

A microscopic image showing a cross-section of a pipe. The central part is a thick, blue, textured layer representing a biofilm. Above and below this layer are complex, branching, purple and green structures, likely representing microbial growth or root-like structures. The image is split vertically down the middle.

Pipe material and microbial growth in water

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My Background

- BSc – Civil Engineering, Virginia Tech
- MSc – Environmental Engineering, Virginia Tech
- PhD – Life sciences Microbiology, Eawag/ETH Zurich, CH

- MSc and PhD work – *Legionella* and ecology in plumbing

- Postdoc – Engineering – Purdue
- Assistant Professor – Agricultural and Biological Engineering & Environmental and Ecological Engineering – Purdue



A cute rubber duck



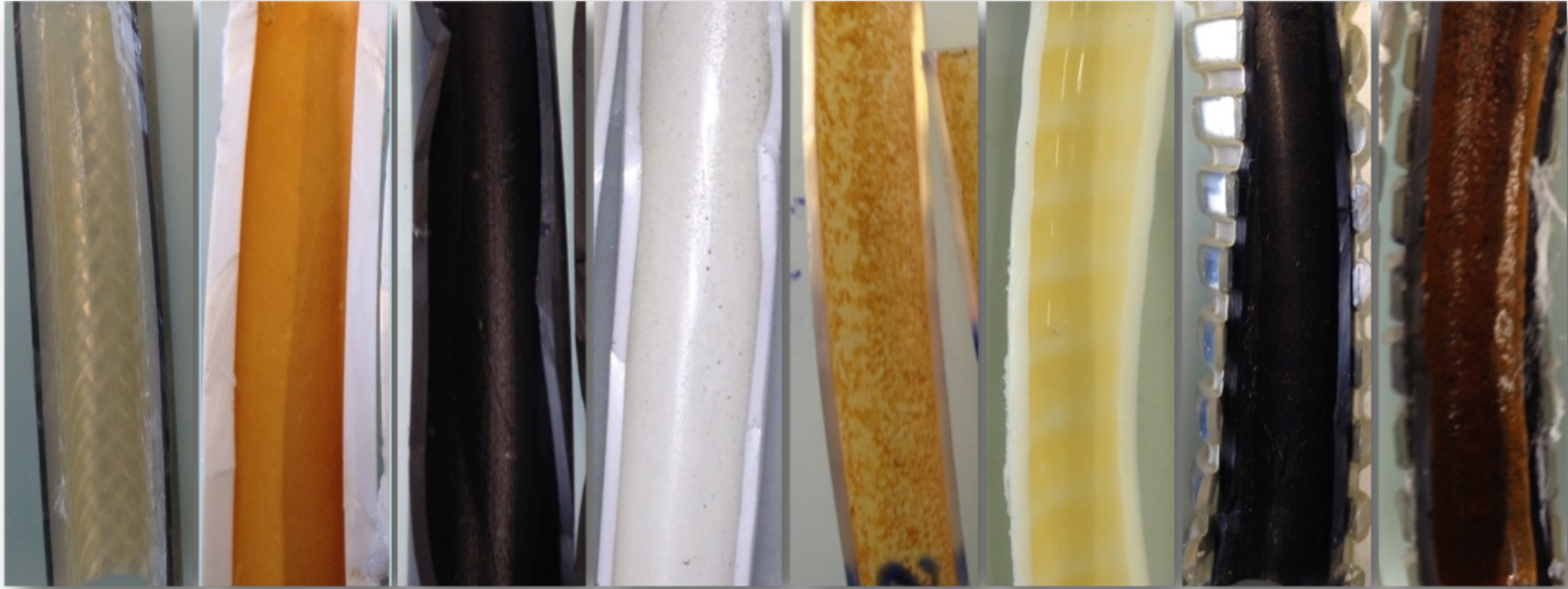
A (not-so) cute rubber duck



Shower hoses – suitable for bacterial growth

- Low or **no disinfectant** residual left
- Warm **temperature** [20 – 45 °C]
- Unknown, uncontrolled, questionable **materials** inside [silicone, PVC-P, PEX, rubber, etc.]
- Long **stagnation** [23.5 hours]





Biofilms are inevitable. But are they a problem?

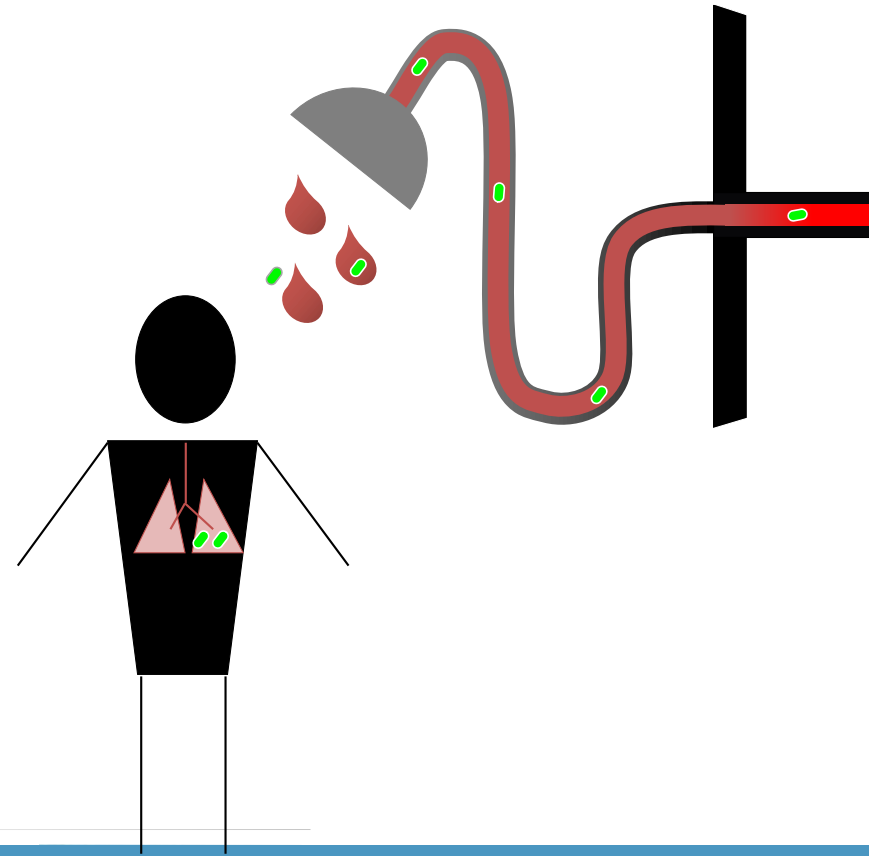
Biofouling

Home to pathogens

Biofilm → water (→ aerosols → lungs)

Difficult to remove

> Shapes system microbiome



Legionella gets a lot of attention...

Latest Legionnaires' Outbreak in the Bronx Kills 1 and Sickens 18

Health officials urged Bronx residents with flulike symptoms to seek medical care after Legionella bacteria were found in cooling towers there.

ABC11

2 cases of Legionnaires' disease may be linked to Wake Forest hotel

Legionnaires' disease is a type of pneumonia caused by a type of bacteria called Legionella that are found usually in water. Wake County Public...

2 weeks ago

South End-Wayne State

Air conditioning shut off at Student Center, legionella found

"We recently discovered elevated levels of what is presumptively legionella in the Student Center building," according to...

Metro

Legionella: Bacteria discovered in Parliament

Legionella bacteria is naturally present in water systems and it can cause disease, which is fatal in 10% of cases.

