Characterization of Relevant PFAS Fate and Transport Processes at Multiple AFFF Sites Using a Mass Balance Approach

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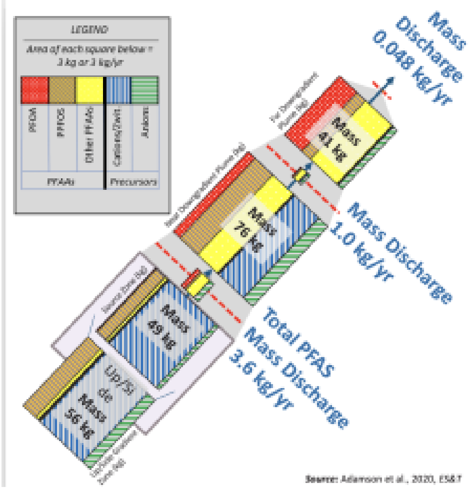

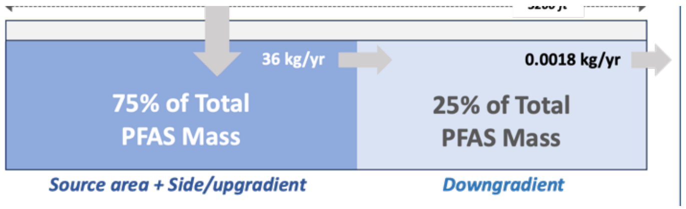

AGENDA / ACKNOWLEDGEMENTS

- Project Descriptions and Motivation
- Objectives
- Mass Discharge/Mass Balance Results from 3 AFFF Sites
- How Can Mass Discharge Estimates Be Used to Evaluate PFAS Monitored Retention (PMR)?
- How Can Mass Balances be Used to Evaluate PMR?

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ESTCP ER-201633
ESTCP ER21-5198

Project Description #1: *ESTCP ER-201633*

ESTCP ER-201633

Motivation:

- Field-validate relevance of F&T processes that have primarily been studied at the lab scale
- Inform Conceptual Site Models for PFAS source areas

Detailed high-resolution sampling at 3 AFFF Sites:

- Site 1: Florida
- Site 2: California
- Site 3: Virginia

Project Description #2: *ESTCP ER21-5198*

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RESEARCH ARTICLE

WILEY

Monitored natural attenuation to manage PFAS impacts to groundwater: Potential guidelines

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Groundwater Monitoring&Remediation

Monitored Natural Attenuation to Manage PFAS Impacts to Groundwater: Scientific Basis

by Charles J. Newell, David T. Adamson, Poonam R. Kulkarni, Blossom N. Nzeribe, John A. Connor, Jovan Popovic and Hans F. Stroo

Motivation:

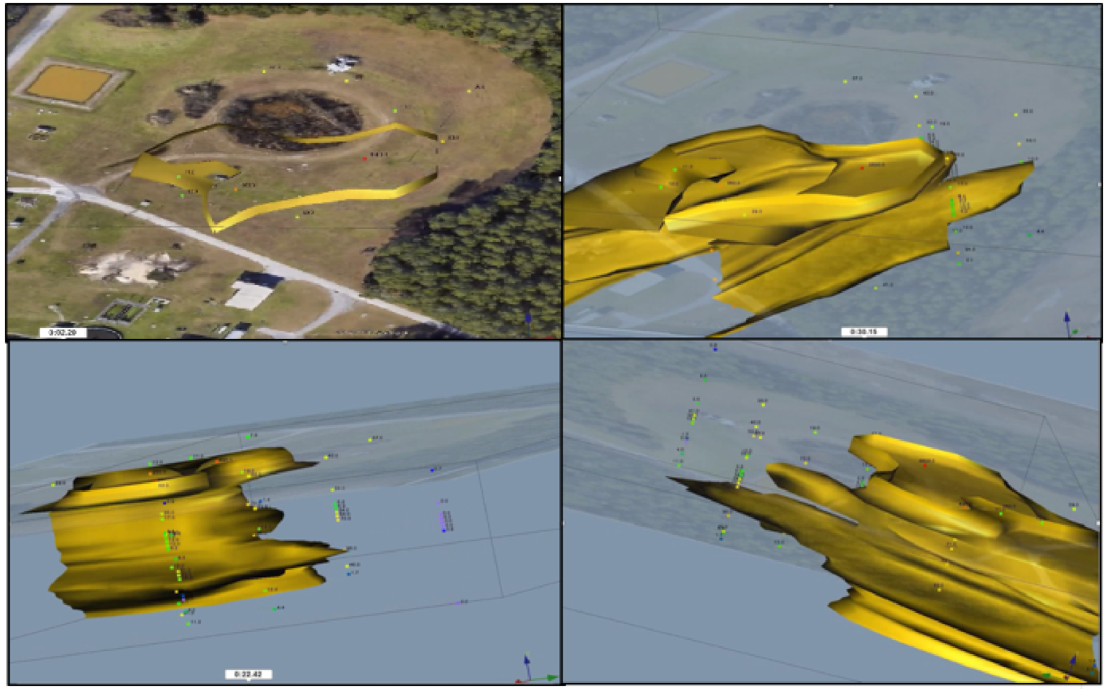
- Use what we've learned about PFAS Retention at these sites (and others) to help develop a framework for PFAS Monitored Retention (PMR)
- At some PFAS sites, PMR may be appropriate as long-term management approach
- Relies on strong air/water partitioning, sorption, matrix diffusion processes

~~MNA~~ → **PMR**

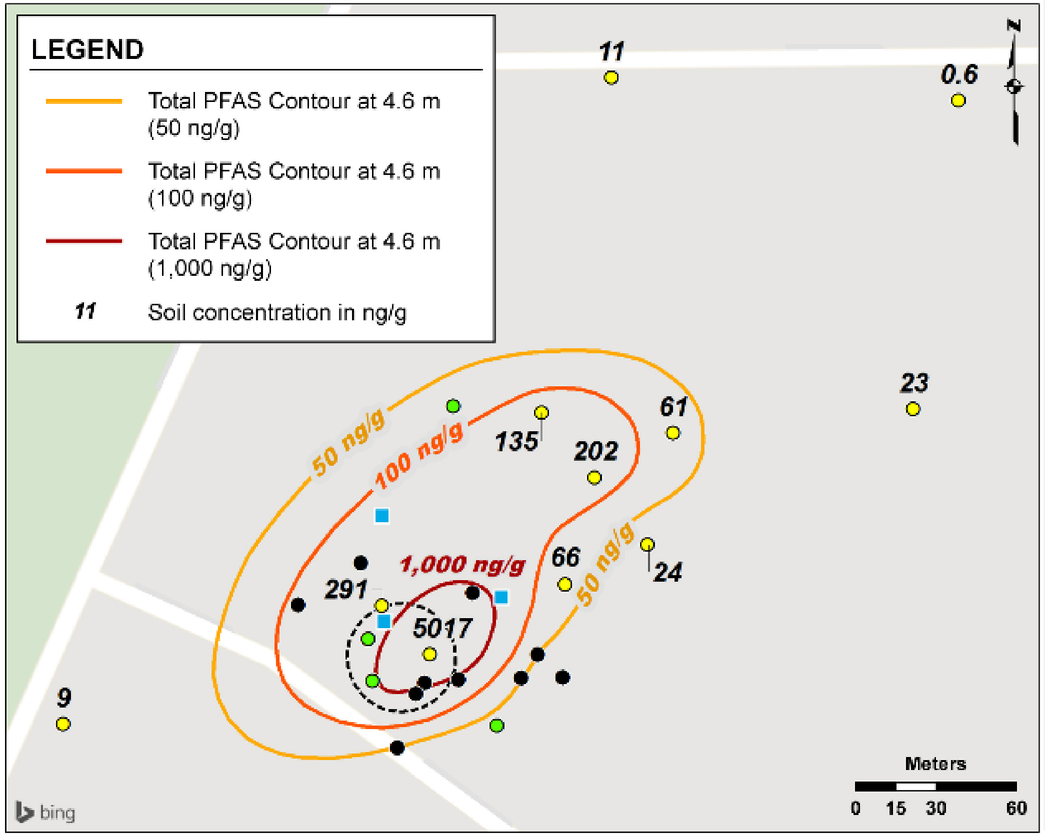
Risk / Triage strategy used with variety approaches

Overall Objectives

- Use mass balance and modeling to help answer key questions:
  - How much PFAS mass is at the site?
  - How much PFAS mass is discharging from the source?
  - How much mass is retained in various soil types?
- Document Lines-of-Evidence approach for PFAS Monitored Retention (PMR) framework



Mass Balance Approaches



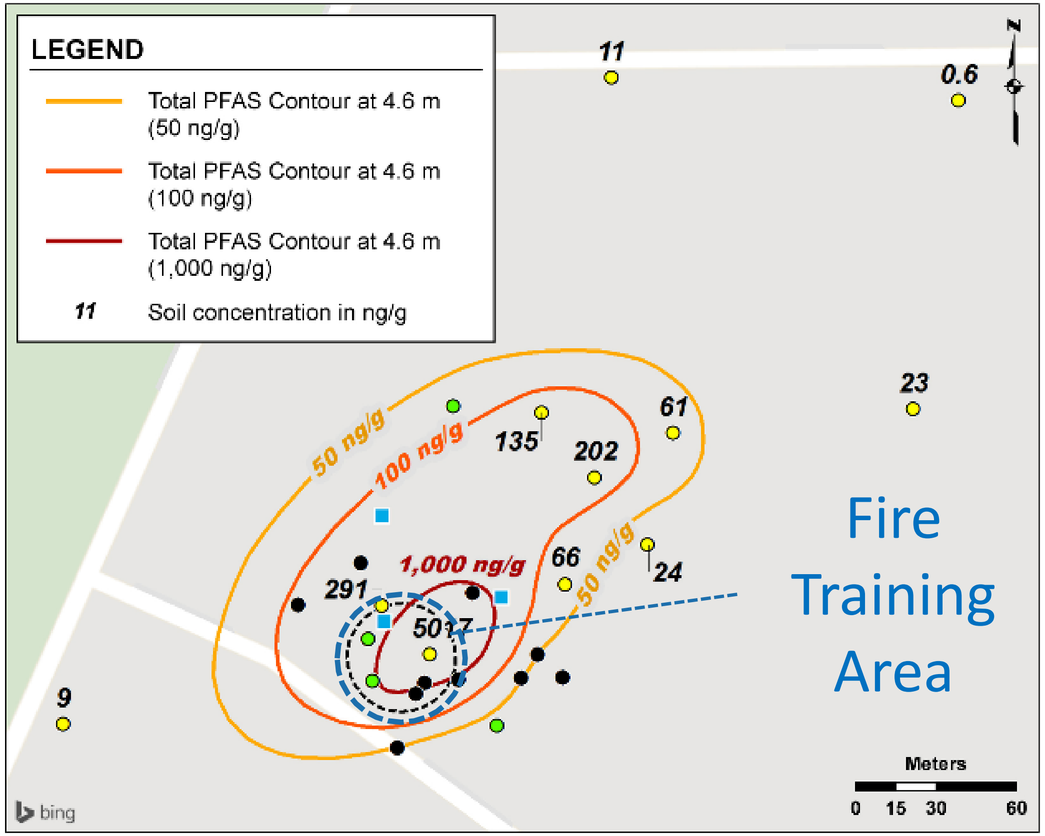
SITE 1

- Create 3-D grid of PFAS soil data and soil type across site
- Divide model domain into 4 different spatial zones
- Use PFAS distribution as basis for interpolating mass and mass discharge

