Electro-Osmosis Removal of PFAS from Impacted Soils

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Problem Statement and State of the Art

- Large number of PFAS-impacted DoD installations (~700) resulting from repeated use of aqueous film-forming foam (AFFF) for fire training and emergency response
- Need to treat PFAS-impacted soil, groundwater, and surface water
- Soil treatment Technologies are still evolving
- Need for In–situ Technologies as the ex-situ technologies might be very expensive

The Challenge: Traditional Soil Remediation

- PFAS can strongly bind to soil particles.
- Many common soil remediation techniques are ineffective for PFAS:
    - Soil Vapor Extraction (Low volatility of PFAS at normal temperature)
    - Bioremediation (Not effective)
- Some methods can address PFAS, but they are expensive and energy-intensive.
    - Thermal desorption (high heat)
    - Soil washing (large volumes of solvent)

Source: https://astenvironmental.com/services/soil-and-waste-excavation/

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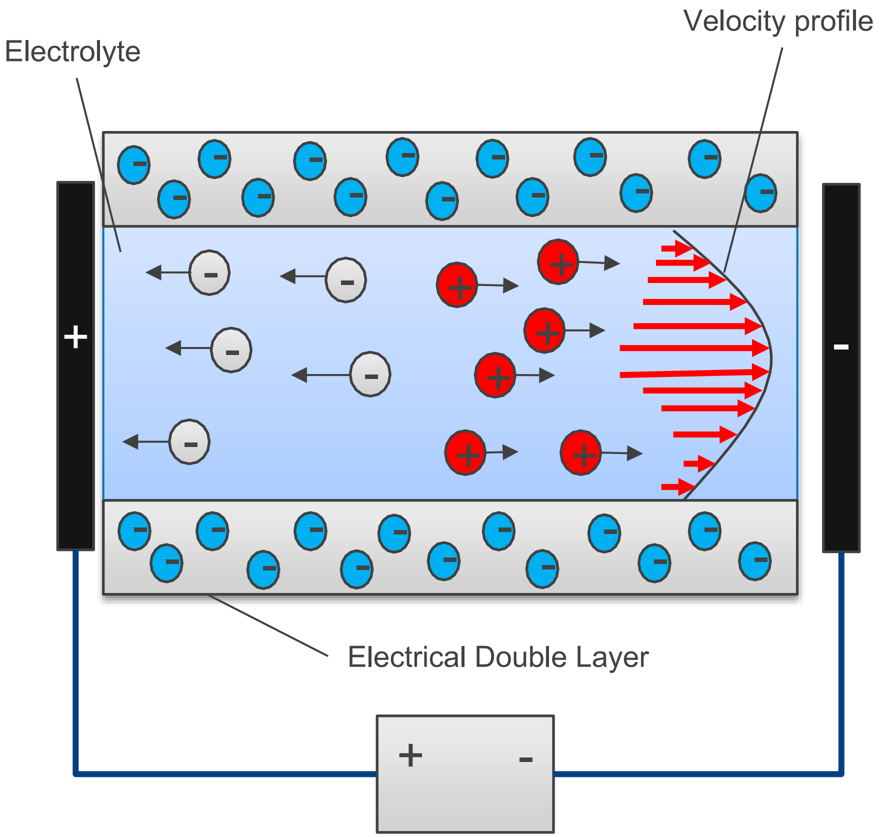
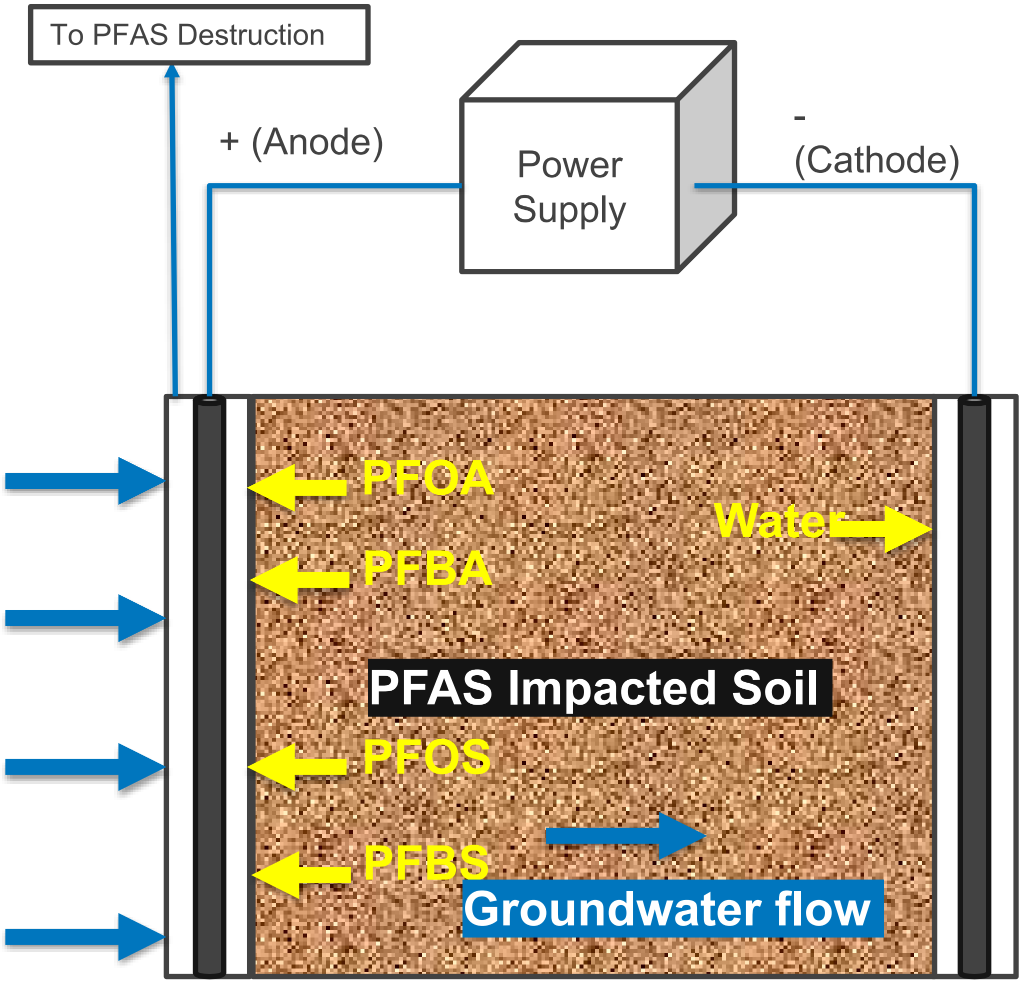
Unveiling Electroosmosis

