

# Engineering Water Infrastructure Microbiomes: Past, Present, Future

**Prof. Kara Nelson**

Civil and Environmental Engineering, UC Berkeley

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# Acknowledgements

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- Banfield/IGI computing cluster
  
- NSF-CBET
- NSF Engineering Research Center: Reinventing the Nation's Urban Water Infrastructure
- Anonymous city in Southern California



# The Past

# A Long Time Ago: Pristine Water Supply



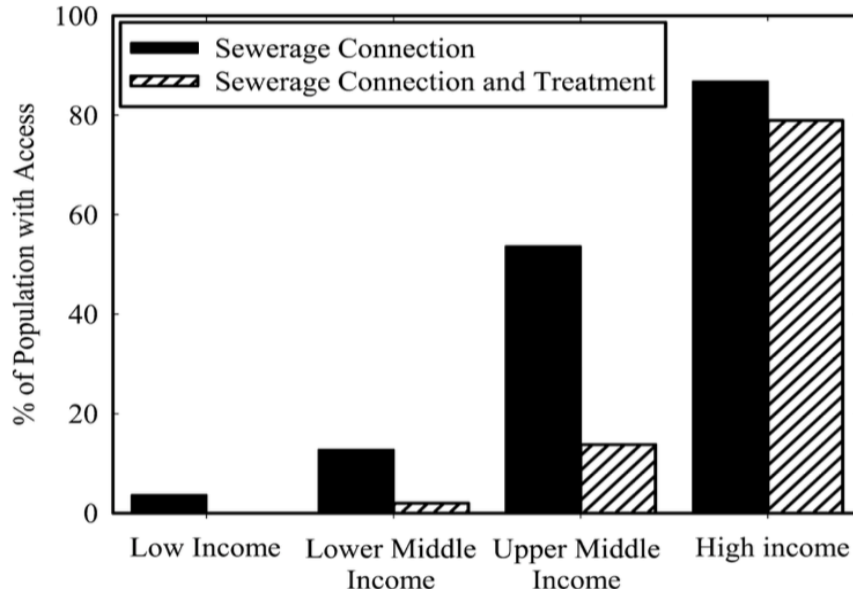
Fresh mountain spring water, Clear Lake, Oregon

# 1800s: Massive Cholera Epidemics



"E.W. aged forty-three, born in Ireland, laborer, resided in Stanton-street; has had diarrhea for four days, attacked with cramps, vomiting, and purging, about noon; and was admitted in the stage of collapse, at six o'clock, P.M. on 24th July. He was rubbed with camphorated mercurial ointment, and given hot toddy to drink -- little improved. Seven o' clock, P.M. was under hospital treatment, until 15th, and died at half-past one, A.M. being ill only seven hours and a half."

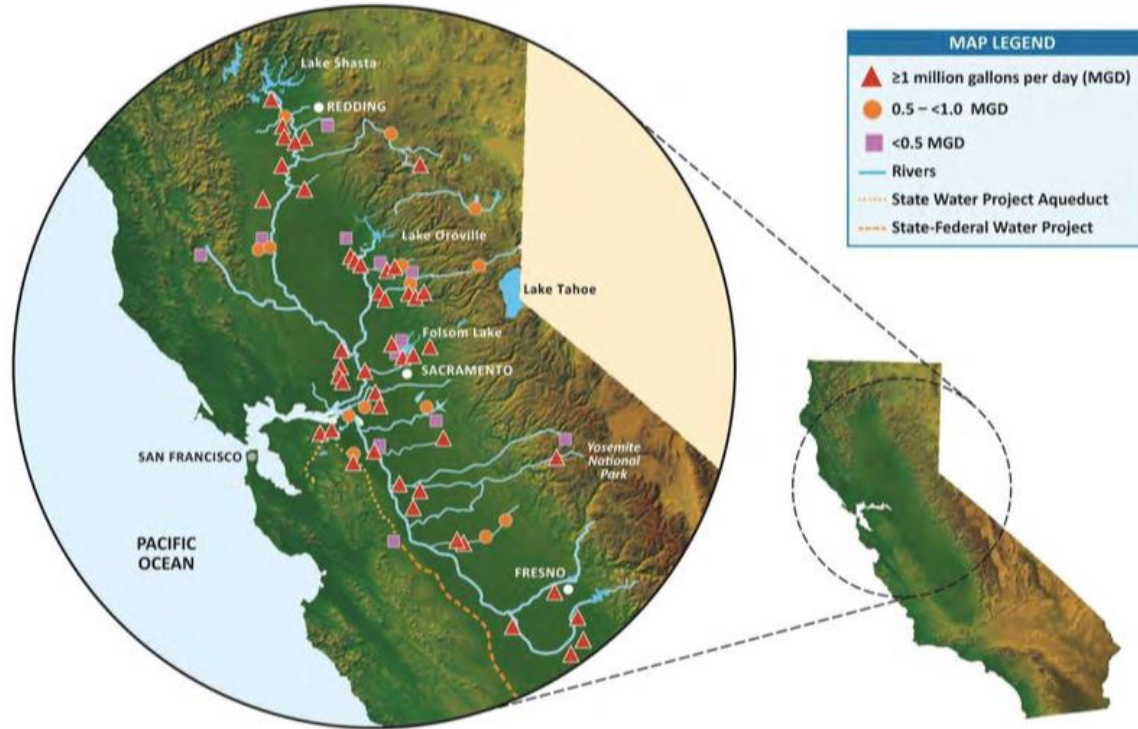
# Global Disparities



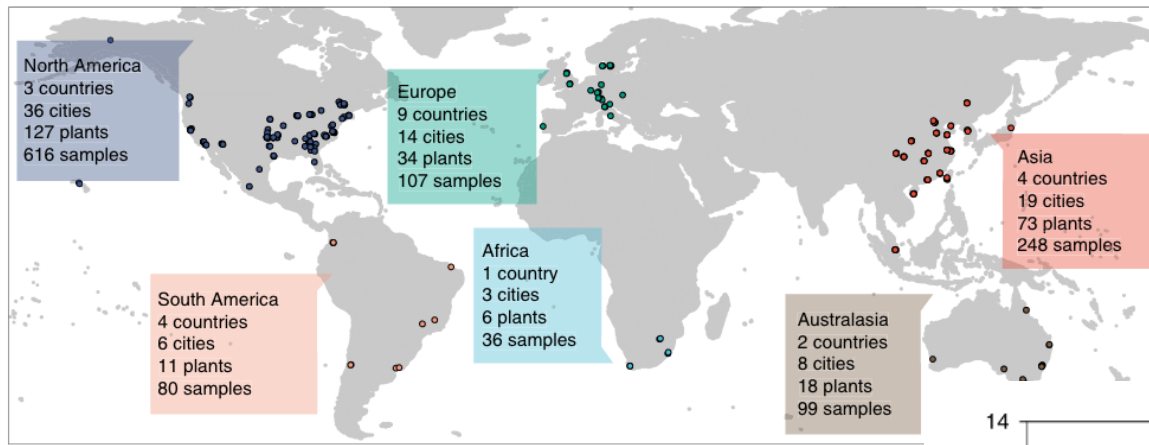
**Figure 2.** Global access to sewerage connection alone and to sewerage connection with sewage treatment in 2010, by country income group.

- Most toilets aren't connected to sewers
- Most waste collected by sewers isn't treated
- ~ 1 million children die each year due to inadequate water, sanitation, hygiene

# Now: Living Downstream

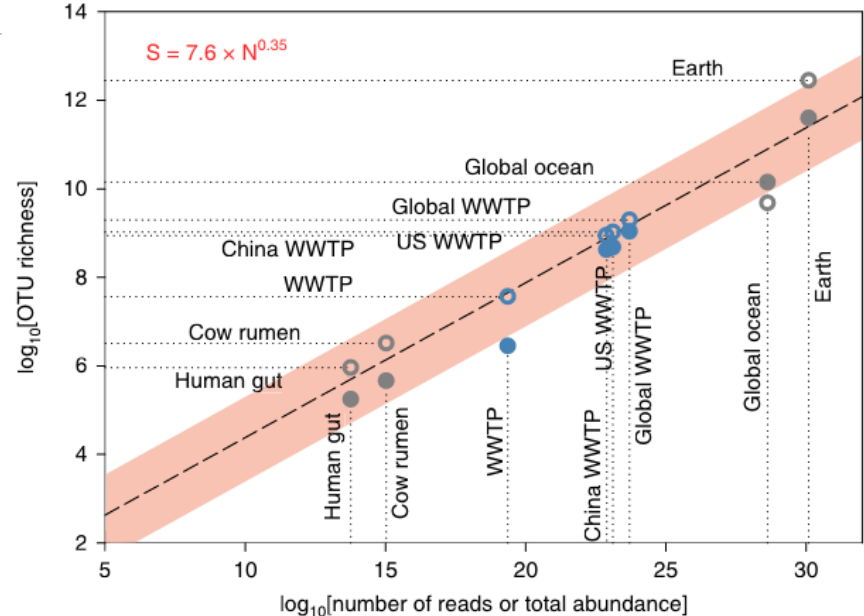


Treated wastewater discharges into the Bay Delta (major drinking water source)



## The Wastewater Treatment Plant Microbiome (WWTP)

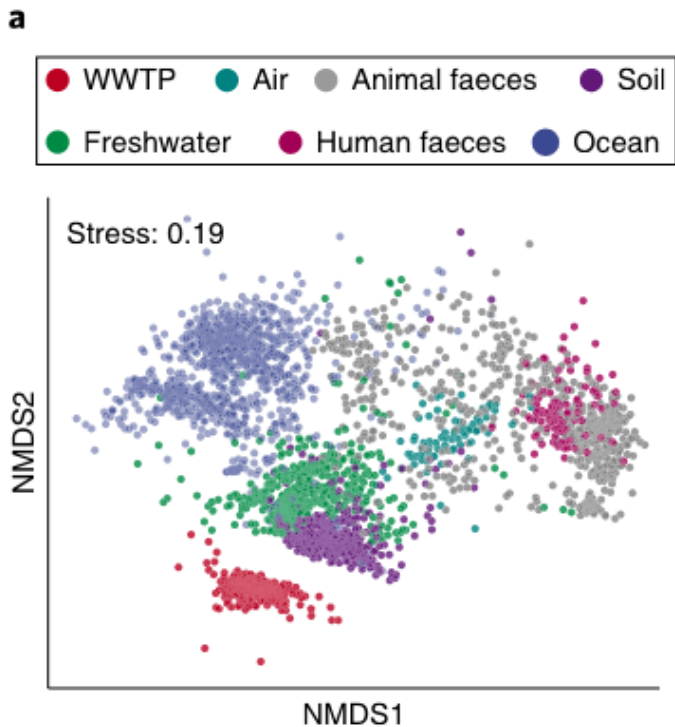
- Is highly diverse
- Is similar around the world



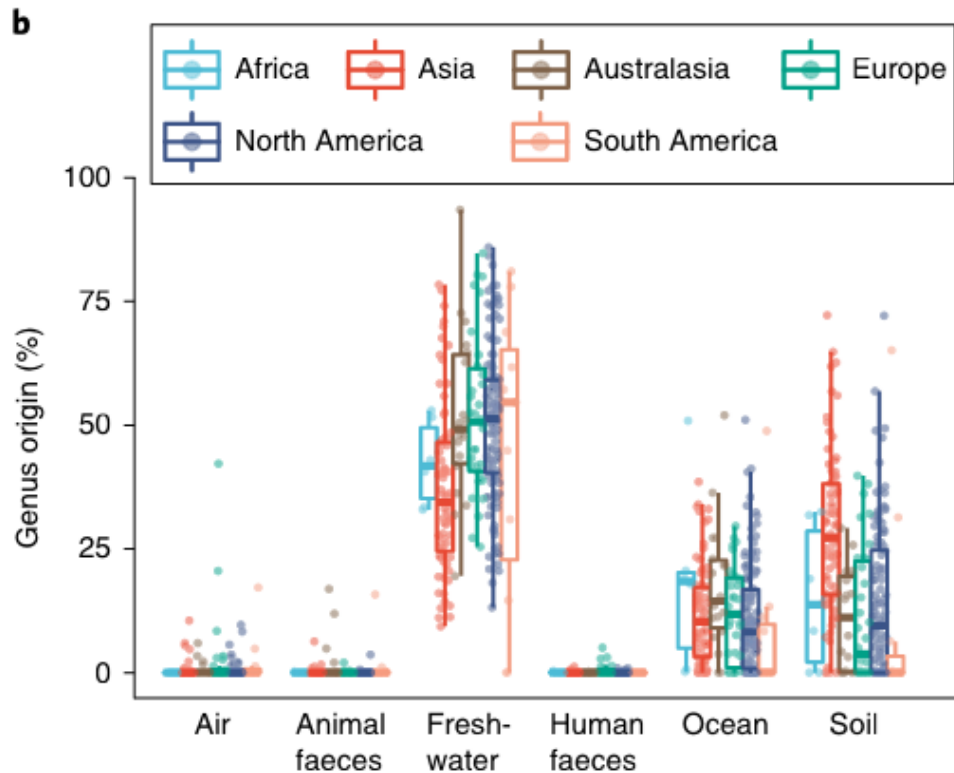
Wu et al. "Global Diversity and Biogeography of Bacterial Communities in Wastewater Treatment Plants." *Nature Microbiology* 4, no. 7 (July 2019): 1183–95.