SITE 2, SITE 3

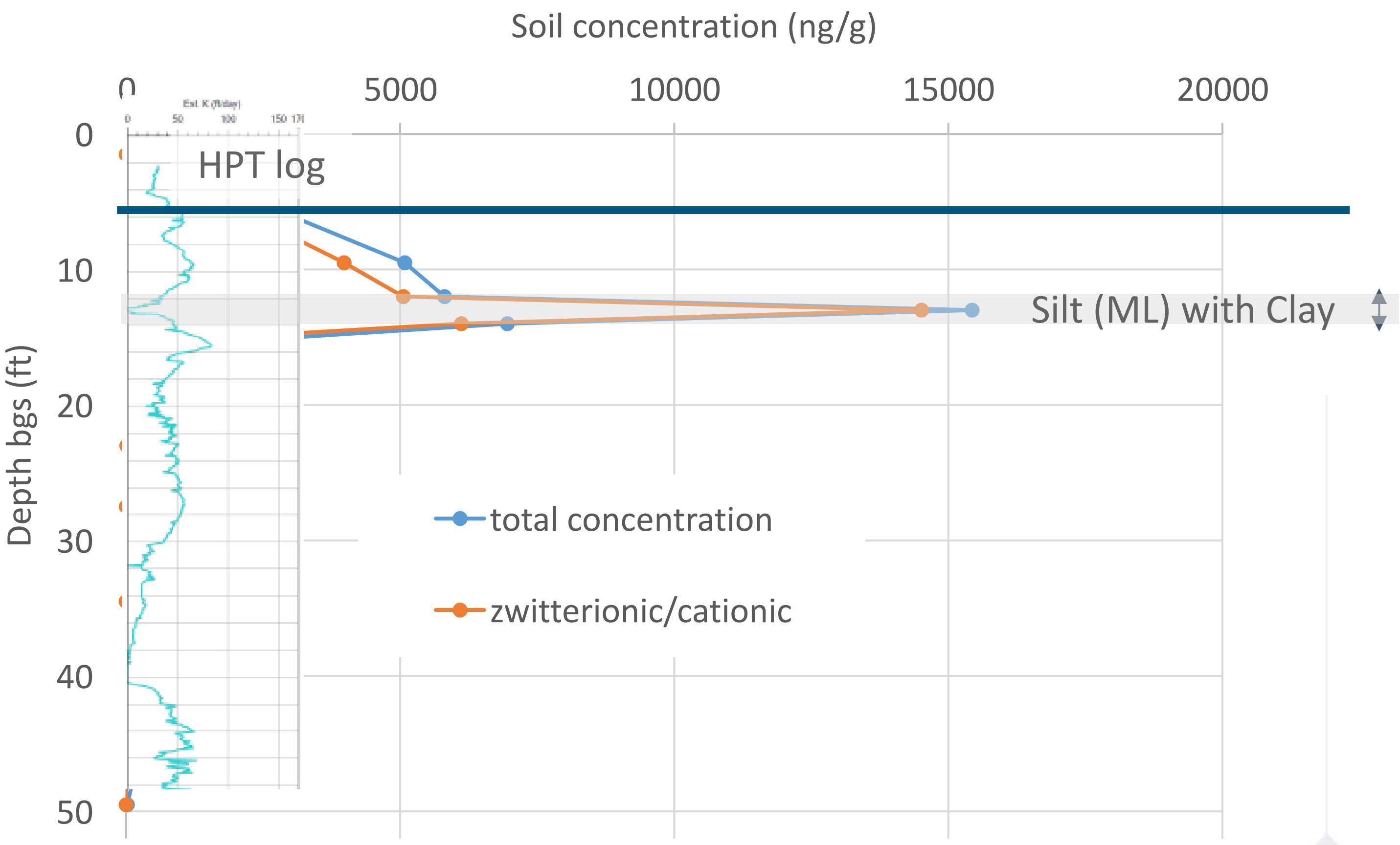
- Simpler interpolation based on contours and representative soil volumes assigned to each sample

AFFF Site 1:
Overview of PFAS Distribution



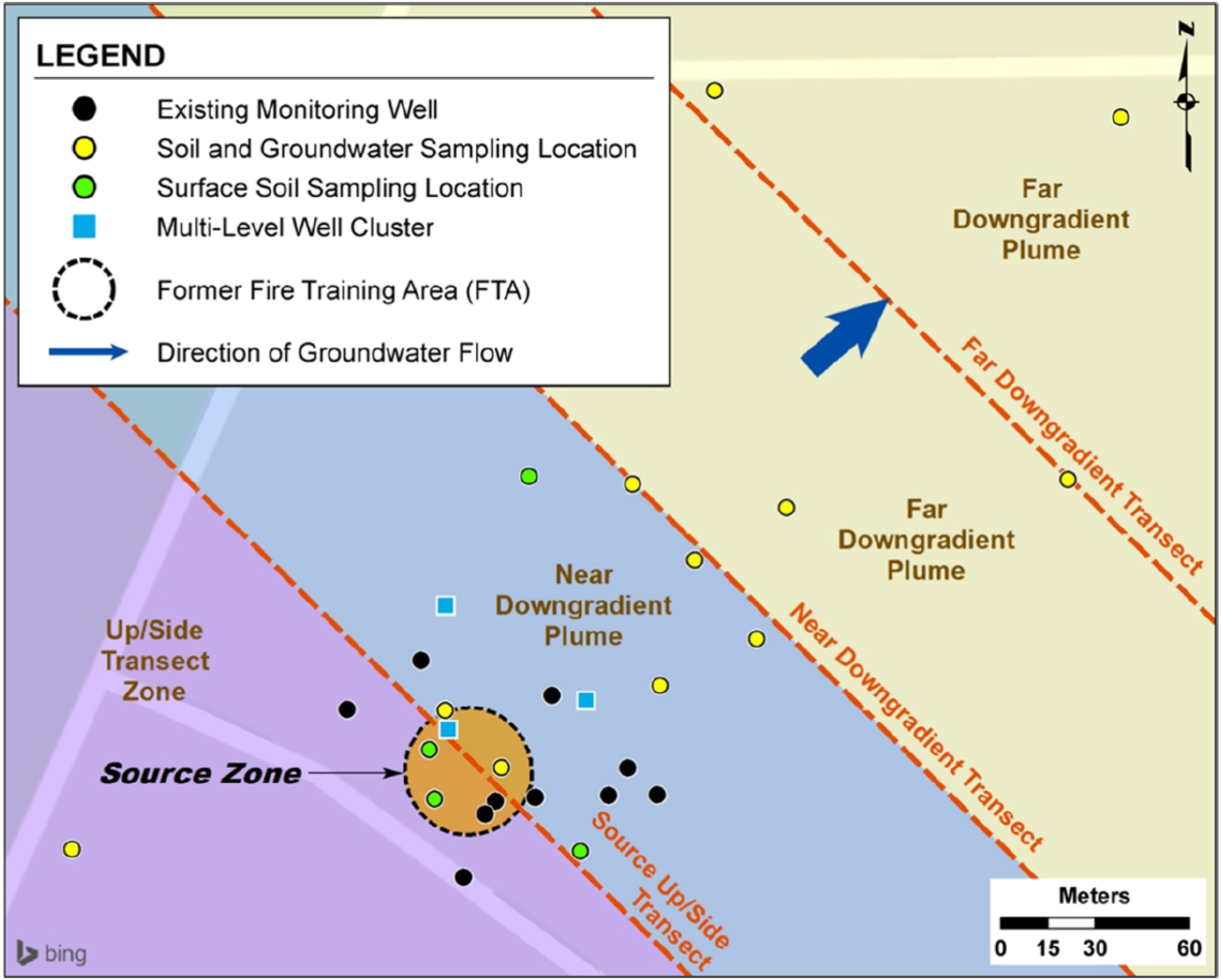
Source: Modified from Nickerson et al., 2020, *ES&T*

Location 3 (Source Area Location)

