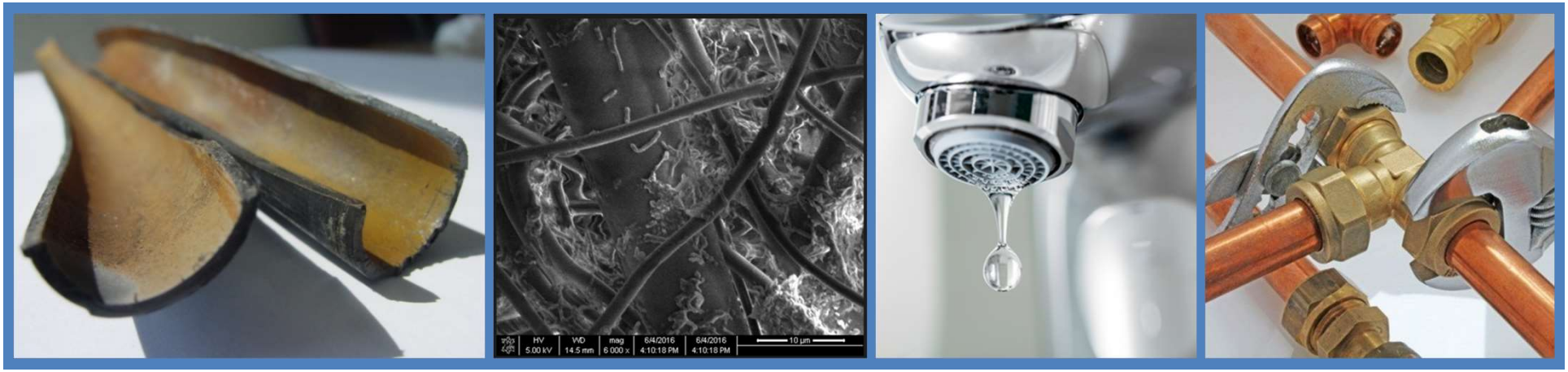
Right Sizing Tomorrow's Water Systems for Efficiency, Sustainability, & Public Health



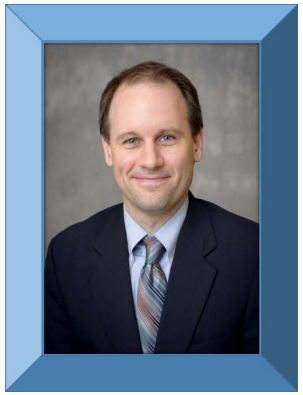
Andrew Whelton (PI), Jade Mitchell, Janice Beecher, Joan Rose, Juneseok Lee, Pouyan Nejadhashemi, Erin Dreelin, Tiong Gim Aw, Amisha Shah, Matt Syal, Maryam Salehi

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

EPA

Presentation 3

Working Towards Safer Drinking Water at Home, Work, and School: Research to Improve Plumbing Safety: To better understand how unsafe drinking water can occur in buildings, the Purdue research team is developing integrated water quality models and identifying piping network design and operational conditions that can decrease health risks. Andy Whelton, lead PI on this grant will describe the project goals and objectives, ultimately leading to a risk based decision support tool for building plumbing systems. Dr. Whelton will also describe the wide variety of industrial partners and stakeholders supporting the project and the various roles and backgrounds for the joint Purdue/Michigan State/San Jose State research team.



Dr. Andrew J. Whelton

Dr. Whelton has 15 years of experience as an environmental engineer and is an assistant professor of Purdue University's Lyles School of Civil Engineering, Division of Environmental and Ecological Engineering. His research efforts have concentrated on the interface of technology, the environment, and public health. He earned a B.S.in Civil Engineering, an M.S. in Environmental Engineering, and a Ph.D. in Civil Engineering from Virginia Tech.

Contact: awhelton@purdue.edu

plumb·ing

[ˈpləmiNG] ***NOUN***

the system of pipes, tanks, fittings, and other apparatus required for the drinking water supply, heating, and sanitation <u>in a building</u>

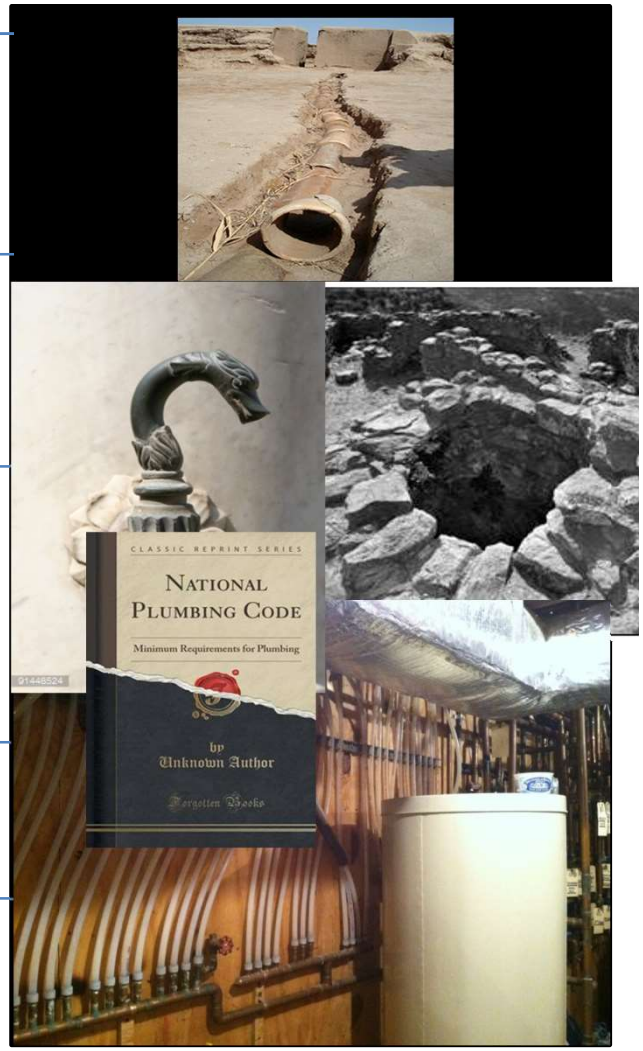
4000-3000 BCE
Copper water pipes in buildings (India)

