PFAS Remediation: What are the Options?

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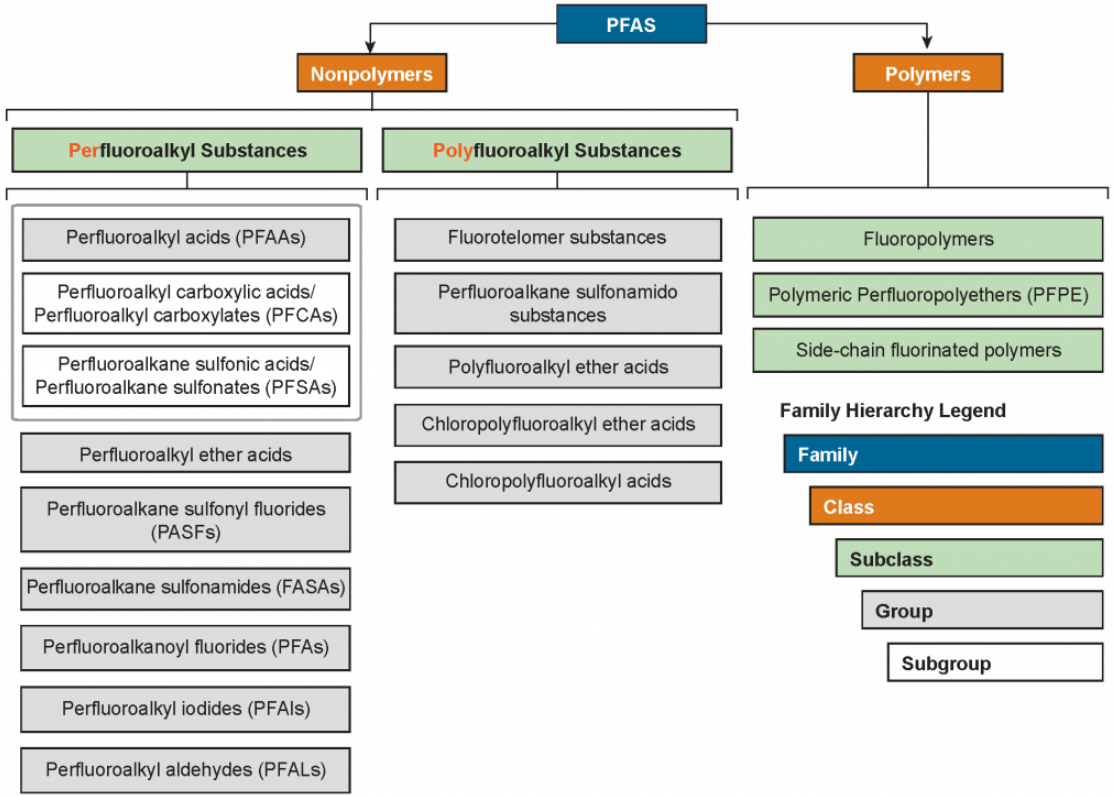
September 16, 2025

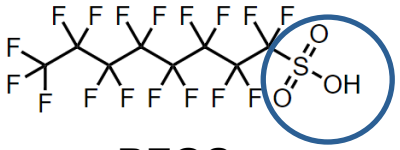
Agenda

- PFAS background
- Solid treatment options
  - Established treatment technologies
  - In-development treatment technologies
- Liquid treatment options
  - Established treatment technologies
  - In-development treatment technologies
- Case studies
- Questions?

