

PFAS⁺

PER- AND POLY-FLUOROALKYL SUBSTANCES



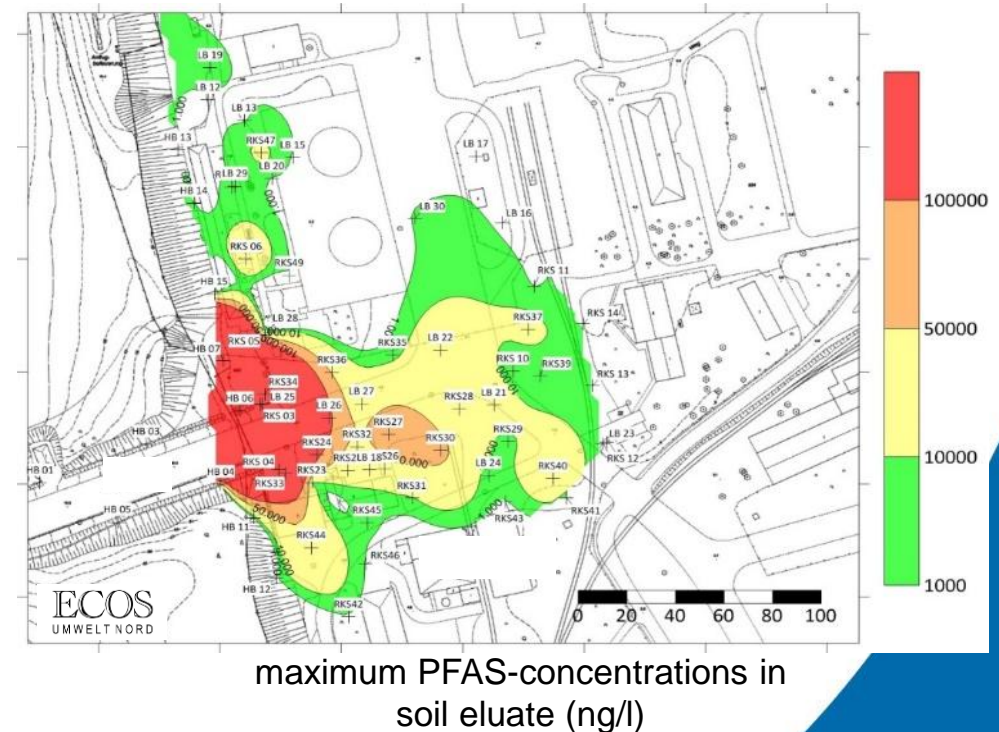
TREATMENT OF SOIL BY IN-SITU
PFAS WASHING WITH PROTEINIC
BIO-POLYMERS – FULL SCALE
APPLICATION AT AN AIRPORT SITE IN
NORTHERN GERMANY

27.11.2025

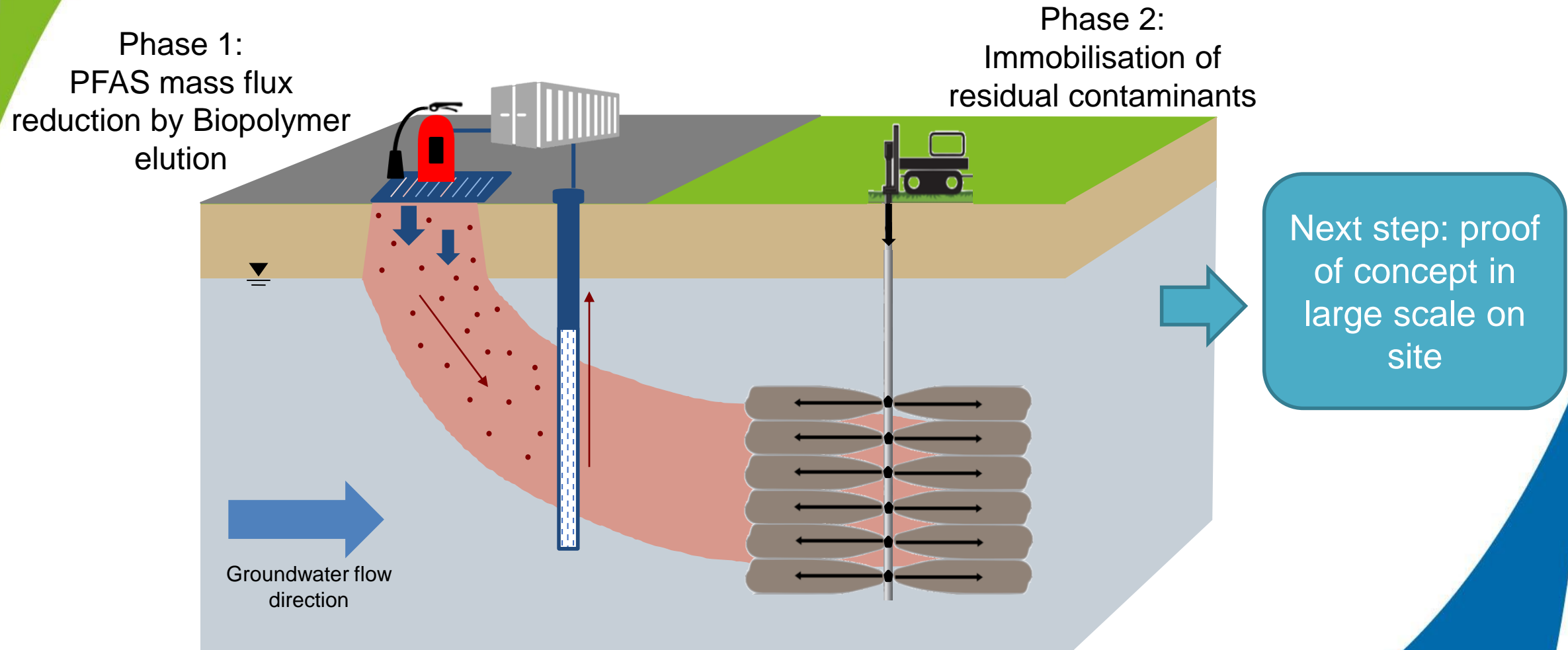
Dr. Stephan Hüttmann

PFAS CONTAMINATED SITE – PREFERRED REMEDIATION STRATEGY

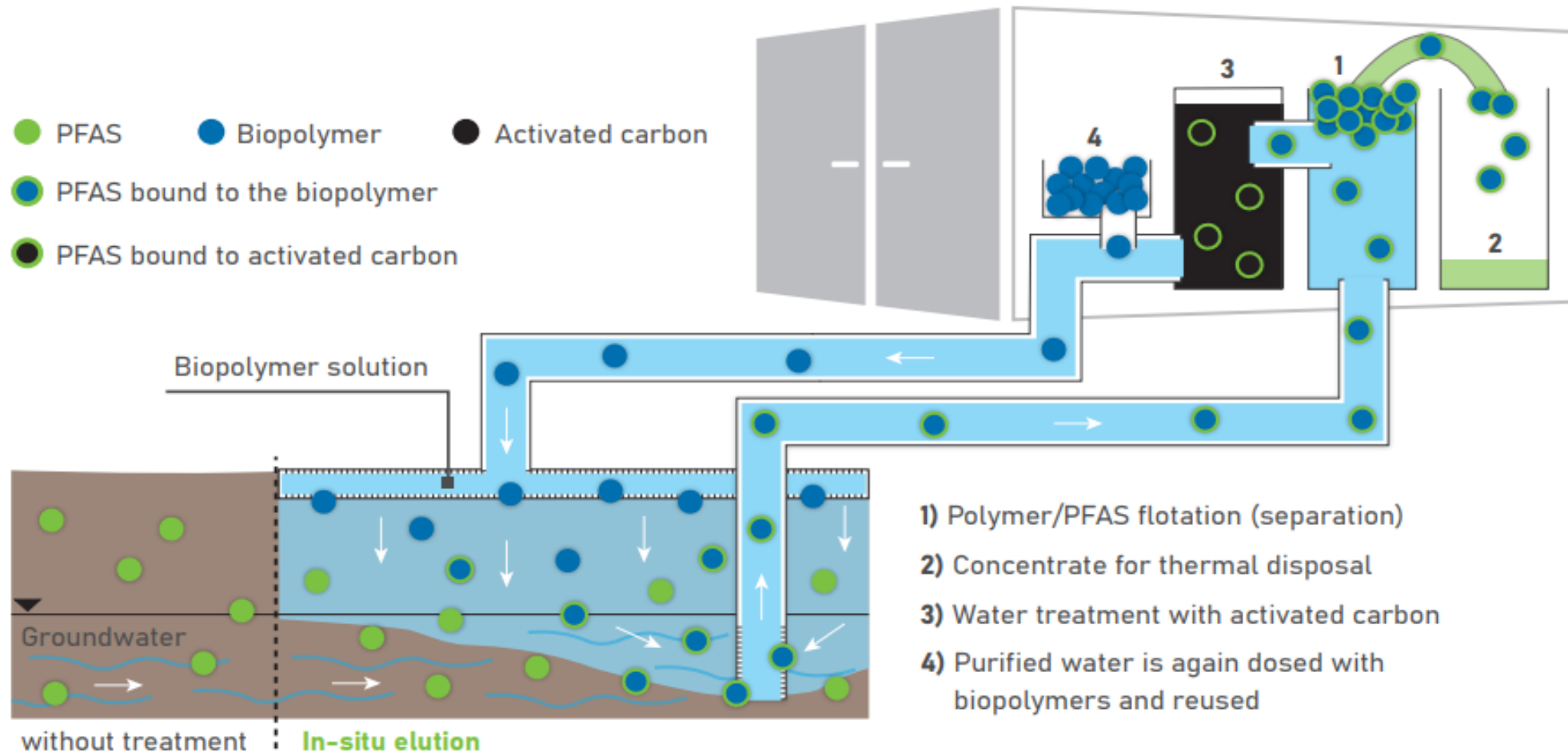
- Introduction of PFAS through AFFF fire fighting foams
 - Multiple points of PFAS entry → multiple contaminant plumes
 - According to remediation analysis the preferred remediation is securing of the site
 - Securing of PFAS close to source zones by means of sorption barriers
 - Securing of plumes only where necessary
 - in situ PFAS soil elution as means to → elimination of PFAS mass flux
 - Maximisation of lifetime of sorption barrier
- ➡ Combined in-situ-remediation strategy



