Colloidal Activated Carbon Used to Enhance Natural Attenuation of PFAS at Airports Worldwide: A Multiple Site Review

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PFAS Sources

Fire Departments

- Local
- Airports – FAA Required for Training until 2019*
  - *FAA has not approved an alternative foam for emergencies
- Fire Training (“Burn Pits”)

Landfills

- Carpets/Furniture
- Food Packaging (Fast Food)
- Contaminated Soils

Water Treatment Plants

- Gardens – Sludge
- Precursor Transformation

Fairbanks International Airport, Picture courtesy of ADOT&PF

Wide-spread Issue: 14 CFR Part 139 517 Airports

- **Part 139 Airport requirements include having a trained rescue and firefighting (AFFF) personnel**

[part139-cert-status-table_2.xlsx (live.com)](part139-cert-status-table_2.xlsx)

Hub size or NPIAS Service Level	Number
Inactive	14
Large Hub	30
Medium Hub	35
Small Hub	80
Non-Hub	226
N/A (Non-Hub NPIAS Service Level)	142
No NPIAS Service Level	4
TOTAL Part 139 Airports	**517**

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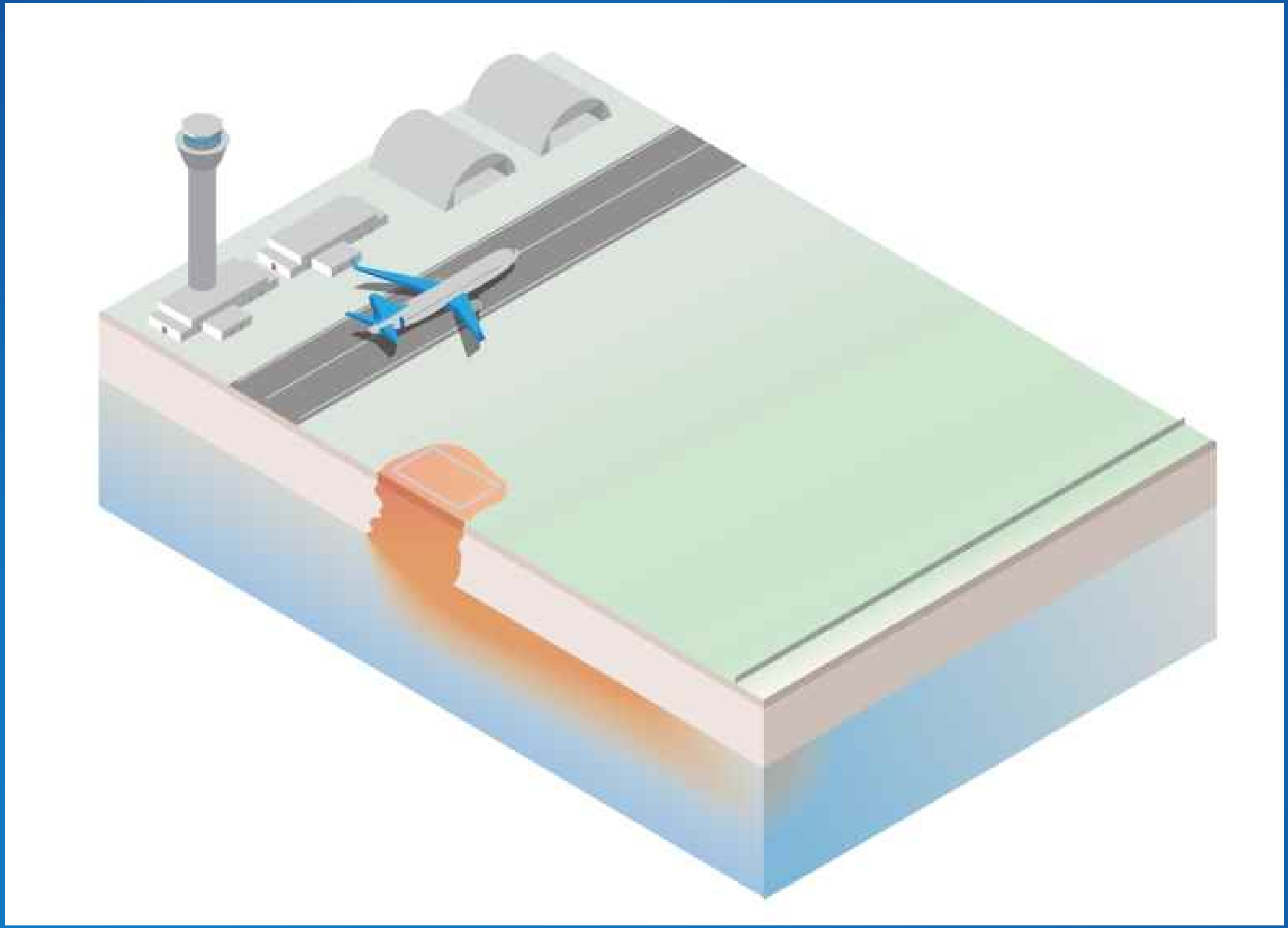
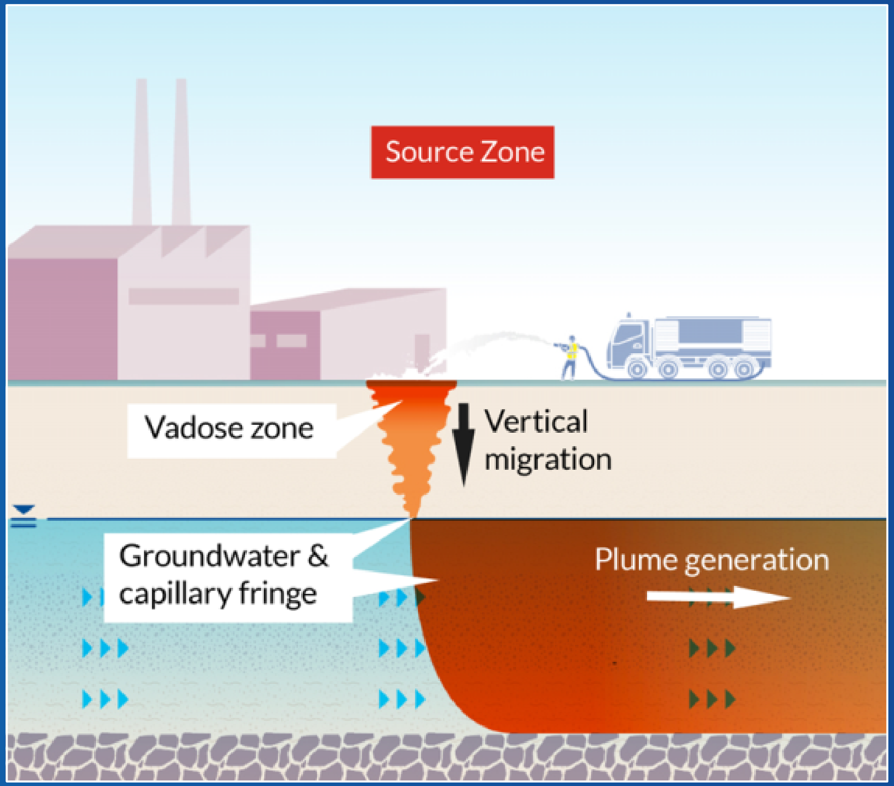
Challenges at Airport Sites

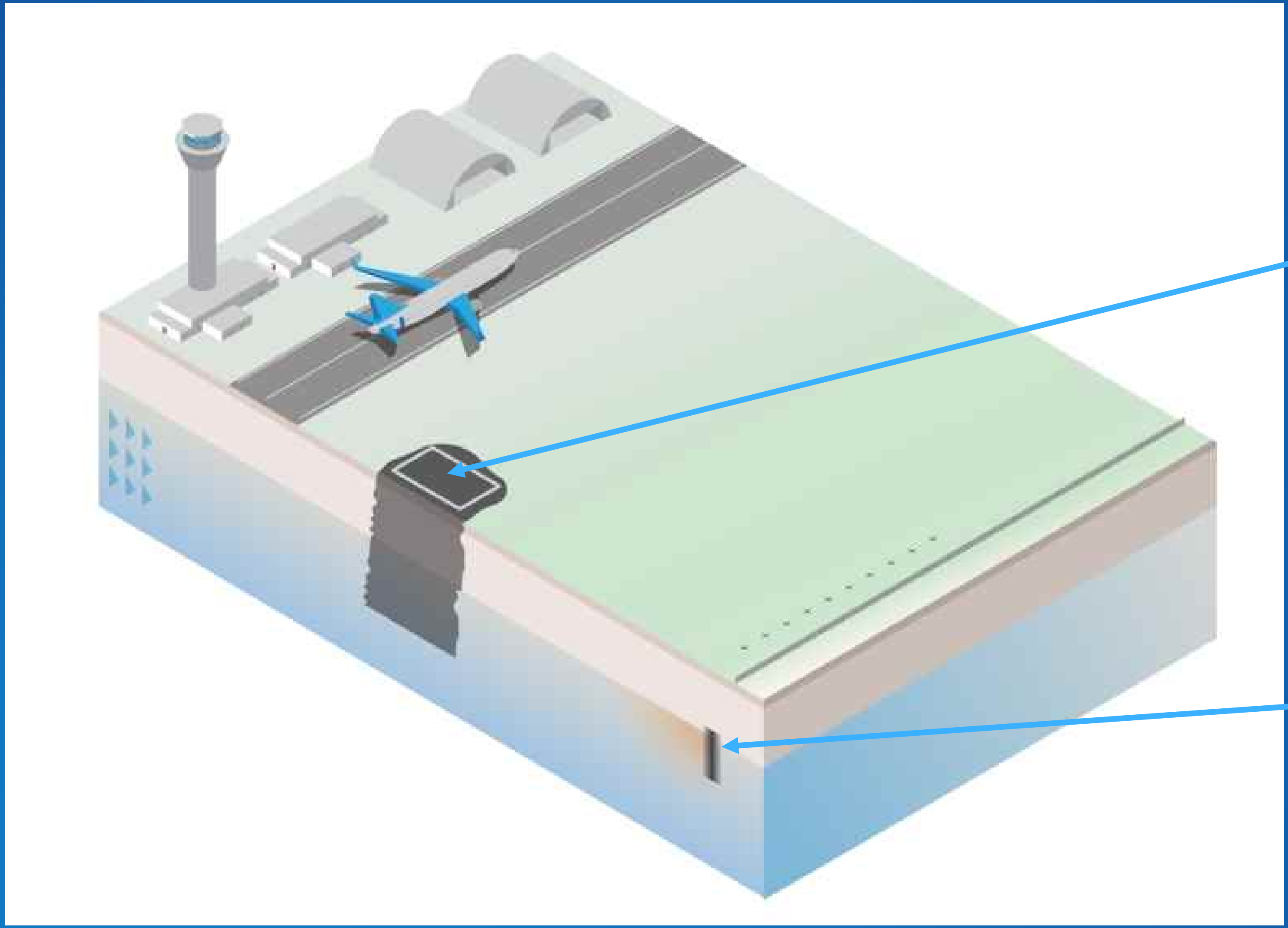
- Sensitive Infrastructure
- Access to contamination
- Airport Operations
- Contaminated Soil/Water Management
- Range of Contaminants
- Emphasis on emerging contaminants PFAS
- Low Regulatory Standards (ng/L)

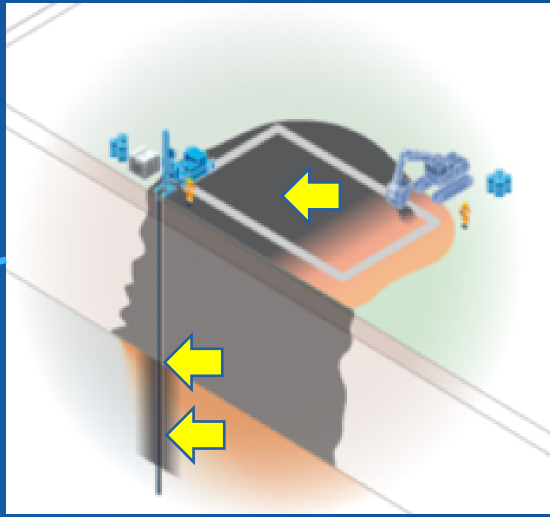
Considering the PFAS Source-Plume system





