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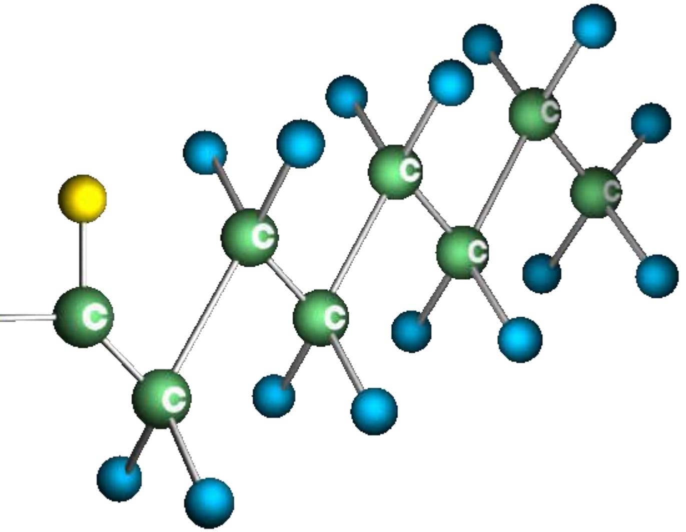
# In-situ Remediation of PFAS using Air Sparging

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# GOVERNMENT ASSIGNMENT

- Research and dissemination regarding investigation and remediation methods for PFAS
- Laboratory studies and pilot-scale projects
- Cooperation with Geological Survey of Sweden and Swedish EPA as well as other government authorities in the implementation of pilot projects
- Strengthen knowledge about PFAS-contaminated areas
- Reporting to the Ministry of Climate and Enterprise on Sept 1st 2026

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# REMEDIATION METHODS WITHIN RU PFAS

**SOIL WASHING**

Remediation of soil

**THERMAL TREATMENT**

Remediation of soil

**STABILIZATION WITH ACTIVATED CARBON**

Limit spreading of PFAS in groundwater

**AIR SPARGING**

Remediate PFAS in soil and groundwater

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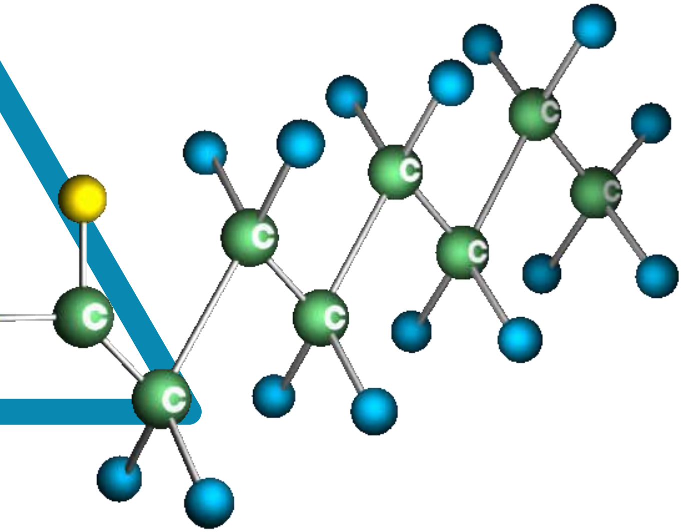
# In-situ Remediation of PFAS using Air Sparging

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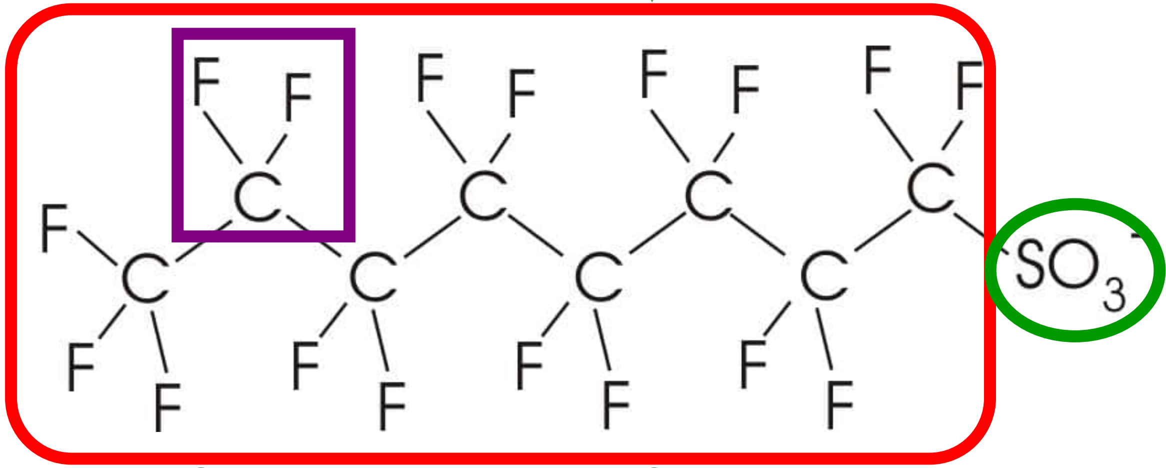
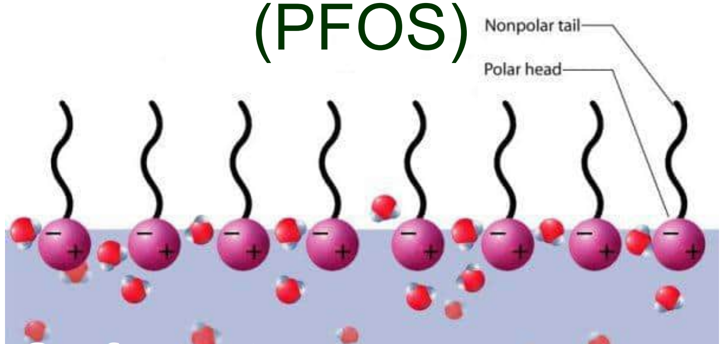
# Introduction to PFAS

- ## What are PFAS?
  - PFAS stands for per- and polyfluorinated alkyl substances (also called highly fluorinated substances)
  - PFAS are persistent environmental pollutants ("Forever Chemicals")
- ## Why are they a problem ?
  - PFAS are highly resistant to degradation
  - Highly mobile in soil and water
  - Adverse health effects due to bioaccumulation (e.g., cancer, immune system issues)

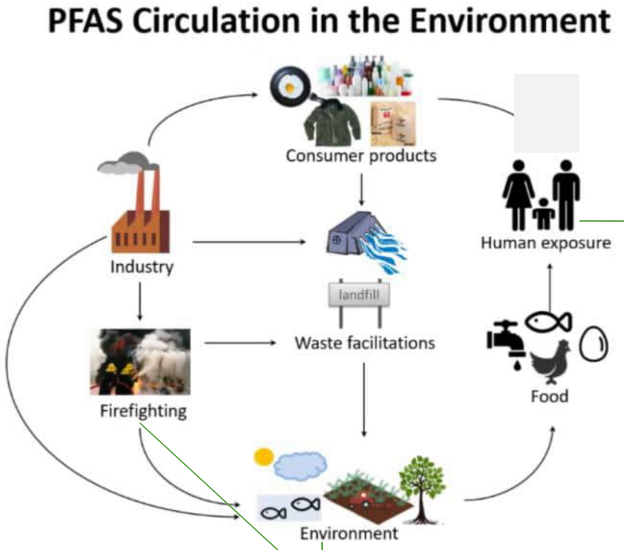



Perfluorooctane sulfonate (PFOS)

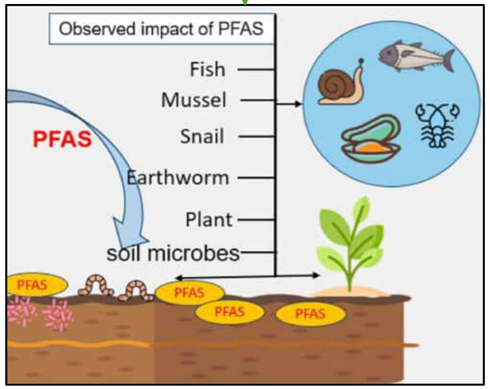


# Introduction to PFAS

## Sources of PFAS




Ehsan.et.al, (2024)