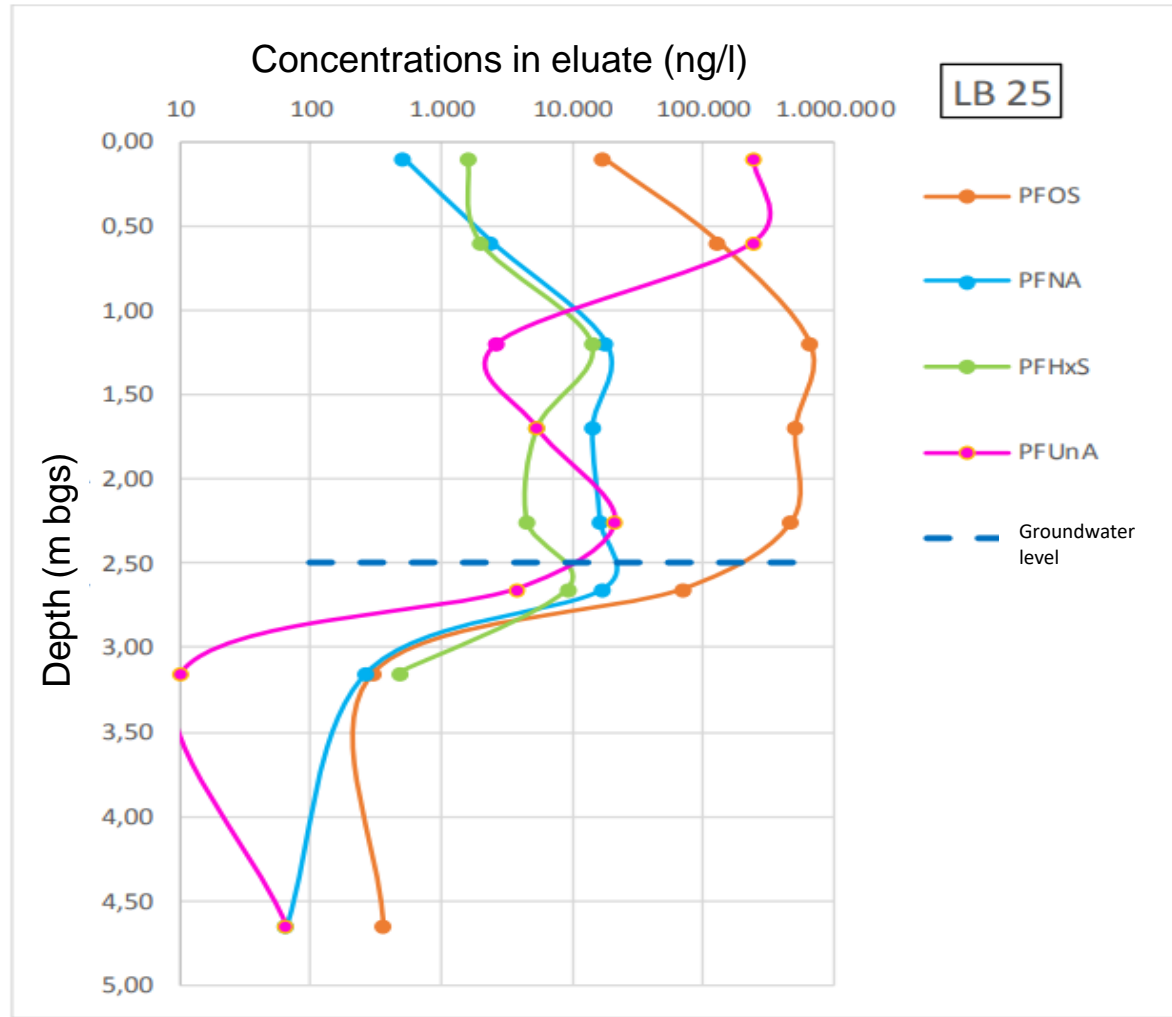
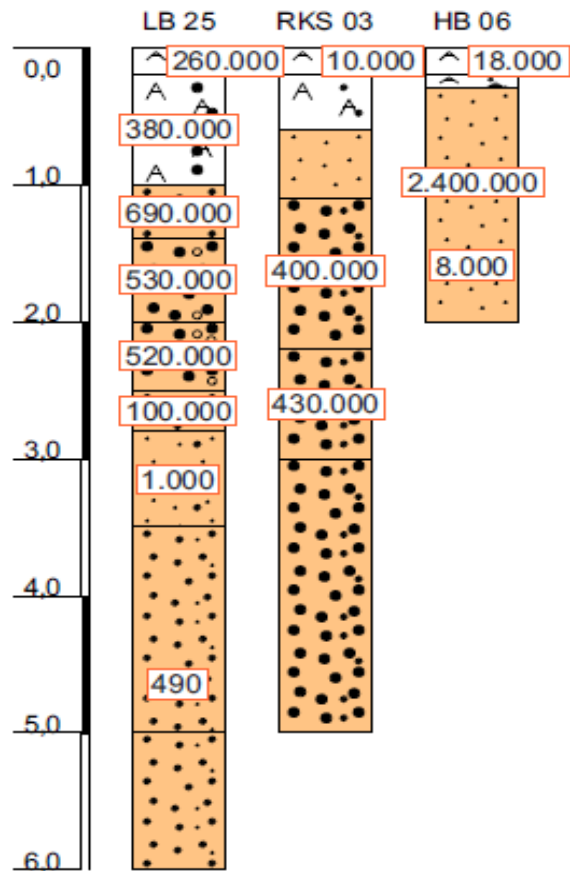
PFAS CONTAMINATED SITE – PREFERRED REMEDIATION STRATEGY



IN-SITU APPLICATION FOR PFAS-ELIMINATION SOIL/GROUNDWATER



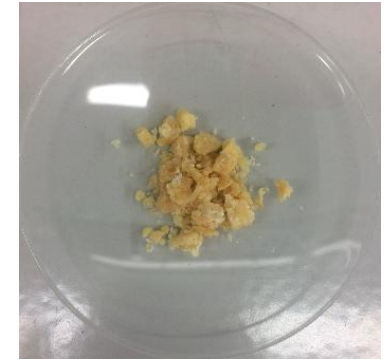
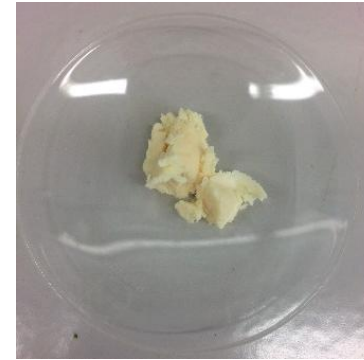
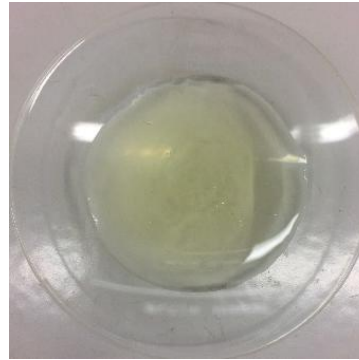
PFAS CONCENTRATION BEFORE ELUTION TREATMENT



