Sustainable In-situ Treatments of PFAS

in contaminated Soil and Groundwater,

Washing with Protein Bio-polymers

and Stabilization by GAC high pressure Injection

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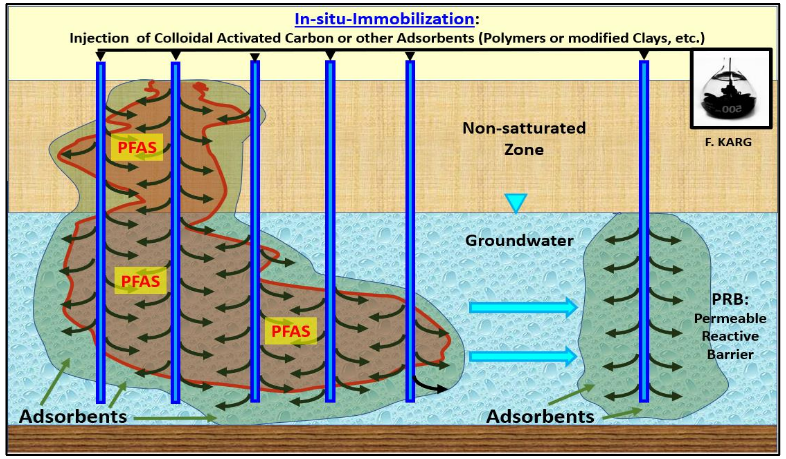

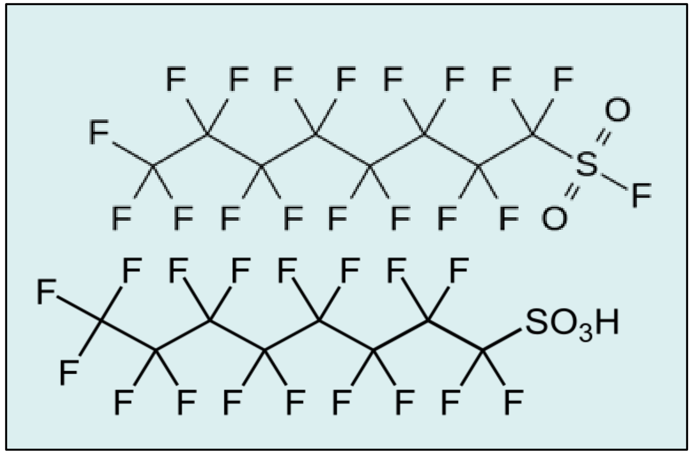

1. **PFAS Contaminations: Advantages of in-situ Remediation Treatments**
2. **In-situ Washing by Proteinic Bio-Polymers**
3. **In-situ Immobilization by Colloidal Activated Carbon versus Stabilization by GAC High Pressure Injection**
4. **Conclusion**

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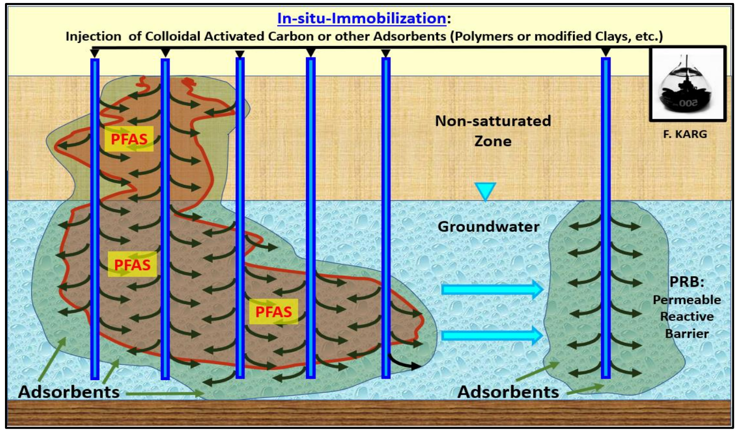
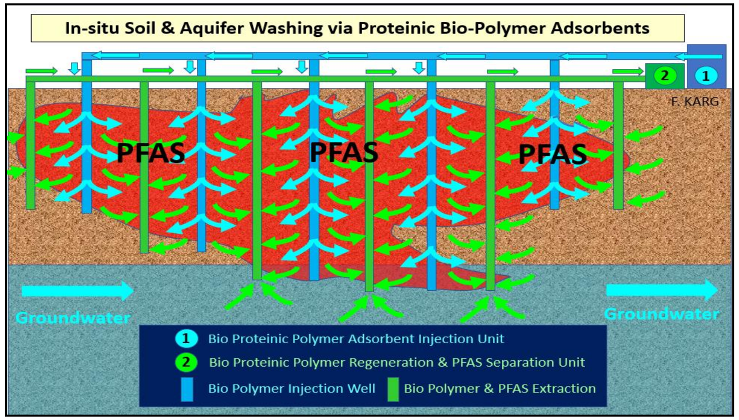
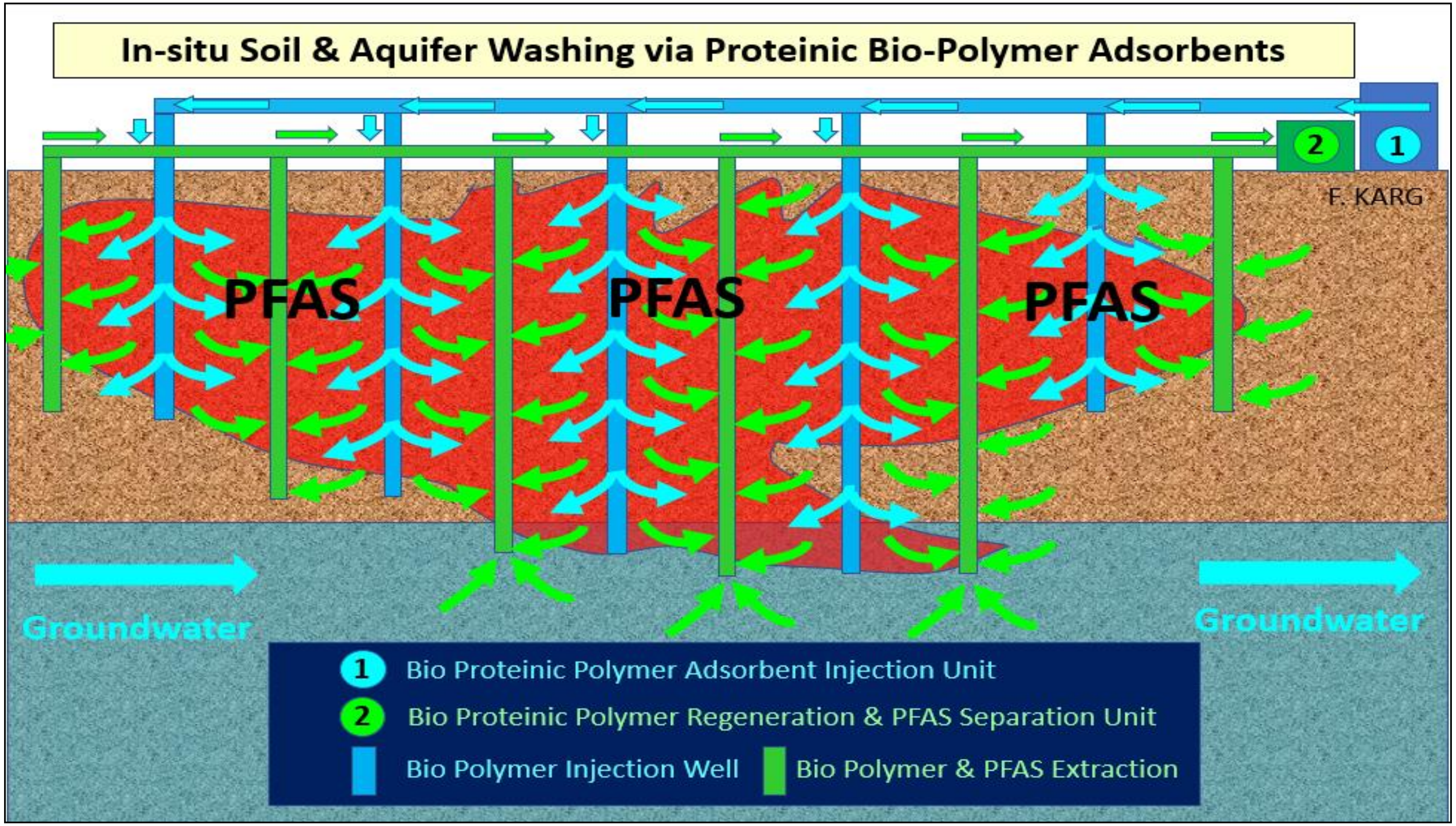
1. PFAS Contaminations: Advantages & Inconvenients of in-situ Remediation Treatments

- **Traditional Soil Treatments as Dig and Dump or Thermal Treatment** are simply the **most expensive** and often even not possible because lots oof Landfills (ISDN, ISDND, ISDD, etc.) and Thermal Waste Treatment Facilities are even **don't accept PFAS !**
- **In-situ Treatment Alternatives are for ex. in-situ Washing** with (Kaolinites, Humic acids), chemical Coagulation by Al(OH)x or **Proteinic Bio-Polymers.**
- Alternatively **in-situ Immobilization or Stabilization** can by applied by use of **Colloidal Activated Carbon** or **GAC High Pressure Injection of Granulated Activated Carbon** or other Adsorbents.

