Water Conservation and Management Unit
USDA-ARS, US ARID-LAND AGRICULTURAL RESEARCH CENTER

Per- and Polyfluoroalkyl Substances (PFAS) in Agroecosystems

PFAS

Per- and polyfluoroalkyl substances

Large class of synthetic compounds widely used due to their:

water- and oil-repellent properties

resistance to heat and degradation

ability to strongly reduce surface tension

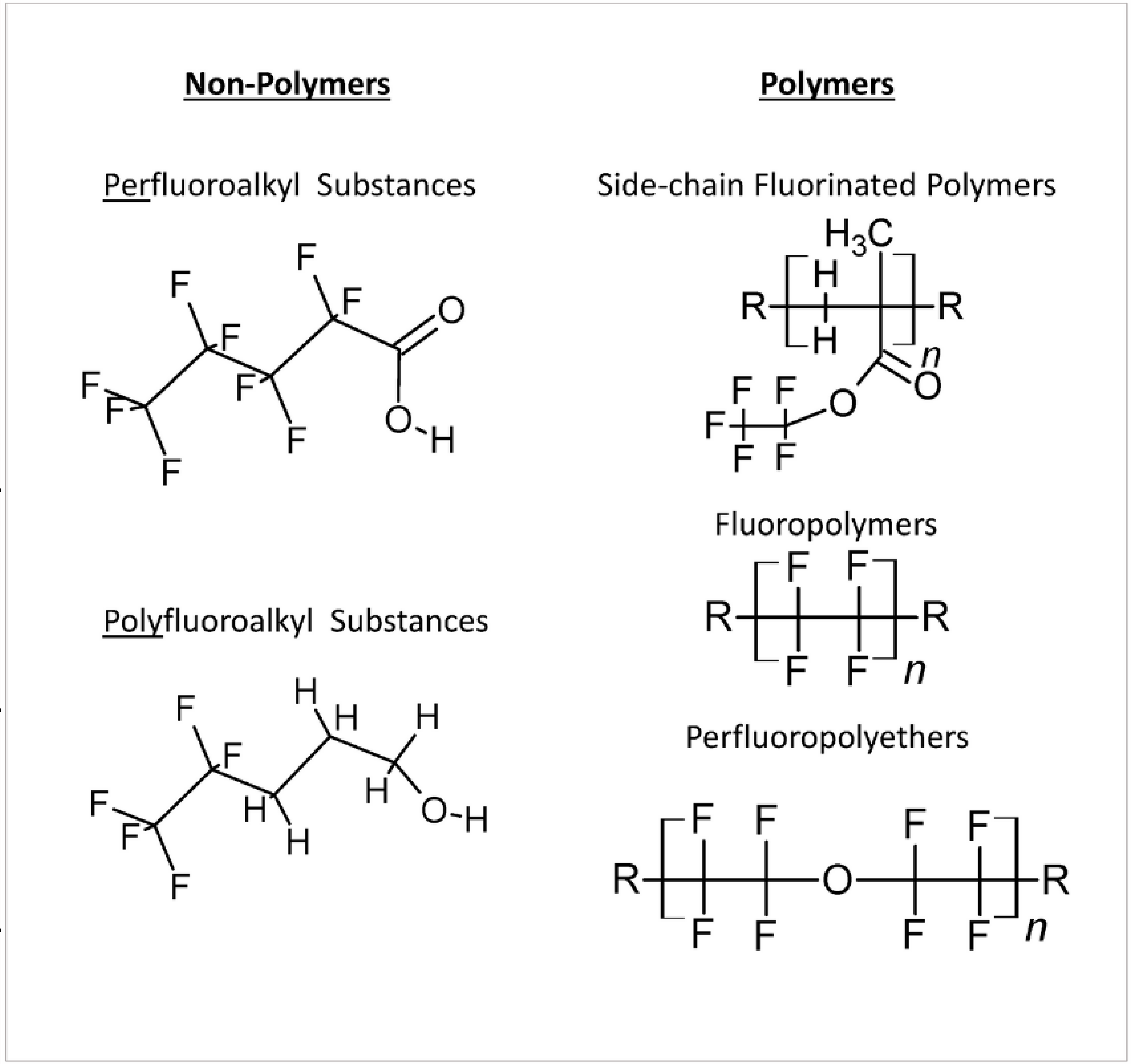


Figure 1. Classification of PFASs major groups (Schiavone & Portesi, 2023).

COMPOUND LIST

EPA United States Environmental Protection Agency

Office of Water

www.epa.gov January 2024

Method 1633

Analysis of Per- and Polyfluoroalkyl Substances (PFAS) in Aqueous, Solid, Biosolids, and Tissue Samples by LC-MS/MS

Table 1. Names, Abbreviations, and CAS Registry Numbers for Target PFAS, Extracted Internal Standards, and Non-extracted Internal Standards[1]

Target Analyte Name	Abbreviation	CASRN
Perfluoroalkyl carboxylic acids		
Perfluorobutanoic acid	PFBA	375-22-4
Perfluoropentanoic acid	PFPeA	2706-90-3
Perfluorohexanoic acid	PFHxA	307-24-4
Perfluoroheptanoic acid	PFHpA	375-85-9
Perfluorooctanoic acid	PFOA	335-67-1
Perfluorononanoic acid	PFNA	375-95-1
Perfluorodecanoic acid	PFDA	335-76-2
Perfluoroundecanoic acid	PFUnA	2058-94-8
Perfluorododecanoic acid	PFDoA	307-55-1
Perfluorotridecanoic acid	PFTrDA	72629-94-8
Perfluorotetradecanoic acid	PFTeDA	376-06-7
Perfluoroalkyl sulfonic acids		
Acid Form		
Perfluorobutanesulfonic acid	PFBS	375-73-5
Perfluoropentansulfonic acid	PFPeS	2706-91-4
Perfluorohexanesulfonic acid	PFHxS	355-46-4
Perfluoroheptanesulfonic acid	PFHpS	375-92-8
Perfluorooctanesulfonic acid	PFOS	1763-23-1
Perfluorononanesulfonic acid	PFNS	68259-12-1
Perfluorodecanesulfonic acid *	PFDS	335-77-3
Perfluorododecanesulfonic acid *	PFDoS	79780-39-5
Fluorotelomer sulfonic acids		
1*H*,1*H*, 2*H*, 2*H*-Perfluorohexane sulfonic acid	4:2FTS	757124-72-4
1*H*,1*H*, 2*H*, 2*H*-Perfluorooctane sulfonic acid	6:2FTS	27619-97-2
1*H*,1*H*, 2*H*, 2*H*-Perfluorodecane sulfonic acid	8:2FTS	39108-34-4
Perfluorooctane sulfonamides		
Perfluorooctanesulfonamide	PFOSA	754-91-6
N-methyl perfluorooctanesulfonamide	NMeFOSA	31506-32-8
N-ethyl perfluorooctanesulfonamide	NEtFOSA	4151-50-2
Perfluorooctane sulfonamidoacetic acids		
N-methyl perfluorooctanesulfonamidoacetic acid	NMeFOSAA	2355-31-9
N-ethyl perfluorooctanesulfonamidoacetic acid	NEtFOSAA	2991-50-6
Perfluorooctane sulfonamide ethanols		
N-methyl perfluorooctanesulfonamidoethanol	NMeFOSE	24448-09-7
N-ethyl perfluorooctanesulfonamidoethanol	NEtFOSE	1691-99-2
Per- and Polyfluoroether carboxylic acids		
Hexafluoropropylene oxide dimer acid	HFPO-DA	13252-13-6
4,8-Dioxa-3*H*-perfluorononanoic acid	ADONA	919005-14-4
Perfluoro-3-methoxypropanoic acid	PFMPA	377-73-1
Perfluoro-4-methoxybutanoic acid	PFMBA	863090-89-5
Nonafluoro-3,6-dioxaheptanoic acid	NFDHA	151772-58-6

Table 1. Names, Abbreviations, and CAS Registry Numbers for Target PFAS, Extracted Internal Standards, and Non-extracted Internal Standards[1]

Target Analyte Name	Abbreviation	CASRN
Ether sulfonic acids		
9-Chlorohexadecafluoro-3-oxanonane-1-sulfonic acid	9Cl-PF3ONS	756426-58-1
11-Chloroeicosafluoro-3-oxaundecane-1-sulfonic acid *	11Cl-PF3OUdS	763051-92-9
Perfluoro(2-ethoxyethane)sulfonic acid	PFEESA	113507-82-7
Fluorotelomer carboxylic acids		
3-Perfluoropropyl propanoic acid	3:3FTCA	356-02-5
2*H*,2*H*,3*H*,3*H*-Perfluorooctanoic acid	5:3FTCA	914637-49-3
3-Perfluoroheptyl propanoic acid	7:3FTCA	812-70-4
EIS Compounds		
Perfluoro-n-[$^{13}C_4$]butanoic acid	$^{13}C_4$-PFBA	NA
Perfluoro-n-[$^{13}C_5$]pentanoic acid	$^{13}C_5$-PFPeA	
Perfluoro-n-[1,2,3,4,6-$^{13}C_5$]hexanoic acid	$^{13}C_5$-PFHxA	
Perfluoro-n-[1,2,3,4-$^{13}C_4$]heptanoic acid	$^{13}C_4$-PFHpA	
Perfluoro-n-[$^{13}C_8$]octanoic acid	$^{13}C_8$-PFOA	
Perfluoro-n-[$^{13}C_9$]nonanoic acid	$^{13}C_9$-PFNA	
Perfluoro-n-[1,2,3,4,5,6-$^{13}C_6$]decanoic acid	$^{13}C_6$-PFDA	
Perfluoro-n-[1,2,3,4,5,6,7-$^{13}C_7$]undecanoic acid	$^{13}C_7$-PFUnA	
Perfluoro-n-[1,2-$^{13}C_2$]dodecanoic acid	$^{13}C_2$-PFDoA	
Perfluoro-n-[1,2-$^{13}C_2$]tetradecanoic acid	$^{13}C_2$-PFTeDA	
Perfluoro-1-[2,3,4-$^{13}C_3$]butanesulfonic acid	$^{13}C_3$-PFBS	
Perfluoro-1-[1,2,3-$^{13}C_3$]hexanesulfonic acid	$^{13}C_3$-PFHxS	
Perfluoro-1-[$^{13}C_8$]octanesulfonic acid	$^{13}C_8$-PFOS	
Perfluoro-1-[$^{13}C_8$]octanesulfonamide	$^{13}C_8$-PFOSA	
N-methyl-d_3-perfluoro-1-octanesulfonamidoacetic acid	D_3-NMeFOSAA	
N-ethyl-d_5-perfluoro-1-octanesulfonamidoacetic acid	D_5-NEtFOSAA	
1*H*,1*H*,2*H*,2*H*-Perfluoro-1-[1,2-$^{13}C_2$]hexane sulfonic acid	$^{13}C_2$-4:2FTS	
1*H*,1*H*,2*H*,2*H*-Perfluoro-1-[1,2-$^{13}C_2$]octane sulfonic acid	$^{13}C_2$-6:2FTS	
1*H*,1*H*,2*H*,2*H*-Perfluoro-1-[1,2-$^{13}C_2$]decane sulfonic acid	$^{13}C_2$-8:2FTS	
Tetrafluoro-2-heptafluoropropoxy-$^{13}C_3$-propanoic acid	$^{13}C_3$-HFPO-DA	
N-methyl-D_7-perfluorooctanesulfonamidoethanol	D_7-NMeFOSE	
N-ethyl-D_9-perfluorooctanesulfonamidoethanol	D_9-NEtFOSE	
N-ethyl-D_5-perfluoro-1-octanesulfonamide	D_5-NEtFOSA	
N-methyl-D_3-perfluoro-1-octanesulfonamide	D_3-NMeFOSA	
NIS Compounds		
Perfluoro-n-[2,3,4-$^{13}C_3$]butanoic acid	$^{13}C_3$-PFBA	NA
Perfluoro-n-[1,2,3,4-$^{13}C_4$]octanoic acid	$^{13}C_4$-PFOA	
Perfluoro-n-[1,2-$^{13}C_2$]decanoic acid	$^{13}C_2$-PFDA	
Perfluoro-n-[1,2,3,4-$^{13}C_4$]octanesulfonic acid	$^{13}C_4$-PFOS	
Perfluoro-n-[1,2,3,4,5-$^{13}C_5$] nonanoic acid	$^{13}C_5$-PFNA	
Perfluoro-n-[1,2-$^{13}C_2$]hexanoic acid	$^{13}C_2$-PFHxA	
Perfluoro-1-hexane[$^{18}O_2$]sulfonic acid	$^{18}O_2$-PFHxS	

[1] The target analyte names are for the acid and neutral forms of the analytes. See Table 2 for the names and Chemical Abstract Service Registry Numbers (CASRN) of the corresponding anion forms, where applicable.