BIOPOLYMERS

- ▶ Surface-active substances
- ▶ Easily biodegradable
- ▶ Amphiphilic

- ▶ Main components:
 - Amino acids
 - Sugar compounds
 - Fatty acids and lipids



Biopolymers

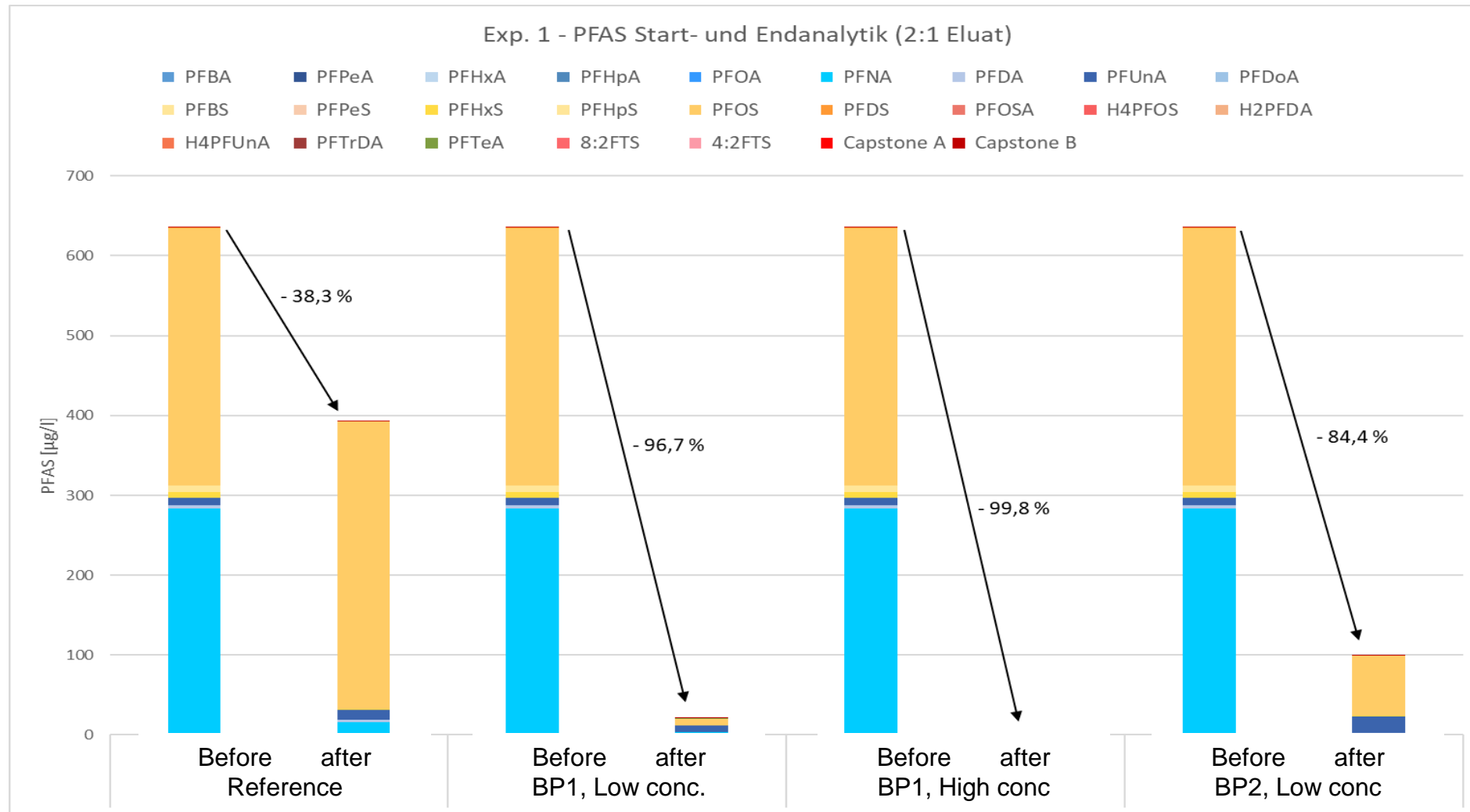
- ▶ **Varying biopolymer compositions provide very different (elution) properties**

DEVELOPMENT IN RECENT YEARS: BIOPOLYMER SCREENING

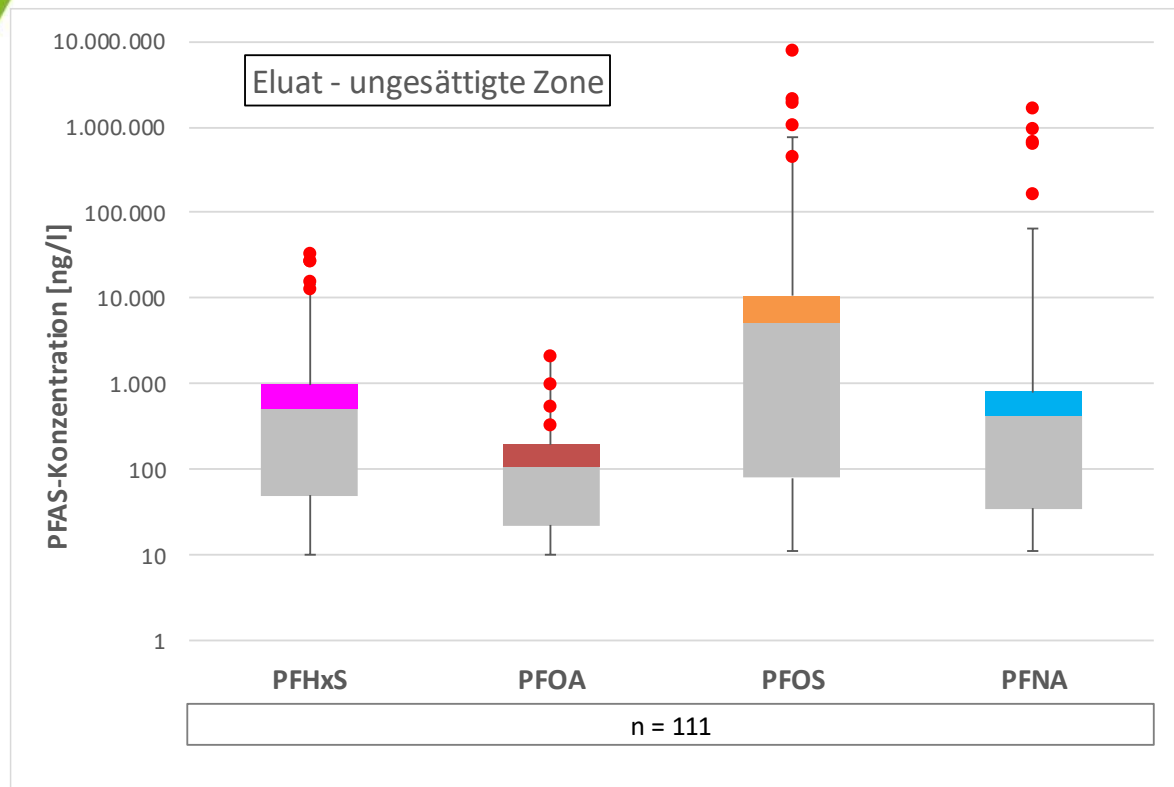
- ▶ Soil column analysis for the verification of PFAS elution and choice of biopolymer
- ▶ Soil from PFAS hot spot
- ▶ Testing procedure:
 - Application of different Biopolymers
 - Application of different concentrations & pH-value of washing solution
- ▶ Identification of PFAS elution efficiency, elution 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



