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Colloidal Activated Carbon for In Situ Remediation of PFAS: A Review of Multiple Case Studies

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Agenda

- PFAS Challenges
- *In situ* sequestration using colloidal activated carbon to eliminate the risk of PFAS
- Three Field Case Studies

PFAS: The Challenges

- Large & dilute plumes
- Low target concentrations
  - Combined 70 ng/L for PFOA + PFOS
  - Lower State regulations
- Extremely recalcitrant compounds
  - Conventional treatment methods have not been effective to date
  - Accepted method: Pump and treat w/ GAC or IX

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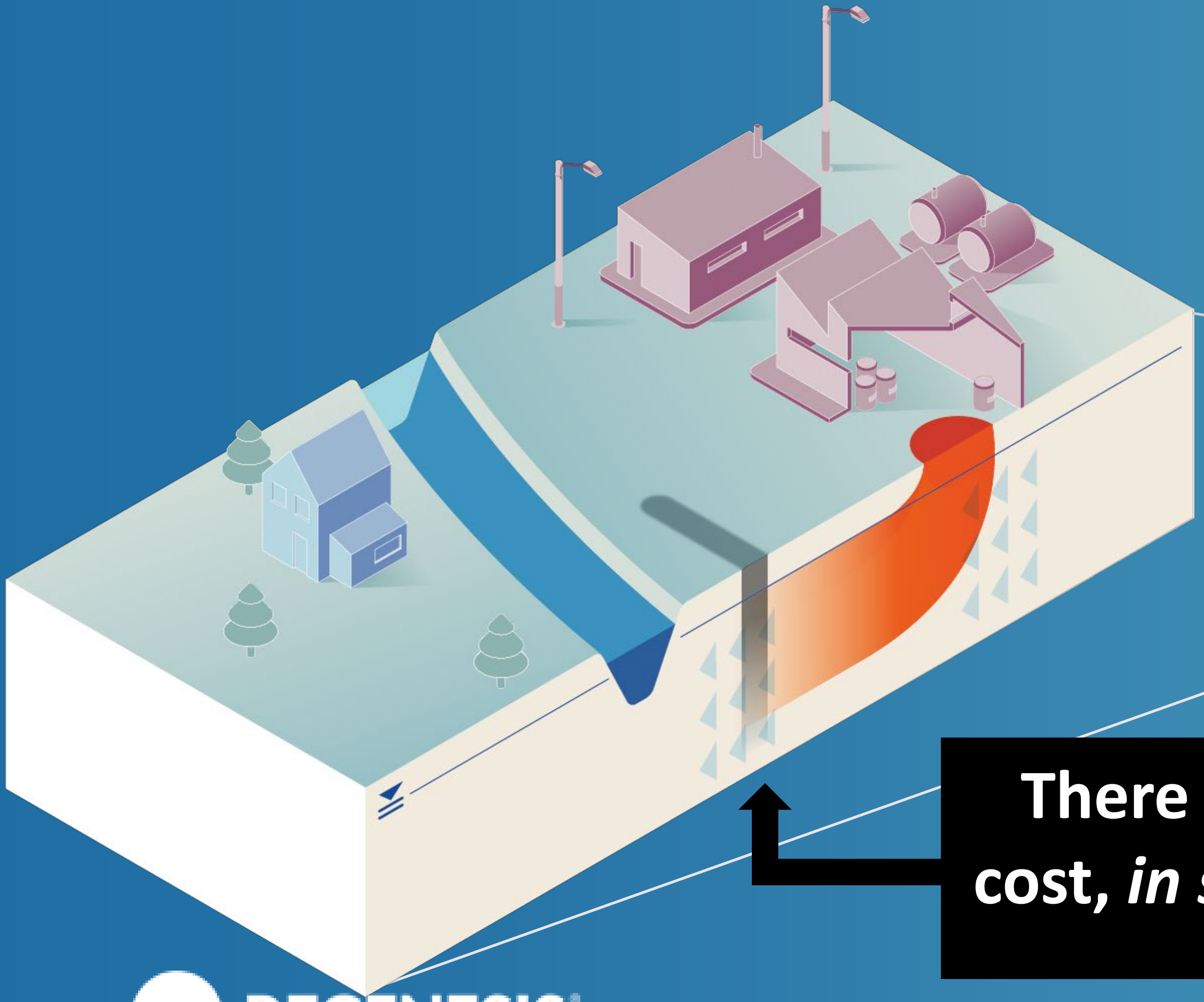
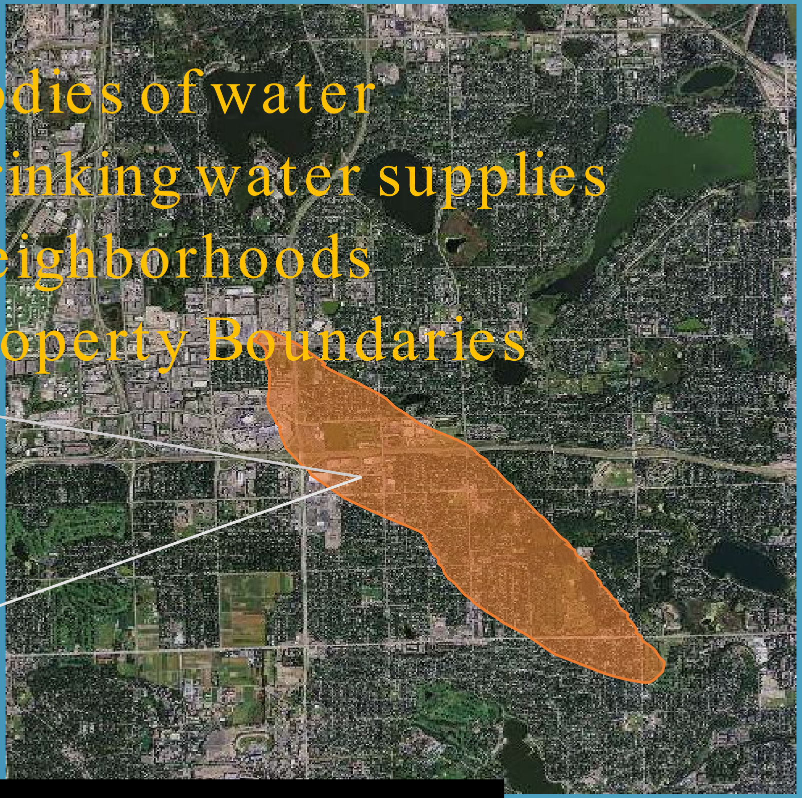
Sensitive Receptors at Risk



- Bodies of water
- Drinking water supplies
- Neighborhoods
- Property Boundaries