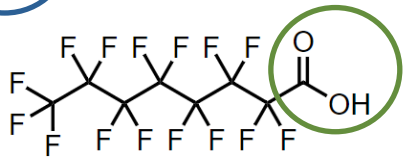
PFAS Background



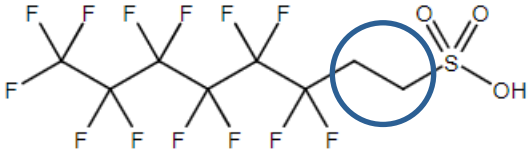
Source: ITRC



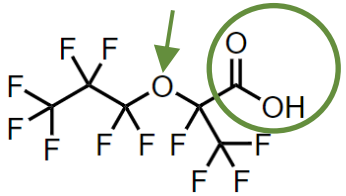
PFOS



PFOA



6:2 FTS



PFAS Background Cont'd

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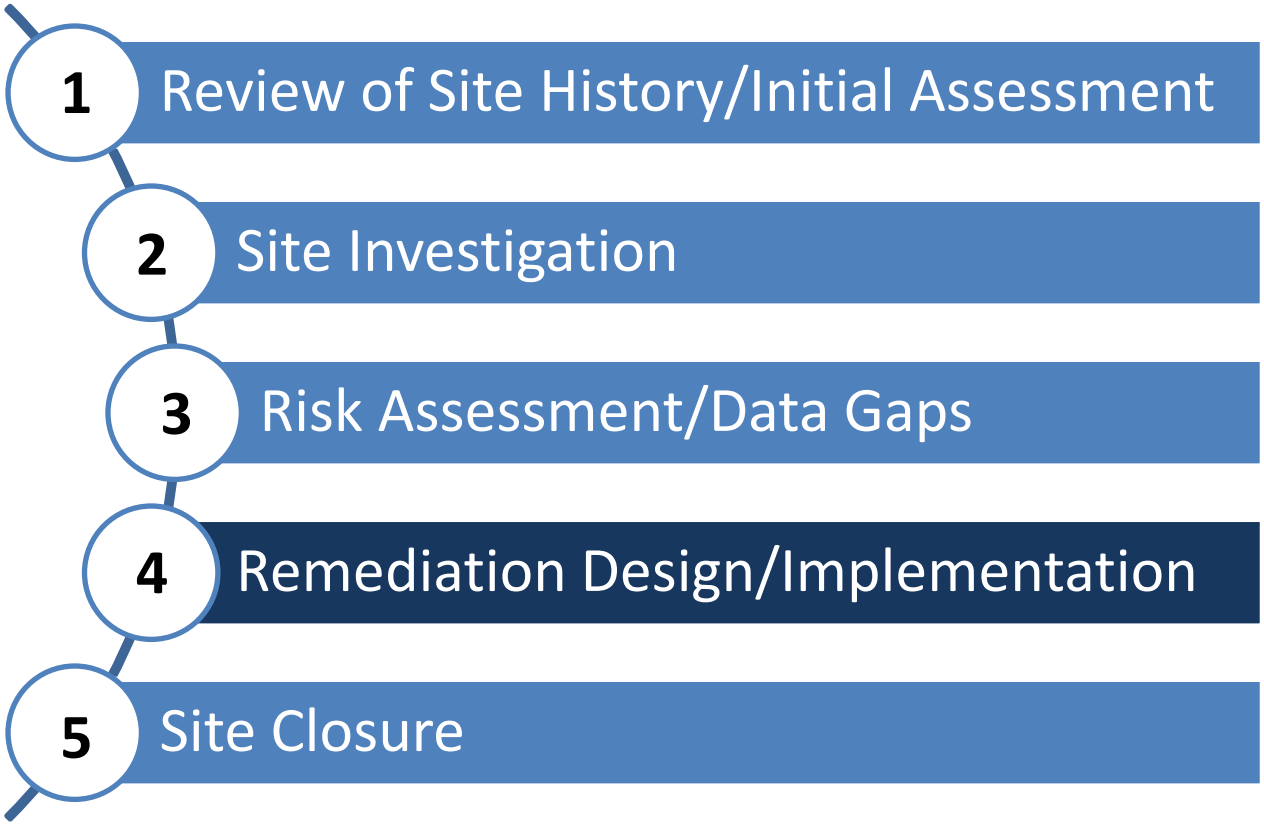
PFAS Attribute	General Outcome
Molecule Size (# of Carbons)	Smaller ≈ more mobile, harder to treat
Linear v. Branched	Branched ≈ more mobile
Degree of fluorination	Fewer fluorenes ≈ more mobile
Functional Groups	
- *Charge*	*Charged ≈ more mobile*
- *Transformations*	*Degrade into terminal PFAS*

NGWA, PFAS Fate and Transport 2021

Remediation Phases



Established Solid Treatment Options

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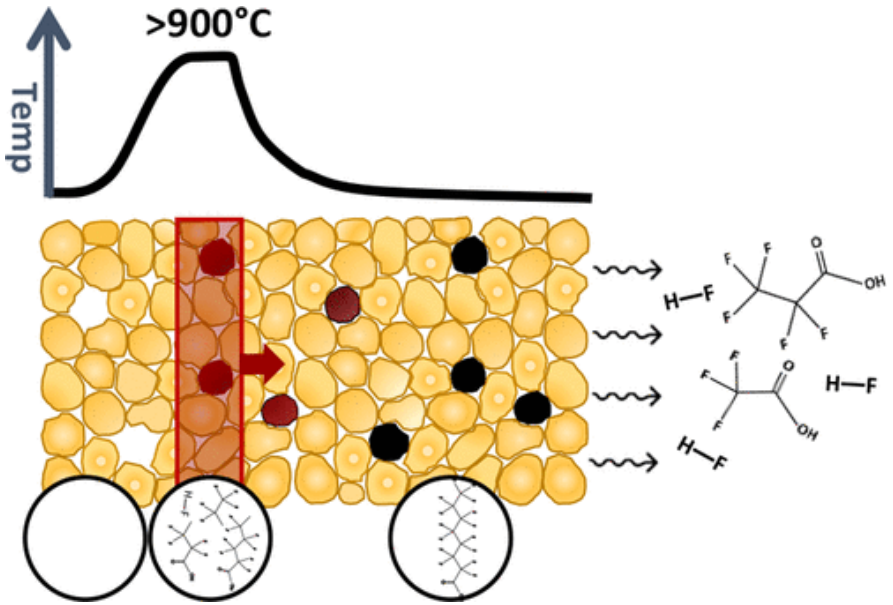
- Incineration
  - Requires >1000 °C temperatures
- Excavation and disposal
  - Could lead to long-term environmental liabilities associated with PFAS
- Sorption and stabilization
  - Simple and low cost to deploy
- Soil washing
  - Produces PFAS laden rinsate

