Naval Facilities Engineering Systems Command
EXWC Engineering and Expeditionary Warfare Center

NAVFAC OER2

Understanding PFAS Leaching: Key Processes, Decision Frameworks, and Management Strategies

7 May 2025

Dr. Charles Schaefer, CDM Smith
Dr. Charles Newell, GSI Environmental

Disclaimer

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OER2 Webinar Series

- **Why Attend?**
  - Obtain and hear about the latest DOD and DON's policies/guidance, tools, technologies and practices to improve the ERP's efficiency
  - Promote innovation and share lessons learned
  - FEEDBACK to the ERP Leadership
- **Who Should Attend?**
  - ERP Community Members: RPMs, RTMs, Contractors, and other remediation practitioners who support and execute the ERP
  - Voluntary participation
- **Schedule and Registration:**
  - Offered quarterly
  - Registration link for each topic (announced via ER T2 email)
- **Topics and Presenters:**
  - ERP community members to submit topics (non-marketing and DON ERP-relevant) to s (Nate Delong at nathan.a.delong2.civ@us.navy.mil or EXWC_T2@us.navy.mil)
  - Selected topic will be assigned Champion to work with presenter

Today’s Speakers

Charles Schaefer

CDM Smith

Charles Newell

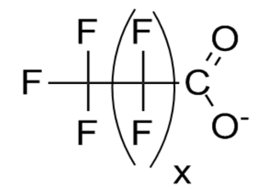
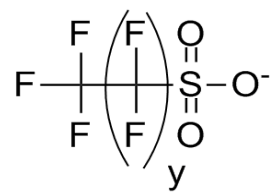
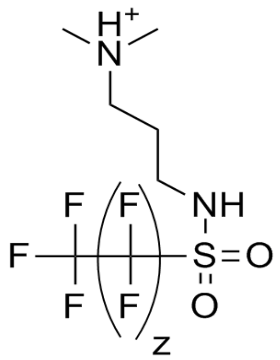
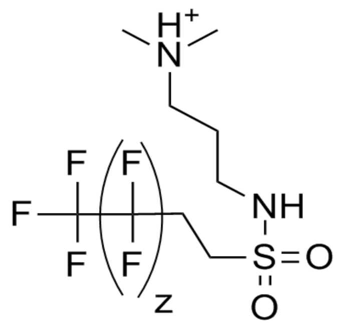
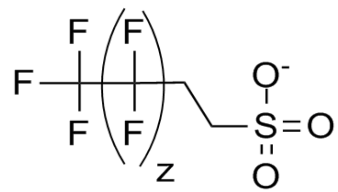
GSI Environmental Inc.

Road Map

1. Introduction: Lets Take a Quick Look at Three Graphics
2. How Does PFAS Leaching Work: Key Processes
3. One Key Decision-Making Framework: PFAS Mass Discharge
4. How to Characterize PFAS Leaching Sources
5. PFAS Leaching Computer Models
6. Key Decisions for Managing PFAS Leaching
7. Wrap Up
8. Q&A

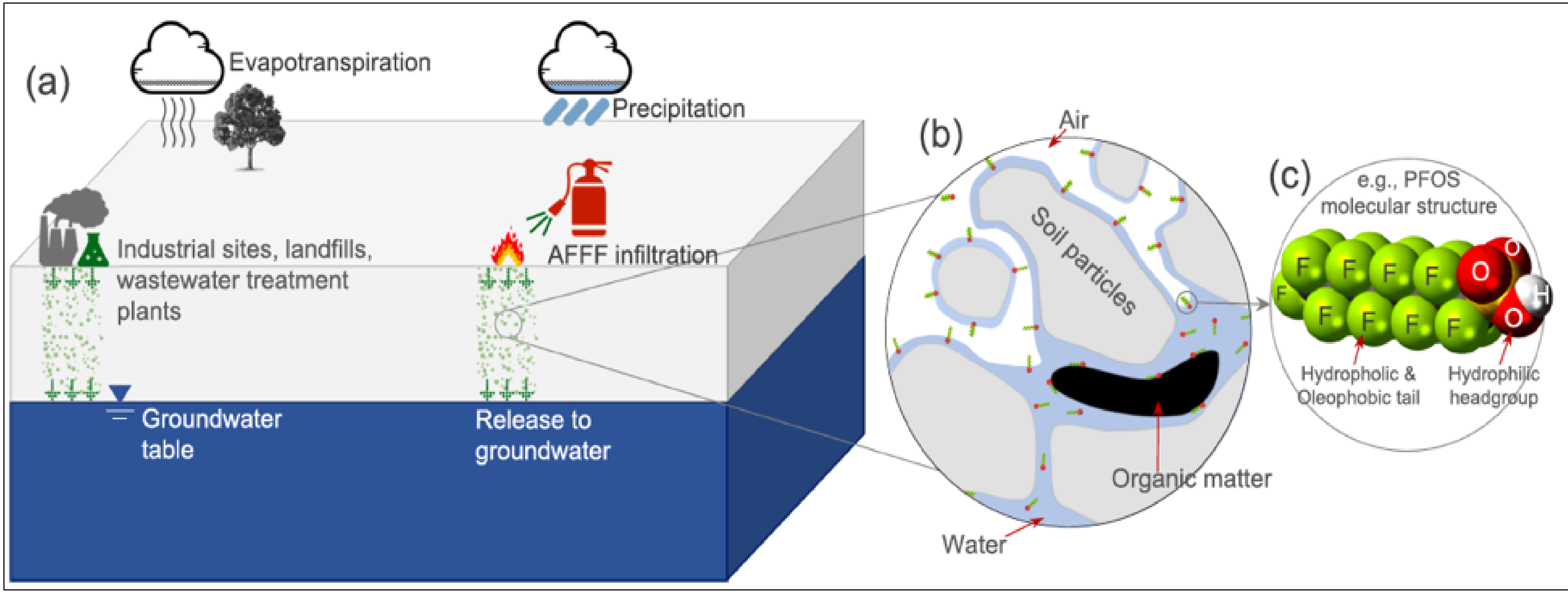
Three Graphics

PFAS Classes and Nomenclature

	Perfluoroalkyl Acids (PFAAs)	Polyfluoroalkyl Acids (Potential Precursors)	Polymers
Carboxylates Sulfonates	 x = 6 PFOA  y = 7 PFOS PFAAs	   PFAA Precursors	PFAS Polymers *Examples:* *PTFE, PVDF, PFA, FEP, FFKM*

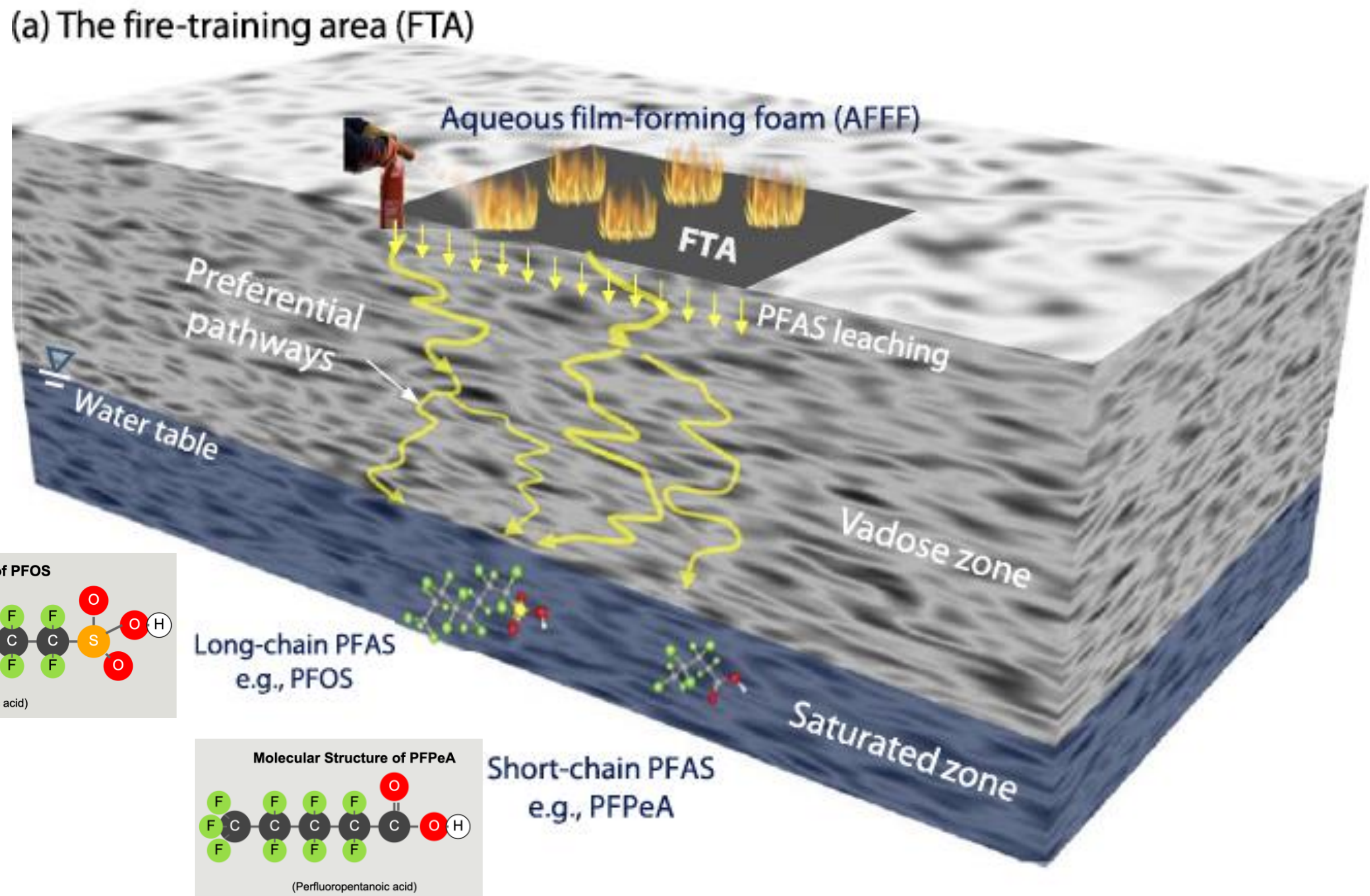
PFAS

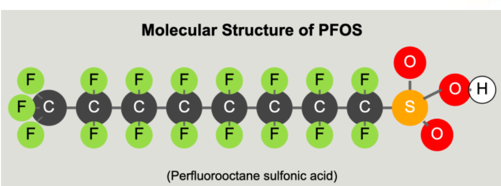
What Is, What Can We Do About PFAS Leaching to Groundwater?



Guo et al., 2023

Another Visualization of PFAS Leaching to Groundwater

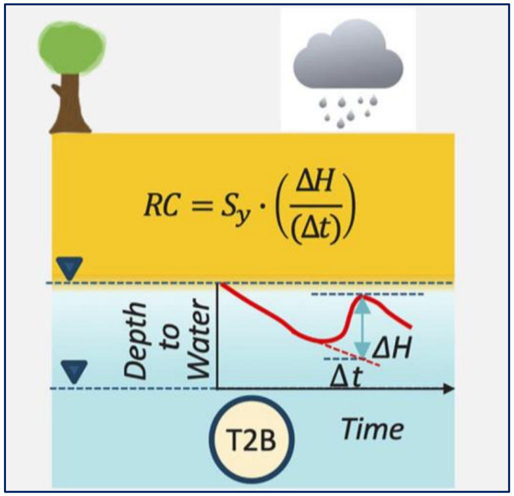




Zeng & Guo (2023)

Key Questions That Need to be Answered

- How does PFAS go from soil down to groundwater?
- What parameters do I need to measure to understand PFAS leaching?
- How do I analyze the leaching data that I collect?
- Is PFAS leaching at my site causing a groundwater problem?
- If it is causing a problem, how do we forecast its future behavior?



Key Decisions for Managing PFAS Leaching

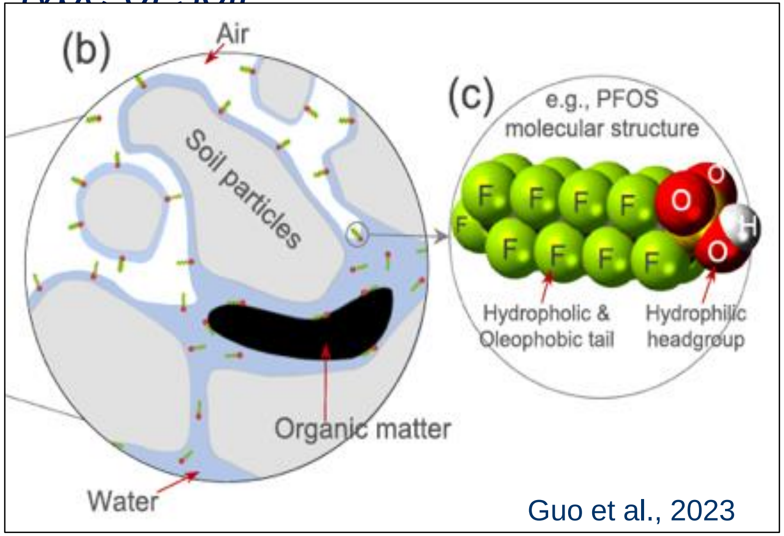
Key Decision	Details
Mass discharge (M_d) (g/yr)?	(Porewater conc) x (recharge) x (area)
How to determine PFAS porewater concentrations & leaching?	• How to install/sample lysimeters? • Other measurements needed?
Recharge rate (inches/yr)?	Multiple methods to estimate or measure
Dilution Factor (-)	Is unsaturated zone leaching impacting the dissolved groundwater plume?
Construct Model of Site?	Is a numerical model always needed?
Key Models?	What models are available?

PFAS Leaching Processes

And Now for Something Completely Different:
PFAS Air/Water Partitioning, Electrostatic Attraction

Air/Water Partitioning

- *Long-chained PFAS have more accumulation at the air-water interface than short-chained PFAS than short-chained PFAS.*
- *It depends on the air/water interfacial area which can be modeled.*
- *This area depends on soil moisture, type of soil*



Guo et al., 2023

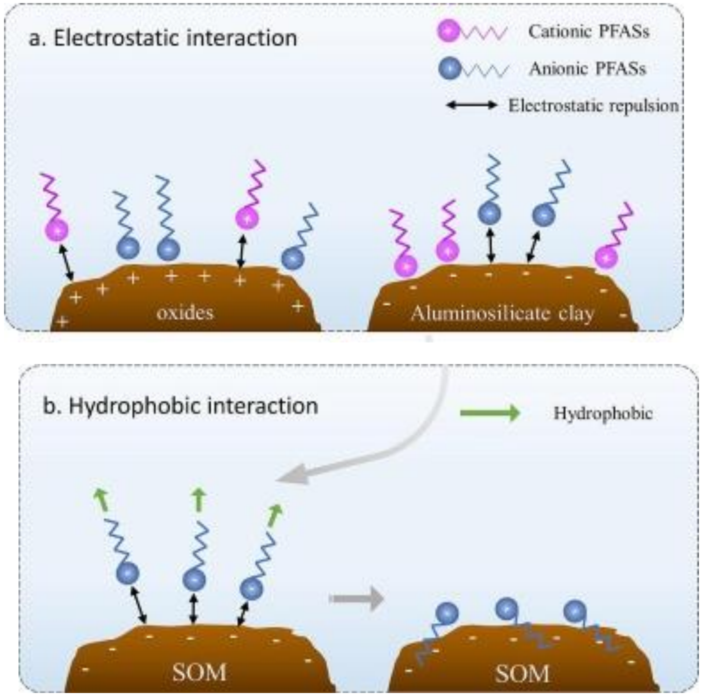
Electrostatic Partitioning

PFAAs are anions (-) and don't stick to soils

Examples: PFOS, PFOA, PFHxS etc.

Some precursors are cations (+) and will stick

Example: TAmPr-N-MeFASA



PFAS Retention at Air-Water Interfaces

Environmental Science & Technology

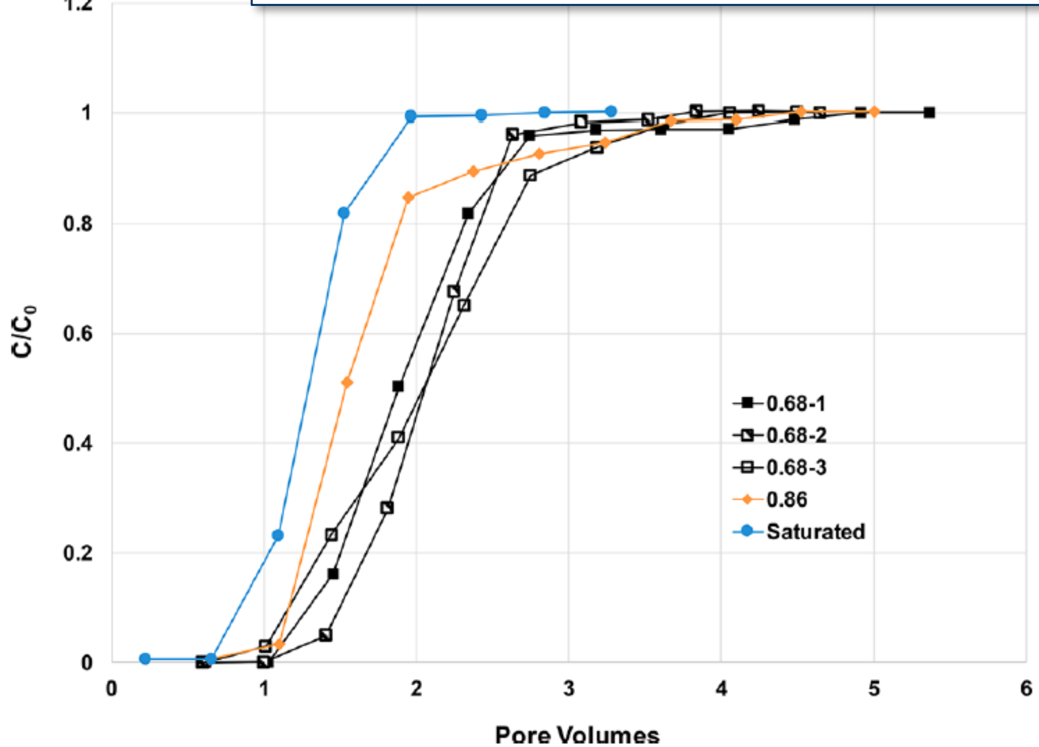
Article

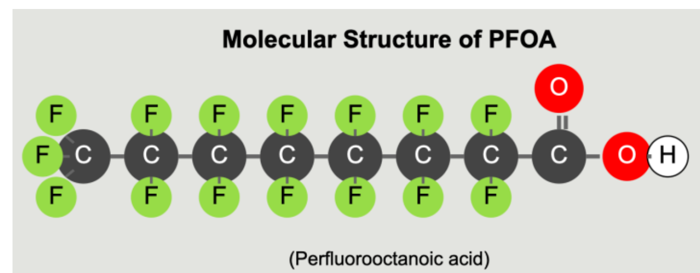
Cite This: Environ. Sci. Technol. 2018, 52, 7745−7753

pubs.acs.org/est

Adsorption of PFOA at the Air−Water Interface during Transport in Unsaturated Porous Media

Ying Lyu,[†,‡,§] Mark L. Brusseau,[*,§] Wei Chen,[§] Ni Yan,[§] Xiaori Fu,[§] and Xueyu Lin[†,‡]





PFAS retention at the air-water interface causes observed retardation in unsaturated column experiments

Measuring PFAS Mass Discharge

One Key Decision-Making Framework: Mass Discharge (grams per year)

Why is this important?