Source: https://riversideca.gov/press/understanding-pfas

# Characteristics of PFASs

Chain Length

Increasing sorption potential

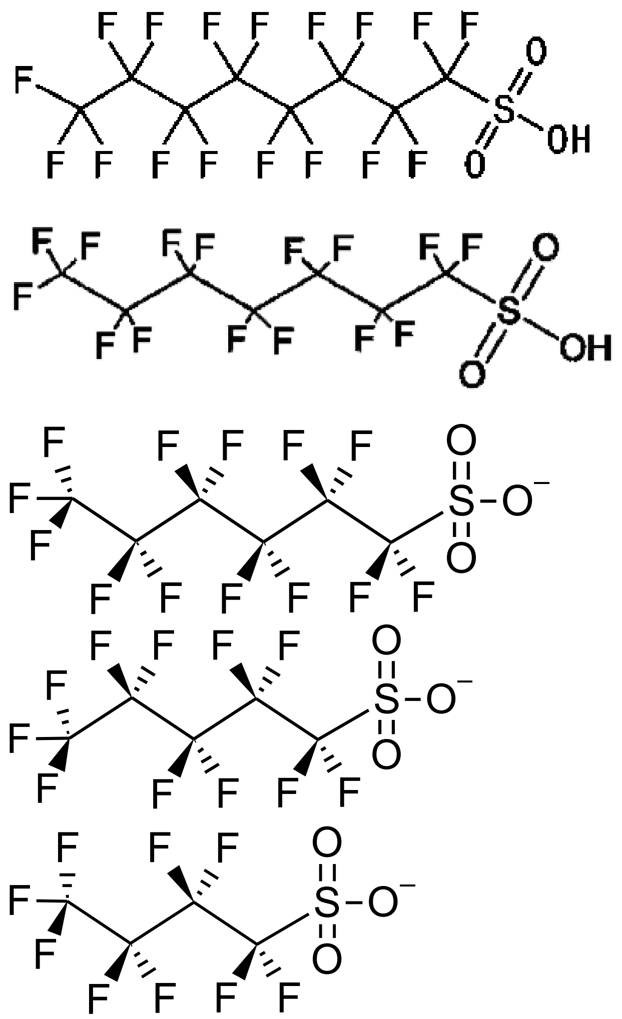
PFOS

PFHpS

PFHxS

PFPeS

PFBS




C-8

C-4

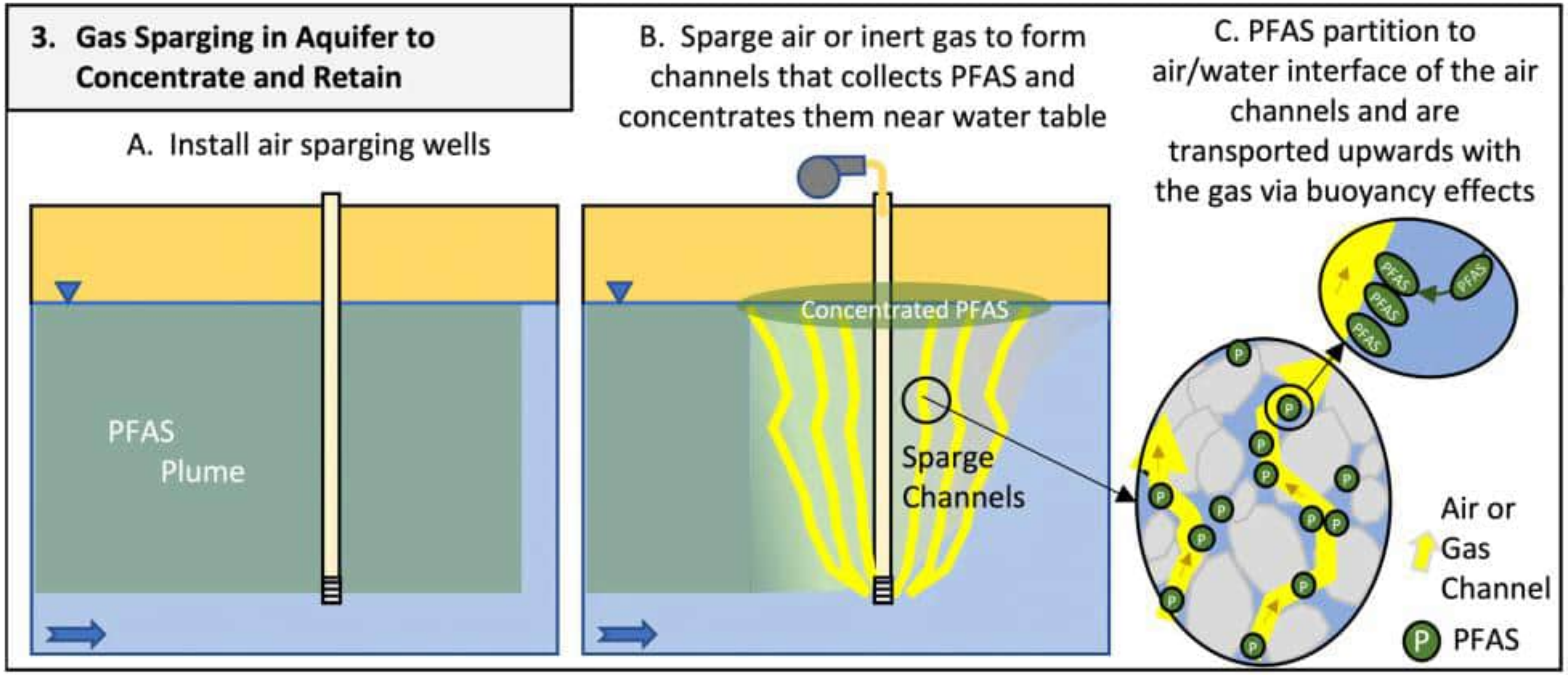
Increasing mobility

# Overview of In-situ PFAS remediation using air sparging

- ## What is air sparging?
  - **Air sparging** is a remediation technique where air is injected into the groundwater to desorb and **mobilize contaminants**
  - It is commonly used for removing volatile organic compounds (VOCs) like LNAPLs
  - While PFAS are not **volatile**, air sparging has been explored for PFAS removal in this study
- ## Potential benefits?
  - **Enhanced desorption: Bubbles formed** increase surface contact between air and PFAS-contaminated soil/water.
  - **Promotes PFAS mobility: PFAS** have surfactant-like properties—can attach to bubbles and migrate upwards.
- ## Limitations?
  - **Originally designed for VOCs**; results are still uncertain due to fewer studies
  - **Soil type, profile:** Porosity, organic content, and grain size can affect PFAS desorption.