6 days ago

ILLINOIS ADVOCATES CALL FOR ACTION AFTER PRISON OFFICIALS MISLEAD ON CONTAMINATED WATER



... but there are many problematic organisms

- These cost the US economy **\$2.39 billion annually**, with new ones continuously being discovered

Organism	Infection incidence (/yr)	Direct Healthcare cost (\$)	Deaths (/year)	Reportable
<i>L. pneumophila</i>	8000-50,000	402 million	995	Yes - CDC
Nontuberculous mycobacteria (NTM)	86,244	1.53 billion	3800	In certain states
<i>P. aeruginosa</i> (pneumonia disease)		453 million	730	In certain states if antibiotic resistant

Other DWPI: Other Legionella species (e.g., *L. longbeachae*, *micdadei*, *bozemanii*, *L. dumoffi*) ; Burkholderia cepacian complex ; Achromobacter; Stenotrophomonas maltophilia, Acinetobacter baumannii, Sphingomonas paucimobili, Aeromonas hydrophila , Hartmanella (Vermamoeba), Acanthamoeba – , Naegleria fowleri , Balamuthia mandrillaris

Each organism is different

Antibiotic resistance

- Different antibiotics used
- NTM has higher resistance

Disinfectant survival

- C*T – difficult to compare
- Need – measure all 3 (and more) in same experiments

DWPI	Disinfectant	
	Chloramine	Free chlorine
L. pneumophila	effective	resists
NTM	resists	resists
P. aeruginosa	effective	resists



e.g., Pryor et al. 2004



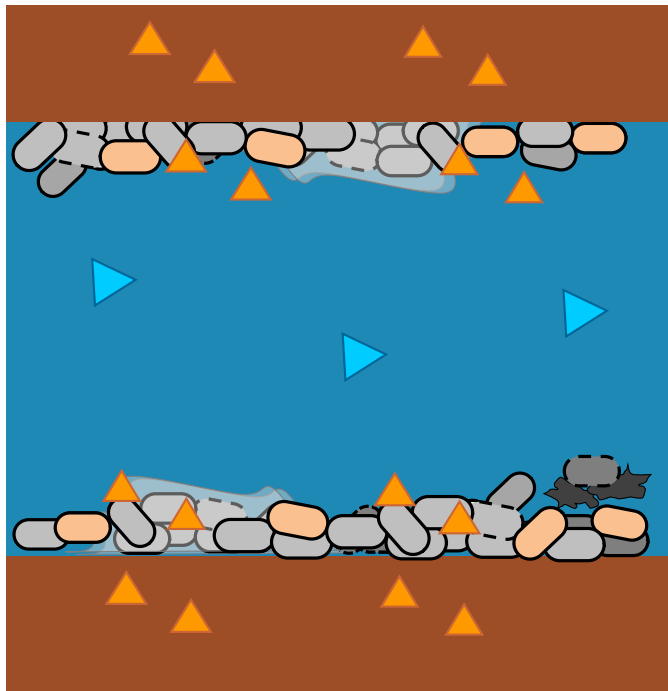
**Choice of pipe material → shapes system
microbiome**

Material – food for bacteria

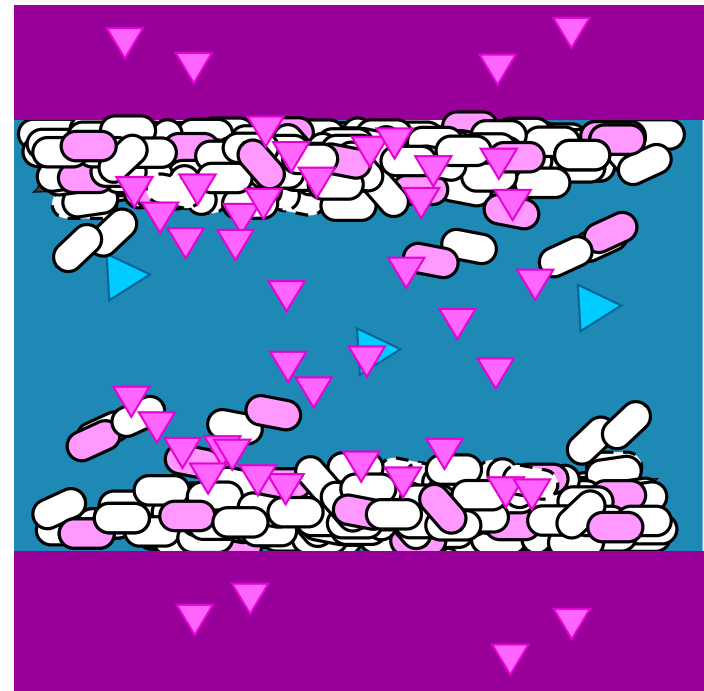


Material – food for bacteria (selection)

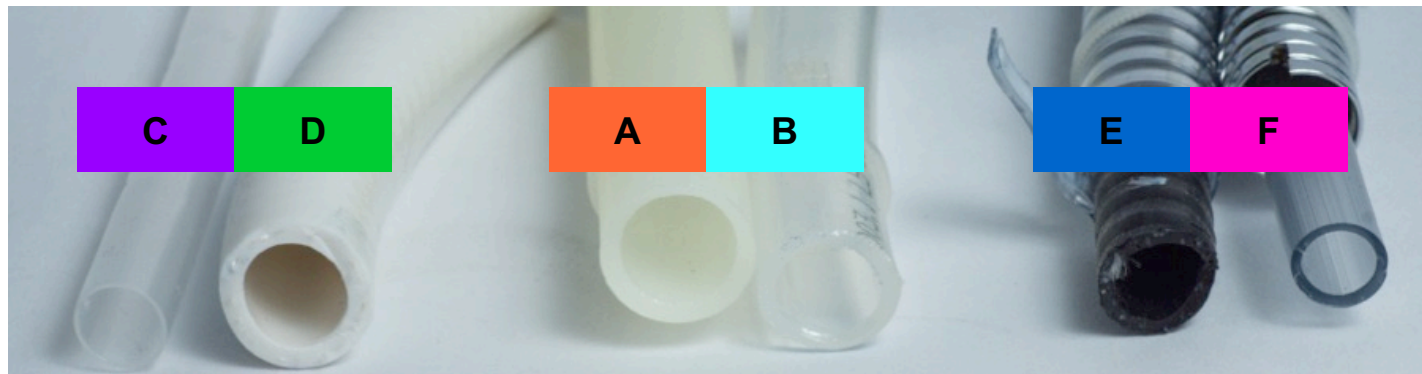
Plastic Pipe #1



Plastic Pipe #2



Material shapes the shower hose microbiome



A – PE-Xc, hard plastic - control

B – PE-X*, drinking water hose

C – silicone

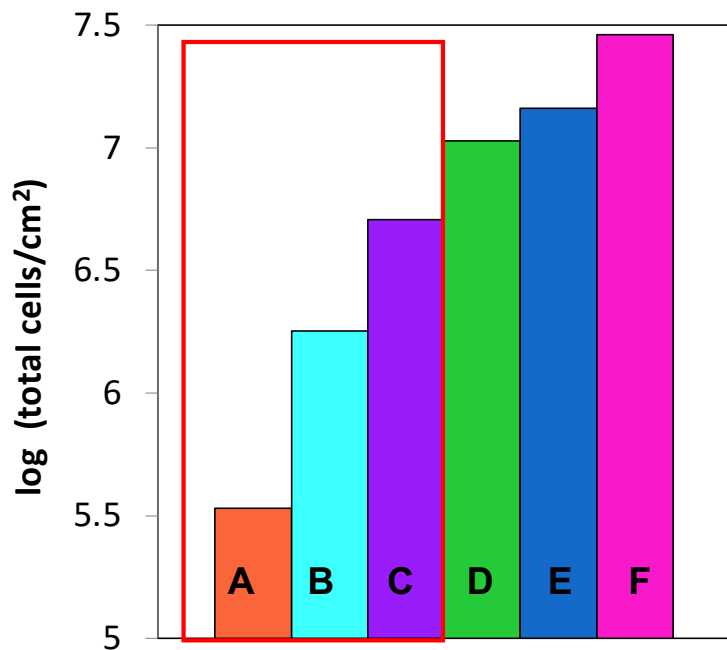
D – Unknown, antibiotic coating

E – PVC-P, with ash, expensive

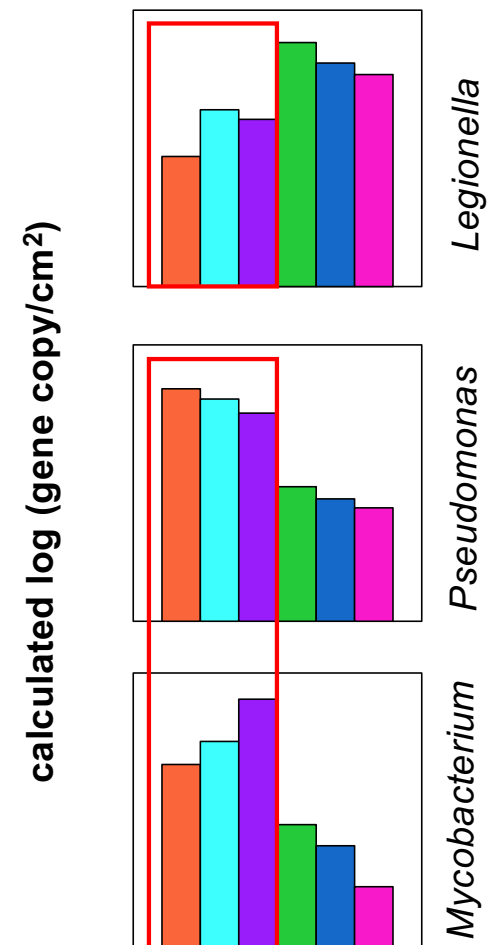
F – PVC-P, cheap



Material shapes the shower hose microbiome



$$\begin{array}{l}
 \text{Absolute Abundance} \\
 \text{gc/cm}^2 \\
 \text{(16S rRNA gene copies)} \\
 \\
 \times \\
 \\
 \text{Relative Abundance} \\
 \% \\
 \text{(16S amplicon sequencing)} \\
 \\
 = \\
 \\
 \text{Calculated Abundance} \\
 \text{(gene copy/cm}^2\text{)}
 \end{array}$$