- *"Soil-to-groundwater contaminant mass discharge (M_d) is the authoritative metric defining source strength at sites impacted by per- and polyfluoroalkyl substances (PFAS) and is increasingly being reported."*
- Mass Discharge integrates three things:
  1. Concentration
  2. Amount of water flowing through the source
  3. The size of the source

Received: 15 December 2022 | Accepted: 6 April 2023
DOI: 10.1002/vzj2.20262
Vadose Zone Journal

REVIEW

Determining groundwater recharge for quantifying PFAS mass discharge from unsaturated source zones

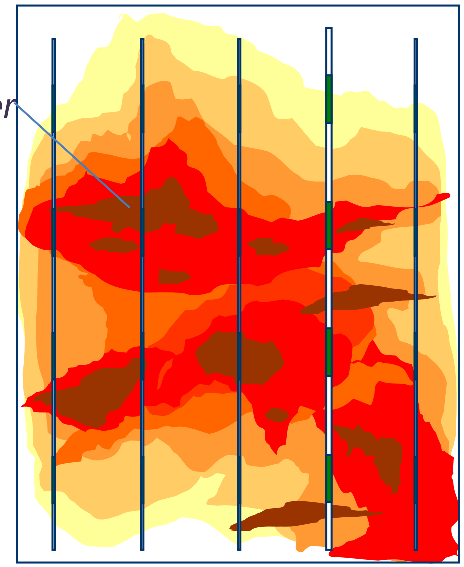
Charles J. Newell[1] | Emily B. Stockwell[1] | Jessica Alanis[1] | David T. Adamson[1] | Kenneth L. Walker[1] | R. Hunter Anderson[2]

Mass Discharge: A Key Decision Making Framework

Mass Flux vs. Mass Discharge in Groundwater

Mass Flux, J — *Integrate* → **Mass discharge**, M_d

0.1 grams per m^2 per year



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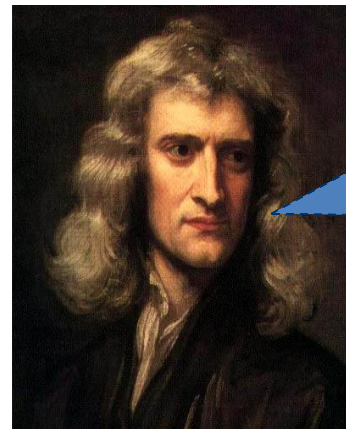


"This plume has a mass discharge of 1.5 grams per year."

Sir Isaac Newton:

"Method of Fluxions"

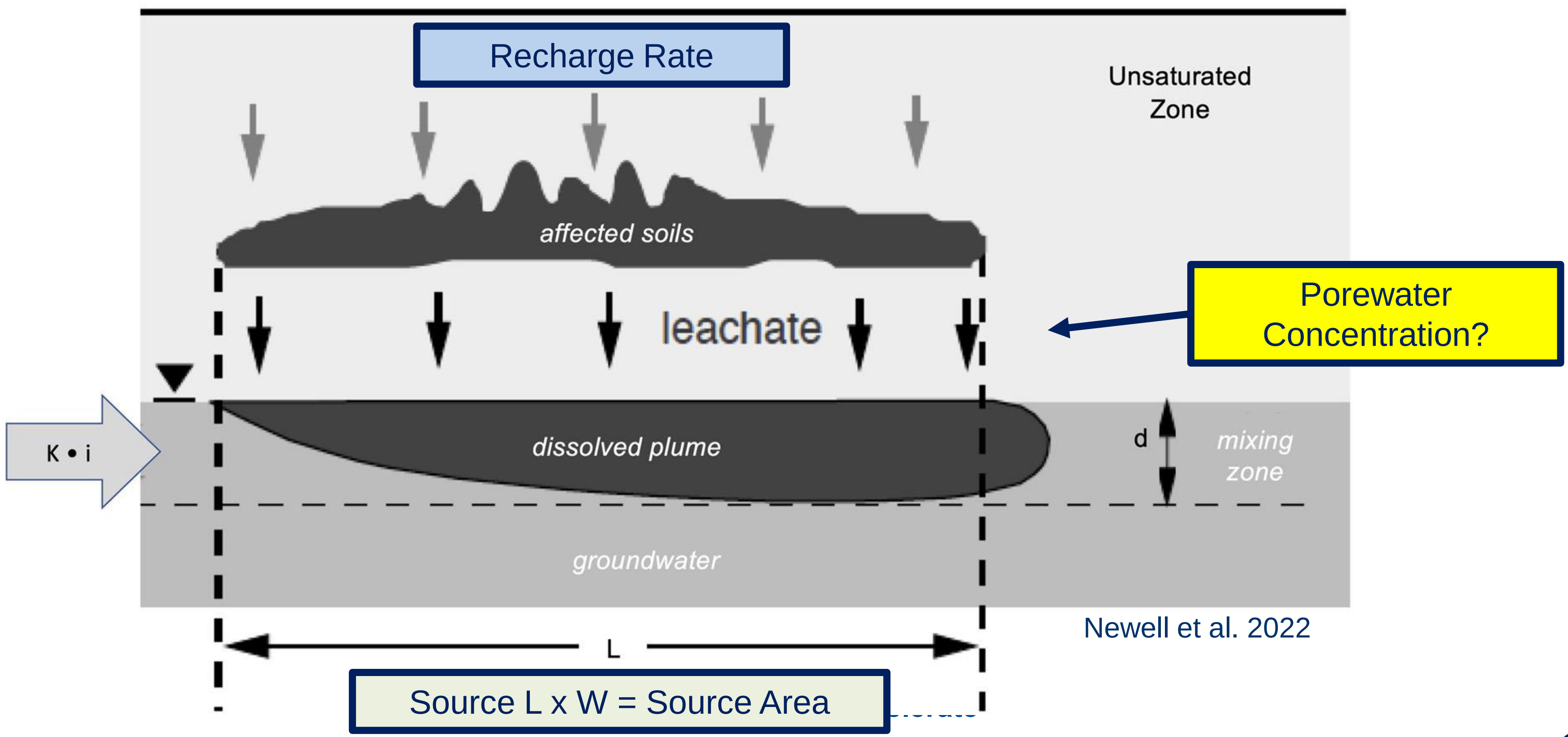
Units: ***Mass per Area Per Time***

Units: ***Mass Per Time*** *(through Vertical Transect)*

Calculating Mass Discharge (grams per year) From Vadose Zone PFAS Sources

Recharge x *PFAS Leachate Concentration* = **PFAS Mass Flux**

PFAS *Mass Flux* x *Area* = **PFAS Mass Discharge (mass/time)**

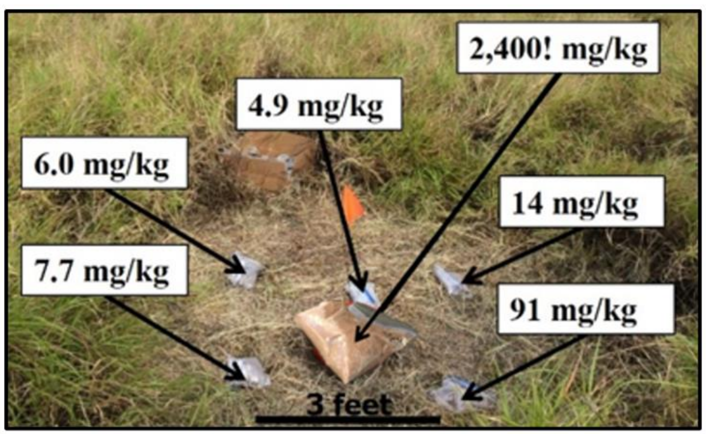


Newell et al. 2022

The Concentration Side: Option 1: Take a Soil Sample and Apply a Soil:Water Partitioning Equation to Get Porewater Conc.

Key idea: Convert ng/Kg data to ng/L data for vadose zone. But we have issues:

- **Simplistic Assumptions:** Linear isotherm partitioning assumes instantaneous, reversible sorption based solely on hydrophobic interactions, which does not capture the complex behavior of PFAS.
- **Difficulty Account for Air/Water Partitioning :** Standard Koc and foc values do not reflect this process.
- **Conclusion:** Despite advances in modeling, the uncertainty remains high, so relying solely on these models for PFAS site management decisions may not be best course of action?



ITRC, 2023

$$R_d^{comp} = \left(1 + K_{d*}\frac{\rho_b}{\theta_w} + H\frac{\theta_a}{\theta_w} + K_n\frac{\theta_n}{\theta_w} + K_{aw*}\frac{a_{aw}}{\theta_w} + K_{nw*}\frac{a_{nw}}{\theta_w} + K_{an*}\frac{a_{an}}{\theta_w} + K_{c*}X_c\right) \quad (2)$$

where a_{an} is the specific air-NAPL interfacial area (L^2/L^3), a_{aw} is the specific air-water interfacial area (L^2/L^3), a_{nw} is the specific NAPL-water interfacial area (L^2/L^3), K_{an*} is the nonlinear air-NAPL interfacial adsorption coefficient (L^3/L^2), K_{aw*} is the nonlinear air-water interfacial adsorption coefficient (L^3/L^2), K_{c*} is the nonlinear distribution coefficient for sorption by colloids (L^3/M), K_{d*} is the nonlinear solid-phase adsorption coefficient (L^3/M), K_n is the NAPL-water partition coefficient (-), K_{nw*} is the nonlinear NAPL-water interfacial adsorption coefficient (L^3/L^2), X_c is the concentration of colloidal material in porewater (M/L^3) and θ_n is volumetric NAPL content (L^3/L^3).

Brusseau and Guo, 2023

The Concentration Side: Developing Unsaturated Zone Soil Clean-Up Criteria

United States Environmental Protection Agency

Office of Solid Waste and Emergency Response Washington, DC 20460

EPA/540/R95/128
May 1996

Superfund

Soil Screening Guidance: Technical Background Document

$$C_p = DF\, C_{gw}$$

$$DF = 1 + \frac{V_{gw} d}{IL}$$

DF = dilution factor
V_{gw} = groundwater velocity
d=mixing thickness in groundwater
I = infiltration rate (rainfall rate x recharge)
L=source length parallel to gw flow

The Concentration Side: Complexities and Challenges with PFAS Leaching in Unsaturated Soils

United States Environmental Protection Agency | Office of Solid Waste and Emergency Response Washington, DC 20460 | EPA/540/R95/128 May 1996

Superfund

Soil Screening Guidance: Technical Background Document

$$C_T = C_p\left(K_d + \frac{\theta_w}{\rho}\right)$$

Traditional approach

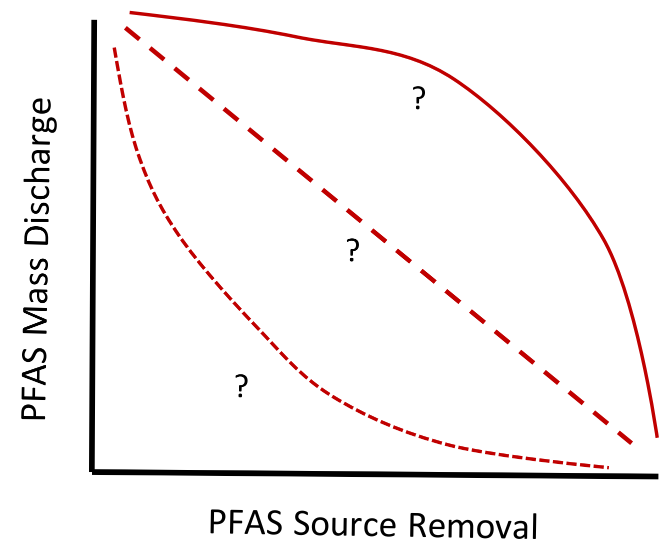
Measured in a soil sample

Present in porewater

$$C_T = C_p\left(K_d + \frac{\theta_w}{\rho} + \frac{k_{ia}a_i}{\rho}\right)$$

for PFAS

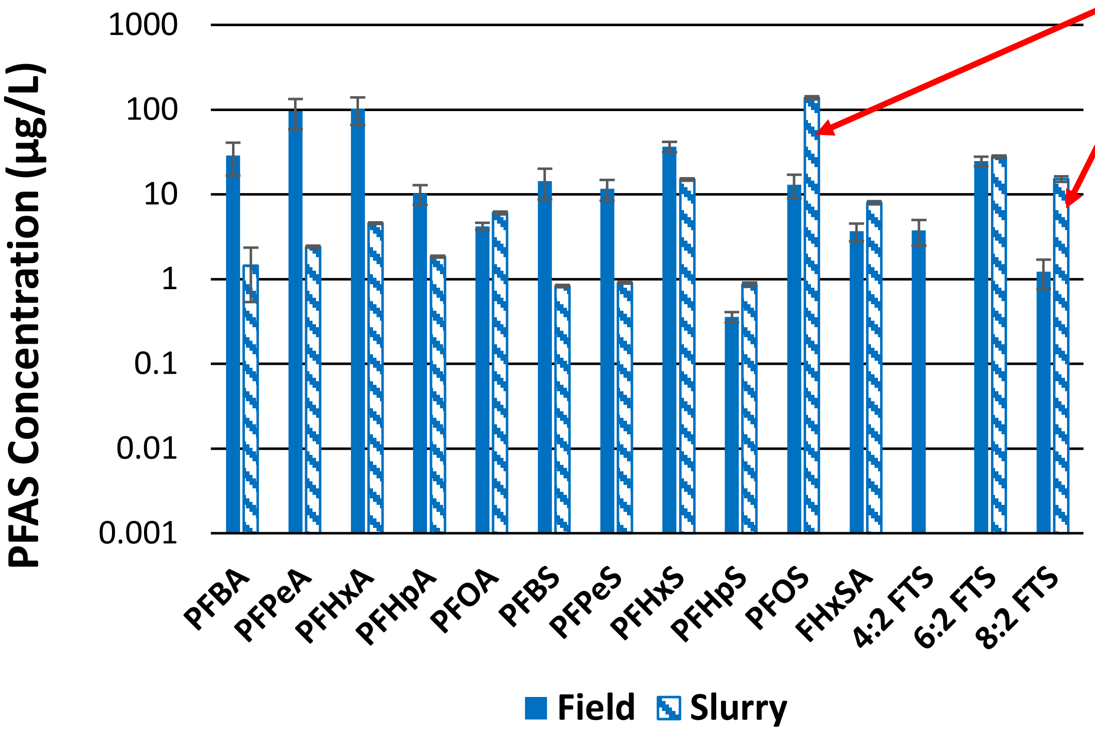
Assumes equilibrium K_d model for soil

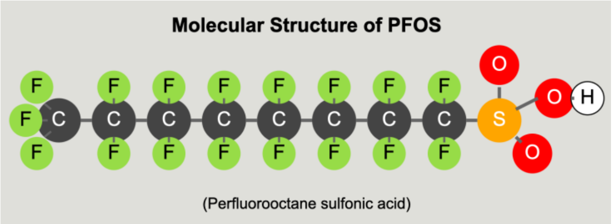


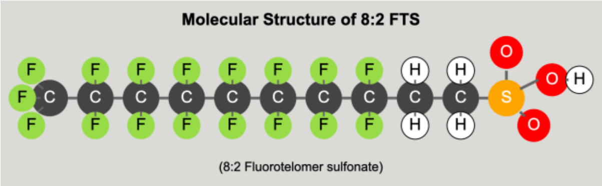
Learning from PFAS Leaching Lab Studies: Air Water Partitioning is A Big Deal for Leaching

$$C_T = C_p \left(K_d + \frac{\theta_w}{\rho} + \frac{k_{ia} a_i}{\rho} \right)$$

PFOS & 8:2 FTS are greater in the slurry than in porewater



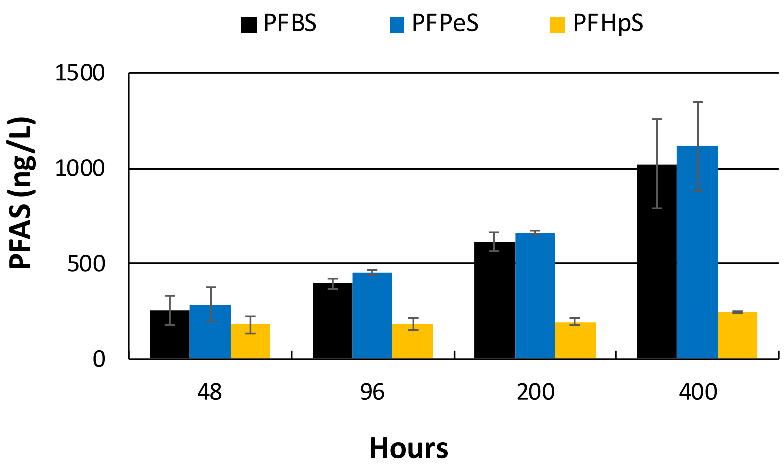




Leaching tests under saturated conditions may not be appropriate for estimating leaching and ultimately developing appropriate soil clean-up criteria

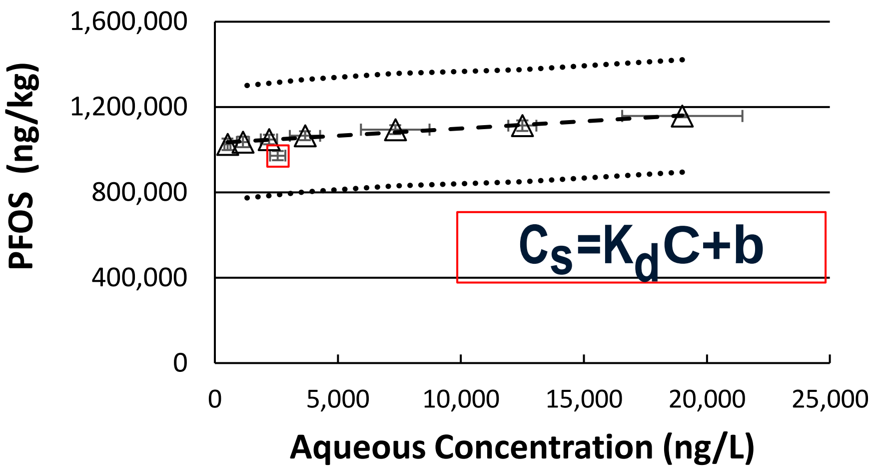
PFAS Desorption from Soil

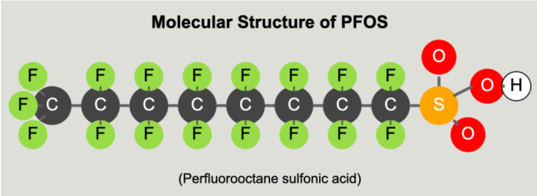
Kinetics



A simple K_d model is typically not appropriate for developing soil clean-up criteria, as much of the PFAS mass in the soil may not readily desorb

Desorption Isotherm





Why air-water interfacial sorption and soil-water desorption are important

ELSEVIER

Contents lists available at ScienceDirect

Journal of Hazardous Materials Letters

journal homepage: www.sciencedirect.com/journal/journal-of-hazardous-materials-letters

Revising the EPA dilution-attenuation soil screening model for PFAS

Mark L. Brusseau[a,b,*], Bo Guo[b]

	PFOS		
Parameter	Standard Model	Revised Model	Revised Desorption Model
Dilution Factor (DF)	20	20	
Attenuation Factor (AF)	1	1	
Dilution-Attenuation Factor (DAF)	20	20	
Bulk density (ρ_b, g/cm^3)	1.5	1.5	
Water content (θ_w, -)	0.2	0.2	
Air content (θ_a, -)	0.2	0.2	
Porosity (n, -)	0.4	0.4	
Sorption coefficient (K_d, cm^3/g)[a]	2	2	
Henry's Law constant (H, -)	0	0	
Air-water interfacial adsorption coefficient (K_{aw}, cm)[b]	NA	0.12	
Air-water interfacial area (a_{aw}, cm^{-1})[c]	NA	446	
Distribution term (R_d, -)	16	283.6	
Target groundwater concentration (C_{gw}, µg/L)[d]	0.1	0.1	
Soil Screening Level (SSL, µg/kg)	4.3	75.6	290

The Concentration Side: Option 2: Can we use Synthetic Precipitation Leaching Test (SPLP) to Evaluate Leaching?

