Colloidal Activated Carbon for *in-situ* Remediation of PFAS: A Review of Multiple Case Studies

Alana Miller
Sr. Northeast District Manager
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re·me·di·a·tion

/rəˌmēdēˈāSH(ə)n/

Noun

A Process used to reduce or eliminate the risk for humans and the environment that may result from exposure to harmful chemicals

Source: ITRC

Eliminates Risk of PFAS

- ~~Risk~~ = Hazard x ~~Exposure~~
- CAC binds up PFAS in situ
- Eliminates potential for down gradient exposure and the Risk
- Approach Consistent with Monitored Natural Attenuation

Precedence Enhanced Attenuation

Established examples of using MNA (& Enhanced Attenuation) on recalcitrant and non-degrading contaminants (e.g., metals)

MNA (& Enhanced Attenuation) Presented as a viable remedy for PFAS

> "Potential enhanced attenuation technologies for PFAS plumes implemented in the saturated zone includes… adding sorbents to increase retention" –*Newell et al.*

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RESEARCH ARTICLE

WILEY

Monitored natural attenuation to manage PFAS impacts to groundwater: Potential guidelines

Charles J. Newell[1] | David T. Adamson[1] | Poonam R. Kulkarni[1] | Blossom N. Nzeribe[2] | John A. Connor[1] | Jovan Popovic[3] | Hans F. Stroo[4]

[1]GSI Environmental Inc., Houston, Texas, USA
[2]GSI Environmental Inc., Austin, Texas, USA
[3]Naval Facilities Engineering and Expeditionary Warfare Center, Port Hueneme, California, USA
[4]Stroo Consulting, LLC, Ashland, Oregon, USA

Correspondence
Charles J. Newell, GSI Environmental Inc., 2211 Norfolk Suite 1000, Houston, TX 770027 USA.
Email: cjnewell@gsi-net.com

Abstract

Practical guidelines based on a three-tiered lines of evidence (LOEs) approach have been developed for evaluating monitored natural attenuation (MNA) at per- and polyfluoroalkyl substances (PFAS)-impacted groundwater sites using the scientific basis described in a companion paper (Newell et al., 2021). The three-tiered approach applies direct measurements and indirect measurements, calculations, and more complex field and modeling methods to assess PFAS retention in the subsurface. Data requirements to assess the LOEs for quantifying retention in both the vadose and saturated zones are identified, as are 10 key PFAS MNA questions and 10 tools that can be applied to address them. Finally, a list of potential methods to enhance PFAS MNA is provided for sites where MNA alone may not effectively manage the PFAS plumes. Overall, a practical framework for evaluating PFAS MNA that can result in more efficient, reliable management of some PFAS sites is provided.

1 | INTRODUCTION

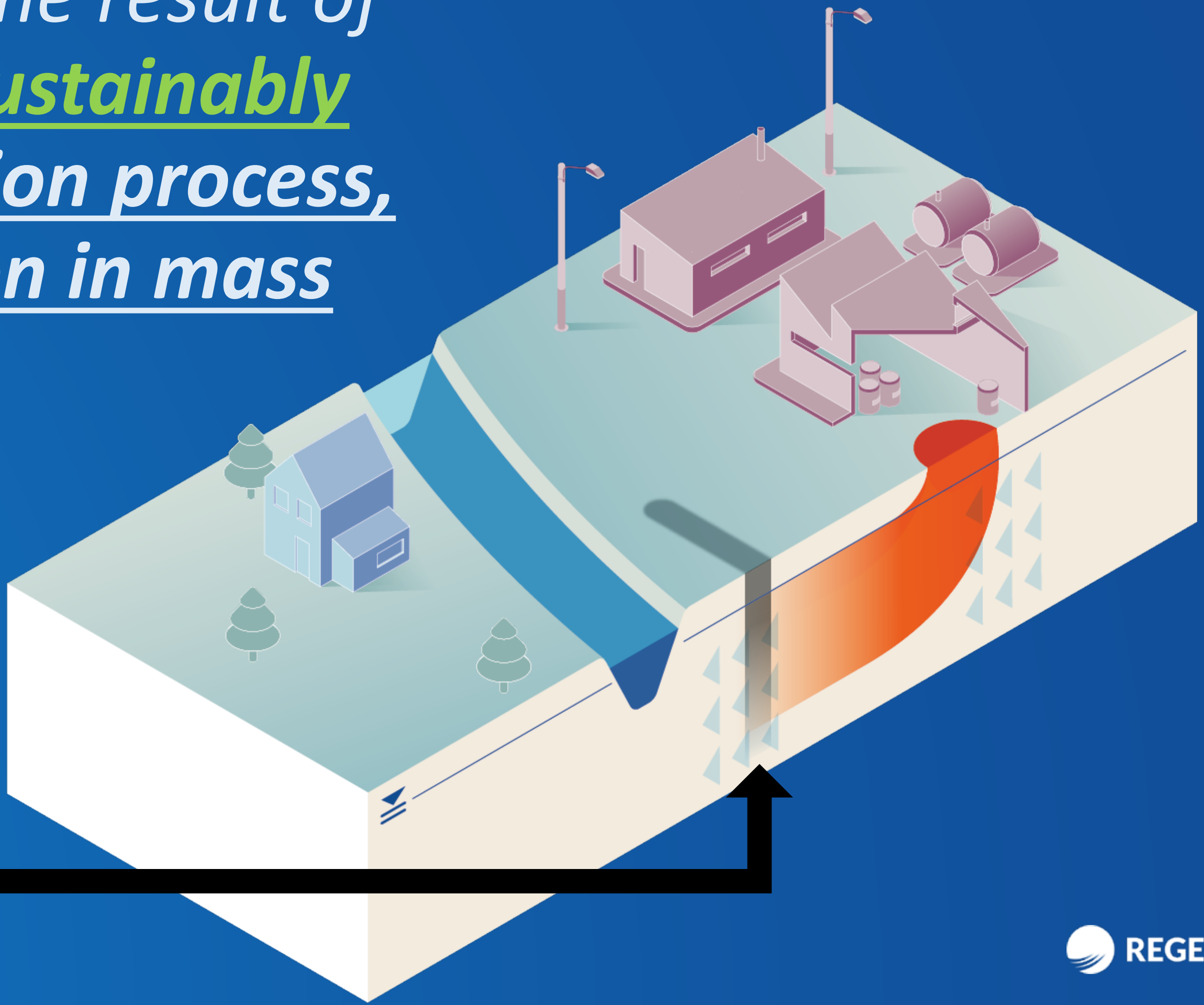
This paper builds upon a companion paper that described the scientific basis for using monitored natural attenuation (MNA) to managing per- and polyfluoroalkyl substances (PFAS) impacts to groundwater (Newell

interphase partitioning, and, potentially, self-assembly phenomena) and matrix diffusion into low-permeability media. Many of the PFAS retention processes are nondestructive and reversible, so that the key attenuation benefit of these processes is "peak shaving" where the original peak mass discharge of PFAS from the source is attenuated to lower,

U.S. EPA. Use of Monitored Natural Attenuation for Inorganic Contaminants at Superfund Sites, Directive 9283.1-36. Published online 2015.
Newell CJ, et al. Monitored Natural Attenuation to Manage PFAS Impacts to Groundwater: Scientific Basis. Groundwater Monitoring & Remediation. 2021;41(4):76-89.
Newell CJ, et al. Monitored natural attenuation to manage PFAS impacts to groundwater: Potential guidelines. Remediation Journal. 2021;31(4):7-17.
ER21-5198. Accessed December 15, 2021. https://www.serdp-estcp.org/Program-Areas/Environmental-Restoration/ER21-5198/ER21-5198.