NA = Not assigned a CAS Registry Number

* These analytes may not perform as well as others in some matrices (see Section 1.6): PFDS, PFDoS, and 11CLPF3OUdS in aqueous samples; PFDoS and 11CLPF3OUdS in biosolid samples; and PFDoS in tissue samples.

Table 2. Cross-reference of Abbreviations, Analyte Names, and CAS Registry Numbers for the Acid and Anion Forms of the Perfluoroalkyl Carboxylates and Perfluoroalkyl Sulfonates

Abbreviation	Acid Name	CASRN	Anion Name	CASRN
Perfluoroalkyl carboxylic acids/anions				
PFBA	Perfluorobutanoic acid	375-22-4	Perfluorobutanoate	45048-62-2
PFPeA	Perfluoropentanoic acid	2706-90-3	Perfluoropentanoate	45167-47-3
PFHxA	Perfluorohexanoic acid	307-24-4	Perfluorohexanoate	92612-52-7
PFHpA	Perfluoroheptanoic acid	375-85-9	Perflluoroheptanoate	120885-29-2
PFOA	Perfluorooctanoic acid	335-67-1	Pefluorooctanoate	45285-51-6
PFNA	Perfluorononanoic acid	375-95-1	Perfluorononanoate	72007-68-2
PFDA	Perfluorodecanoic acid	335-76-2	Perfluorodecanoate	73829-36-4
PFUnA	Perfluoroundecanoic acid	2058-94-8	Perfluoroundecanoate	196859-54-8
PFDoA	Perfluorododecanoic acid	307-55-1	Perfluorododecanoate	171978-95-3
PFTrDA	Perfluorotridecanoic acid	72629-94-8	Perfluorotridecanoate	862374-87-6
PFTeDA	Perfluorotetradecanoic acid	376-06-7	Perfluorotetradecanoate	365971-87-5
Perfluoroalkyl sulfonic acids/anions				
PFBS	Perfluorobutanesulfonic acid	375-73-5	Perfluorobutane sulfonate	45187-15-3
PFPeS	Perfluoropentanesulfonic acid	2706-91-4	Perfluoropentane sulfonate	175905-36-9
PFHxS	Perfluorohexanesulfonic acid	355-46-4	Perfluorohexane sulfonate	108427-53-8
PFHpS	Perfluoroheptanesulfonic acid	375-92-8	Perfluoroheptane sulfonate	146689-46-5
PFOS	Perfluorooctanesulfonic acid	1763-23-1	Perfluorooctane sulfonate	45298-90-6
PFNS	Perfluorononanesulfonic acid	68259-12-1	Perfluorononane sulfonate	474511-07-4
PFDS	Perfluorodecanesulfonic acid	335-77-3	Perfluorodecane sulfonate	126105-34-8
PFDoS	Perfluorododecanesulfonic acid	79780-39-5	Perfluorododecane sulfonate	343629-43-6

CASRN = Chemical Abstracts Service Registry Number

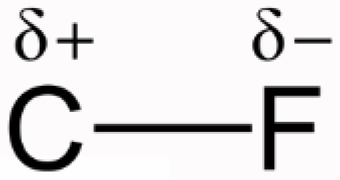
Why "forever chemicals"?

1. High Electronegativity of Fluorine:

Highly polarized covalent bond

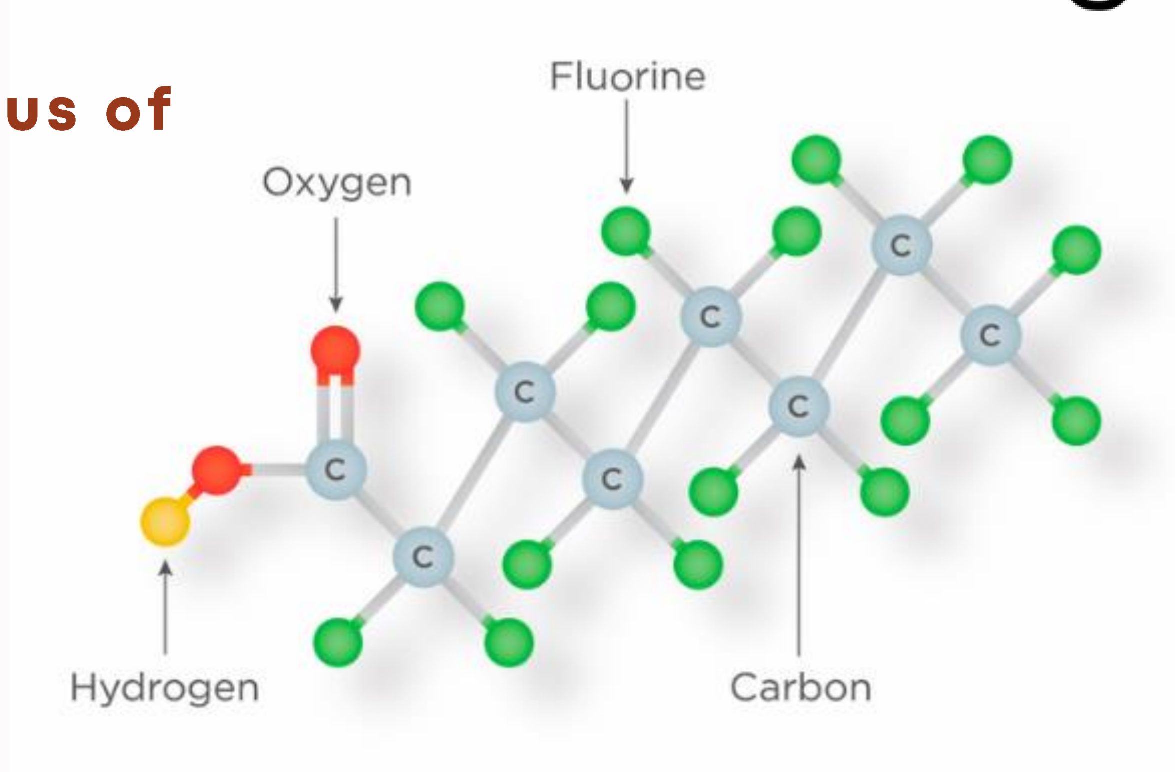
3. Strength of the C–F Bond:

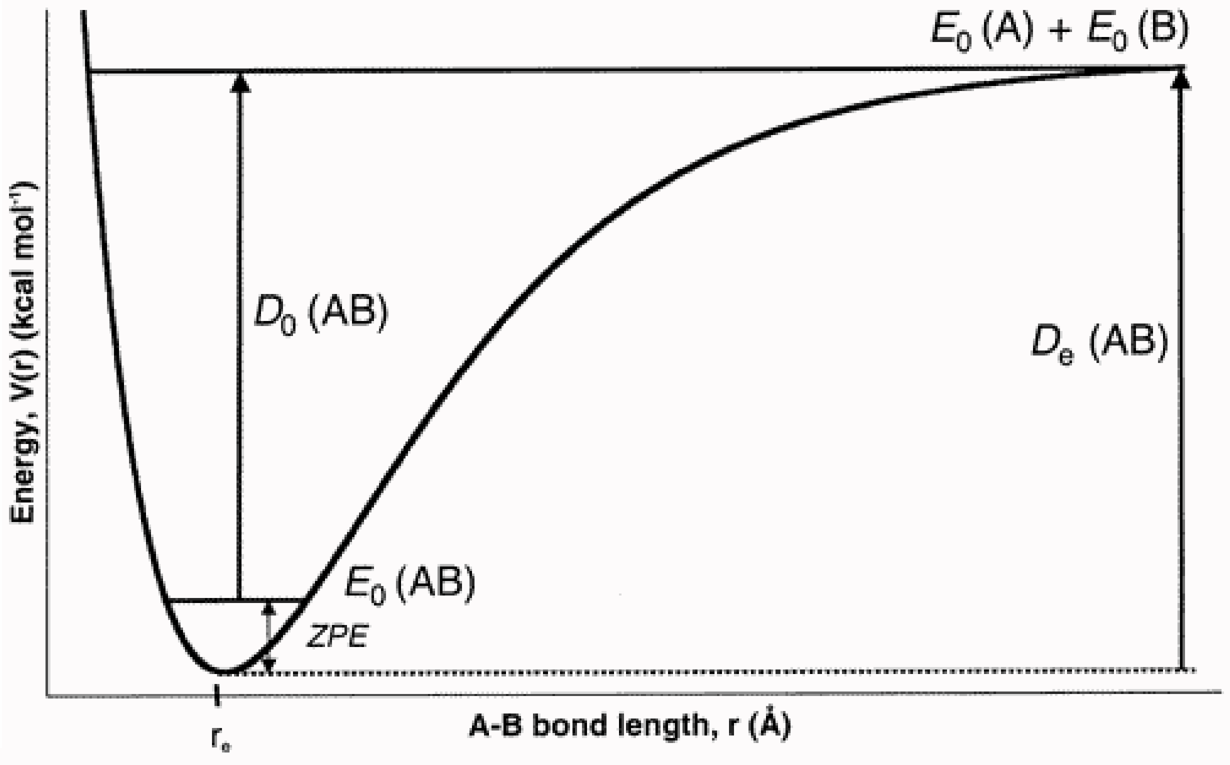
Energy required to break a C–F bond ~563 kJ/mol.
<u>One of the highest bond energies for a single carbon-element bond.</u>



2. Small Atomic Radius of Fluorine:

Short and strong bond





*The <u>**high energy required to break the C–F bond**</u> explains why PFAS are so persistent in the environment. They do **not** easily degrade through natural processes such as: hydrolysis, oxidation, or biodegradation.*

4. Comparison with C–H Bond:

The bond between (C–H) is much weaker in comparison.
Energy required to break a C–H bond : ~436 kJ/mol.
(less polarized and less resistant bond).

PFAS

A diverse group of *thousands of chemicals* used in hundred of products.

PFAS can be found in water, soil, air, and food from industrial sites, wastewater treatment plants, and household products.

non-stick cookware

firefighting foam

food packaging

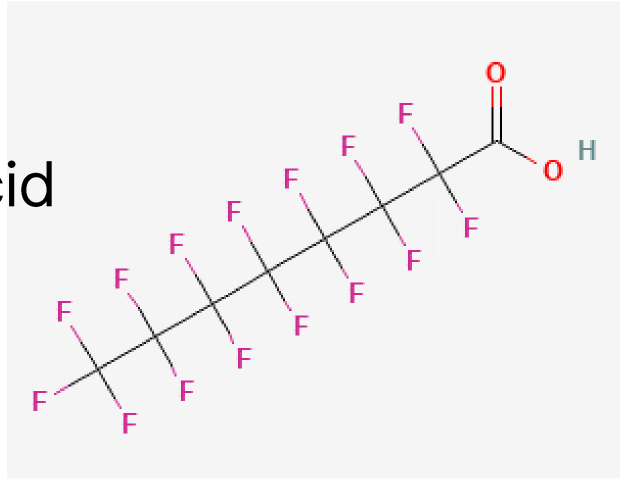
waterproof clothing

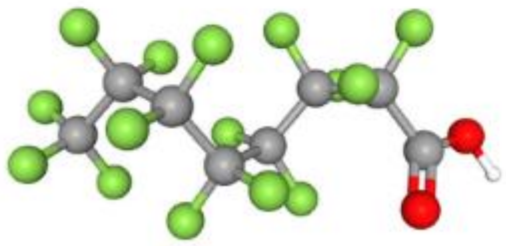
PFAS

The PFAS backbone is constituted by single-bonded carbon atoms with fluorine atoms covalently bonded to the alkyl chain.