<https://doi.org/10.1038/s41564-019-0426-5>.



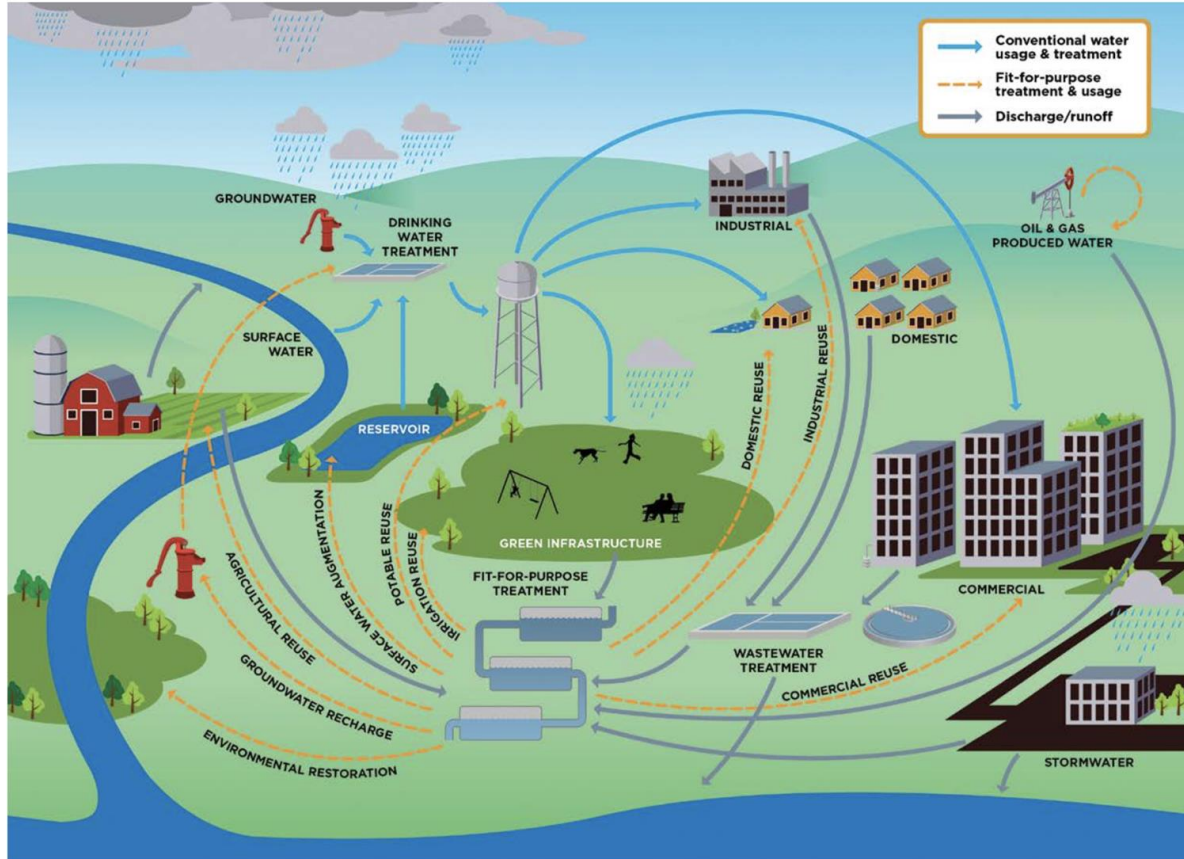


The WWTP microbiome is distinct from other microbiomes



The WWTP microbiome is more like freshwater and soil than feces

# One Water: Integrated Water Systems



# The Present

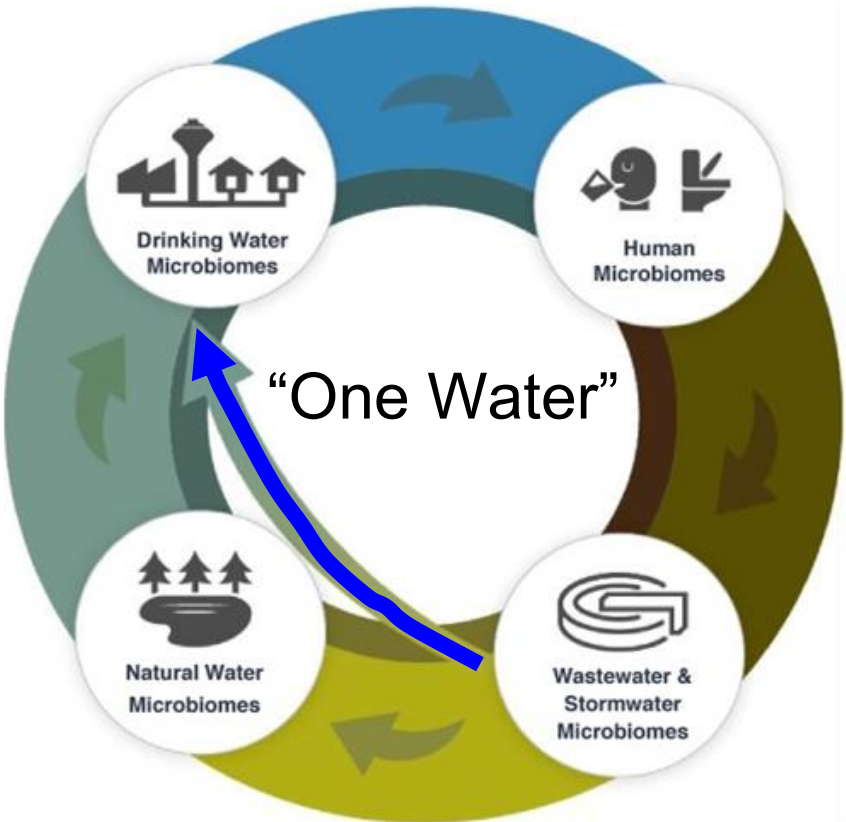
# Microbiome Continuum of One Water Systems



Raskin and Nielsen (2019)

# Microbiome Continuum of One Water Systems

## 1. Advanced water treatment

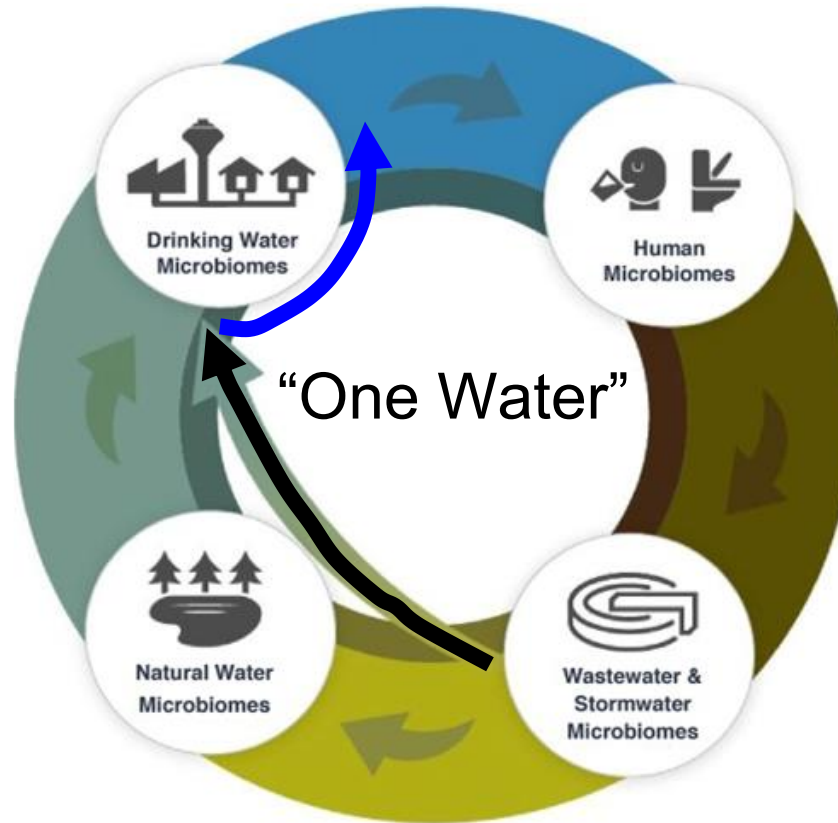


Raskin and Nielsen (2019)

# Microbiome Continuum of One Water Systems

1. Advanced water treatment

2. Direct Potable Reuse



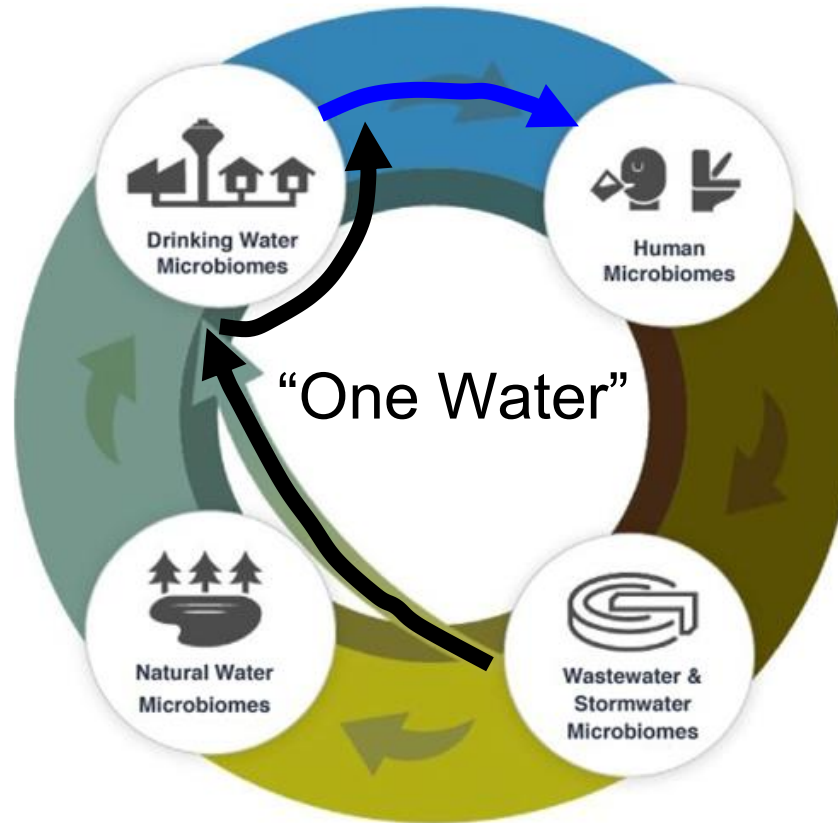
Raskin and Nielsen (2019)

