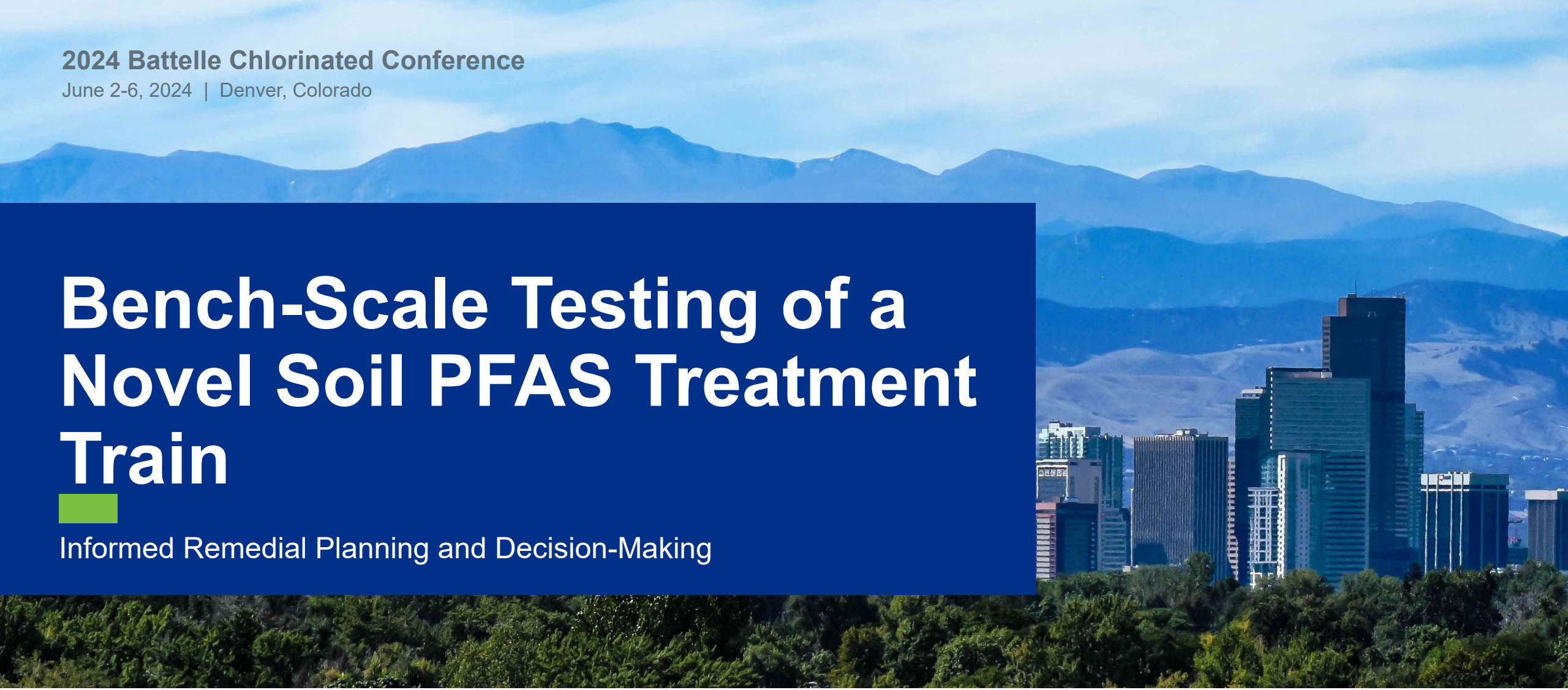
2024 Battelle Chlorinated Conference
June 2-6, 2024 | Denver, Colorado



Bench-Scale Testing of a Novel Soil PFAS Treatment Train

Informed Remedial Planning and Decision-Making

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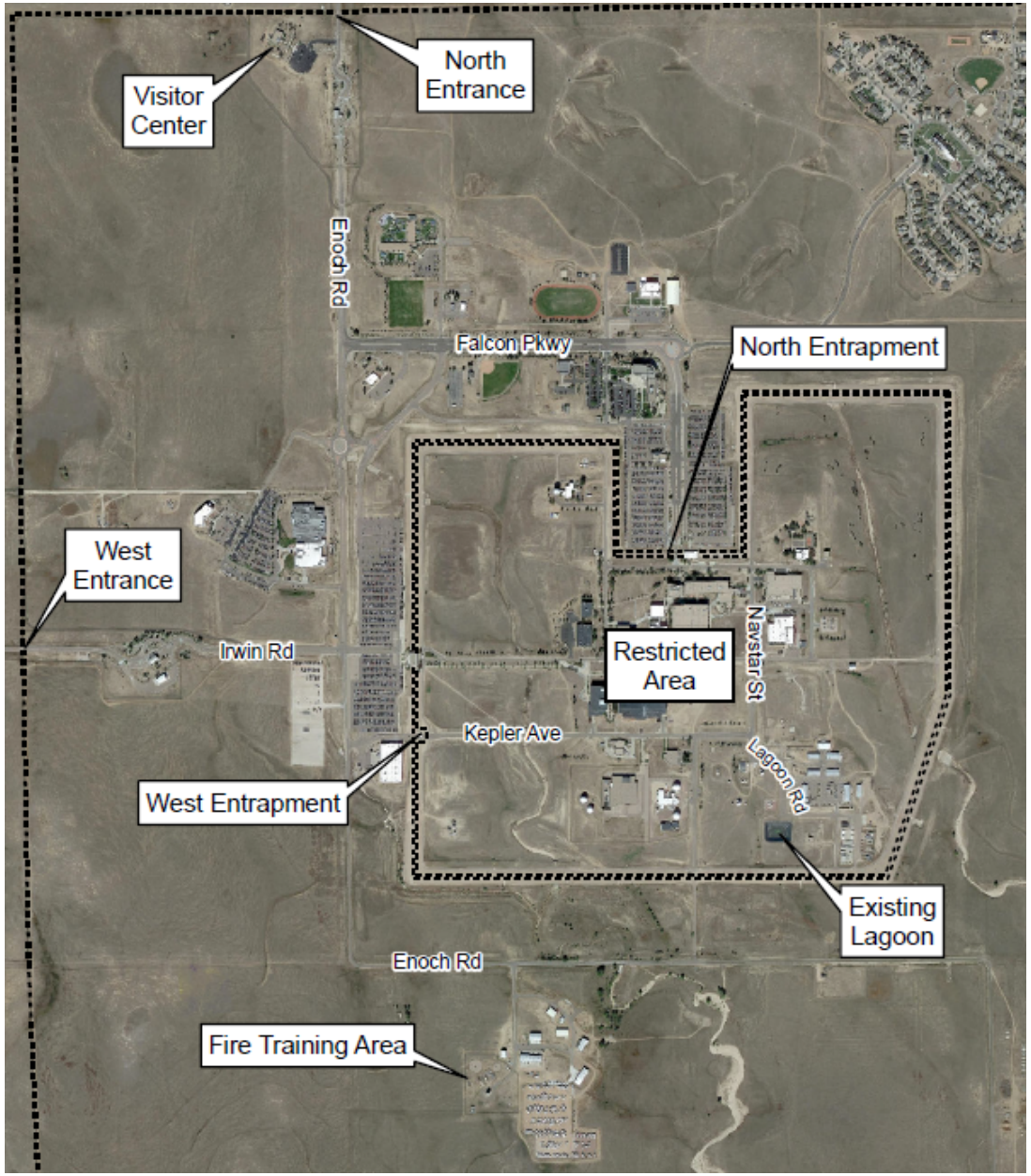
Project Overview and Objectives

