TEMPE CELL METHOD FOR QUANTIFYING VADOSE ZONE LEACHING OF PFAS SOURCES

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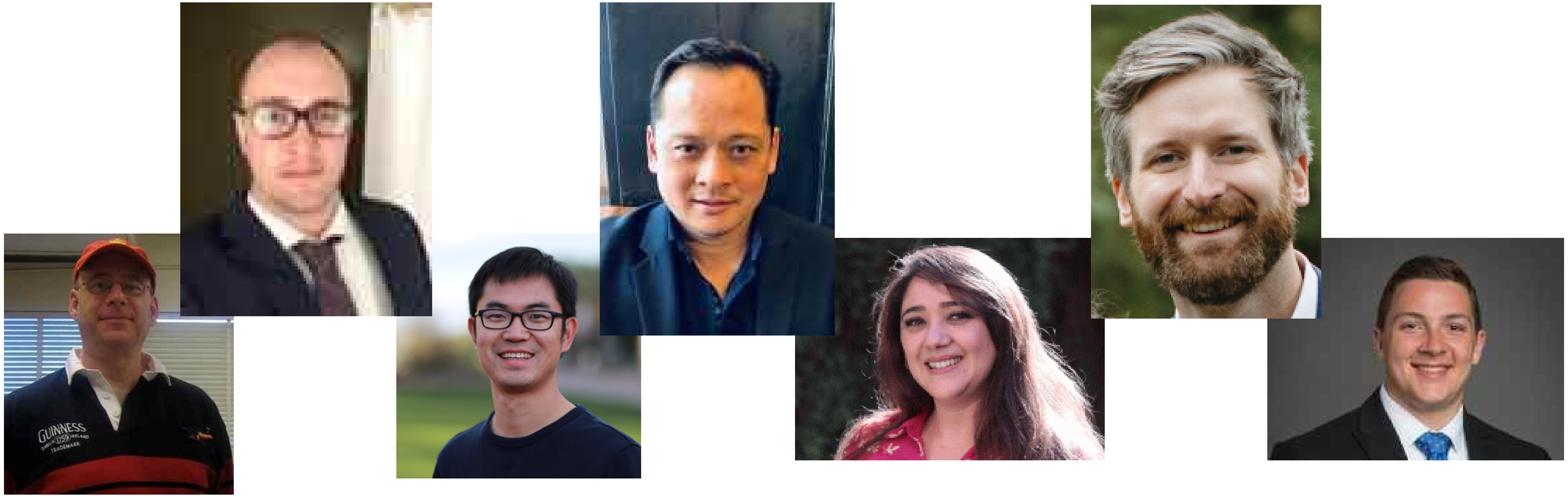
  - Bo Guo, Mark Brusseau, Asma El Ouni, Ryan Russell – University of Arizona
  - Jeffrey Davis - AFCEC



Agenda

- Objective
- Project Overview
- Ongoing Testing/Method development
- PFAS Leach Modeling and Tempe Cell sampling
- Next steps
- Q&A

Problem Statement

Cost-effective, reliable method to characterize PFAS leaching is needed

USEPA generic soil-to-groundwater pathway criteria for PFOA and PFOS are less than detection limits

PFAS leaching and retention behavior is vadose zone source soils is more complicated than conventional hydrophobic interactions

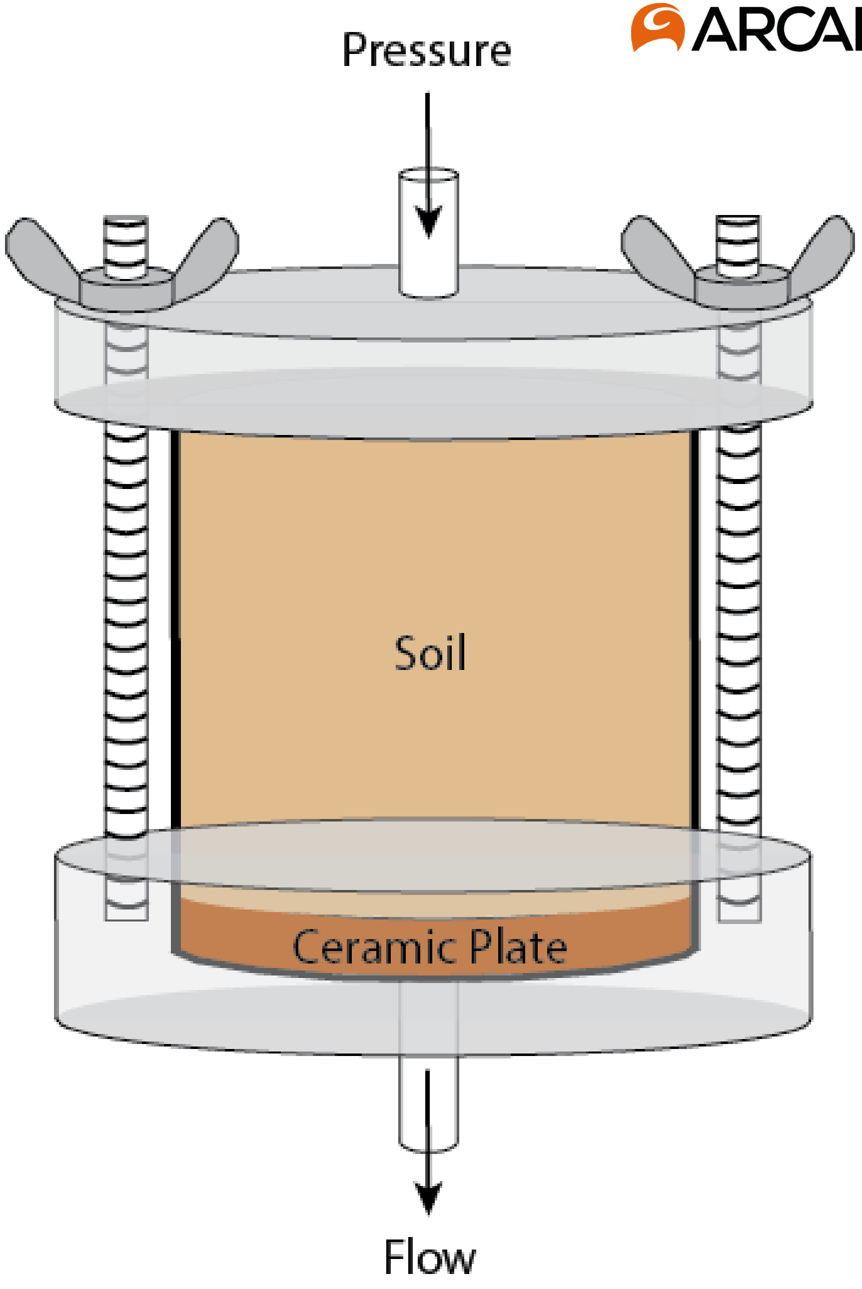
- Partitioning at the air-water interface is key differentiator for PFAS