# Microbiome Continuum of One Water Systems

1. Advanced water treatment

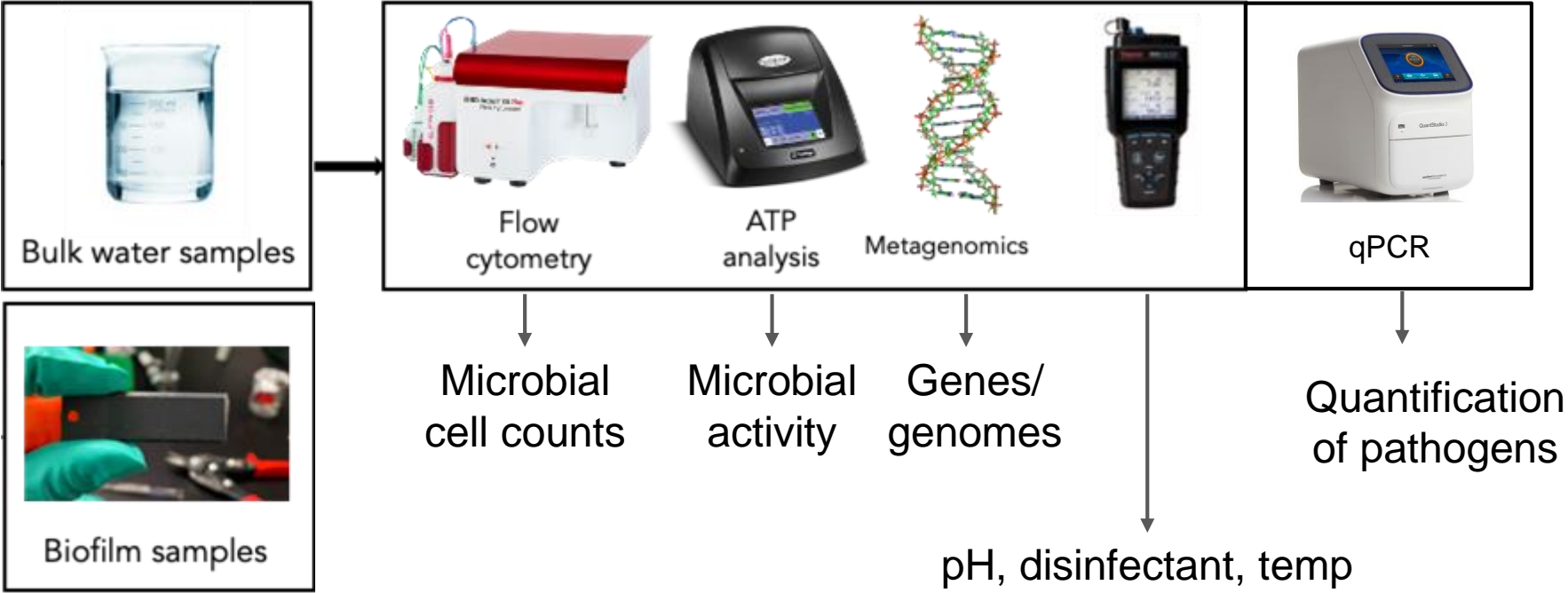
2. Direct Potable Reuse

3. Drinking water distribution system



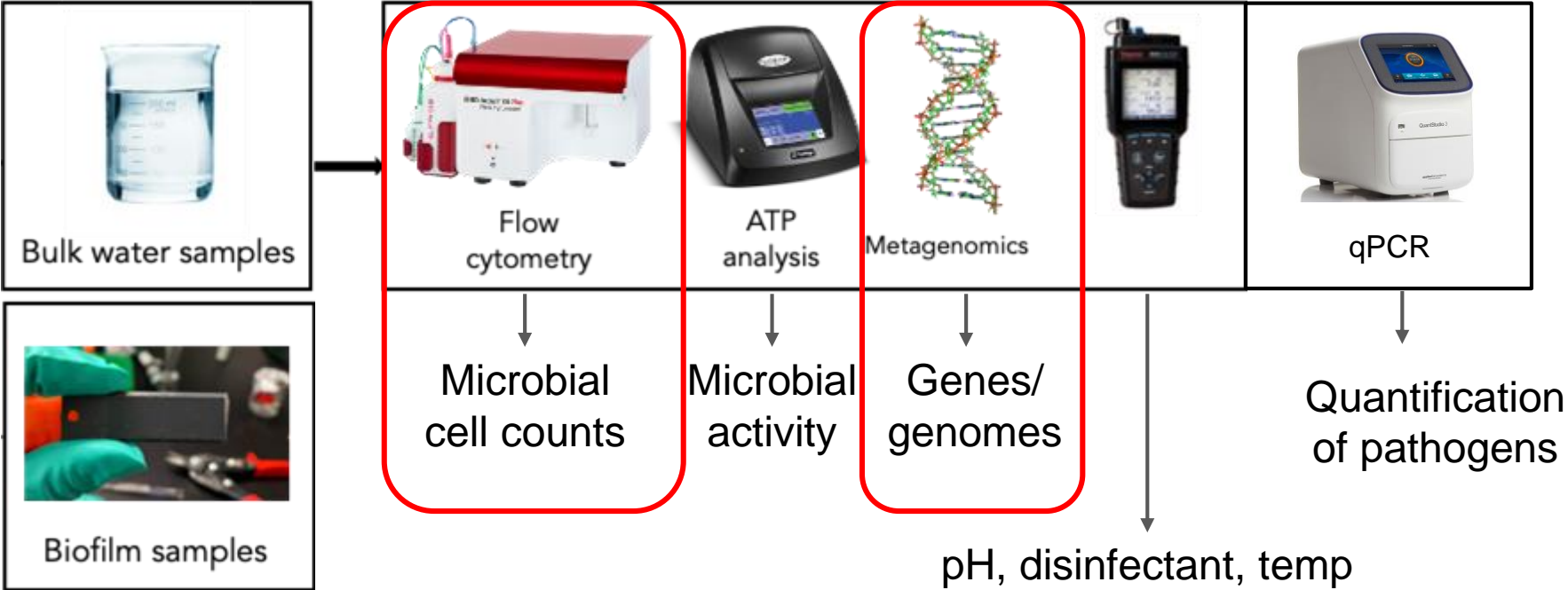
Raskin and Nielsen (2019)

# Observing impacts on water microbiomes





# Observing impacts on water microbiomes



# How do changes in water systems affect microbial communities?

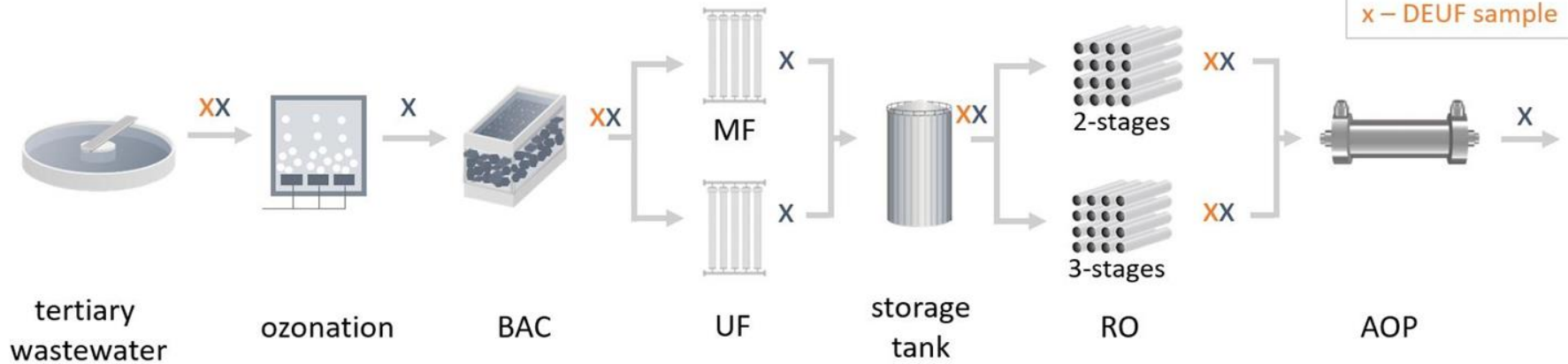
## 1. Advanced water treatment



Raskin and Nielsen (2019)

