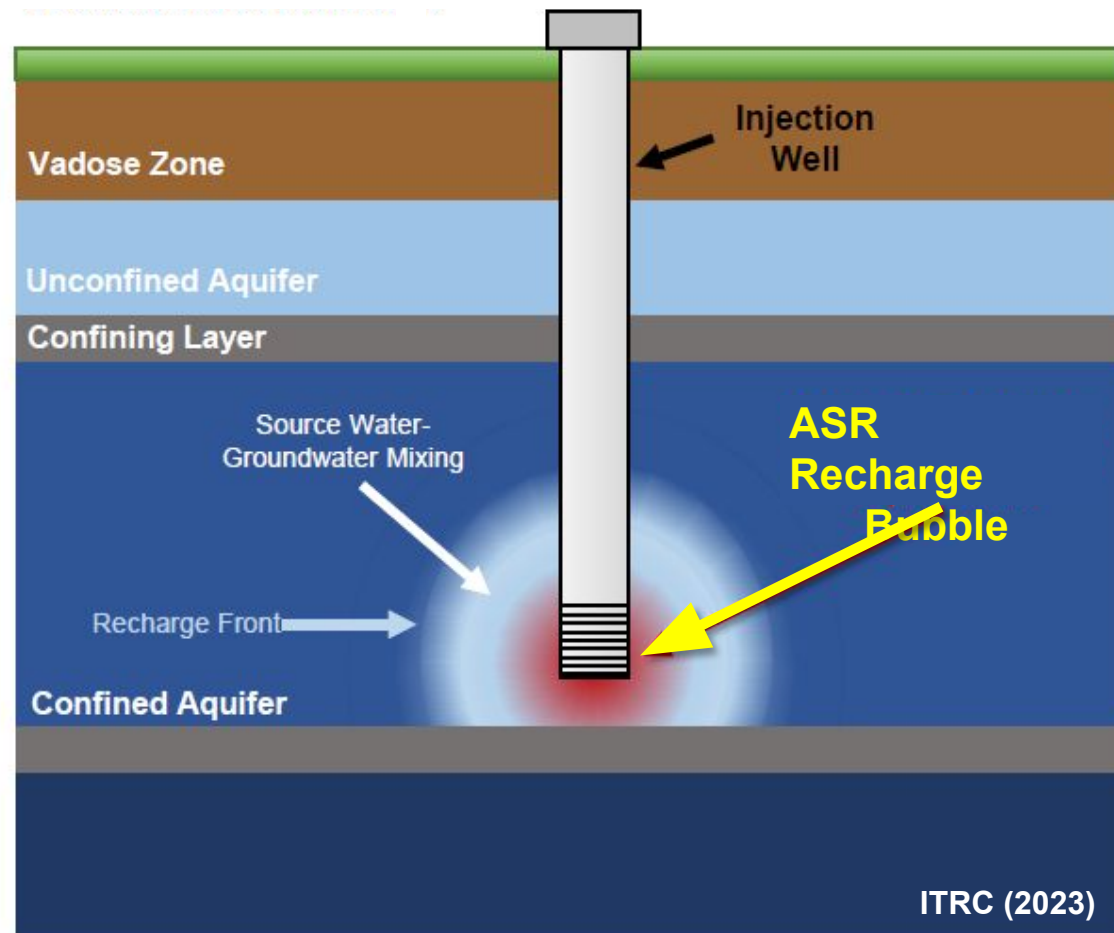


# Evaluation of PFAS Fate and Transport During Aquifer Storage and Recovery

Brad Bessinger, PhD, PG, RG, and DeEtta Fosbury, RG

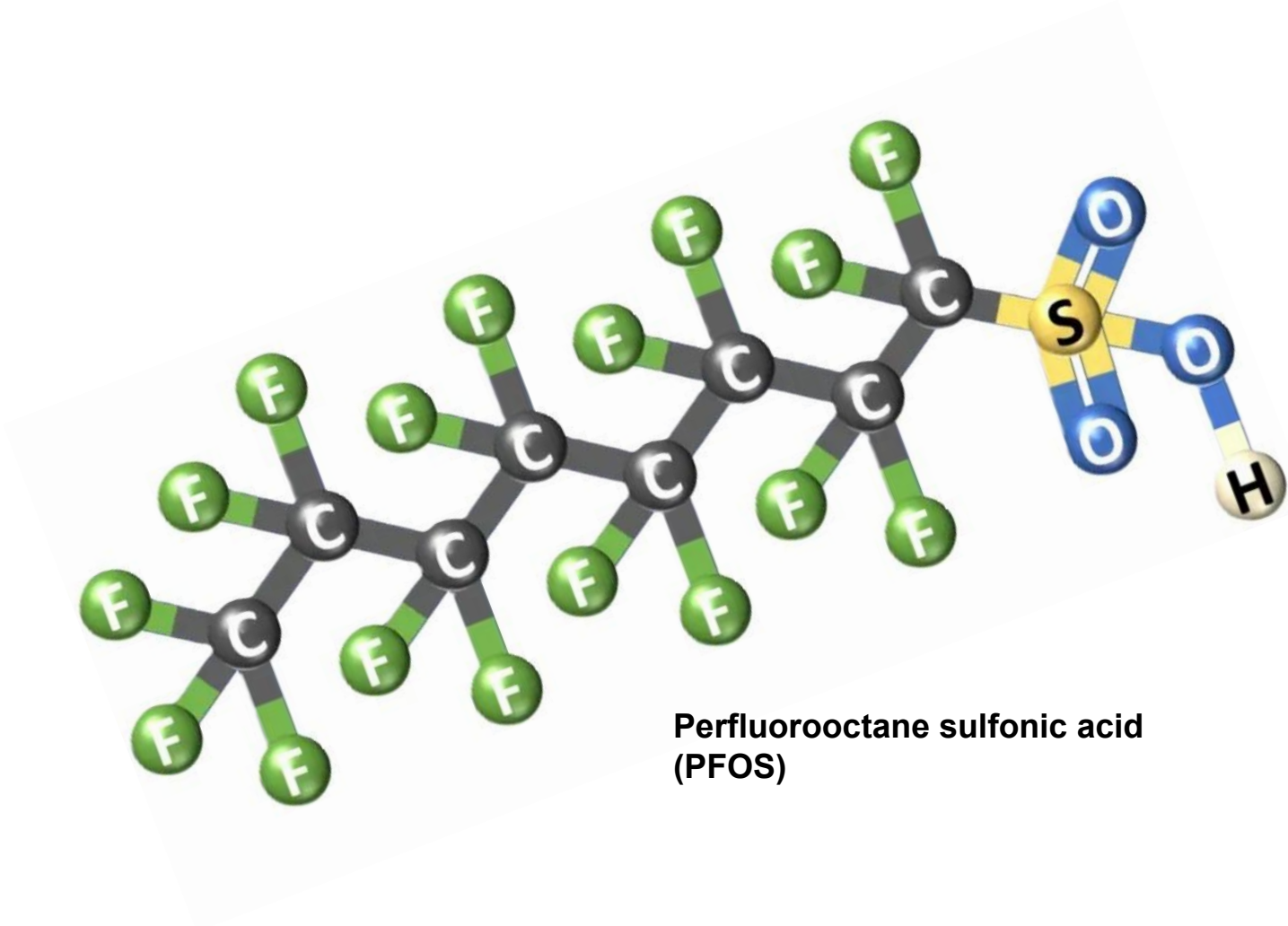
## Question

Is it possible to operate aquifer storage and recovery (ASR) in a PFAS-contaminated aquifer?



