Treatment of soil by in-situ PFAS washing with proteinic Bio-polymers – Feasibility studies from Belgium, Germany, the Netherlands and Sweden

Traitements in-situ des PFAS par lavage via des Bio-polymères protéiniques – Etudes de Cas en Belgique, Allemagne, Pays Bas et Suède.

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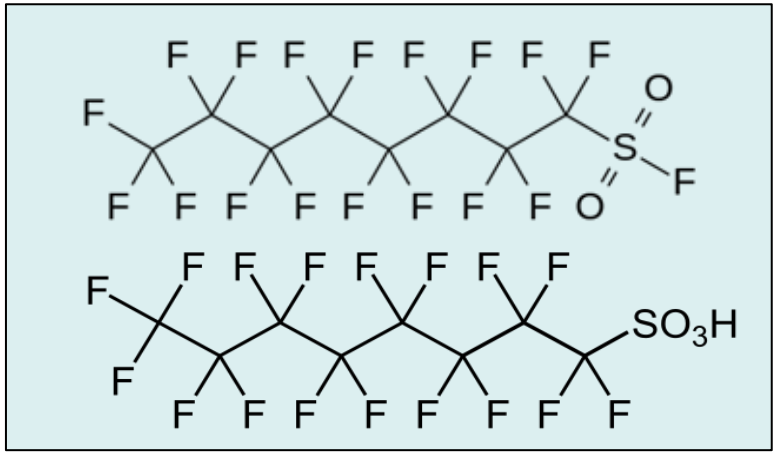
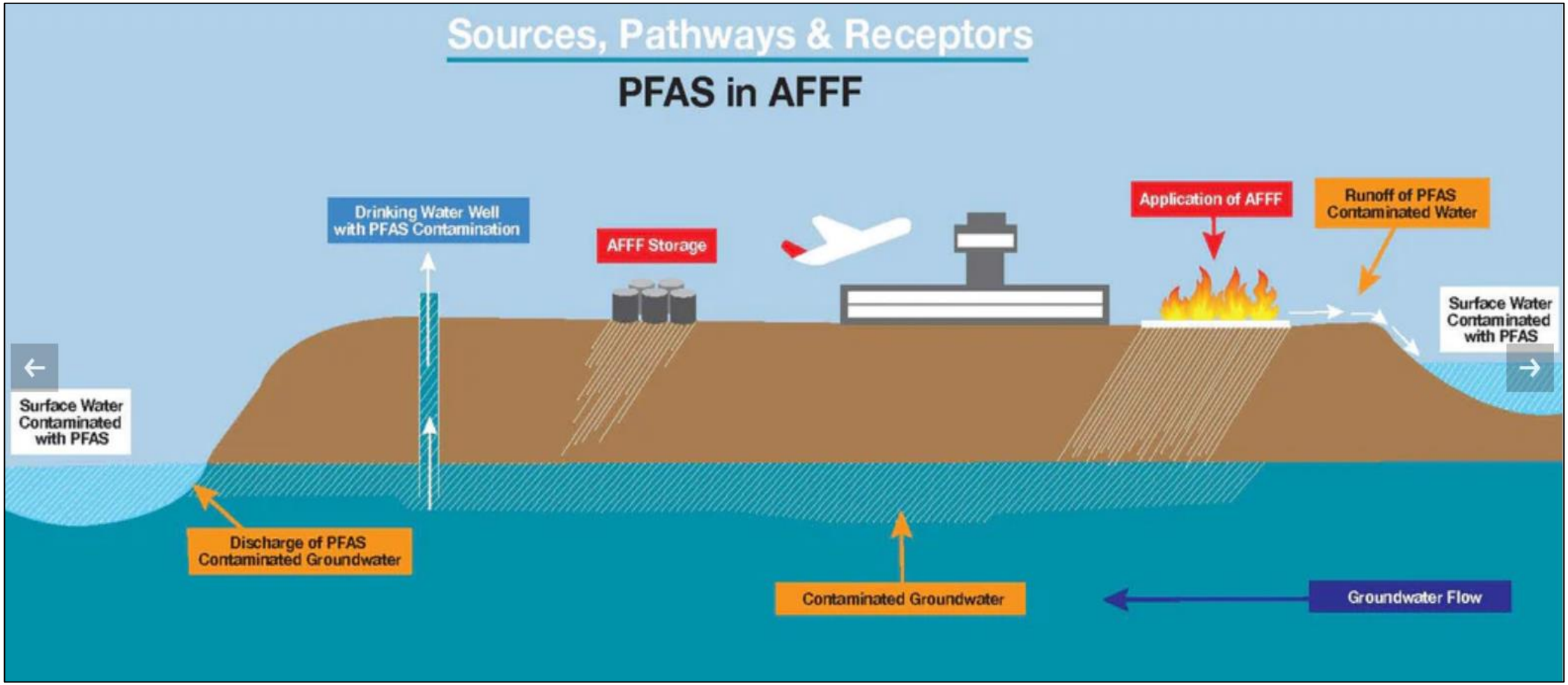


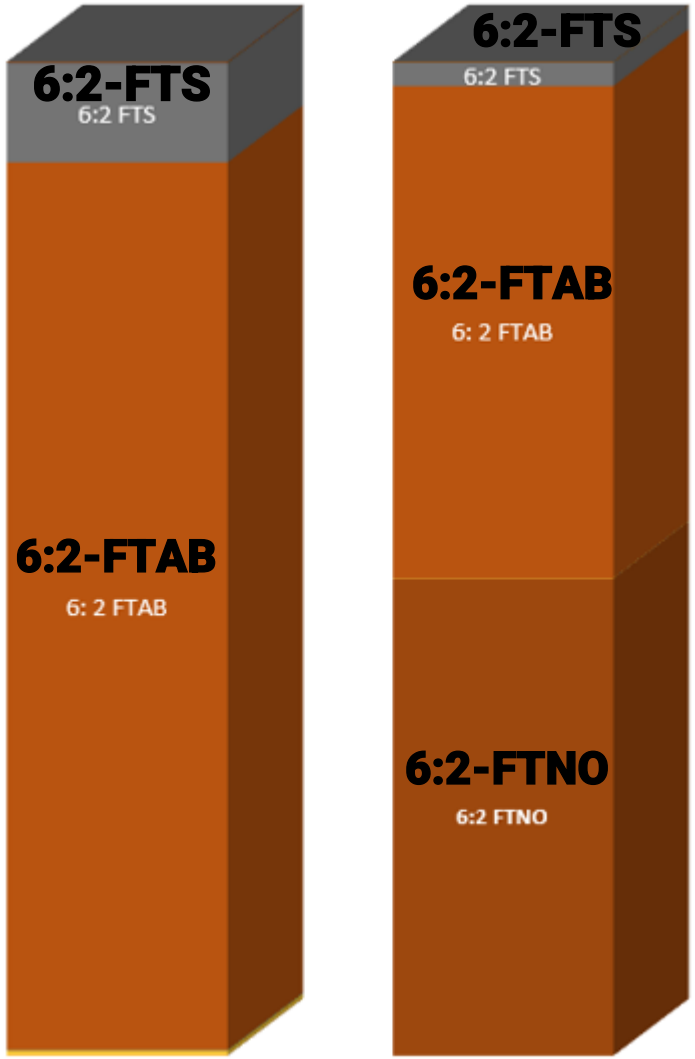
Remediation & Decontamination:

- **Airport PFAS pollutions are principally based on AFFF:** Aqueous Film Forming Foam
- **Modern AFFF (since 2006 – 2026) are principally based on 6:2-FTAB and or 6:2-FTNO**
- **Microbiological rehabilitation** is currently not possible.
- **Classical Soil Remediation** including Excavation and disposal or off-site incineration or Groundwater Treatments by P&T: Pump and Treat are much too expensive !
- **Alternatives are principally Washing / Elution** of Soil saturated and non-saturated zones, for example by Bio-Protein Polymers, etc.
- The extracted **Washing Leachates are treated**, for ex. by Flotation for **Bio-Protein Polymers Regeneration and PFAS Separation & Elimination.**