Approach: Enhanced Attenuation

Enhanced Attenuation (ITRC): *"the result of applying an enhancement that* ***sustainably manipulates a natural attenuation process, leading to an increased reduction in mass flux of contaminants.*** *"*



Permeable Reactive Barrier

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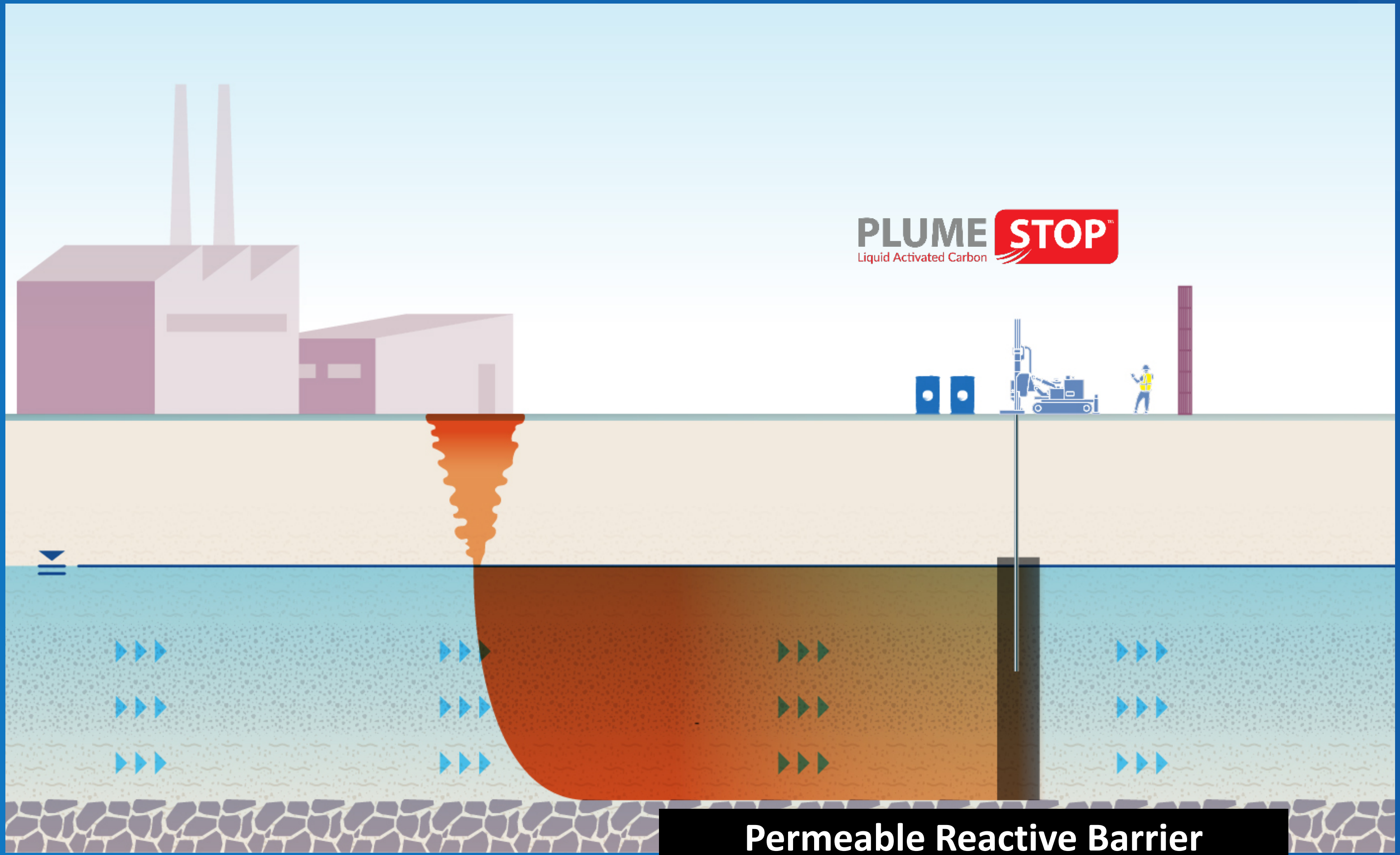
Plume Management Solution: Enhanced Attenuation



Permeable Reactive Barrier of colloidal activated carbon

Common Questions:

- Is there any destruction of PFAS?
  - PFAS will still be on my site?
- Can you effectively implement a colloidal activated carbon barrier?
- How long will the treatment last?
  - Can you predict the longevity?
  - What impacts the longevity?
  - Will the barrier eventually 'fill up'?

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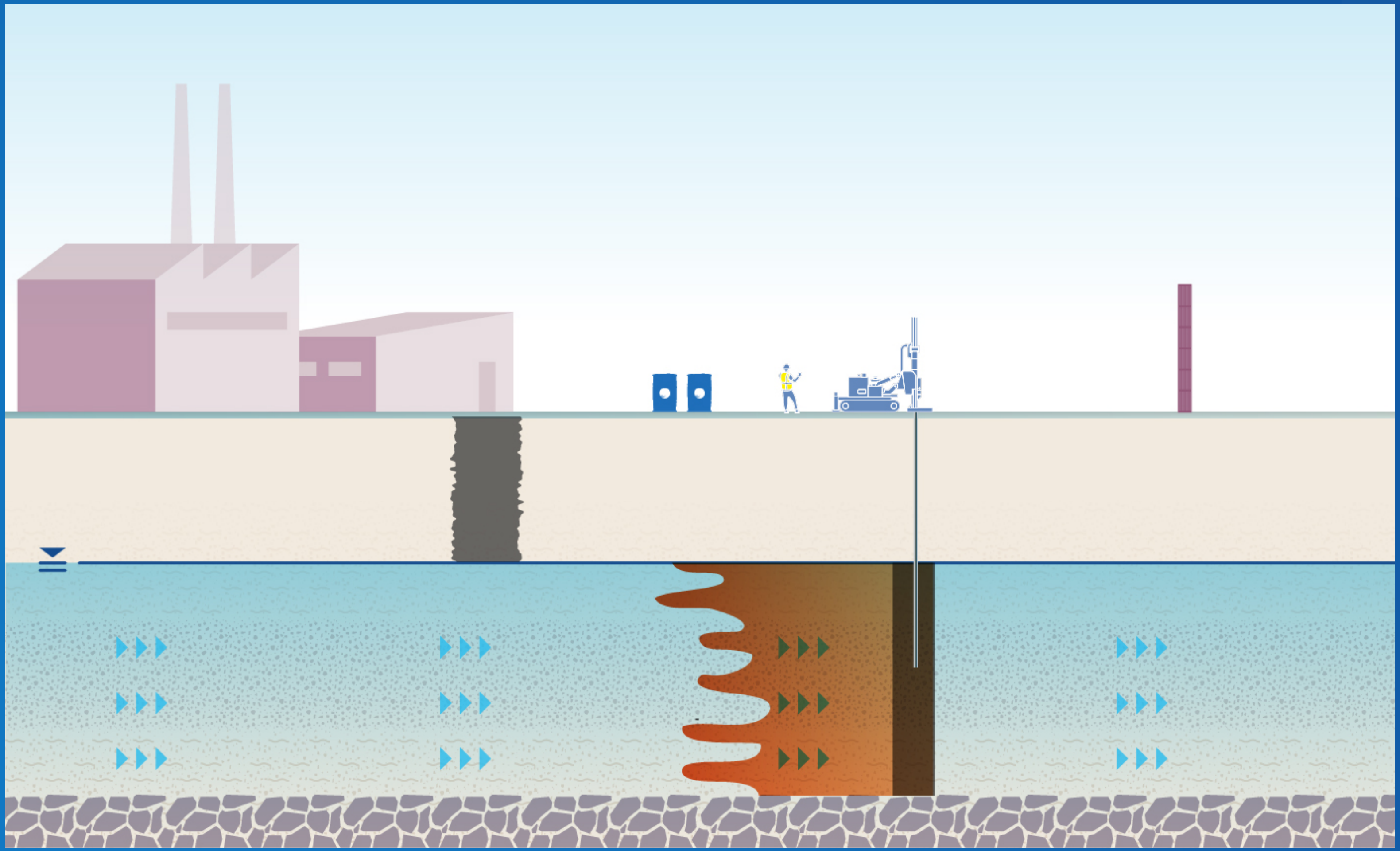
Plume Barrier Longevity:
Extended with Source Control Measures