# Outline

1. Project Background
2. PFAS Fate and Transport
3. Model Description
4. Model Results
5. Summary and Implications





# Part I: Project Background



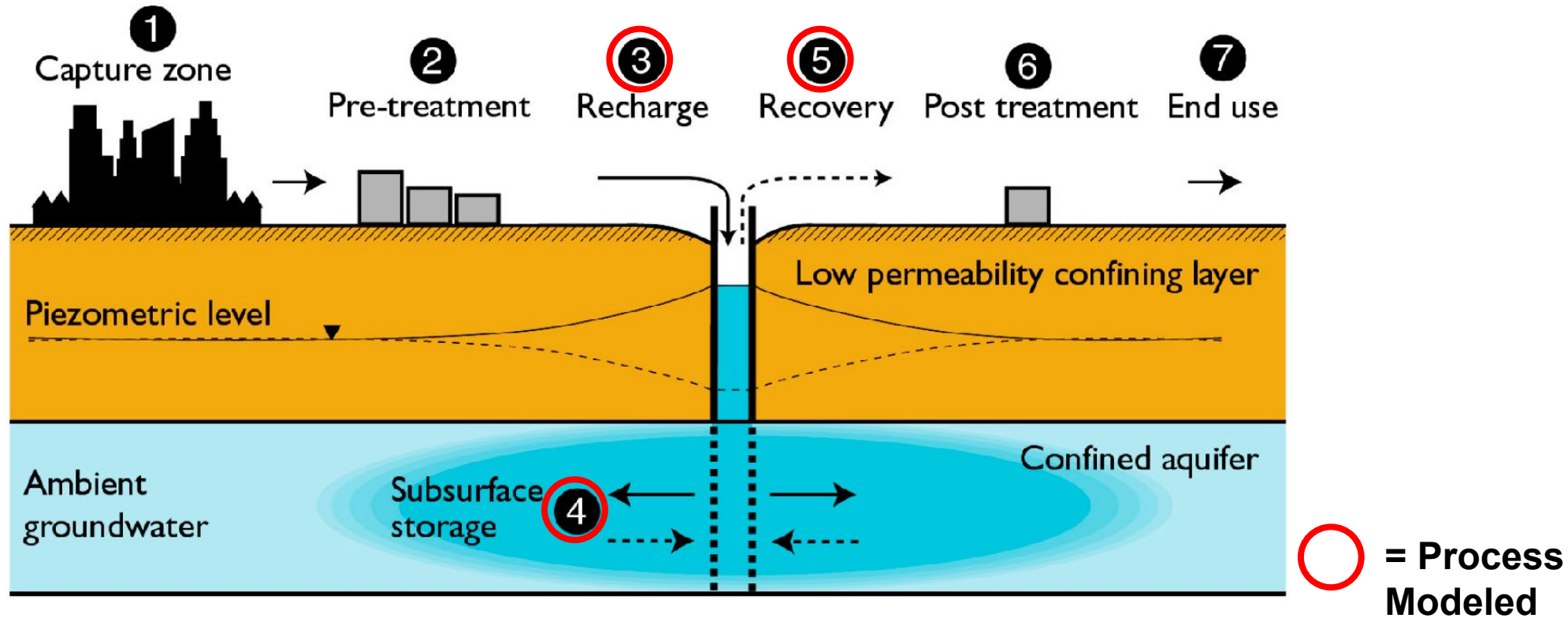


## Project Background

1. A city in Washington State has been operating multiple production wells for domestic water supply
2. In 2023, several wells began reporting elevated PFAS concentrations (e.g., PFOS concentrations were 5–25 ng/L, which are concentrations greater than the EPA MCL (4 ng/L))
3. Due to the elevated PFAS, the affected wells were removed from production
4. The City is currently evaluating water management options, including alternative water sources, blending strategies, and treatment technologies
5. One option the City is considering is whether implementing ASR at the well with the lowest PFOS concentration (5 ng/L) is possible (by lowering concentrations sufficiently to meet the drinking water standard)

# Project Approach

1. Develop a reactive transport model (RTM) to simulate PFAS during ASR in City wells



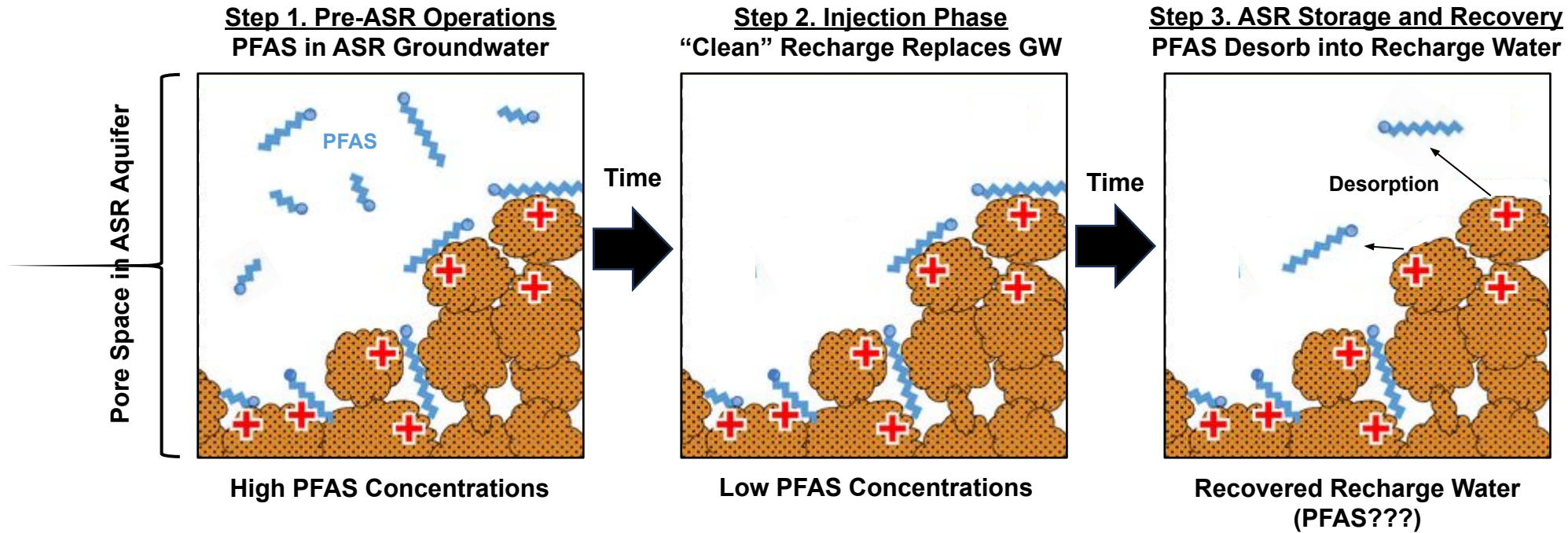
2. RTM Output: PFAS concentrations in recovered recharge water, which were compared to EPA drinking water MCLs

## Part II: PFAS Fate and Transport



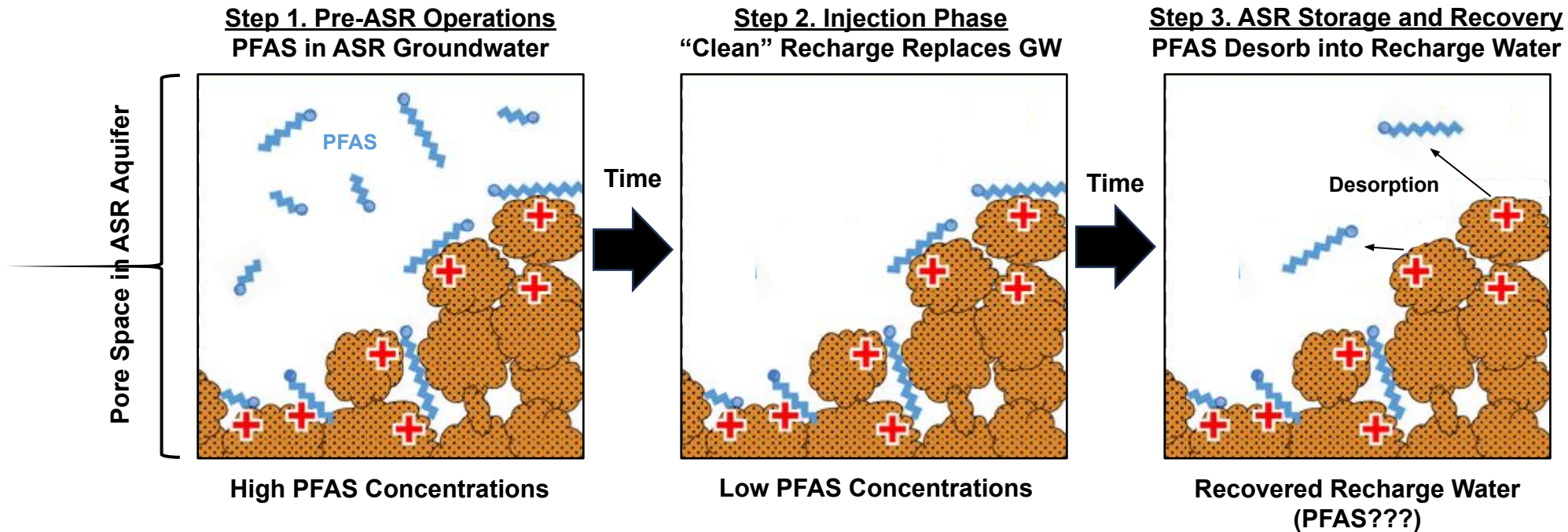


# Conceptual Model of PFAS Fate and Transport in ASR





# Conceptual Model of PFAS Fate and Transport in ASR



- **Summary:** During ASR operations, PFAS can desorb from soils into recharge water within the ASR recharge bubble, potentially resulting in recovered recharge water concentrations > MCLs