Smaller bubbles have a longer residence time

# Applying air sparging in the field

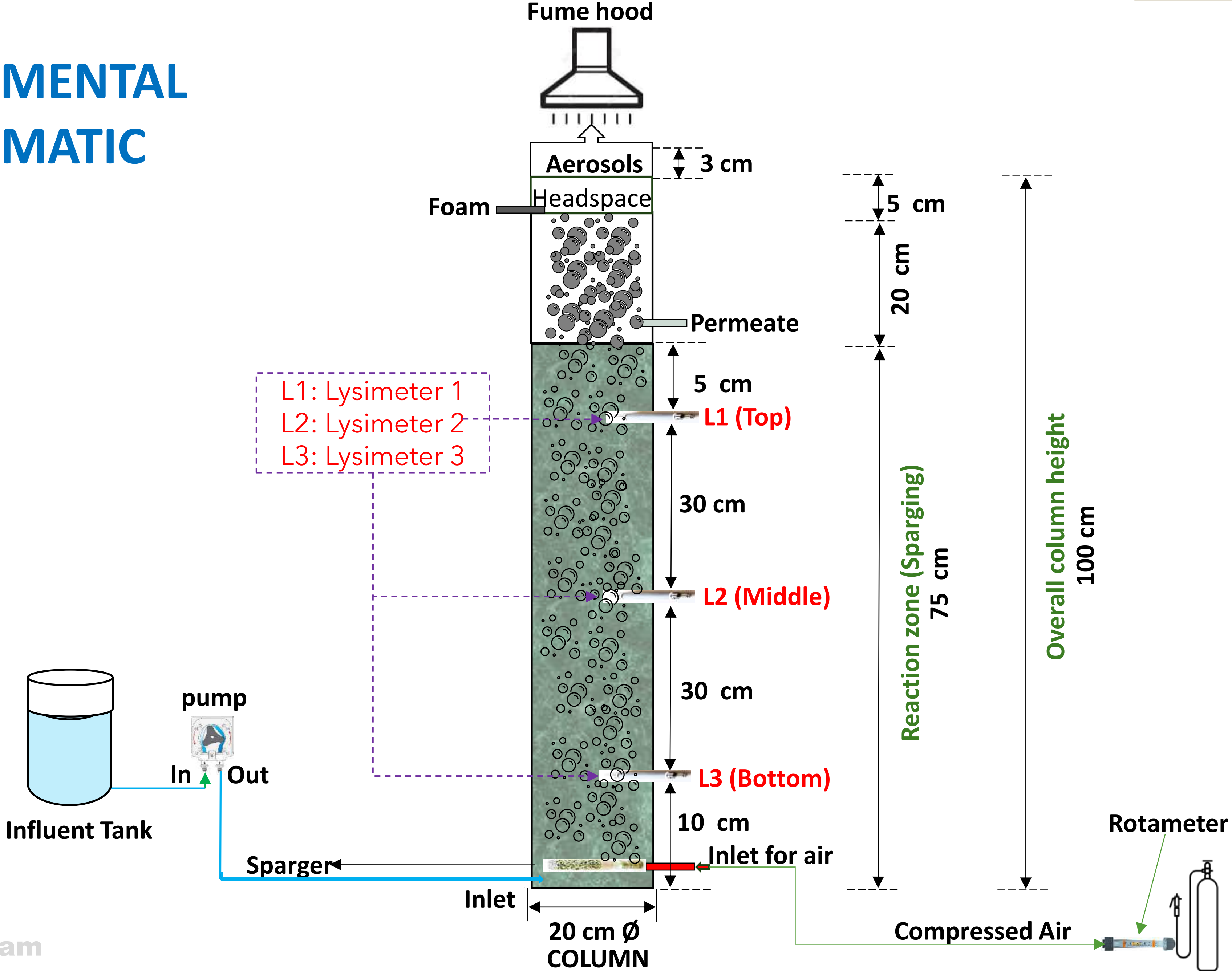



From Newell et al. 2022

# Objectives of the study

- Investigate the impact of in-situ air sparging on PFAS desorption from soil
- Is it possible to move PFAS up through the groundwater zone and concentrate PFAS in the upper part of the groundwater zone ?
- Compare **sparged vs. non-sparged columns** under controlled conditions
- Assess compound-specific behaviors:
  - **Short-chain vs long-chain PFAS**
  - **Precursors (6:2 FTSA, 6:2 FTAB)**
- Determine the **role of foam fractionation** in PFAS remediation

# EXPERIMENTAL SCHEMATIC



# Sampling


Sampling location: Sundsvall Timra Airport – AFFF training site

Processed soil

Sampling conducted : 2 m depth

Sieved with 0.2 um sieve

- Samples were from an aqueous film-forming foam (AFFF) training site at Sundsvall Timra, Sweden
- A total of half a ton of soil was collected and processed
- The samples were analyzed for a baseline reference

# Experimental Conditions

| Trial | Column* | Sparging Rate (L/min) | Flow Rate (mL/min) | Soil Height (cm) | Effective Porosity | Soil Volume (L) | Pore Volume (L) | Duration | Foam Collection |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 1* | 0 | 50 | 40 | 0.38 | 12.56 | 4.90 | 3 hours | No |
| 1 | 1 | 1 | 50 | 40 | 0.38 | 12.56 | 4.90 | 3 hours | Yes |
| 2 | 1 | 0 | 50 | 80 | 0.38 | 25.12 | 9.0 | 3 hours | No |
| 2 | 2 | 1.5 | 50 | 80 | 0.38 | 25.12 | 9.0 | 3 hours | Yes |
| 3 | 1 | 1.5 | 2.0 | 80 | 0.38 | 28.31 | 9.7 | 5 days | No |
| 3 | 2 | 1.5 | 2.0 | 80 | 0.38 | 28.31 | 9.7 | 5 days | No |

Focus of the presentation

*Short-term* (trials 1–2)

*Long-term* (trial 3)

# Experimental Conditions

**Trial 1**: Columns operated half-bed condition

**Trial 2**: Columns operated in full-bed condition

**Trial 3 (Long Term)**: Columns operated for 5 days (Not included in this talk)

**Targeted PFAS in pore water and foam**

| Compound (ng/L) | Abbreviation |
|---|---|
| **Perfluorobutanoic acid** | **PFBA** |
| **Perfluoropentanoic acid** | **PFPeA** |
| **Perfluorohexanoic acid** | **PFHxA** |
| **Perfluoroheptanoic acid** | **PFHpA** |
| **Perfluorooctanoic acid** | **PFOA** |
| **Perfluorononanoic acid** | **PFNA** |
| Perfluorodecanoic acid | PFDA |
| Perfluoroundecanoic acid | PFUdA |
| Perfluorododecanoic acid | PFDoA |
| Perfluorotetradecanoic acid | PFTeDA |
| 7H-Perfluoroheptanoic acid | HPFHpA |
| Perfluoro-3,7-dimethyloctanoic acid | P37DMOA |
| **Perfluorobutanesulfonic acid** | **PFBS** |
| **Perfluoropentanesulfonate** | **PFPeS** |
| **Perfluorohexanesulfonic acid** | **PFHxS** |
| **Perfluoroheptanesulfonic acid** | **PFHpS** |
| **Perfluorooctanesulfonic acid** | **PFOS** |
| Perfluorononanesulfonate | PFNS |
| Perfluorodecanesulfonic acid | PFDS |
| Perfluorotridecanoic acid | PFTrDA |
| Perfluorododecanesulfonate | PFDoS |
| 4:2 Fluorotelomer sulfonate | 4:2 FTSA |
| **6:2 Fluorotelomer sulfonate** | **6:2 FTSA** |
| 8:2 Fluorotelomer sulfonate | 8:2 FTSA |
| **6:2 Fluorotelomer betaine** | **6:2 FTAB** |
| Perfluorooctanesulfonamide | FOSA |
| N-methylperfluorooctanesulfonamide | MeFOSA |
| N-ethylperfluorooctanesulfonamide | EtFOSA |
| N-methylperfluorooctanesulfonamide-ethanol | MeFOSE |
| N-ethylperfluorooctanesulfonamide-ethanol | EtFOSE |
| Perfluorooctanesulfonamide-acetic acid | FOSAA |
| N-methylperfluorooctanesulfonamide-acetic acid | MeFOSAA |
| N-ethylperfluorooctanesulfonamide-acetic acid | EtFOSAA |

**Targeted PFAS in soil**

| Compound (ng/L) | Abbreviation |
|---|---|
| **Perfluorobutanoic acid** | **PFBA** |
| **Perfluoropentanoic acid** | **PFPeA** |
| **Perfluorohexanoic acid** | **PFHxA** |
| **Perfluoroheptanoic acid** | **PFHpA** |
| **Perfluorooctanoic acid** | **PFOA** |
| **Perfluorononanoic acid** | **PFNA** |
| Perfluorodecanoic acid | PFDA |
| Perfluoroundecanoic acid | PFUnDA |
| Perfluorododecanoic acid | PFDoDA |
| Perfluorotridecanoic acid | PFTrDA |
| **Perfluorobutanesulfonic acid** | **PFBS** |
| **Perfluoropentanesulfonic acid** | **PFPeS** |
| **Perfluorohexanesulfonic acid** | **PFHxS** |
| **Perfluoroheptanesulfonic acid** | **PFHpS** |
| **Perfluorooctanesulfonic acid** | **PFOS** |
| Perfluorononanesulfonic acid | PFNS |
| Perfluorodecanesulfonic acid | PFDS |
| Perfluorododecanesulfonic acid | PFDoS |
| Perfluorotridecanesulfonic acid | PFTrDS |
| Perfluoroundecanesulfonic acid | PFUnDS |
| Perfluorooctanesulfonamide | FOSA |
| Methylperfluorooctanesulfonamide | MeFOSA |
| Ethylperfluorooctanesulfonamide | EtFOSA |
| Methylperfluorooctanesulfonamidoethanol | MeFOSE |
| Ethylperfluorooctanesulfonamidoethanol | EtFOSE |
| Perfluorooctanesulfonamidoacetic acid | FOSAA |
| Methylperfluorooctanesulfonamidoacetic acid | MeFOSAA |
| Ethylperfluorooctanesulfonamidoacetic acid | EtFOSAA |
| Fluorotelomer sulfonate (4:2) | 4:2 FTSA |
| **Fluorotelomer sulfonate (6:2)** | **6:2 FTSA** |
| Fluorotelomer sulfonate (8:2) | 8:2 FTSA |
| **Fluorotelomer betaine (6:2)** | **6:2 FTAB** |