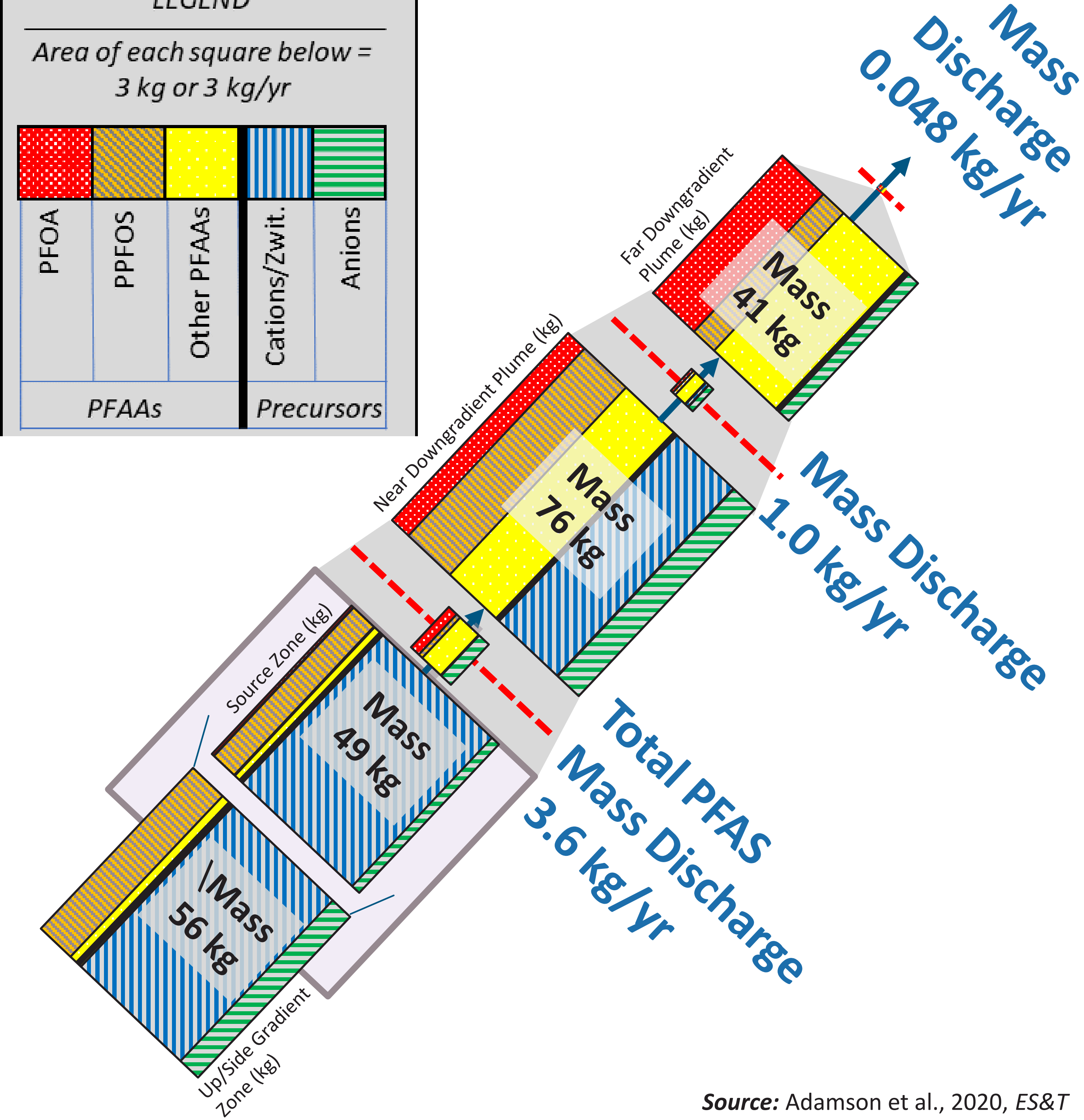


AFFF Site 1

Data Analysis Layout



Source: Modified from Nickerson et al., 2020, *ES&T*



Source: Adamson et al., 2020, *ES&T*

AFFF Site 1: *Key Results*

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- **Estimated total PFAS = 222 kg**
- 47% of remaining mass is in source/near-source areas
- 52% of remaining mass is in the form of polyfluorinated "precursors"
  - 83% of precursor mass is zwitterionic/cationic

AFFF Site 1:
Key Results

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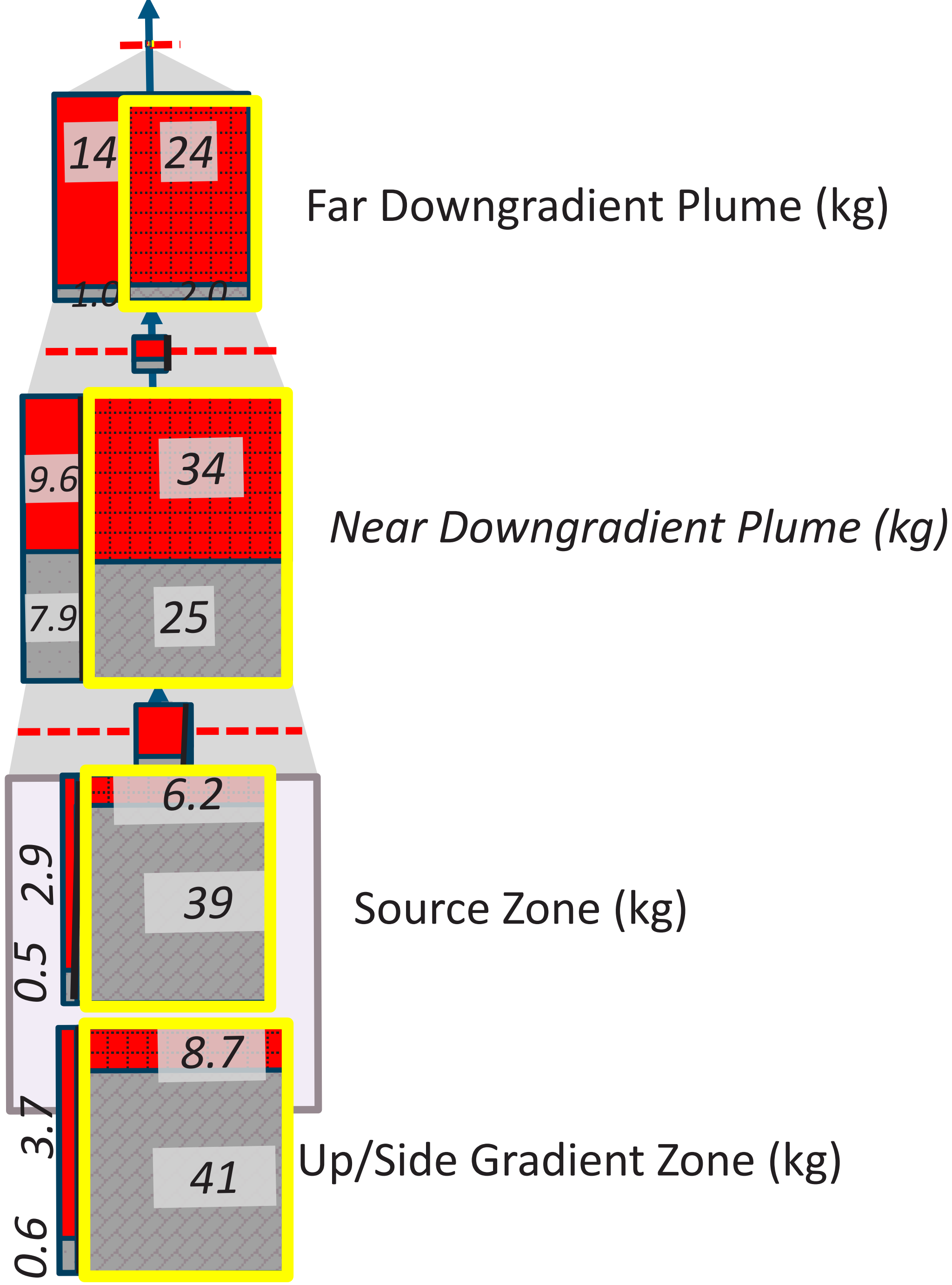
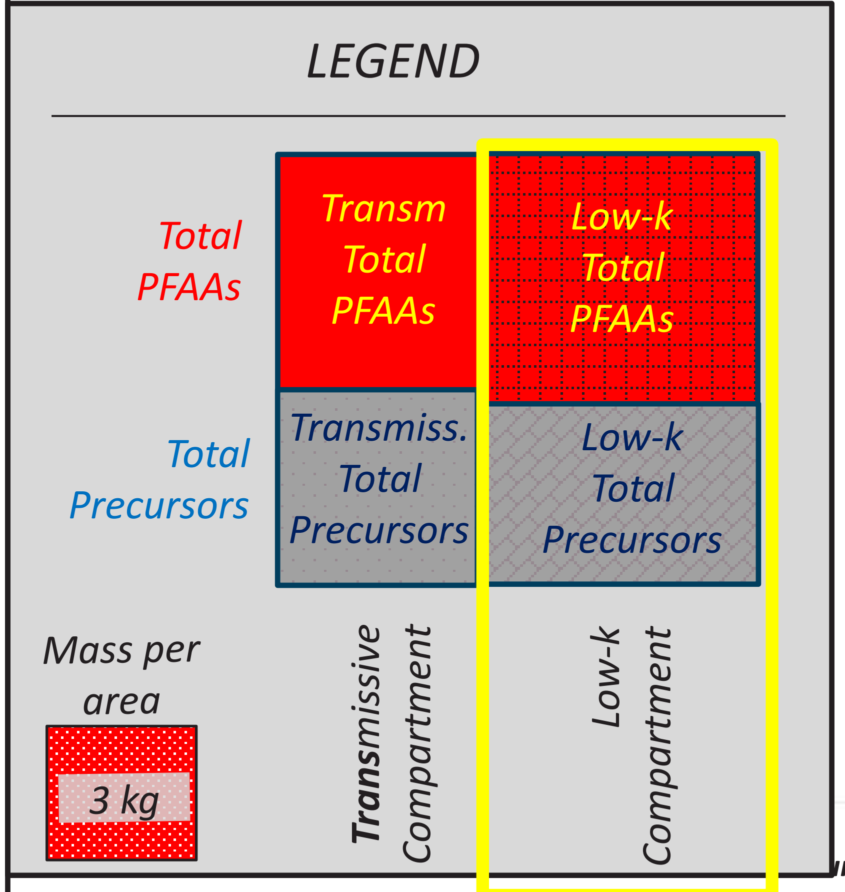
- 82% of PFAS mass in lower permeability soils (SM, ML, CL)

