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Sustainable PFAS Remediation: the Environmental Impact of Enhanced Attenuation using Colloidal Activated Carbon

How should we treat PFAS?

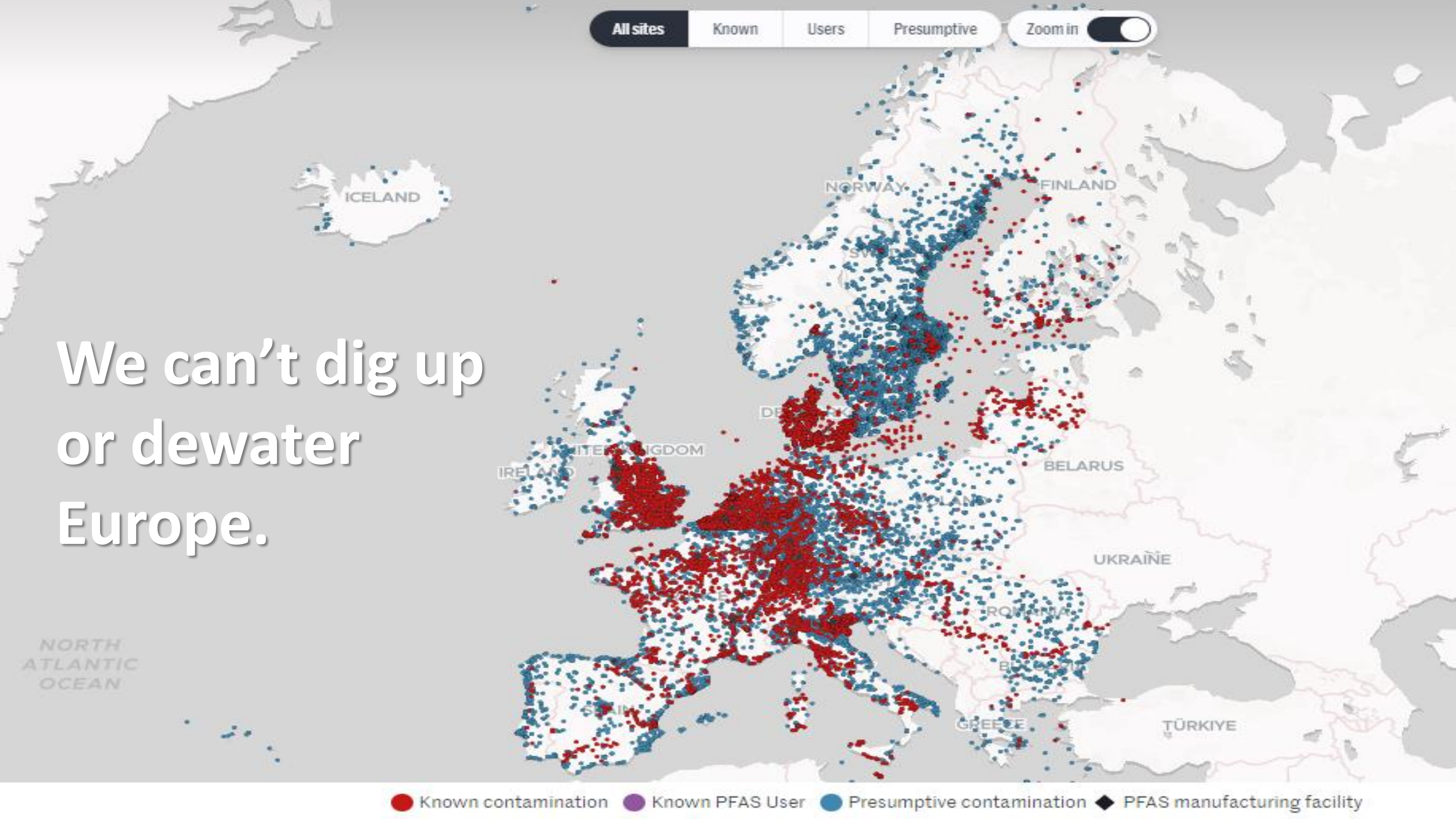
PFAS – have we been here before?

- >7000 species of PFAS?!
  - tetracontane ($C_{40}H_{82}$) has 62,491,178,805,831 possible structural isomers!
- Persistent
  - Heavy metals
  - Dioxins
  - PCBs
- Clean-up criteria in ppq!?

PFAS – Possible Future Groundwater Remediation Scenarios

- **Scenario 1:**
  Use pump and treat or *in situ* injection/emplacement of sorbents at **all PFAS groundwater sites** needing plume control

We can’t dig up or dewater Europe.



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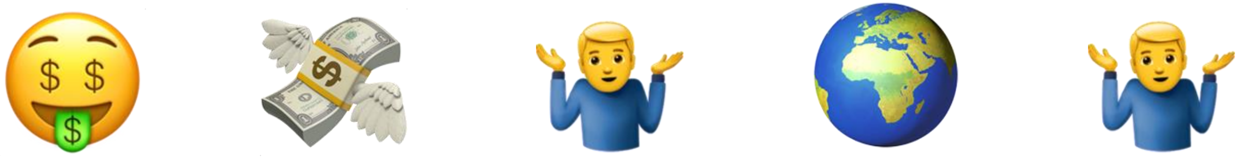


- **Scenario 2:**
  If "silver bullet" PFAS remediation technologies emerge
  - Chlorinated solvent site remediation methods the early 2000s
  - Still – so widespread; is it ***really*** going to be used everywhere?

- **Scenario 3:**
  Implement triage approach:
  - Point-of-use treatment for large sites
  - Improved pump and treat
  - Enhanced Natural Attenuation

How <u>should</u> we treat PFAS?

Adopt a sustainable remediation approach

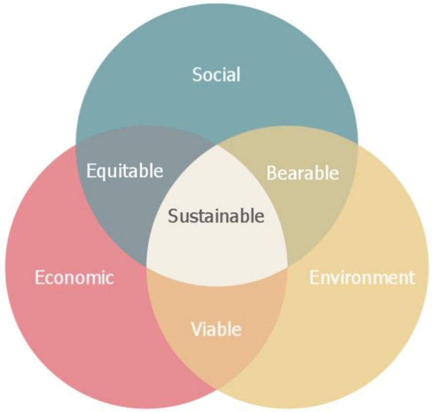
(ISO 18504:2017) definition:

Sustainable Remediation is the

*'elimination and/or **control** of unacceptable **risks** in a safe and timely manner **whilst***

optimizing the environmental, social and economic value

of the work.'



Pumping huge volumes, Landfill, Energy, Equipment, Transport, Cost

High ongoing carbon footprint

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Enhanced Attenuation of PFAS?!

But some PFAS don't biodegrade?

Correct! (Maybe)

But Natural Attenuation ***<u>doesn't</u>*** just mean biological degradation:

- Diffusion
- Volatilisation
- Sorption
- Chemical (abiotic) degradation

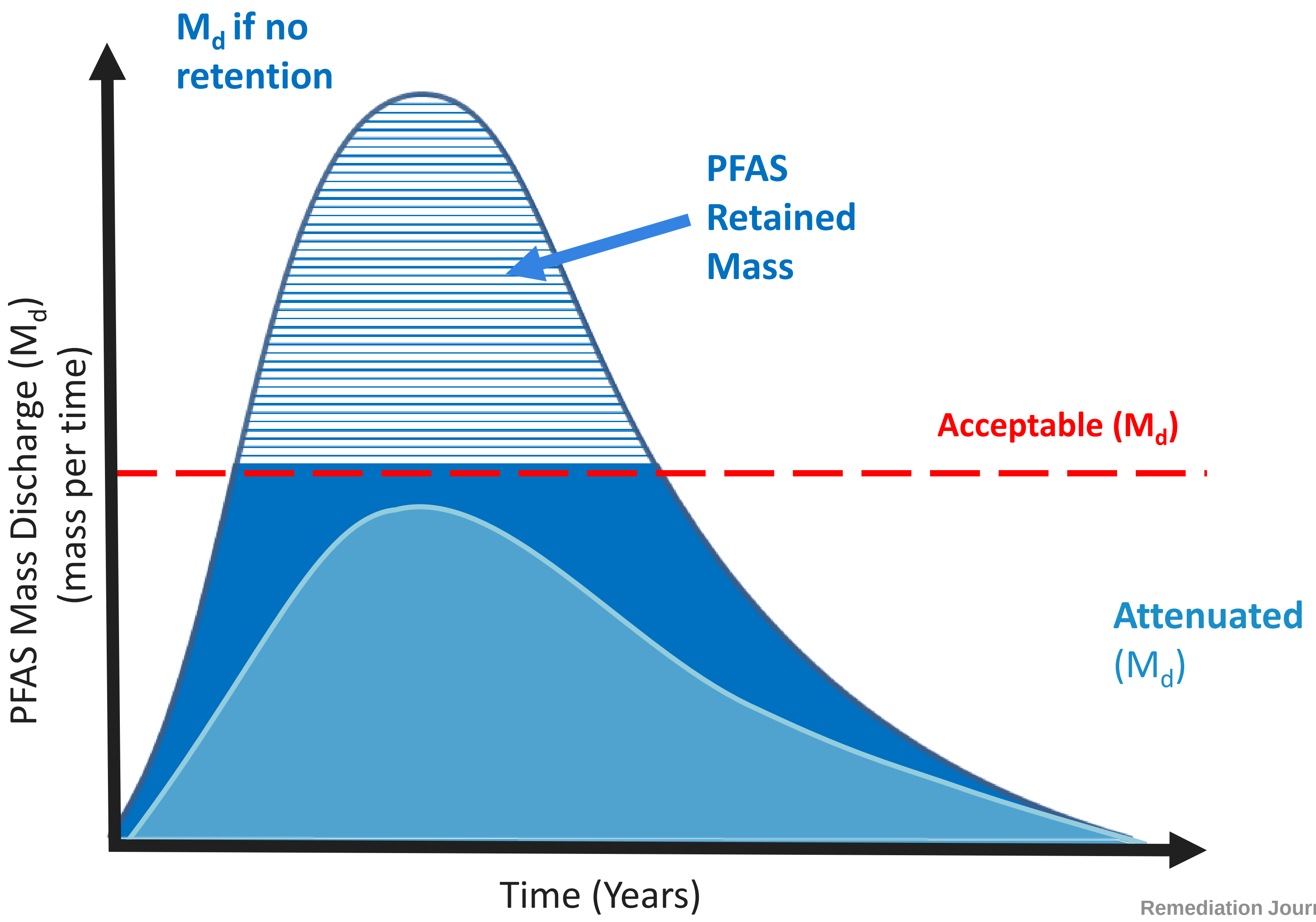
The Interstate Technology and Regulatory Council (ITRC, 2008) defined EA as:

> "Any type of intervention that might be implemented in a source-plume system to increase the magnitude of attenuation by natural processes beyond that which occurs without intervention. Enhanced attenuation is the result of applying an enhancement that sustainably manipulates a natural attenuation process, leading to an increased reduction in mass flux of contaminants."