- Application of electro-osmosis for the removal of contaminants from soil is a Battelle-patented technology (US 5,098,538) which could be applied for PFAS removal from soil using less energy intensive conditions.
- Movement of a liquid through a channel under the influence of an electric field.
- This phenomenon occurs in porous materials, capillary tubes, and biological membranes.
- The interaction of the electrical double layer with the electric field causes the phenomenon.



PFAS Electro-Osmosis

- This technique uses an electric current to mobilize PFAS ions in the soil, enabling their separation and removal.
- Electroosmosis can be applied as in situ and ex-situ treatment technology.
- Extracted PFAS could be further treated using commercially available PFAS destruction technologies.



Technology Approach - Electroosmotic Modeling

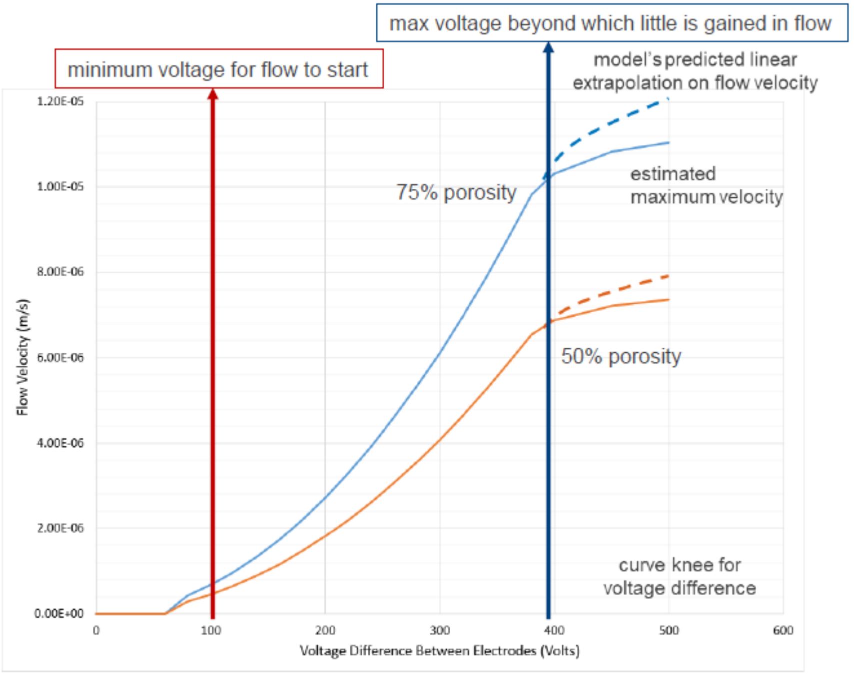
- Applying electrical field modeling and physics to understand phenomena, design experiments, and develop fieldable systems.

Factors Influencing Electroosmosis:

- Surface charge density (Zeta Potential)
- Applied electric field strength
- Liquid viscosity
- Microchannel Geometry
- Chemical of Interest properties (Dielectric Constant, Ionization Potential, Density, etc..)

