Colloidal Activated Carbon Used to Treat PFAS Impacts at AFFF Training and Use Areas at Three Regional Airports: A Multi-Site Pilot Testing Review

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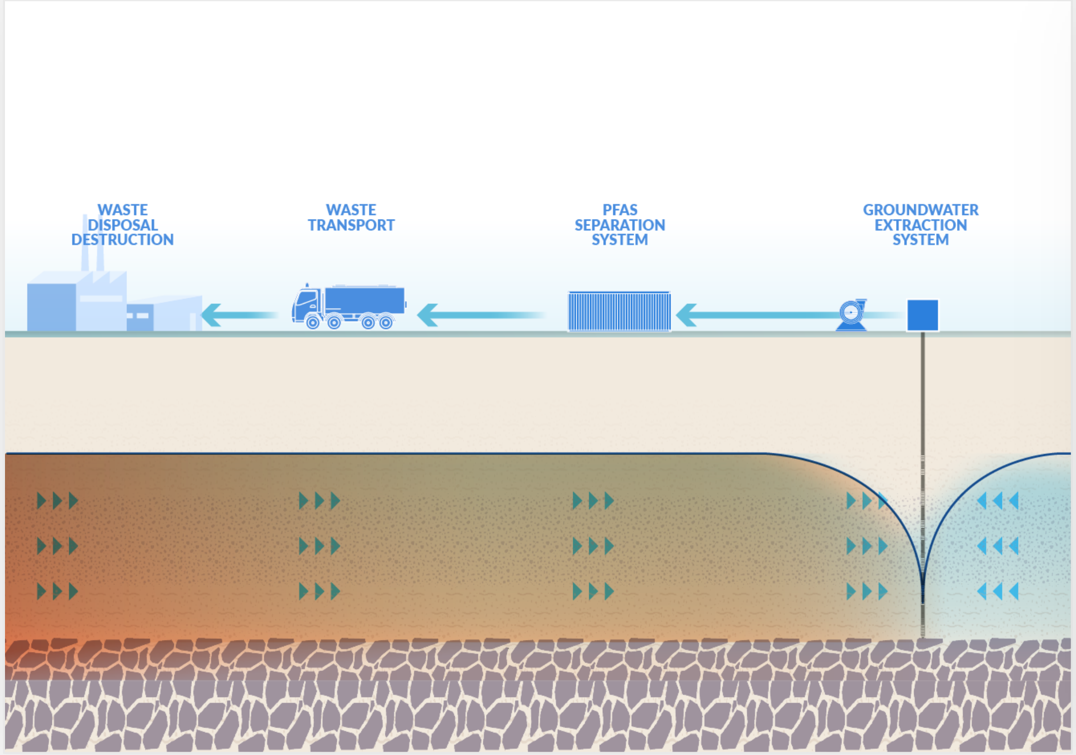
Remediation of PFAS in Groundwater

Two Available Approaches:

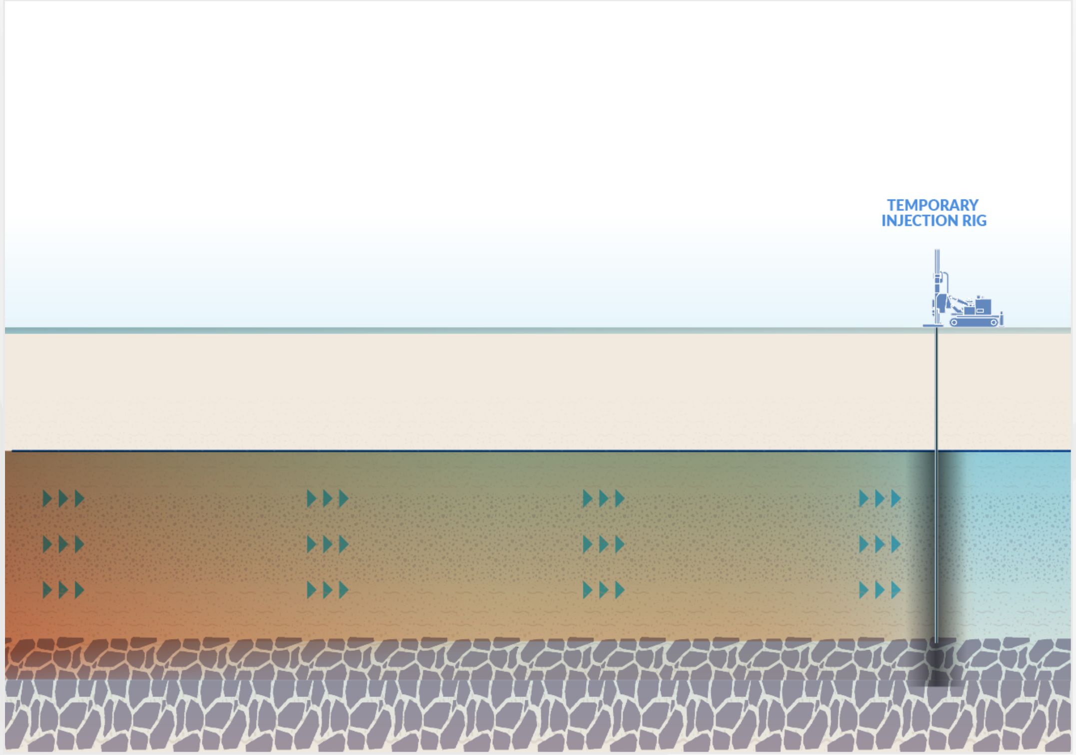
Pump & Treat (ex-situ)

Contain plume with pumping



In Situ Remediation

Immobilize the PFAS within the aquifer



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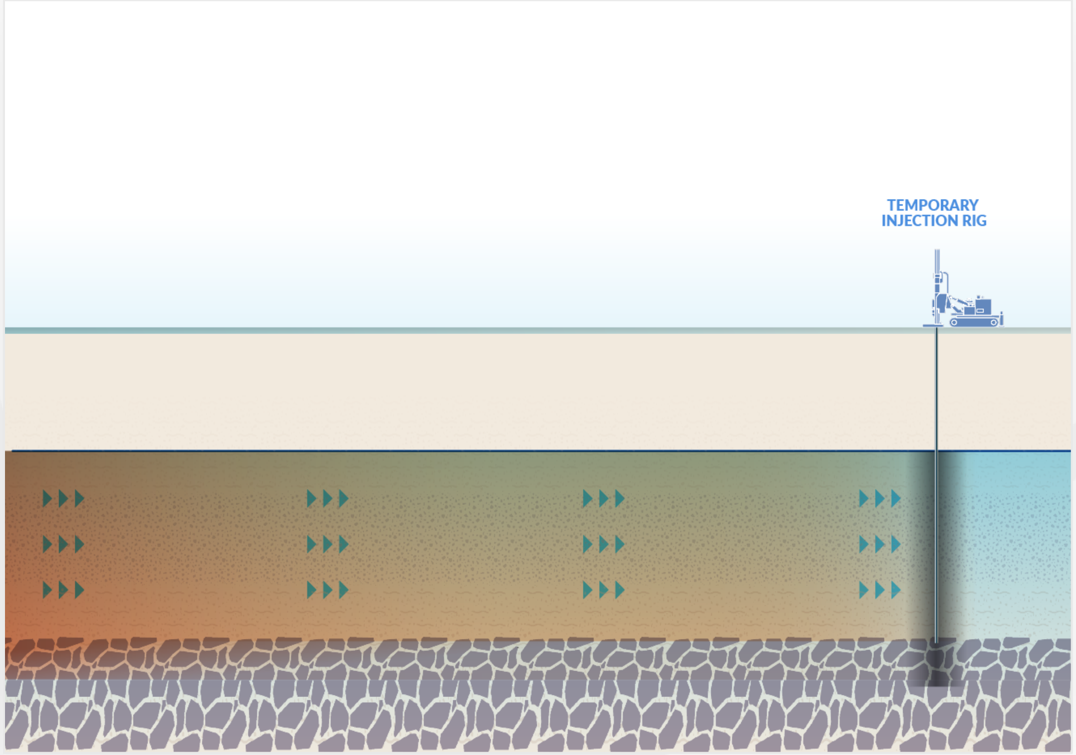