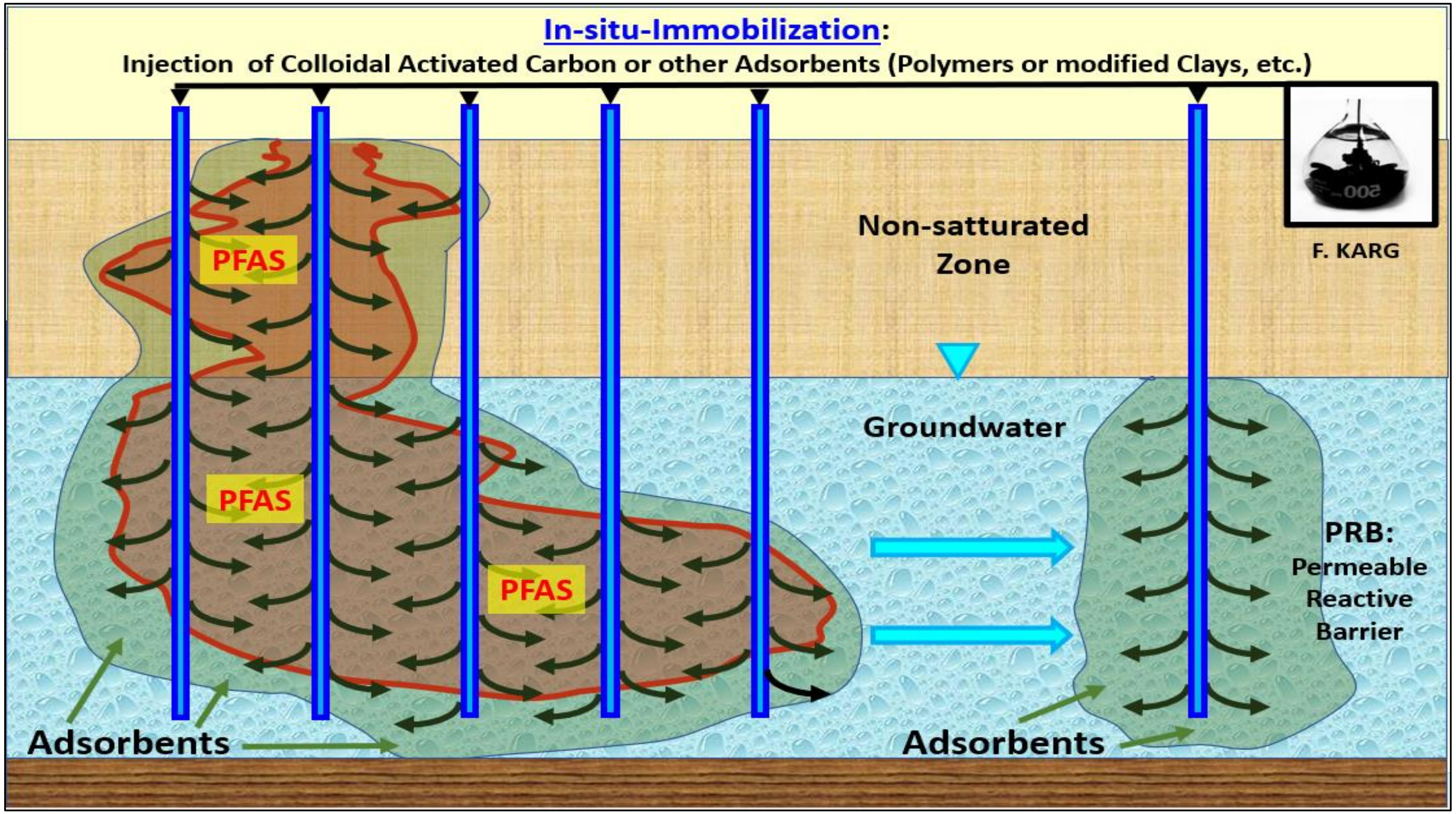




Example of PFAS Treatment via in-situ Washing by use of Proteinic Bio-Polymers



Example of PFAS Treatment via in-situ Immobilization or Stabilization by use of Colloidal Activated Carbon



Examples of other in-situ PFAS Treatments

Groundwater & Soil Washing Leachate: Adsorption on Protein-Polymers & RemBind (Kaolinites, Humic acids), chemical Coagulation by Al(OH)x (in- & ex-situ): FABEKO-SENSATEC

- Adsorption on Liquid Activated Carbon (in & ex-situ): Regnesis + Others

- Concentrations by air/water Inter-face Foam (ex-situ): ALLONIA

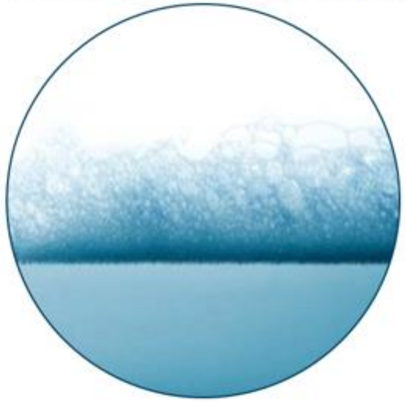
- Concentrations by biodegradable Floculant (ex-situ): Cornelsen/TRS

- Modified Clay Adsorbens (ex-situ): CETCO & ETEC2

PLUME STOP
Liquid Activated Carbon

Courtesy of Regenesis

SAFF®
Foam Fractionation



Courtesy of Allonnia

PerfluorAd®

Courtesy of Cornelsen/TRS

FLUOROSORB®

Courtesy of CETCO

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RnD-project: Sustainable In-situ and On-site treatment of PFAS in contaminated soil by Bio-Polymer washing