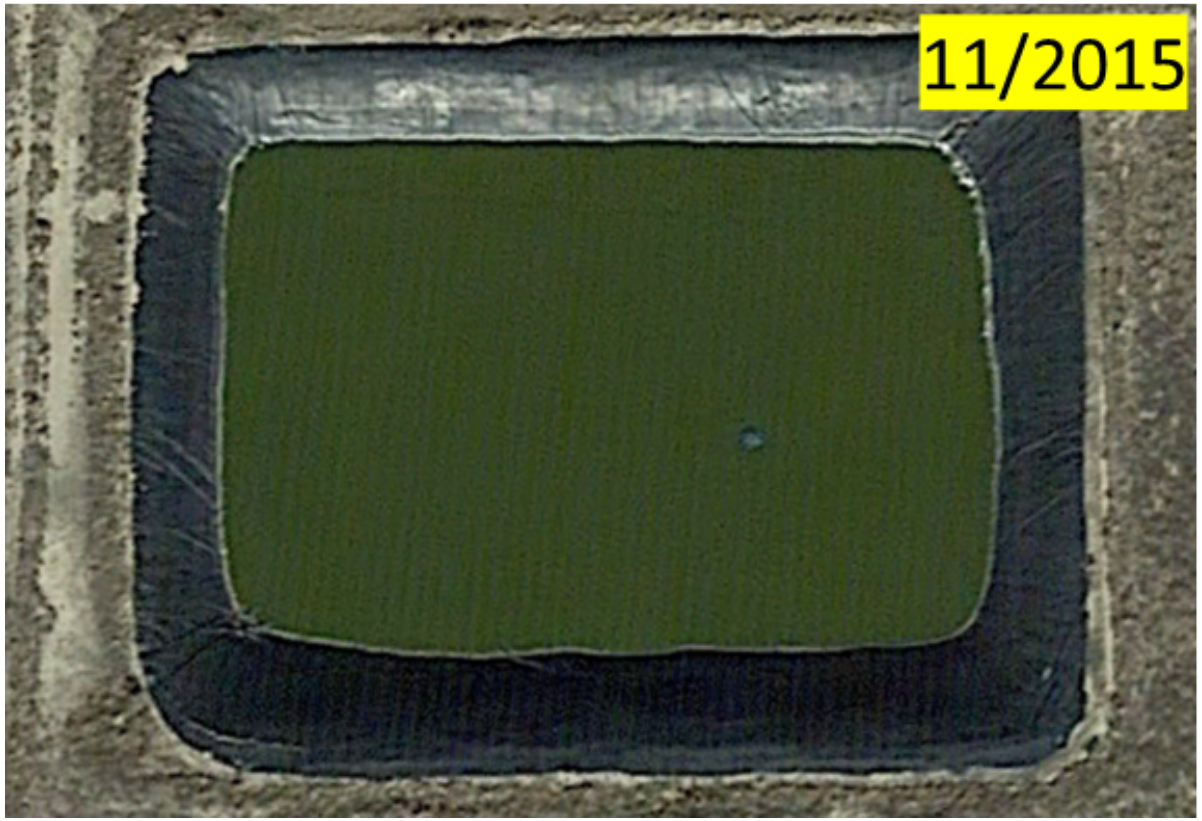
- **USACE Omaha District treatability study**
- **Goal = to address PFAS contamination in surface water, soil, and sediment**
- **Tasks:**
  - Site characterization
  - Treatability studies using site-specific materials
  - Pilot testing of soil washing, foam fractionation (SAFF) & electrochemical oxidation (ECO)
- **Treatment objectives:**
  - Soil/sediment: <126 µg/kg for PFOA & PFOS
  - Water: <70 ng/L for PFOA & PFOS (individually or combined)

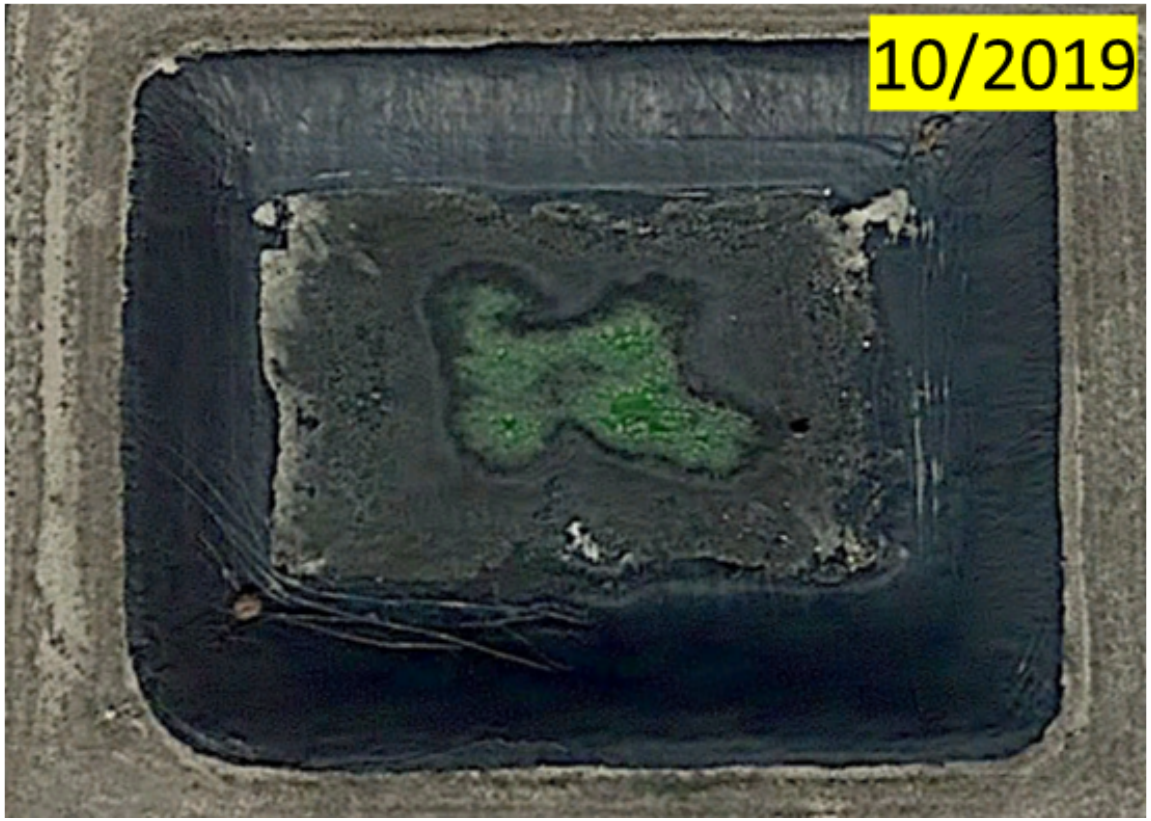
Site Background

- **Schriever Space Force Base, Colorado Springs, CO**
- **Area of interest:**
  - Fire Training Area (FTA)
  - Existing Lagoon (EL)
- **Media of interest**
  - Surface water
  - Soil at the FTA
  - Sediment above liner at the EL



Surprise!





Scope Change

Soil Characterization at FTA

Limited assessment of sediment above liner at EL

SAFF treatment of water in EL

Destruction using ECO

Scope Change

Soil Characterization at FTA

Comprehensive assessment of sediment above liner at EL

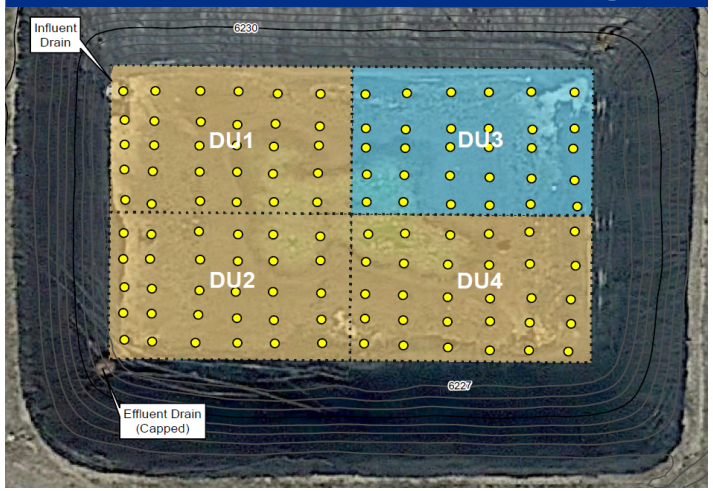
Comprehensive assessment of soil beneath the EL

