Opportunities for enhanced attenuation of trace organics during infiltration

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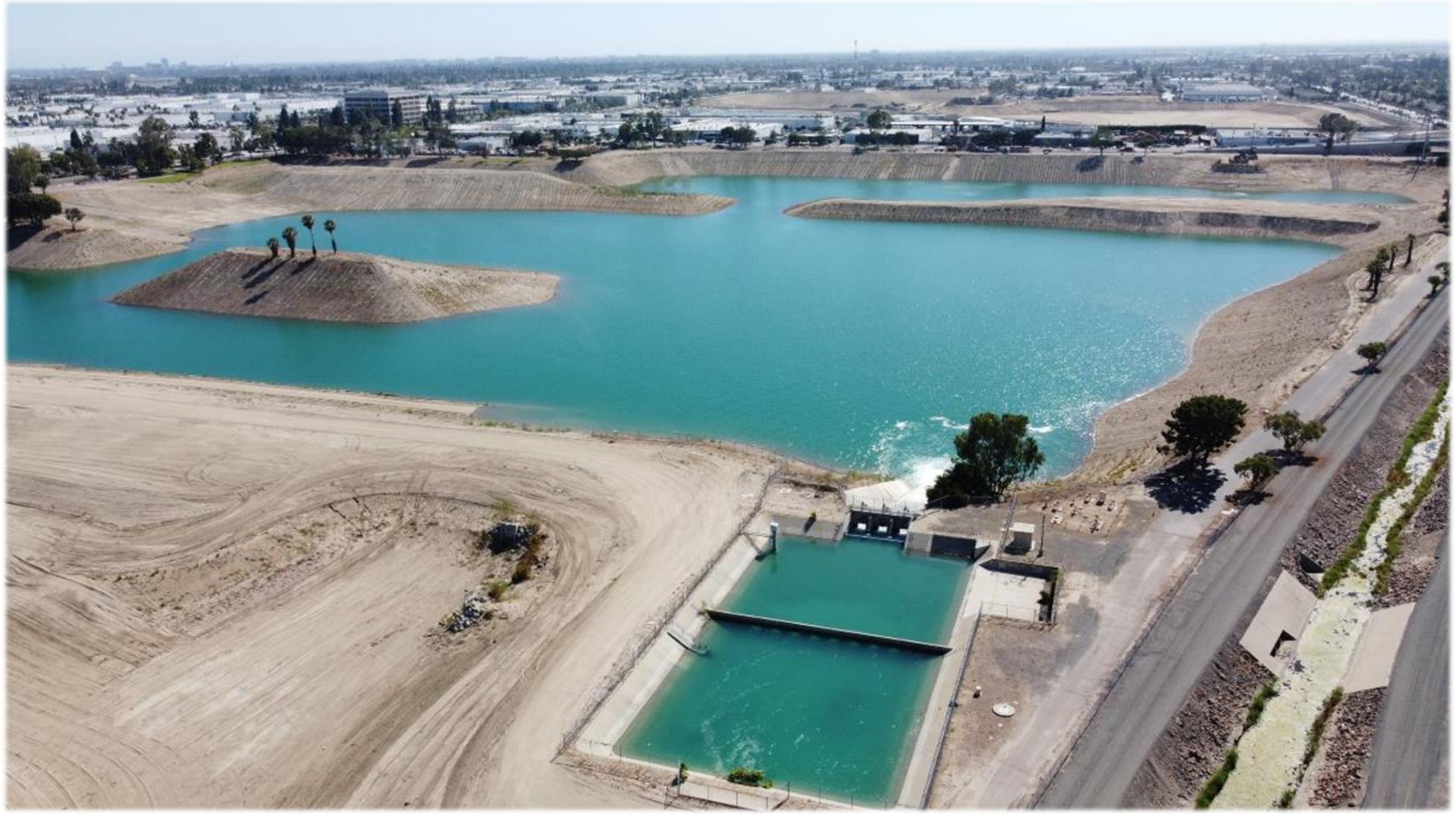


Photo Credit: Megan Plumlee, Orange County Water District

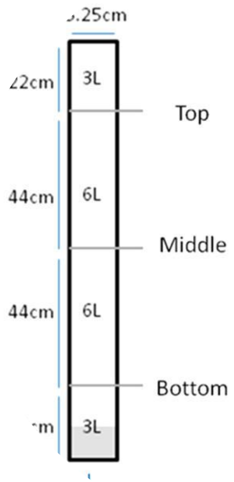
Nature-based solutions for water treatment and storage

Goal: Purify water while increasing supply in water stressed regions

Approach: Develop, study, and optimize nature-based systems with multifaceted treatment (biological and abiotic).

Opportunities:

1) Water resource applications
2) Reliable & clean water supply
3) Sustainable: People, planet, & profit



