The microbiomes of engineered water environments

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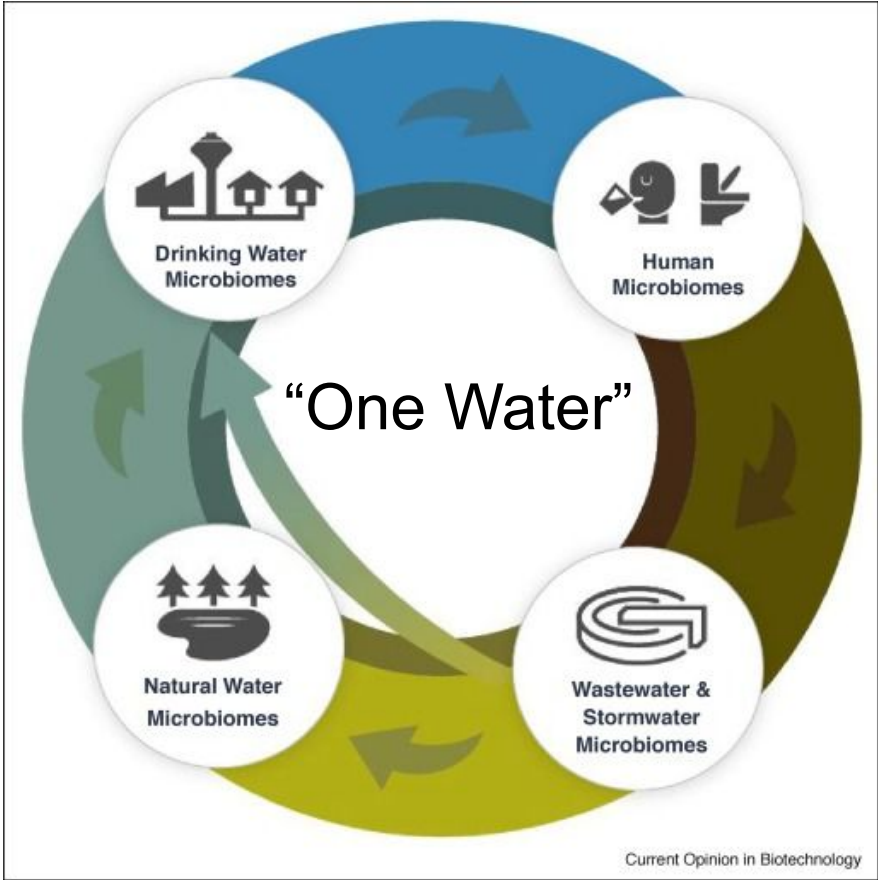
Acknowledgements and funding

What does the **Changing Planet** mean for **water**?

- Drought
- Flooding
- Warming
- Demand changes
- Pollution

→

- Strain on aging infrastructure
- Human and environmental health impacts
- Economic impacts

Changes affect **interconnected engineered water environments**

"One Water"

Raskin and Nielsen (2019)

Changes affect **interconnected engineered water environments**

1. Advanced water treatment

"One Water"

Raskin and Nielsen (2019)

Changes affect **interconnected engineered water environments**

1. Advanced water treatment

2. Direct Potable Reuse

"One Water"

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Changes affect **interconnected engineered water environments**

1. Advanced water treatment

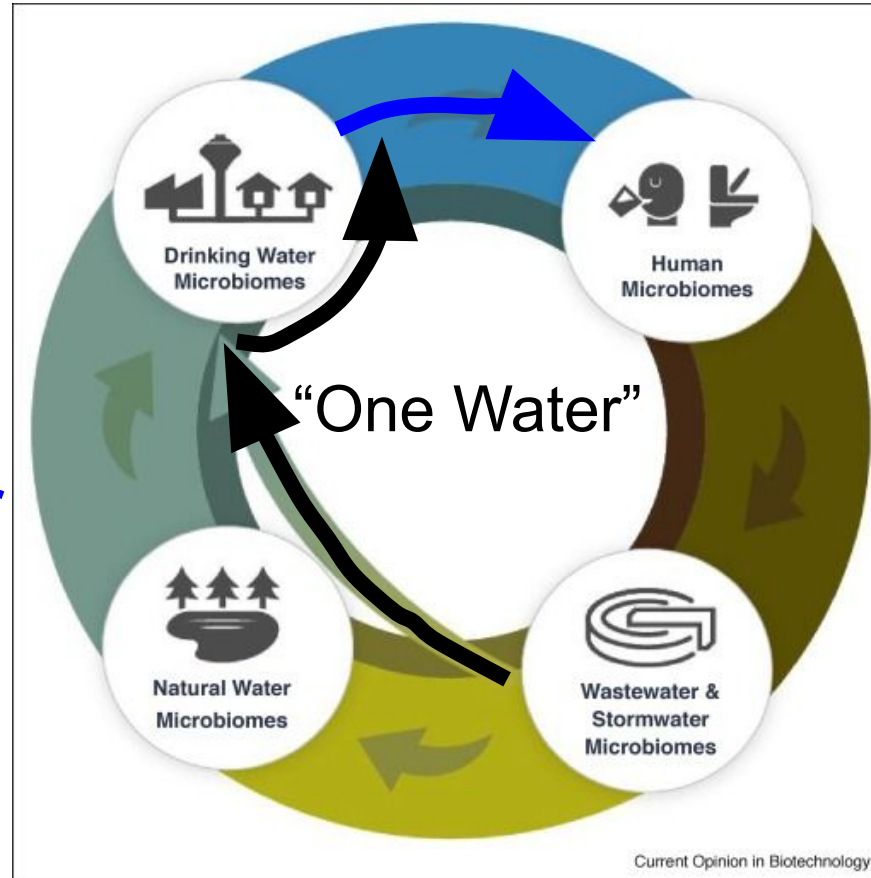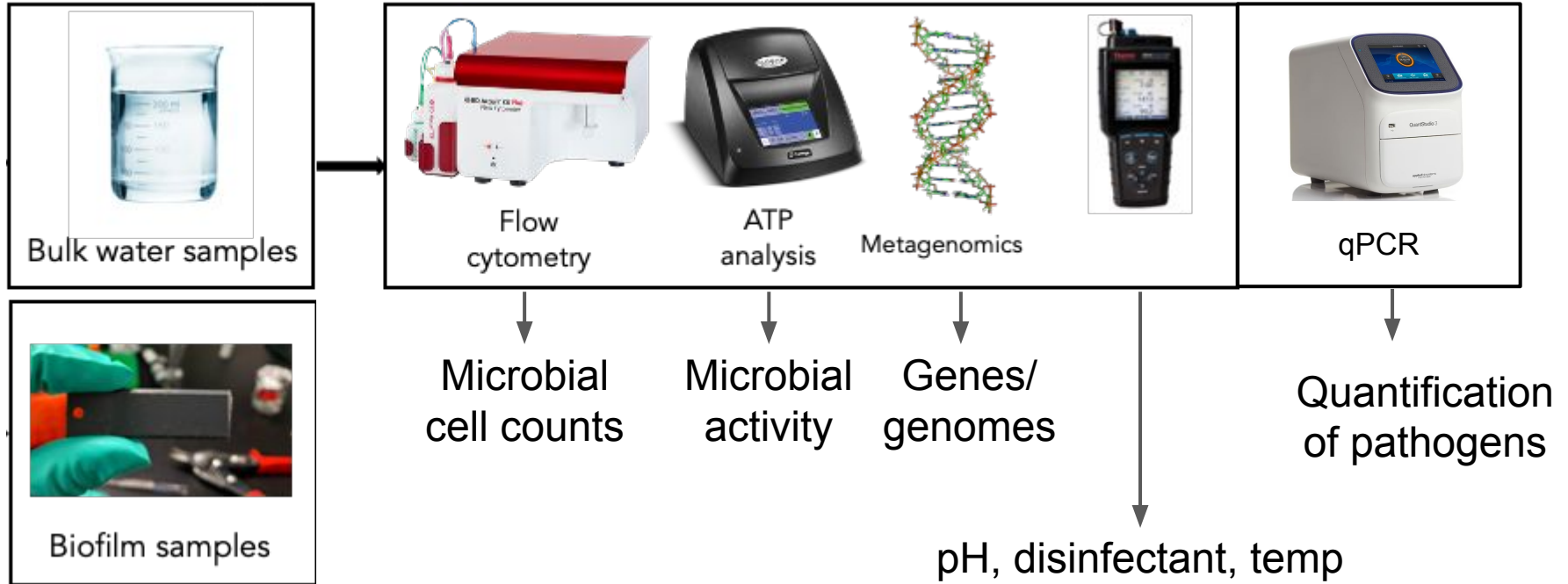**2. Direct Potable Reuse**
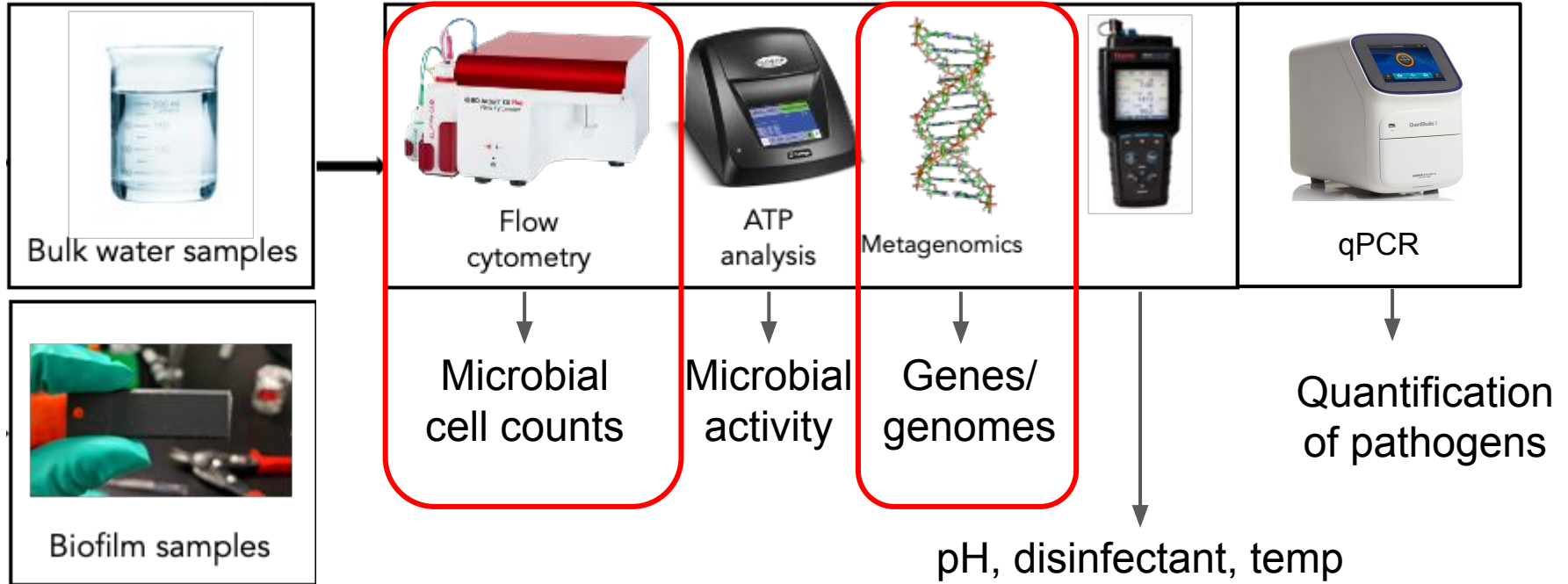
3. Drinking water distribution system