From lab experiments to field scale application

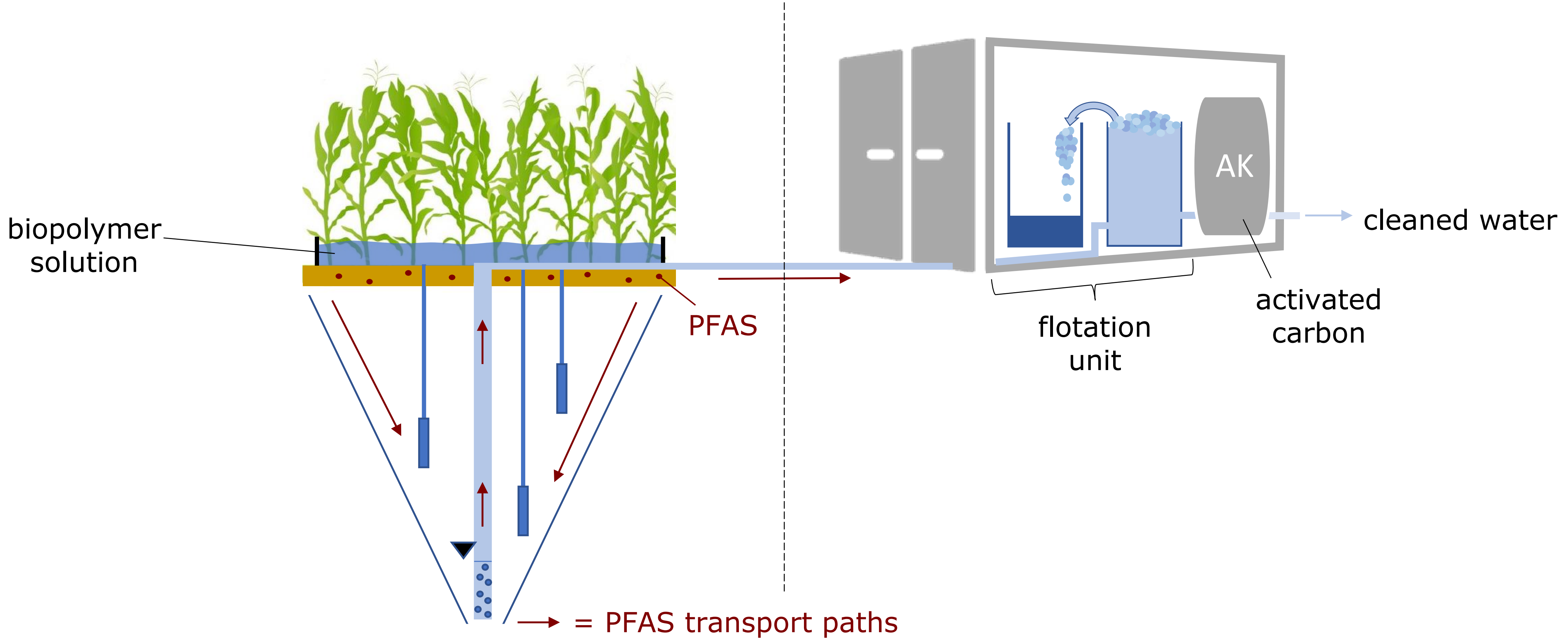
Fabeko-Partners involved:

GEFÖRDERT VOM

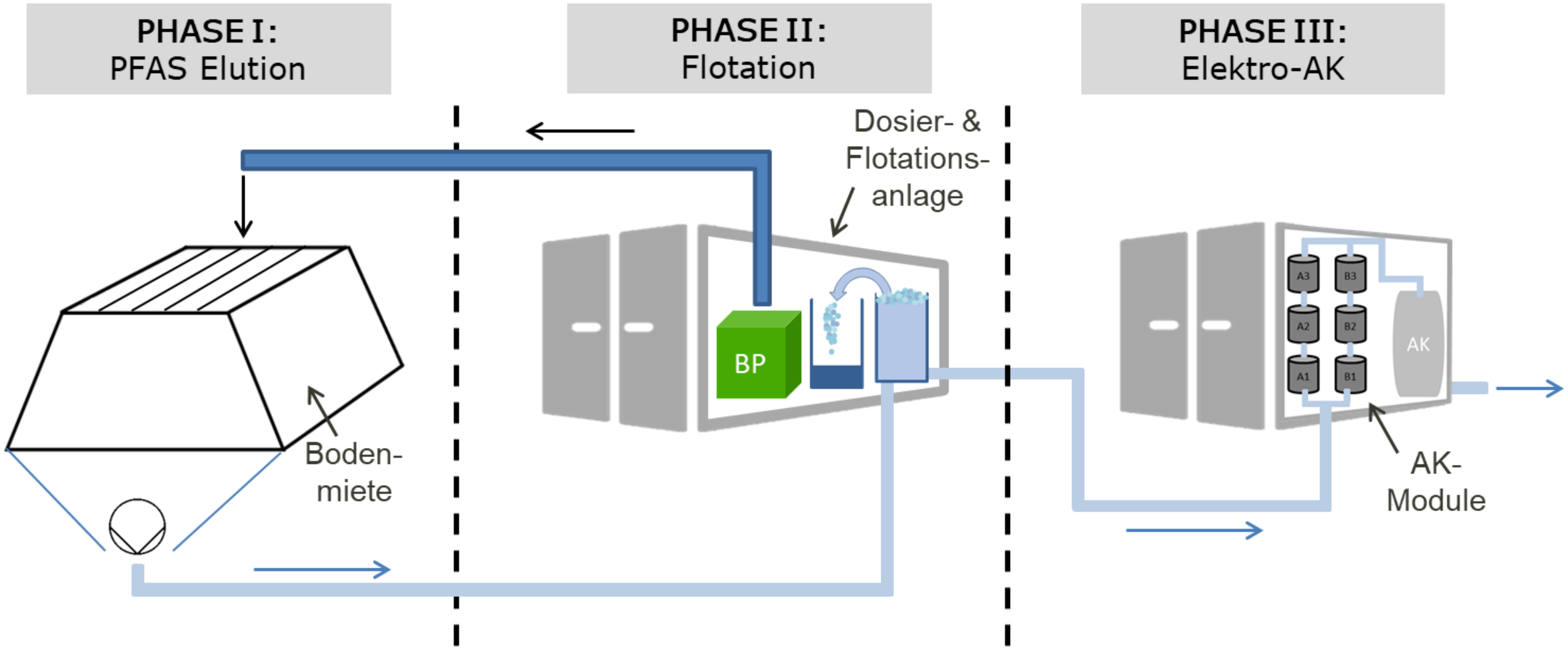
Bundesministerium für Bildung und Forschung

General remediation concept in-situ

PHASE I: PFAS elution from top soil	PHASE II: PFAS removal from water



General remediation concept on site

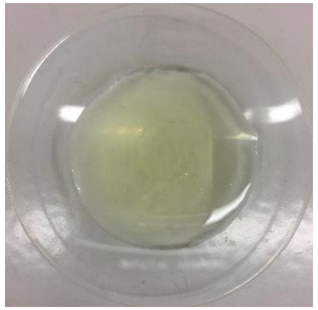


Type of biopolymers developed

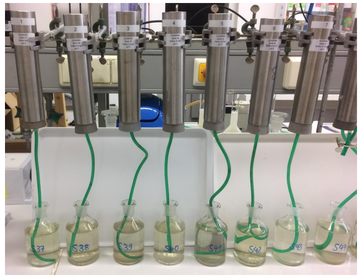
- Surface-active reagents (surfactants)
- Easily biodegradable
- amphiphilic

- Main ingredients:
  - Amino acids
  - Sugar compounds
  - Mixture of fatty acids and lipids

- Varying composition of biopolymers results in different PFAS- elution characteristics



From lab to field – development steps



Lab tests for biopolymer mixture

Tests in technical scale

Pilot scale plant

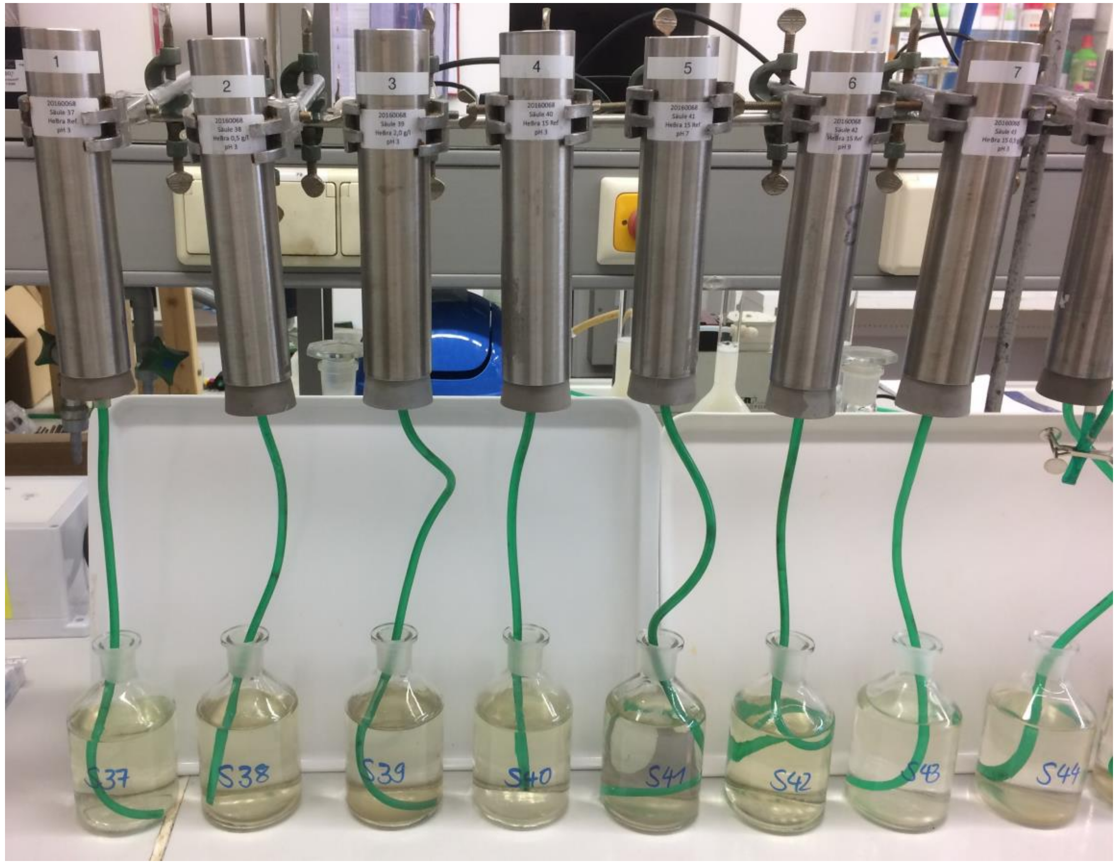
In-situ field appl.