Trade-offs between DWPI – holistic approach needed



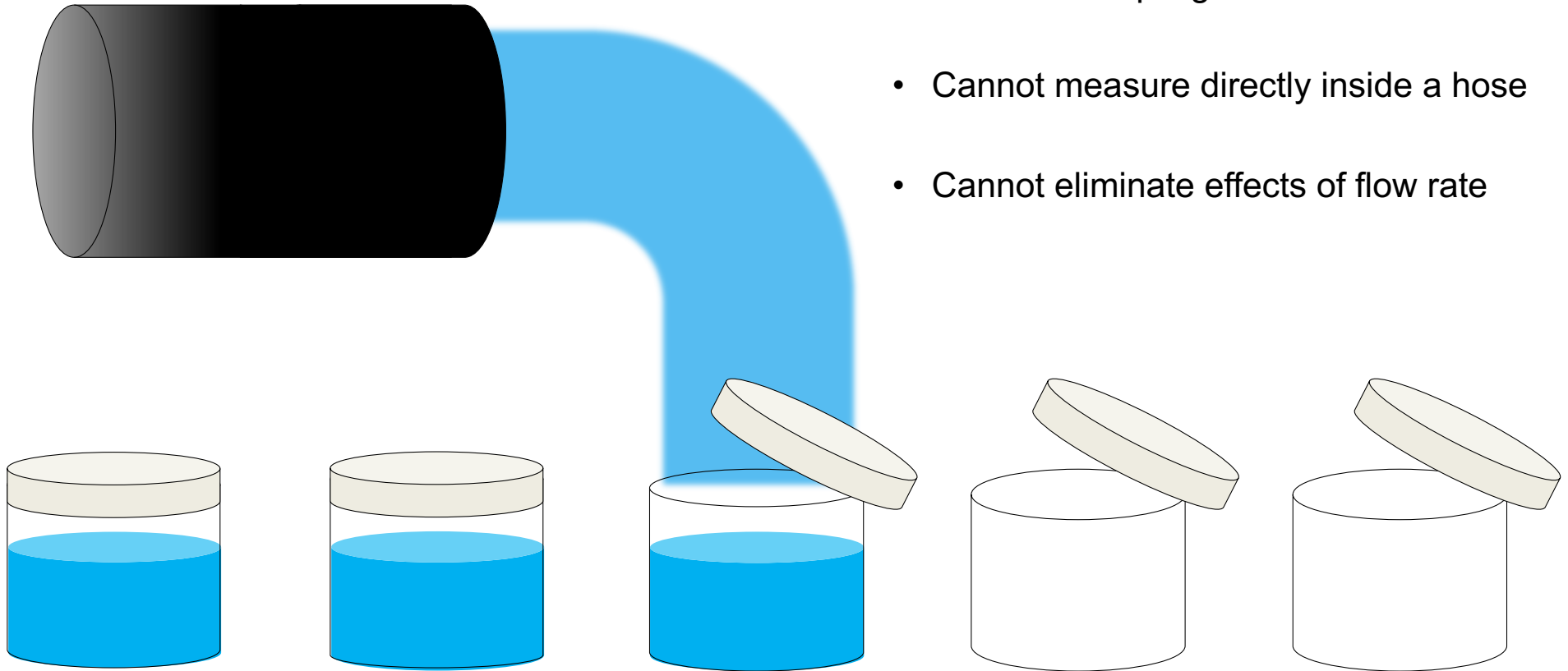


Stagnation

Water sitting still in pipes

Measuring bacterial shifts in pipes

- Discrete sampling
- Cannot measure directly inside a hose
- Cannot eliminate effects of flow rate



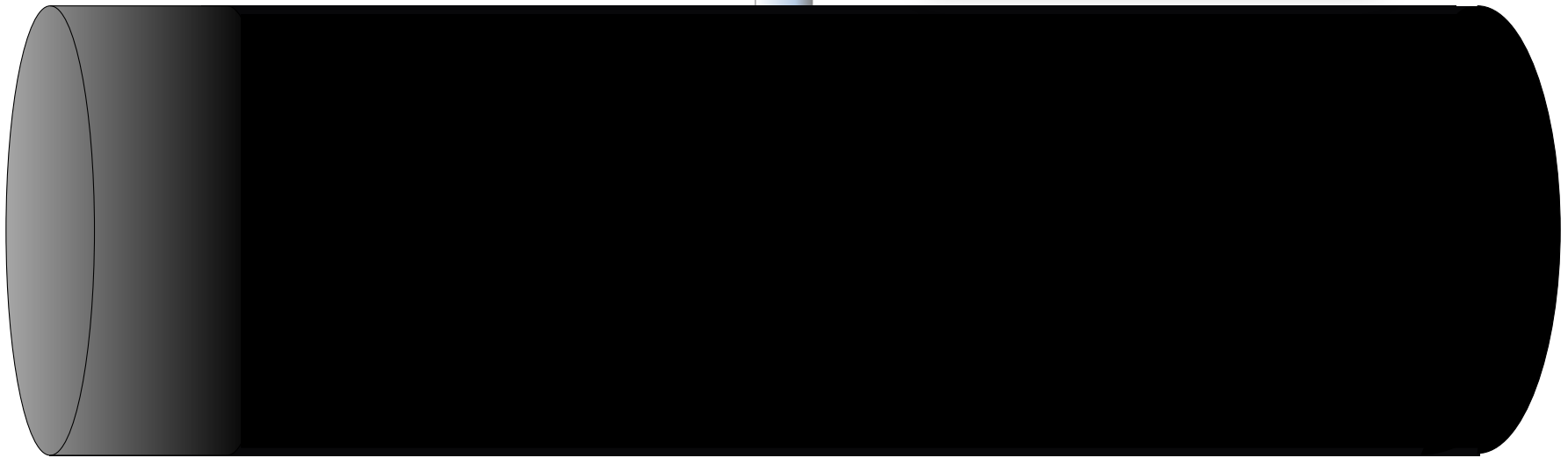
Measuring bacterial shifts in pipes

- Continuous sampling
- Measurement directly inside the shower hose
- Measure during flow and stagnation

- Discrete sampling
- Cannot measure directly inside the shower hose
- Cannot eliminate effects of flow rate