Synthetic Precipitate Leaching Procedure (SPLP) is destructive, worst-case approach

Lysimeter porewater sampling is thought to be more representative, but more complicated especially in arid environments

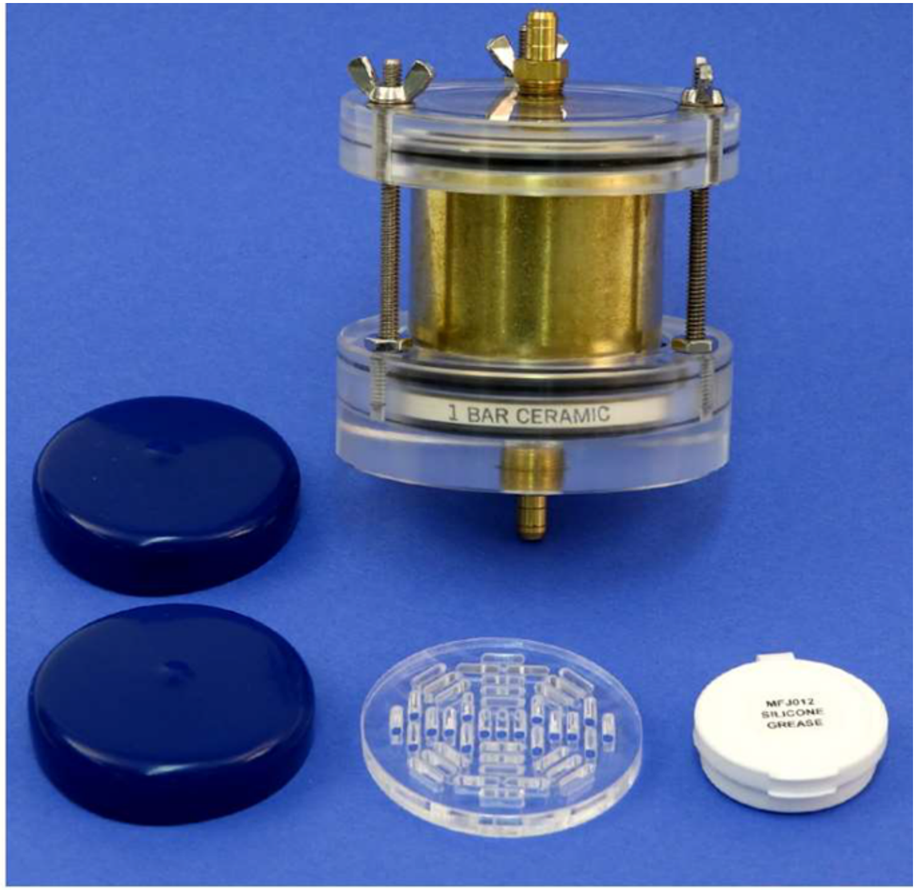
Objectives

- Apply Tempe Cells to evaluate vadose zone leaching behavior:
  - Conduct porewater sampling as a function of saturation during systematic drainage on intact or repacked cores
  - Compare results to lysimeter porewater sampling
- Use PFAS Leach modeling suite to determine sampling strategies
- Goal is to develop method that commercial laboratories can implement
  - Provide alternative SPLP and lysimeters



Tempe Cell Approach to Leaching Measurement

- Tempe cells have long been used by practitioners in vadose zone flow and transport modeling to develop (Wallayce and Lu 2011):
  - Intact or repacked cores subjected to imbibition and drainage
    - soil water retention curves,
    - permeability vs saturation, and
    - air-water interfacial area estimates.
  - Mining heap-leach experiments examined behavior using Tempe Cells in 1990s



Typical Tempe Cell with sample sleeve, end caps, porous ceramic plate, and fitting to set up apparatus for testing. Soil Moisture.

