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Sustainable PFAS Remediation: Comparing the Environmental Impact of Enhanced Attenuation using Colloidal Activated Carbon to Pump and Treat

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Department, Ramboll

Talk outline

- I am going to assume everyone knows what PFAS is ☺
- Overview of how we CAN treat PFAS

- Back Diffusion?
- Back Diffusion…
- Back Diffusion!

- How should we treat PFAS?
- Introduction to enhanced attenuation of PFAS
- Efficacy – Norwegian case study!
- Sustainability Study – UK Site
- Conclusion

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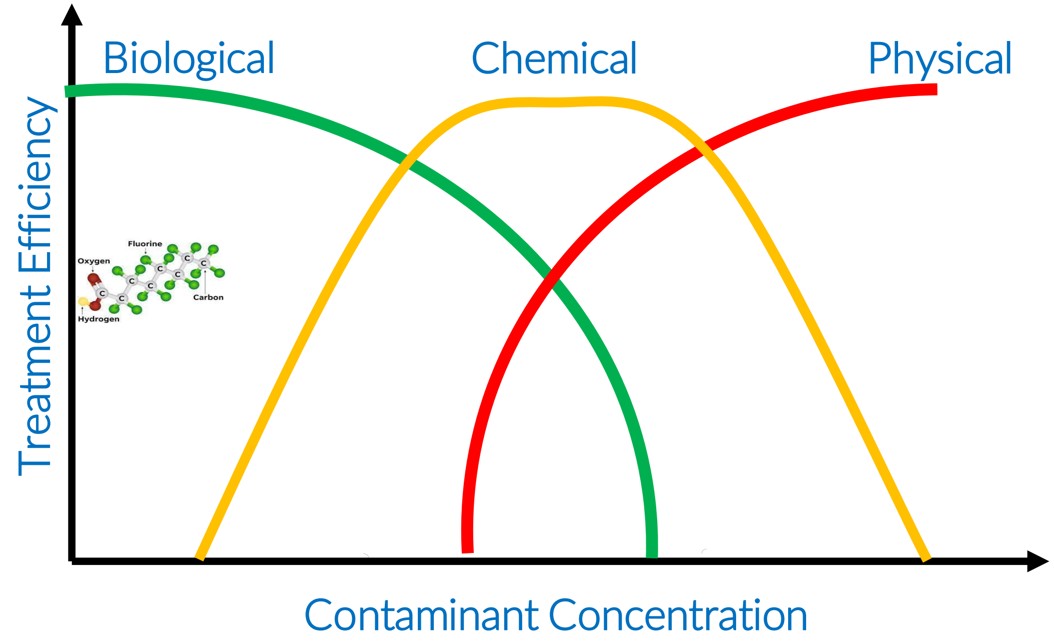
How can we treat PFAS?

Removal and destruction, right?



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

Carbon footprint

Back Diffusion?

Advection:

Movement of groundwater containing chemicals

Diffusion:

Movement of chemicals contained in groundwater

Colorado State University

Civil and Environmental Engineering

Center for Contaminant Hydrology

CCH

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Back Diffusion…

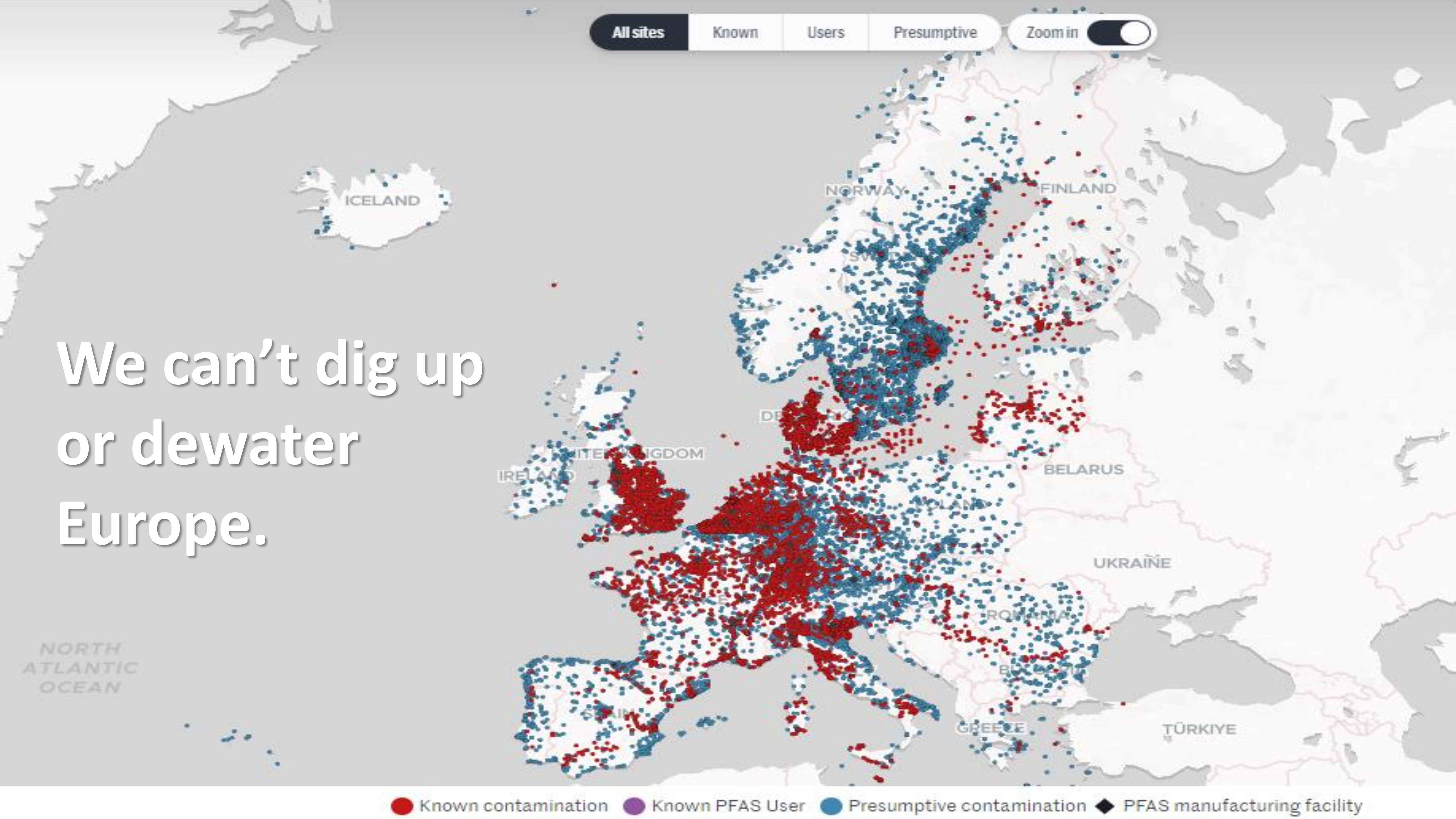
Back Diffusion!

Limitations on PAT systems due to diffusional transport were first noted roughly three decades ago (Keely 1989; Mackay and Cherry 1989; Mercer et al. 1990), and publications on the topic have continued (Mackay et al. 2000; LaBolle and Fogg 2001; Ishimori et al. 2006; McDade et al. 2013; Seyedabbasi et al. 2013; Guo et al. 2019). Several publications have indicated that PAT in settings with back diffusion may require timeframes on the order of one or more centuries for restoration (LaBolle and Fogg 2001; Lemming et al. 2012; McDade et al. 2013; Guo et al. 2019). For example, LaBolle and Fogg (2001) simulated PAT remediation using the alluvial aquifer characteristics found at the Lawrence Livermore National Laboratory Superfund Site in Livermore, California. The model used four hydrofacies to represent the subsurface geology, and κ = 5 using the highest and lowest *K* estimates. Results of their simulations indicated that mass removal due to PAT from the leading edge of the plume was more rapid than mass removal from the trailing edge of the plume near the source area because the latter experienced a longer duration of forward diffusion than the former. For a non-degrading contaminant, their results suggested that the residence time in the LPZ for the system modelled would be on the order of centuries to millennia and that mass recovery from the LPZ due to PAT would be insignificant on the time scale of decades.

mg/L ⟶ ug/L ⟶ ng/L

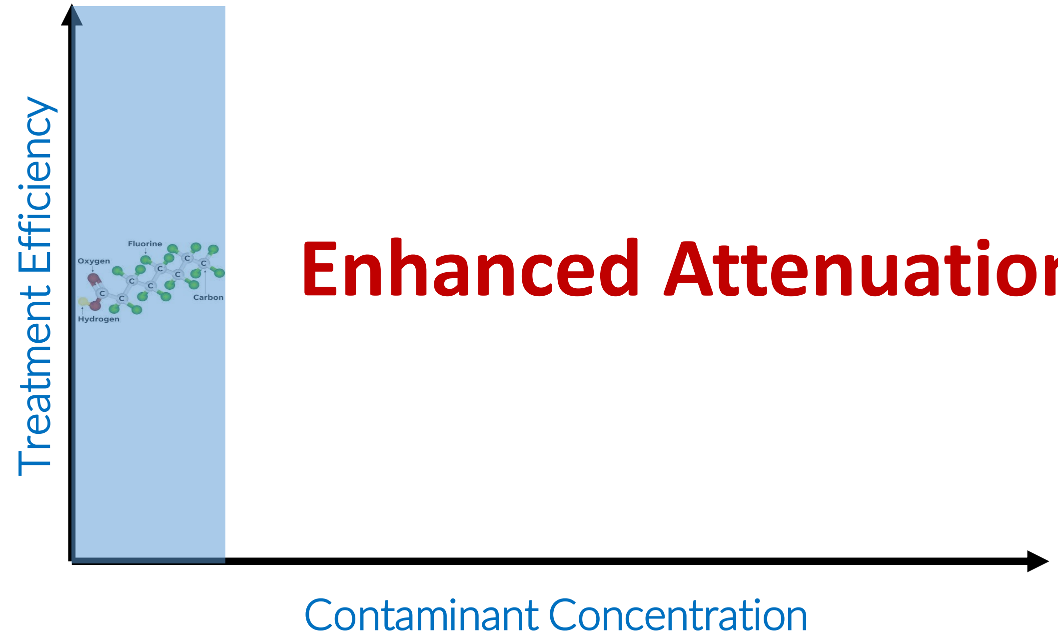
Brooks MC, Yarney E, Huang J. Strategies for Managing Risk due to Back Diffusion. Ground Water Monit Remediat. 2020;41(1):76-98. doi: 10.1111/gwmr.12423. PMID: 34121833; PMCID: PMC8193763.