Research perspective 1:

- Potentially, but needs validation at additional sites

> - With few modifications, SPLP provides an excellent framework for impact-to-groundwater evaluation at PFAS-contaminated sites
> - Application provides flexibility to address the needs of particular projects
> - Validation at additional sites is ongoing to determine whether results hold across varied geologic and hydrologic conditions, different PFAS compositions

Rovero et all, 2023 Battelle

DOE, 2016

Research perspective 2:

- *But Potential Unrealistic Testing Conditions*: The SPLP employs liquid-to-solid ratios that exceeding natural pore volumes, eliminating key retention mechanisms.
- *Disruption of Soil Integrity*: Aggressive agitation disperses water-stable aggregates and colloids, artificially boosting contaminant desorption.

Anderson et al., 2022

Research perspective 3:

- DoD SERDP/ESTCP is harmonizing PFAS-leach testing by applying SPLP and EPA LEAF (Leaching Environmental Assessment Framework) Methods 1313-1316 to soils, concrete, and asphalt
- Key projects using these protocols: ER20-1126, ER20-5088, ER23-3761 (plus related ER23-3835 and ER-5041)

The Concentration Side Option 3: A Review of Using Porous Cup Suction Lysimeters (PCSLs) for PFAS Leaching (Constanza et al., 2025)

Application of Suction Lysimeters

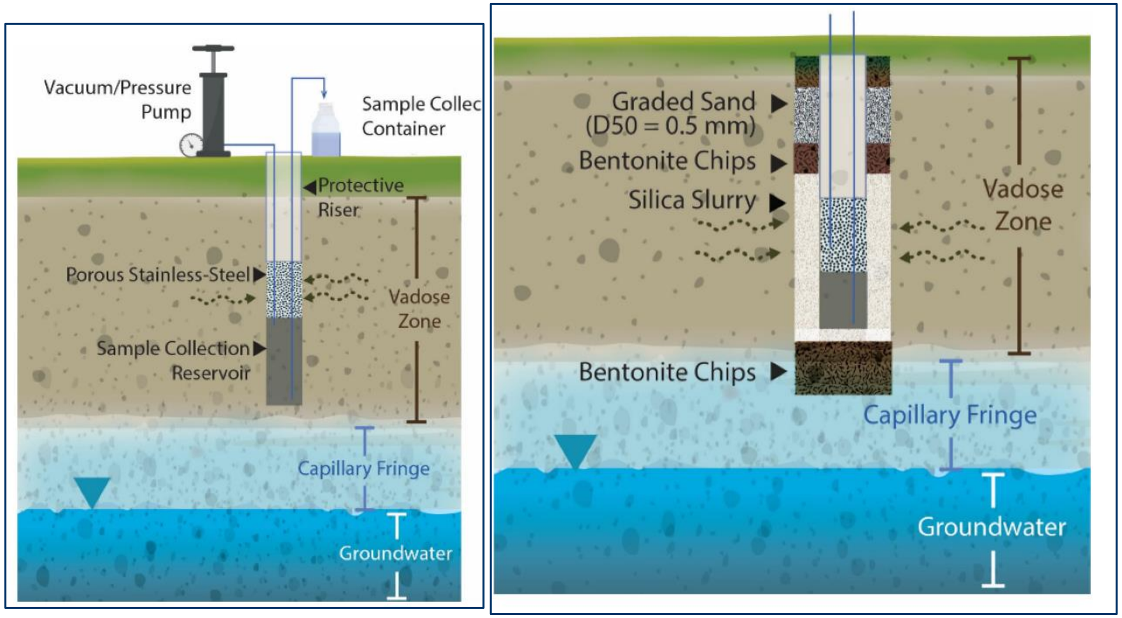
- Widely used for evaluating the mobility of PFAS from vadose zone soils to groundwater.
- Collect porewater samples by applying vacuum, suitable for fine to medium sandy soils.

Key Advantages

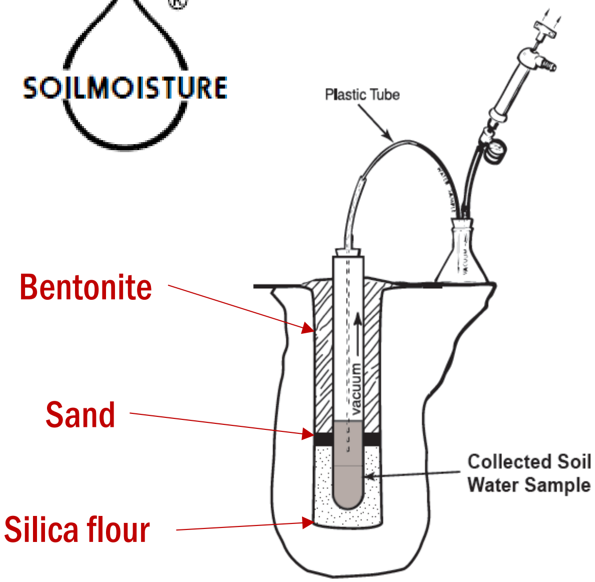
- Provides direct measurements of porewater concentrations.
- Easier and less intrusive installation compared to drainage lysimeters.

Preliminary Limitations

- May not be representative of all PFAS due to interactions with lysimeter materials, air-water interfaces, and vacuum application.
- Spatial and temporal variability requires numerous lysimeters for accurate site representation.



The Concentration Side: Porous Cup Suction Lysimeters (PCSLs)



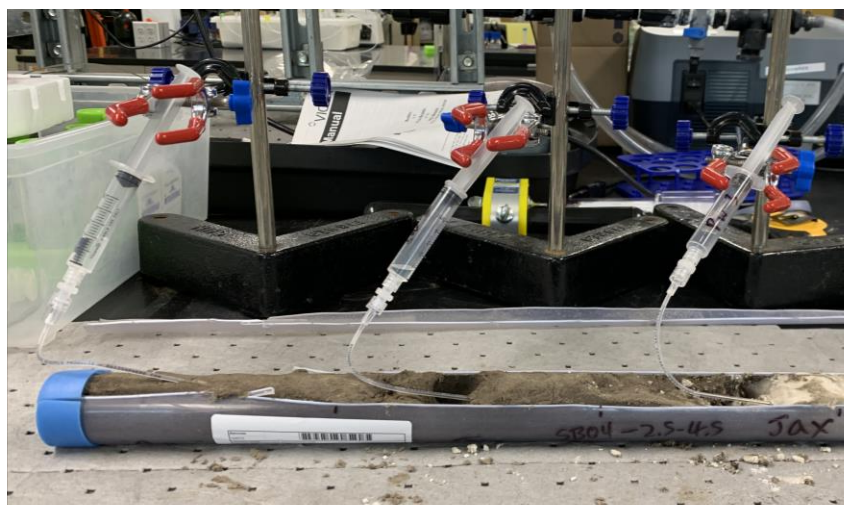
- Pre-rinsing (PFAS-free water and methanol)
- Limit annular space (6.4 cm borehole / 4.8 cm diameter PCSL)
- *PFOS* sorption:
  - Sorption tests to silica flour showed negligible uptake
  - Negligible PFOS sorption
- Bromide tracer added to the silica flour slurry
- First collected round of porewater samples not used for PFAS testing

The Concentration Side: Porewater Extraction from Collected Soil Cores

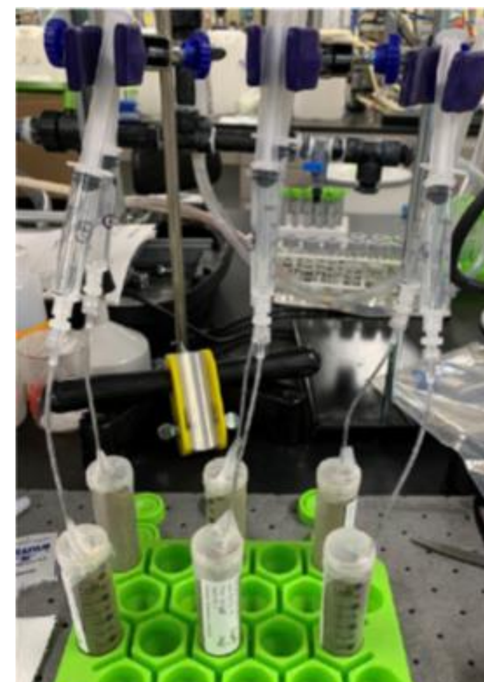
- 0.95 cm dia. "microlysimeter"
- Equilibrated ≥3 days
- 55 cb applied vacuum

- Heterogeneous or structured flow?
- Validity of effective equilibrium assumptions?

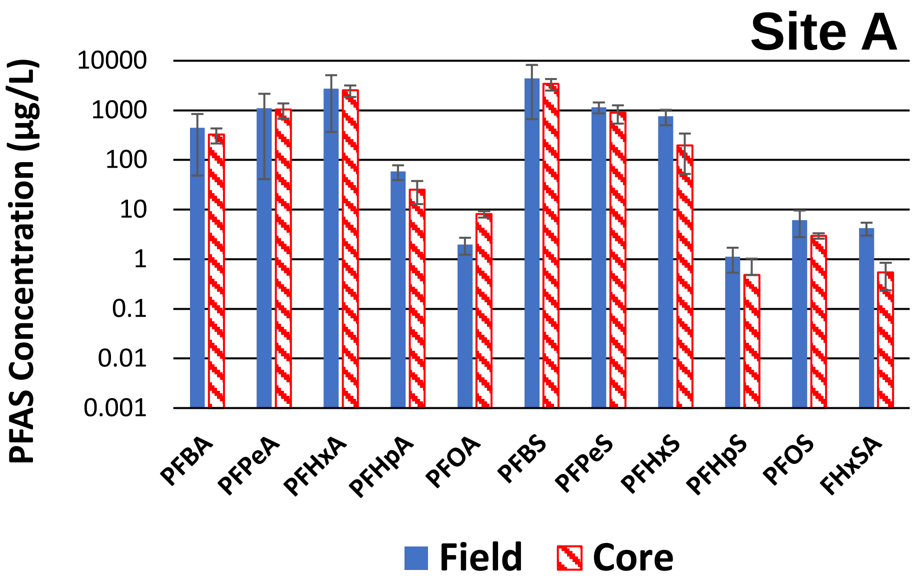
Intact Soil Core

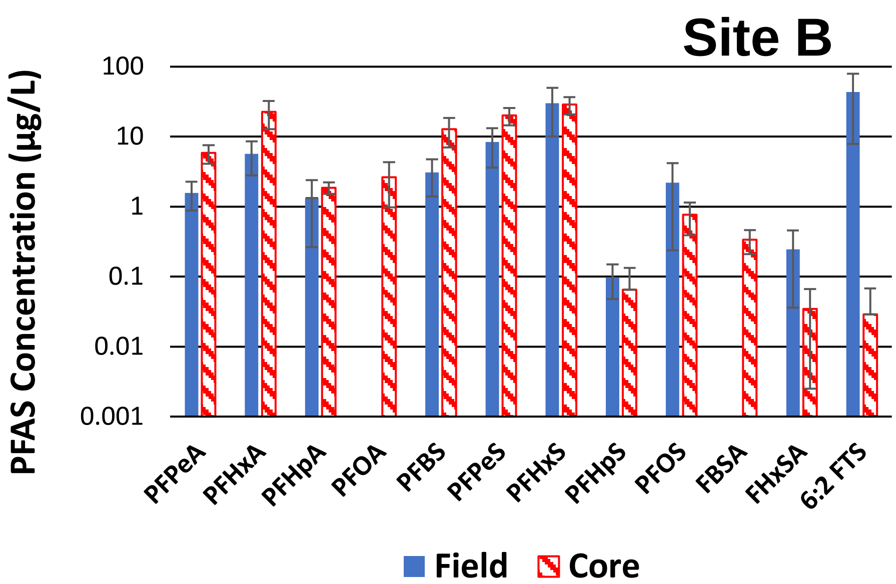


Wetted and Re-Packed Soil



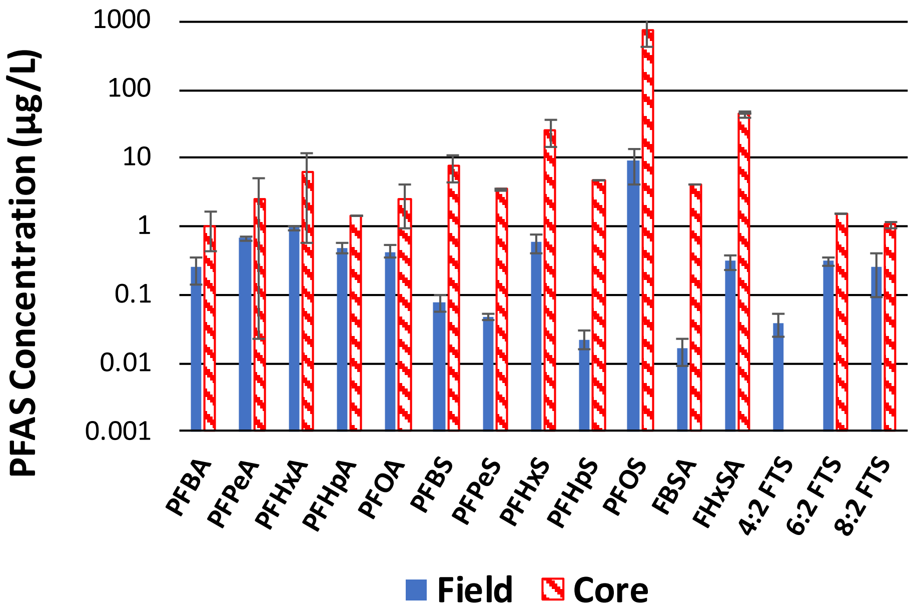
The Concentration Side: PCSL Porewater Sampling Results Compared to Effectively Equilibrated Bench-Scale Testing



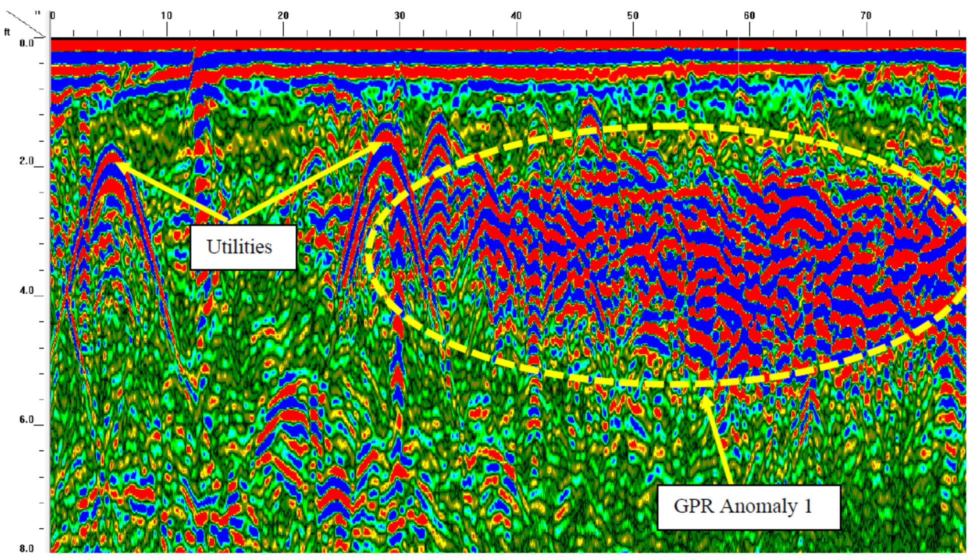


Validation of PCSL Representativeness & Apparent Local Equilibrium Assumptions

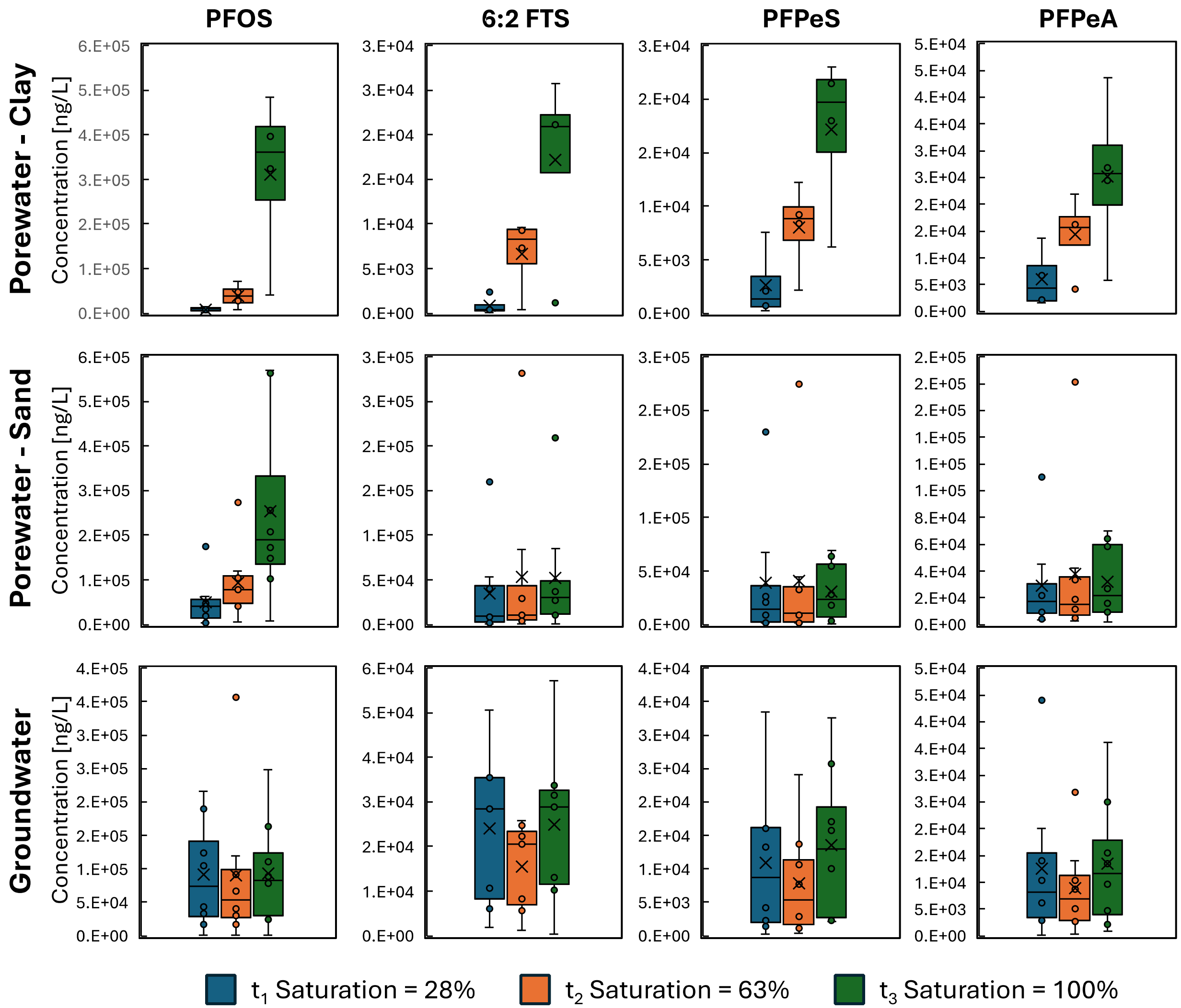
The Concentration Side: But Agreement Between Field PCSLs vs. Porewater Samples from Soil Cores is Not Always Observed