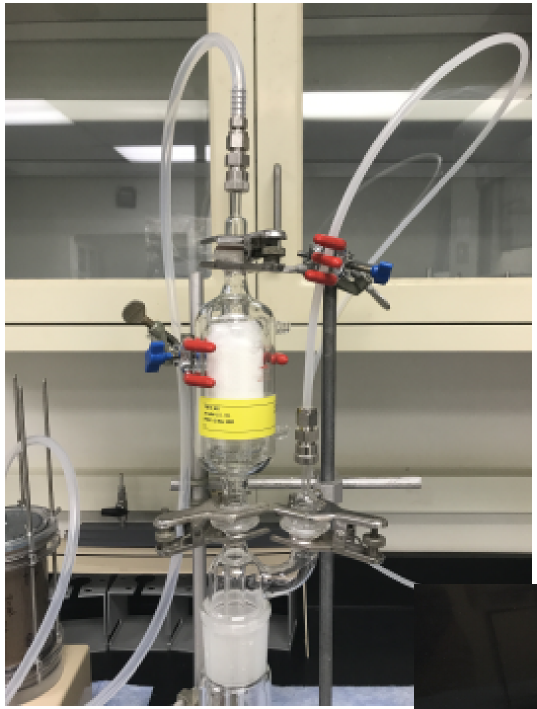
Wallayce, Alexandra and Ning Lu, 2012, Transient water release and imbibitions method for rapidly measuring wetting and drying soil water retention and hydraulic conductivity functions, doi: 10.1520/GTJ103596

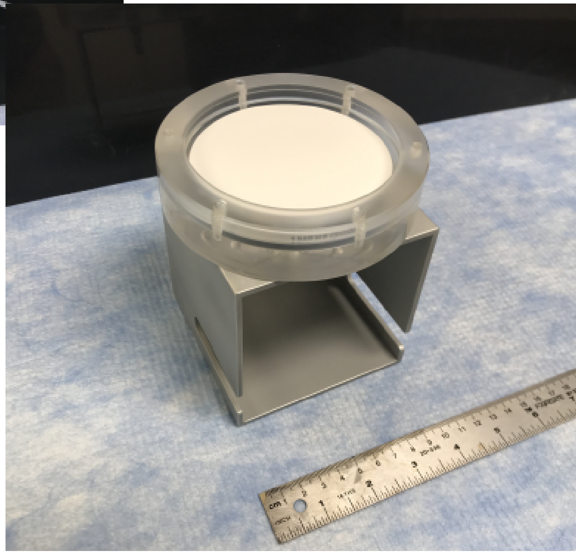
Project Overview – Field Locations

- Phase 1 – Initial testing and method development
  - Ellsworth AFB – fieldwork Summer 2023
  - Method development and refinement for phase 2 application (on-going)
- Phase 2 – Apply Tempe Cell to 3 additional sources (Summer /Fall 2024)
  - Eielson AFB
  - Cape Cod AFB
  - Charleston AFB

Ongoing Testing / Method Development

- **Verification that oil-less compressor is PFAS-free**
  - Modified OTM-45 applied to compressor air stream with and without GAC treatment
  - 2,000 L compressed air through XAD canister/condensate trap
  - Short Chain PFCAs detected at very low levels < ng/M^3
- **Ceramic plate PFAS sorption testing**
  - Water testing before and after ceramic plate showed good agreement – no evidence of loss to plate
    - Average RPD 7% for PFSAs
    - Average RPD 3% for PFCAs





Bench Scale Experiments – University of Arizona

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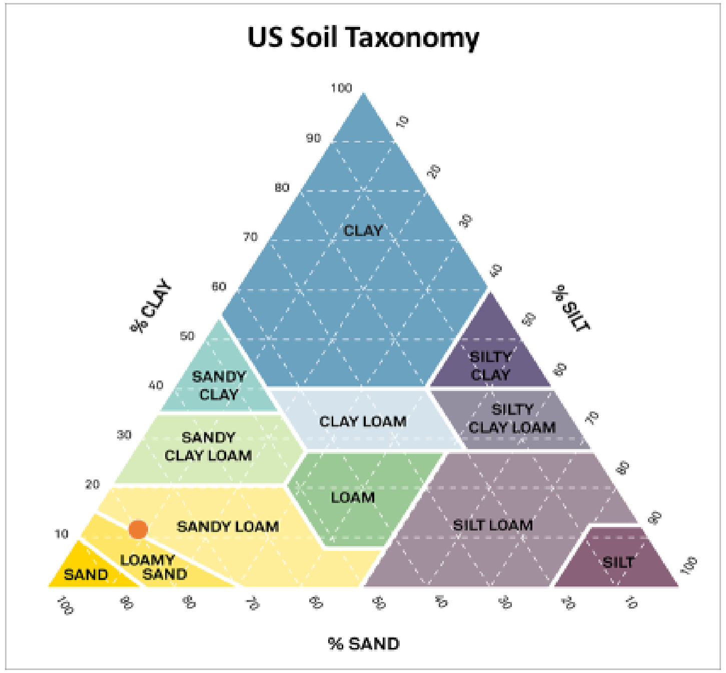
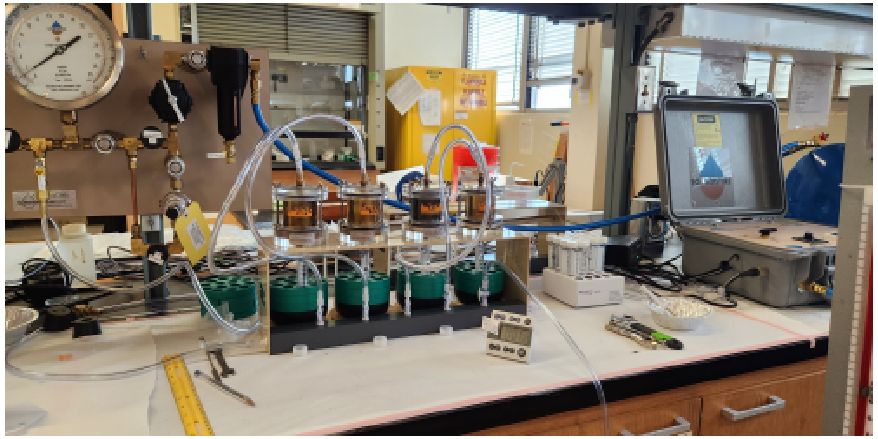
- Initial testing conducted for soil samples collected at Ellsworth site