We can’t dig up or dewater Europe.



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

Adopt a sustainable remediation approach



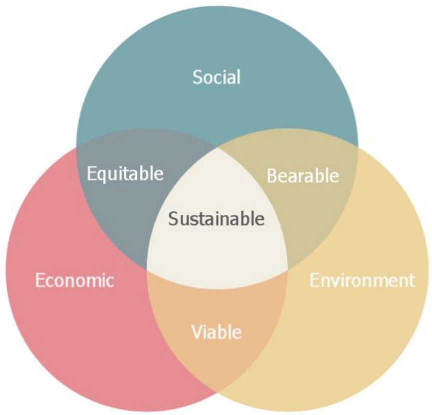
(ISO 18504:2017) definition:

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

Carbon footprint

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Enhanced Attenuation of PFAS?!

But PFAS don't biodegrade?

Natural Attenuation ***doesn't*** just mean biological degradation:

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

Increase the ability of the aquifer to sorb PFAS
'Retention'
=**Enhanced Attenuation** of the PFAS plume


DOI: 10.1002/rem.21731

RESEARCH NOTE

WILEY

Enhanced attenuation (EA) to manage PFAS plumes in groundwater

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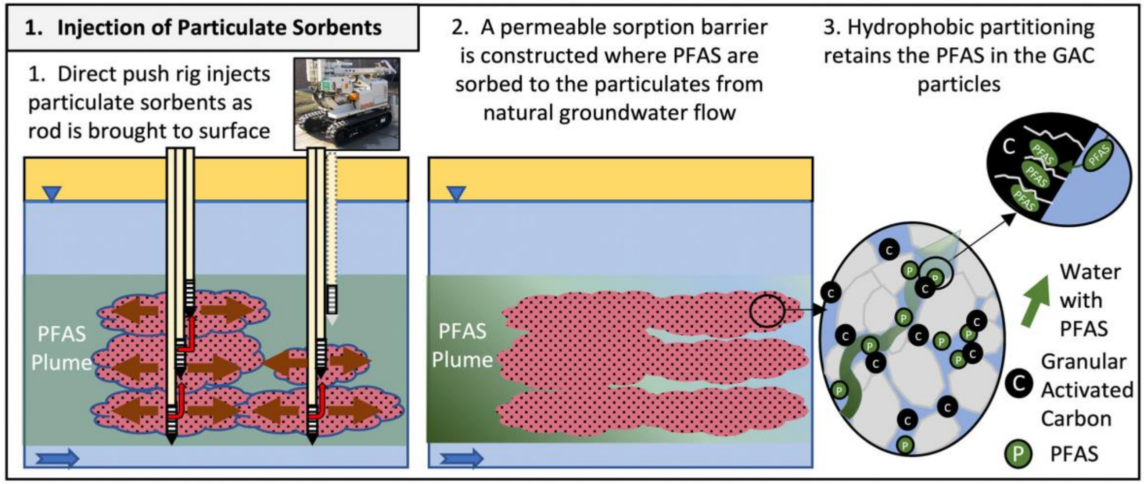
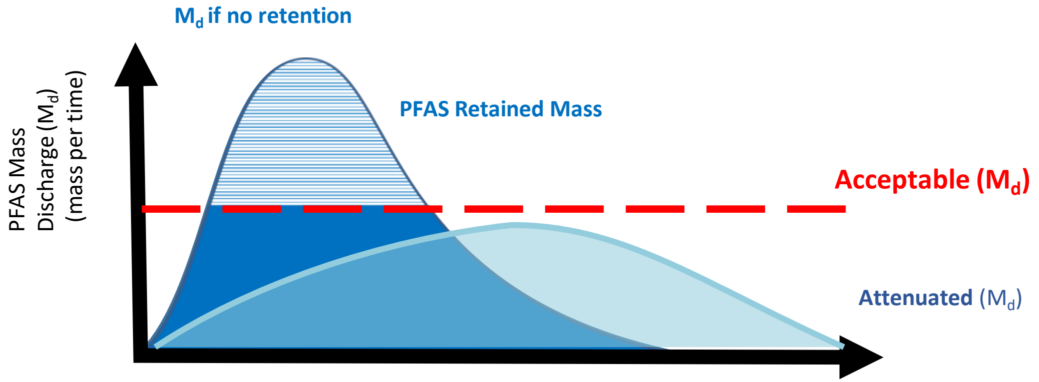
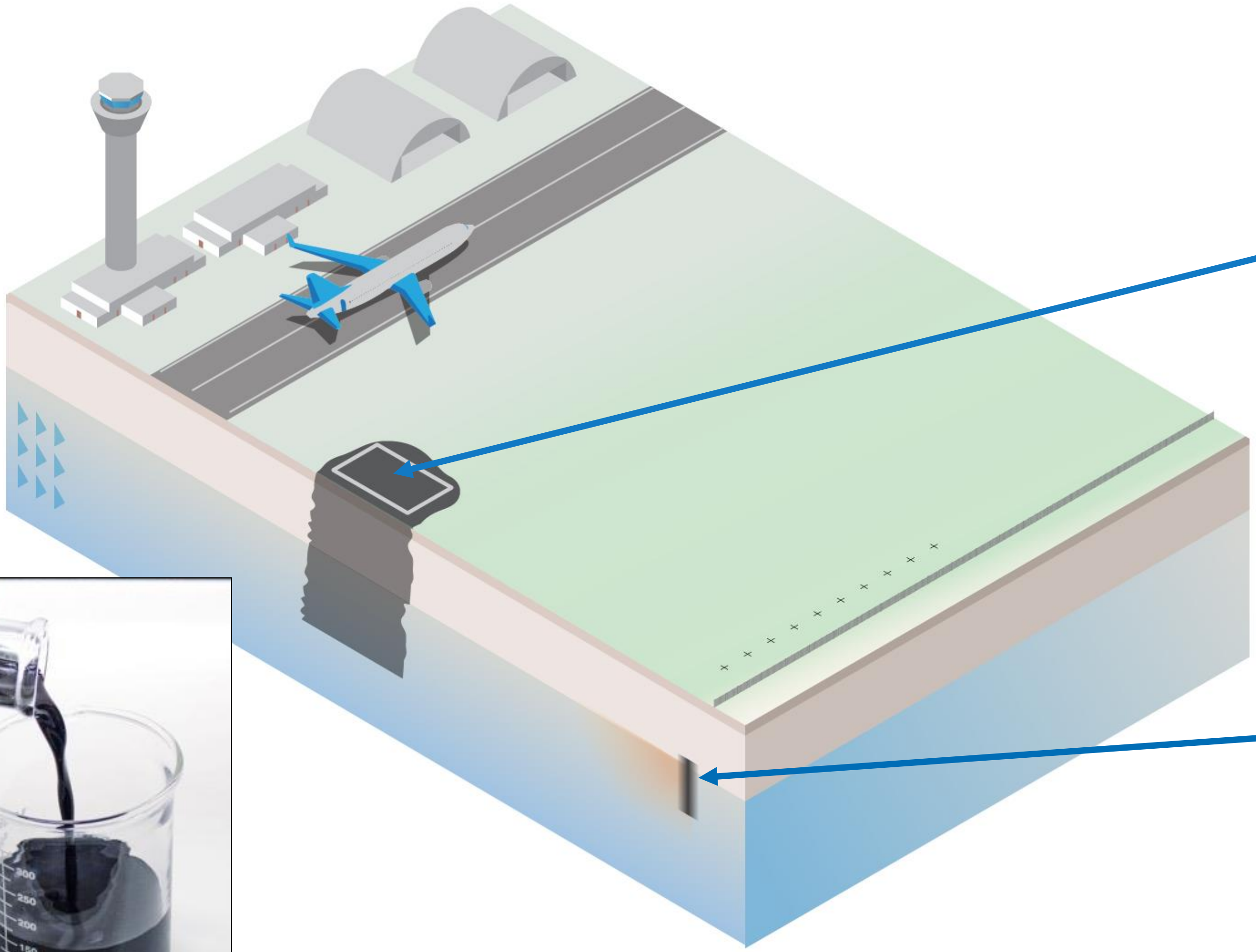
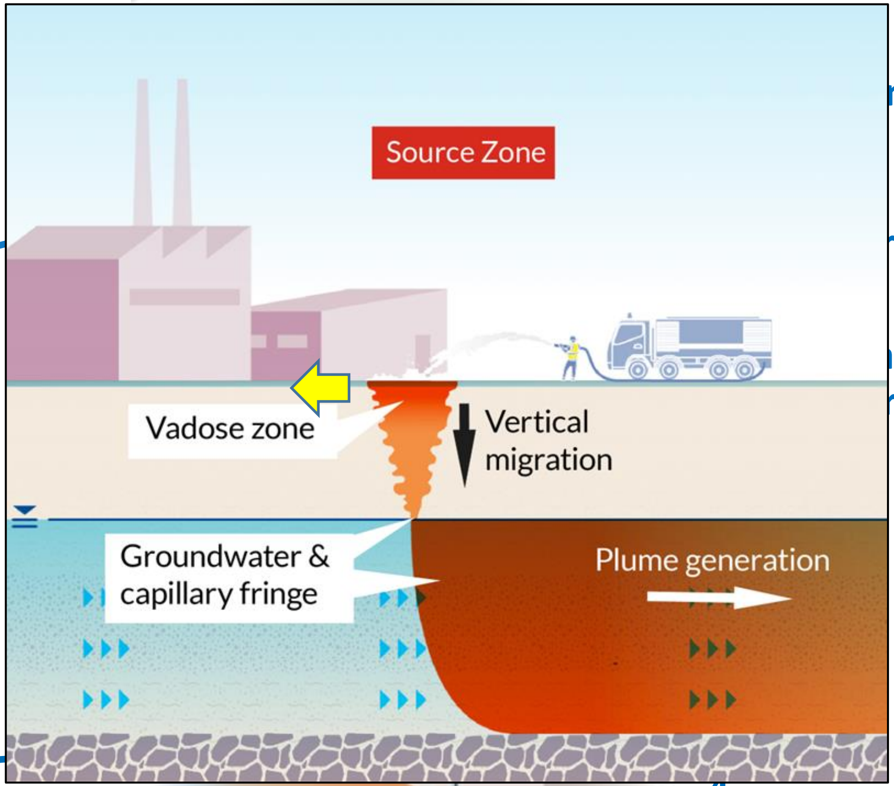