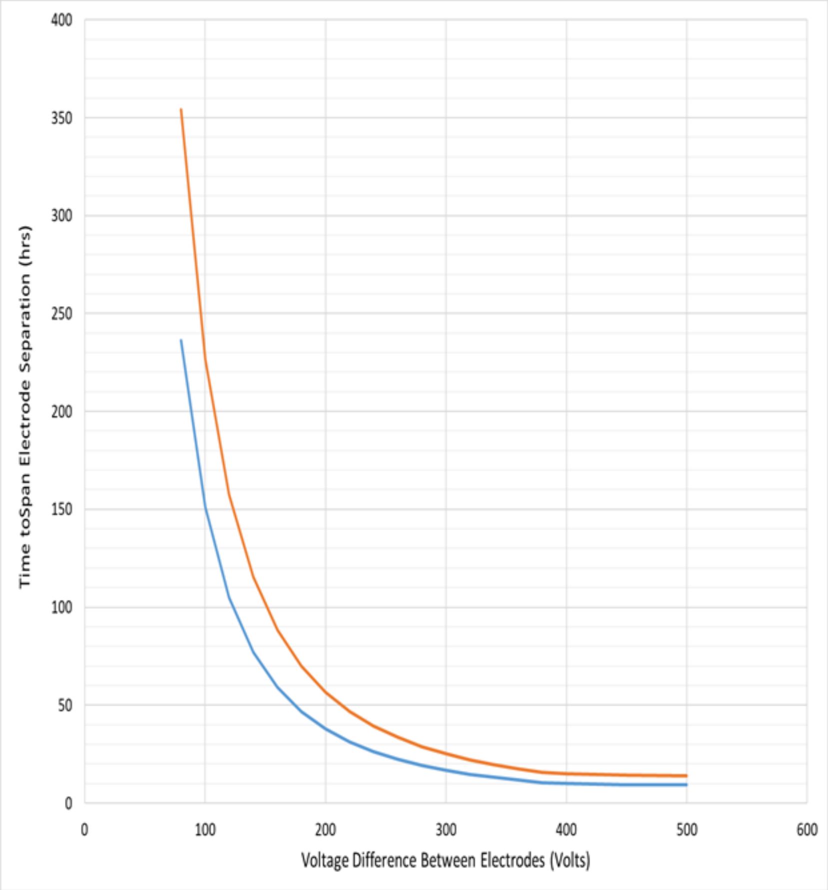
Electric force on fluid

$$\rho \frac{dv}{dt} = -\nabla p + \underbrace{\mu \nabla^2 v}_{\text{Viscous resistance to electrical flow}} + F_E$$



Modeling Results

- The modeling allows us to estimate the time a PFAS molecule is needed to flow from one electrode to another.
- The time to cover the electrode span significantly decreases with higher voltage
- One can initiate electroosmotic flow at the minimum lower voltage, but significantly faster flow will occur at the upper limit.