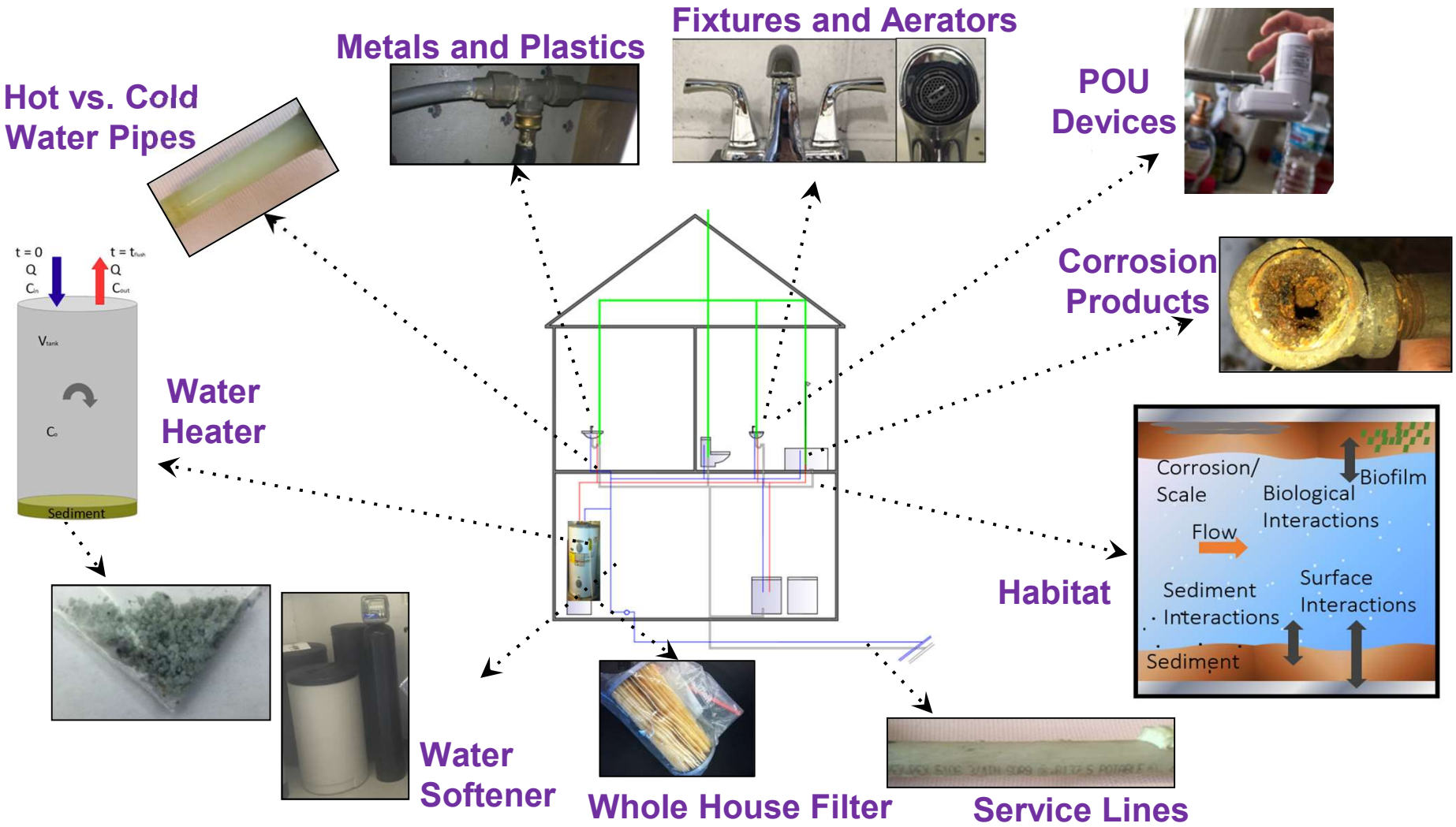
1500 BCE
Rainwater cisterns (Greece)

500 BCE- 250 AD
Lead & bronze pipes, marble fixtures, gold & silver fittings (Egypt)

1928
First US plumbing code

1966
Copper shortage enabled plastics entry




Hot vs. Cold Water Pipes
Metals and Plastics
Fixtures and Aerators
POU Devices
Corrosion Products
Water Heater
t = 0
Q
Cin
t = tflush
Q
Cout
Vtank
Cs
Sediment
Habitat
Corrosion/ Scale
Biofilm
Biological Interactions
Flow
Sediment Interactions
Surface Interactions
Sediment
Water Softener
Whole House Filter
Service Lines

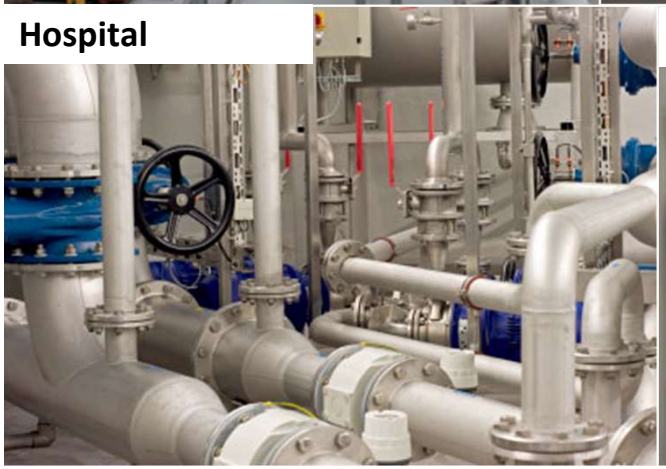
Premise plumbing is complex

Food Prep Facility

Domestic Hot Water

PEX pipe with copper manifold

Hospital



Cartridge Filters

Some images courtesy of: Gordon & Rosenblatt, LLC

Copper pipe to cPVC pipe

How old is your water before reaching the faucet?

$$\frac{\text{Volume of water stored in pipes}}{\text{Flowrate of water exiting the Faucet}}$$

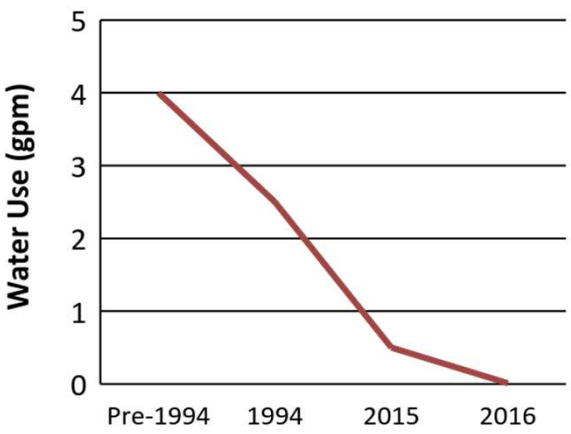
How old is your water before reaching the faucet?

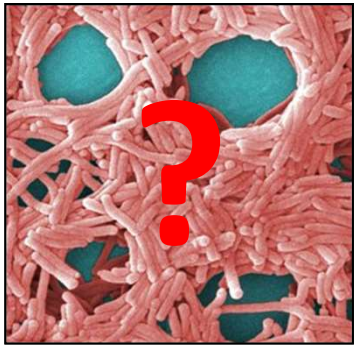
$$\frac{\text{Volume of water stored in pipes}}{\text{Flowrate of water exiting the Faucet}}$$

…our water systems are not designed to handle lower use

Our Project Goal

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





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.

Core Team

PURDUE UNIVERSITY

SJSU SAN JOSÉ STATE UNIVERSITY

Tulane University

MICHIGAN STATE UNIVERSITY

Our Project was Developed Based on Feedback from the Public, Regulators, Water Utilities, Building Designers, Owners, and Educational Institutions

Core Team Expertise

- Environmental Engineers
- Hydraulics Engineers
- Civil Engineers
- Microbiologists
- Analytical Chemists
- Data Scientists
- Risk Assessors
- Political Scientists

Partners

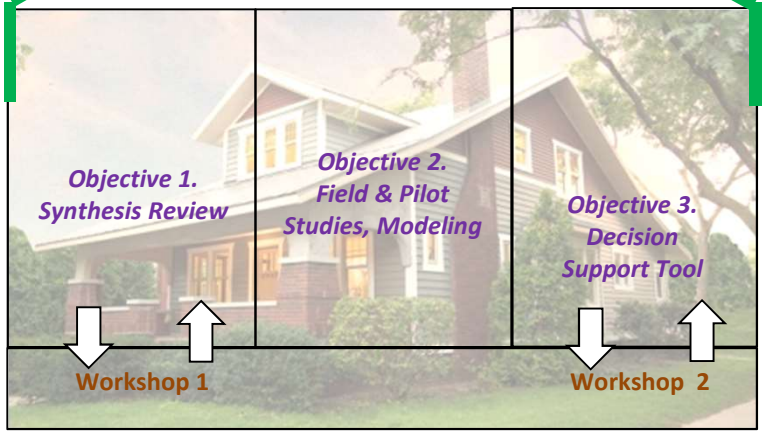
- Drinking water providers
- Architectural, Plumbing, and Engineering Firms
- Nonprofit organizations
- Educational institutions
- Professional associations

The Project Has 3 Main Objectives

Full-Scale Test Sites
ReNEWW Home
LEED Platinum Office Bldg
LEED cert. Middle School
LEED Silver Office Bldg
Renovated Office Bldg