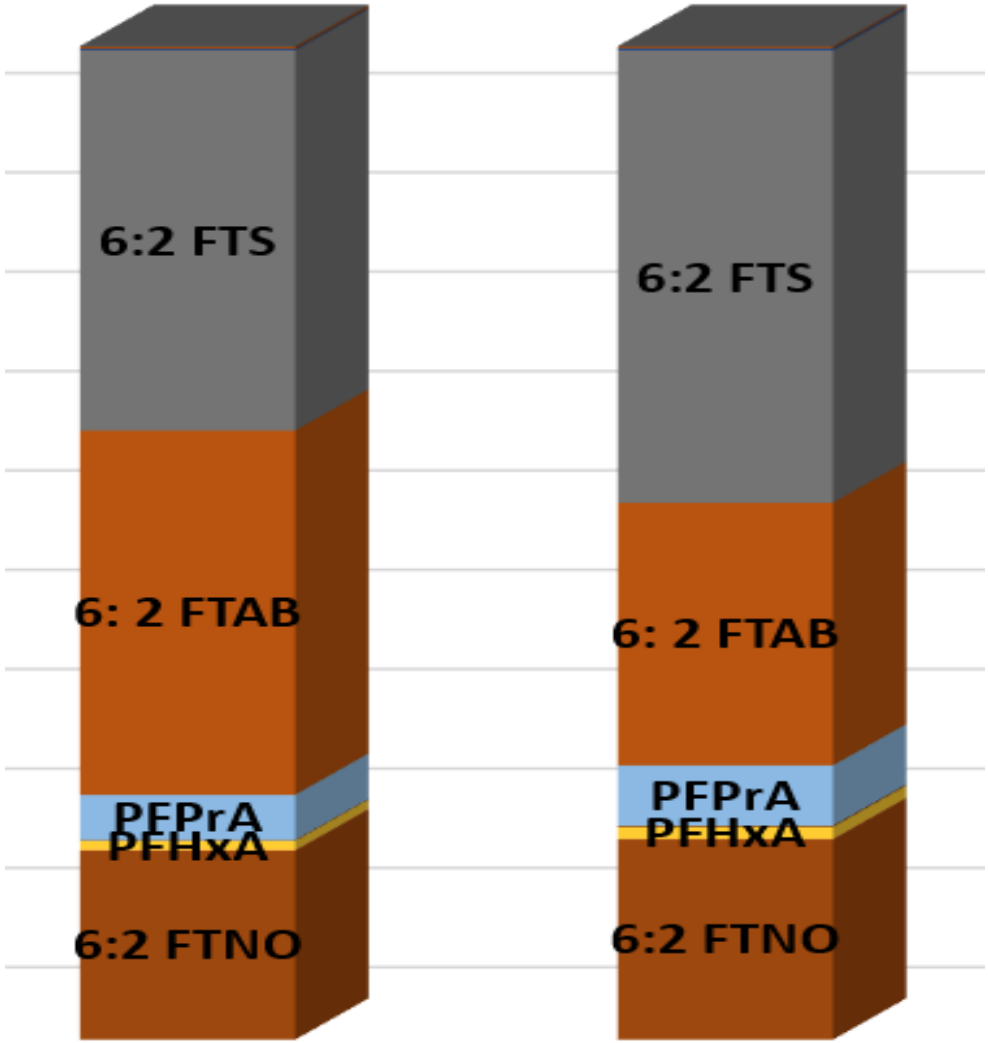

Sources, Pathways & Receptors
PFAS in AFFF
Drinking Water Well with PFAS Contamination
AFFF Storage
Application of AFFF
Runoff of PFAS Contaminated Water
Surface Water Contaminated with PFAS
Surface Water Contaminated with PFAS
Discharge of PFAS Contaminated Groundwater
Contaminated Groundwater
Groundwater Flow


Fire Fighting Foam (AFFF) Lawyer of 1,2 m on German NATO Site
Quelle: Spiegel Online 19.11.2016 / KTVU-TV / AP

Typical modern AFFFs: Anti Fire Fighting Foams (produced after 2006 – 2014)

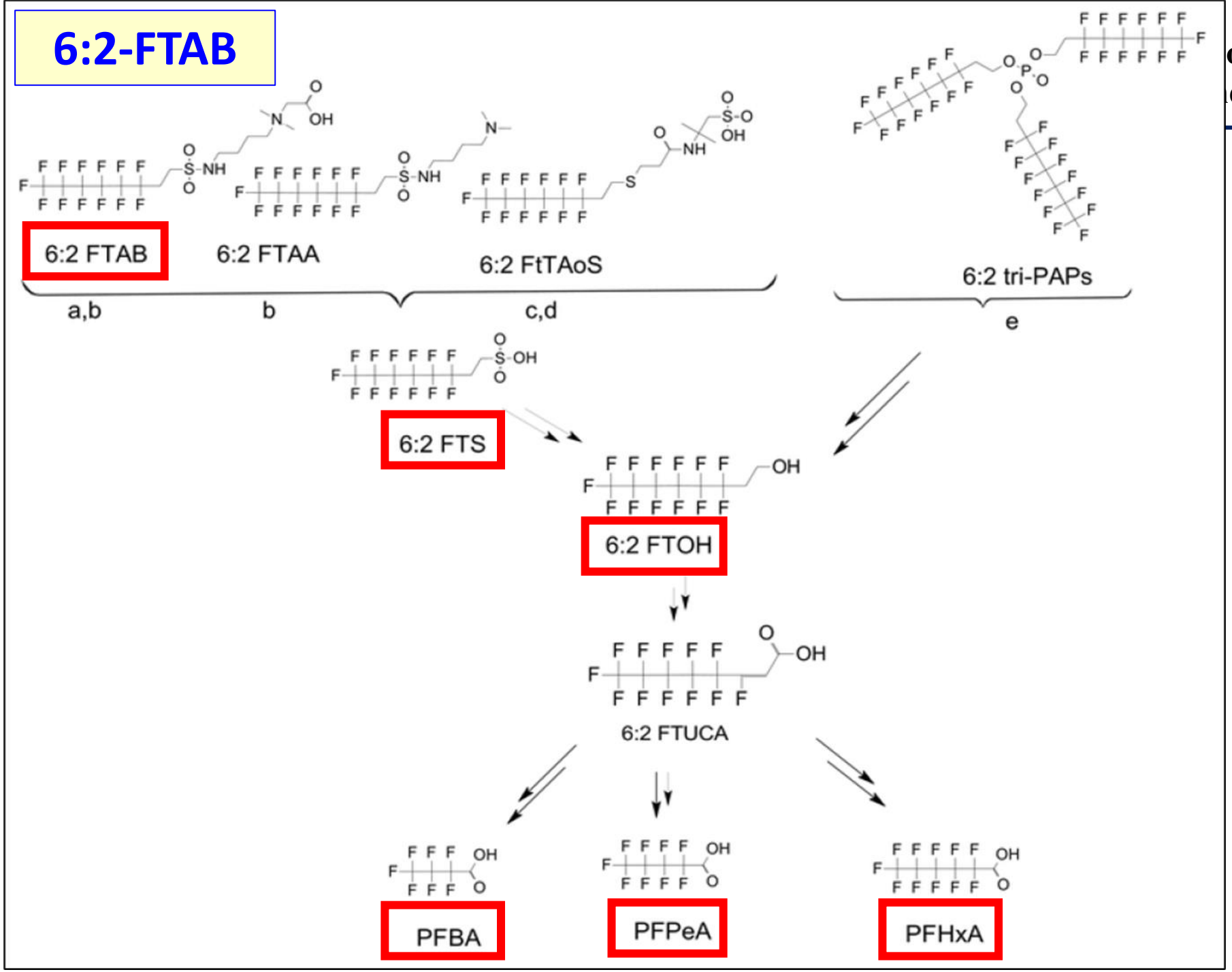


Typical modern AFFFs: Anti Fire Fighting Foams (produced after 2006 – 2014): After < 1 year in Soil