PFOA

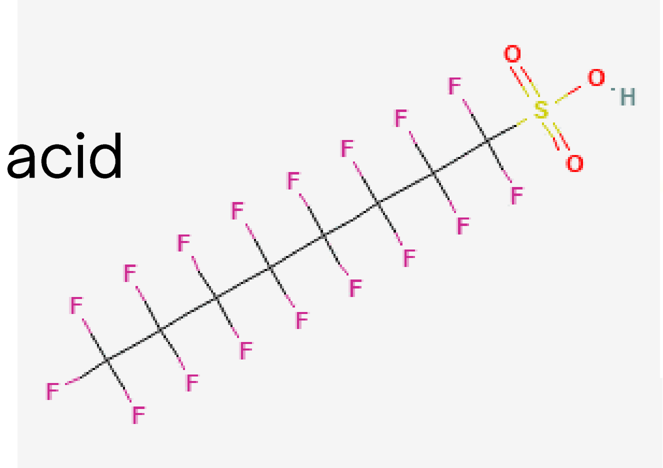
Perfluorooctanoic acid
C8HF15O2
414.07 g/mol

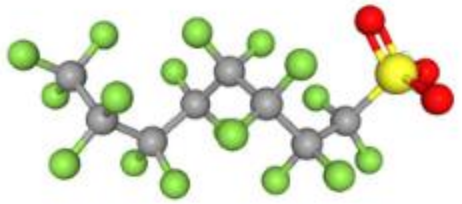




PFOS

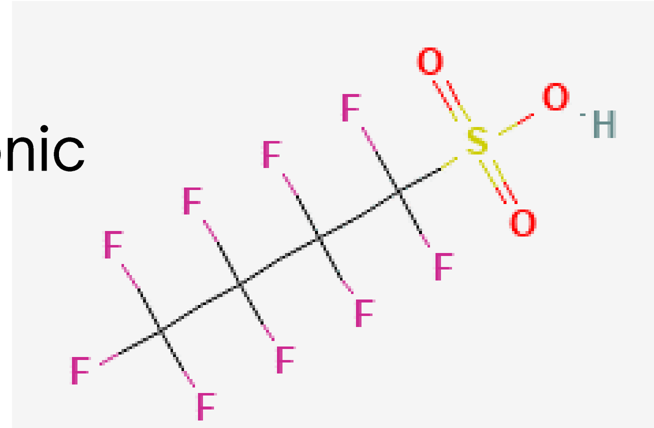
Perfluorooctanesulfonic acid
C8F17SO3H
500.13 g/mol

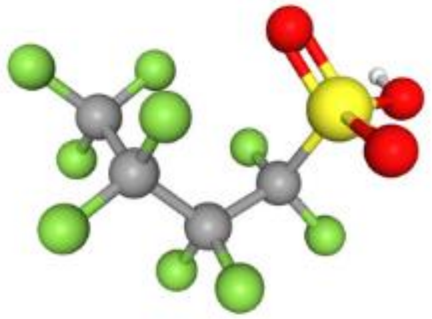




PFBS

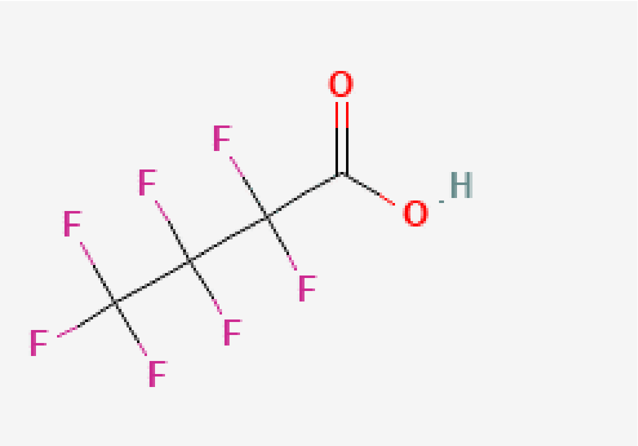
Perfluorobutanesulfonic acid
C4F9SO3H
300.10 g/mol

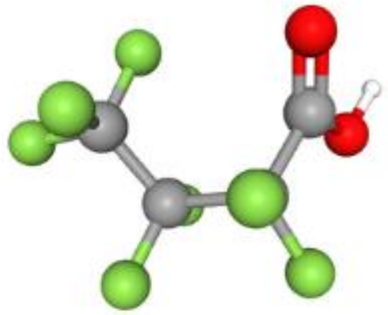




PFBA

Heptafluorobutyric acid
C4HF7O2
214.04 g/mol

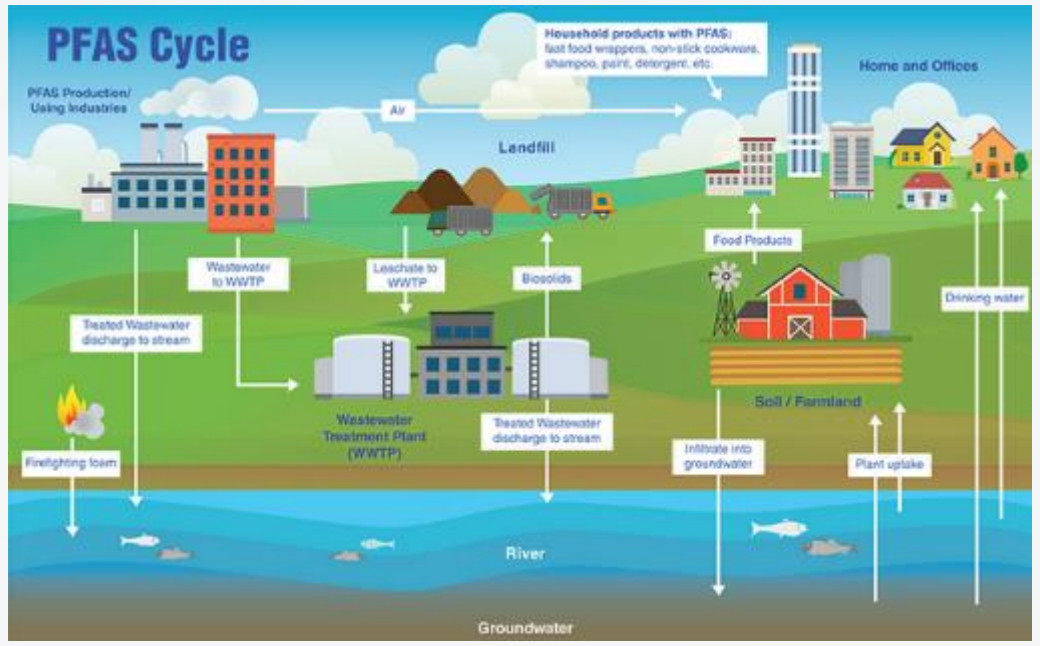




PubChem (2024).

PRESENCE IN ENVIRONMENTAL SAMPLES

Widespread contamination



PFASs have been detected in surface water, groundwater, sediments, soils, and the atmosphere.

Sources of contamination

Include industrial activities, landfills, sewage sludge application, and the use of products containing PFASs.

Dispersion mechanisms:

*Due to their **high persistence and mobility**, PFASs can disperse widely in the environment, accumulating in both aquatic and terrestrial ecosystems.*

EPA United States Environmental Protection Agency

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Safe Drinking Water Act

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Per- and Polyfluoroalkyl Substances (PFAS)

Final PFAS National Primary Drinking Water Regulation

- Summary
- Supporting Materials
  - General Information
  - Communications Toolkit
  - Technical Information for States, Tribes and Water Systems
  - Español
- Regulatory Information and Supporting Documents
- Webinars
- Background

Compound	Final MCLG	Final MCL (enforceable levels)
PFOA	Zero	4.0 parts per trillion (ppt) (also expressed as ng/L)
PFOS	Zero	4.0 ppt
PFHxS	10 ppt	10 ppt
PFNA	10 ppt	10 ppt
HFPO-DA (commonly known as GenX Chemicals)	10 ppt	10 ppt
Mixtures containing two or more of PFHxS, PFNA, HFPO-DA, and PFBS	1 (unitless) Hazard Index	1 (unitless) Hazard Index

- Public water systems must monitor for these PFAS and have **three years to complete initial monitoring (by 2027),** followed by ongoing compliance monitoring. Water systems must also provide the public with information on the levels of these PFAS in their drinking water beginning in 2027.
- Public water systems have **five years (by 2029) to implement solutions that reduce these PFAS** if monitoring shows that drinking water levels exceed these MCLs.
- **Beginning in five years (2029), public water systems that have PFAS in drinking water** which violates one or more of these MCLs must **take action** to reduce levels of these PFAS in their drinking water and must **provide notification** to the public of the violation.

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Regulatory Toxicology and Pharmacology

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

Range of the perfluorooctanoate (PFOA) safe dose for human health: An international collaboration

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Table 1
Safe doses of PFOA and PFOS from international authorities.

Authority	Safe Dose ug/kg-day	Point of Departure (POD_{HED})	Uncertainty Factors
Alliance for Risk Assessment (this paper)	0.01–0.07	Various (see text): 4.35 to 23 µg/ml of serum	Animal-human kinetic factor = 1[a] Animal-human dynamic factor = 3[b] Human toxicodynamic factor = 3[c] Human toxicokinetic factor = 8.4[d] Database uncertainty factor = 1[e] Human clearance = 0.23 ml/day-kg[f]
European Food Safety Authority (EFSA, 2020)	0.00063[g]	17.5 ng/mL ($BMDL_{10}$) Decreased anti-tetanus and anti-diphtheria antibody concentration	• None applied • BMD derived in sensitive population (infants) and response is risk factor for disease rather than a disease.
Food Standards Australia/New Zealand (2017)	0.16	4.9 µg/kg-day	Within human variability = 10 Animal to human extrapolation = 3
Health Canada (2018)	0.02	0.52 µg/kg-day	Within human variability = 10 Animal to human extrapolation = 2.5
US Environmental Protection Agency (2022)	0.0000015	0.0000149 µg/kg-day decreased anti-tetanus antibody concentration	Within human variability = 10
US Environmental Protection Agency (2023 DRAFT)	0.00003[h]	Various (human): 0.000305 µg/kg-day (decreased anti-tetanus and anti-diphtheria antibody concentration), 0.000275 µg/kg-day (increased serum cholesterol) 0.000292 µg/kg-day (decreased birth weight)	Within human variability = 10
World Health Organization (2022)	0.02	Estimated based on PFOA water level of 100 ng/L	• WHO made a risk management call of 100 ng/L • This value can be used to estimate the comparable safe dose of 0.02 µg/kg-day using 2 L of water consumption per day, a 60 kg body weight and a 20% relative source contribution.

[a] Factor is not needed since PODs are based on serum concentrations.
[b] The use of a 3 is the US EPA default position (U.S. Environmental Protection Agency EPA, 2014); the IPCS (2005) default is 2.5.

…nce of average group from Zhang et al. (2013, Table 2) by a
…ang et al. (2013, Table 2).

…ning steady state.

…ent endpoints in different populations to derive an RfD.

Many government agencies and expert groups have estimated a dose-rate of perfluorooctanoate (PFOA) that would protect human health. Most of these evaluations are based on the same studies (whether of humans, laboratory animals, or both), and all note various uncertainties in our existing knowledge. Nonetheless, the values of these various, estimated, safe-doses vary widely, with some being more than 100,000 fold different. This sort of discrepancy invites scrutiny and explanation. Otherwise what is the lay public to make of this disparity?