Considering the PFAS Source-Plume system

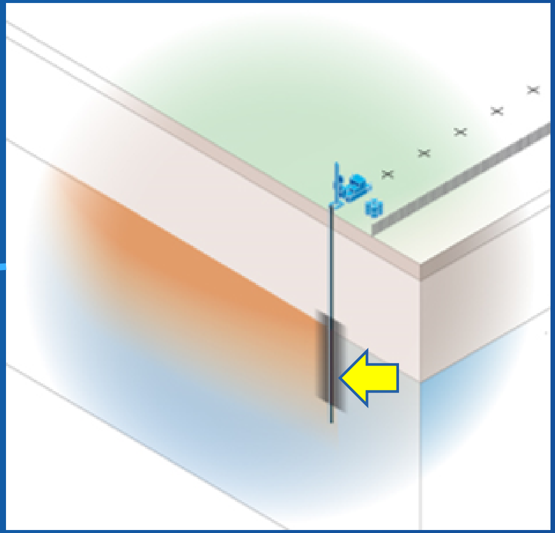




1. Soil – vadose zone

2. Soil - capillary fringe

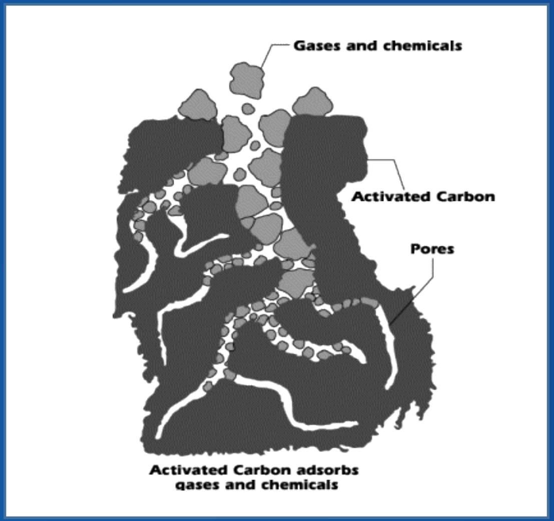
3. Groundwater - Source area

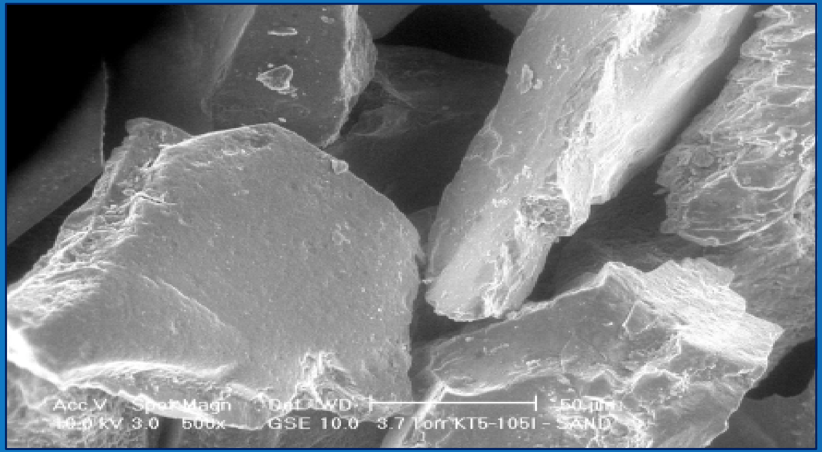


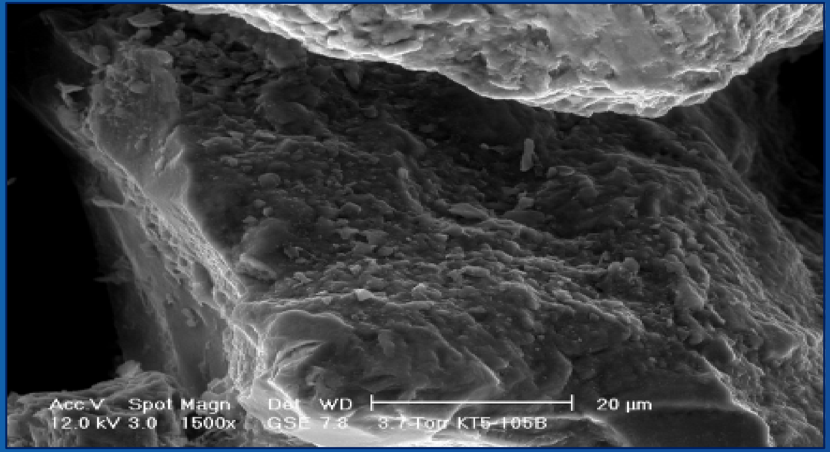
4. Groundwater - Plume

Colloidal Activated Carbon: SourceStop and PlumeStop

- Size: 1 – 2 µm
  - Size of a red blood cell
- Suspended in water
- Wide area distribution
  - No high-pressure fracturing needed
- Coats aquifer surfaces
  - Creates subsurface activated carbon filter
- Extremely fast sorption of PFAS
  - Smaller particles provide more exterior surface
  - Shorter distance to all the sorption sites compared to GAC
  - **Xiao, Ulrich, Chen & Higgins. Environ. Sci. Technol. 2017, 51, 6342-6351.**

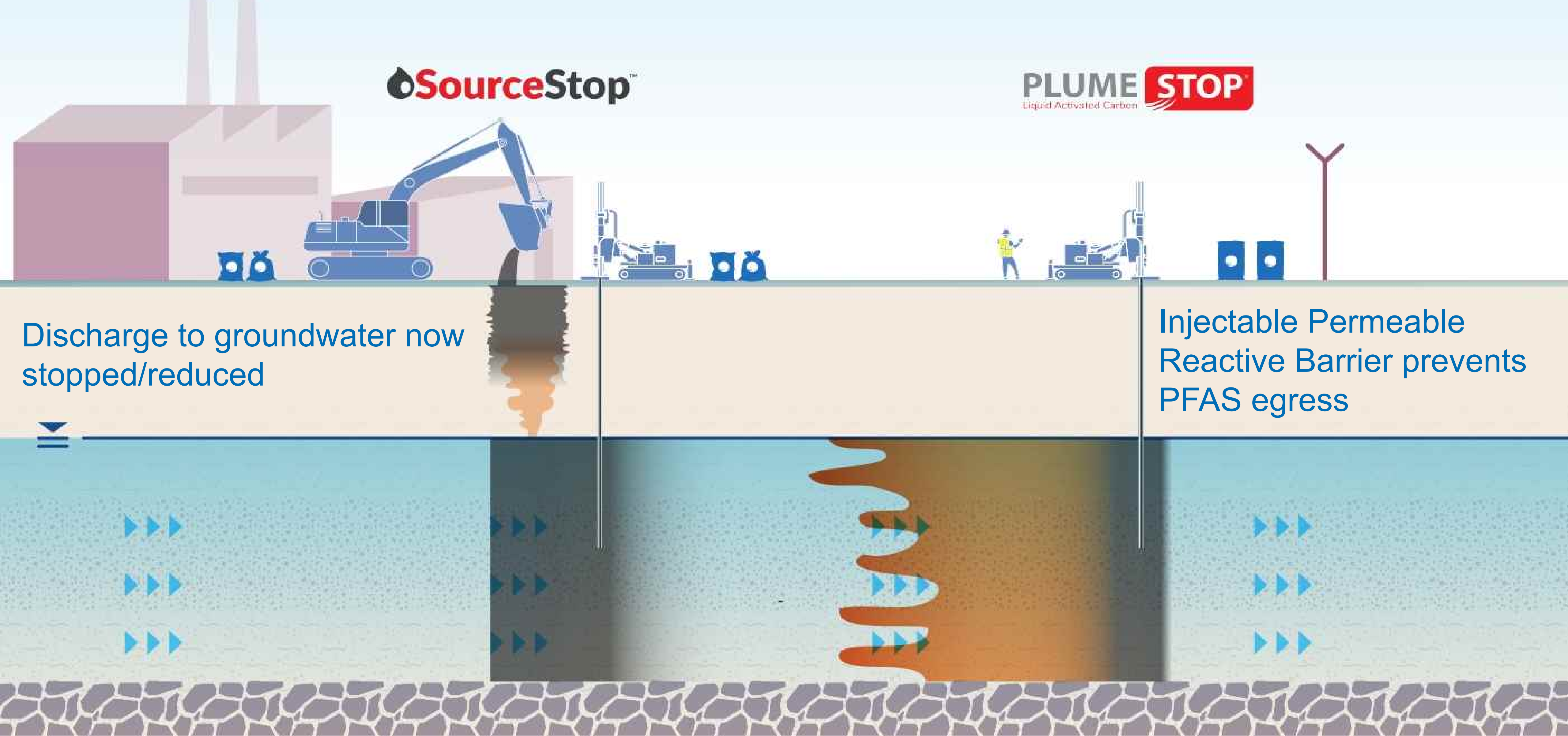






Source treatment = Enhanced Attenuation

Combine with Plume treatment = rapid risk removal



PlumeStop

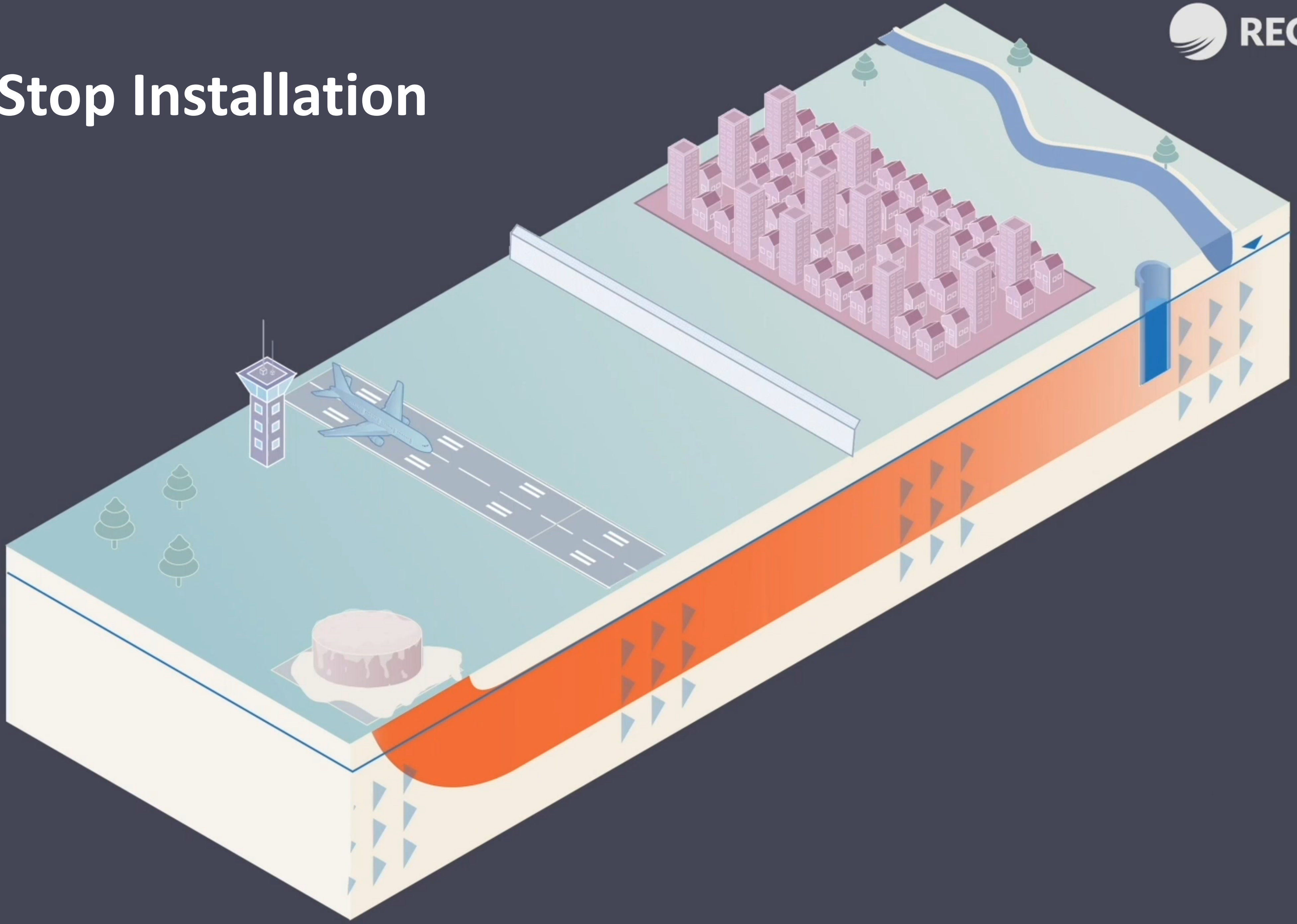
PlumeStop Colloidal Activated Carbon

PLUME STOP™
Liquid Activated Carbon

Powdered Activated Carbon (PAC)