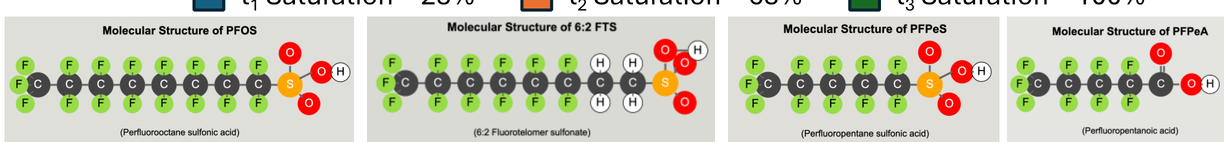


- In situ PFAS porewater concentrations much less than measured in the laboratory
- Soil had been thermally treated then back-filled



The Concentration Side: Impacts of Changing Moisture Content (Soil Texture at JBCA)

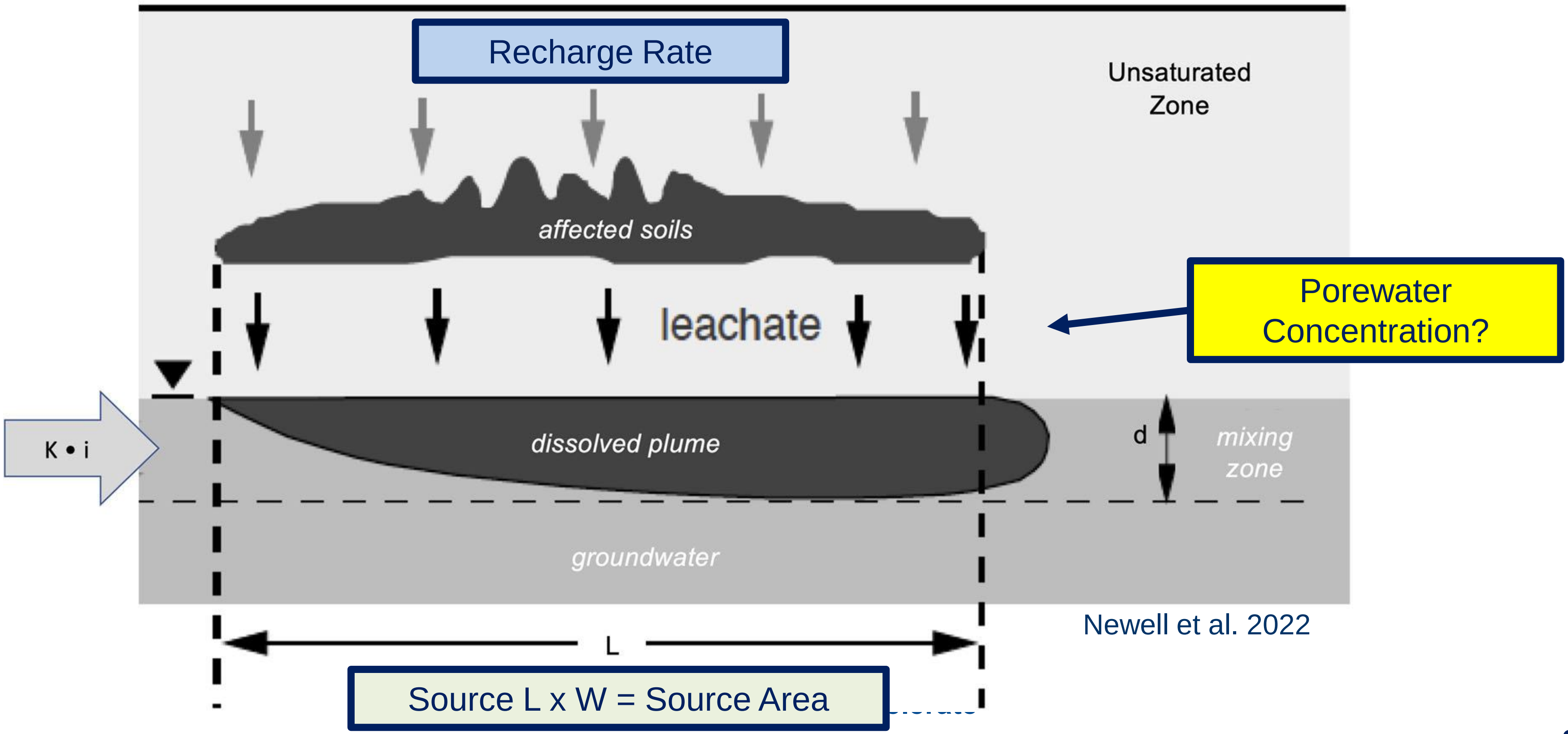




Calculating Mass Discharge (grams per year) From Vadose Zone PFAS Sources

Recharge x *PFAS Leachate Concentration* = **PFAS Mass Flux**

PFAS *Mass Flux* x *Area* = **PFAS Mass Discharge (mass/time)**

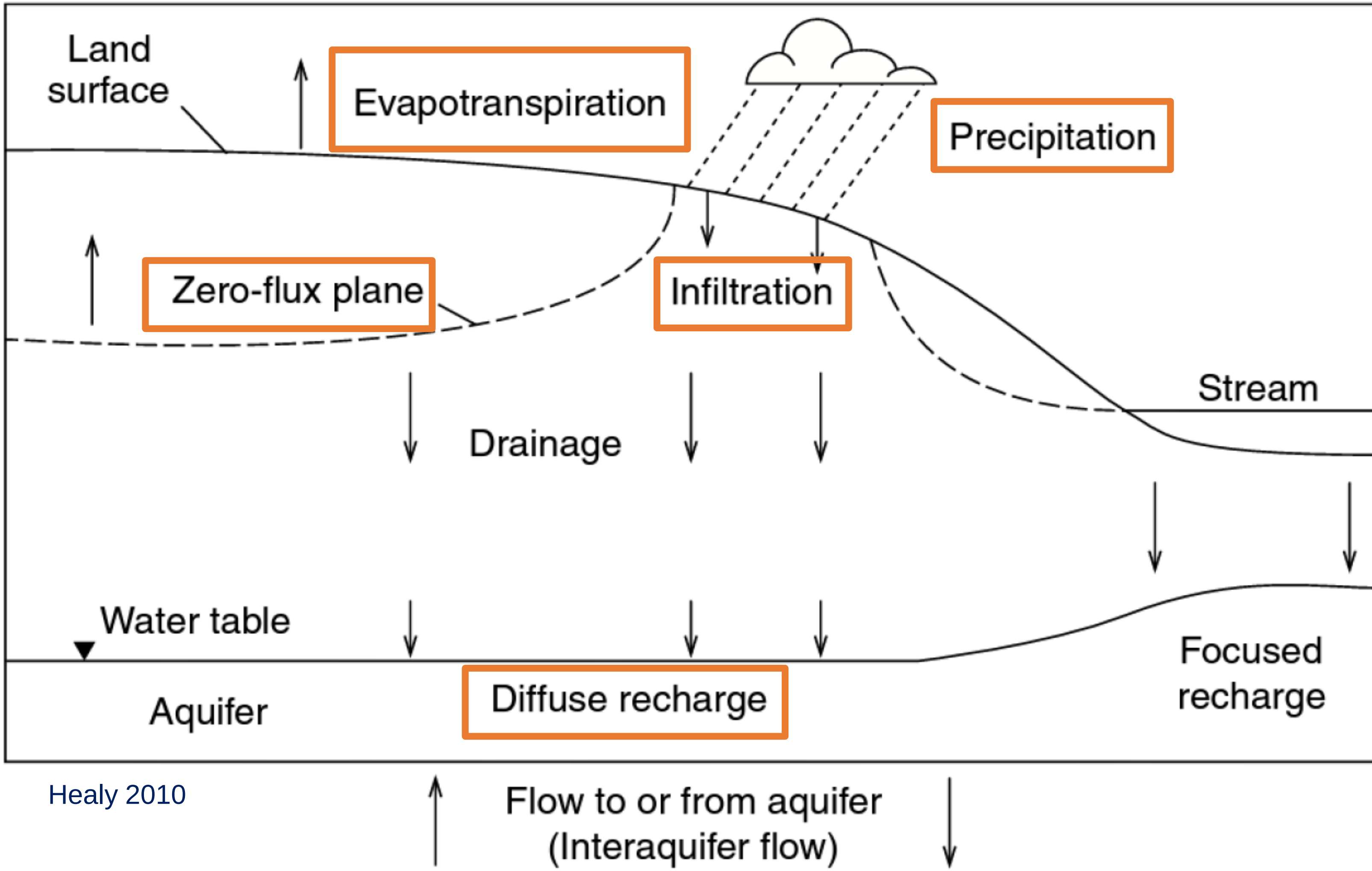


Newell et al. 2022

The Hydrology Side: What is Recharge? How Do I Measure it at My Site?

Conceptual vertical cross section of key recharge processes *(Healy, 2010).*

*There are roughly **40 different methods** to estimate recharge*



Healy 2010

The Hydrology Side: Tiered Approach To PFAS Recharge

Tier	Objective	Target PFAS Sites	Need Field Data?	Level of Effort
Tier 1 *(4 types)*	Simple source zone recharge estimate	Smaller, low risk	No	Little or no field time. A few hours for analysis.
Tier 2 *(6 types)*	Moderate level of effort	Moderate risk	Limited	A few days in the field and a few days for analysis.
Tier 3 *(5 types)*	Detailed recharge estimates	Most complex, important sites (e.g., exposure, litigation)	Extensive	More extensive field and analysis time than Tier 2 methods.

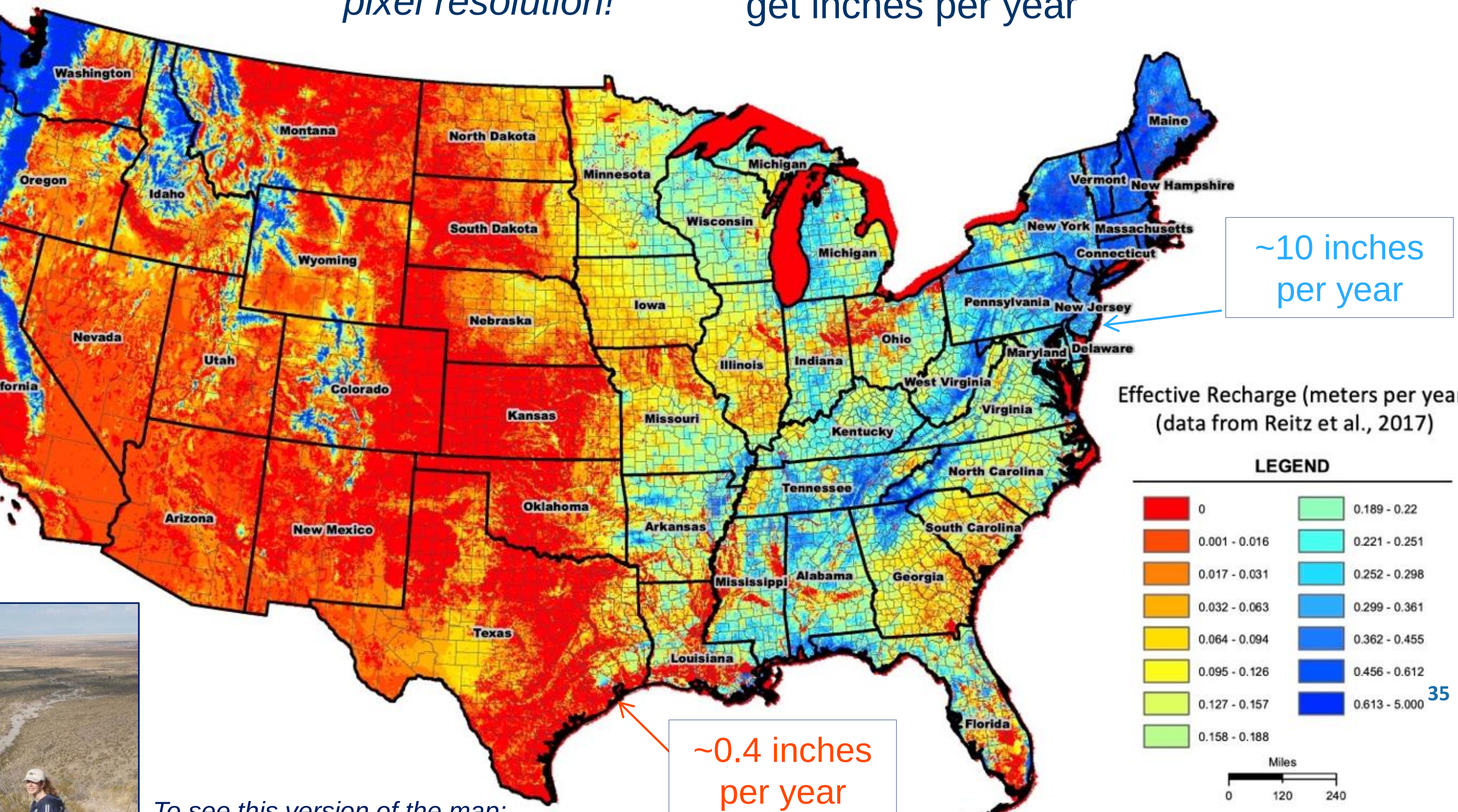
Newell et al., 2022
Search: PFAS vadose recharge
Open access paper.

The Hydrology Side: Example of Tier 1 Recharge Method
Groundwater Recharge Map by Reitz et al. (2017)

Method T1-B
Tier 1 Method

800 x 800 meter pixel resolution!

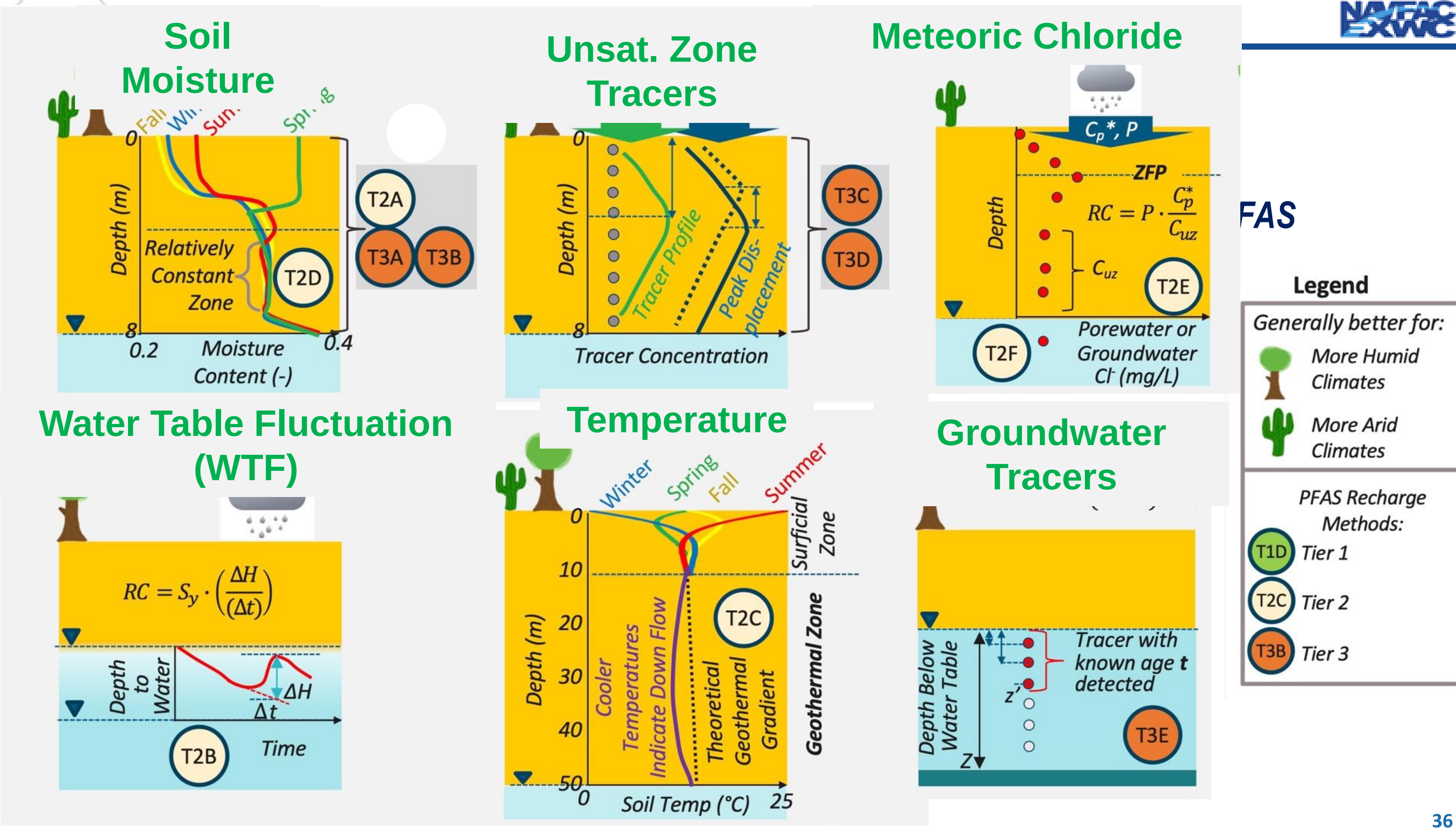
Multiply by about 39 to get inches per year