Considering the PFAS Source-Plume system





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4. Groundwater - Plume

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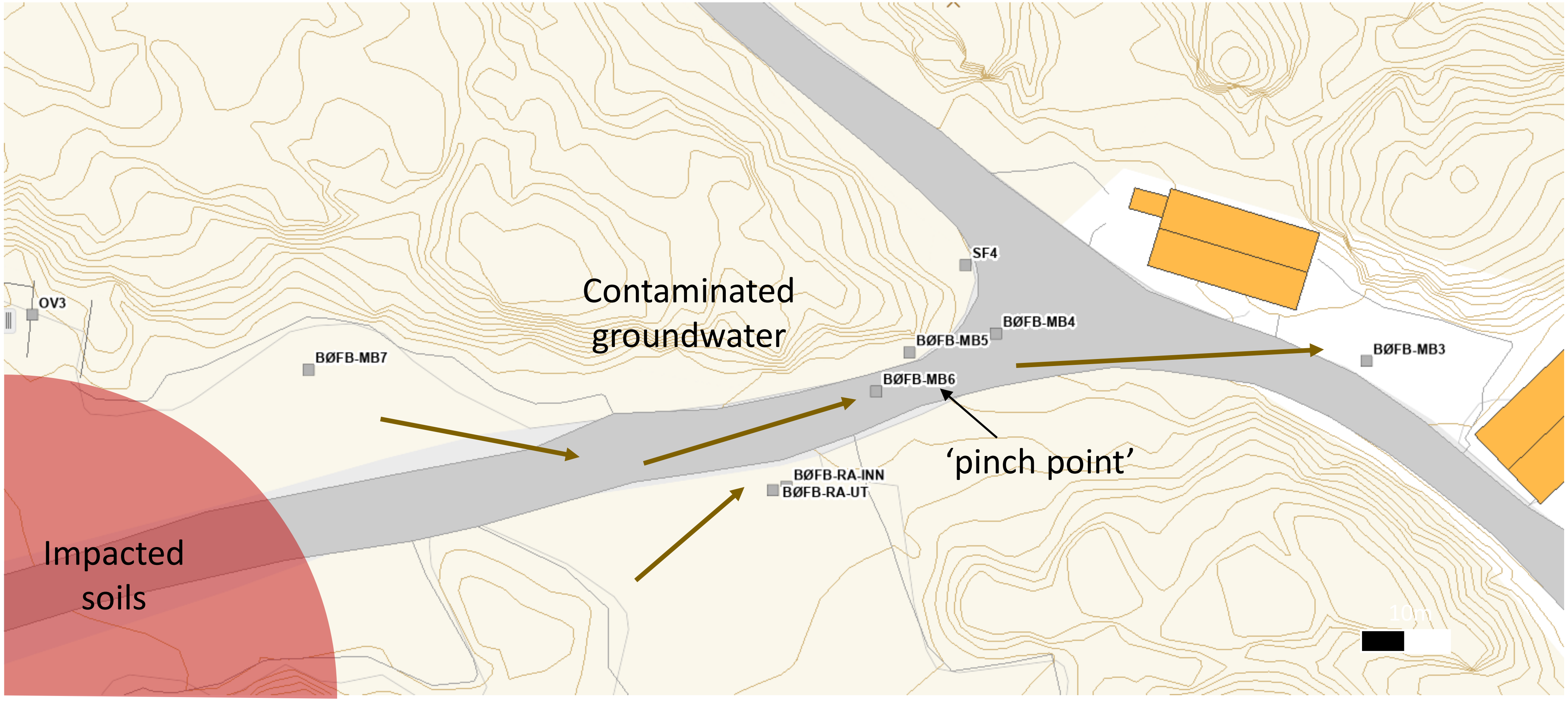
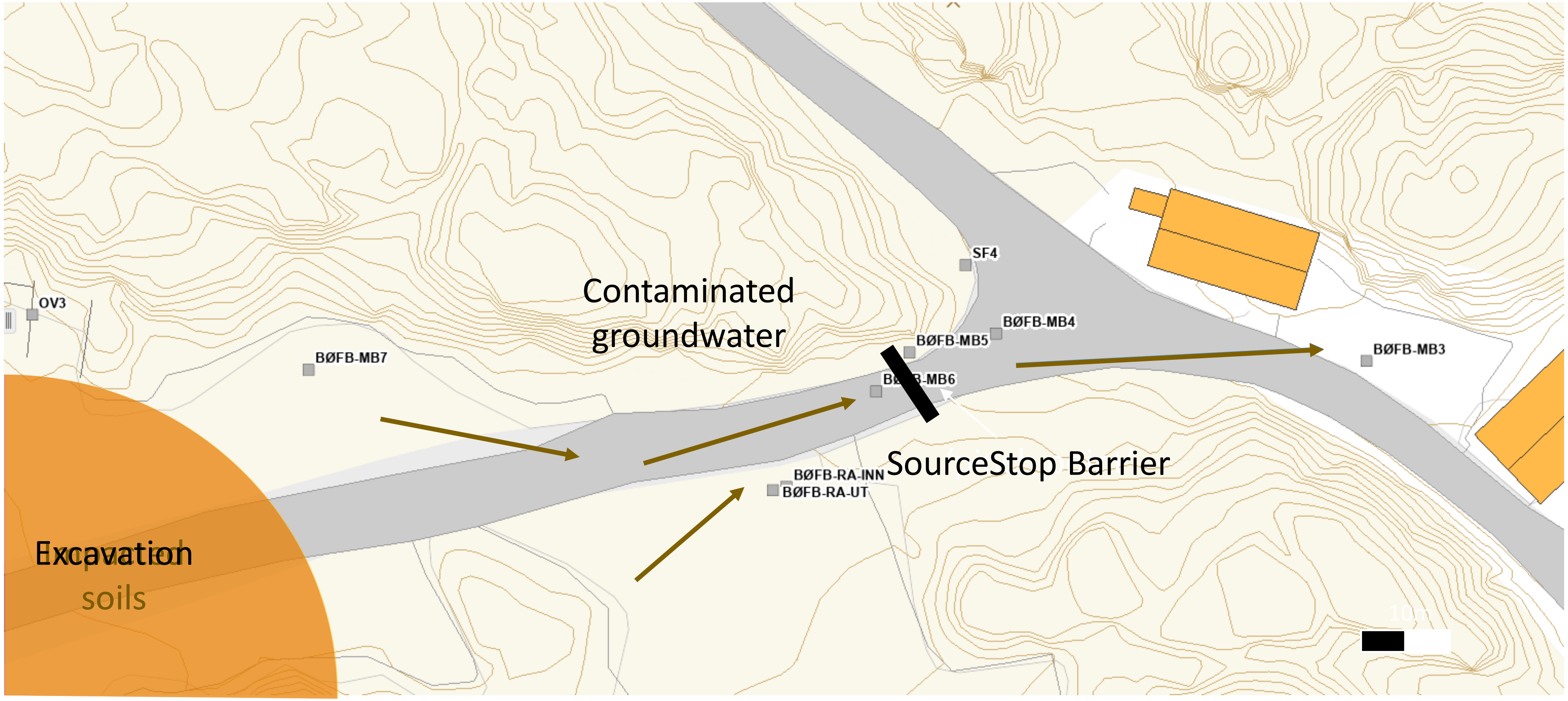
Case Study: Norway