If mass discharge from the source is minimal or decreasing, then:

- Plume CAC barrier treatment longevity will extend
- Single barrier application may suffice

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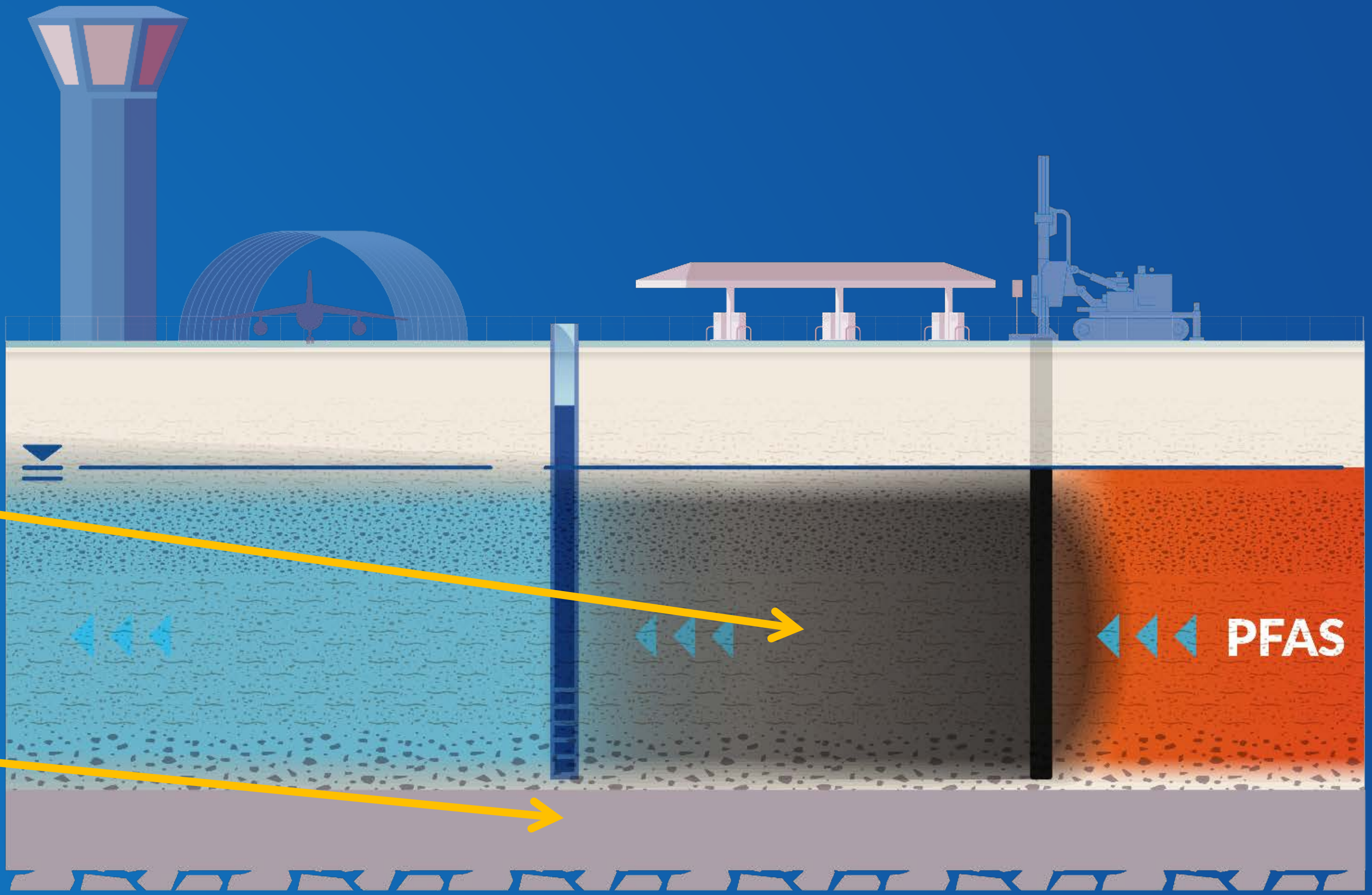
What is it?

- Colloidal/Liquid Activated Carbon
- Particle Sizes 1 – 2 µm
- Suspended as a colloid in a polymer solution
- Distributes Widely Under Low Pressure
- Provides extremely fast sorption sites
- Converts underlying geology into purifying filter

Treatment of Flux Zones and Control of Back Diffusion



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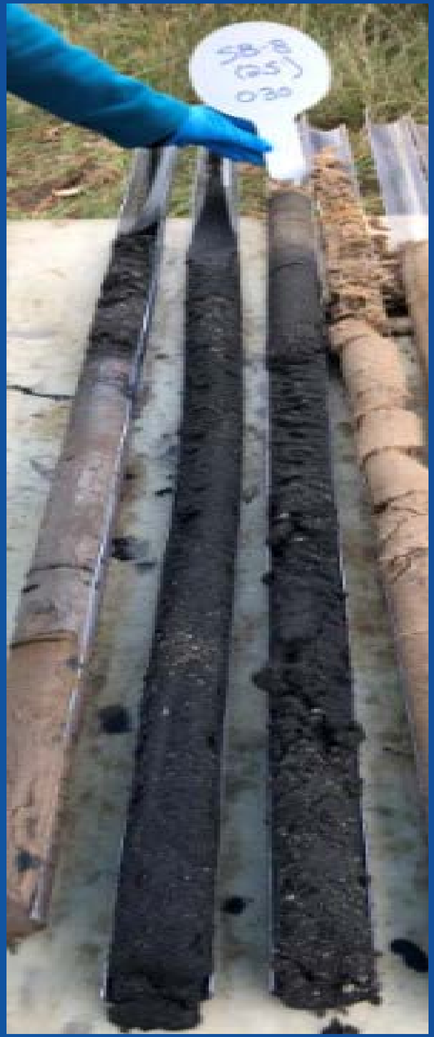
Considerations for using CAC

- Identity of the target contaminants of concern
  - Longer chain PFAS > shorter chain PFAS
- Presence of other non-target compounds
  - Compete for sorption sites (carbon demand)
- Contaminant Flux
  - Groundwater velocity
  - Contaminant concentrations
- Application
  - Design Verification Testing
  - “Building an underground fence”



Soil borings from Camp Grayling

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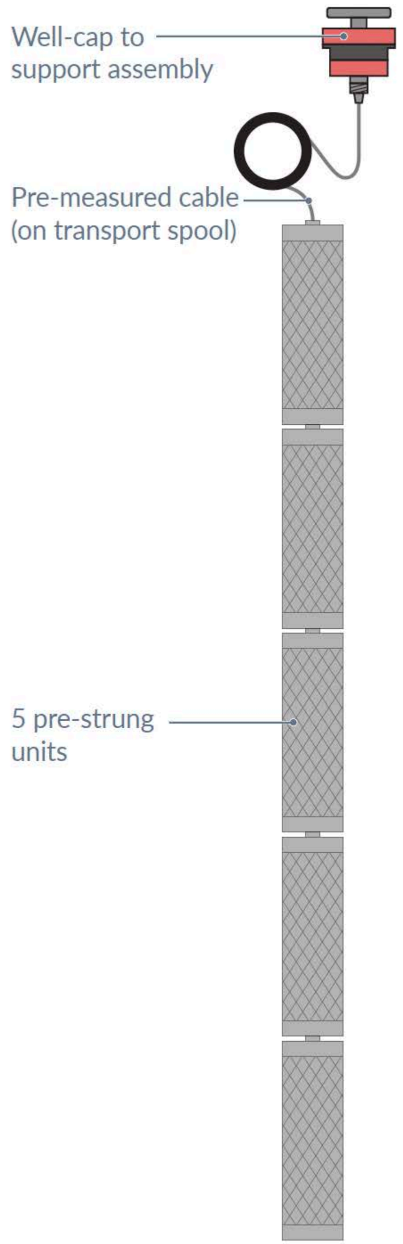
Flux Mapping Tool