Measured parameters:
- Tempe cell SWCC
- Particle size distribution
- Organic carbon
- Metal oxides



Example of Particle Size Distribution: sample FT001P-SO-T03



Metal Oxides

Sample ID	Al	Cr	Mn	Fe	Co	Ni	Cu	Zn	As	Mo	Ag	Cd	Pb
	[ug/g]	[ug/g]	[ug/g]	[ug/g]	[ug/g]	[ug/g]	[ug/g]	[ug/g]	[ug/g]	[ug/g]	[ug/g]	[ug/g]	[ug/g]
E11SW1	10522.56	28.61	1483.232697	45988.90	11.91	30.74	36.93	73.71	27.64	5.56	0.05	0.35	12.35
E11SW2	11547.87	22.46	1135.948202	32214.09	10.44	26.02	29.48	57.65	22.98	3.86	0.05	0.25	12.40
E11SW3	10861.18	23.30	1540.03436	48724.06	13.59	30.65	40.23	75.95	31.57	4.49	0.11	0.42	13.21
E11SW4	335.8462657	0.57	2.28	127.394348	0.00	0.18	0.62	0.99	0.17	BDL	0.03	0.01	0.37

Total Organic Carbon/TN

Sample ID	TN wt %	Total C wt %	TS wt %
LOD	0.005 mg	0.005 mg	0.022 mg
	Mean (wt %)	Mean (wt %)	Mean (wt %)
E11SW1	0.01	1.59	BDL
E11SW2	0.01	1.52	BDL
E11SW3	0.01	1.48	BDL
E11SW4	BDL	BDL	BDL
E11SW4	BDL	BDL	BDL

Tempe Cell Conceptual Model

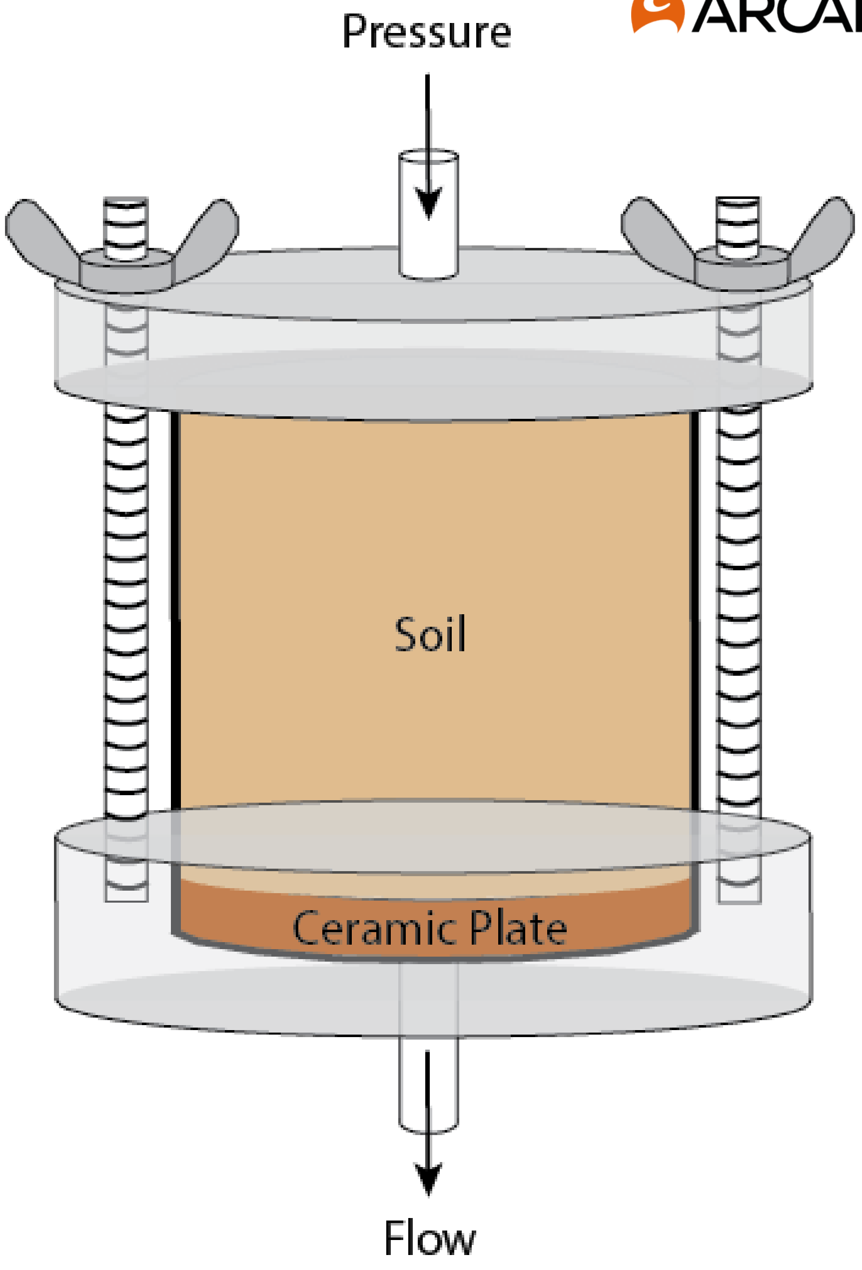
Utilize the PFAS-LEACH models to:

- Establish pressure setpoints for sampling during implementation of Tempe Cell Method
- Understand and quantify the leaching process during imbibition and drainage cycles.