To see this version of the map: Newell et al., 2022

Meters per year

The Hydrology Side: Tier 2 and Tier 3 Recharge Methods For PFAS Sites



Newell et al., 2022

Mass Discharge (M_d) Estimates From Five Sites

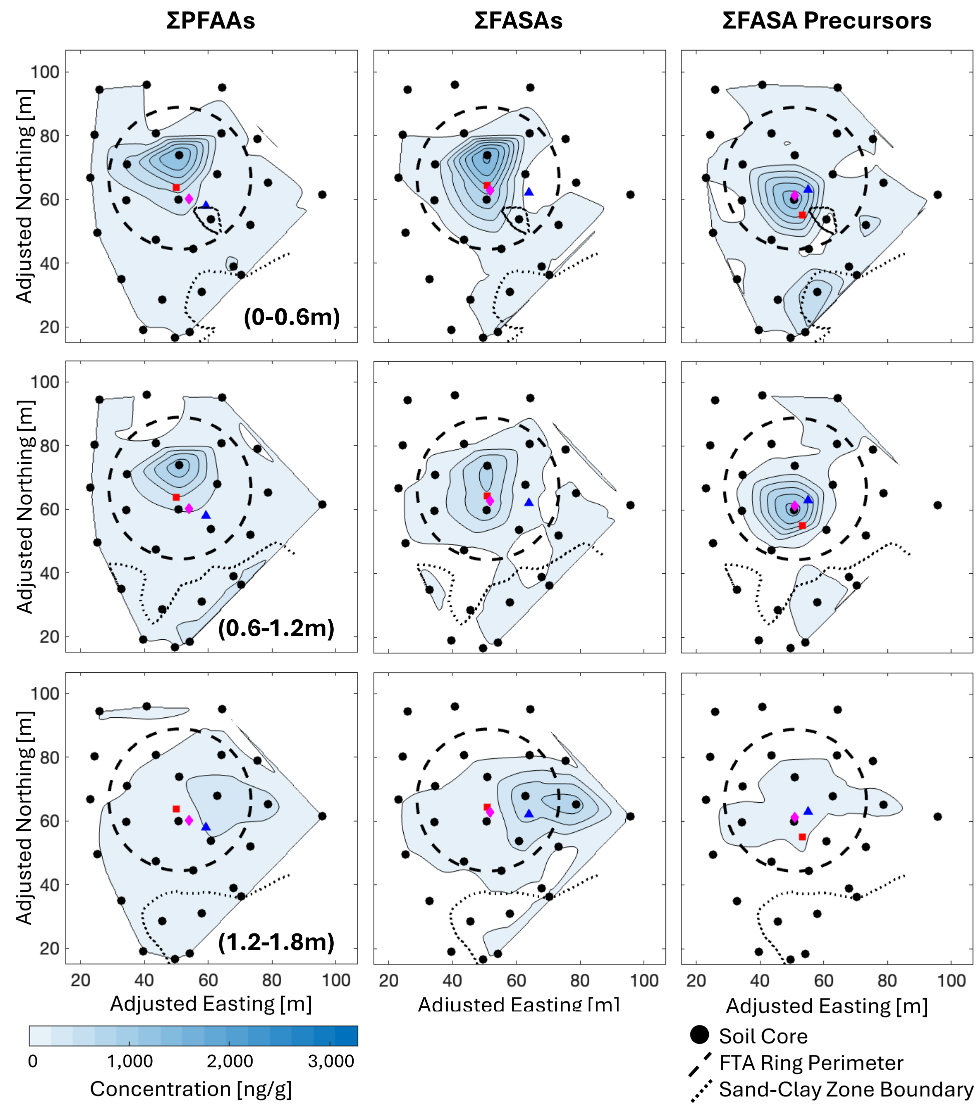
Site	PFAS	Vertical M_d Unsaturated Zone (g/year)	Horizontal M_d Saturated Zone (g/year)	Unsat ÷ Sat Zone (%)
JBCA, SC	Total PFAS	1,300	7,200	18%
FE Warren AFB, Wyoming	Total PFAS	64	4800	1%
Arnold AFB, Tennessee	Total PFAS	22	pending	-
South Dakota Site (Anderson et al,. 2022 (Carey et al,. 2022)	PFOA	17	270	6%
Camp Grayling, MI (Quinnan et al., 2021)	PFOS + PFOA	0.4	22	2%

Leaching Investigation: Obtaining the Right Information

Performance Assessment: Key Data Requirements

- **Geologic Investigation**
  - *Grain size*
  - *OC*

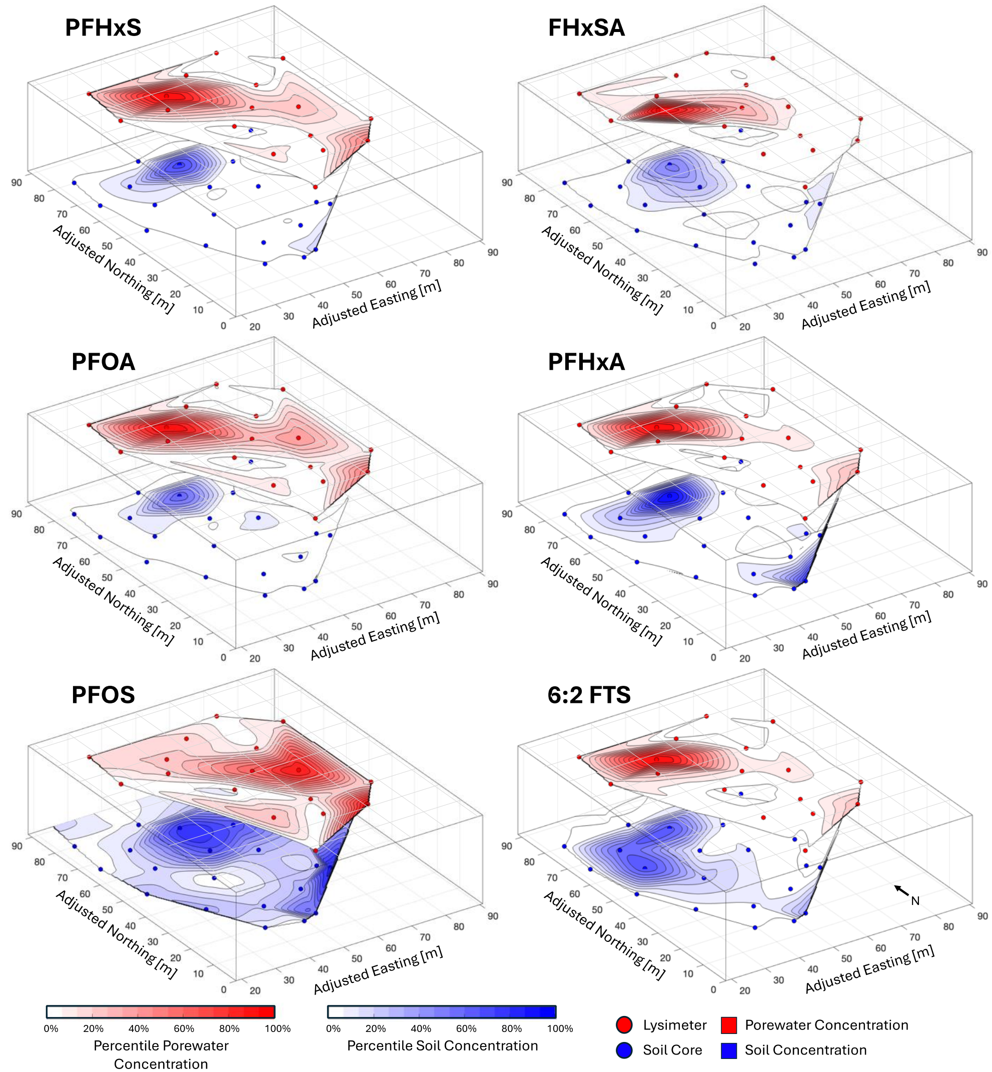
- **<u>Example</u> Soil Investigation**
  - *Homogenized 1 foot intervals through first 5 feet*
  - *Larger intervals beyond 5 foot if needed*
  - *Must consider geology*
  - *Initial work might focus on trying to understand higher concentrations at sites…*
  - *Then additional borings at more interrogative intervals can be a separate effort in just primary soil source zones.*



Performance Assessment: Key Data Requirements

Lysimeter Installation

- Guided by PFAS soil data
  - *Soil locations >> lysimeter locations*
  - *PFAS concentration*
  - *PFAS composition*
- Guided by geology
- Collect soil sample within interval of lysimeter porous cup
- Placement 1 to 2 ft above seasonal high water table, but:
  - *Consider PFAS soil profile*
  - *Consider soil moisture/recharge*
  - *Geology*
  - *Surface/root impacts vs. groundwater*
  - *Consider multi-depth lysimeters?*
- Background? (compare mass discharges)

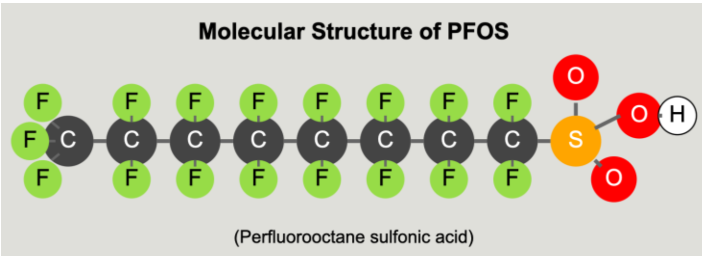


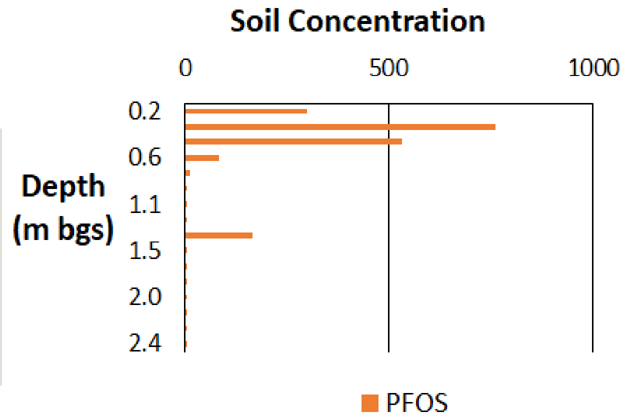
PFAS Concentration vs. Depth

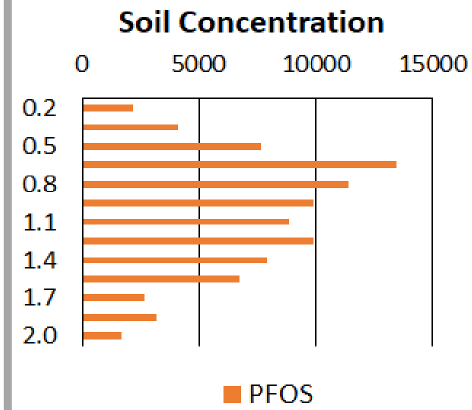
Semi-Arid Site

Humid Site

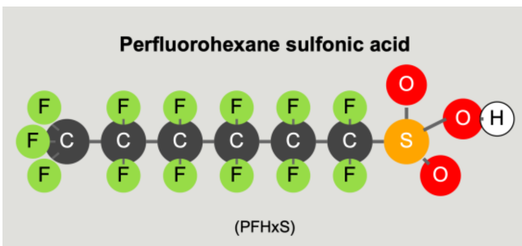
PFOS

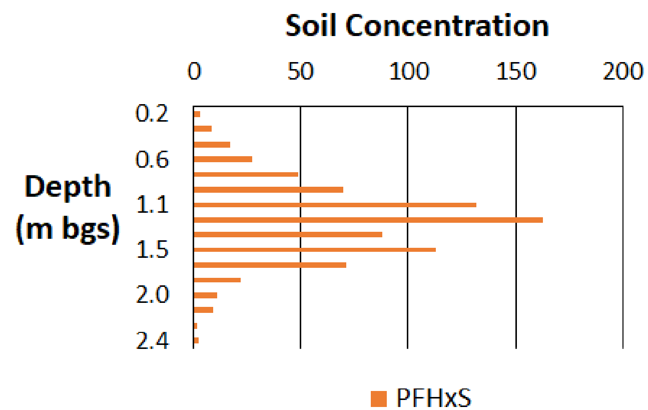


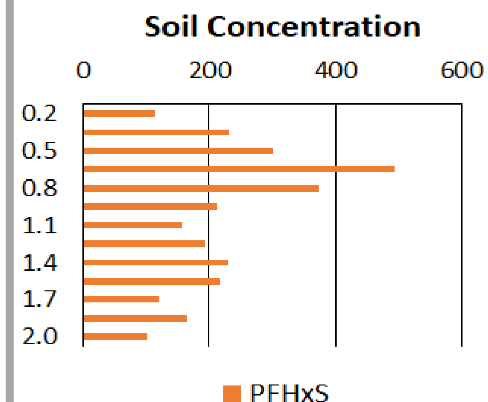




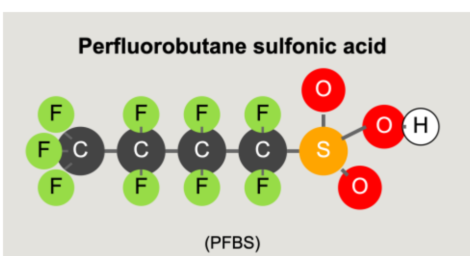
PFHxS

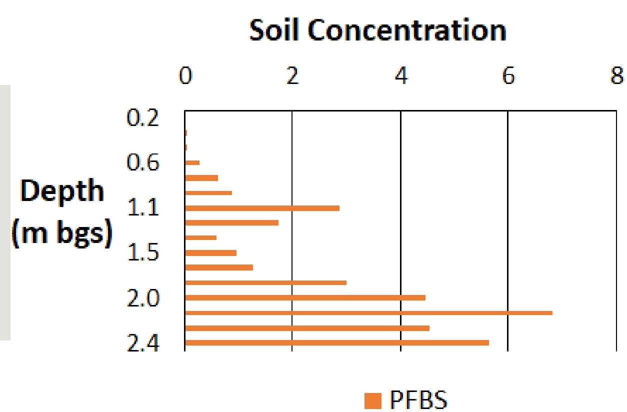


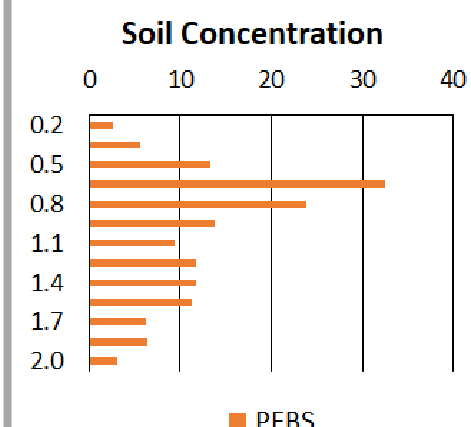




PFBS







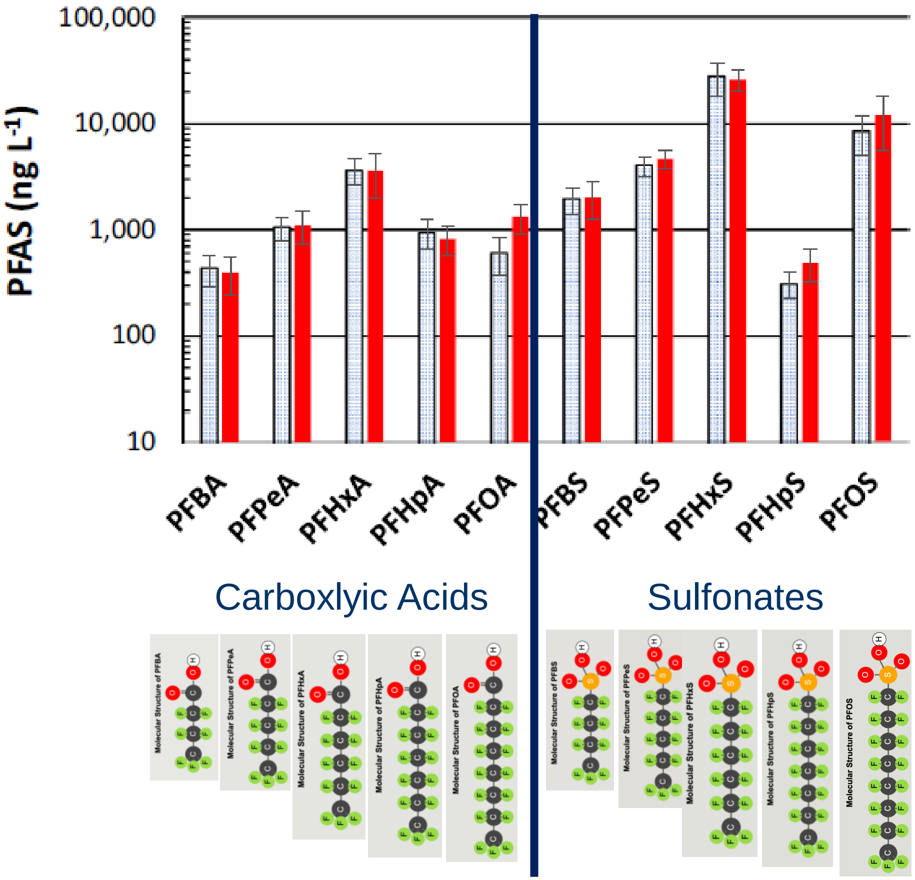
Schaefer et al.

Performance Assessment: Key Data Requirements

Lysimeter Sampling

- Corresponding soil moisture content
- Monitor water table elevation
- Example Sampling Program:
    - 4 rounds of sampling (after purge round) to assess temporal and site-specific climatic ranges of leaching rates.
- Coordinate with rainfall events (esp. in arid climates)

    - Consider low vs high infiltration events
- Minimum sample volume?



Performance Assessment: Key Data Requirements

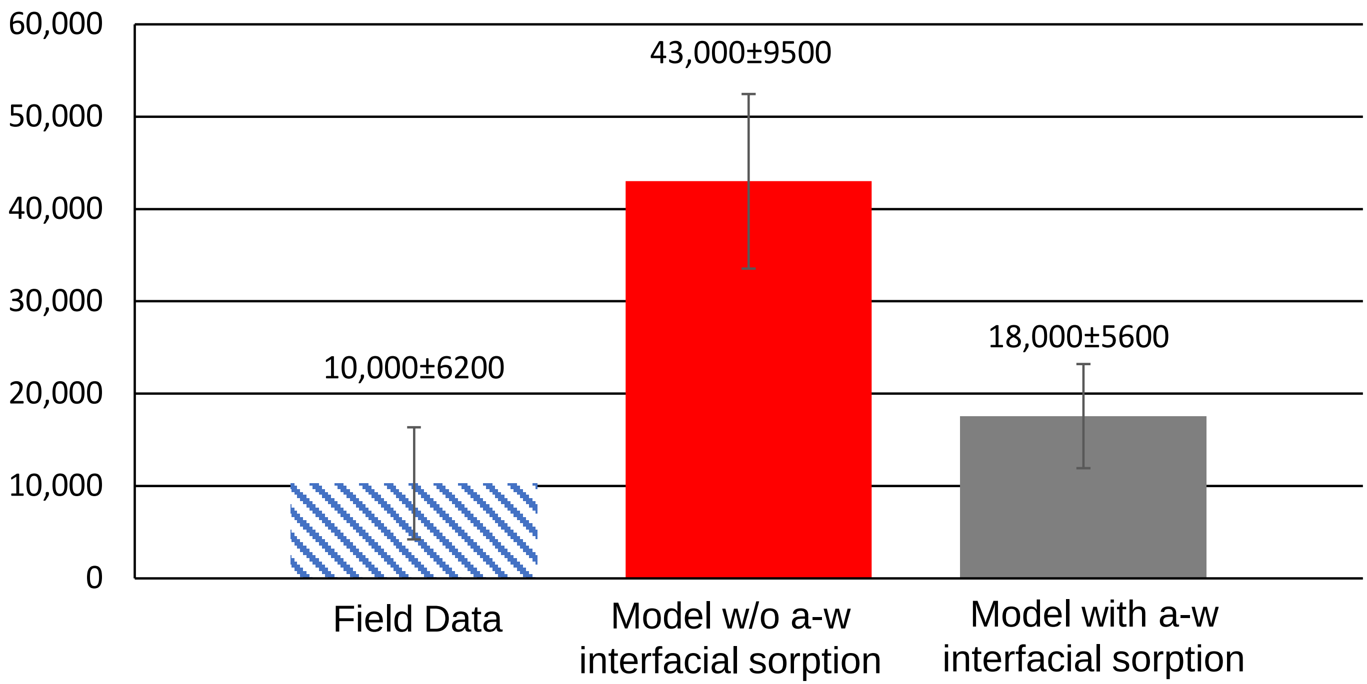
- **Desorption behavior (kinetic and isotherm)**
  - Batch soil slurry testing
- **K_i**
  - Empirical correlations
  - PFAS concentrations
  - Porewater ionic strength
- **Air-water interfacial area**
  - Grain size and moisture content
- **Soil moisture content**

Enables estimate of PFAS porewater concentrations

- **Recharge estimate**
- **Porewater extractions (e.g., microlysimeters)**
  - *Can be used at depth when soil is too dry for lysimeters*
  - *Verification of field data*

Predicting PFOS Porewater Concentrations With Mass Balance Model

- Desorption isotherms
- K_i estimates
- $a_{a\text{-}w}$ estimates



Background PFAS as Priority for DoD

PFAS background assessments will be a component of remedial decision-making at DoD facilities

- **MCL: maximum contaminant level**

CLEARED
For Open Publication
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OFFICE OF PREPUBLICATION AND SECURITY REVIEW

ASSISTANT SECRETARY OF DEFENSE
3400 DEFENSE PENTAGON
WASHINGTON, DC 20301-3400

ENERGY, INSTALLATIONS, AND ENVIRONMENT

September 3, 2024

MEMORANDUM FOR ASSISTANT SECRETARY OF THE ARMY (INSTALLATIONS, ENERGY AND ENVIRONMENT)
ASSISTANT SECRETARY OF THE NAVY (ENERGY, INSTALLATIONS AND ENVIRONMENT)
ASSISTANT SECRETARY OF THE AIR FORCE (INSTALLATIONS, ENVIRONMENT AND ENERGY)
DIRECTOR, NATIONAL GUARD BUREAU (JOINT STAFF, J3/4/7)
DIRECTOR, DEFENSE LOGISTICS AGENCY (INSTALLATION MANAGEMENT)

SUBJECT: Prioritization of Department of Defense Cleanup Actions to Implement the Federal Drinking Water Standards for Per- and Polyfluoroalkyl Substances Under the Defense Environmental Restoration Program

On April 26, 2024, the Environmental Protection Agency (EPA) published a final National Primary Drinking Water Regulation (NPDWR) establishing nationwide drinking water standards for certain per- and polyfluoroalkyl substances (PFAS) under the Safe Drinking Water Act (SDWA). This rule applies to public drinking water systems. DoD remains committed to fulfilling our PFAS-related cleanup responsibilities and will take necessary actions to incorporate SDWA levels into our cleanup program, in accordance with the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) and the National Contingency Plan (40 C.F.R. Part 300). The CERCLA process can take time to complete, but also provides a consistent, science-based approach across the Nation for cleanup and includes federal and state environmental regulator review and public participation. This memorandum describes DoD's plans to incorporate the drinking water rule into DoD's ongoing PFAS cleanups and prioritize actions to address private drinking water wells with the highest levels of PFAS from DoD activities.