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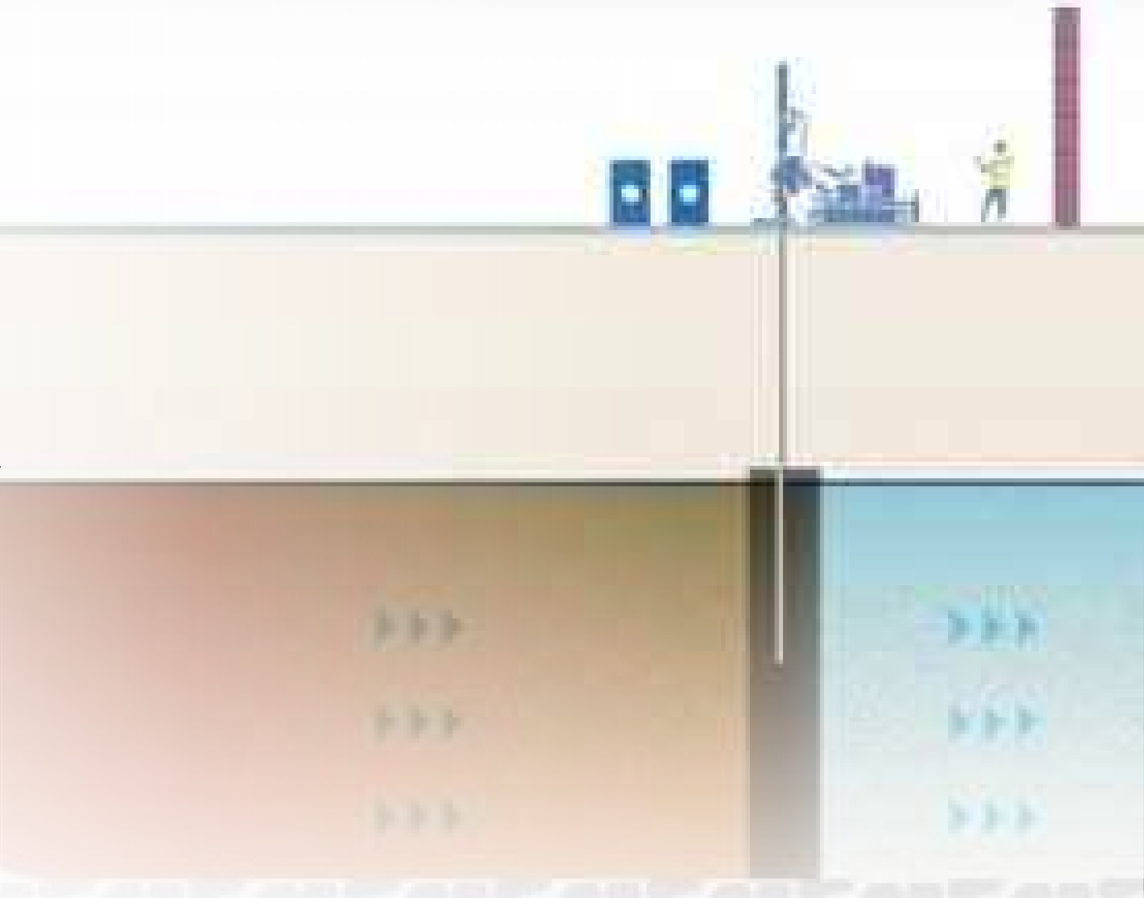
In Situ CAC Remediation

How is Remediation Achieved?

- CAC particles permanently coat the aquifer matrix creating an in-situ filter
- CAC engineers the K_d of the aquifer increasing the adsorptive capacity by several orders of magnitude
- PFAS is immediately removed from groundwater
- PFAS risk is eliminated by removing the exposure pathway to receptors



Remediation

*“A process used to reduce or eliminate the risk for humans and the environment that may result from exposure to harmful chemicals” **

*Interstate Technology Regulatory Council (ITRC), 2020

Colloidal Activated Carbon

What is it?

- Form of activated carbon the size of a red blood cell (1 – 2 µm)
- Small enough to move through soil pores to evenly coat and penetrate the soil particles
- Formulated in a liquid solution or solid conglomerate

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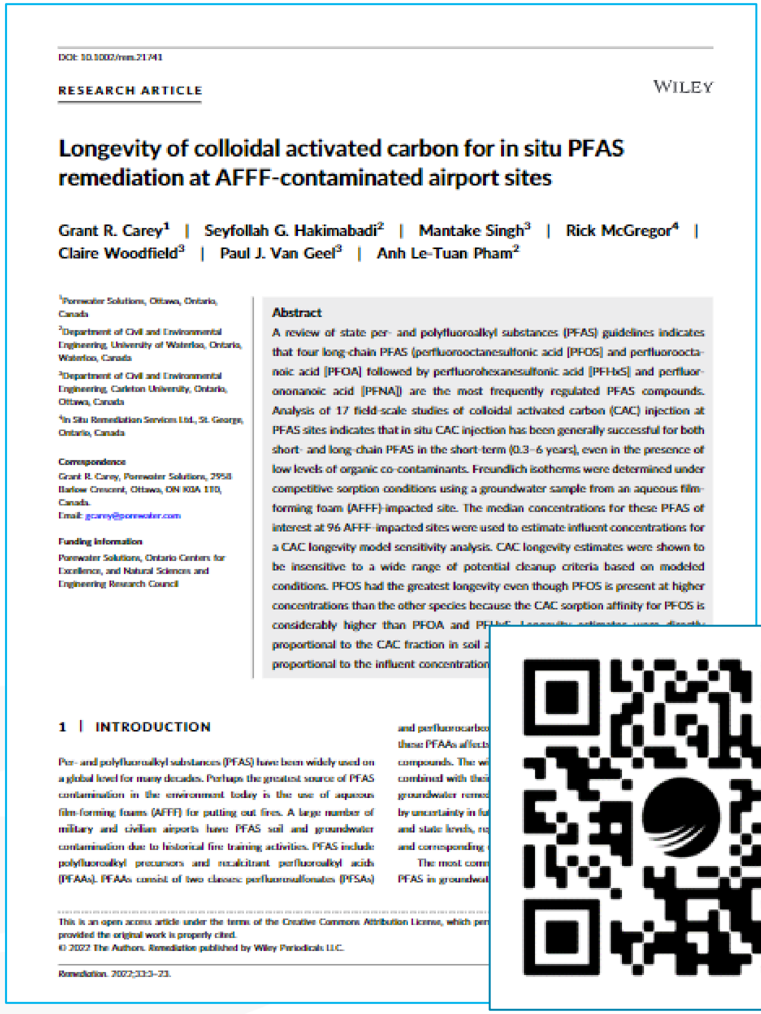
Independent Assessment of PFAS CAC Applications at Airport Sites

- Mixed plume (PHC/VOCs/PFAS) performance is well-documented for 17 different sites[1]
- Competitive sorption is real and must be considered in the design
- Modeling indicates decades of treatment longevity (single injection)
- Longevity impacted mostly by incoming mass flux
- 82% dominated by PFOS and PFHxS Preferentially sorbed to AC



DOI: 10.1002/rem.21741

RESEARCH ARTICLE

WILEY

Longevity of colloidal activated carbon for in situ PFAS remediation at AFFF-contaminated airport sites

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Funding information
Porewater Solutions, Ontario Centers for Excellence, and Natural Sciences and Engineering Research Council

Abstract
A review of state per- and polyfluoroalkyl substances (PFAS) guidelines indicates that four long-chain PFAS (perfluorooctanesulfonic acid [PFOS] and perfluorooctanoic acid [PFOA] followed by perfluorohexanesulfonic acid [PFHxS] and perfluorononanoic acid [PFNA]) are the most frequently regulated PFAS compounds. Analysis of 17 field-scale studies of colloidal activated carbon (CAC) injection at PFAS sites indicates that in situ CAC injection has been generally successful for both short- and long-chain PFAS in the short-term (0.3–6 years), even in the presence of low levels of organic co-contaminants. Freundlich isotherms were determined under competitive sorption conditions using a groundwater sample from an aqueous film-forming foam (AFFF)-impacted site. The median concentrations for these PFAS of interest at 96 AFFF-impacted sites were used to estimate influent concentrations for a CAC longevity model sensitivity analysis. CAC longevity estimates were shown to be insensitive to a wide range of potential cleanup criteria based on modeled conditions. PFOS had the greatest longevity even though PFOS is present at higher concentrations than the other species because the CAC sorption affinity for PFOS is considerably higher than PFOA and

1 | INTRODUCTION

Per- and polyfluoroalkyl substances (PFAS) have been widely used on a global level for many decades. Perhaps the greatest source of PFAS contamination in the environment today is the use of aqueous film-forming foams (AFFF) for putting out fires. A large number of military and civilian airports have PFAS soil and groundwater contamination due to historical fire training activities. PFAS include polyfluoroalkyl precursors and recalcitrant perfluoroalkyl acids (PFAAs). PFAAs consist of two classes: perfluorosulfonates (PFSAs)

Remediation. 2022;33:3–23.