## Part III: Model Description

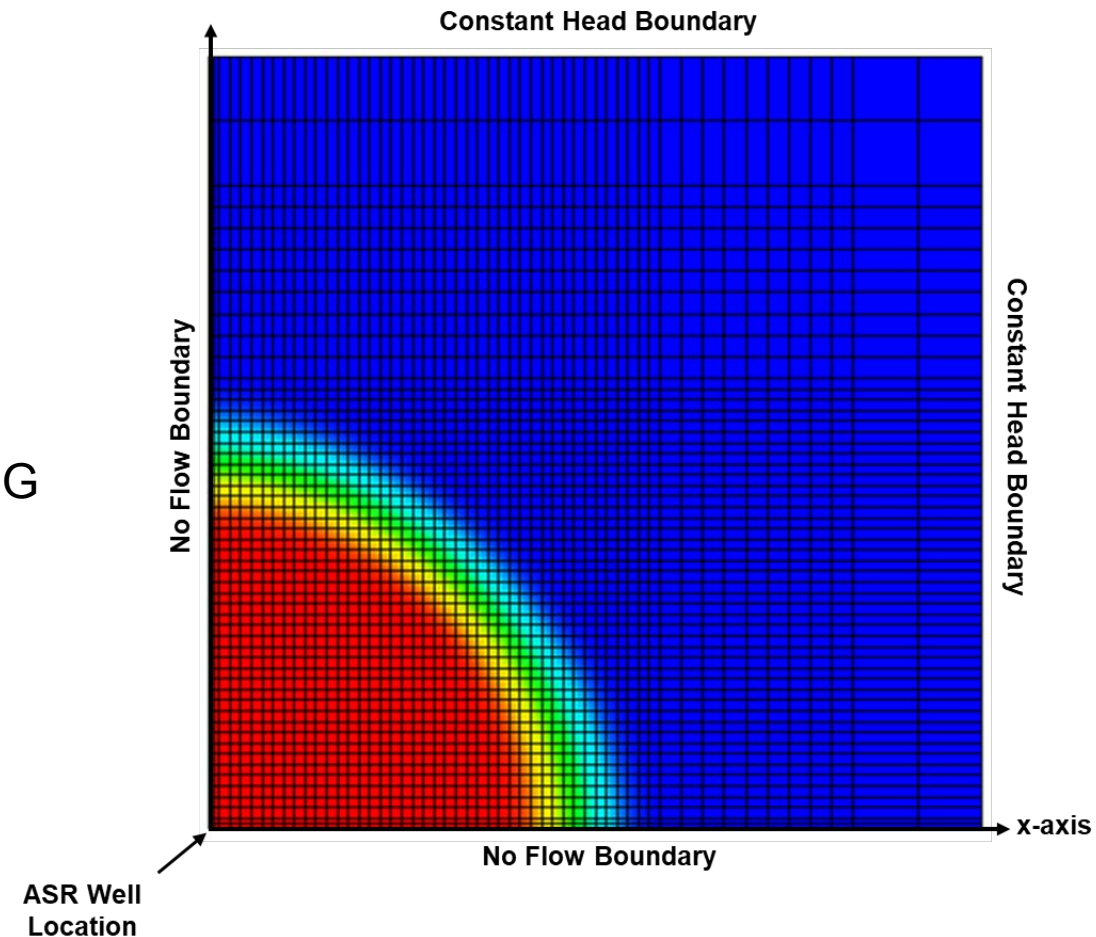




# RTM Domain and Scenarios for USGS PHAST

1. 2D model of City's production wells (see figure)
2. Four Scenarios, Three Wells
  - **S-1, Well #1:** Low PFAS (5 ng/L PFOS)  
3 ASR Cycles (17 MG water total)
  - **S-2, Well #2:** High PFAS (25 ng/L)  
3 ASR Cycles (17 MG water total)
  - **S-3, Well #2:** High PFAS (25 ng/L)  
12 ASR Cycles and 80% recovery (17 MG water total)
  - **S-4, Well #3:** Med PFAS (10 ng/L)  
3 ASR Cycles (17 MG water total)
3. RTM Output: PFAS concentrations in recovered recharge water to determine if ASR cycling can create a relatively PFAS-free ASR bubble that will result in concentrations below the MCL in recovered water

Reactive Transport Model Domain and Recharge Bubble



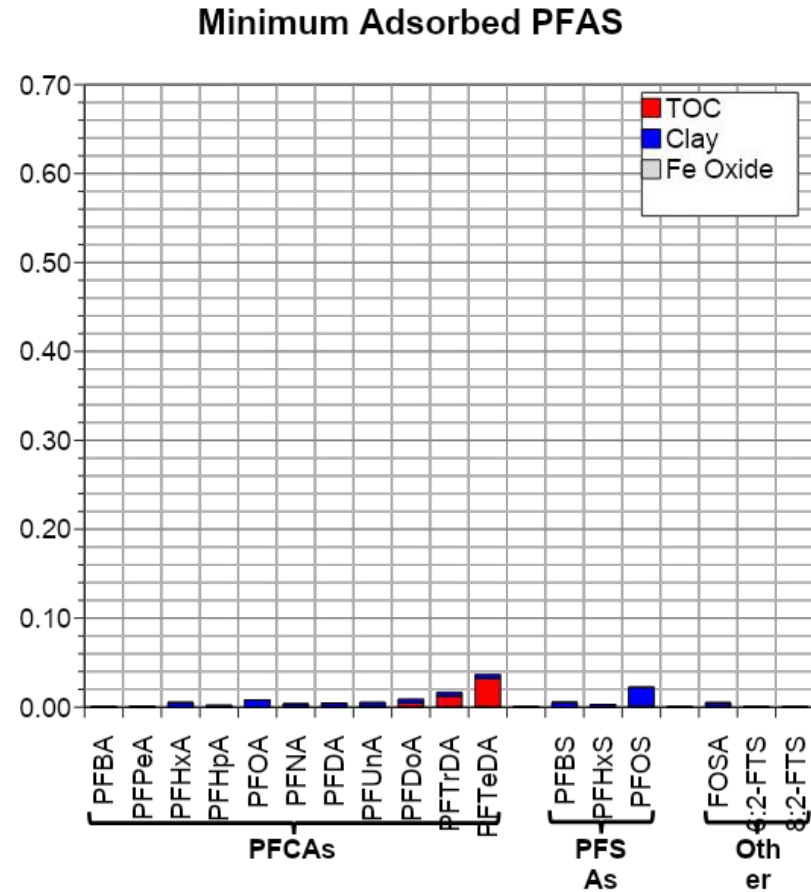
## Part IV: Model Results





## Scenario-1, Well #1: Low PFAS (5 ng/L PFOS) and 3 ASR Cycles

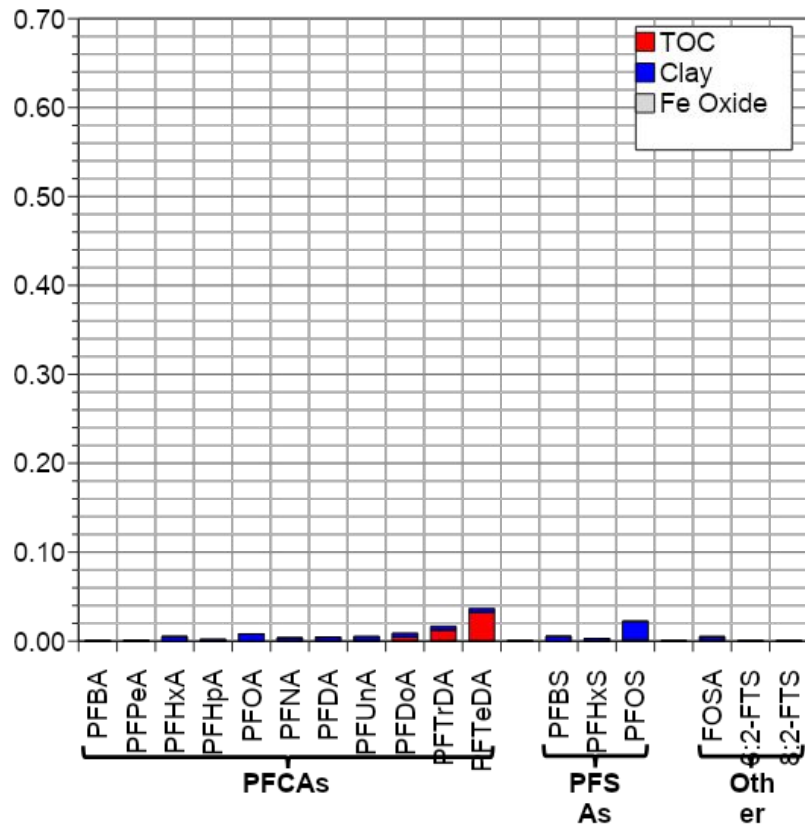
- Initial distribution of adsorbed PFAS in ASR aquifer (ng/g) for different mineral estimates



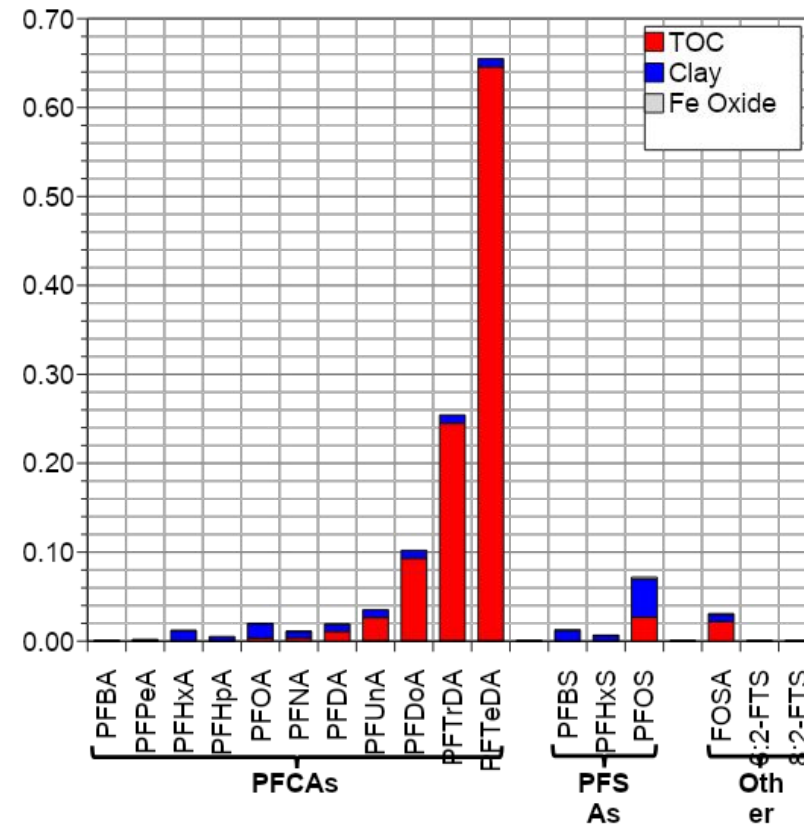
## Scenario-1, Well #1: Low PFAS (5 ng/L PFOS) and 3 ASR Cycles