"One Water"

Raskin and Nielsen (2019)

Observing impacts on water microbiomes

Bulk water samples

Biofilm samples

Flow cytometry

ATP analysis

Metagenomics

qPCR

Microbial cell counts

Microbial activity

Genes/ genomes

Quantification of pathogens

pH, disinfectant, temp

Observing impacts on water microbiomes

Bulk water samples

Biofilm samples

Flow cytometry → Microbial cell counts

ATP analysis → Microbial activity

Metagenomics → Genes/ genomes

pH, disinfectant, temp

qPCR → Quantification of pathogens
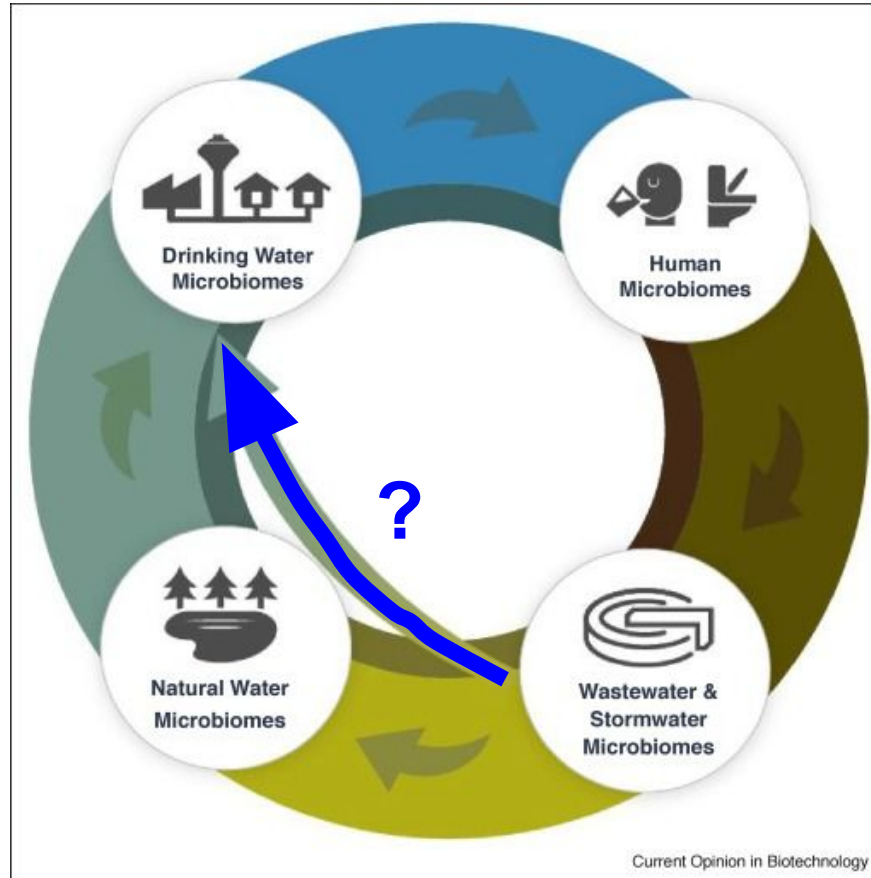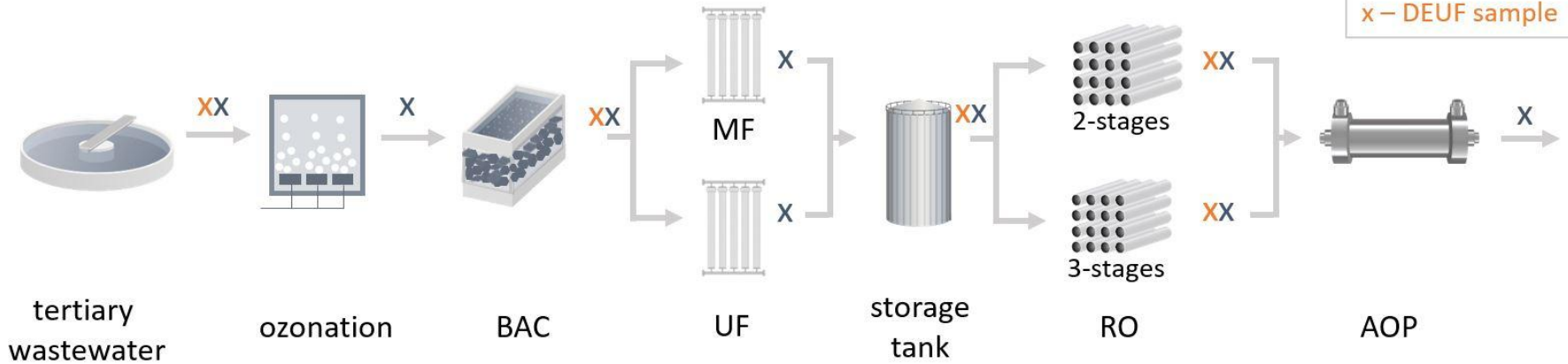
How do changes in water systems affect microbial communities?

1. Advanced water treatment

Raskin and Nielsen (2019)

Advanced Water Treatment Plant
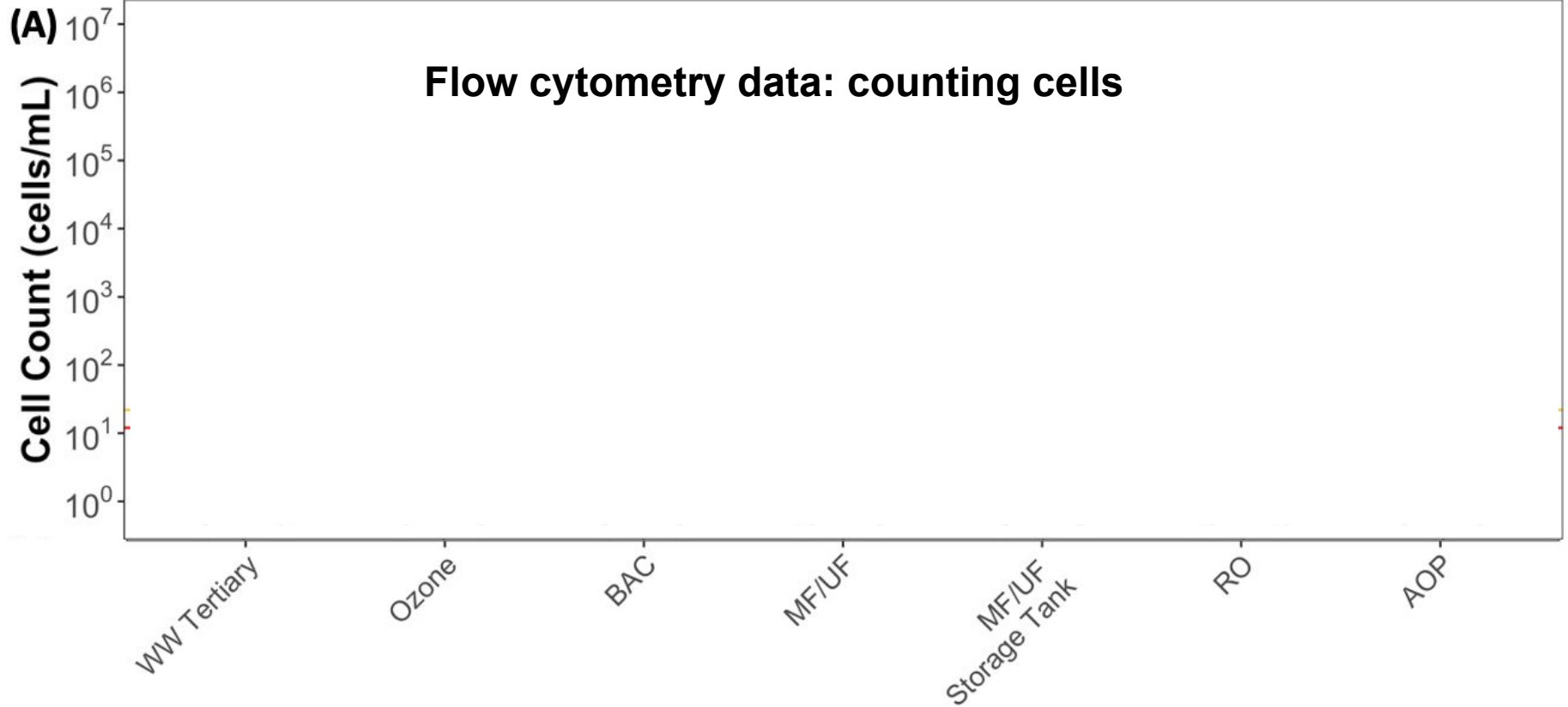
Potable reuse treatment train

x – FCM sample
x – DEUF sample

MF

UF

storage
tank

2-stages

3-stages

tertiary
wastewater

ozonation

BAC

RO

AOP

O_3 + activated carbon
remove organic matter

Membrane
Filters

UV + oxidant

Figure by Jorien Favere

Advanced treatment removes microorganisms from water

(A)

Cell Count (cells/mL)

10^7

10^6

10^5

10^4

10^3

10^2

10^1

10^0

Flow cytometry data: counting cells

WW Tertiary

Ozone

BAC

MF/UF

MF/UF Storage Tank

RO

AOP

Advanced treatment removes microorganisms from water

(A)

Cell Count (cells/mL)

10^7
10^6
10^5
10^4
10^3
10^2
10^1
10^0

Flow cytometry data: counting cells

Intact cells in drinking water (in CA)
(Kennedy 2021, Env. Sci. Water Res. & Tech.)