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

Discussion

Estimated scale of costs to remove PFAS from the environment at current emission rates

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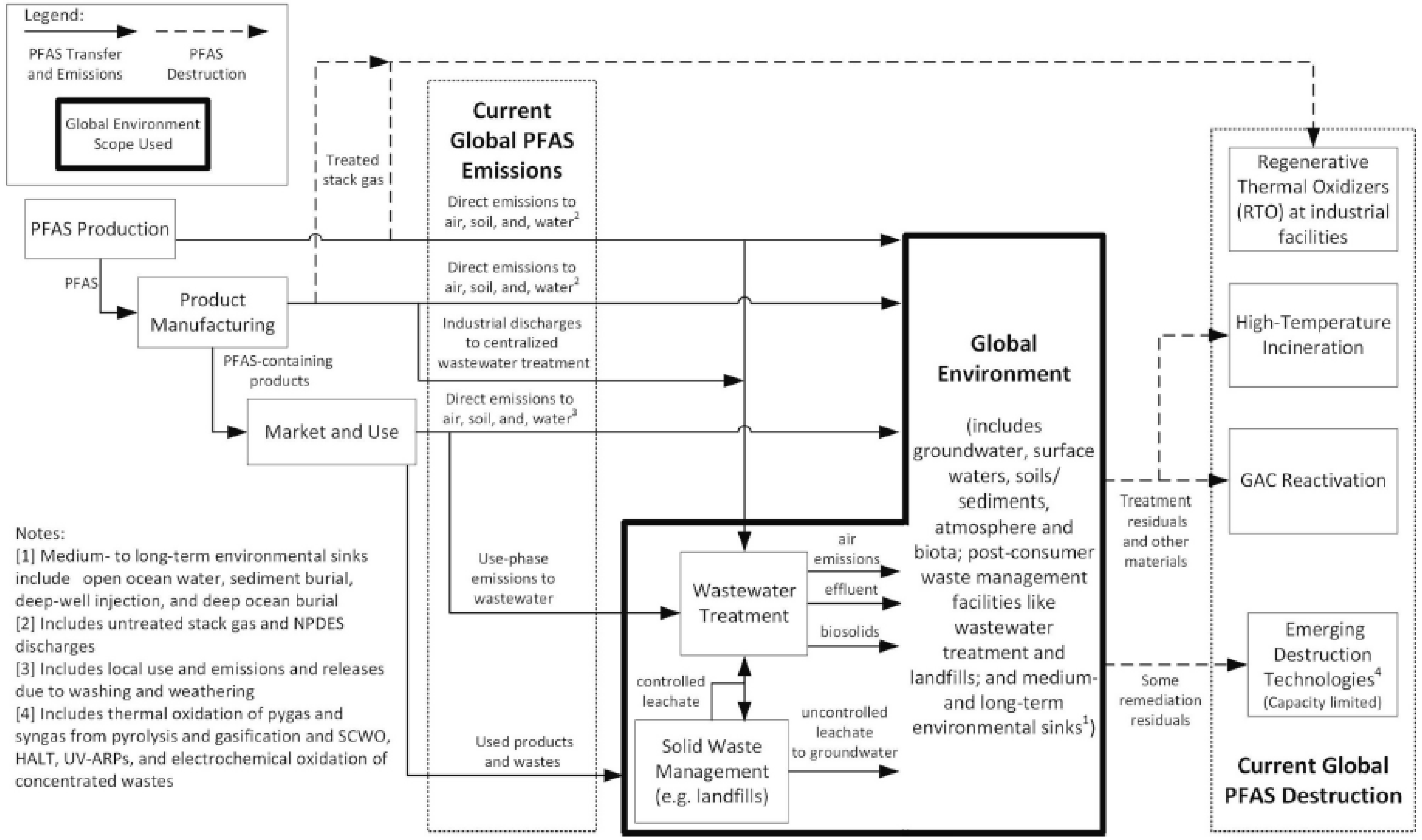


4.1. *Theoretical cost estimate for steady-state global PFAAs*

Using estimated emission rates of 20,000 to 100,000 metric tonnes per year of PFAAs and precursors and applying estimated unit costs of 0.9 million to 67 million USD per kg PFAA removed and destroyed, cost to achieve steady-state global PFAA stocks would be between 20 and 7000 trillion USD per year. This range brackets the estimated global GDP of 106 trillion USD (International Monetary Fund, 2023). This order-of-magnitude cost estimate is subject to significant, compounding uncertainties, including those associated with variations in treatment efficacy, characteristics and concentrations of specific PFAA, which PFAA are reported, and site-specific constraints that cannot be captured in a broad survey. However, the estimated scale of costs (tens to thousands of trillions of USD per year) provides a useful benchmark highlighting the impracticality of relying on environmental remediation alone to control global stocks of PFAAs in the environment.

Method 1633
Analysis of Per- and Polyfluoroalkyl Substances (PFAS) in Aqueous, Solid, Biosolids, and Tissue Samples by LC-MS/MS

Clean all equipment prior and after each use cleaning solvents used include

- ❑ Water
- ❑ Methanol
- ❑ methanolic ammonium hydroxide

Prior to use, baked glassware must be solvent rinsed and then air dried

- ❑ methanolic ammonium hydroxide (1%)
- ❑ Toluene
- ❑ methanol

- Do not use PTFE-lined caps on sample containers.

Liquid samples

- ❑ Waters
- ❑ Sludges
- ❑ similar materials < 50 mg solids

  - ➢ Sample bottle, HDPE
  - ➢ with linerless HDPE or polypropylene caps

Solid samples

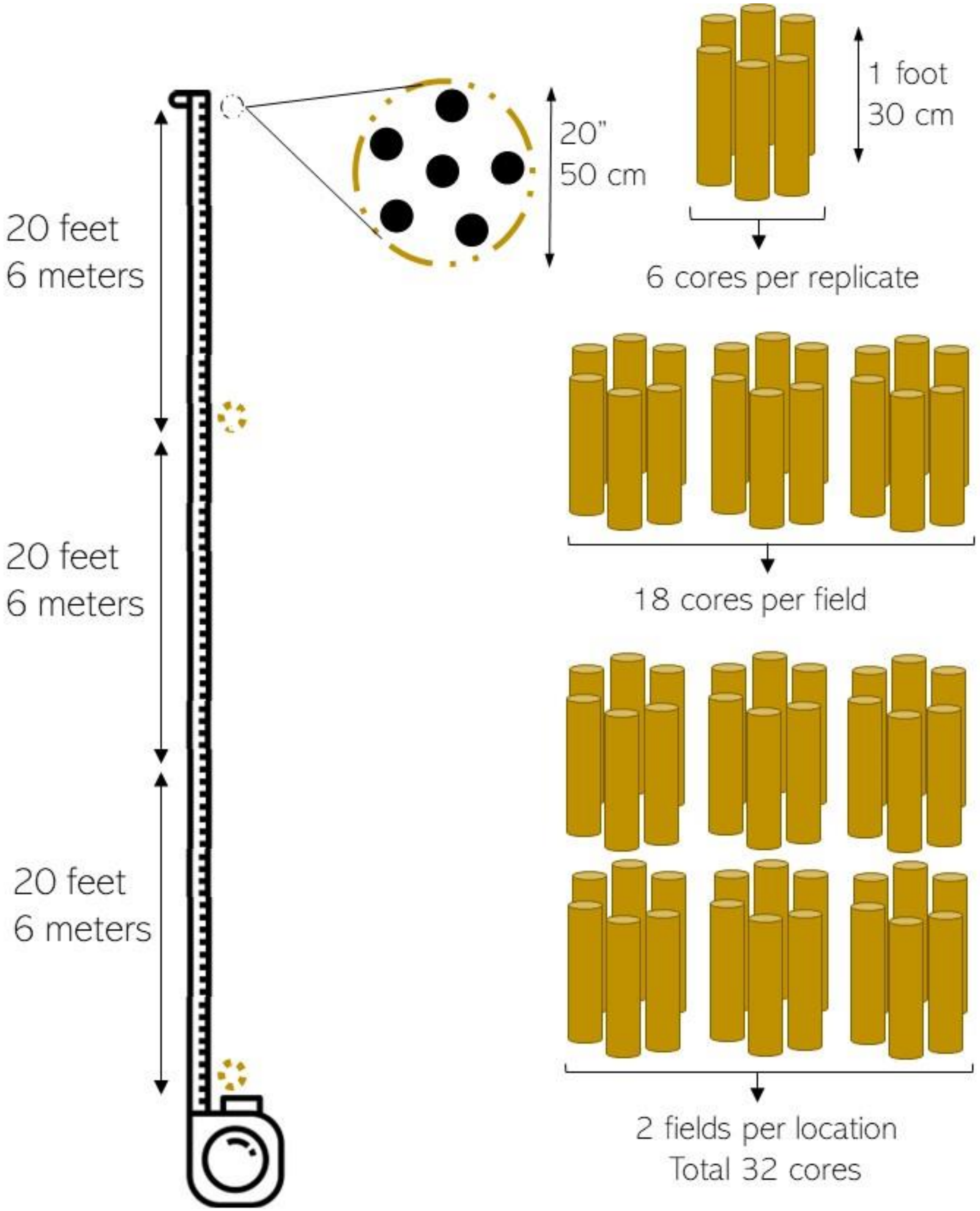
- ❑ Soils
- ❑ sediments
- ❑ biosolids
- ❑ contain more than 50 mg solids

  - ➢ Sample bottle or jar
  - ➢ wide-mouth, HDPE
  - ➢ with linerless HDPE or polypropylene caps

Aliquots

- ❑ Disposable polypropylene collection tubes

- To mix soil cores and to store samples for other analysis, polyethylene sealed bags were used.



Collecting water

- Do not fill the bottle past the shoulder, to allow room for expansion during frozen storage

- ❑ sources that flow freely (e.g., effluents) are collected as grab samples.

- ❑ if the purpose of the sampling is to characterize the PFAS content of the waterbody, samples should be collected from below the surface to avoid the enrichment in the surface layer .

- ❑ the nominal sample size is 500-mL.

- Maintain all aqueous and solid samples protected from light and at or below 6 ^{o}C from the time of collection until shipped to the laboratory.

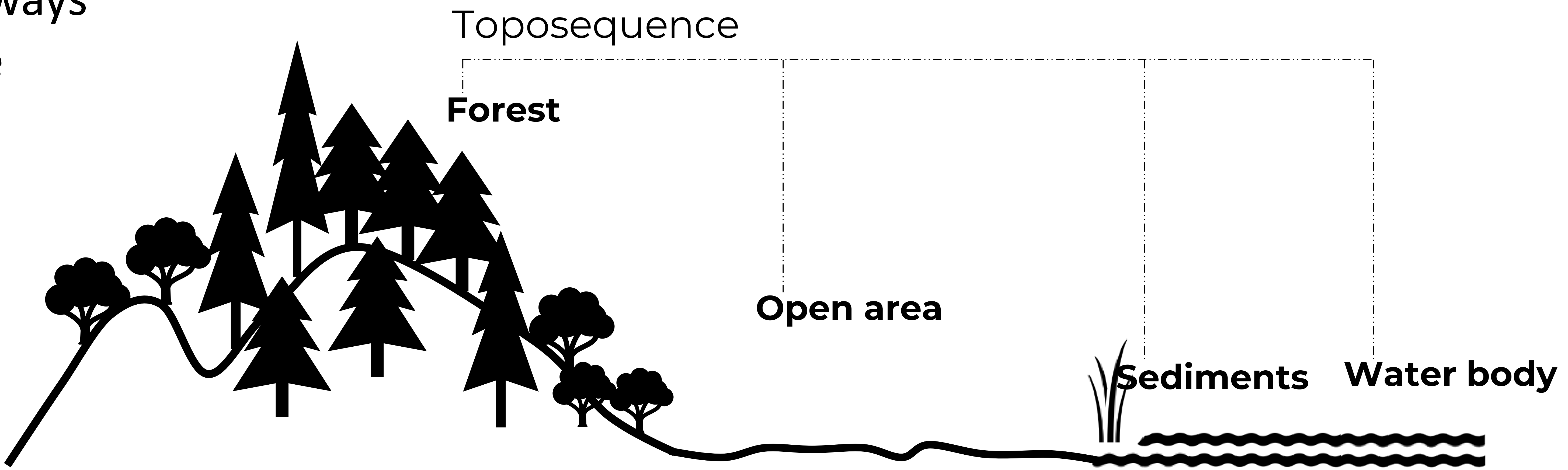
- Once received by the laboratory, the samples may be stored at 0 - 6 ^{o}C or at or below -20 ^{o}C, until sample preparation

- when sampling long distances cooler and ice are required to keep the samples always refrigerated.
- once possible samples are transferred to freezers/fridges.

Field protocol

Samples are always collected in the same order:

- ❑ Water
- ❑ Sediments
- ❑ soil









AMS 7/8" X 33" Plated Soil Probe w/ Handle, 5/8" Thread

- ❑ soil samples are collected using a plated soil probe. We use water from the area to wash it.
- ❑ once clean the probe is thoroughly sprayed with methanol LC_MS grade
- ❑ lastly the probe is thoroughly sprayed with water LC_MS grade.
- ❑ All cleaning residues are kept.

- Average collection time was 2.5 hours per location
- Clay loam soils took up to 4 hours

- Samples must be shipped with sufficient ice to maintain the sample temperature at or below 6 ºC during transport for a period of at least 48 hours to allow for shipping delays.