On-site appl.

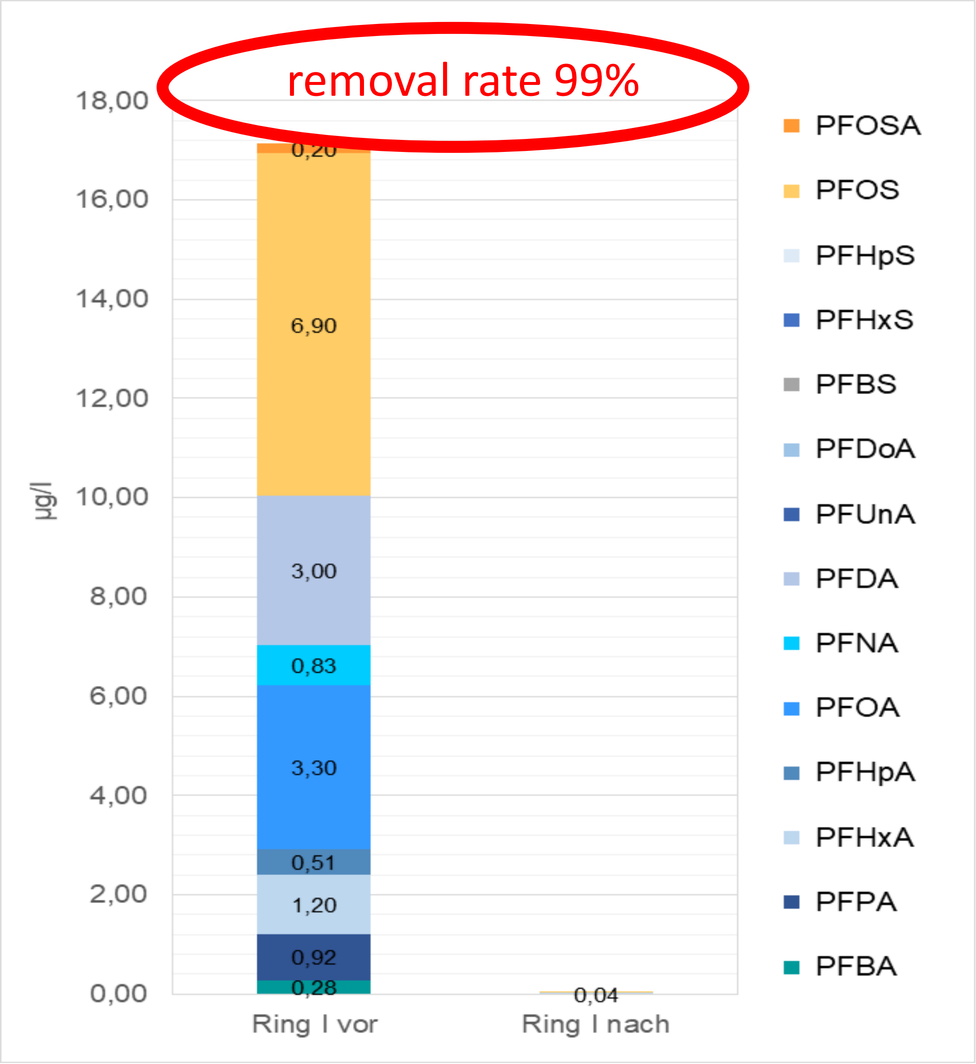
2018 2019 2020 2022 2023

Biopolymer selection

- column experiments to determine the polymer-specific PFAS elution potential
- Soil samples from Rastatt area (= largest PFAS contamination in Germany)
- research variables:
  - biopolymer types
  - concentration and pH-values of biopolymer solution
- PFAS analysis in eluate
  → 27 standard substances



Verfication of PFAS-transport in lysimeters



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Remediation unit for water cycle and PFAS removal

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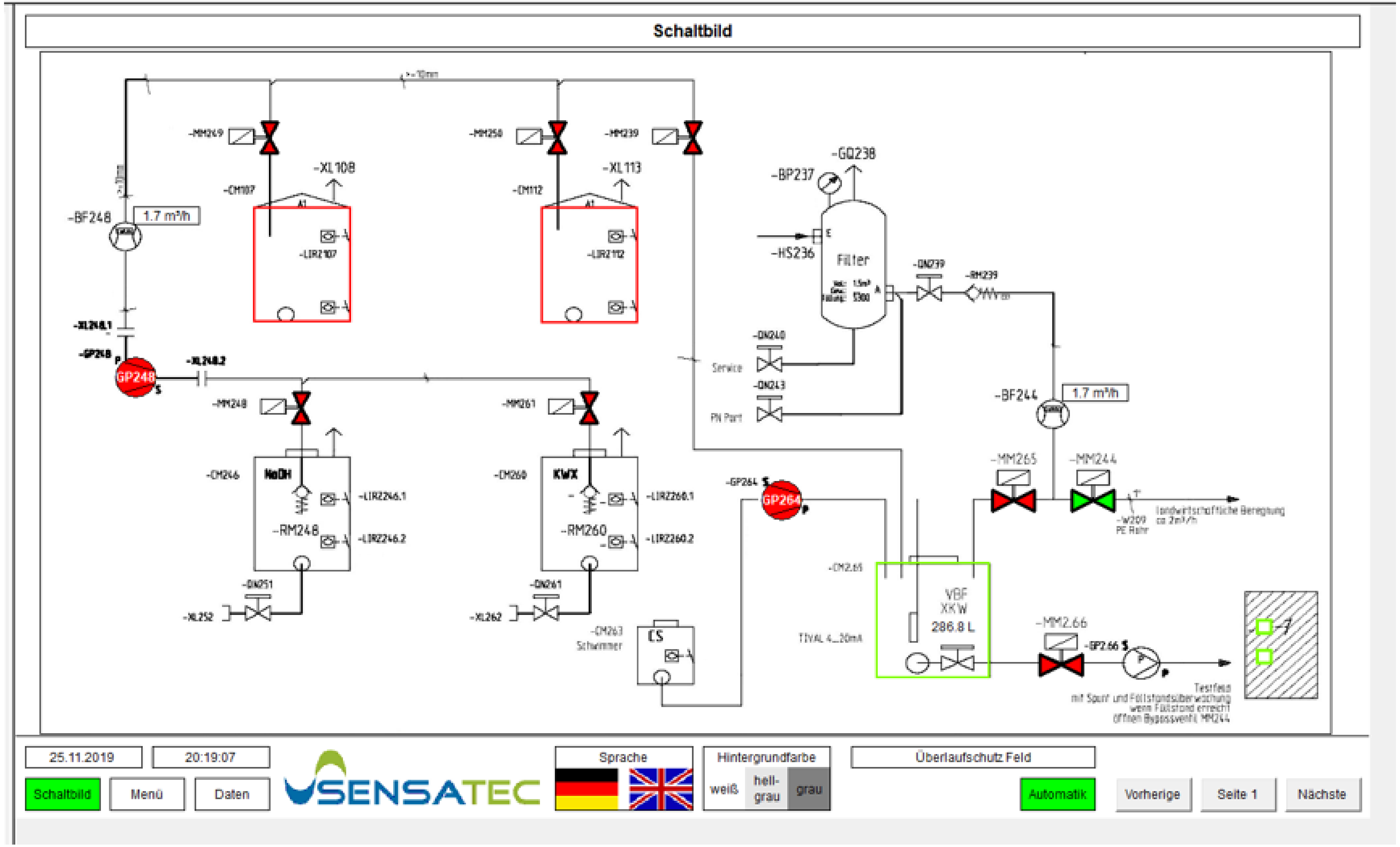
Remote monitoring interface