Remedial Design



Application

AVINOR

COWI

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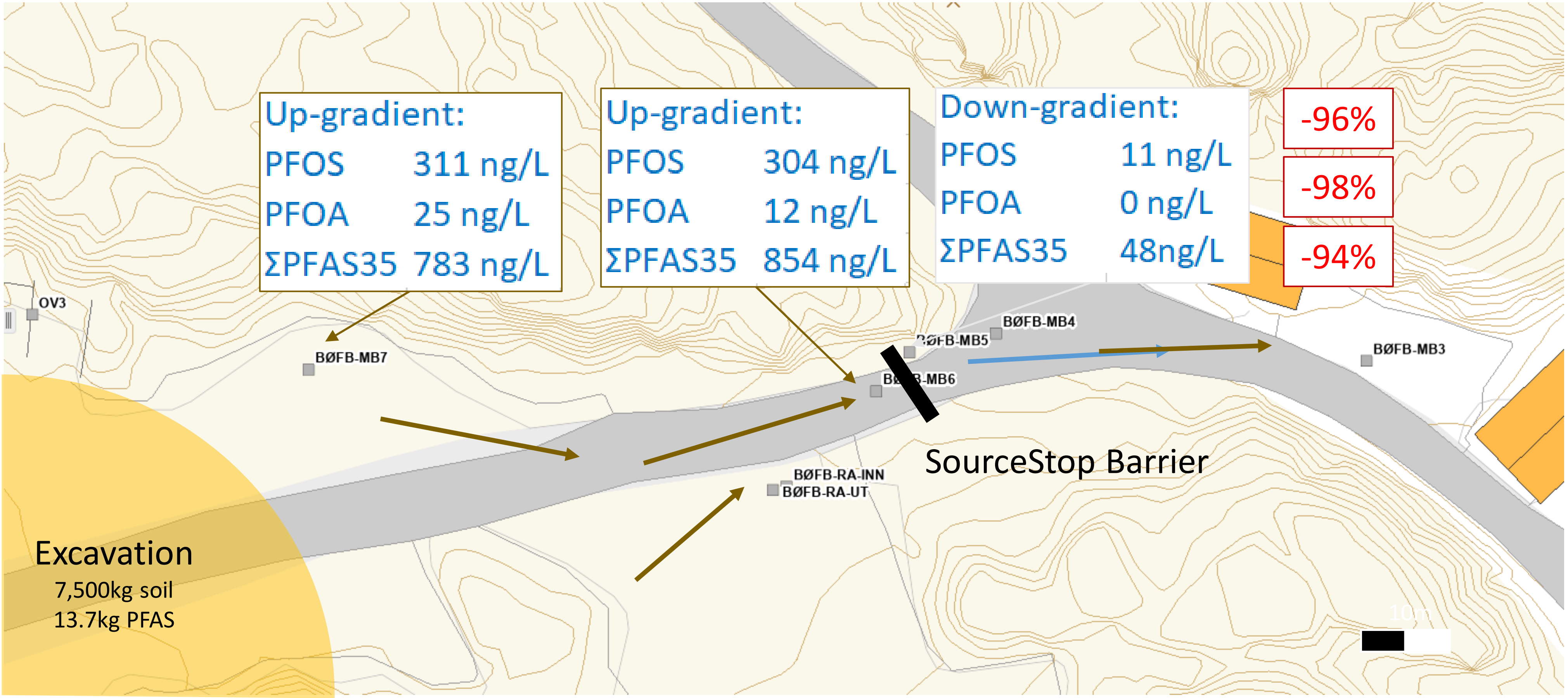
Results

Mean concentrations – monthly sampling over 9 months post application



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Bright ideas.
Sustainable change.

Sustainability assessment of in situ and ex situ remediation of PFAS contaminated groundwater.

15.5.2023

The theory:

- **Low disruption**
- **Injection completed in weeks**
- **Low energy**
- **No equipment onsite**
- **Low maintenance**
- **Only validation sampling needed**
- **Fraction of site visits needed**
- **No waste produced**

We need a third-party study!

Date of Completion	Groundwater Darcy Velocity [cm/day]	Length of Barrier [m]	Depth of Barrier [m]	Days Since Addition	Volume of Water Remediated Since Application [Liters]	Remediation Forecasts [L/day]
12/2/2023	16.4	86	5	407	29,515,520	70,250

Overview of Study

PFAS Contaminated Airport, UK

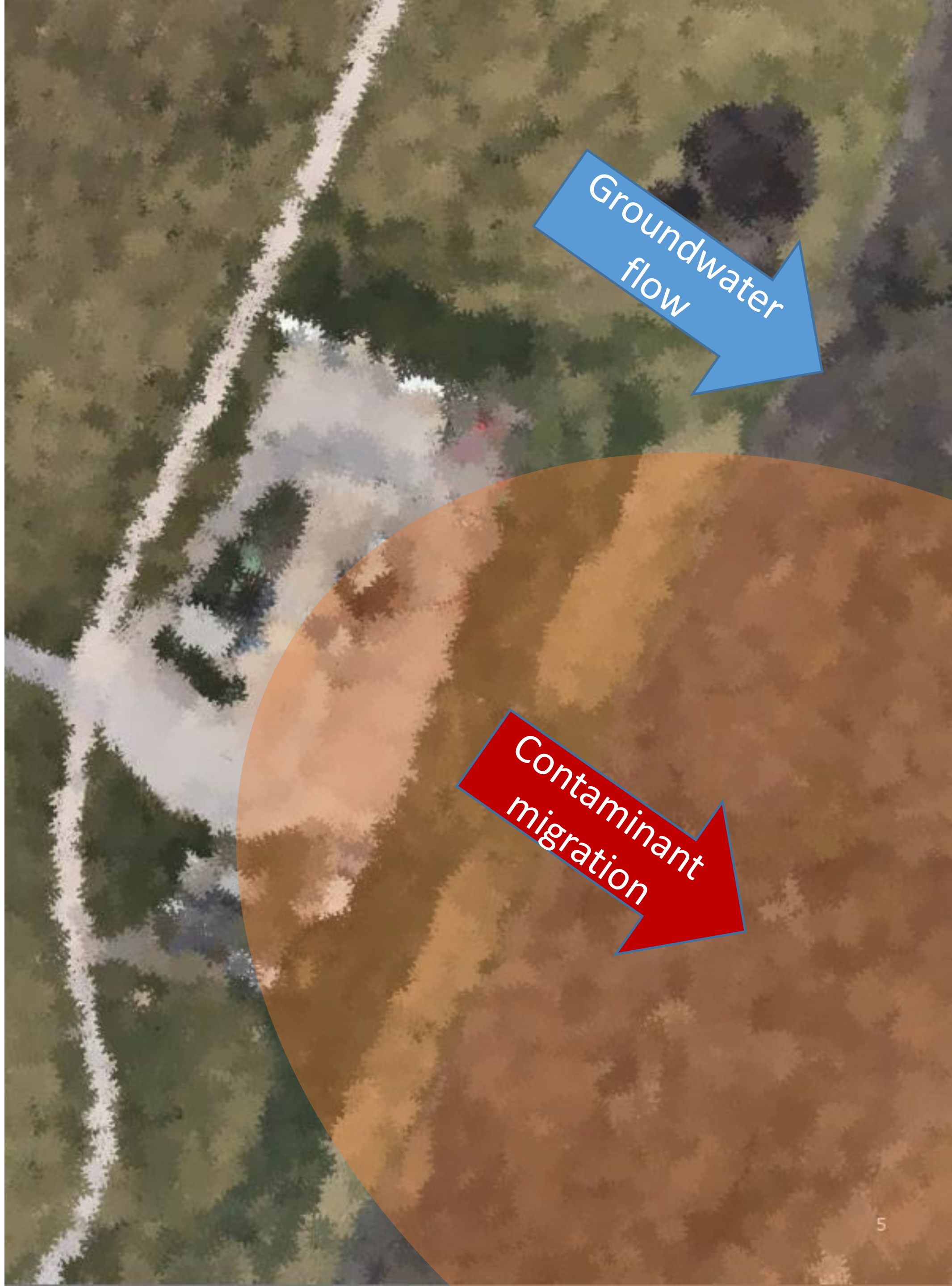
- Immediately prevent/reduce offsite PFAS migration
- Source treatment to follow

Compare the Life Cycle Analysis for two remedial approaches:

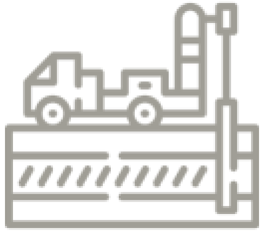
- **In Situ Sorption and Retention Barrier**
  - Passive barrier of colloidal activated carbon (PlumeStop)
  - Recently implemented at the site
- **Ex Situ Pump and Treat**
  - Utilized granular activated carbon (GAC)
  - Theoretical, best-practice design