**13 compounds** were above the limit of quantification (LOQ) in water, foam, and soil

Short-chain Perfluorocarboxylic acids
PFBA, PFPeA, PFHxA

Long-chain PFCAs
PFHpA, PFOA, PFNA

Short- and Long-chain Perfluorosulfonic acids
PFBS, PFPeS, PFHpS, PFHxS, PFOS

Precursor compounds
6:2 FTS, 6:2 FTAB



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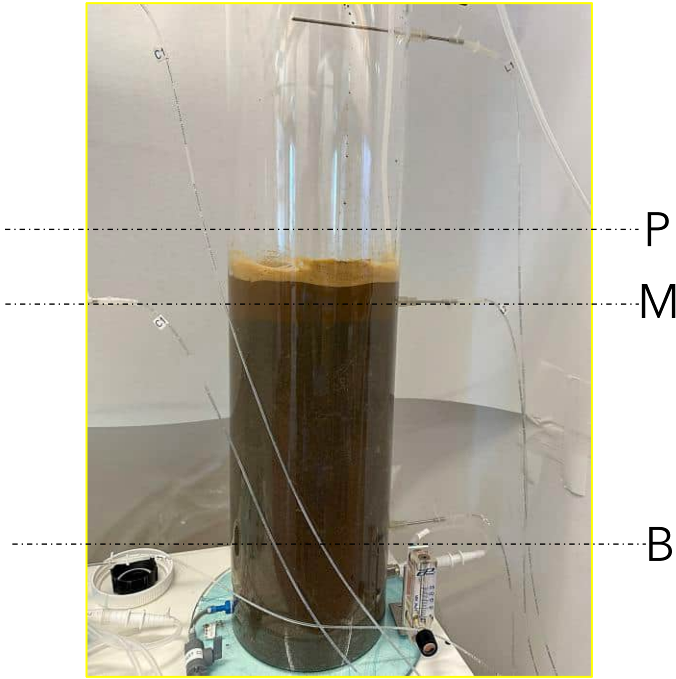
# Experimental Conditions – Trial 1

| Trial | Design | Label | Air rate (L/min) | Water flow (mL/ min) | Soil height (cm) | Effective porosity | Soil volume (L) | Run duration (h) | Foam collected |
|---|---|---|---|---|---|---|---|---|---|
| 1 | Single column, sequential | Baseline (water-only) | 0.0 | 50 | 40 | 0.38 | 12.6 | 3 | No |
| 1 | Single column, sequential | Sparging (air+water) | 1.0 | 50 | 40 | 0.38 | 12.6 | 3 | Yes |