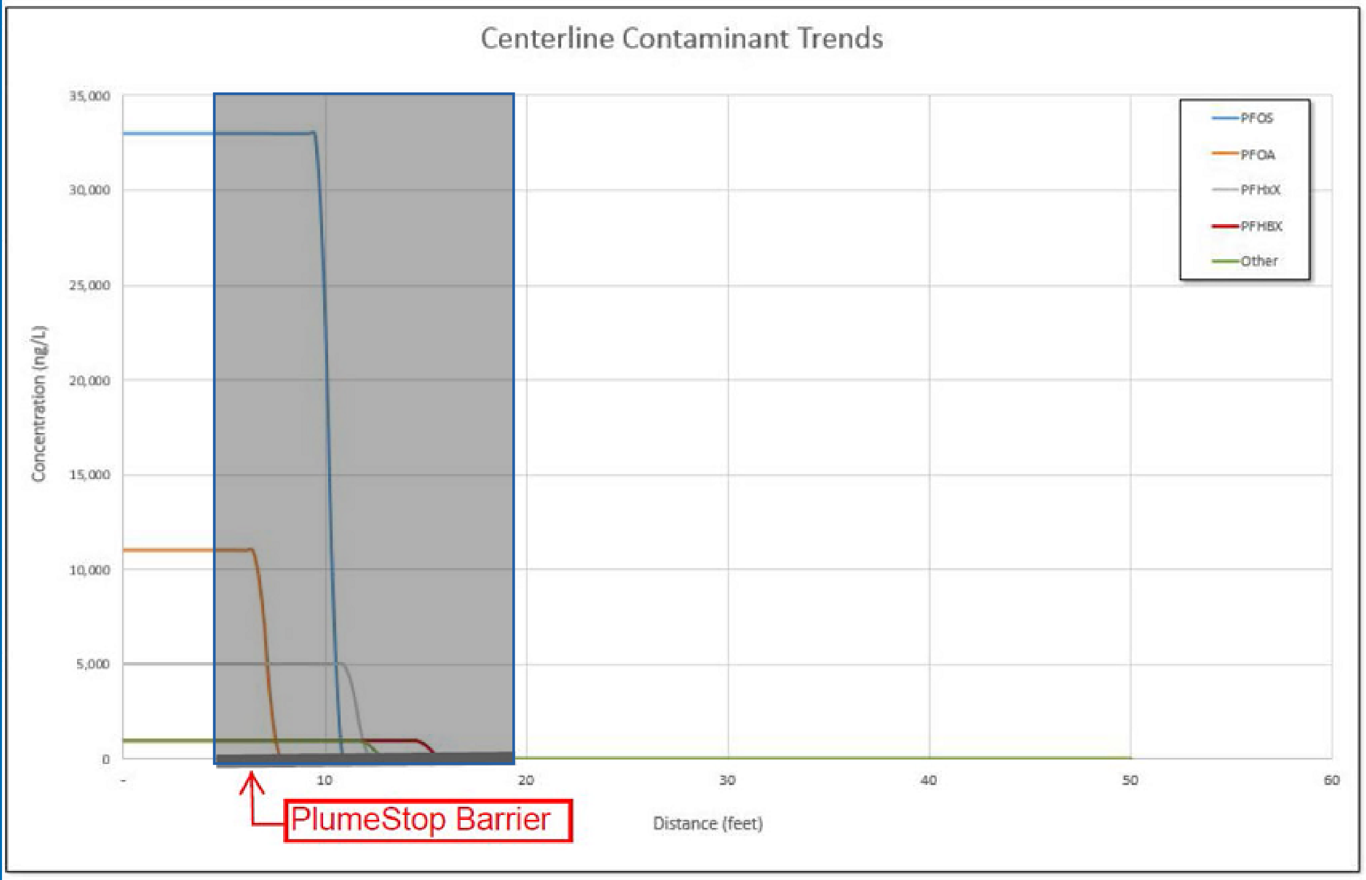
Time Lapse = 12 minutes

PlumeStop Installation



Designing the Treatment

- Barrier lifespan modelled on isotherms, dynamic sorption
- Dose based on:
  - Target contaminant flux
  - Competitive sorption:
    - Other contaminants
    - Natural organics (will degrade)
- Combined treatment to reduce influx
  - Source Treatment, capping
  - Sorption > rate of discharge from source
    - Allows attenuation below Action Levels



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DVT
Design Verification Testing

Flux Measurements with Passive Flux Meters
Vertical Profiling

PlumeStop Design
Competitive Sorption, Back Diffusion, Calibration

Injection
Distribution Verification

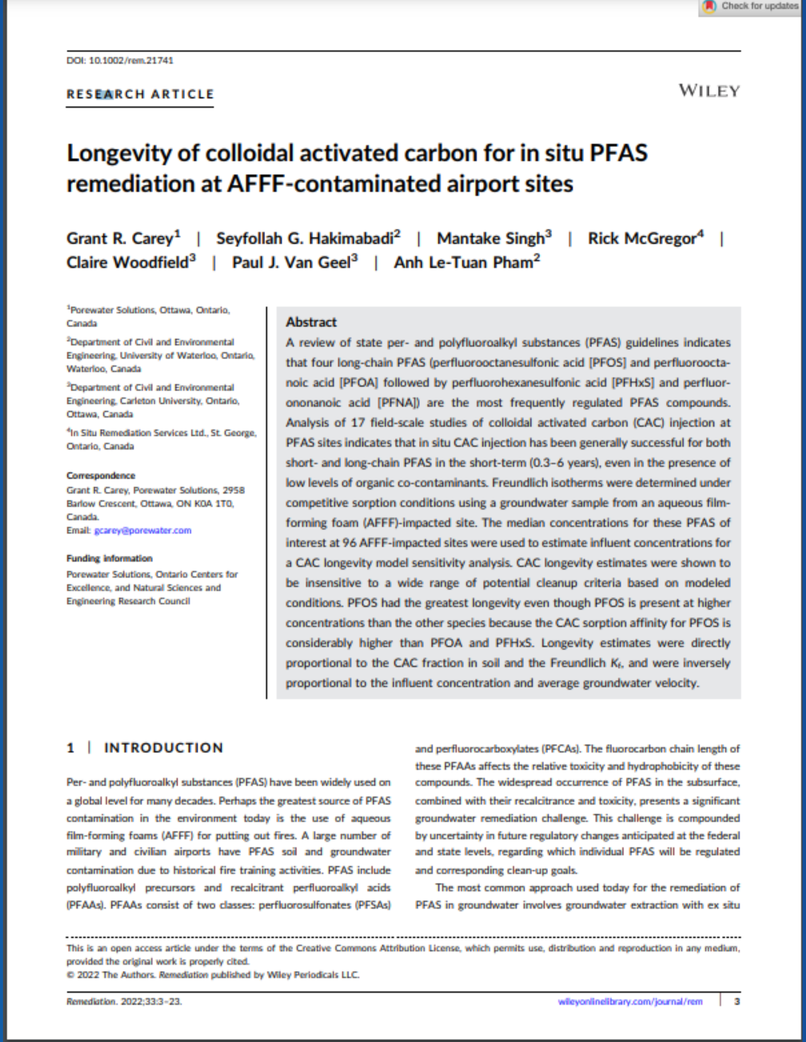
Technical Review of Performance

Does it Work?
How Long Will it Last?

Third Party Review: A study reviewed PFAS sampling data from 96 AFFF-contaminated airport sites, and performance data from 17 *in situ* CAC applications

Key findings include:

1. CAC preferentially sorbs contaminants found at airports (PFOS, PFHxS, PFOA, PFNA)
2. Contaminant breakthrough times for in situ CAC treatments are much longer than ex-situ pump-and-treat carbon use.
3. Seventeen (17) field sites show successful results with co-contaminants present
4. Modeling indicates decades of treatment longevity (single injection).
5. Longevity can be extended by reducing the incoming mass flux.


Check for updates
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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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 PFHxS. Longevity estimates were directly proportional to the CAC fraction in soil and the Freundlich K_f, and were inversely proportional to the influent concentration and average groundwater velocity.

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) and perfluorocarboxylates (PFCAs). The fluorocarbon chain length of these PFAAs affects the relative toxicity and hydrophobicity of these compounds. The widespread occurrence of PFAS in the subsurface, combined with their recalcitrance and toxicity, presents a significant groundwater remediation challenge. This challenge is compounded by uncertainty in future regulatory changes anticipated at the federal and state levels, regarding which individual PFAS will be regulated and corresponding clean-up goals.

The most common approach used today for the remediation of PFAS in groundwater involves groundwater extraction with ex situ

Airport Projects: Successfully Treated with PlumeStop CAC

		PFOA/PFOS max (ug/L)	Results
MA airport	barrier	0.014/.79	Met remediation Goals in 3 months
Camp Grayling Air Field	barrier	ND/.06	Met Remediation Goals, maintained 4+ years
MI airport	barrier	0.024/.51	Met Remediation Goals in 3 months
UK Int airport	barrier	.316/.014	Met remediation goals
UK commercial airport	barrier	5.66/.62	Met Remediation Goals, project under Plume Shield Warranty
Fairbanks AK	barrier	.24/.28	Met Remediation Goals, maintained 2+ years
Federal Facility Airport	grid	.64/.57	Met Remediation Goals
Ontario	barrier	0.042/1.5	downgradient wells trending downward 50% reduction observed, does not have near barrier well
NY airport	barrier	0.17/.82	waiting for data

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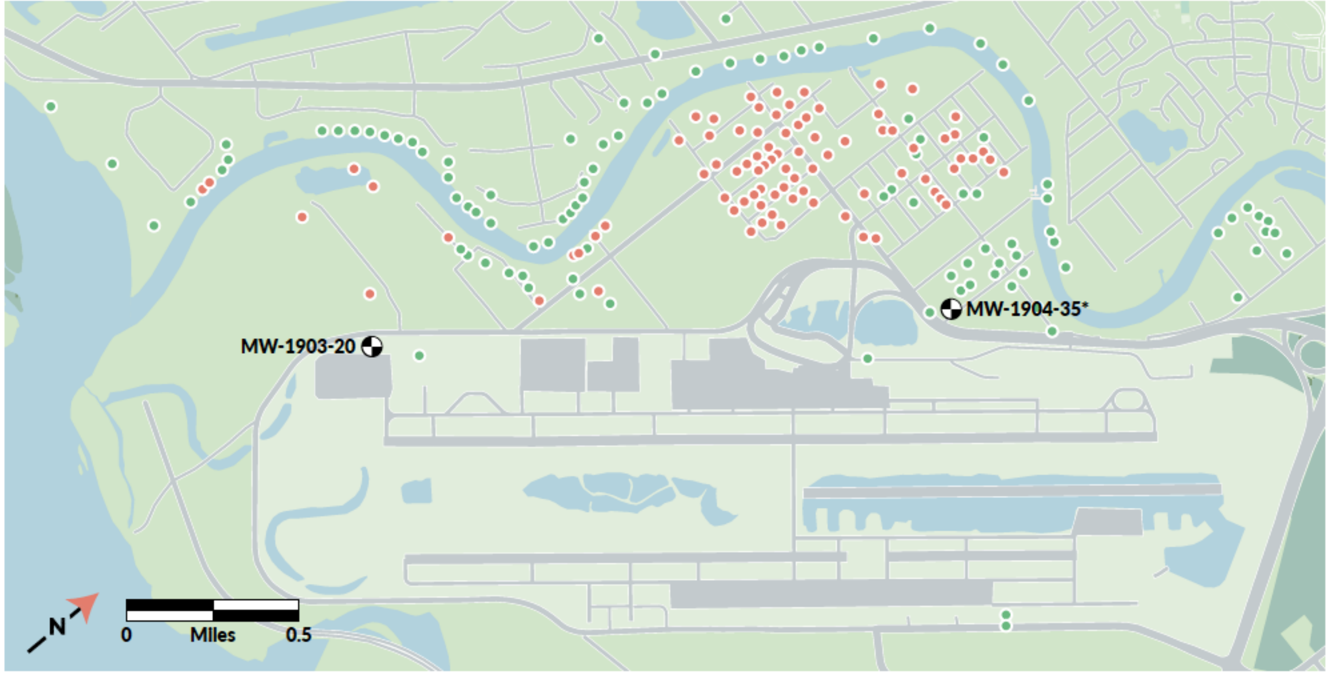
Case Study:
Fairbanks International Airport