1. Carey, G.R., et. al. 2022. Remediation, 33: 3-23

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Pilot Test Site Review

- Pilot testing completed to resolve questions in efficacy and efficiency in risk reduction
- Pilot testing also allows the practitioner to find ways to remove variables in the design and application process to more easily scale up to larger applications
- Three pilot tests presented here will show results and also methods for process assessment

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Westchester County Airport (HPN)

Case Study: Groundwater Pilot Test

Westchester County Airport (HPN) (sometimes called White Plains) is a county-owned airport in Westchester County, New York

- 33 miles north of Manhattan
- 702 acres at an elevation of 439 feet
- Airport opened in 1942 as an Air National Guard Unit to protect Rye Lake, part of the NYC's water supply system
- Local conservation advocacy groups raised concerns about the stormwater runoff
- PFAS compounds discovered in groundwater testing between the airport and the watershed

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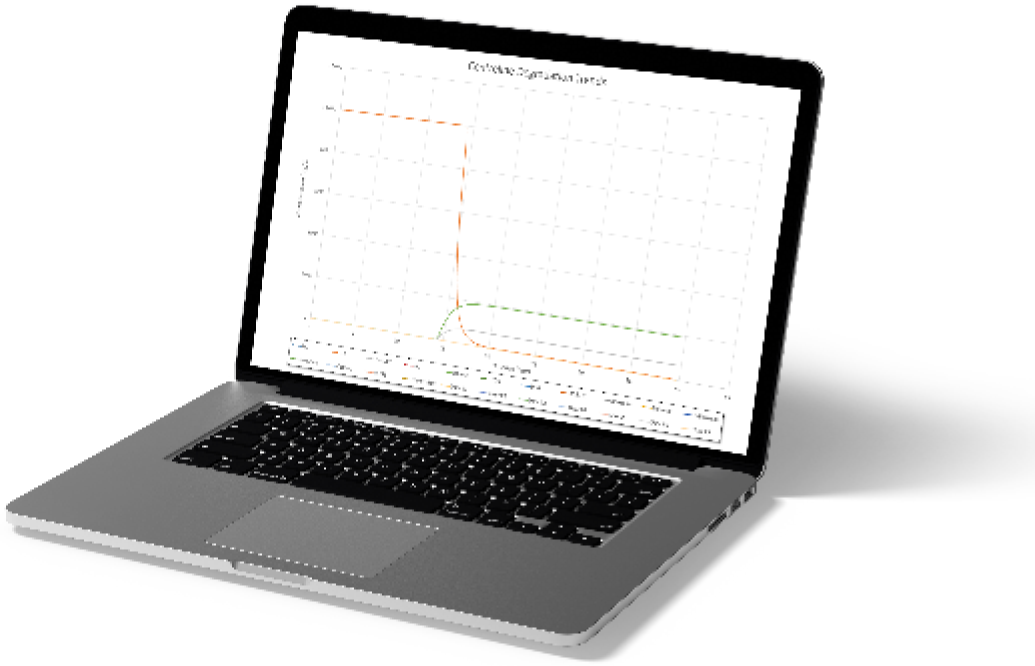
Modeling in the Design Process

Multi-phase finite-difference model accommodating dynamic sorption, destruction and competitive interactions between target and non-target species It predicts groundwater concentrations at any point in time in the modeled domain.

- **Key Factors:**
  - Target contaminant of concern
    - VOCs, PFAS, etc.
    - Compound Specific Isotherms
  - Contaminant Mass Flux
  - Non-target compounds present
  - Competitive Sorption and Degradation (if applicable)
- **Model Considerations:**
  - Carbon Dose
  - Vertical Variations
  - Barrier Thickness
  - Time



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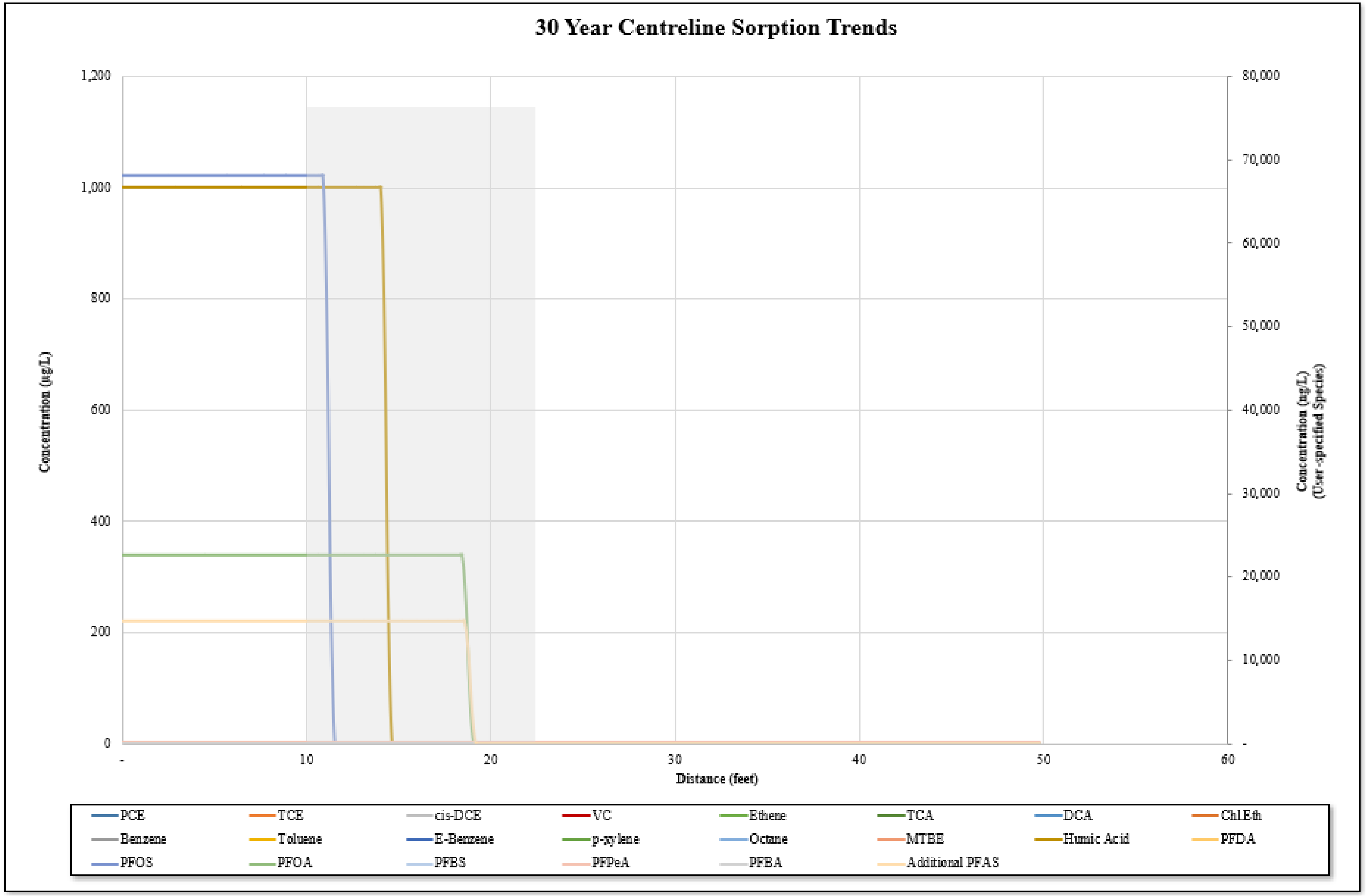
Modeling in the Design Process