EPA's drinking water rule includes enforceable maximum contaminant levels[1] (MCL) for five PFAS: perfluorooctanoic acid (PFOA), perfluorooctane sulfonic acid (PFOS), perfluorononanoic acid (PFNA), hexafluoropropylene oxide dimer acid (HFPO-DA, commonly known as GenX), and perfluorohexane sulfonic acid (PFHxS). It also includes a Hazard Index (HI) MCL, for a mixture of at least two or more of PFHxS, PFNA, perfluorobutane sulfonic acid (PFBS), and HPFO-DA (GenX) chemicals. The rule provides five years for regulated public water systems to comply with these MCLs as specified below.

- Individual MCLs in parts per trillion (ppt):
  - PFOS = 4 ppt
  - PFOA = 4 ppt

[1] SDWA defines a "maximum contaminant level" or MCL to be "the maximum permissible level of a contaminant in water which is delivered to any user of a public water system." 42 U.S.C. § 300f(3).

September 3, 2024, memo on prioritization of DoD Cleanup Actions to implement PFAS MCLs

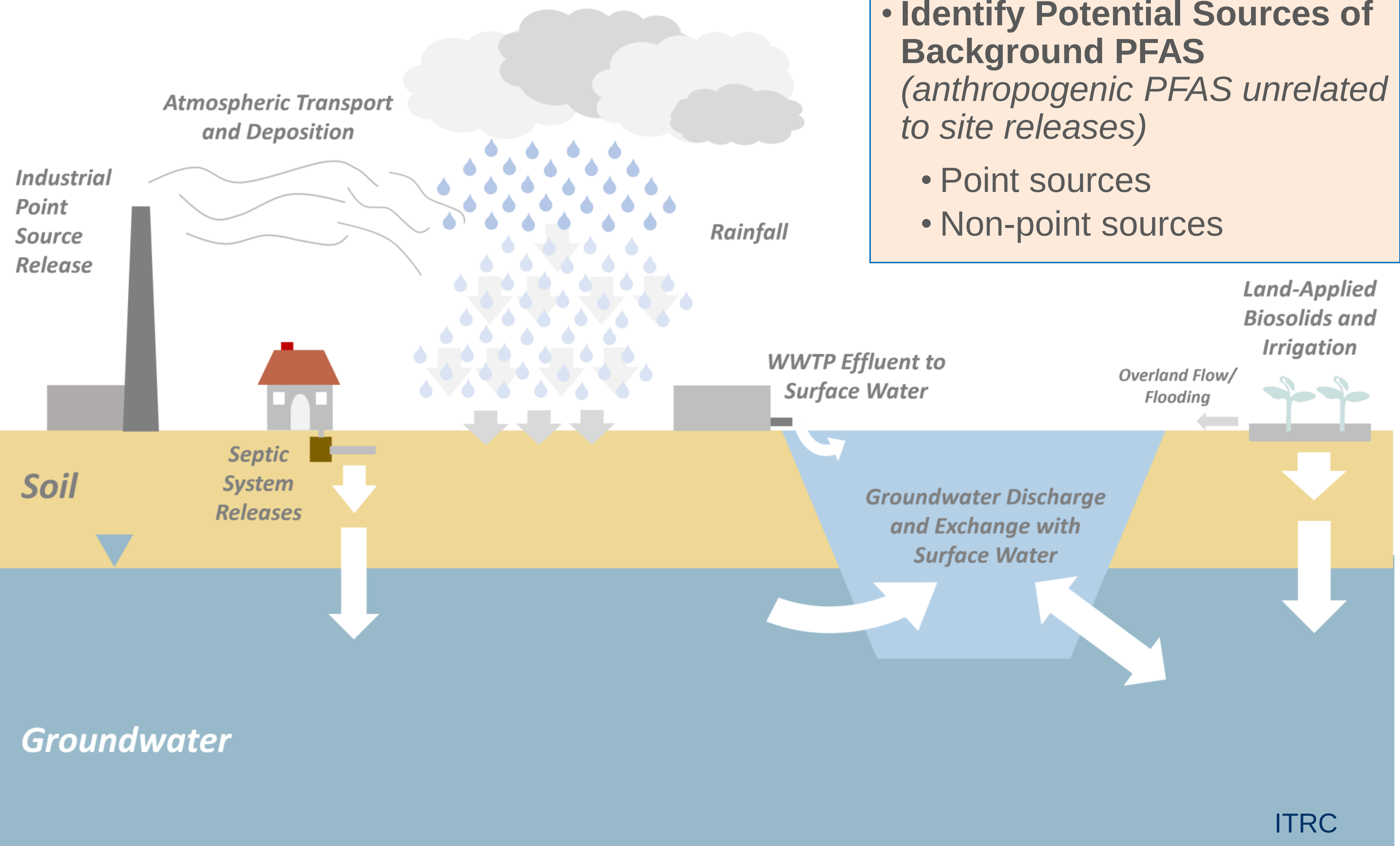
Long-Term Remedial Actions

CERCLA requires a site-specific risk assessment during the remedial investigation to establish risk-based cleanup levels. This includes considerations of "background" levels of chemicals present at a site, which can be highly variable across the country. Throughout the CERCLA process DoD coordinates with both EPA and state regulators and EPA and DoD jointly select remedies at National Priorities List sites. Accordingly, DoD will work with EPA and state regulators, as appropriate, to evaluate background levels of PFAS on a site-specific basis to determine a final cleanup level.

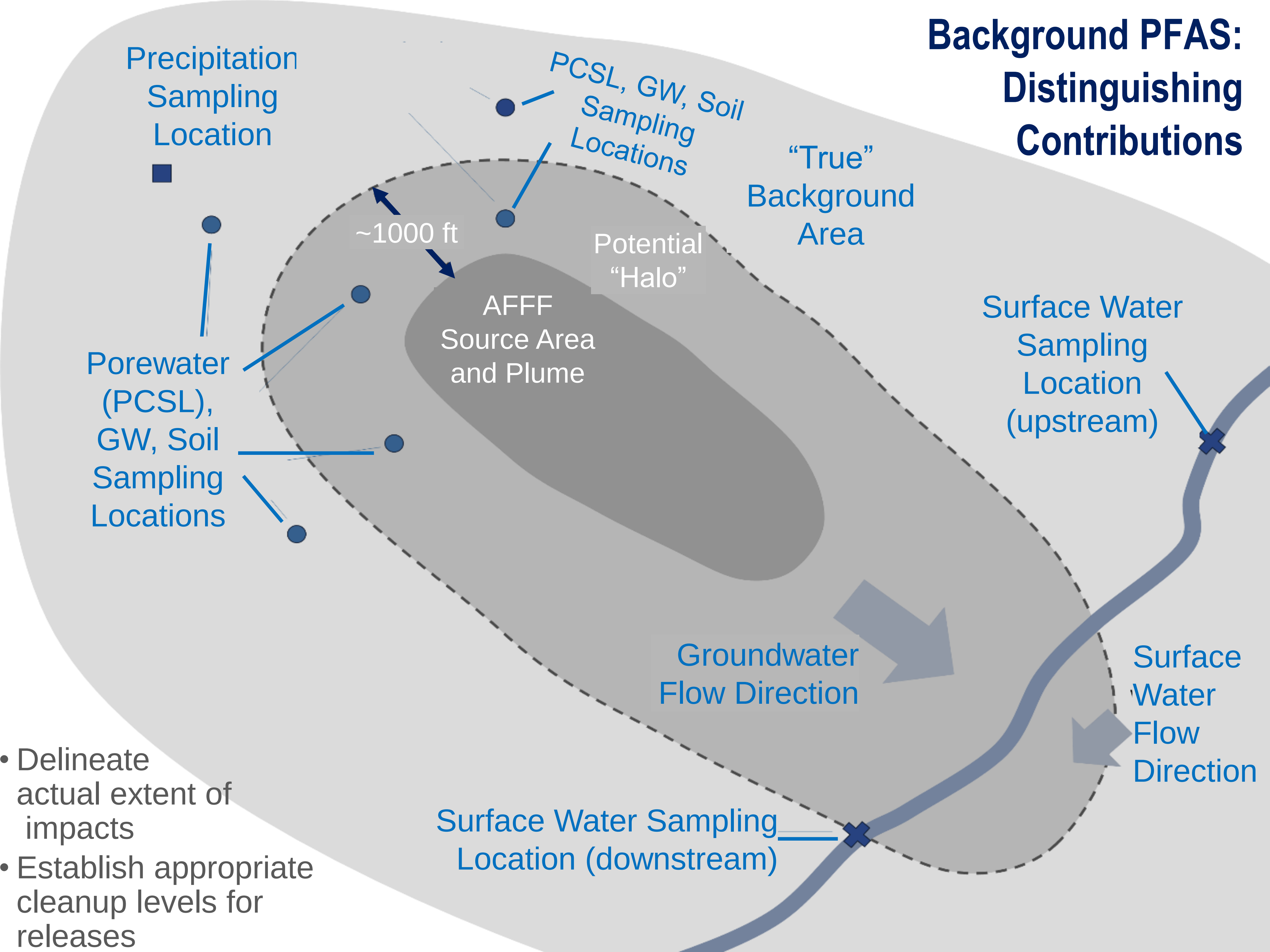
For remedial actions, the DoD Components will address drinking water down to the MCLs or background, in accordance with CERCLA, once the DoD Component has established levels of PFAS are below the MCLs, then DoD Components will take remedial actions to address PFAS that will meet the MCLs as the final cleanup levels.[6] If background levels of PFAS are found above an MCL at a site, DoD Components will work collaboratively with regulators and transparently with the public to determine the appropriate remedial goals (i.e., final cleanup levels) at that site.

Background PFAS – Assessment Objectives

- **Identify Potential Sources of Background PFAS** *(anthropogenic PFAS unrelated to site releases)*
  - Point sources
  - Non-point sources



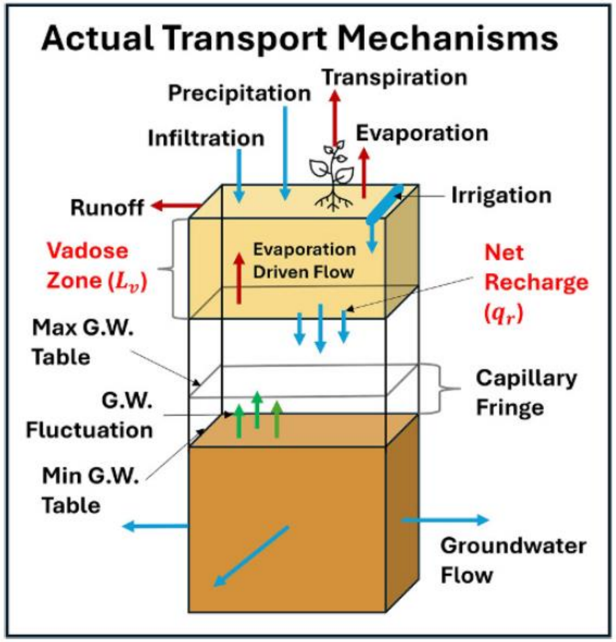
Background PFAS: Distinguishing Contributions

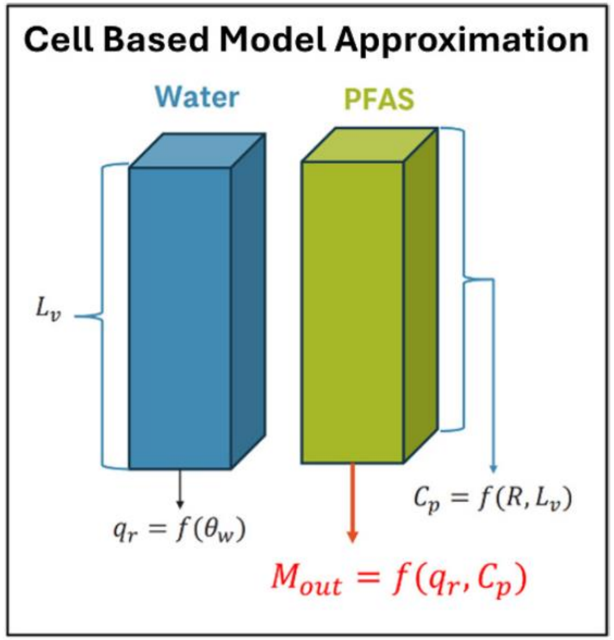


- Delineate actual extent of impacts
- Establish appropriate cleanup levels for releases

PFAS Leaching Models

Simplified Models for Screening





- Spreadsheet-based
- Average recharge rate (steady flow)
- Desorption, K_i, A_{aw} estimated based on lab data and empirical models
- A_{aw} constant
- ***Estimate of mass discharge and source longevity***

Contents lists available at ScienceDirect

Science of the Total Environment

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

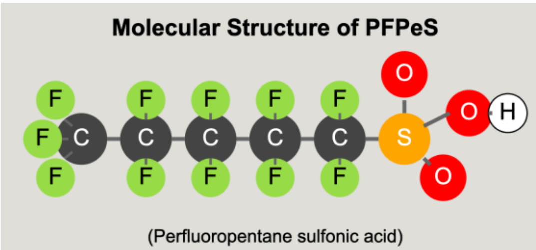
ELSEVIER

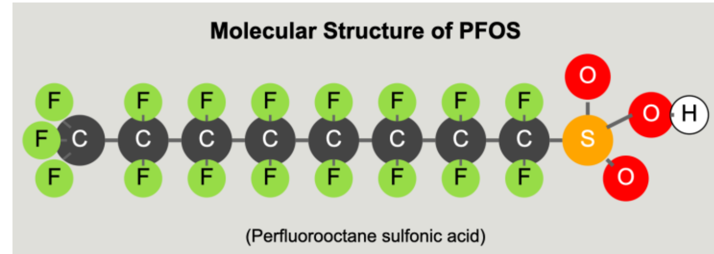
Short Communication

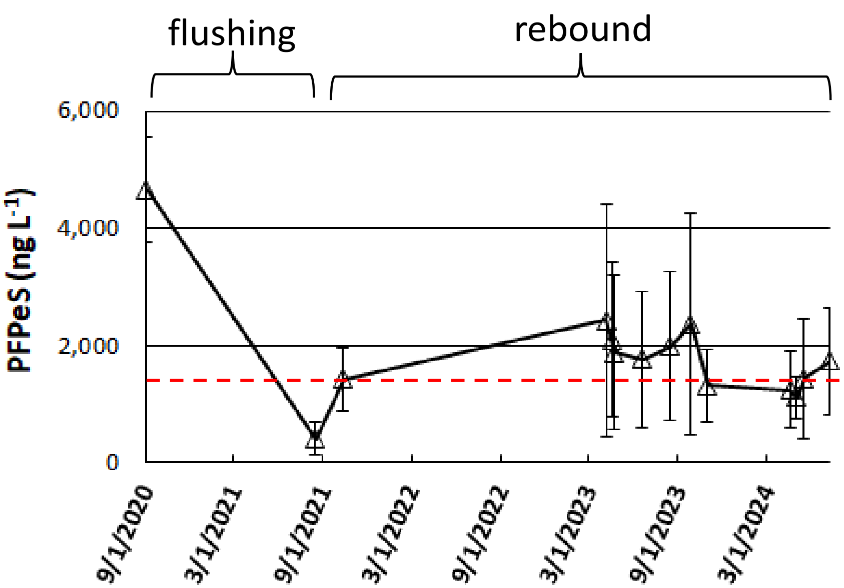
Laboratory validation of a simplified model for estimating equilibrium PFAS mass leaching from unsaturated soils

John F. Stults [a,*], Charles E. Schaefer [b], Tamzen MacBeth [c], Yida Fang [a,d], Julie Devon [a], Isreq Real [e], Fangfei Liu [f], David Kosson [f], Jennifer L. Guelfo [e]

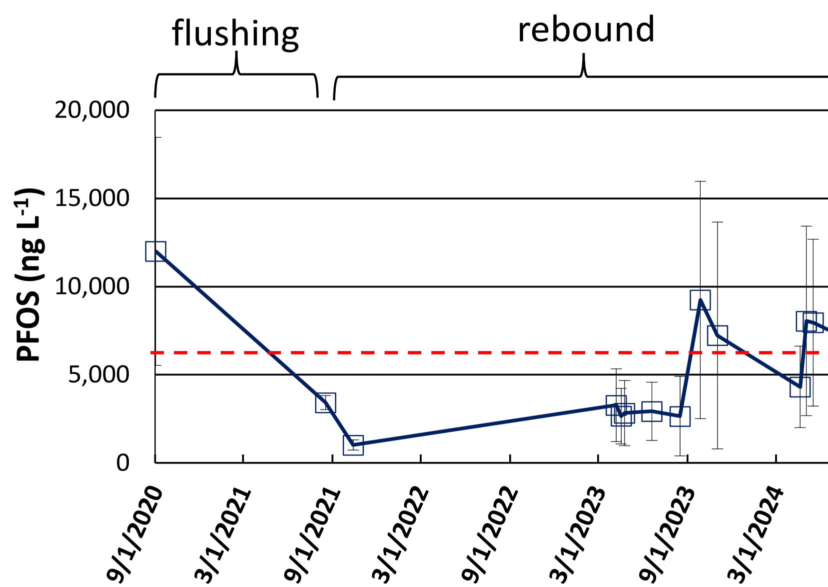
Screening Model: Long-Term PFAS Rebound in Porewater