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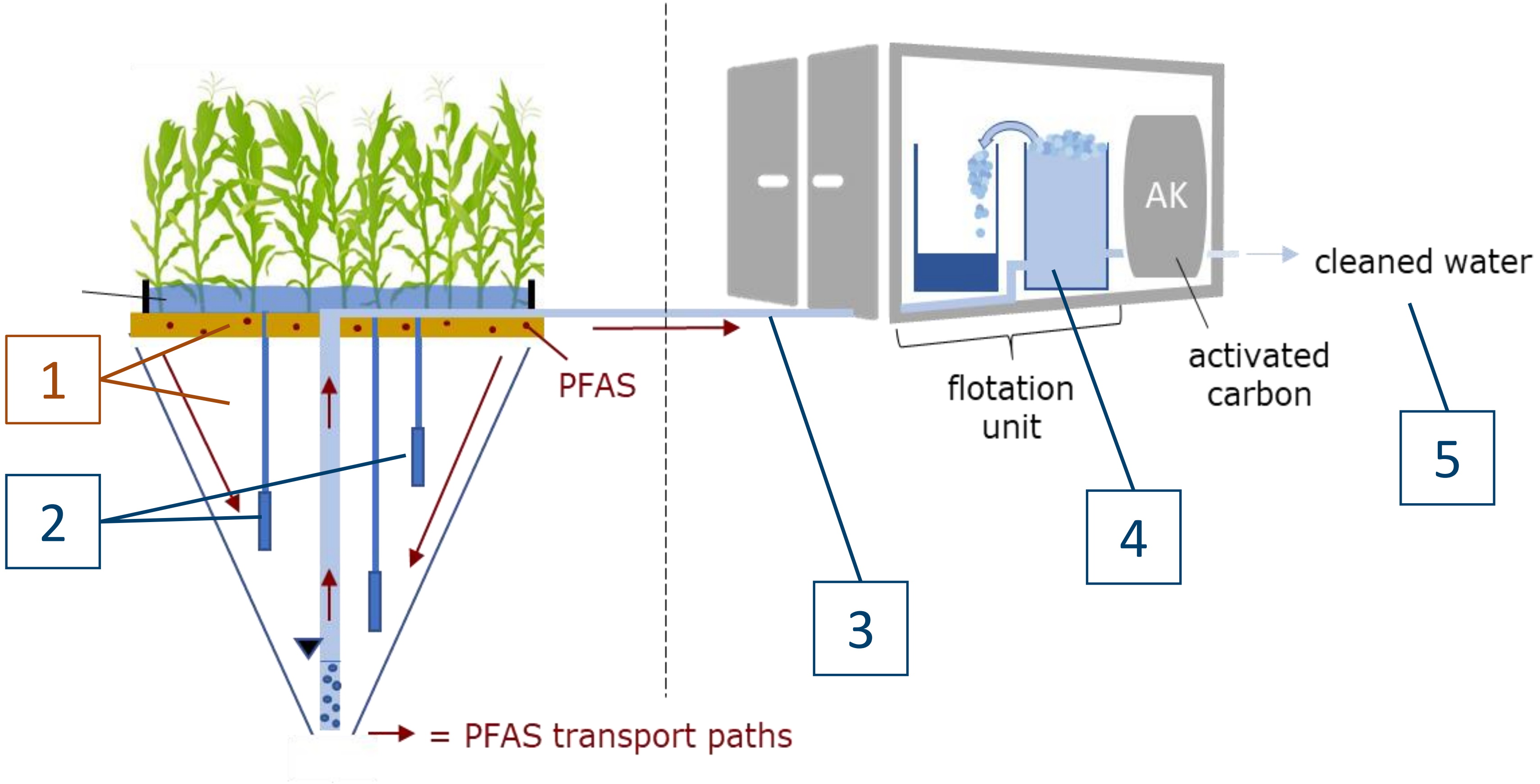
Field application of in-situ PFAS soil washing in-situ