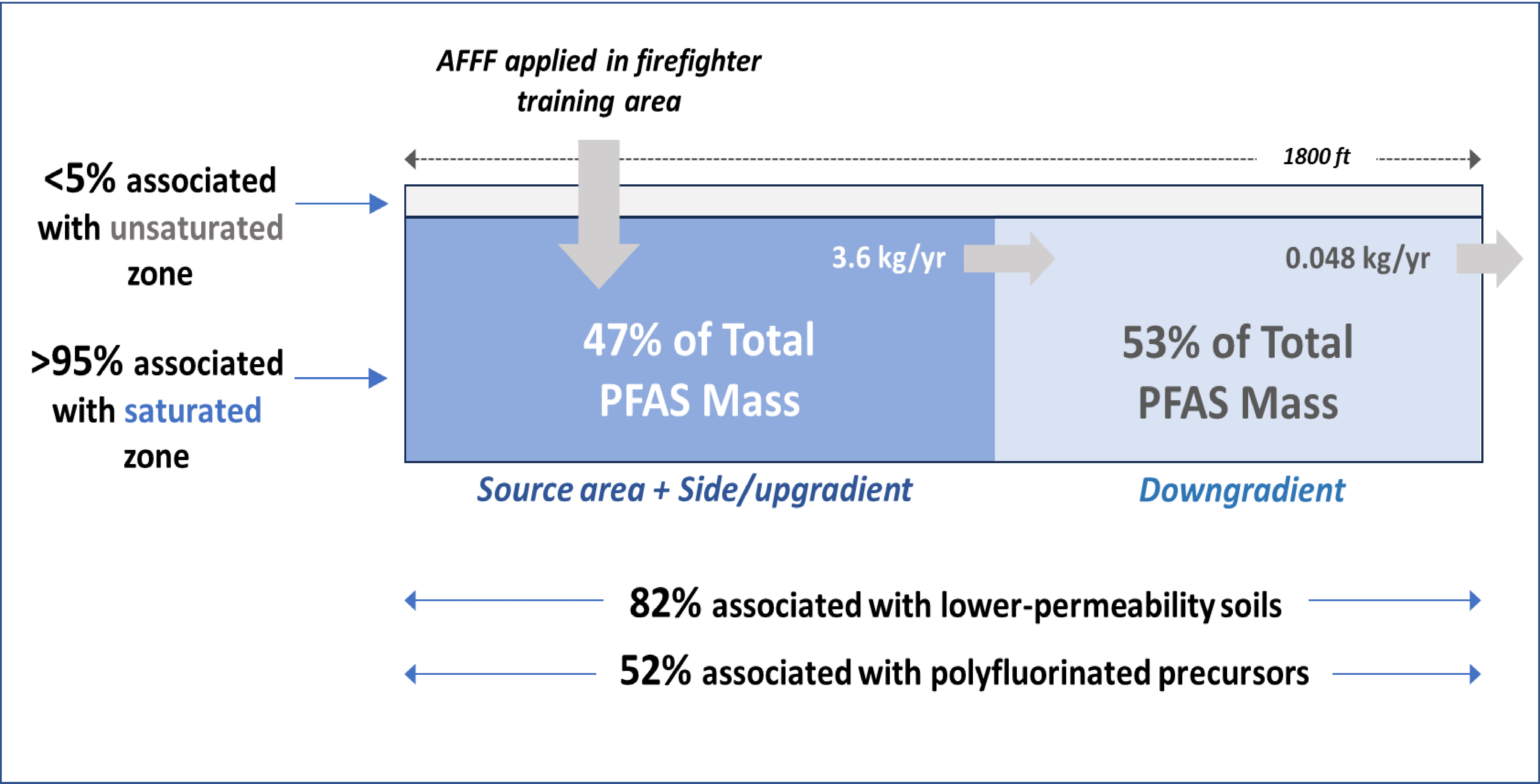




PFAS Mass in Low-K Units

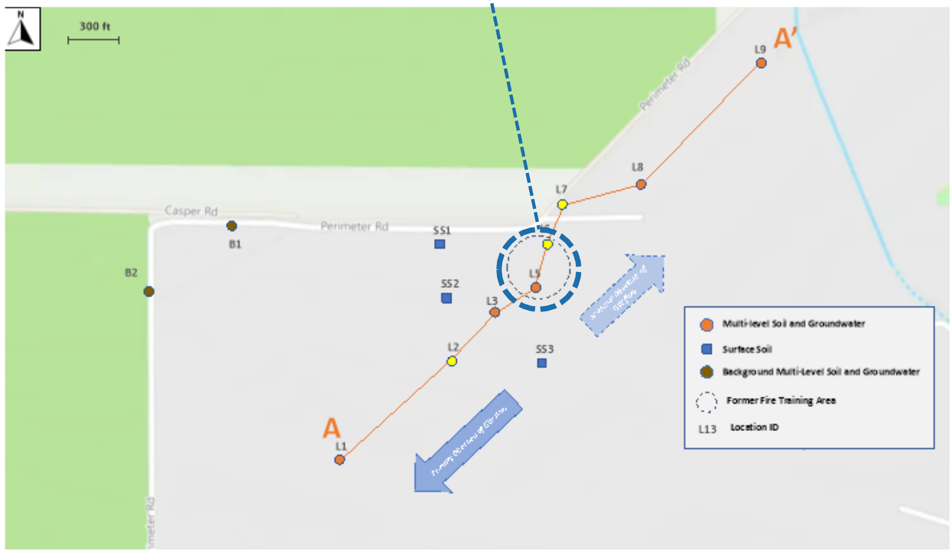
rce: Adamson et al., 2020, *ES&T*

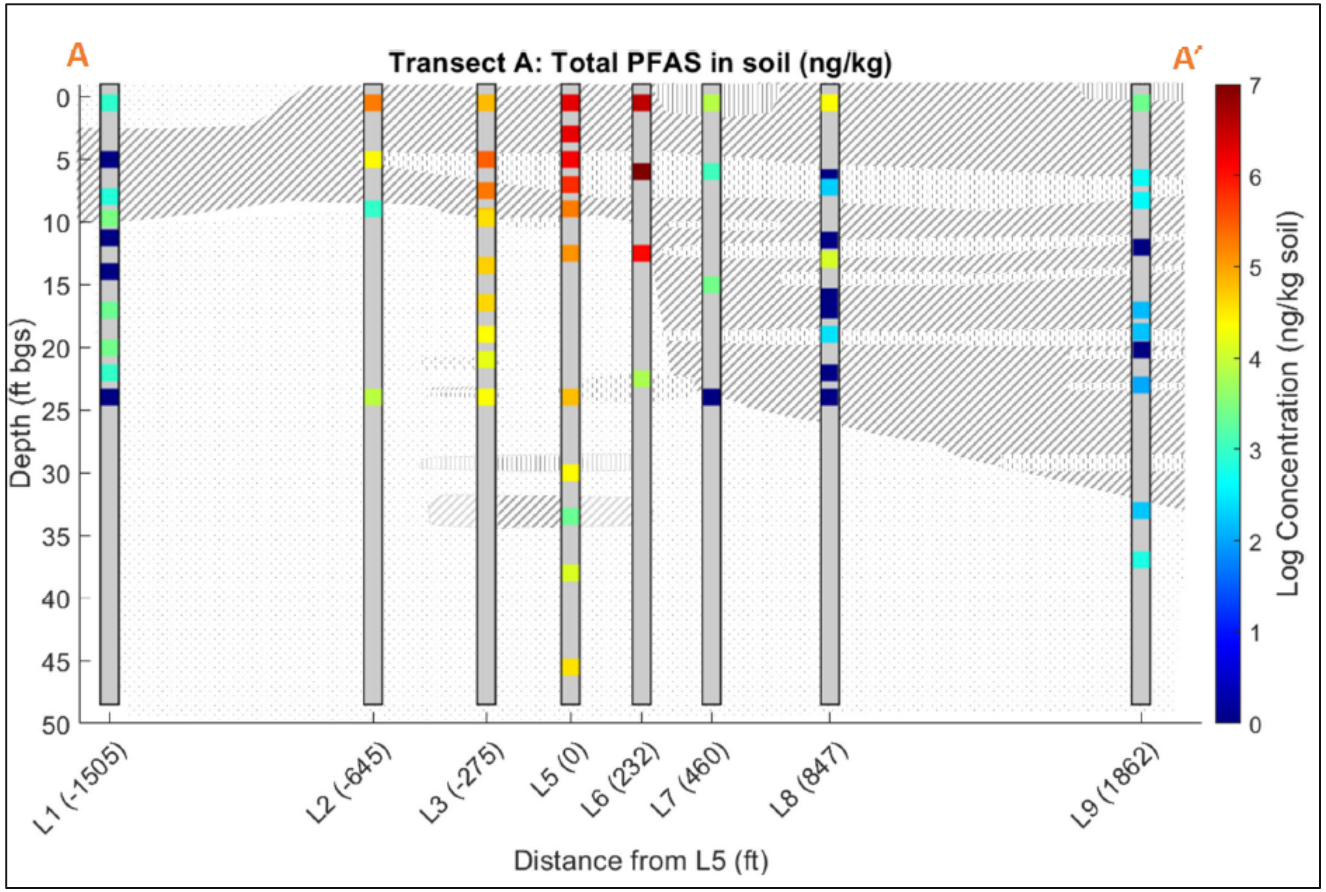
SITE 1: Total PFAS Mass = 222 kg



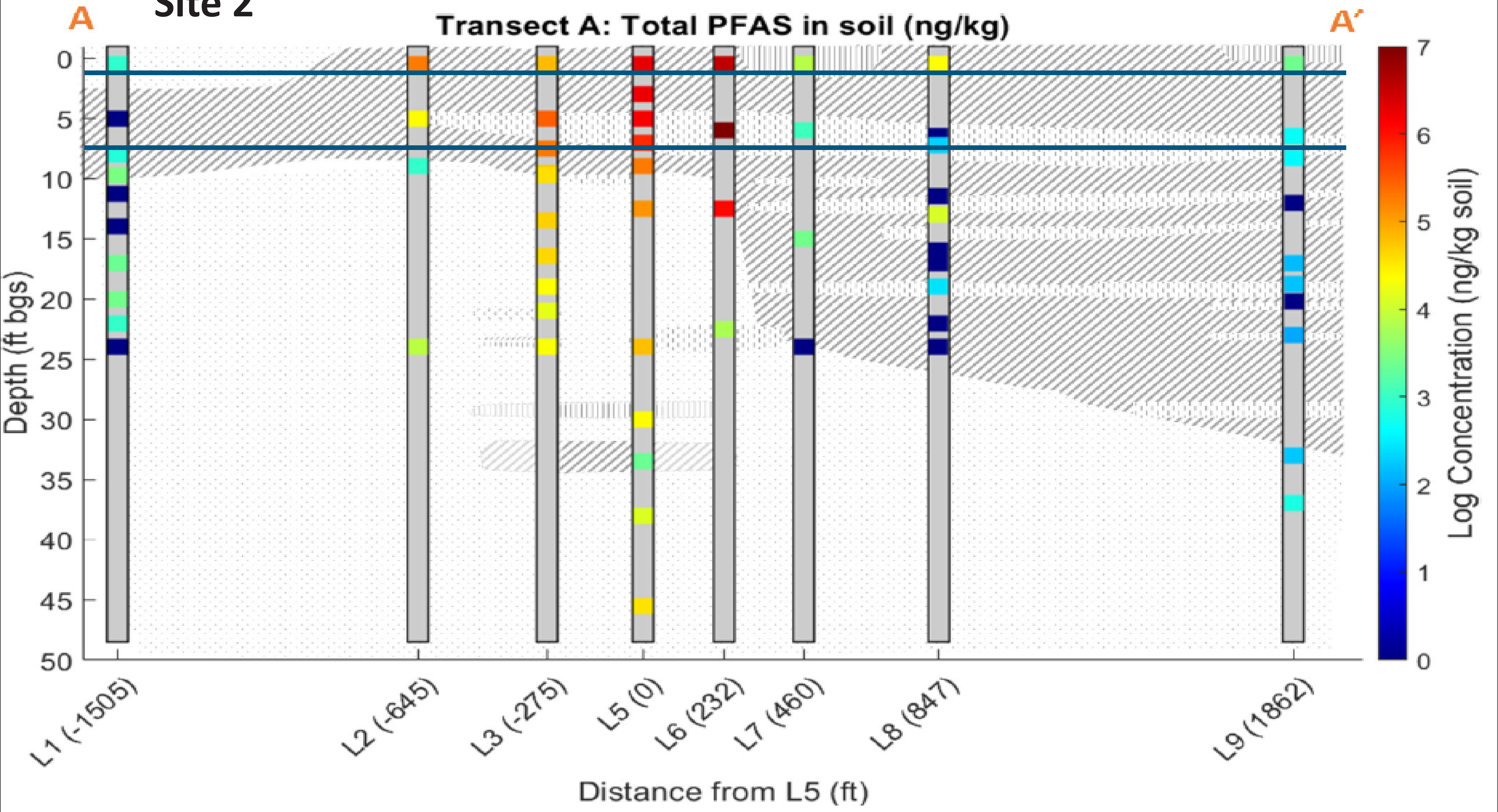
AFFF Site 2:
Overview of PFAS Distribution