Humic Acid	1,000
PFDA	-
PFOS	68,100
PFOA	22,600
PFBS	72
PFPeA	146
PFBA	92
Additional PFAS	14,712

Westchester Output

- PFOS/PFOA
- 30 Year Model Run
- Sensitivity Analysis
- Seepage Velocity 220 ft/yr
- Model derived carbon dose and water volumes to obtain necessary ROI

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Pilot Test Setup

A pilot test area was selected along the western area of the airport grounds downgradient of any AFFF use and upgradient of the watershed

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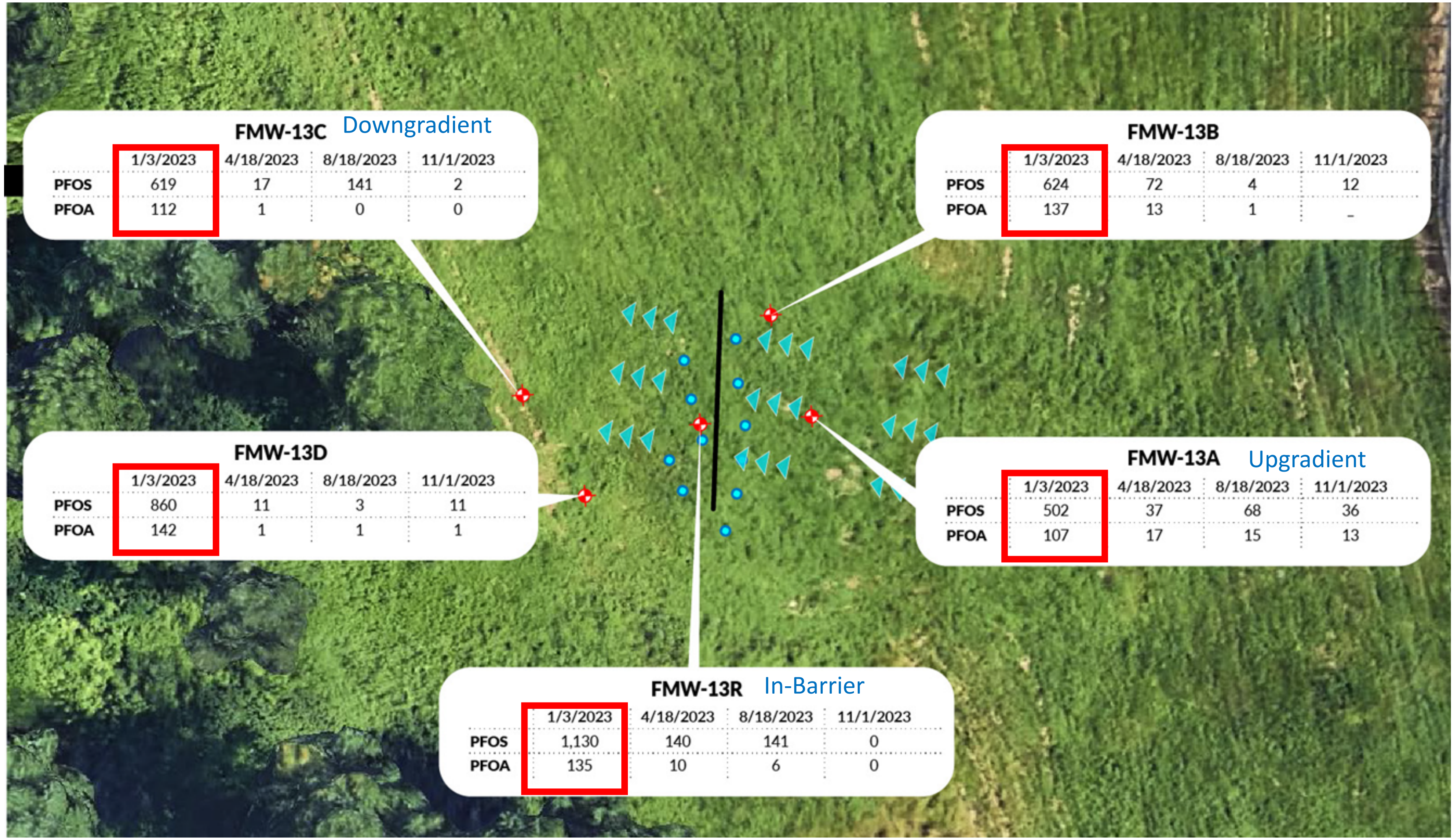
Pilot Test Results



FMW-13C Downgradient

	1/3/2023	4/18/2023	8/18/2023	11/1/2023
PFOS	619	17	141	2
PFOA	112	1	0	0

FMW-13B

	1/3/2023	4/18/2023	8/18/2023	11/1/2023
PFOS	624	72	4	12
PFOA	137	13	1	-

FMW-13D

	1/3/2023	4/18/2023	8/18/2023	11/1/2023
PFOS	860	11	3	11
PFOA	142	1	1	1

FMW-13A Upgradient

	1/3/2023	4/18/2023	8/18/2023	11/1/2023
PFOS	502	37	68	36
PFOA	107	17	15	13

FMW-13R In-Barrier

	1/3/2023	4/18/2023	8/18/2023	11/1/2023
PFOS	1,130	140	141	0
PFOA	135	10	6	0

Martha’s Vineyard Airport (MVY)

TETRA TECH

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Case Study: Groundwater Pilot Test

Martha's Vineyard Airport is centrally located on an island off the coast of Massachusetts

- PFAS from fire training activities has impacted the groundwater, and the plume has moved off-site
- Private water wells supply drinking water to residents at risk

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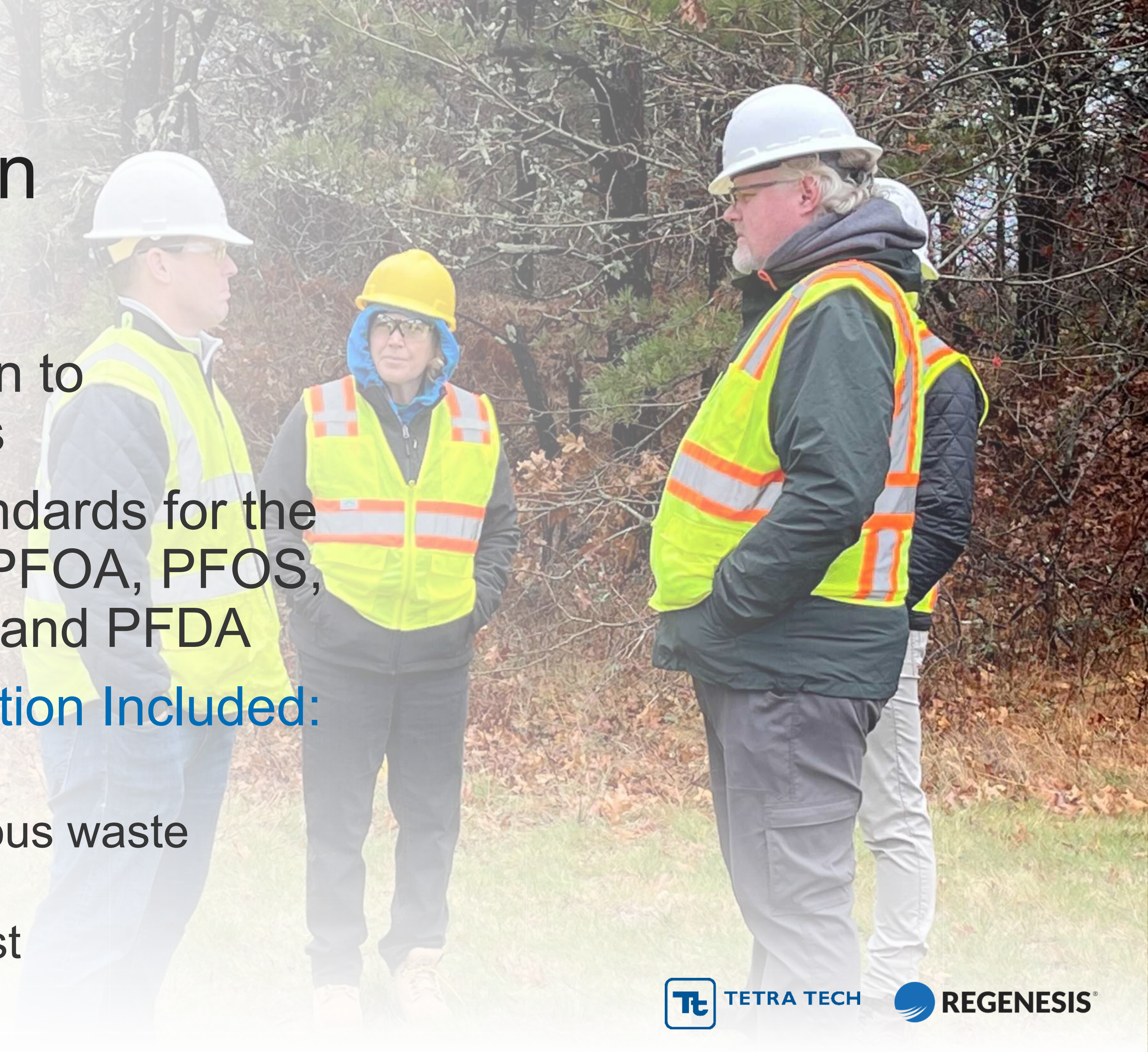
Remedy Selection