Holding times

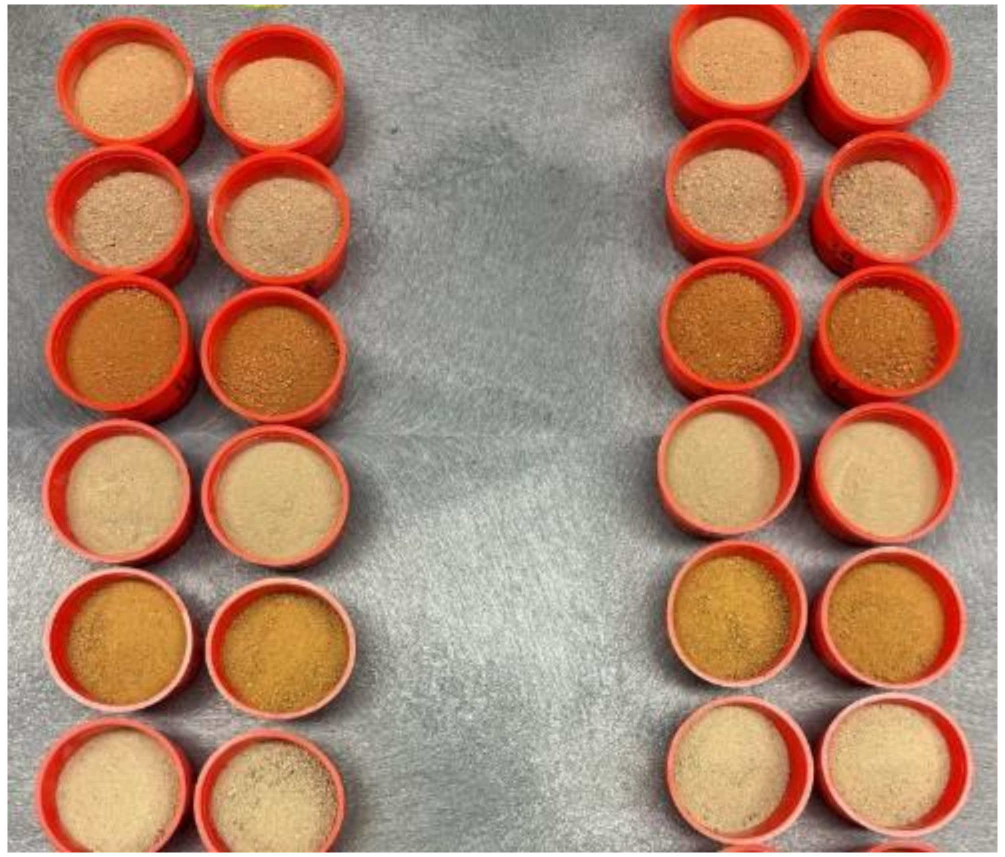
- ❑ Aqueous samples may be held for up to 28 days when stored at or below 6 °C, or 90 days when stored at or below -20 °C and protected from the light.
- ❑ Soil and sediment samples may be held for up to 90 days, if stored by the laboratory in the dark at either 0 - 6 °C, or at below -20 °C.
- ❑ Biosolids samples may be held for up to 90 days, if stored by the laboratory in the dark at 0 - 6 °C, but preferably at or below -20 °C.
- ❑ EPA recommends that samples be frozen if they need to be stored for more than a few days before extraction.

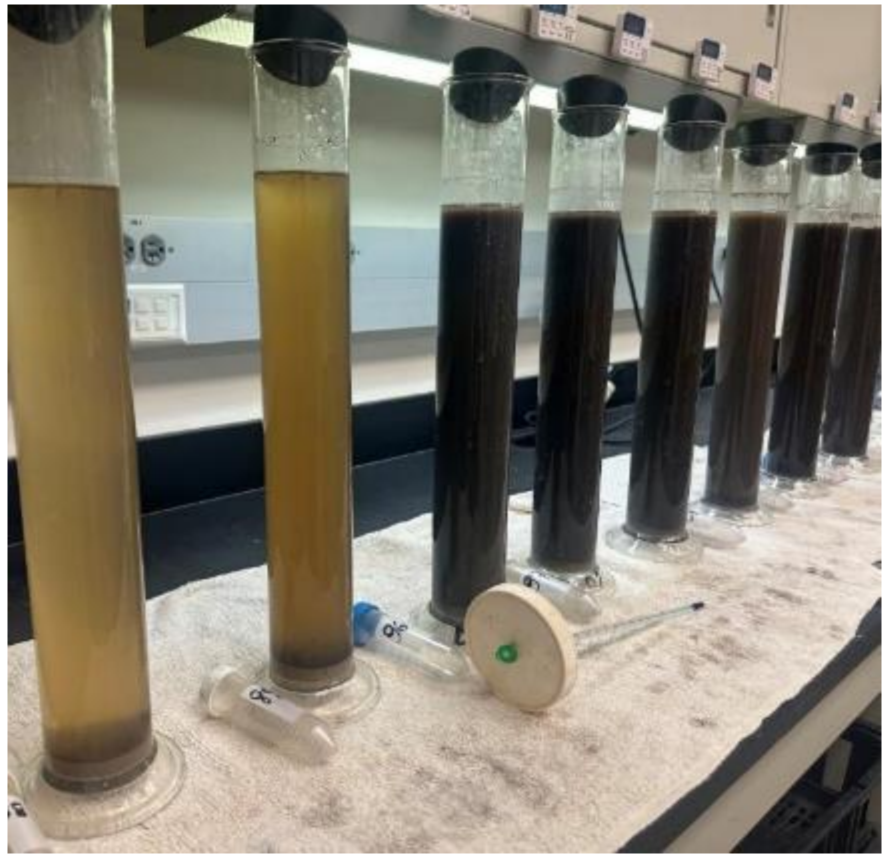
- issues have been observed with certain perfluorooctane sulfonamide ethanols and perfluorooctane sulfonamidoacetic acids after 7 days.
  - likely to elevate the observed concentrations of other PFAS compounds via the transformation of these precursors.

- soils and sediments may exhibit microbial growth when stored at 0 - 6 °C.
  - samples may need to be extracted as soon as possible if NFDHA is an important analyte

Extra samples may be needed for other analysis

- ❑ Texture
- ❑ Nutrients
- ❑ Organic matter
- ❑ pH
- ❑ ...





Sample Preparation and Extraction

Aqueous samples

- pH should be 6.5 ± 0.5 - adjust with 50% formic acid or ammonium hydroxide
- all parts of the SPE manifold must be cleaned between samples with methanolic ammonium hydroxide (1%) and air dried prior to use
- sonication with methanolic ammonium hydroxide (1%) may be used

❑ Homogenize the sample

❑ Pre-condition the cartridges

❑ Do not allow the WAX SPE to go dry

- Do not use any fluoropolymer articles or task wipes in these extraction procedures.
- Use only HDPE or polypropylene wash bottles and centrifuge tubes.

- maximum sample weight for sediment or soil is 5 g dry-weight
- maximum sample weight for biosolids is 0.5 g dry-weight

Soil samples

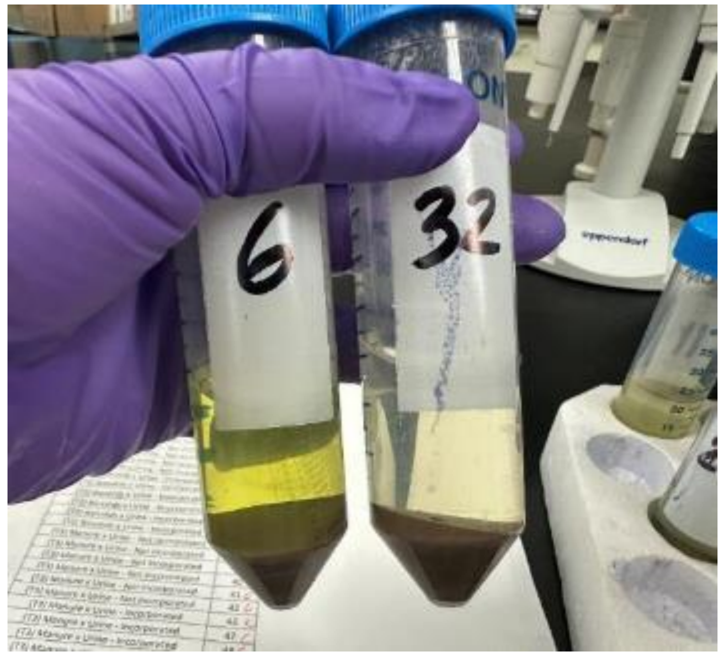
24 hs
- ❑ mix the sample
- ❑ determine water content in sample

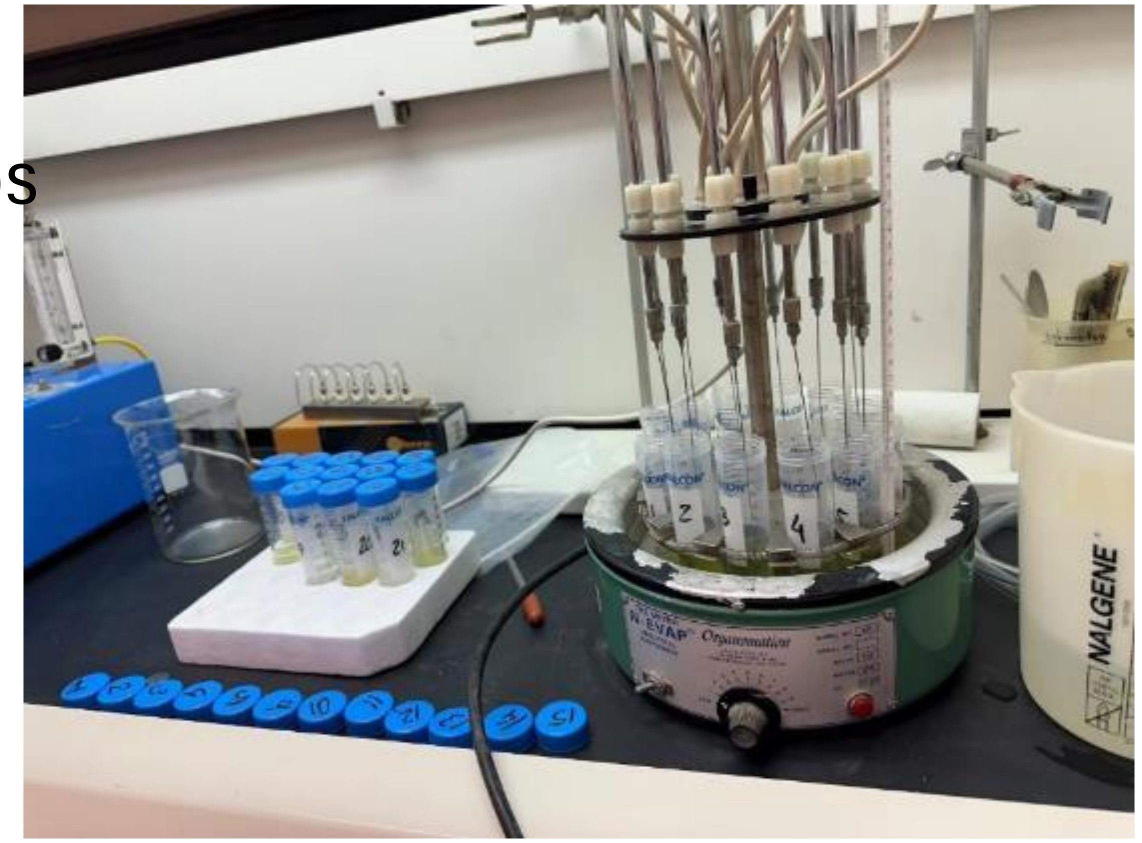
3 hs
- ❑ weigh aliquot
- ❑ add 0.3% methanolic ammonium hydroxide
- ❑ vortex
- ❑ shake for 30 minutes
- ❑ centrifuge for 15 minutes
- ❑ repeat the extraction steps 2 times