Innovation Partner:
Whirpool Corporation

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



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

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

Government Collaborators
Genesee Co. Health Dept.
NIST
NAVFAC
Army PHC

EPA

Presentation 4

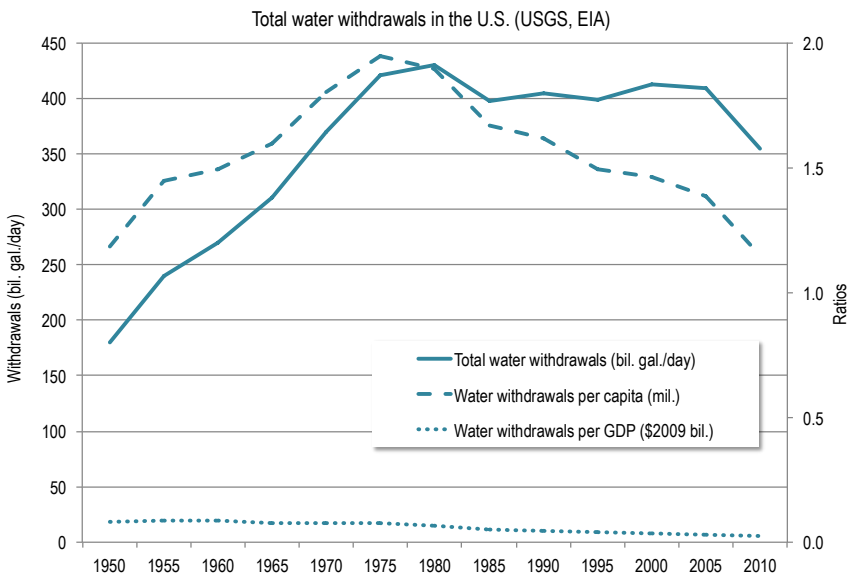
Yesterday's Demand, Tomorrow's Water Systems: Adjusting to Normals: As water fixtures, appliances, and water-use practices have become more efficient, aggregate and per-capita usage has declined. Systems serving legacy cities have seen further declines in the wake of lost economic activity and populations. Due to these and other factors, existing water utility and premise plumbing systems may be oversized relative to needs and pose potential health risks associated with stagnant water. Dr. Beecher will review the planned approach to analyzing and summarizing these trends for the purposes of this study.

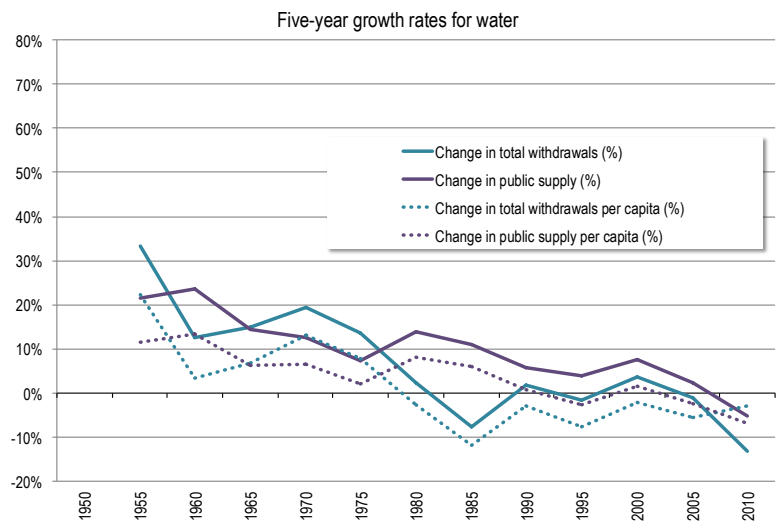
Dr. Janice Beecher

Dr. Janice Beecher has served as Director of the Institute of Public Utilities at Michigan State University since 2002. Her areas of interest include regulatory institutions, governance, and pricing, and she specializes in the water sector. She is presently serving on EPA's Environmental Finance Advisory Board and recently completed service on Michigan's 21st Century Infrastructure Commission. She has a Ph.D. in Political Science from Northwestern University and faculty appointments in MSU's College of Social Science, where she has taught graduate courses in public policy and regulation.

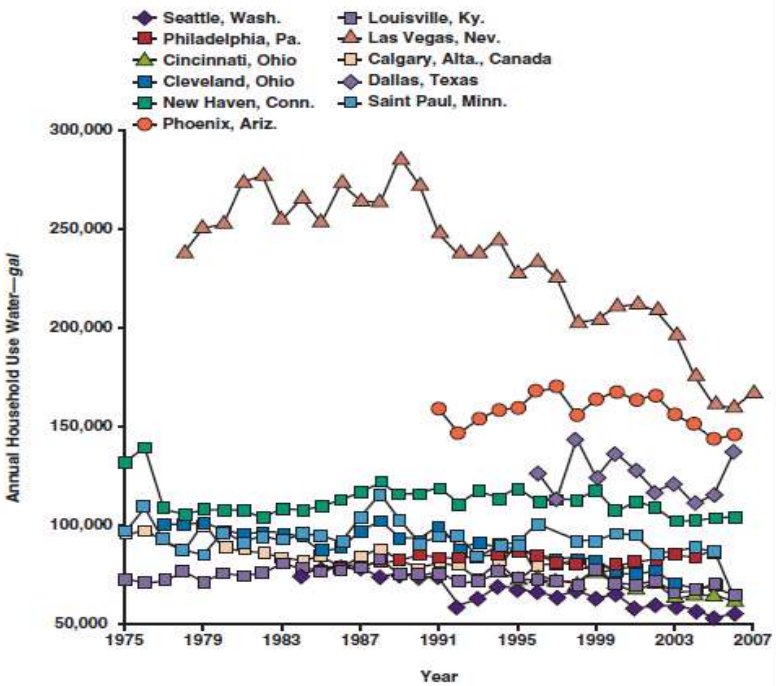
Contact: beecher@msu.edu

Aggregate water demand: negative growth rates

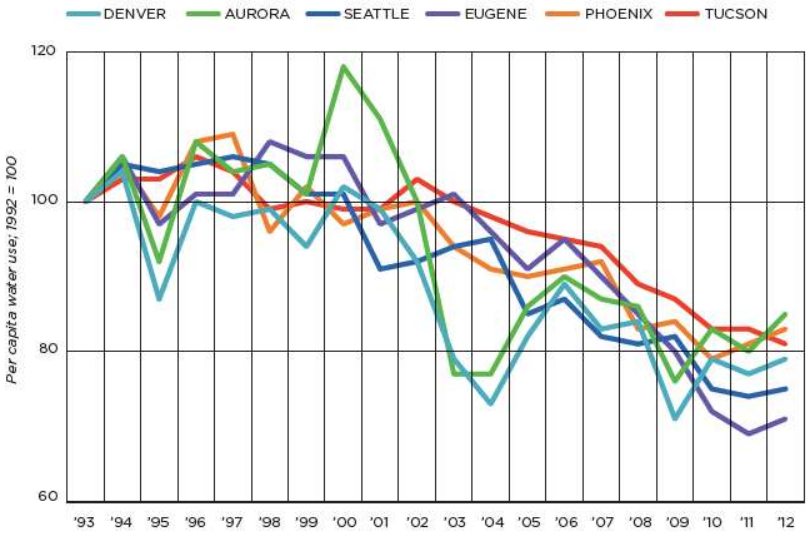




Water usage in U.S. cities



Source: Coomes, P., T. Rockaway, J. Rivard, and B. Kornstein. North American Water Usage Trends Since 1992. *©2010 Water Research Foundation. Reprinted with permission.*