Ramboll

- Head of Circular Solutions and Climate Specialist team, Finland

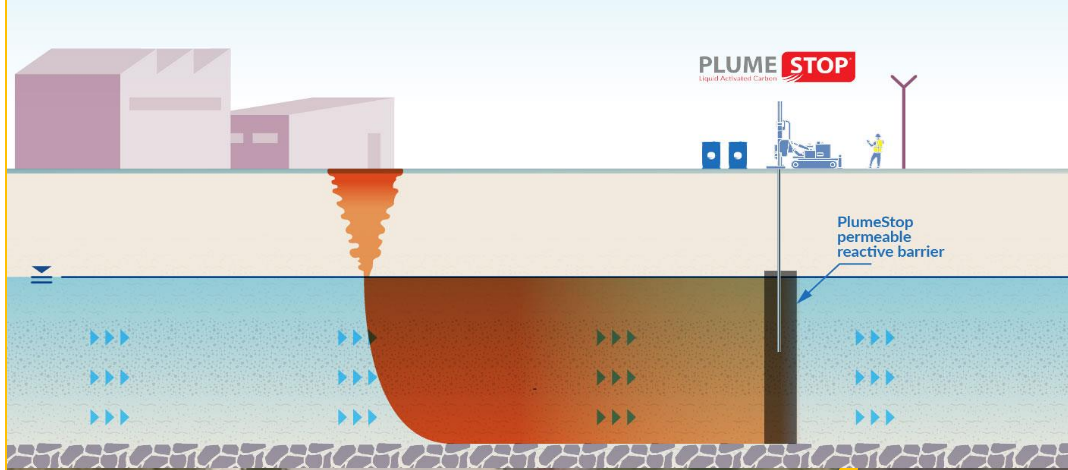


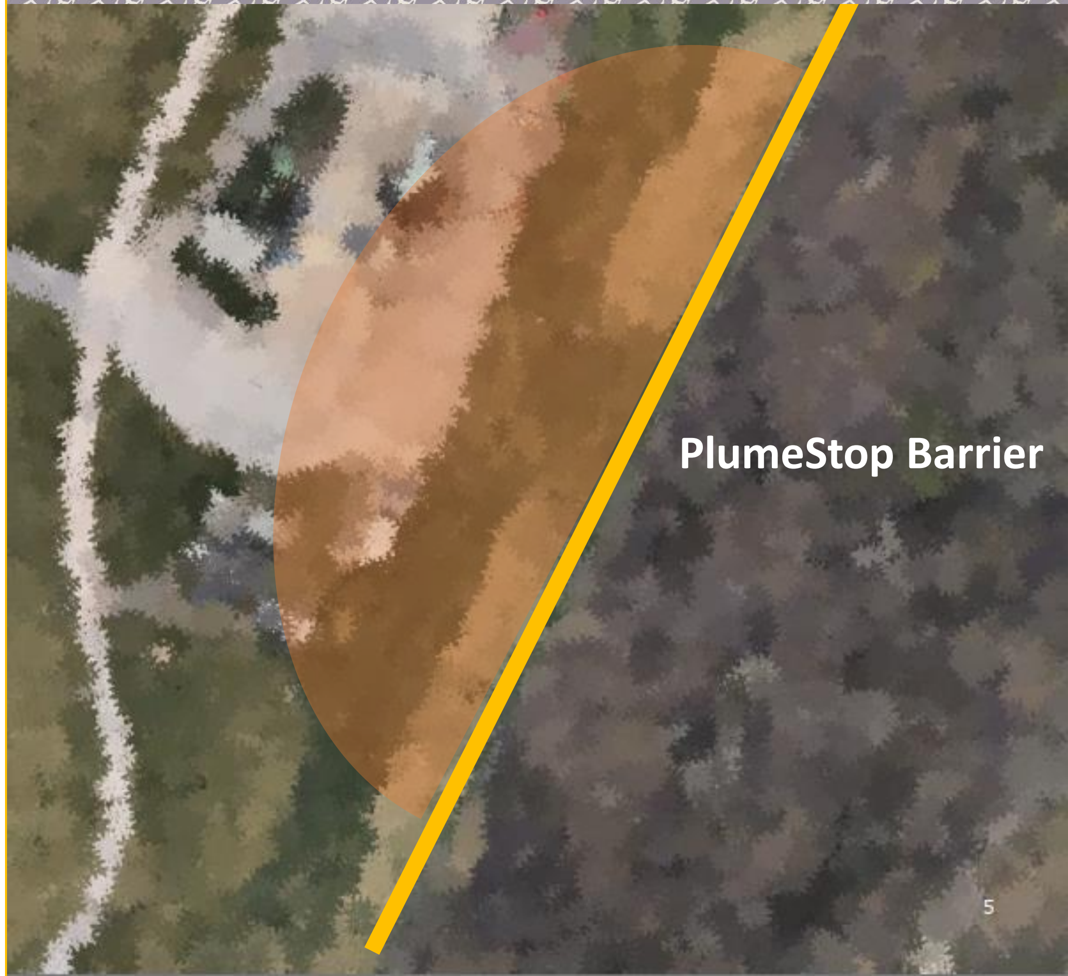
Life Cycle Inventory Analysis



Immobilization with PlumeStop ®

- Single injection round
- Designed for minimum 15 years of efficacy
- 102 injection points
- 86 m long
- 33,565 Kg PlumeStop
- 1,589 L fuel used for injection
- 3 monitoring wells, 11m deep
- 2 times/yr, environmental monitoring





Scope of Assessment: Cradle to Grave

System boundary

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

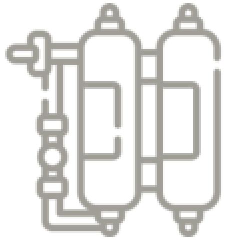
In situ: PlumeStop

PlumeStop product			US to UK	Injection		Monitoring	

Methods/Software

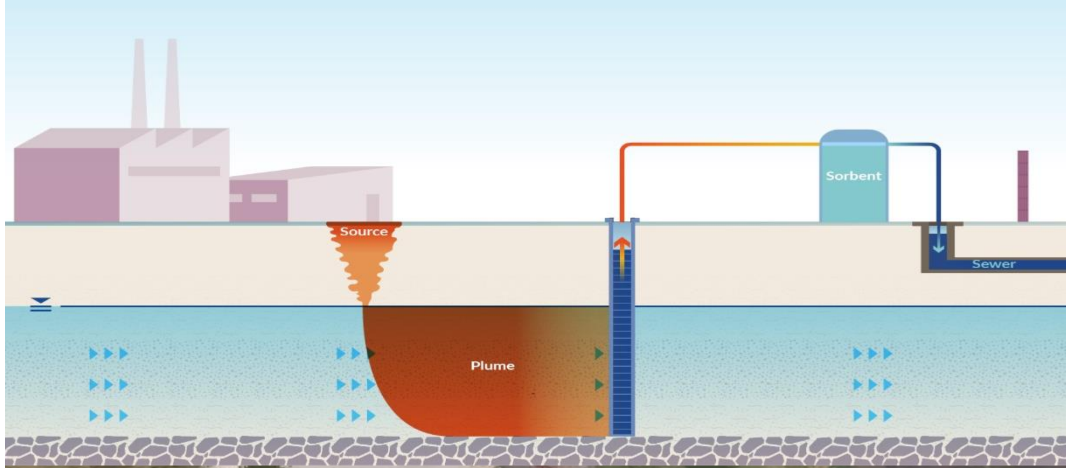
- ISO 14040:2006, ISO 14044:2006, ISO 14067:2018, PCR for Basic Chemicals
- GaBi 10 Professional, Sphera, Ecoinvent 3.8

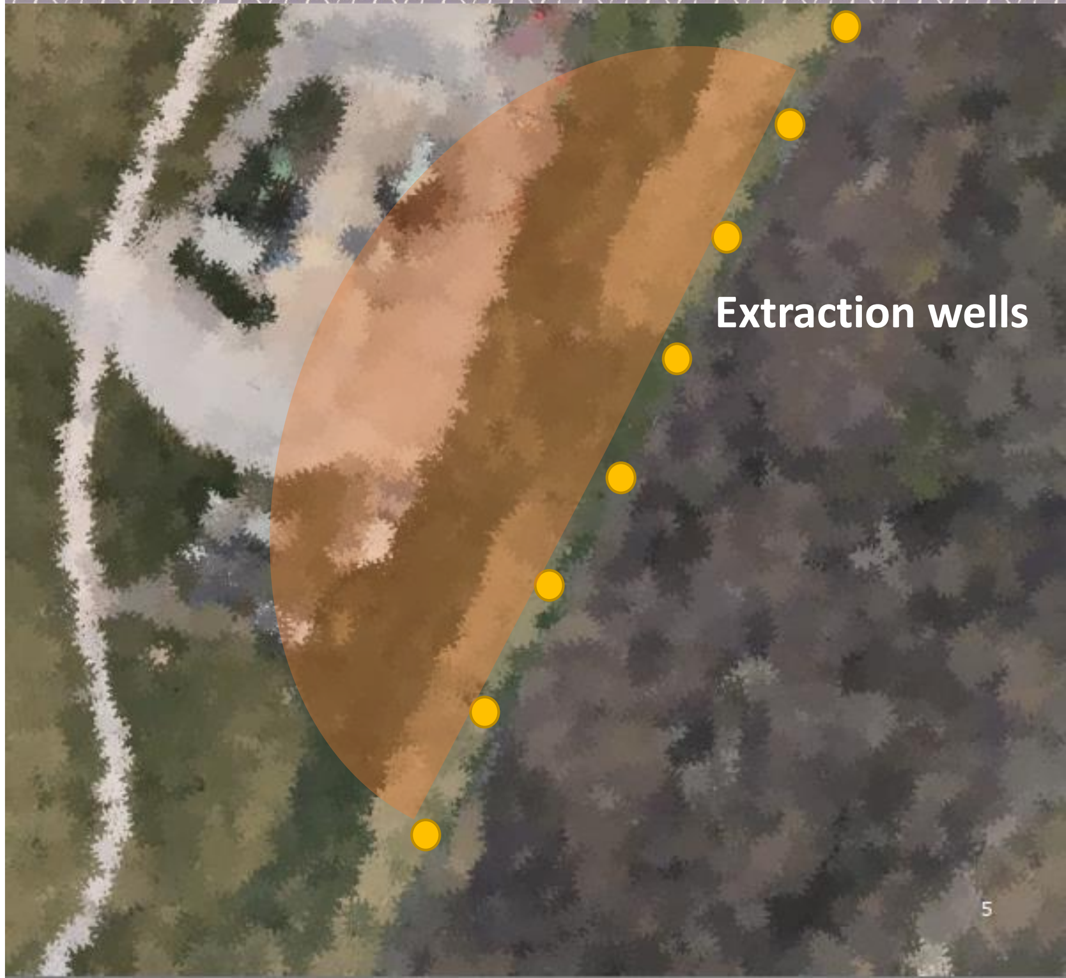
Life Cycle Inventory Analysis



Pump & Treat with GAC filtration

- Fixed equipment installation
- Continuous operation 15 years, 95% uptime
- 8 extraction wells, 8m deep
- 6m3/min pumping rate
- 24,000 kg GAC/yr usage rate
  - 100 mg/kg adsorption capacity
- 960 MWh/yr electricity consumption
- 4 times/yr O&M inspection from office
- 1,500L fuel used for installation
- 3 monitoring wells, 11 feet deep
- 2 times/yr, environmental monitoring