5-7 hs
- ❑ concentrate the extract
- ❑ add reagent water

5-7 hs/ batch
- ❑ SPE

5-8 hs
- ❑ elution
- ❑ concentrate /reconstituted





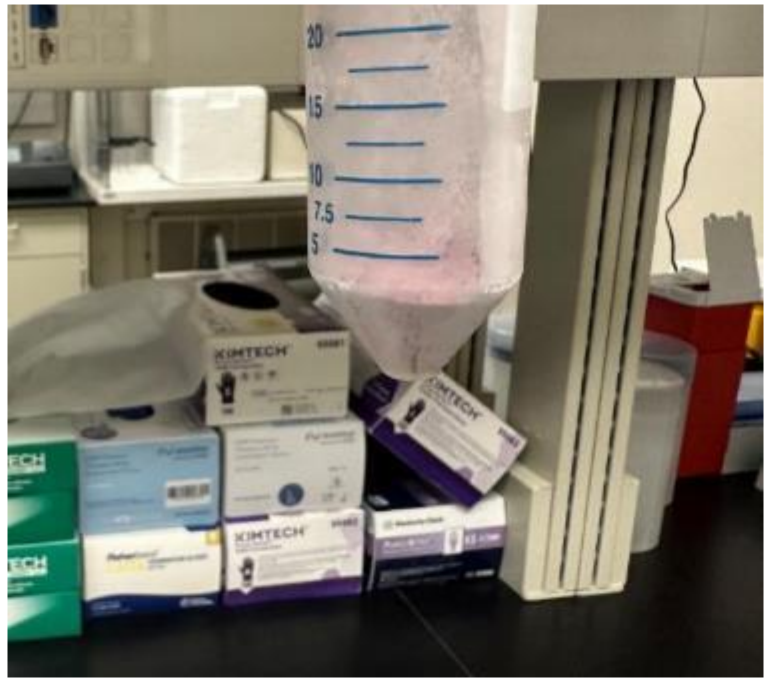
Plant tissue

3 – 14 days
- ❑ freeze dry

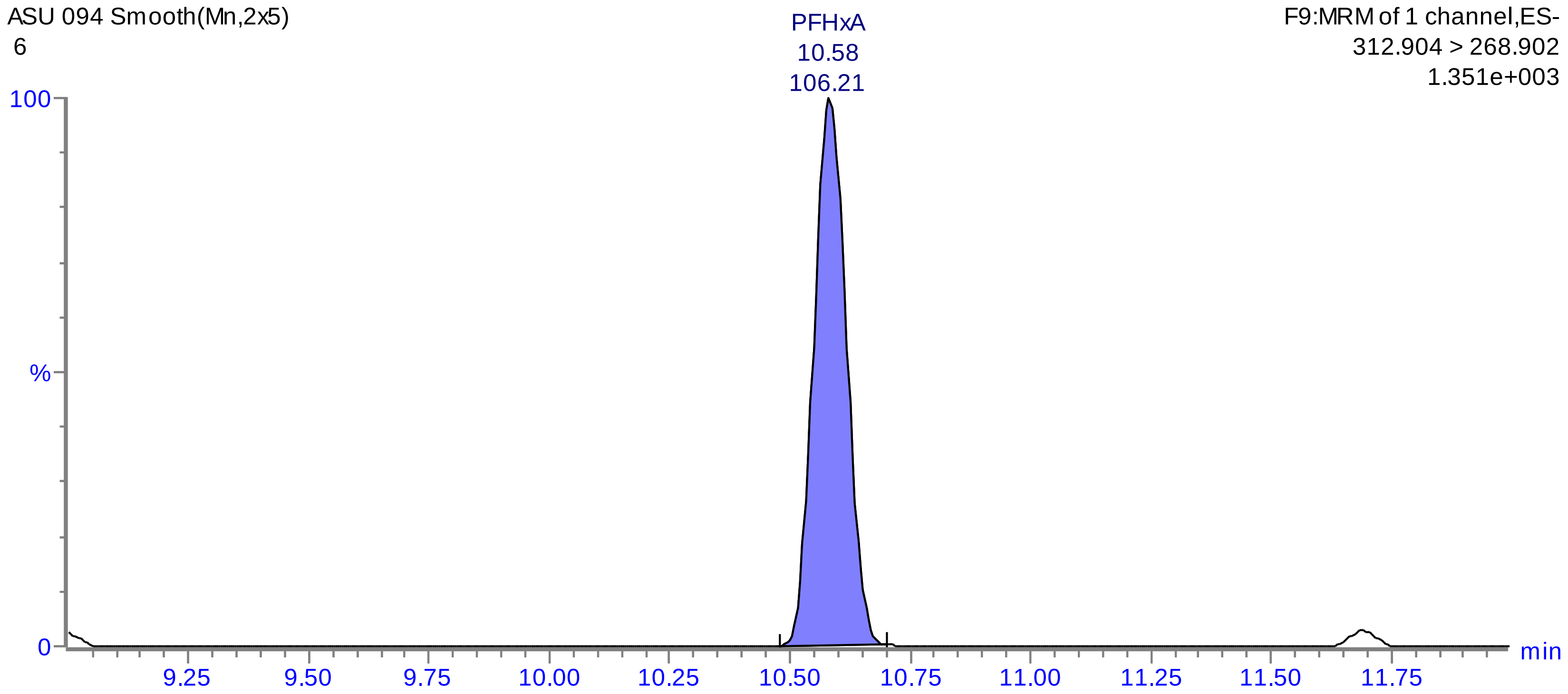
3 – 10 days
- ❑ manually grind

3-4 hs
- ❑ weigh aliquot
- ❑ add MeOH with 400 mM ammonium acetate
- ❑ vortex
- ❑ ultrasonicated for 30 minutes
- ❑ centrifuge for 15 minutes
- ❑ repeat the extraction steps 2 times