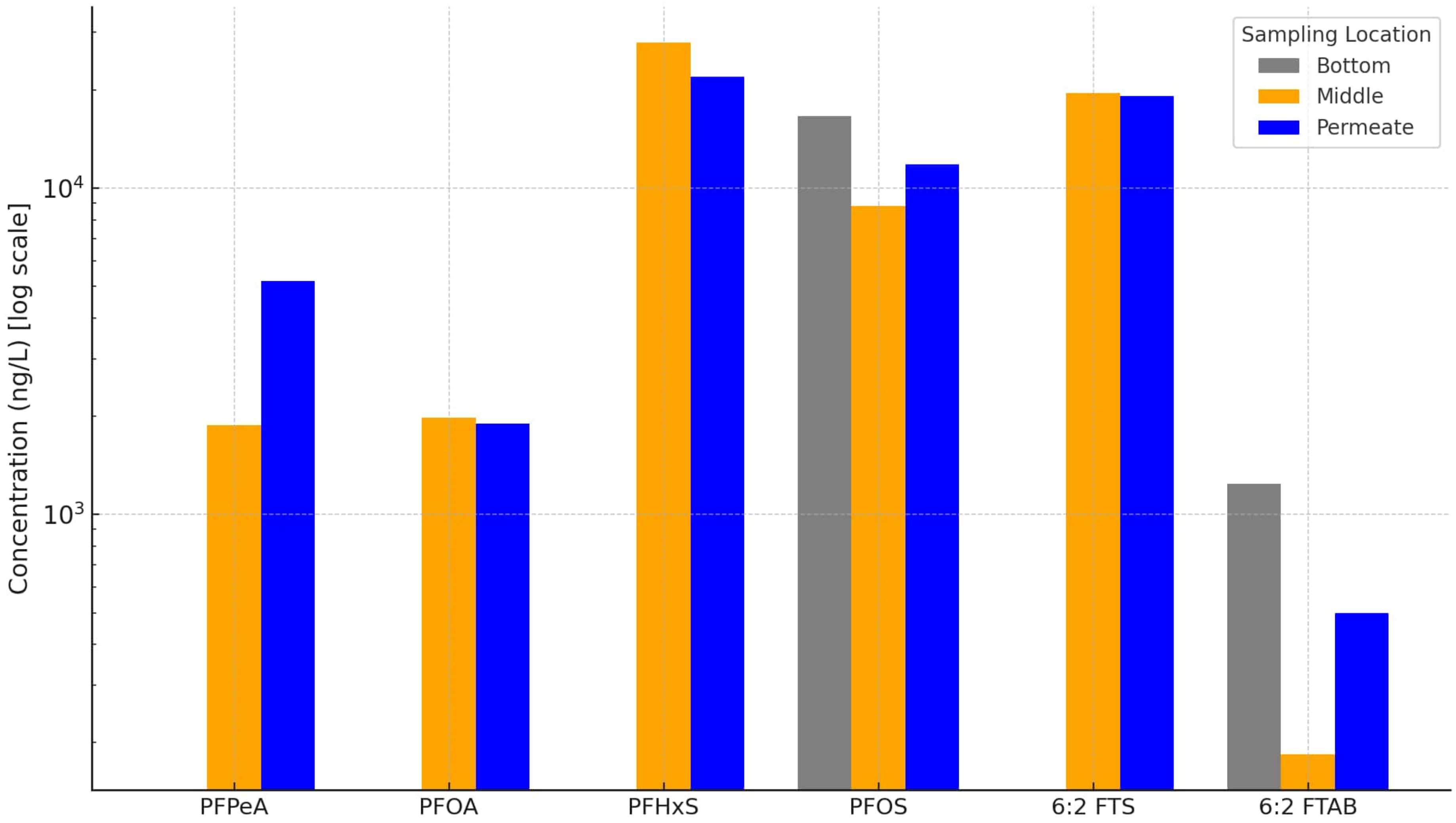
*Short-term*

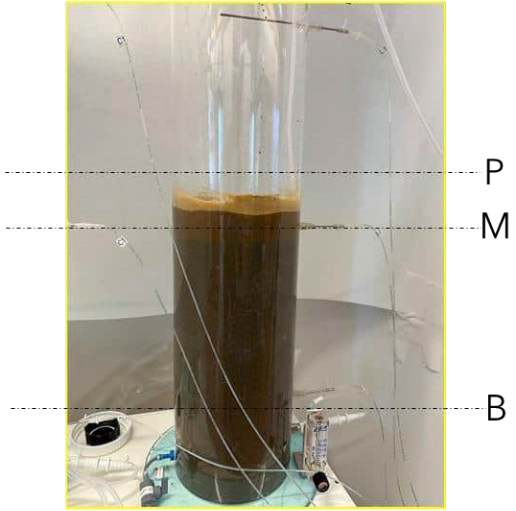



**Trial 1**: Columns operated in half-bed condition

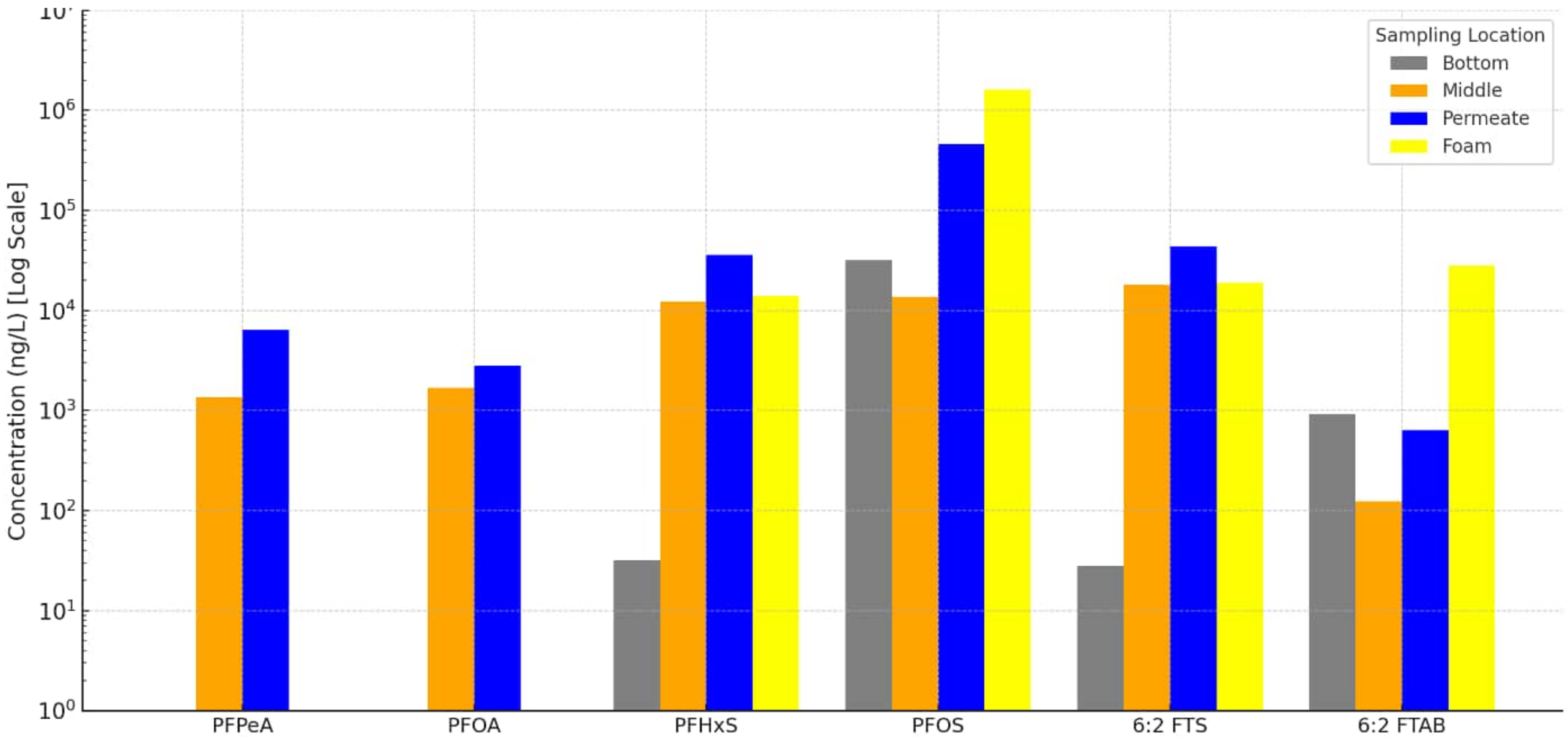
P = Permeate; M = Middle B = Bottom

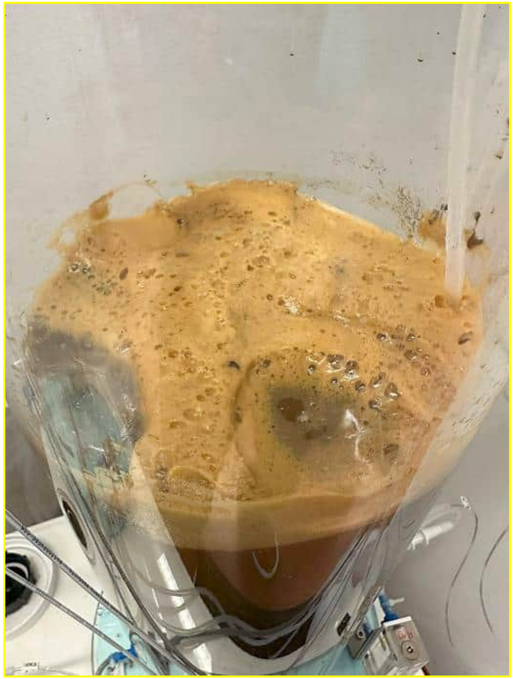
## Before Sparging – Beginning of experiment (Water Phase)



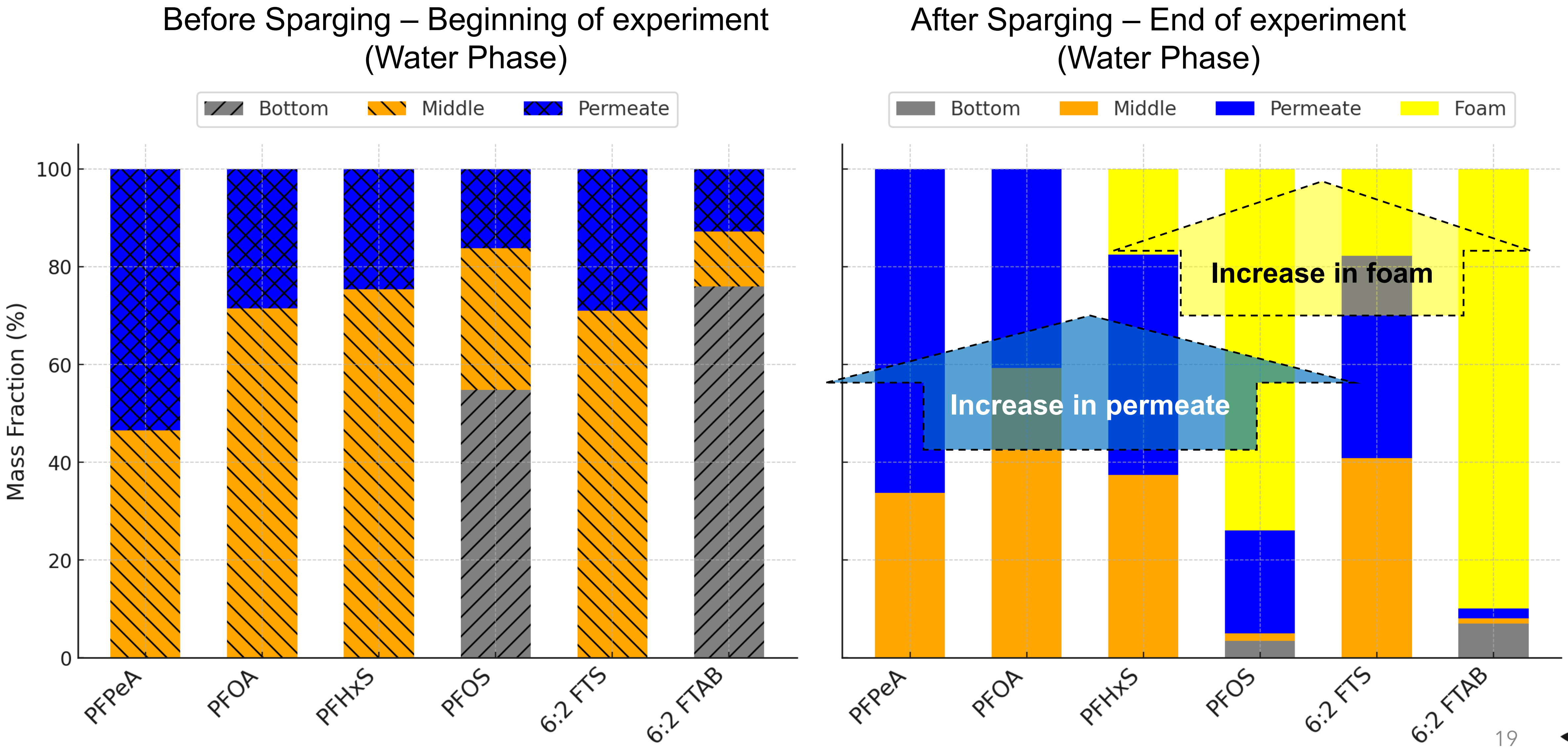
# After Sparging – End of experiment (Water phase)



A thick foam layer was found after 30 min of sparging

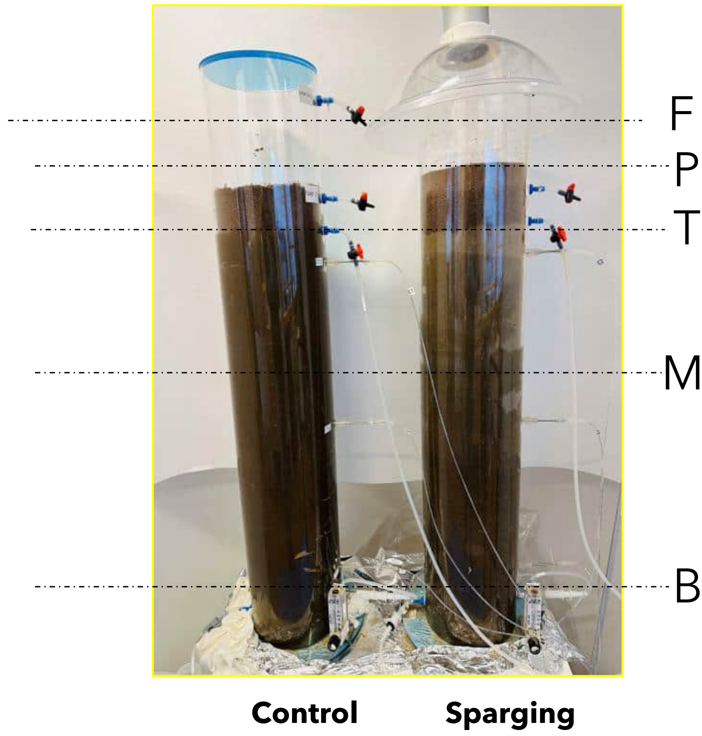
# Mass distribution across water and foam compartments (Trial 1)



# Experimental Conditions – Trial 2

| Trial | Design | Label | Air rate (L/min) | Water flow (mL/min) | Soil height (cm) | Effective porosity | Soil volume (L) | Run duration (h) | Foam collected |
|---|---|---|---|---|---|---|---|---|---|
| 1 | Single column, sequential | Baseline (water-only) | 0.0 | 50 | 80 | 0.38 | 25.12 | 3 | No |
| 1 | Single column, sequential | Sparging (air+water) | 1.5 | 50 | 80 | 0.38 | 25.12 | 3 | Yes |