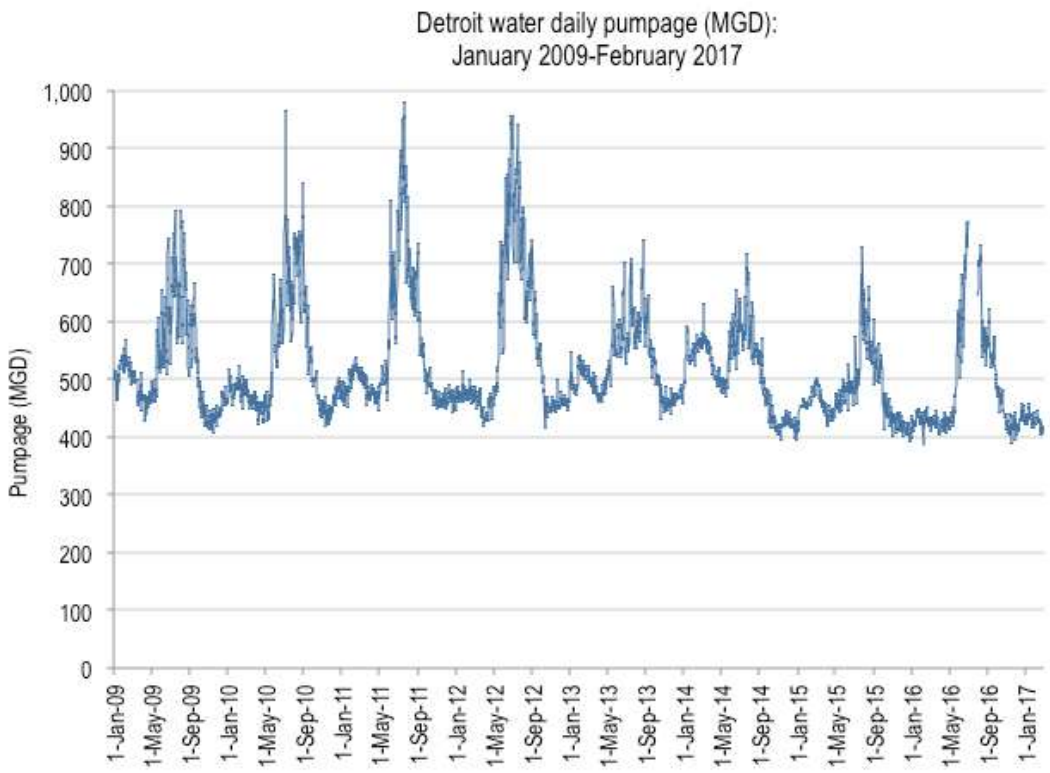


SOURCES: Denver Water, Aurora Water, Seattle Public Utilities, Eugene Water and Electric Board, Phoenix Water Service, Tucson Water

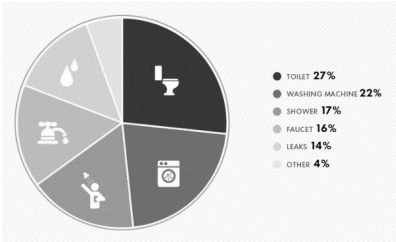
Challenge for legacy cities

Loss of population and economic activity

Oversizing and stagnant water



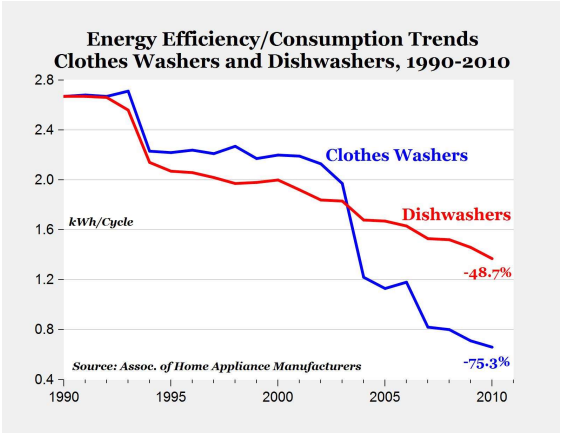
Apparent causes for falling water usage

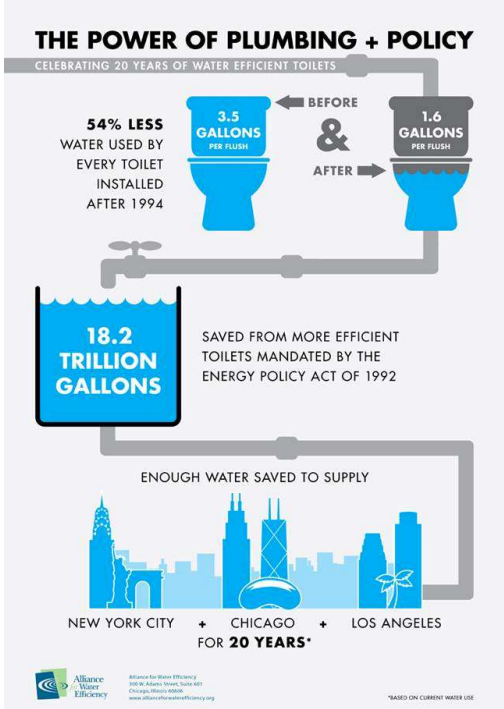


- Per-connection or per household
  - Demographic shifts (population, household size)
  - Property (lot) size and growth policies
  - Nature of commercial and industrial activities
  - Irrigation efficiency (practices, codes, efficiencies)
  - Effects of recession on economy and income (temporary?)
  - Cost and price effects on discretionary use (elasticity)
  - Aging water meters that under-register (very minor role)
- Per-capita or per-function
  - Efficiency standards (EP Act 1992), codes, and ordinances
  - Commercial and industrial processes an technologies
  - Changing culture and environmental ethic (e.g., lawn watering)
- No offsetting new uses for potable water (unlike energy)

Energy efficiency of home appliances

- Water efficiency standards for toilets, urinals, faucets, and showerheads were established by the National Energy Policy Act of 1992

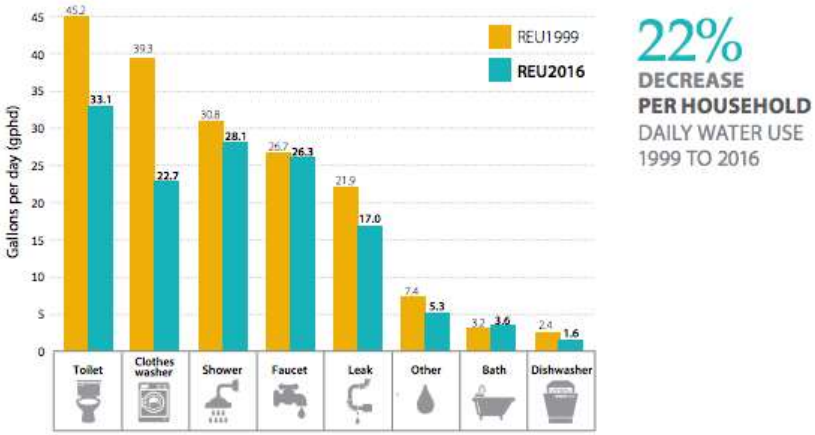




End-use savings

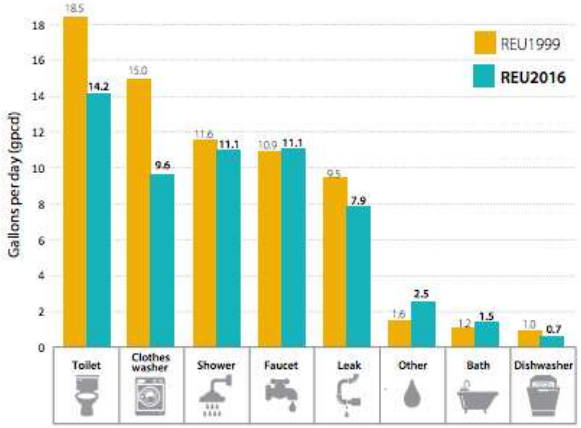
- Residential End Use Water Study (WRF, 2016)
  - Attributes reductions in household usage to efficiency standards
  - Rather than changes in occupancy patterns or consumer behavior
  - Role of price needs more consideration going forward (discretionary use)