Key Benefits:

- **Arrives pre-assembled and ready to deploy**
- **Vertically delineates contaminant mass flux and groundwater speed within an existing monitoring well**
- **Collects information to aid in site characterization and remedial designs**
- **Better site characterization and more specific design choices lead to better remedial outcomes**

How it Works:

- **FluxTracer is deployed for two weeks and retrieved**
- **Device is sent back to REGENESIS for sample analysis**
- **Results are used to provide a report containing useful information such as contaminant mass flux and groundwater Darcy flux**



Global PFAS Sites Treated

Alaska Airport Site

Southeast UK Airport Site

Southern UK Airport Site

Ontario Airport Site

Michigan Army Airfield

Confidential Air Force Base

Ontario Industrial Site

New York Industrial Site

Southern Sweden Port Site

Southeast Sweden Manufacturing Facility

Midwest Chemical Manufacturing Facility

Former Aero-Motive Company Plant

Industrial Facility With Fractured Bedrock

Western New York Industrial Site

Middle East Bulk Storage Facility

Former Refinery

Fire Training Area

Connecticut Superfund Site

Pennsylvania Landfill Site

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CASE STUDIES

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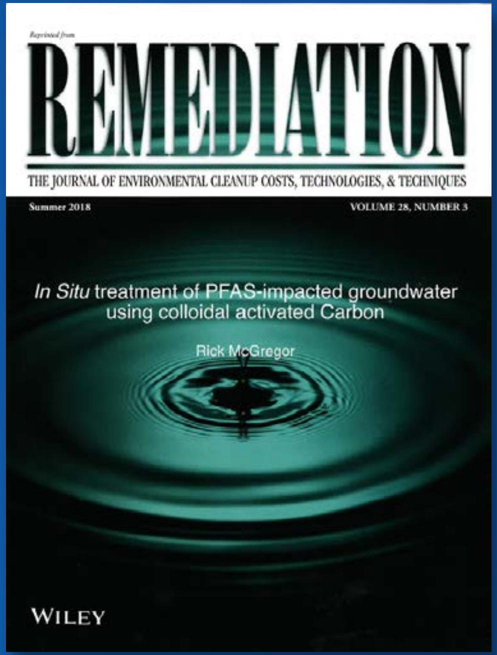
FORMER FURNITURE FACILITY

ONTARIO, CANADA

INSITU
REMEDIATION SERVICES



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

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Background

Initial Driver: Hydrocarbons

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

Formation

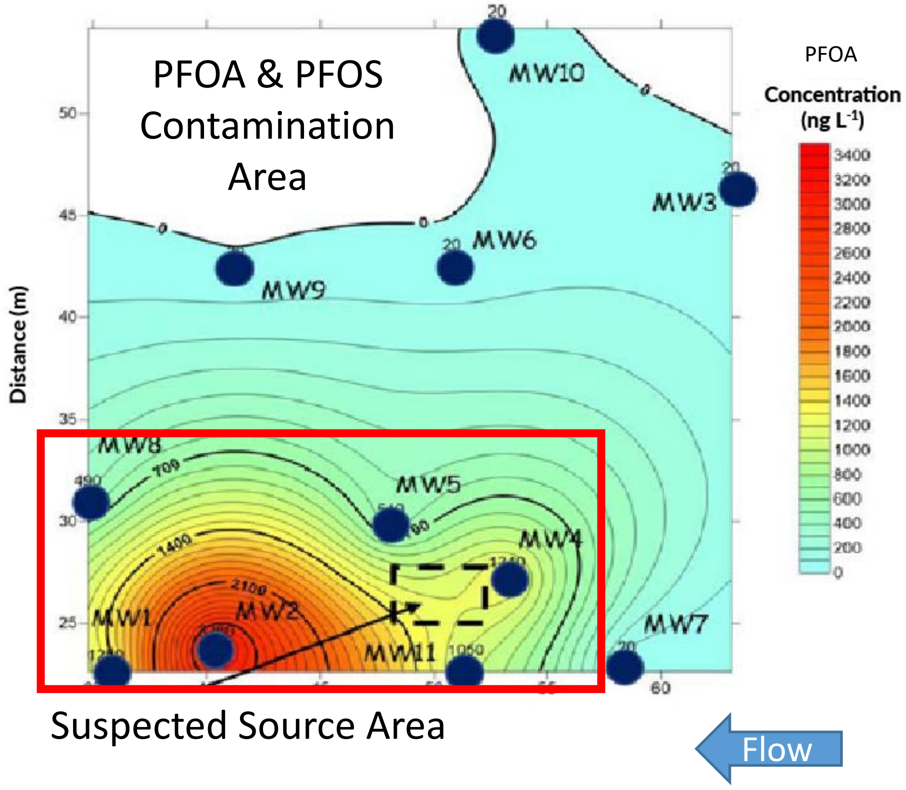
- GW Velocity: .8m/day
- Silty sand – till based with sand seams
- Water at 3 – 5' below grade

Former Fire Training Area

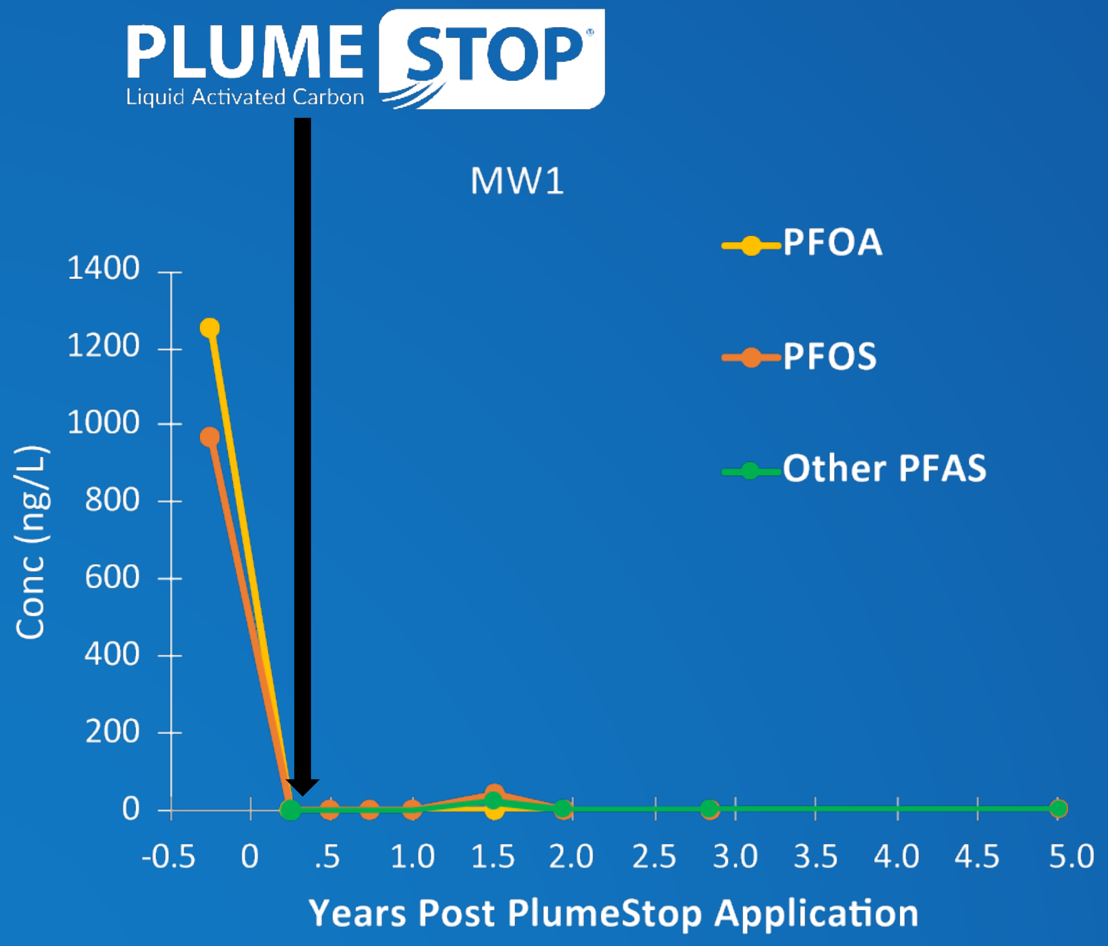
- History of furniture manufacturing
- PFAS tested for just in case and found!
  - 6 wells impacted by PFOS (300 to 1,400 ng/L) & PFOA (400 to 3,400 ng/L)