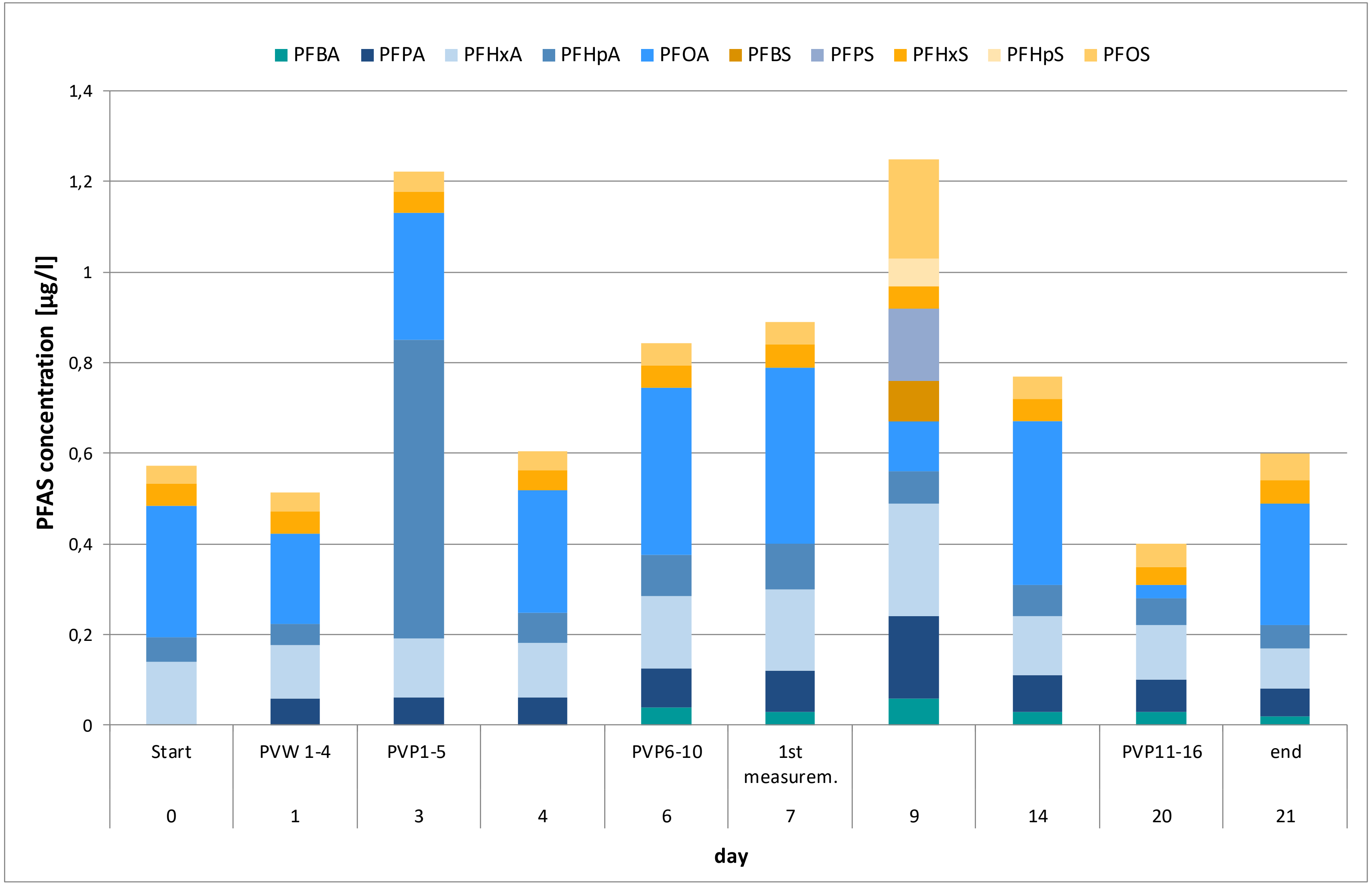
Monitoring points

PHASE I: PFAS elution from top soil	PHASE II: PFAS removal from water



1	Soil before and after elution
2	Suction cups
3	Untreated water
4	Flotation unit
5	Cleaned water

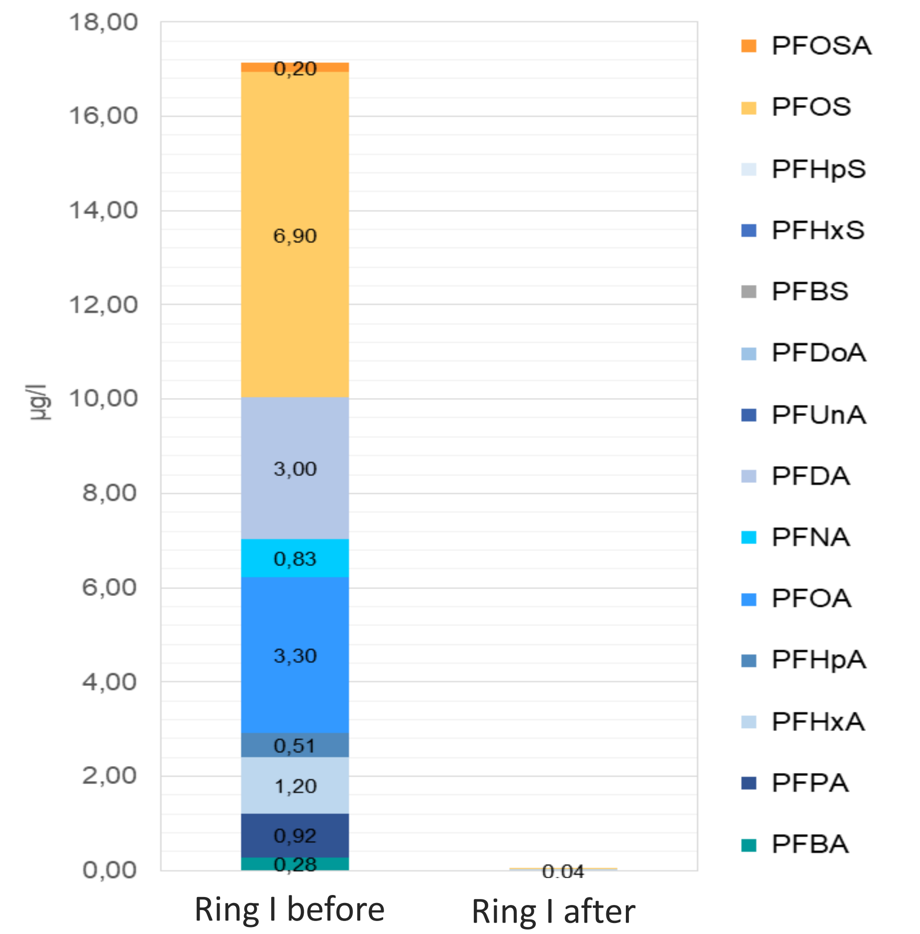
PFAS elution – when just adding water to the soil…



Soil analysis – PFAS removal

Lysimeter eluate

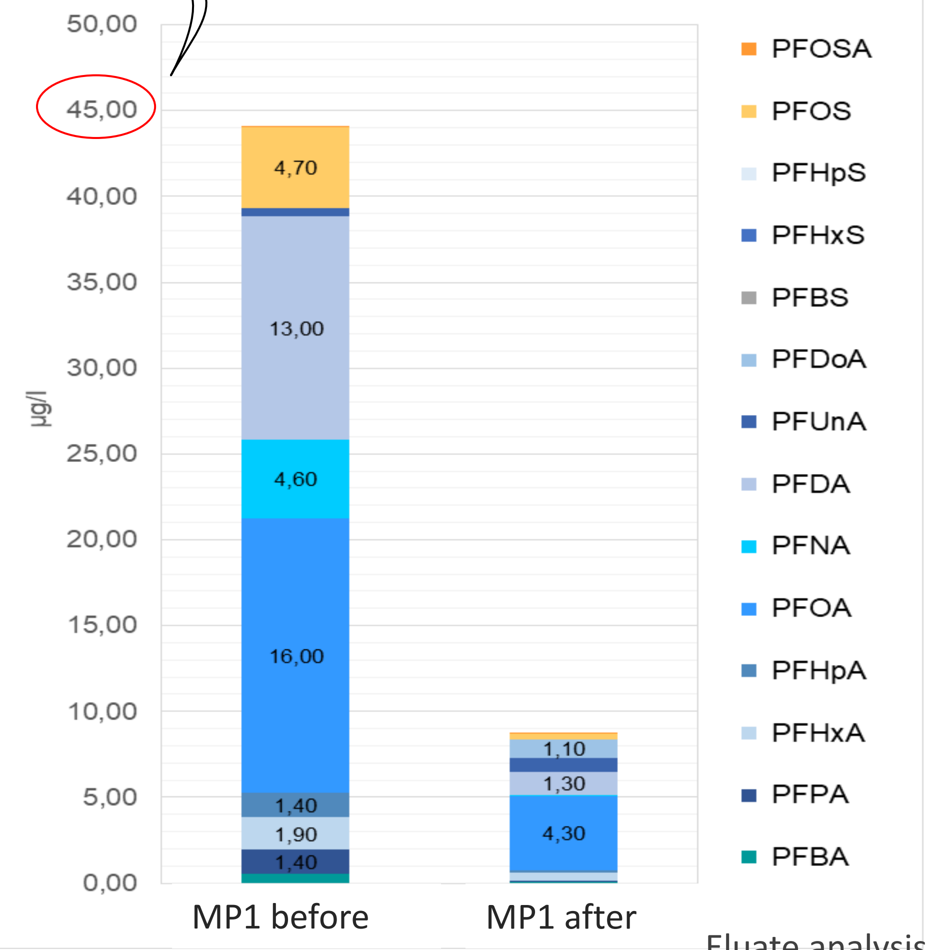
removal rate 99%



starting concentration
3x higher than in lysimeter!

Soil eluate after field appl. in 3 week

removal rate 80%



Eluate analysis standard PFAS

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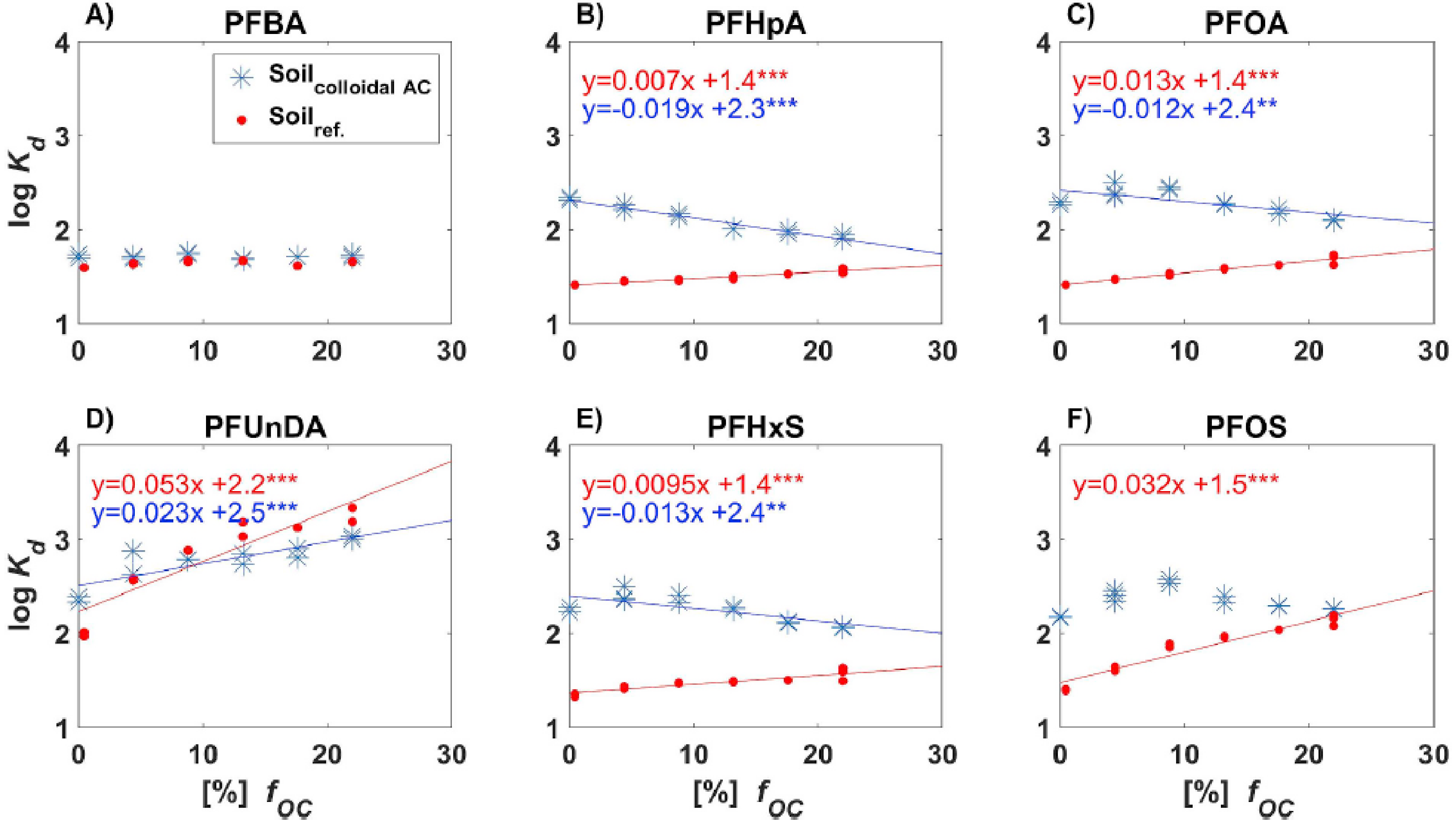
Adsorption on colloidal active carbon: problem short chain PFAS and Organic Carbon