WW Tertiary   Ozone   BAC   MF/UF   MF/UF Storage Tank   RO   AOP

Advanced treatment removes microorganisms from water

Miller et al. (2022)
ES&T engineering

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

Amplicon seq data:
counting unique taxa

Observed ASVs (y-axis): 0, 250, 500, 750, 1000, 1250

Sampling location (x-axis): Tertiary_WW, BAC, MF, RO

Kantor et al. (in prep)

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

Kantor et al. (in prep)

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

Amplicon seq data: Comparing communities

Location
- ⊠ Treated WW
- ■ BAC
- ▲ MF
- ● RO combined
- ● RO 3–stage
- ● RO 2–stage

Kantor et al. (in prep)

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

Kantor et al. (in prep)
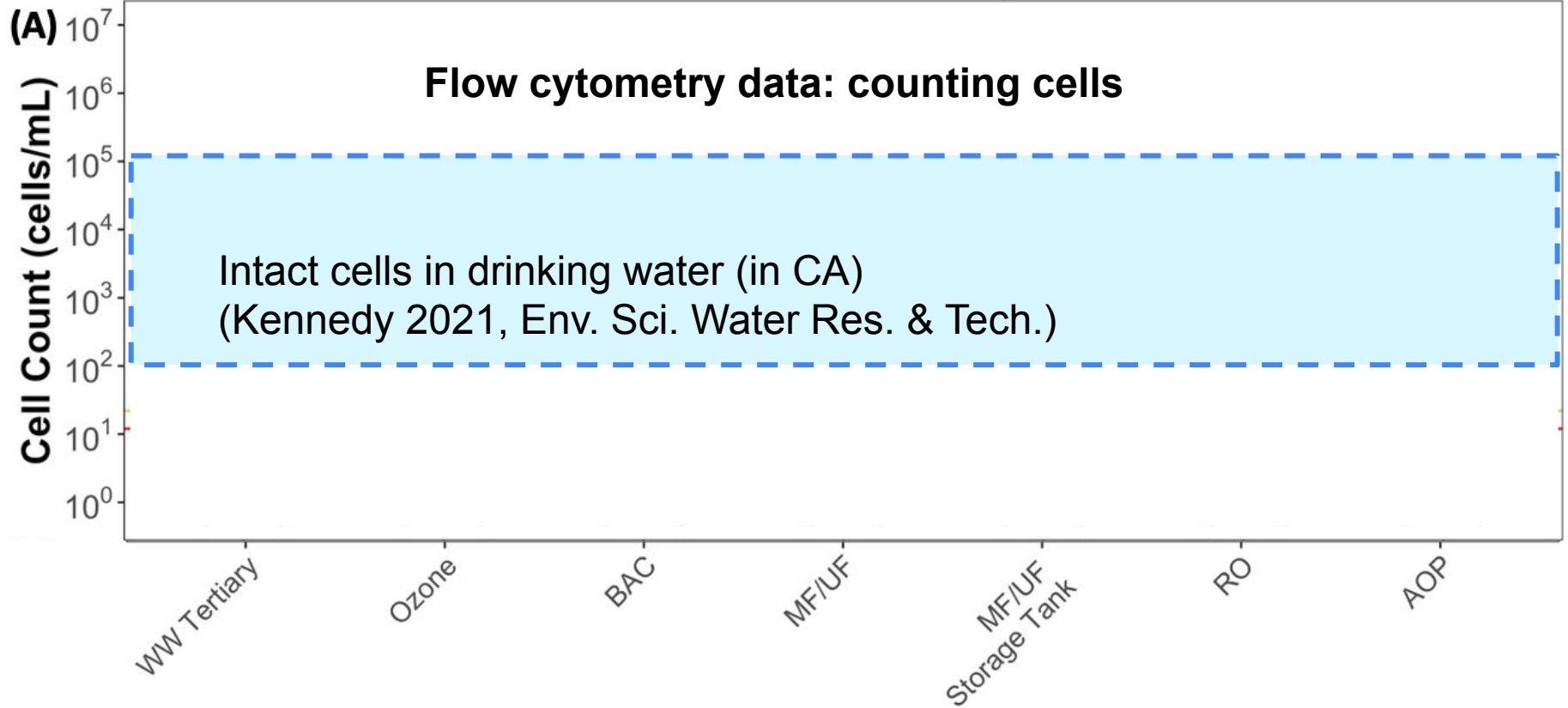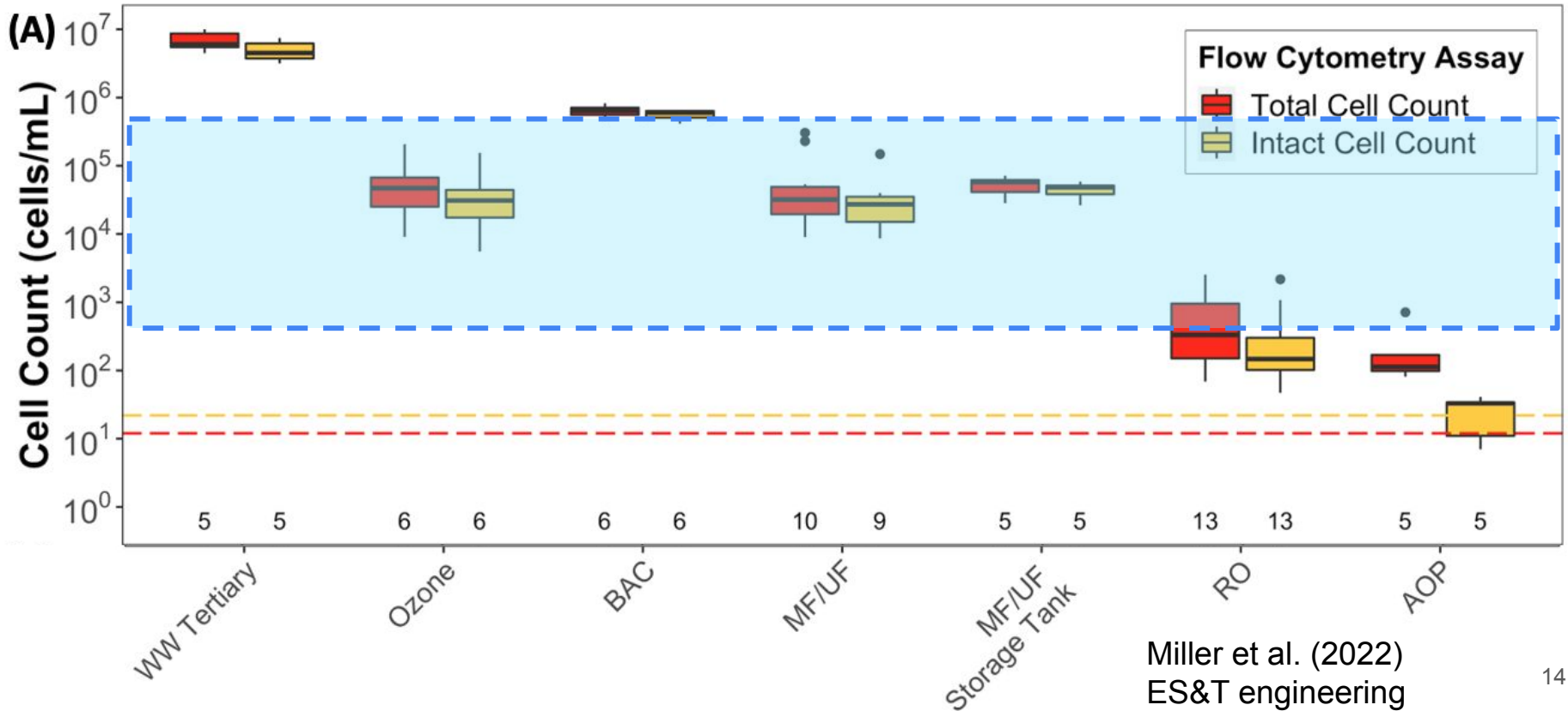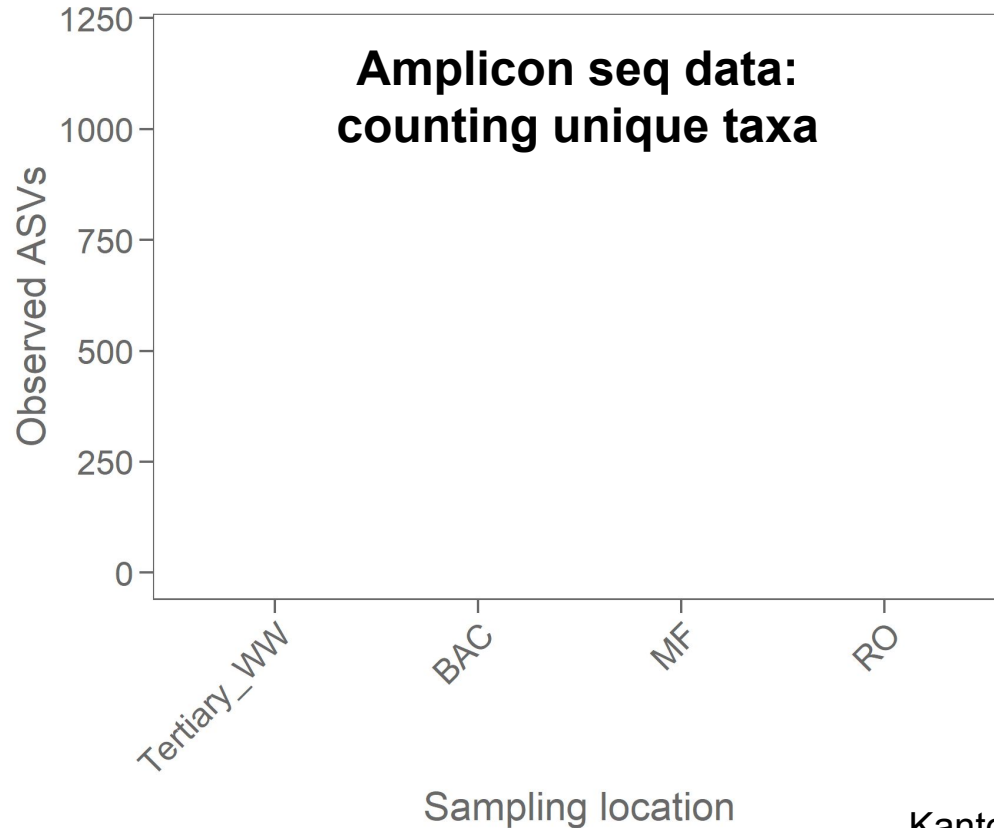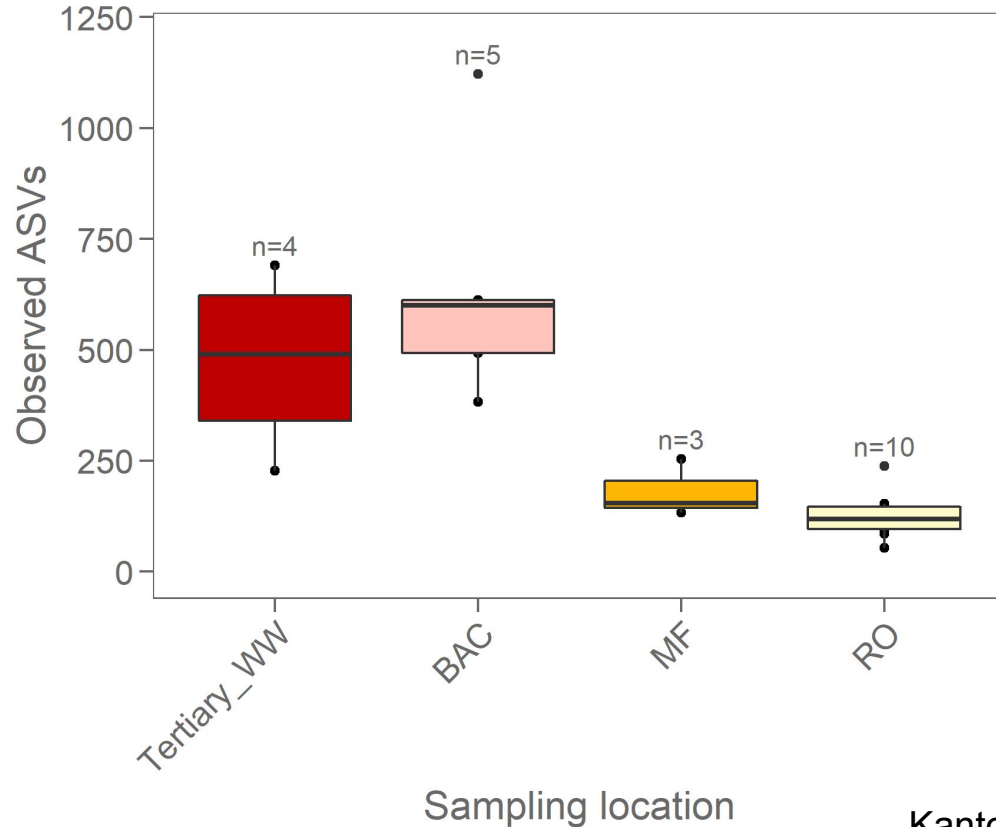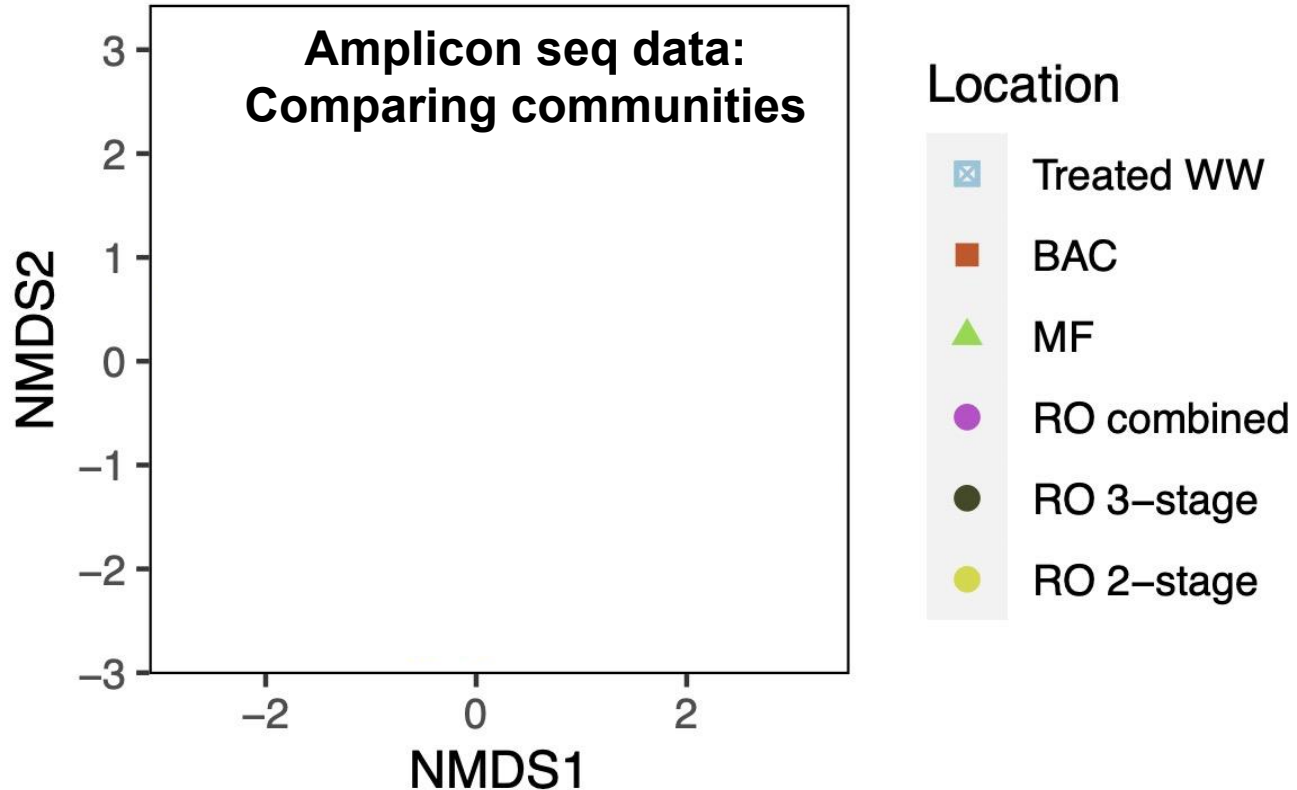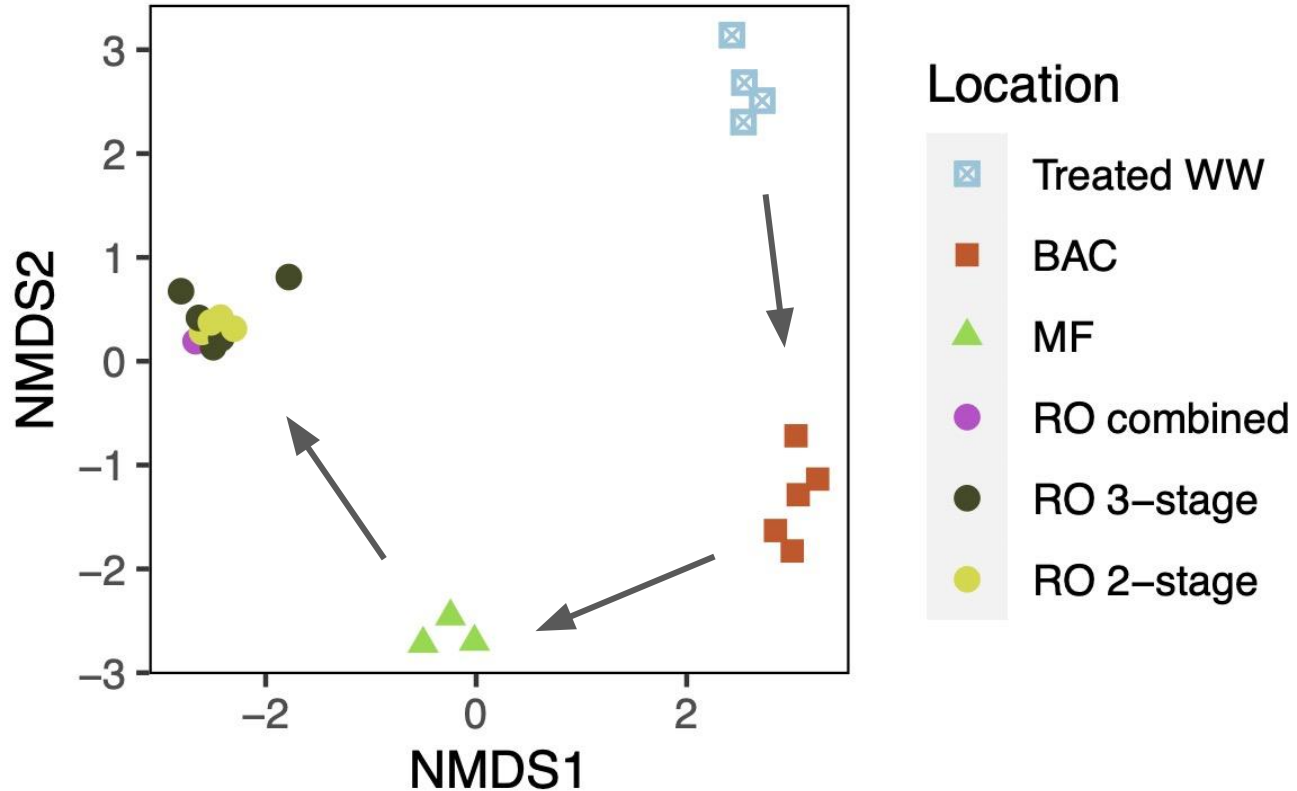
How do changes in water systems affect microbial communities?

