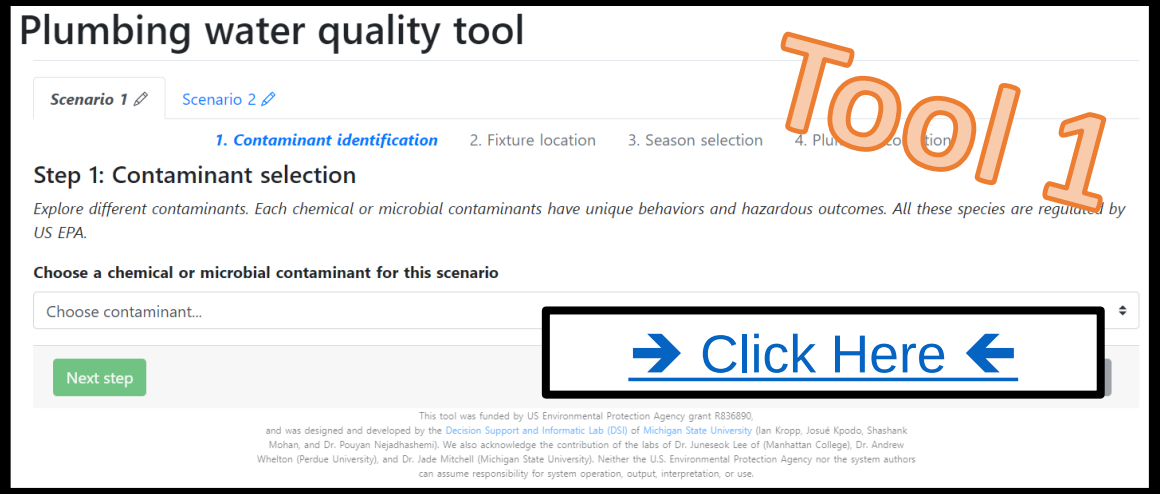
No other full-scale models are available for predictions. This is a first.

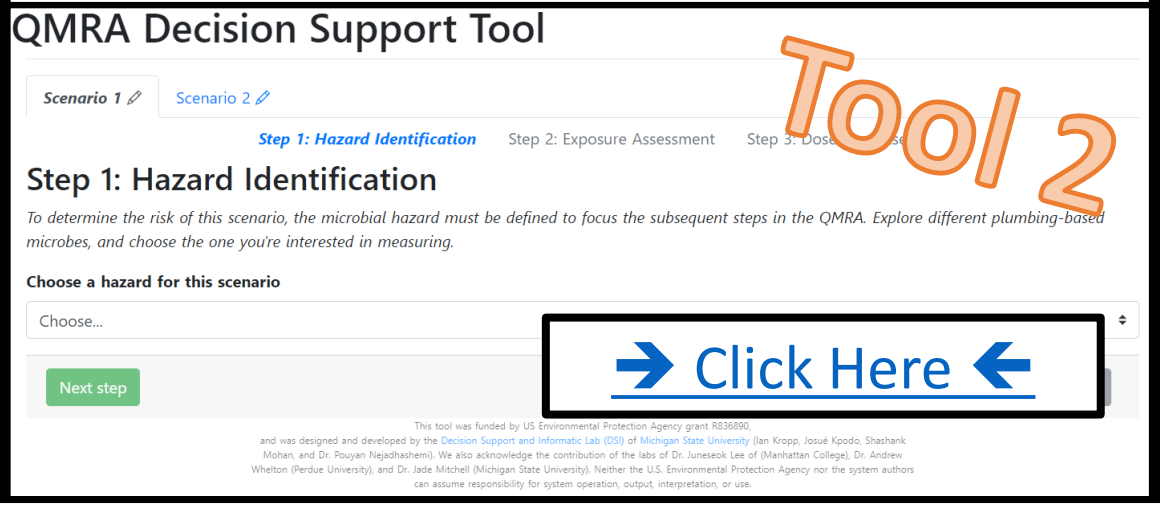
Carrying capacity of *Legionella spp.* (and other organisms) in other buildings is unknown

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

OBJECTIVE 3. Create a risk-based decision support tool to help guide decisions through the identification of plumbing characteristics, operations and maintenance practices that minimize health risks to building inhabitants.