(Source: Sørengård et al., 2019)



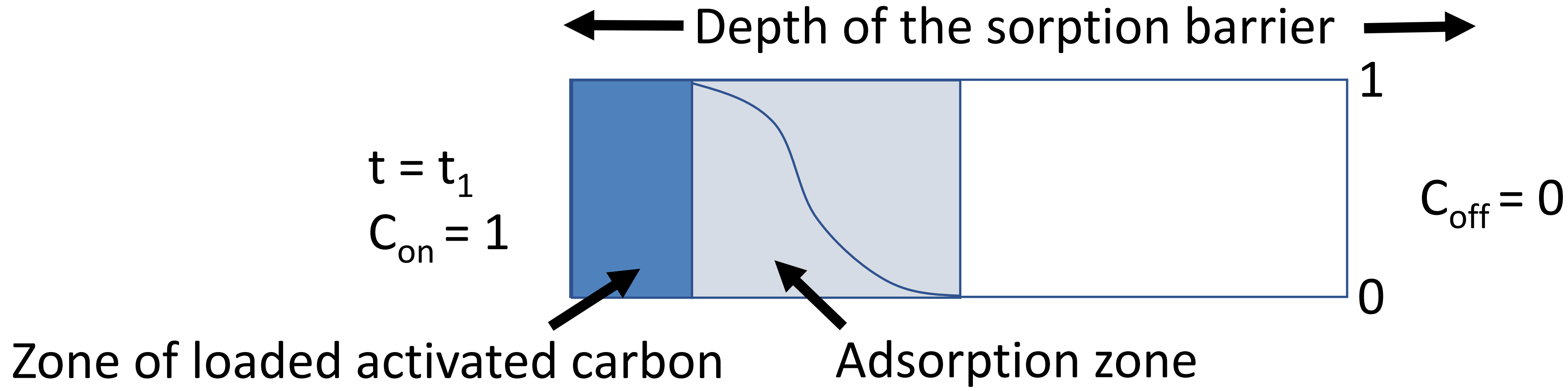
Soil-water partitioning coefficient log Kd as a function of soil organic carbon fraction (fOC) for: A) perfluorobutanoate (PFBA), B) perfluoroheptanoate (PFHpA), C) perfluorounoctanoate (PFOA), D) perfluoroundecanoate (PFUnDA), E) perfluorohexane sulfonate (PFHxS) and D) perfluorooctane sulfonate (PFOS), in six different colloidal AC treated and non-treated soils. *p < 0.05; **p < 0.01; ***p < 0.001.

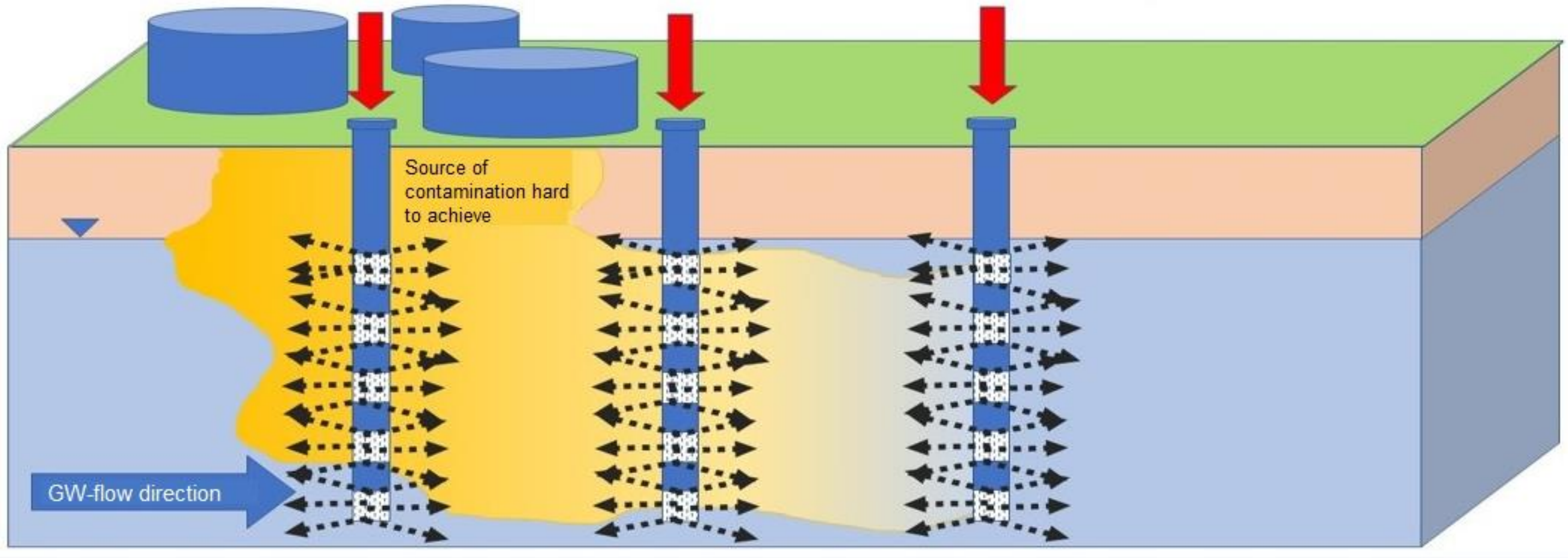
Application aspects for colloidal activated carbons

- Manufacturer recommendation: 1 wt% colloidal activated carbon based on soil weight (Sørengård et al., 2019).
- Little to no effect on very short-chain and very long-chain PFAS (Sørengård et al., 2019).
- The higher the TOC, the lower the adsorption effect of colloidal activated carbon on PFAS (Sørengård et al., 2019).
- Migration of colloidal activated carbon cannot always be accurately controlled, resulting in the following problems:
  - colloidal activated carbon enters in monitoring wells, leading to false monitoring results
  - colloidal transport of colloidal activated carbon together with PFAS
- Illustration in report: https://dot.alaska.gov/airportwater/docs/Fairbanks%20International%20Airport/2021.12%20FAI%20PlumeStop%20Pilot%20Study%20Report%20for%20Public.pdf

Therefore, we recommend discrete placement of non moving active carbon in the PFAS mass flux relevant zones by direct injection placement

Adsorption of PFAS on injected activated carbon





Dimensioning of the activated carbon mass input

$$Mass_{(AC)}\ (kg) = A \times Q \times t \times F_{Ad} \times F_E \times F_S$$

A: Flow-through area barrier (m^2)

Q: PFAS-load x time ($kg/a \times m^2$)

t: Desired lifetime of the barrier(a)

F_{Ad}: Factor (adsorption capacity; kg/kg)