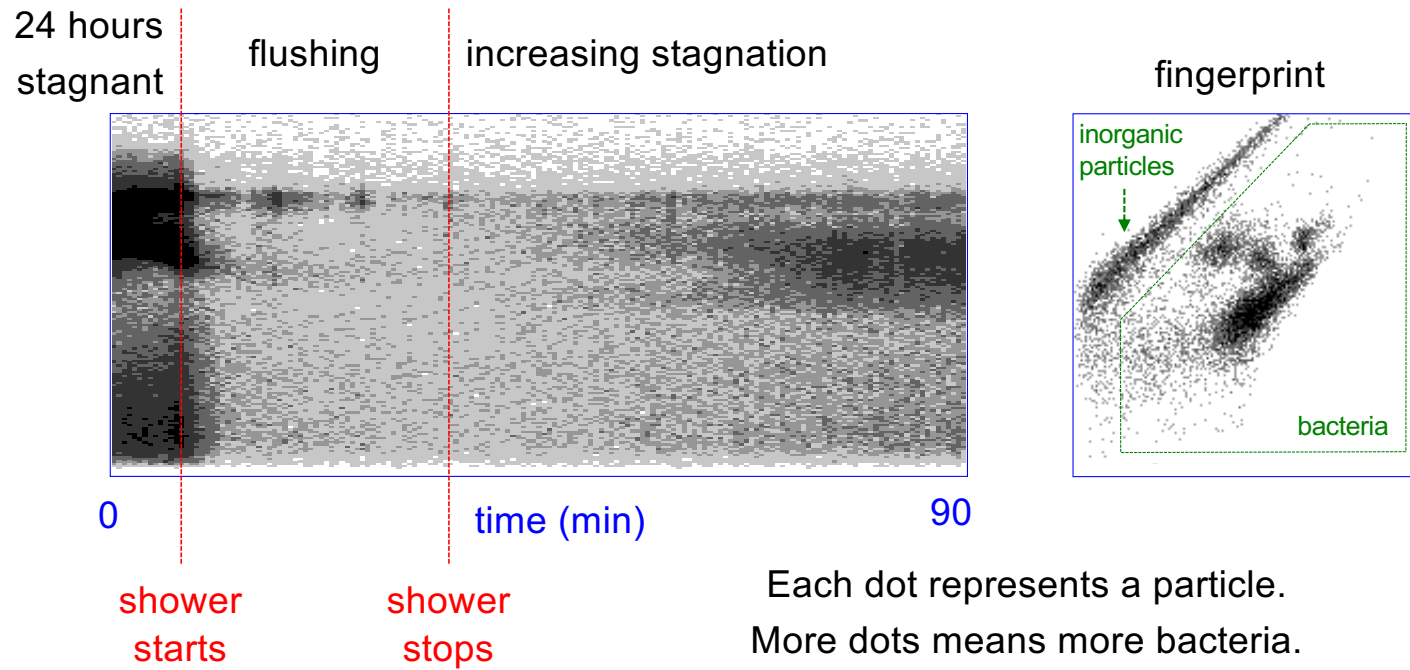


**Flow cytometer
Real-time FCM
attachment**



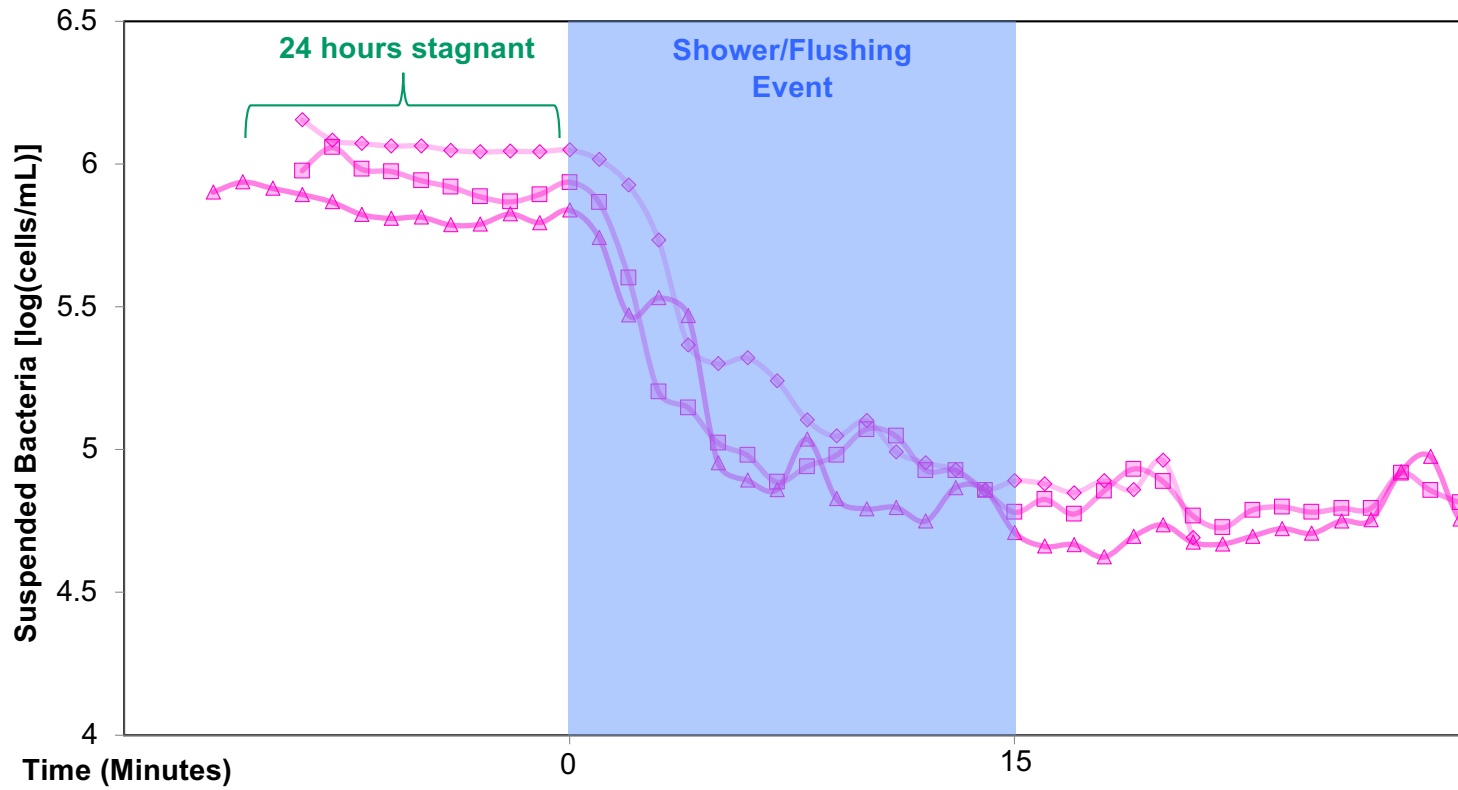
Measuring bacterial shifts in pipes

Continuous in-situ measurement during flow and stagnation



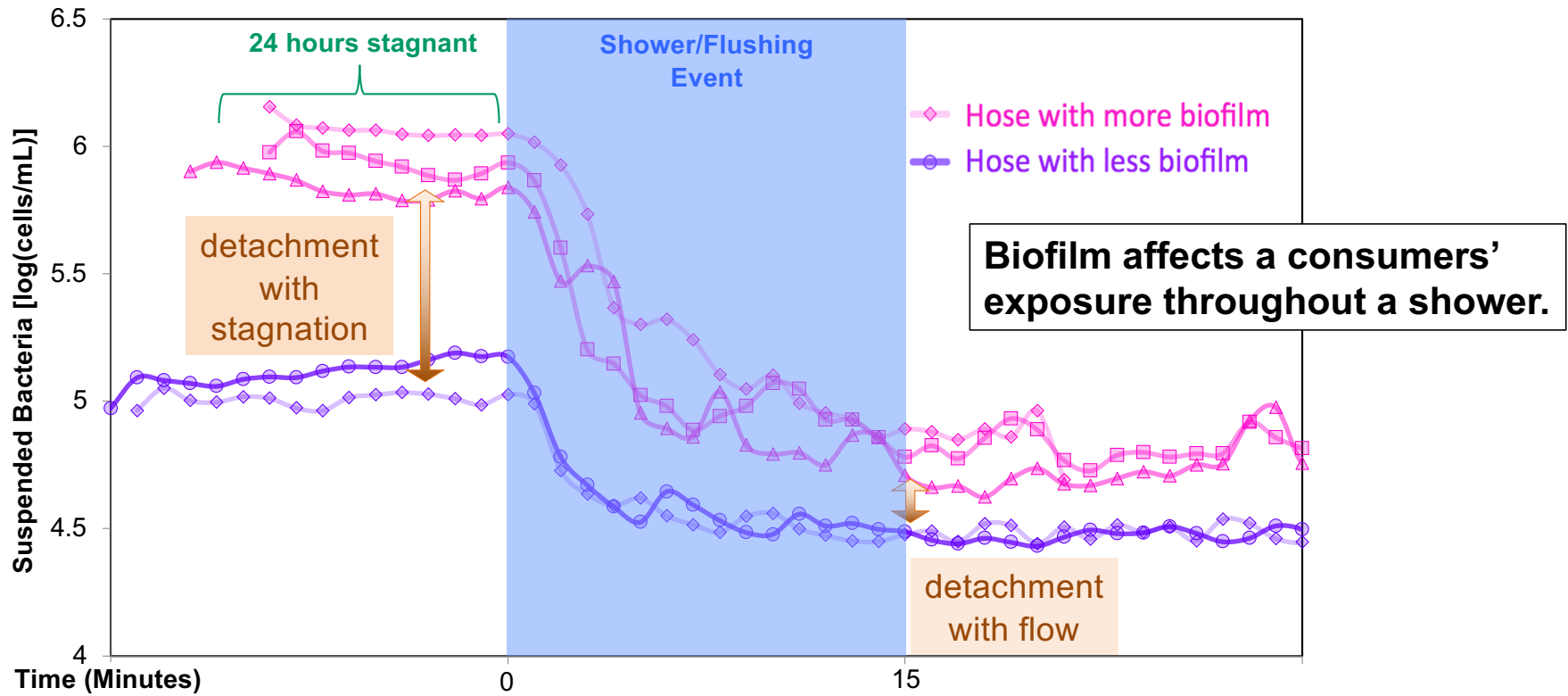
Measuring bacterial shifts in pipes

Continuous in-situ measurement during flow and stagnation



Measuring bacterial shifts in pipes

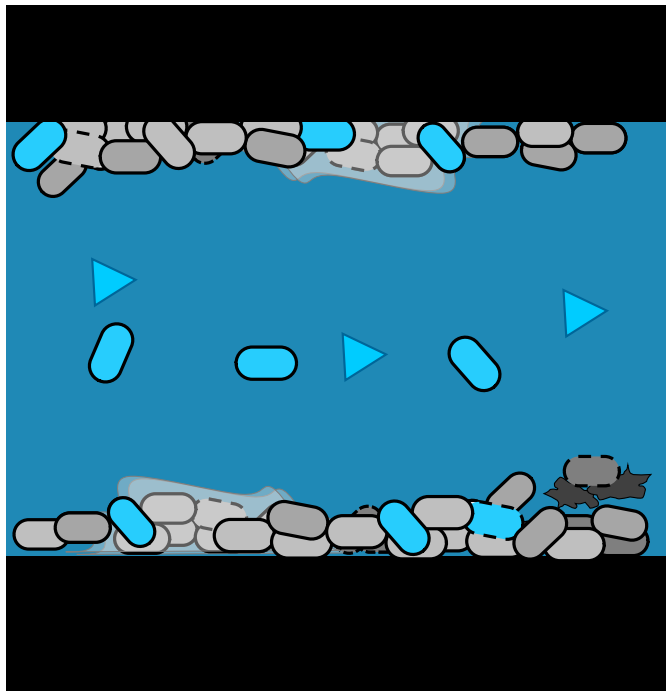