Increase the ability of the aquifer to sorb PFAS ('retention')
=**<u>Enhanced Attenuation</u>** of the PFAS plume

Enhanced Natural Attenuation of PFAS?

Peak Shaving and Hysteretic Retention…



Peak Shaving:

Following source treatment and the application of colloidal activated carbon, the plume will be subject to **"hysteretic" retention** processes:

- ***Fast sorption*** and **<u>slow desorption</u>**


- **Result:** decrease the mass discharge of the plume
- Spreading it out over a longer period
    - known as **Peak Shaving**

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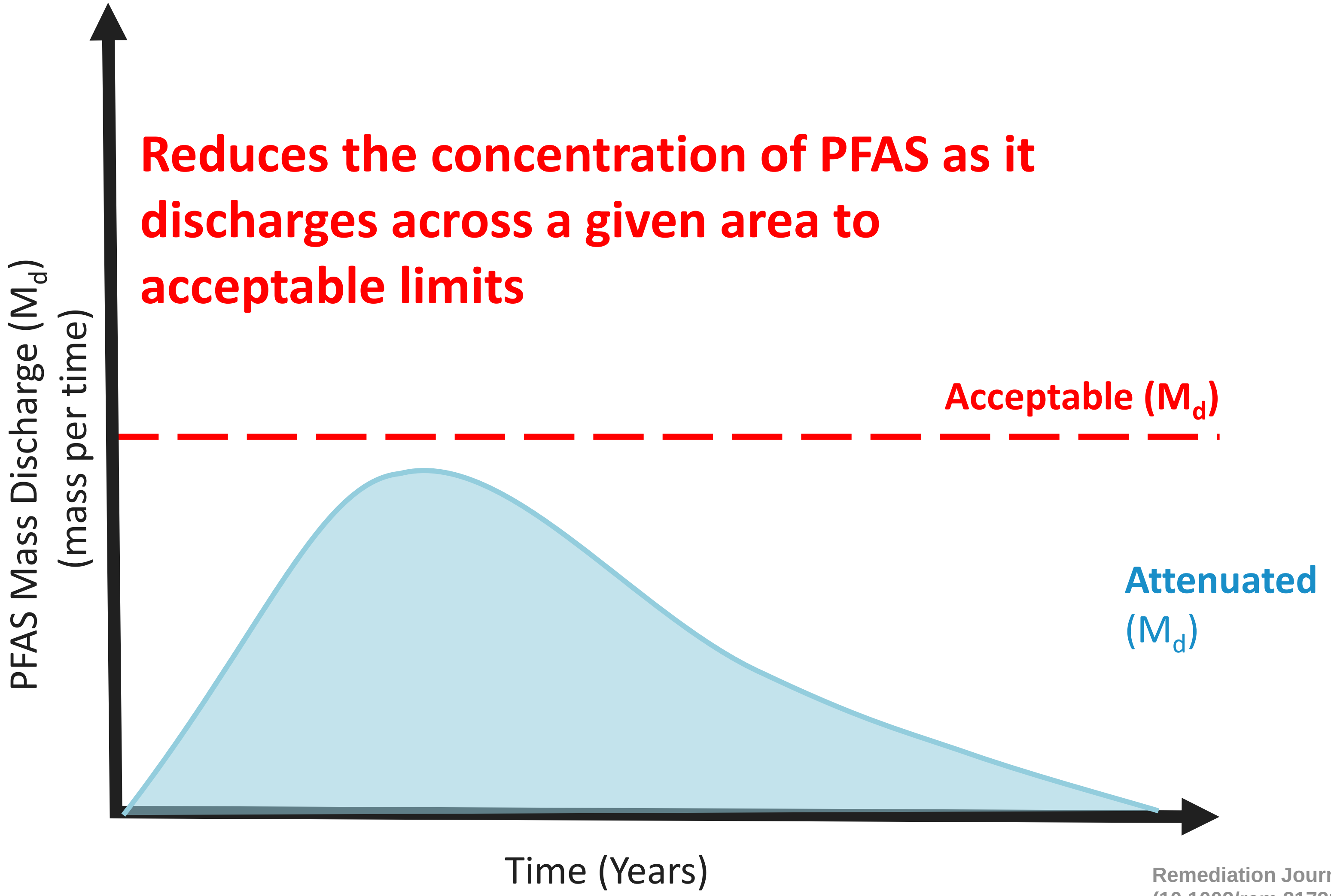
Inflow in Reservoir
Reservoir Storage
Flood threshold limit
Controlled outflow
Flow (volume per unit time)
Time (days-months)

Enhanced Natural Attenuation of PFAS – Sequestration

Expectations



- No breakthrough **<u>if the source has been sufficiently treated</u>**
- Never significant breakthrough for low flux plumes where source treatment is not possible

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Enhanced Attenuation

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RESEARCH NOTE

WILEY

Enhanced attenuation (EA) to manage PFAS plumes in groundwater

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Abstract

Remediation of per- and polyfluoroalkyl substances (PFAS) in groundwater is particularly challenging because of their unique chemical and fate and transport properties. Many conventional in-situ remediation technologies, commonly applied to address other groundwater contaminants, have proven ineffective for treatment of PFAS. Given their stability, destruction of PFAS in-situ has remained elusive as an in-situ treatment option. Consequently, new approaches to manage PFAS groundwater plumes are of great interest to environmental practitioners. We propose that enhancing PFAS retention can play an important role in reducing PFAS mass flux and providing long-term protection of downgradient groundwater receptors. Enhanced retention of PFAS fits directly into the enhanced attenuation (EA) framework, an established groundwater remediation strategy that was developed in the first decade of the 2000s for other groundwater contaminants. In this paper, we propose eight EA approaches for PFAS in groundwater, including technologies that are currently being implemented at PFAS sites (e.g., injection of particulate carbon amendments), applications of conventional remediation technologies to PFAS sites (e.g., capping to retain PFAS in the vadose zone), and novel, innovative approaches (e.g., intentional food grade LNAPL emplacement to retain PFAS) for enhanced PFAS retention. These EA approaches leverage the properties of PFAS to (i) facilitate sorption to conventional and novel sorbents, (ii) concentrate PFAS at air/water interface via gas sparging, and/or (iii)

https://onlinelibrary.wiley.com/share/QZTYKVUAJYDCKAC92B8W?target=10.1002/rem.21731

Colloidal Activated Carbon and PFAS

#CAC and PFAS

Colloidal Activated Carbon

What Is It?

- Liquid **activated carbon**
  - Particle sizes 1 – 2 µm
- Suspended as a **colloid** in a polymer solution
- **Distributes widely** under low pressure
  - No high-pressure fracturing is needed
- Provides **extremely fast sorption sites**
  - Converts underlying geology into purifying filter
- Does not “washout” of the aquifer
- Is **non-toxic**