Online and FREE Building Water Quality Tools Now Available

Usefulness

Examine plumbing design impacts
(pipe length, cold vs. hot, conservation)

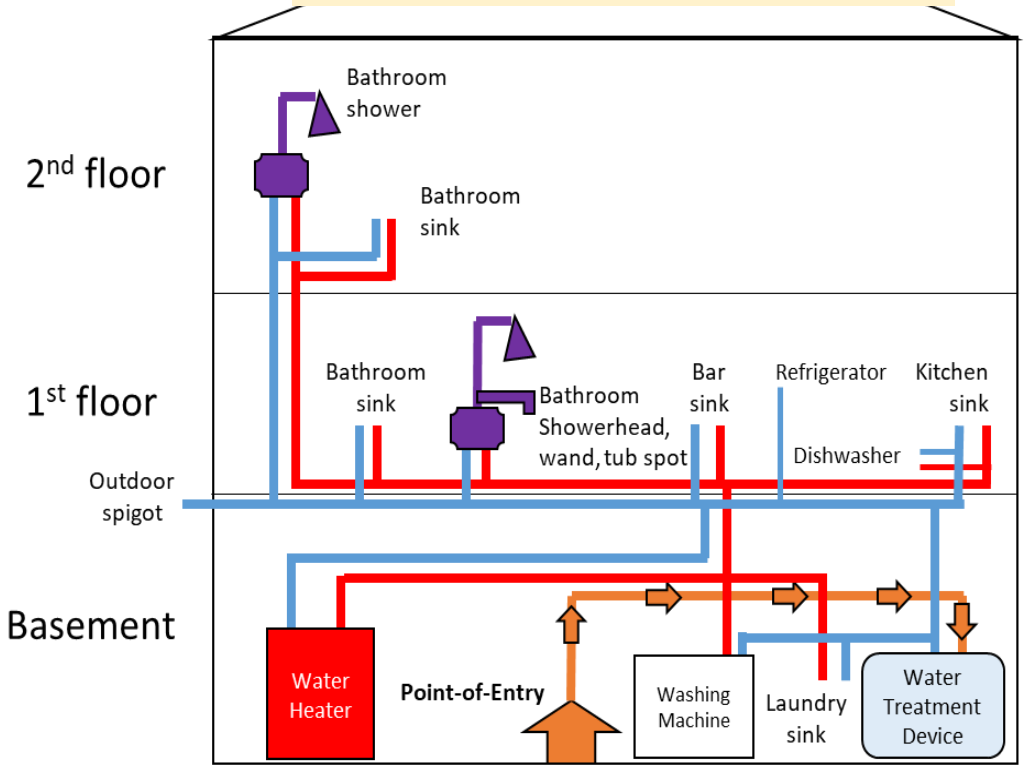
Evaluate water use impacts
(fixture type, seasons)

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

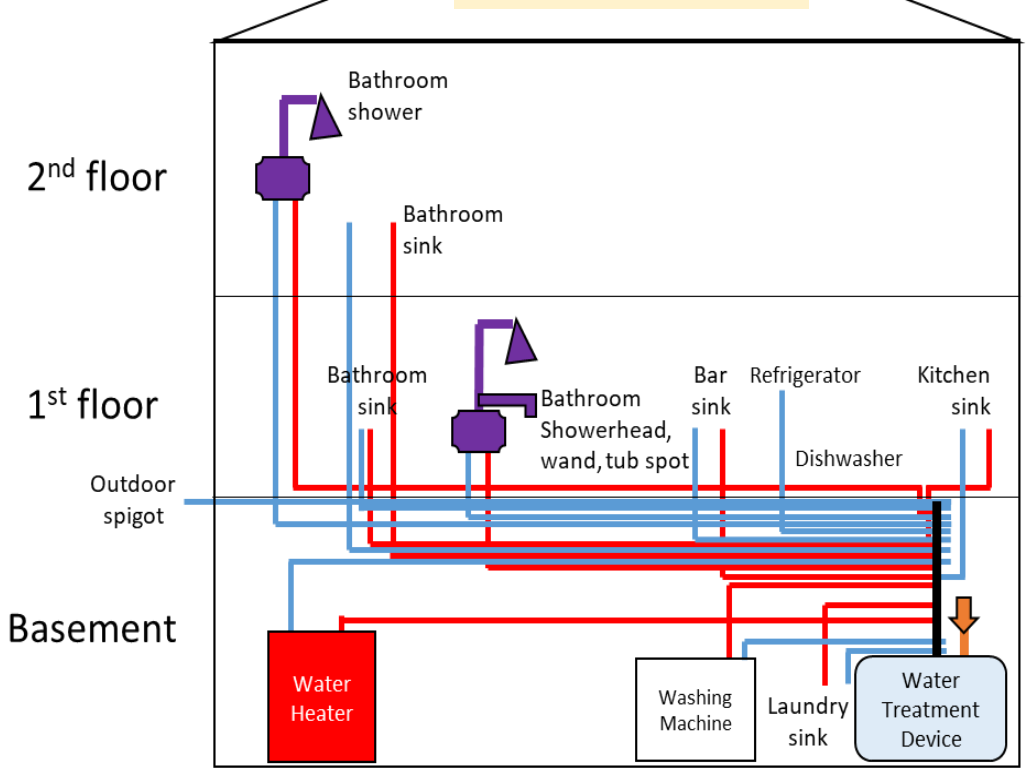
PURDUE UNIVERSITY · MICHIGAN STATE UNIVERSITY · SJSU SAN JOSÉ STATE UNIVERSITY · MANHATTAN COLLEGE · Tulane University · THE UNIVERSITY OF MEMPHIS