SAFF treatment of soil washwater

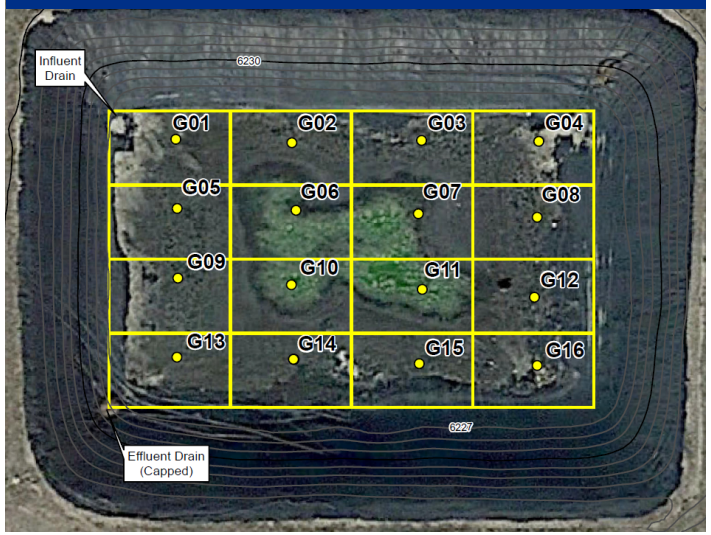
Destruction using ECO

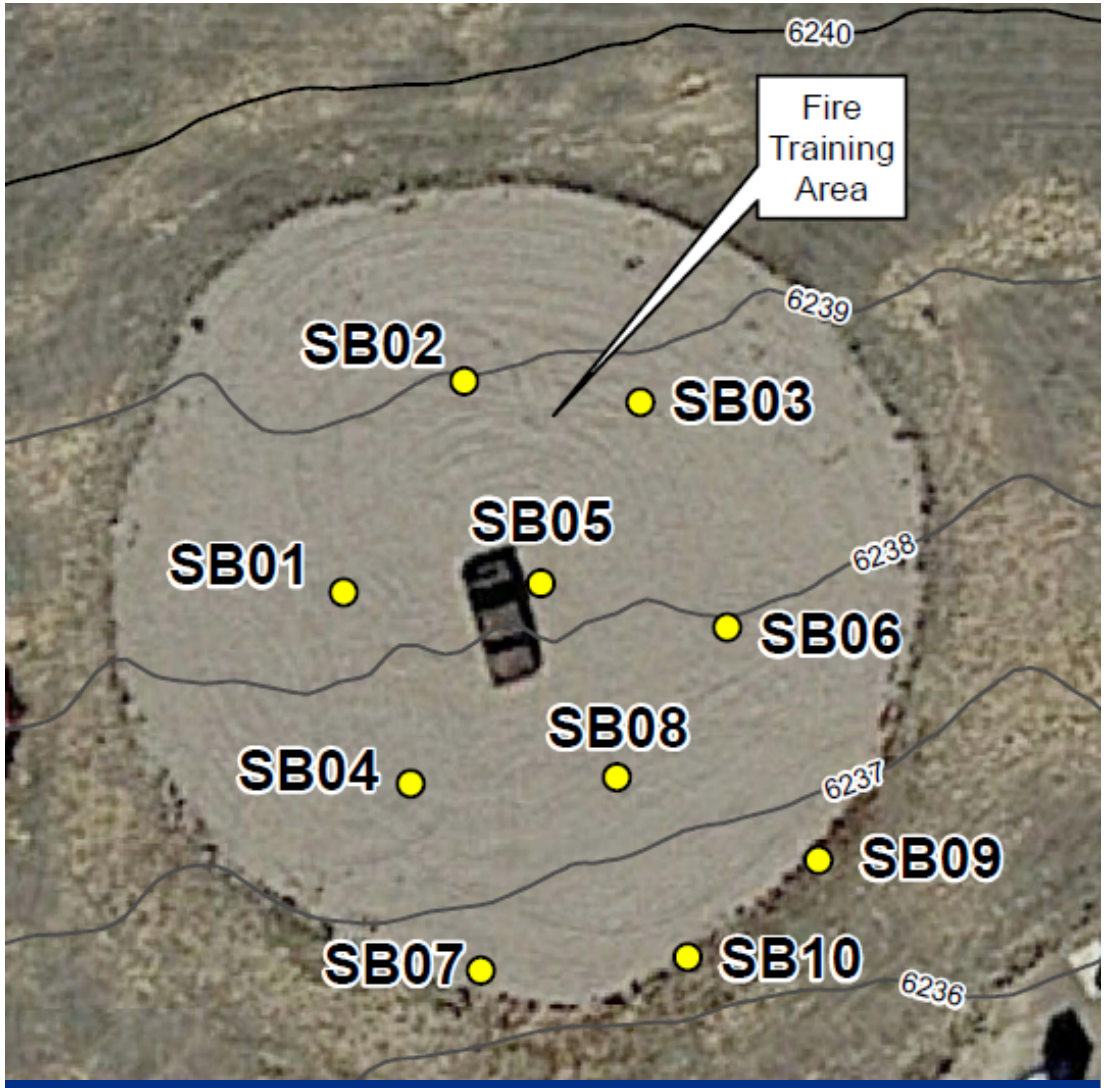
Soil and Sediment Characterization

EL Soil ISM Sampling



EL Sed Grab Sampling



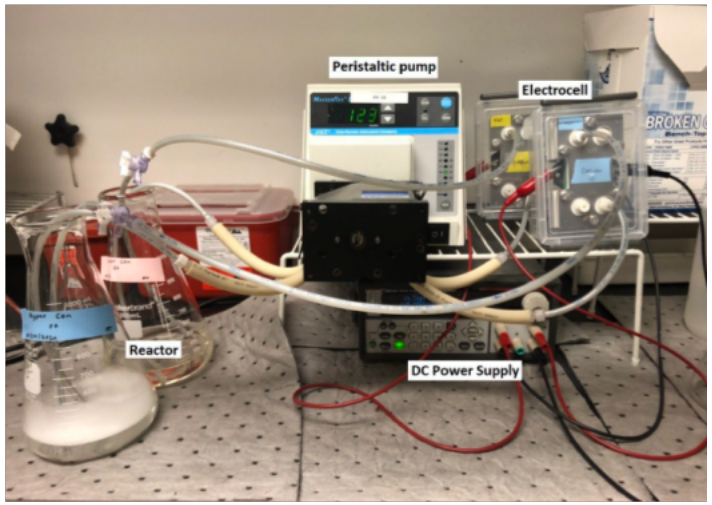


Grab Sampling at the FTA

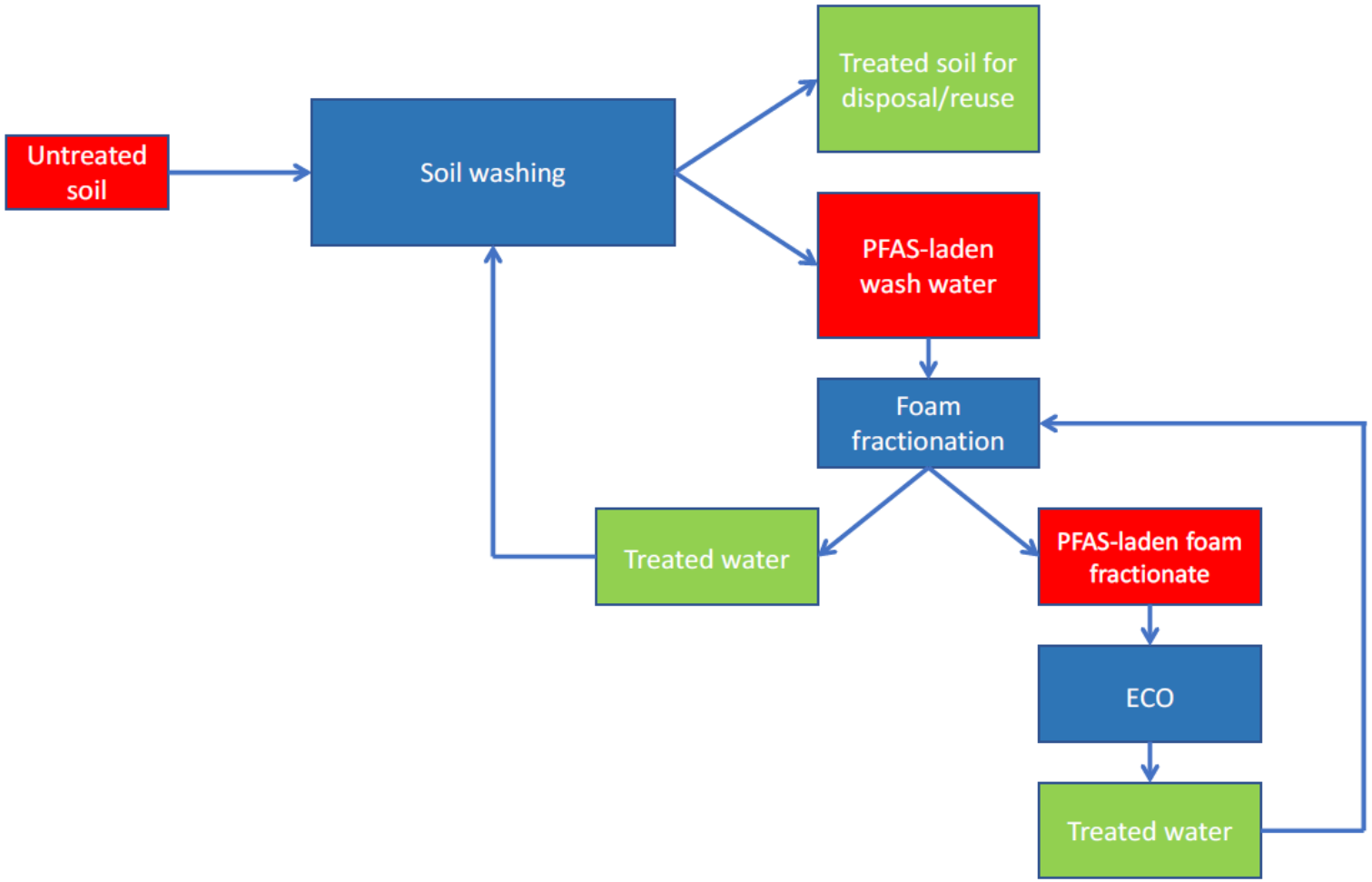
Technology Description

Soil washing

Foam fractionation



Electrochemical oxidation



Experimental Design

- **2 different types of media:**
  - EL soil (below liner)
  - EL sediment (above liner)
- **Wash water = hydrant water collected at the EL**
- **2 main stages simulated:**
  - Screening
  - Attrition scrubbing
- **Batch desorption (kinetics + isotherms) studies conducted side-by-side at CDM Smith's laboratory**