Define two model layers (soil and ceramic plate)

Assume 1D flow and PFAS transport

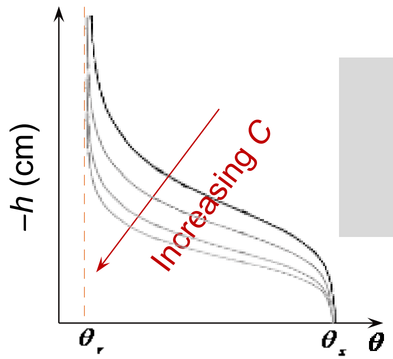
- Evaluate hydraulic and chemical equilibration time between sample steps



Mathematical Model

Soil Water Flow:

$$\frac{\partial \theta}{\partial t} - \nabla \cdot [\boldsymbol{K}(\theta) \nabla (h - z)] = 0$$



Surfactant-induced flow

$$h = \frac{\sigma(C) \cos \gamma(C)}{\sigma_0 \cos \gamma_0} h_0$$

(Leverett J scaling)

- PFAS Transport

$$\frac{\partial (\theta C)}{\partial t} + \rho_b \frac{\partial C_s}{\partial t} + \frac{\partial C_{aw}}{\partial t} + \nabla \cdot (\theta \boldsymbol{v} C) - \nabla \cdot \left(\theta \boldsymbol{D} \frac{\partial C}{\partial z} \right) = 0$$

Advection

Dispersion

Nonlinear and rate-limited solid-phase adsorption

$$C_{s,1} = F_s K_f C^N \qquad \frac{dC_{s,2}}{dt} = \alpha_s [(1 - F_s) K_f C^N - C_{s,2}]$$

Instantaneous

Kinetic

Nonlinear and rate-limited air-water interfacial adsorption

$$C_{aw,1} = F_{aw} A_{aw} K_{aw} C \qquad \frac{dC_{aw,2}}{dt} = \alpha_{aw} [(1 - F_{aw}) A_{aw} K_{aw} C - C_{aw,2}]$$

Instantaneous

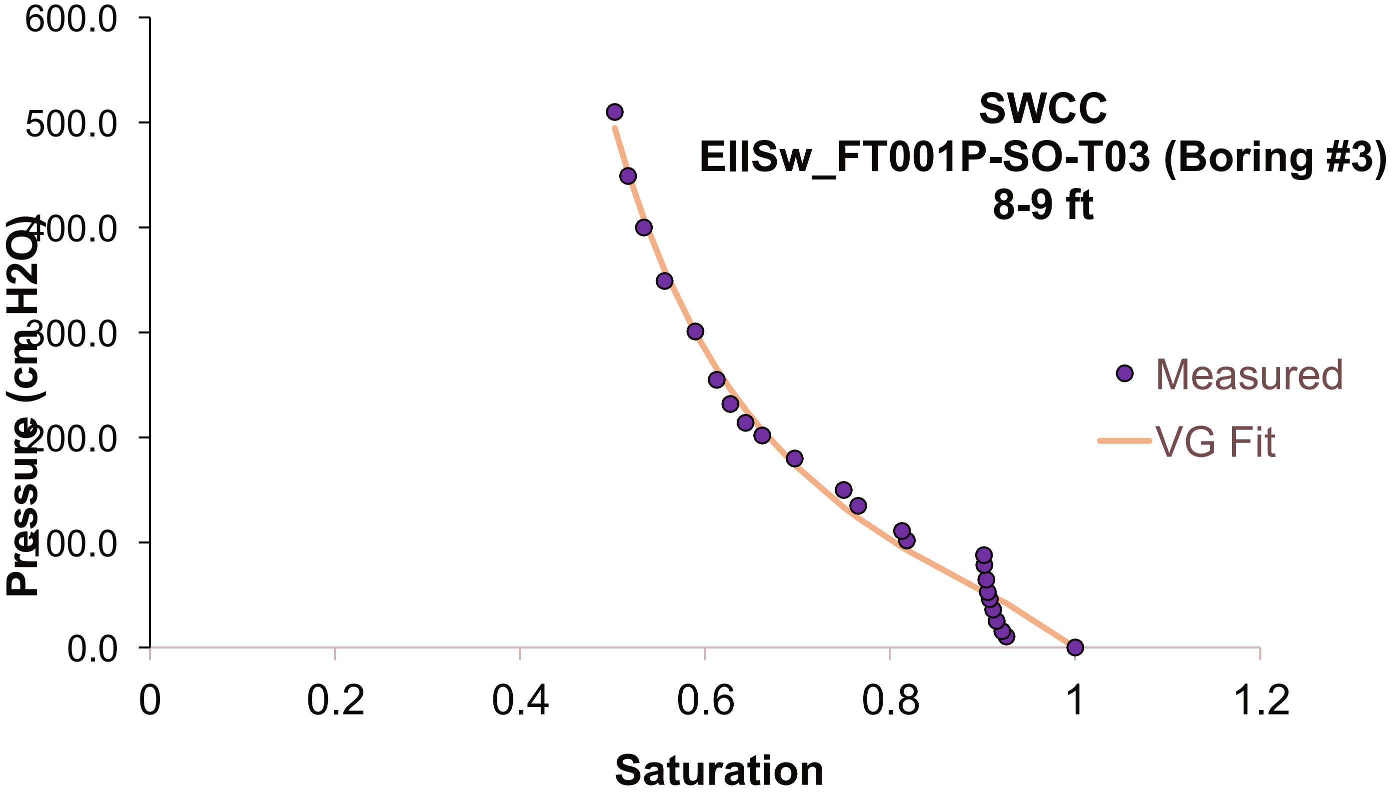
Kinetic

Guo, Zeng, Brusseau, 2020 WRR
Zeng & Guo, 2021 AWR

Estimation of Model Parameters

Fit van Genuchten parameters to experimental soil water characteristic curve (SWCC) data