2. Direct Potable Reuse
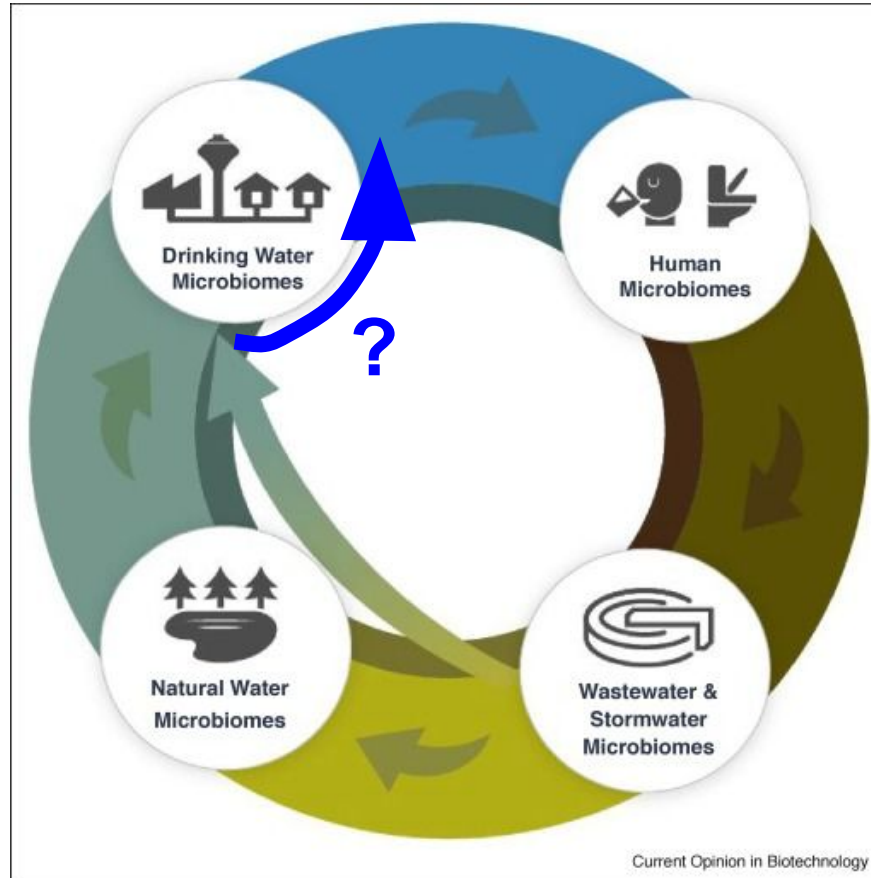
Raskin and Nielsen (2019)

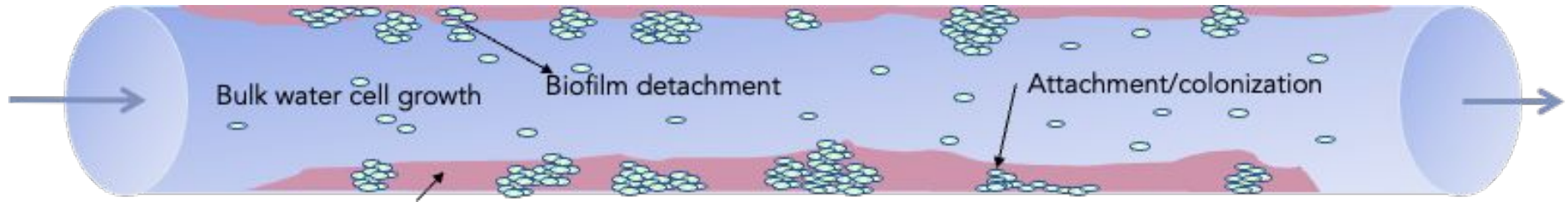# Drinking water distribution systems are complex, not sterile