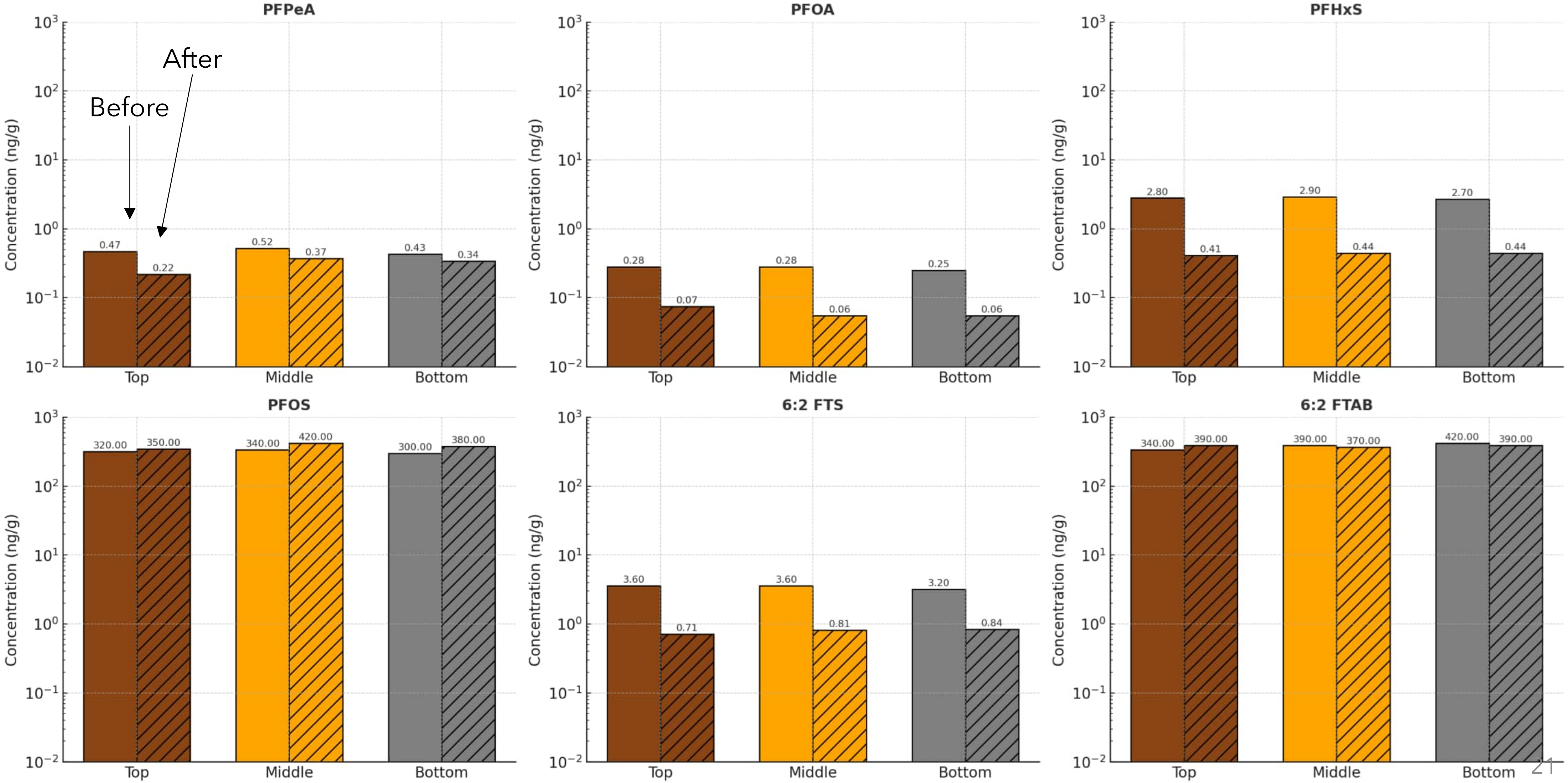
*Short-term*



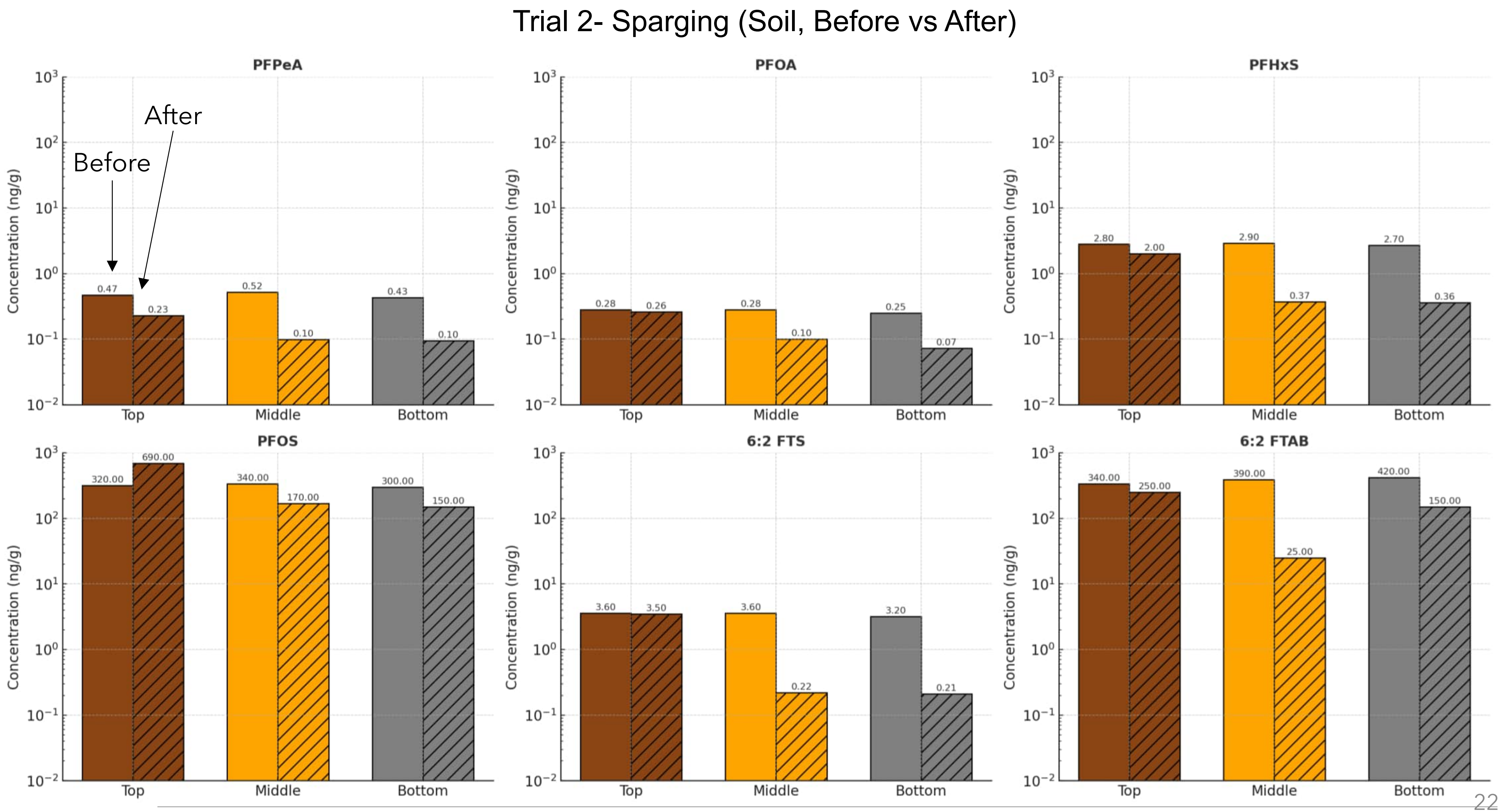

F= Foam, P = Permeate; T = Top, M = Middle B = Bottom

# Vertical distribution of PFAS in soil: Spatial distribution and mobilization (Trial 2)

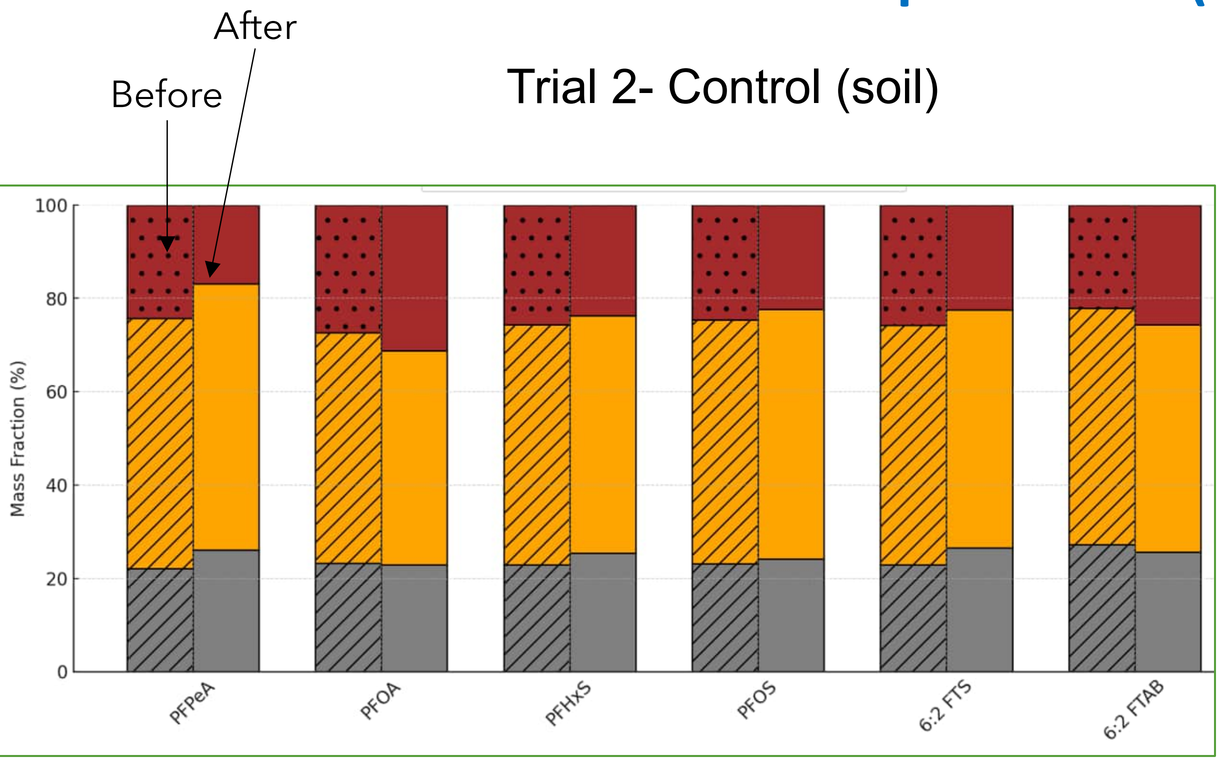
Trial 2- Control (Soil, Before vs After)

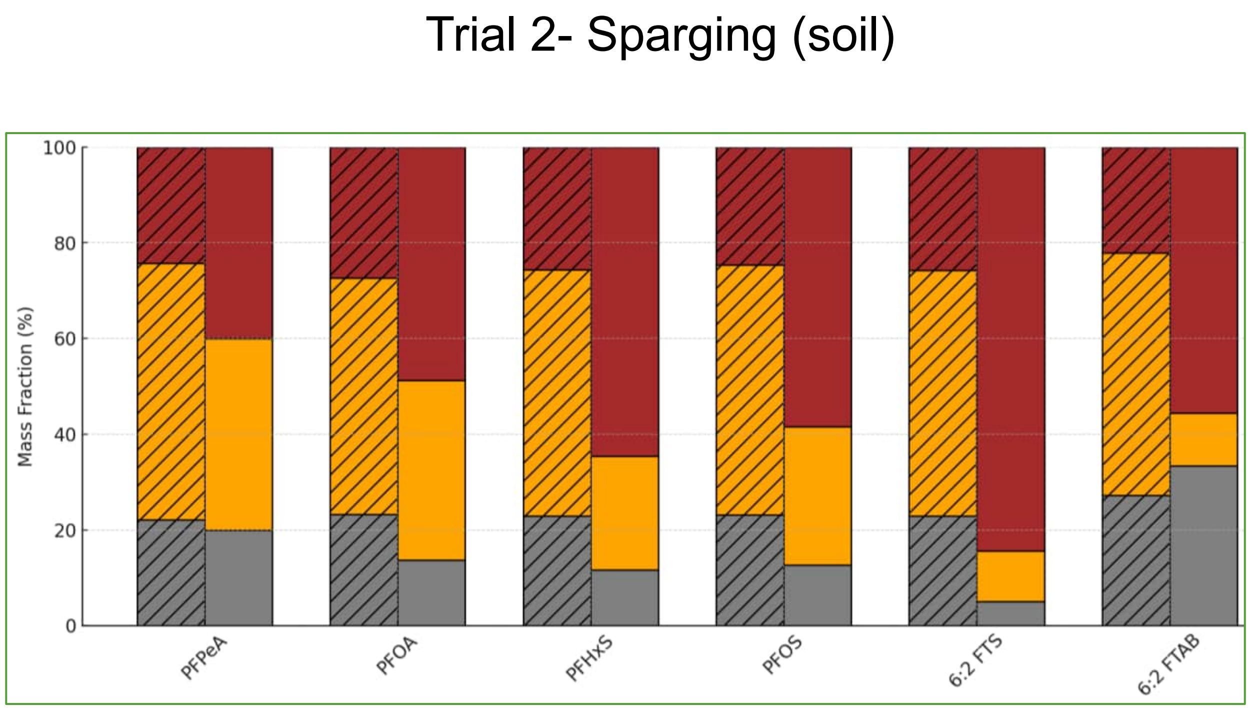