SourceStop™

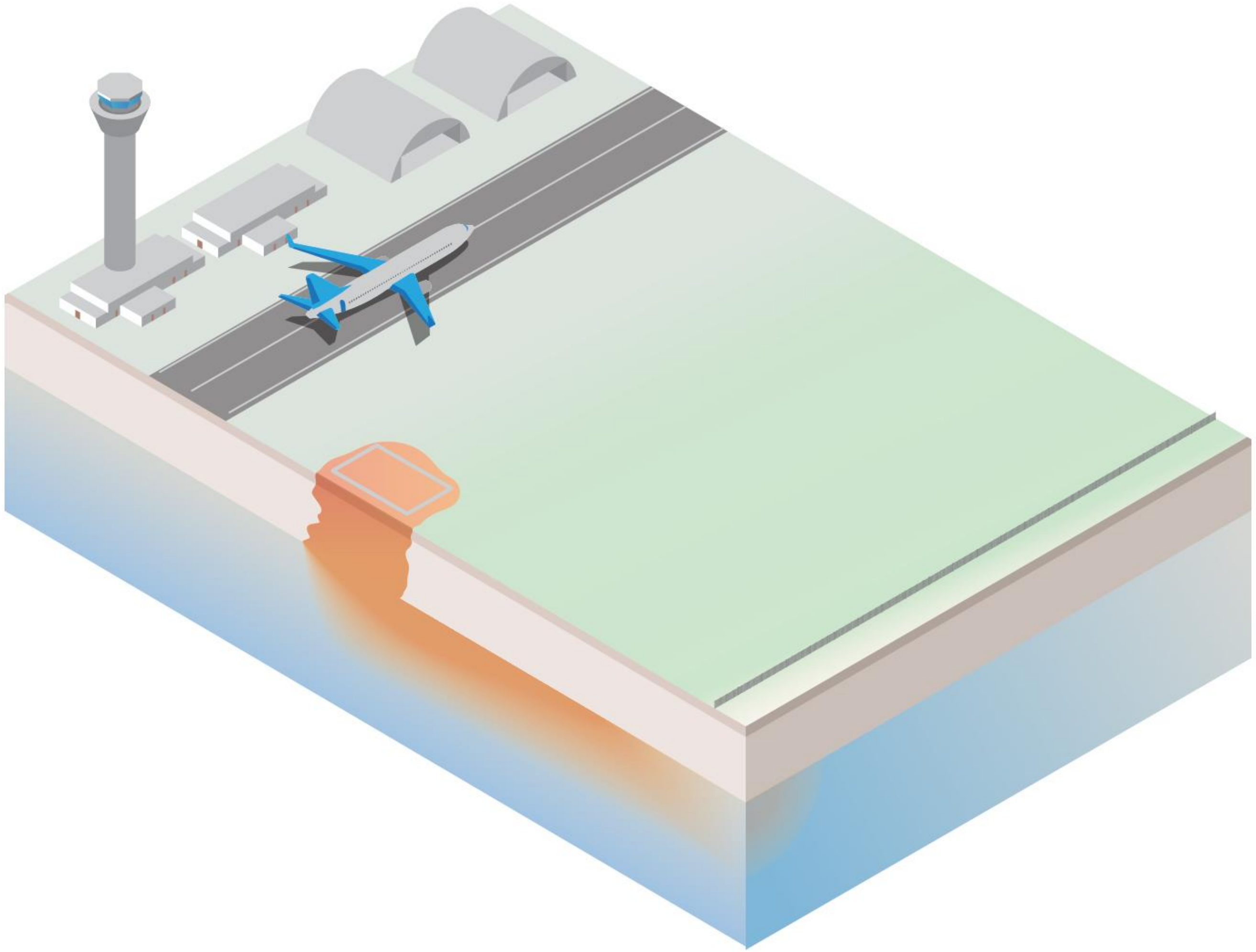
REGENESIS®

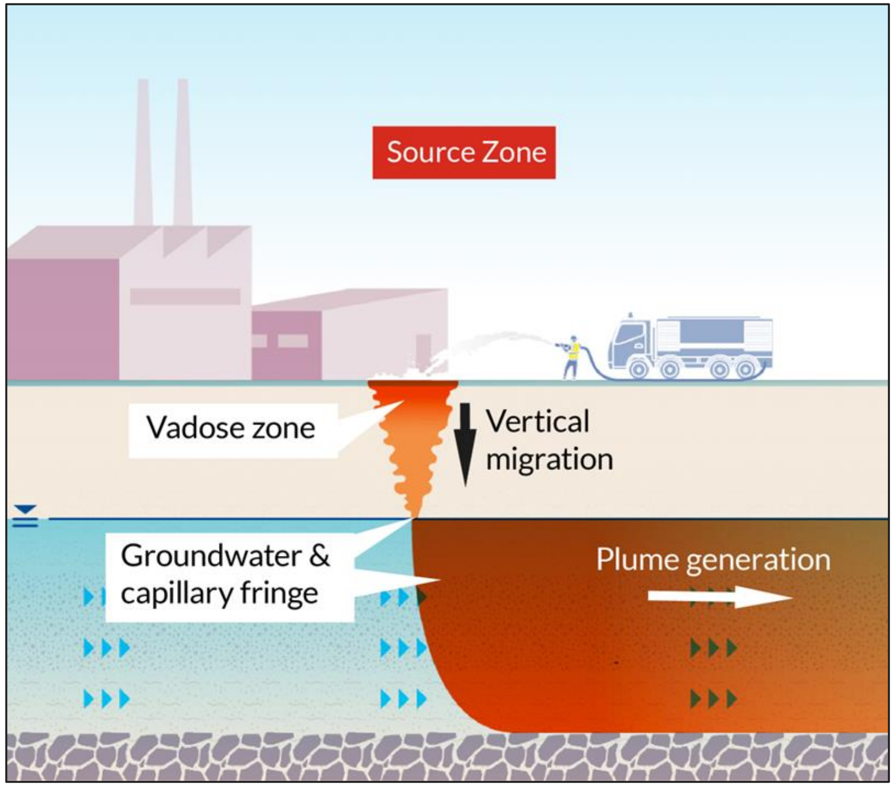
PLUME STOP®
Liquid Activated Carbon

CAC: Reduces Risk of PFAS

- ~~Risk~~ = Hazard x ~~Exposure~~
- CAC binds up PFAS *in situ*
- Reduces potential for downgradient exposure
- Reduces the risk

Considering the PFAS Source-Plume System





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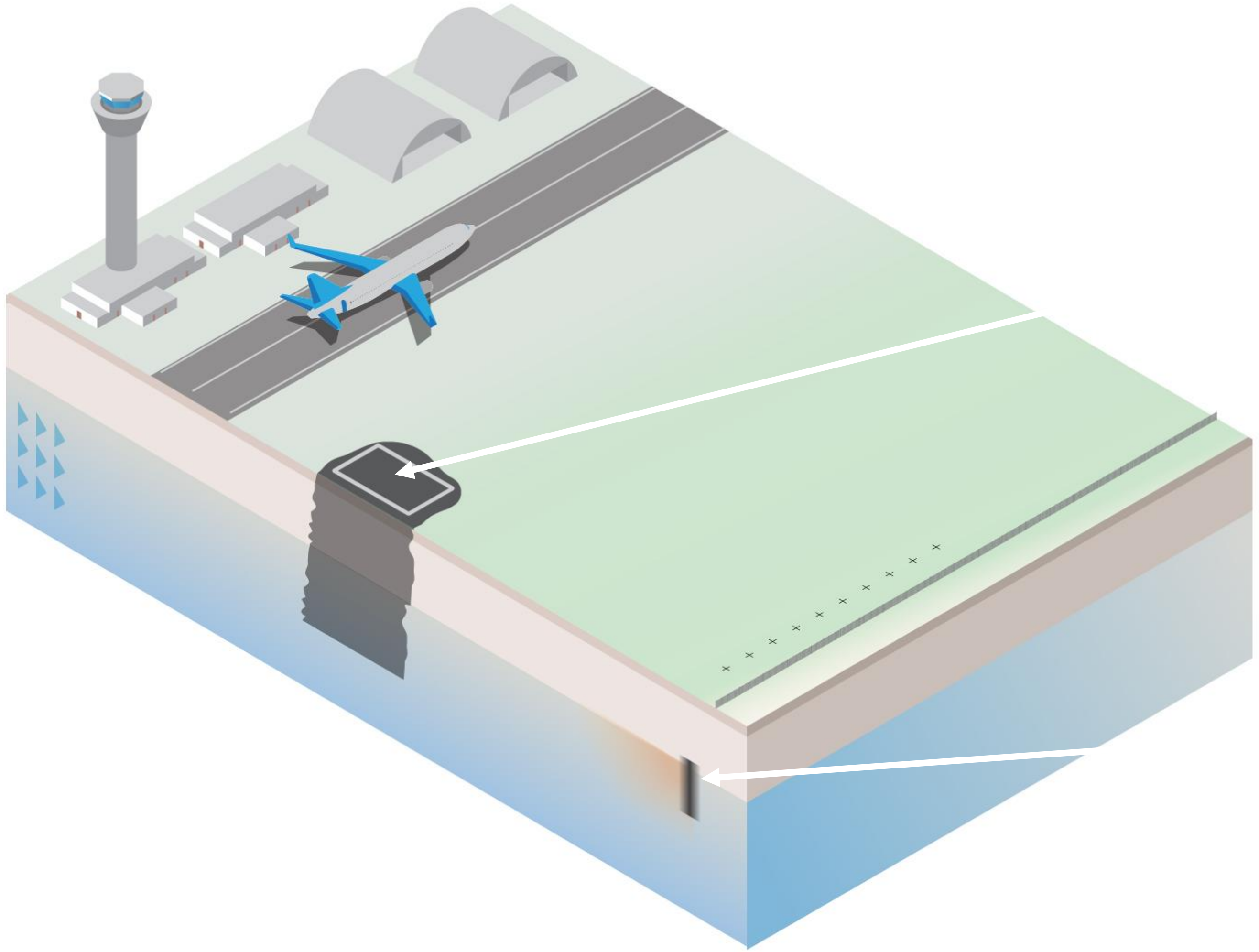
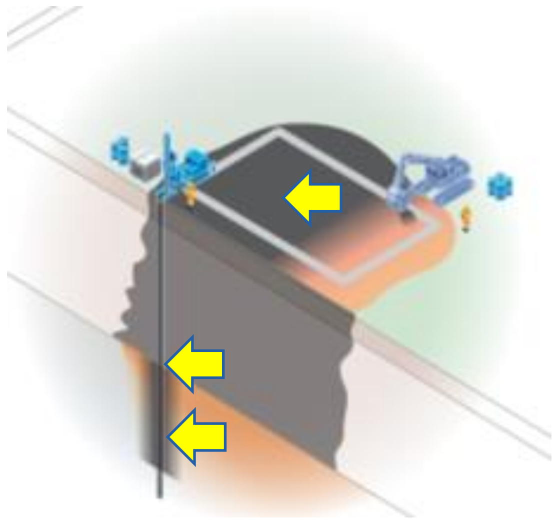
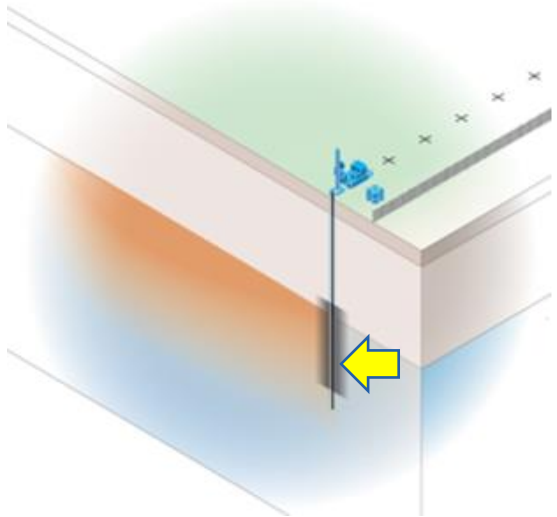
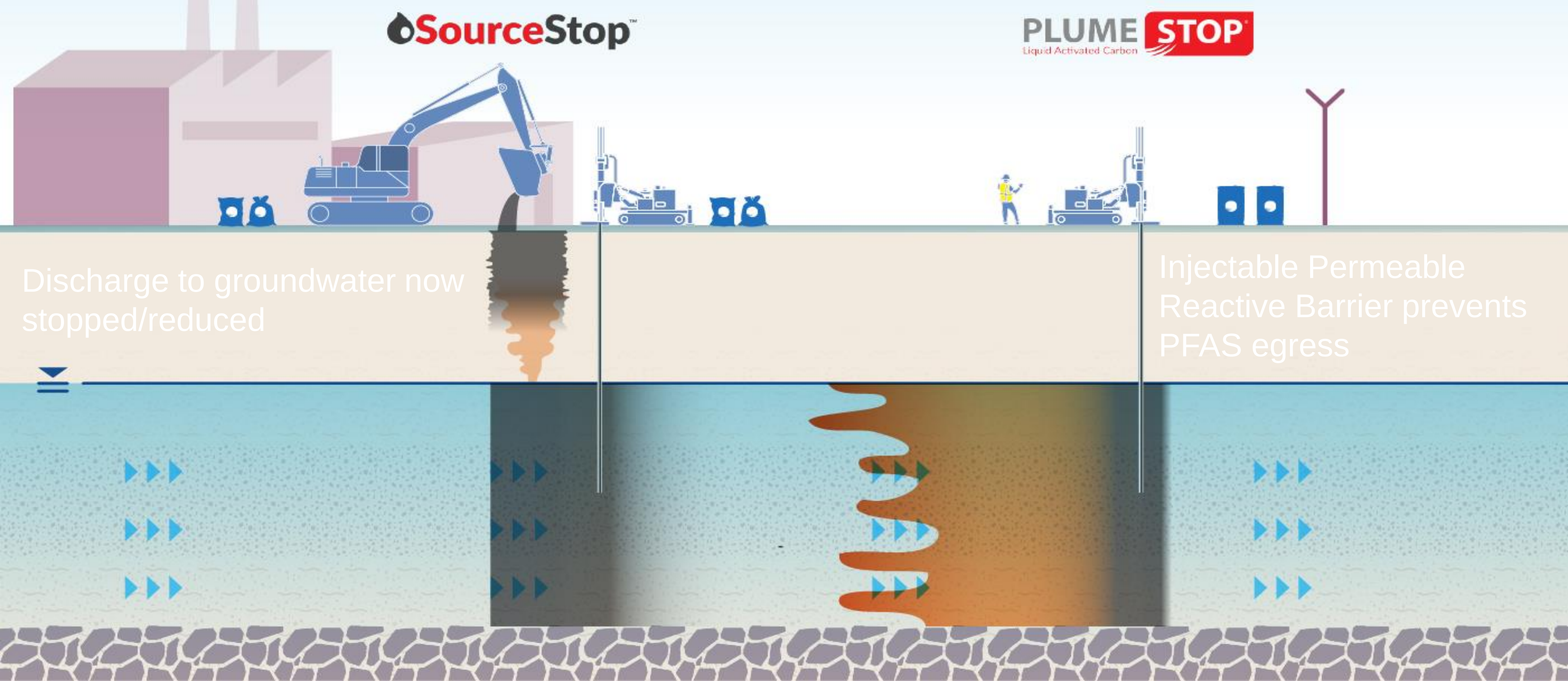