Bulk water cell growth Biofilm detachment Attachment/colonization

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

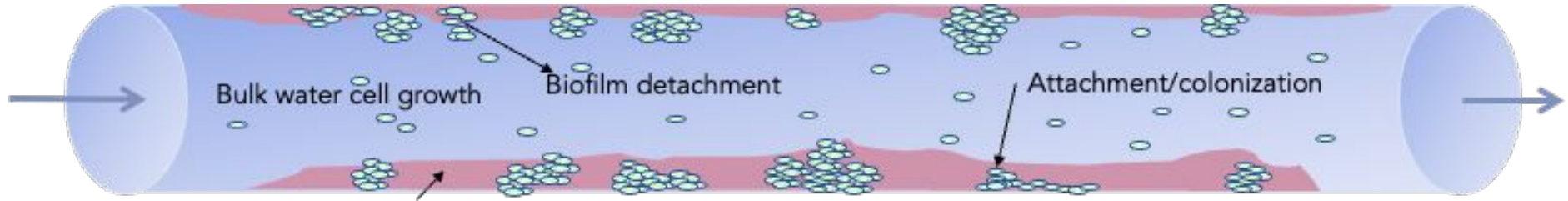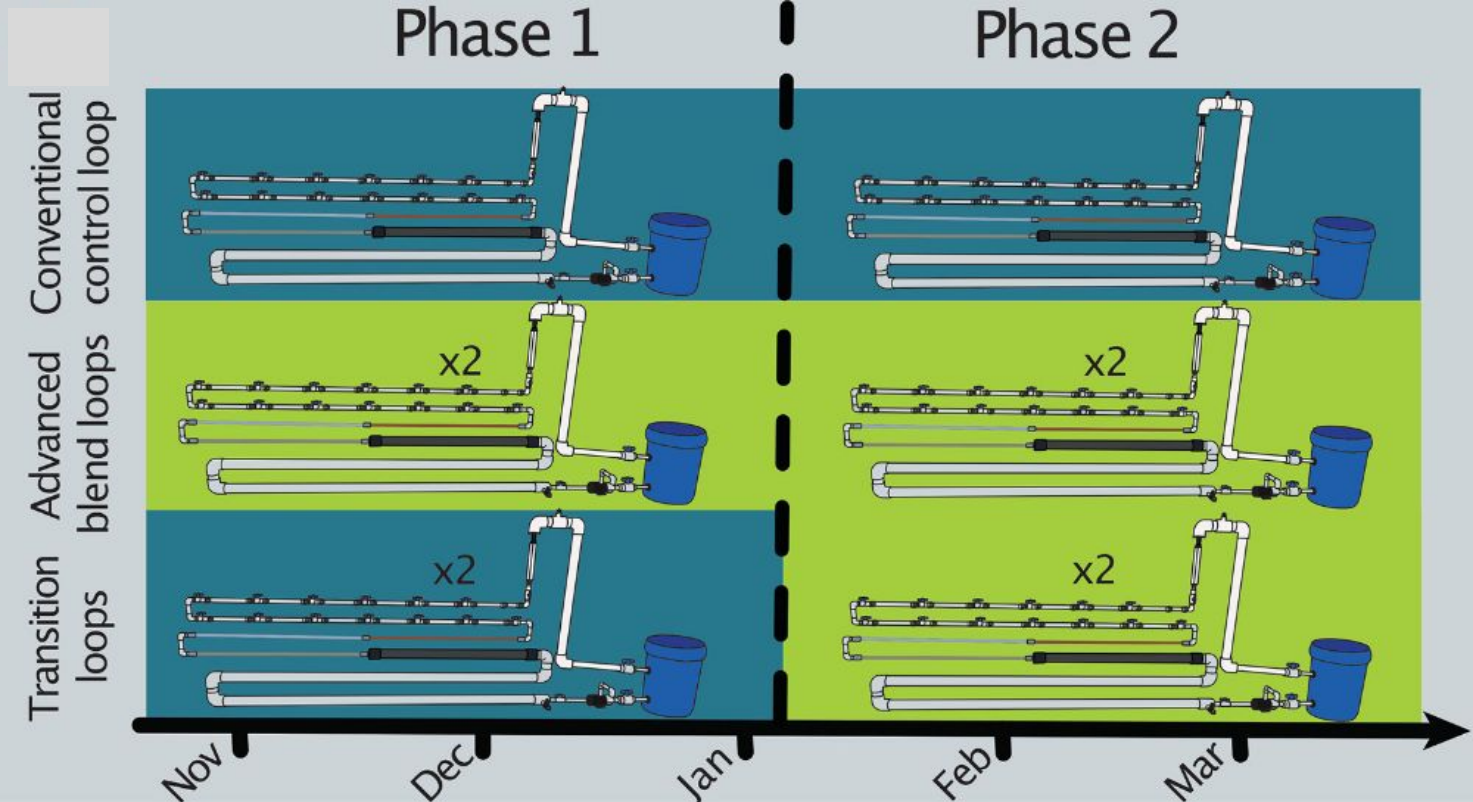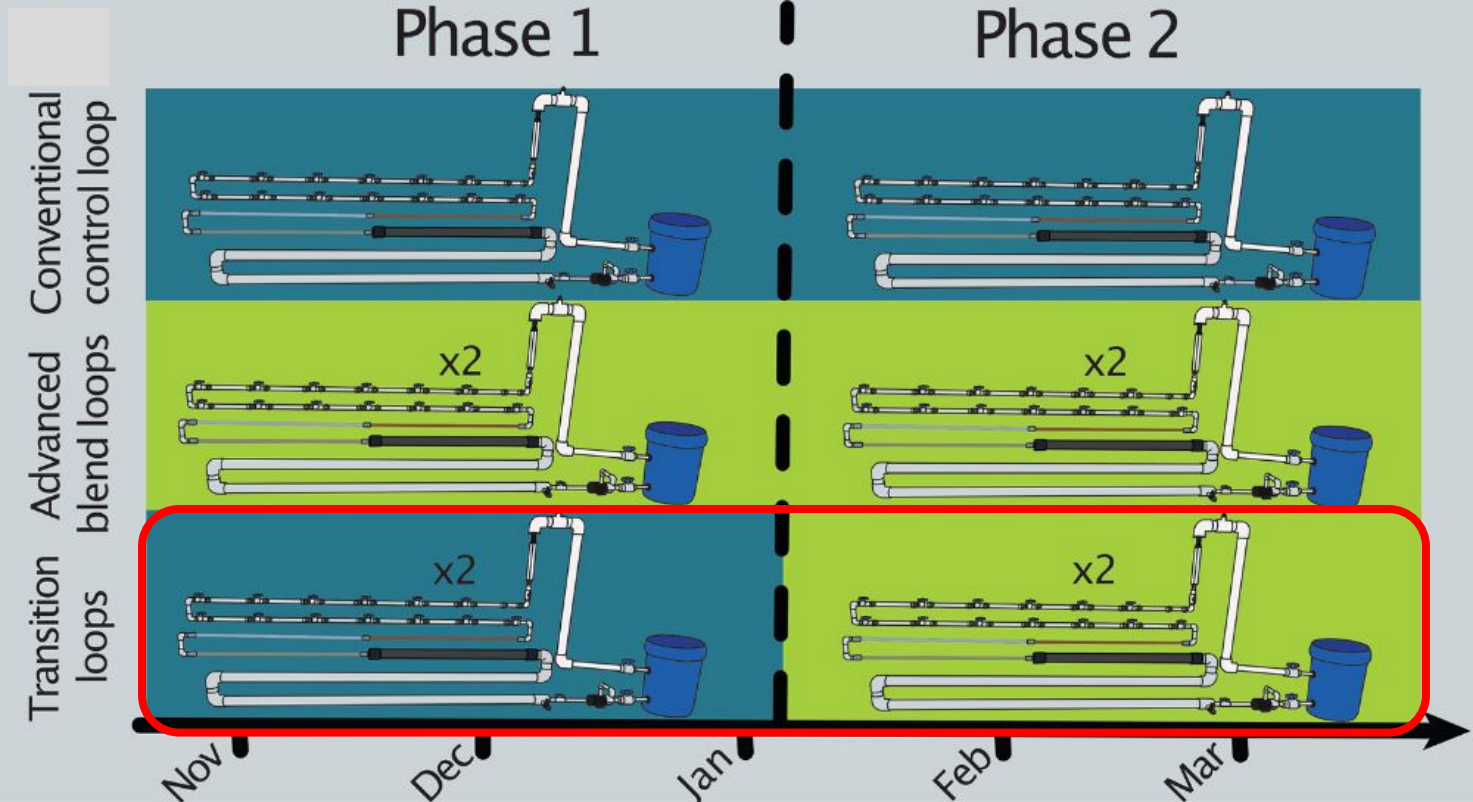Bulk water cell growth   Biofilm detachment   Attachment/colonization

Image by Hannah Healy

Pipe loops as a model system to study direct potable reuse

Introduction of advanced treated water to pipe loops

Kennedy et al. (2023) ESWRT

Introduction of advanced treated water to pipe loops
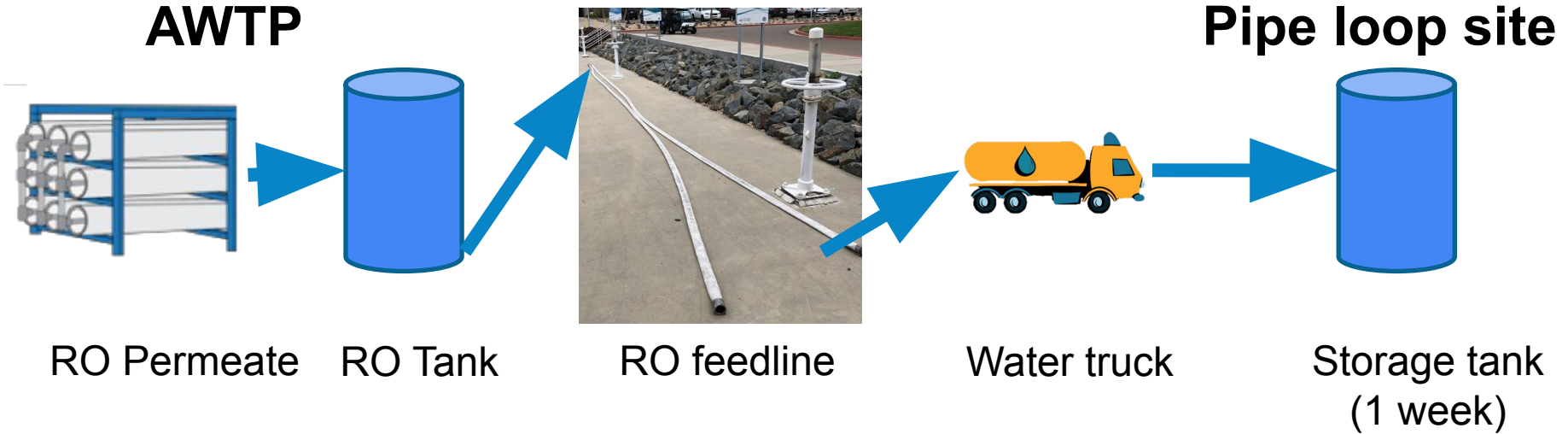