Fire Training Area





Site 2

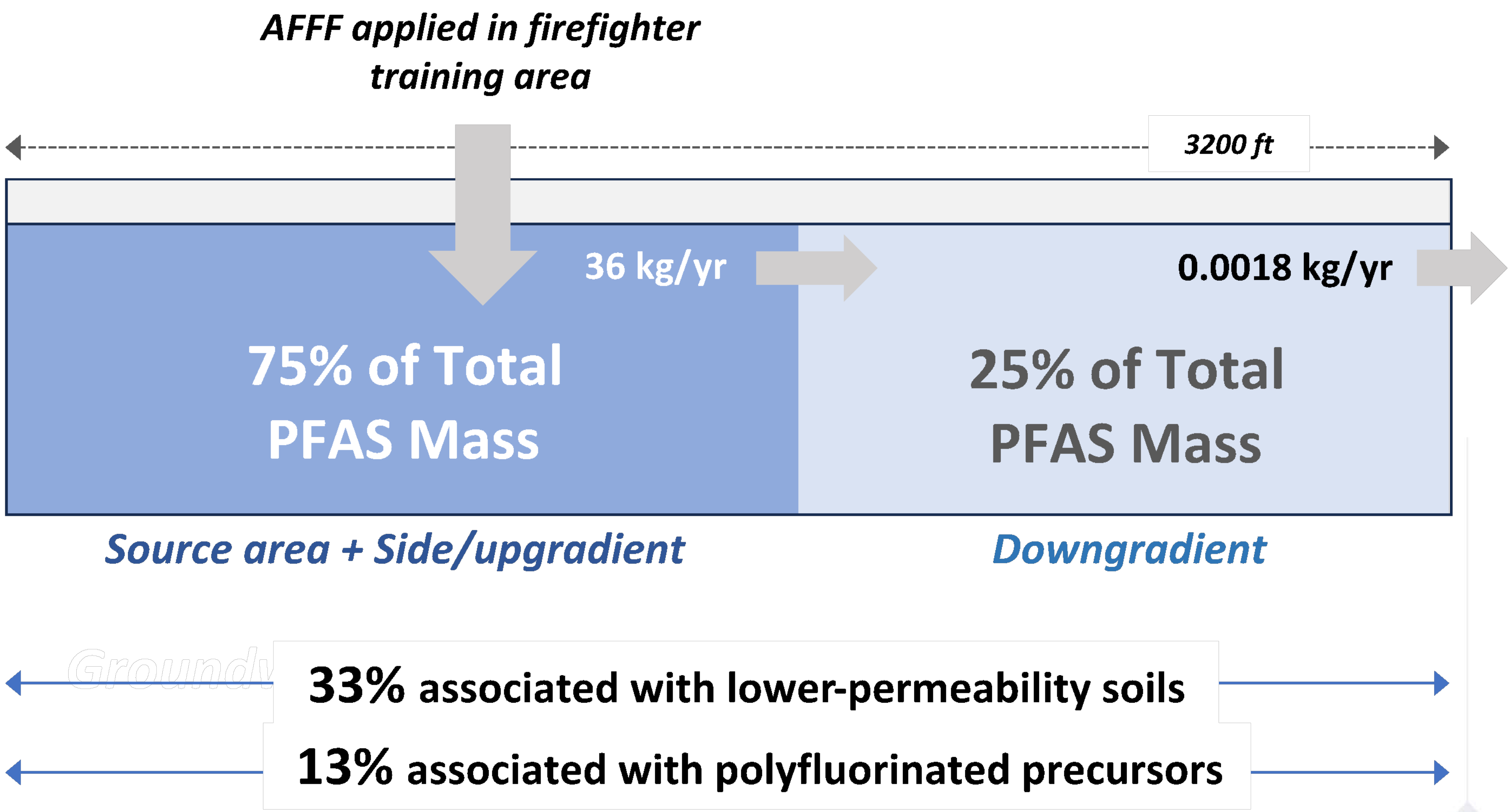

A
A′
Transect A: Total PFAS in soil (ng/kg)
Depth (ft bgs)
0
5
10
15
20
25
30
35
40
45
50
L1 (-1505)
L2 (-645)
L3 (-275)
L5 (0)
L6 (232)
L7 (460)
L8 (847)
L9 (1862)
Distance from L5 (ft)
Log Concentration (ng/kg soil)
0
1
2
3
4
5
6
7