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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

On-site: Pump & Treat

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

Methods/Software

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

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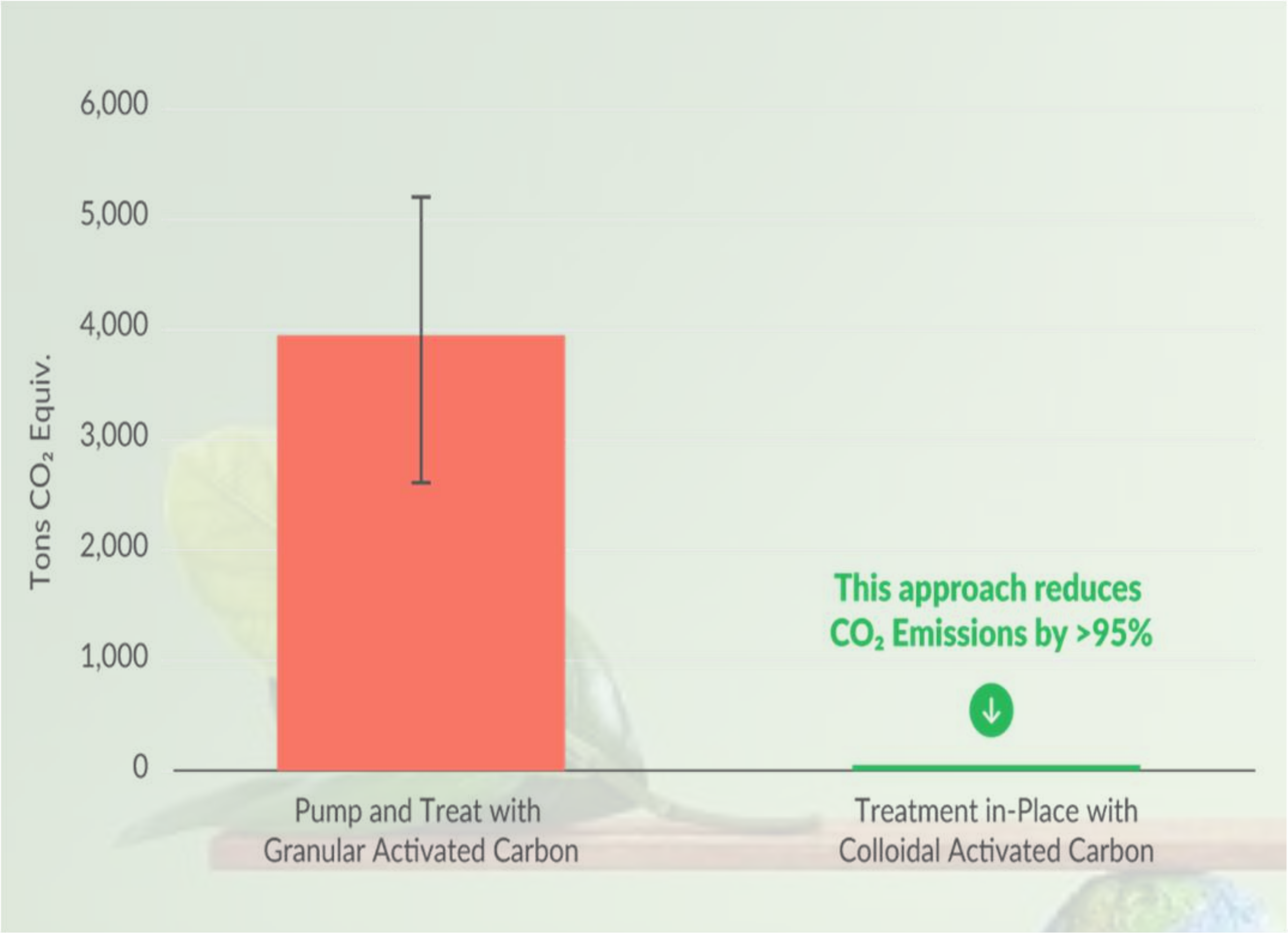
Carbon Footprint



	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**

Carbon Footprint

- GAC footprint most significant impact
- Assumes landfill
  - Incineration in future
  - Actually increase impact
- Are there options to reduce or remove GAC?

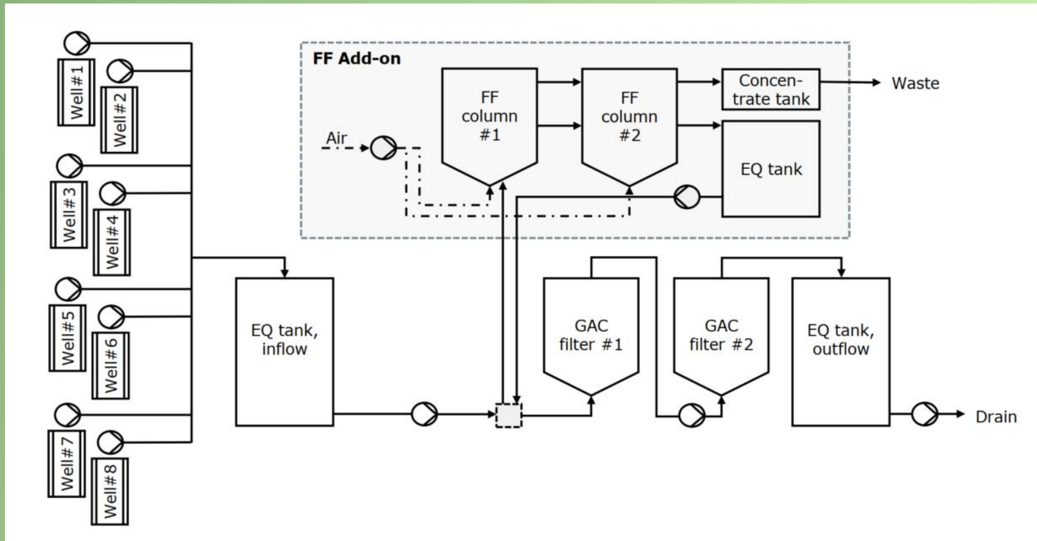
	PlumeStop	P&T w/ GAC
Remediation equipment		15,2
Civil works		
Fixed installations	0,05	0,9
Machinery	1,0	1,3
Remediation and operations		
PlumeStop / GAC	50,5	2 860
Electricity		281
Maintenance		3,6
Monitoring	4,0	4,0
Waste management		
Hazardous waste		112
Wastewater treatment		644
Total carbon footprint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

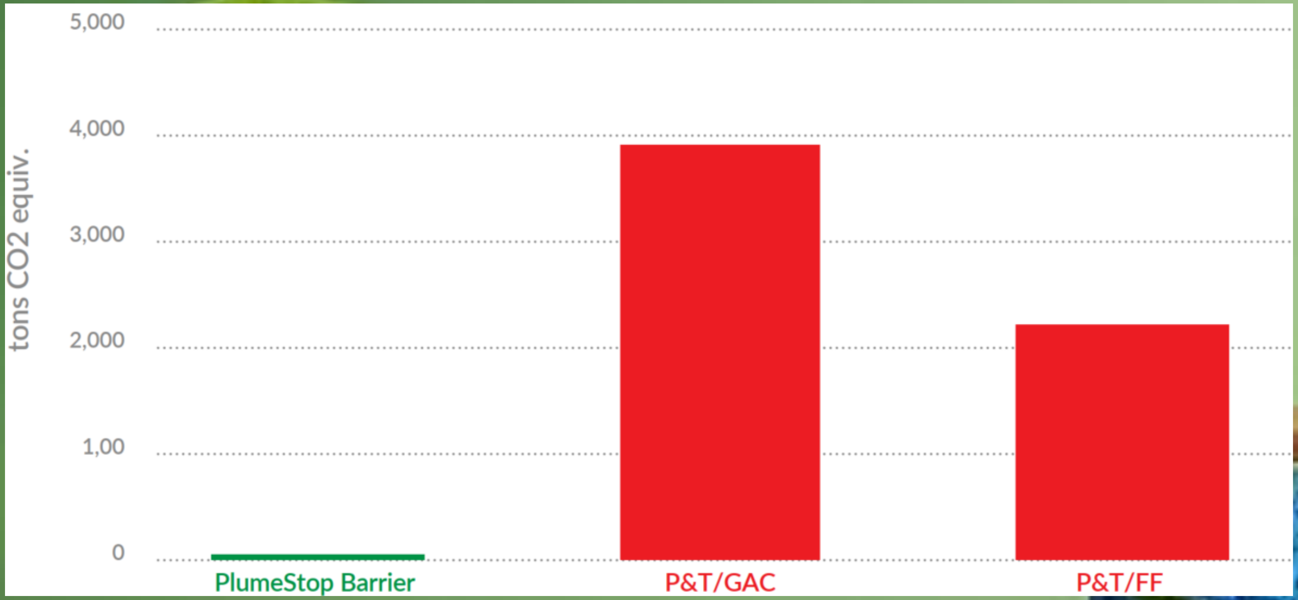
Carbon Footprint

We also modelled Foam Fractionation (FF):