Remediation Goal:

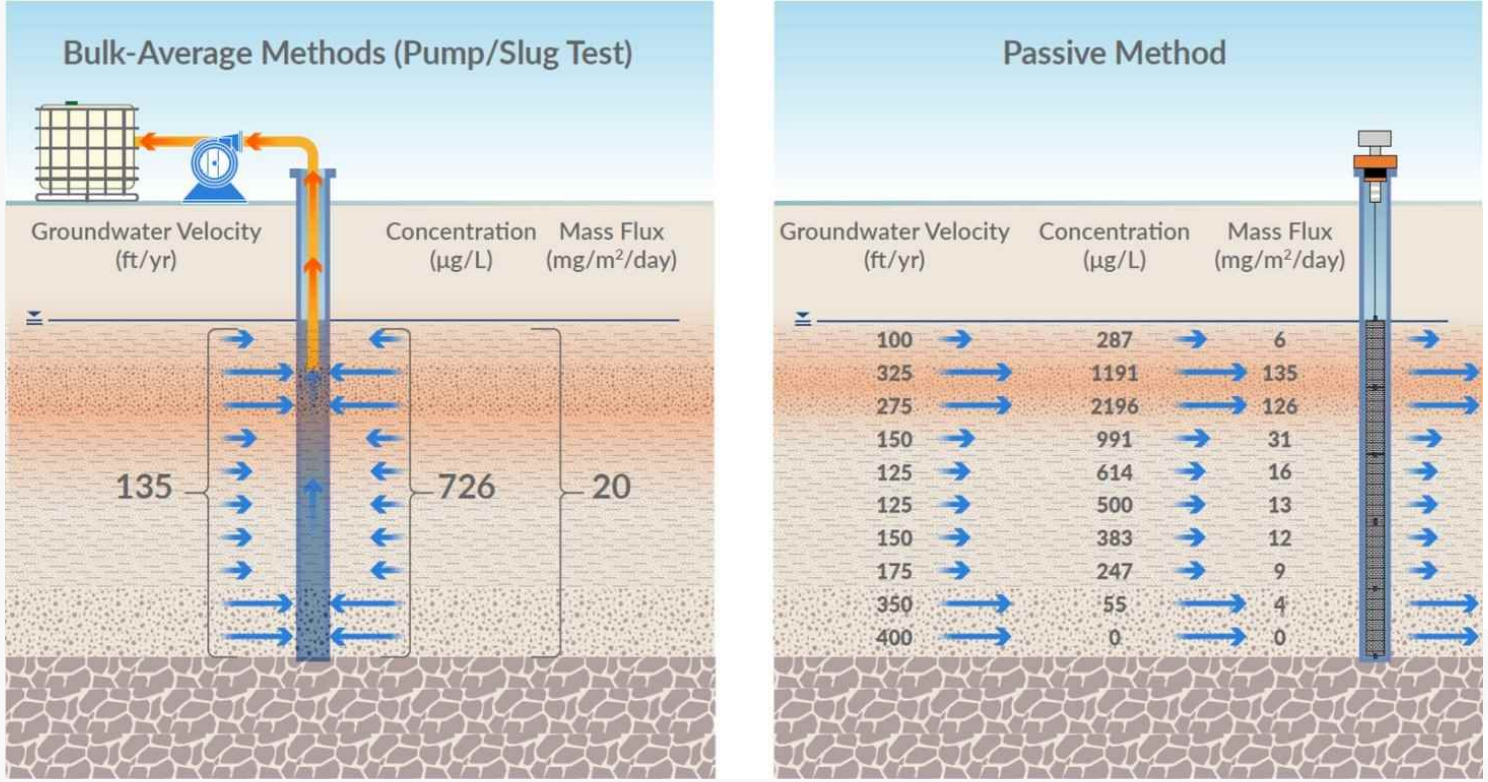
- Reduce PFAS migration to downgradient residents
- Achieve regulatory standards for the MA6 (sum of 20ng/L): PFOA, PFOS, PHHxS, PFNA, PFBS, and PFDA

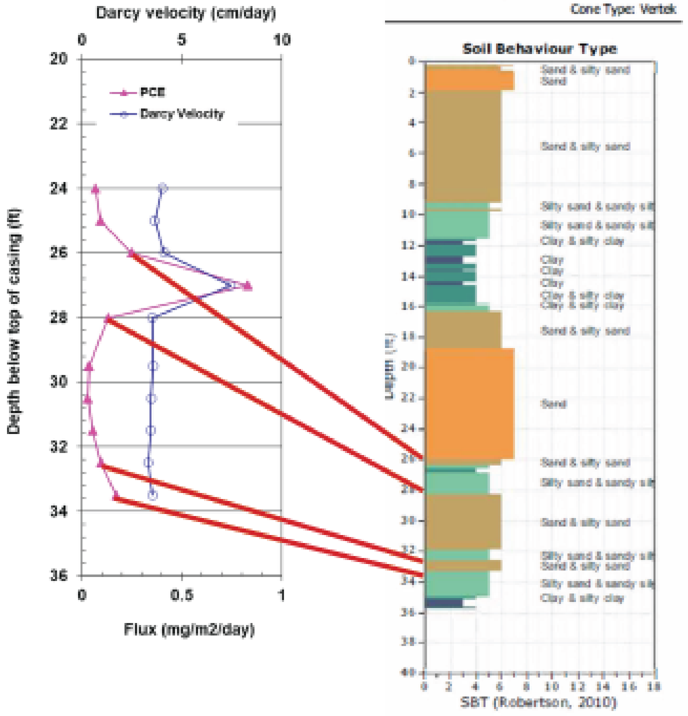
Key Factors in the Selection Included:

- Sustainability
- Avoiding PFAS hazardous waste disposal
- Short and long term cost