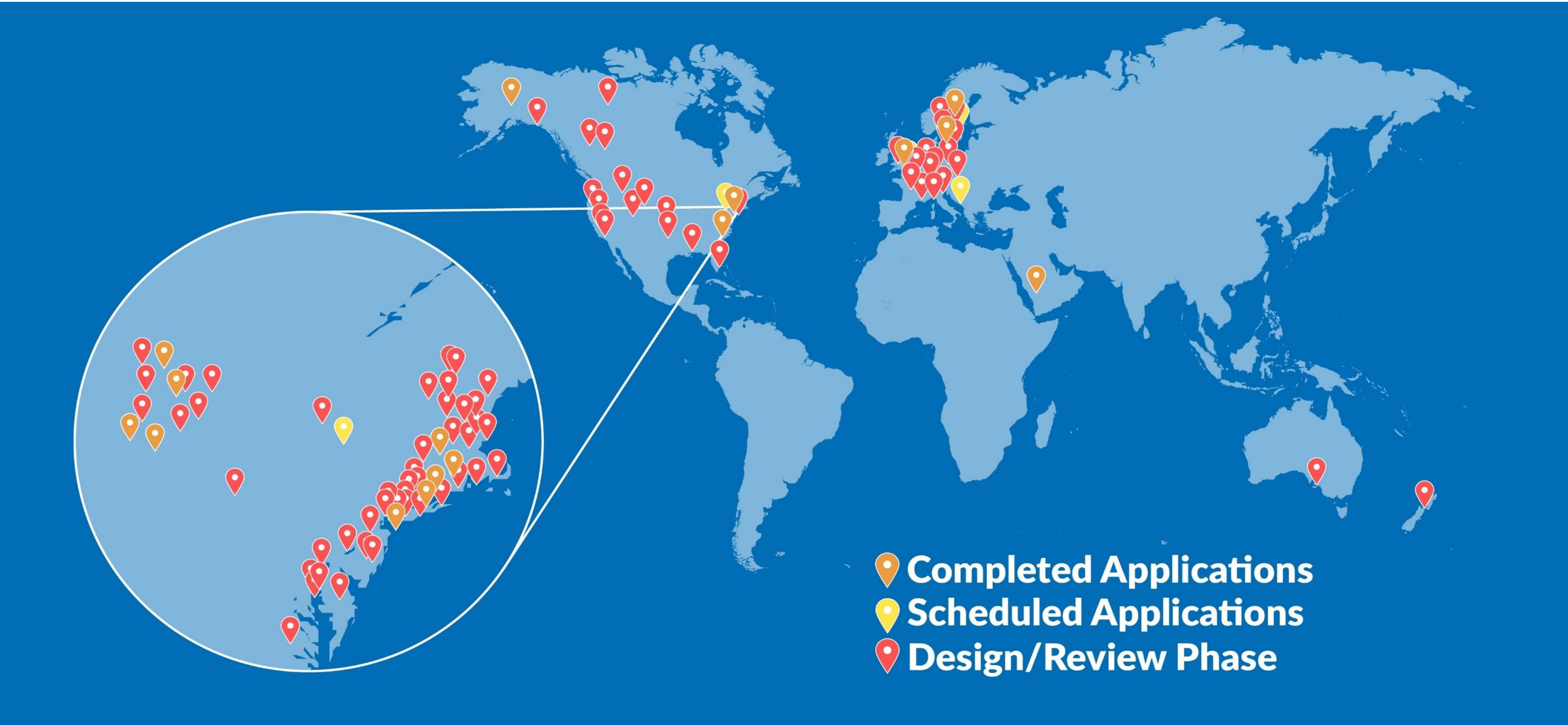




Source Treatment = Enhanced Attenuation
Combine With Plume Treatment = Rapid Risk Removal



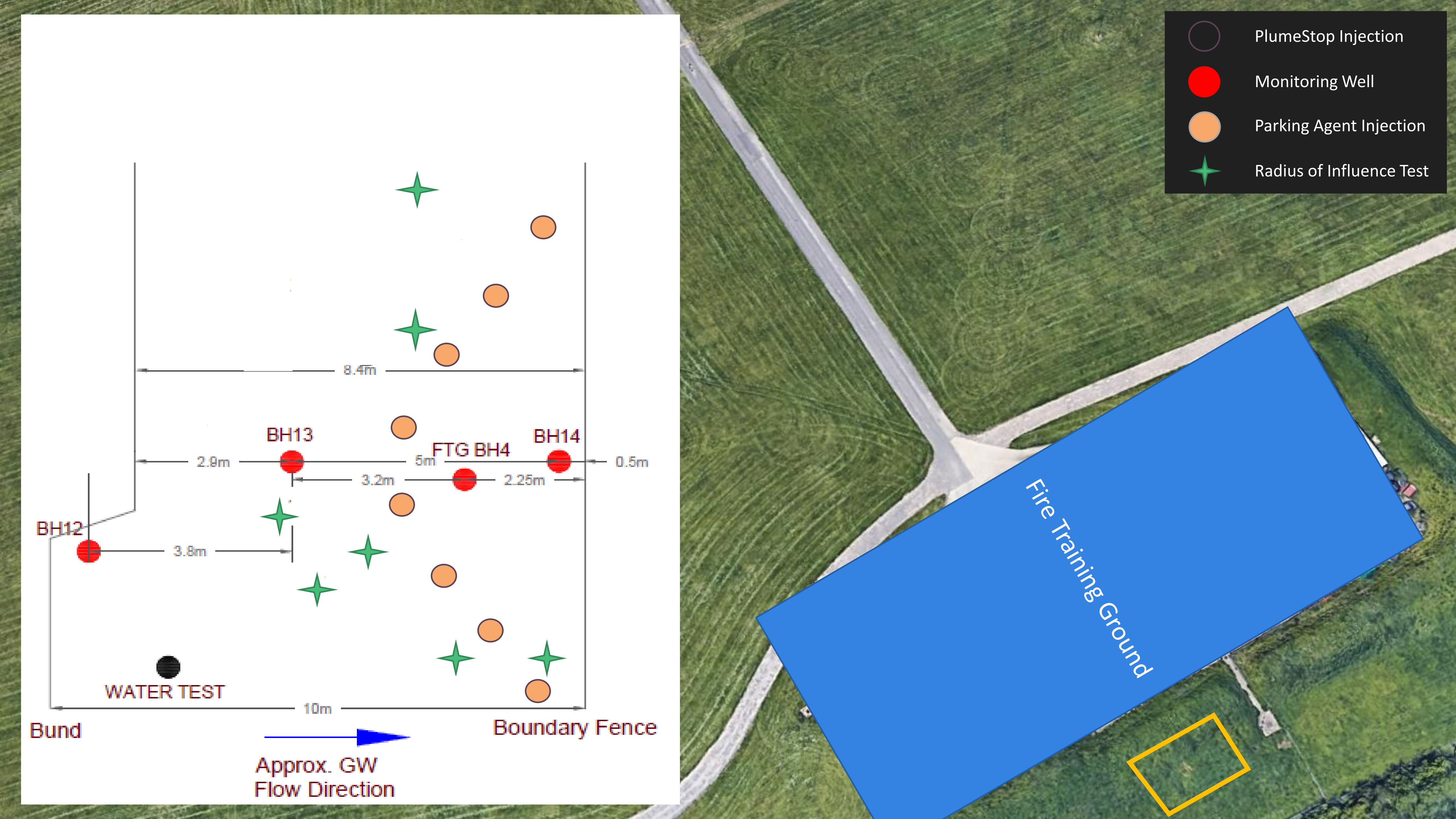
PlumeStop: Proven on PFAS Sites Worldwide



Case Studies

UK International Airports

6-Month PFAS Pilot Trial
Full-Scale Results


PlumeStop Injection
Monitoring Well
Parking Agent Injection
Radius of Influence Test
8.4m
BH13
FTG BH4
BH14
2.9m
5m
0.5m
3.2m
2.25m
BH12
3.8m
WATER TEST
10m
Bund
Boundary Fence
Approx. GW
Flow Direction
Fire Training Ground