Remedial Approach

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



Monitoring & Results



Monitoring events:

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

Results for MW1 are shown

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

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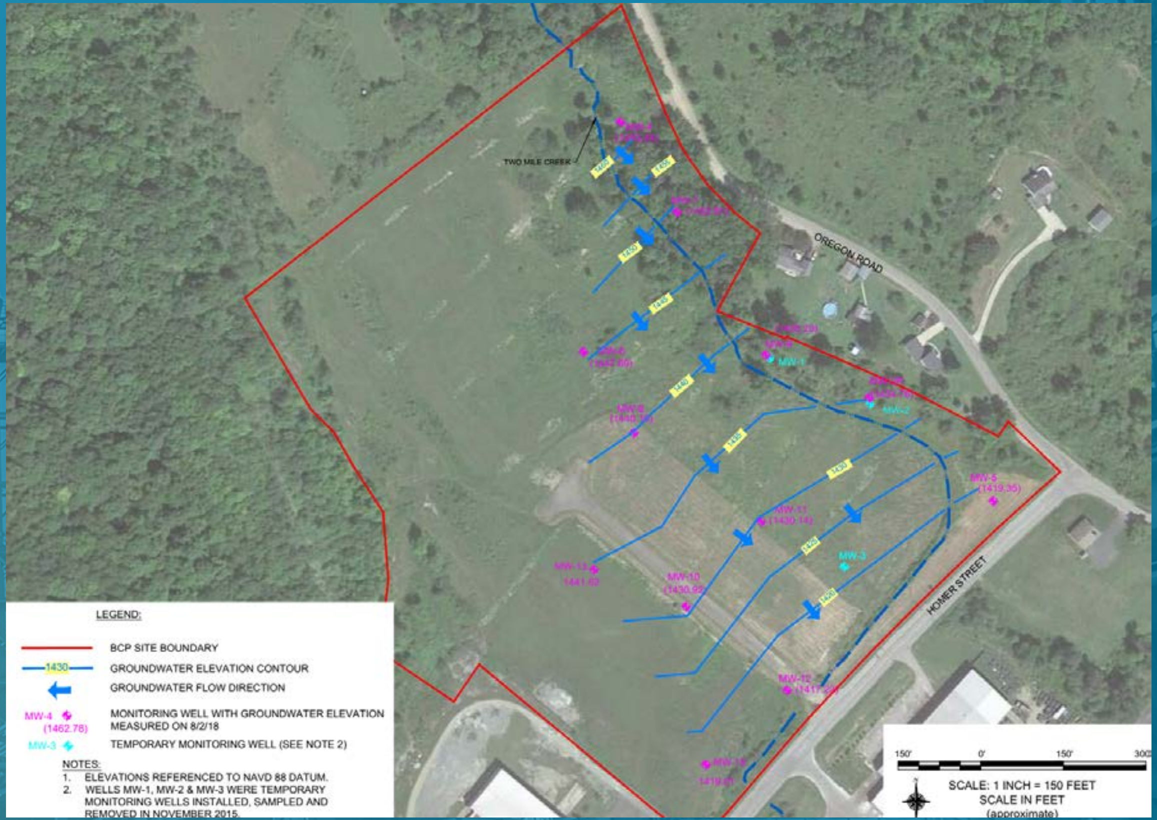
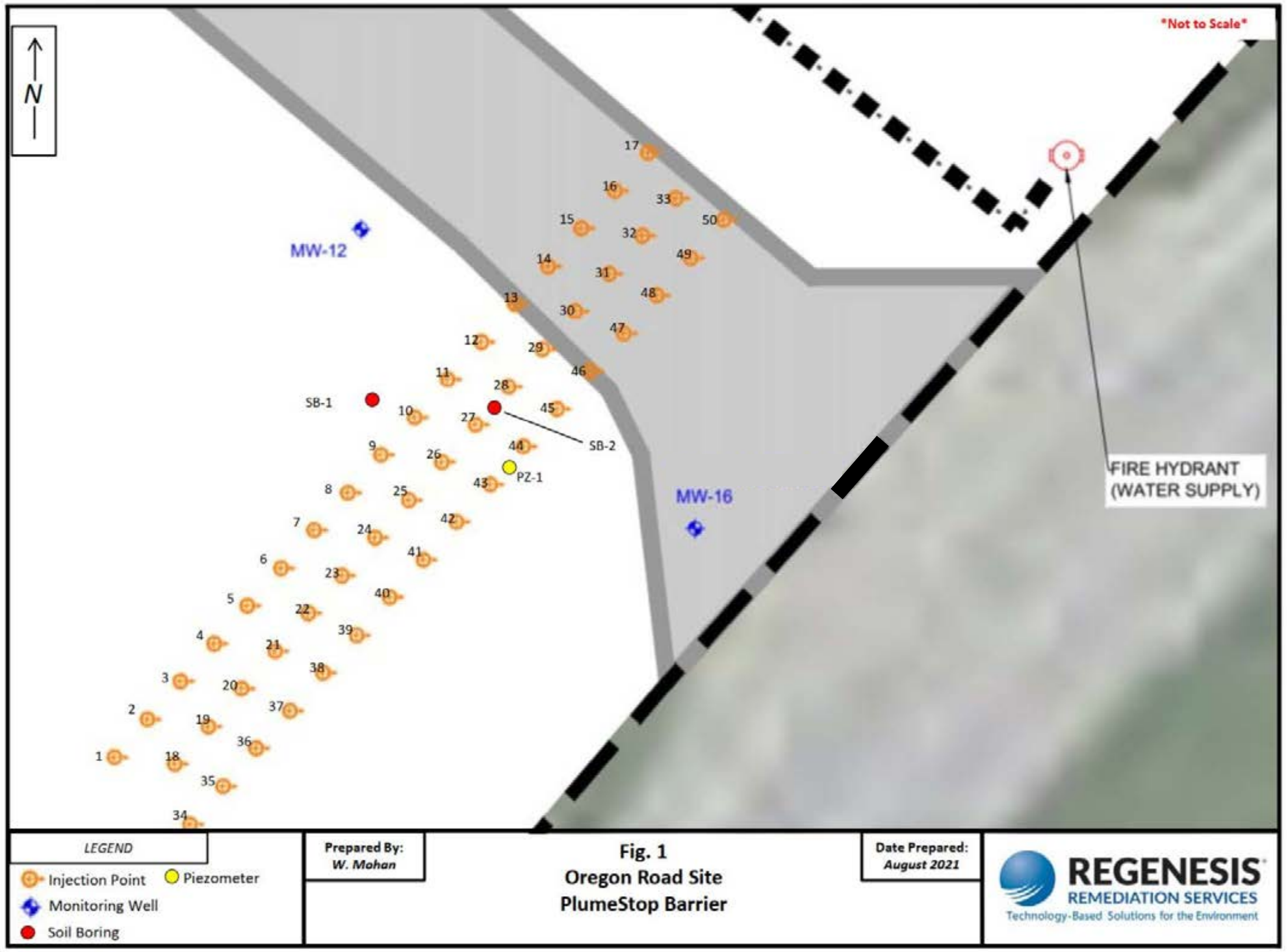
NYS Brownfield site