Mass Flux in the Design Process





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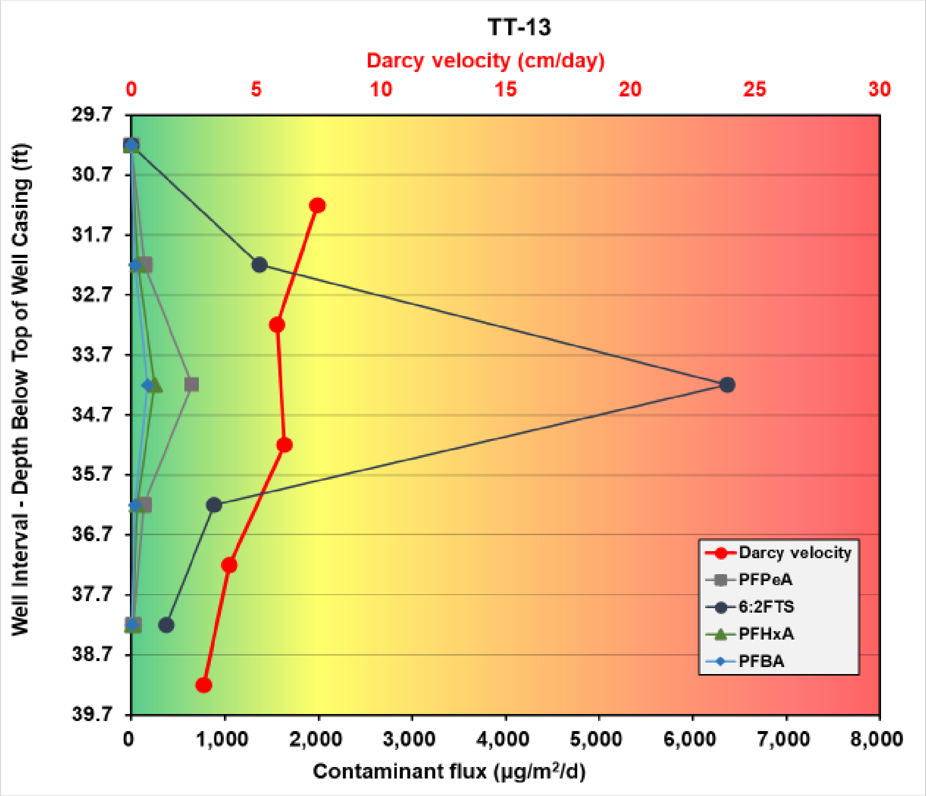
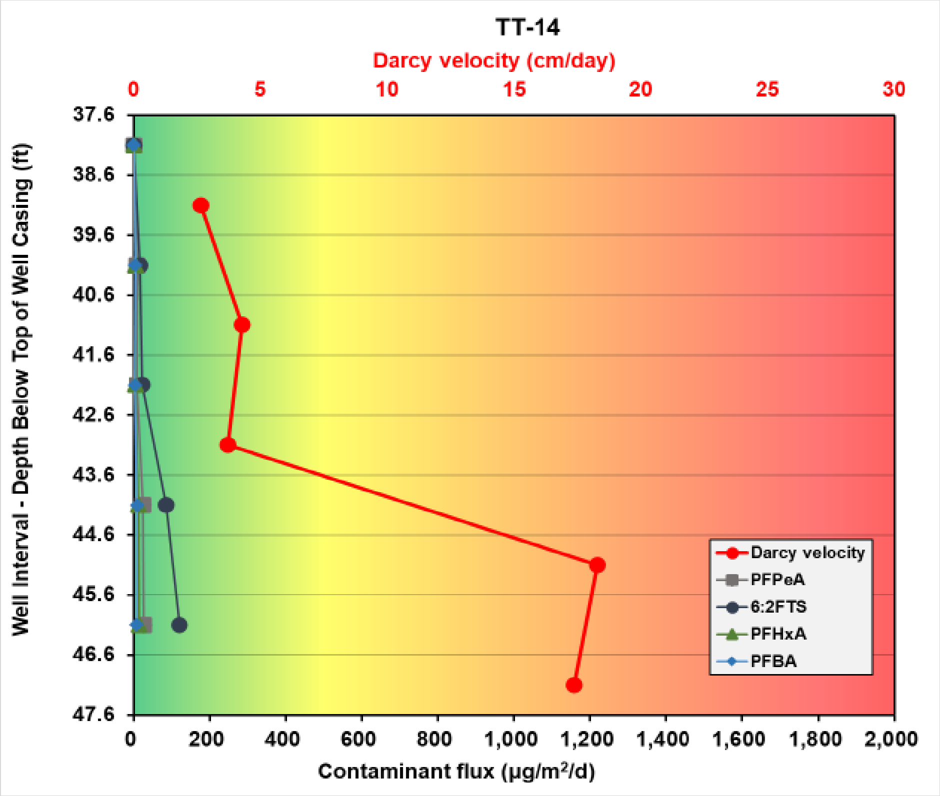
Mass Flux in the Design Process

Upgradient/Near-Source



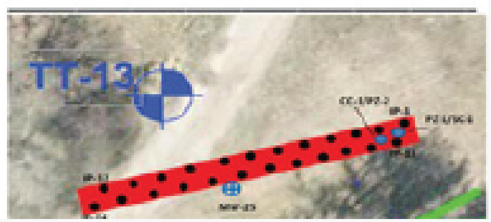
Downgradient

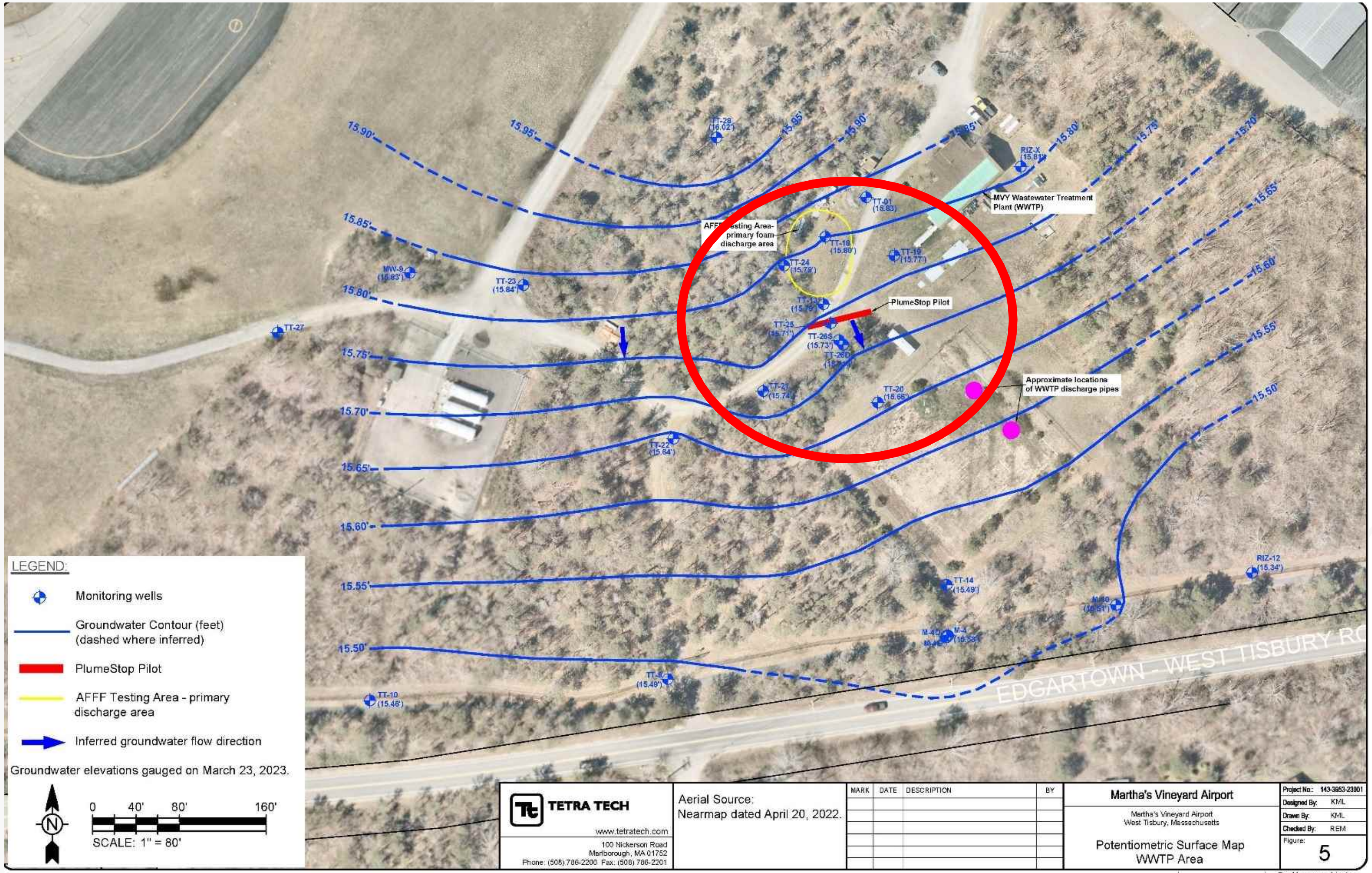


Flux data suggested a change in geometry of the barrier: 30' long 20' interval to 60' long 10' interval