INFILTRATION

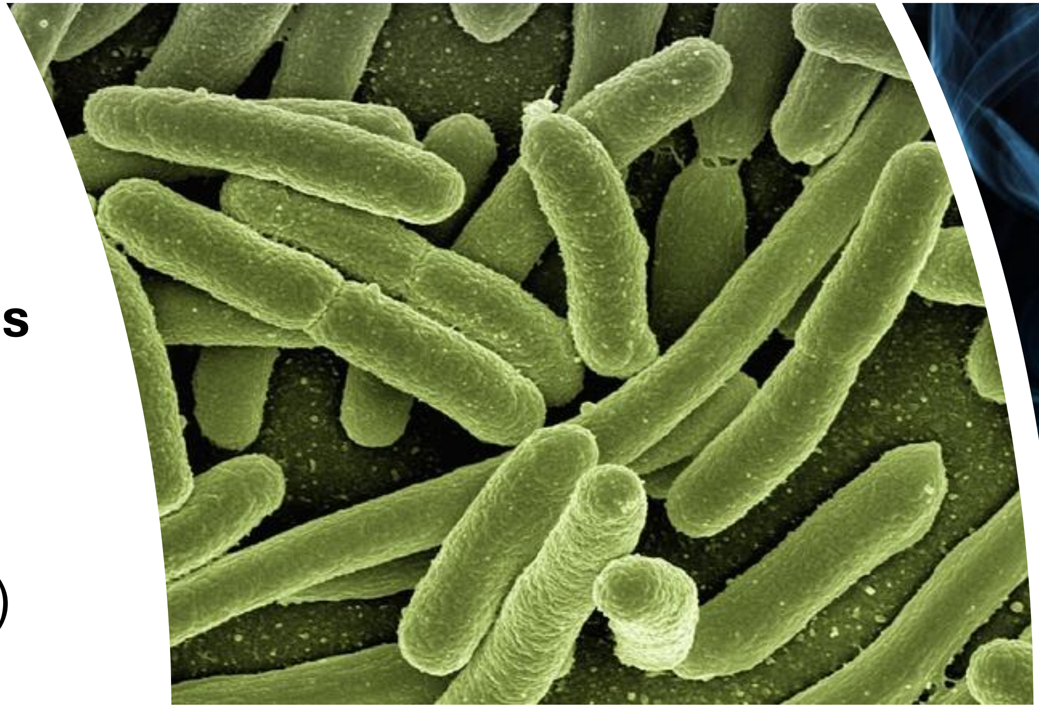
Water Quality Challenges

TDS/turbidity

Shifts in redox/pH
Precipitation (e.g. Fe, Mn)
Mobilization (e.g. As, U)

Introduction
(e.g. DBPs, Pharma, PFAS)

Attenuation Mechanisms
physical
chemical
biological



INFILTRATION

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Introduction
Nitrosamines, Pharma, PFAS

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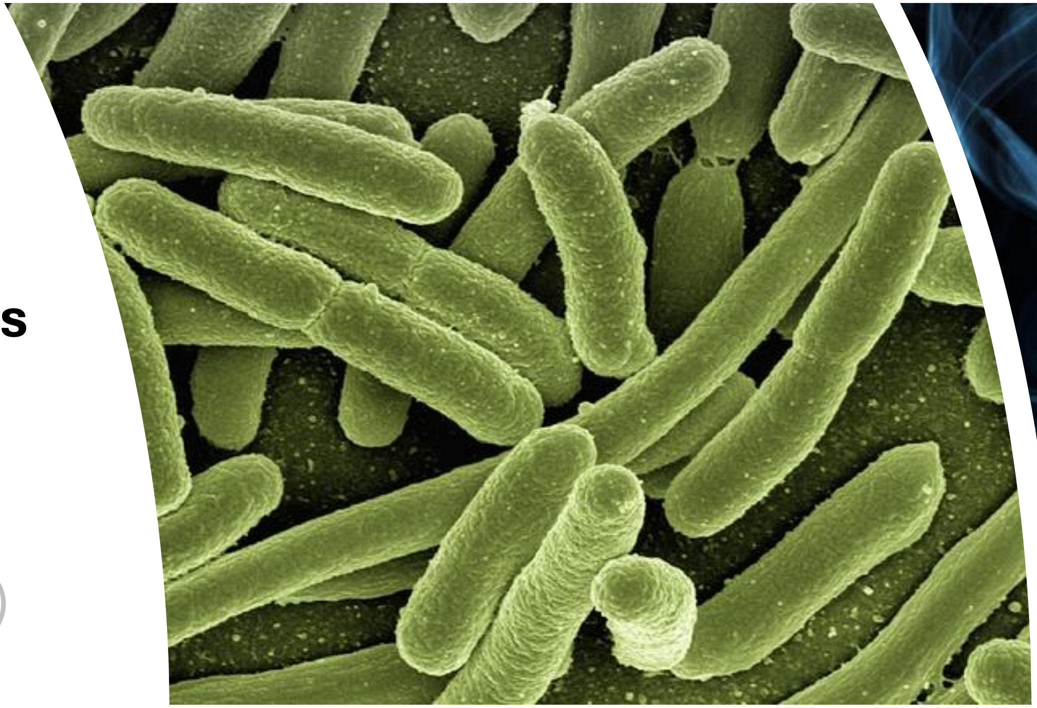
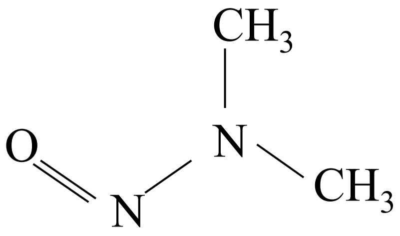


Pharmaceuticals are a ubiquitous class of trace organics associated with water reuse

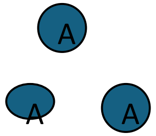
Bexfield et al., 2020 ES&T

Kolpin et al., 2002 ES&T

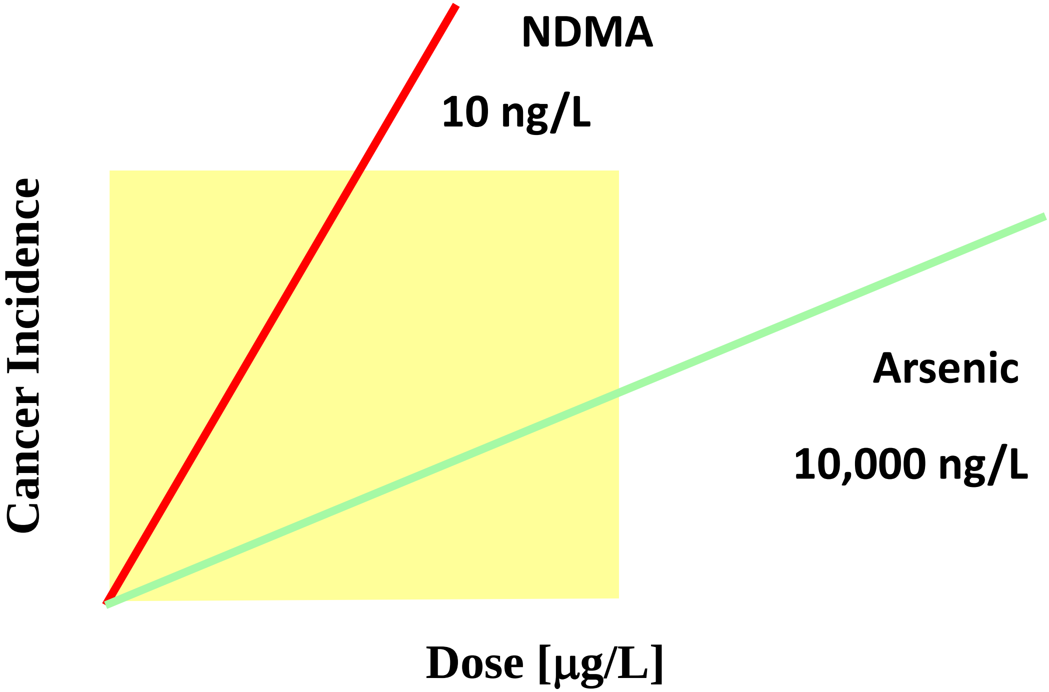
Disinfection can form carcinogenic (and recalcitrant) byproducts



"It' s tasteless, odorless, and dissolves instantly in water....“



Acute Exposure = Toxin
(Homicide ≤ 1.5 grams)



Chronic Exposure = Carcinogen
(EPA safe exposure = 0.7 ng/L)


Nature based-solutions offer a sustainable treatment alternative

Can we manage infiltration (and other nature-based systems) to increase biotransformation capabilities?