- PFOS and PFOA above regulatory standards
- No co-contaminants
- Soil : variable – permeable zones within silt/ clay
- Objective: Source Remediation (vadose soil) and Cut off Migration of PFOA and PFOS



Injection Plan

Figure 1: Site Map with Treatment Area and Well Locations



- MW12
  - PFOS 1020 ppt
  - PFOA 49 ppt
  - Total PFAS: 2271 ppt
- Apply CAC in three rows
- Application August 2021
- Certificate of Completion Issued by NYS Dec 2021

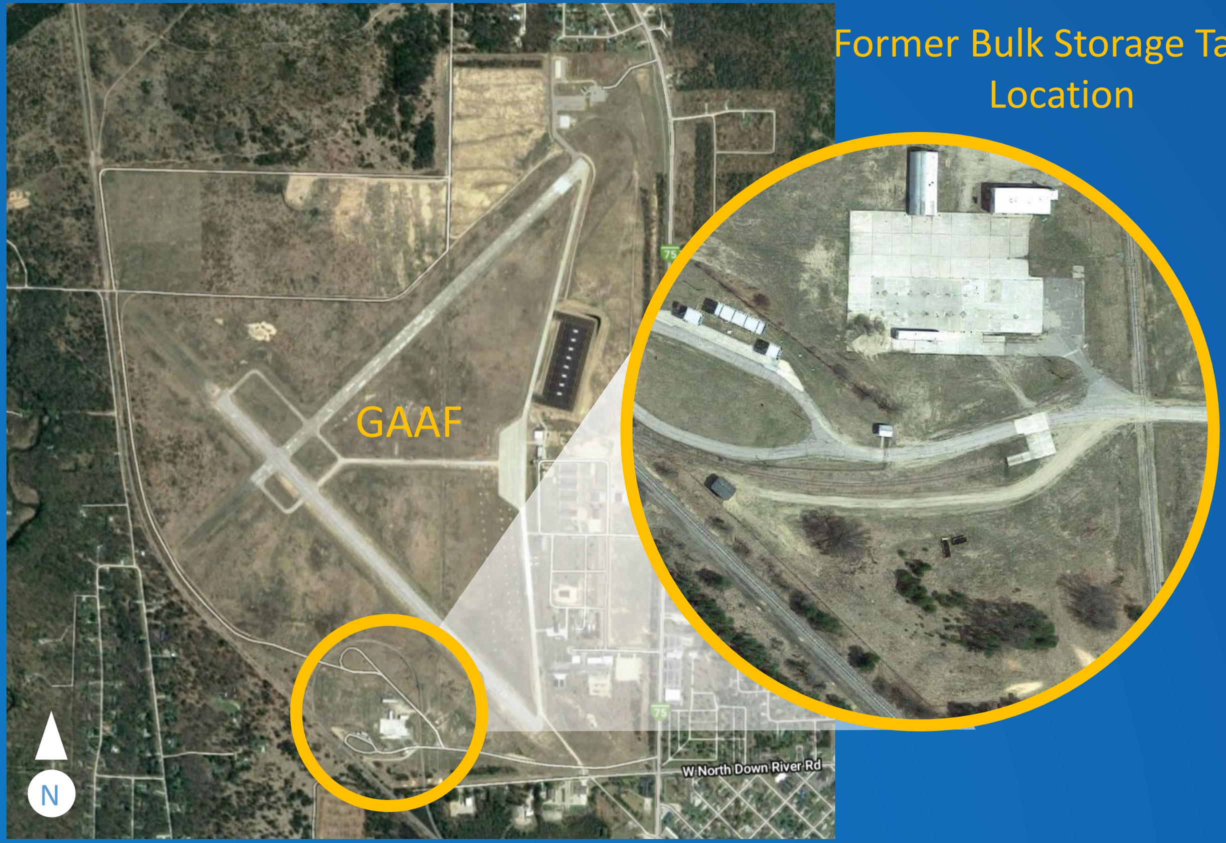
PFAS REMAINS AT NON-DETECT

CASE STUDY:
Michigan Dept. of Military and Veteran Affairs Employs CAC at Grayling Army Airfield

Background

- Founded 1913
- 147,000 Acres
- Largest National Guard Training Center in the Country
- Home to Grayling Army Airfield (900 Acres)
- Contaminant Release History:
  - Diesel, PCE/TCE, PFAS
- Remediation History:
  - Pump and Treat, Air Sparging/SVE

Case Study: Pilot Test



Site Details

GW Velocity	250 ft/yr
Vertical Treatment Interval	15’-27’ bgs.
Injection Wells	9
Soil Type	Sand & Gravel, some clay layers
Sensitive Receptors	Residences, Surface water bodies, Property Boundary
Contaminants of Concern	10 µg/L PCE 130 ng/L Total PFAS (PFOS, PFHxS)