There is a need for a flexible, low cost, *in situ* strategy to address PFAS

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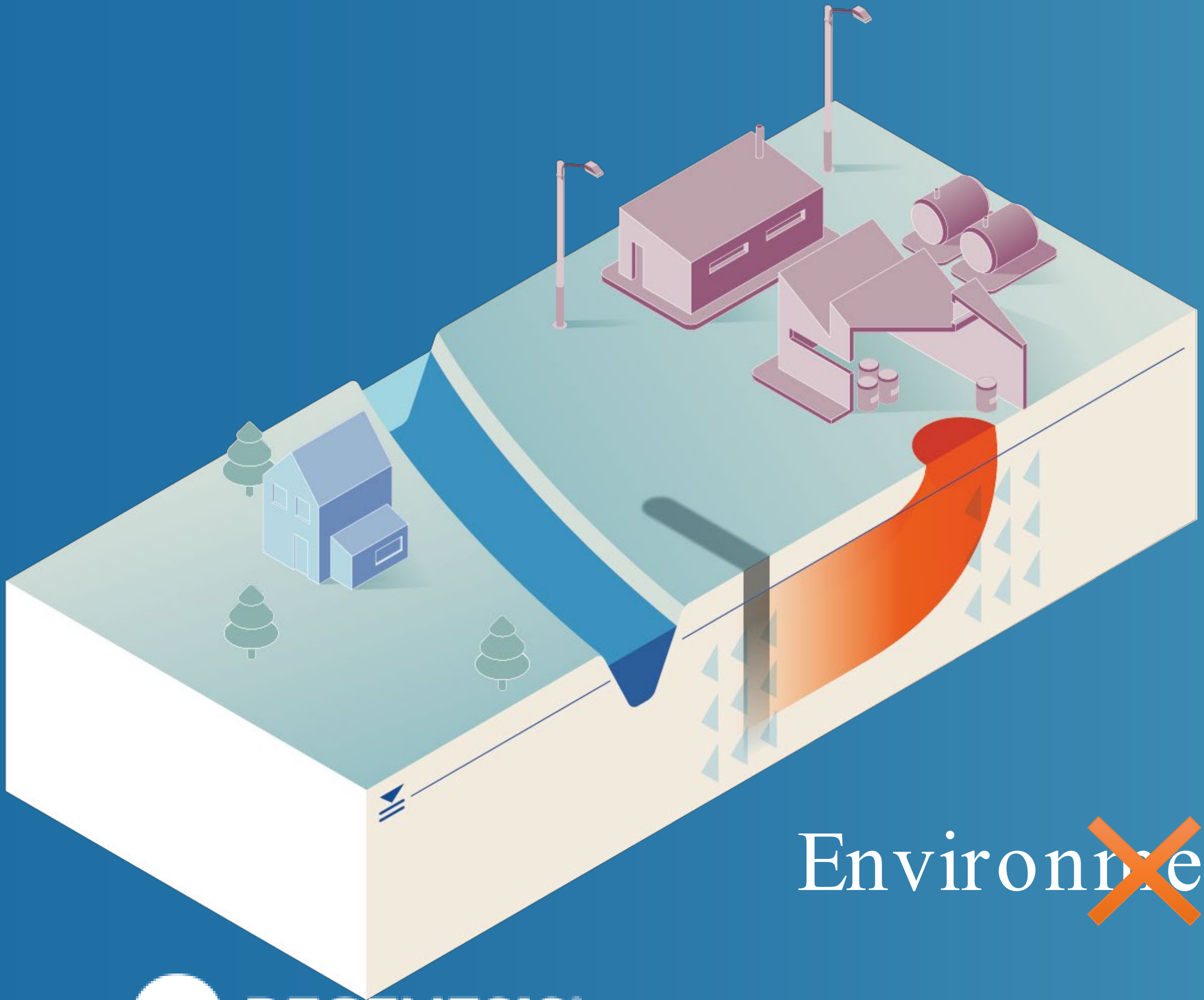
Remediation Strategy: Eliminating Risk



- No viable destructive options to date
- *In Situ* Sequestration
  - Prevents contaminant migration
  - Removes exposure → removes the immediate risk
- Examples:
  - Stabilize/immobilize
    - Ex. Reducing hex chrome to insoluble Cr(III)
  - Physical barrier
    - Ex. Sheet pile for containment

Environmental Risk = Hazard x Exposure

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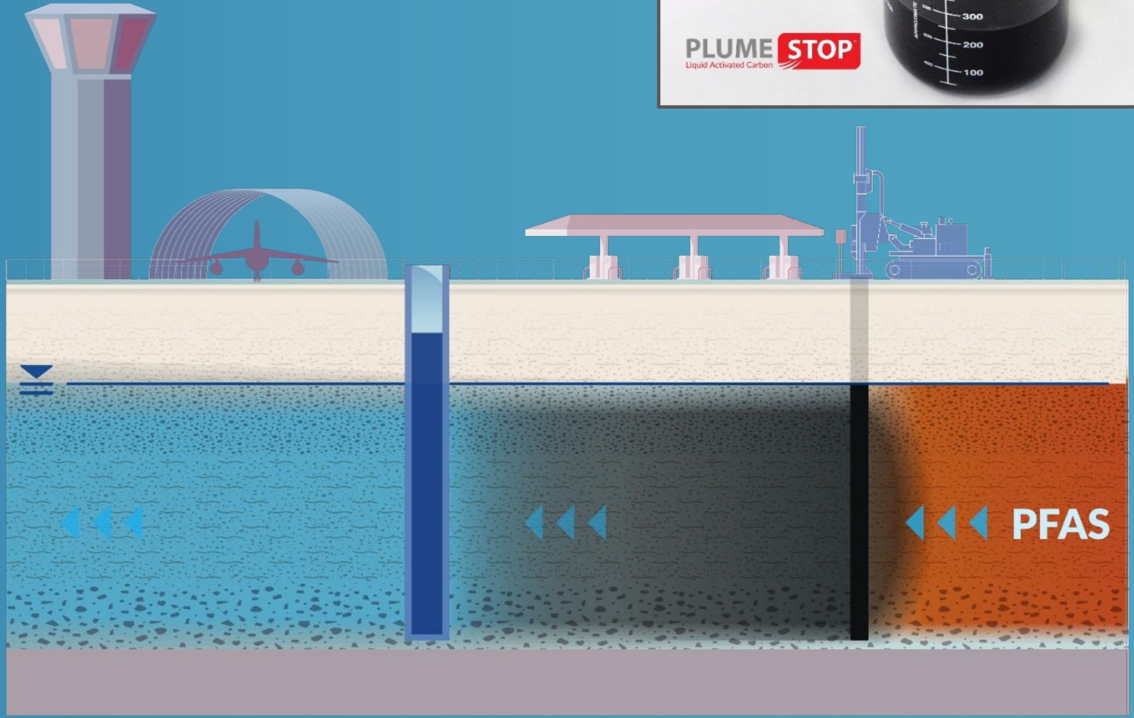
PlumeStop: Colloidal Activated Carbon (CAC)

- Activated carbon formulated to widely distribute *in situ* under low pressures
  - 1-2 microns in size
- Mode of Action for PFAS:
  - Dynamic adsorption
    - Not a permanent immobilization
  - Effect: Increases the retardation of a PFAS plume
    - Natural retardation factors for PFAS: 3-20
    - Retardation factors achievable with PlumeStop: 10,000
      - Sequester for decades!