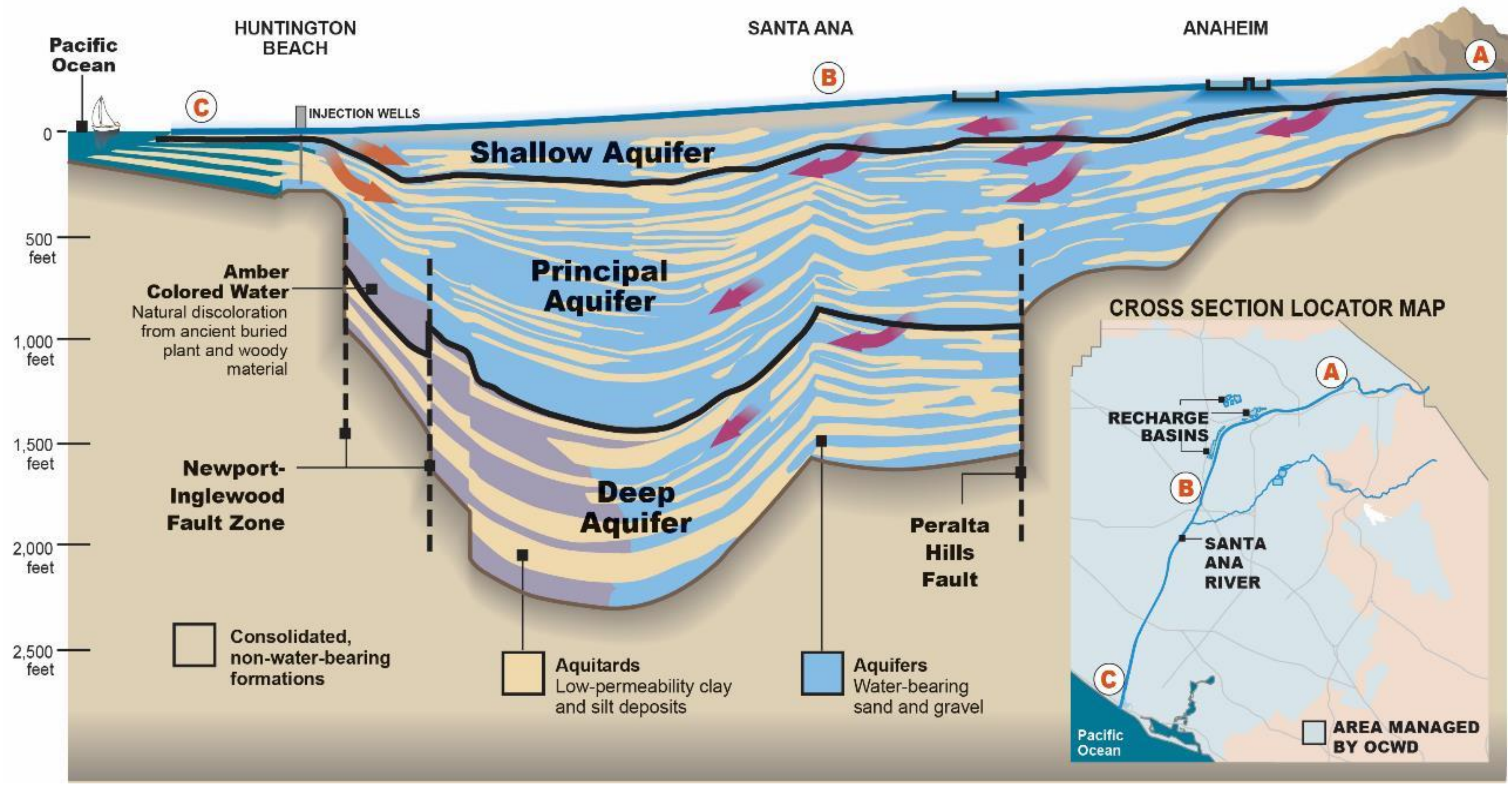


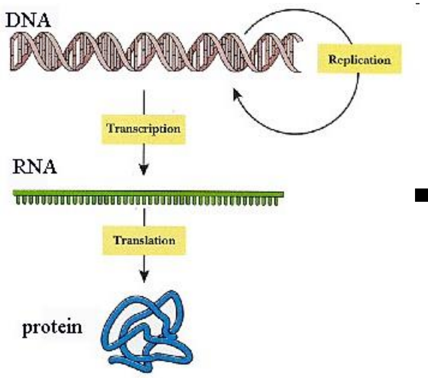
Image of Orange Country Groundwater Basin: Courtesy of OCWD

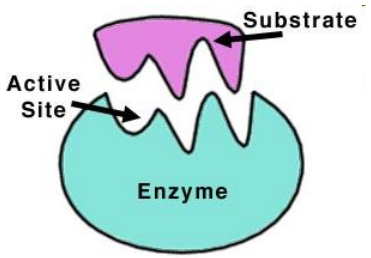
The challenge of trace organics and biodegradation

1ppt = ng/L = 1×10^{-12}
There are 5×10^{10} drops of water in an Olympic size swimming pool

Growth is supported by mg/L or more: How can we select for desirable attributes?