Sampling buildings and decontamination activities need to take into consideration the actual plumbing

Trunk-and-branch



Manifold



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

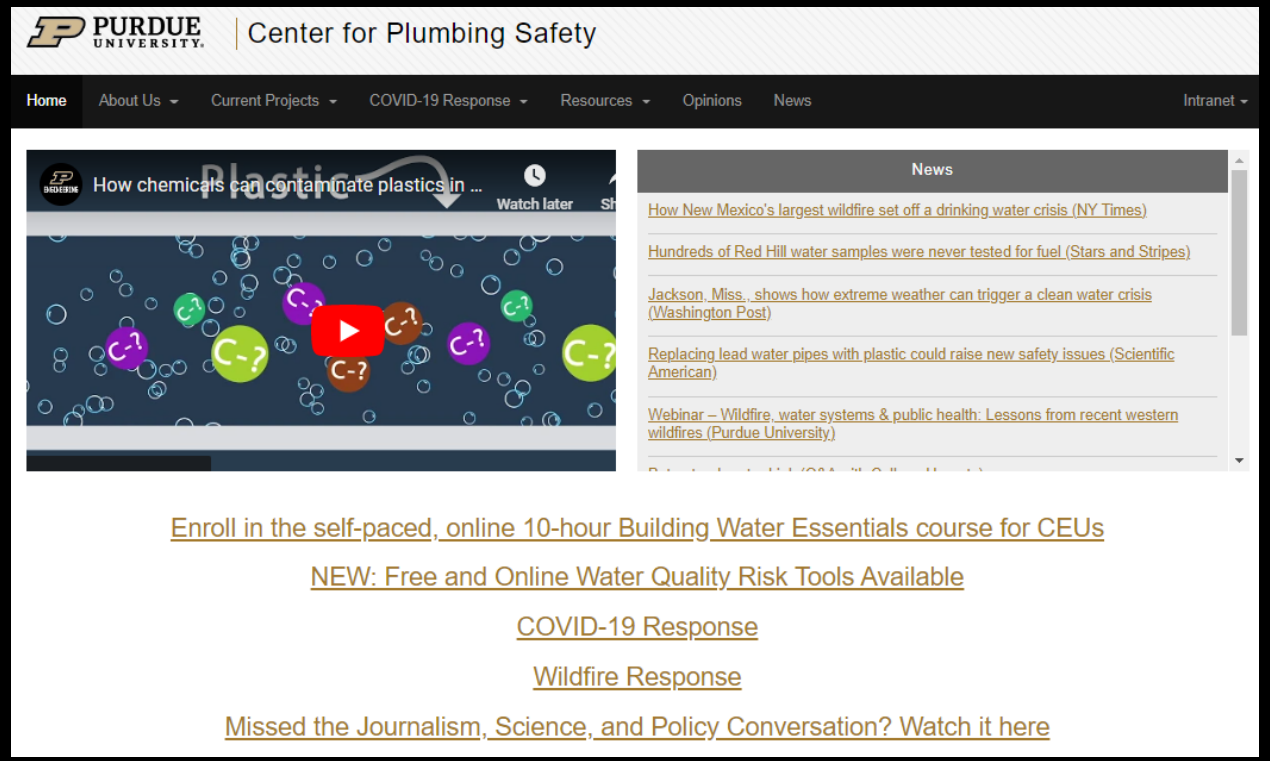
Intellihot

Cu 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

Thank you. Final report now on PlumbingSafety.org

Andrew Whelton, Ph.D. awhelton@purdue.edu @TheWheltonGroup



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

PURDUE UNIVERSITY · MICHIGAN STATE UNIVERSITY · SJSU SAN JOSÉ STATE UNIVERSITY · MANHATTAN COLLEGE · Tulane University · THE UNIVERSITY OF MEMPHIS