Screening

Attrition scrubbing

Batch desorption experiments

EL Soil vs. Sediment Characterization Data

Analyte	Soil Concentration (µg/kg)	Sediment Concentration (µg/kg)
PFBS	7.3	5,400
PFPeS	7.4	4,800
PFHxS	44	19,000
PFHpS	5.4	1,200
PFOS	280	28,000
PFBA	9.2	7,300
PFPeA	8.5	6,800
PFHxA	28	22,000
PFHpA	1.7	1,100
PFOA	4.9	1,700
Organic content	0.5%	14%
Material type	Medium to fine-grained sand	Desiccated organic material with little to no sand or coarser-grained fraction

Data from composited soil/sediment samples shown

Soil Washing Results

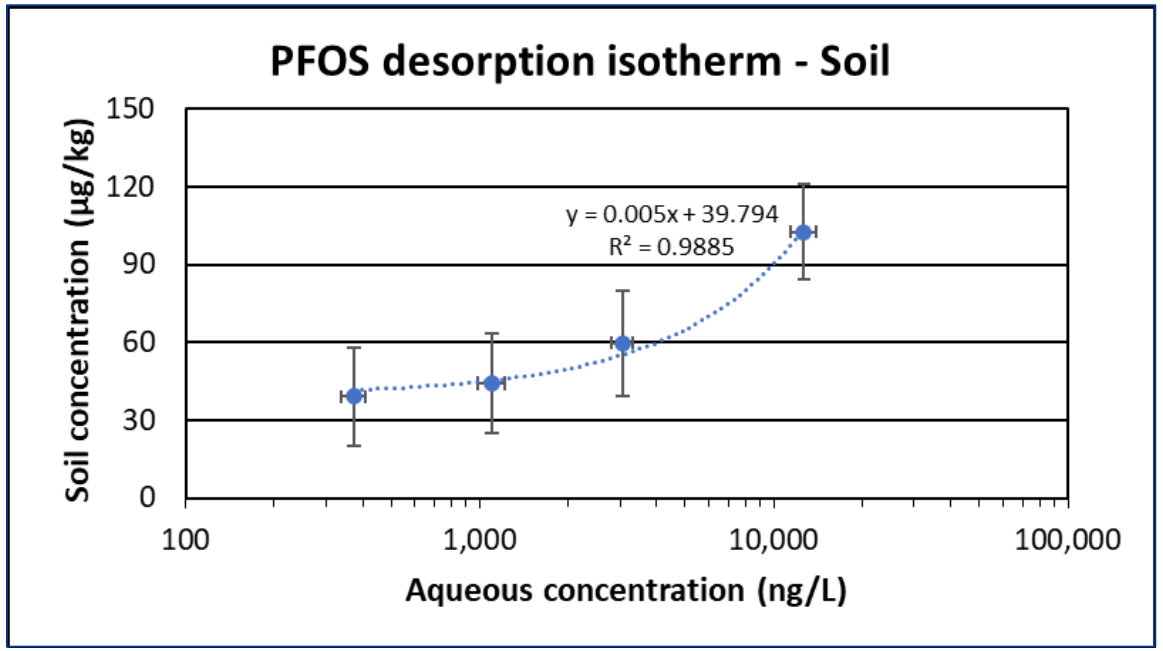
Sediment Above Liner

Material Type	Unit	PFBS	PFOA	PFOS	SUM PFAS
Untreated		5,400	1,700	**28,000**	98,120
Sand (<2mm + 0.063 mm)	ug/kg	NA	NA	NA	NA
	RE%				
Fines (<0.063 mm)	ug/kg	ND	220	**27,000**	29,730
	RE%	> 99%	87%	**3.6%**	69.7%

Soil Below Liner

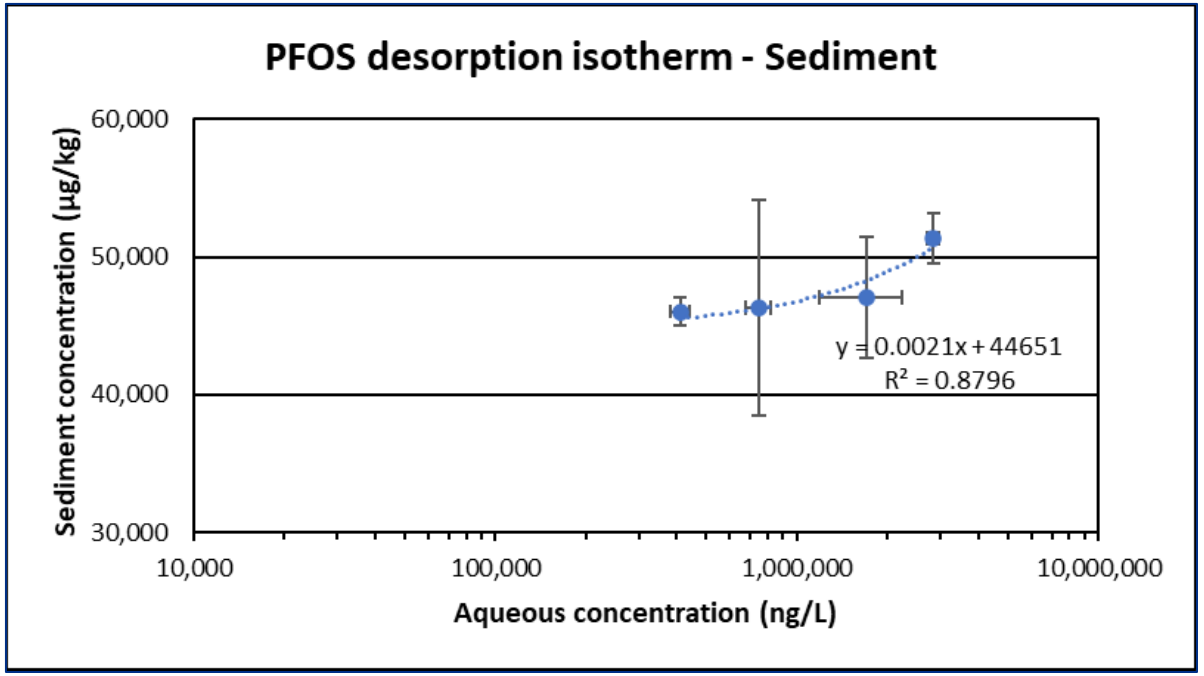
Material Type	Unit	PFBS	PFOA	PFOS	SUM PFAS
Untreated		7.3	4.9	**280**	402
Sand (<2mm + 0.063 mm)	ug/kg	ND	ND	**2**	2
	RE%	>99%	>99%	**99.2%**	99.5%
Fines (<0.063 mm)	ug/kg	1.1	ND	**130**	153.2
	RE%	84.9%	>99%	**53%**	61.8%

PFOS Desorption Isotherms



Material Type	Post Soil Washing PFOS Concentration (µg/kg)	
	*Measured by soil washing bench study**	*Predicted by batch desorption study*
Composited soil	20	40
Composited sediment	27,000	45,000

* *Grain size distribution taken into consideration to assess overall PFOS reduction*