HPC INTERNATIONAL SAS

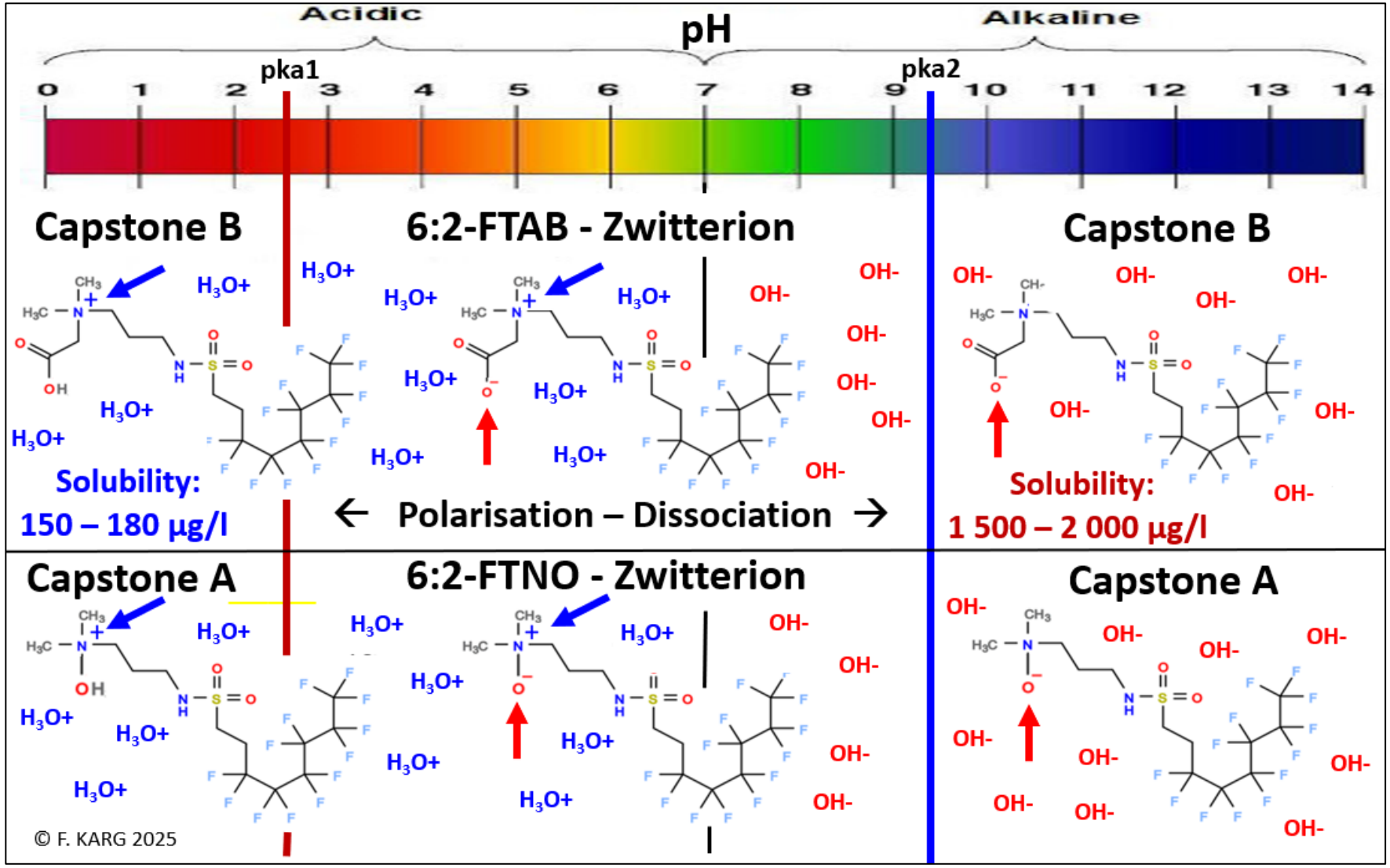
6:2-FTAB



6 :2 FTAB: Degradation

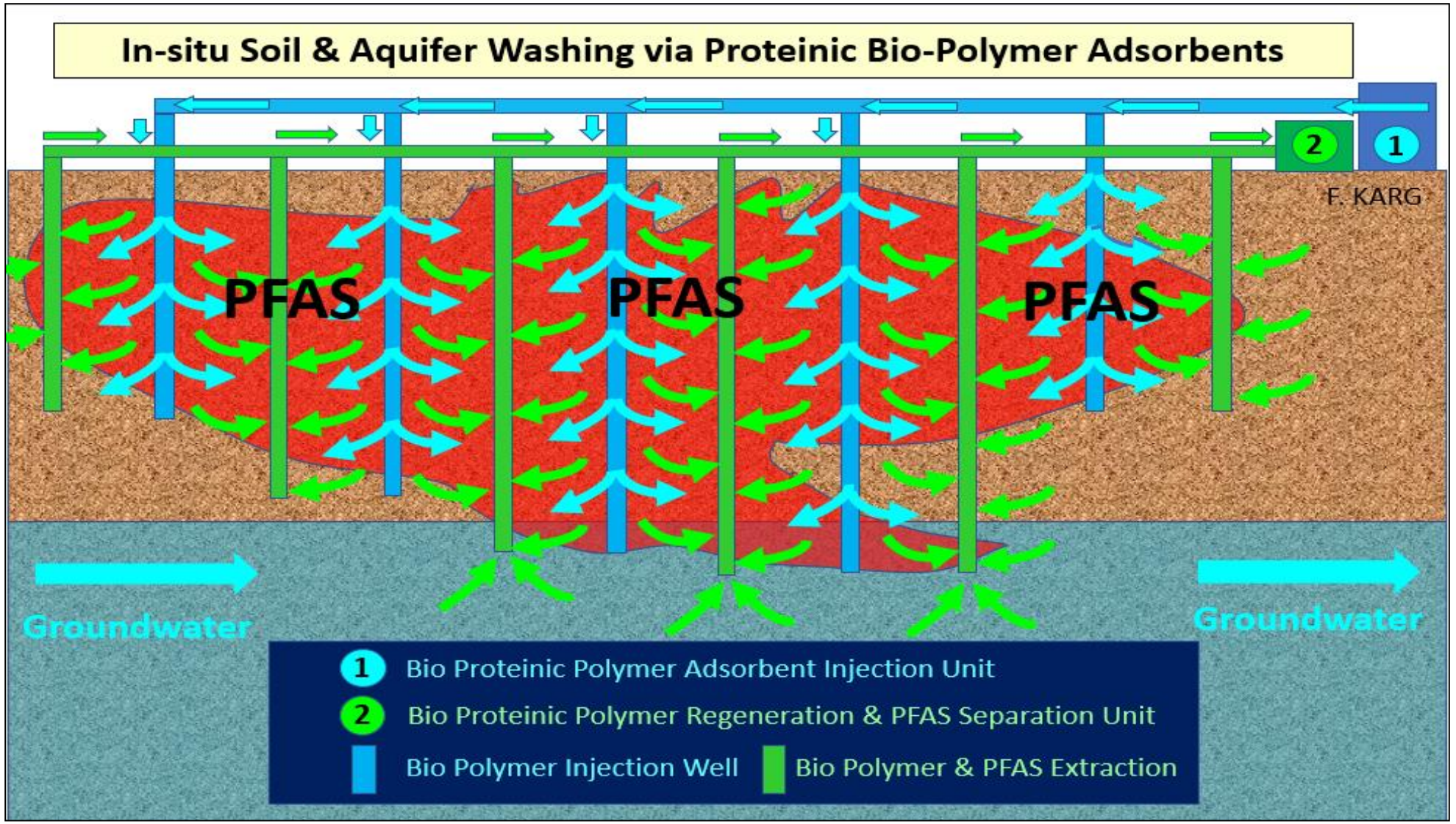
via 6 :2 FTS and 6 :2 FTOH to per-fluorinated PFBA, PFPeA & PFHxA

(LaFond et al. 2023, D.M.J. Shaw et al. 2019 ,Ying Shi, 2018 and V. Mendeza et. al. 2022)



Environmental Chemistry according pH of Capstone A & B

Remediation & Decontamination: In-situ-Washing Experiences



AGENDA

- Background on development of Biopolymer soil washing
- Technology Application
  - in-situ
  - on-site
- Kiel airport site introduction
- Results from lab – pilot – field application
- Second step: stabilization of residual PFAS in-situ
- Outlook

INTRODUCTION

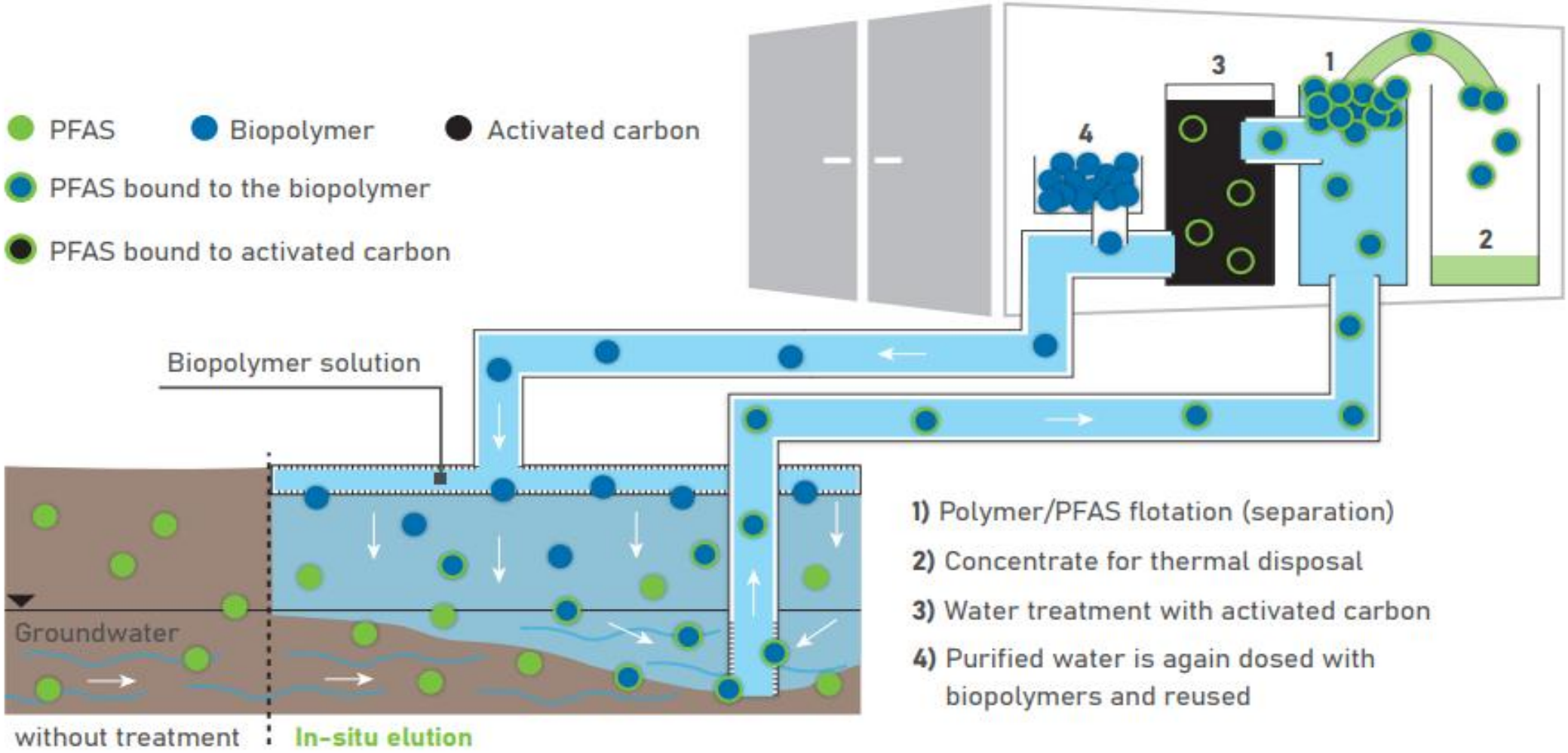
- technology to treat PFAS contaminated soils using biopolymers

  aim: PFAS elution

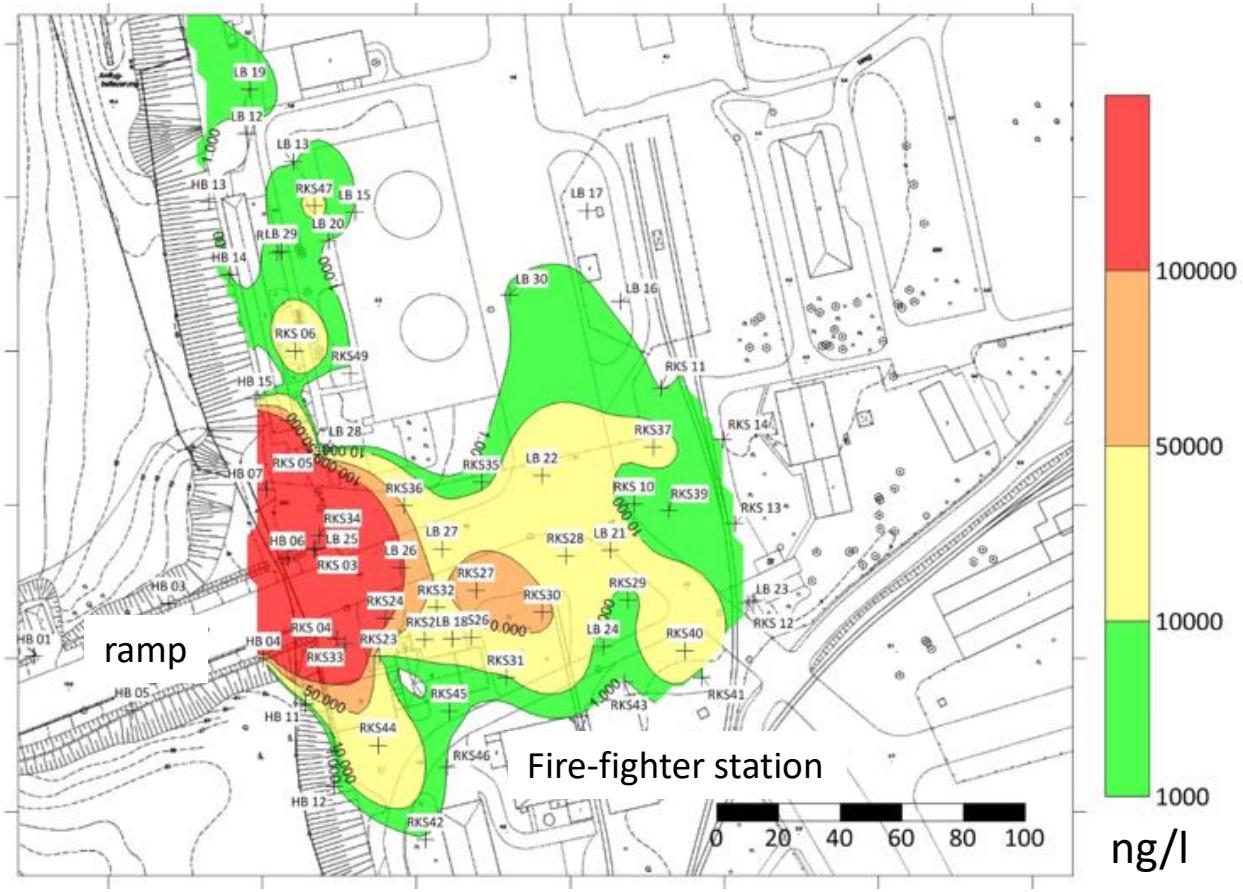
- technology development within the scope of two research project funded by the Federal German Ministry for research and education
  - BioKon (2016-2020) // TU Berlin, GEOlogik, Sensatec
  - FABEKO (2021-2024) // UFZ, GEOlogik, Mull & Partner, Sensatec