Measure K_{sat} via laboratory experiments

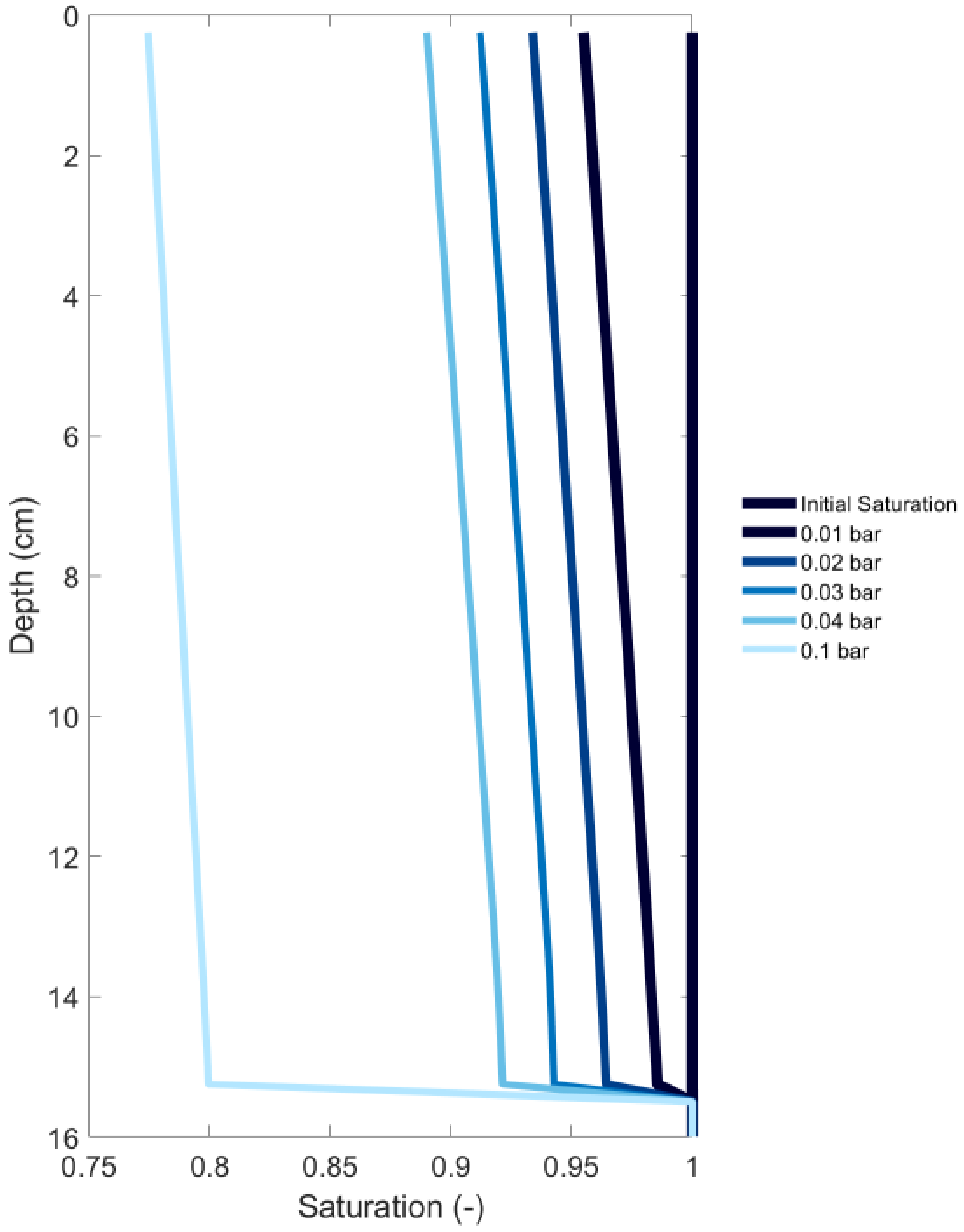


Model Layer	θ_r	θ_s	α (1/cm)	n	Ksat (cm/d)
Boring #3	0.0631	0.336	0.0112	1.539	223.3
Ceramic Plate	0.04	0.38	1E-07	1.1	0.0599