Figure 4. Average daily indoor per household water use REU1999 and REU2016



22%
DECREASE PER HOUSEHOLD
DAILY WATER USE
1999 TO 2016

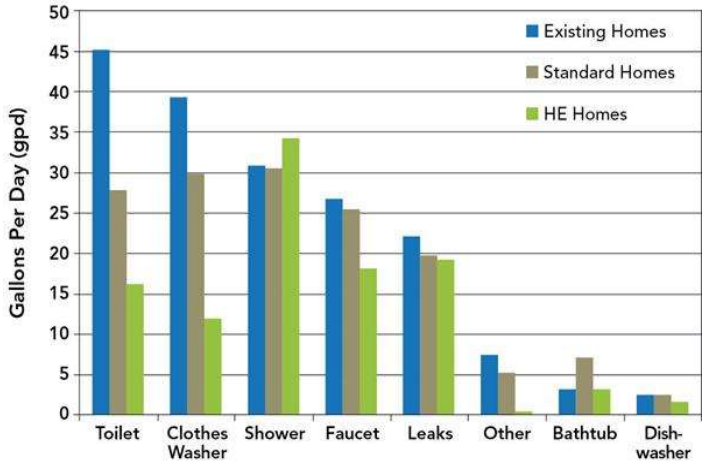
Figure 5. Average daily indoor per capita water use REU1999 and REU2016



15%
DECREASE PER CAPITA
DAILY WATER USE
1999 TO 2016

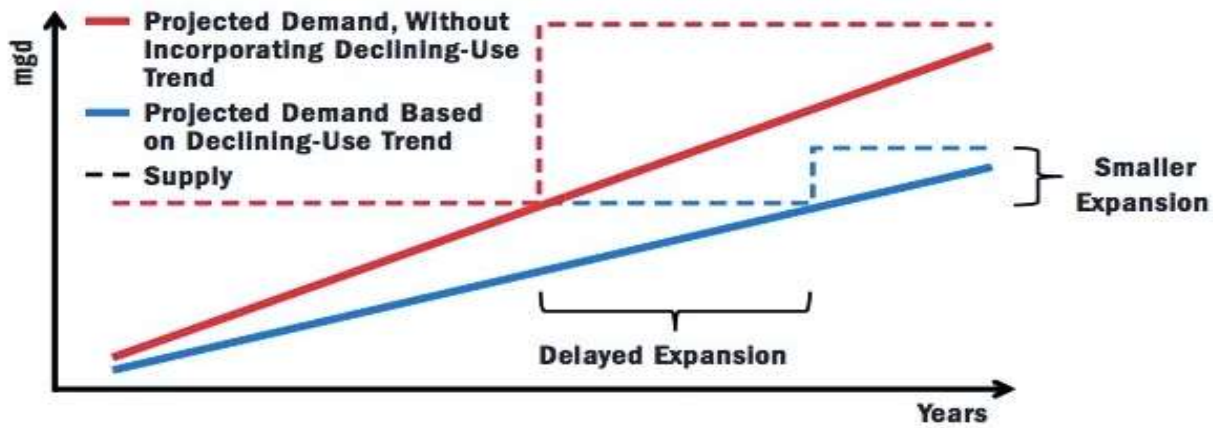
Hyper-efficiency for indoor water usage

- Technological standards could continue to drive indoor usage down
- Hyper-efficiency (<25 gpcd) may have operational consequences
  - Low flows may cause water pressure and quality issues (need for flushing)
  - Low flows also affect wastewater operations (flushing, pressure, or vacuums)
  - Increased use of maintenance water may offset conservation savings



The new normal

- Declining demand of 1-2% annually is not uncommon
  - A nonlinear trend expected to stabilize in the coming decade
  - Saving variable operating costs in short term, capital costs in long term
- Policy implications
  - Upward pressure on rates, need for better forecasting and capital planning
  - Time to reoptimize assets – don't build tomorrow infrastructure to yesterday's demand



Presentation 5

Water Microbiology Associated with Plumbing and Health Risks: Water conservation can lead to low flows and increased water age in distribution systems and premise plumbing. The reduced chlorine residual over time can subsequently allow for microbial growth in drinking water and biofilms along the piping materials. Additionally, organic carbon from certain types of pipes may provide nutrients for increased growth. Dr. Mitchell will review how the synergy among these events contribute to microbial risks, especially those produced by opportunistic pathogens.

Dr. Jade Mitchell

Dr. Jade Mitchell is an assistant professor in the Biosystems and Agricultural Engineering Department at Michigan State University. Her research broadly focuses on applications of quantitative microbial risk assessment (QMRA) to water quality, food safety and other environmental exposure pathways. Dr. Mitchell obtained a B.S. in Civil and Environmental Engineering from University of Pittsburgh, and an M.S. in Civil Engineering and a Ph.D. in Environmental Engineering from Drexel University.

Contact: jade@msu.edu

Objective 2

Objective 2A
Conduct Full- and Pilot-Scale Testing

Objective 2B
Develop Integrative Hydraulic-Water Quality Predictive Tools that Closely Mimic Residential and Large Buildings

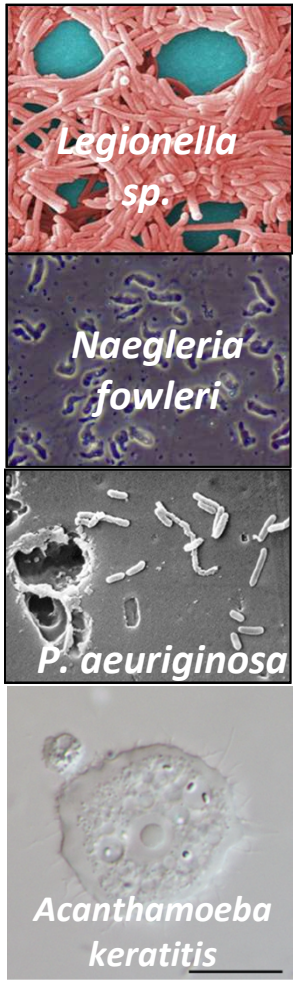
Objective 2C
Predictive Water Quality Modeling to Identify Significant Determinants of Public Health Risk

*"Pathogens in plumbing are the **primary** source of waterborne disease in developed countries"* *Pruden et al. (2013)*

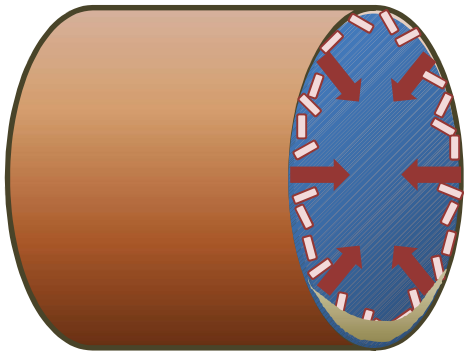
Opportunistic pathogens

More than 95% of the U.S. population receives drinking water from community water systems