# Advanced Water Treatment Plant

## Potable reuse treatment train

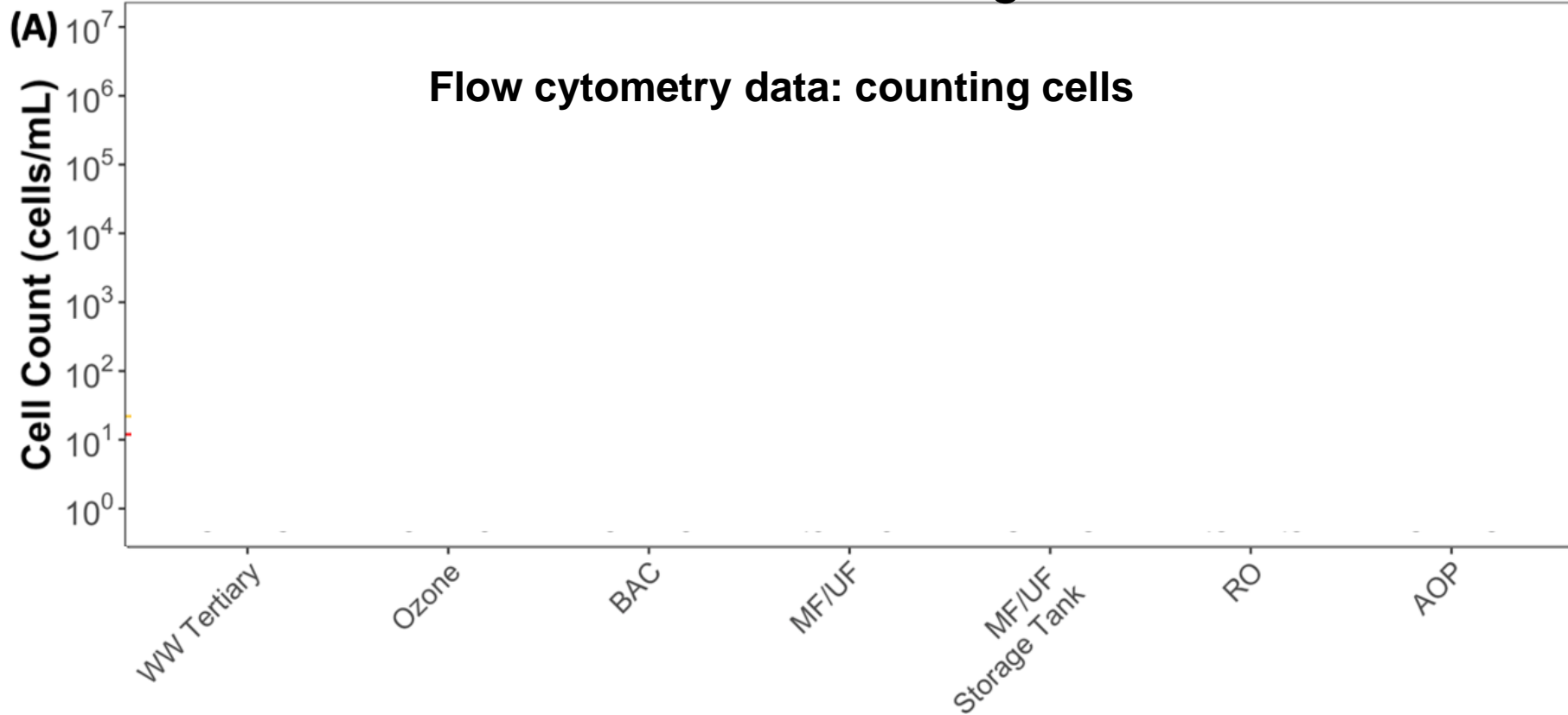


$O_3$  + activated carbon  
remove organic matter

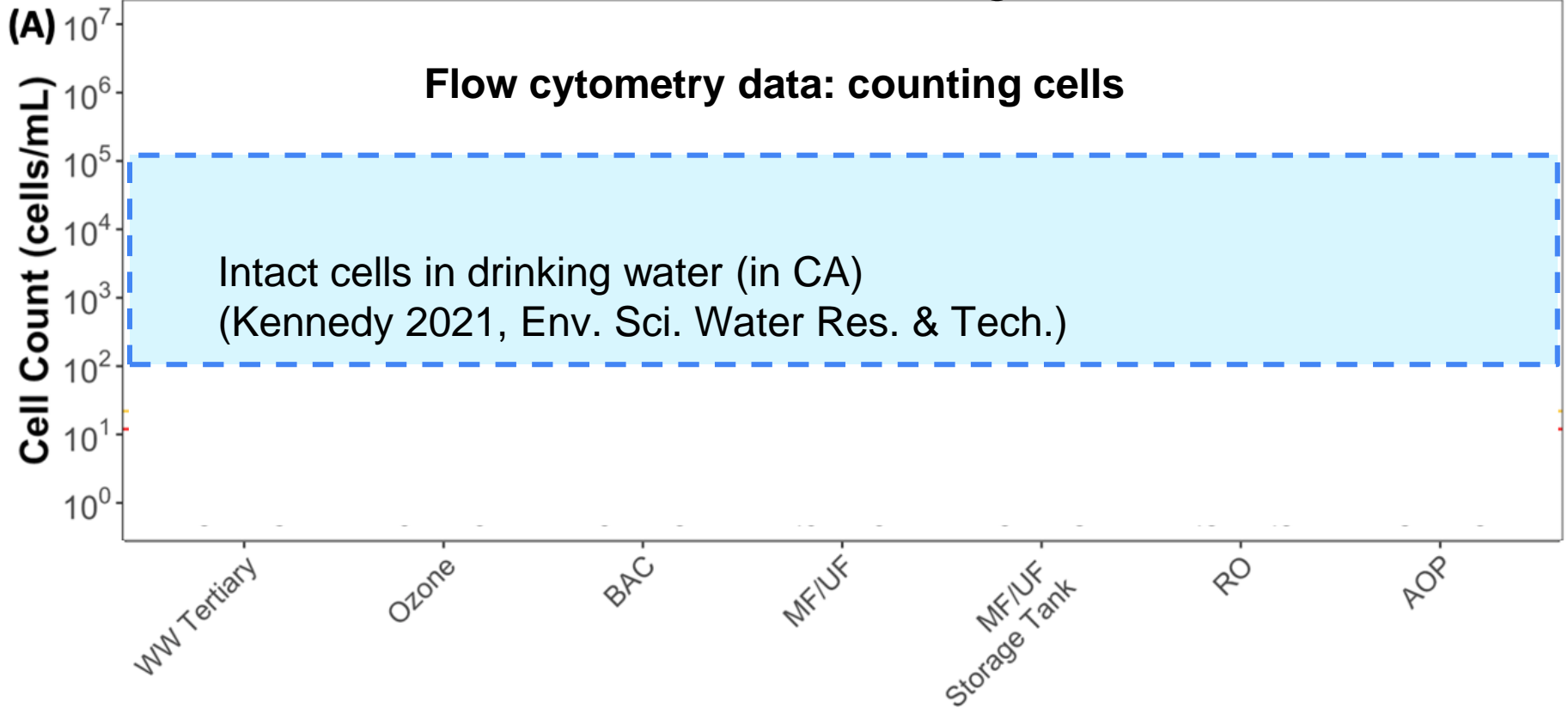
Membrane  
Filters

UV + oxidant

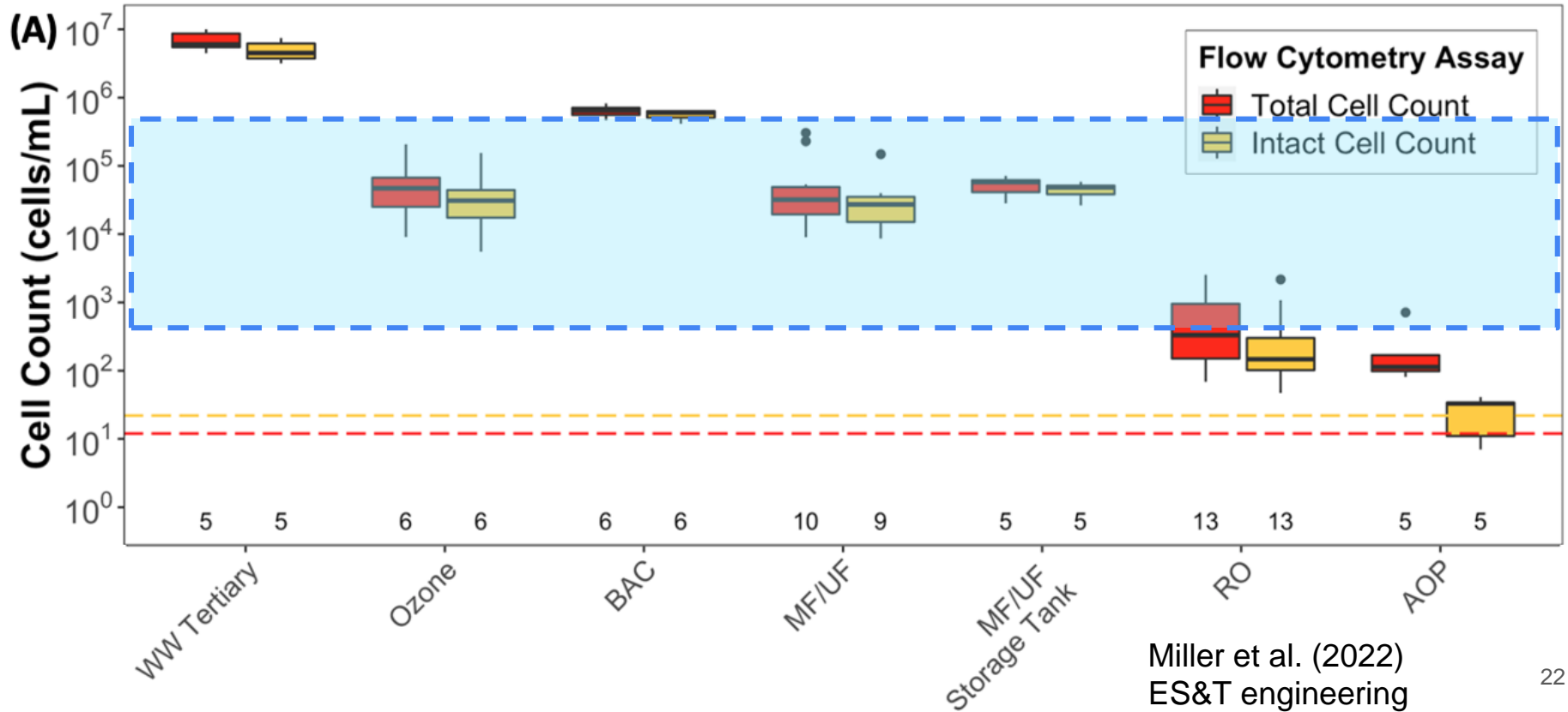
# Advanced treatment removes microorganisms from water



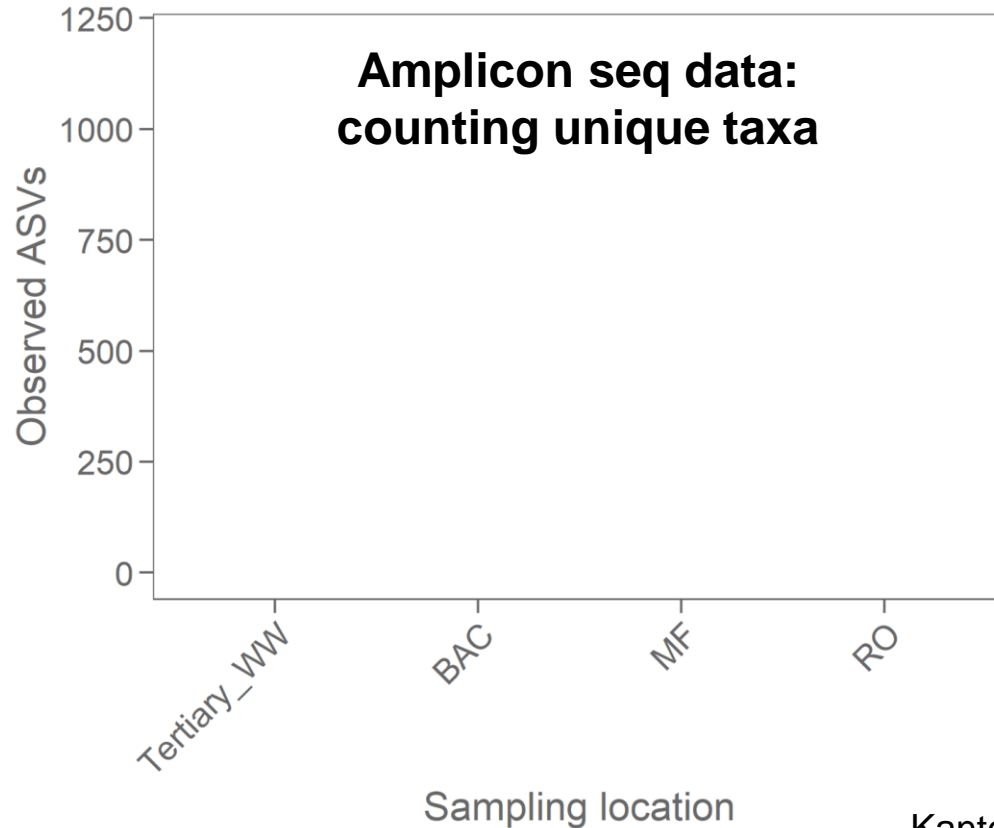
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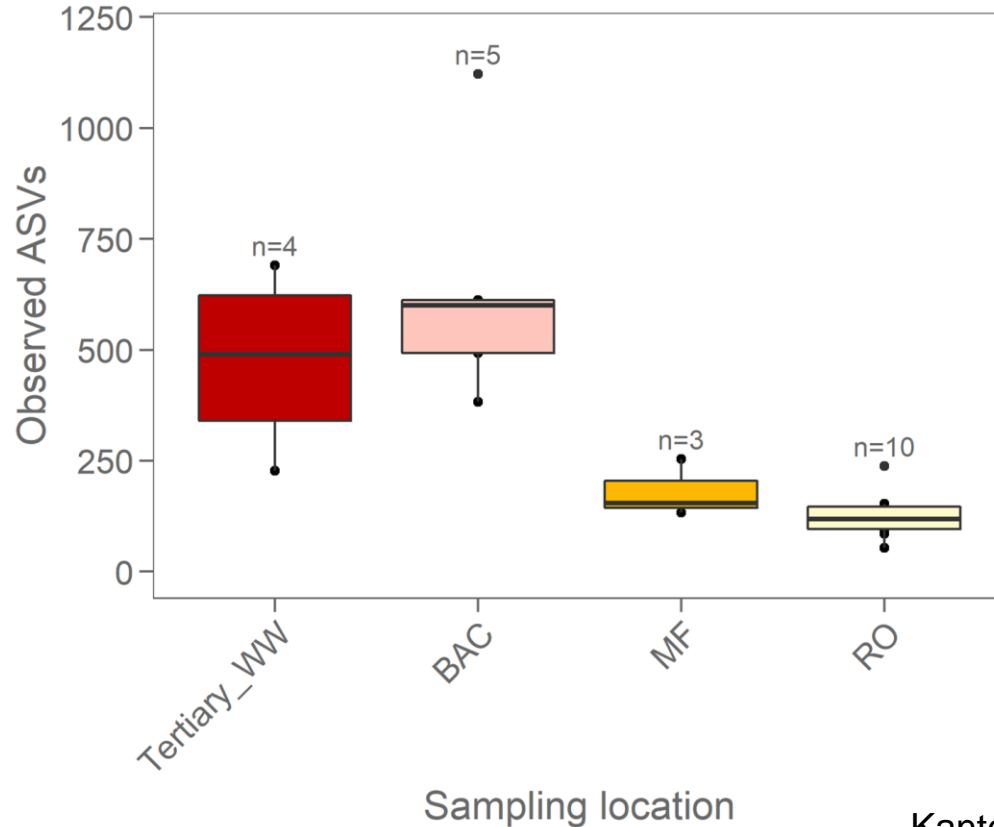
# Advanced treatment removes microorganisms from water