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Benefits of CAC vs. GAC

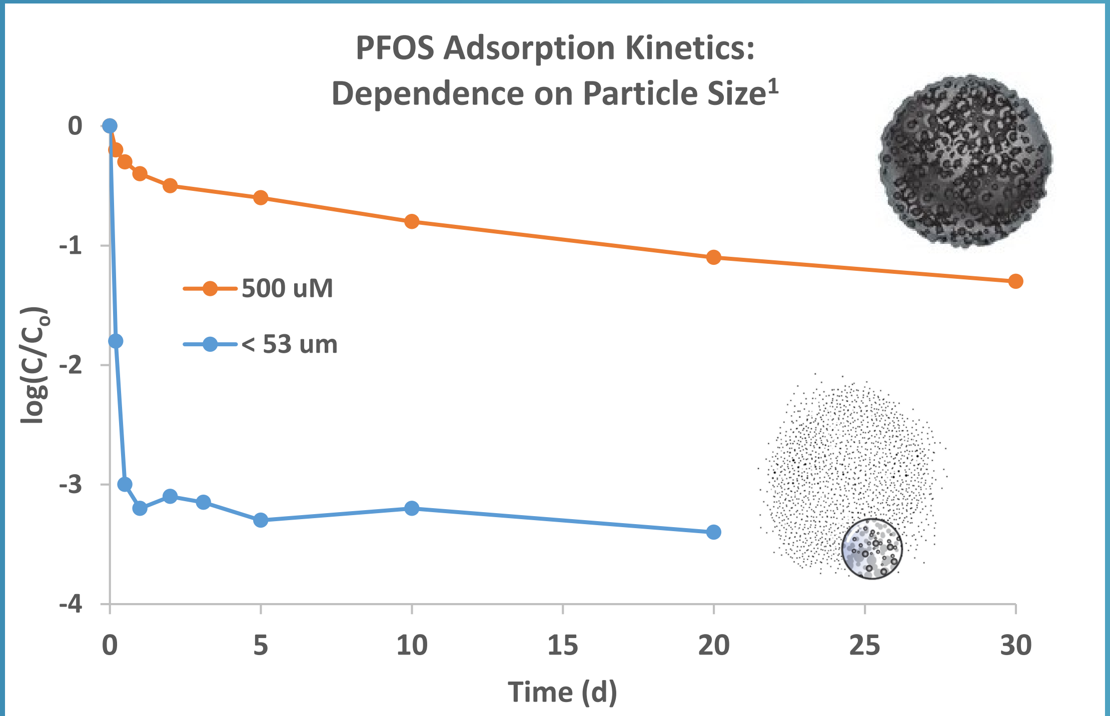
✓Faster adsorption kinetics due to smaller particle size[1]

- GAC: 500-1,000 µm
- CAC: 1-2 µm

✓Increased contact time

- GAC: Minutes under pumping conditions
- CAC: Weeks to months under natural GW flow

➢ Better relative performance with smaller-sized activated carbon



✓ Smaller particles reached equilibrium with a day

✓ GAC particles haven't reached equilibrium in a month

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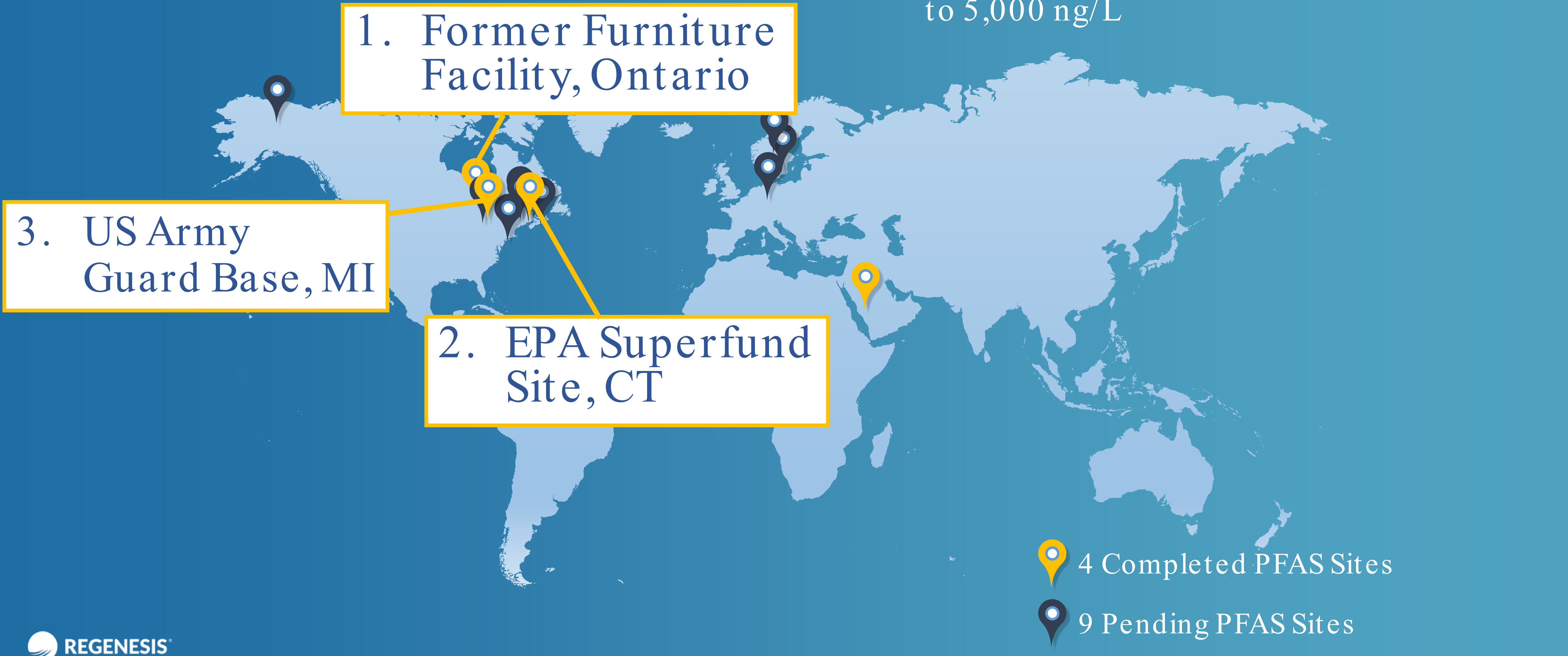
[1]Xiao, Ulrich, Chen & Higgins. Environ. Sci. Technol. 2017, 51, 6342-6351.