Ubiquitous in well operated water distribution systems and premise plumbing



The problem with water that sits

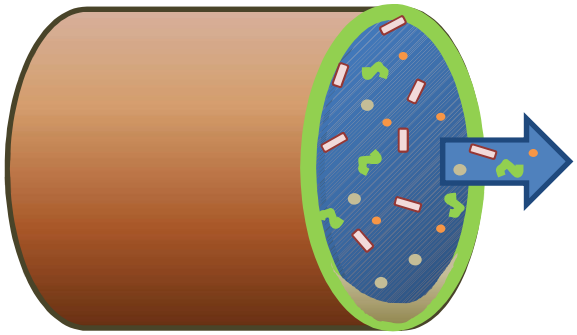


Leaching of chemicals

Growth of pathogens

Sedimentation

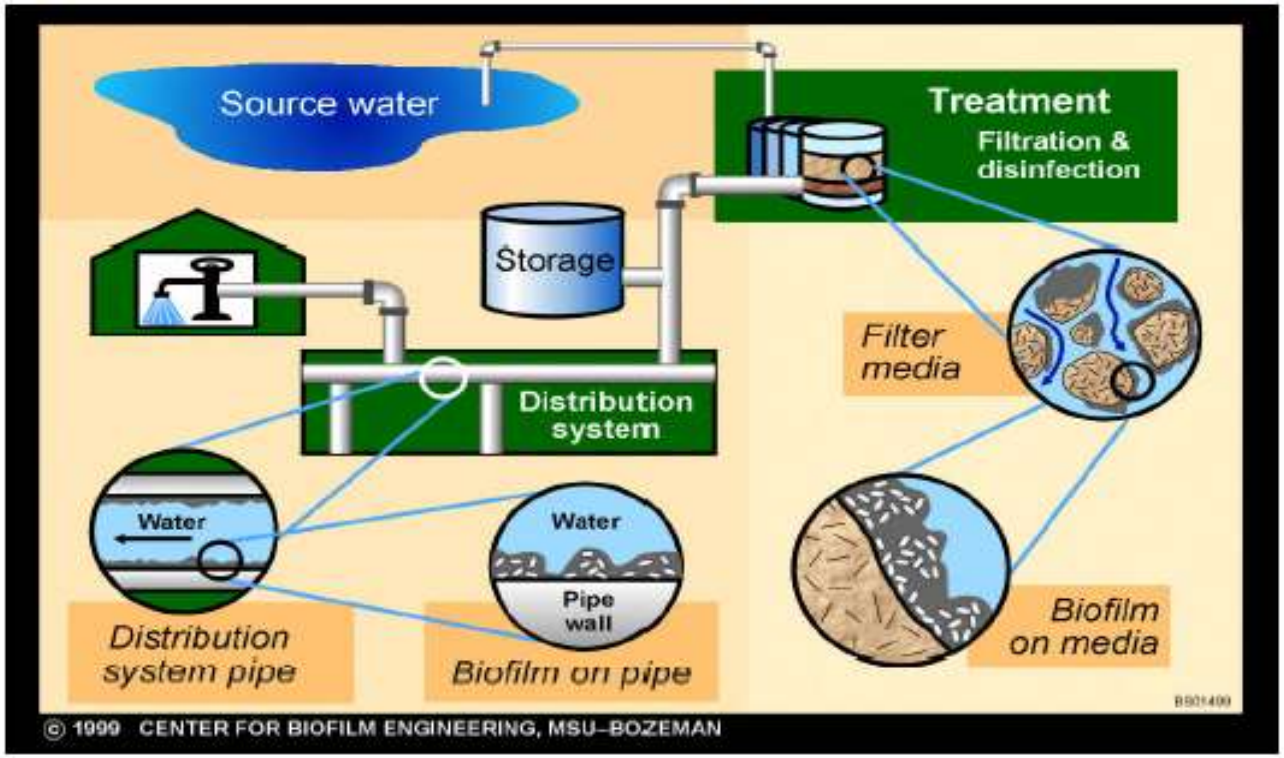
The problem with water that flows

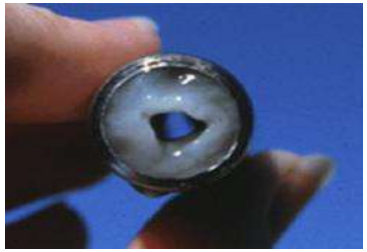


Mobilization of

- Biofilm
- Pathogens
- Sediment
- Contaminants

Biofilms are common in all pipes





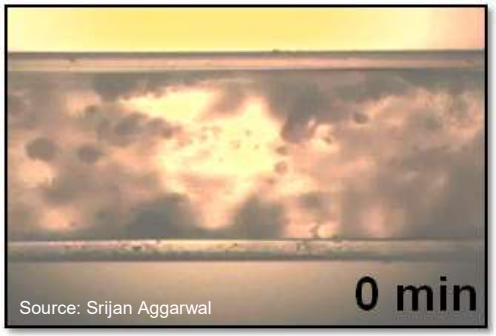
Source: The Biofilms Hypertextbook; http://biofilmbook.hypertextbookshop.com/public_version/contents/chapters/chapter001/section001/green/page001.html

Source: Dr. Joan Rose http://www.nature.com/nature/journal/v523/n7562/fig_tab/nature14660_SV1.html

Biofilm niche

- Water distribution systems
  - –Low disinfectant residual
  - –Warm to hot water temperature
  - –Proliferate inside protozoan symbionts
- Showers
- Water faucets
- Humidifiers
- Therapy pools
- Toilets
- Etc.

1) Slough & Detach
2) Aerosolize
   - Droplets & Particles
3) Inhalation



Source: Srijan Aggarwal

http://www.ufag-laboratorien.ch/en/food-analysis/legionella.html

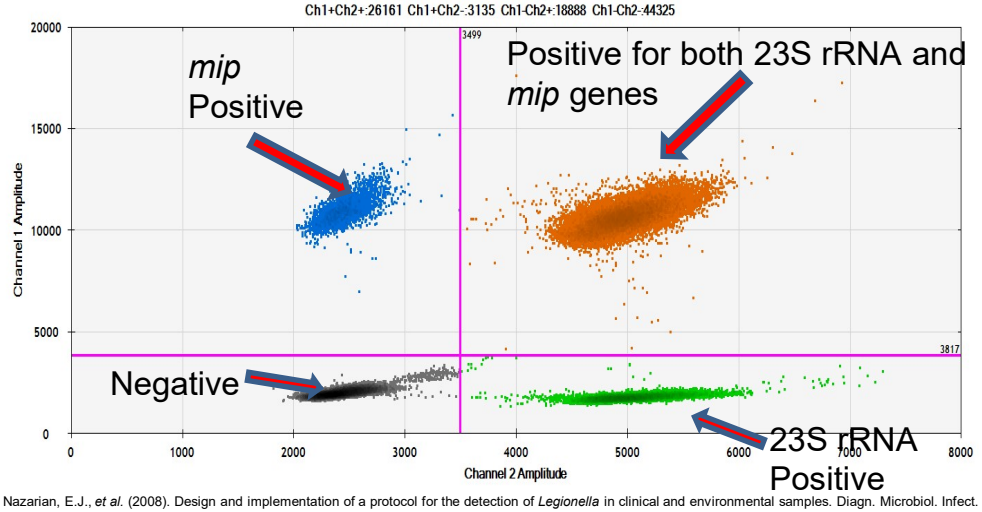
Source: Dr. Joan Rose http://www.nature.com/nature/journal/v523/n7562/fig_tab/nature14660_SV1.html

Monitoring

Exposure will be assessed through monitoring in multiple building types and susceptible areas

HPC, *Psuedomonas*, *Legionella spp* and *L. pnuemophila* and ameoba

- 23s rRNA gene for all *Legionella* spp.
- *mip* gene for *L. pneumophila*
- > 10,000 tests (droplets) per well