- Initial distribution of adsorbed PFAS in ASR aquifer (ng/g) for different mineral estimates

Minimum Adsorbed PFAS



Maximum Adsorbed PFAS

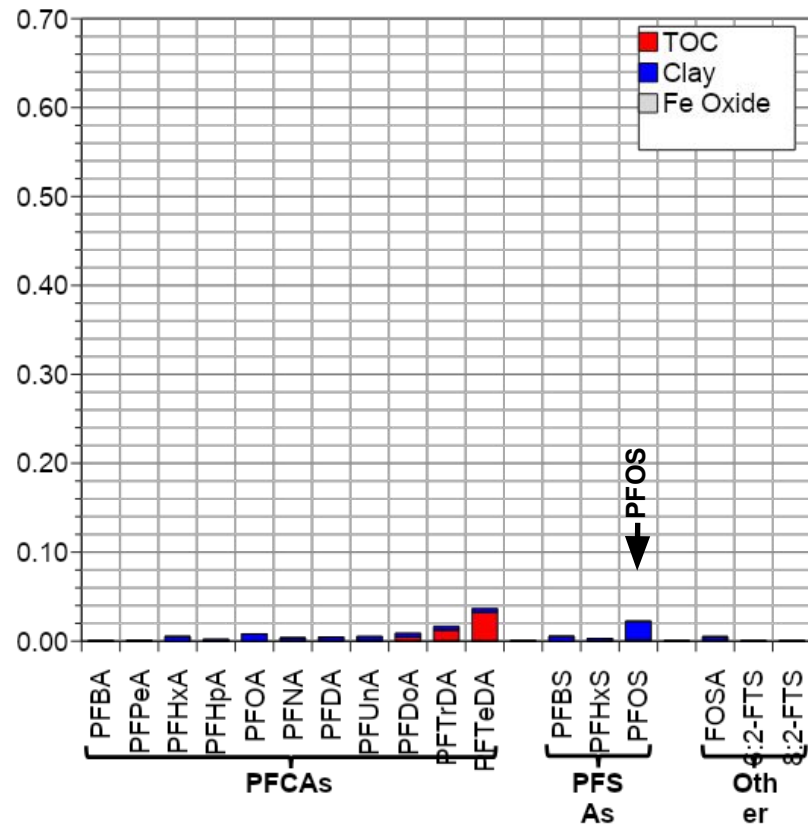




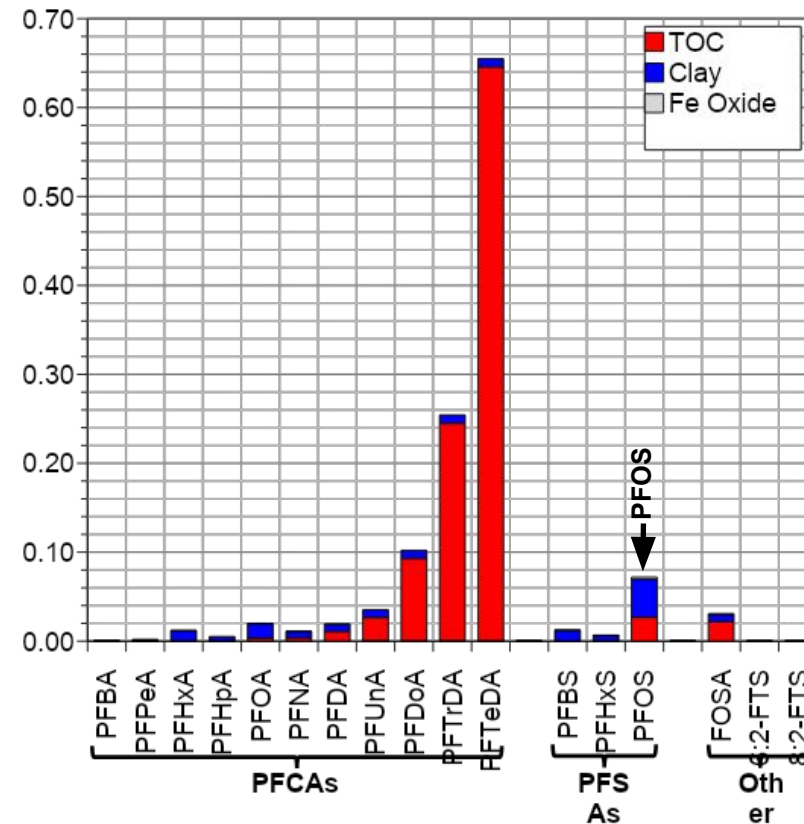
## Scenario-1, Well #1: Low PFAS (5 ng/L PFOS) and 3 ASR Cycles

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Minimum Adsorbed PFAS

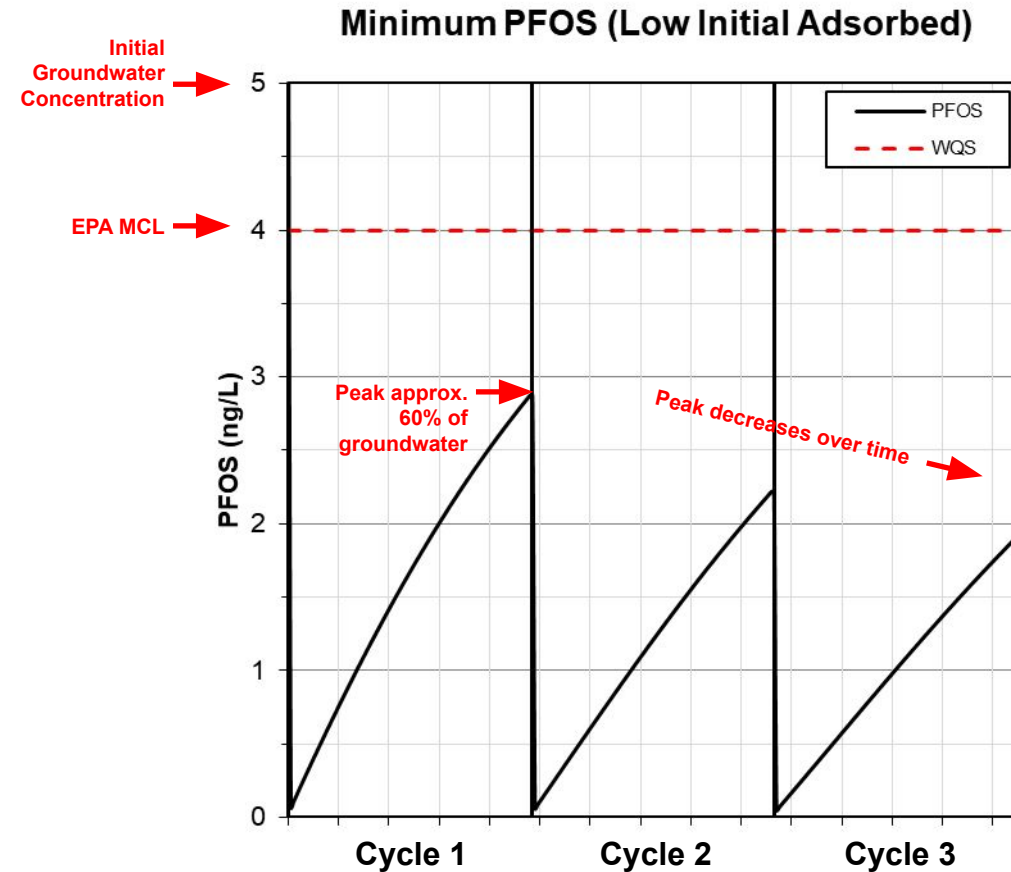


Maximum Adsorbed PFAS



## Scenario-1, Well #1: Low PFAS (5 ng/L PFOS) and 3 ASR Cycles

- Predicted recovered recharge water PFOS concentrations (3 cycles)