Keys to Success with Colloidal Activated Carbon

- Distribution Confirmation
  - "Building an underground fence"
- Longevity of performance
  - Depends on:
    - Identity of contaminants and other species that can adsorb
      - Competition between species, Poster: Wed. #76
    - Contaminant Flux: concentrations and velocity
    - Dose of adsorbent

Case Studies Overview

- These sites are co-mingled plumes with TPH or CVOCs
- Total PFAS concentrations range: 100 ng/L to 5,000 ng/L



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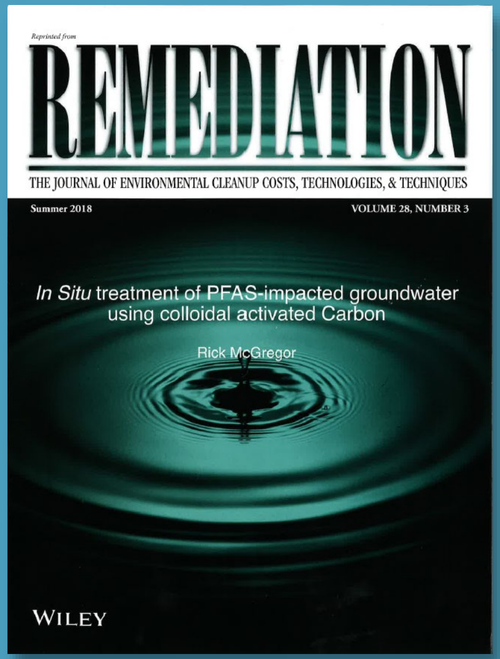

CASE STUDY #1

FORMER FURNITURE FACILITY

ONTARIO, CANADA

INSITU
REMEDIATION SERVICES

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McGregor, R. In Situ Treatment of PFAS-impacted groundwater using colloidal activated carbon. *Remediation*. 2018;28:33-41.

Case Study #1 Background

Initial Driver: Hydrocarbons

- Mixed chain lengths, 100 – 5,000 µg/L

Formation

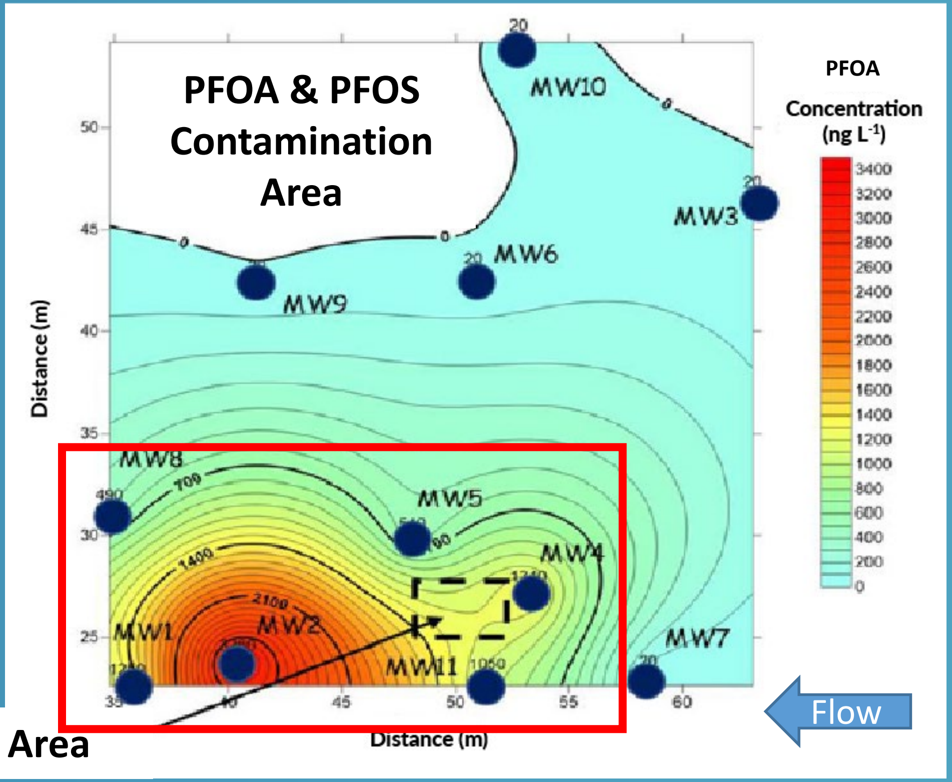
- GW Velocity: 2-3 ft/day
- Silty sand – till based with sand seams
- Water at 3 – 5' below grade

Former Fire Training Area

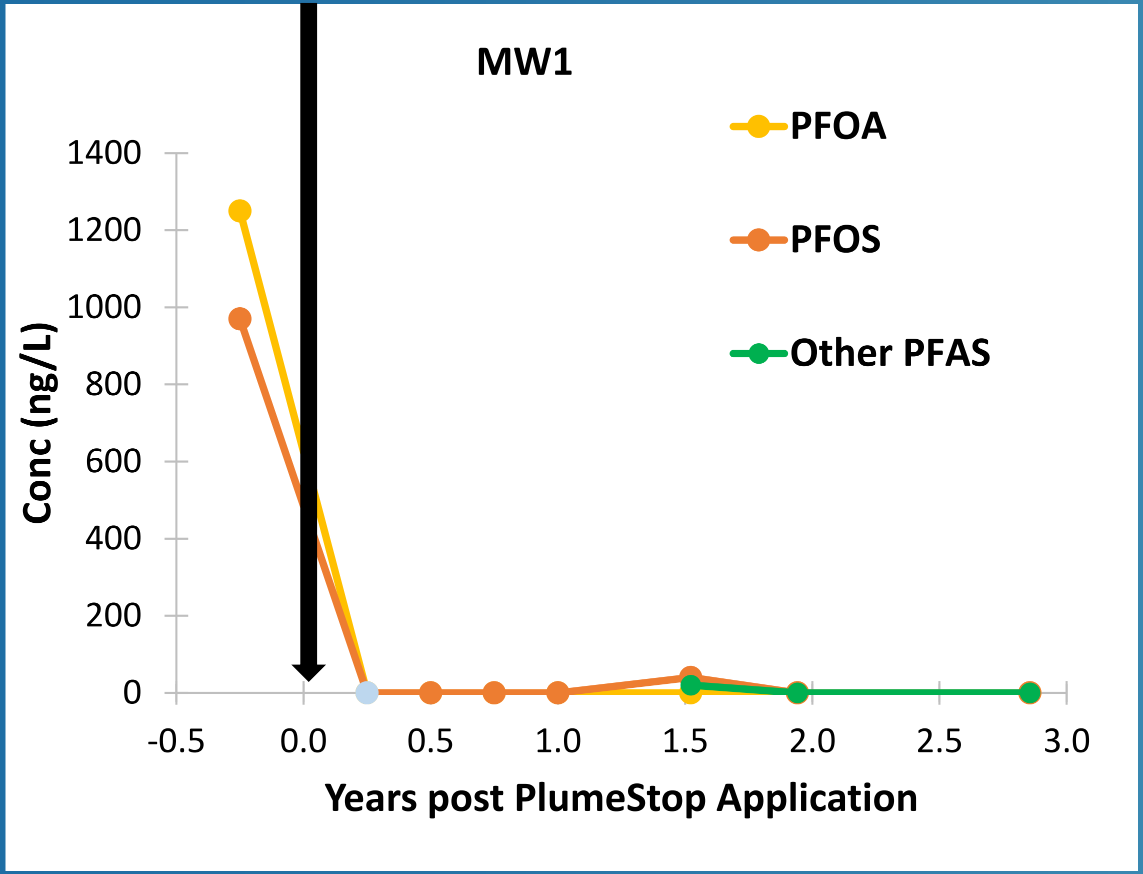
- History of furniture manufacturing
- PFAS tested for just in case and found!
  - 6 wells impacted by PFOS (300 to 1,400 ng/L) & PFOA (400 to 3,400 ng/L)