Environmental stress can promote nitrosamine biodegradation



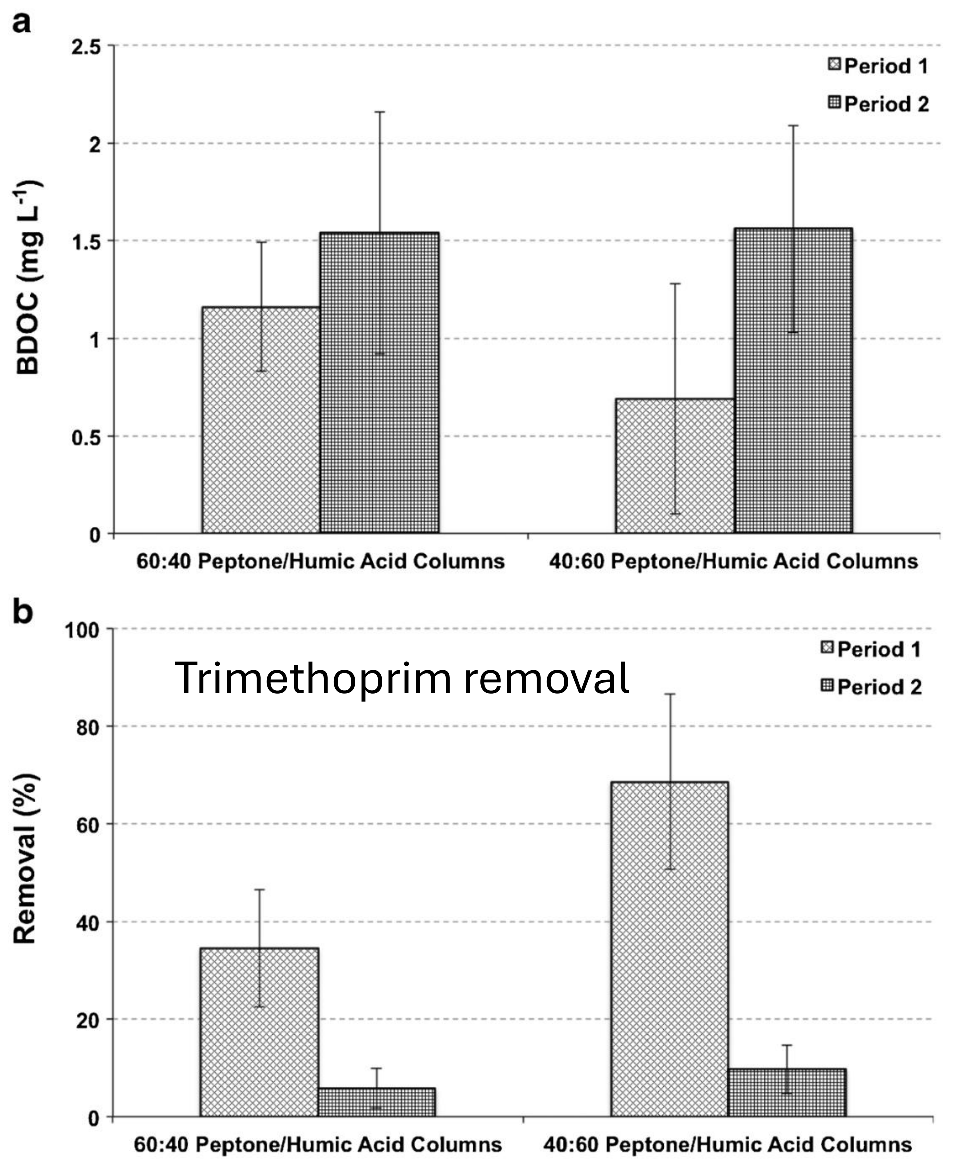


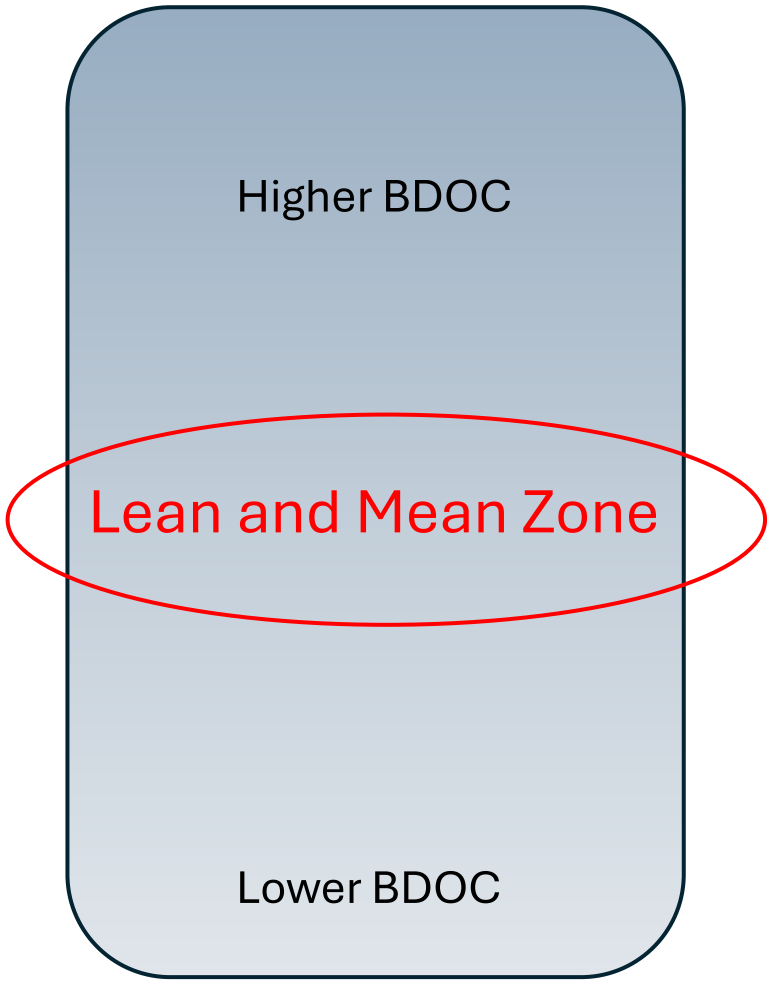
↑ environmental stress = ↑ oxygenases = ↑ biodegradation

Food
Oxygen
Desiccation
Toxicity

Sharp et al (2007). An inducible propane monooxygenase is responsible for *n*-nitrosodimethylamine degradation by *Rhodococcus* sp. Strain RHA1. *Appl Environ Microbiol*. **73**:6930-6938