70% PFPeS mass removed

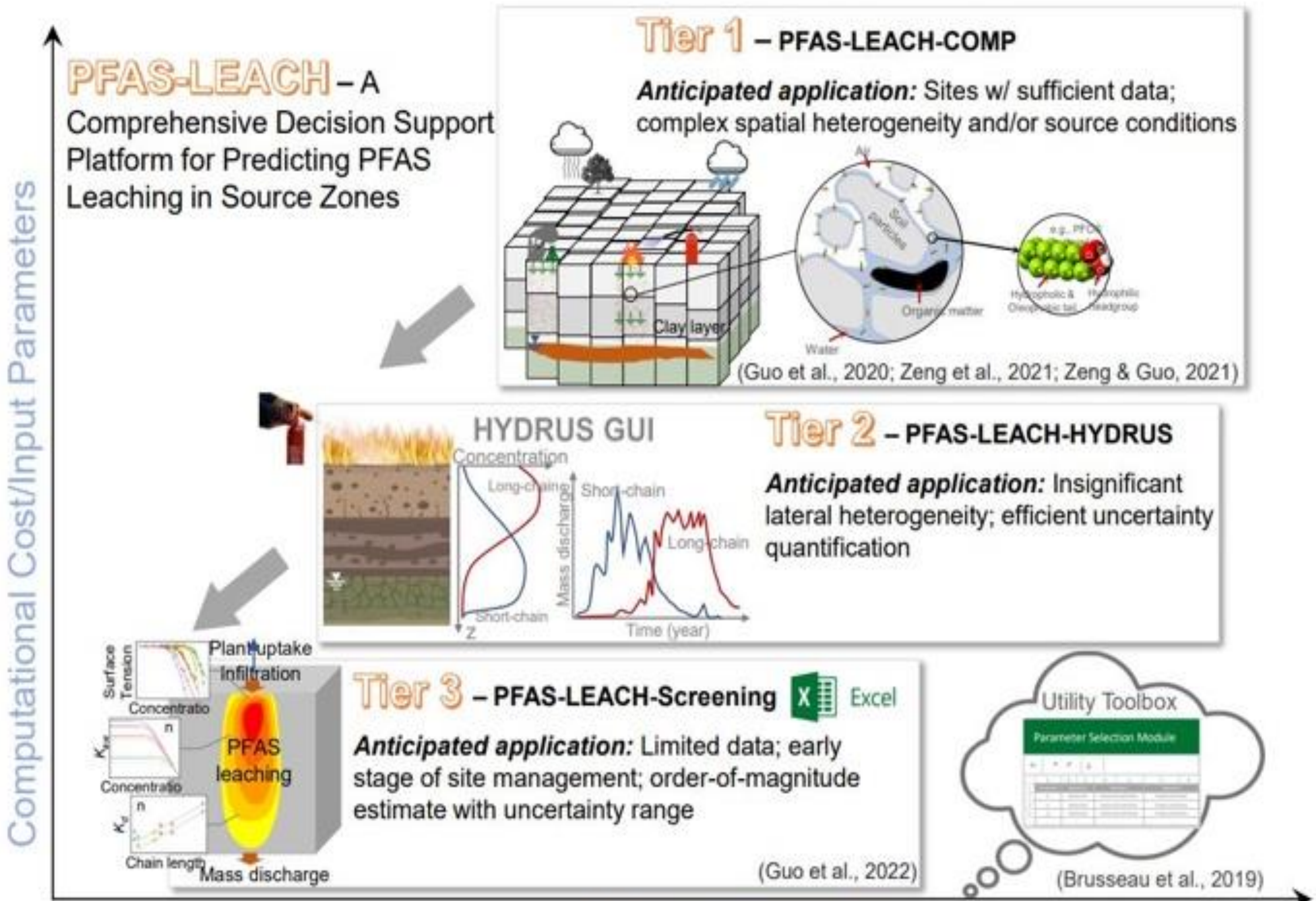


7% PFOS mass removed

- - - - - - - - - - - - - - - - *predicted rebound level [based on measured mass removal and desorption isotherm]*

Bench-scale testing informs on field-scale behavior

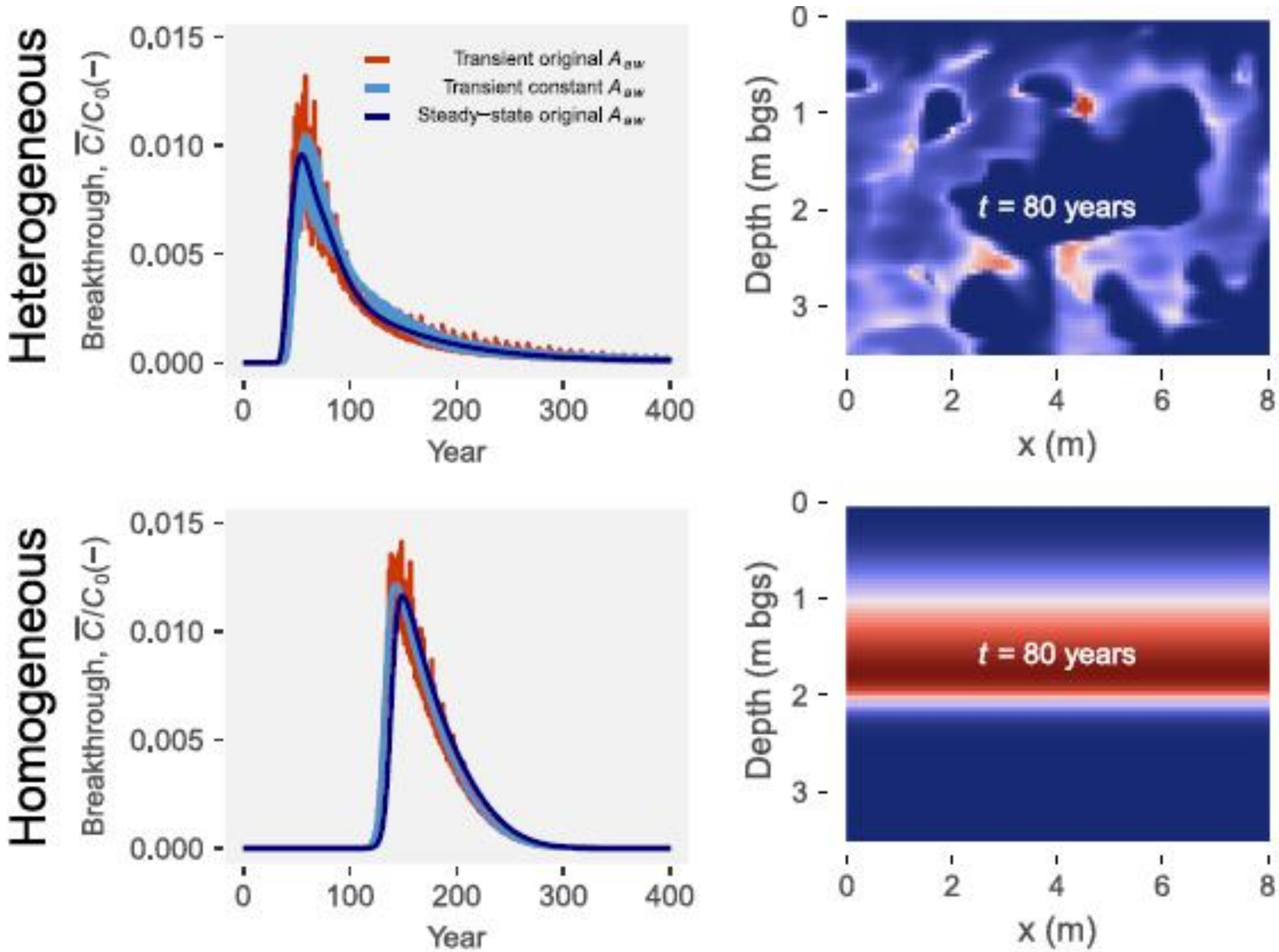
ESTCP's PFAS Leach Platform (Guo et al.)

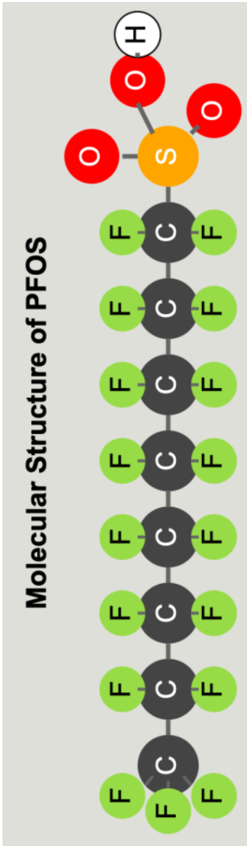


Guo et al., 2022 – Search ER21-5041

Detailed PFAS Modeling of Vadose Zone
Zeng & Guo (2023): Heterogeneities Matter

Simulated PFOS





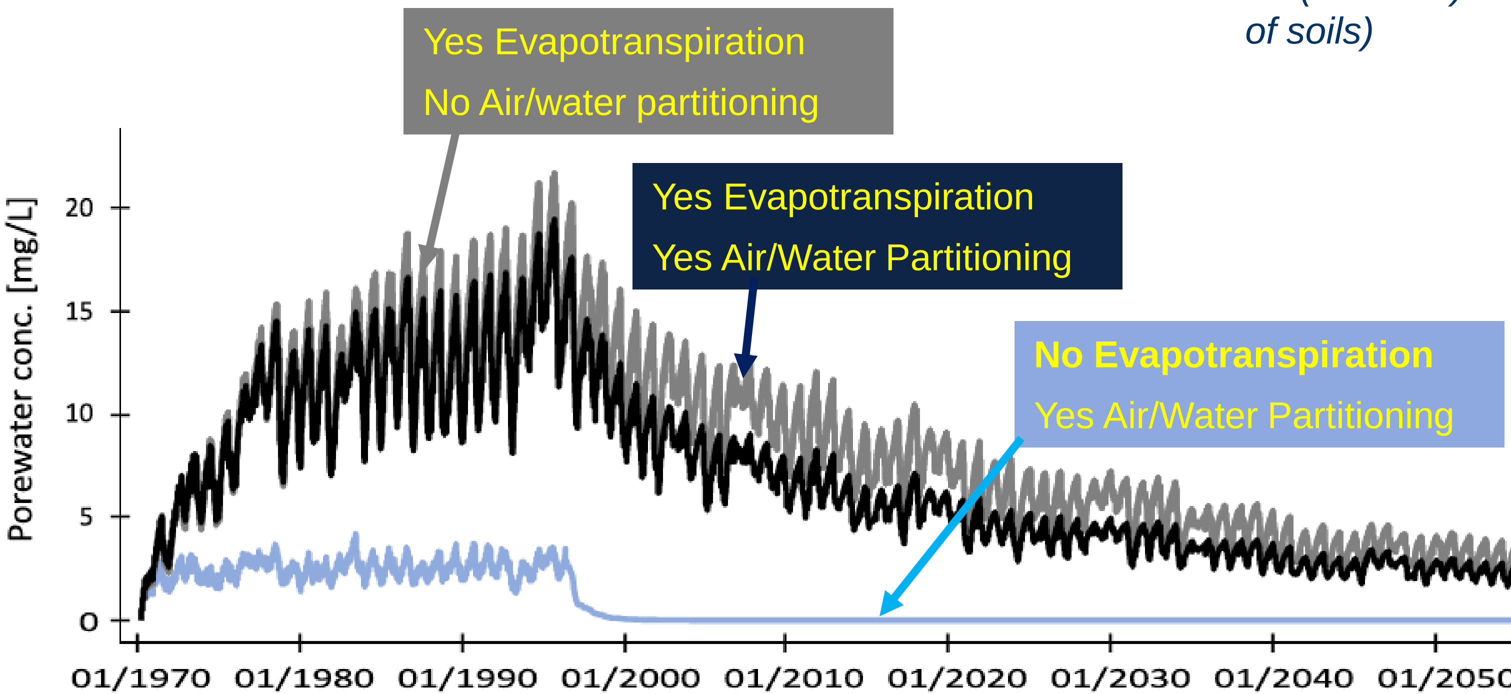
Modeling porewater concentrations of PFAS within the upper soil profile

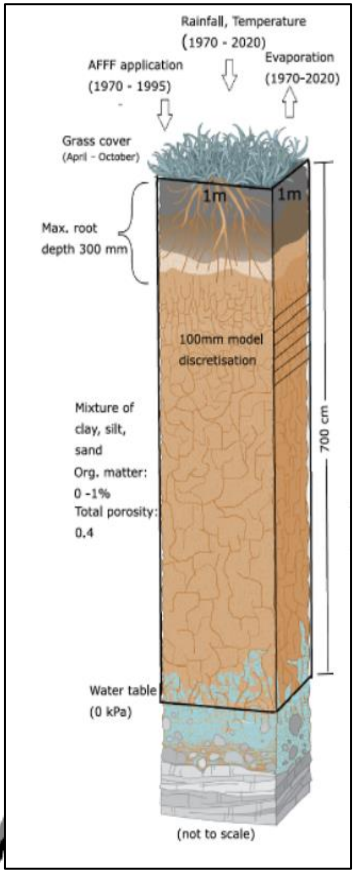
Model-based identification of vadose zone controls on PFAS mobility under semi-arid climate conditions

Ilka Wallis[a,*], John Hutson[a], Greg Davis[b], Rai Kookana[c], John Rayner[b], Henning Prommer[b,d]

Wallis et al., 2022

(Total PFAS in the top 100 mm (4 inches) of soils)





Wrap Up

Key Decisions for Managing PFAS Leaching

Key Decision	Details
Mass discharge (M_d) (g/yr)?	(Porewater conc) x (recharge) x (area)
How to determine PFAS porewater concentrations & leaching?	• How to install/sample lysimeters? • Other measurements needed?
Recharge rate (inches/yr)?	Desktop methods: T1-A, T1-B, T1-C. Field methods? T2-B (humid), T2-E (arid)
Dilution Factor (-)	Compare vertical leaching flow to horizontal groundwater flow
Construct Model of Site?	Yes if you want to forecast M_d vs. time No if you just want to know current M_d
Key Models?	Screening Model, ESTCP's PFAS-LEACH, REMFluor-MD

Points of Contact

Questions? Email to
EXWC.T2@us.navy.mil

- **Jovan Popovic, PhD**
jovan.popovic.civ@us.navy.mil

- **Nikki Andrzejczyk, PhD**
nicolette.e.andrzejczyk.civ@us.navy.mil

Wrap Up

A short Survey Monkey will be emailed to webinar registrants and participants

Stay tuned for upcoming OER2's via email: EXWC_T2@us.navy.mil

You can find previous presentations on the *ERB Website> OER2 Presentations* and our *OER2 YouTube channel* all found on https://exwc.navfac.navy/go/erb

Thank you for participating!

SPARE SLIDES

The Concentration Side: Pros and Cons of Different Porewater Conc. Methods (Navarro et al., 2024)

Method	Pros	Cons
Batch Leaching Methods	Quick, simple, cost-effective; conservative estimates	May not represent realistic field conditions; disrupts soil structure and neglects air-water interfaces
Column Methods	Realistic conditions; simulates leaching kinetics; assesses transport processes	Complex, time-consuming, costly; typically conducted under saturated conditions
Static Leaching	Simpler than column; moderate realism; useful for point-in-time assessments	Less rigorous; may underestimate leaching in dynamic conditions
Rainfall Simulation and Ponding Experiments	Incorporates wet/dry cycles and runoff; realistic for surface leaching	Large-scale setup; requires substantial resources
Lysimeters (Pan and Suction)	Direct in-situ measurement; captures real field conditions; detailed temporal data	High cost; complex installation; potential variability

Overall Recommendations

- Align method choice with assessment objectives and scenarios.
- Combine multiple methods for comprehensive evaluation.

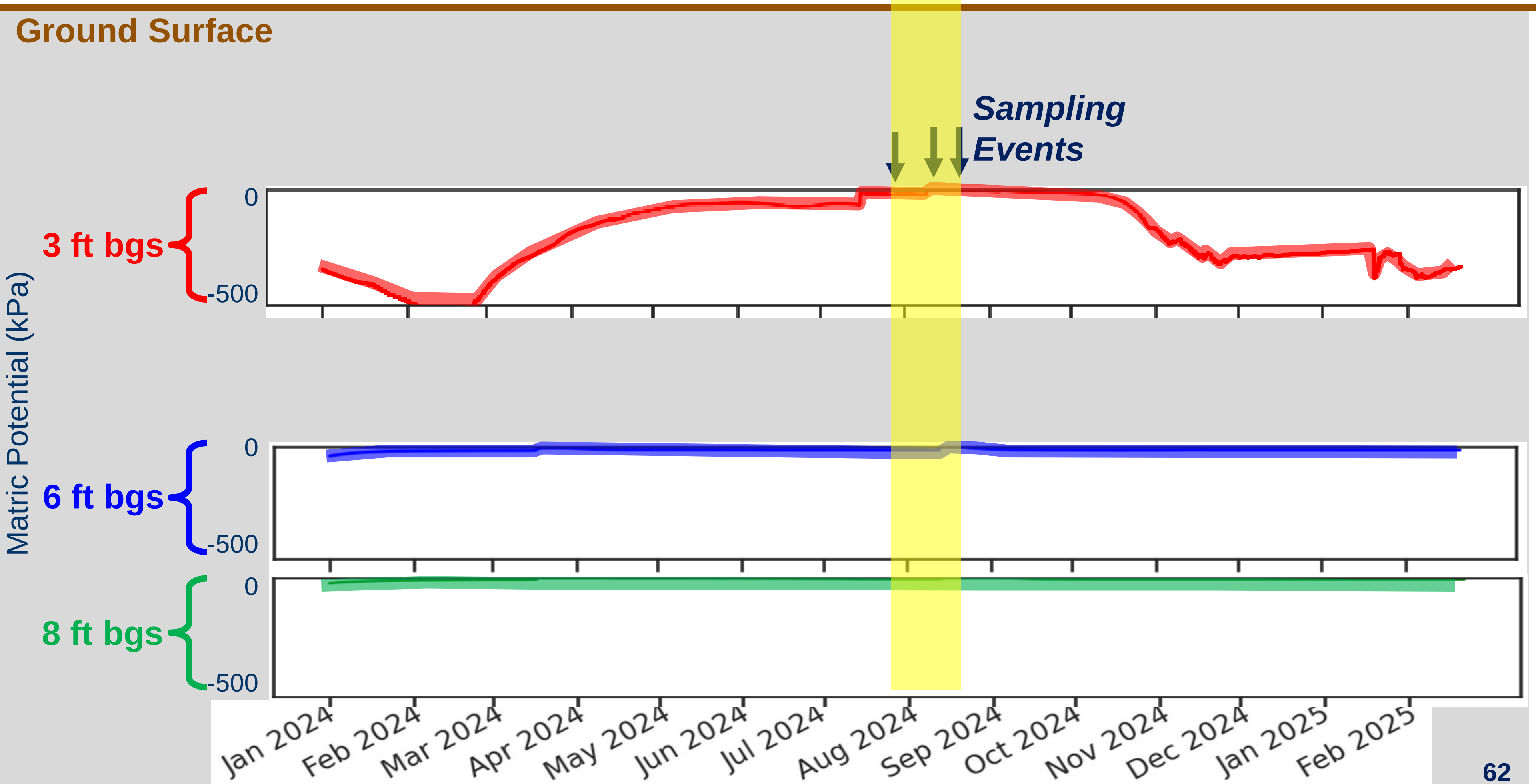
METHODS TO ESTIMATE METRIC 1 ($M_{d\text{-}vad}$) – PFAS MASS DISCHARGE FROM VADOSE ZONE

Images from CDM Smith-led SERDP Project ER18-204 “Insights into the Long-Term Mass Discharge & Transformation of AFFF in the Unsaturated Zone” field site. CDM Smith’s porous cup suction lysimeter (PCSL) is shown to the right.