AFFF Site 2: *Key Results*

SITE 2: Total PFAS Mass = 450 KG

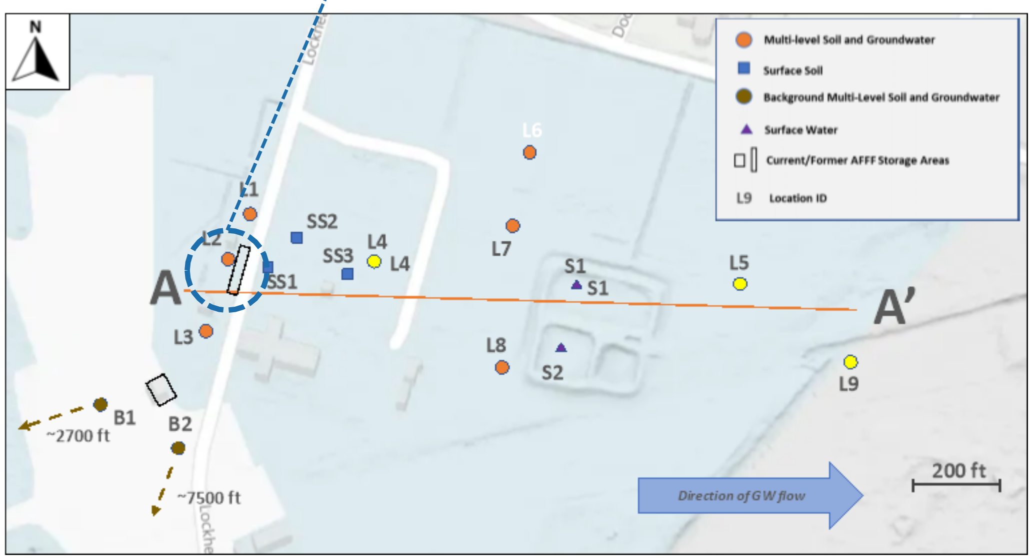
16% associated with unsaturated zone

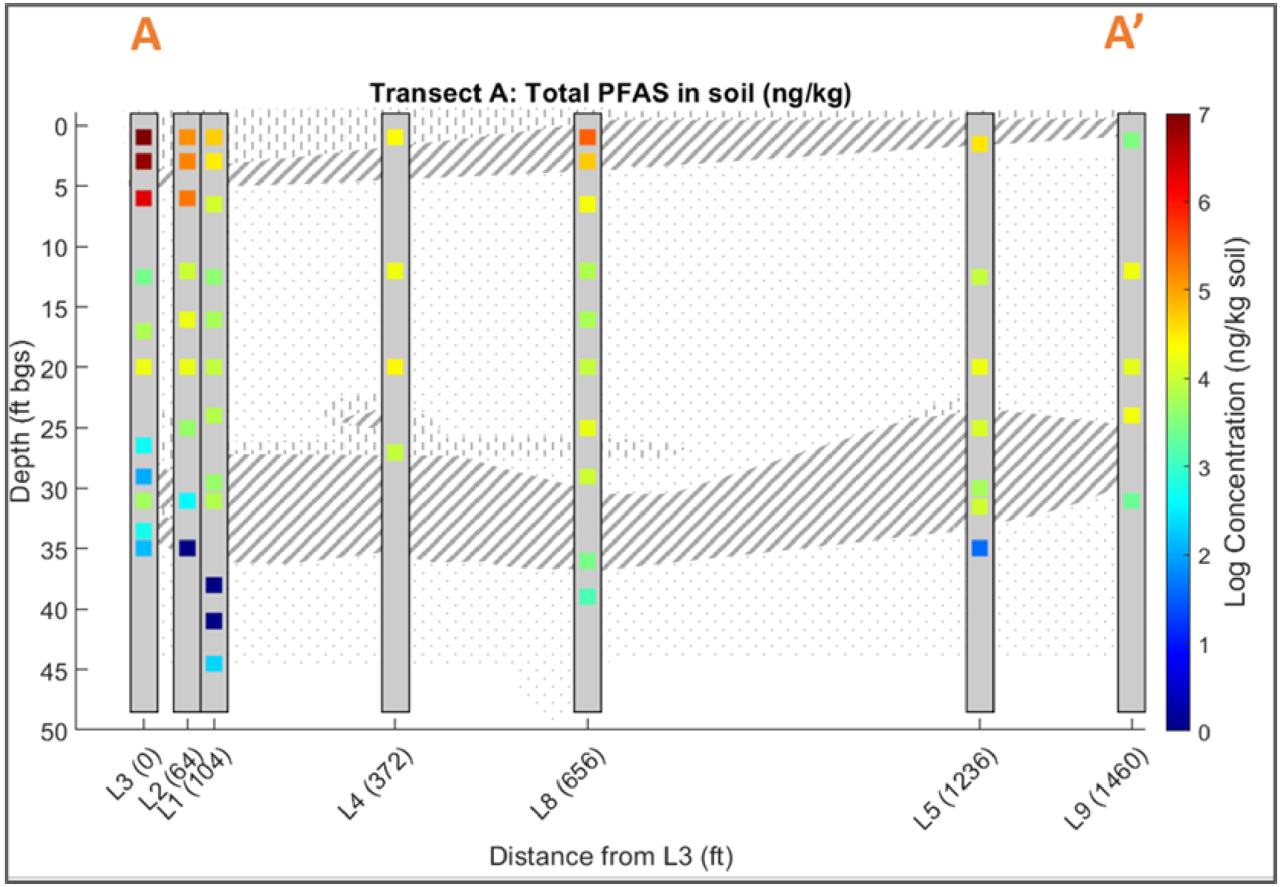
84% associated with saturated zone



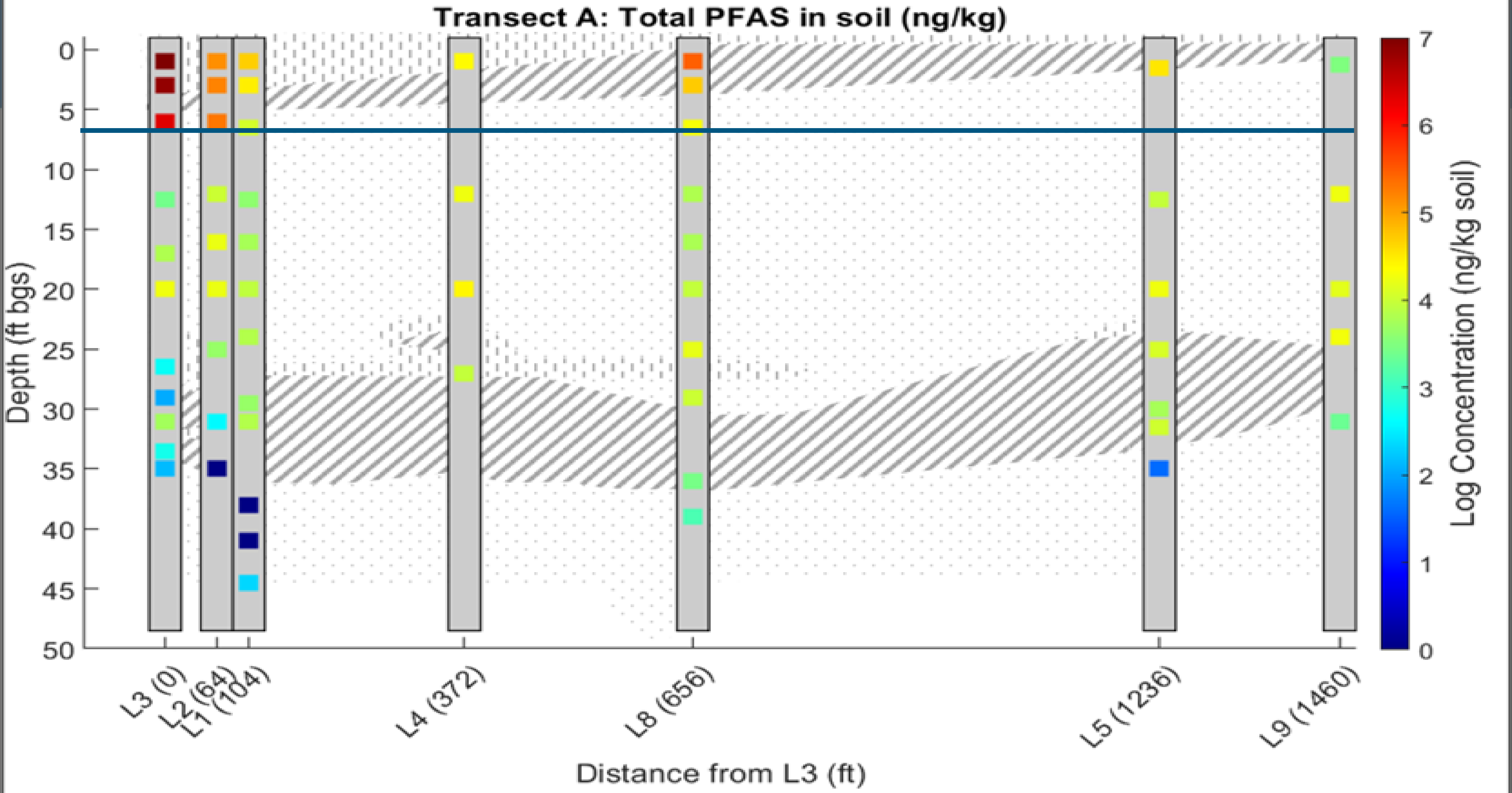
AFFF Site 3:
Overview of PFAS Distribution

AFFF Storage/Transfer Area



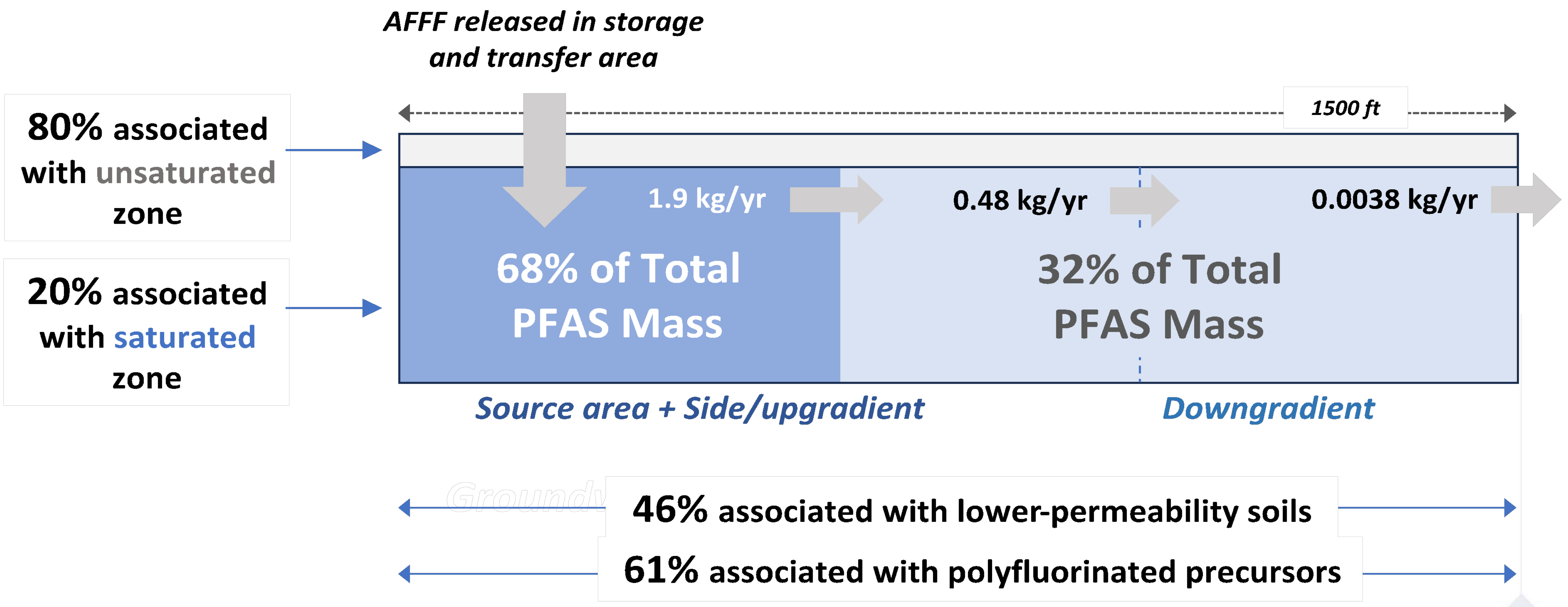


Site 3 A A′


Transect A: Total PFAS in soil (ng/kg)
Depth (ft bgs)
0
5
10
15
20
25
30
35
40
45
50
L3 (0)
L2 (64)
L1 (104)
L4 (372)
L8 (656)
L5 (1236)
L9 (1460)
Distance from L3 (ft)
Log Concentration (ng/kg soil)
7
6
5
4
3
2
1
0

AFFF Site 3: *Key Results*

SITE 3: Total PFAS Mass = 86 KG



Summary of PFAS Mass Distribution from All Three AFFF Sites

	Total PFAS Mass (kg)	Total PFAAs (%)	Total Precursors (%)	In Low-K Geology (%)	PFOS (%)	PFOA (%)	PFHxS (%)
Site 1	222 kg	52%	48%	82%	18%	9%	~10%
Site 2	450 kg	87%	13%	65%	9%	5%	32%
Site 3	86 kg	39%	61%	46%	28%	4%	4%

Summary of Mass Discharge from All Three AFFF Sites

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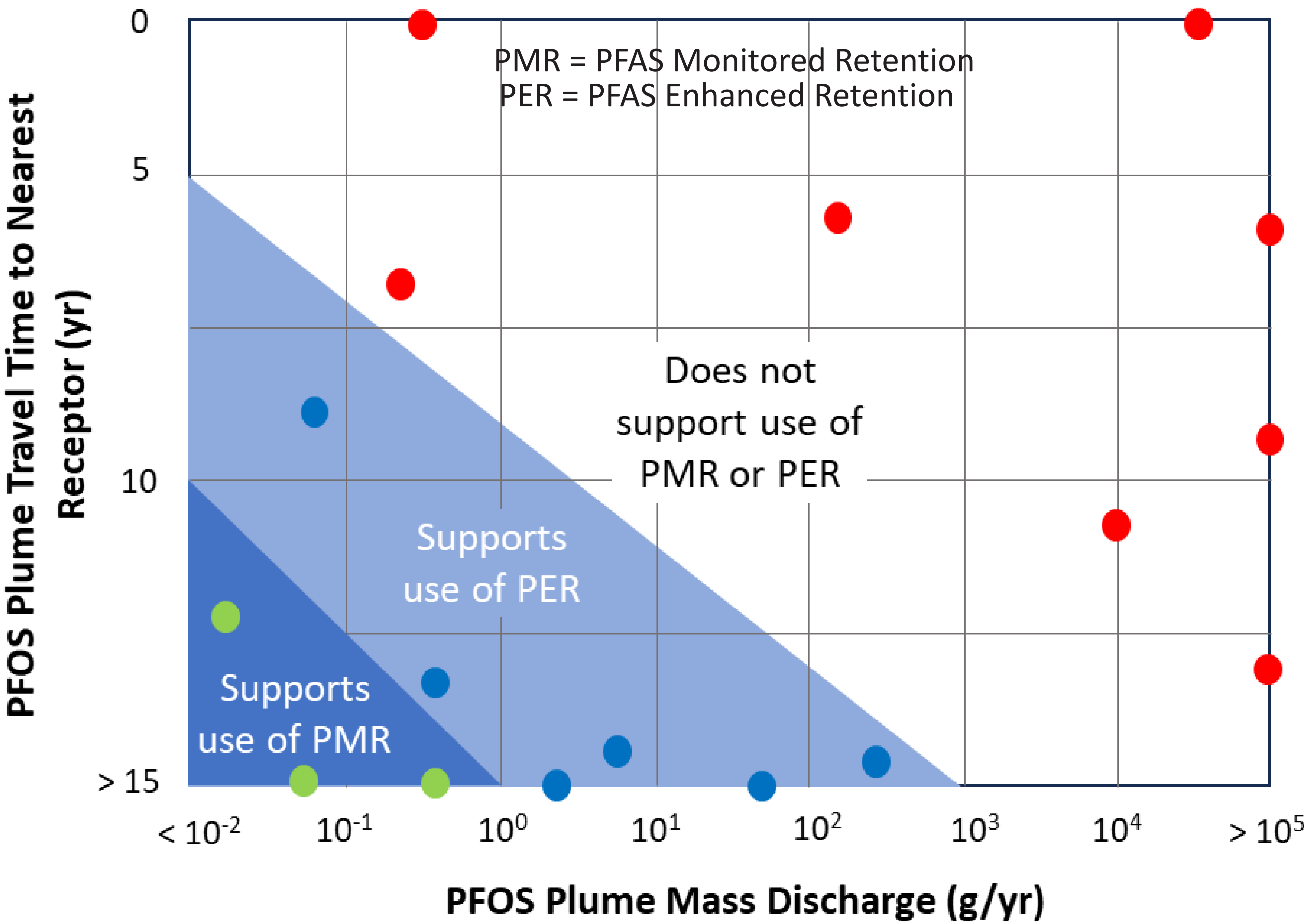
Site/Reference	Climate[1]	Unsaturated Zone Mass Discharge (g/yr)		Saturated Zone Mass Discharge (g/yr)	
		PFOS	Total PFAS[2]	PFOS	Total PFAS[2]
Anderson et al. 2022	Semi-Arid	10	188 (6 PFAS)	-	-
Quinnan et al. 2021, Source Area	Semi-Humid	0.4	-	22	23 (PFOS+PFOA)
Site 1 (Adamson et al. 2020; Nickerson et al. 2020)	Humid	-	-	310	3600 (58 PFAS)
Site 2	Semi-Arid			36	
Site 3	Humid			1.9	