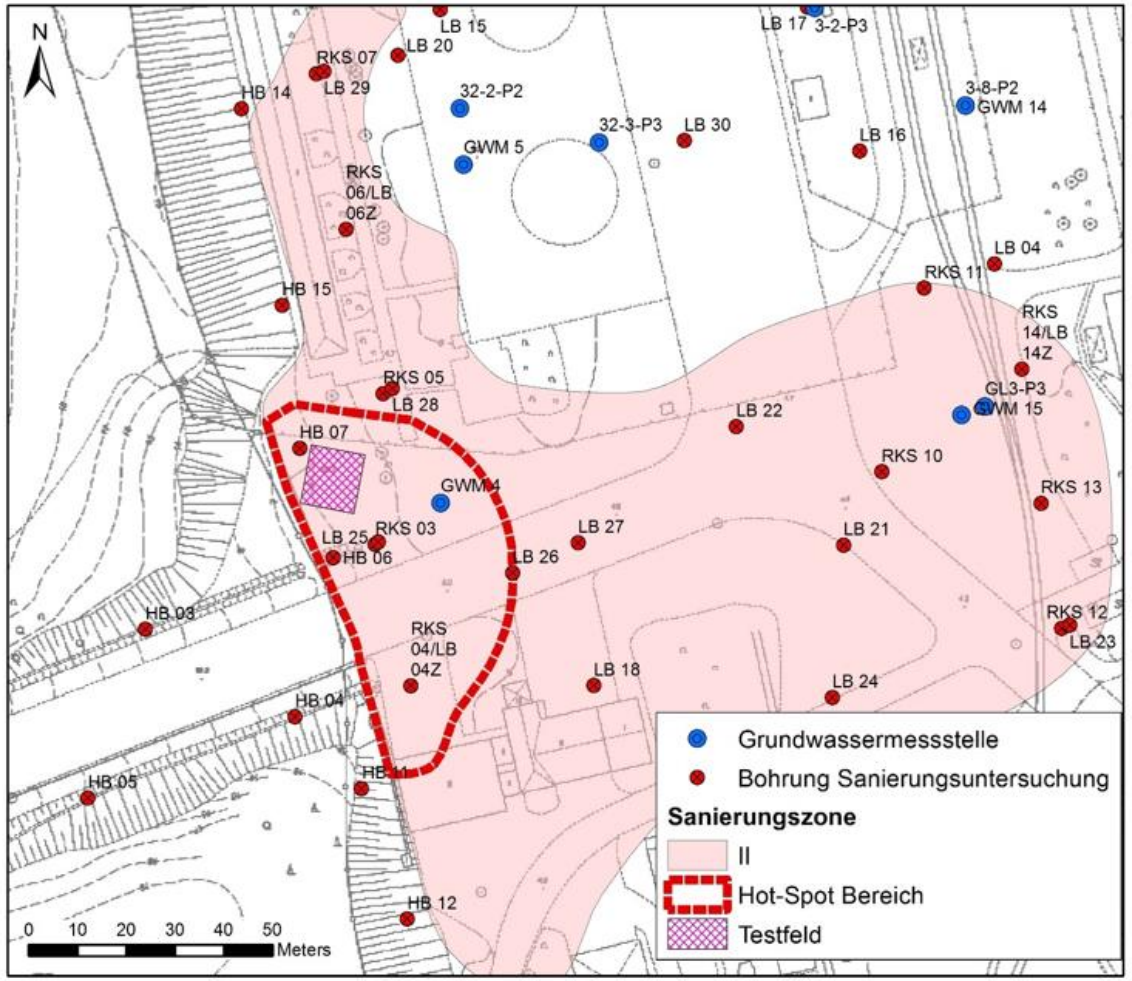
- In-situ and On-site application possible