# Advanced treatment affects the microbial **richness** of water

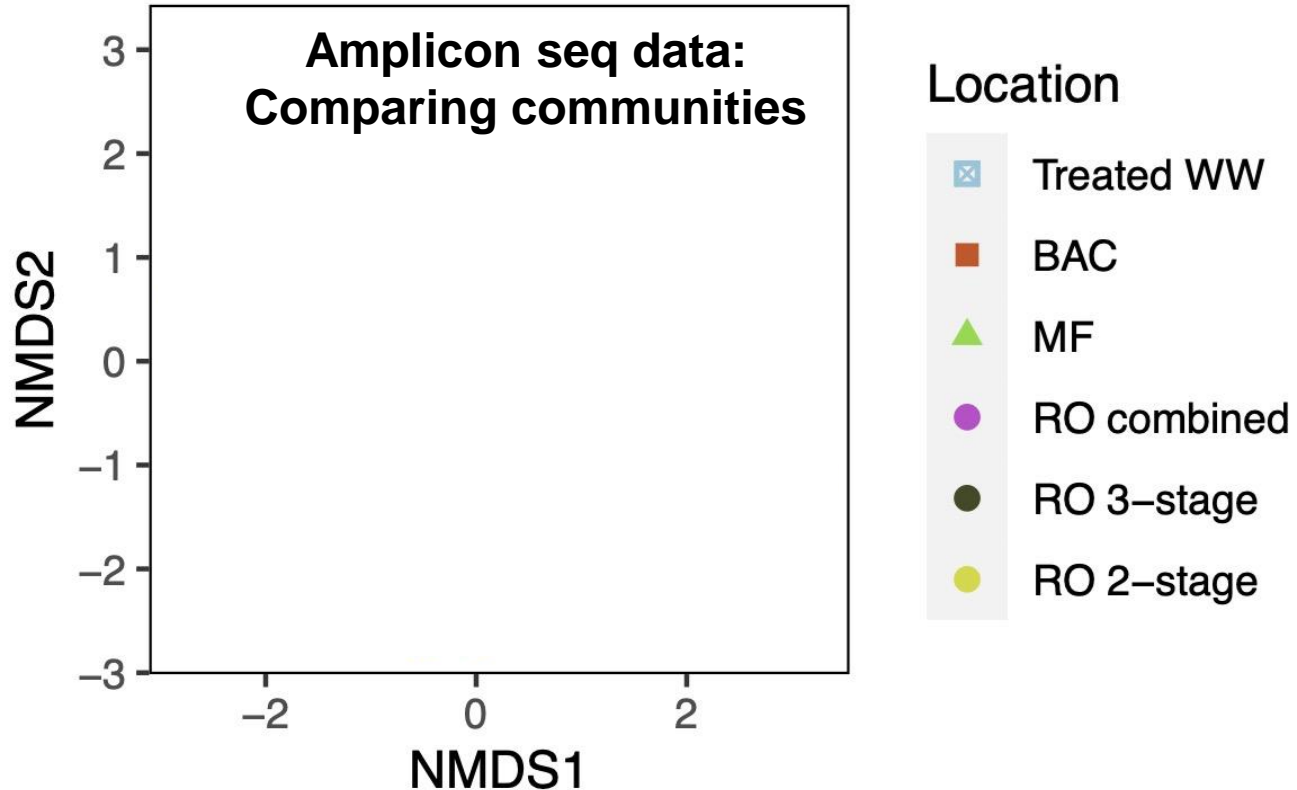


# Advanced treatment affects the microbial **richness** of water

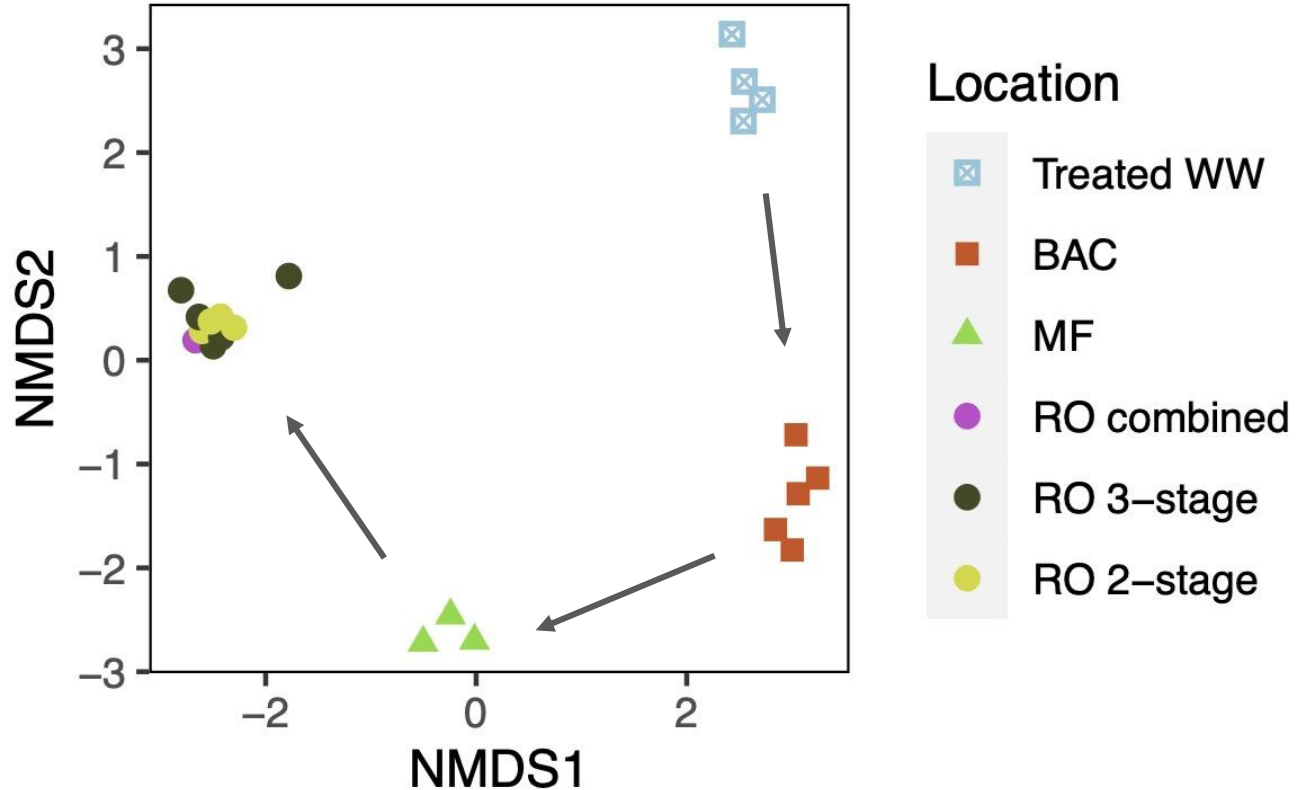




# Advanced treatment affects the microbial **profile** of water



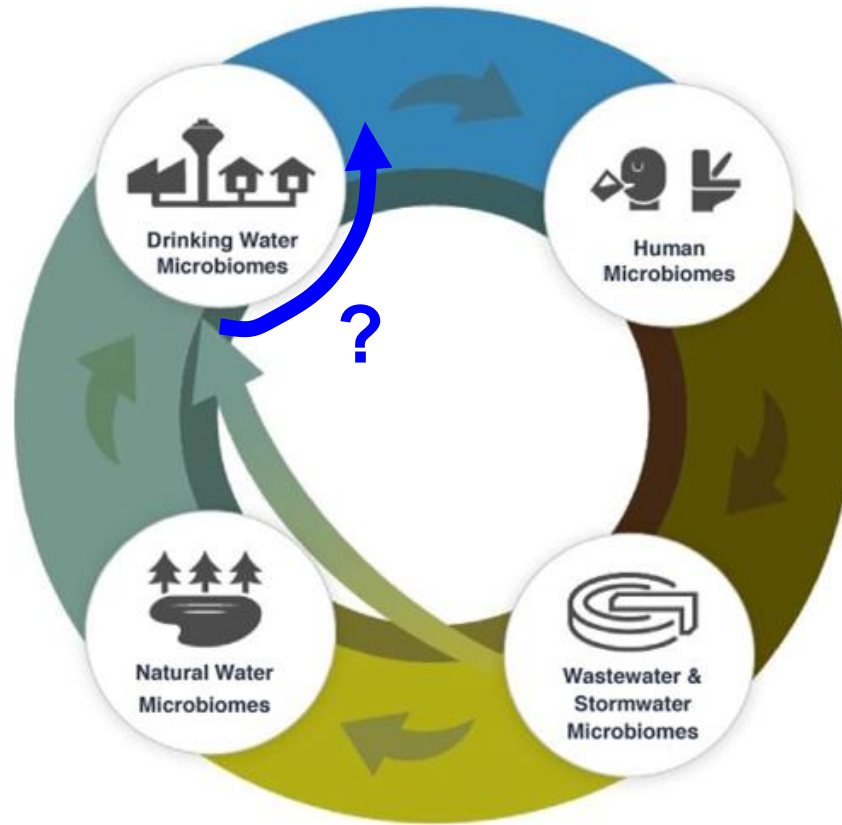
# Advanced treatment affects the microbial **profile** of water



# How do changes in water systems affect microbial communities?

1. Advanced water treatment

2. Direct Potable Reuse



Raskin and Nielsen (2019)

# Drinking water distribution systems are complex, not sterile

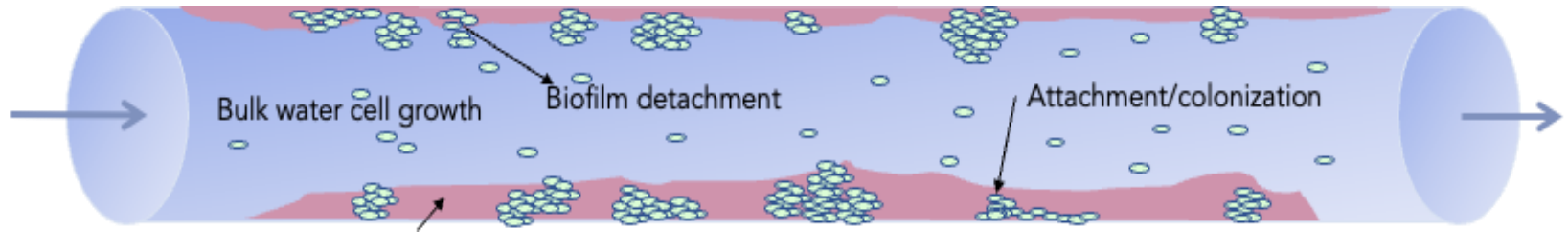


Image by Hannah Healy

What happens when we add highly purified water with lower nutrients and fewer cells?

# Drinking water distribution systems are complex, not sterile

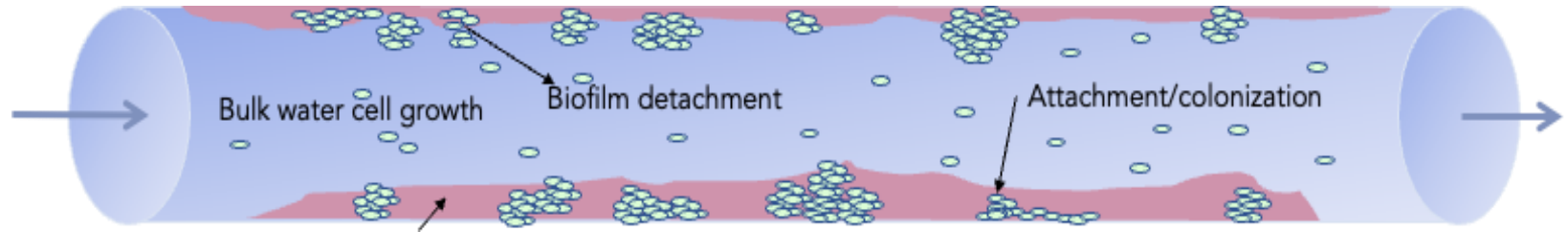
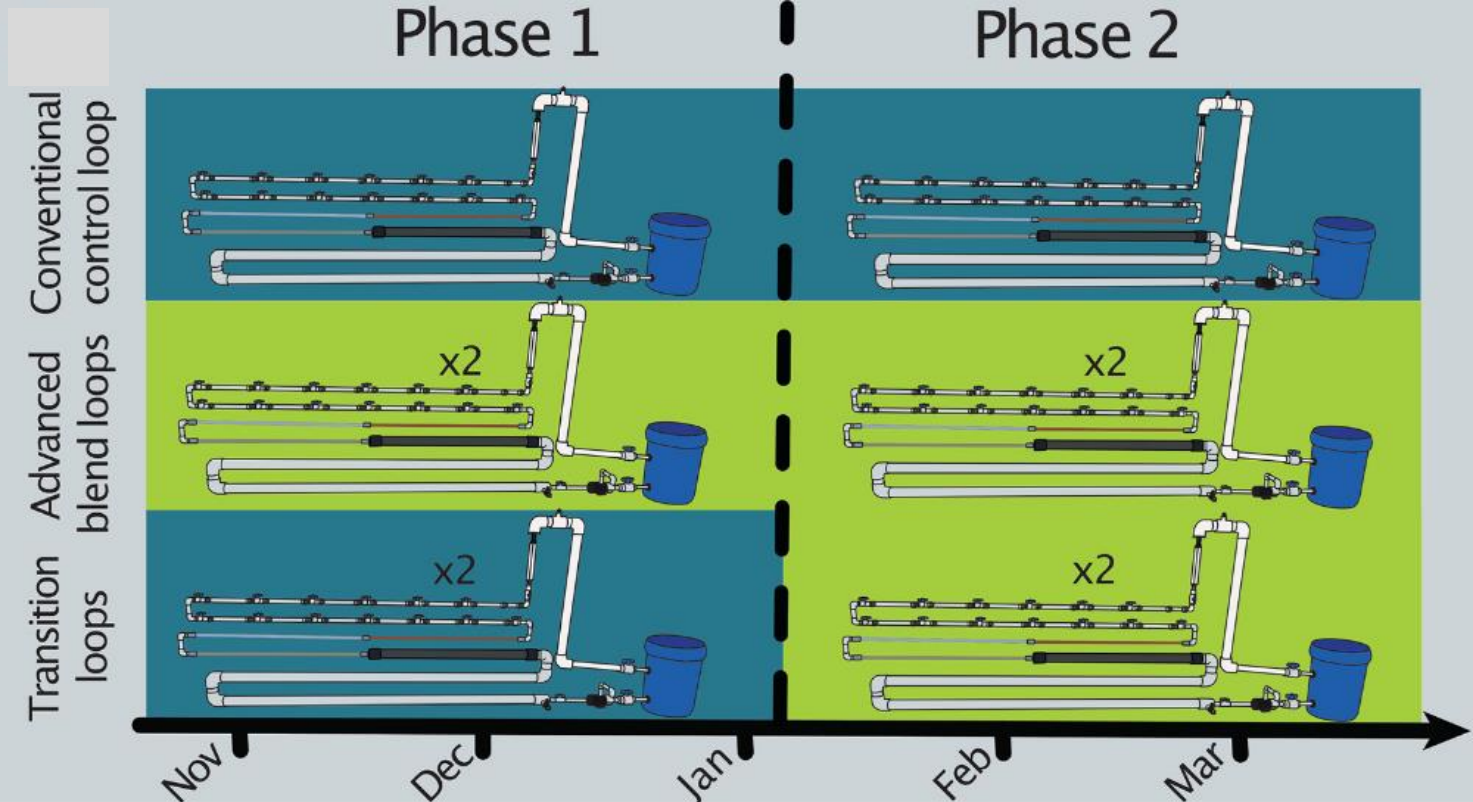