Remedial Approach

- Aerobically degrade hydrocarbons
- PlumeStop to prevent off-site plume migration



Case Study #1 Monitoring & Results



Monitoring events:

- PFOS + PFOA
  - Baseline
  - 3, 6, 9, 12, 18, 24, 32 months
- Extended PFAS list (12 more)
  - 18, 24, 32 months
  - No baseline data available

Results for MW1 are shown

- Non-detect (typical 20 ng/L)
- Only one hit of PFOS at 18 months, just above RL
- Data are representative of all 6 wells

Case Study #1 Independent Research: Evaluating Longevity

DOI: 10.1002/rem.21593

RESEARCH ARTICLE

WILEY

Evaluating the longevity of a PFAS *in situ* colloidal activated carbon remedy

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Abstract

The remediation of per- and polyfluoroalkyl substances by injection of colloidal activated carbon (CAC) at a contaminated site in Central Canada was evaluated using various visualization and modeling methods. Radial diagrams were used to illustrate spatial and temporal trends in perfluoroalkyl acid (PFAA) concentrations, as well as various redox indicators. To assess the CAC adsorption capacity for perfluorooctane sulfonate (PFOS), laboratory Freundlich isotherms were derived for PFOS mixed with CAC in two solutions: (1) PFOS in a pH 7.5 synthetic water that was buffered by 1 millimolar $NaHCO_3$ (K_f = 142,800 mg^{1-a} L^a/kg and a = 0.59); and (2) a groundwater sample (pH = 7.4) containing PFOS among other PFAS from a former fire-training area in the United States (K_f = 4,900 mg^{1-a} L^a/kg and a = 0.24). A mass balance approach was derived to facilitate the numerical modeling of mass redistribution after CAC injection, when mass transitions from a two-phase system (aqueous and sorbed to organic matter) to a three-phase system that also includes mass sorbed to CAC. An equilibrium mixing model of mass accumulation over time was developed using a finite-difference solution and was verified by intermodel comparison for prediction of CAC longevity in the center of a source area. A three-dimensional reactive transport model (ISR-MT3DMS) was used to indicate that the CAC remedy implemented at the site is likely to be effective for PFOS remediation for decades. Model results are used to recommend remedial design and monitoring alternatives that account for the uncertainty in long-term performance predictions.

Grant Carey, PhD

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Case Study #1 Independent Research: Evaluating Longevity

- Analysis included:
  - Generating PlumeStop-specific isotherms
  - Numerical models
    - Field dose of PlumeStop, isotherms
  - Performing a sensitivity analysis to account for possible interferences that impact longevity
- Key Result:
  - Estimate 60+ years of treatment for PFOS

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UNIVERSITY OF TORONTO

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Carey, G., McGregor, R., Pham, A., Sleep, B, Hakimabadi, S. Evaluating the Longevity of a PFAS *in situ* colloidal activated carbon remedy. *Remediation*. 2019;29:17-31.