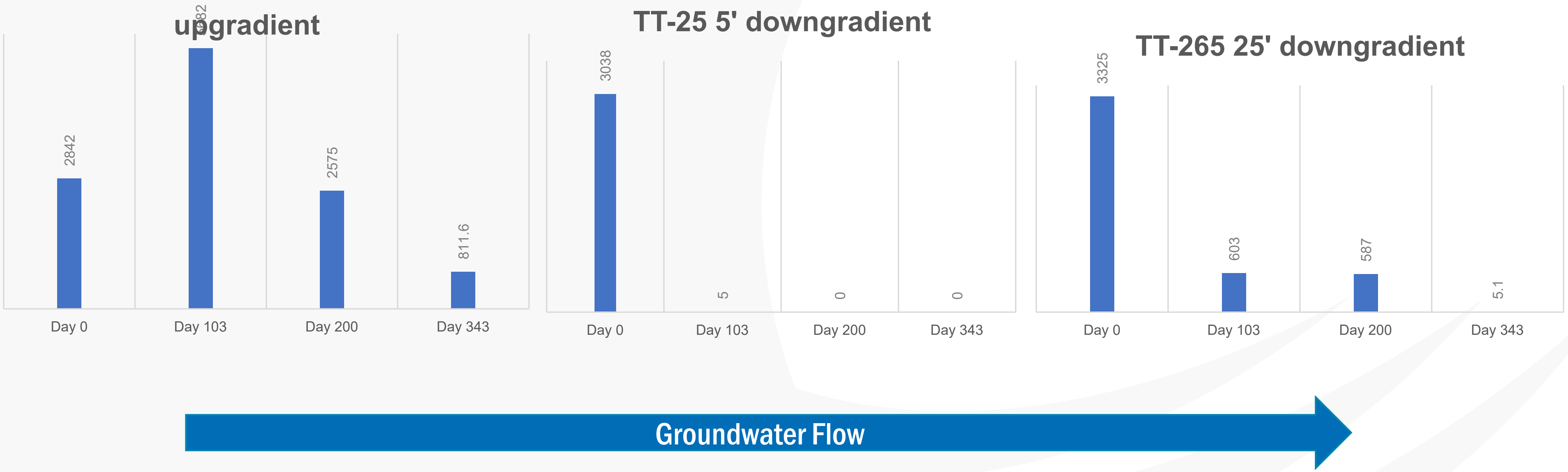
Application

- December 2022
- 60’ PRB length, 30-40’ bgs
- 24 IPs in a double row
- ~10,000 gallons of CAC solution
- Coarse sand with silts and clays





Results: MVY Regulated 6 PFAS Compounds



PFAS total MA 6 compounds PFOS, PFOA, PFHxS, PFNA, PFHpA, and PFDA: 20ng/L

Midwest Regional Airport

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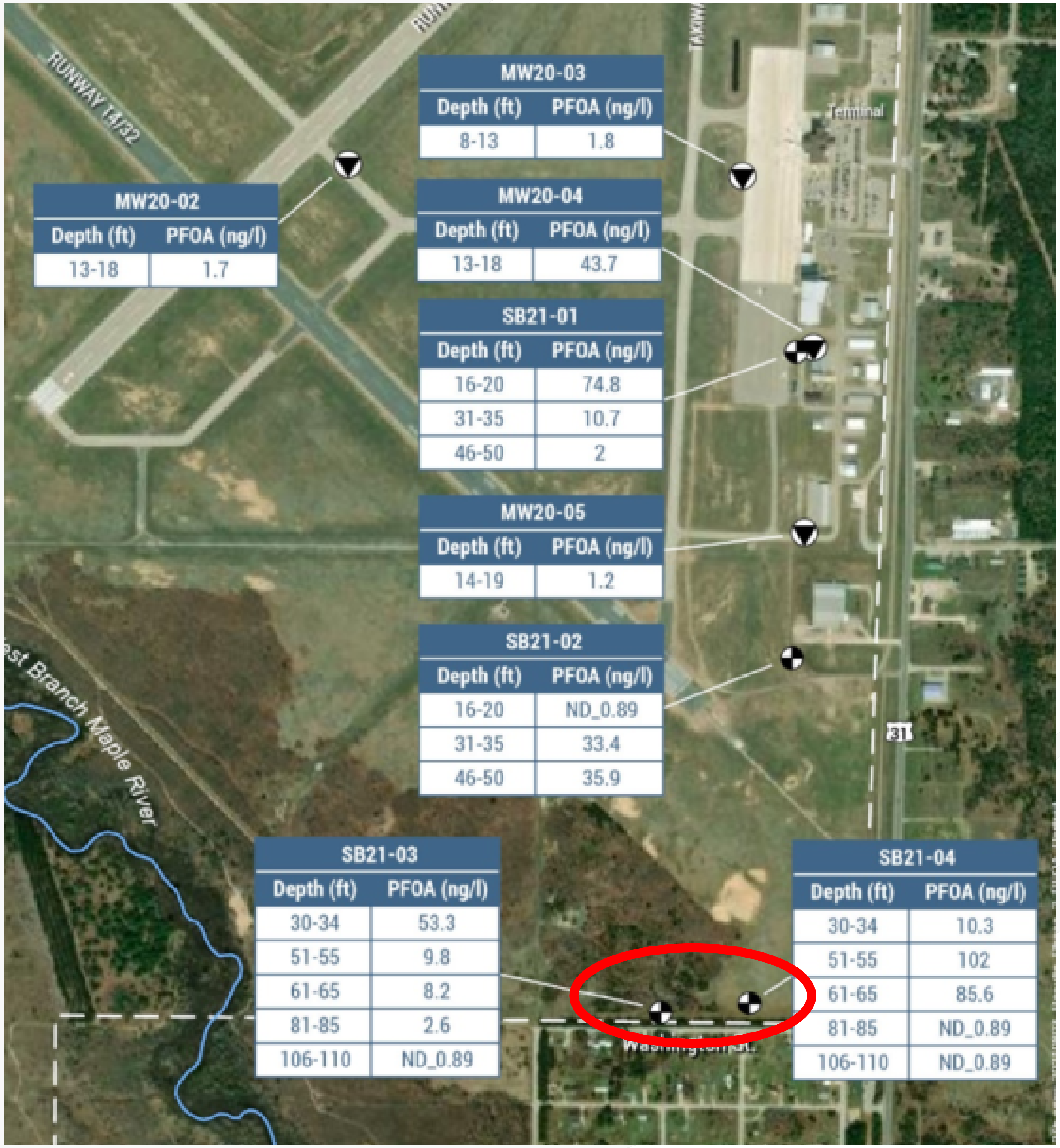
Case Study: Groundwater Pilot Test

This regional airport has a PFAS plume migrating under a small town.