PFAS Monitored Retention Framework

Mass discharge is a *primary* Line of Evidence for a PMR evaluation because it helps establish relative risk

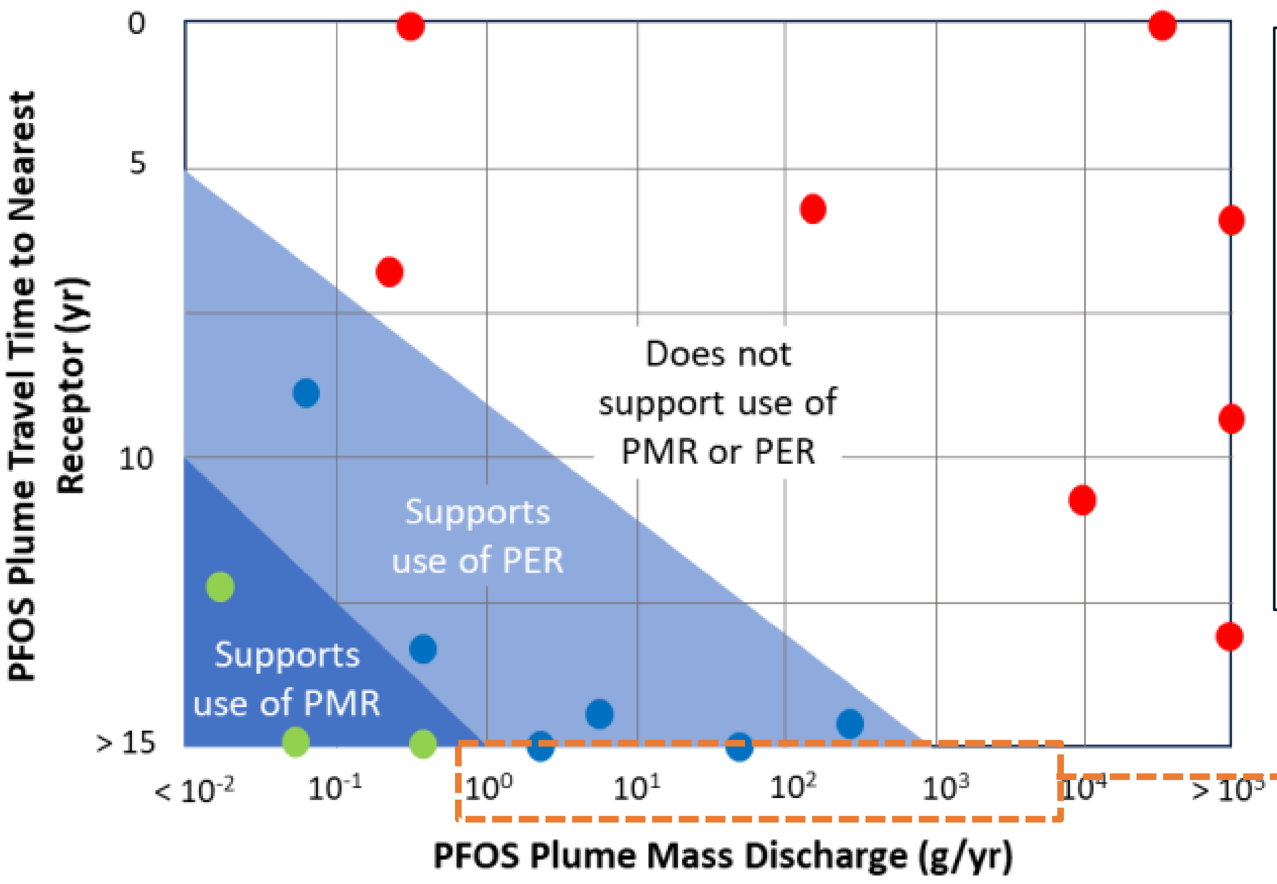
X-Axis represents PFOS mass discharge that could potentially impact water supply well pumping at 100 gpm

Axis ranges are preliminary



How Can Mass Discharge Estimates Be Used in a PMR Evaluation?

Each dot represents a *<u>hypothetical</u>* PFAS site being evaluated within a large portfolio



Higher-priority sites – likely to need P&T, POET, or other action

Medium-priority sites – enhanced retention options should be considered

Lower-priority sites – PMR should be considered for short-term or long-term management

Y-Axis represents PFOS mass discharge that could potentially impact water supply well pumping at 100 gpm

How Can Mass Balances Be Used in a PMR Evaluation?

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Mass balances are a *secondary* Line of Evidence for a PMR evaluation because they help establish relevancy of various retention processes

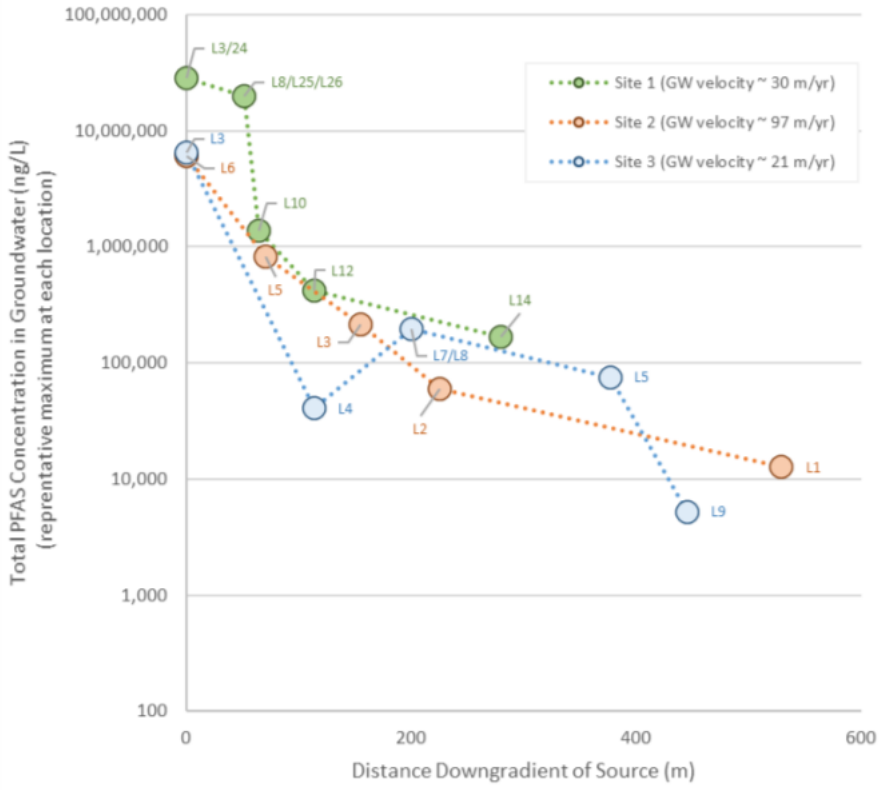
Site No.	Hydrophobic partitioning	Electrostatic interactions/ Salting out	Air-water interfacial partitioning	Matrix diffusion	Precursor transformation
Site 1	Yes	Yes	No[a]	Yes	Yes
Site 2	Yes	Yes [b]	Yes	Yes	Yes
Site 3	Yes	Yes	Yes	Yes	Yes

[a] Shallow vadose zone soils were disturbed due to historic remedial efforts (excavation and low-temperature thermal desorption followed by refilling with treated soil); [b] Includes salting out effects from high groundwater salinity.