Continuous in-situ measurement during flow and stagnation



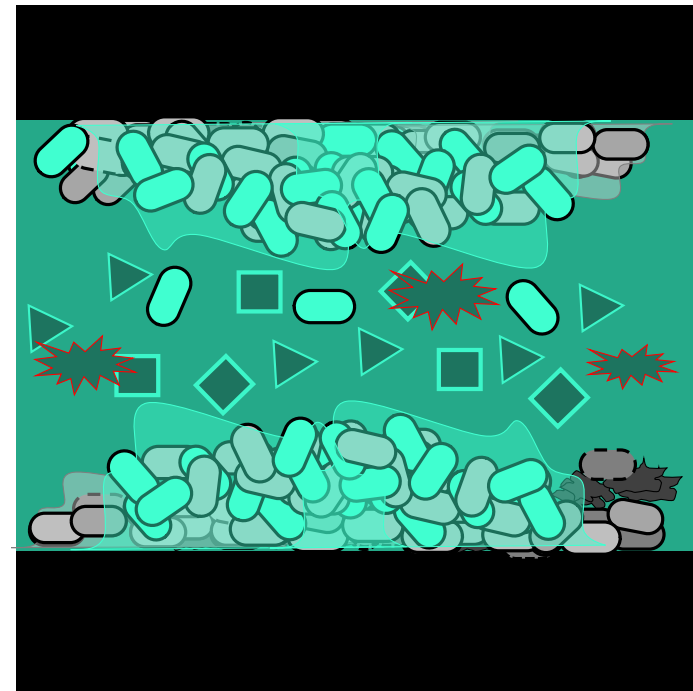
FLUSHING - Periodically introduce bacteria

Frequency controls levels of stress, nutrients

Water #1



Water # 2



Controlled plumbing systems

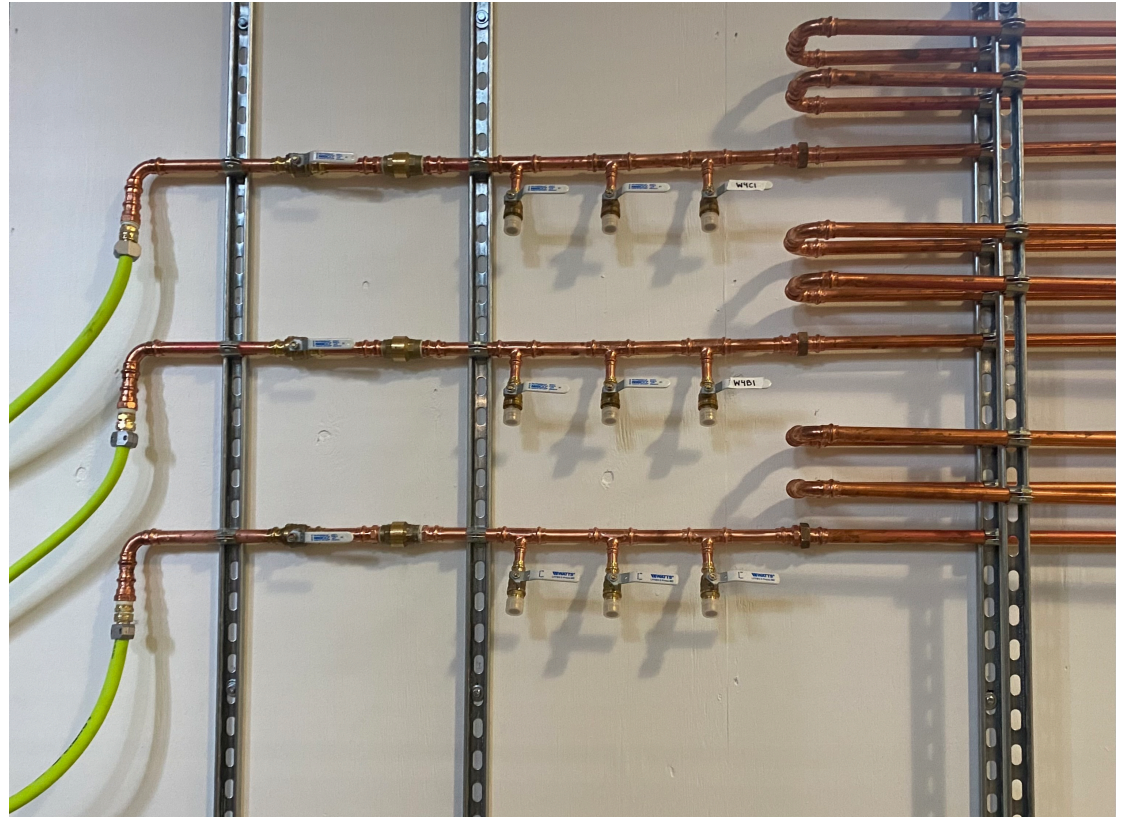


- 4 identical plumbing systems
- Each system has:
 - Water softener
 - Water heater – used as a storage tank
 - Triplicate 50' loops of copper pipe