Kennedy et al. (2023) ESWRT

Introduction of advanced treated water to pipe loops shifted abundance of key organisms
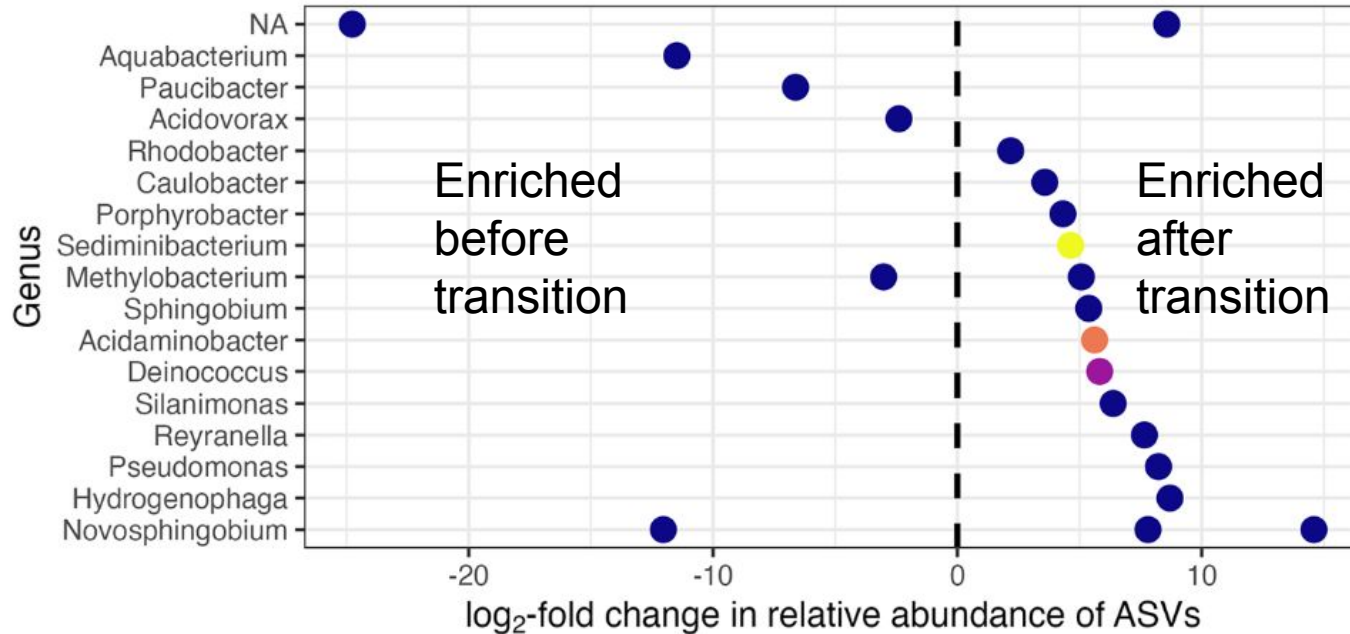
Kennedy et al. (2023)
ESWRT

But…
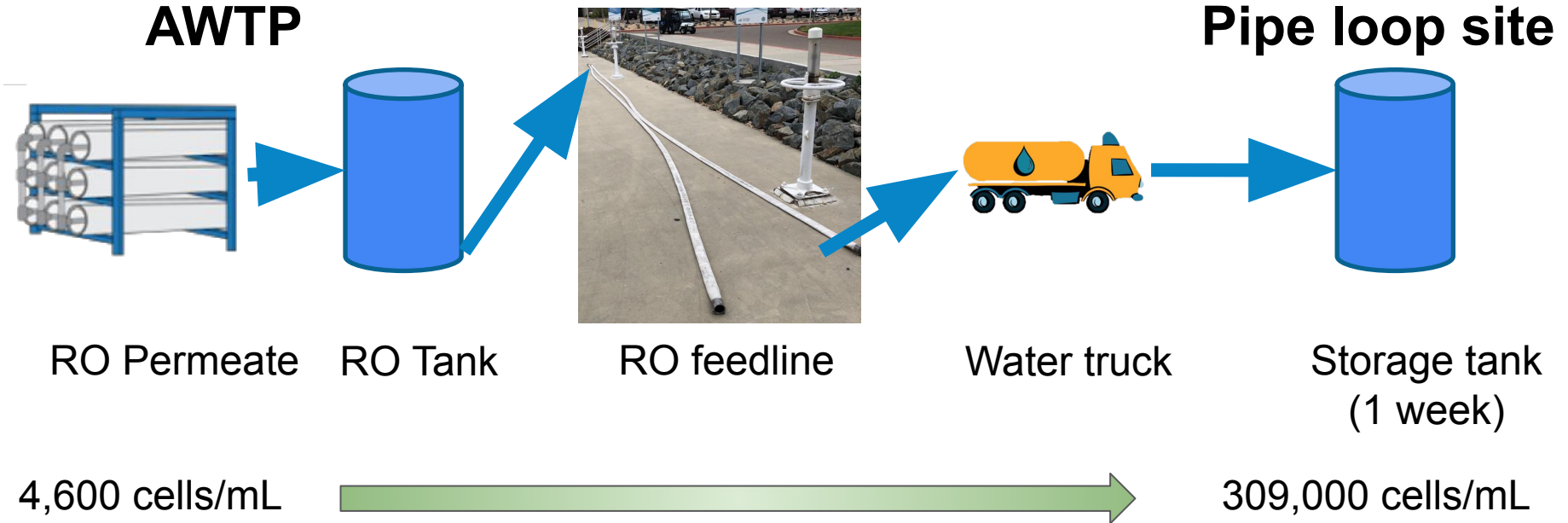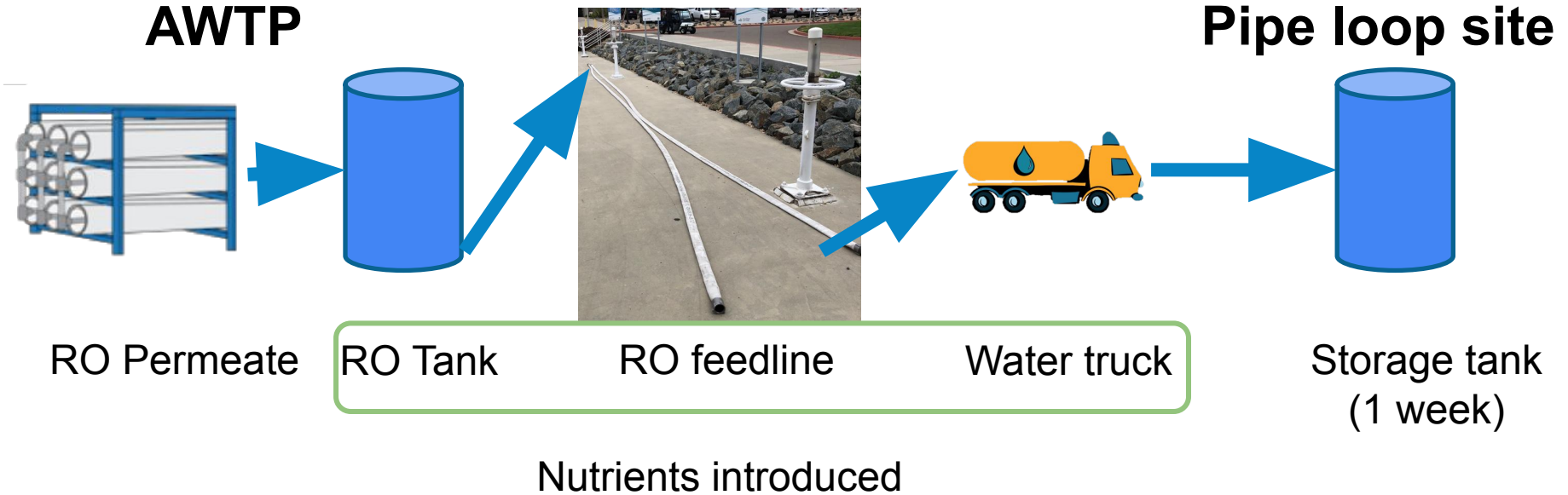# Advanced treated water is influenced by storage / transport

AWTP

Pipe loop site

RO Permeate   RO Tank   RO feedline   Water truck   Storage tank (1 week)

But…
Advanced treated water is influenced by storage / transport

AWTP

Pipe loop site

RO Permeate   RO Tank   RO feedline   Water truck   Storage tank (1 week)

4,600 cells/mL   →   309,000 cells/mL

Kennedy et al. (2023)
ESWRT

But…
Advanced treated water is influenced by storage / transport

AWTP

Pipe loop site

RO Permeate　　RO Tank　　　RO feedline　　　Water truck　　Storage tank (1 week)

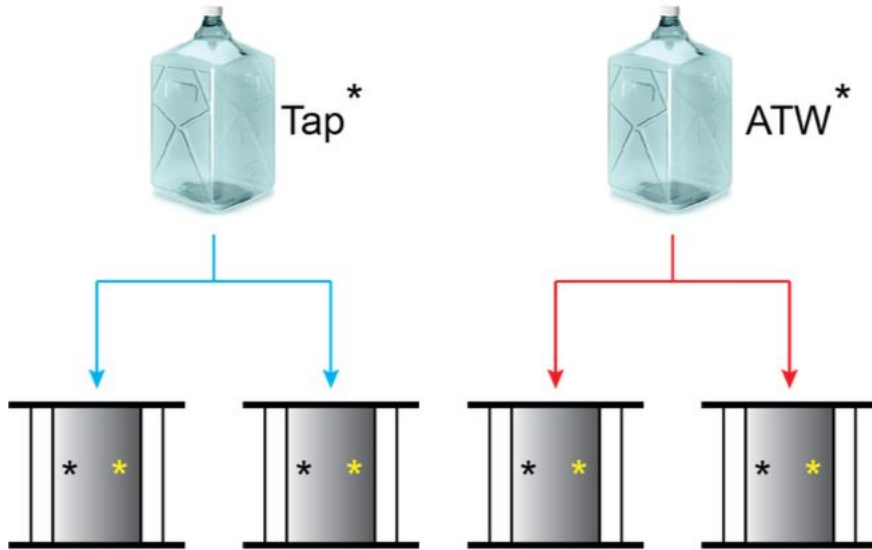Nutrients introduced

Kennedy et al. (2023)
ESWRT

Controlled inoculation of Advanced Treated Water: (work in progress)

See poster today!!