Source: Adamson et al., 2022, *Environmental Advances*

Key Take-Aways

- High-resolution characterization data can help build quantitative estimates of mass distribution and plume strength
- F&T processes for PFAS are relatively unique and influence the extent of retention vs. migration
- Relevance of these processes vary by site
- Mass discharge and other mass balance approaches help establish Lines of Evidence for management-based approaches like PFAS Monitored Retention (PMR)



Source: Adamson et al., 2022, *Environmental Advances*

Backup Slides

References

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Environmental Science & Technology
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Article

Mass-Based, Field-Scale Demonstration of PFAS Retention within AFFF-Associated Source Areas

David T. Adamson,* Anastasia Nickerson, Poonam R. Kulkarni, Christopher P. Higgins, Jovan Popovic, Jennifer Field, Alix Rodowa, Charles Newell, Phil DeBlanc, and John J. Kornuc

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Article

Spatial Trends of Anionic, Zwitterionic, and Cationic PFASs at an AFFF-Impacted Site

Anastasia Nickerson, Alix E. Rodowa, David T. Adamson, Jennifer A. Field, Poonam R. Kulkarni, John J. Kornuc, and Christopher P. Higgins*

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ELSEVIER

Characterization of relevant site-specific PFAS fate and transport processes at multiple AFFF sites

David T. Adamson[a,*], Poonam R. Kulkarni[a], Anastasia Nickerson[b], Christopher P. Higgins[b], Jennifer Field[c], Trever Schwichtenberg[c], Charles Newell[a], John J. Kornuc[d]

ELSEVIER
Journal of Contaminant Hydrology
Volume 247, May 2022, 103986

Modeling a well-characterized perfluorooctane sulfonate (PFOS) source and plume using the REMChlor-MD model to account for matrix diffusion

Poonam R. Kulkarni[a], David T. Adamson[a], Jovan Popovic[b], Charles J. Newell[a]

Influence of Source Composition and Site Stratigraphy on Vertical Distribution

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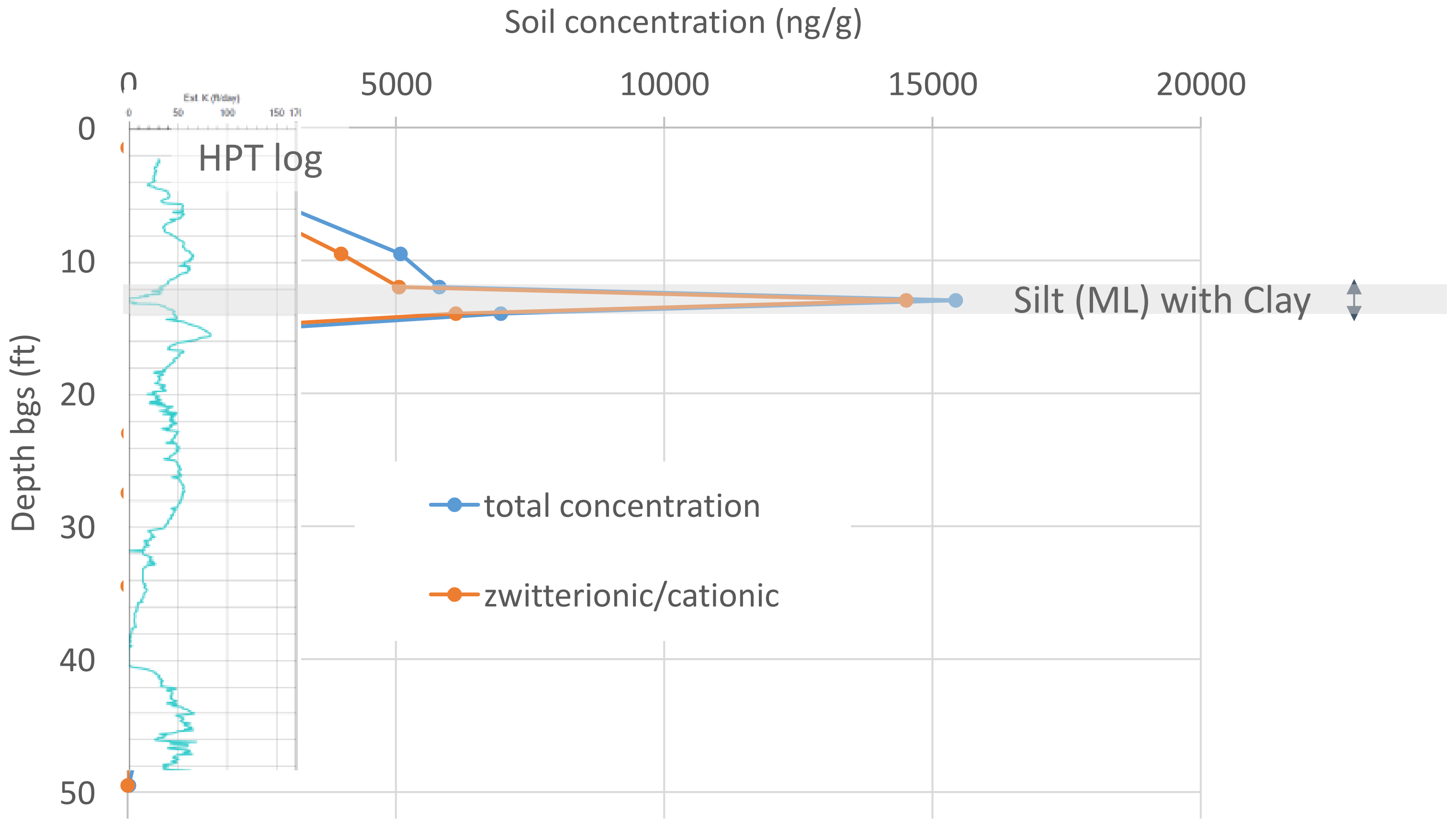
Location 3 (Source Area Location)

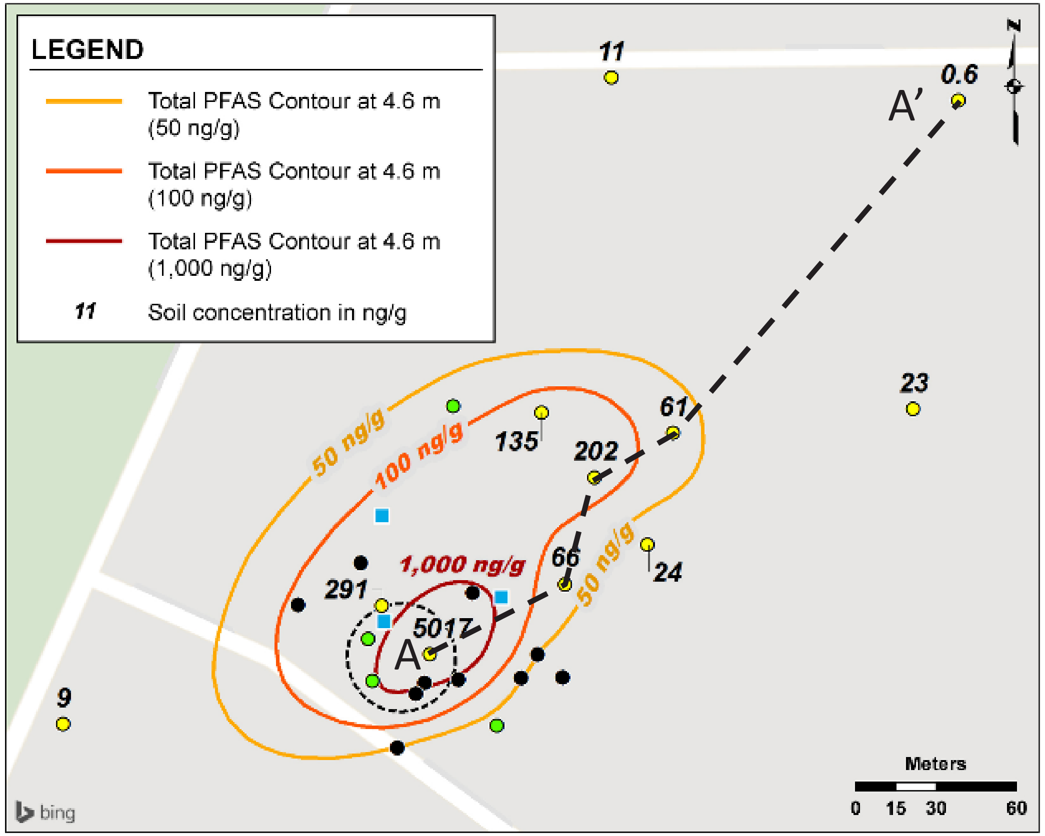


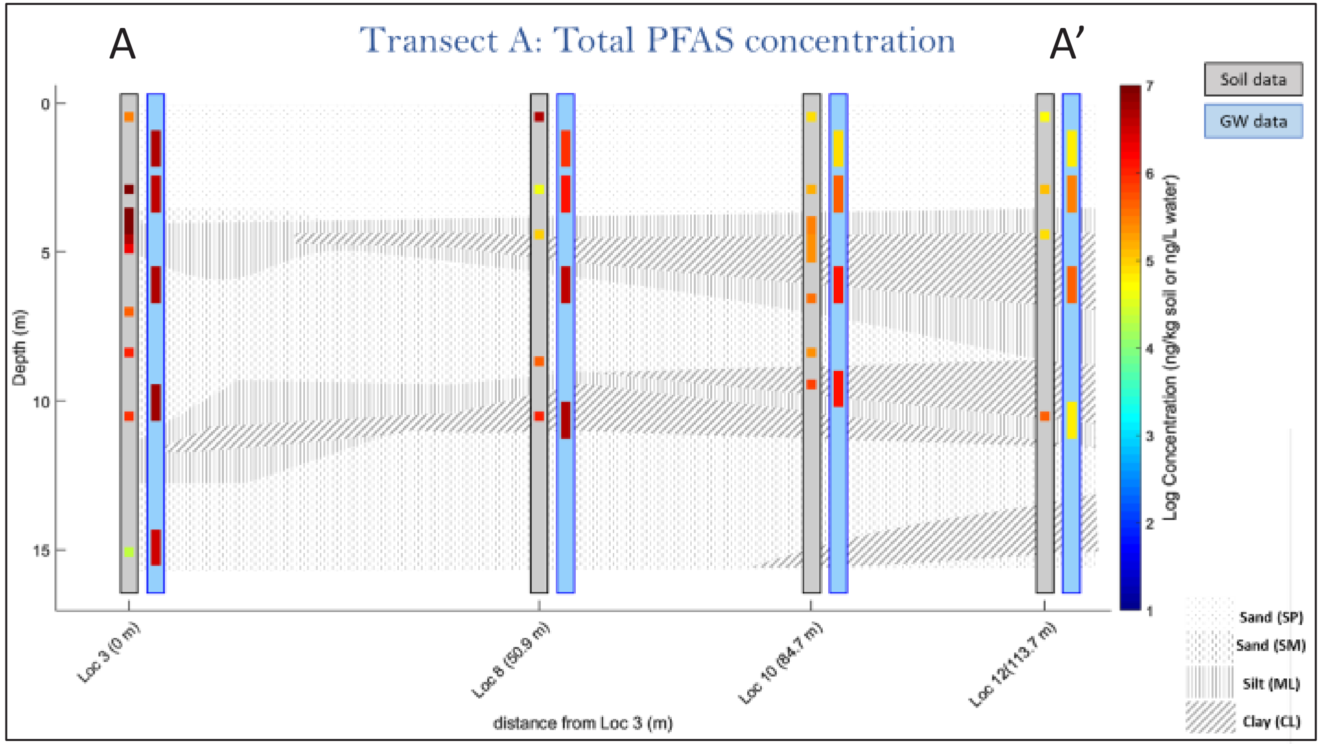
Source: Modified from Nickerson et al., 2020, *ES&T*

- Significant portion of soil PFAS in the source zone is from zwitterionic and cationic compounds
- Highly associated with lower-permeability soil intervals

Overview of PFAS Distribution

SOIL





Source: Nickerson et al., 2020, *ES&T*