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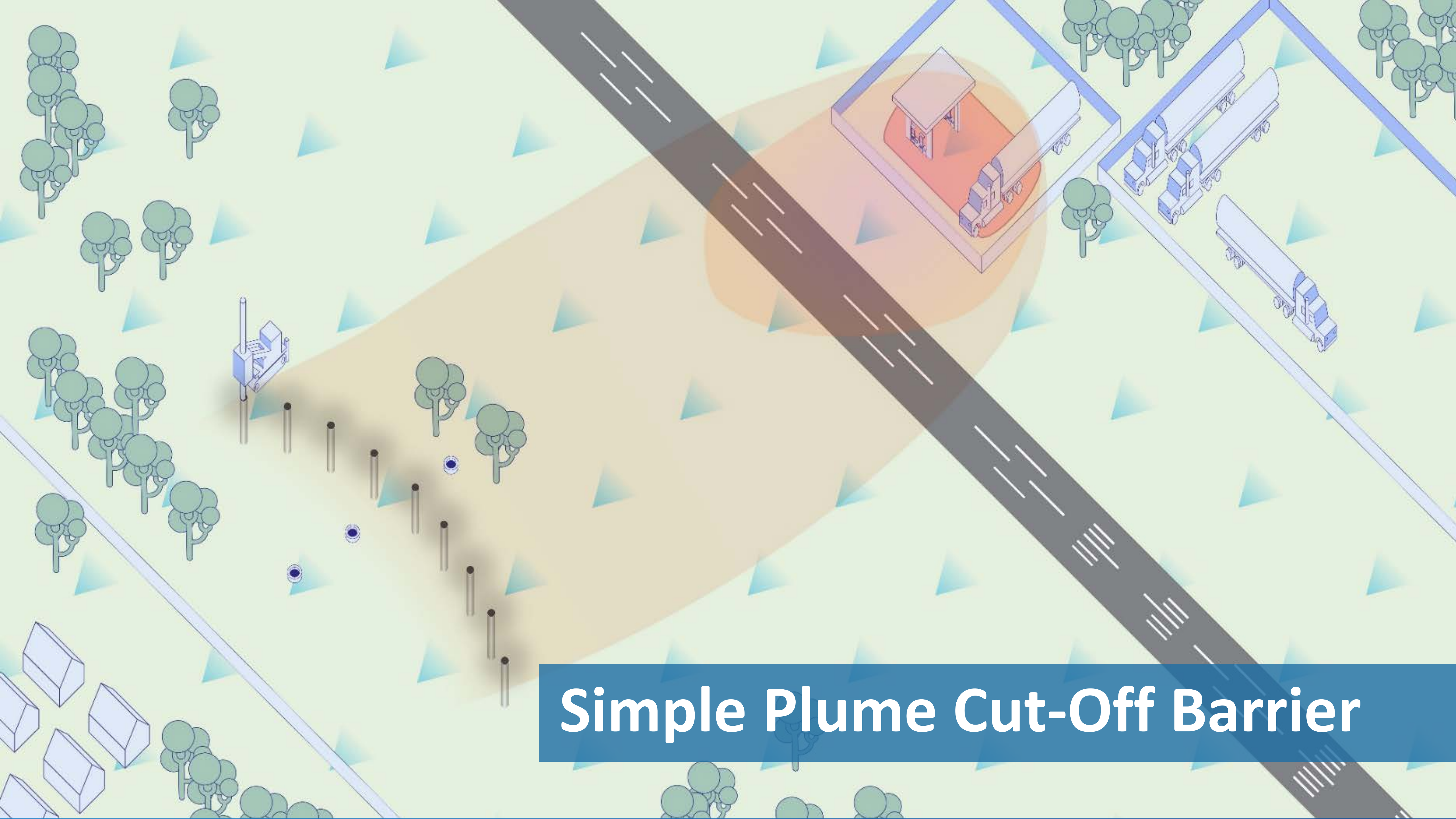
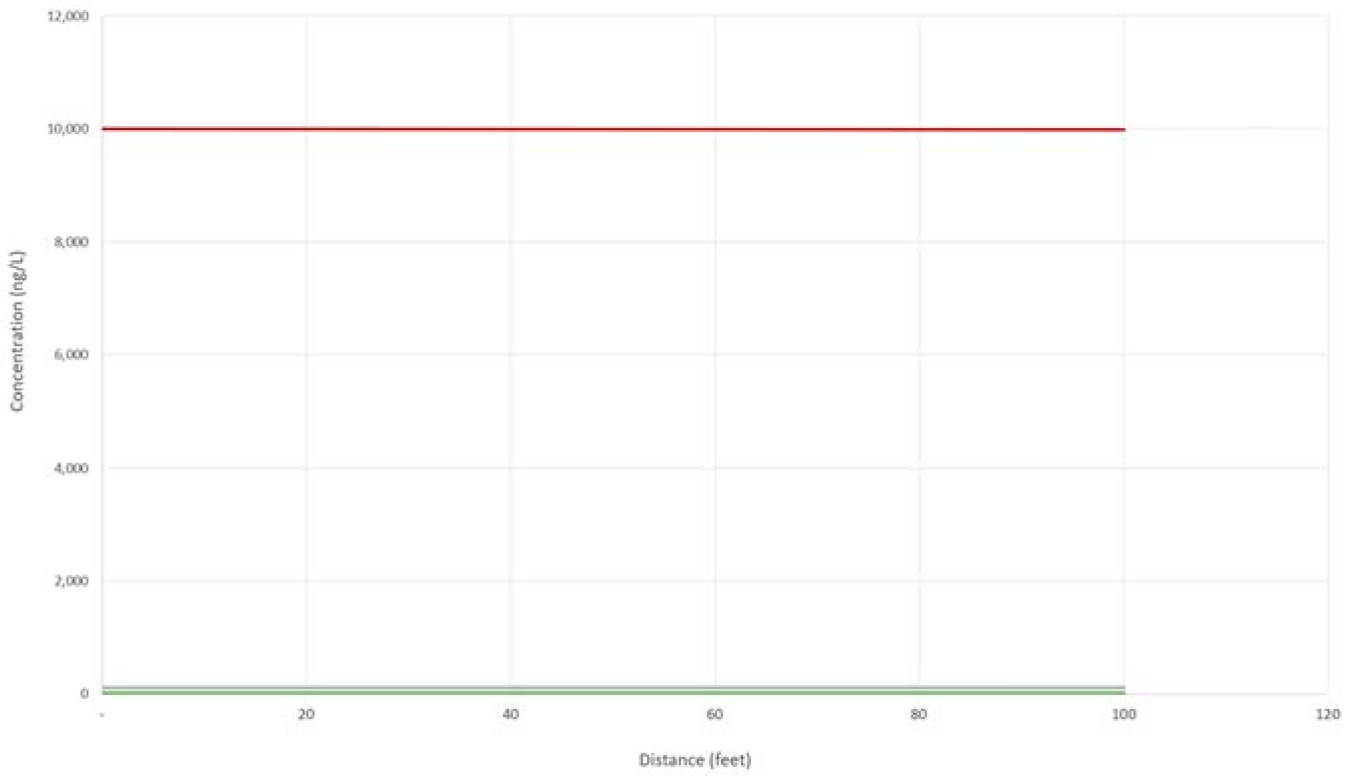


Simple Plume Cut-Off Barrier

Modeling in the Design Process

Centerline Contaminant Trends – Multiple Year Simulation



Key

- PFOS
- PCE/TCE
- PFHxA-HpA- HxS
- PFOA
- Other PFAS

Inputs

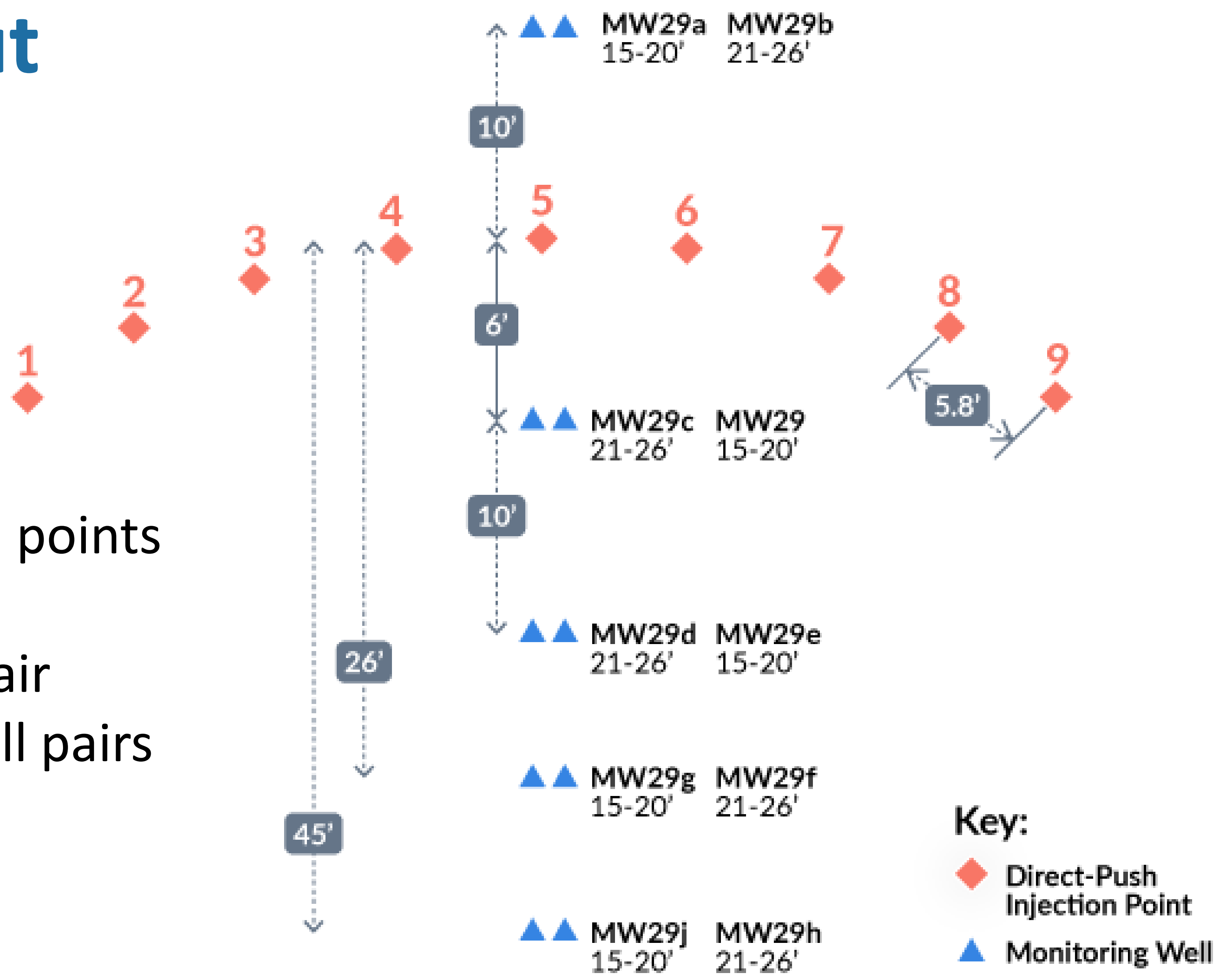
Groundwater Flow

- **GW 219 ft/yr**
- **Infinite Source**
- **PFOS 110 ng/L**
- **PFOA 8 ng/L**
- **PFHxA-HpA-HxS 112 ng/L**
- **Other PFAS 9 ng/L**
- **PCE 10 ug/L**
- **No degradation of any PFAS compound or CVOCs**
- **Time (>75 Years)**