- PFAS detected onsite
- FAI responded immediately
- Properties connected to municipal water line



Maximum Combined PFOS/PFOA Concentrations Below HAL (<65 ppt)

Over 65 ppt

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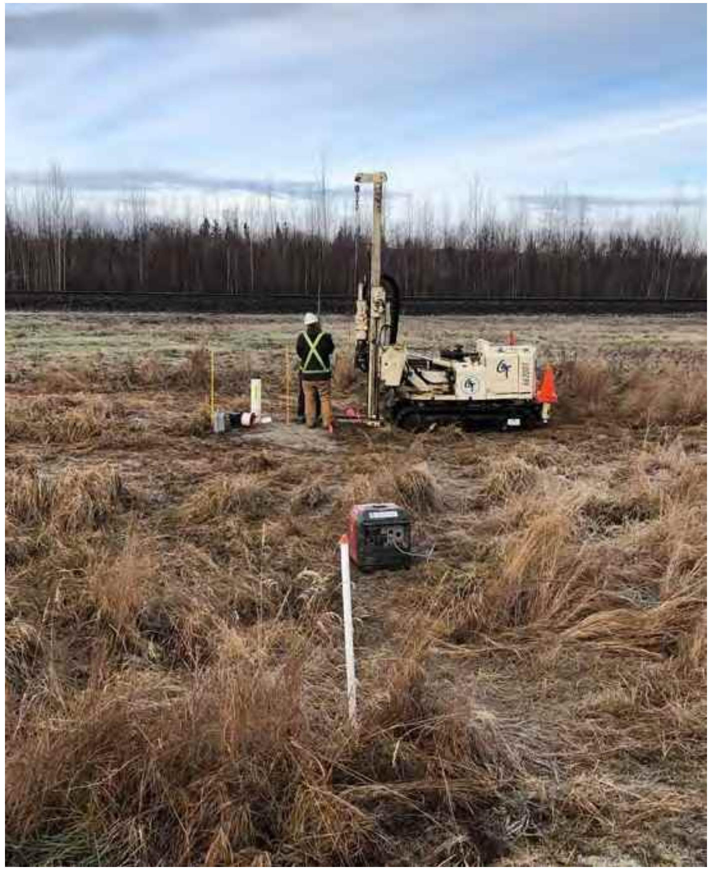
PlumeStop Application

- **Purpose:**
  - Treatment designed to address PFOS, PFOA, PFHpA, PFHxS, and PFNA
- **Objectives**
  - Inject PlumeStop to address contamination in vicinity of MW1902-20
  - Monitor PFAS levels in MW for minimum of one year
  - Extend barrier 2023



PlumeStop Pilot Study - Application

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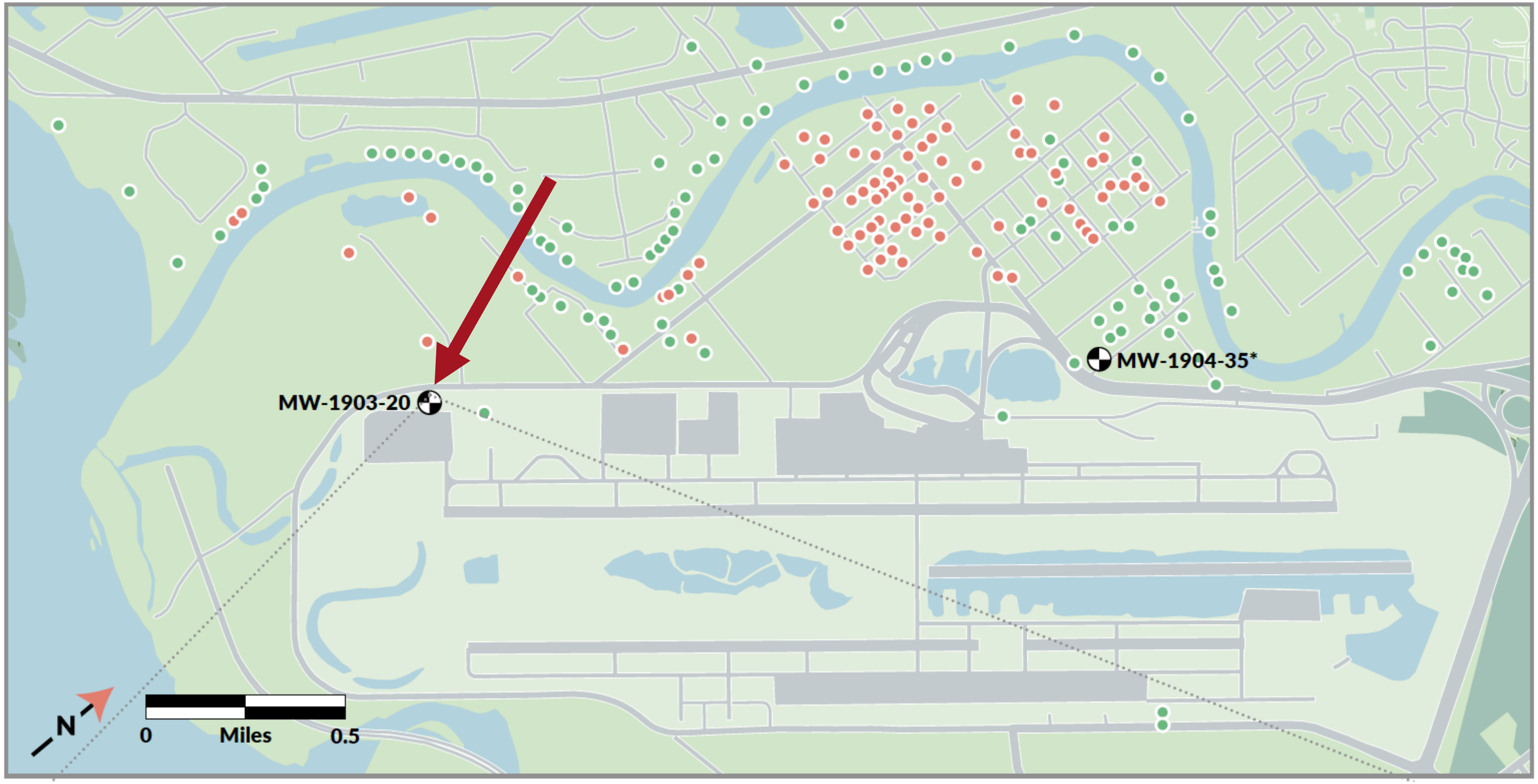
Injection Locations



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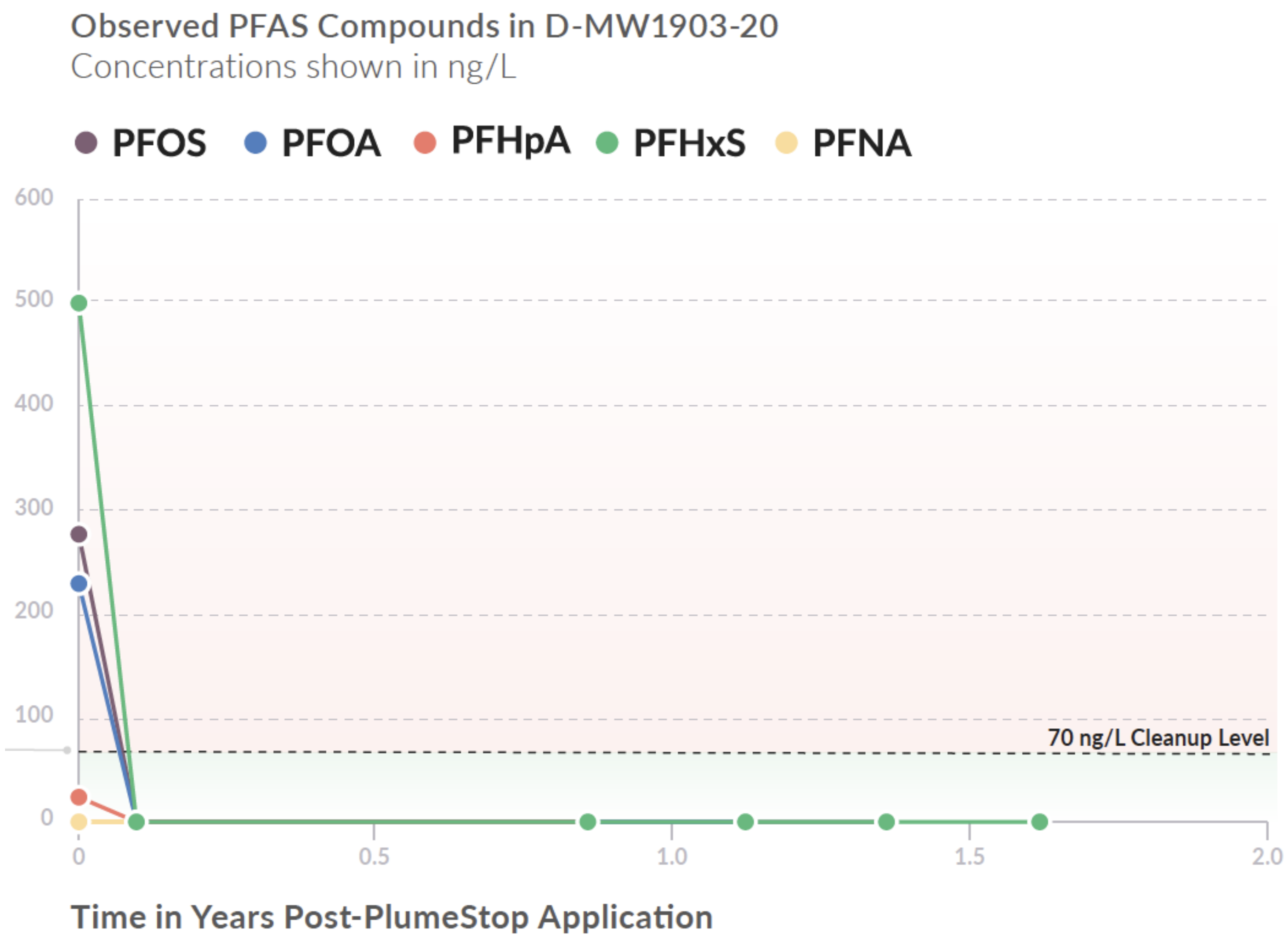
Results

Baseline Sampling

- **PFOS = 270 ng/L**
- **PFOA = 240 ng/L**
- **PFHxS = 530 ng/L**
- **PFHxA = 200 ng/L**
- **PFBS = 100 ng/L**
- **PFBA = 24 ng/L**

June 2021 – Removal Rates

- **PFOS = 100%**
- **PFOA = 100%**
- **PFHxS = 100%**
- **PFHpA = 100%**
- **PFNA = ND**



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Martha’s Vineyard Airport Selects PlumeStop to Treat PFAS

Cost-Effective *In Situ* Approach Addresses PFAS Risk with No Greenhouse Gases or Hazardous Waste

TETRA TECH REGENESIS

Martha’s Vineyard Airport Selects PlumeStop to Address PFAS

- Martha’s Vineyard Airport is centrally located on an island off the coast of Massachusetts.
- AFFF leached into the underlying groundwater impacting it with PFAS and plume extends beyond airport property boundaries
- Private water wells supplying drinking water to residents at risk

TETRA TECH REGENESIS®

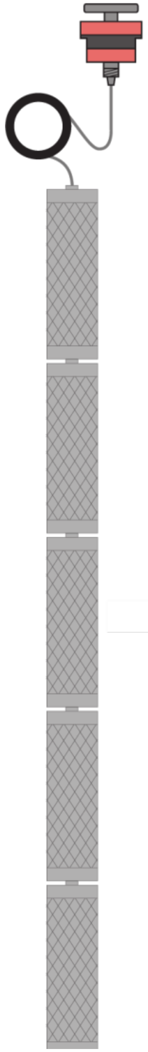
Remedy Selection

Remediation Goal:

- Prevent further PFAS movement away from the site
- Reduce PFAS migration to downgradient residents
- Achieve regulatory standard:
  20 ppt sum of:
  PFOA, PFOS, PFHxS, PFNA, PFBS, PFDA
- **15+ year Design single application**

Key factors in the selection included:

- Avoiding greenhouse gas emissions
- Avoiding PFAS hazardous waste disposal
- Cost



- Flux Tracer deployed to gather mass flux data
- These data are used to refine design and input into to model to confirm barrier longevity meets project requirements (15+ years)