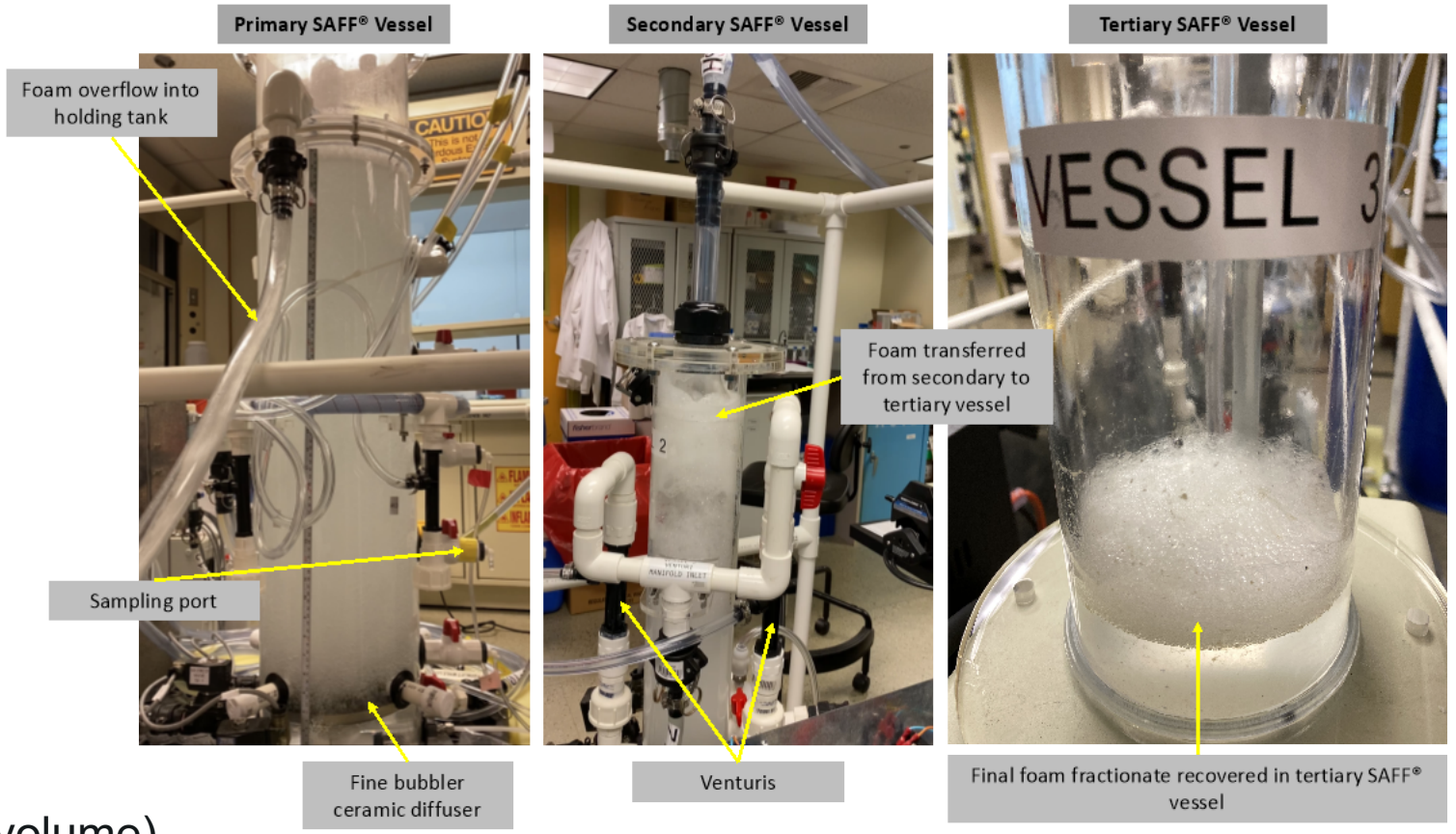
- PFAS mass flux to groundwater may diminish much more rapidly than PFAS mass in soil
- Y-intercepts represent the PFAS fractions that are not readily desorbable
- Substantial fraction of sorbed PFOS not readily desorbable

Site Characterization and Soil Washing Summary

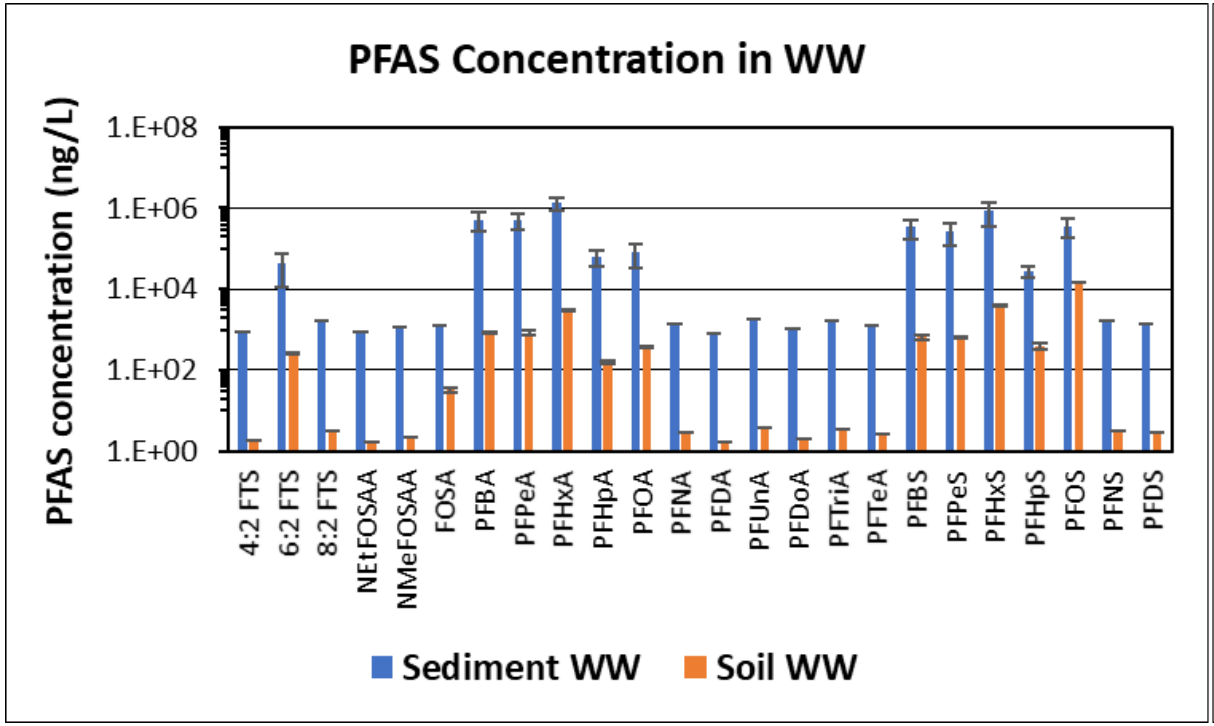
- Only minor exceedances in FTA soil → no treatment required
- Soil underneath liner at EL was much less impacted than the sediment above the liner
- Sand fraction was very effectively treated
- EL sediment was not amenable to treatment
- Batch desorption experiments can be used to reasonably predict soil washing performance (based on our limited data)