- Bubble/skim off PFAS

- Swapping GAC for equipment/electricity



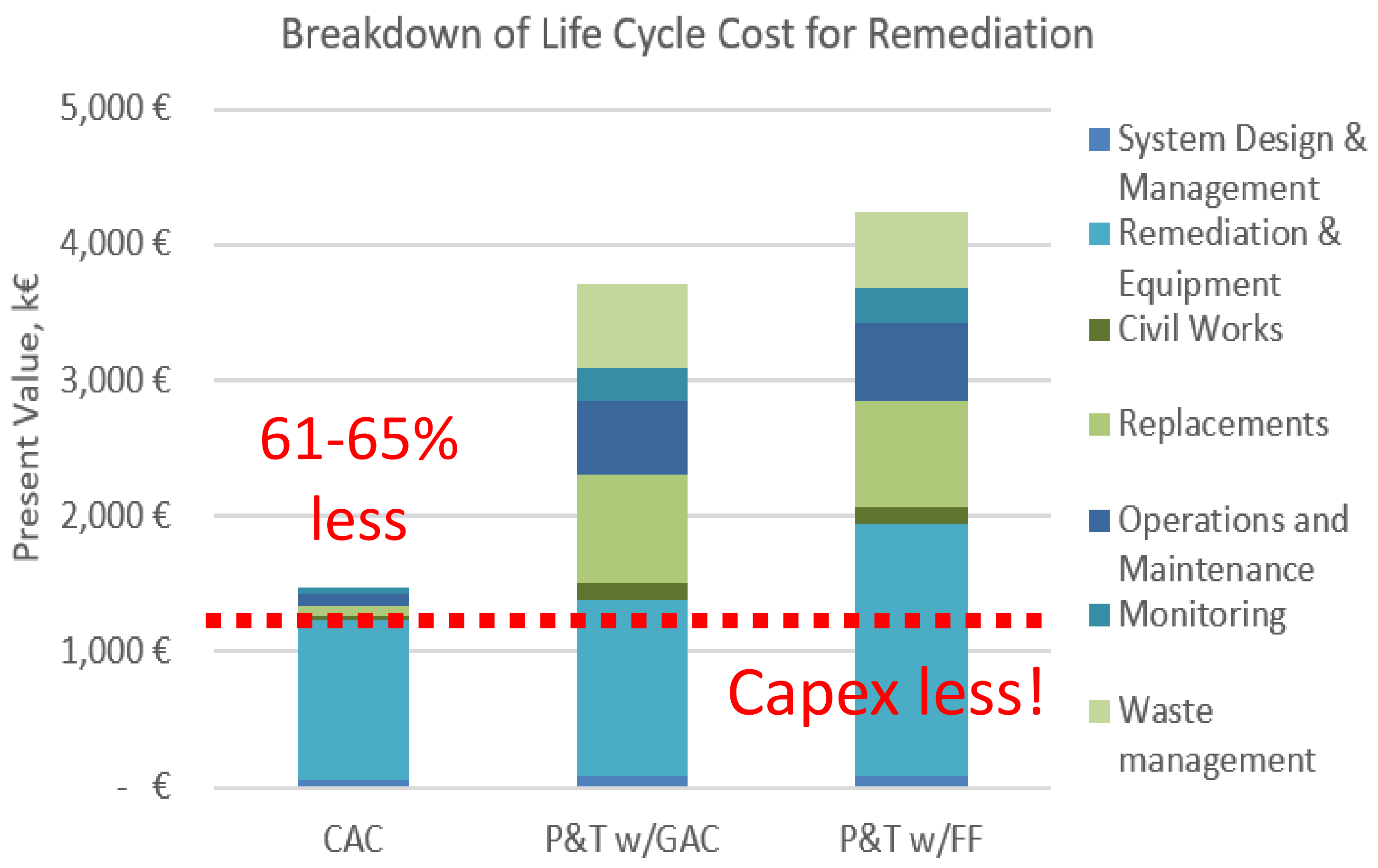


- In situ retention still 97.5% lower

- **Changing treatment ≠ significant reduction**
- **Pumping alone = 1-2 Orders Of Magnitude increase in Carbon Footprint compared to in situ retention**
- **ANY filtration or destructive treatment technique <u>only adds to this</u>**

Life Cycle Cost Analysis

- Pricing analysis by Ramboll
- For 15-year treatment
- Net Present Value:
  - PlumeStop barrier = $1.608M
  - P&T with GAC = $4.039M
  - P&T with FF = $4.623M
- CAC solution costs 61-65% less than P&T (GAC or FF)



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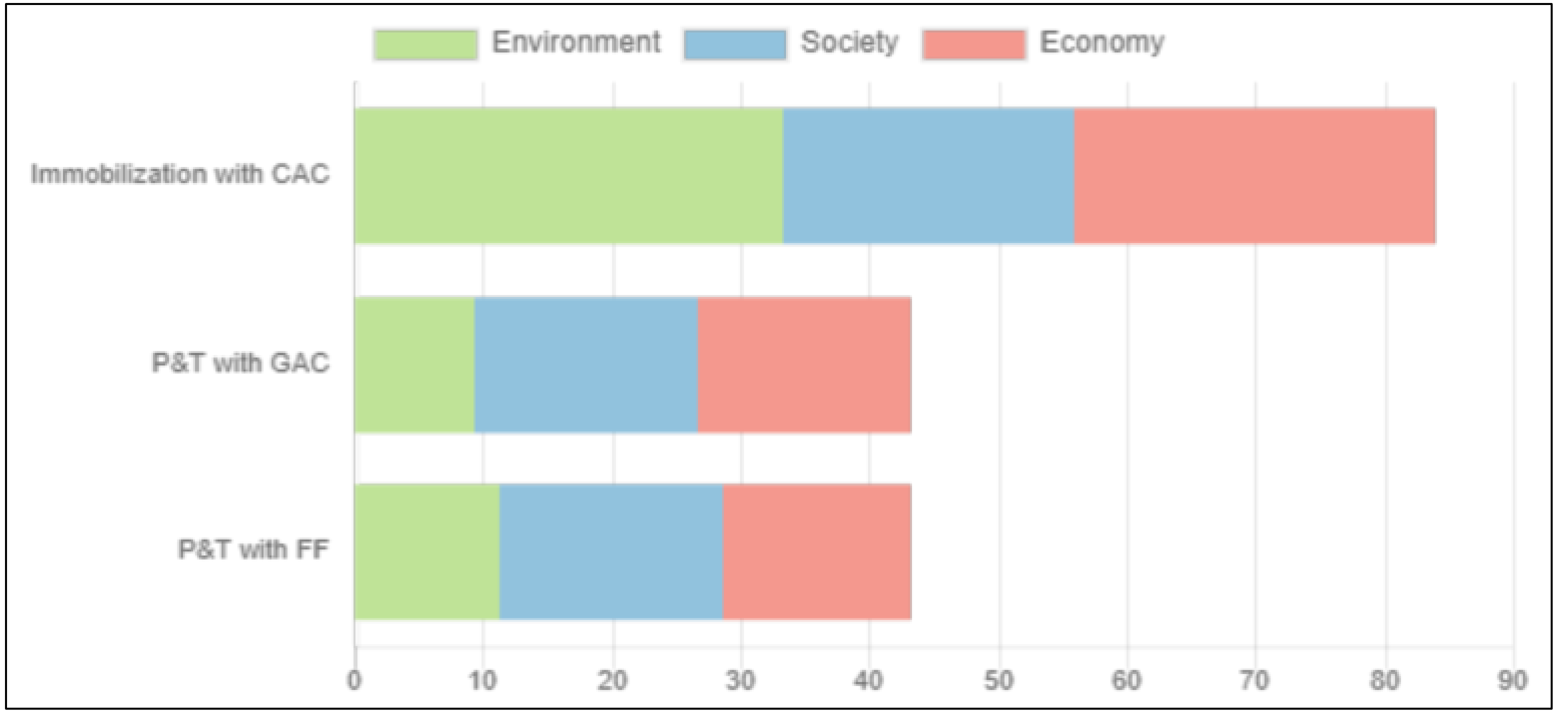
Reviewing other impact factors

- Completed by Ramboll using their SURE tool
- In line with:
  - ISO18507:2017 definition of sustainable remediation
  - SuRF-UK framework for assessing the sustainability of soil and groundwater remediation
- Brings together summary of other impact factors (qualitative and quantitative)
  - Creates a semi-quantitative score (out of 100)