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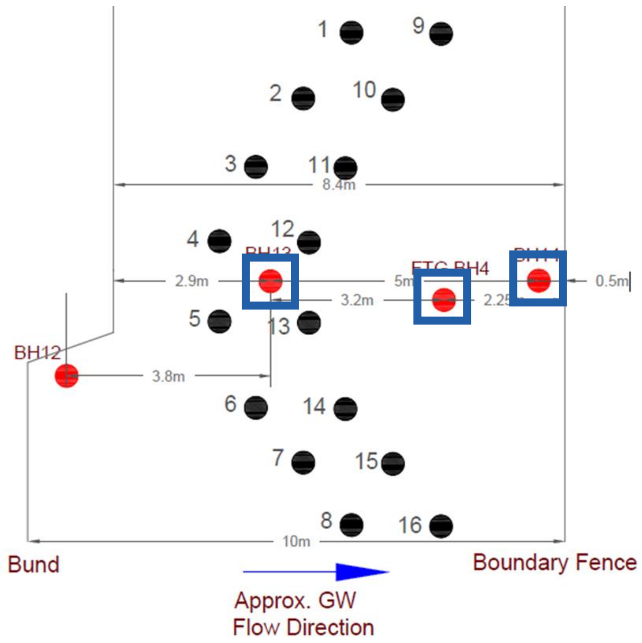
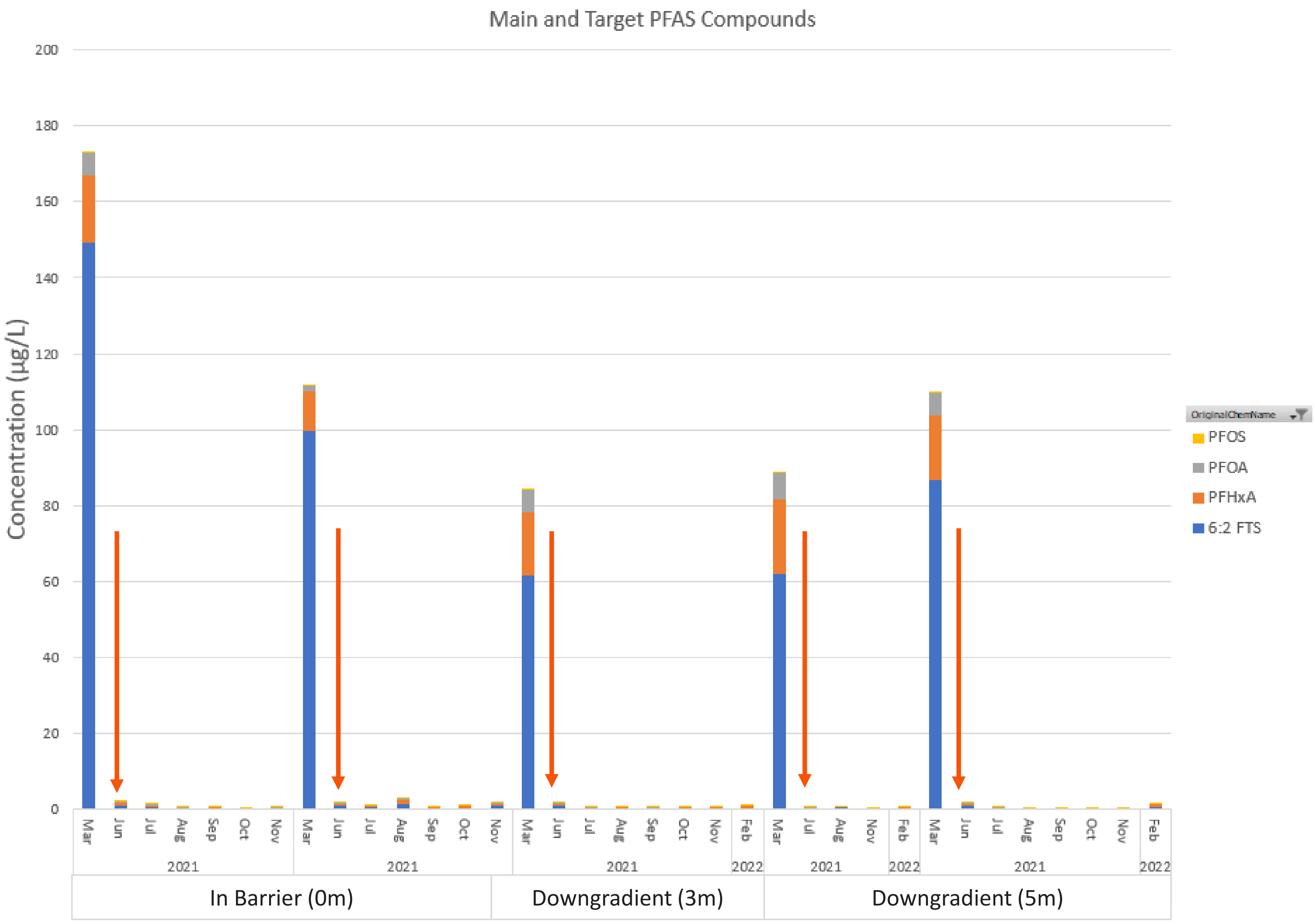
Results

Project goal: ‘betterment’ approx. >90% reduction in target contaminants PFOS and PFOA

PFOA/PFOS reduced to < detection limits

96-99% reduction in SUM24 PFAS





Full-Scale Barrier

104 no. injection points

76m extension of barrier

2x upgradient monitoring locations

4x in "barrier wells"

6x downgradient monitoring locations

PetroFix barrier

Parking agent

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Is the concept credible?	Can it work in practice?	Is the science sound?	Has the hypothesis been tested?	Are the results repeatable?

Sustainability Comparison

Overview of Study

Ramboll

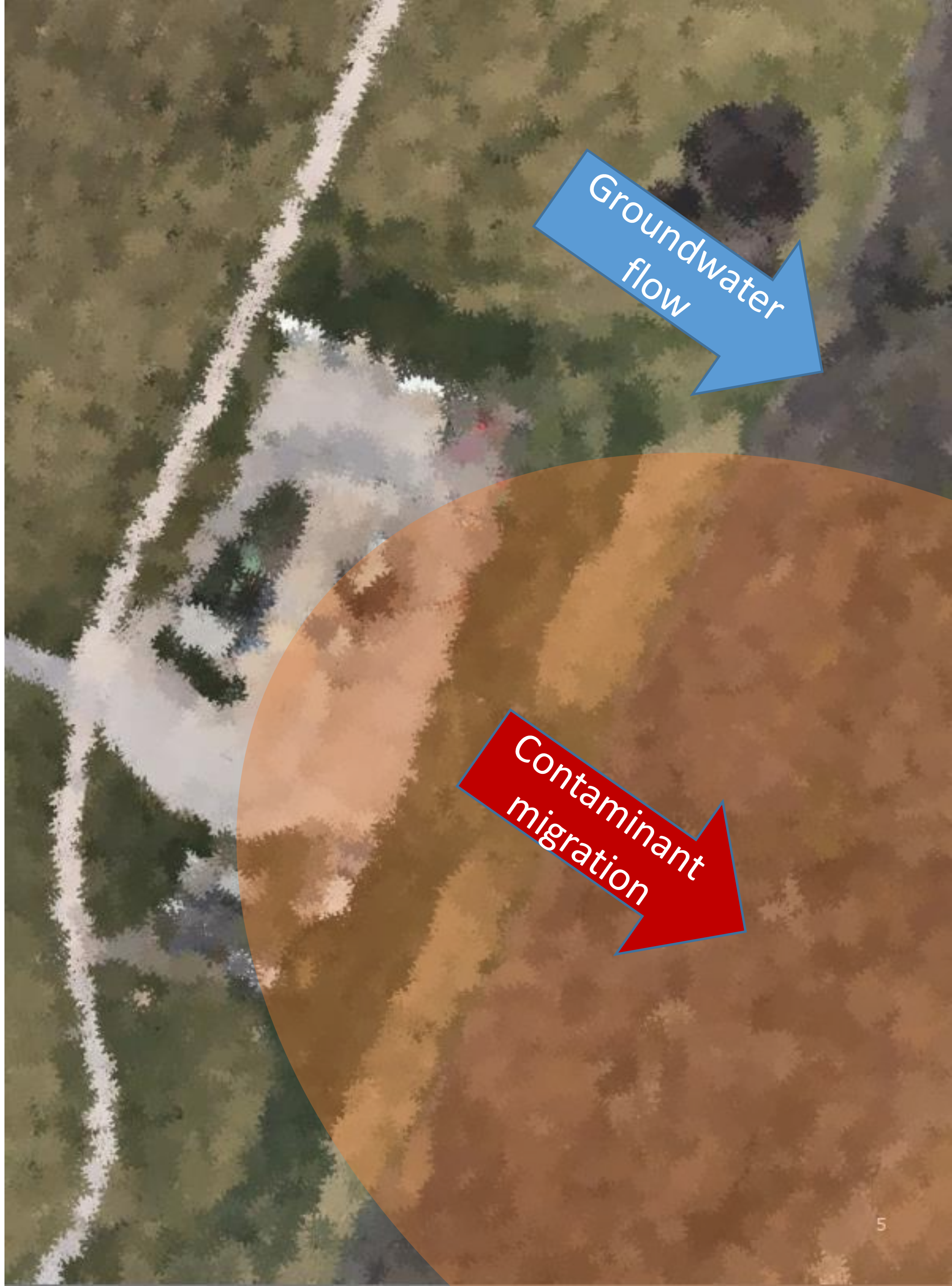
- Head of Circular Solutions and Climate Specialist team, Finland

PFAS Contaminated Airport, UK

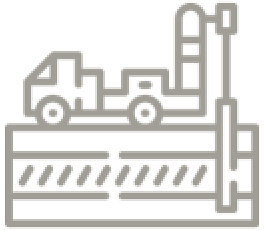
- Immediately prevent/reduce offsite PFAS migration
- Source treatment to follow

Compare the Life Cycle Analysis for:

- **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

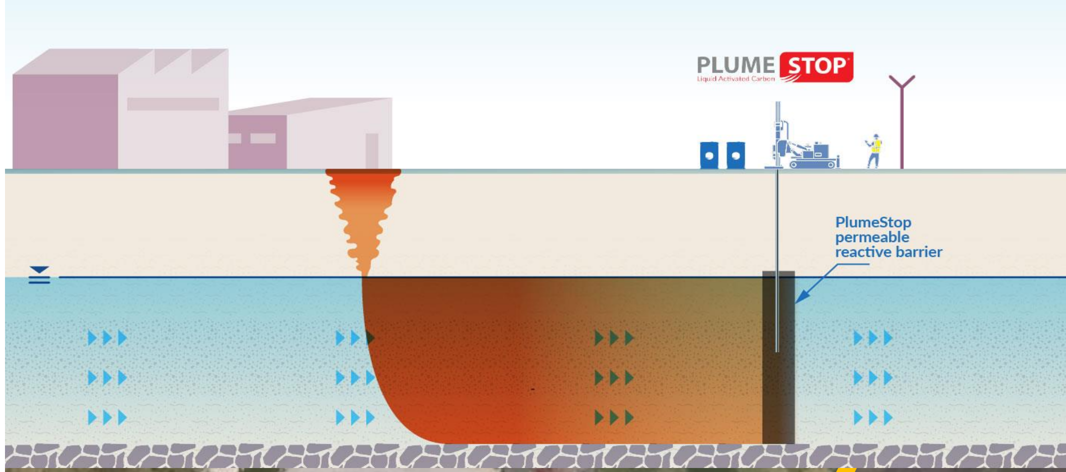


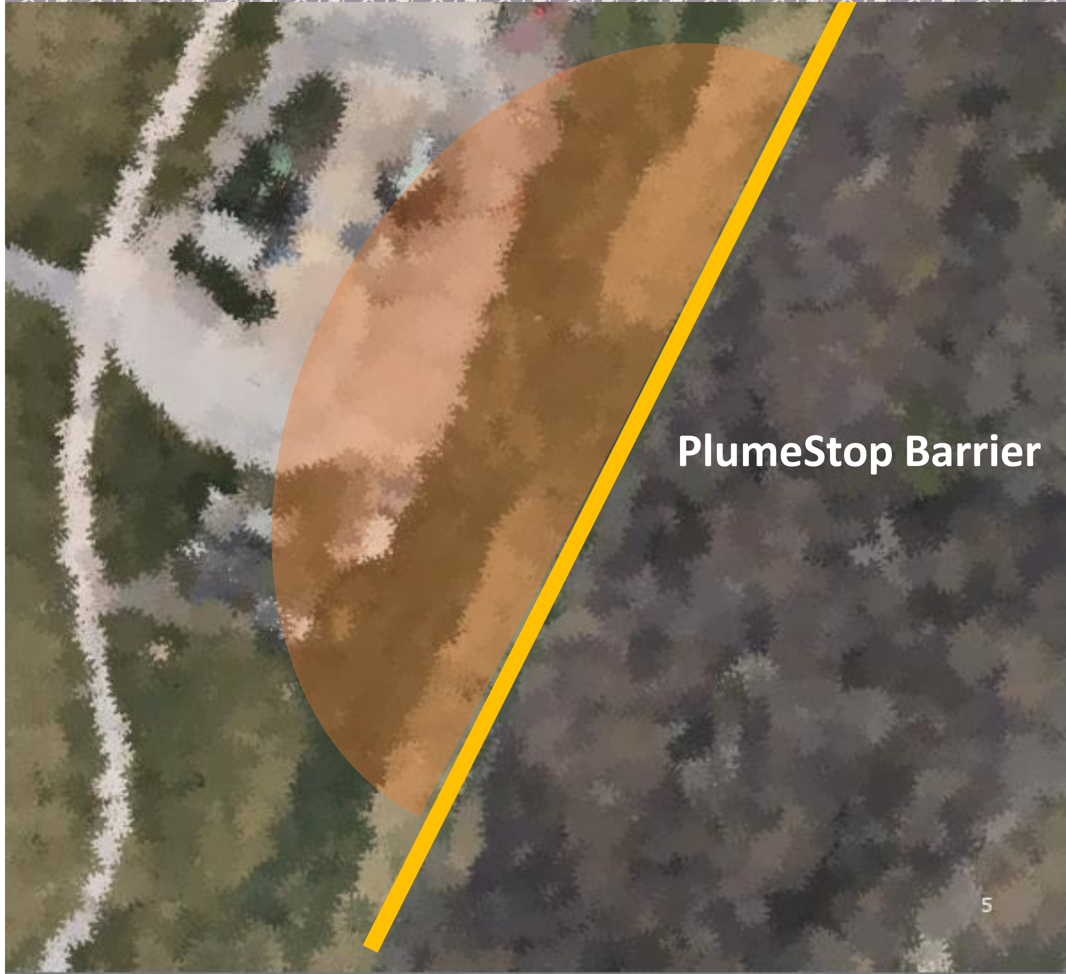
Life Cycle Inventory Analysis



Immobilization with PlumeStop ®

- Single injection round is scheduled.
- The design guarantees a minimum of 15 years of efficacy.
- There are 102 injection points.
- The length of the operation area is approximately 110 meters.
- A total of 33,566 kilograms of PlumeStop is used.
- 1,590 liters of fuel is consumed for the injection process.
- There are 3 monitoring wells, each approximately 10 meters deep.
- Environmental monitoring takes place twice a year.





Scope of Assessment: Cradle to Grave

Methods/Software

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

System boundary

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

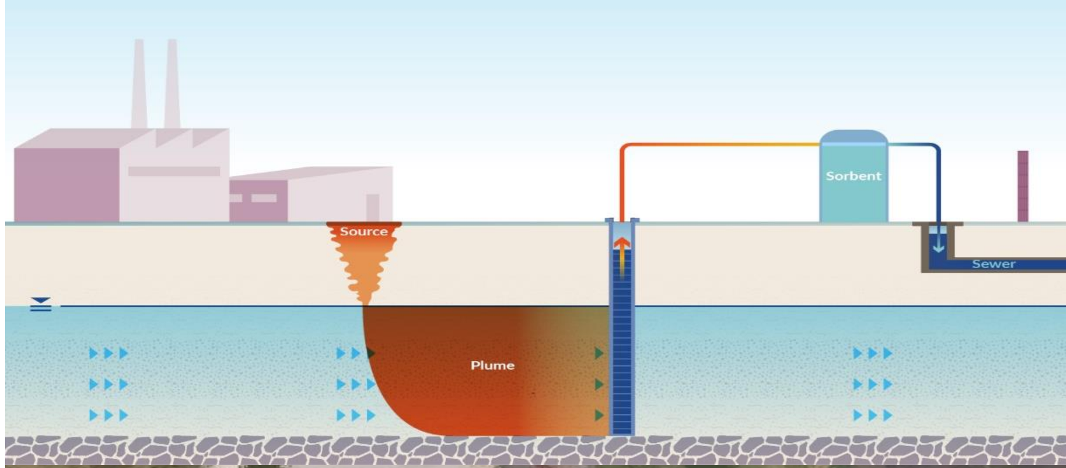
In situ: PlumeStop

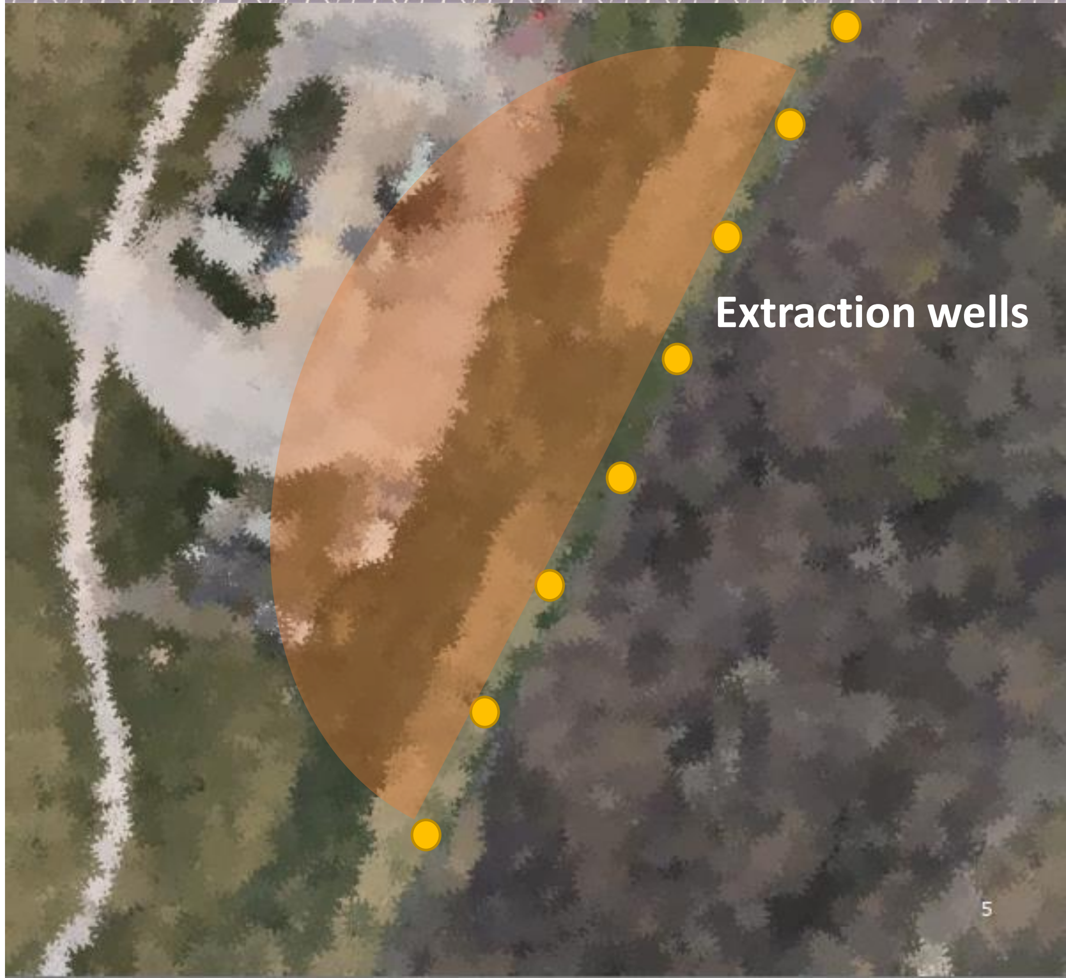
PlumeStop product	US to UK	Injection	Monitoring

Life Cycle Inventory Analysis

Pump & Treat with GAC filtration

- Consensus achieved from 3 P&T designers.
- Fixed equipment installation is planned.
- Continuous operation for 15 years with a 95% uptime.
- There are 8 extraction wells, each approximately 8 meters deep.
- The design is to avoid excess draw-down resulting in vertical spread/smear.
- The pumping rate is about 98 liters per minute.
- The usage rate of GAC is approximately 24,040 kilograms per year.
- The adsorption capacity is 100 milligrams per kilogram.
- The electricity consumption is 960,000 kWh per year.
- Office O&M inspections occur 4 times per year.
- Around 1,590 liters of fuel is used for the installation process.
- There are 3 monitoring wells, each approximately 10 meters deep.
- Environmental monitoring takes place twice a year.





Scope of Assessment: Cradle to Grave

System boundary

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

On-site: Pump & Treat

- Pump & Treat Equipment
- Extraction wells and transfer lines
- Civil works
- Materials
- Energy
- Maintenance
- Monitoring
- Waste management

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
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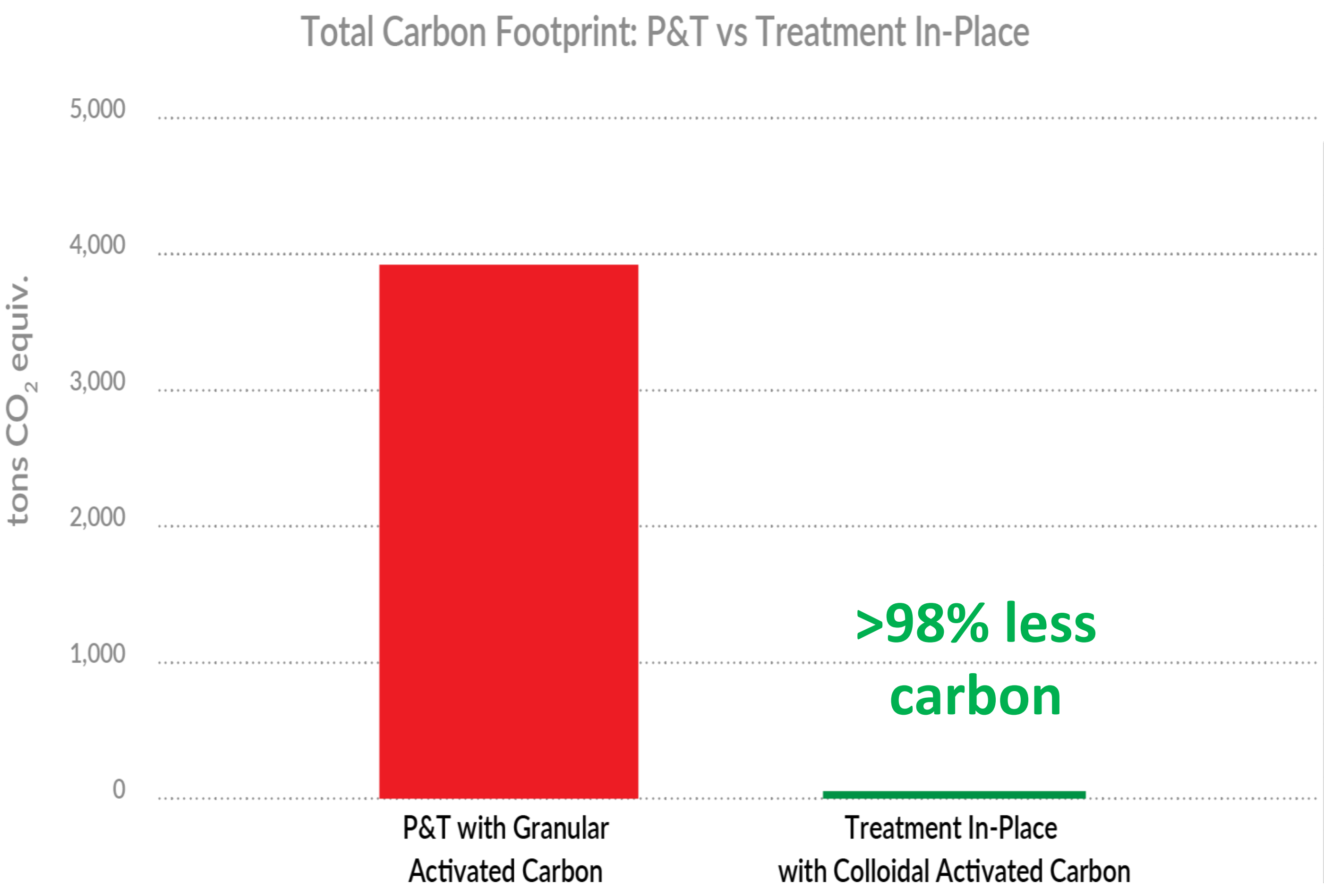
Carbon Footprint