IN-SITU APPLICATION FOR PFAS-ELIMINATION SOIL/GROUNDWATER

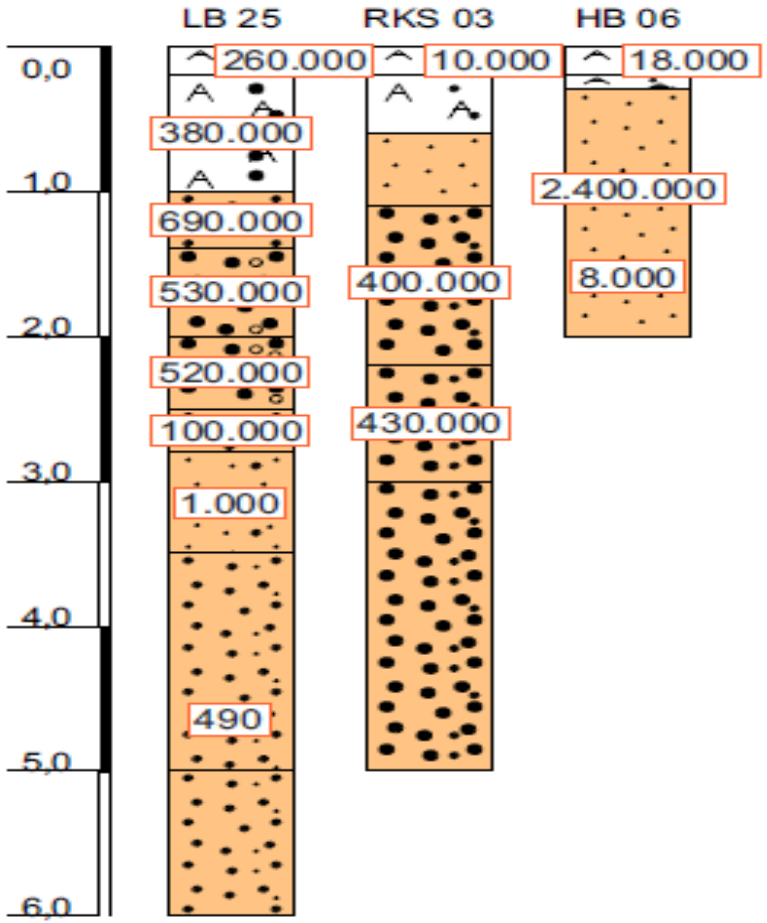


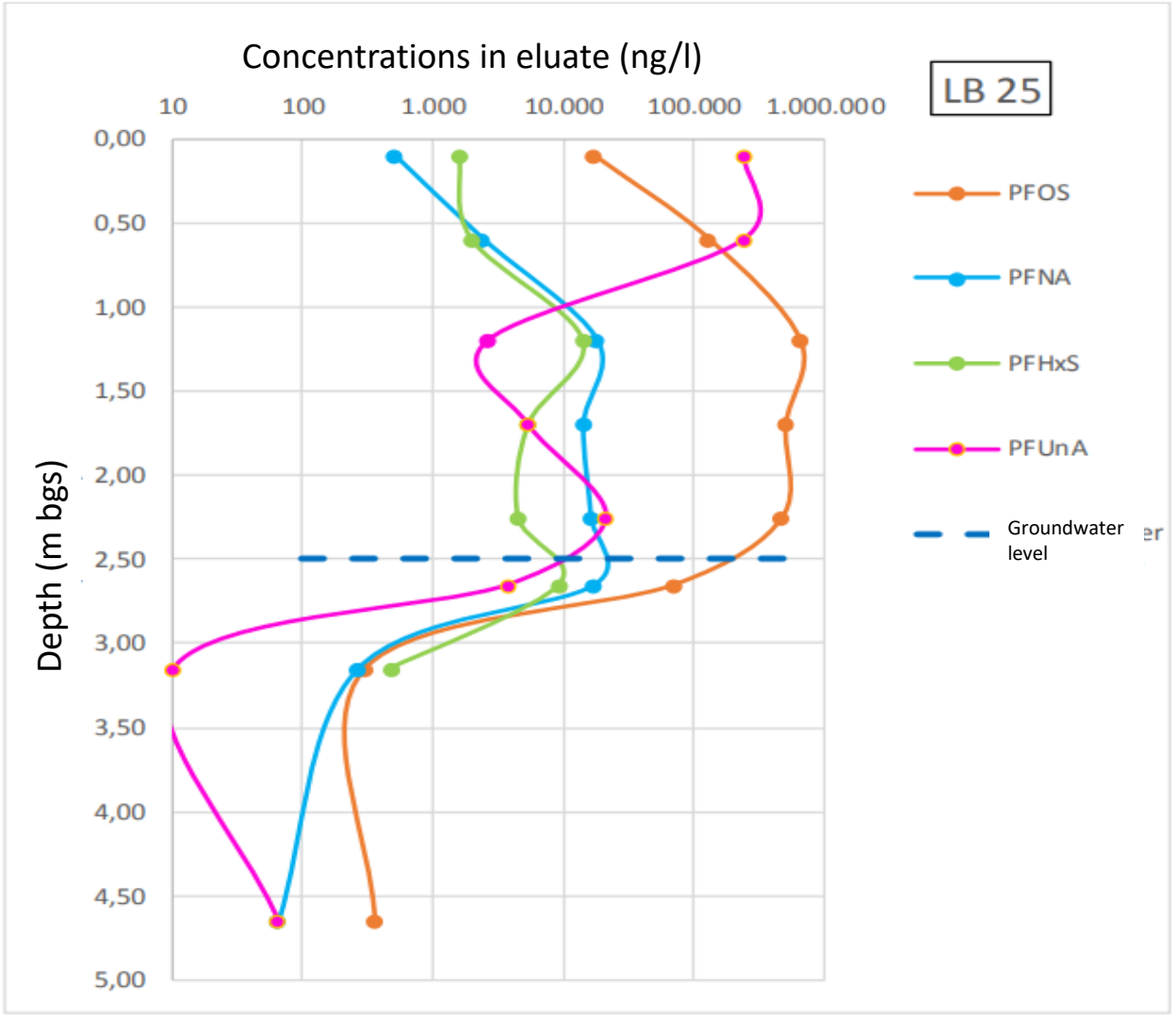
PFAS CONTAMINATION AT AIRPORT SITE





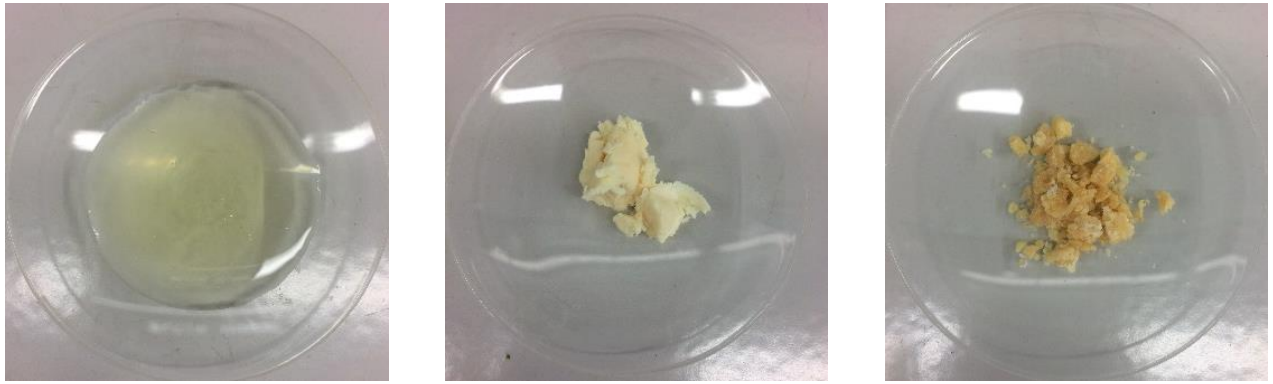
PFAS CONCENTRATION BEFORE ELUTION TREATMENT





BIOPOLYMERS

- surface-active substances
- easily biodegradable
- amphiphilic



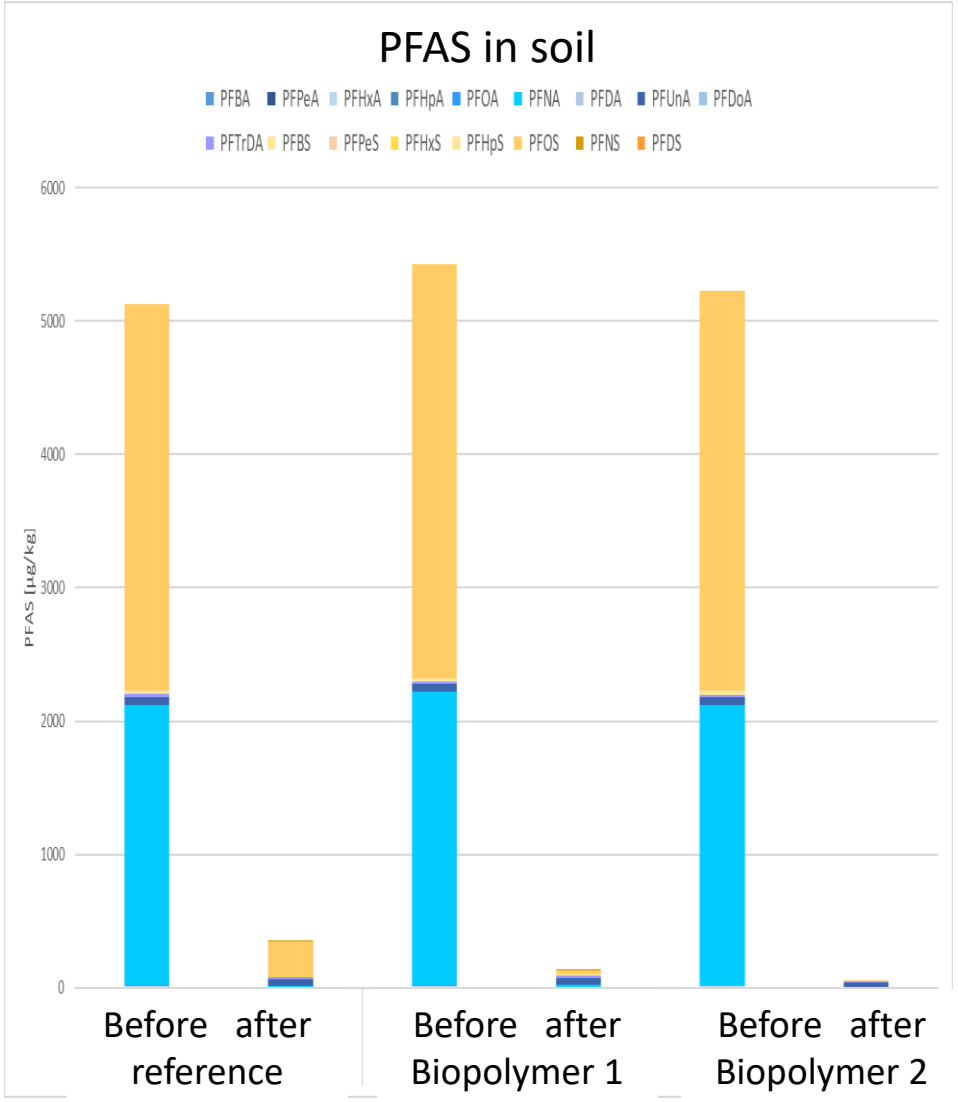
biopolymers

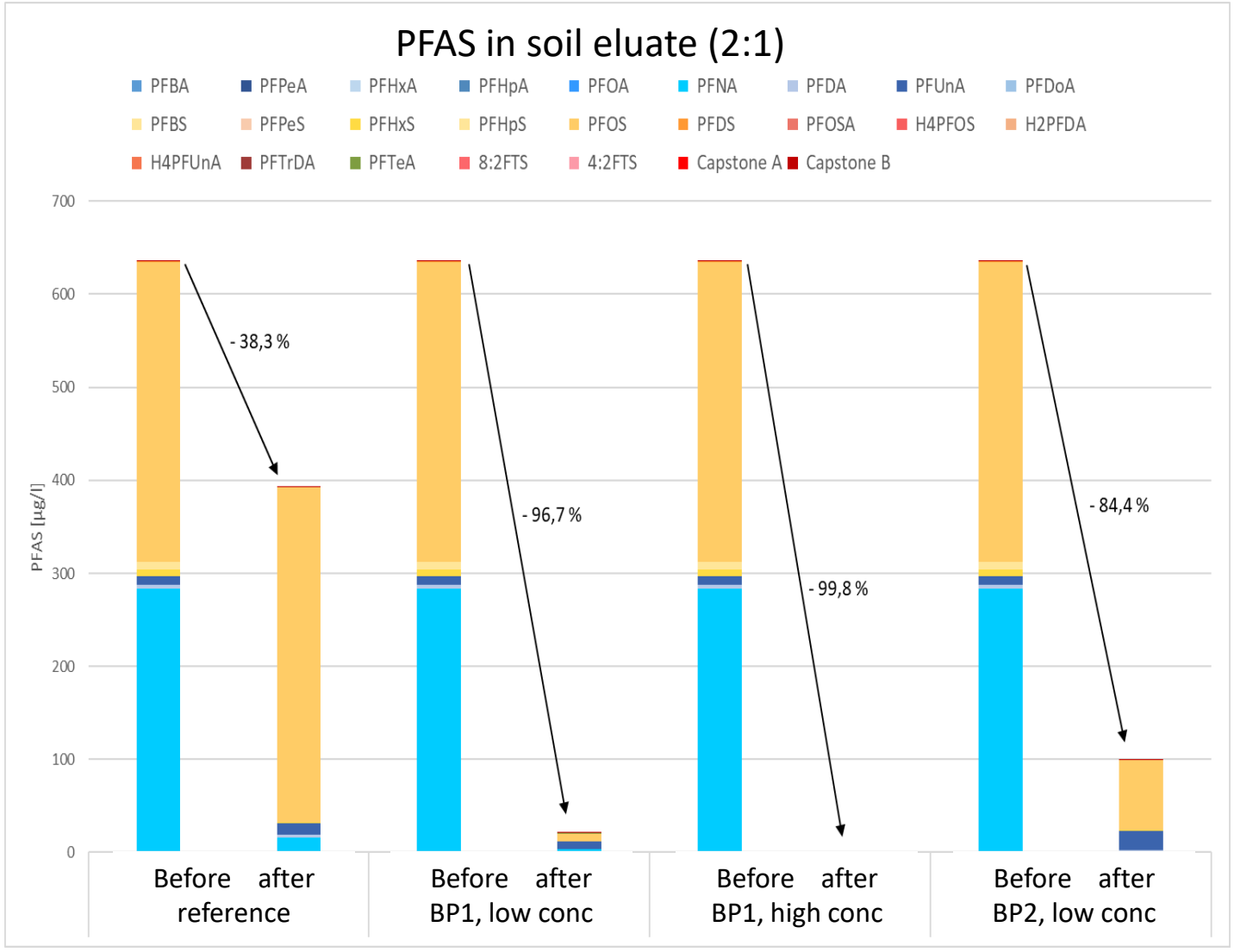
- main components:
  - amino acids
  - sugar compounds
  - fatty acids and lipids
- varying biopolymer compositions provide very different (elution) properties