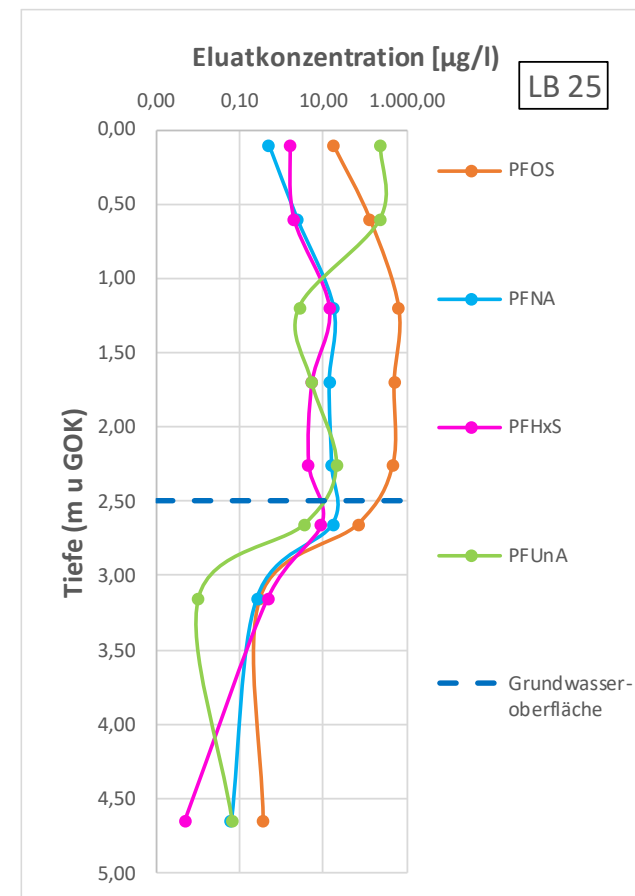
INITIAL SOIL CONTAMINATION BEFORE REMEDIATION START



Boxes: distribution of data during site investigation

red dots: initial contamination in remediation area

➡ pilot application in maximum „Hot-Spot area“

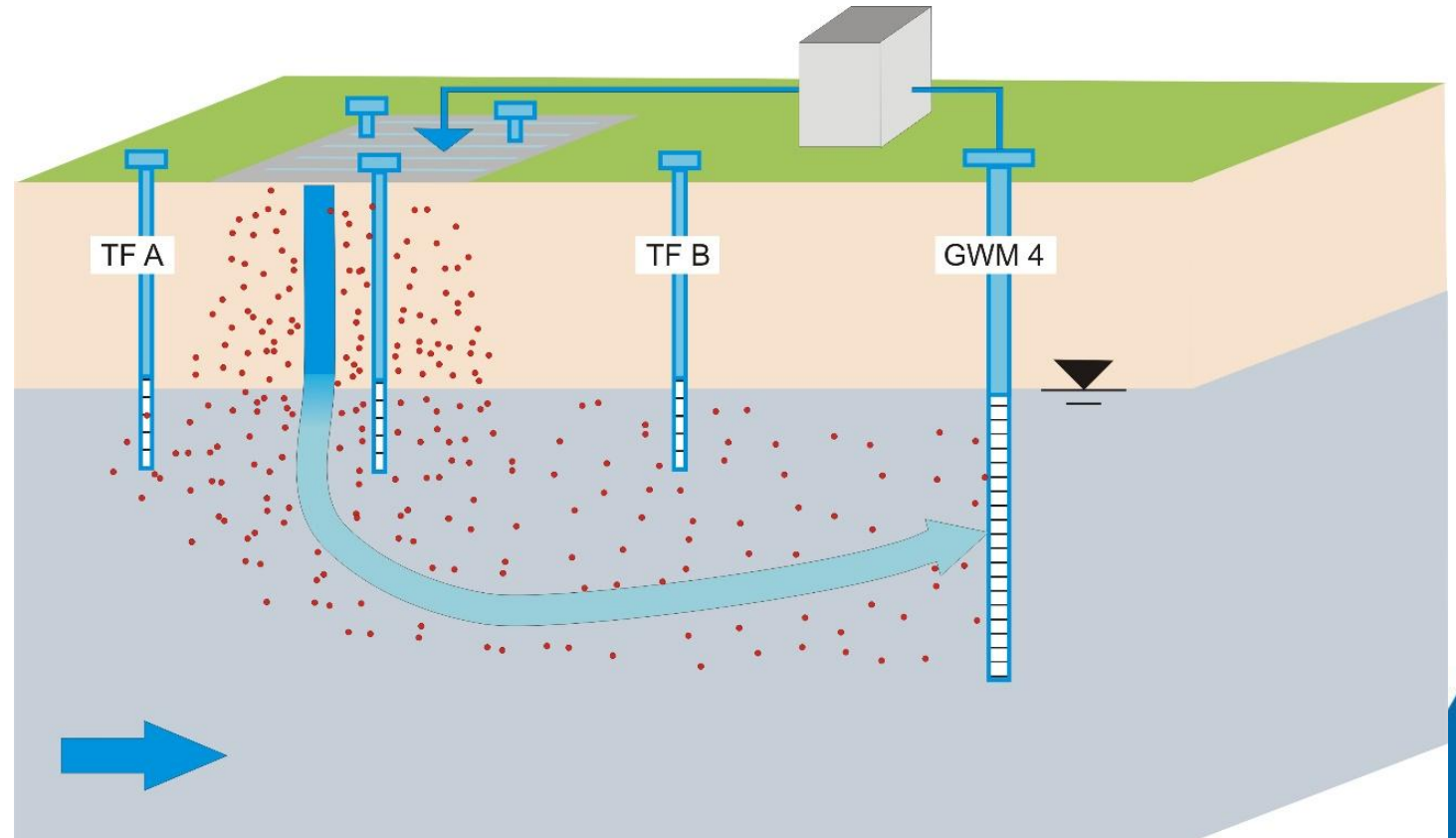
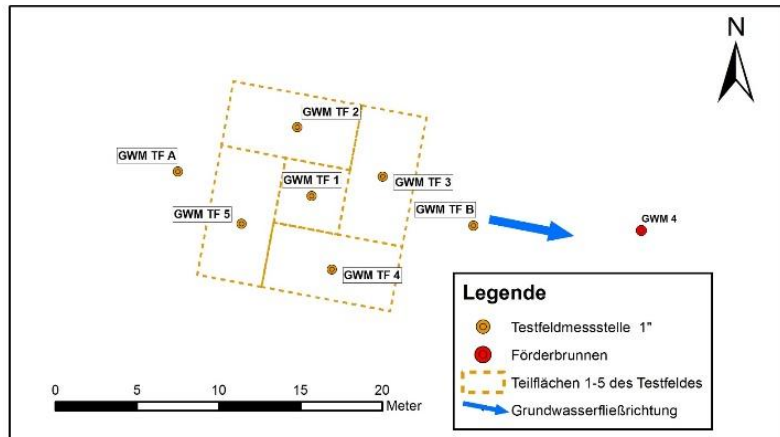


Vertical distribution of PFAS:

PFOS, PFNA and PFHxS: similar

PFUnDA: low vertical transport

APPLICATION OF PFAS IN-SITU ELUTION AT THE SITE



EXECUTION FOR 5 MONTHS MOSTLY DURING WINTER TIME

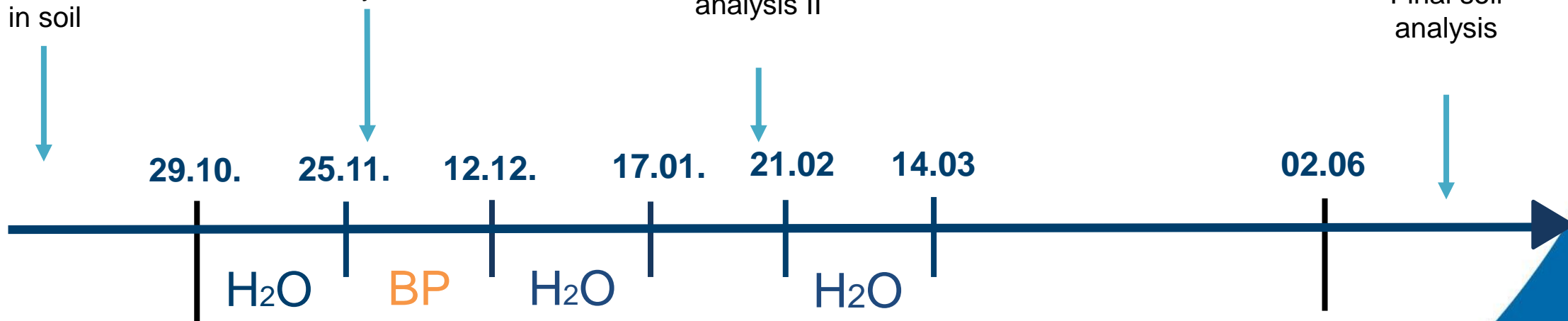


investigation
of
contamination
in soil

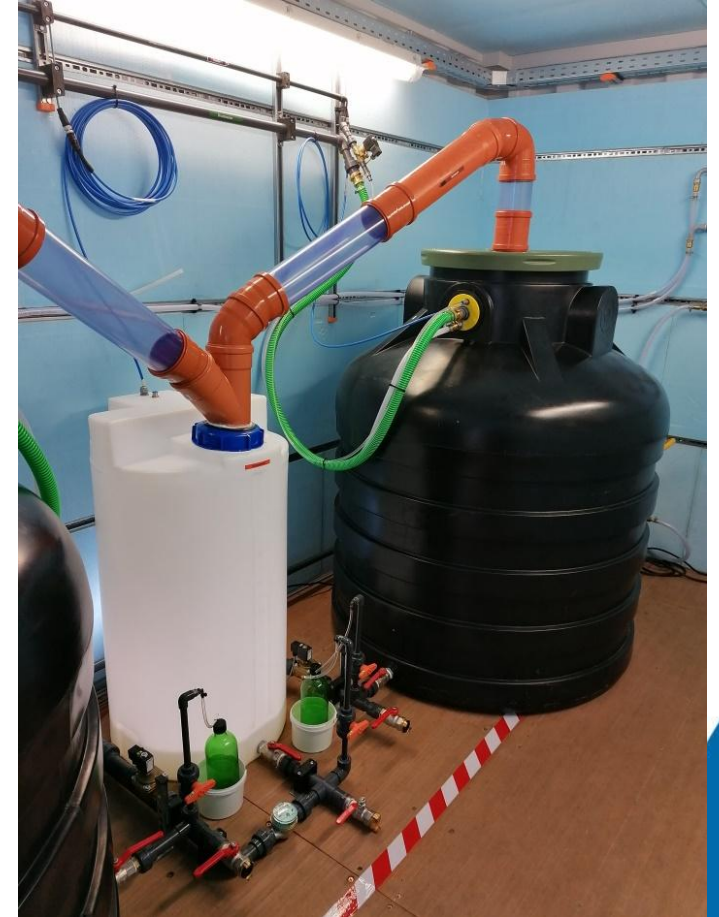
Intermediate soil
analysis I

Intermediate soil
analysis II

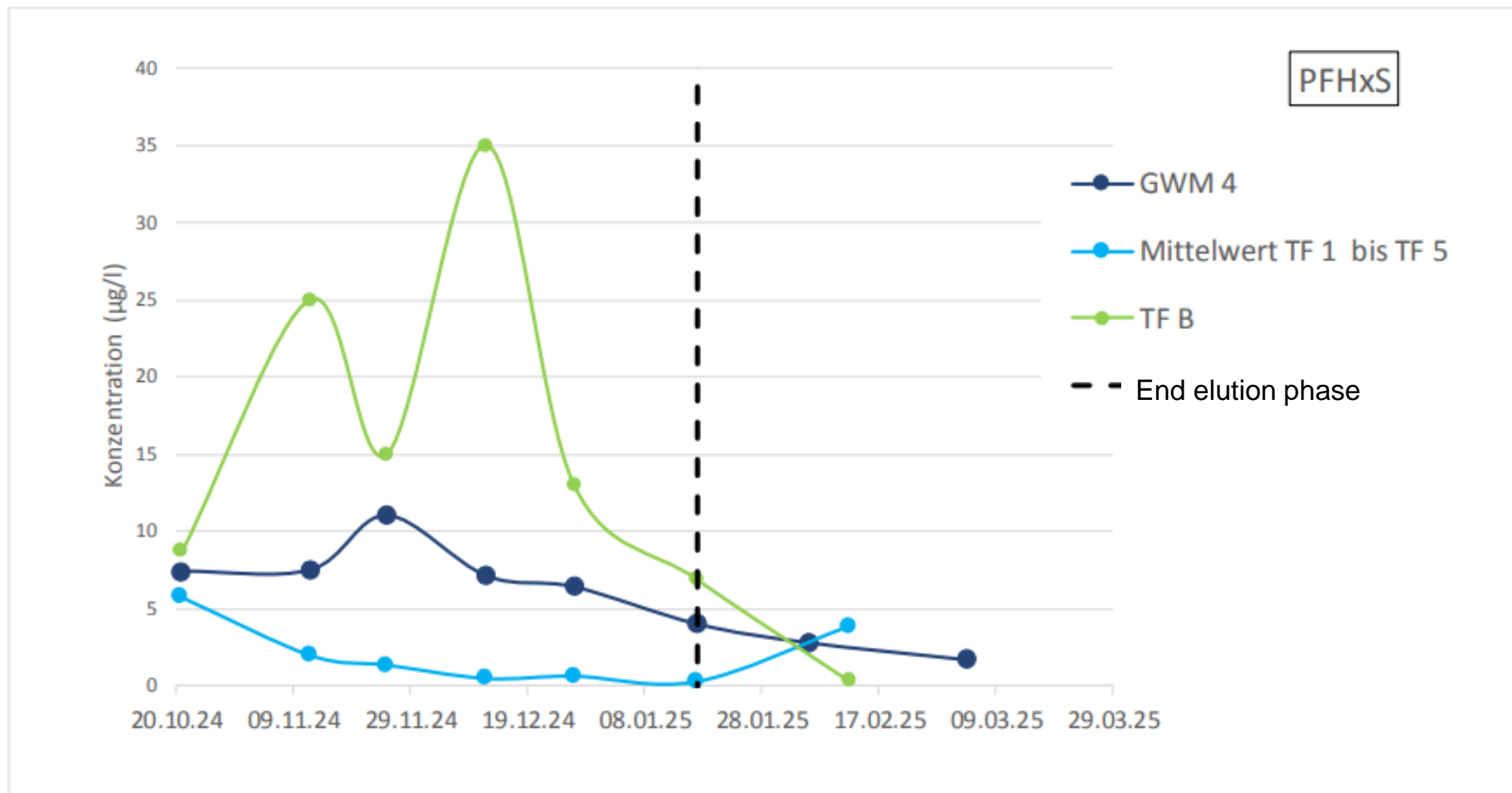