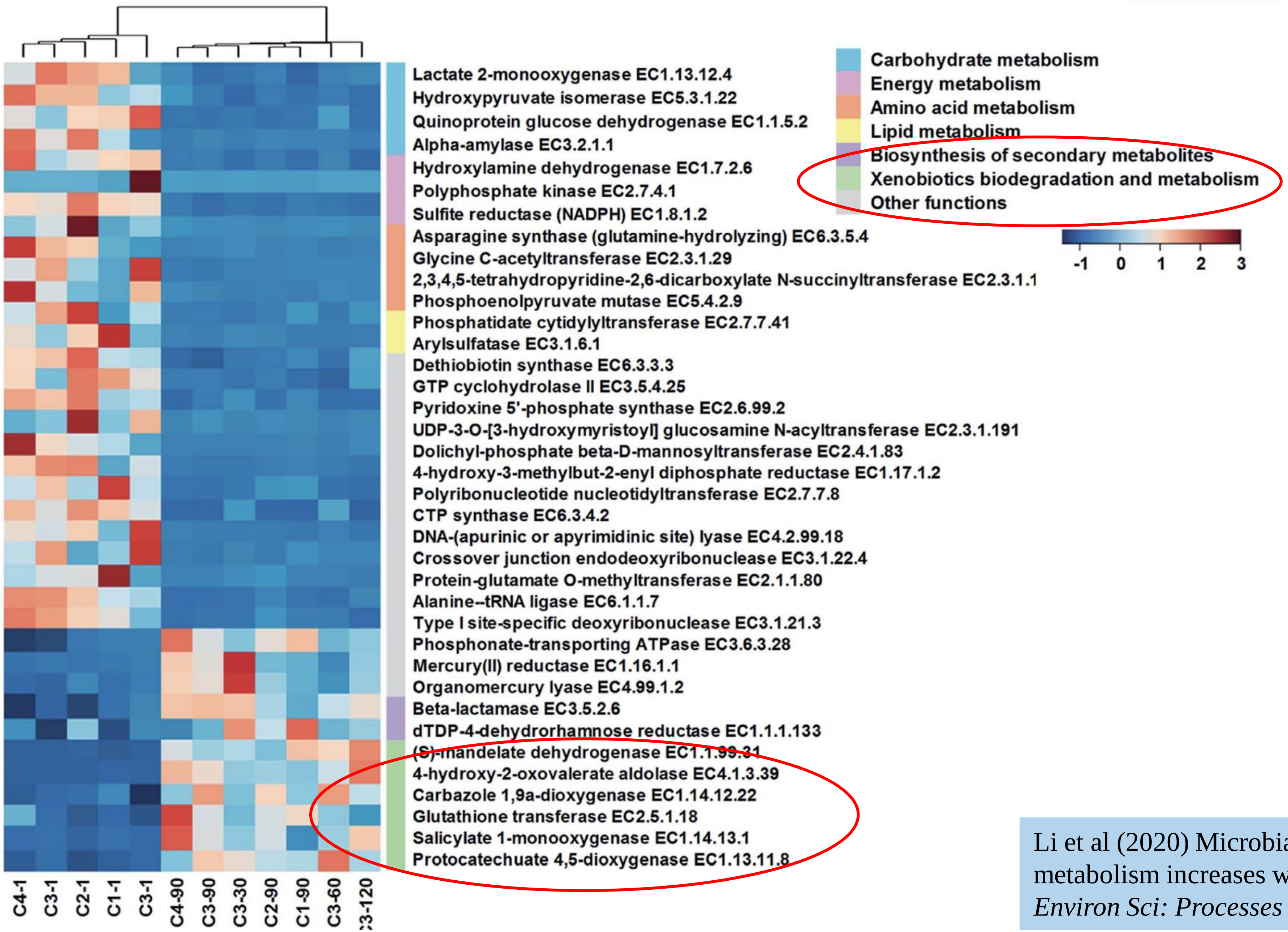
Apply this toward antibiotics during simulated infiltration





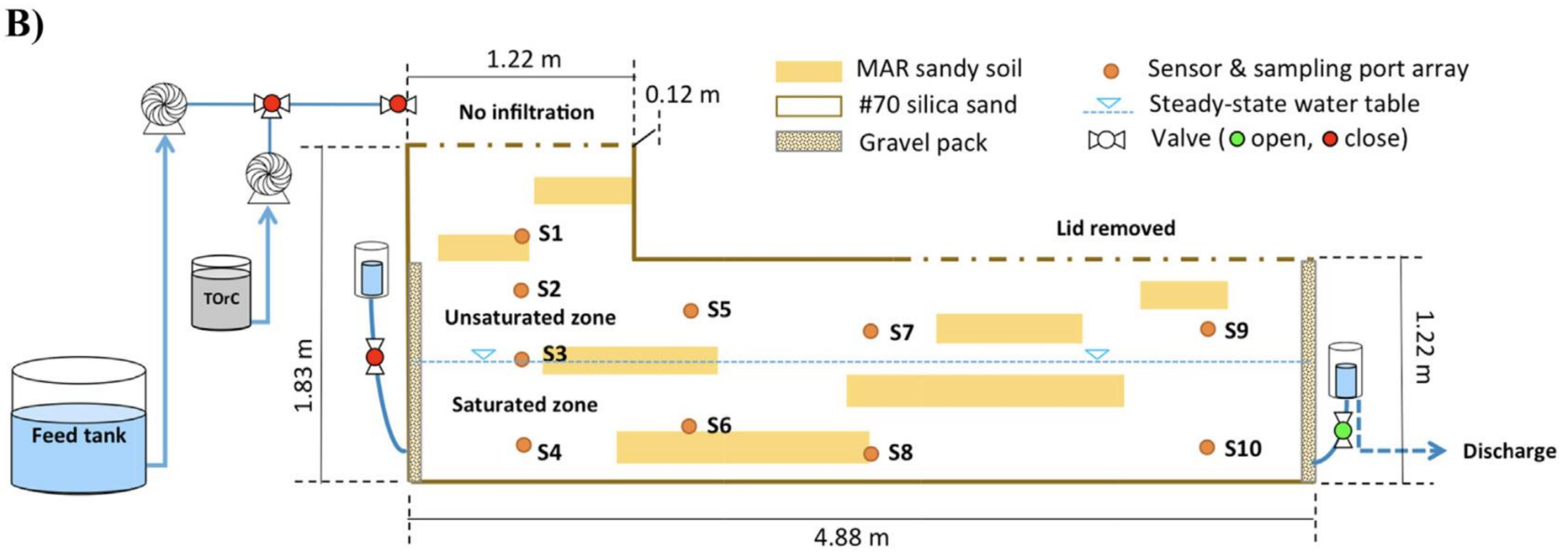
Li et al (2014) Role of primary substrate composition on microbial community structure and function and trace organic chemical attenuation in managed aquifer recharge systems. *Appl. Micro. Biotechnology* 98:5747