In-Development Solid Treatment Options

- **Smoldering combustion**
  - Can be deployed in-situ or ex-situ
  - Flameless oxidation reaction mineralizes PFAS
- **Ball milling**
  - Uses mechanochemical process to degrade PFAS
- **Electron-beam**
  - Creates radicals with a high-energy electron



State of the Practice – Liquid Treatment

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Established Technologies (Removal/Concentration)

- Best available technologies GAC/IX/RO
- Extensively deployed at full-scale for various applications
- Performance widely understood
- May require significant pretreatment
- Residuals management concerns – media, brine, pretreatment sludge

Emerging Removal Technologies

- Foam fractionation, novel adsorbents, regenerable ion exchange, enhanced pretreatment, precipitation/coagulation/flocculation
- Not yet widely deployed at scale (some full-scale installations)
- Performance dependent on application
- Residuals management concerns – quantity and quality

Destruction Technologies

- Electrochemical oxidation, hydrothermal alkaline treatment, supercritical water oxidation, photocatalysis
- Limited by hydraulic through put (e.g., up to 15 gpm for an EOx unit)
- High energy consumption
- Used in conjunction with removal/concentration technologies (matrix dependency of technologies)

PFAS Specific Pretreatment → PFAS Removal or Concentration → PFAS Destruction in Residuals → Discharge

Established Liquid Treatment Options

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- Granular activated carbon (GAC)
  - More effective on longer chain PFAS
  - PFAS adsorption impacted by total organic carbon (TOC), pH and contact time
  - Generates solid waste
- Ion exchange resin (IX)
  - Can effectively remove long and short chain PFAS
  - Regeneration available, but most often single use
  - Competition from sulfate, iron, manganese, bicarbonate, and chloride, TOC
  - Generates solid waste
- Combination of GAC followed by IX
  - High O&M costs
  - May require significant pretreatment

Established Liquid Treatment Options Cont'd

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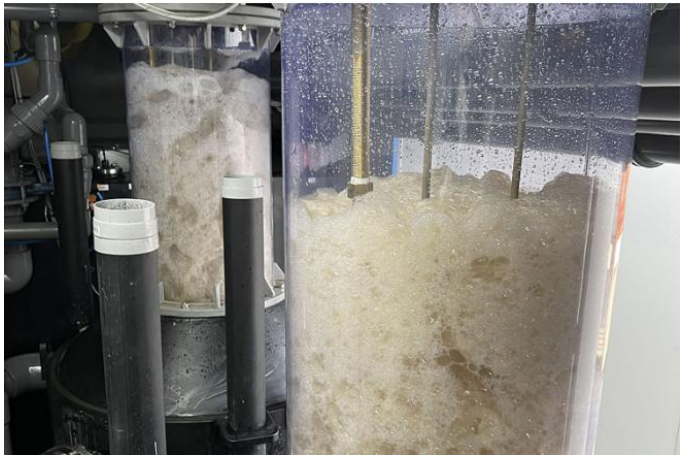
- Reverse osmosis (RO) or nanofiltration
  - Effective for both long and short chain PFAS compounds
  - Requires significant pretreatment to reduce negative impact on membrane performance
  - Generates liquid waste with high concentration of PFAS that requires disposal

Reverse Osmosis or Nanofiltration (RO or NF)

Source: OCWD PFAS Workshop 2022

Established Liquid Treatment Options Cont'd

- Colloidal activated carbon
  - Requires carbon to be injected in the subsurface
  - Long-term fate of the carbon is not well understood (removal or replacement may be required)
- Foam fractionation
  - Generates liquid waste with high concentration of PFAS that requires disposal
  - Addition of surfactants are required to remove short-chained PFAS



https://epocenviro.com/products/

In-development Liquid Treatment Options

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- Sorption technologies
  - Biochar, regenerable IX, modified clay, fluorogels, beta-cyclodextrin
- Precipitation/coagulation/flocculation
- Chemical oxidation and reduction
  - Electrochemical oxidation, photolysis/photocatalysis, sonolysis, activated persulfate, ozonation, zero-valent iron, plasma, supercritical water oxidation, E-beam
- Hydrothermal alkaline treatment
- Biodegradation

Case Study 1 – PFAS Treatment Design & Operations at a Bulk Fuel Terminal

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- Treatment of PFAS-impacted stormwater and groundwater (300 gpm)
- Includes pretreatment (ultrafiltration), TPH filters, GAC and IX
- Pre-design investigation and testing, design, permitting, and ongoing performance monitoring and operations oversight
- To date, system has treated >100 million gallons of impacted stormwater and groundwater with zero PFAS exceedances