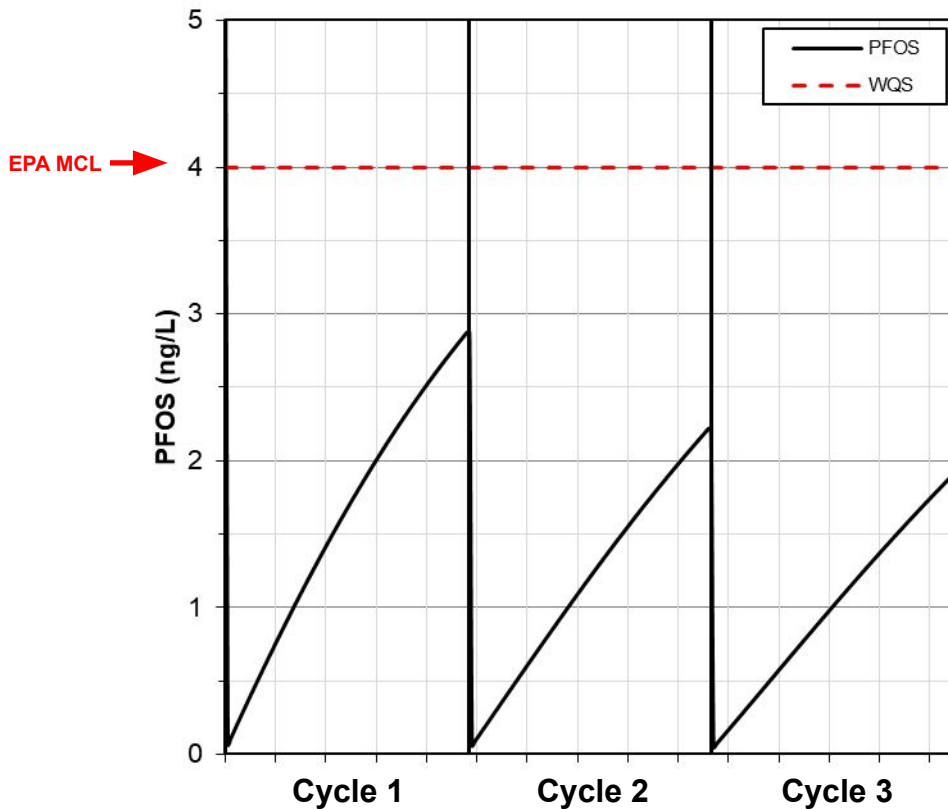
Note: x-axis results for each cycle are from 0% recovery (*left*) to 100% recovery (*right*)



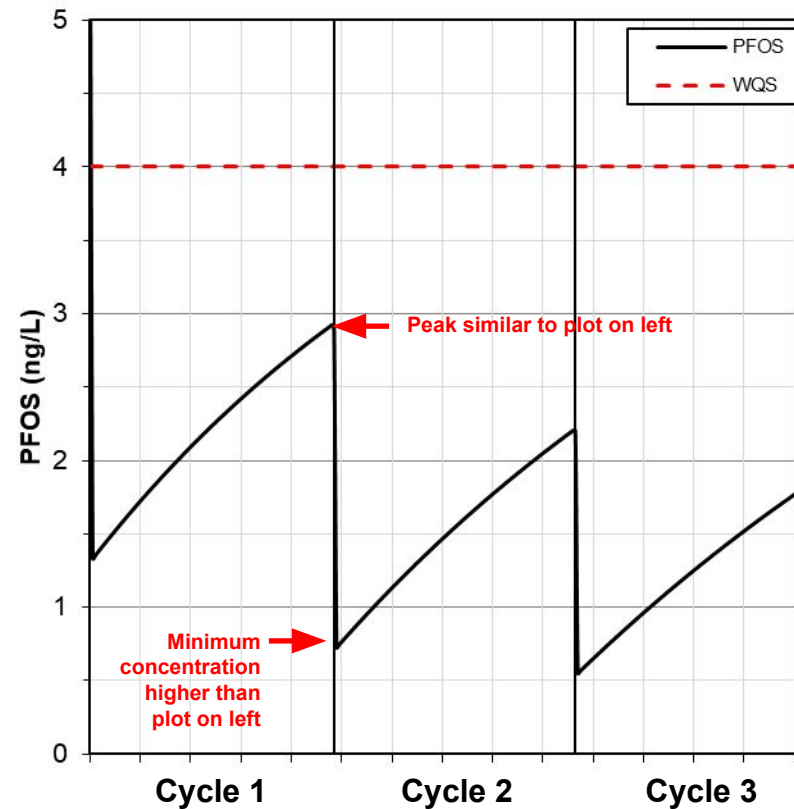
## Scenario-1, Well #1: Low PFAS (5 ng/L PFOS) and 3 ASR Cycles

- Predicted recovered recharge water PFOS concentrations (3 cycles)

Minimum PFOS (Low Initial Adsorbed)



Maximum PFOS (High Initial Adsorbed)



Note: x-axis results for each cycle are from 0% recovery (left) to 100% recovery (right)

## **Scenario-1, Well #1: Low PFAS (5 ng/L PFOS) and 3 ASR Cycles**

- Findings:

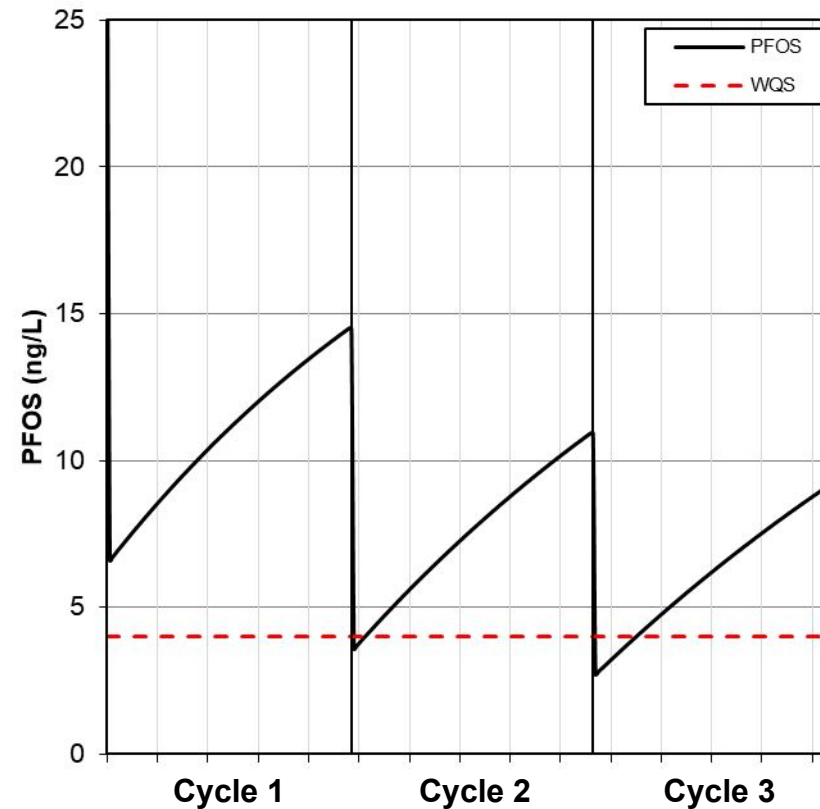
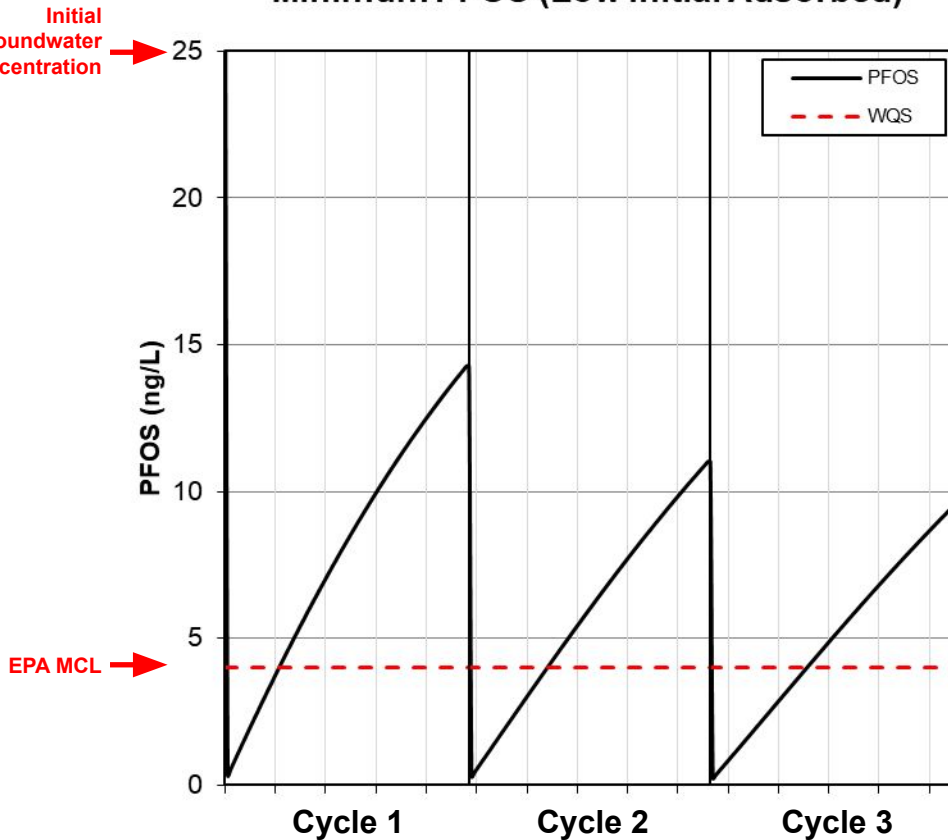
1. Large range in levels of adsorbed PFAS (ng/g)
2. More PFAS adsorption if clay and organic matter is more abundant
3. The more PFAS adsorbed initially, the higher the average PFAS concentrations in recovered recharge water
4. Well #1 with 5 ng/L could be used as an ASR well (e.g., PFOS in recovered recharge water < MCL)