F_E: Factor (site-specific adsorption efficiency)

F_S: Safety factor mixture of materials

- PFAS load: requires horizon-specific analyses of PFAS load + time prognosis
- Adsorption capacity factor: according to manufacturer's specifications
- Sorption efficiency factor: site-specific sorption analysis in the laboratory
- Factor mixture of materials: safety factor due to displacement of short-chain PFAS

Project example: 50 m wide, 10 m deep PFAS adsorption barrier

$$\text{Mass}_{(AC)}\ (\text{kg}) = A \times Q \times t \times 1/F_{Ad} \times F_E \times F_S$$

A: Flow-through area barrier (m²) = 500 m²

Q: PFAS-mass flux x time (kg/a x m²) = 0,05 kg/a x m²

t: Desired lifetime of the barrier(a) = 10 a

F_{Ad}: Factor (adsorption capacity; kg/kg) = 0,01 kg/kg

F_E: Factor (site-specific adsorption efficiency) = 1,5 (high DOC)

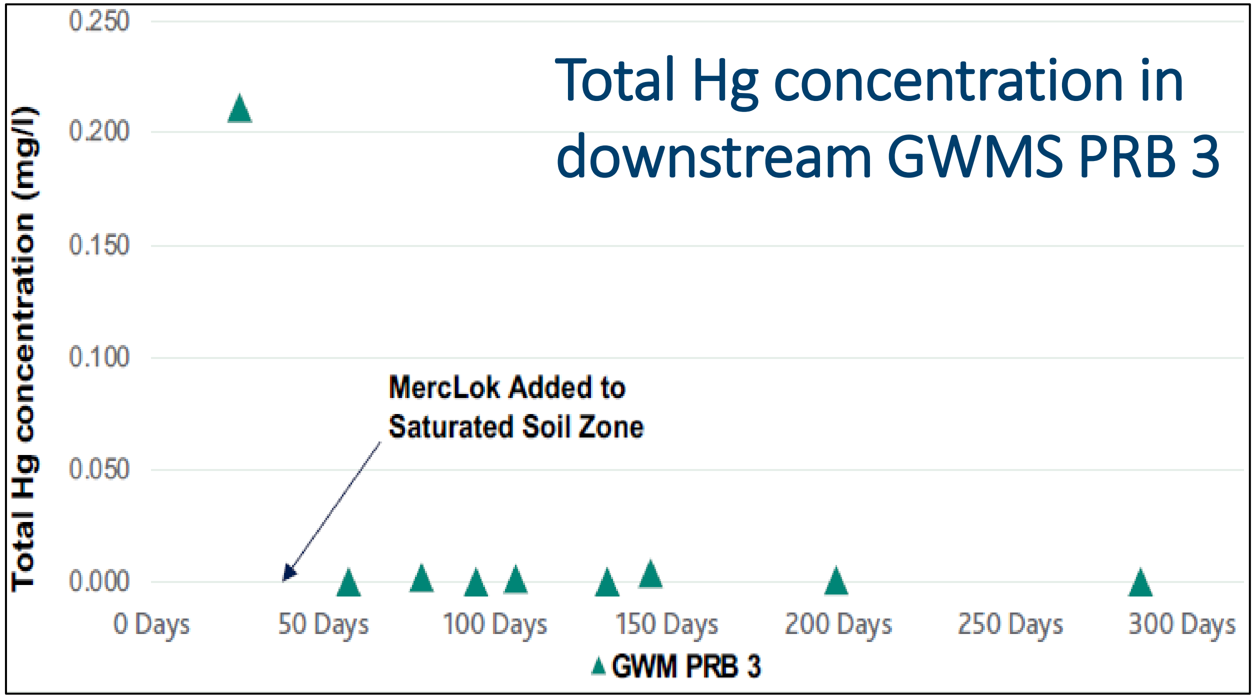
F_S: Safety factor mixture of materials = 2

- Result: 75 000 kg of active carbon to be injected for a moderate application design!

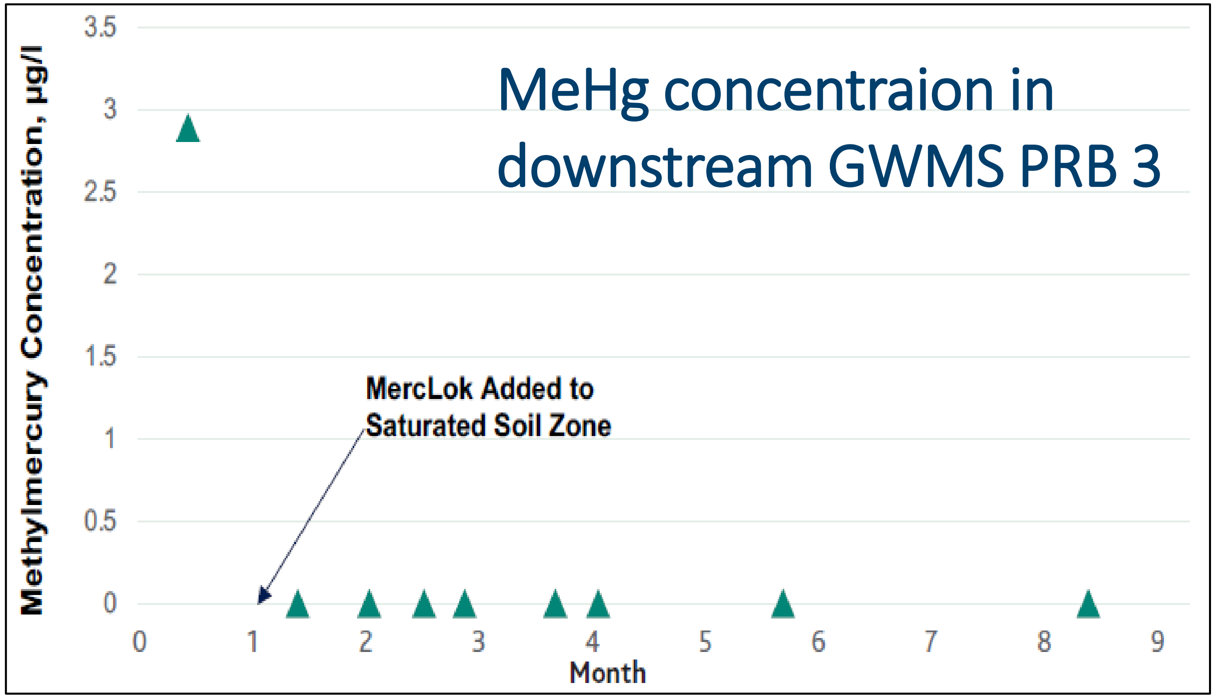
- Consequence: Stable PFAS immobilization requires tons (!) of activated carbon
- An efficient active carbon placement / injection technology is mandatory!
- Targeted Solids Emplacement (TSE) technology can be a technical solution!

Example "Minimally invasive activated carbon injection" using TSE

Evaluation efficiency of Hg-adsorption after injection of solid active carbon (Merclok) by TSE technology (Sensatec)



Immediate and complete Hg-reduction (<1 µg/L) after adding active agents



Immediate and complete MeHg-reduction (<0,1 µg/L „not quantifiable“) after adding active agents

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Detailed Feasibility Studies for PFAS removal/reliable immobilization are highly recommended

1. Analysis of PFAS composition, elution potential and soil specific biopolymer transport for specification of approach

2. Identification of site-specific AC adsorption capacity and kinetics under consideration of accompanying geochemical processes (Fe, carbonates, DOC)

3. Analysis of PFAS immobilization in soil material; equilibrium leaching tests, batch leaching tests, synthetic precipitation test

4. Dimensioning tests for adsorptive barriers in groundwater – reduction of relevant cost factors!

Conclusions

1. PFAS mobilization and immobilization processes require a sophisticated approach in the planning phase and in technical implementation.
2. The choice of the most suitable biopolymers for PFAS washing depends on the PFAS composition as well as on site characteristics and should be lab-verified.
3. Adsorbent materials with good efficacy for the entire PFAS spectrum are available – rather large quantities of AC may be necessary for reliable immobilization in-situ.
4. Remediation of PFAS affected sites by a combination of soil washing and adsorption by GAC can be a viable and economic option for PFAS site remediation.

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Thank You !

Questions? Remarks? Requests?

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