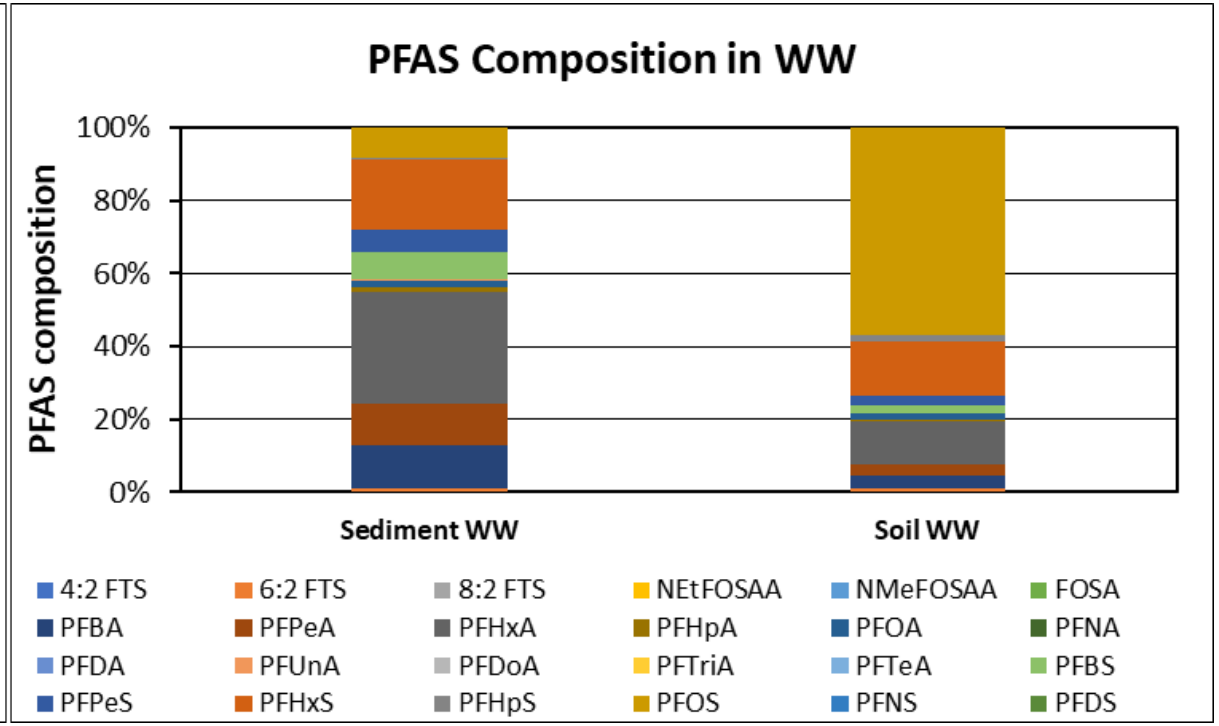
SAFF Experimental Design

- **2 different types of wash waters (WWs):**
  - EL soil WW
  - EL sediment WW
- **All testing in duplicate**
- **EL soil WW**
  - 2 treatment stages
  - With surfactant addition (at T0 min)
- **EL sediment WW**
  - 1 treatment stage (due to insufficient volume)
  - With surfactant addition (~60 mins)
- **Analyses = PFAS, EoF, pH, TOC, alk., cond., TSS/TDS, total/dissolved metals & CTAB**



WW Characterization



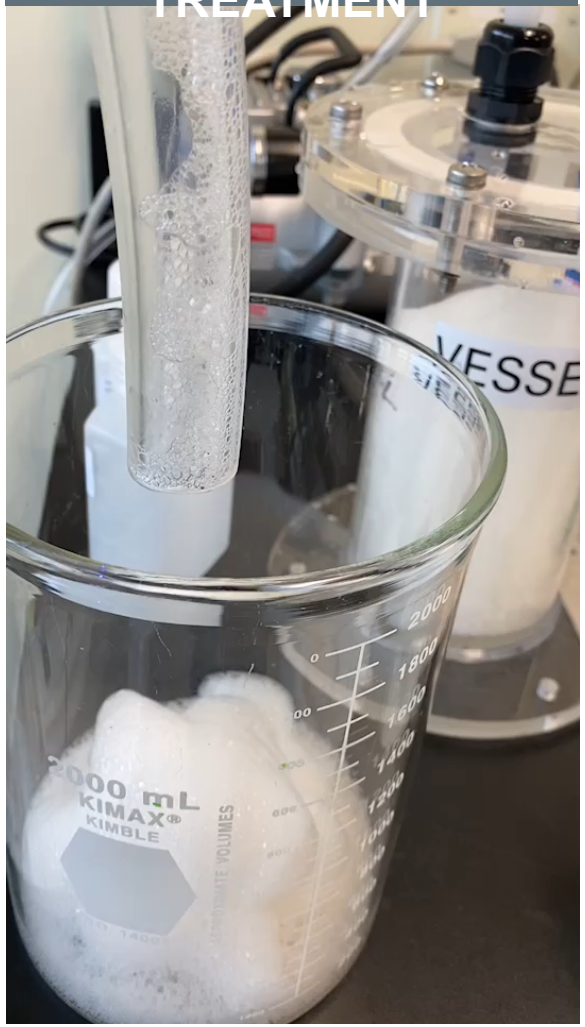


- Significantly higher PFAS concentrations in sediment WW
- Foaming potential: soil WW = very low; sediment WW = very high!
- Primary PFAS in soil WW = PFOS (57%) & PFHxS (15%)
- Primary PFAS in sediment WW = PFHxA (30%) & PFHxS (19%)

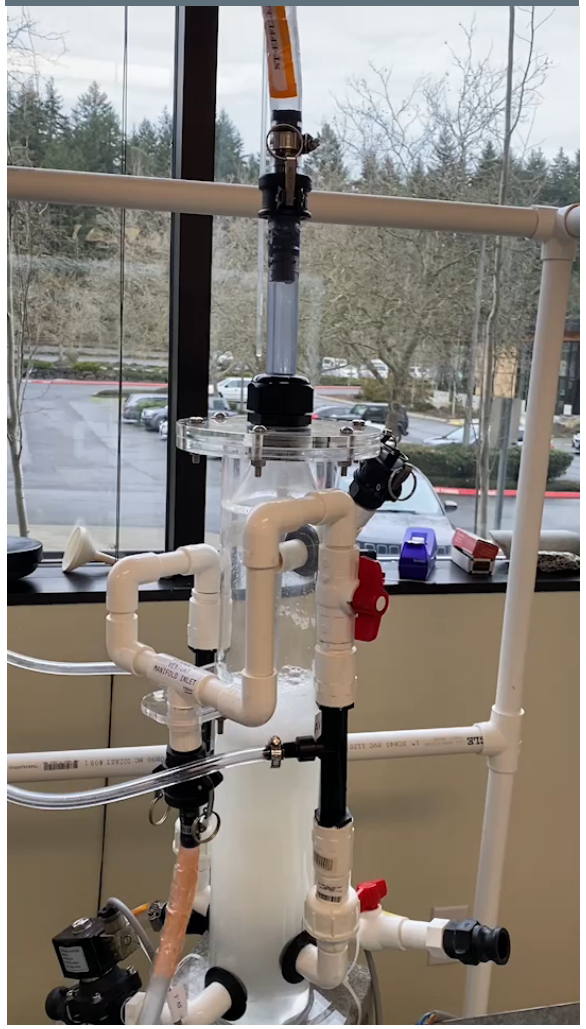
EL Soil Wash Water (with CTAB)