Final soil
analysis



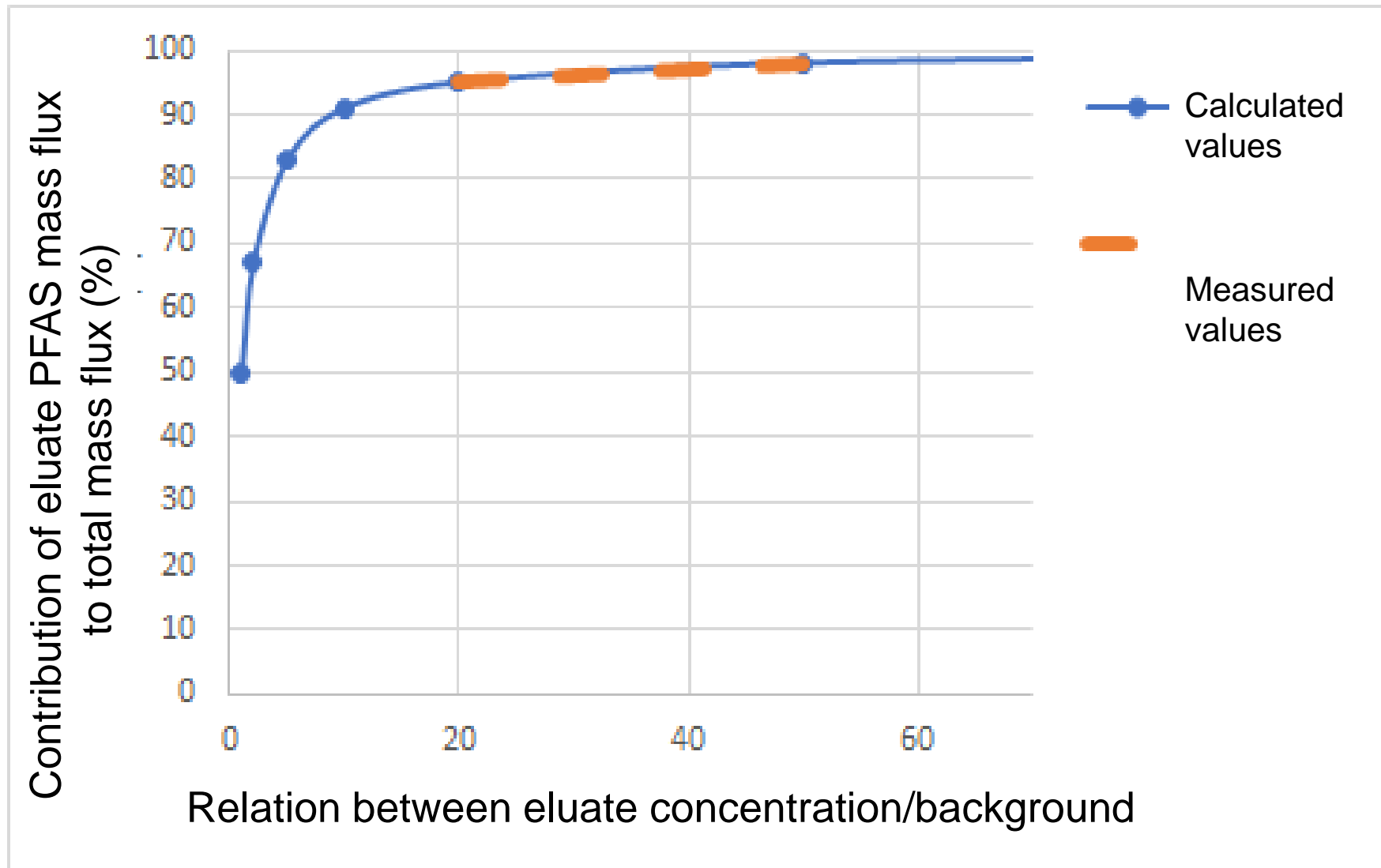
TREATMENT UNIT FOR PILOT APPLICATION



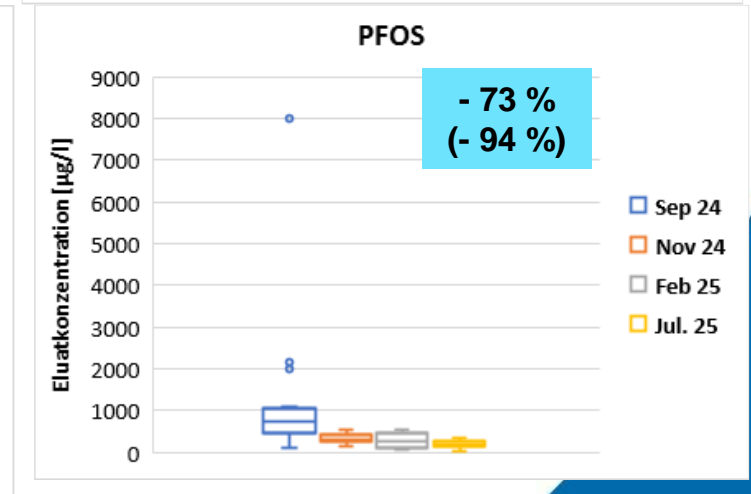
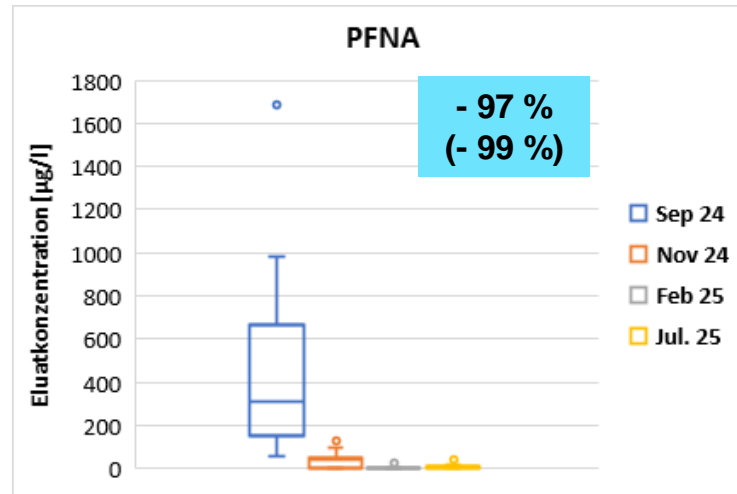
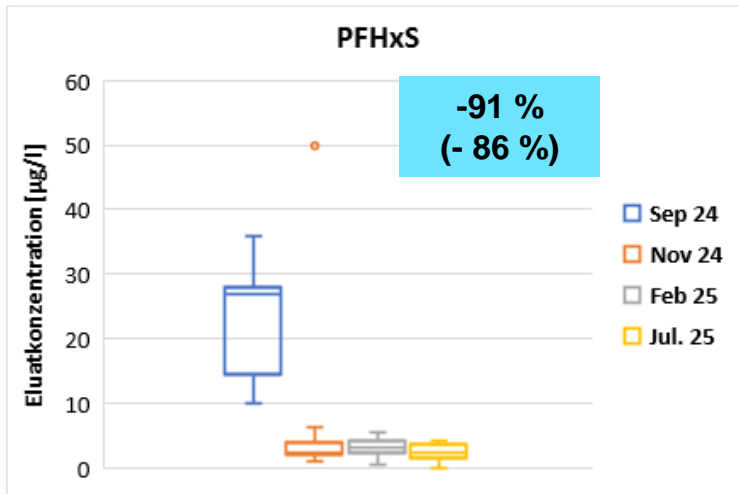
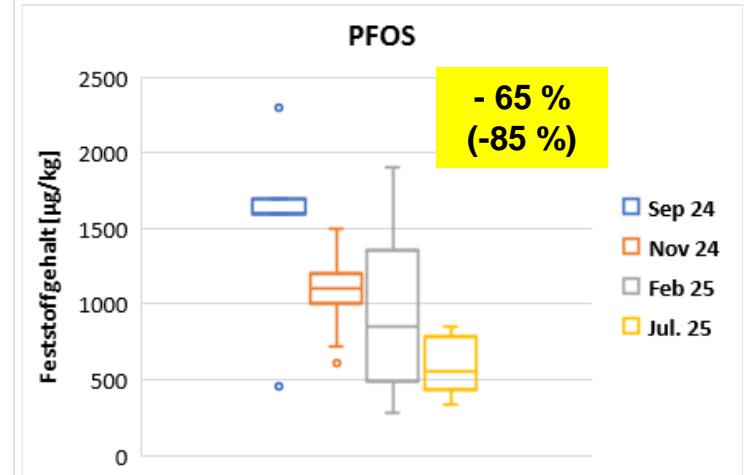
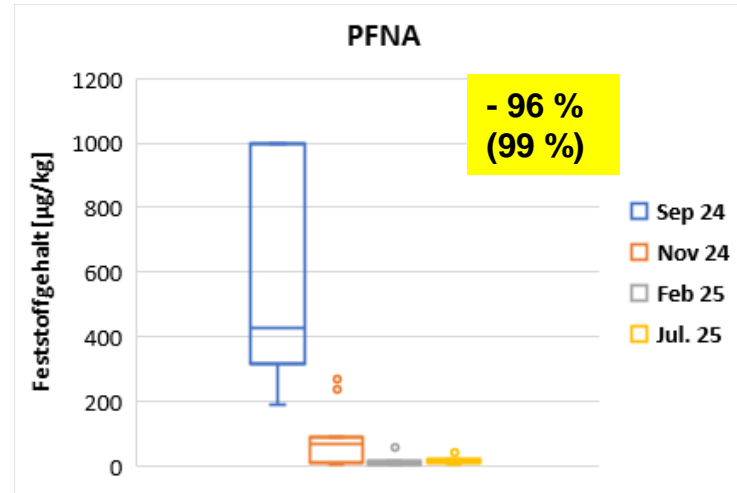
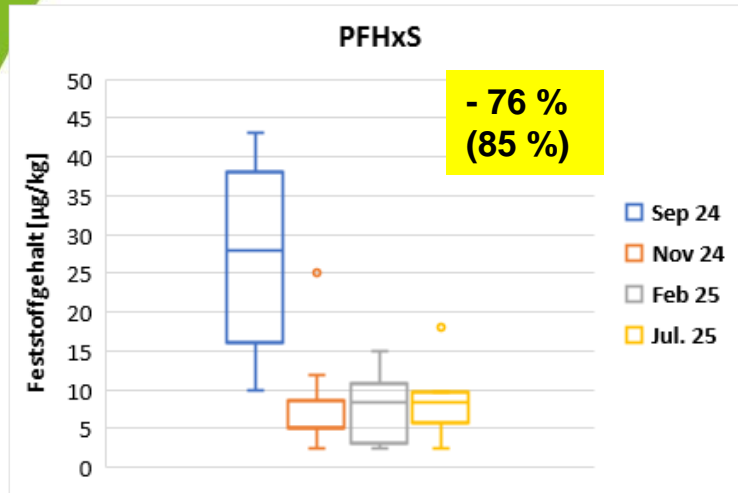
PFAS MASS FLUX DEVELOPMENT IN GROUNDWATER