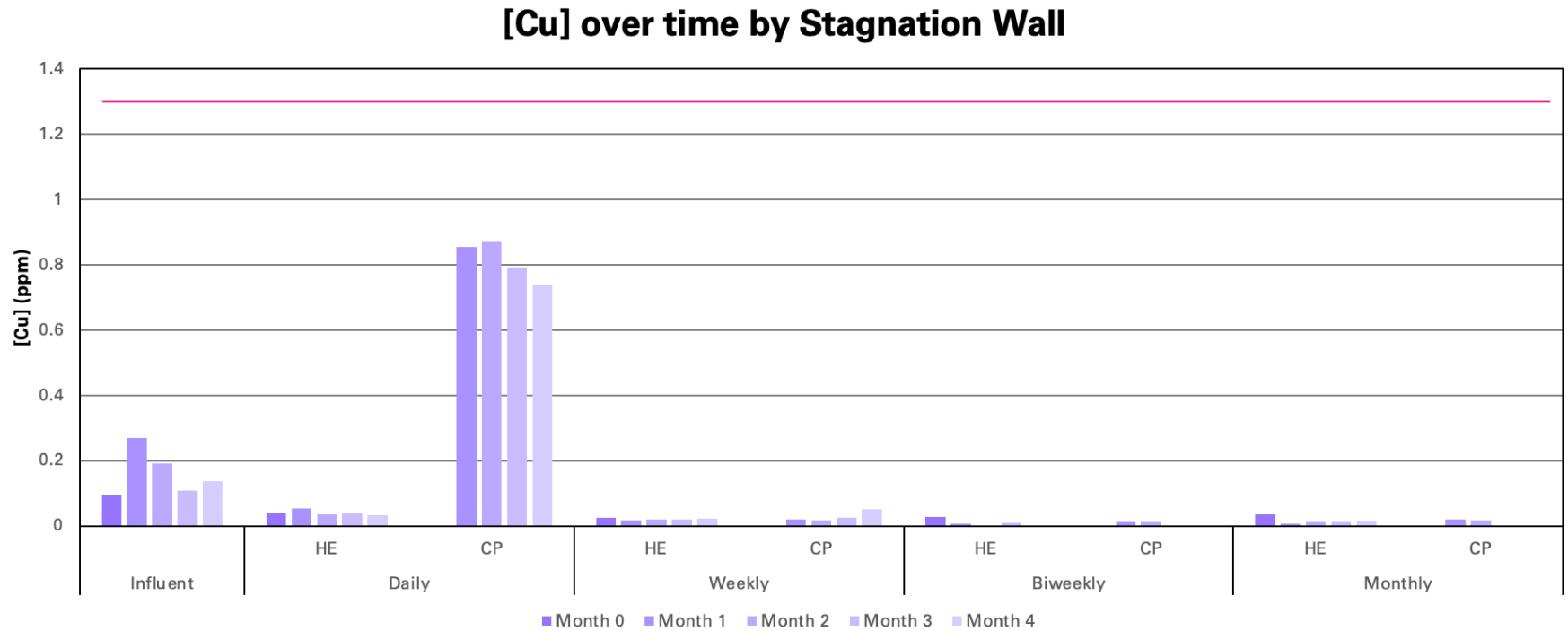


Intermittent flow

- 10 minute flush per line
- Daily
- Weekly
- Extended
 - Biweekly
 - Monthly



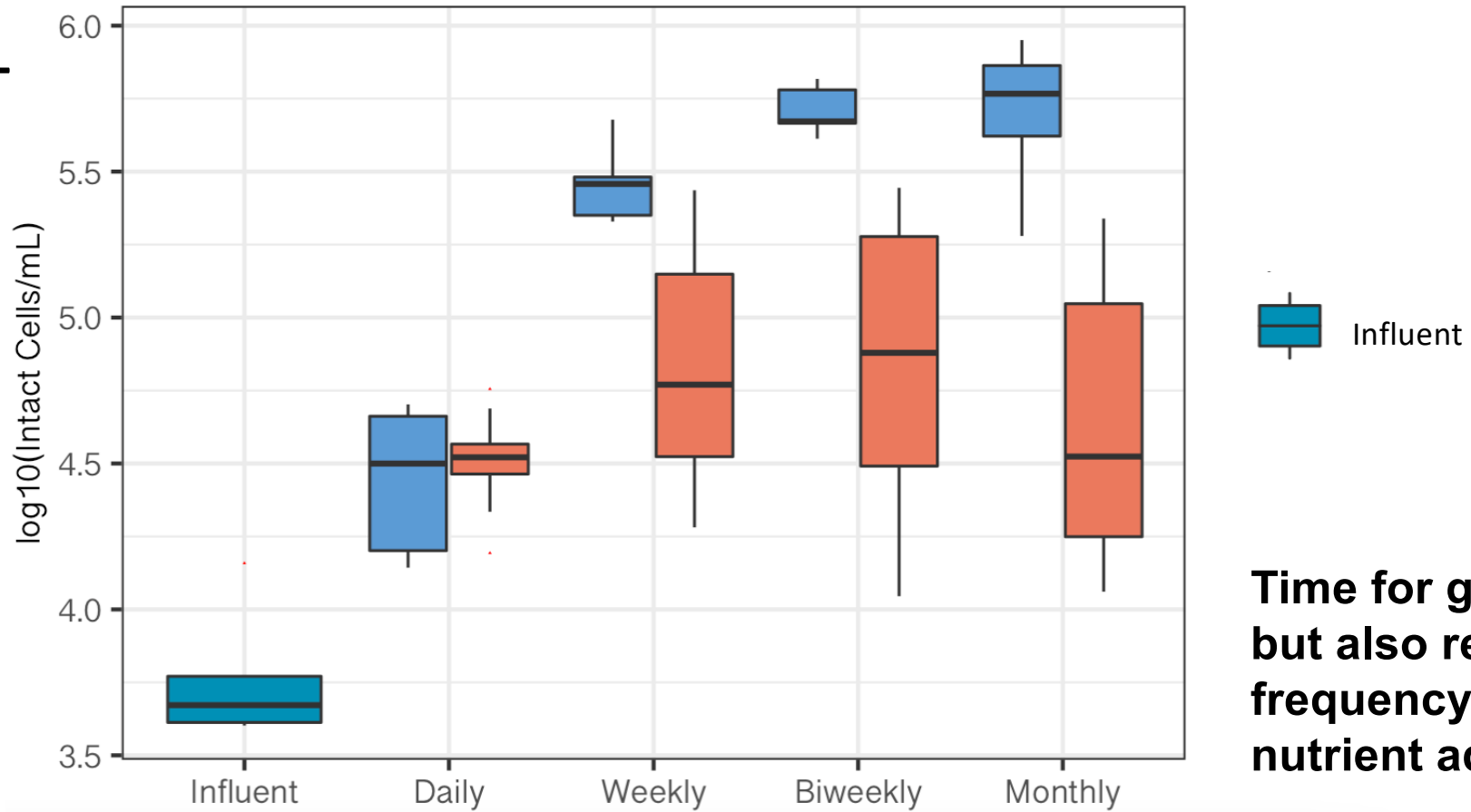
COPPER



Highest in “daily” flush wall, in copper pipes -- potential scale build-up with stagnation?



TOTAL CELLS



**Time for growth,
but also reduced
frequency of
nutrient addition**



Legionella pneumophila occurrence in reduced-occupancy buildings in 11 cities during the COVID-19 pandemic

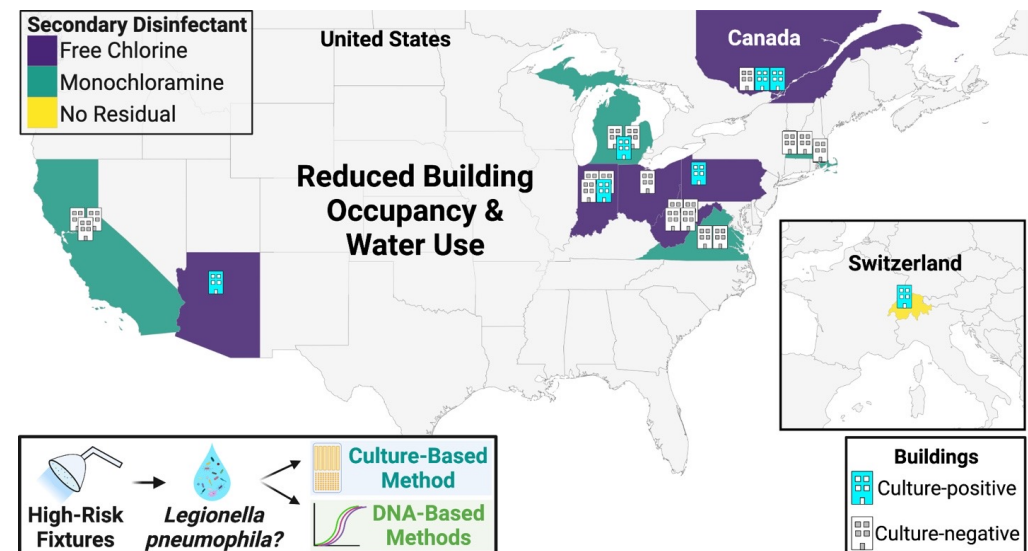
Katherine S. Dowdell^{1,}** and **Hannah D. Greenwald^{2,**}**, Sayalee Joshi^{3,4}, Marianne Grimard-Conea⁵, Sarah Pitell⁶, Yang Song⁷, Christian Ley^{8,13}, Lauren C. Kennedy^{2,9}, Solize Vosloo¹⁶, Linxuan Huo¹⁰, Sarah-Jane Haig^{6,11}, Kerry A. Hamilton^{3,4}, Kara L. Nelson², Ameet Pinto¹⁰, Michele Prévost⁵, Caitlin R. Proctor^{12,13}, Lutgarde M. Raskin¹, Andrew J. Whelton^{13,14}, Emily Garner^{15*}, Kelsey J. Pieper^{16,*}, and William J. Rhoads^{17*}