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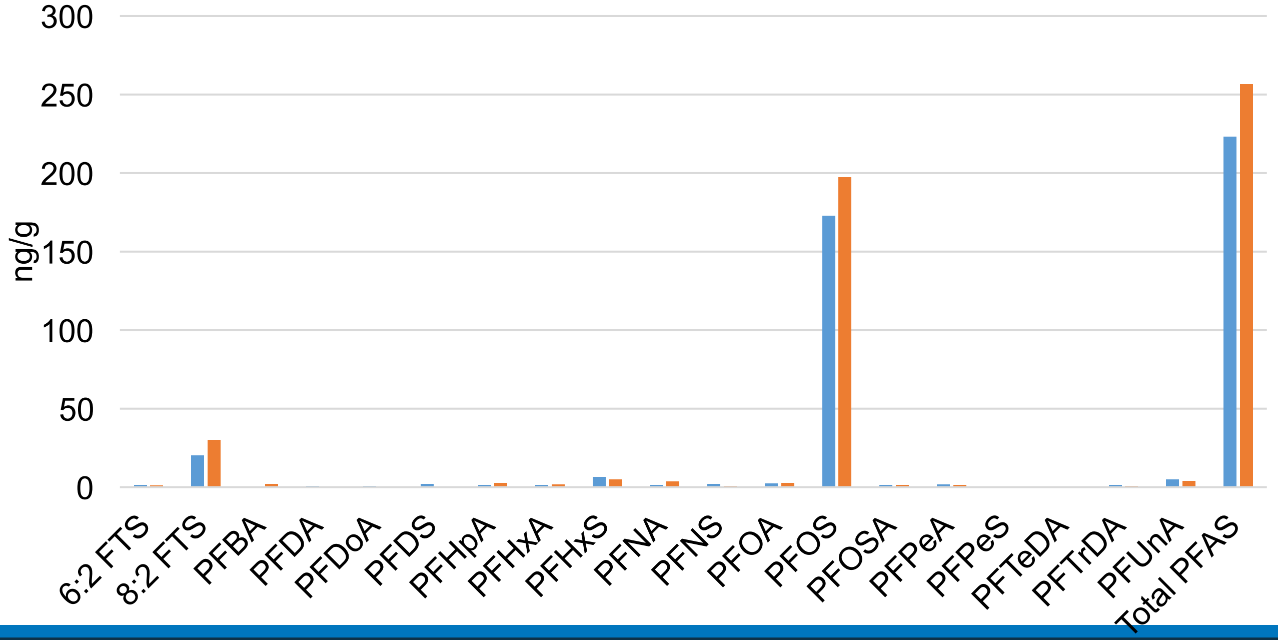
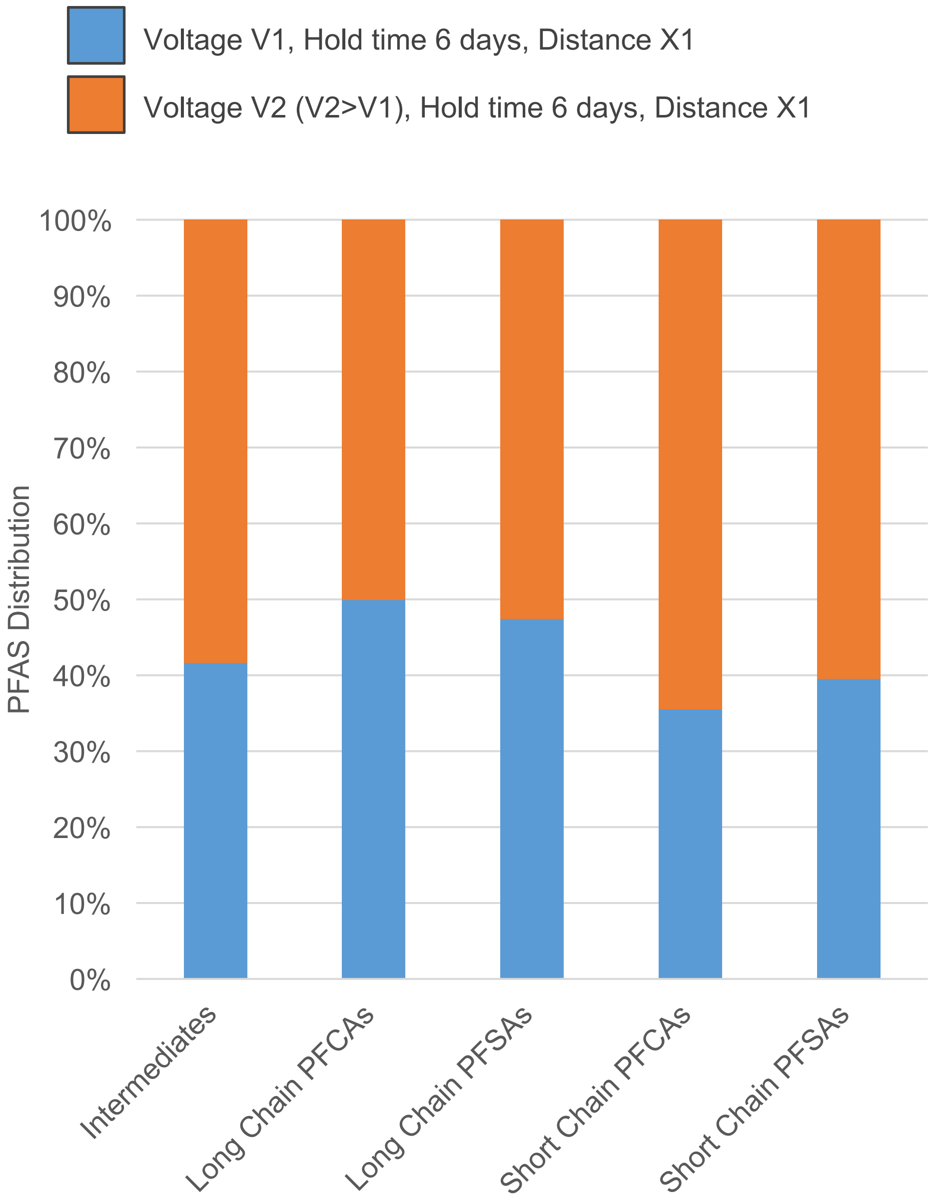
Experimental Results

- Field-collected soil characteristics
  - Zeta Potential: -20.5 mV
  - Moisture Content: 18.06%
  - Porosity: 75%
  - pH: 7.2
  - Cation Exchange Capacity: 7.8 meq/100g