Contaminants not shown are at or below 0 ng/L or outside detectable limits

Pilot Test Layout

- 9 Direct-push injection points spaced 5.8 feet apart
- One upgradient well pair
- Four downgradient well pairs



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Field Test Layout

CAC-Distribution Confirmation

27 feet bgs

0 feet bgs

15 feet bgs

30 feet bgs

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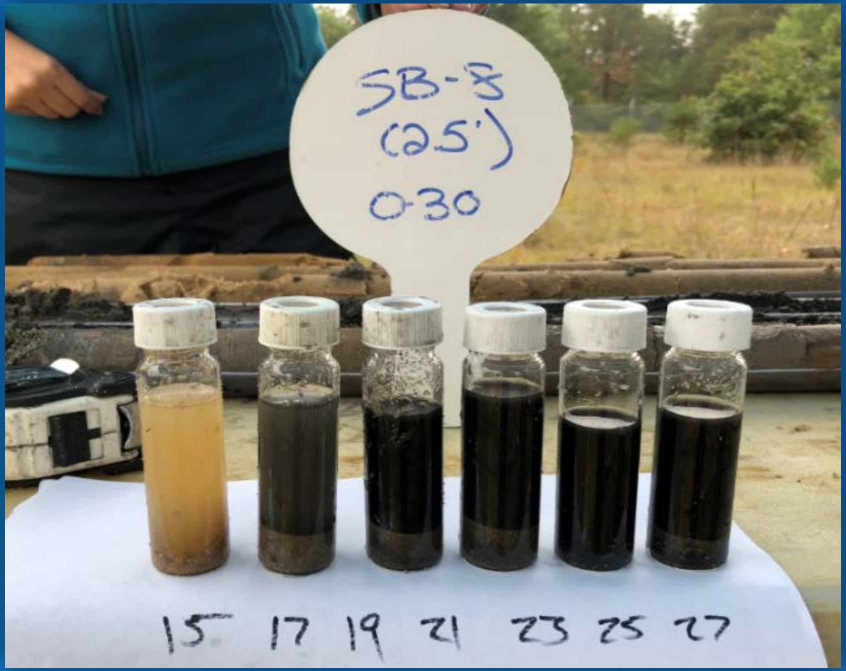
CAC-Distribution Confirmation



Soil Vial Shake Test

MW-29c

Field Test Kit

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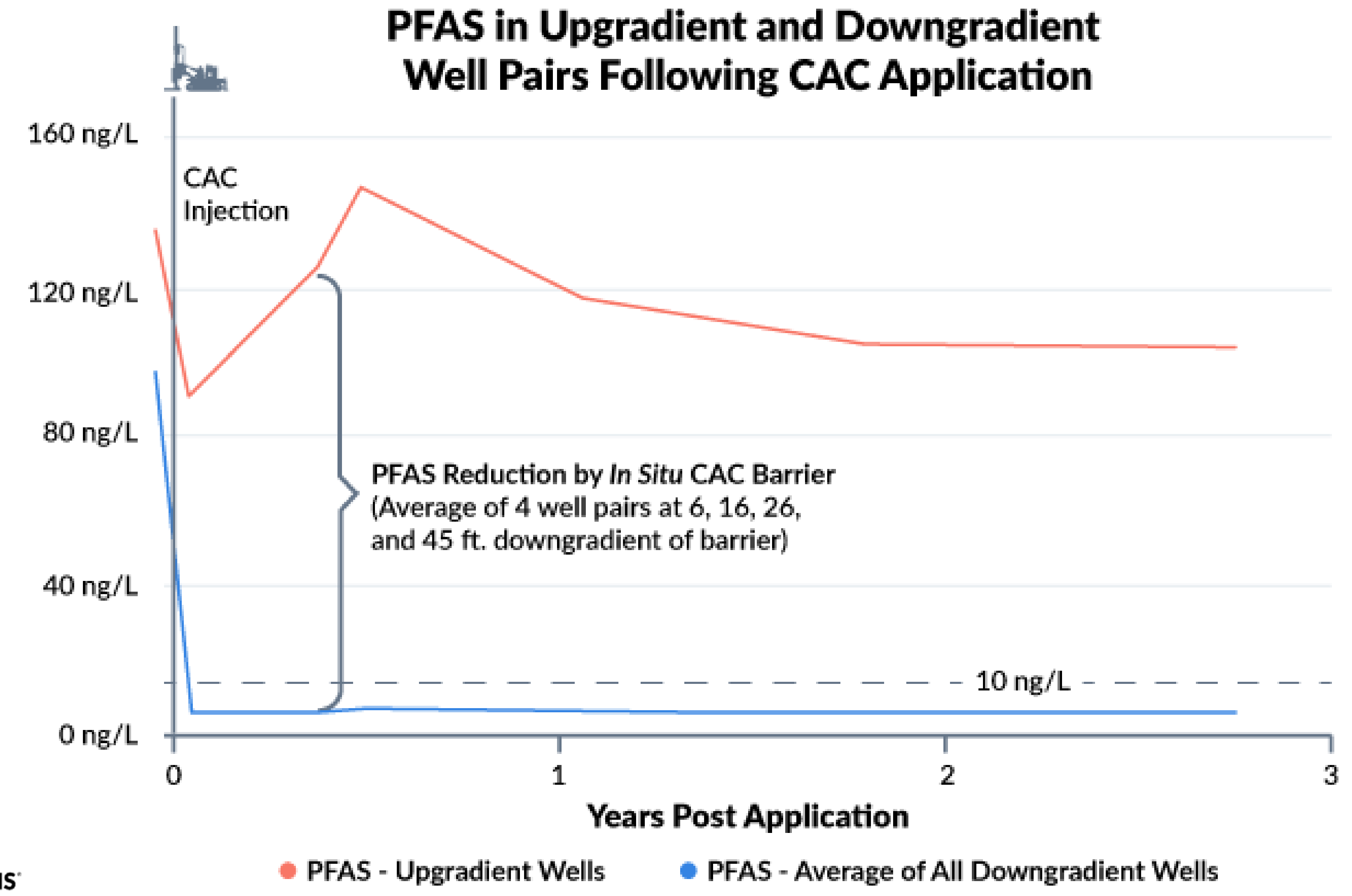
PFAS in Upgradient and Downgradient
Well Pairs Following CAC Application
160 ng/L
120 ng/L
80 ng/L
40 ng/L
0 ng/L
CAC
Injection
PFAS Reduction by *In Situ* CAC Barrier
(Average of 4 well pairs at 6, 16, 26,
and 45 ft. downgradient of barrier)
10 ng/L
0
1
2
3
Years Post Application
PFAS - Upgradient Wells
PFAS - Average of All Downgradient Wells
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Summary

- Multiple Successful Applications
  - Verified distribution of CAC
  - Sustained reductions of PFAS over time
  - Anticipated to last for decades
  - Low cost alternative for possible remediation
- CAC provides a flexible, effective, *in situ* option to address PFAS
  - Passive plume control & containment
  - Prevent expansion of the problem
  - Manages the risk of PFAS in groundwater for years

Thank You!

Alana Miller

Sr. Northeast District Manager
REGENESIS

amiller@regenesis.com

(646) 838-2926

Additional PFAS Resources:

PFAS Training Portal

PFAS Resource Center

New Third-Party Journal Articles by Rick McGregor, President of IRSL

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