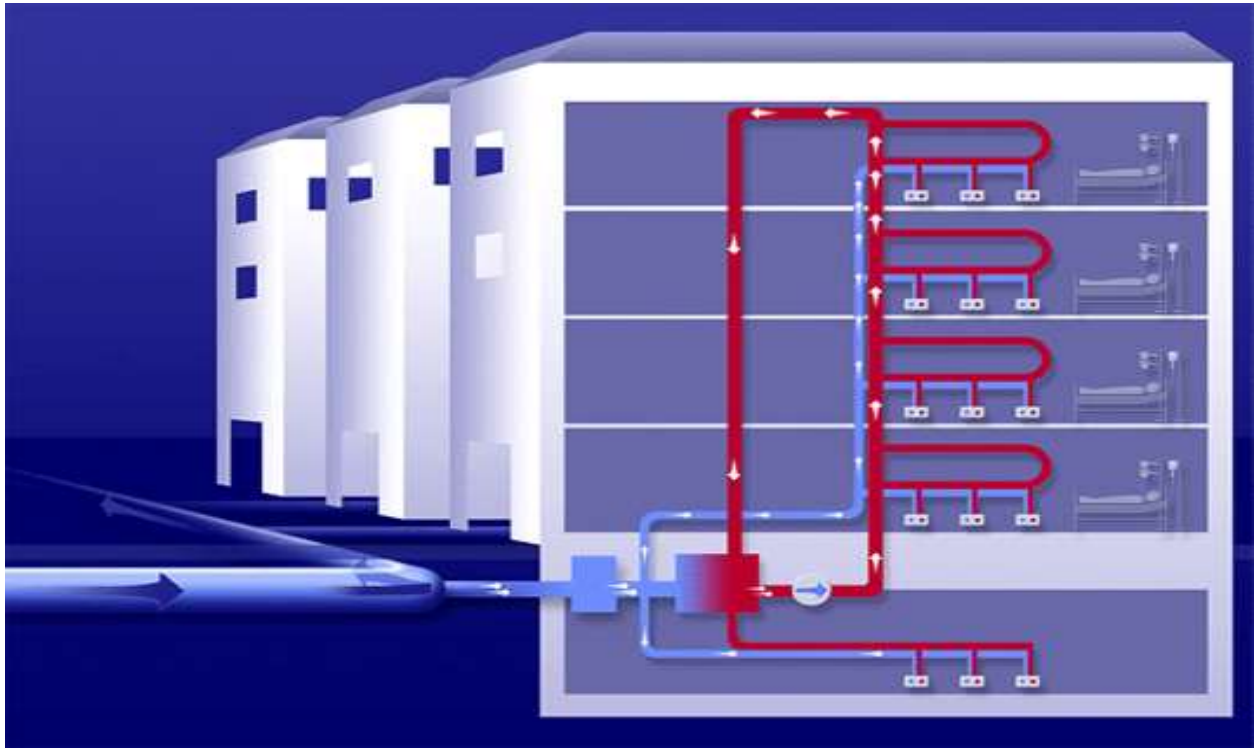


Nazarian, E.J., *et al.* (2008). Design and implementation of a protocol for the detection of *Legionella* in clinical and environmental samples. Diagn. Microbiol. Infect. Dis. 62:125-132.

ddPCR *Legionella* spp. & *L. pneumophila* duplex

Source: Dr. Joan Rose http://www.nature.com/nature/journal/v523/n7562/fig_tab/nature14660_SV1.html

Bacterial Numbers Increase
10 to 1,000 fold Inside Building Plumbing

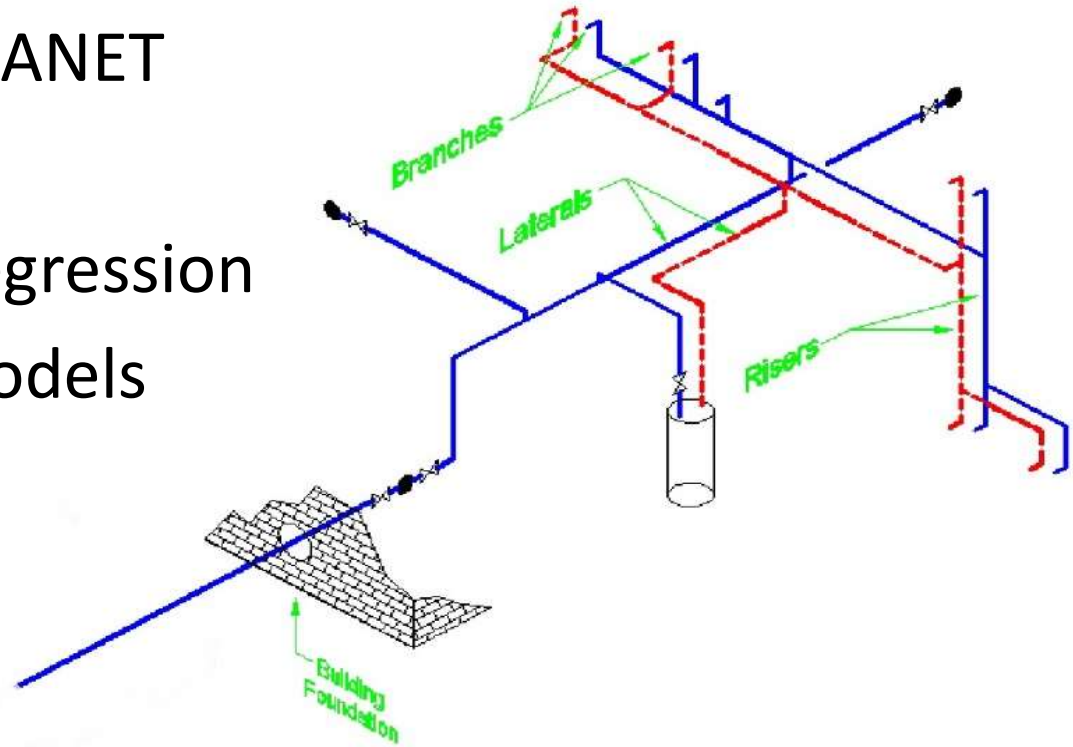


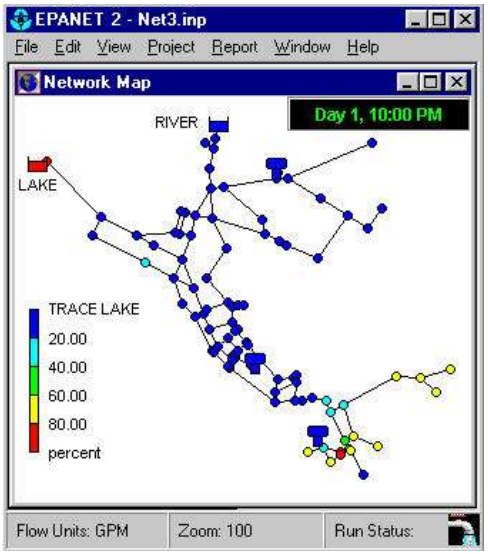
Source: Dr. Joan Rose http://www.nature.com/nature/journal/v523/n7562/fig_tab/nature14660_SV1.html