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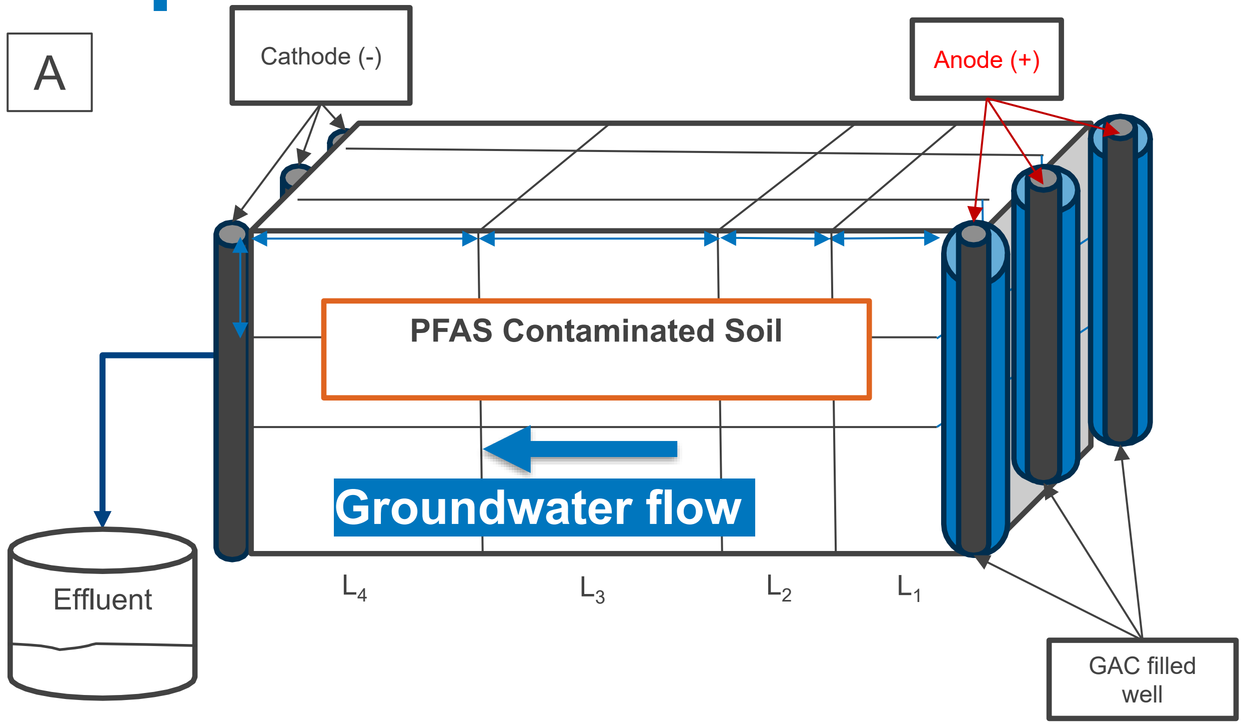
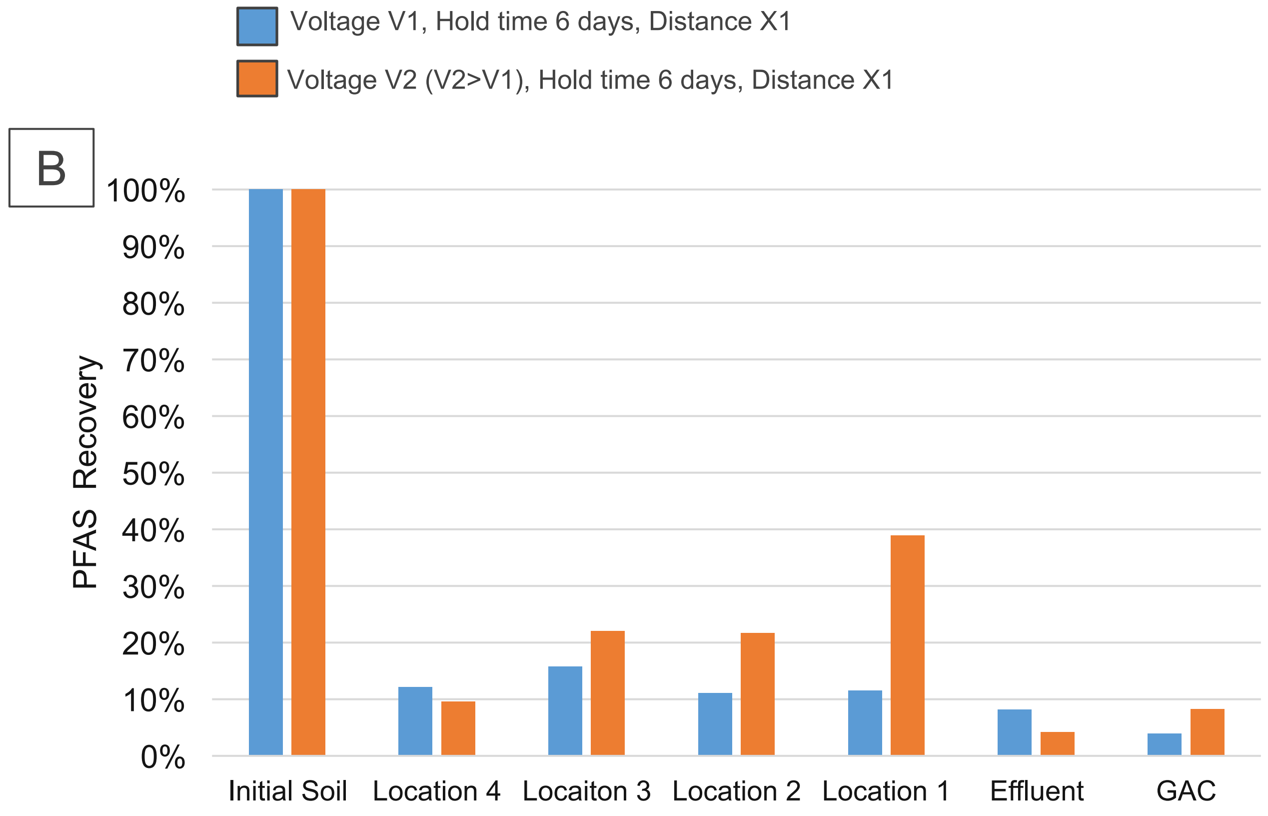
Experimental Results