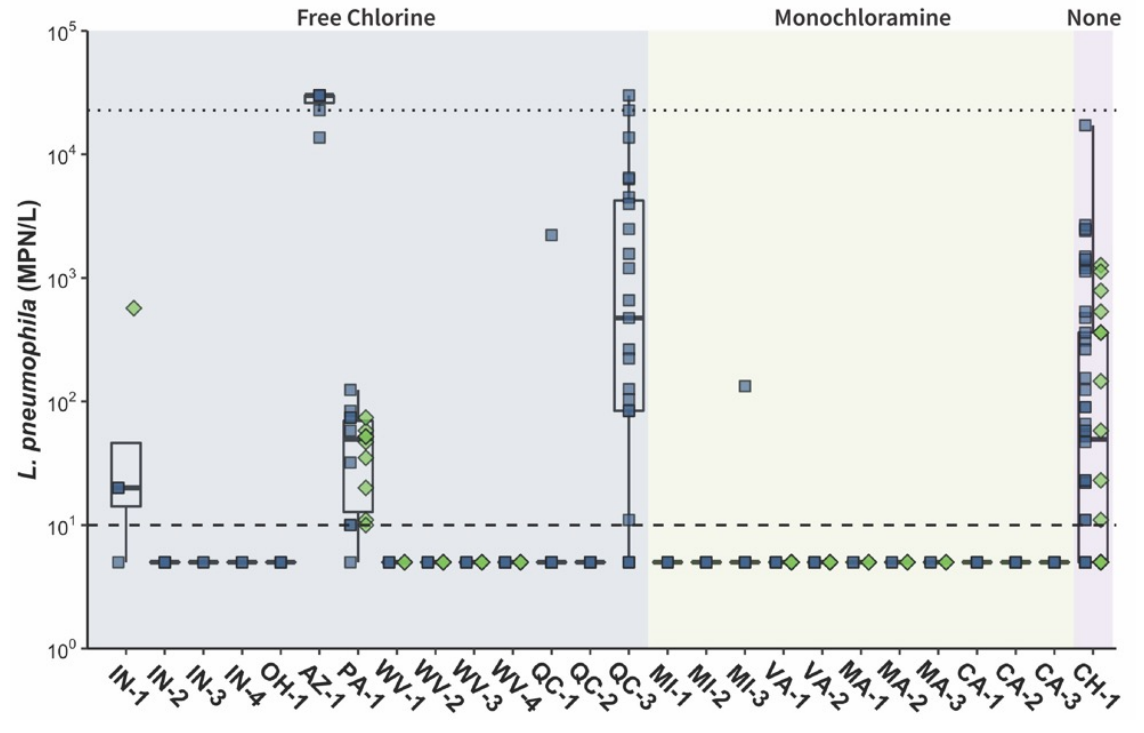
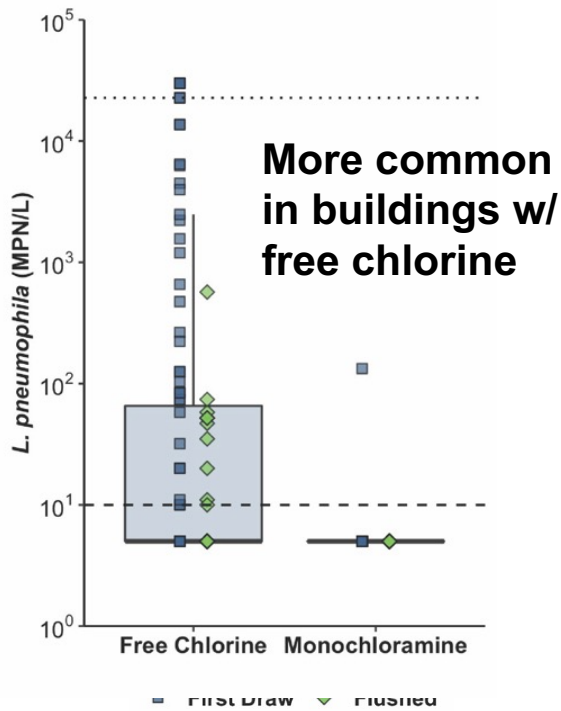
Katherine Dowdell