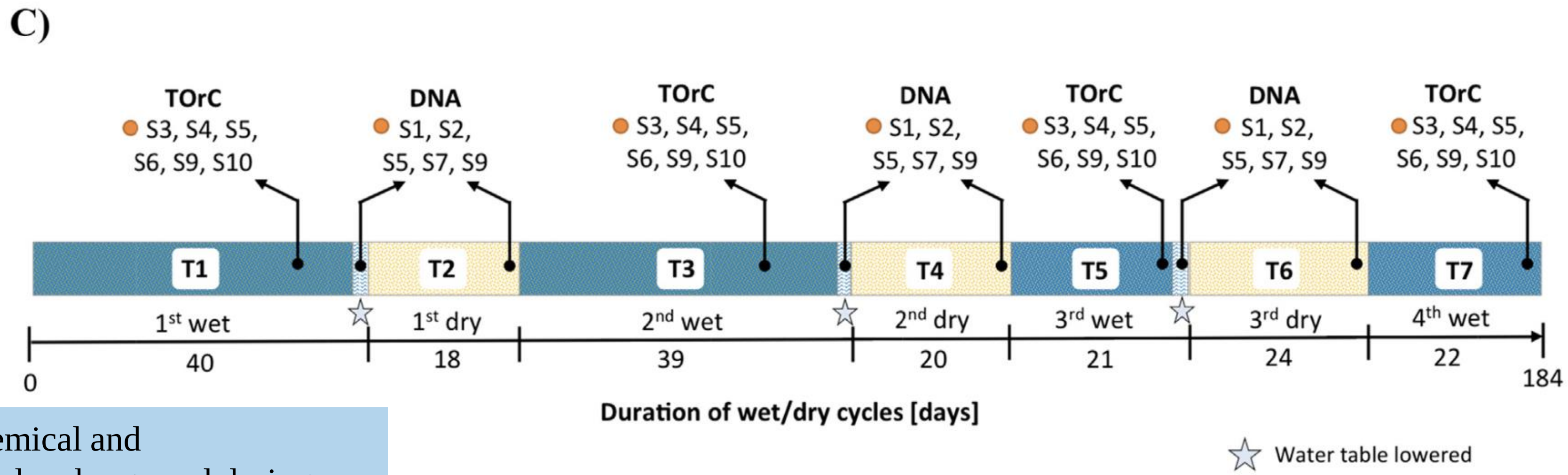
Spatial profiles reveal increased biodegradation potential



Li et al (2020) Microbial genetic potential for xenobiotic metabolism increases with depth during biofiltration. *Environ Sci: Processes Impacts.* 22: 2058-2069

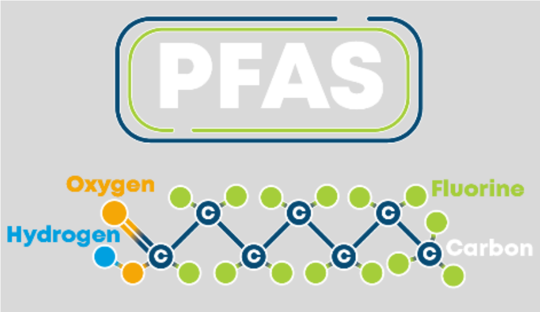
Wet/dry cycles can further influence biodegradation potential





Regnery et al (2020) Hydrogeochemical and microbiological effects of simulated recharge and drying within a 2D meso-scale aquifer. *Chemosphere*. *241*, 125116.

A looming threat for subsurface banked water



- PFAS = Per- and Polyfluoroalkyl Substances
  - ”Forever chemicals”
  - PFOA = Perfluorooctanoic Acid ($C_8HF_{15}O_2$)
  - PFOS = Perfluorooctane Sulfonate ($C_8HF_{17}O_3S$)
- Man-made compounds, no natural occurrence
- Used since the 1950s in many industrial and municipal applications
  - Heat resistant/ flame retardant, oil resistant, water resistant
- Properties which make these compounds useful also result in their persistence in the environment
- Varying (and moving target) approaches to regulation of concentration in drinking water at the State and Federal Level

Compound	Proposed MCL
PFOA	4 ppt (ng/L)
PFOS	4 ppt (ng/L)
PFNA	1.0 (Hazard Index)
PFHxS	
PFBS	
HFPO-DA(GenX0	

$$\frac{\text{PFHxS: } [0] \text{ ppt}}{9.0 \text{ ppt}} + \frac{\text{PFNA: } [0] \text{ ppt}}{10.0 \text{ ppt}} + \frac{\text{HFPO-DA (Gen-X): } [0] \text{ ppt}}{10.0 \text{ ppt}} + \frac{\text{PFBS: } [0] \text{ ppt}}{2000.0 \text{ ppt}} + \;=\; [0]$$

Hazard Index (unitless)

The good: PFAS can undergo biodegradation
The bad: long time, the more fluorinated (per vs. poly) the more difficult
The ugly: often incomplete, precursors and reformation

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Contents lists available at ScienceDirect

Science of the Total Environment

journal homepage: www.elsevier.com/locate/scitotenv

Review

A review of microbial degradation of per- and polyfluoroalkyl substances (PFAS): Biotransformation routes and enzymes

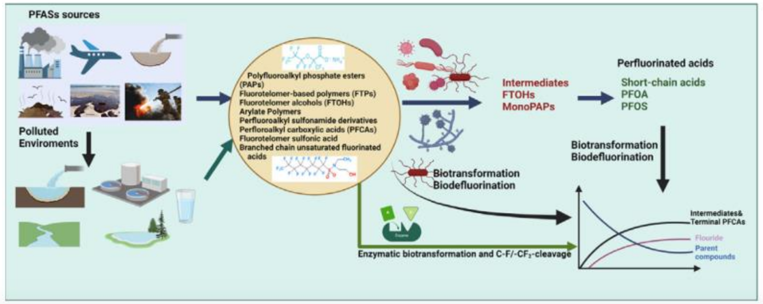
Ashenafi Berhanu [a,b,1], Ishmael Mutanda [a,1], Ji Taolin [a], Majjid A. Qaria [a], Bin Yang [c], Daochen Zhu [a,*]

[a] Biofuels Institute, School of Environmental and Safety Engineering, Jiangsu University, Zhenjiang, Jiangsu 212013, China
[b] Haramaya Institute of Technology, Department of Chemical Engineering, Haramaya University, Dire Dawa, Ethiopia
[c] Bioproducts, Sciences and Engineering Laboratory, Department of Biological Systems Engineering, Washington State University, Richland, WA 99354, USA

HIGHLIGHTS

- PFAS are toxic, bioaccumulative and persistent due to their recalcitrancy to microbial degradation.
- Physicochemical properties of PFAS relevant to biodegradation are discussed.
- Overview of occurrence of PFAS and their microbial degradation in environmental matrices
- Comprehensive synthesis of progress in microbial transformation/defluorination pathways
- Factors affecting PFAS biodegradation, challenges and prospects for bioremediation are discussed.