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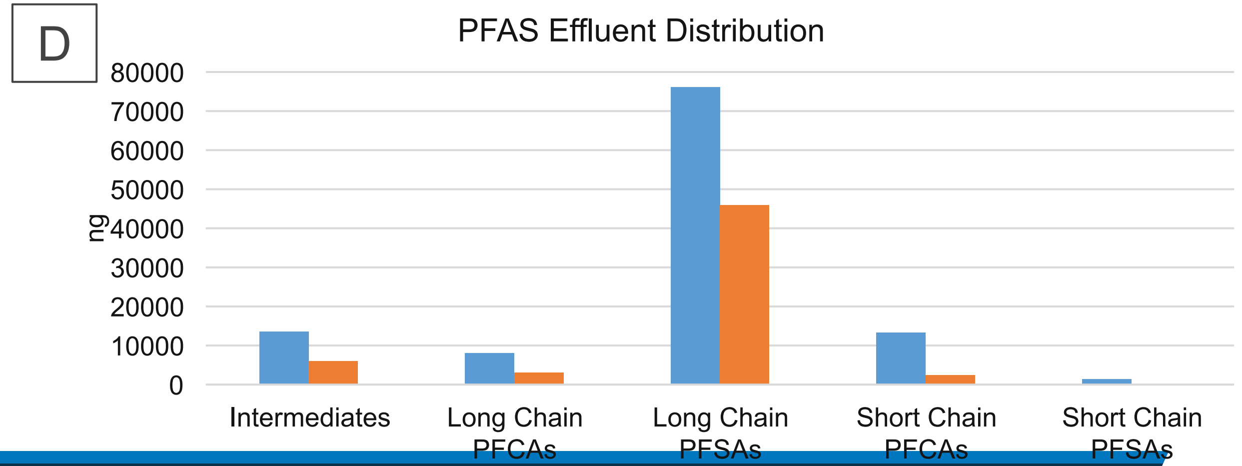
Sample	Voltage 1	Voltage 2
Initial Soil	100.00%	100.00%
Location 4	12.18%	9.60%
Location 3	15.74%	22.04%
Location 2	11.06%	21.71%
Location 1	11.52%	38.93%
GAC	3.90%	8.30%
Effluent	8.21%	4.20%
Total Recovered	62.61%	104.77%