Case Study 1 – PFAS Treatment Design & Operations at a Bulk Fuel Terminal

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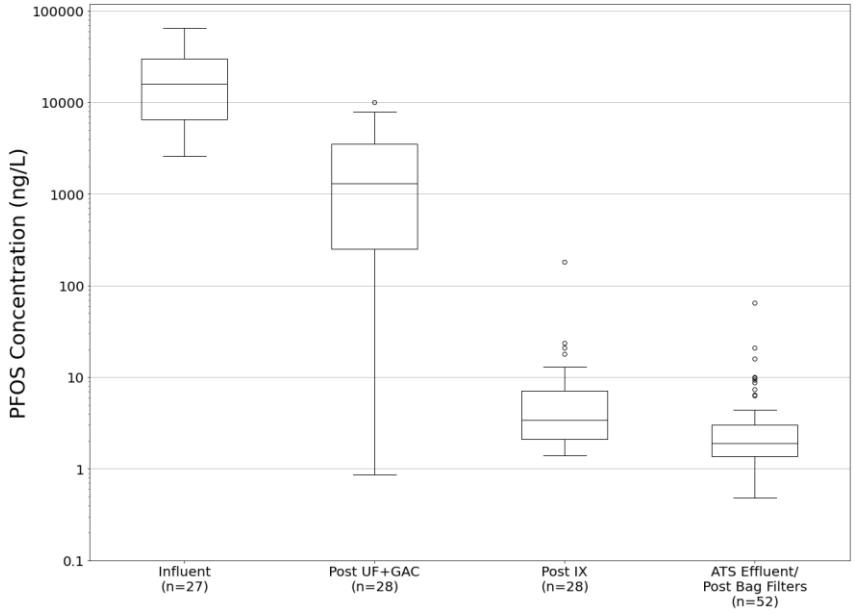