# Vertical distribution of PFAS in soil: Spatial distribution and mobilization (Trial 2)



# Mass distribution across soil compartments (Trial 2)




Bottom Before | Top Before | Middle After
Middle Before | Bottom After | Top After



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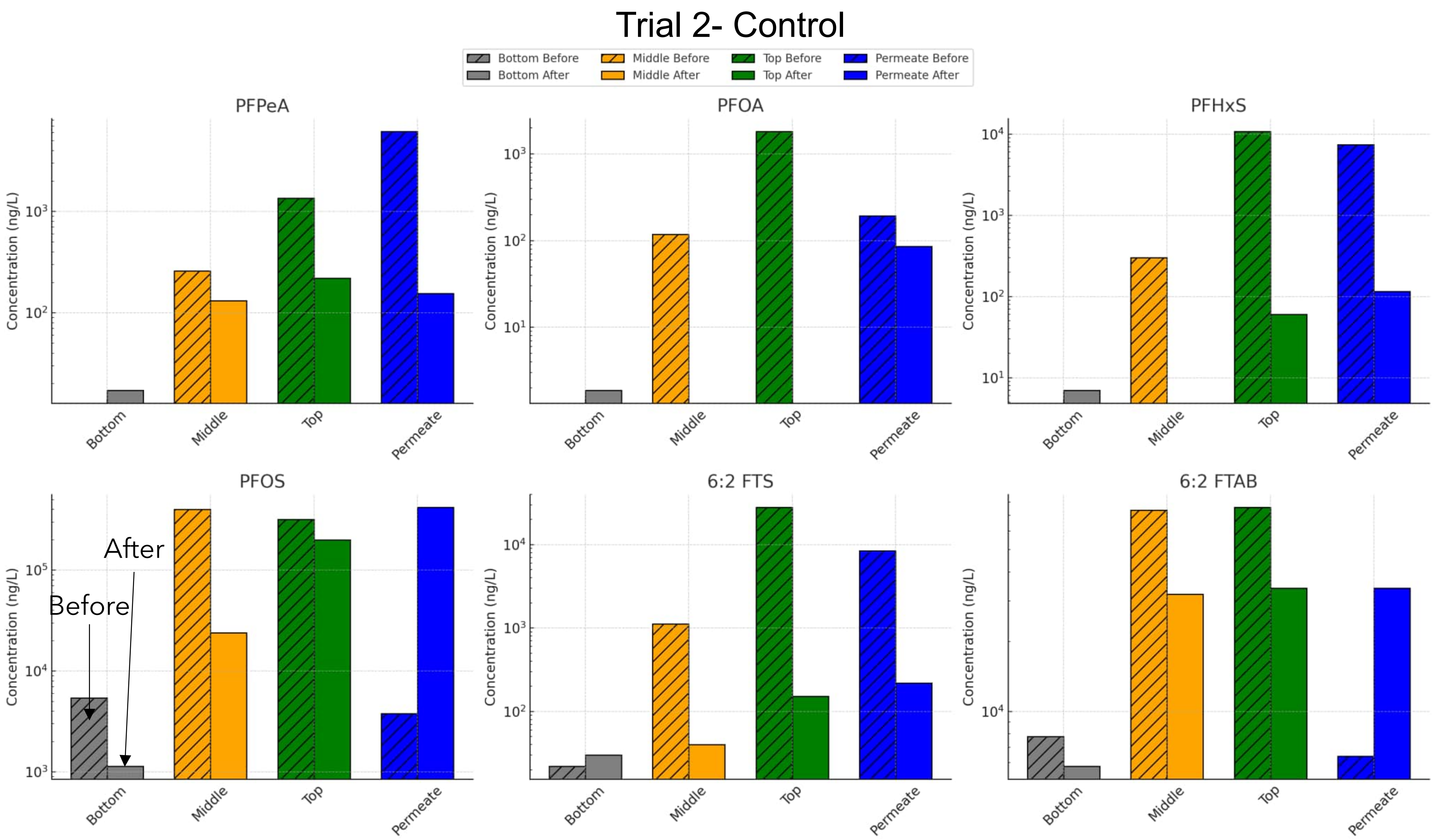
# Vertical distribution of PFAS in water: Spatial distribution and mobilization (Trial 2)