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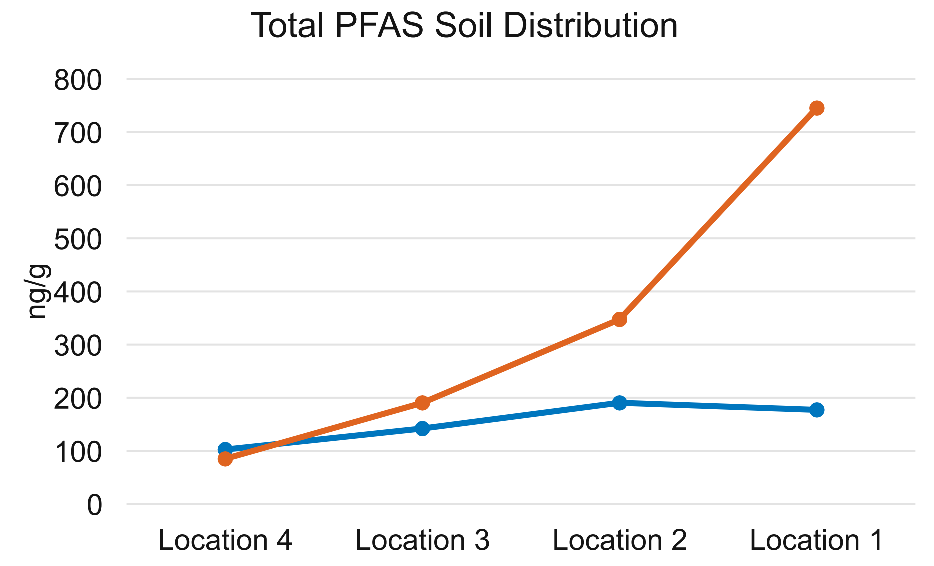
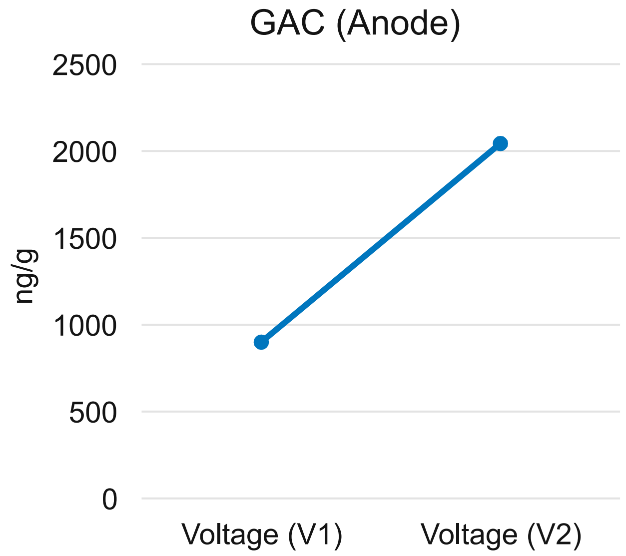
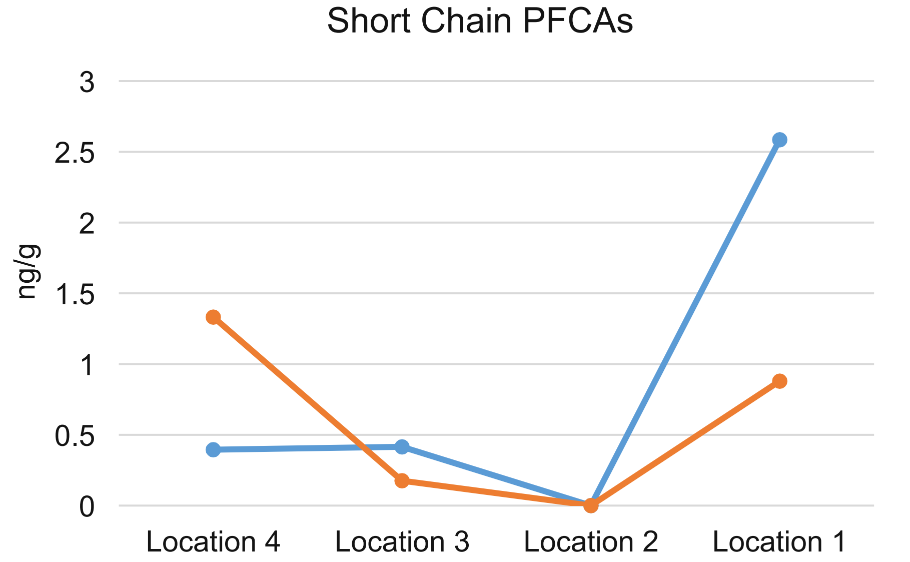
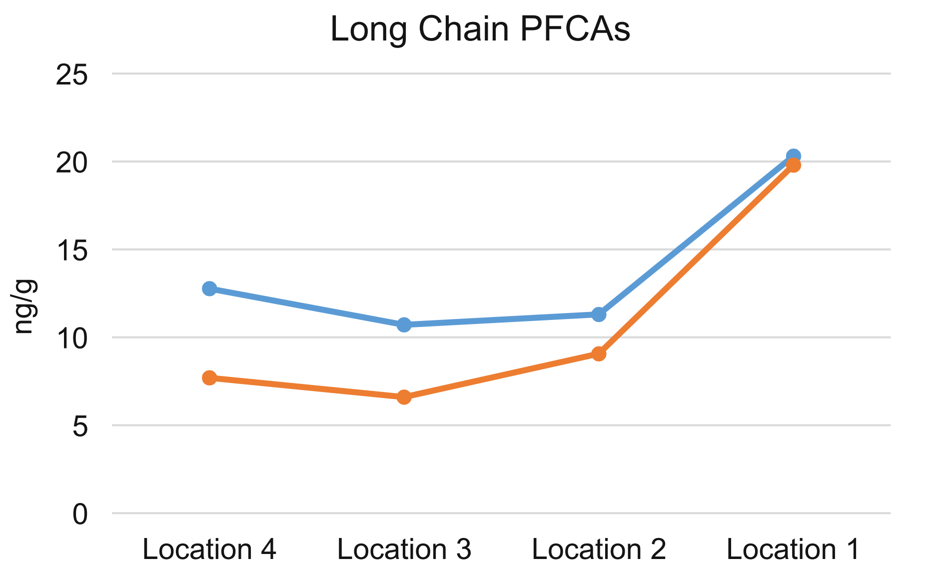
Results Continue…