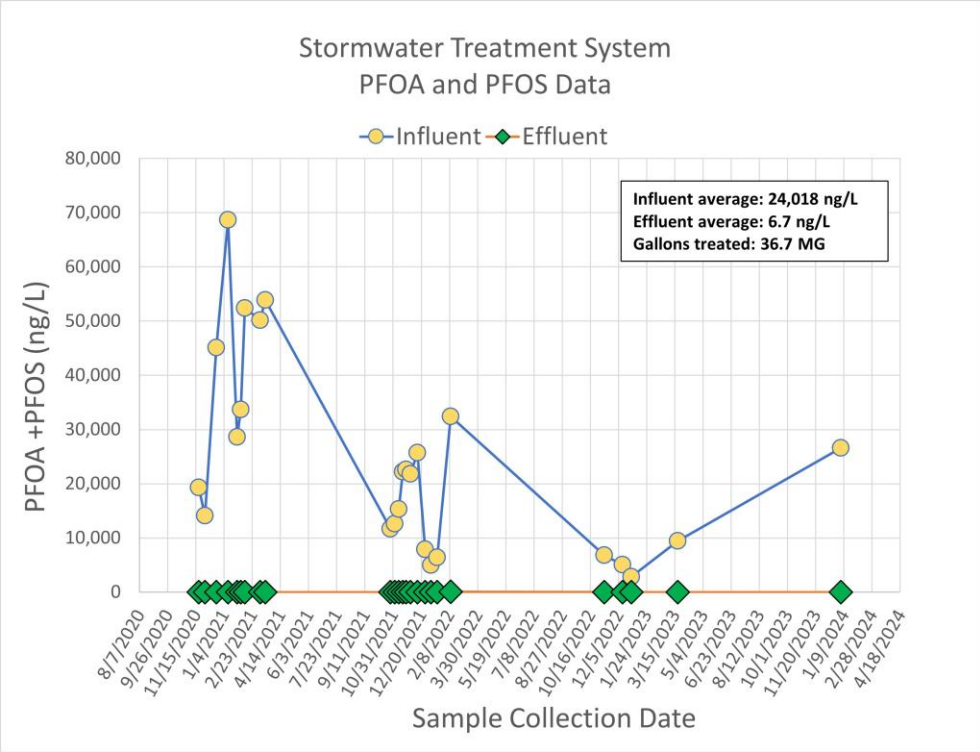

Case Study 2 – Passive In-situ GAC Treatment

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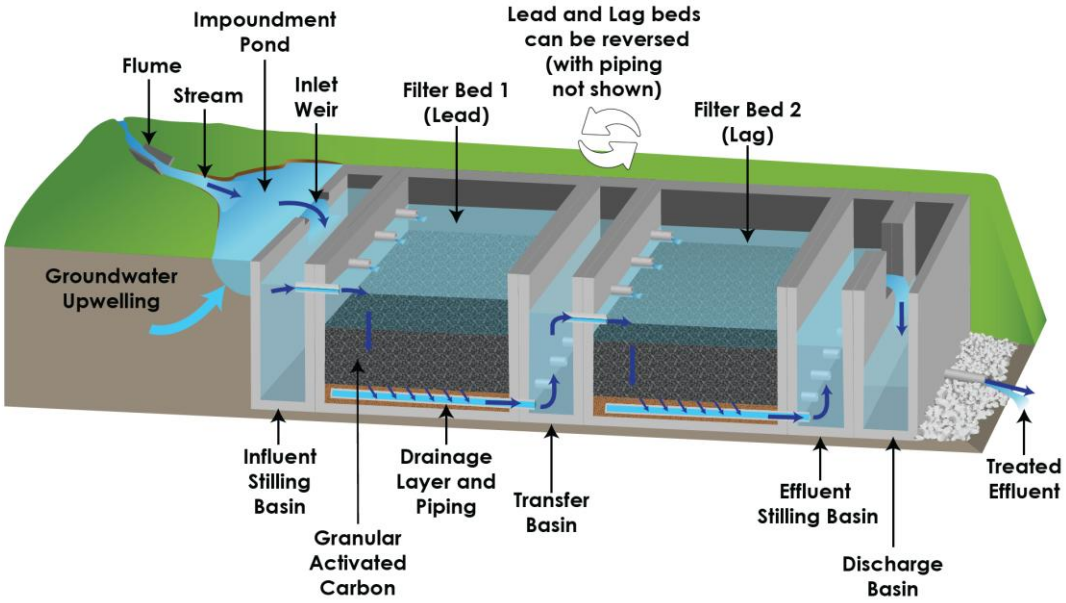
- Time-critical interim remedy was needed to treat PFAS-impacted groundwater seeps
- Passive filter beds were designed to reduce a minimum of 80% of the PFAS mass for a 690 gpm flow



Case Study 2 – Passive In-situ GAC Treatment

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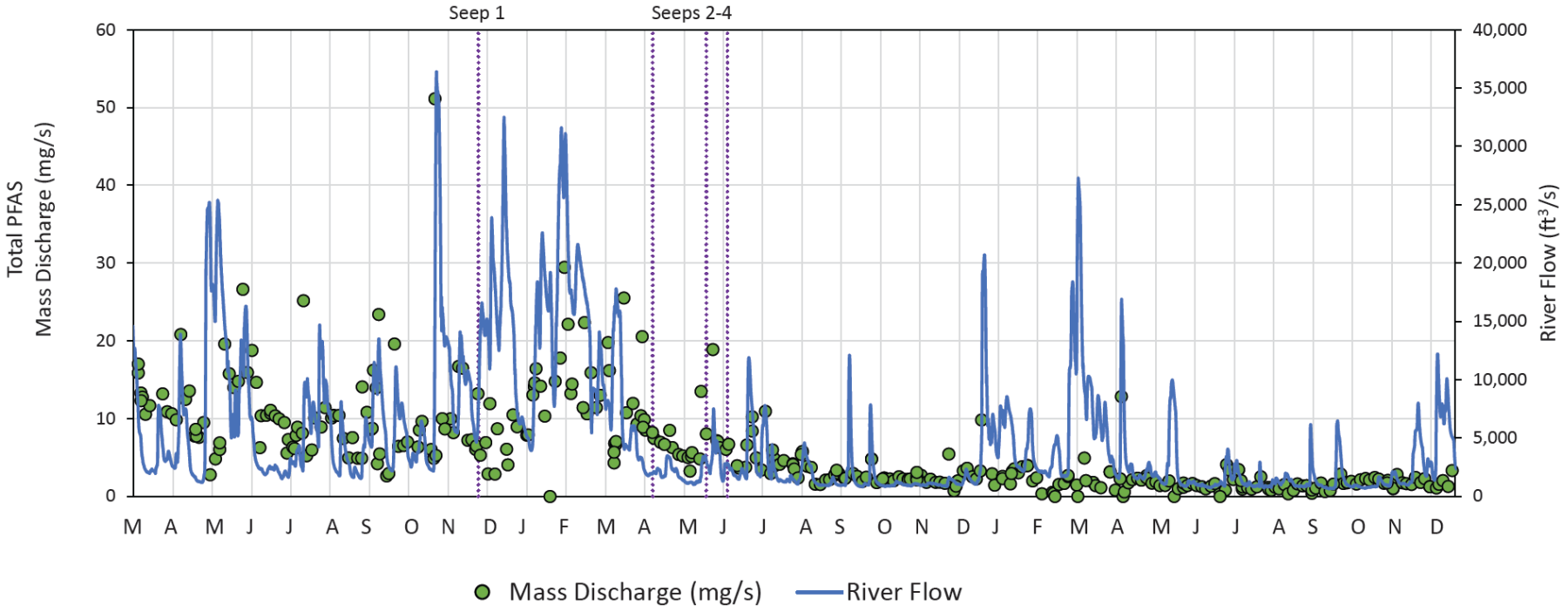

Case Study 3 – Sediment, Pondwater, and Secondary Liquid PFAS Treatment at Peterson SFB