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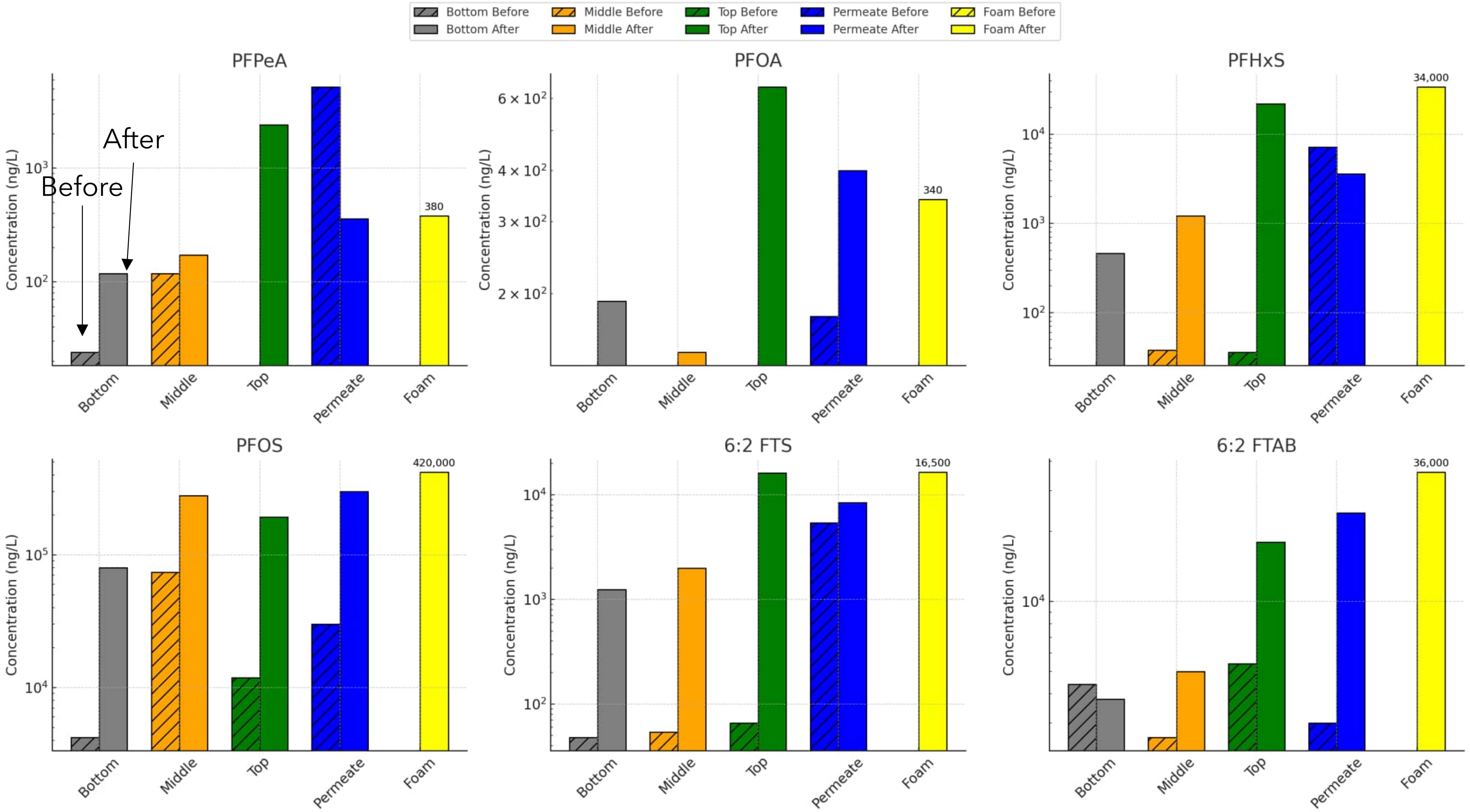
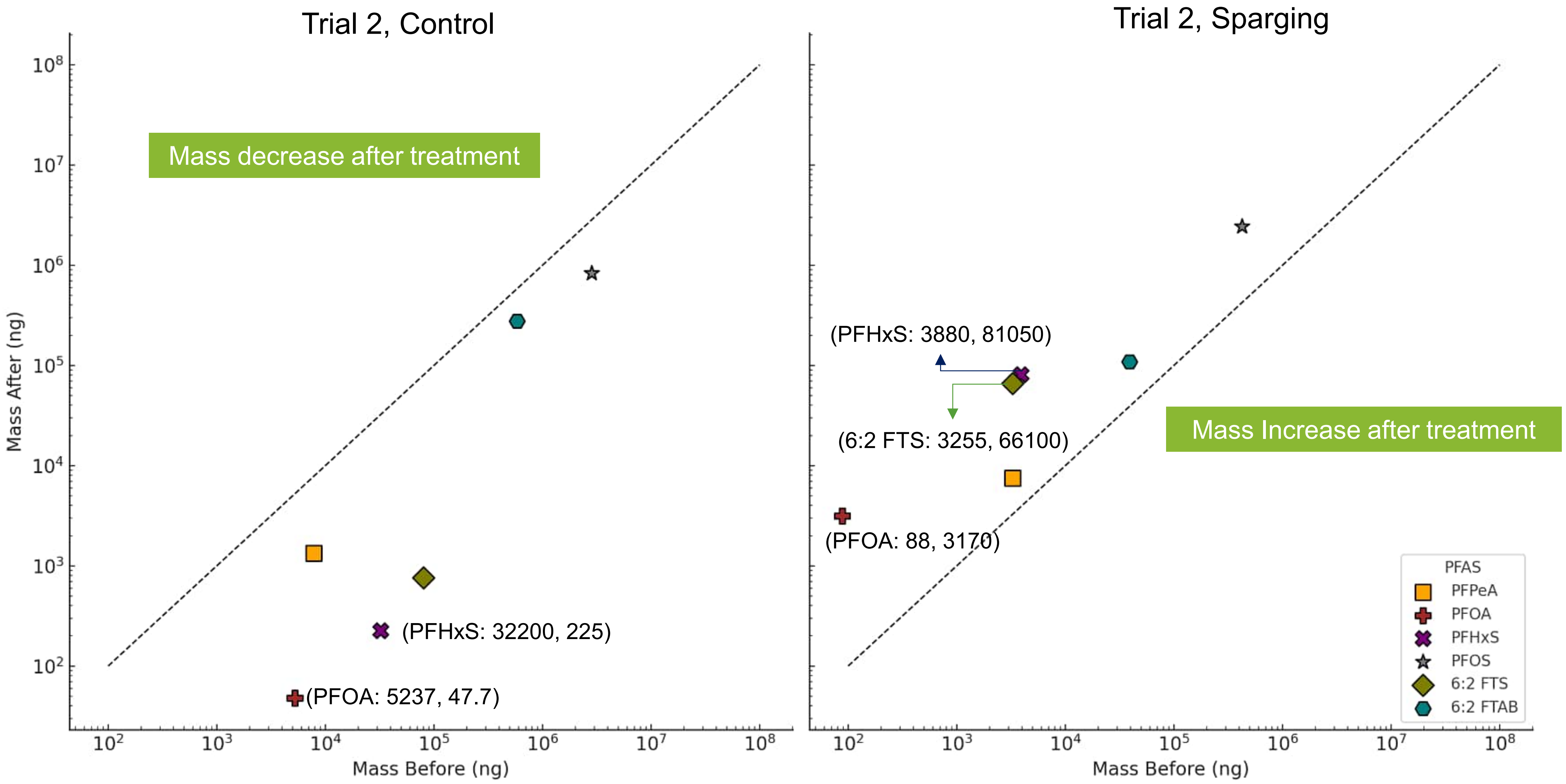
# Vertical distribution of PFAS in water: Spatial distribution and mobilization (Trial 2)

Trial 2- Sparging



# Mobilization of PFAS Mass (Total) into water and foam



# Conclusion, challenges and prospects

- Mass balance after sparging: Post-sparging PFAS soil mass decreased with an increase in PFAS mass in water/foam, demonstrating effective mobilization
  - This mobilization supports the potential for soil remediation, particularly in vadose zone or shallow saturated layers, where PFAS are sorbed but accessible to air channels.
- Class-specific behavior: Short/mid-chain PFCAs extracted in the water phase, while long-chain PFSAs and precursors extracted in the foam
- Foam: Foam fractionation could be a major removal pathway for surface-active PFAS (long-chains, precursors)
- Operations: Performance depends on sparger design, column depth, air flow rate, pore volumes, and residence time; over-aggressive sparging can destabilize hydraulics
- Path to field scale: This study does not claim that PFAS can be lifted from deep groundwater zones to the surface (it's unclear due to lack of trials). However, at the field scale, it could be used to mobilize and concentrate PFAS within the upper part of the saturated zone.

# Thank you for listening

## Questions