CASE STUDY #2

US EPA SUPERFUND SITE

CONNECTICUT

de maximis, inc. GEI Consultants

Case Study #2 Background

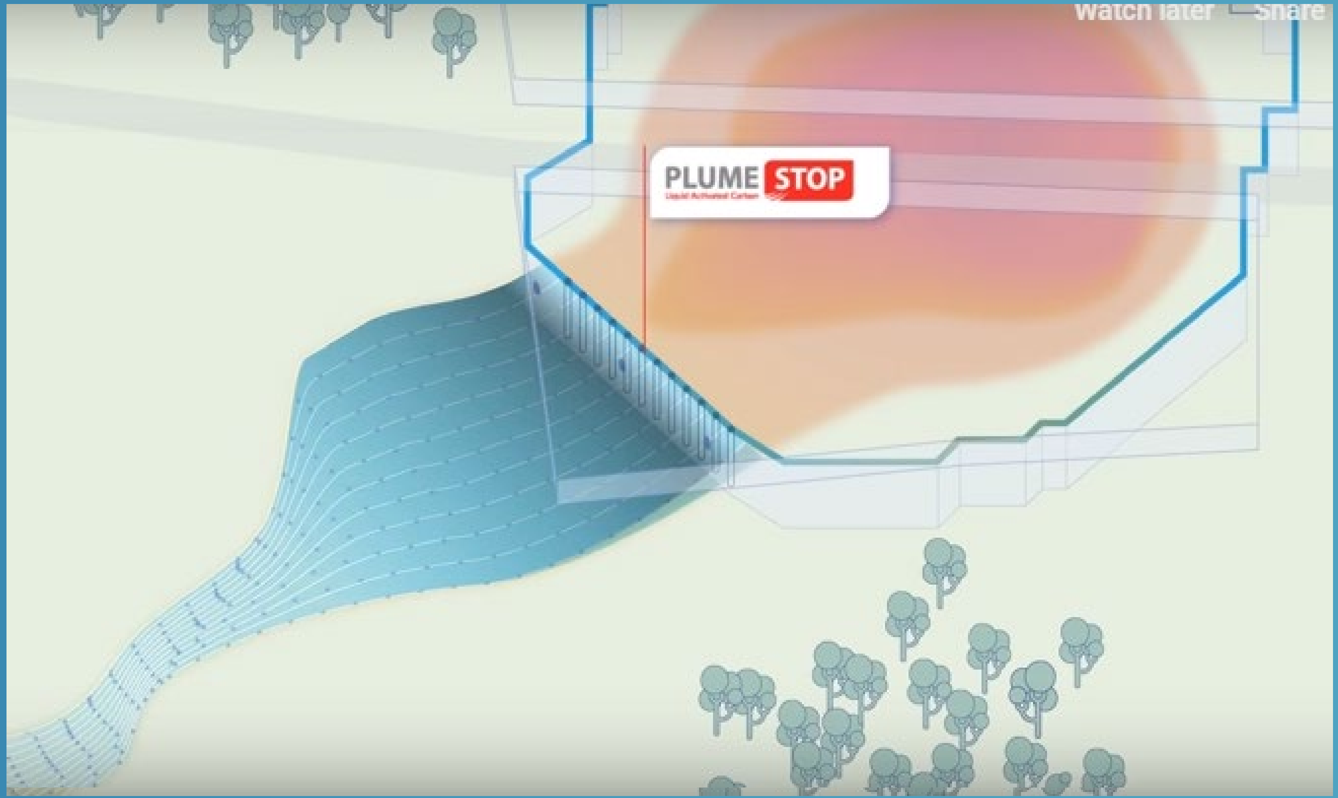
Solvent distillation facility

- 1958 to 1991
- 1983 US EPA Superfund site

History of Remediation:

- Excavation, capping
- Hydraulic containment: sheet pile, pump and treat
- In situ thermal

- Residual Contamination
  - ppb of benzene, TCE, VC
  - PFAS: 150 ng/L total



Current Approach:

- PlumeStop: Address PFAS migration
- Target combined 5 compounds 70 ppt: PFOA, PFOS, PFNA, PFHxS, PFHpA

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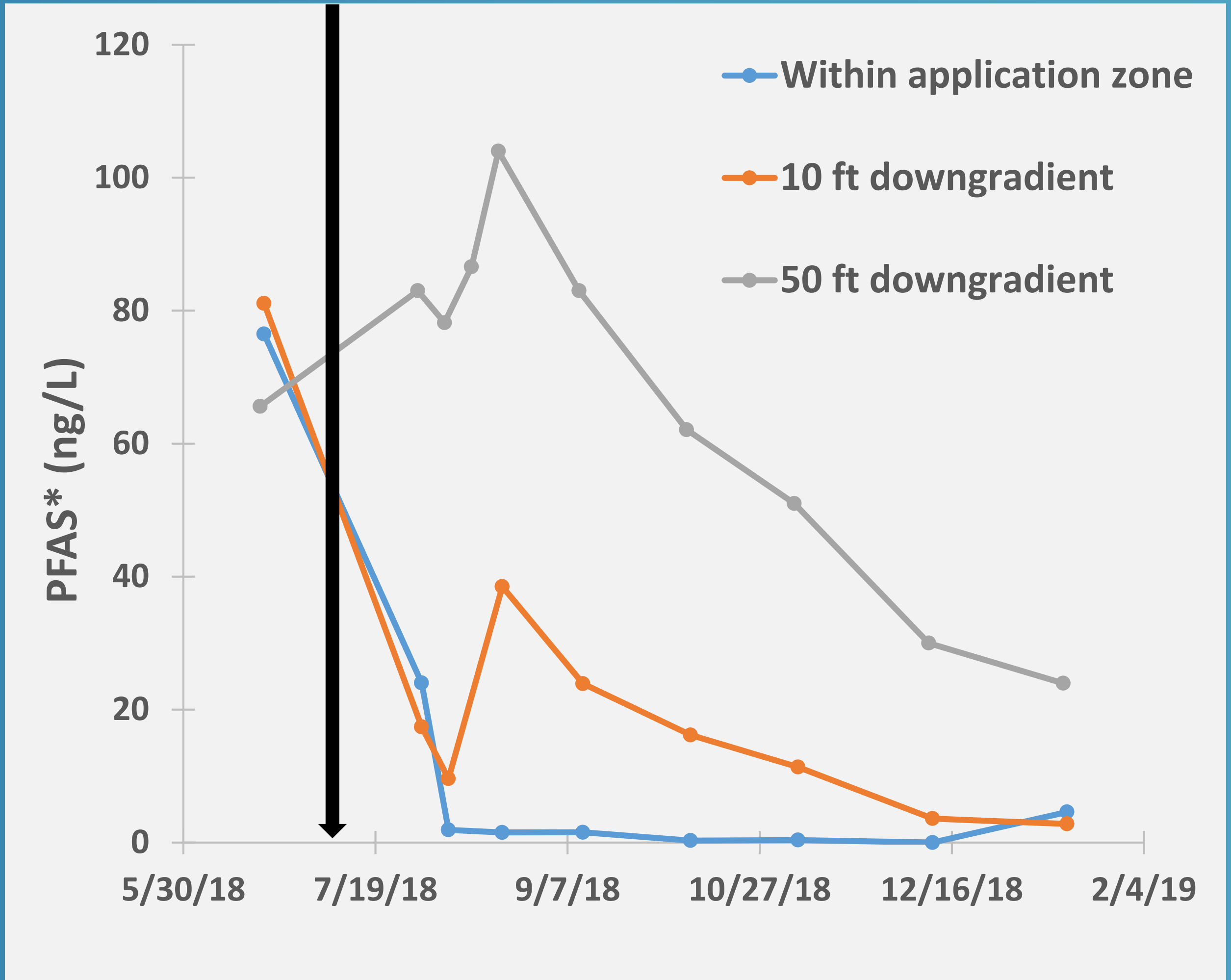
Case Study #2 Results

- Fast reductions within the application zone
- Observing decreasing concentrations in downgradient wells
- Second application planned
  - Optimized to flow dynamics coming through sheet pile
  - Slug of VOCs from source area

PLUMESTOP Liquid Activated Carbon



*PFAS concentration: Sum of 5 PFAS compounds: PFOA, PFOS, PFNA, PFHpA, and PFHxS

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CASE STUDY #3

Grayling Army Airfield

Grayling, Michigan

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Case Study #3 Background

Site Location:
Camp Grayling Joint Maneuver Training Center

- Founded 1913
- 147,000 acres
- Largest National Guard training center in the country
- Home to the Grayling Army Airfield

Contaminant Release History:

- Diesel, PCE/TCE, PFAS

Remediation History:

- Pump and Treat, air sparging/SVE

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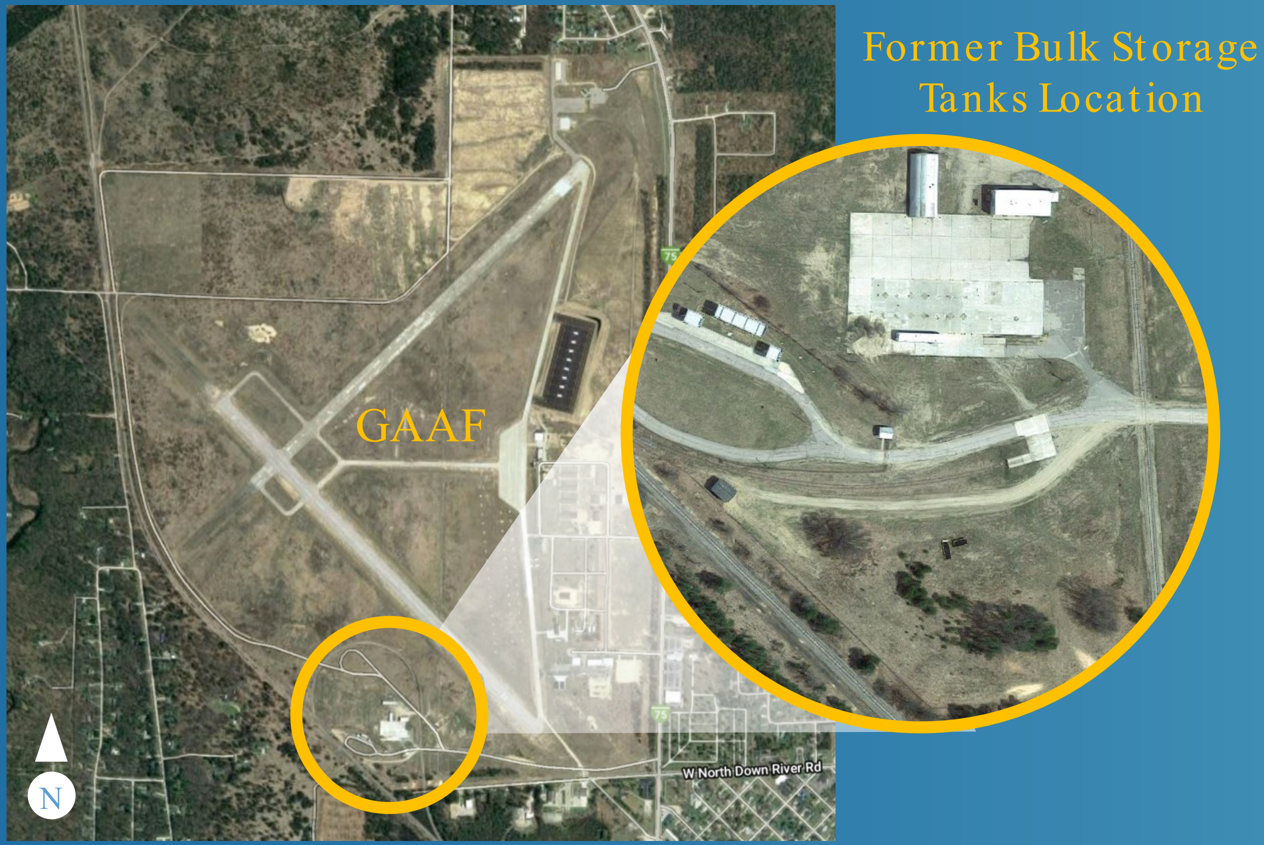
Case Study #3: Pilot Test

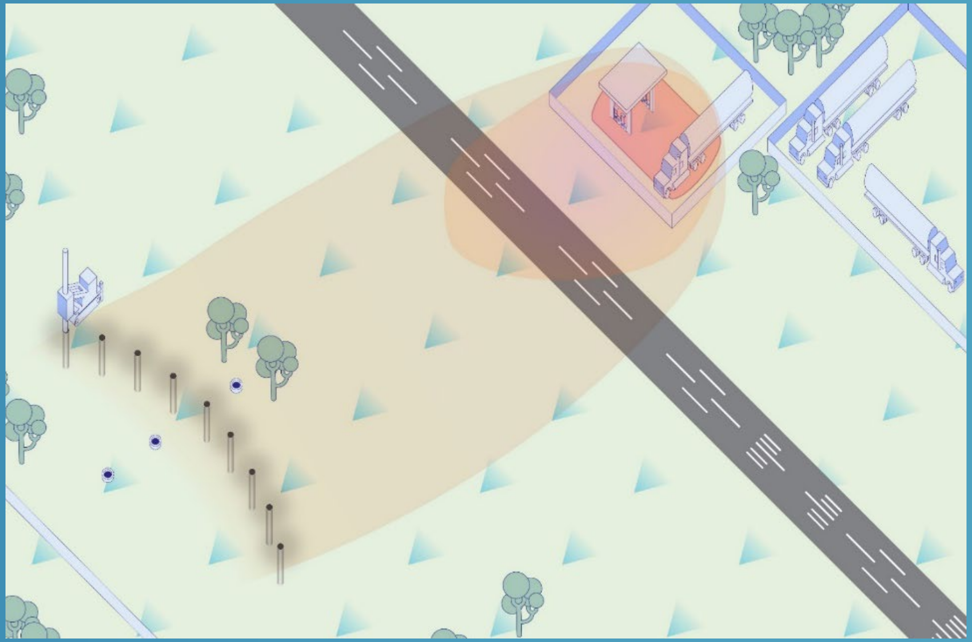


Contaminant levels:

- 10 µg/L PCE
- 130 ng/L Total PFAS (PFOS, PFHxS)

Remediation Strategy:

- PlumeStop cut-off barrier
    - Prevent PFAS and PCE migration



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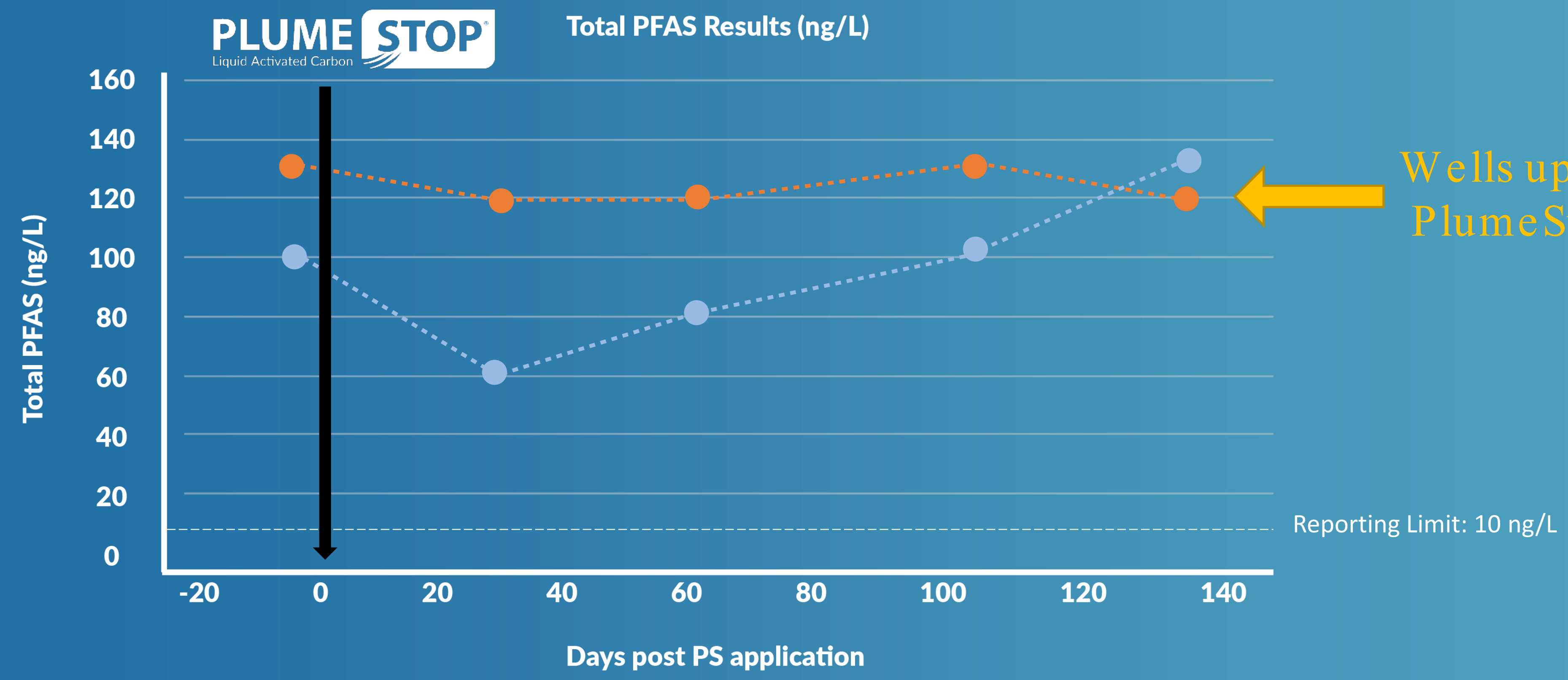
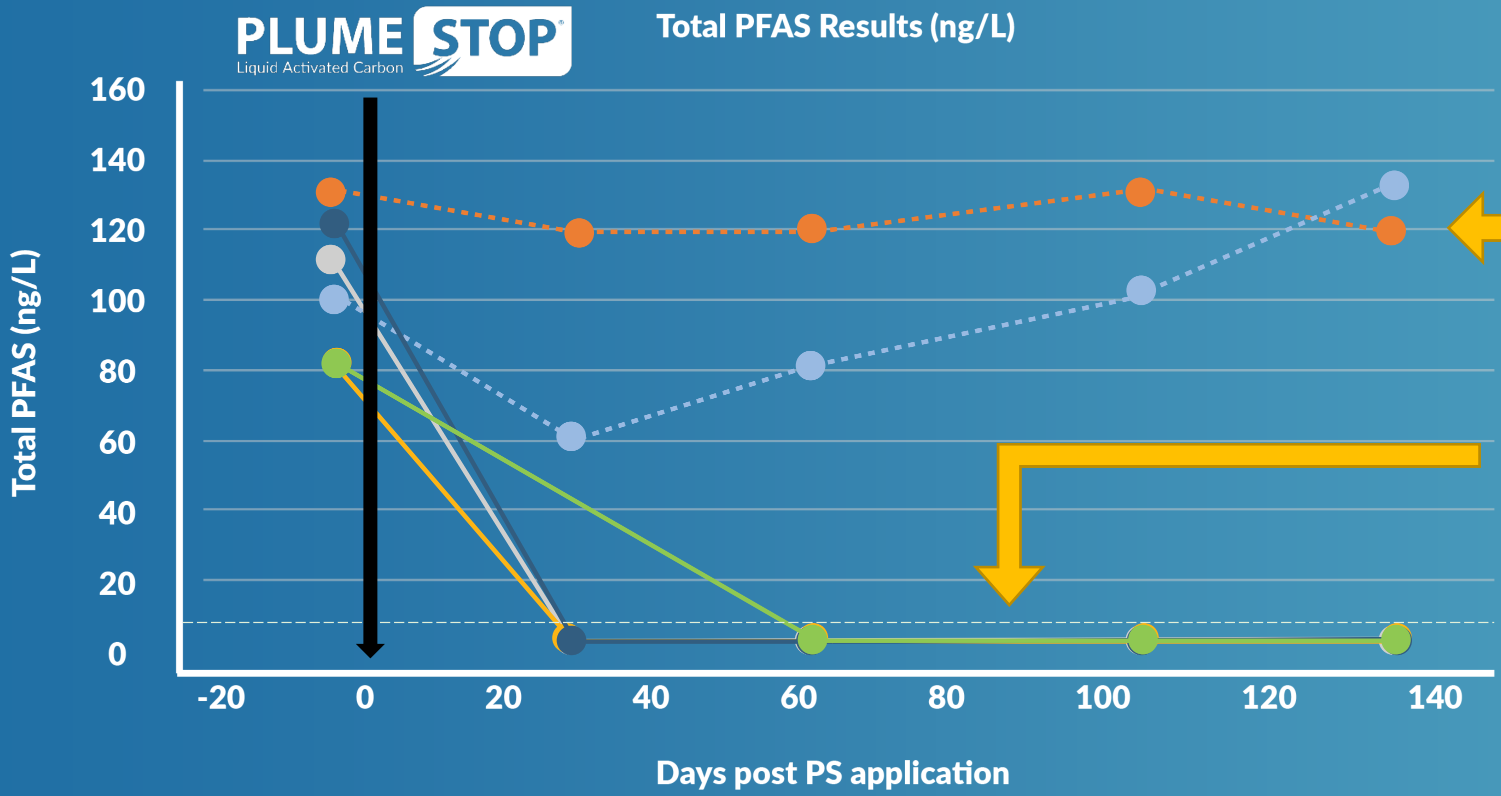
Case Study #3 Results



Wells upgradient of PlumeStop barrier

Case Study #3 Results



Wells upgradient of PlumeStop barrier

Wells downgradient of PlumeStop barrier

Reporting Limit: 10 ng/L

SUMMARY

- PlumeStop provides a flexible, low cost, *in situ* option to address PFAS
- Eliminates the RISK of PFAS in groundwater
- Data from three sites have been promising
  - More sites in the queue