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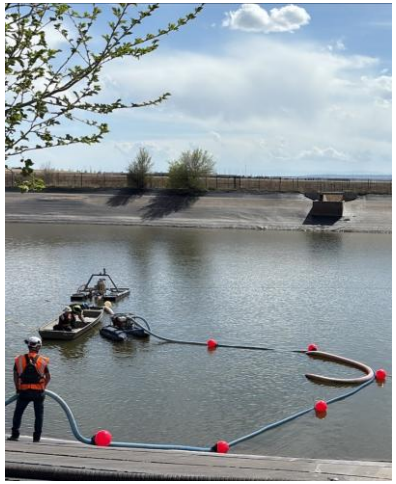
- Approximately 10 cubic yards of sediment were removed from a stormwater detention pond via hydraulic dredging
- Sediment was dewatered >70% solids and homogenized prior to solid treatment

	Sediment	Pond Water	Foam Fractionate
Total PFAS	55 µg/kg	881 ng/L	874 µg/L
PFOS (PFSAs)	40 (44) µg/kg	240 (402) ng/L	345 (577) µg/L
PFOA (PFCAs)	2.9 (8.7) µg/kg	82 (408) ng/L	98 (154) µg/L
6:2 FTS (FTSs)	2.7 (3.9) µg/kg	60 (64) ng/L	110 (126) µg/L
TOC	38,000 mg/kg	8 mg/L	N/A



Side-by-Side Evaluation of Field-Scale Treatment of PFAS-Impacted Sediments: Smoldering, Thermal Desorption, and Soil Washing followed by SCWO, HALT, and UV/SGM

Case Study 3 – Sediment, Pondwater, and Secondary Liquid PFAS Treatment at Peterson SFB

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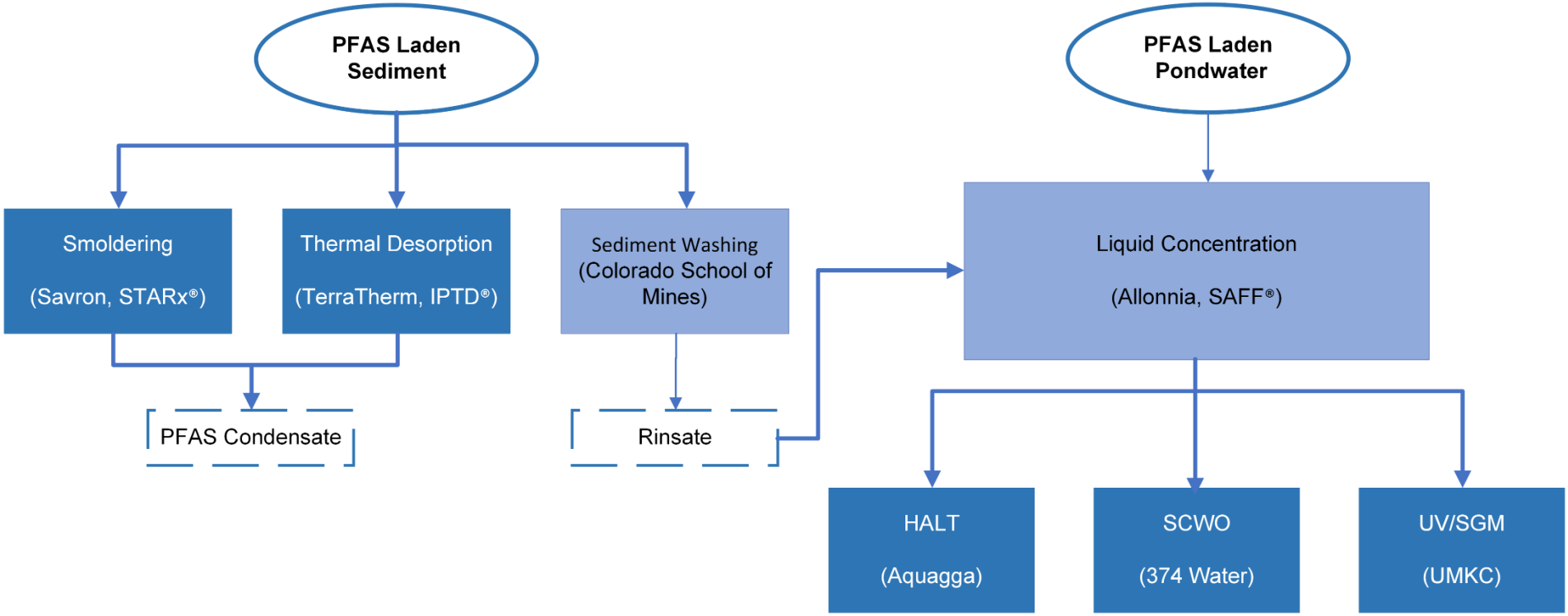
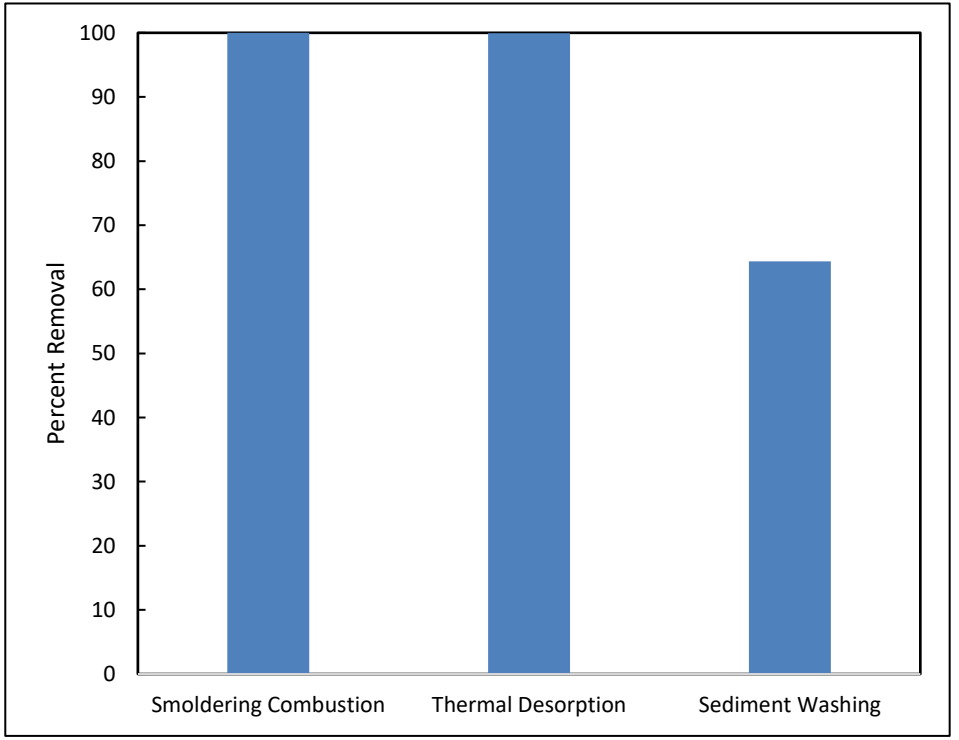