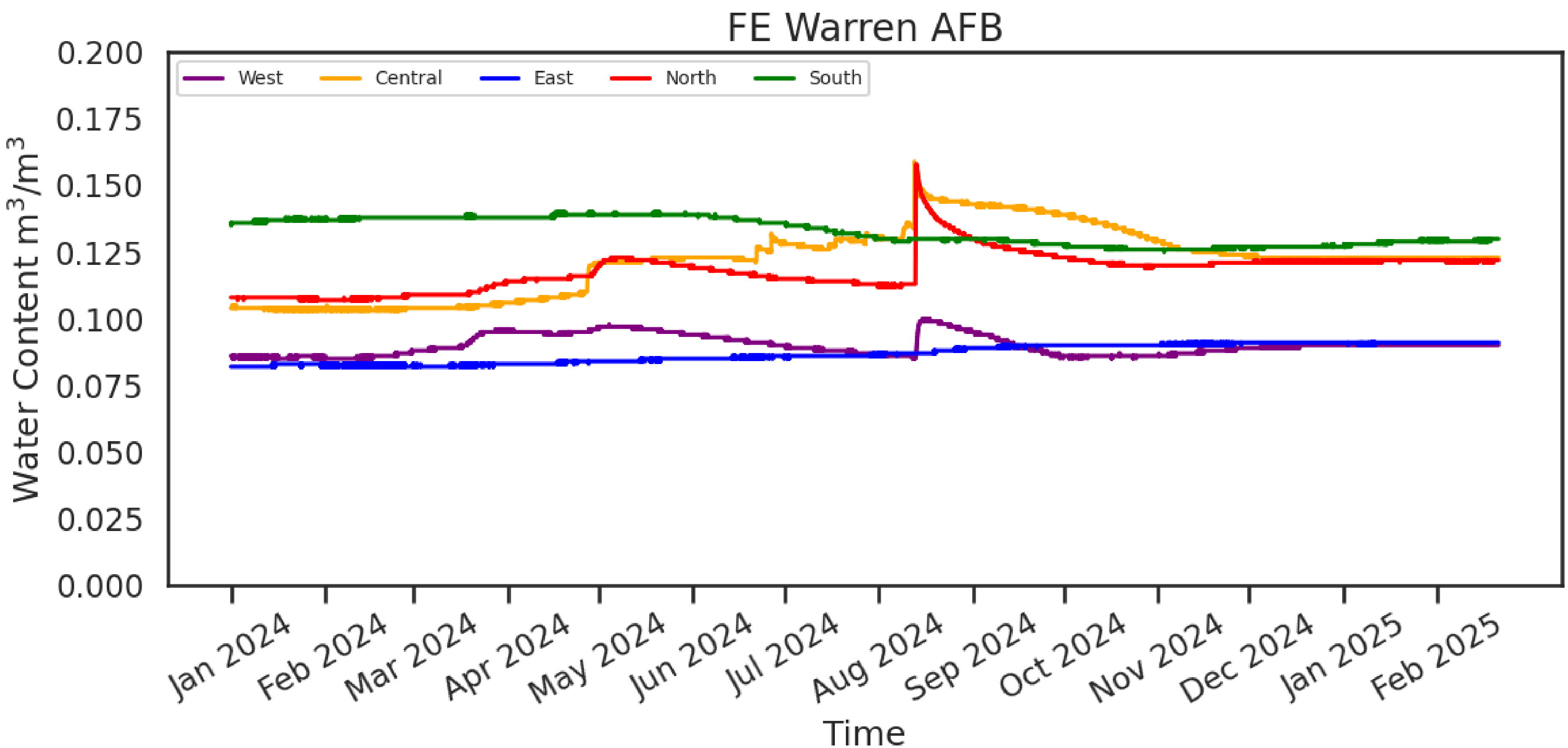
Two ESTCP PFAS Leaching Demonstration Sites

Matric Potential (Suction Required to Remove Water from Soil) Over Time and Depth (Arid Site)

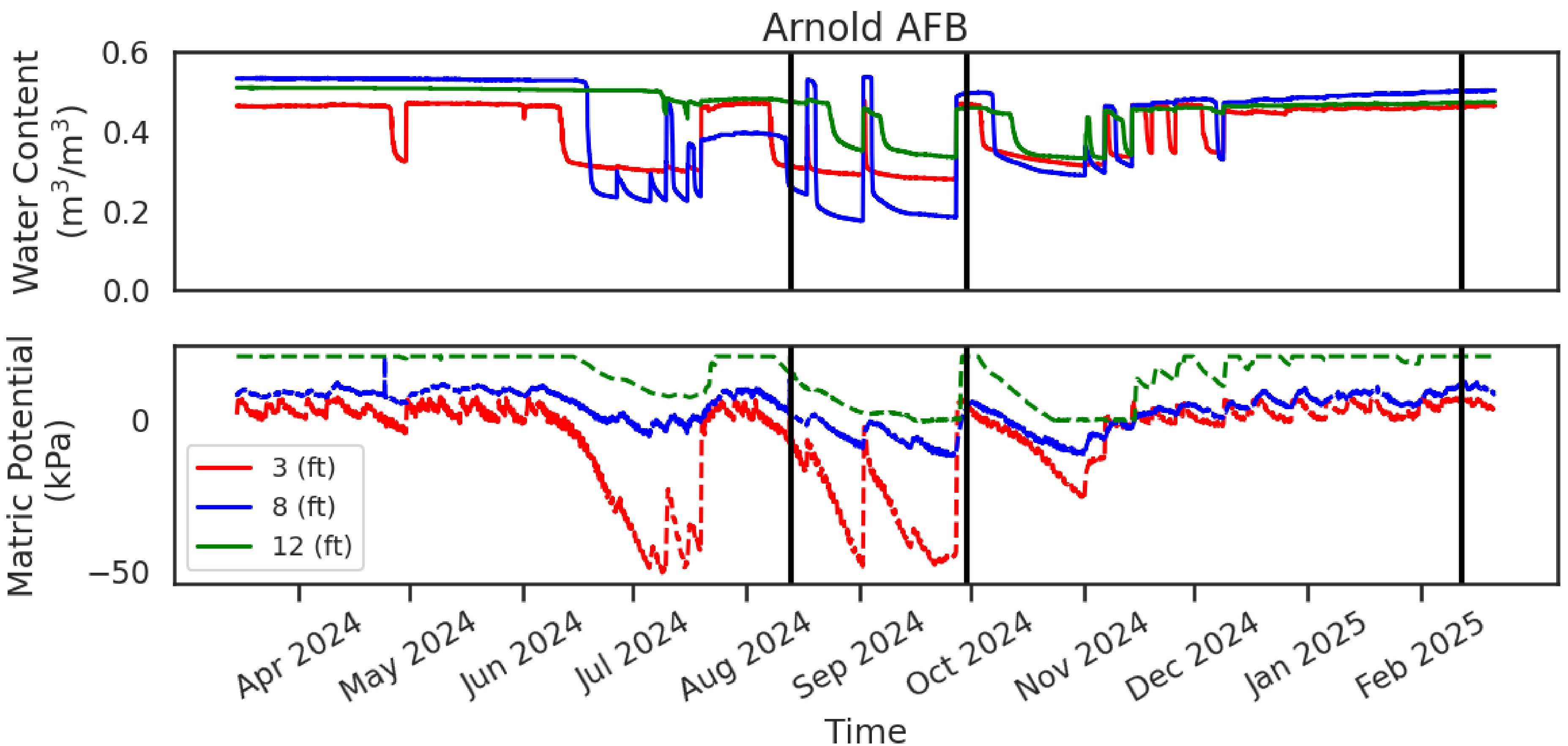
Key Point: Deep Matric Potential Does Not Change Much Over Time



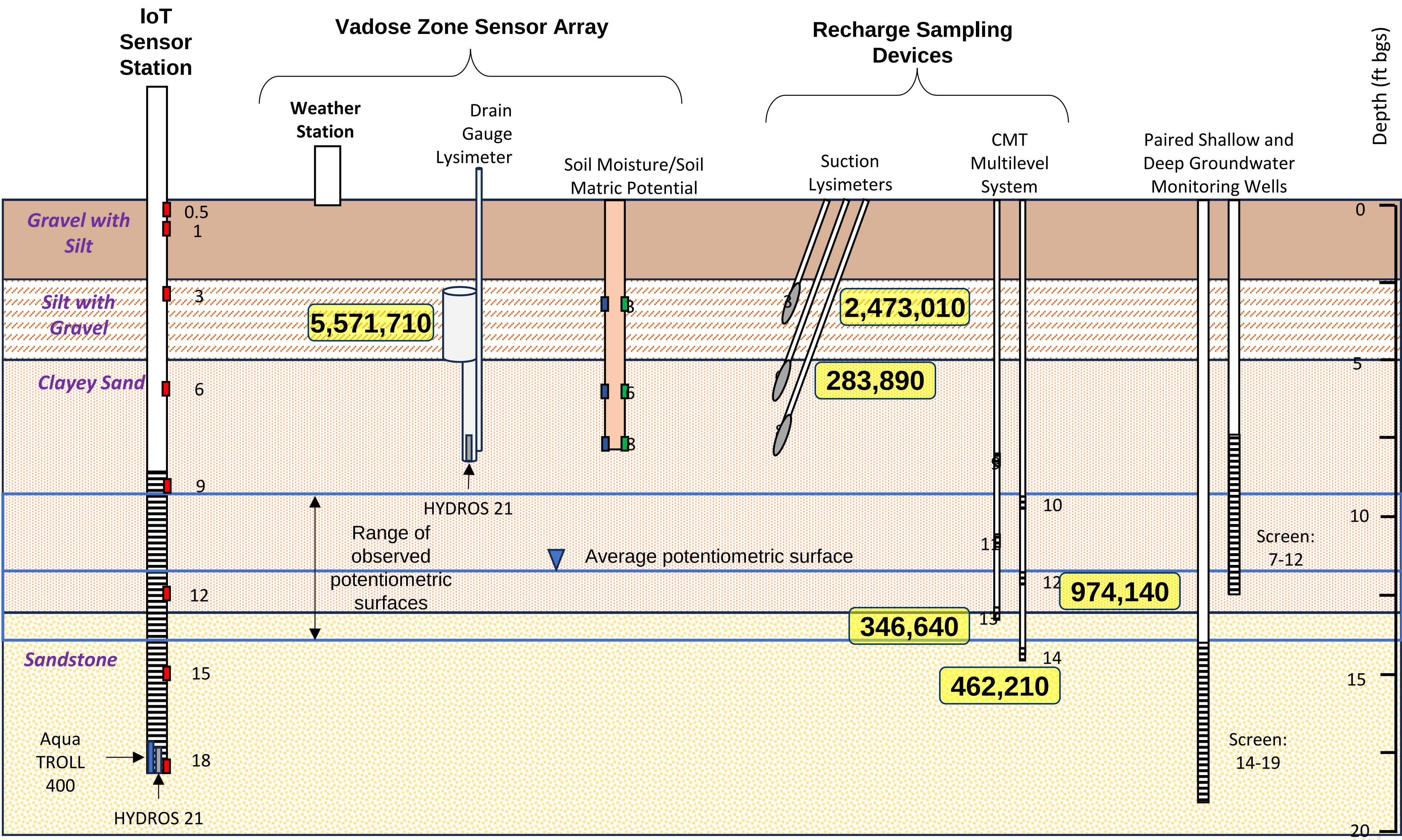
Performance Assessment:
Spatial Profiles of Water Content (3 ft bgs)



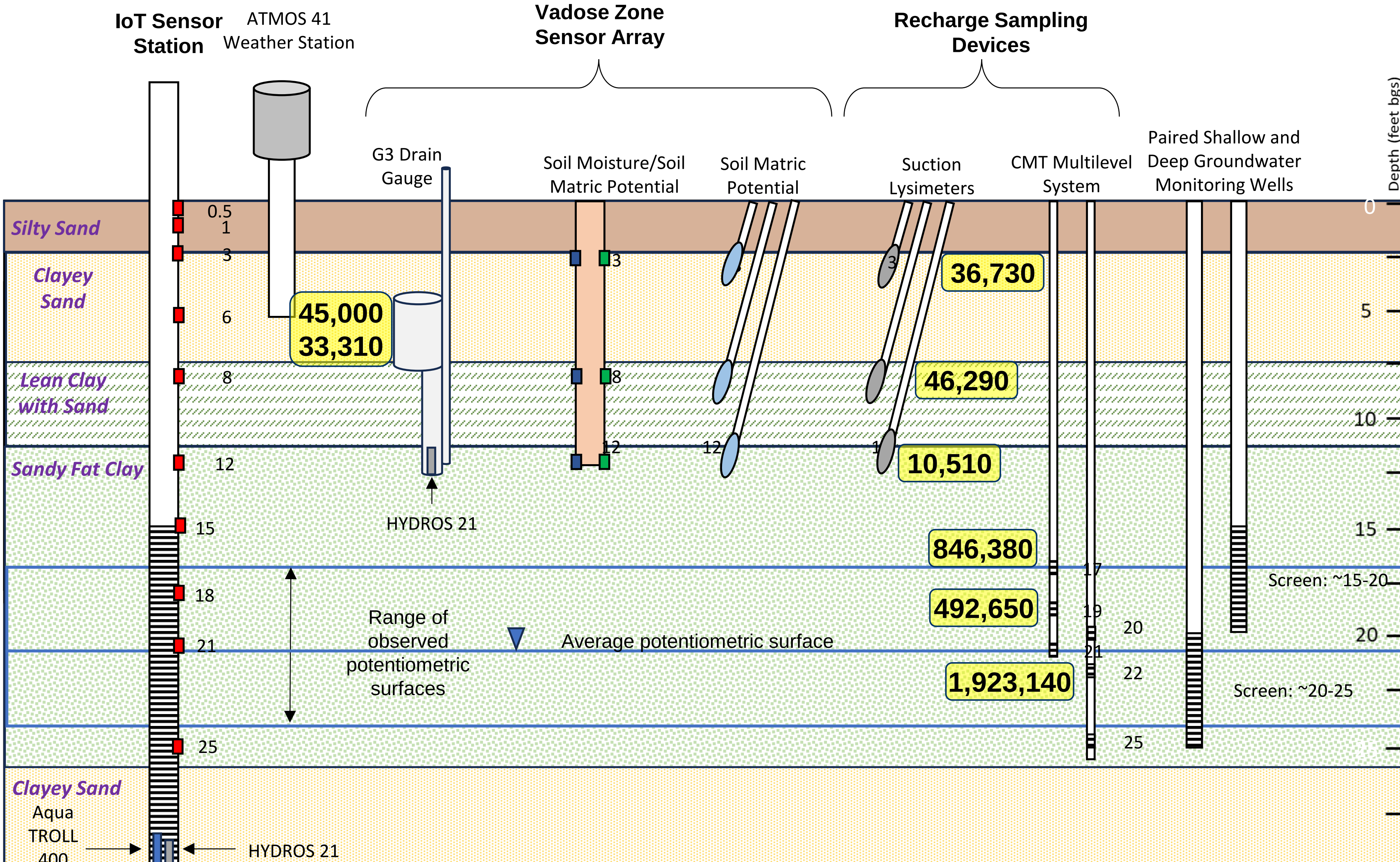
Performance Assessment:
TEROS 32 Sensors at Arnold AFB



FE Warren – 31 July 2024: Total PFAS (ng/L)

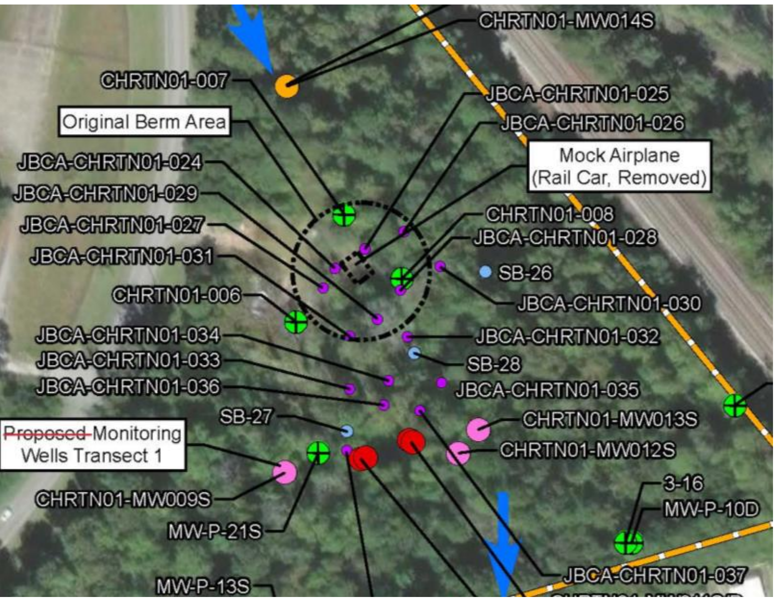


Arnold – 13-14 August 2024: Total PFAS (ng/L)

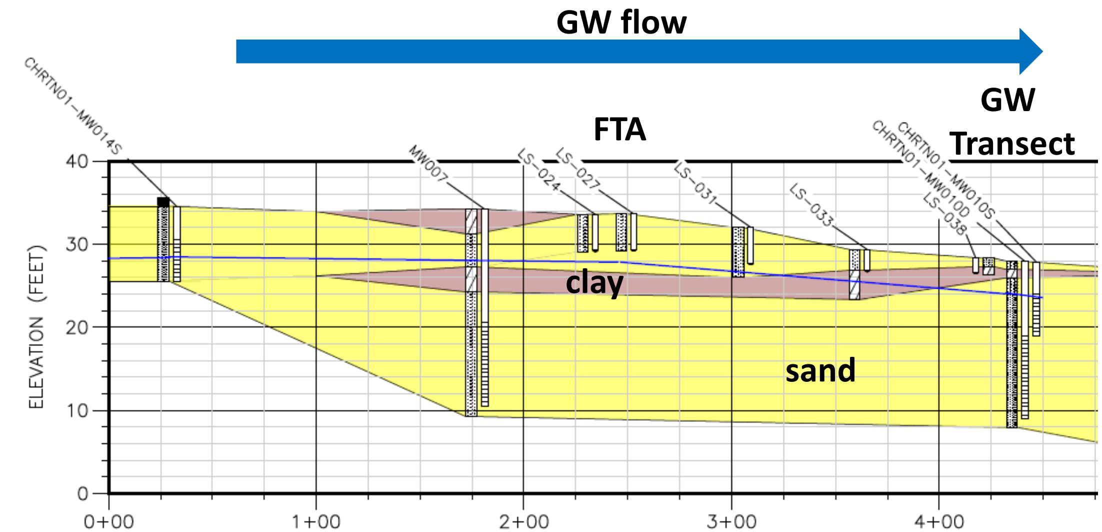


PFAS Mass Discharge: JBCA

Is PFAS leaching from the unsaturated zone sustaining the PFAS groundwater plume?



Preliminary screening data from AFCEC BAA 2108 (CDM Smith and Colorado School of Mines)



Unsaturated Zone Porewater	Groundwater
$\sum$PFAS = 1,045 μg/L	$\sum$PFAS = 545 μg/L
PFAS mass discharge = 1,300 g/yr	PFAS mass discharge = 13,000 g/yr