## Scenario-2, Well #2: High PFAS (25 ng/L PFOS) and 3 ASR Cycles

- Predicted recovered recharge water PFOS concentrations (3 cycles)

Minimum PFOS (Low Initial Adsorbed)

Maximum PFOS (High Initial Adsorbed)



Note: x-axis results for each cycle are from 0% recovery (*left*) to 100% recovery (*right*)



## **Scenario-2, Well #2: High PFAS (25 ng/L PFOS) and 3 ASR Cycles**

- Findings:

1. For initial groundwater PFOS of 25 ng/L, PFOS in some recovered recharge water will exceed the MCL
2. Well #2 with 25 ng/L PFOS cannot be used as an ASR well if the goal is to achieve recovered recharge water concentrations less than the MCL

## Scenario-2, Well #2: High PFAS (25 ng/L PFOS) and 3 ASR Cycles

- Findings:

- For initial groundwater PFOS of 25 ng/L, PFOS in some recovered recharge water will exceed the MCL
- Well #2 with 25 ng/L PFOS cannot be used as an ASR well if the goal is to achieve recovered recharge water concentrations less than the MCL

- Questions:

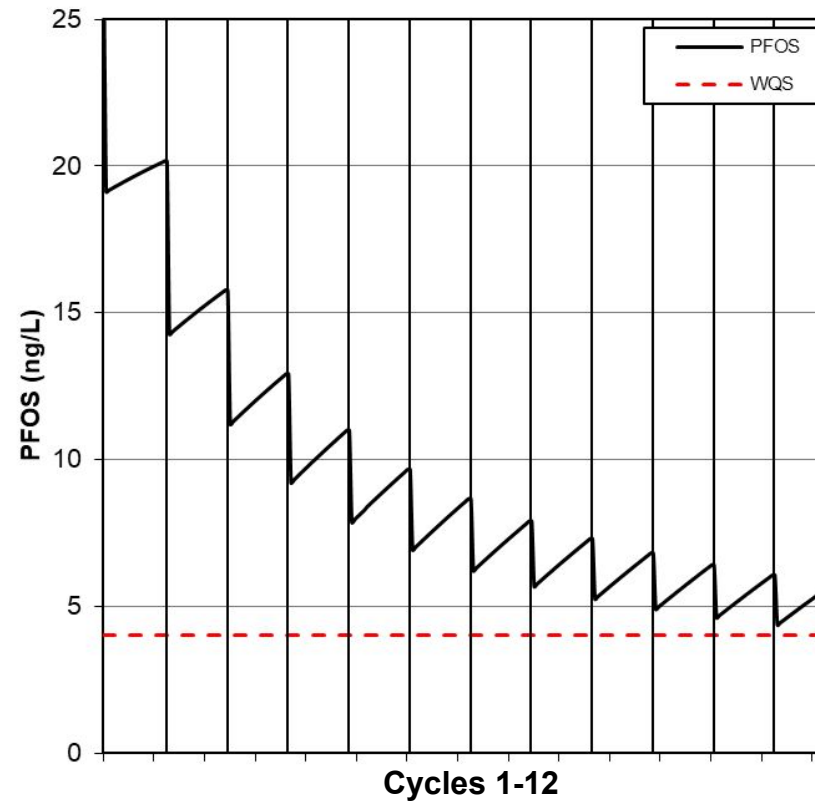
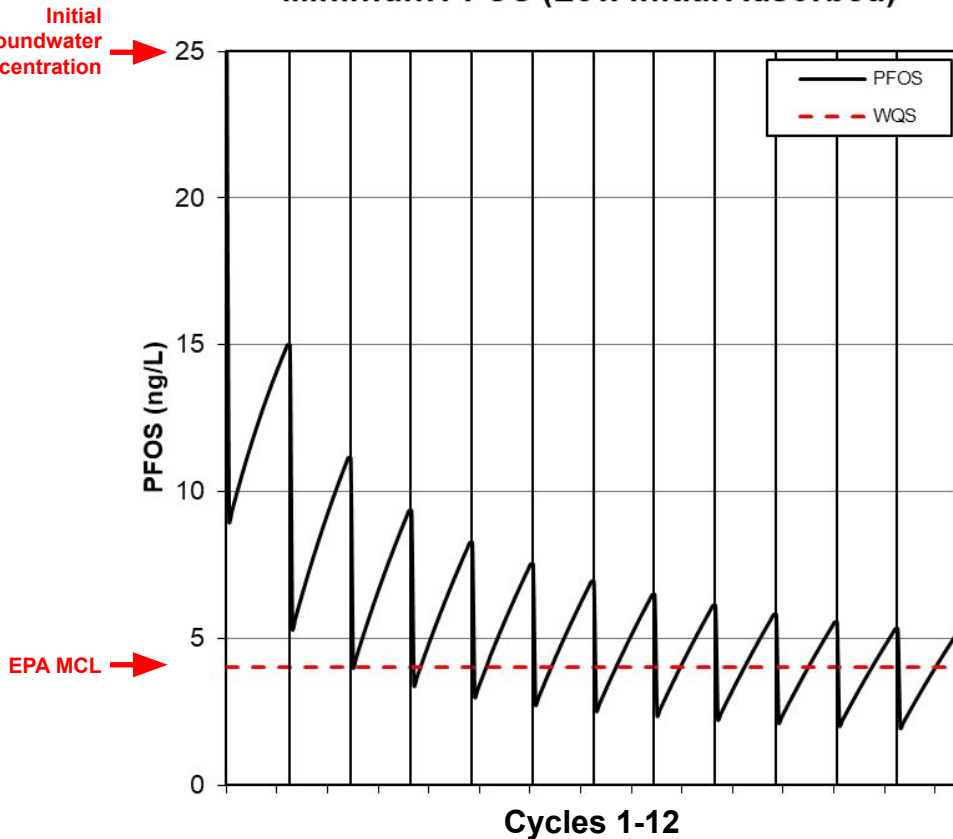
- Are there any changes in operations that can reduce PFAS concentrations in recovered recharge water?
- What is the maximum level of groundwater PFAS that will allow a well to be used for ASR?

## Scenario-3, Well #3: High PFAS (25 ng/L PFOS), 12 ASR Cycles, 80% Recovery

- Predicted recovered recharge water PFOS concentrations (12 cycles)

Minimum PFOS (Low Initial Adsorbed)

Maximum PFOS (High Initial Adsorbed)

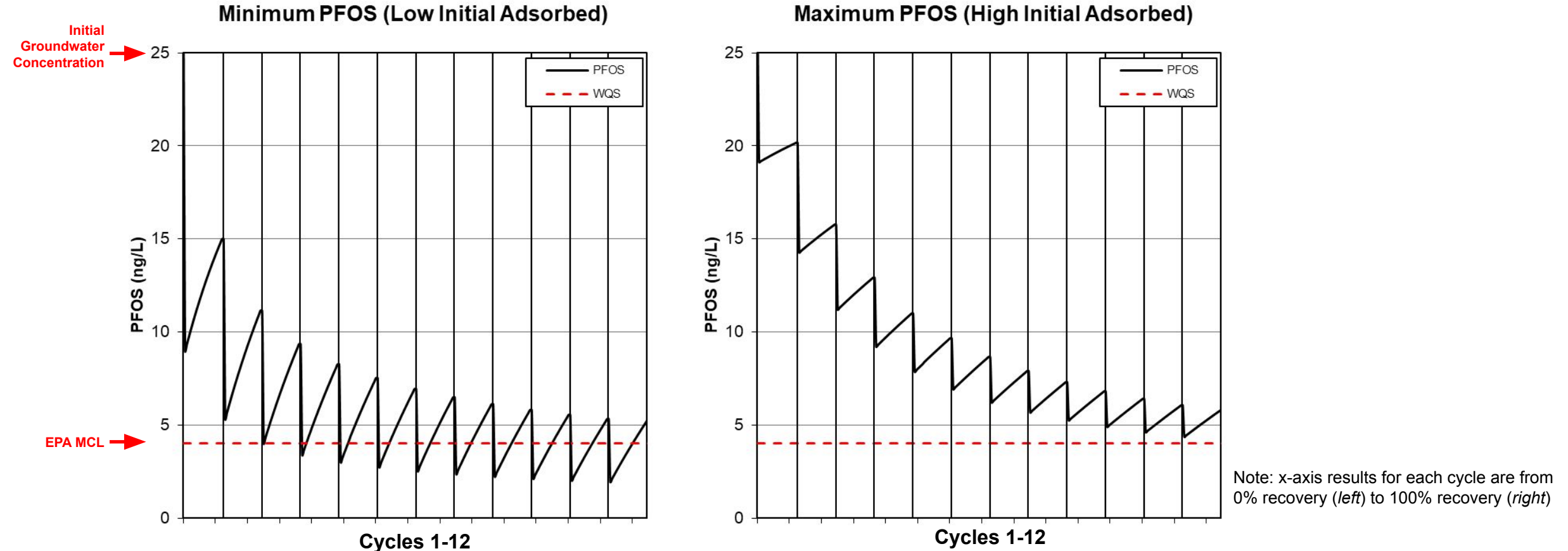


Note: x-axis results for each cycle are from 0% recovery (left) to 100% recovery (right)