DEVELOPMENT IN RECENT YEARS: BIOPOLYMER SCREENING

- Soil column analysis for the verification of PFAS elution and choice of biopolymer
- Soil from PFAS hot spot
- Testing procedure:
  - Application of different Biopolymers
  - Application of different concentrations & pH-value of washing solution
- Identification of PFAS elution efficiency, elution speed, best biopolymer concentration and elution procedure
- Quantification of PFAS elimination in soil eluate as well as solid matter analysis

RESULTS LAB FEASIBILITY AND OPTIMISATION STUDY





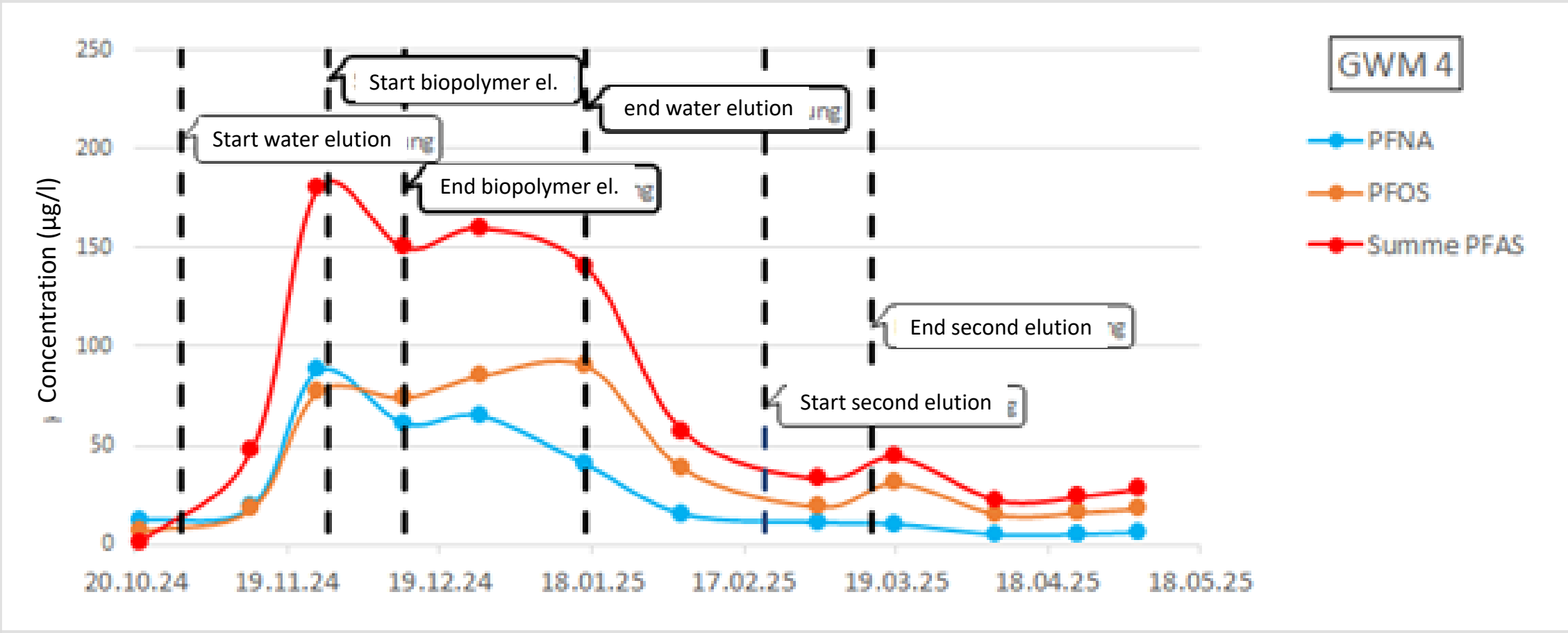
COMPLETED PROJECT – PFAS IN-SITU ELIMINATION AT KIEL AIRPORT

Project description:

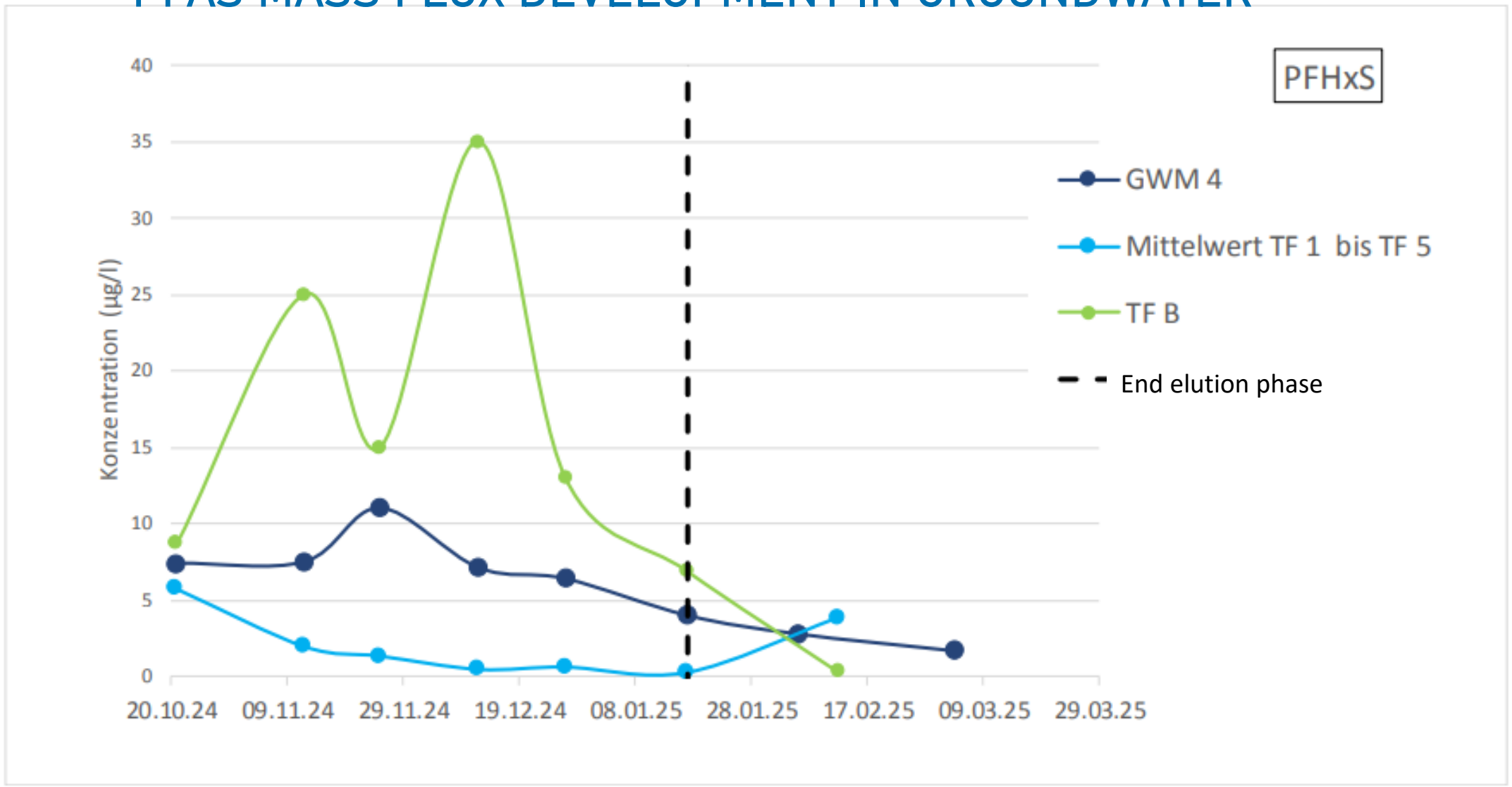
- Approx. 200 m² PFAS-contaminated site
- PFAS from fire-fighting event
- In-situ remediation approach 3 months
- Soil types: sand and loamy sand
- Application in winter months
- Total costs: below > 90,- €/to soil