CONTRIBUTION OF BIOPOLYMER FLUSHING TO PFAS MASS FLUX > 95%



FINAL SAMPLING: RELEVANT REDUCTION OF PFAS IN SOIL AND IN SOIL ELUATE



CONCLUSIONS AFTER COMPLETION OF PFAS SOIL ELUTION

Project outcome:

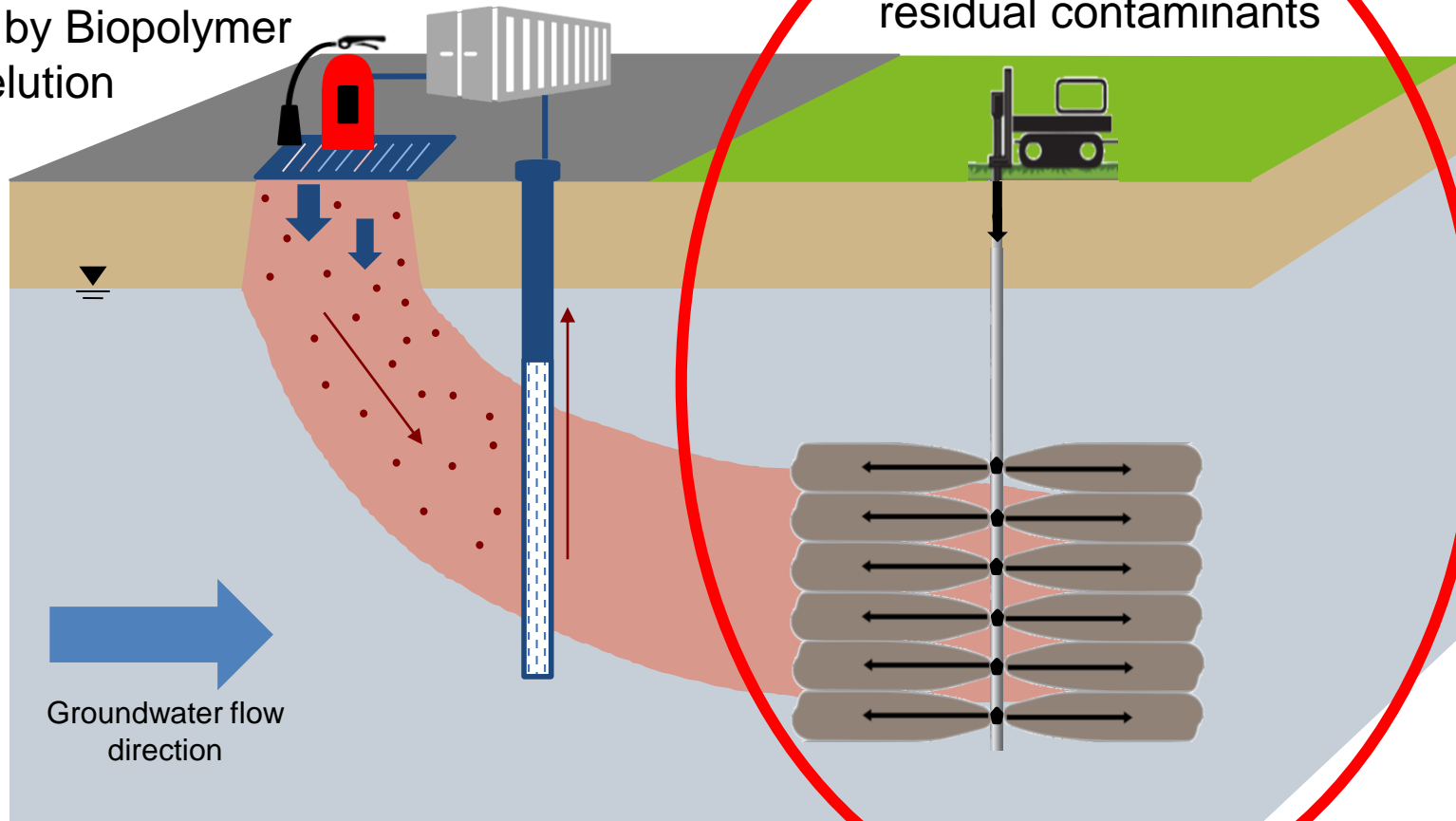
- 1000 m³ PFAS-contaminated soil treated
- > 90% of PFAS mass flux eliminated
- Remediation time 5 months
- Soil functions remained intact
- No waste created except for PFAS conc.
- Costs: below > 90,- €/to soil



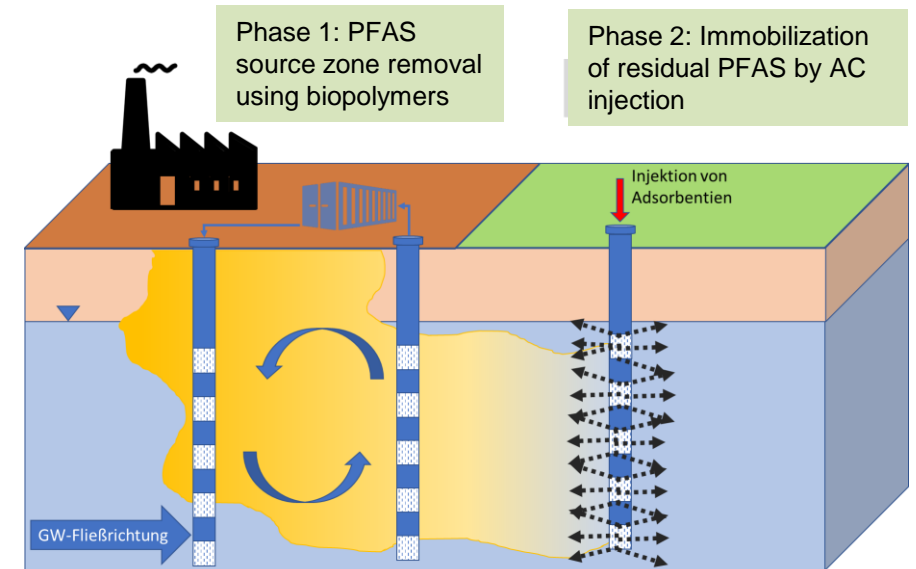
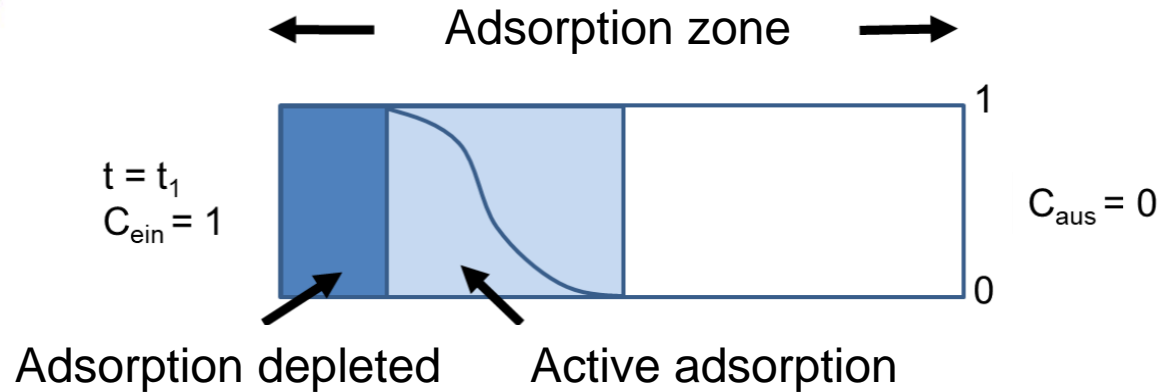
STEP 2: IMMOBILIZATION OF RESIDUAL PFAS