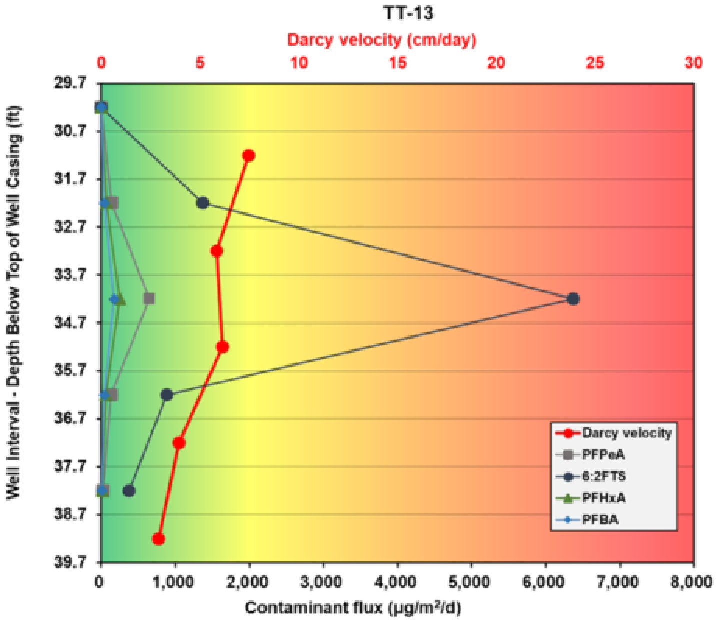
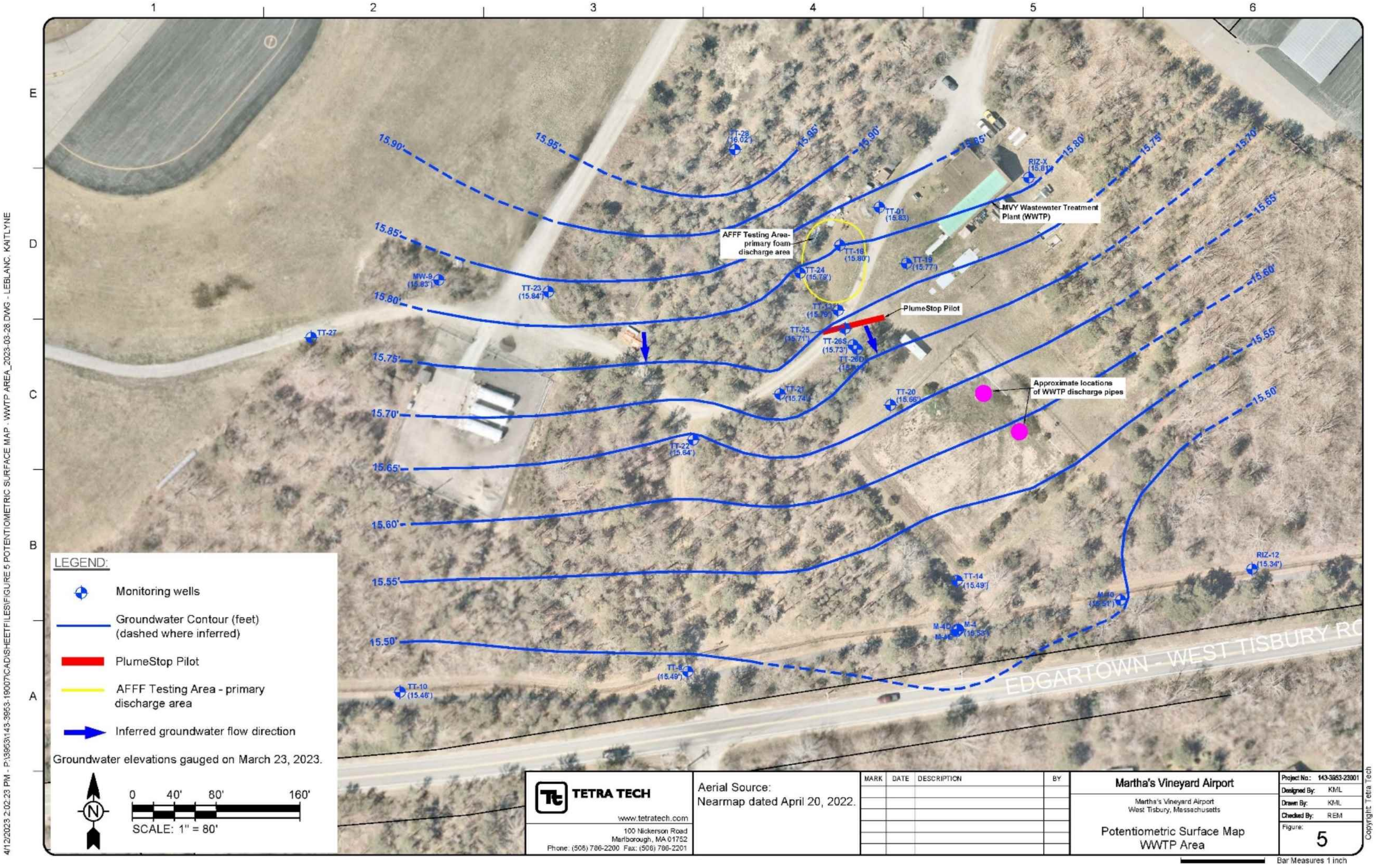


Figure 1. TT-13 Contaminant flux (µg/m^2/d), Darcy velocity, and depth below casing.


LEGEND:
Monitoring wells
Groundwater Contour (feet) (dashed where inferred)
PlumeStop Pilot
AFFF Testing Area - primary discharge area
Inferred groundwater flow direction
Groundwater elevations gauged on March 23, 2023.
0 40' 80' 160'
SCALE: 1" = 80'
AFFF Testing Area- primary foam discharge area
MVY Wastewater Treatment Plant (WWTP)
PlumeStop Pilot
Approximate locations of WWTP discharge pipes
EDGARTOWN - WEST TISBURY RD
15.95'
15.90'
15.85'
15.80'
15.75'
15.70'
15.65'
15.60'
15.55'
15.50'
TT-28 (16.02')
TT-01 (15.83')
RIZ-X (15.81')
TT-18 (15.80')
TT-19 (15.77')
TT-24 (15.78')
MW-9 (15.83')
TT-23 (15.84')
TT-27
TT-25 (15.71')
TT-26S (15.73')
TT-21 (15.74')
TT-20 (15.66')
TT-22 (15.64')
TT-14 (15.49')
RIZ-12 (15.34')
TT-10 (15.46')
(15.49')
TETRA TECH
www.tetratech.com
100 Nickerson Road
Marlborough, MA 01752
Phone: (508) 786-2200 Fax: (508) 786-2201
Aerial Source:
Nearmap dated April 20, 2022.
MARK DATE DESCRIPTION BY
Martha's Vineyard Airport
Martha's Vineyard Airport
West Tisbury, Massachusetts
Potentiometric Surface Map
WWTP Area
Project No.: 143-3953-23001
Designed By: KML
Drawn By: KML
Checked By: REM
Figure: 5
Bar Measures 1 inch
Copyright: Tetra Tech
4/12/2023 2:02:23 PM - P:\3953\143-3953-19007\CAD\SHEETFILES\FIGURE 5 POTENTIOMETRIC SURFACE MAP - WWTP AREA_2023-03-28.DWG - LEBLANC, KAITLYNE

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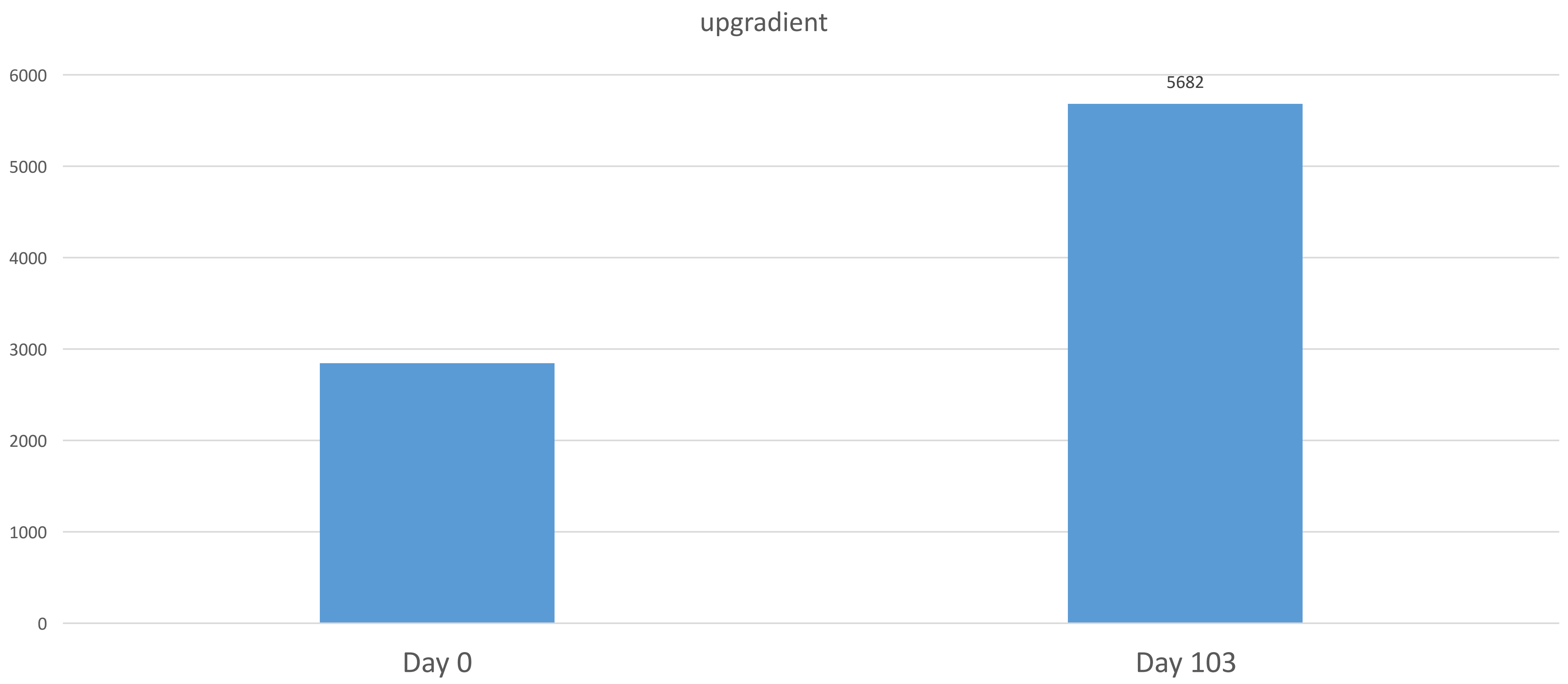
Upgradient Barrier: Regulated 6 PFAS