TREATMENT UNIT FOR PILOT APPLICATION

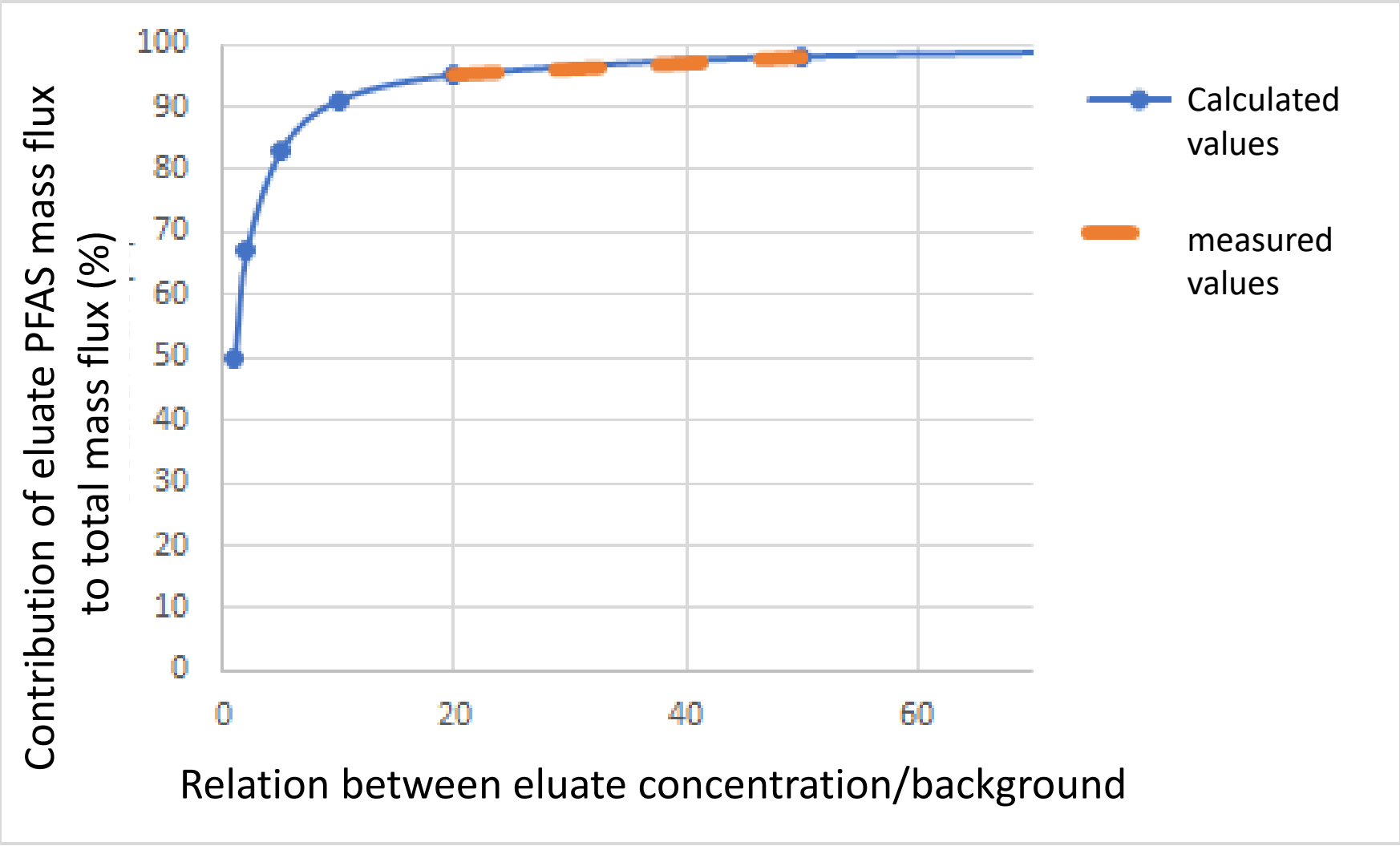
MOBILISATION OF PFAS DURING BIOPOLYMER FLUSHING



PFAS MASS FLUX DEVELOPMENT IN GROUNDWATER



CONTRIBUTION OF BIOPOLYMER FLUSHING TO PFAS MASS FLUX > 95%



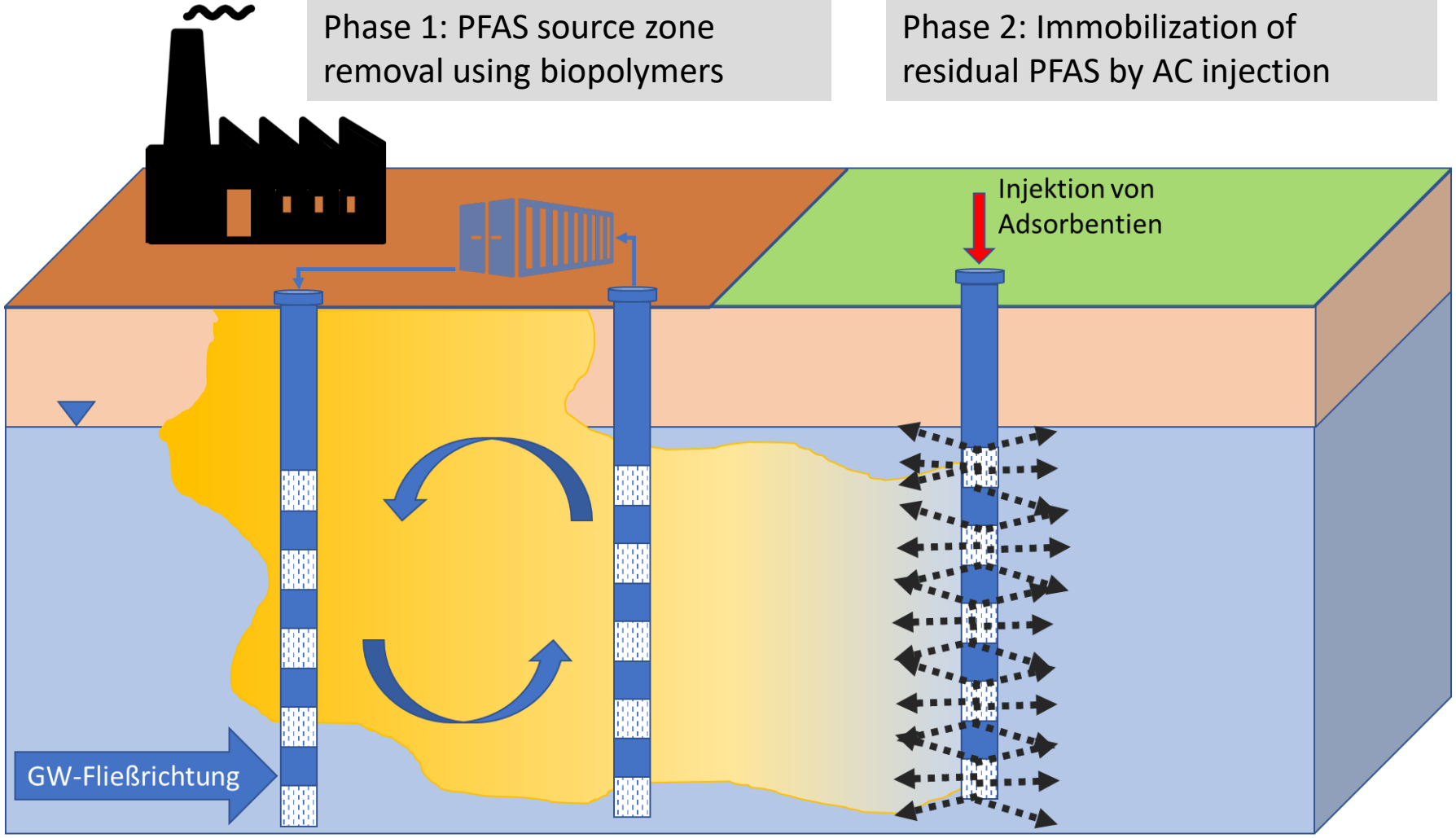
INTERMEDIATE CONCLUSIONS

- In-situ PFAS elution was very reliable
- PFAS mass flux elimination of >90% in 3 months application achieved
- Highest elution efficiency with short-chain PFAS (C4 to C8)
- soil specific characteristics and soil function remained intact
- Low PFAS elution potential remaining on site
- Economic solution for long-term securing of site after soil flushing desired
- Solution for long term-site securing: TSE drilling injection of high-quality GAC

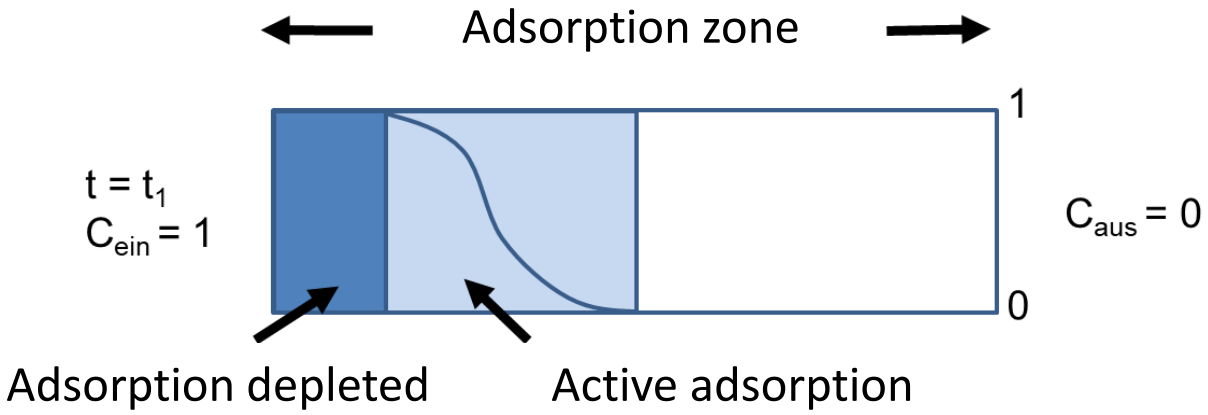
TREATMENT TRAIN FOR RESIDUAL PFAS

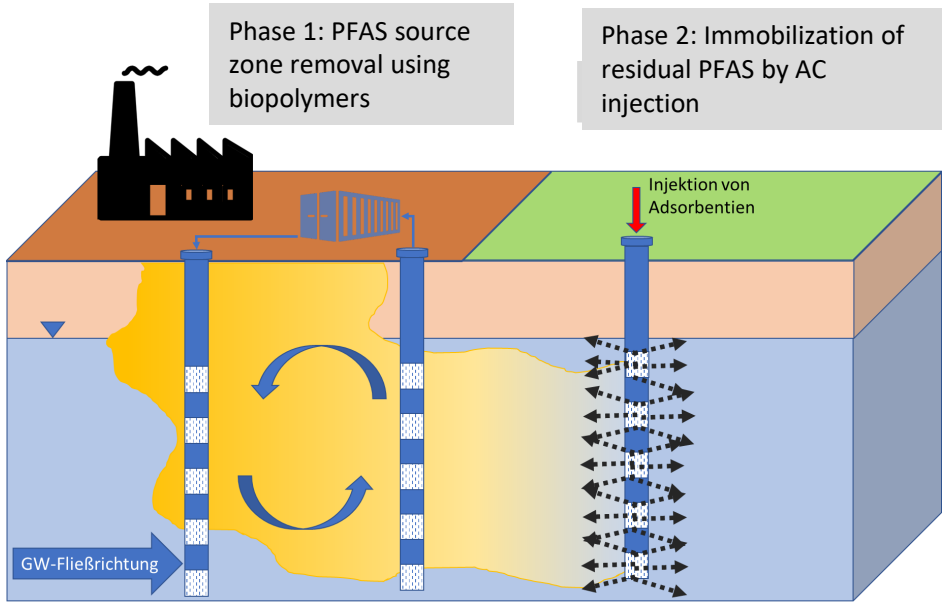
Phase 1: PFAS source zone removal using biopolymers