PRIMARY TREATMENT

SECONDARY TREATMENT

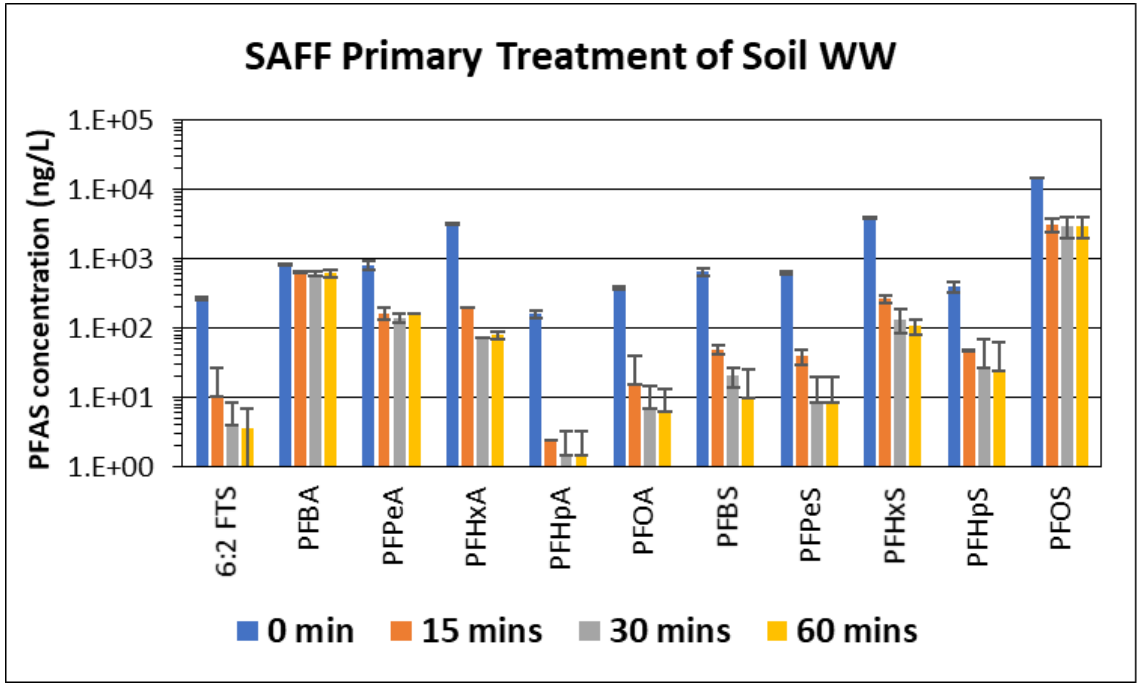


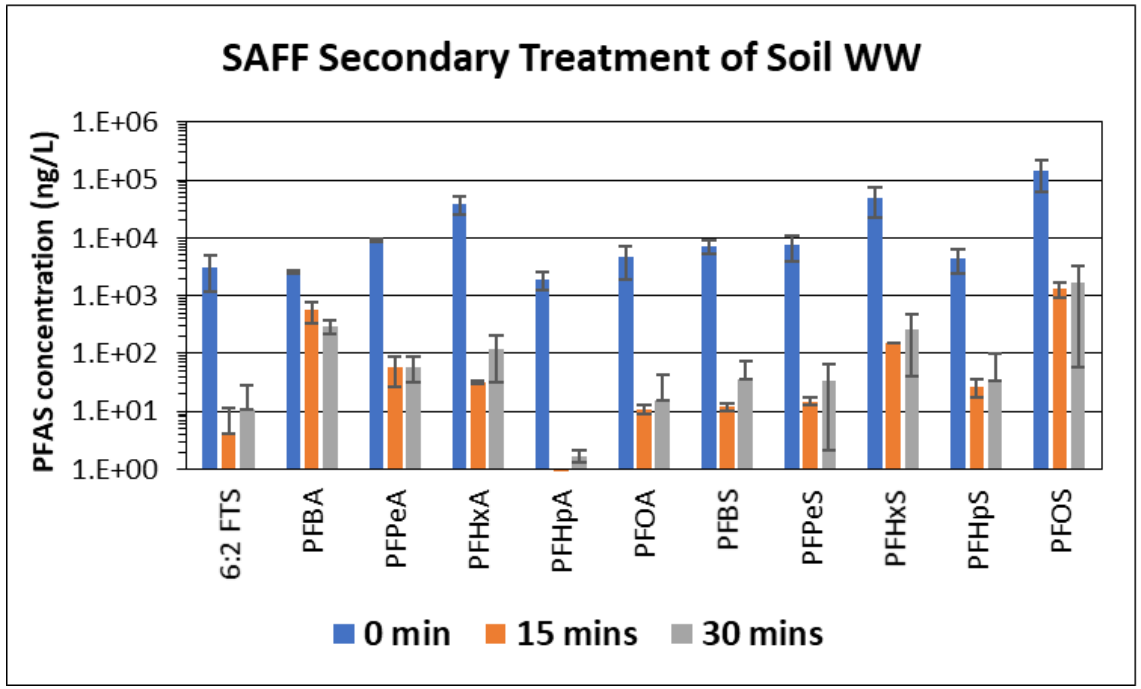
FINAL FOAM



Very dry foam & good volume reduction with CTAB addition (~1,000x)

Soil WW Treatment



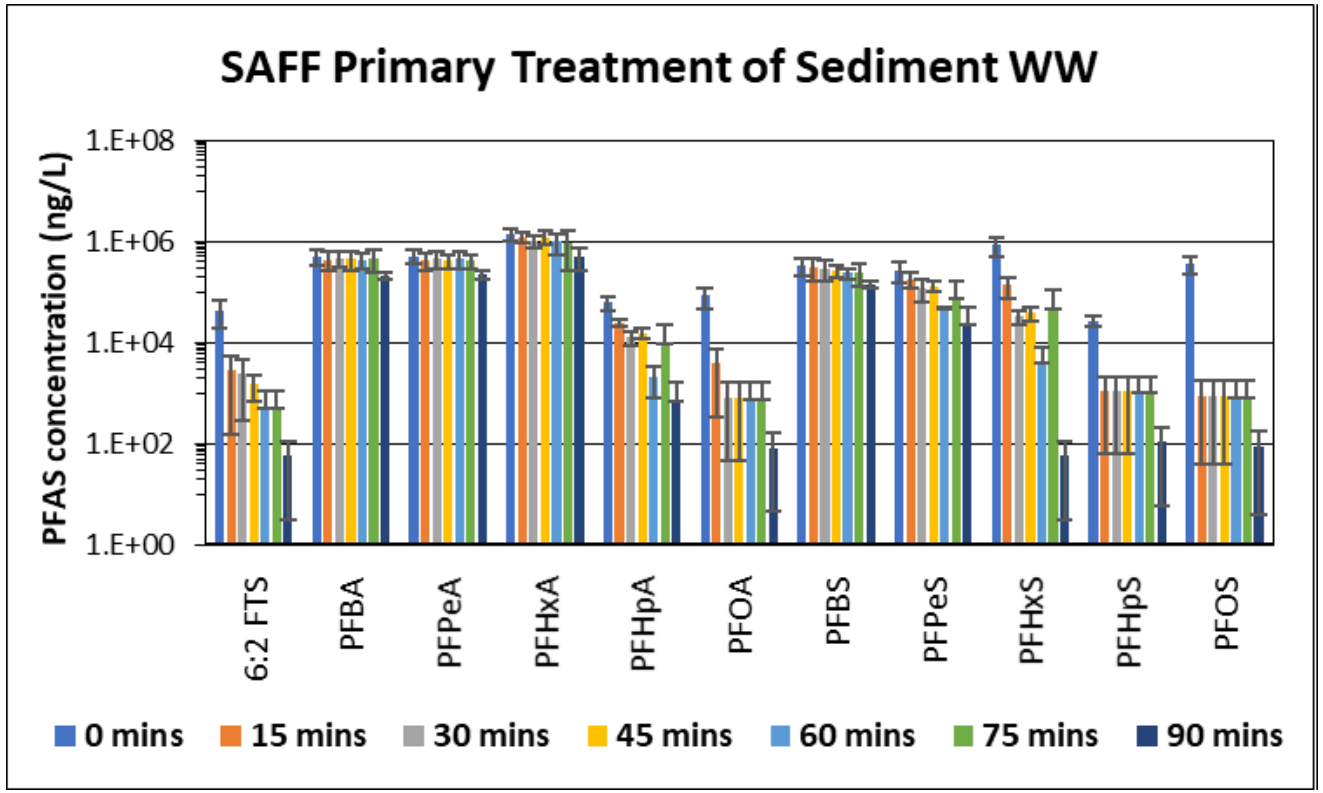


- Good removal of FTS and most short- & long-chained PFCAs & PFSAs
- In general, long-chained PFAAs were treated more effectively
- Most of the PFAS removal occurred within the first 15 mins of treatment

Notable Results/Observations – Soil WW

- Did not foam readily → surfactant addition will likely be needed to facilitate foaming
- CTAB addition resulted in generation of dry foam & very good waste volume reduction (~1,000x)
- Good PFAS treatment generally observed across two treatment stages
- CTAB readily removed from bulk solution

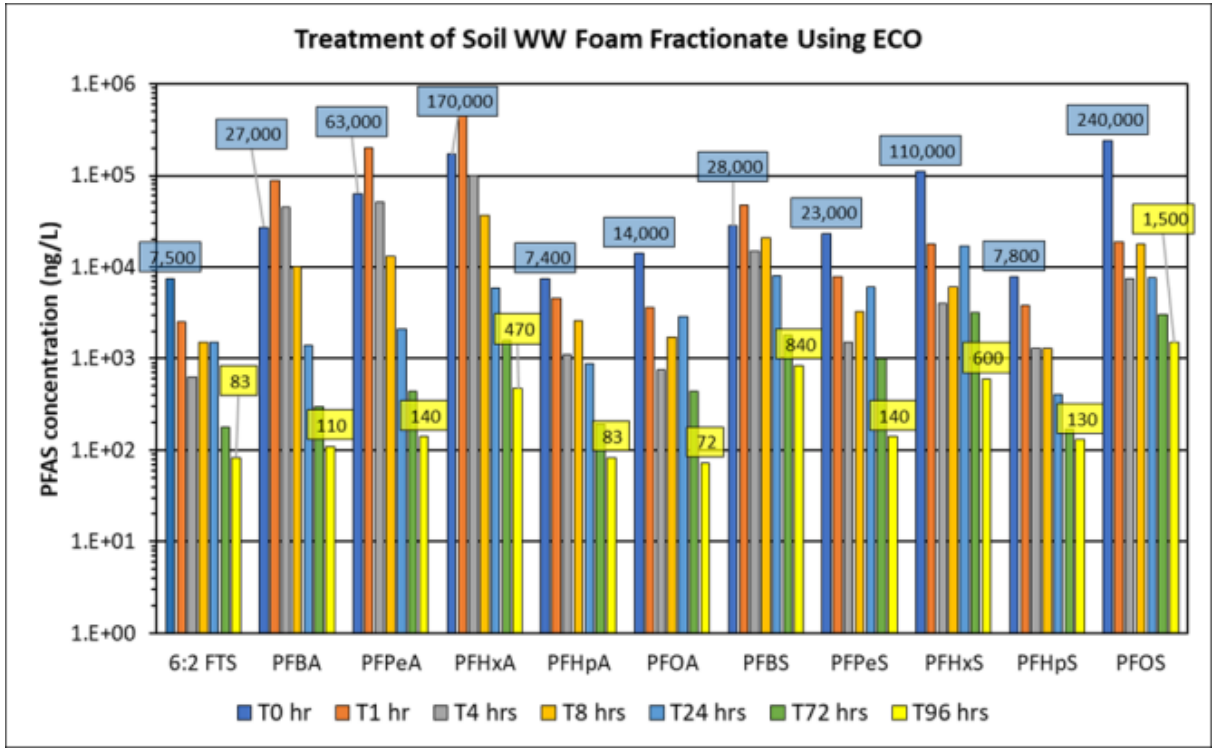
Sediment WW – Primary SAFF Treatment



- Multi-log reduction of FTS and all long-chained PFAAs
- CTAB addition after 60 mins improved overall treatment effectiveness
- Good PFAS mass balance for most long-chained PFAAs; poor recoveries for others likely due to analytical interferences