Preliminary Simulations

Water saturation profiles plotted when model is equilibrated to pressure BC

Results consistent with SWCC experiments



Preliminary Simulations – PFOS

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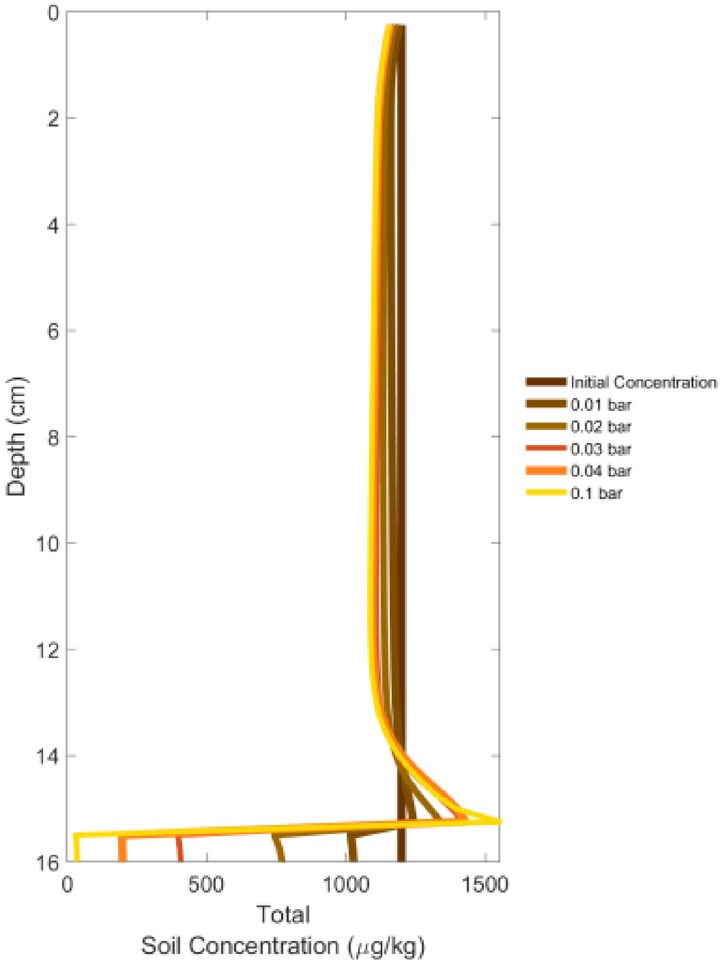
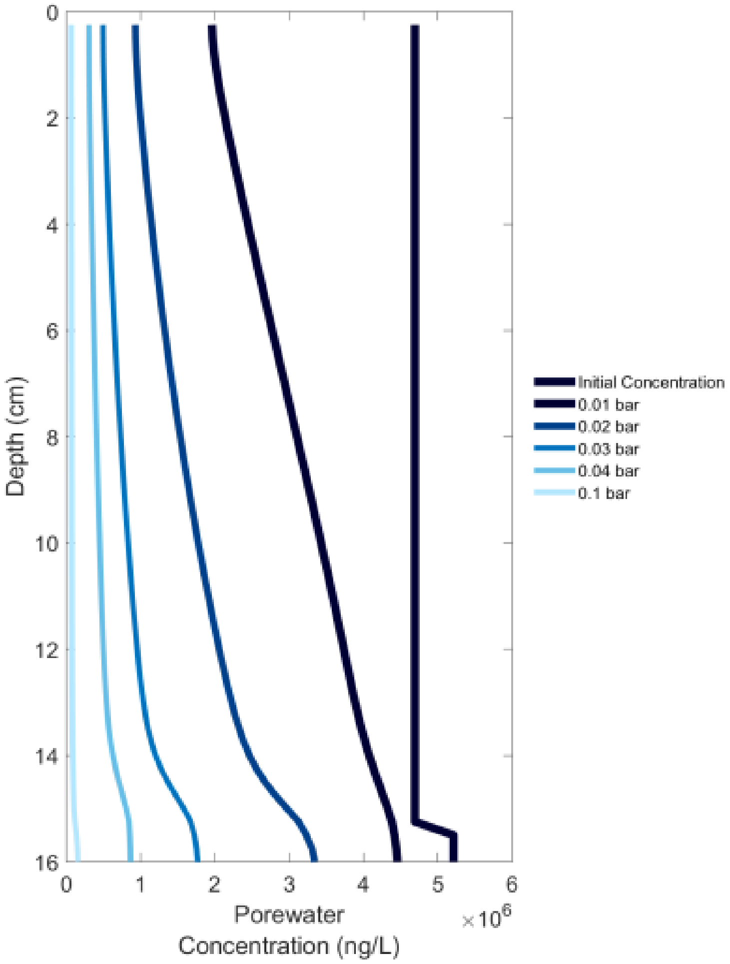
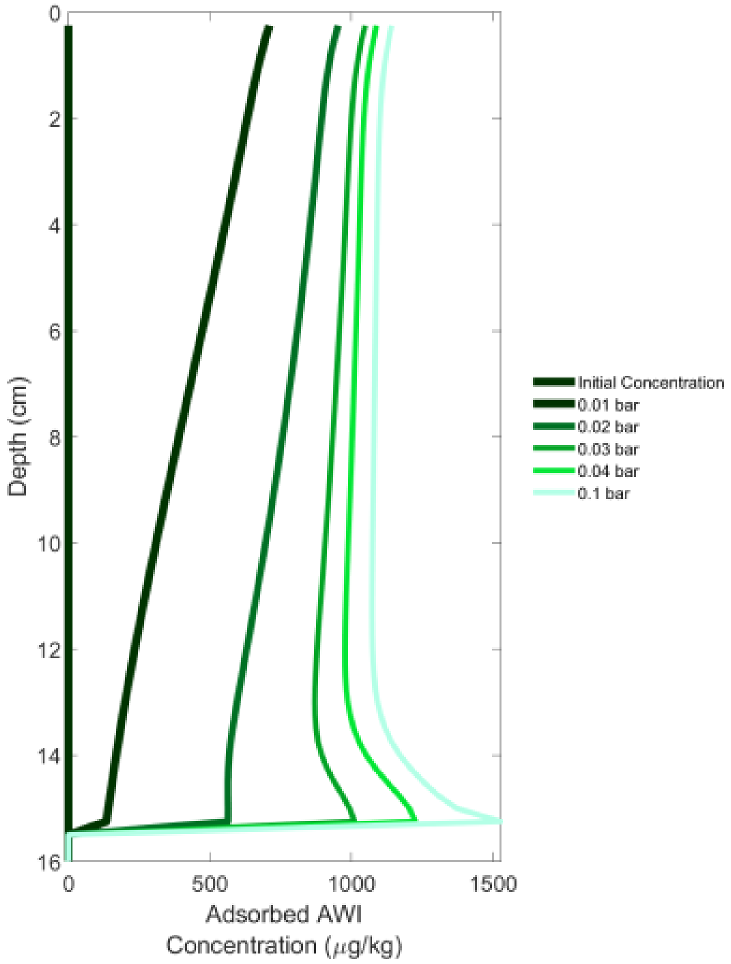