Phase 2: Immobilization of residual PFAS by AC injection



ANALOGY OF ACTIVE CARBON FILTERS AND ADSORPTION BARRIER



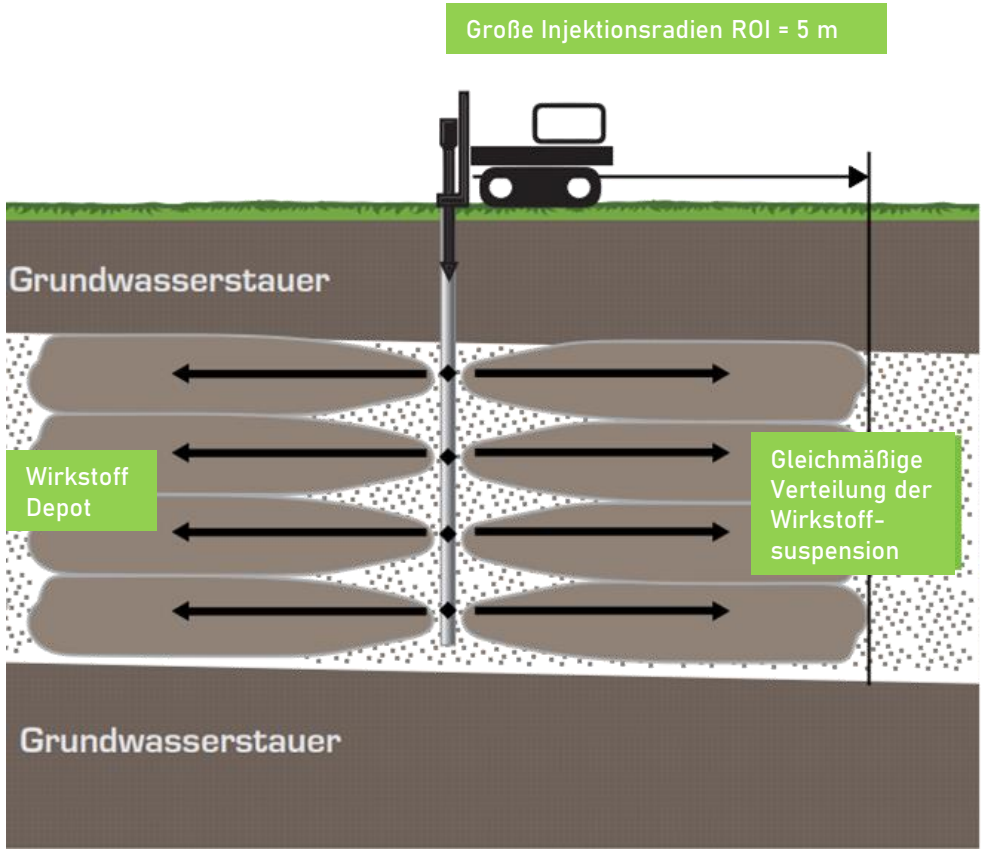


- Dimensioning the adsorption barrier is dependent on:
  - PFAS-yield and remediation target levels
  - PFAS-composition (especially short chain PFAS)
  - Groundwater flow velocity
  - PFAS adsorption isotherms = site dependent, especially on DOC, pH
  - Quantitative analysis in lab scale via site specific soil column tests

ACTIVE CARBON FOR THE IMPLEMENTATION OF PFAS ADSORPTION BARRIERS

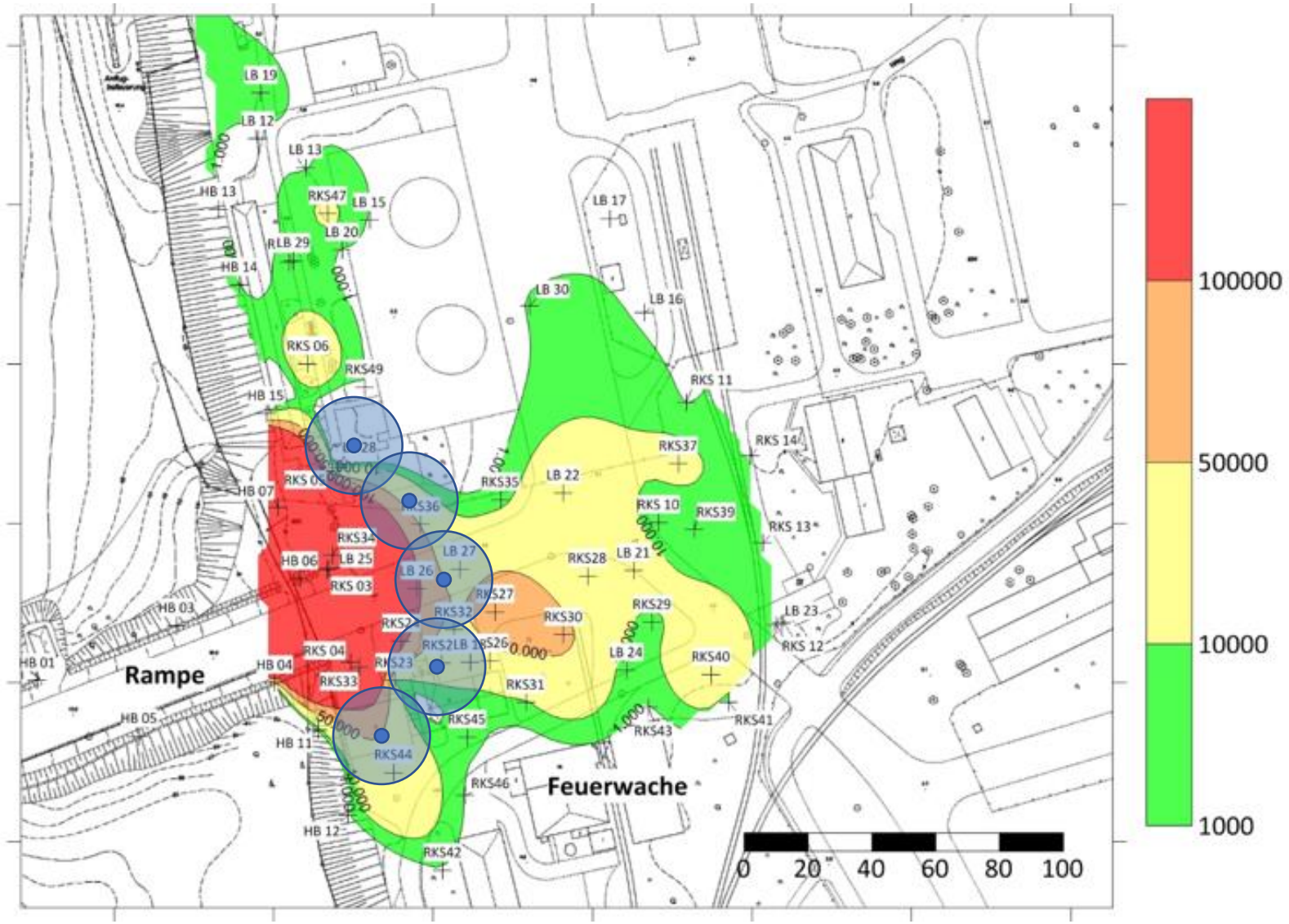
- granular / pulverized active carbon for high performance sorption of PFAS – no negative effect on hydraulic conductivity, can only be injected by solid matter injection technologies (e.g. TSE)
- Injected active carbon particles remain non-mobile in the aquifer
- When short-chain PFAS (C4 – C6) are present, only selected high quality active carbon material should be applied for good adsorption performance
- Colloidal active carbon products – easy to be applied, but will not work for short chain PFAS and is potentially very mobile in the aquifer (producing an activated carbon „plume“ facilitating PFAS mass flux increase)
- Competing sorption processes have to be taken into consideration for dimensioning active carbon barriers, especially soluble active carbon, pH-levels, polyvalent cations

TSE-TECHNOLOGY FOR THE INJECTION OF HIGH-QUALITY GRANULAR ACTIVE CARBON



- TSE technology: depth-specific injection of a highly viscous slurry by applying high hydraulic pressure via the drill casing directly onto the soil matrix (Environmental Fracturing)
- Carrier slurry prevents a separation of particles and ensures high injection radius of influence
- High pressure injection allows for injection also in a soil matrix with low hydraulic conductivity (clay, silt) and even rock structures
- Injection of solid particles creates a huge depot of adsorption matter in the aquifer
- If desired, large quantities of active carbon particles may be injected depth-specifically at a given site (several 100 kg / injection meter)

LONG TERM GAC IN-SITU BARRIER FOR REMAINING PFAS AFTER MASS FLUX BREAKDOWN



CONCLUSIONS AND OUTLOOK

- PFAS in-situ elution technology works reliably in the field
- The technology is applicable In-situ and On-site
- PFAS removal of up to 95% technically feasible
- PFAS mass flux breaks down by > 90%
- soil specific parameters are not destroyed and stay intact
- Technical option for long-term securing – TSE-injection of high-quality GAC
- Very economic solution and alternative to dig and dump
- Cooperation in Europe between Sensatec and Greensoil

Management of PFAS: Per- & Polyfluoro-Alkyl Substances:

Environmental Contaminations & Health Risk

Thank You !

Questions? Remarks? Requests?

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