Phase 1:
PFAS mass flux
reduction by Biopolymer
elution

Phase 2:
Immobilisation of
residual contaminants



ANALOGY OF ACTIVE CARBON FILTERS AND ADSORPTION BARRIER



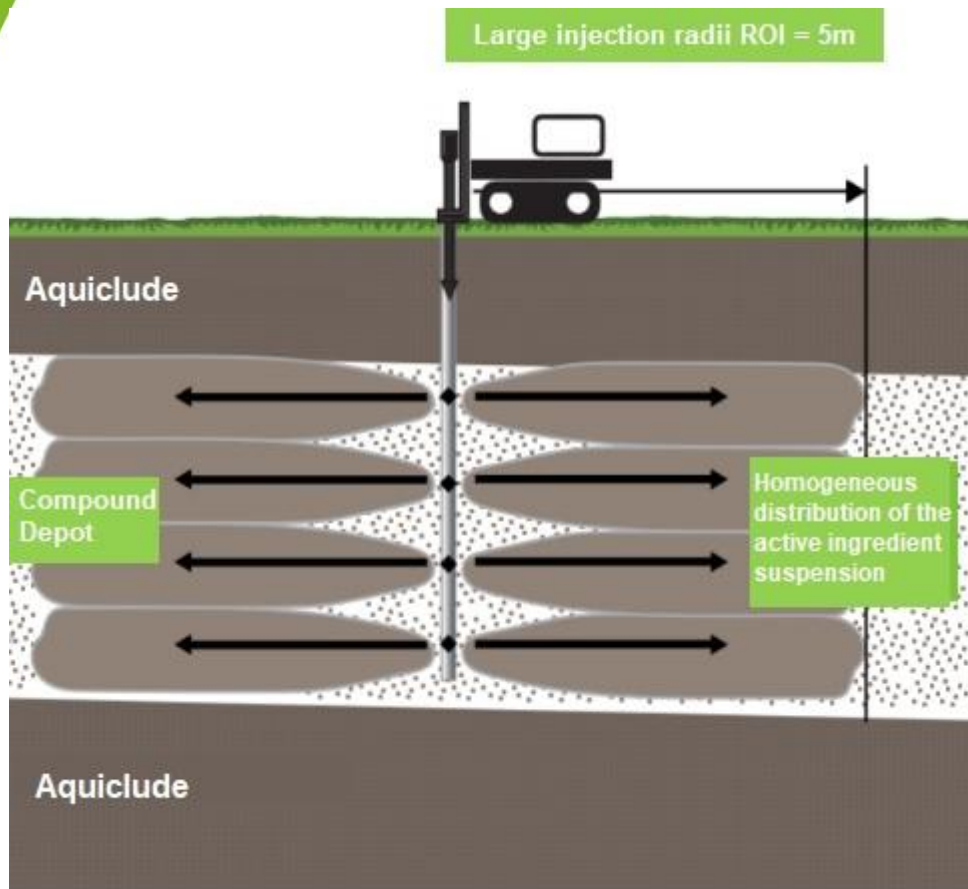
► Design of the adsorption barrier is based on:

- 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

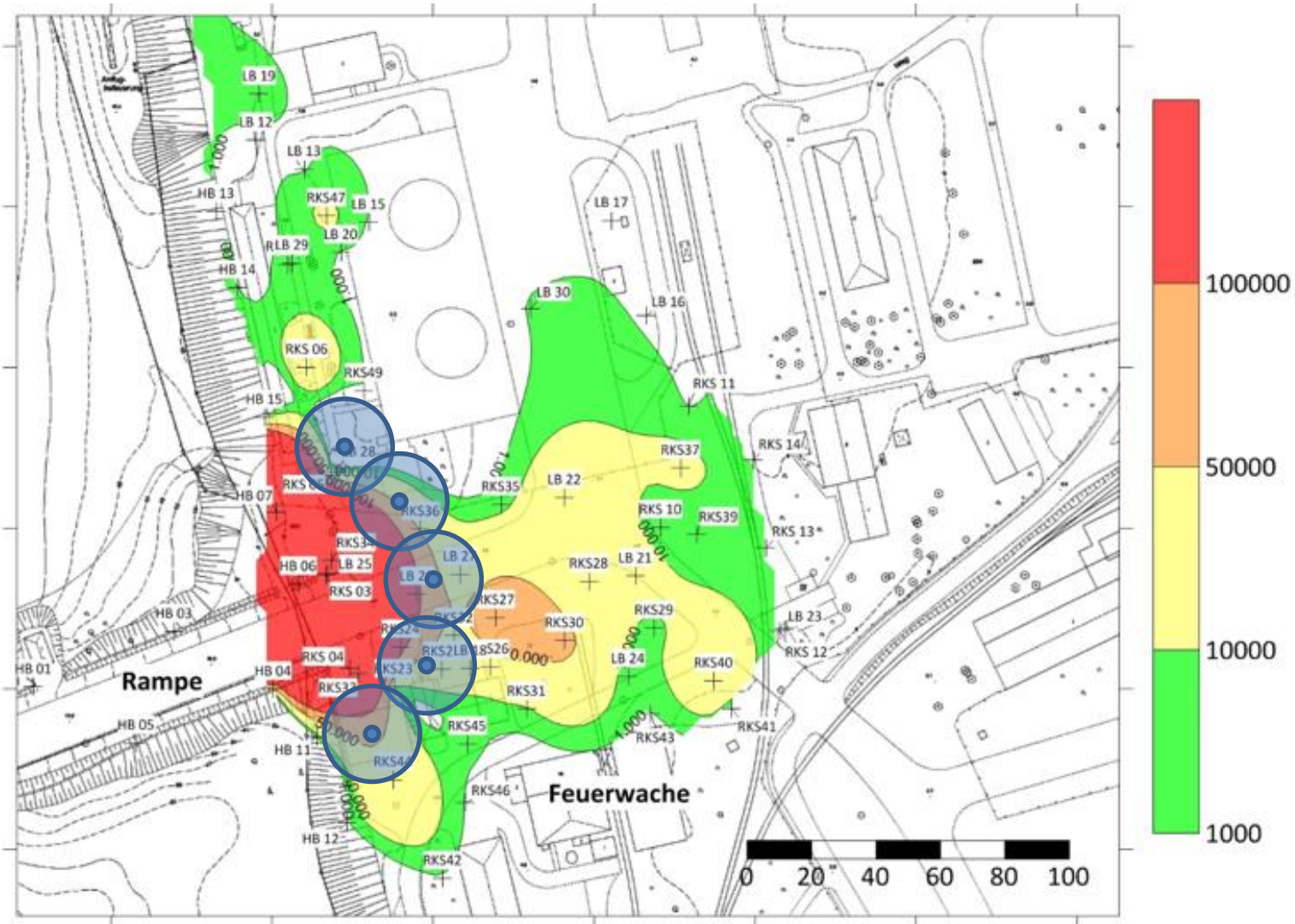


- ▶ TSE technology: depth-specific injection of a highly viscous slurry by applying high hydraulic pressure via the drill casing directly onto the soil matrix (Environmental Fracturing)
- ▶ Carrier slurry prevents a separation of particles and ensures high injection radius of influence
- ▶ High pressure 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)

TSE-TECHNOLOGY APPLIED IN THE FIELD FOR GAC INJECTION



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

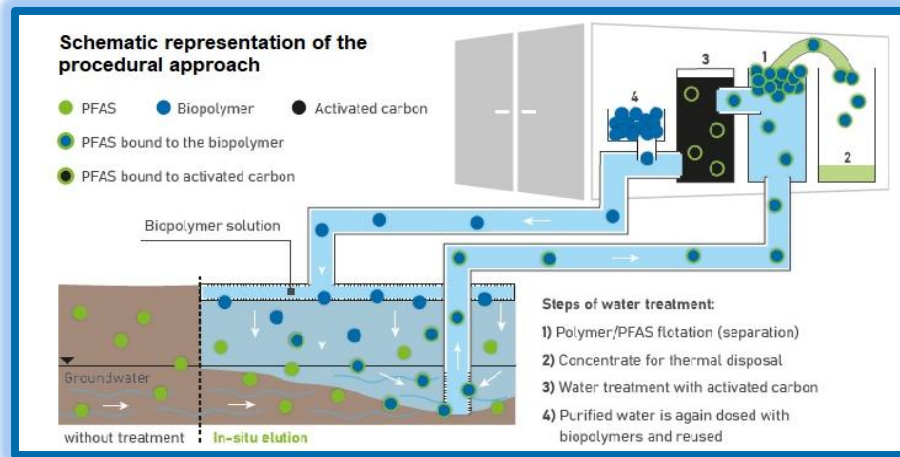


CONCLUSIONS AND OUTLOOK

- ▶ 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% is feasible, mass flux reduction > 90%
- ▶ soil specific parameters are not destroyed, soil functions not compromised
- ▶ Technical option for long-term securing – TSE-injection of high-quality GAC
- ▶ No waste created except for PFAS concentrate, relevant alternative to dig and dump
- ▶ Cooperation in Europe between Sensatec, Greensoil and HPC International

THANK YOU !

QUESTIONS? REMARKS? REQUESTS?



KONTAKT

Sensatec GmbH
Sanierungs- und Sensoriktechnologien

Friedrichsorter Str. 32
D-24159 Kiel

s.huettmann@sensatec.de
a.wilken@sensatec.de

info@sensatec.de

www.sensatec.de