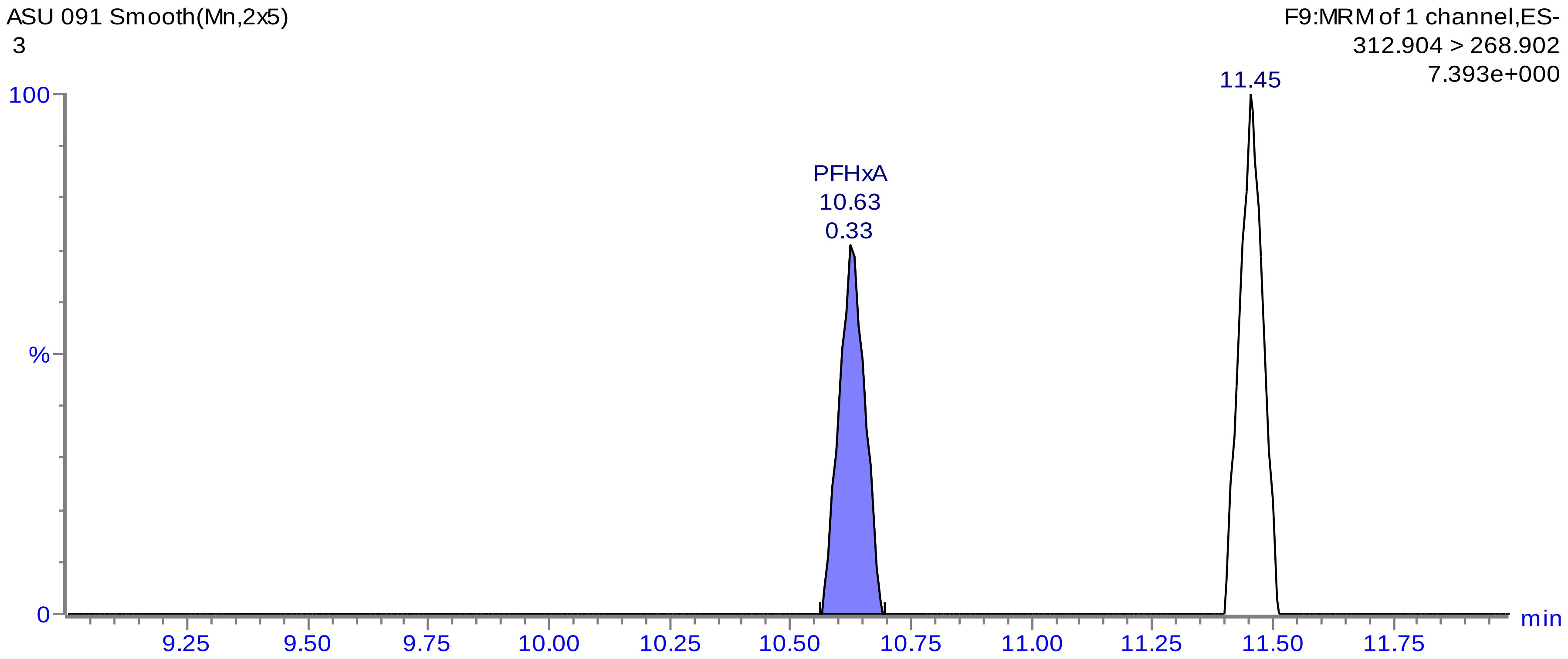
5-10 hs/batch
- ❑ SPE
- ❑ concentrated



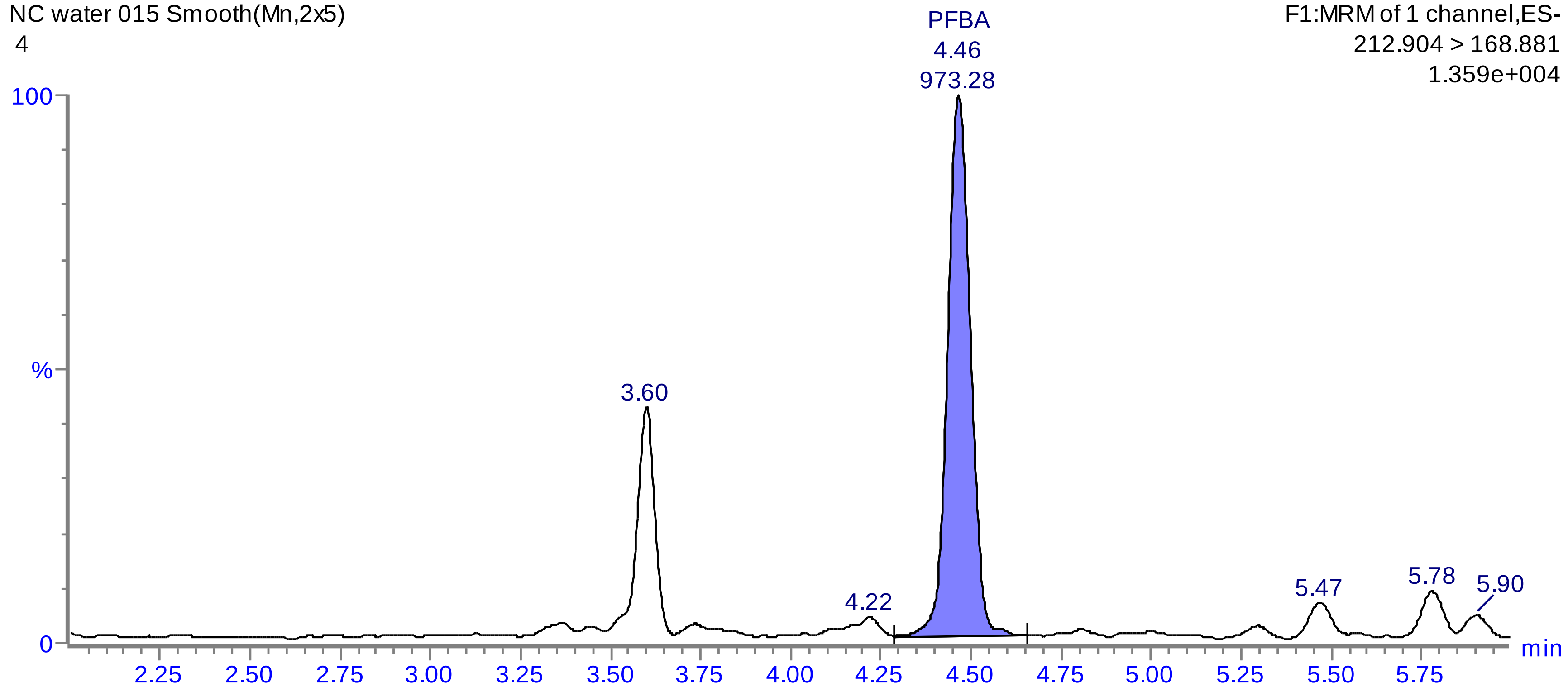
- Biosolids



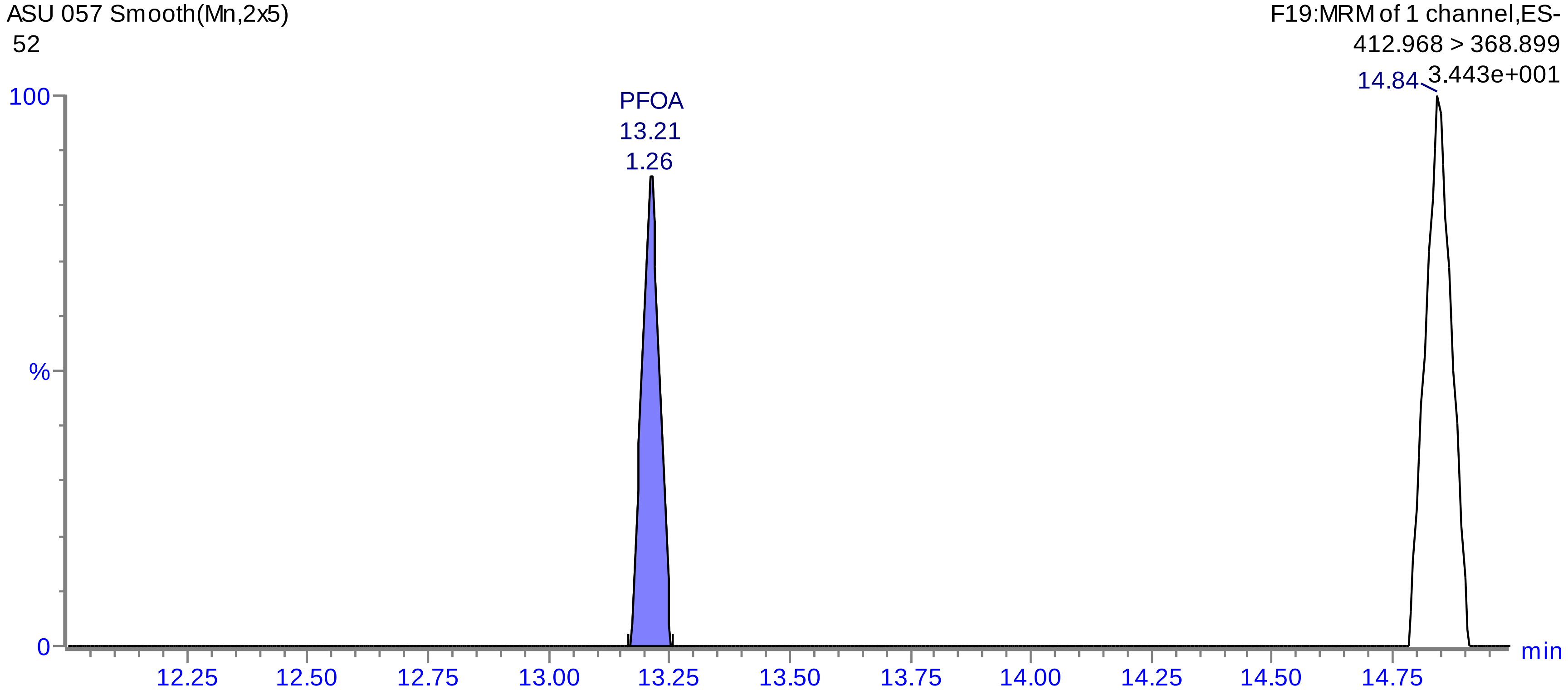
- Manure



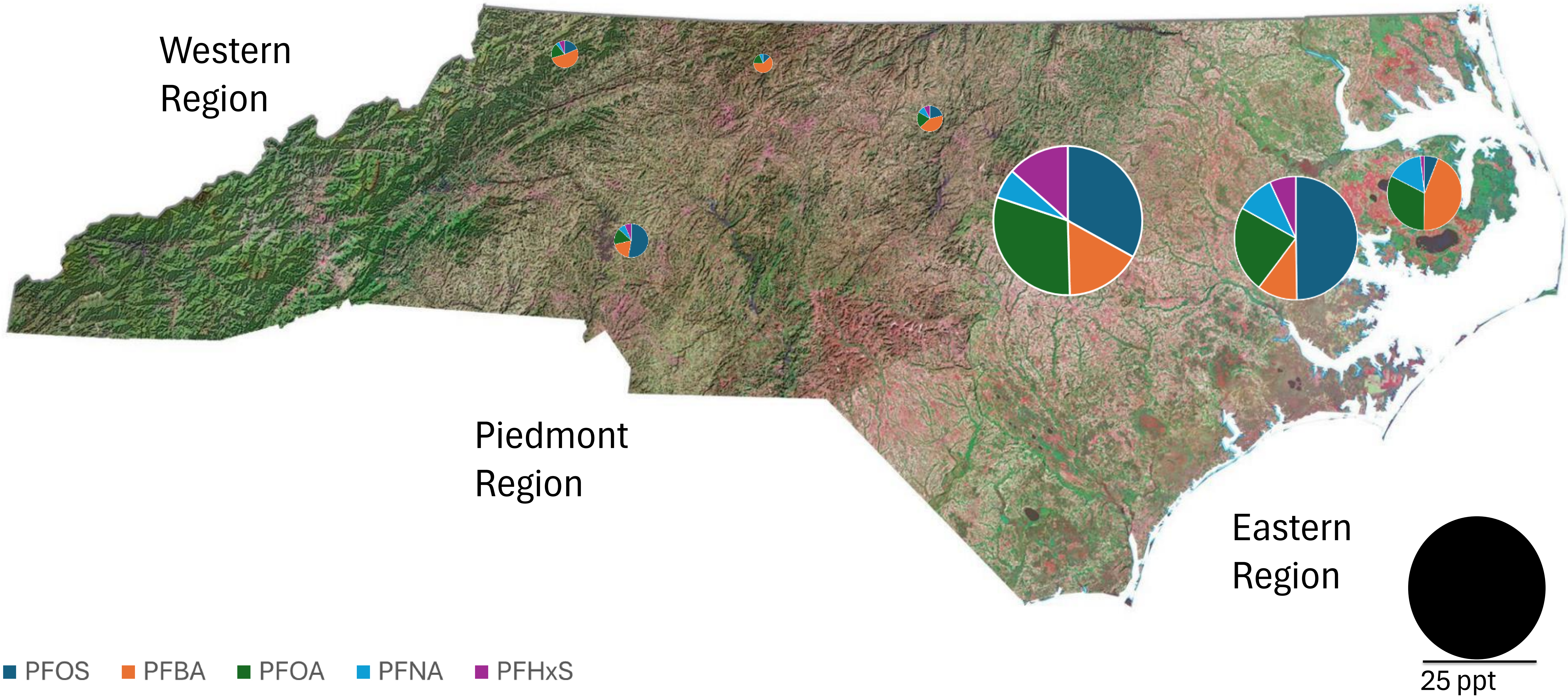
- Aqueous Matrices

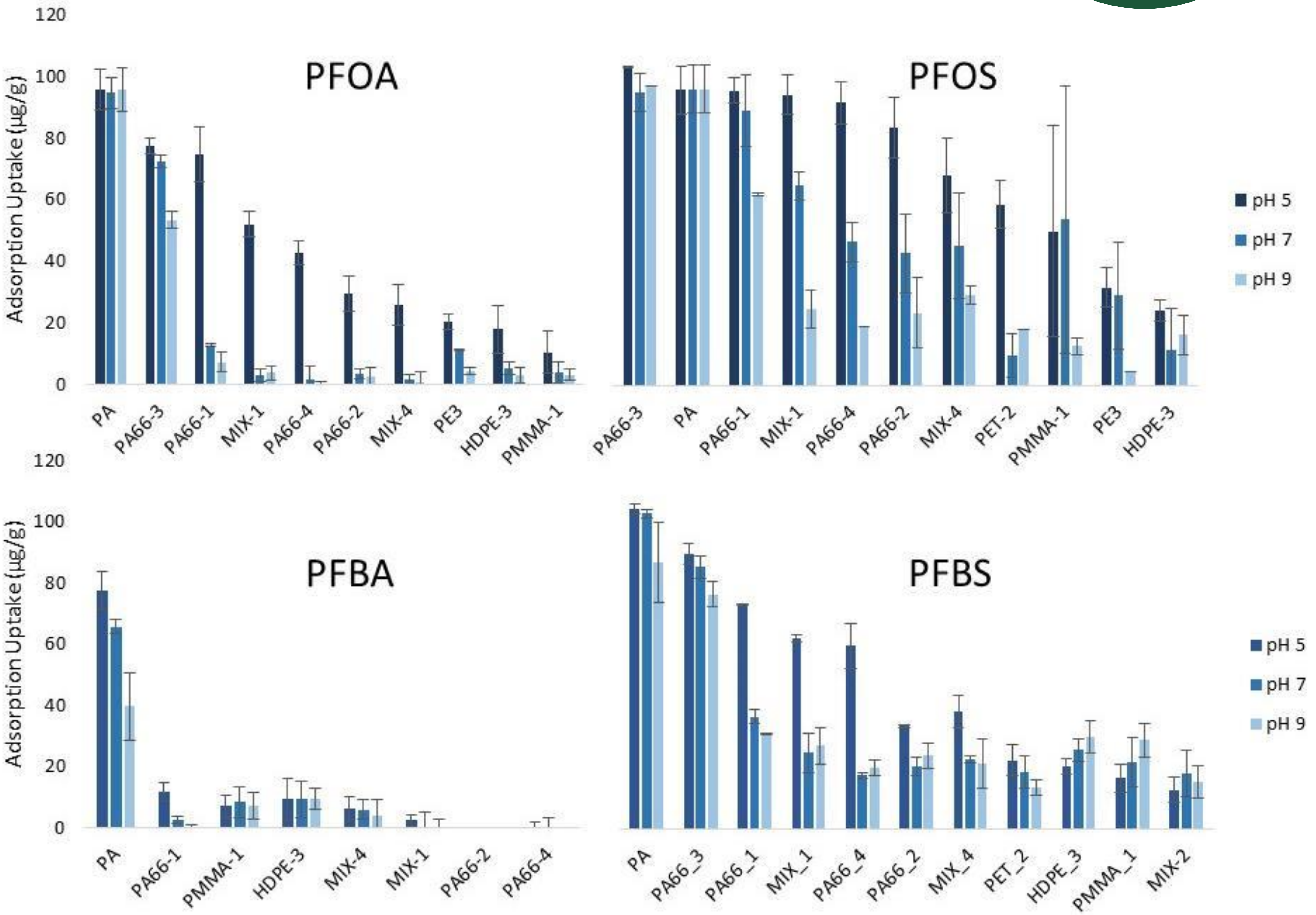


- soil



❑ PFAS occurrence in aqueous matrices in North Carolina

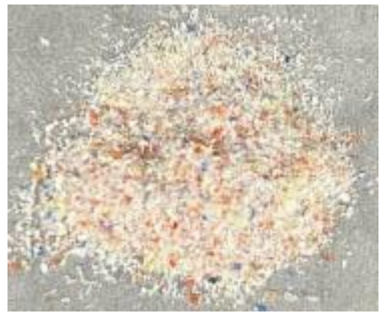



PFOA
PFOS
PFBA
PFBS
Adsorption Uptake (µg/g)
Adsorption Uptake (µg/g)
0
20
40
60
80
100
120
pH 5
pH 7
pH 9
PA
PA66-3
PA66-1
MIX-1
PA66-4
PA66-2
MIX-4
PE3
HDPE-3
PMMA-1
PA66-3
PA
PA66-1
MIX-1
PA66-4
PA66-2
MIX-4
PET-2
PMMA-1
PE3
HDPE-3
PA
PA66-1
PMMA-1
HDPE-3
MIX-4
MIX-1
PA66-2
PA66-4
PA
PA66_3
PA66_1
MIX_1
PA66_4
PA66_2
MIX_4
PET_2
HDPE_3
PMMA_1
MIX-2