Alma Bartholow

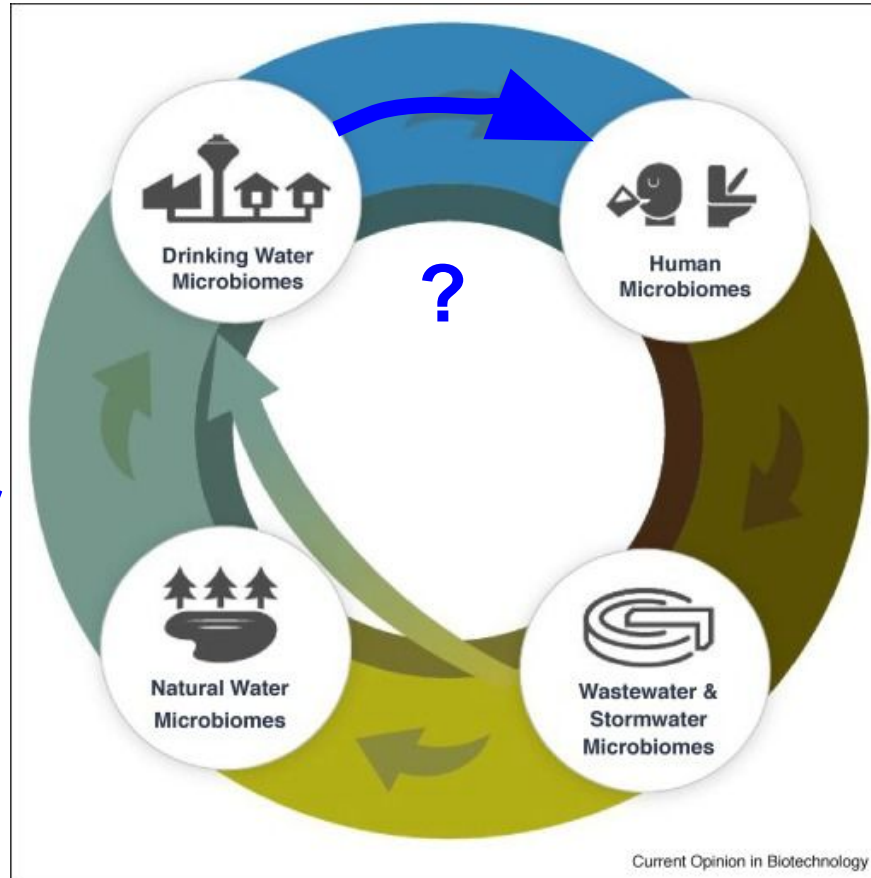# Controlled inoculation of Advanced Treated Water

Image credit: Alma Bartholow

Controlled inoculation of Advanced Treated Water

Image credit: Alma Bartholow
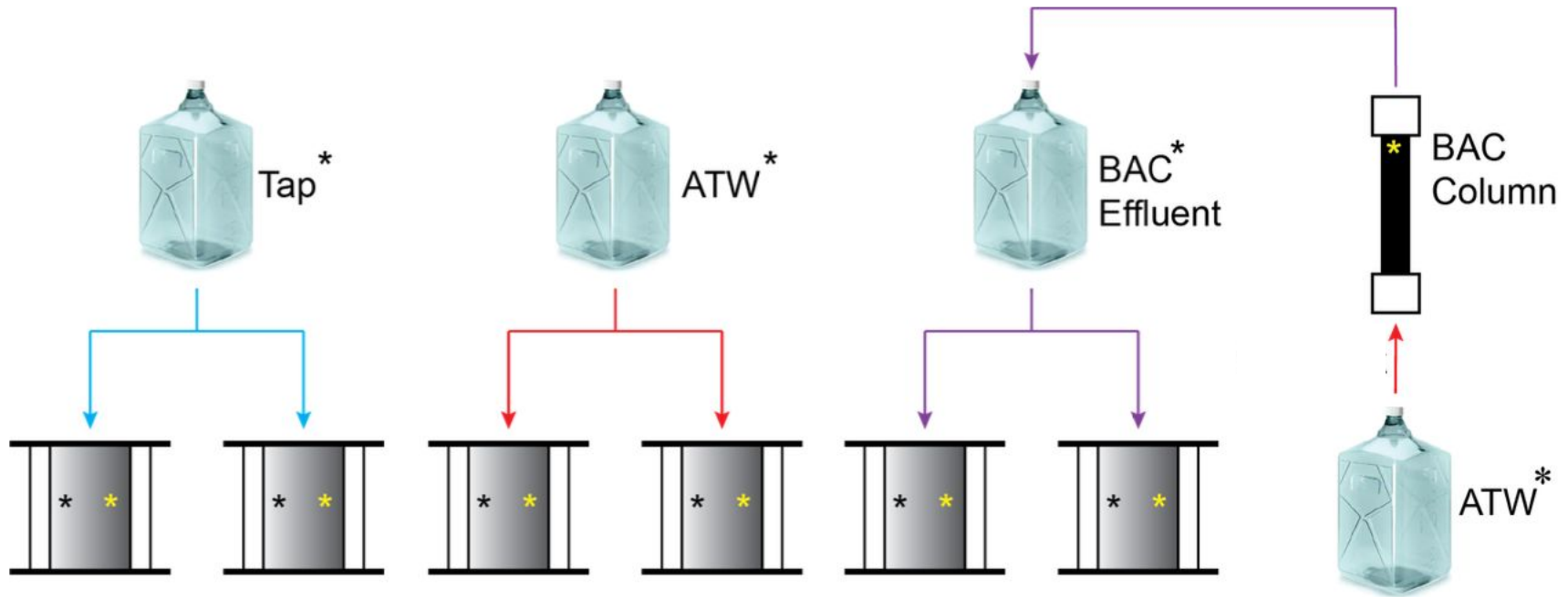
How do changes in water systems affect microbial communities?

3. Drinking water distribution system

Drinking Water Microbiomes

Human Microbiomes

?

Natural Water Microbiomes

Wastewater & Stormwater Microbiomes

Current Opinion in Biotechnology

Raskin and Nielsen (2019)

Low water use in annular reactors: a pandemic experiment
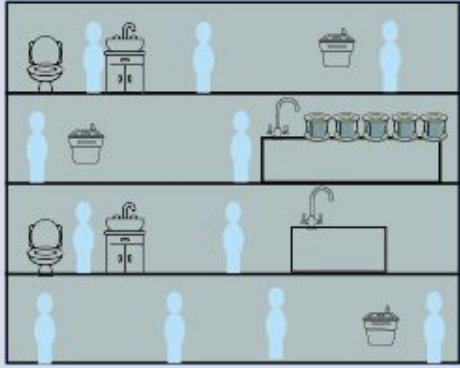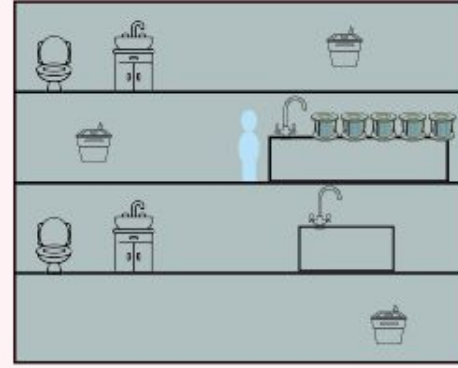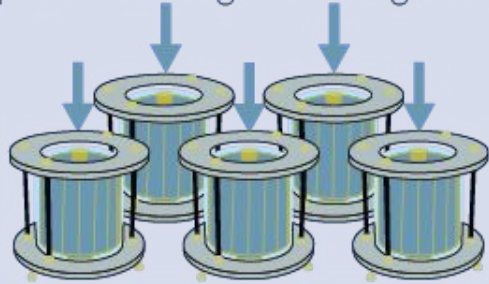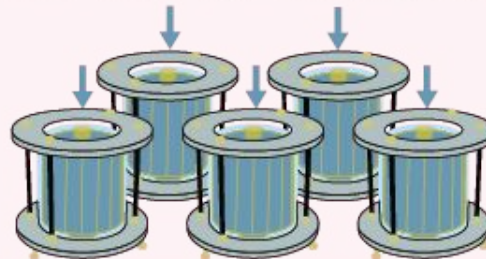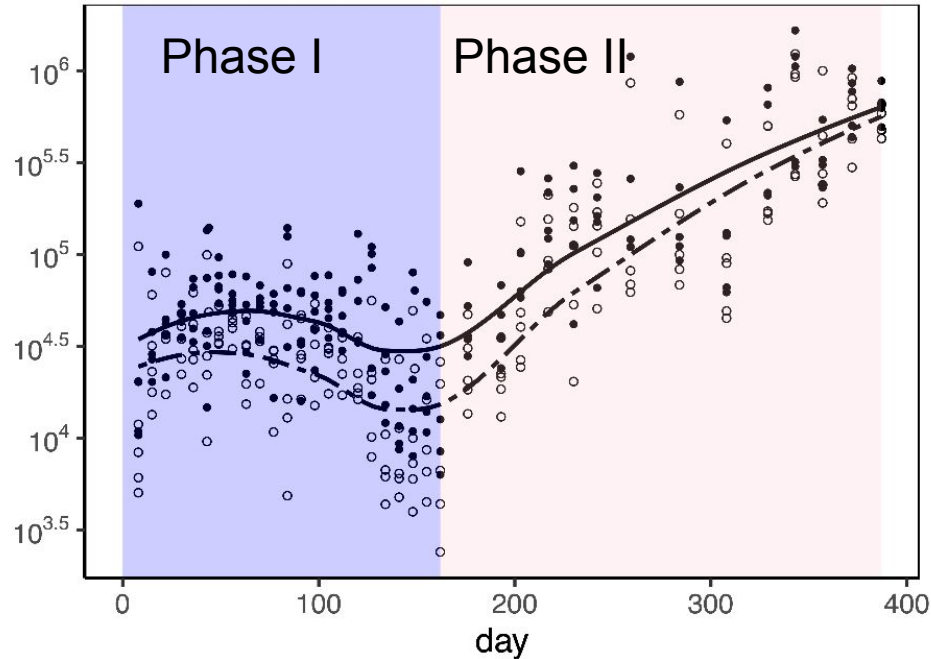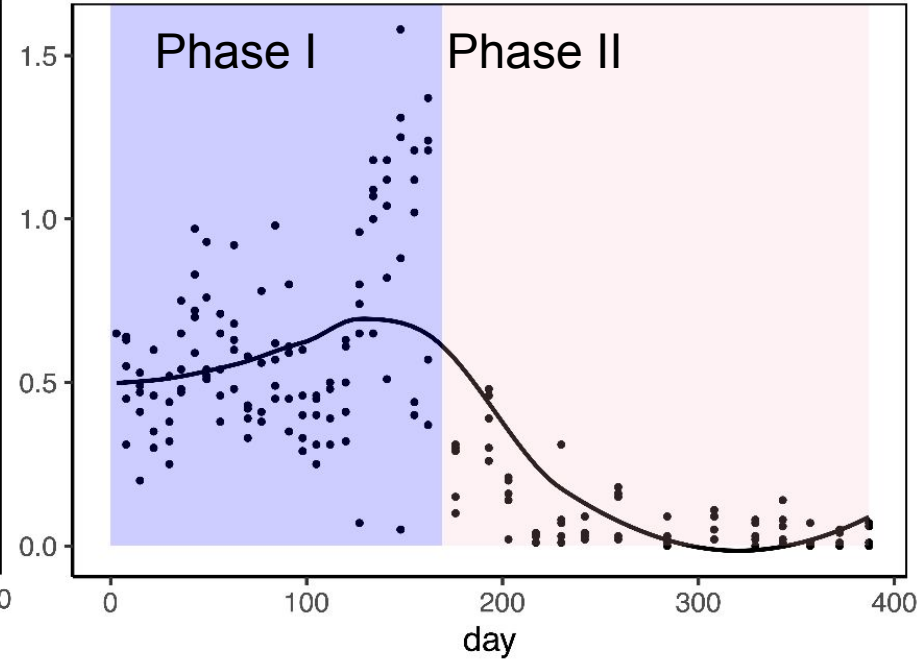
Cell counts increased and chlorine decreased