Modeling

EPANET

Regression models

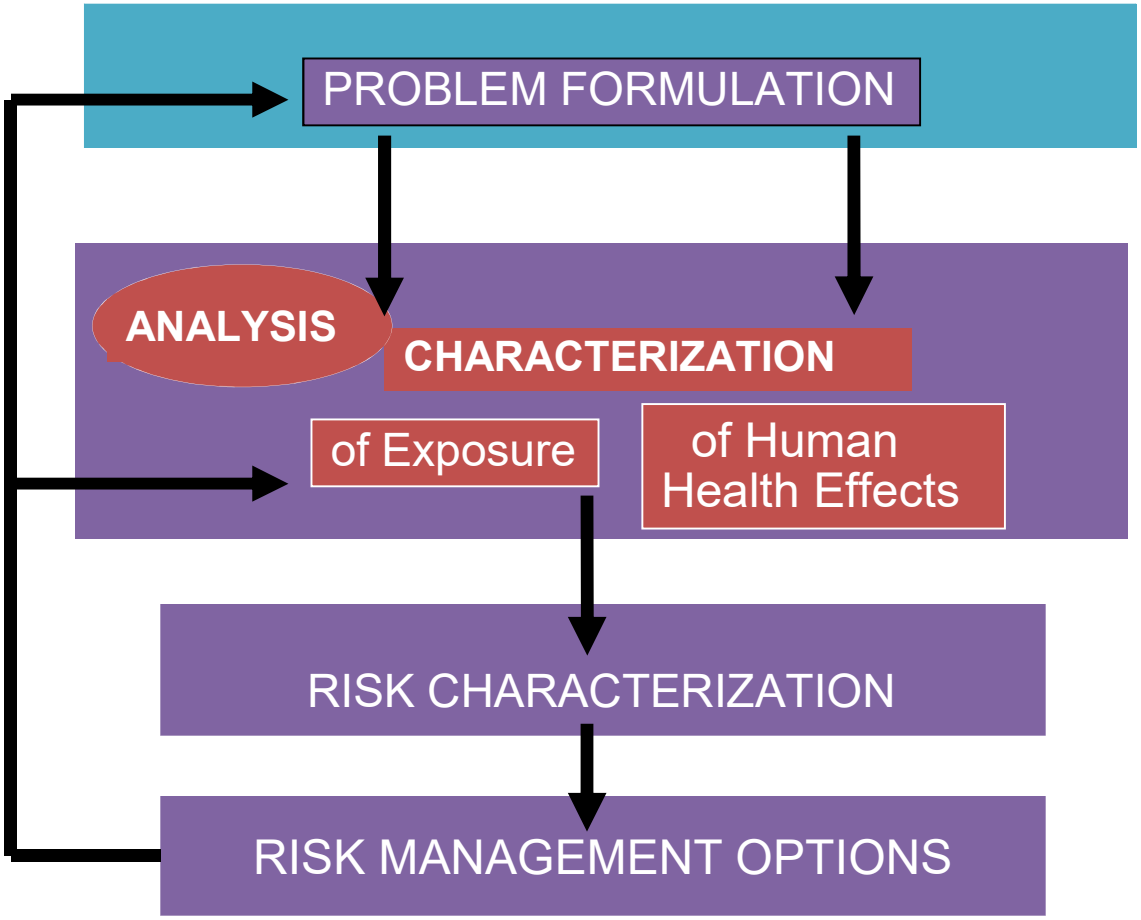




Objective 3

Objective 3a. Risk Model Development

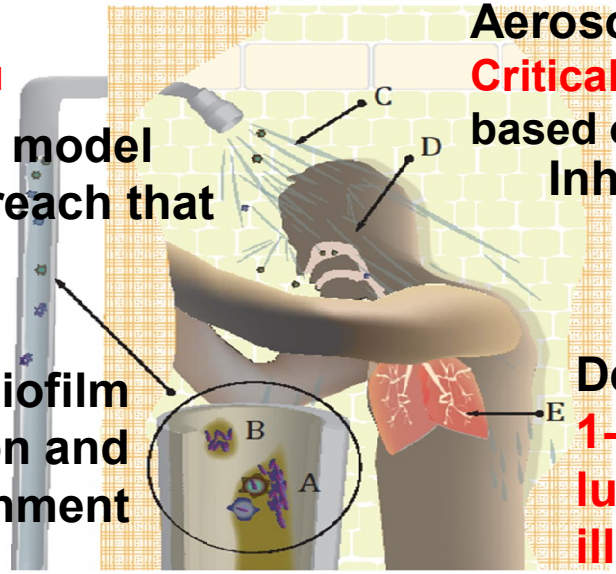
Objective 3b. Decision Support Tool Development



‘Reverse’ QMRA for critical *Legionella* densities – informed Dutch, German & ASHRAE

Critical # in DW
10^6 – 10^8 CFU L^{-1}
based on QMRA model
Needs hosts to reach that

Aerosolization
Critical # 35 – 3,500 CFU m^{-3}
based on QMRA model
Inhalation

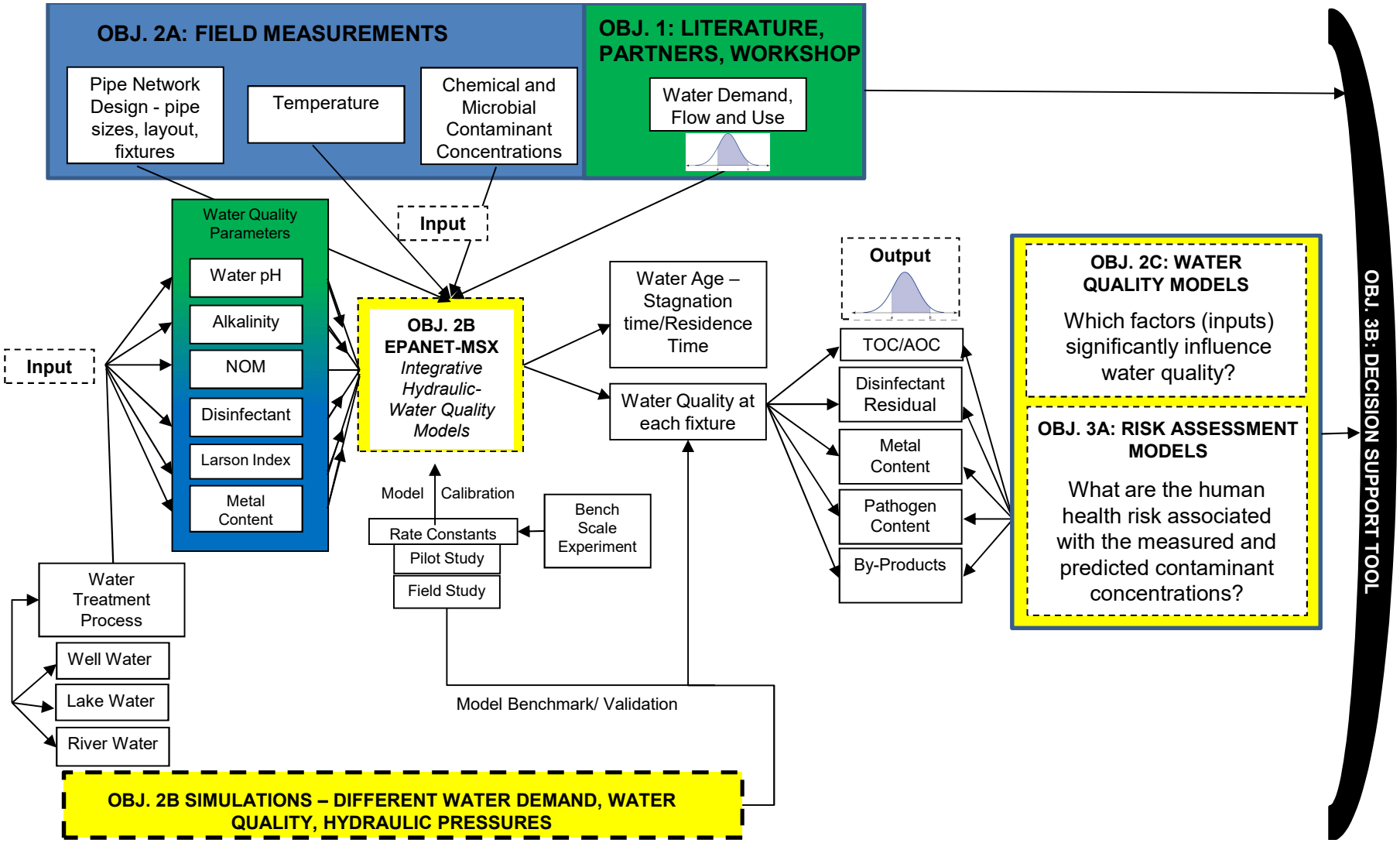


Biofilm colonization and detachment

Deposition
1-1,000 CFU in lung for potential illness

Schoen & Ashbolt (2011) Water Research 45(18): 5826-5836
American Soc Heating, Refrigerating & Air-Conditioning Eng

Source: Dr. Joan Rose http://www.nature.com/nature/journal/v523/n7562/fig_tab/nature14660_SV1.html


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

Schedule of Major Activities

Objectives and Activities		Year 1				Year 2				Year 3			
		Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	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.)													

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

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