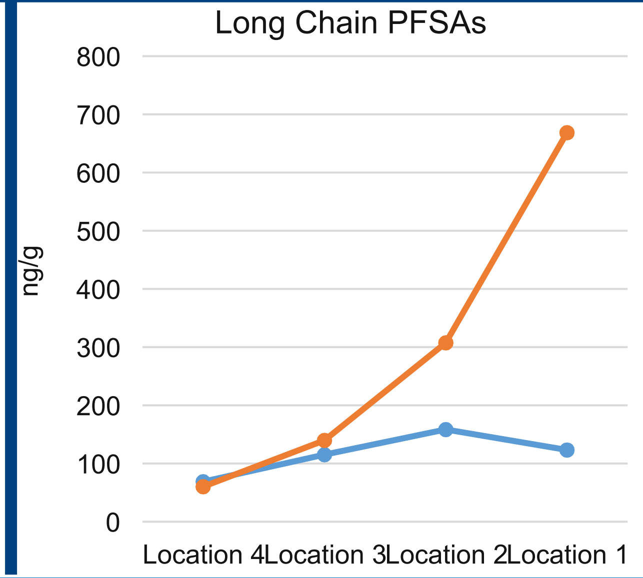
Voltage V1, Hold time 6 days, Distance X1
Voltage V2 (V2>V1), Hold time 6 days, Distance X1

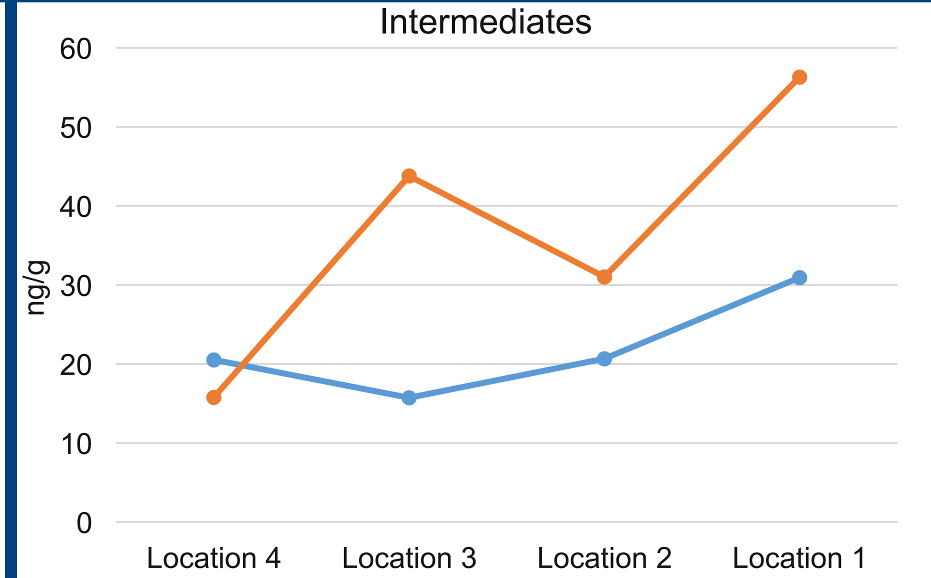












Challenges

- Ionic species get depleted due to their movement by electromigration
  - A process is currently being developed to mitigate this effect, this process will also lead to less energy consumption
- Gas Production and Joule Heating
  - Electrolysis of water can occur. This can lead to the formation of hydrogen gas at the cathode and oxygen gas at the anode.
- Non-uniform Material Properties
  - Proposed for ex situ applications

Future Tests

- Explore Different Kinds of soils
- Optimizing Electrode Design and Placement
- Combined Electroosmosis with certain methods to enhance fluid immobilization

Conclusions – Electro-osmosis Technology

- Current proof-of-concept experiments show great promising data to demonstrate the movement of PFAS from the soil under the tested conditions.
- PFAS collected in effluent can be destroyed using SCWO or other destruction technologies.
- Concentration of PFAS near the anode helps reduce the volume of soil requiring treatment.
- Bench scale pilot treatment results show the great performance of the treatment.
- Currently exploring opportunities to apply for the field scale pilot demonstration – In-situ/Ex-situ treatment.
- Electrokinetic treatment demonstrates a viable technology for clean up of soils – field scale treatment demonstrated on other contaminants.

It can be done

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Back-up Slides

Cost of Technology

Electro-osmosis	ISTD	Soil Washing	Soil Stabilization
• Cost estimated ~ $200-$400 per Ton • Additional treatment of concentrated PFAS	• Cost - $400-$800 per Ton • Does not work on soils with high water table • Additional treatment of concentrated PFAS	• Cost - $400-$500 per Ton • Up to 35% is left as fines, which needs further treatment • Additional treatment of rinsate with concentrated PFAS	• Lower costs compared to other technologies • Concerns on the longevity of treatment • Concerns on the short chain PFAS leaching out of the cap

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