>98% less carbon

carbon footprint = 70 x smaller

	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	**56**	**3 922**

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Carbon Footprint

- GAC footprint most significant impact
- Assumes landfill
  - Incineration in future
  - Will increase impact
- Options to reduce or remove GAC?

	PlumeStop	P&T w/ GAC
Remediation equipment		15,2
Civil works		
Fixed installations	0,05	0,9
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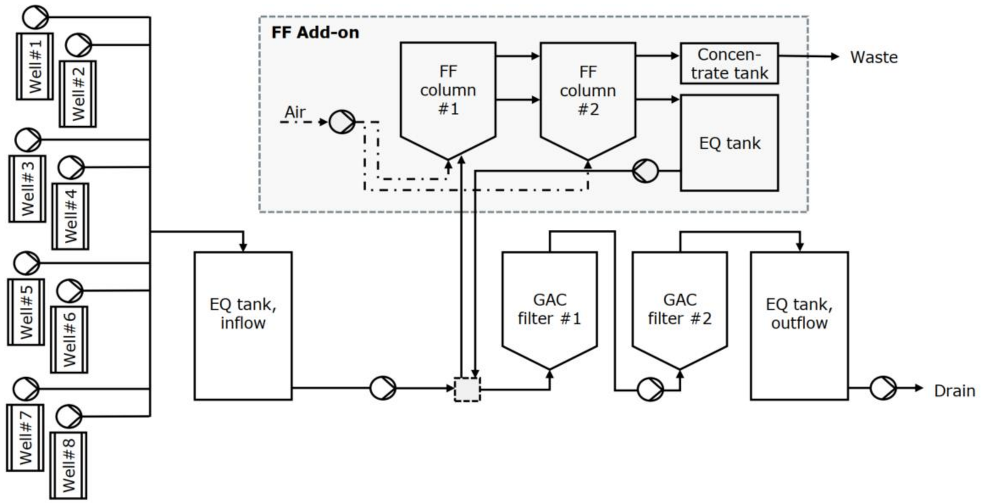
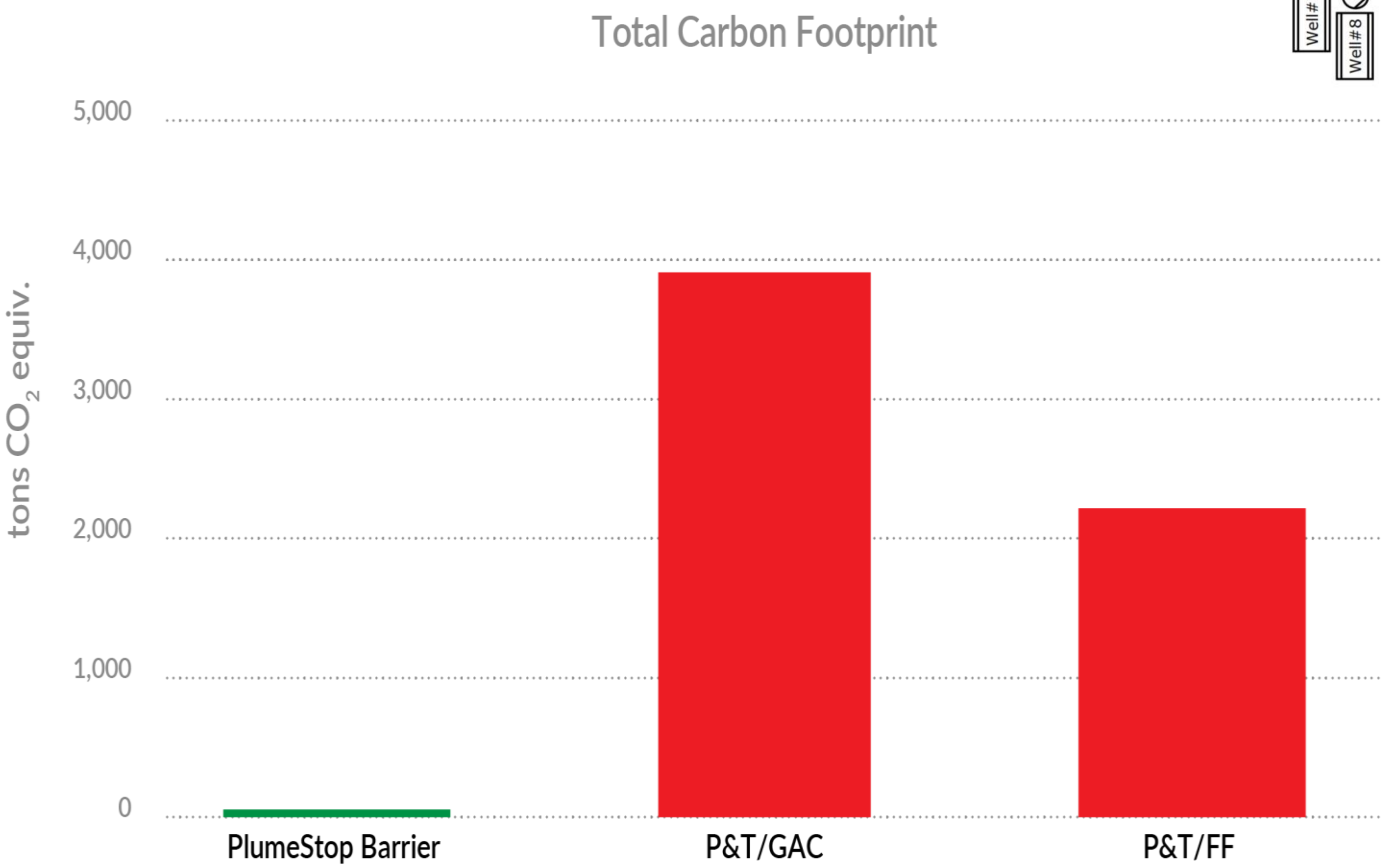
Carbon Footprint

We also modelled Foam Fractionation (FF):

- Bubble/skim off PFAS
- Reducing GAC
- Increasing equipment/electricity





- In situ retention still 97.5% lower (carbon footprint = 40 x smaller)

- Changing treatment ≠ significant reduction
- Pumping alone = 1-2 Orders Of Magnitude increase in Carbon Footprint
- ANY filtration or destructive treatment technique only adds to this

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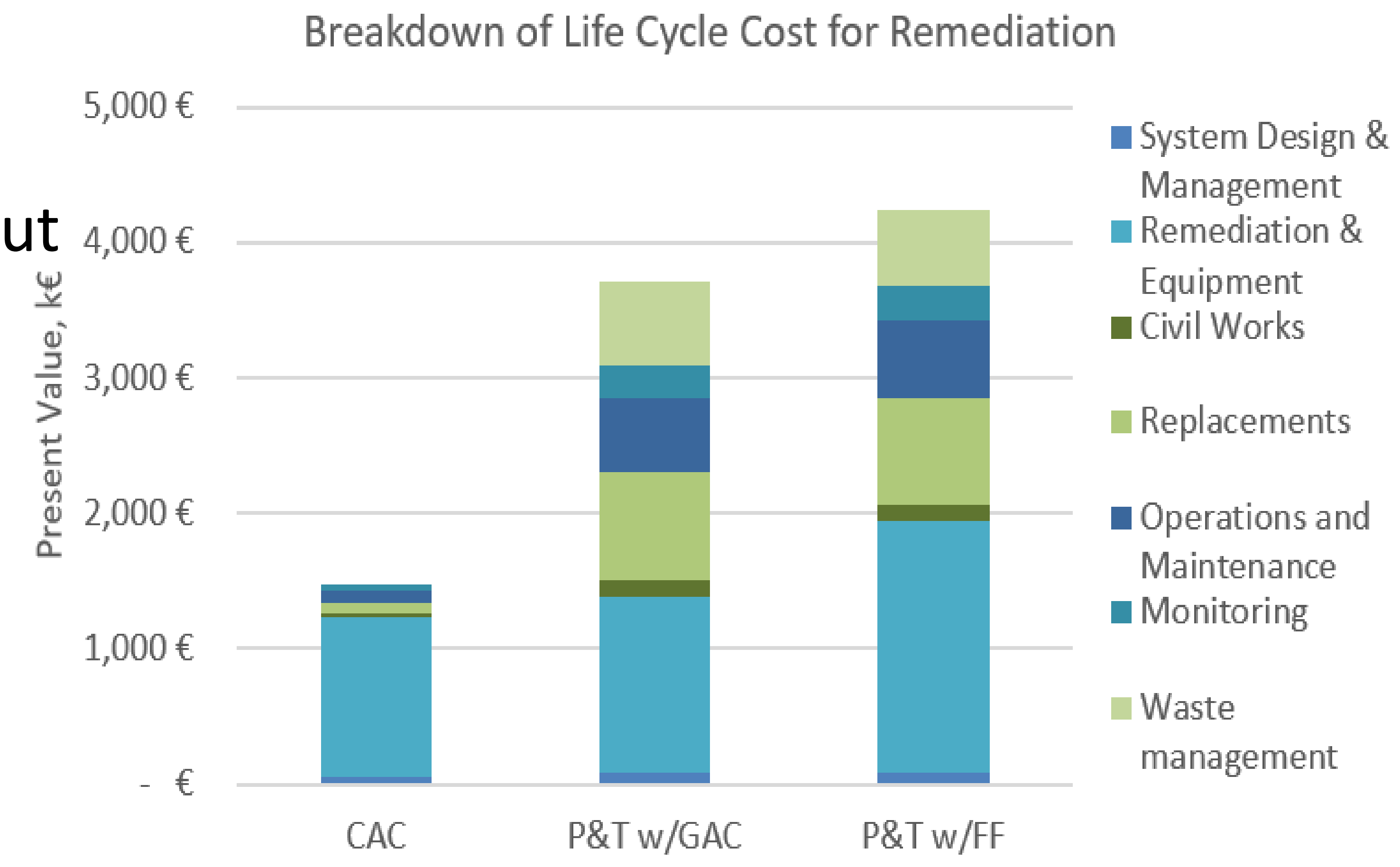
Life Cycle Cost Analysis