Sorption Experiments and Analytical Method

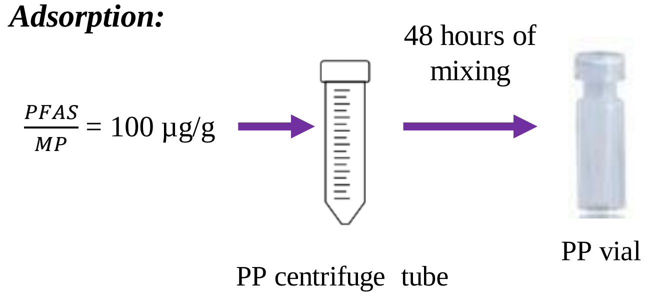

Aged PET -1


Aged PET -2

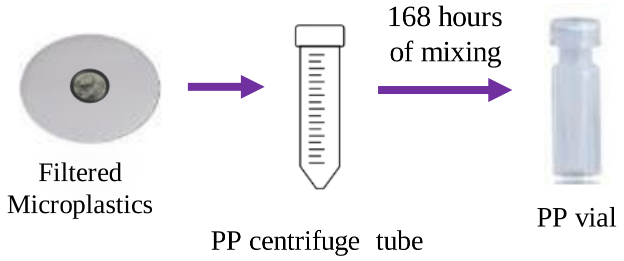

Aged PET -3

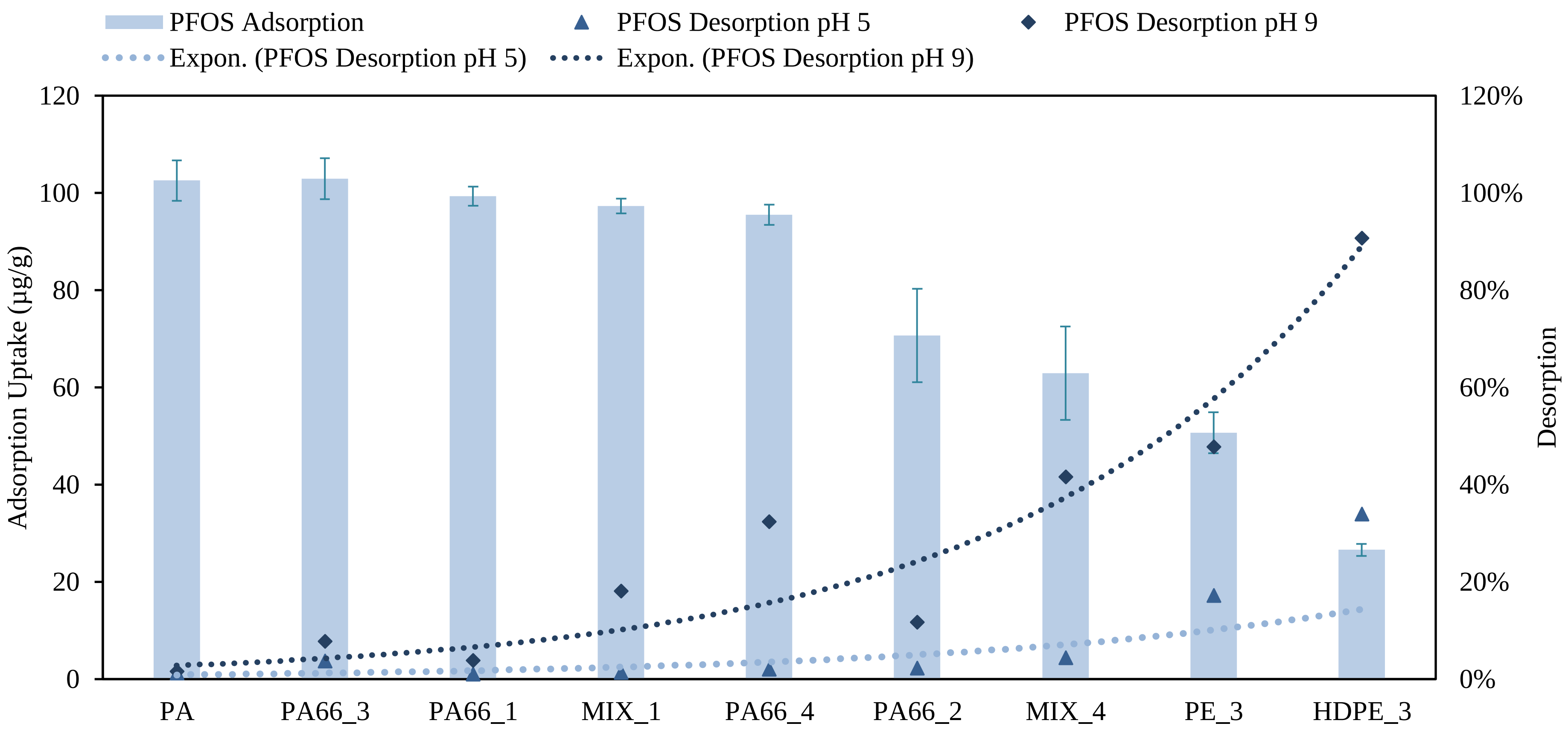

Virgin PET

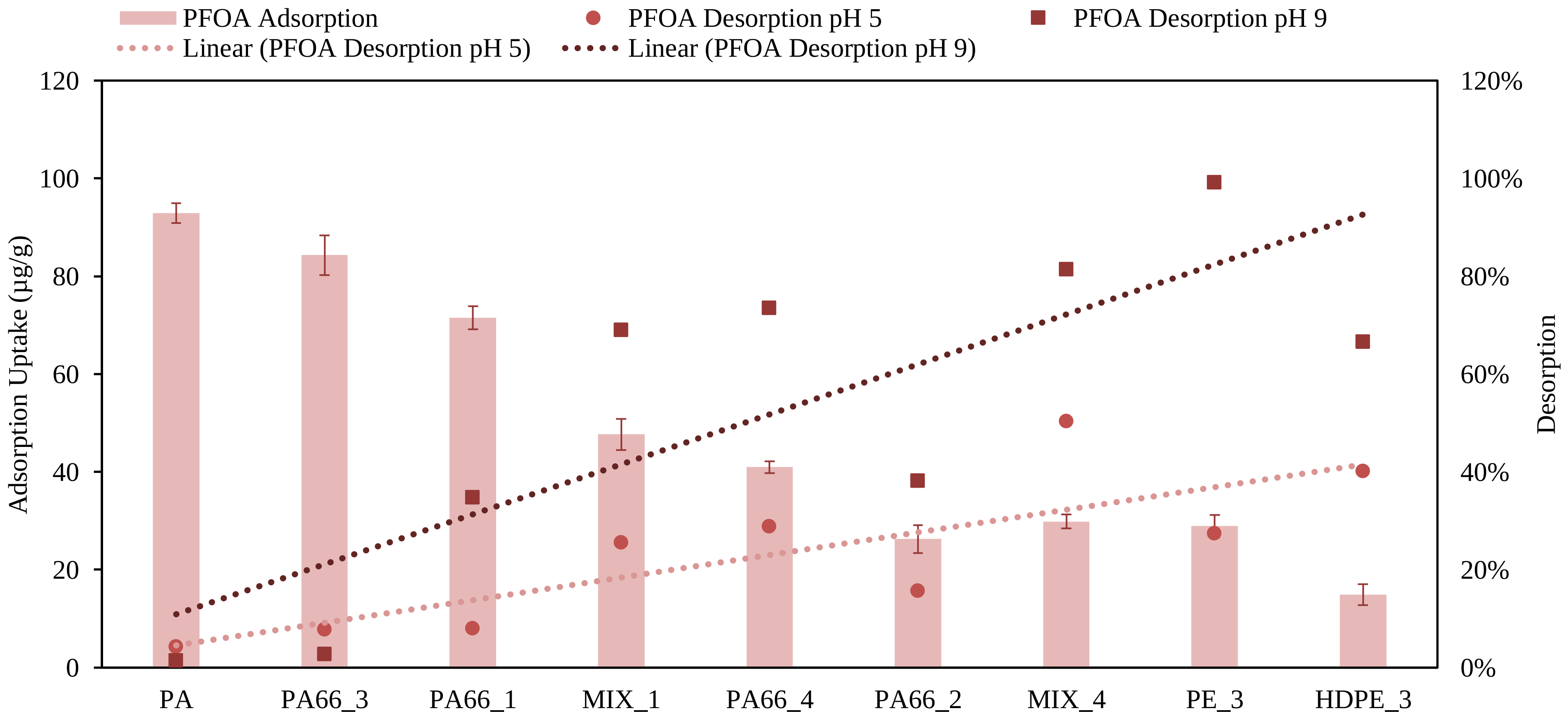
Adsorption:



Desorption:

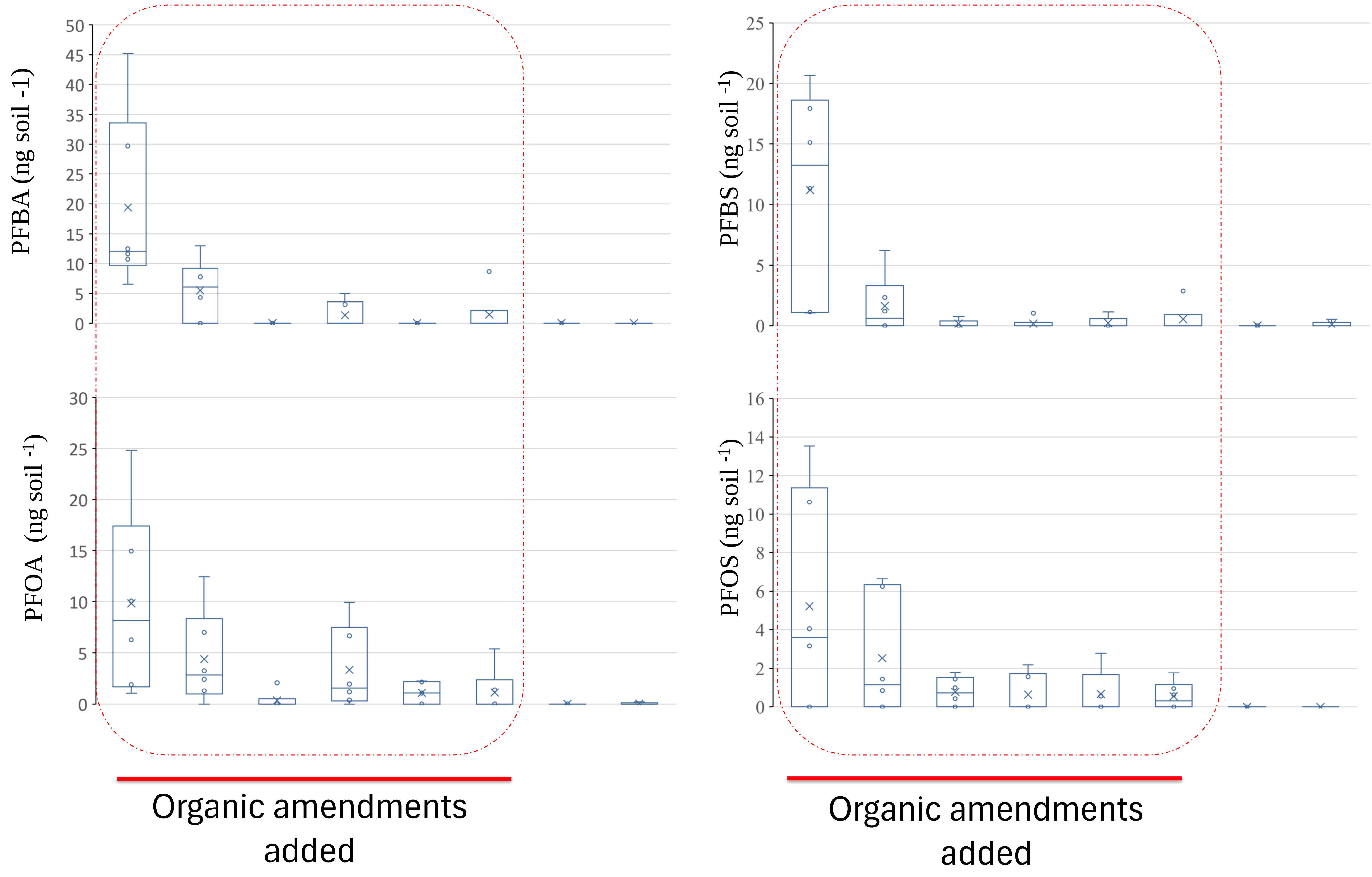







Urea Not incorporated
Biosolids x Manure - Not incorporated
Manure - Not incorporated
Biosolids Not incorporated
19 days after sowing
54 days after sowing (after plant harvest)

❑PFAS occurrence in soil



COLLABORATIONS

USDA Agricultural Research Service

Water Management and Conservation Research Unit

Arizona State University

Natural Resources Conservation Service