GRAPHICAL ABSTRACT



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Review

Microbial biotransformation of aqueous film-forming foam derived polyfluoroalkyl substances

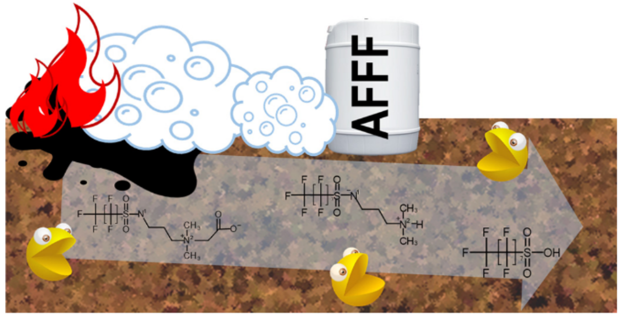
Youn Jeong Choi [a,e], Damian E. Helbling [b], Jinxia Liu [c], Christopher I. Olivares [d], Christopher P. Higgins [a,*]

[a] Department of Civil and Environmental Engineering, Colorado School of Mines, Golden, CO, USA
[b] School of Civil and Environmental Engineering, Cornell University, Ithaca, NY, USA
[c] Department of Civil Engineering, McGill University, Montreal, Quebec, Canada
[d] Department of Civil and Environmental Engineering, University of California, Irvine, CA, USA
[e] Department of Agronomy, Purdue University, West Lafayette, IN, USA

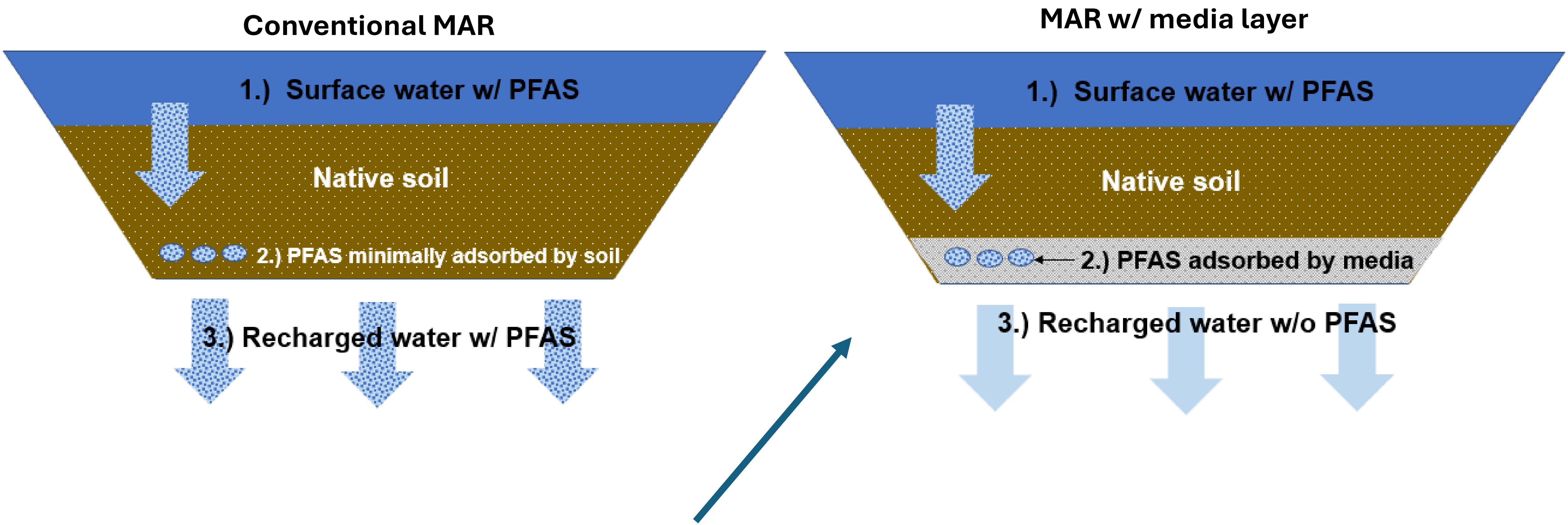
HIGHLIGHTS

- Microbial biotransformation of AFFF-derived PFASs was reviewed.
- ECF-derived and fluorotelomer-derived PFASs share head-group transformation pathways.
- Dealkylation at N- and S-head groups are dominant biotransformation mechanisms.
- FASAs are semi-recalcitrant transformation products, and not all microcosm transformation products are found in the field.
- Further research is needed for transformation mechanisms on secondary amide and sulfonamides adjacent to fluorinated tails.