Image by Hannah Healy

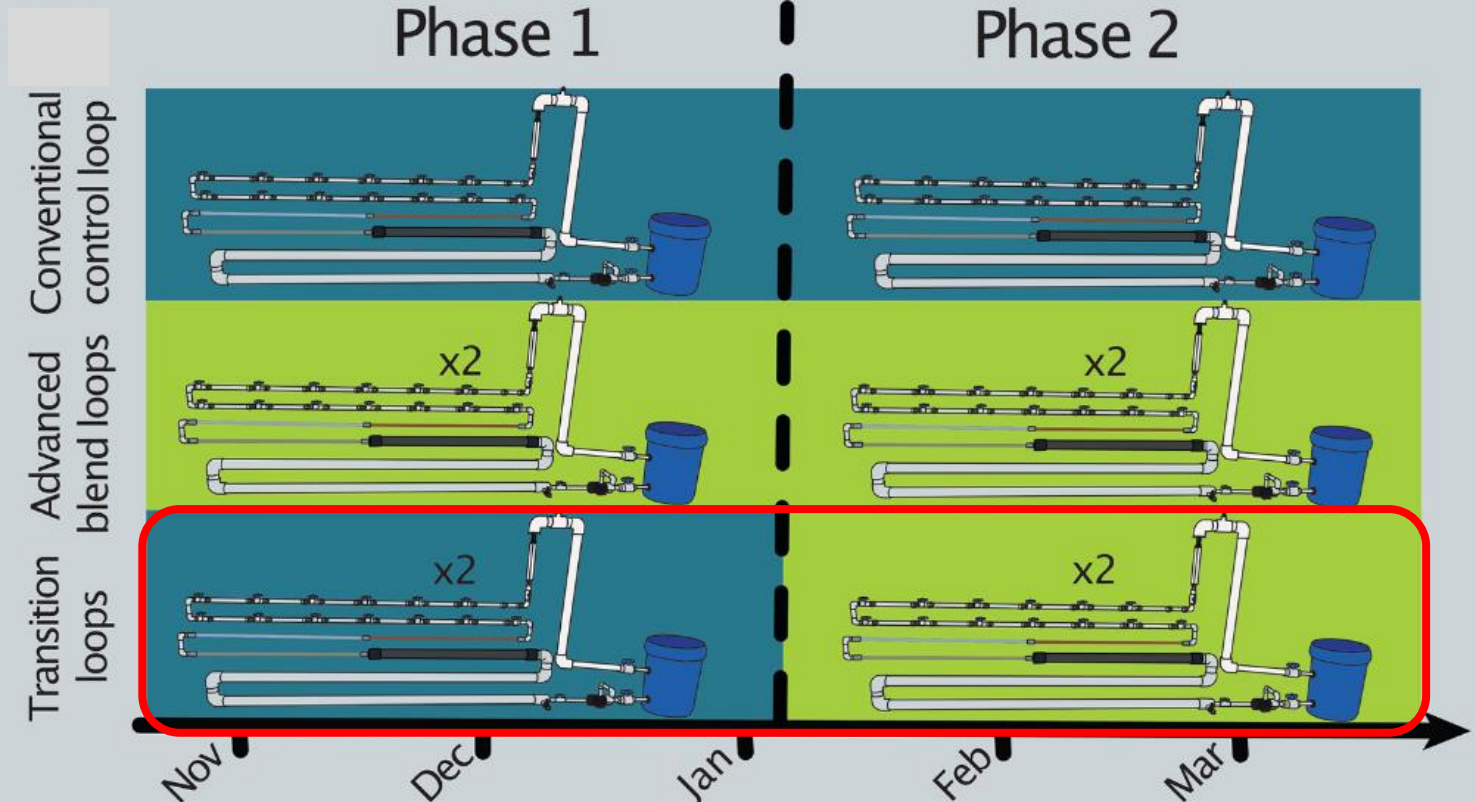


Pipe loops as a model system to study direct potable reuse

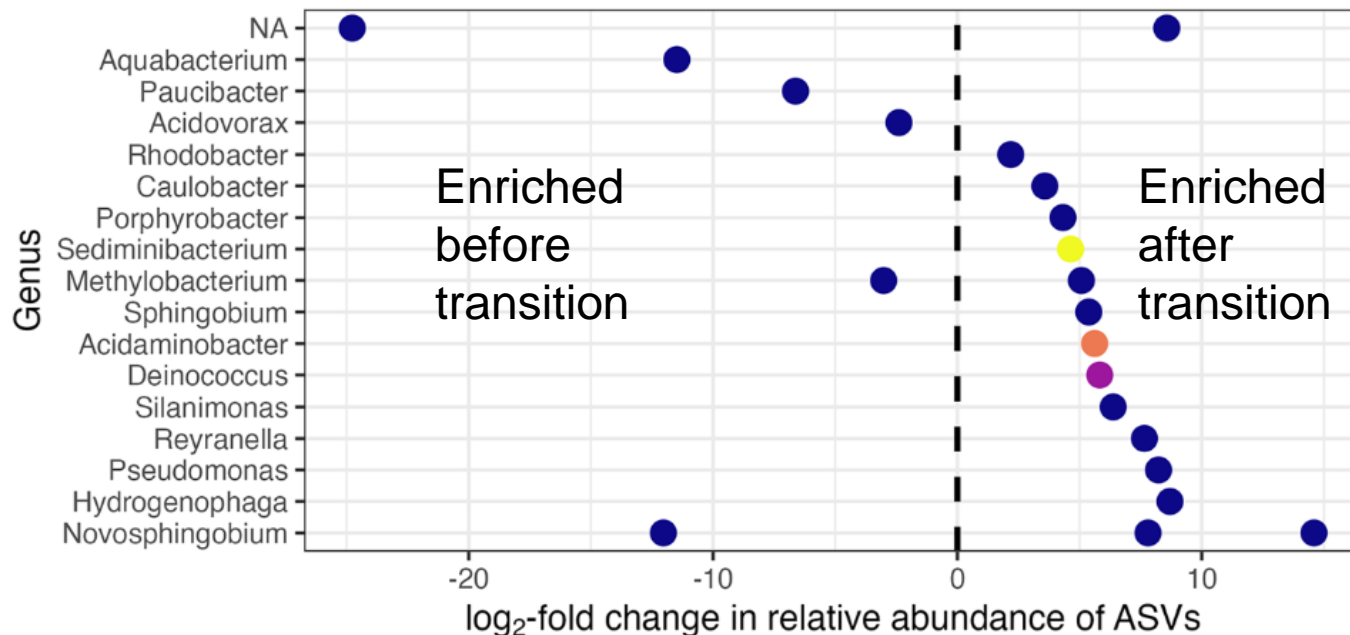
# Introduction of advanced treated water to pipe loops



# Introduction of advanced treated water to pipe loops



# Introduction of advanced treated water to pipe loops shifted abundance of key organisms



Kennedy et al. (2023)  
ESWRT

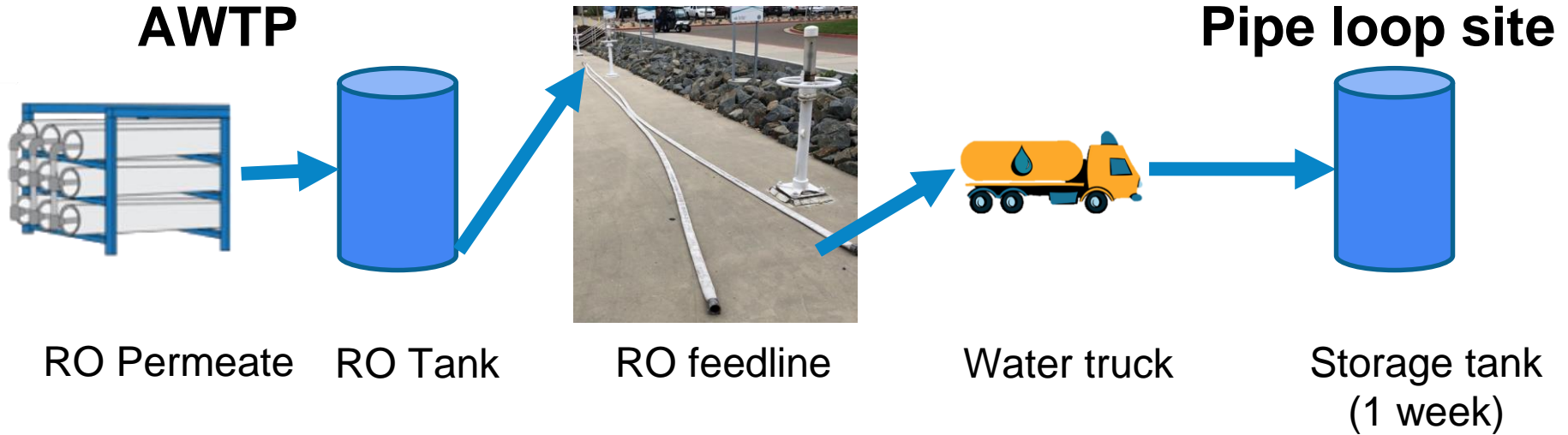
Phylum

- Proteobacteria
- Firmicutes
- Deinococcus-Thermus
- Bacteroidetes



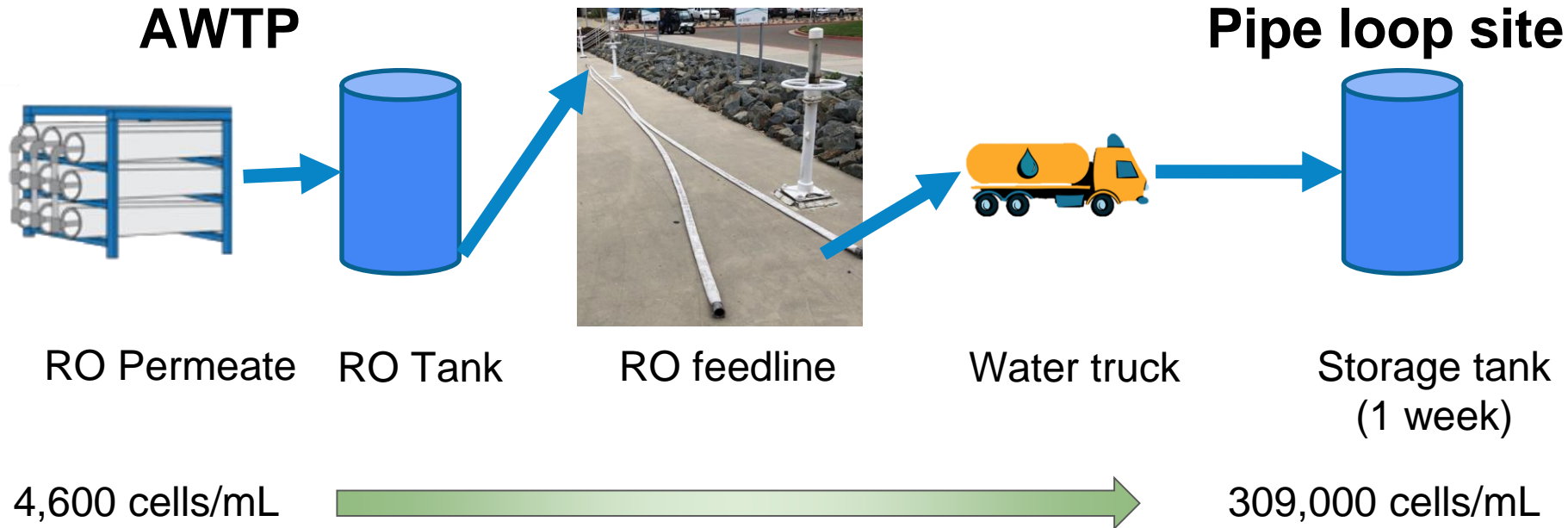
But...

Advanced treated water is influenced by storage / transport



But...

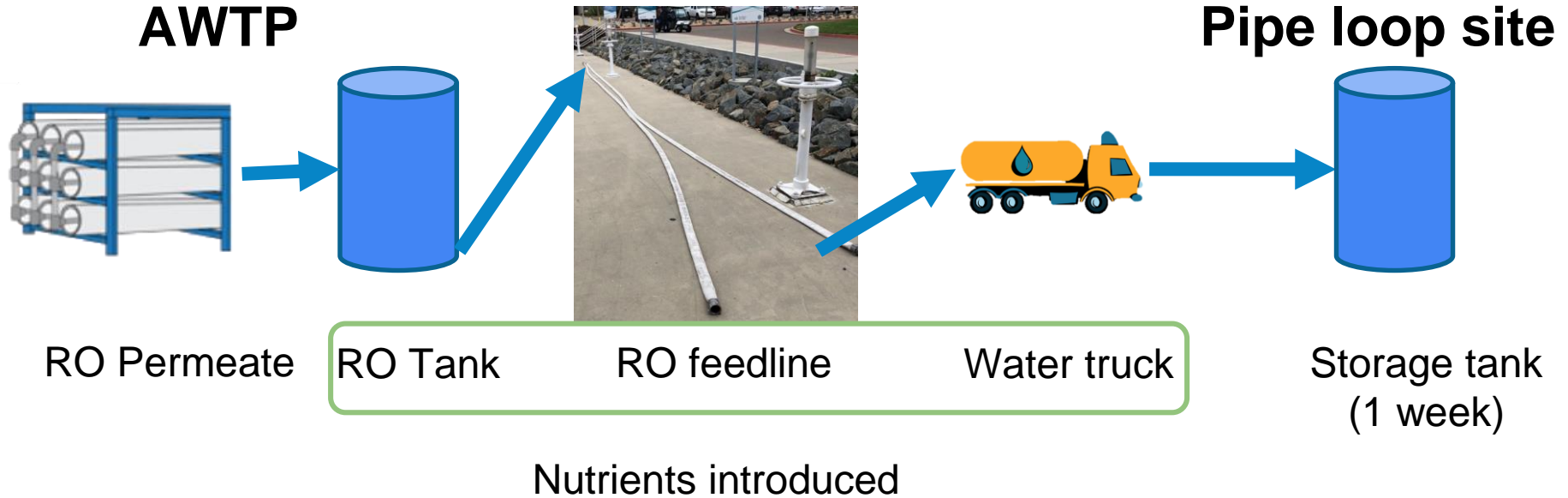
Advanced treated water is influenced by storage / transport