Case Study 3 – Sediment Treatment Summary



Case Study 3 – Pondwater Treatment Summary

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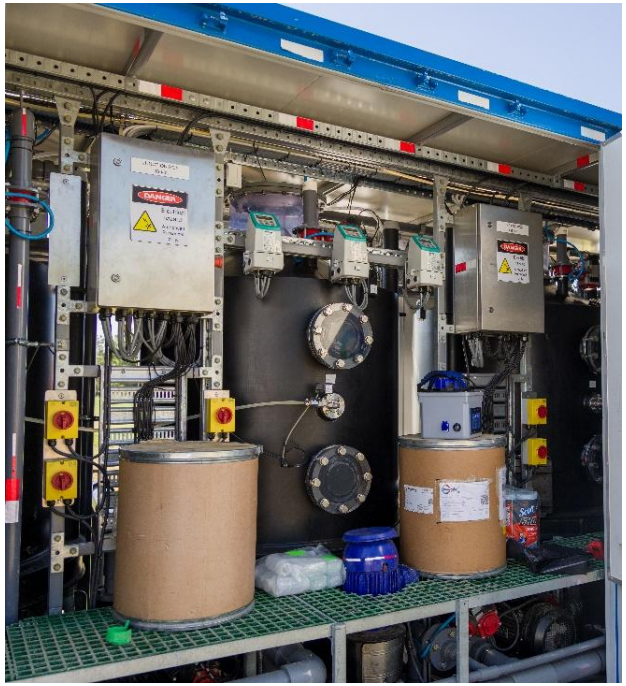
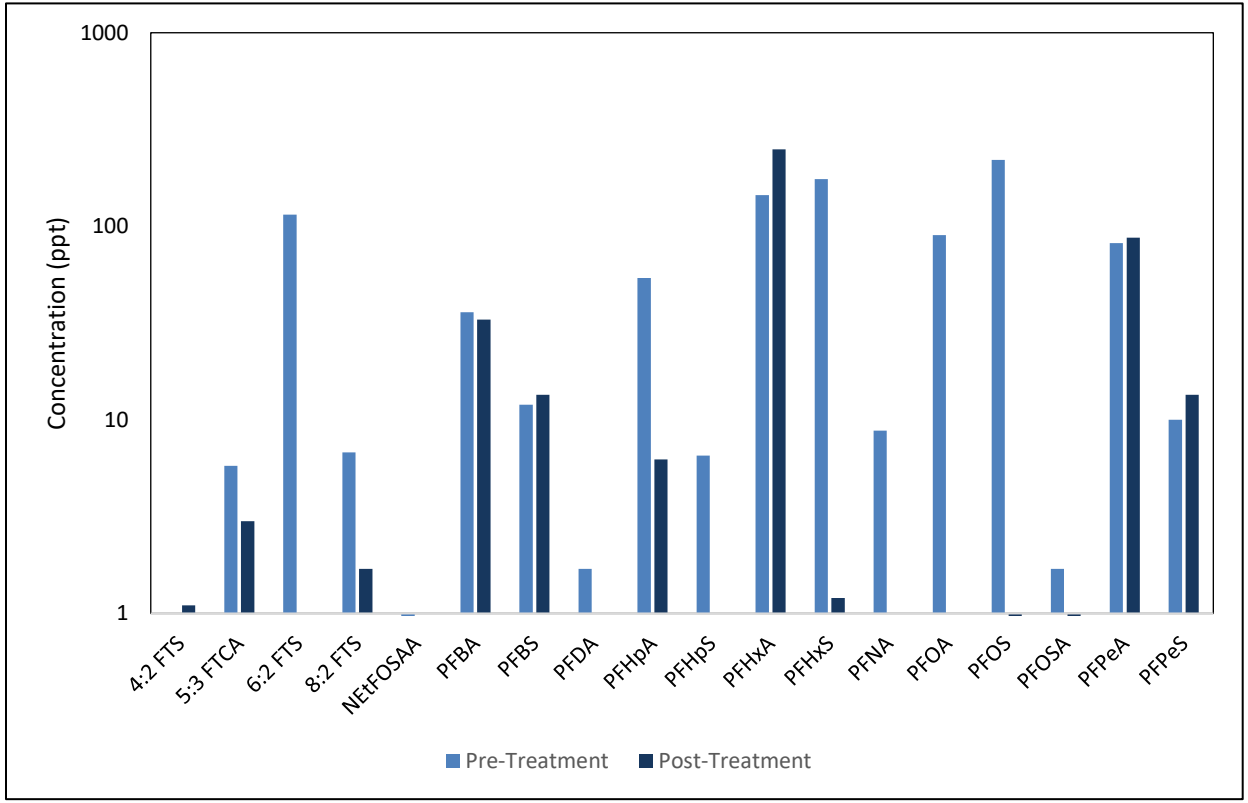