GRAPHICAL ABSTRACT



Engineer infiltration layers with targeted functions



Deploy a thin layer of activated zeolite (fluorosorb) or analogous sorbent with a lifespan of decades+

Collaborative study underway to explore this for percolation basins

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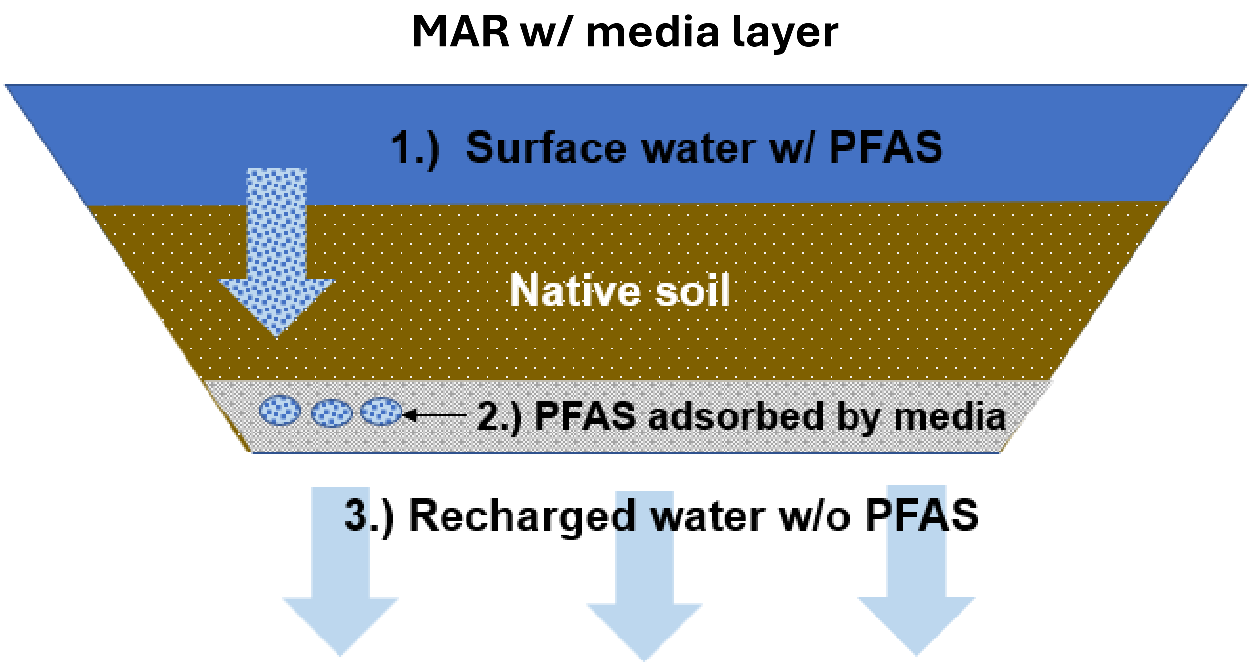
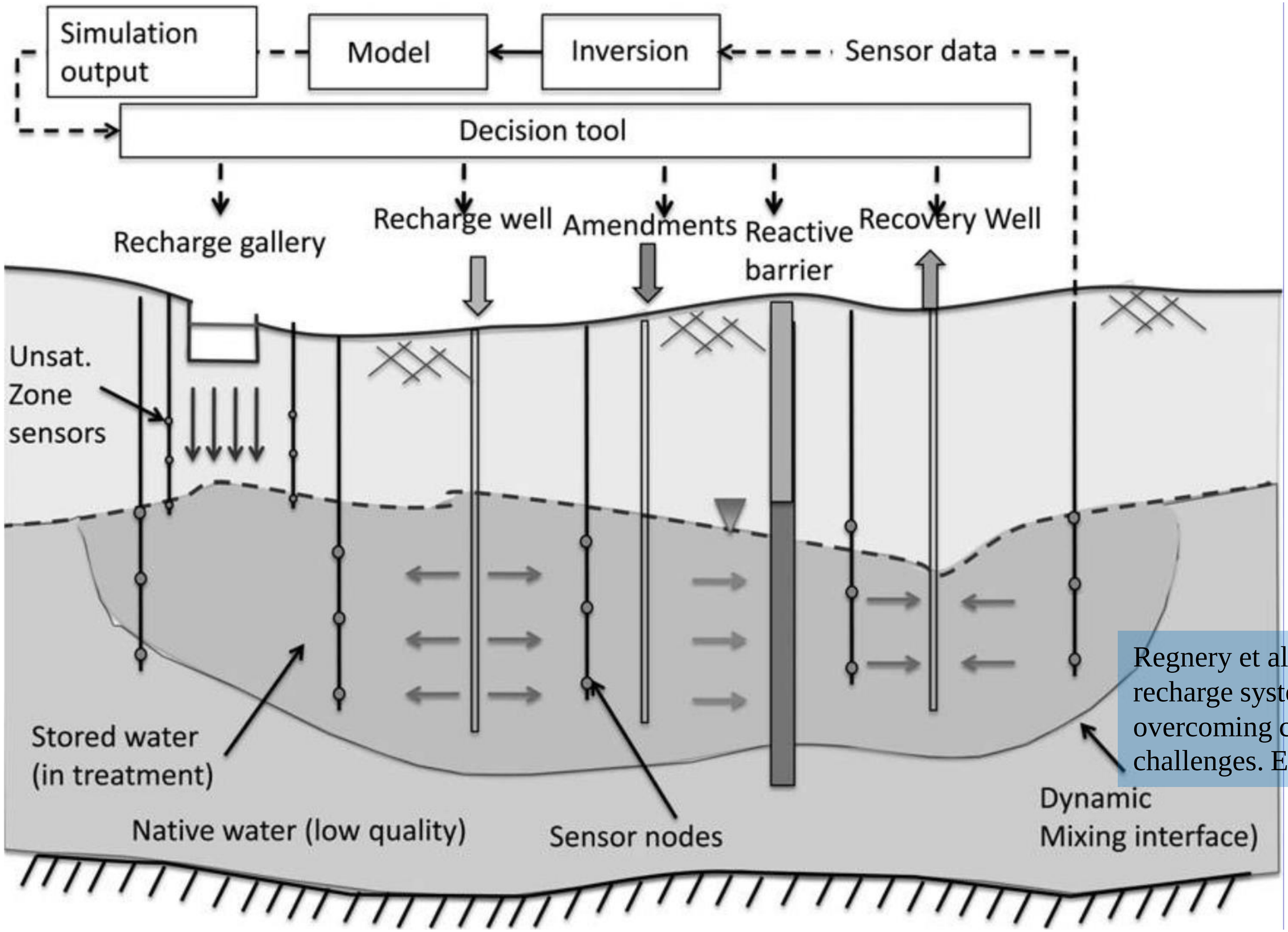


- Upper sediment layers remove: TSS, OM, nuts. & trace organics)
- Engineered geomedia is then more effective for targeted sorption of PFAS

Actively manage and operate these ”passive” systems



Regnery et al (2013) Integration of managed aquifer recharge systems in urban water infrastructure – overcoming current limitations and engineering challenges. Environ Engrg Science. 30(8): 421-436

Acknowledgements and Questions

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