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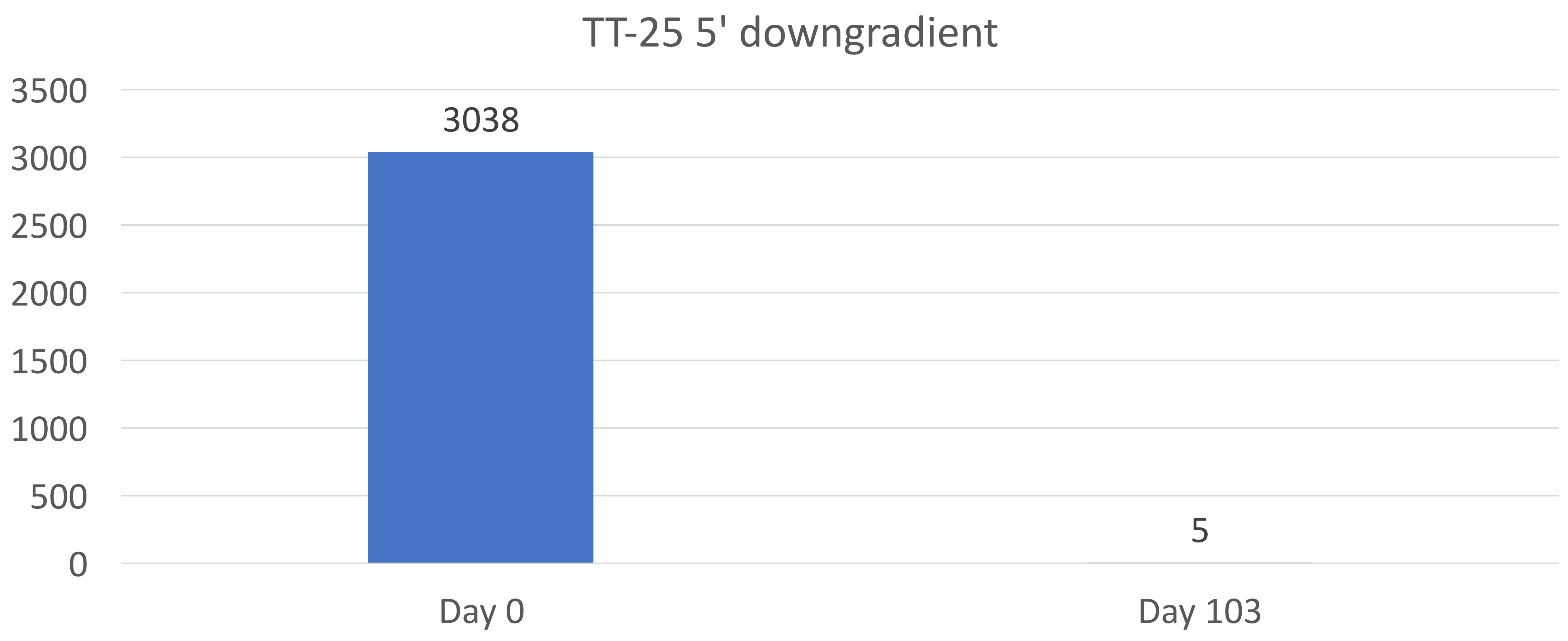
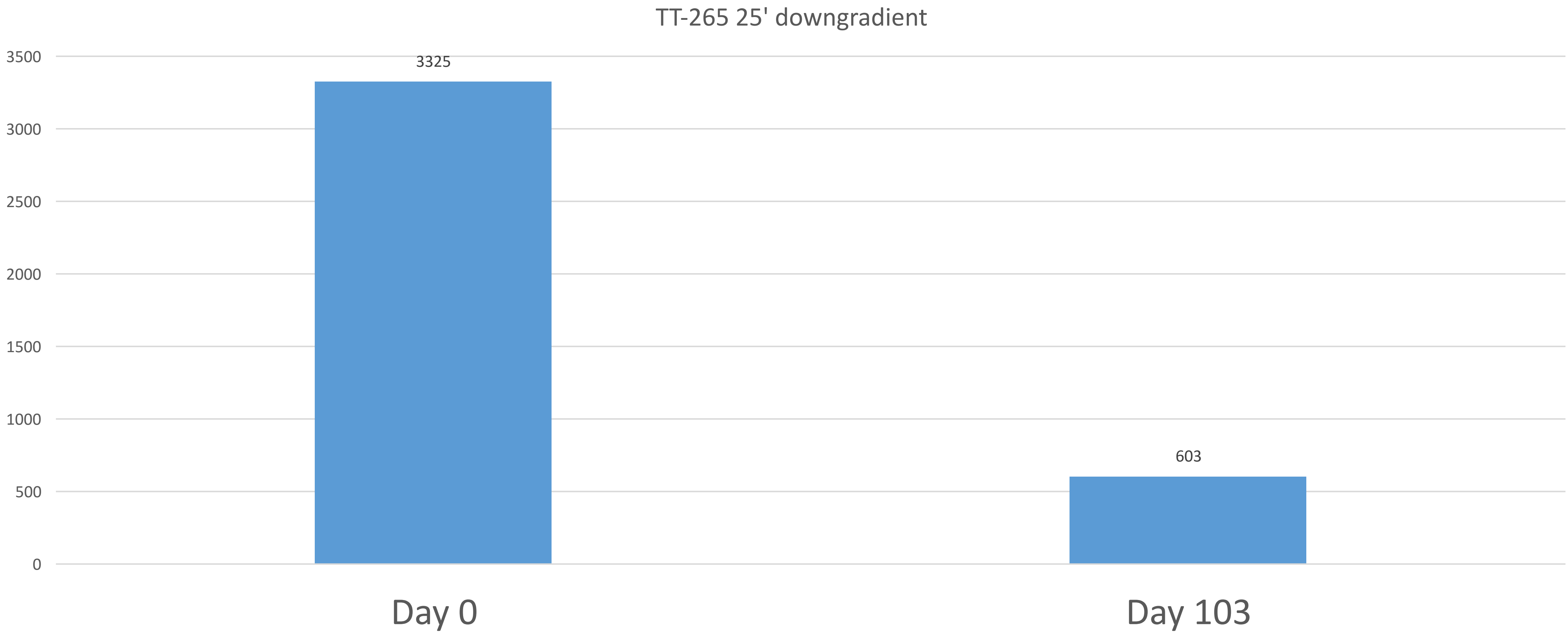
5’ Downgradient: Regulated PFAS 6



TT-25 installed post injection and baseline Day 0 is estimated as average of upgradient well TT-13:

*Total detectable PFAS based on analytical method

25’ Downgradient Regulated PFAS 6



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Private UK Airport

Successful PFAS Pilot Trial Leads to PlumeShield-Guaranteed Full-Scale Installation

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Site Features

Site

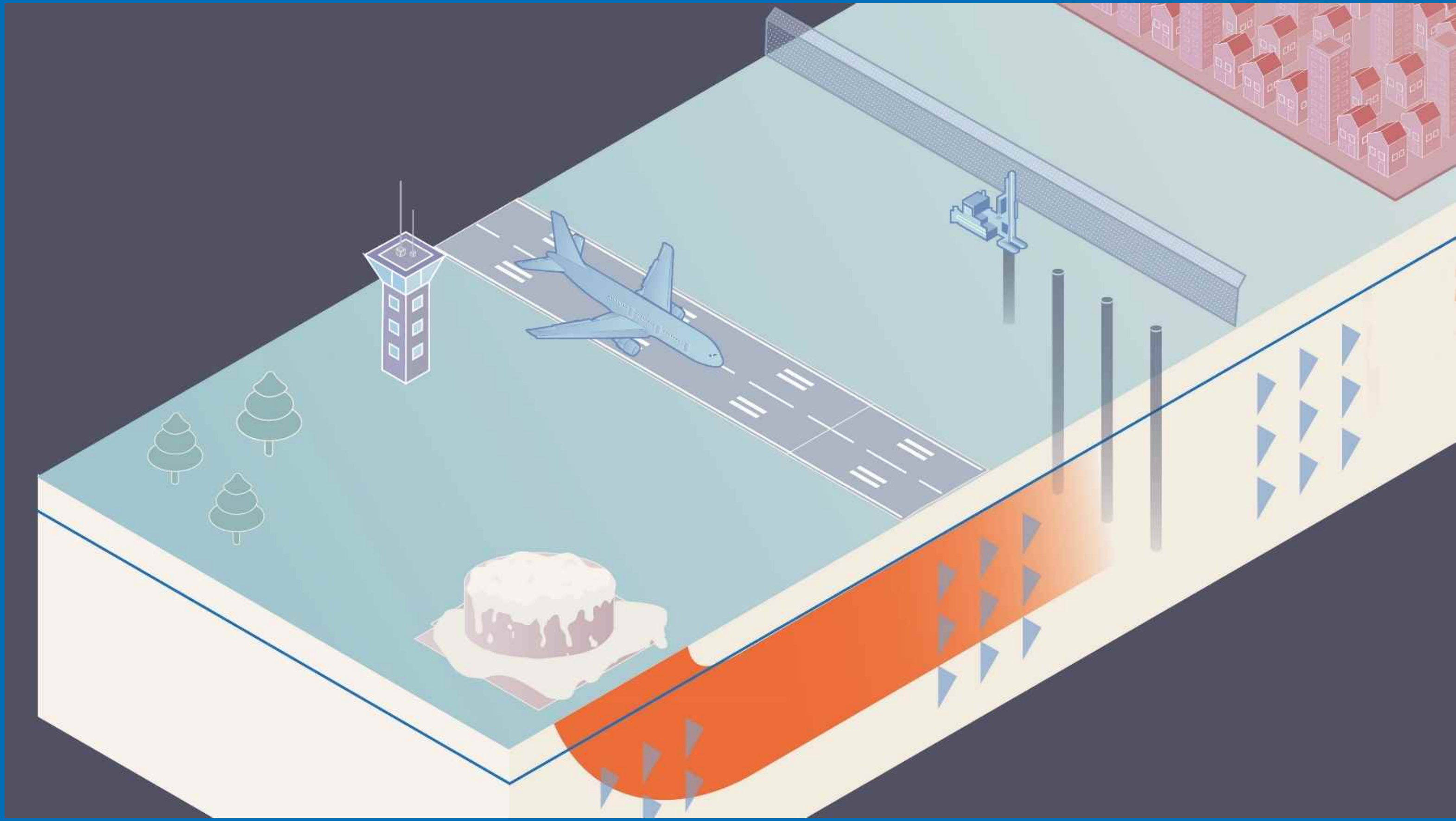
- Fire fighting training area
- Land divestment

Contamination

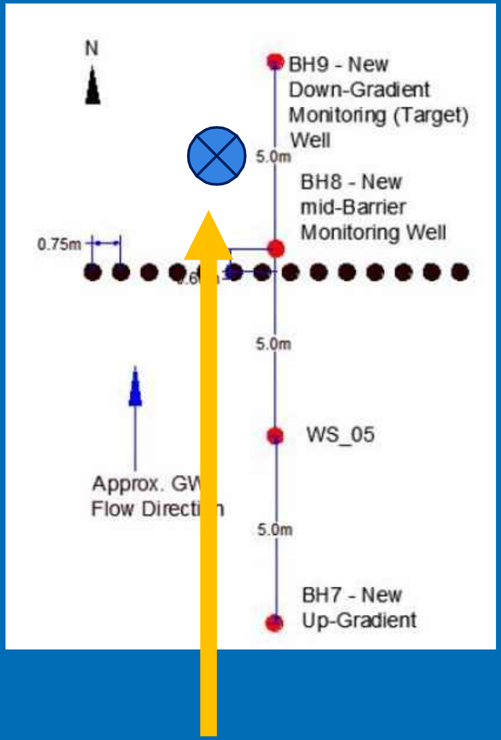
- PFOS (320 ng/L)
- PFOA (6,320 ng/L)

Formation

- Weathered chalk
- Higher permeability layers
- Slow and fast-flowing flux zones
- Groundwater at 3m BGL