84

43

43

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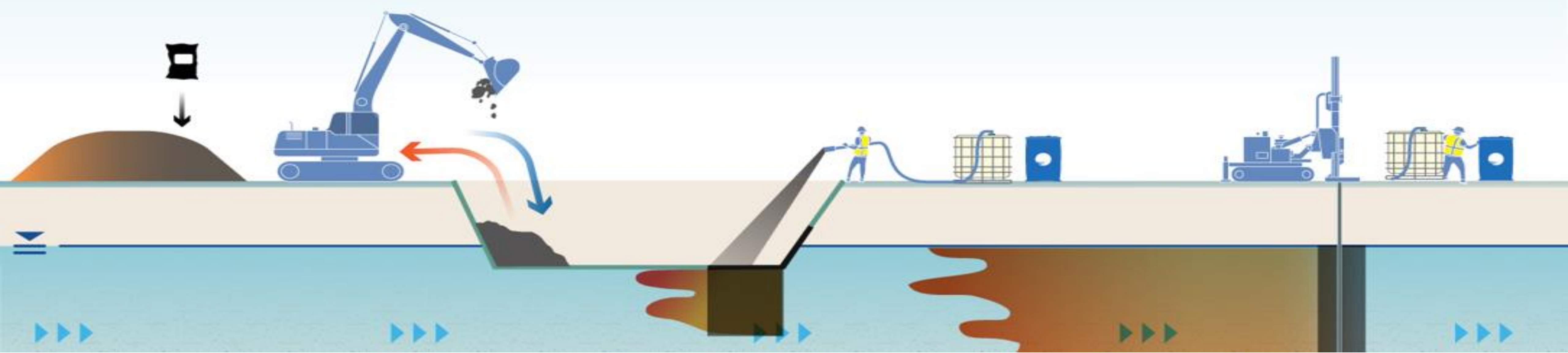
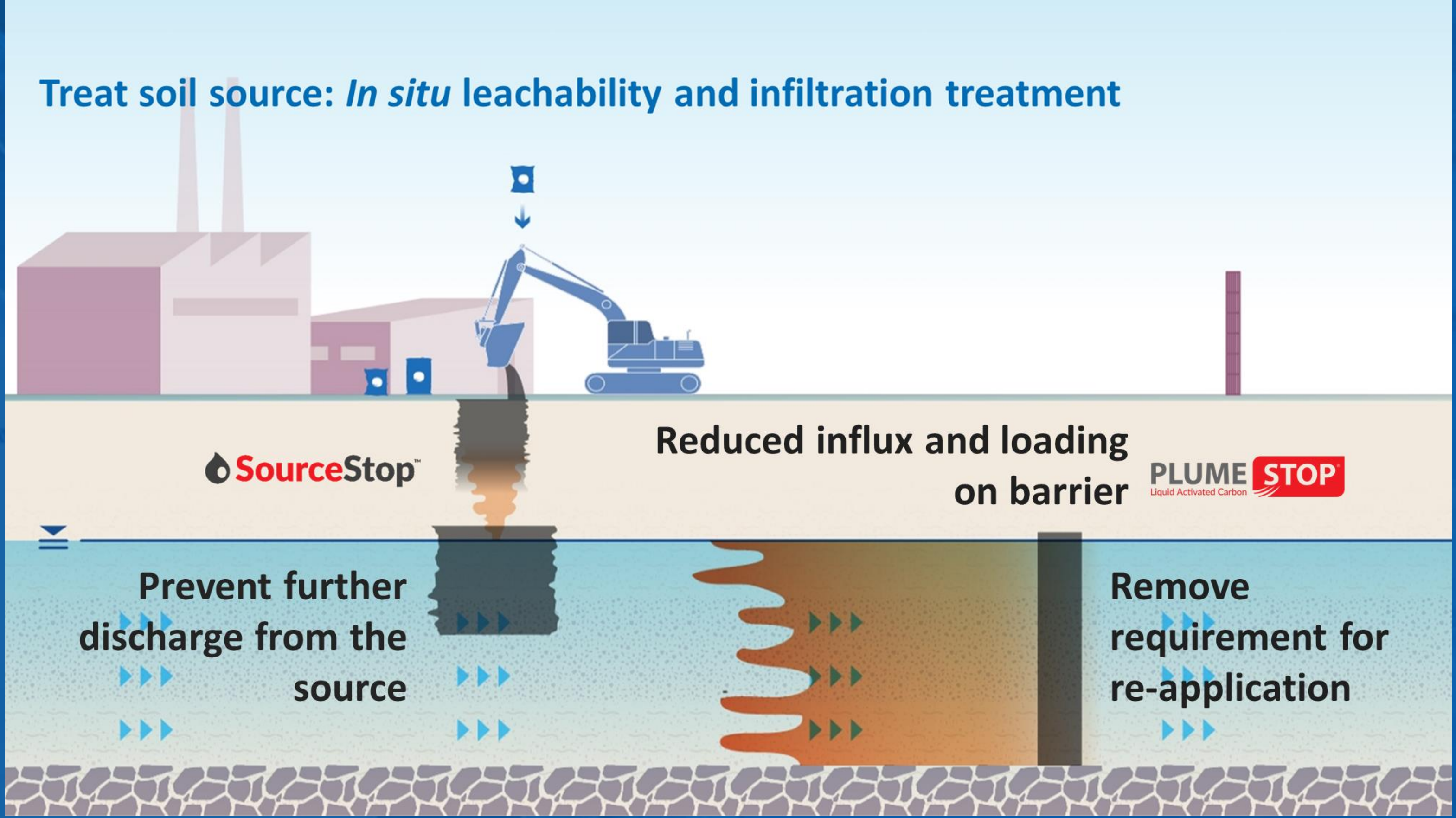
Conclusion

- 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 has a higher impact than in situ
  - ANY Treatment will add to that impact
- Enhanced attenuation of PFAS through retention by CAC injection
  - Effective and Sustainable approach to address a global pollution issue





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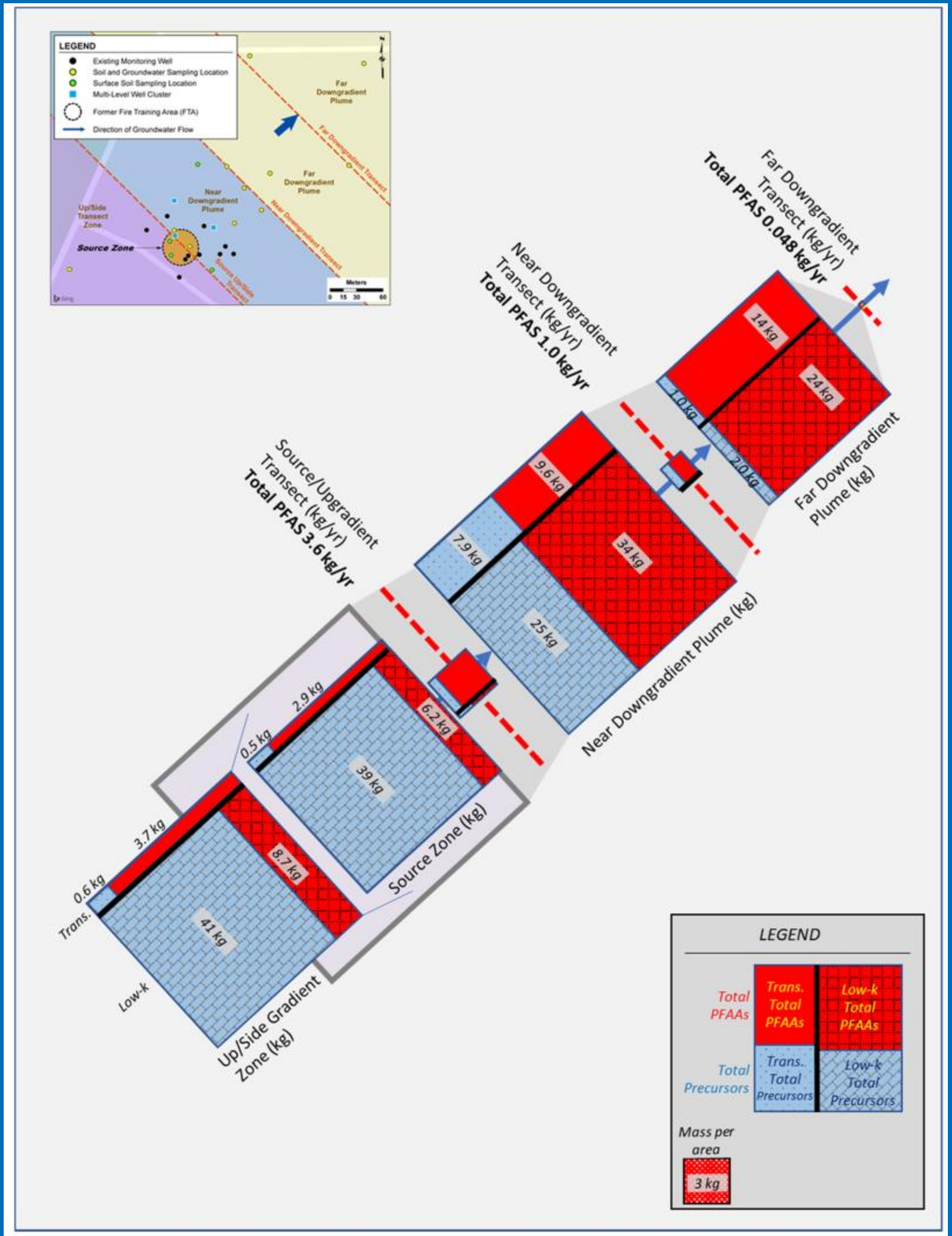

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Environmental Science & Technology 2020 54 (24), 15768-15777

DOI: 10.1021/acs.est.0c04472