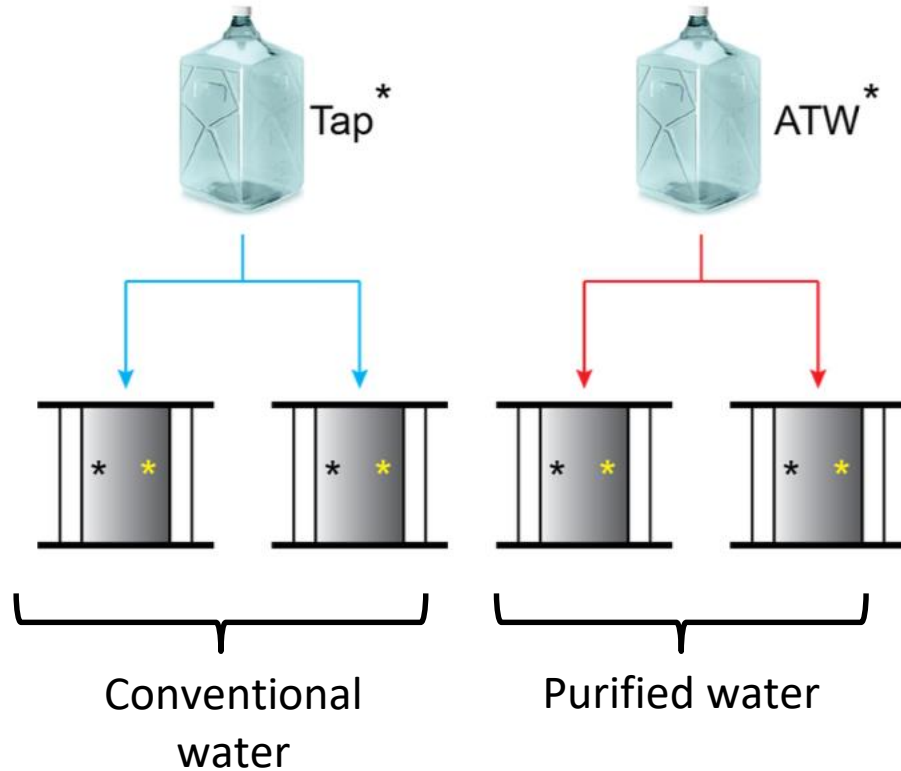
Kennedy et al. (2023)  
ESWRT

But...

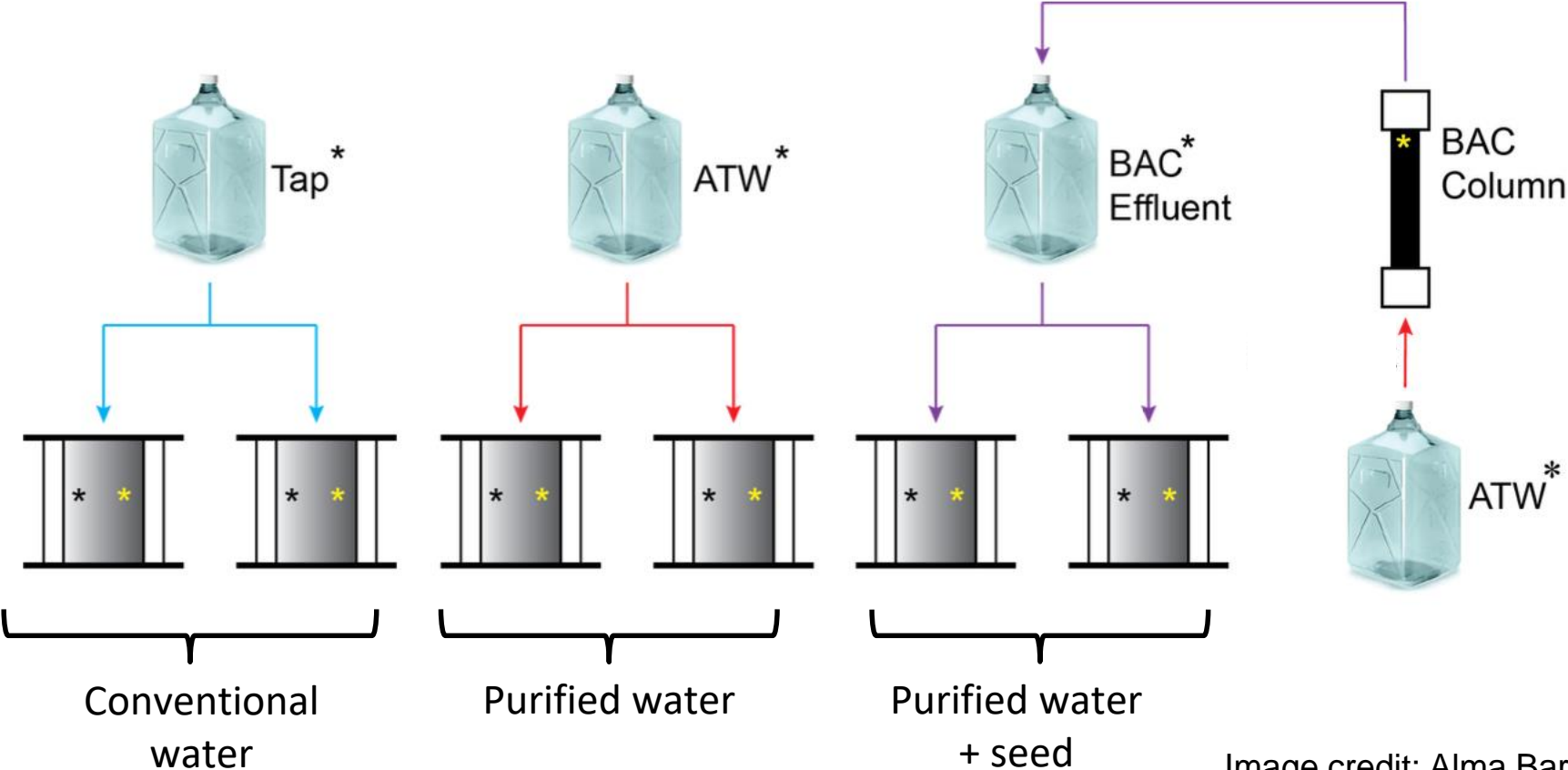
Advanced treated water is influenced by storage / transport



# Controlled inoculation of Advanced Treated Water

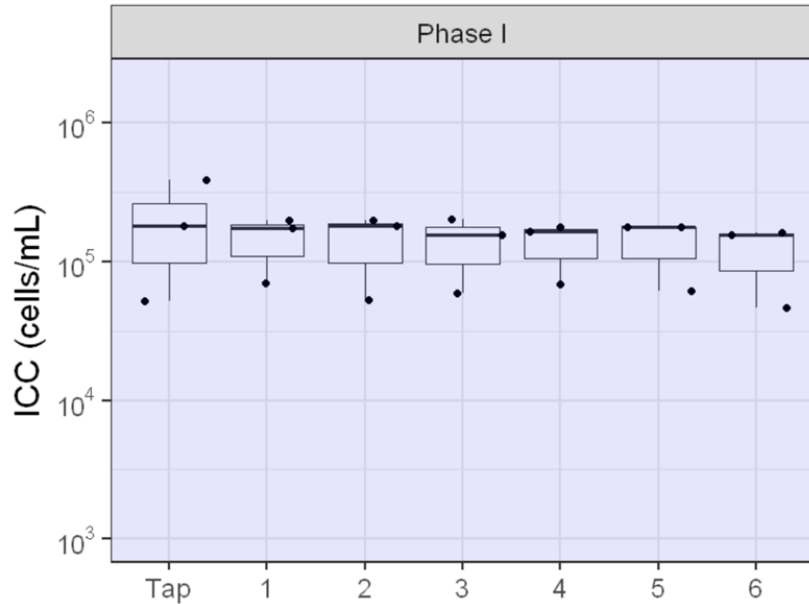


# Controlled inoculation of Advanced Treated Water

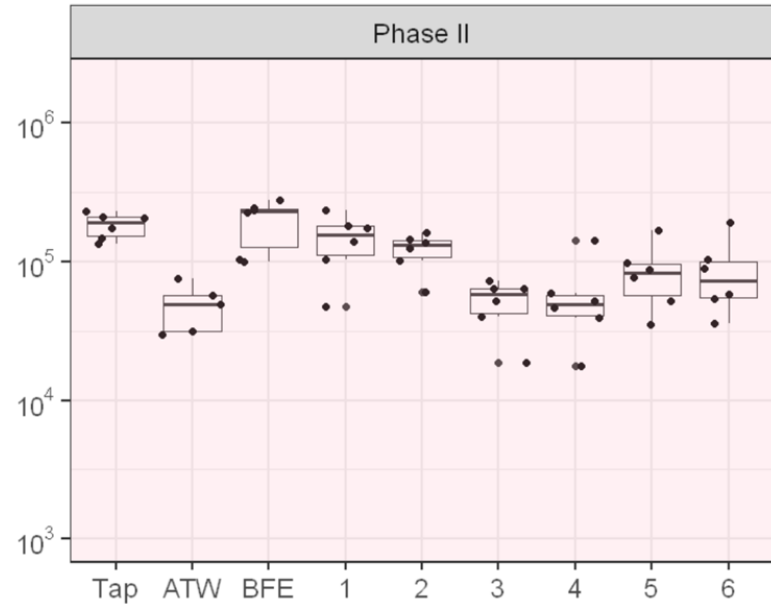


# Initial Results: Intact Cell Counts

(microbial community analysis: stay tuned)



All reactors fed with tap water



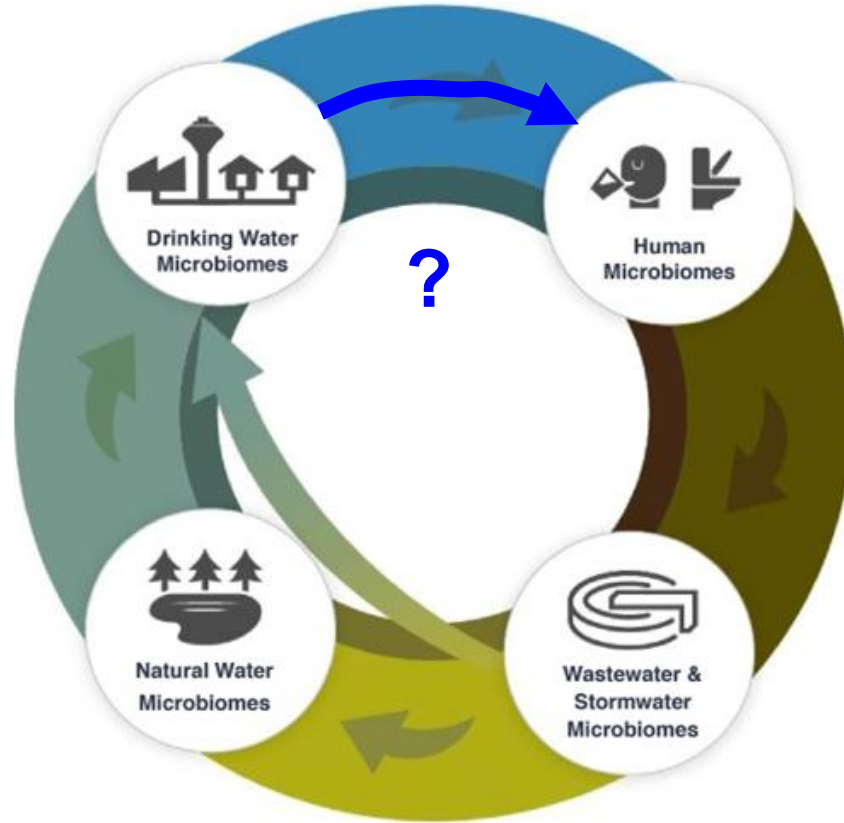
Tap ATW ATW + seed

# How do changes in water systems affect microbial communities?

1. Advanced water treatment

2. Direct Potable Reuse

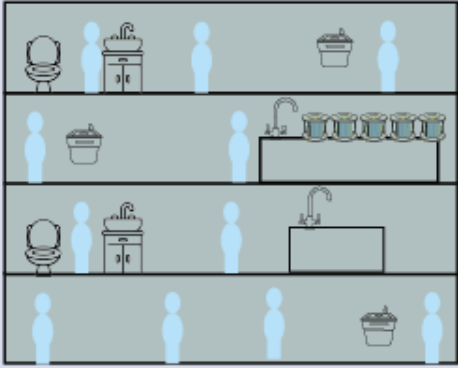
3. Drinking water distribution system



Raskin and Nielsen (2019)