Surface Active Foam Fractionation



Case Study 3 – Foam Fractionate Treatment Summary

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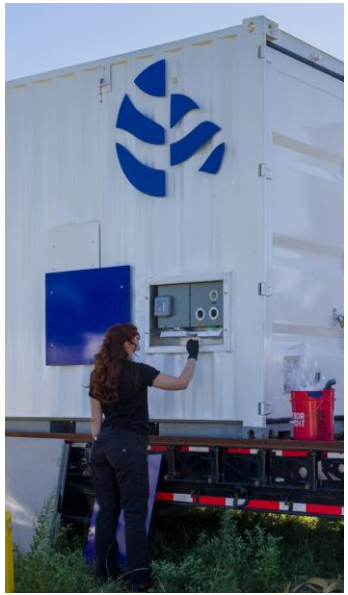

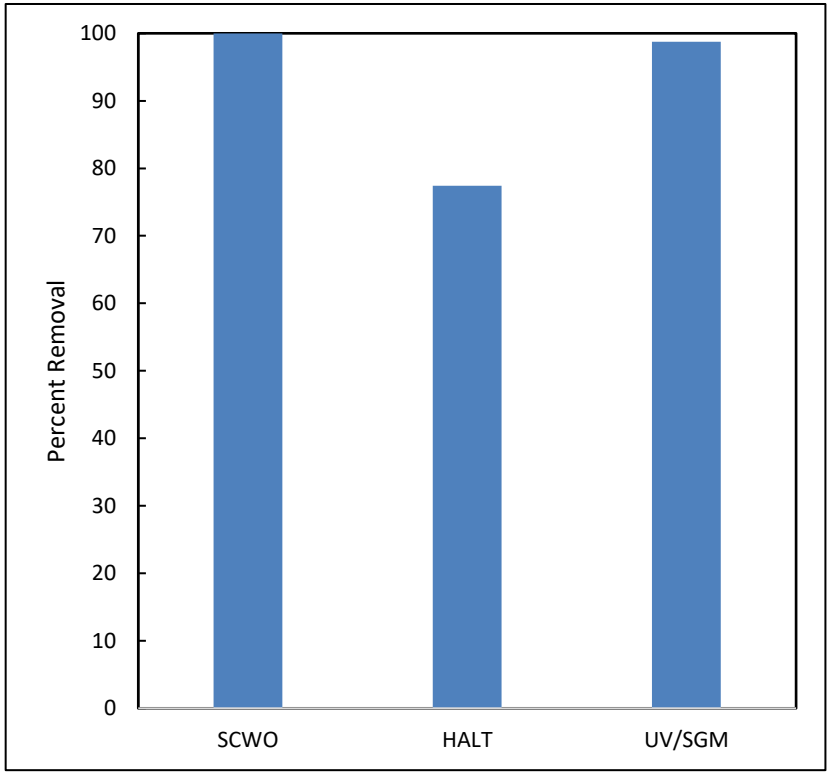

PFAS Remediation: A Complex Challenge Requiring Strategic Solutions

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- Impacted sites do not start with remediation, but once you get there a variety of technologies are available to treat PFAS.
- There is not a “one size fits all” technology for treatment.
- Treatment trains are often developed to treat PFAS and co-contaminants.
- Many destructive technologies are in development, however, cost and energy implications are still being evaluated.

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