No significant changes in total concentration

Concentration at air-water interface (AWI) increases as porewater concentration decreases

Adsorbed solid-phase concentration decreases as water saturation decreases

Framework for Estimating Pressure Setpoints

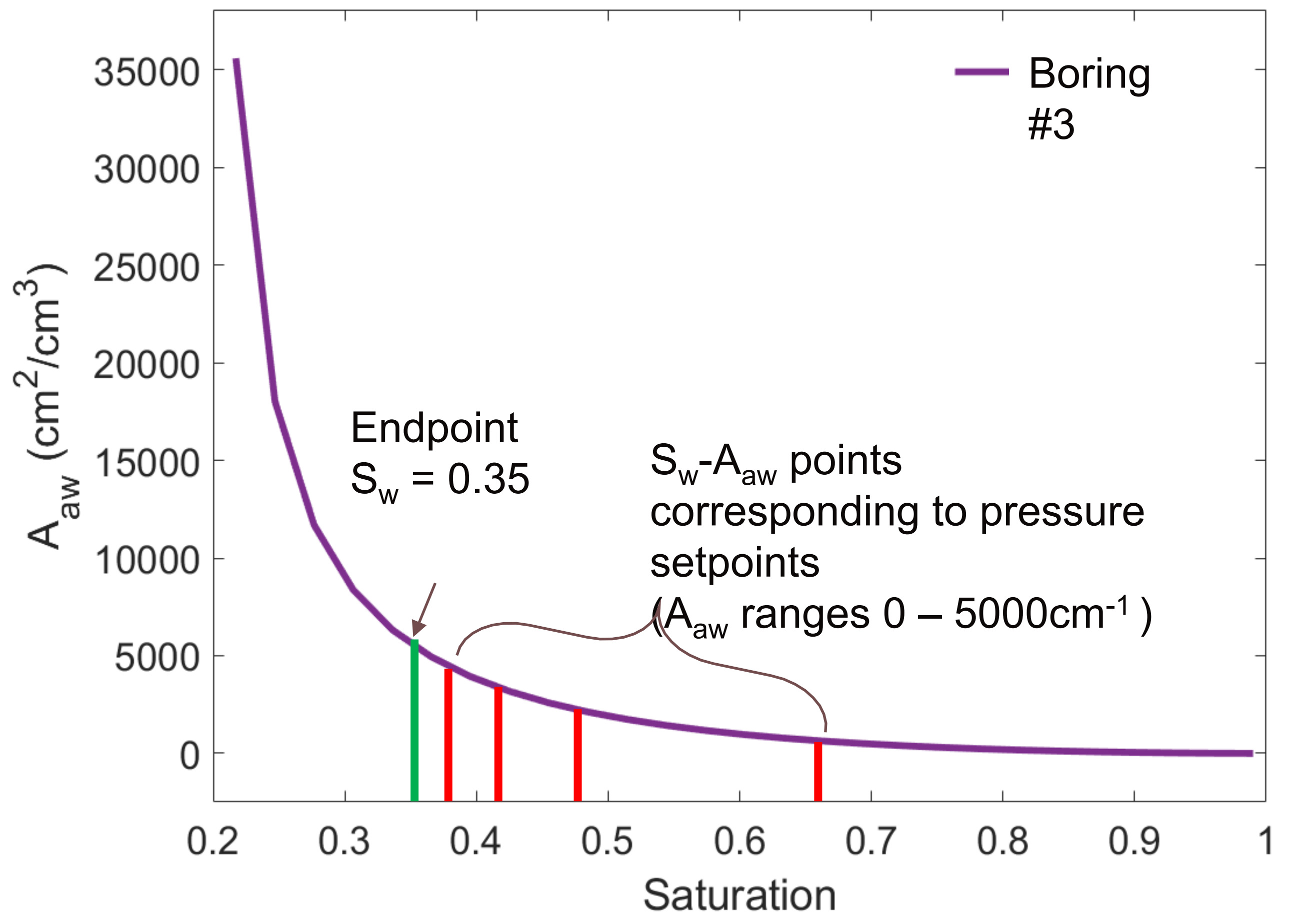
Investigate relationship between S_w , A_{aw} , and PFAS porewater concentration

Use simple-mass balanced approach Define endpoint S_w and corresponding A_{aw}

Determine n, evenly spaced intervals based on endpoint A_{aw}:

$$A_{aw} \longrightarrow S_w \longrightarrow p$$

Use model simulations to estimate time duration between pressure setpoints to reach hydraulic and chemical equilibrium.



Next Steps

- Conduct Tempe cell sampling vs pressure based on PFAS Leach modeling of hydraulic equilibrium at first site – Ellsworth AFB
- Conduct soil sampling and core collection at Eielson AFB, Cape Cod AFB and Charleston AFB this summer
- Refine approach based on lesson learned and complete Tempe Cell sampling
- Complete BAA Report and Peer Reviewed Paper in 2025
- Collaborate with Commerical Laboratories to bring method to market

Q&A

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