# Low water use in annular reactors: a pandemic experiment

Phase I



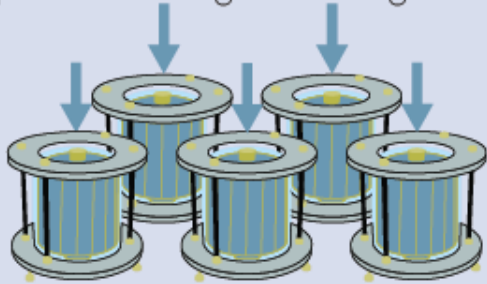
typical  
water  
usage

Phase II

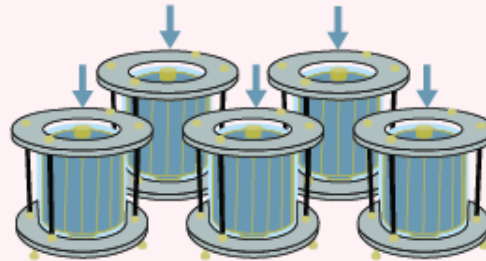


reduced  
water  
usage

typical water age entering reactors



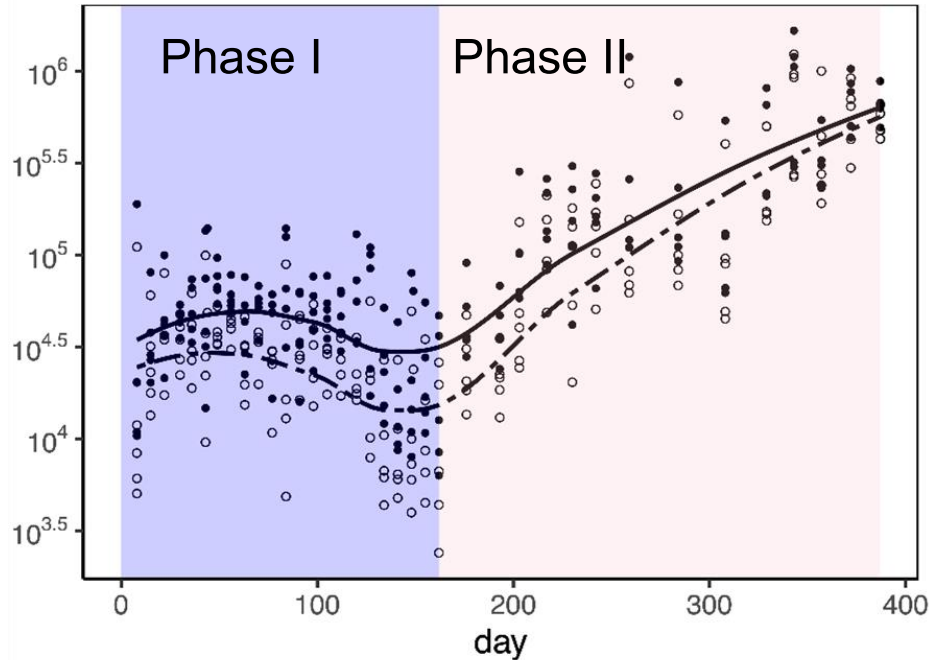
elevated water age entering reactors



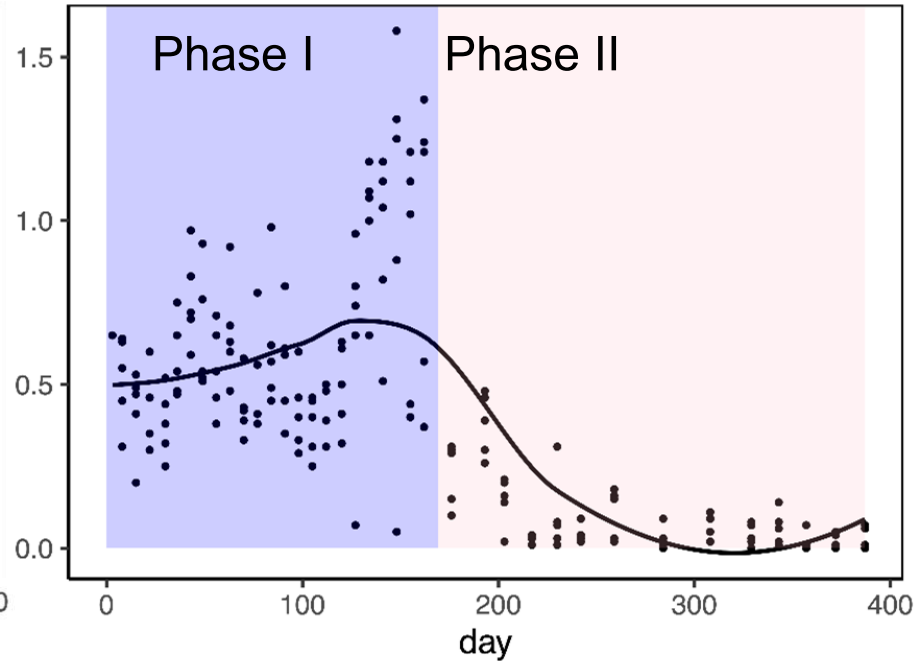


# Cell counts increased and chlorine decreased

Cell counts



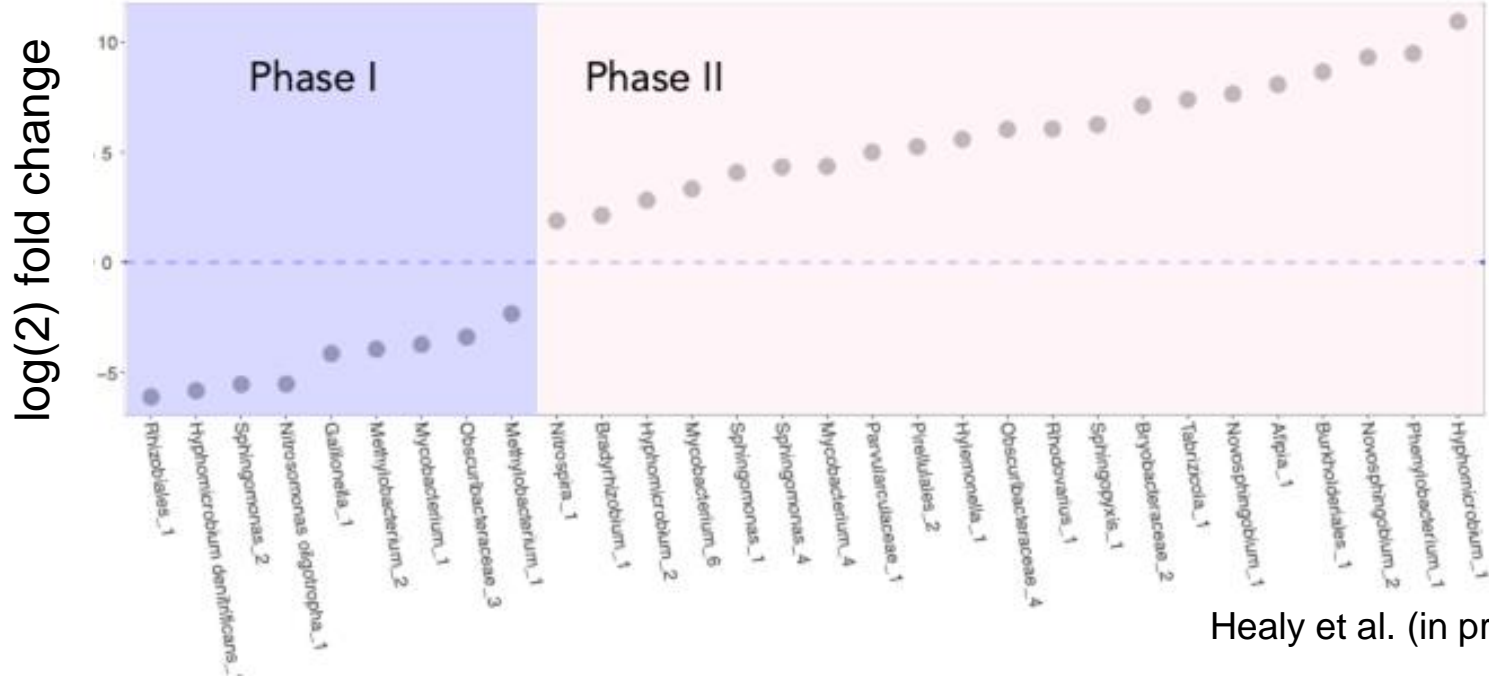
Total chlorine



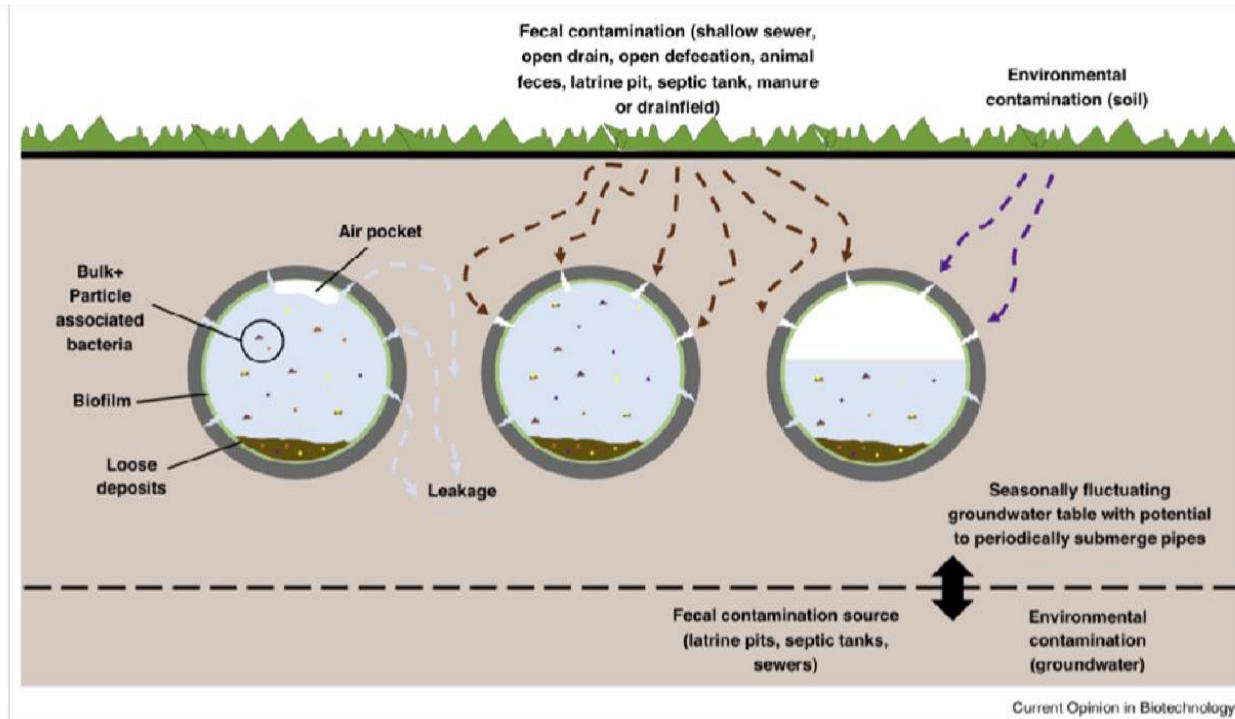
\*but each reactor behaved somewhat differently

# Community & functional changes with increased water age

Enrichment of functional genes related to the degradation of histidine, leucine, tyrosine, and pyrimidine



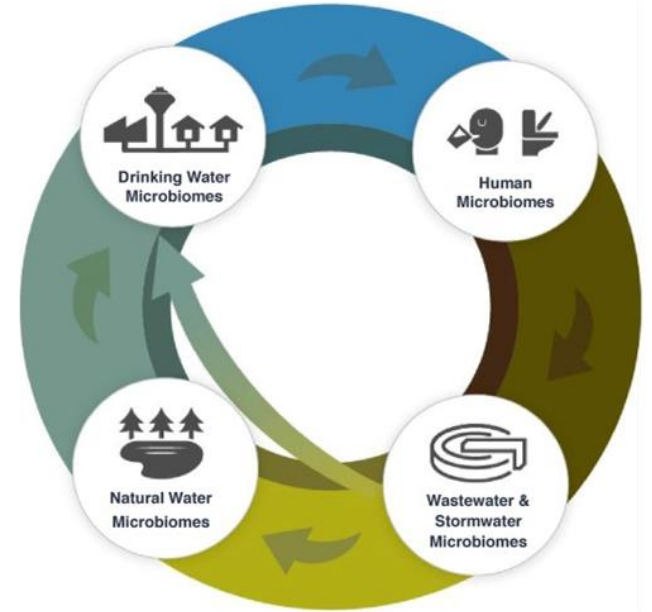
# The Microbiome of Intermittent Water Supply



The Future

# The Future

1. Controlled inoculation
2. Water as a probiotic
3. Synthetically engineered microorganisms?





## NSF Engineering Research Center

PreMiEr's vision is to develop an integrated framework that enables the bioinformed design of smart and healthy built environments while also broadly advancing microbiome engineering technologies.

<https://premier-microbiome.org/>

Thank you!