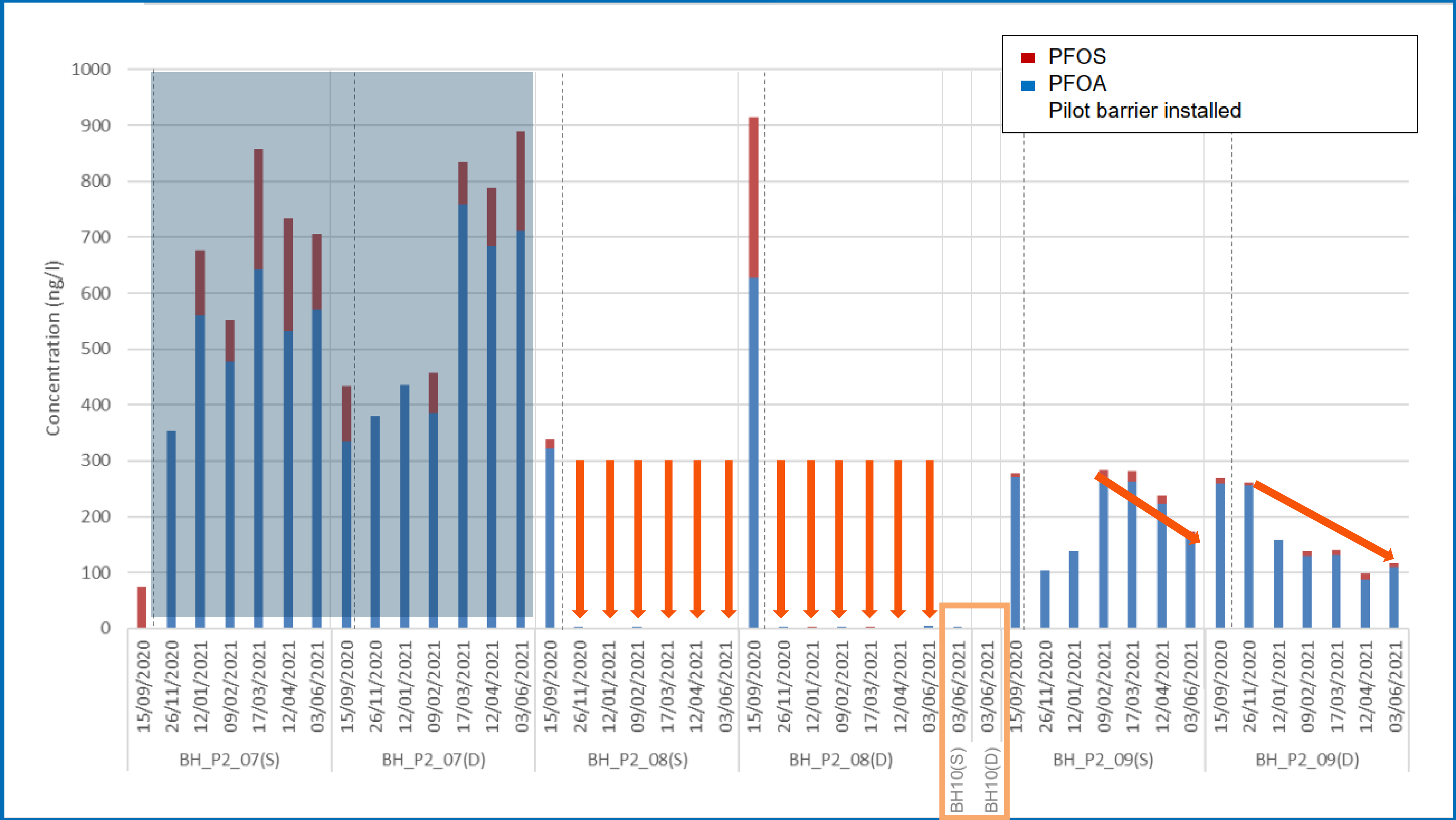


PlumeStop Pilot Installation – Summary



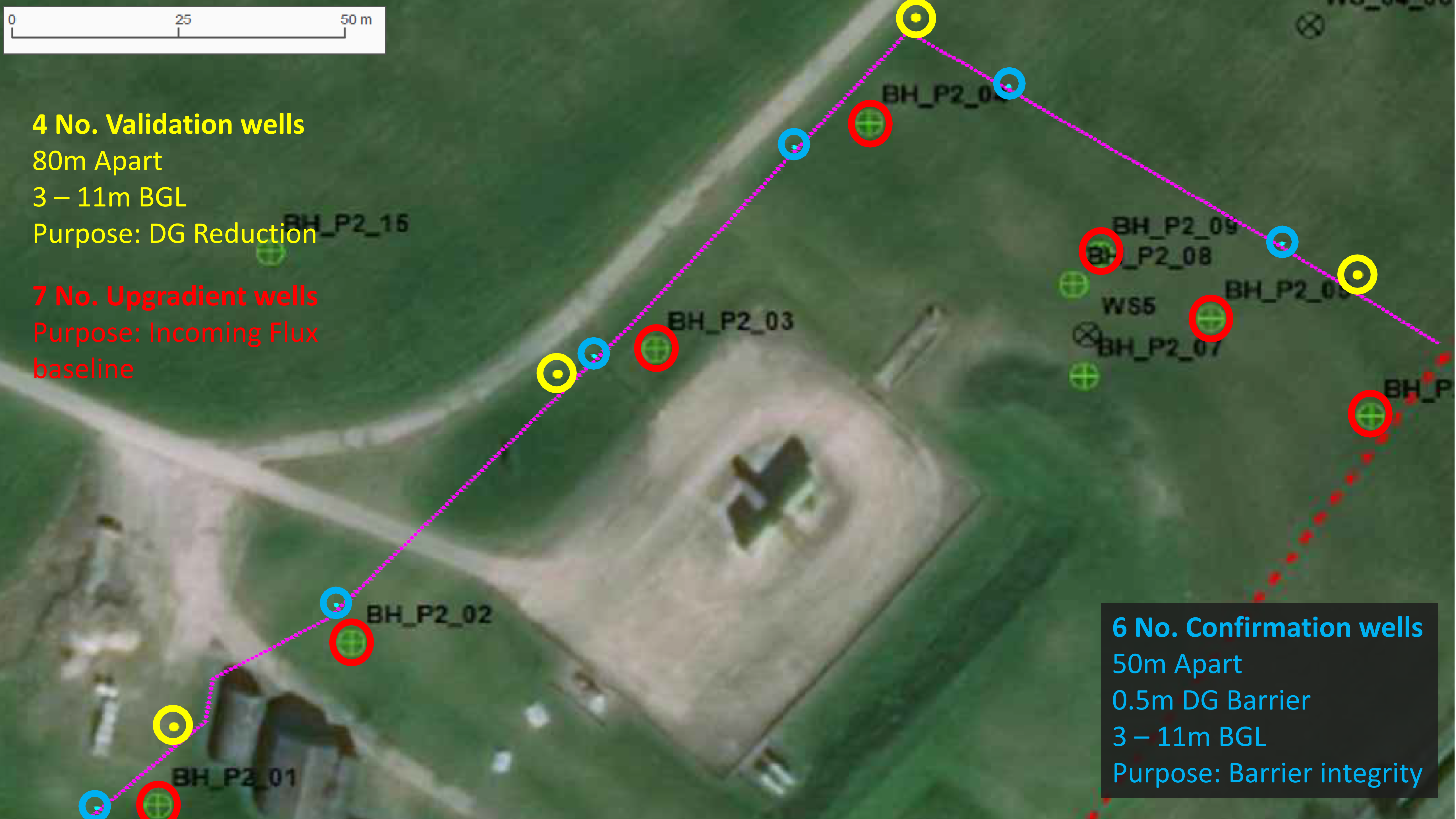
New BH 2.5m down gradient

(Installed by REGENESIS in April 2021)

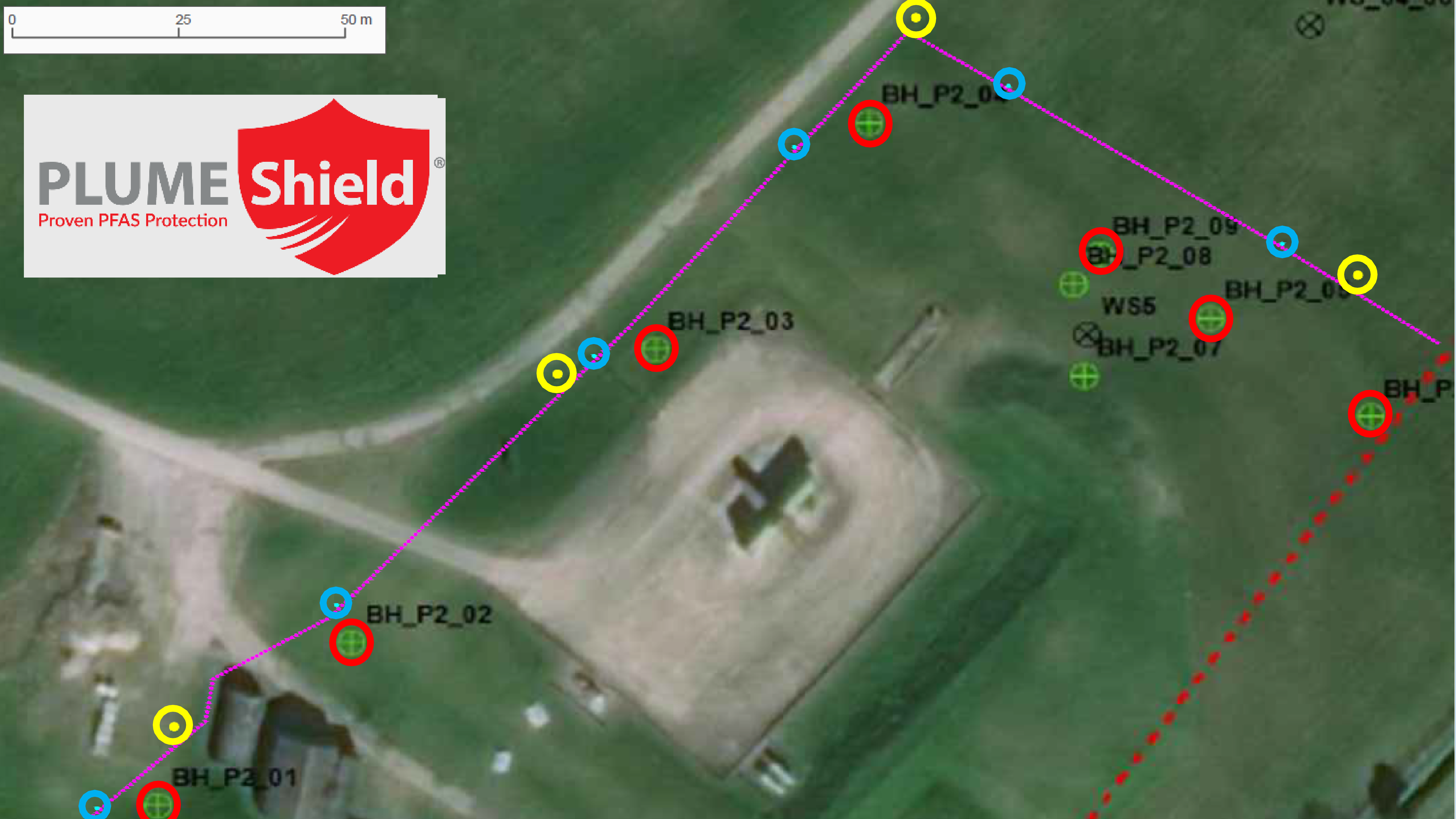


PlumeStop Pilot Installation – Concluded

- 0.5m and 2.5m down gradient of the barrier we are seeing a >99% reduction in PFOA/PFOS (<0.1ug/L)
  - **Barrier is working**
- **Clear evidence of reducing concentrations** 5m downgradient in deeper well (BH09 (D))
  - Faster flowing flux zone
  - Wave of cleaner water arriving sooner
- **Robust results** that allow to:
  - **Move to full-scale installation**



0
25
50 m
4 No. Validation wells
80m Apart
3 – 11m BGL
Purpose: DG Reduction
7 No. Upgradient wells
Purpose: Incoming Flux baseline
6 No. Confirmation wells
50m Apart
0.5m DG Barrier
3 – 11m BGL
Purpose: Barrier integrity
BH_P2_15
BH_P2_09
BH_P2_08
WS5
BH_P2_07
BH_P2_03
BH_P2_02
BH_P2_01


0
25
50 m
PLUME Shield
Proven PFAS Protection
BH_P2_09
BH_P2_08
WS5
BH_P2_07
BH_P2_03
BH_P2_02
BH_P2_01

Life Cycle Analysis:
PFAS Contaminated Airport, UK

Overview of Study

- **In Situ Sorption and Retention Barrier**
  - Passive barrier of colloidal activated carbon (PlumeStop)
  - Recently implemented at the site

- **Ex Situ Pump and Treat**
  - Utilized granular activated carbon (GAC)
  - Theoretical, best-practice design

Scope of Assessment: Cradle to Grave

System boundary

Raw materials → Transport → Manufacture → Transport → Installation → O & M → Monitoring → End of life