- Pricing analysis by Ramboll
- Based on a 15-year treatment
- Costs at different times throughout
- Net Present Value:

CAC retention barrier = $1.608M

P&T with GAC = $4.039M

P&T with FF = $4.623M



61-65% less

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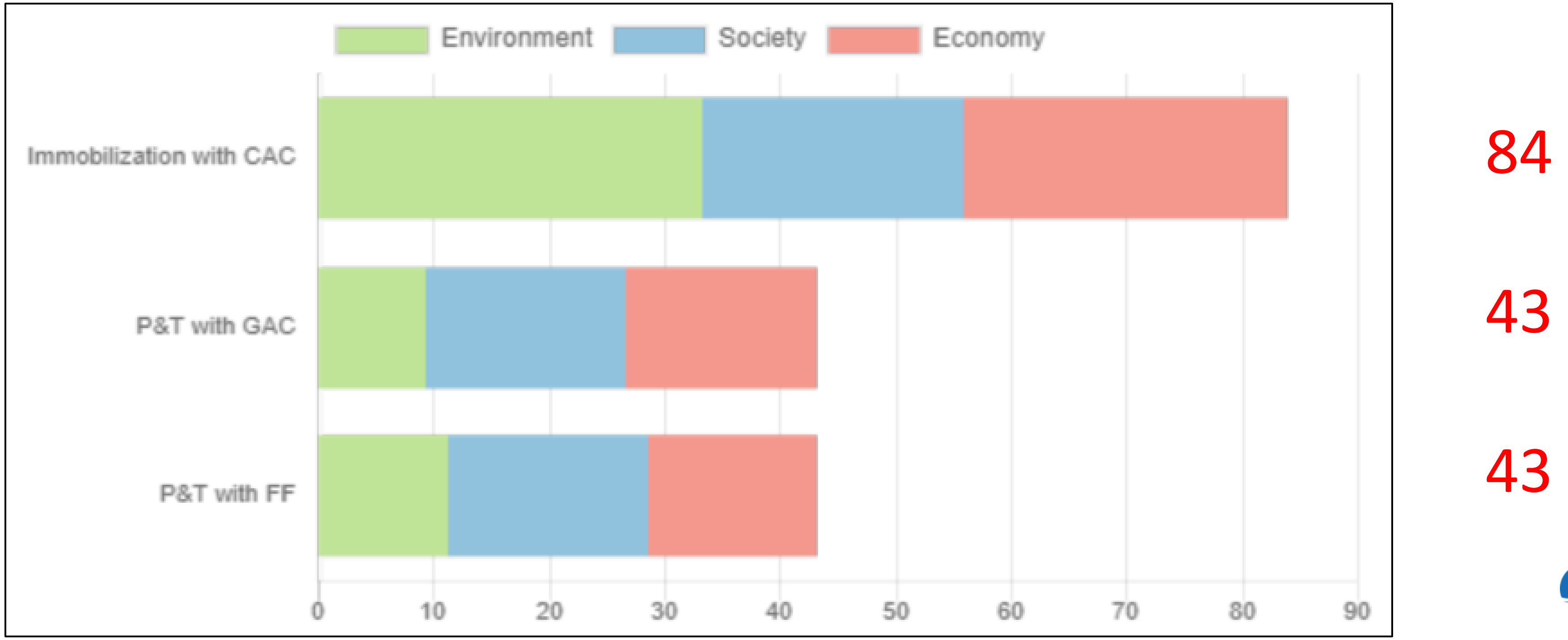
Reviewing other impact factors

- A ‘Tier 2’ sustainability assessment was completed by using SURE by Ramboll (SURE).
- SURE is based on standards from ISO and ASTM, and aligned with the Sustainable Remediation Forum (UK) guidance.
- Linear-additive multi-criteria analysis (MCA) method and is designed to incorporate both qualitative and quantitative information.
- 15 sustainability indicators encompassing each sustainability domain weighted and scored
- Comparison remedial options



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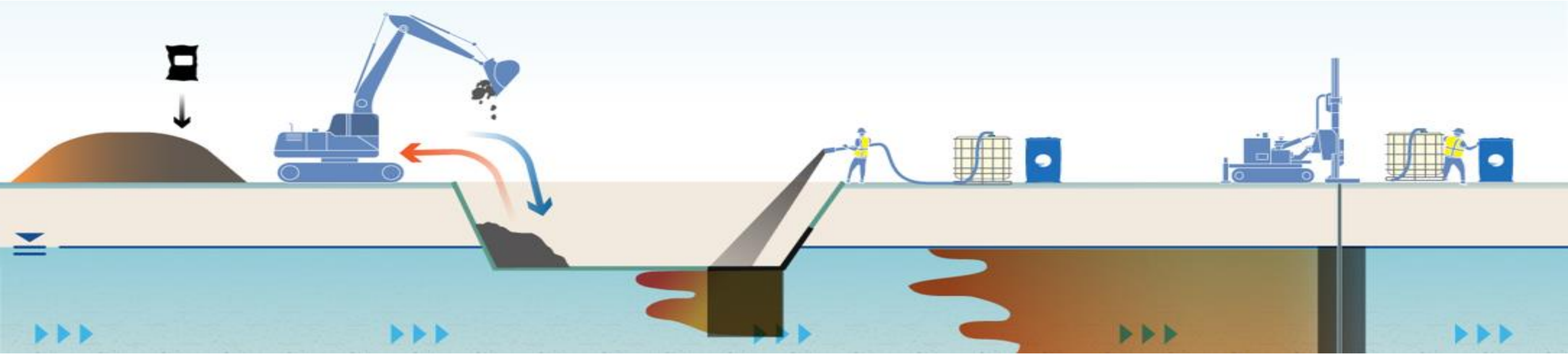
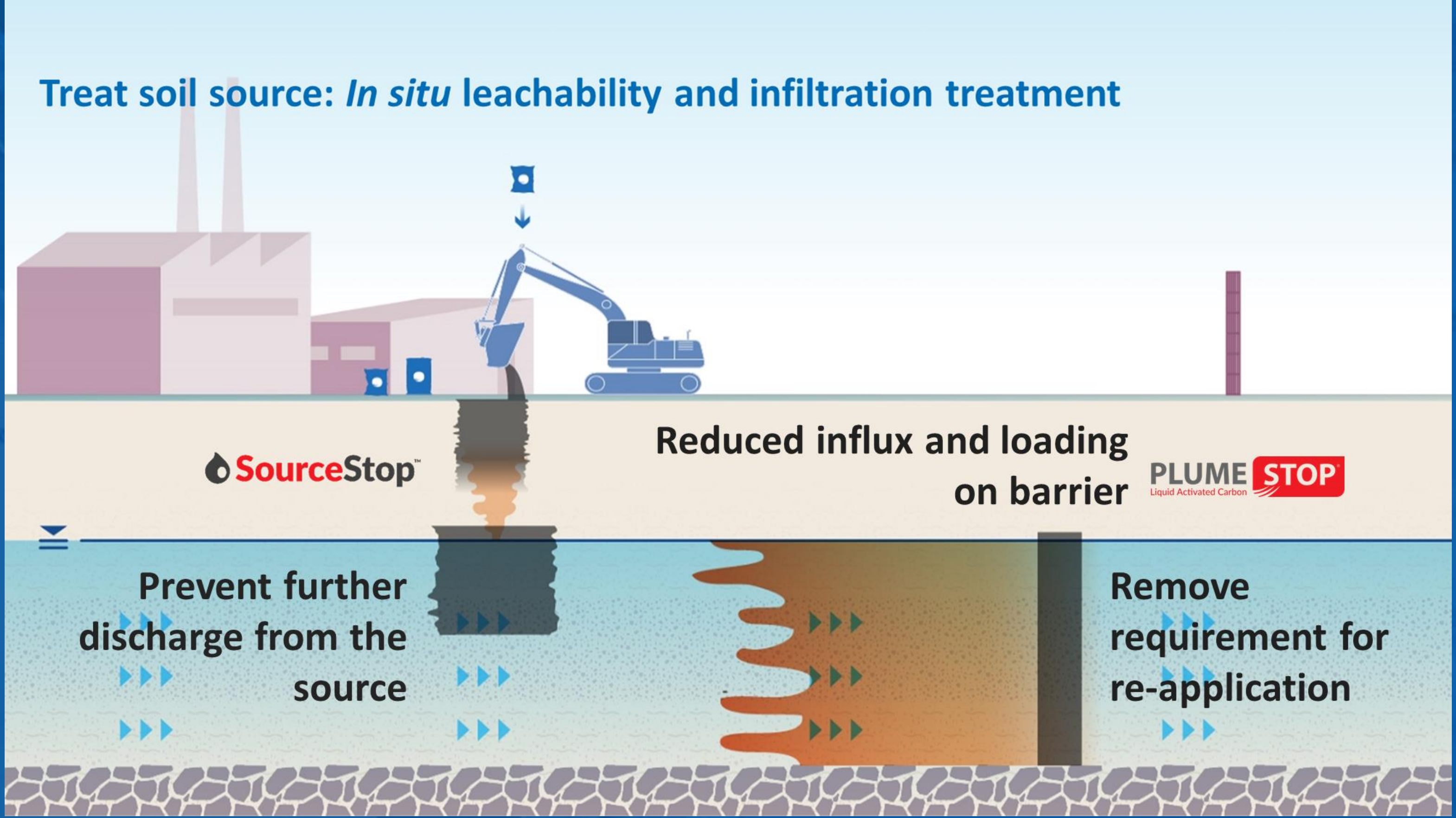
Conclusion

- Remediation of a PFAS site should consider sustainability
  - A way of ensuring the site is not managed in isolation
- Pump & Treatment has a carbon footprint for both components
  - Pumping alone has a MUCH higher impact than in situ treatment
  - ANY ex-situ Treatment will add to that impact
- Enhanced attenuation of PFAS through retention by CAC injection
  - Effective and Sustainable approach to address a <u>global pollution issue</u>





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