Hannah Greenwald



Culturable *Legionella pneumophila* across 11 cities



Still an issue in individual buildings

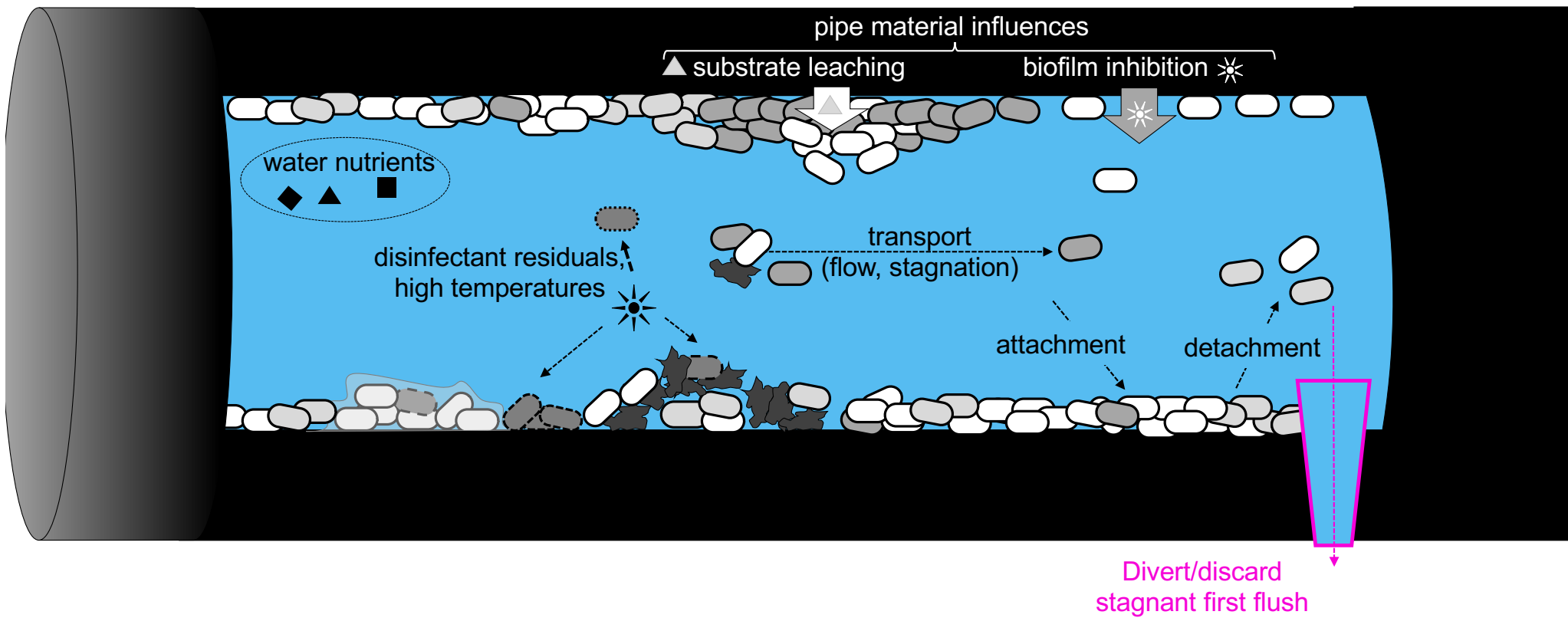




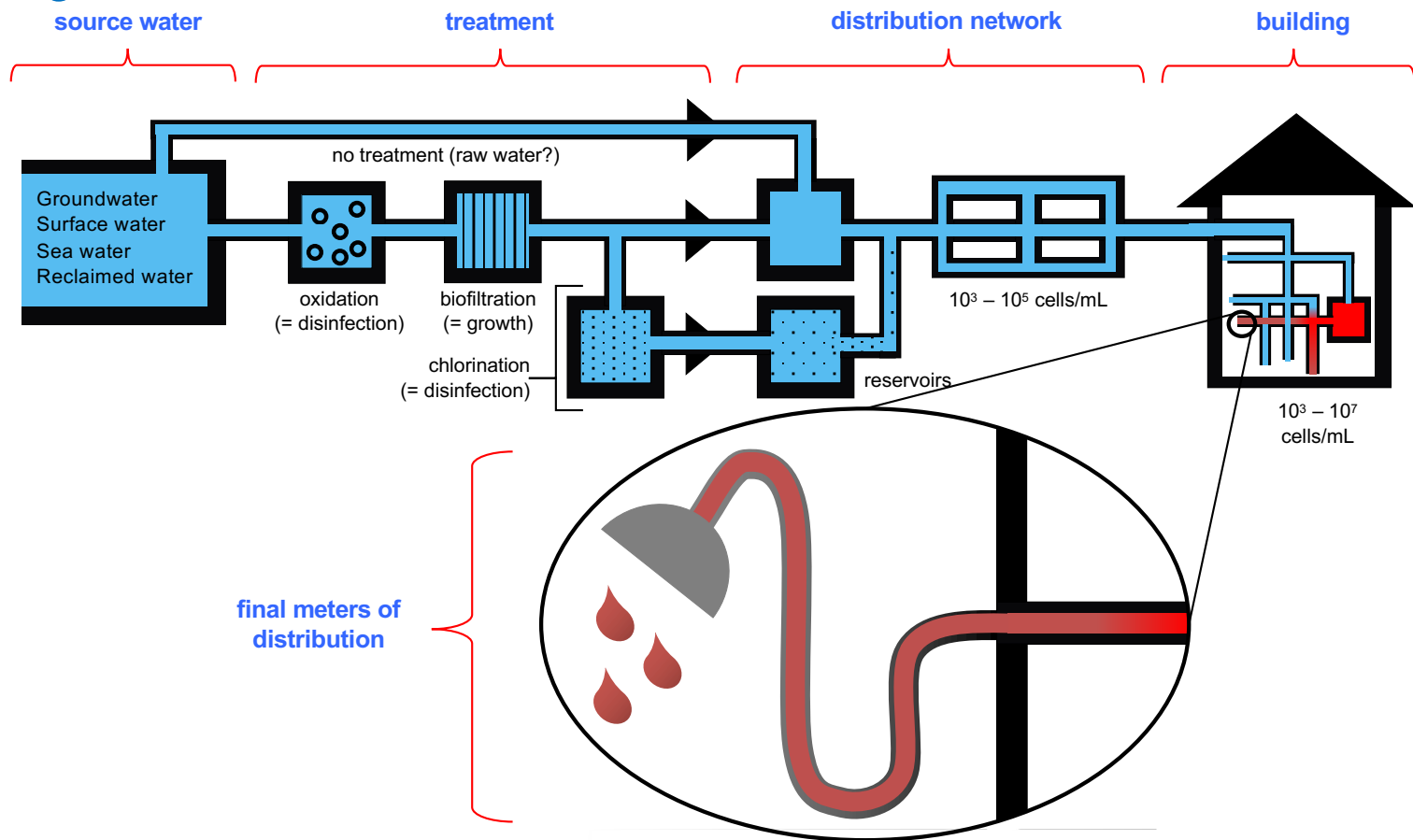
Controlling biofilms

Using selection, dispersal,
and bacteria movement

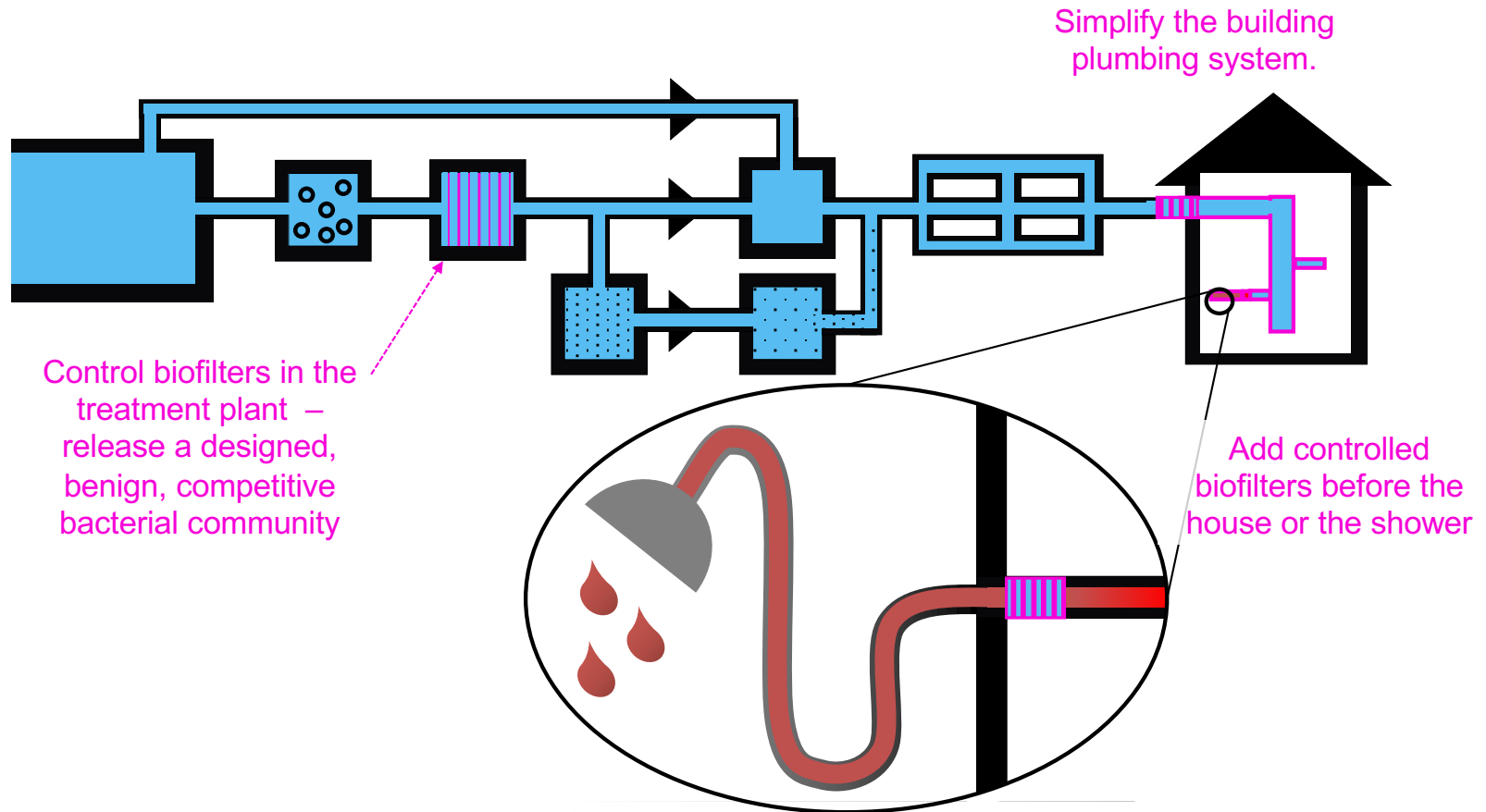
Controlling biofilm



Controlling biofilm



Controlling biofilm





Safer biofilms

Current control mechanisms
fail

Creativity needed

Acknowledgements

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- Aliya Ehde
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- Kyungyeon Ra
- Danielle Angert

Many other collaborators!



Sampling on a deserted campus (2020)



Part of the Proctor group, spring 2022



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Thanks for your time.

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