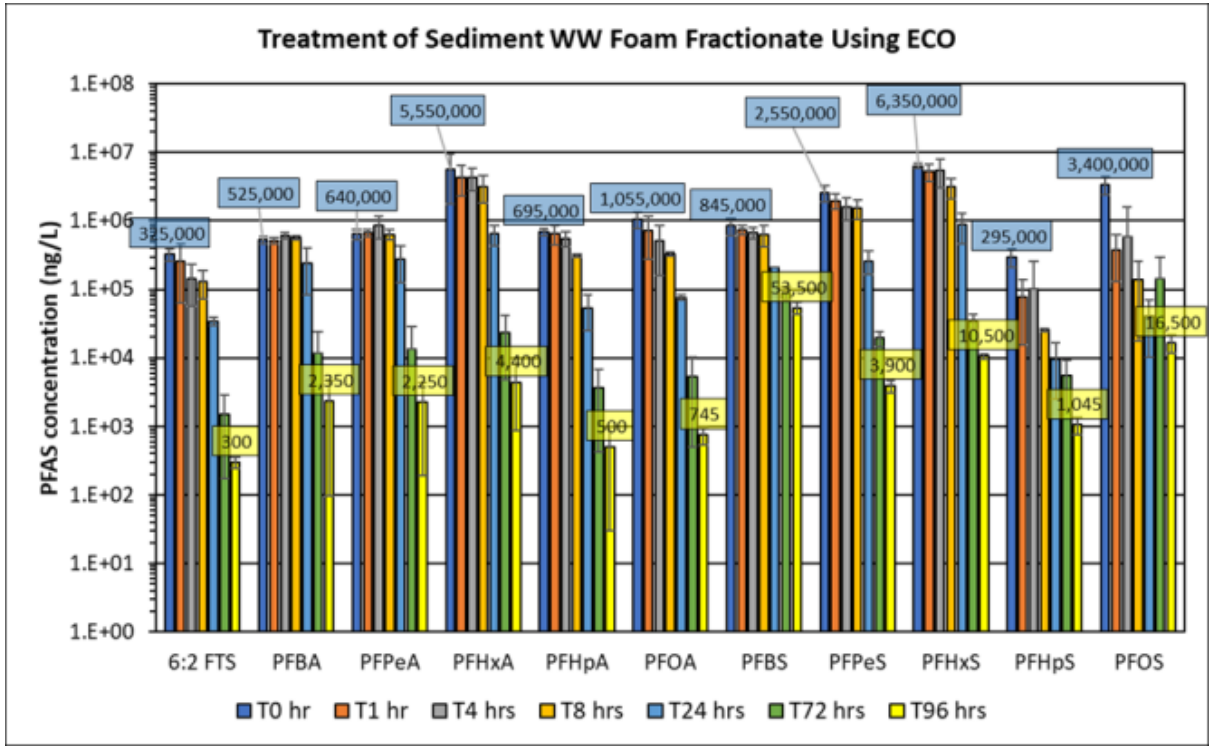
Error bars = 95% CI; only 1 treatment stage performed

Treatment of Foam Fractionates Using ECO



- **Multi-log reduction** of all compounds within 96 hours
- **Transient generation of short-chain PFCAs** after the first hours of treatment
- Unable to achieve the 70 ng/L treatment goal for PFOA & PFOS
- Cannot discharge directly; **treatment polishing needed**!

- Very little PFAS degradation seen with sediment WW within the first 24 hours of treatment
- **Multi-log reduction** of all compounds within 96 hours
- Unable to achieve the 70 ng/L treatment goal for PFOA & PFOS



Conclusions and Key Implications

- AFFF-impacted sandy soils with low organic content may be amenable to treatment via **soil washing**
- Removal of hydrophobic PFAS, such as PFOS, from organic-rich sediments may be very challenging
- Simple batch tests can potentially be used as a predictive tool for assessing treatment efficacy of soil washing
- **Foam fractionation** may be effective in removing and concentrating the PFAS present in the soil WWs
- **ECO** can effectively reduce PFAS concentrations in the foam fractionate generated during foam fractionation by several orders of magnitude
- Generation of unwanted products may warrant further treatment and/or disposal
- The **proposed combined treatment train** may be applicable in select applications and therefore should be further explored at the pilot-scale.

Thank you!

To learn more, contact:

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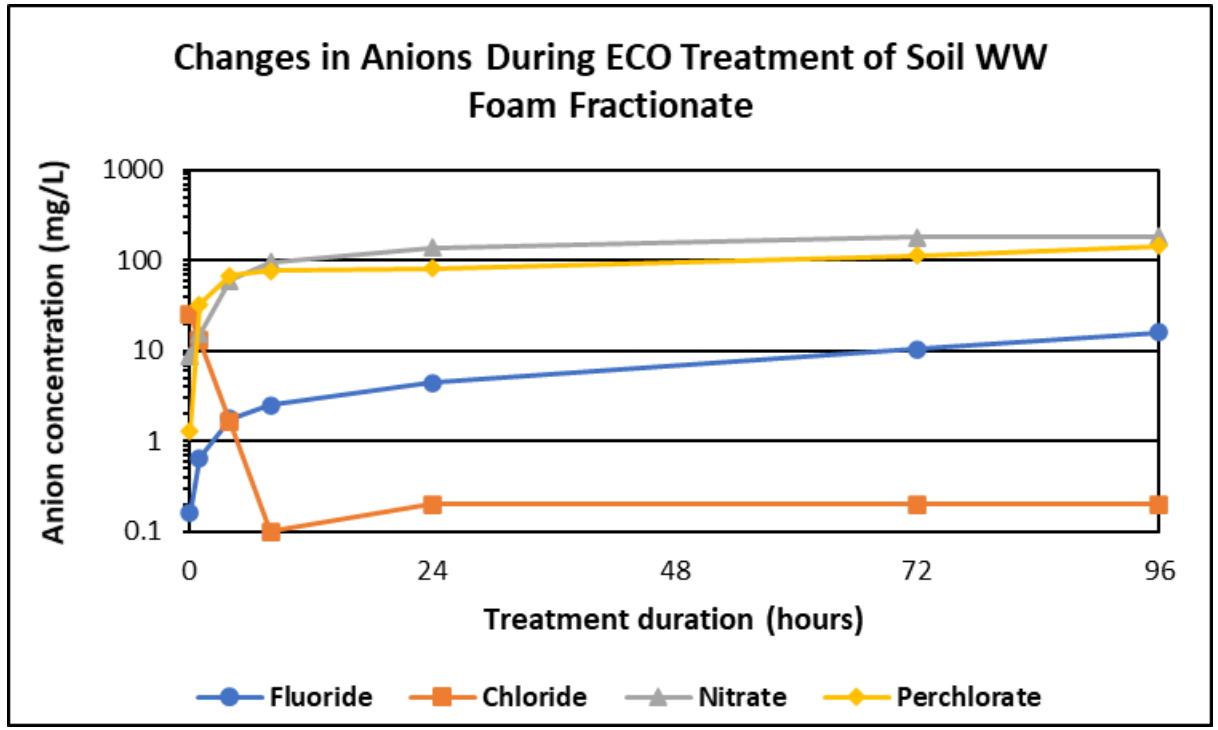
Secondary Water Quality Changes Due to ECO



→ Good fluoride mass balance

→ Complete oxidation of chloride to perchlorate

→ Nitrate generated as a result of CTAB oxidation