- Private wells are impacted
- No municipal drinking water
- November 2022
- 30’ PRB 25-40’ bgs
- 12 IPs in a double row
- 8,300 gallons of CAC solution
- Silty sand geology



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Placement Validation

- Real-time and post-injection evaluation of CAC distribution
- Real-time PV allows for dynamic remediation (on-the-fly adjustments)
- Collection of pre-injection soil cores and soil cores during and after injection to observe distribution
- Emplacement of sentinel observation points to observe groundwater for ROI both in presence, timing, and concentration
- Tooling can range from simple bailer testing, to field colorimetric testing, to the use of complex multi-probes for real-time geochemical observation and logging
- More recently, field personnel has utilized pressure/flow rate ratios for 3D mapping either in-field or post-mobilization
- A unique PV plan is developed for each project

Placement Validation

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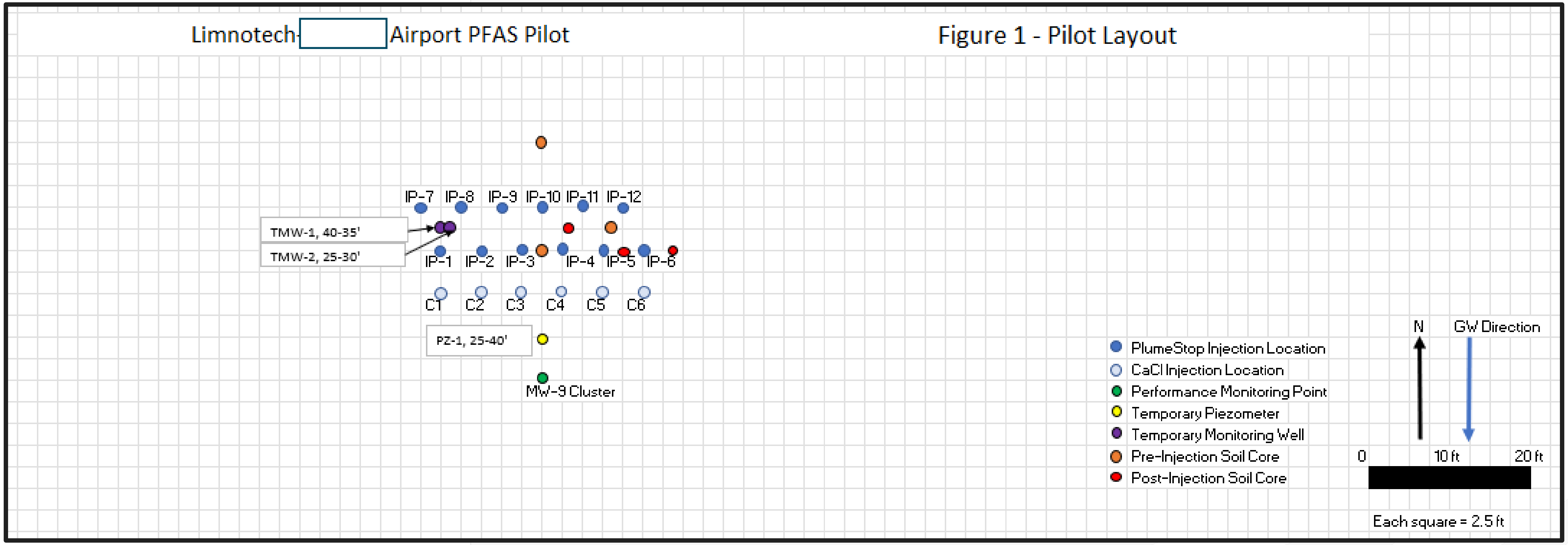
Midwest Regional Airport



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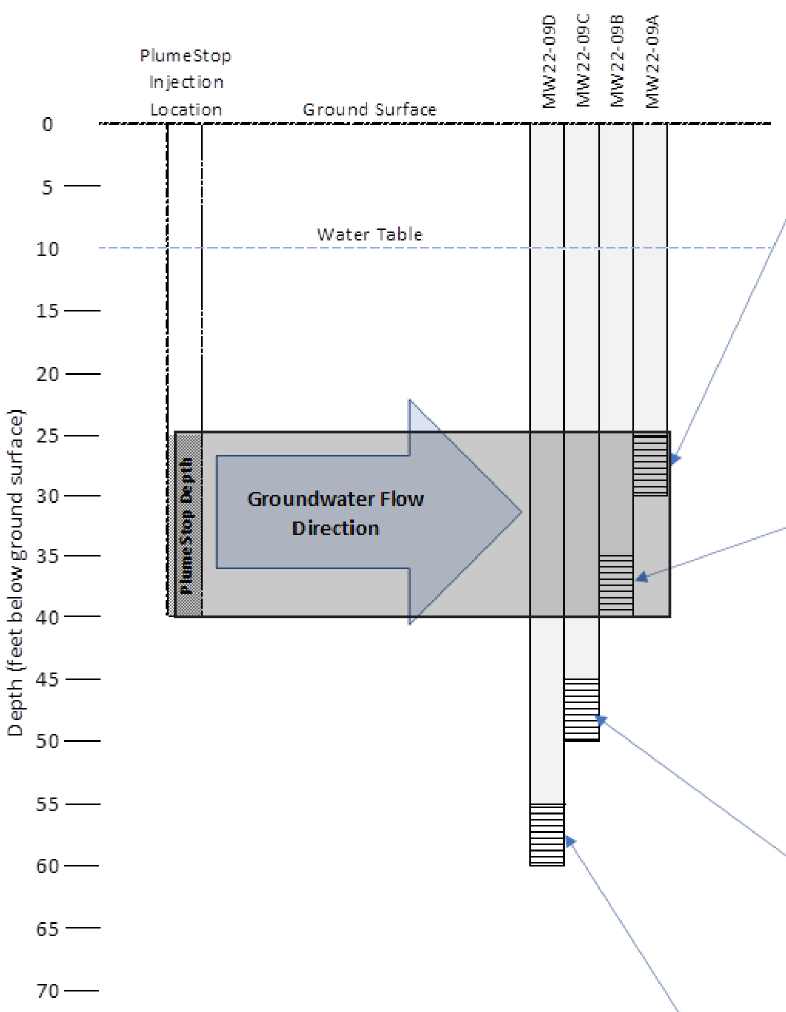
Midwest Regional Airport

Analytical Results

- **Dominated by PFOS and PFHxS**
- **>99.9% reductions within the target treatment zone**
- **Currently identifying funding sources for further monitoring and treatment**



MW22-09A

Compound	10/4/2022	12/5/2022	2/8/2023	6/14/2023
PFHxA	ND_0.93	ND_0.98	ND_0.89	ND_0.93
PFOA	ND_0.93	ND_0.98	ND_0.89	ND_0.93
PFNA	ND_0.93	ND_0.98	ND_0.89	ND_0.93
PFBS	1.4	ND_0.98	ND_0.89	ND_0.93
PFHxS	9.9	ND_0.98	ND_0.89	ND_0.93
PFOS	ND_0.93	ND_0.98	5.3	ND_0.93
HFPO-DA (GenX)	ND_1.9	ND_2.0	ND_1.8	ND_1.9
Total PFAS	12.4	0	7.7	0

MW22-09B

Compound	10/3/2022	12/5/2022	2/8/2023	6/14/2023
PFHxA	22.2	ND_2.4	ND_2.0	ND_2.0
PFOA	26.7	ND_2.4	ND_2.0	ND_2.0
PFNA	ND_0.93	ND_2.4	ND_2.0	ND_2.0
PFBS	17.9	ND_2.4	ND_2.0	ND_2.0
PFHxS	453	ND_2.4	ND_2.0	ND_2.0
PFOS	511	ND_2.4	ND_2.0	ND_2.0
HFPO-DA (GenX)	ND_1.9	ND_4.8	ND_4.0	ND_4.0
Total PFAS	1695	0	0	0

MW22-09C

Compound	10/4/2022	12/5/2022	2/8/2023	6/14/2023
PFHxA	32.7	ND_3.1	18	17.1
PFOA	64	ND_3.1	32	23
PFNA	2	ND_3.1	1.1	ND_0.93
PFBS	15.9	ND_3.1	8.3	8
PFHxS	670	10.6	368	294
PFOS	416	8	172	144
HFPO-DA (GenX)	ND_1.9	ND_6.3	ND_0.1.9	ND_0.1.9
Total PFAS	1561	19	743	620

MW22-09D

Compound	10/3/2022	12/5/2022	2/8/2023	6/14/2023
PFHxA	20.6	21.4	22.3	18.2
PFOA	58.4	65.2	68.3	57.2
PFNA	2.5	2.4	2.8	2.8
PFBS	4.5	4.3	4.7	3.3
PFHxS	217	232	267	208
PFOS	319	281	329	256
HFPO-DA (GenX)	ND_1.9	ND_1.9	ND_1.9	ND_1.9
Total PFAS	761	751	843	679

Conclusions

- Colloidal Activated Carbon is a commonly used and successful means for in-situ remediation of PFAS compounds
- A well-designed process for preparing in-situ remediation plans produces results; the process includes modeling, flux measurement, and placement validation; many additional technologies can be added
- Pilot test remedial technology is tested not only in contaminant reduction to goal, but through the design and application process
- With success clearly defined and the technology properly vetted, the end result will be elimination of environmental risk to human health and the environment

Questions?

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