## Scenario-3, Well #3: High PFAS (25 ng/L PFOS), 12 ASR Cycles, 80% Recovery

- Predicted recovered recharge water PFOS concentrations (12 cycles)



- Smaller ASR cycles & less recovery decrease PFOS to near the MCL, but not enough to reduce recovered recharge water PFOS < MCL

## **Are there any changes in operations that can be used to reduce PFAS concentrations in recovered recharge water?**

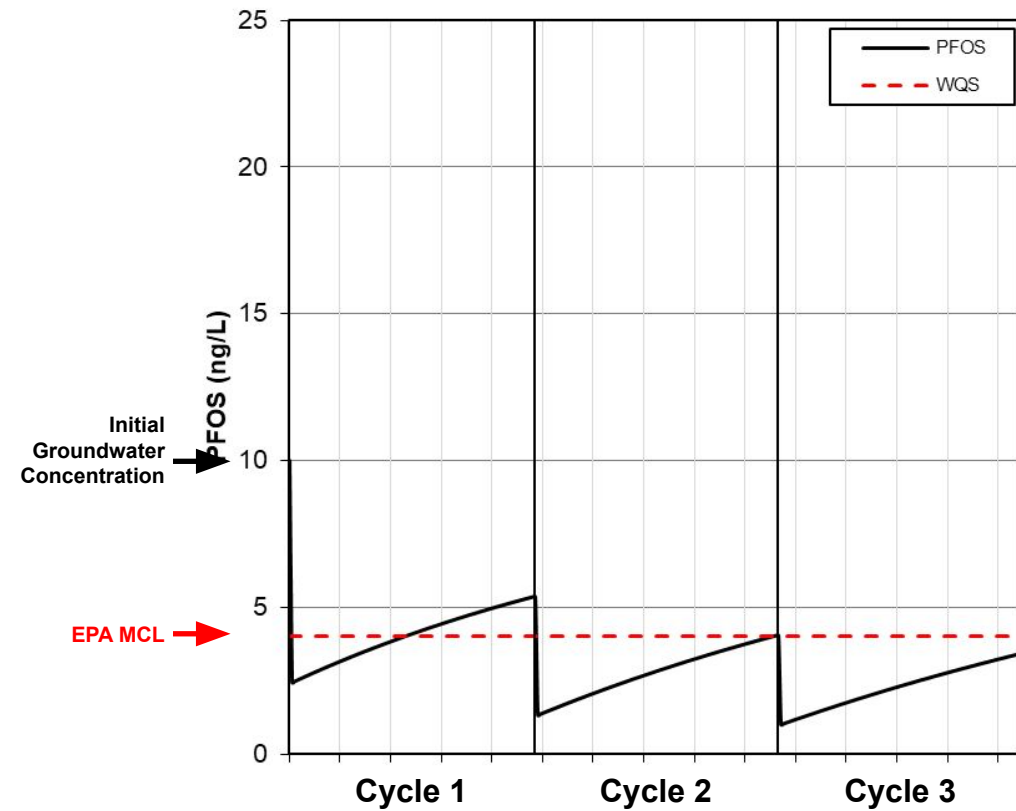
- **Answer:**

Yes. Shorter cycles create a smaller recharge bubble that scrubs out adsorbed PFAS faster (this reduces the average PFAS concentration); also, less than 100% recovery reduces the amount of groundwater mixing (which controls the PFAS peak concentration)

## Scenario-4, Well #3: Med PFAS (10 ng/L) and 3 ASR Cycles

- Predicted recovered recharge water PFOS concentrations (3 cycles)

Maximum PFOS (High Initial Adsorbed)



Note: x-axis results for each cycle are from 0% recovery (*left*) to 100% recovery (*right*)



## **What is the maximum level of groundwater PFAS that will allow a well to be used for ASR?**

- **Answer:**

10 ng/L of PFOS in groundwater can result in recovered water with concentrations less than the MCL after the first ASR cycle (the first water would need to be blended/treated)

## Part V: Summary and Implications



## Major Findings

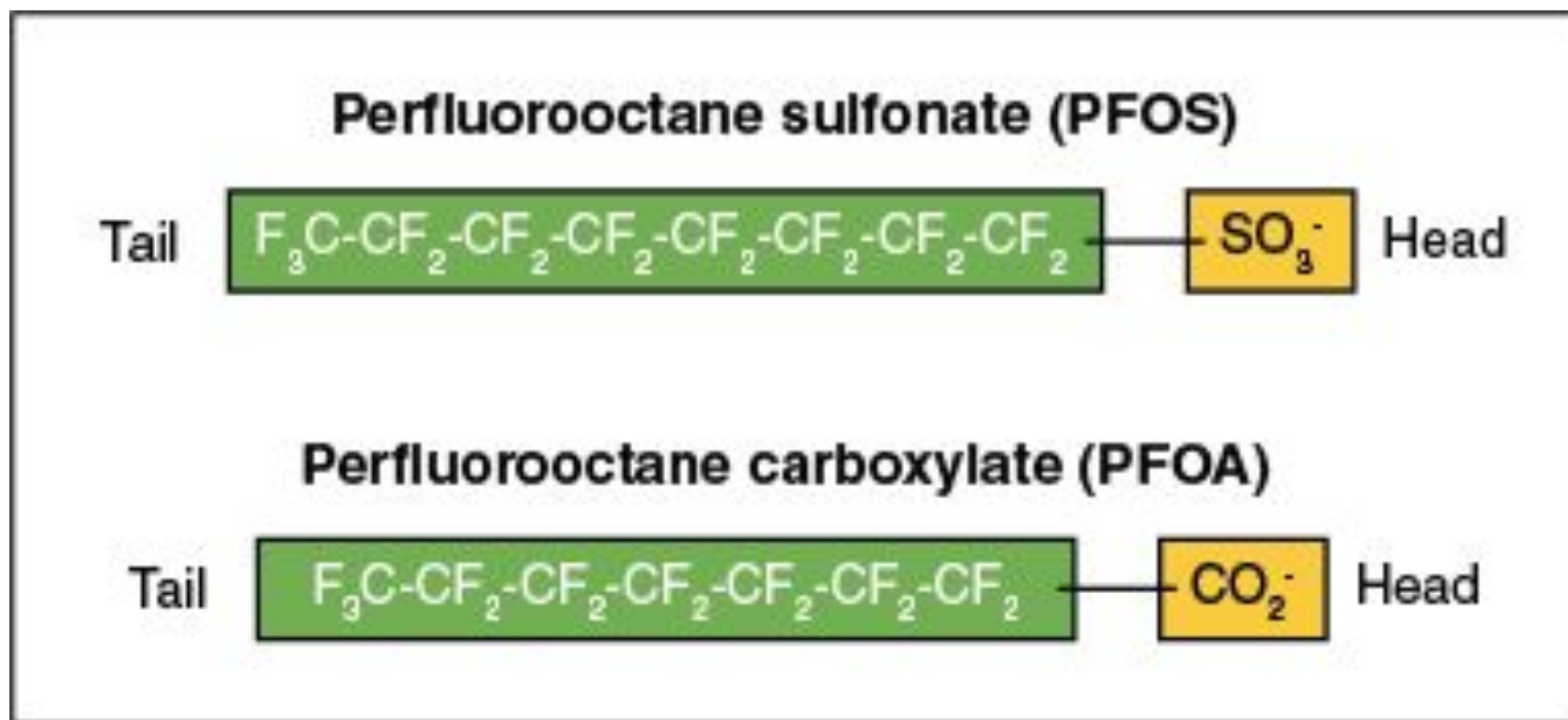
1. During ASR, recovered water is mostly recharge water with low PFAS concentrations; however, due to groundwater mixing and PFAS desorption from aquifer minerals, recovered recharge water PFAS concentrations can exceed MCLs
2. Repeated ASR operations (i.e., cycling) dilutes groundwater PFAS and reduces the amount of adsorbed PFAS; consequently, recovered recharge water will have lower PFAS concentrations over time
3. ASR cycling can reduce PFAS concentrations in recovered water sufficiently to meet the MCL at the well with low PFAS concentrations (5 ng/L of PFOS), but not at the well with high concentrations (25 ng/L of PFOS)



Questions?