Cell counts

Total chlorine

*but each reactor behaved somewhat differently
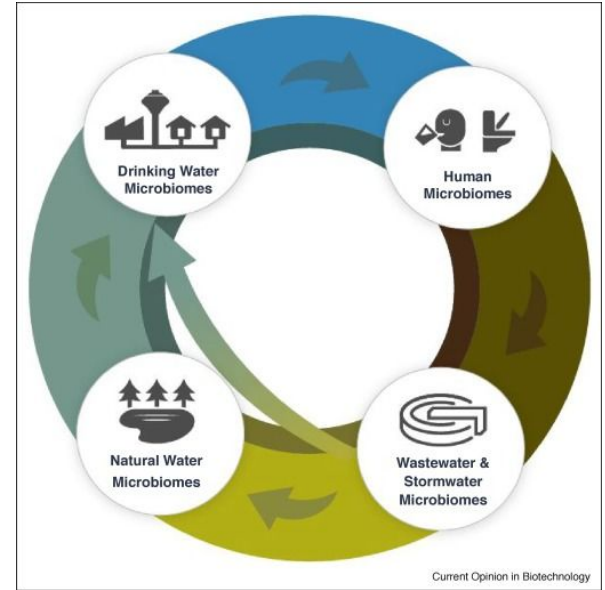
Healy et al. (accepted)

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Community & functional changes with increased water age

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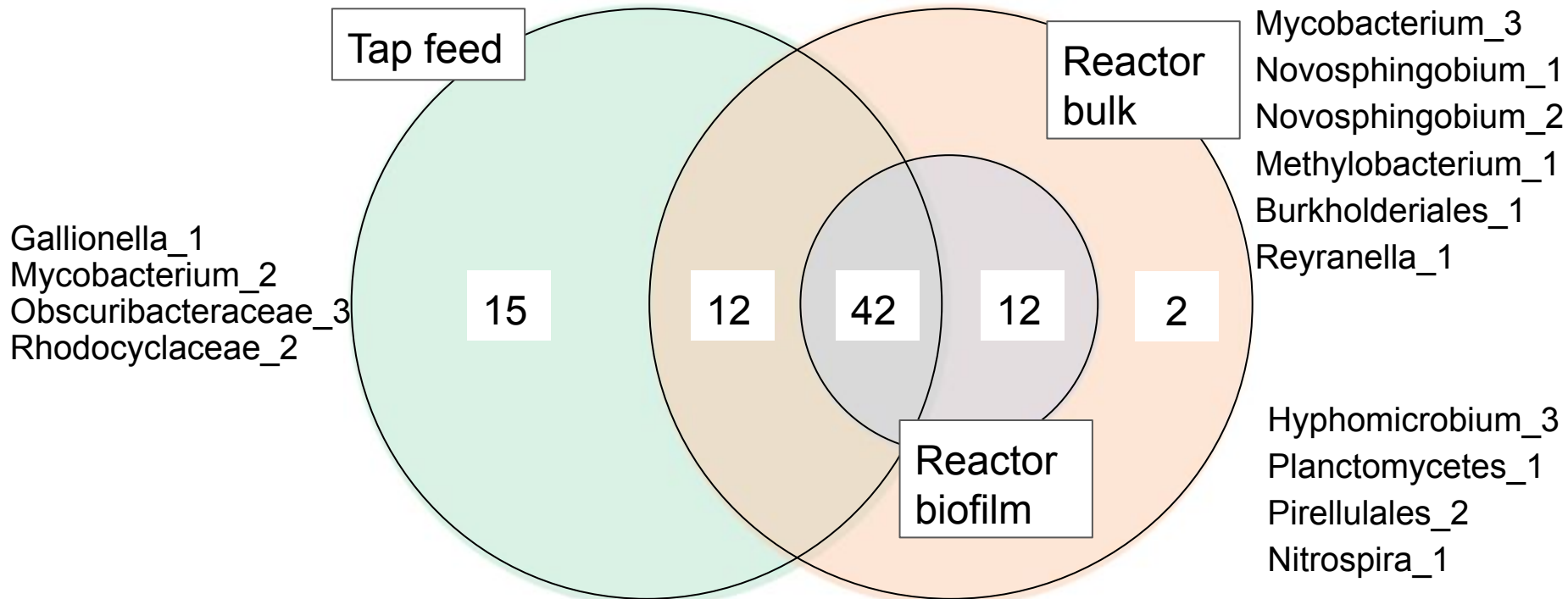

log(2) fold change

Phase I

Phase II
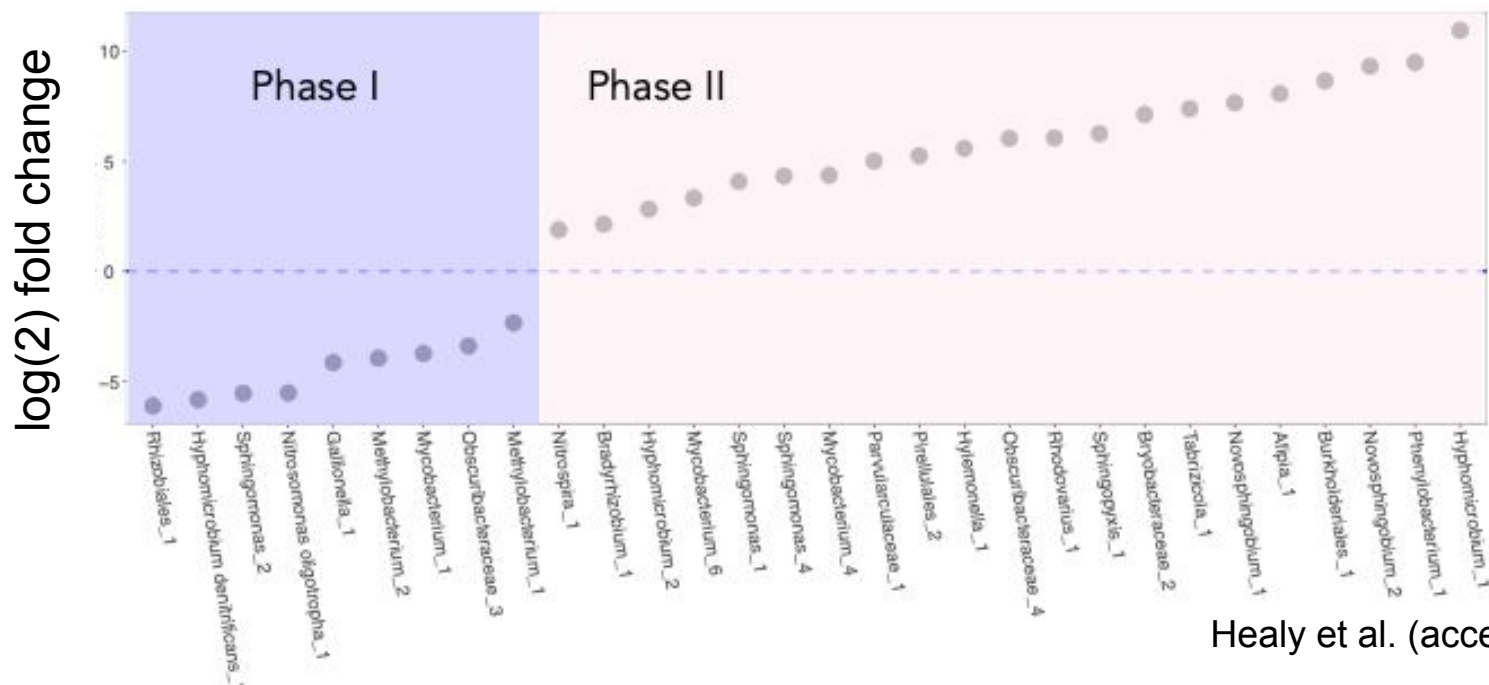
Key takeaways

1. Drinking water ≠ sterile

2. Advanced treatment → transformed microbial community

3. Pure water can be easily contaminated

   a. Could controlled microbial inoculation increase stability?

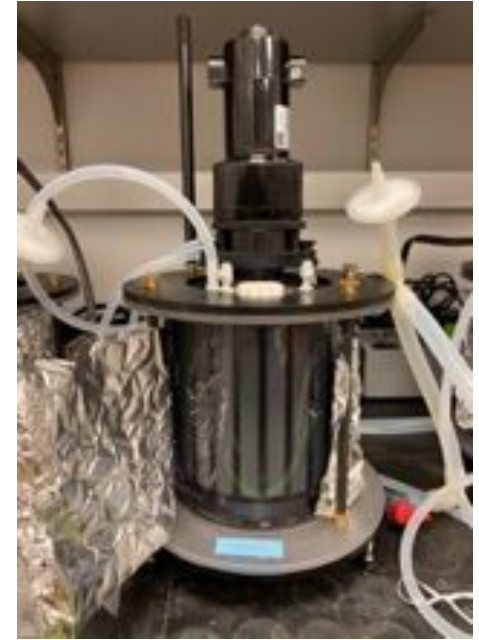4. Within distribution system, the water age affects the community

rkantor@berkeley.edu

83 high quality metagenome-assembled genomes (MAGs) some enriched in reactor feed, bulk, or biofilm

Tap feed

Reactor bulk

Reactor biofilm

Gallionella_1
Mycobacterium_2
Obscuribacteraceae_3
Rhodocyclaceae_2

15 | 12 | 42 | 12 | 2

Mycobacterium_3
Novosphingobium_1
Novosphingobium_2
Methylobacterium_1
Burkholderiales_1
Reyranella_1

Hyphomicrobium_3
Planctomycetes_1
Pirellulales_2
Nitrospira_1

Healy et al. (accepted)

Drinking water distribution system models

Pipe loops

Annular reactors

Questions about changes to water microbiomes

1. What happens as wastewater becomes drinking water: advanced water treatment

2. What happens when advanced treated water enters a distribution system: potable reuse

3. What happens when a distribution system experiences low use/stagnation?