In situ: PlumeStop

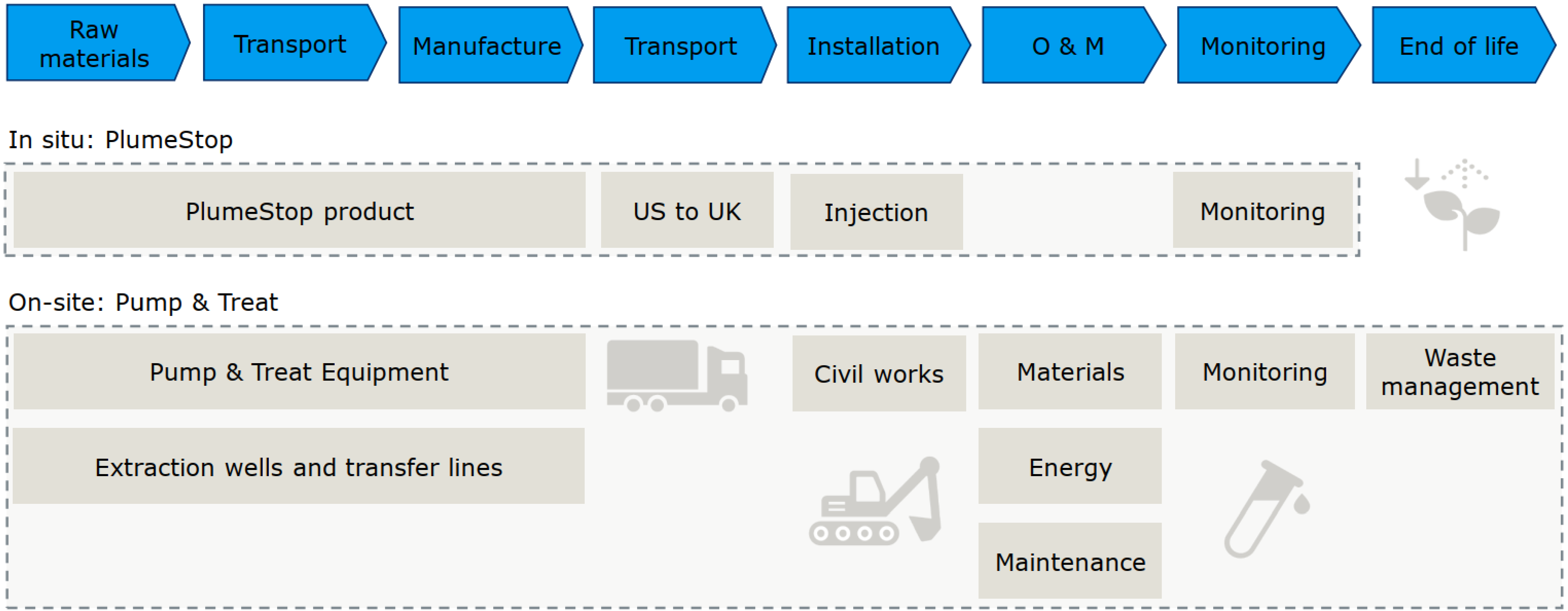
PlumeStop product	US to UK	Injection		Monitoring

Methods/Software

- ISO 14040:2006, ISO 14044:2006, ISO 14067:2018, PCR for Basic Chemicals
- GaBi 10 Professional, Sphera, Ecoinvent 3.8

Scope of Assessment: Cradle to Grave

System boundary

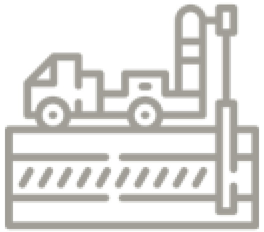


Methods/Software

- ISO 14040:2006, ISO 14044:2006, ISO 14067:2018, PCR for Basic Chemicals
- GaBi 10 Professional, Sphera, Ecoinvent 3.8

RAMBOLL REGENESIS

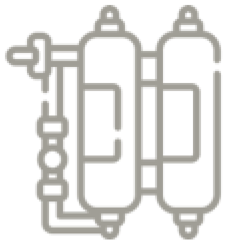
Life Cycle Inventory Analysis



Immobilization with PlumeStop ®

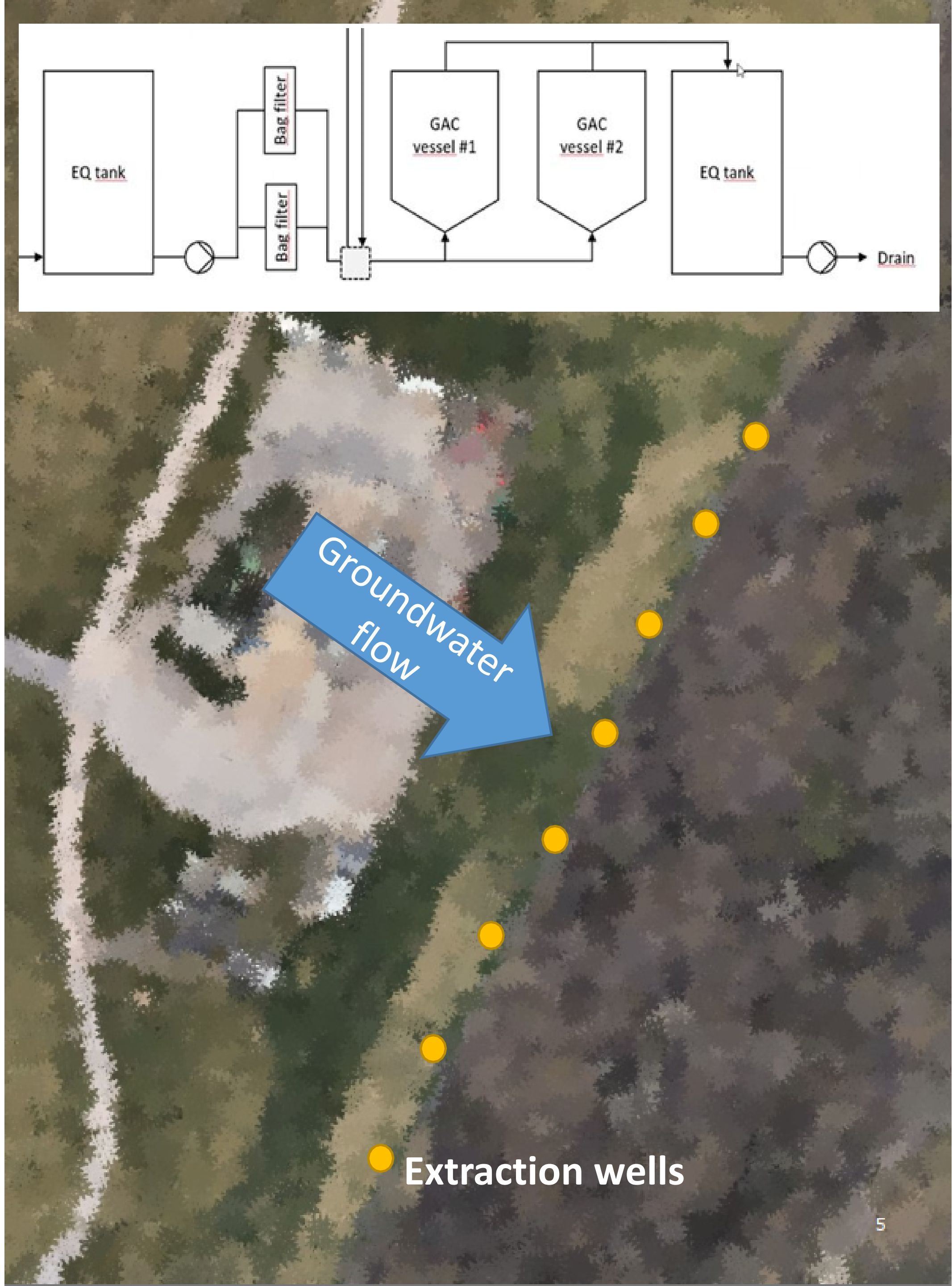
- Single injection round
- Designed for 15 years of efficiency
- 102 injection points
- 120 yards long
- 74,000 lbs PlumeStop
- 420 gallons fuel used for injection
- 3 monitoring wells, 33 feet deep
- 2 times/yr, environmental monitoring
- Cost (15 yrs): $1.2M

Life Cycle Inventory Analysis



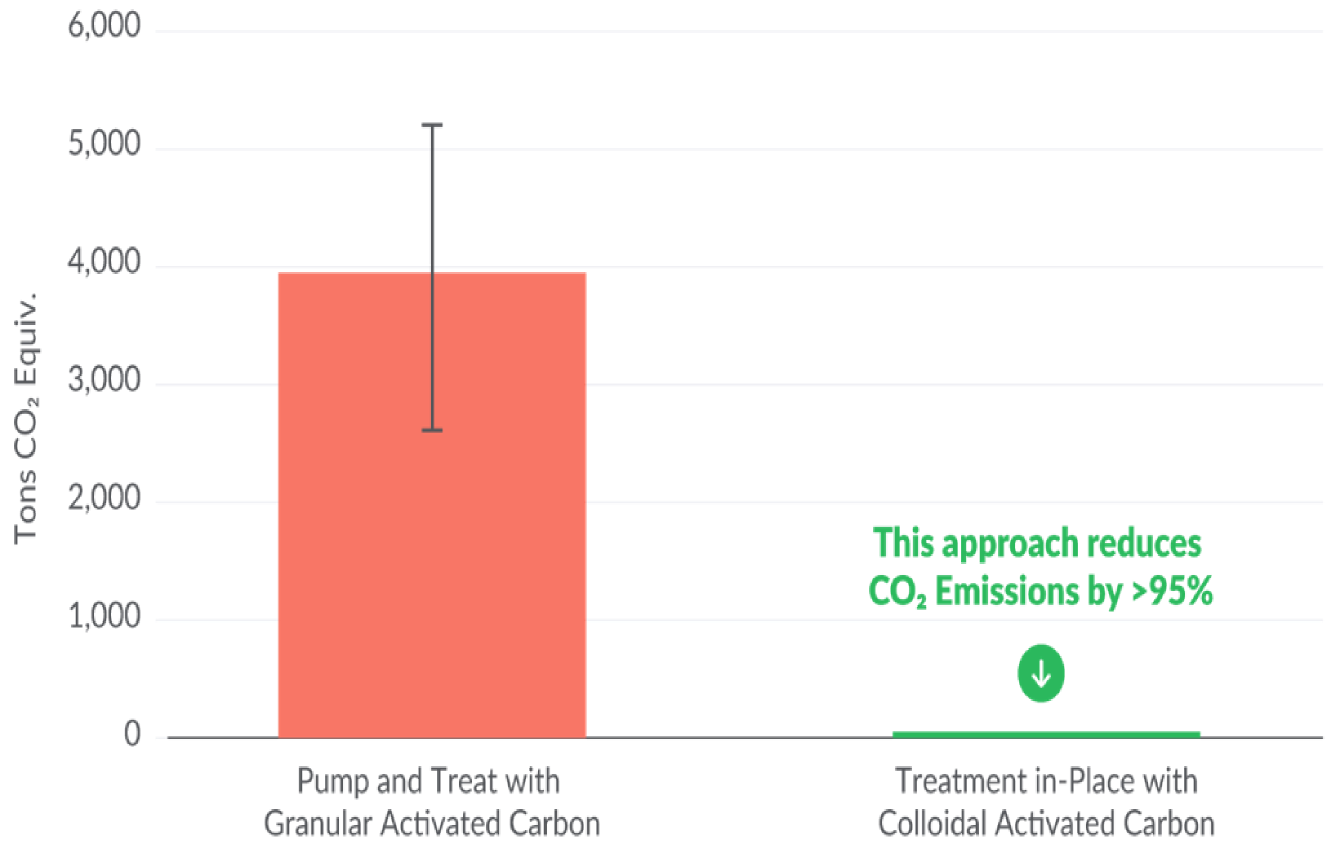
Pump & Treat with
GAC filtration

- Fixed equipment installation
- Continuous operation 15 years, 95% uptime
- 8 extraction wells, 25 feet deep
- 26 gal/min pumping rate
- 53,000 lbs GAC/yr usage rate
    - 100 mg/kg adsorption capacity
- 960 MWh/yr electricity consumption
- 4 times/yr O&M inspection from Bristol
- 420 gallons fuel used for installation
- 3 monitoring wells, 33 feet deep
- 2 times/yr, environmental monitoring
- Est. Cost (15 yrs): $7.4M



Results

Calculated Project Carbon Footprints



	PlumeStop	P&T w/ GAC
Remediation equipment		15,2
Civil works		
Fixed installations	0,05	0,9
Machinery	1,0	1,3
Remediation and operations		
PlumeStop / GAC	50,5	2 860
Electricity		281
Maintenance		3,6
Monitoring	4,0	4,0
Waste management		
Hazardous waste		112
Wastewater treatment		644
Total carbon footprint	**55,5**	**3 922**

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Summary: CAC Treatment PFAS in Groundwater at Airport Sites

- CAC used to remediate PFAS contamination at multiple aviation sites
- Regulatory standards met
- A single application can be effective for decades
- No waste is generated
- CAC applications are sustainable
- CAC remediation programs are cost effective

Example of Global PFAS Sites Treated

Alaska Airport Site
2- UK Airport Sites

Ontario Airport Site

NY Airport Site

Midwest Airport Site

Martha’s Vineyard Airport Site

Michigan Army Airfield

Confidential Air Force Base

Confidential East coast Navy Facility

Confidential East coast Air-Field

Ontario Industrial Site

New York Industrial Site

Southern Sweden Port Site

Southeast Chemical Manufacturing

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

Midwest Former Refinery

Fire Training Area

Connecticut Superfund Landfill Site

Pennsylvania Landfill Site

Michigan Landfill Site

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Questions?

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