## Factors Affecting PFAS Fate and Transport in ASR

1. Molecular Structure: PFAS molecules have a hydrophobic chain and hydrophilic (anionic) head group



ITRC (2023)

## Factors Affecting PFAS Fate and Transport in ASR

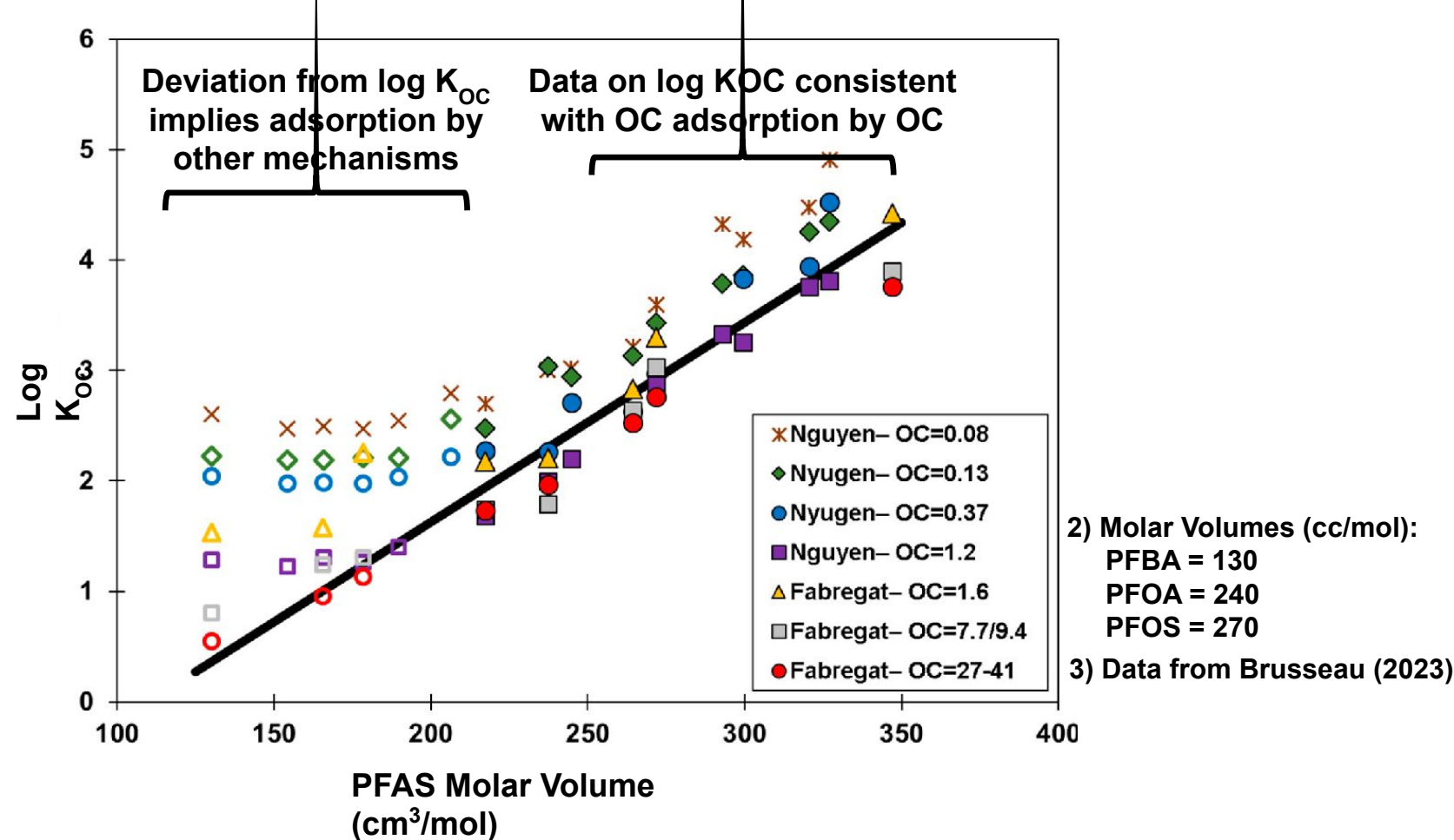
2. PFAS Chain Length: There are both short and long-chain PFCAs & PFSAAs (with hydrophobicity increasing with chain length)

Number of Carbons	4	5	6	7	8	9	10	11	12
PFCAs	Short-chain PFCAs				Long-chain PFCAs				
	PFBA	PFPeA	PFHxA	PFHpA	PFOA	PFNA	PFDA	PFUnA	PFDnA
PFSAs	PFBS	PFPeS	PFHxS	PFHpS	PFOS	PFNS	PFDS	PFUnS	PFDnS
	Short-chain PFSAs		Long-chain PFSAs						

ITRC (2023)

# Factors Affecting PFAS Fate and Transport in ASR

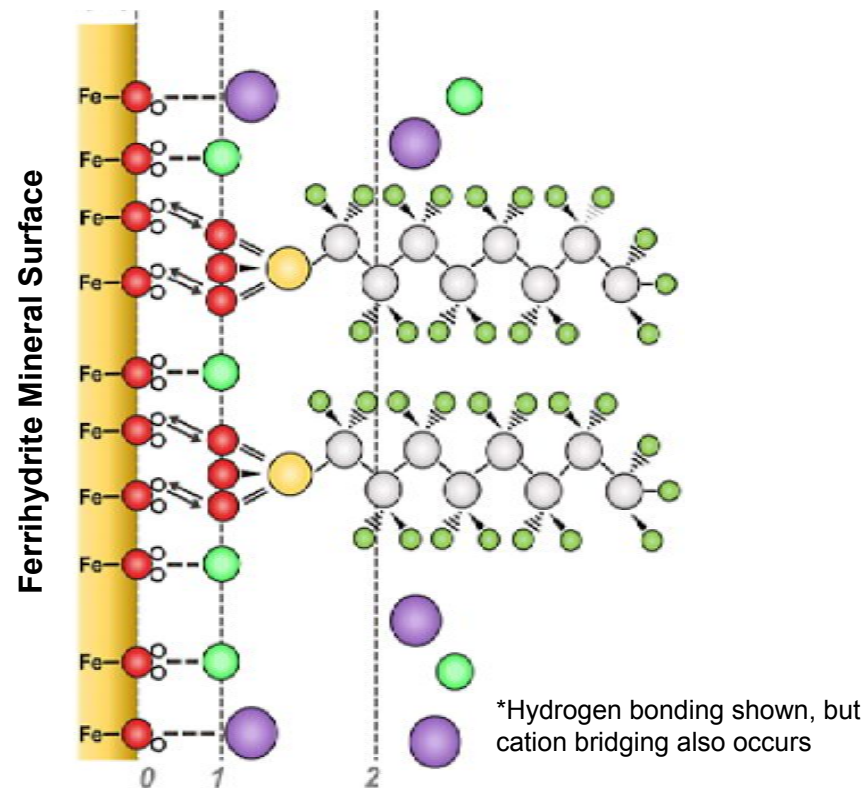
- 3. Adsorption: PFAS are adsorbed by soil minerals (not just organic matter); however, importance of organics to adsorption increases with chain length)



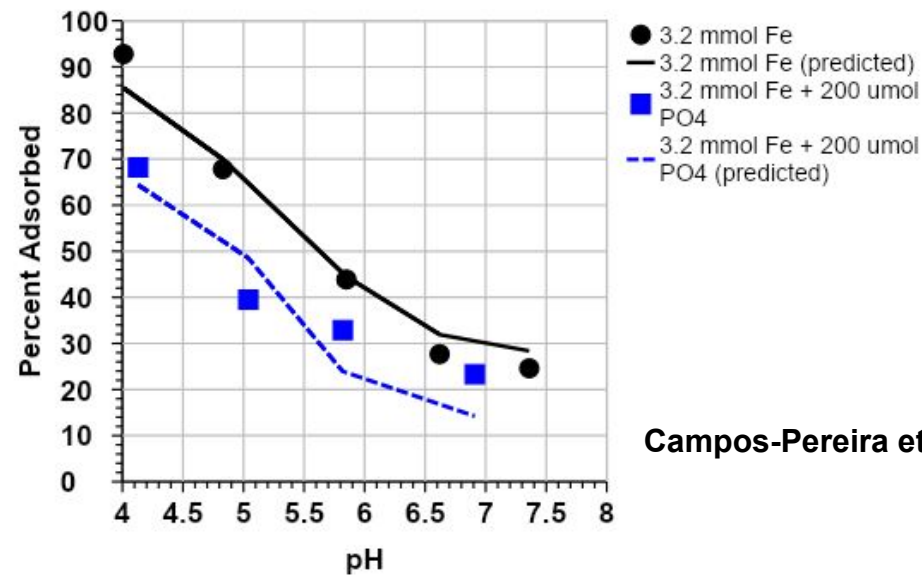


# RTM Simulated Adsorption Processes Added to USGS’s PHAST Software

- 1. Organic matter (TOC):  $K_{D,TOC} \text{ (L/kg)} = K_{OC} \times f_{OC}$  (Brusseau 2023)
- 2. Clay:  $K_{D,Clay} \text{ (L/kg)} = -131.7 - (0.0005 \times MW^2) + (0.675 \times MW) + (0.374 \times CEC)$  (Ahmad et al. 2023)
- 3. Iron oxyhydroxides:  $\text{Log } K_{Fe-SCM} = \text{Predicted using CD-MUSIC Model approach (Cogorno and Rolle (2024))}$



PhreePlot Fit PFOS Adsorbed to Ferrihydrite



Campos-Pereira et al. (2020)