Universität Stuttgart
Research Facility for Subsurface Remediation

VEGAS

PFAS Fate and Transport in the Subsurface

and Remediation Approaches

Claus Haslauer claus.haslauer@iws.uni-stuttgart.de

Copenhagen, 6-Nov-2024

VEGAS Vision & Strategy

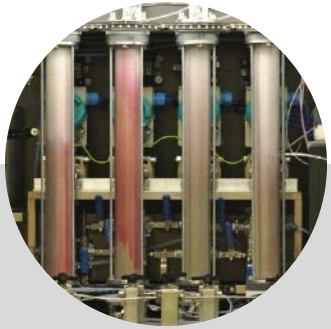
Bridging the Gap Across Scales

High Information Density

Batch

Varying concentrations and behavior of reactions

0D



Columns

Interaction with porous media, hydraulic processes

1D

„Sand box“

Additional processes, contaminant migration

2D

VEGAS tank™

9 m x 6 m x 4 m

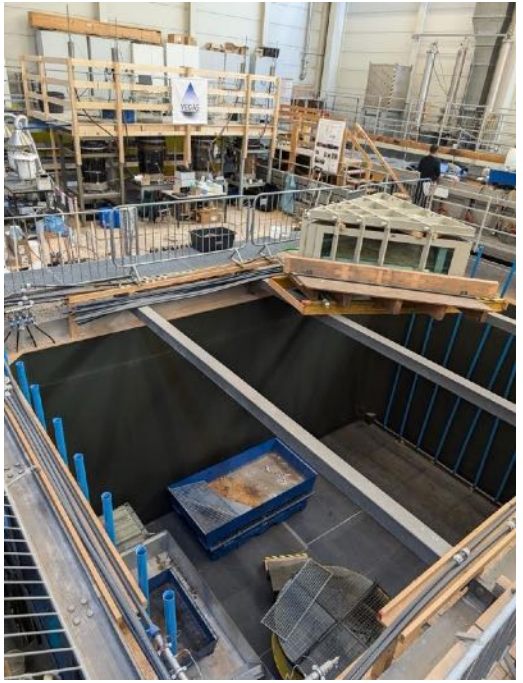
Verification, heterogeneity, density-effects, pilot-scale

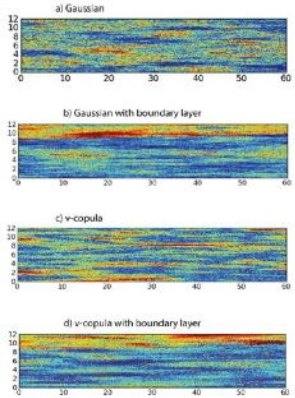
3D

VEGAS Methods

analytical chemistry lab
all major contaminants
(e.g., Orbitrap, CIC, ICP)

well-controlled experiments at various scales

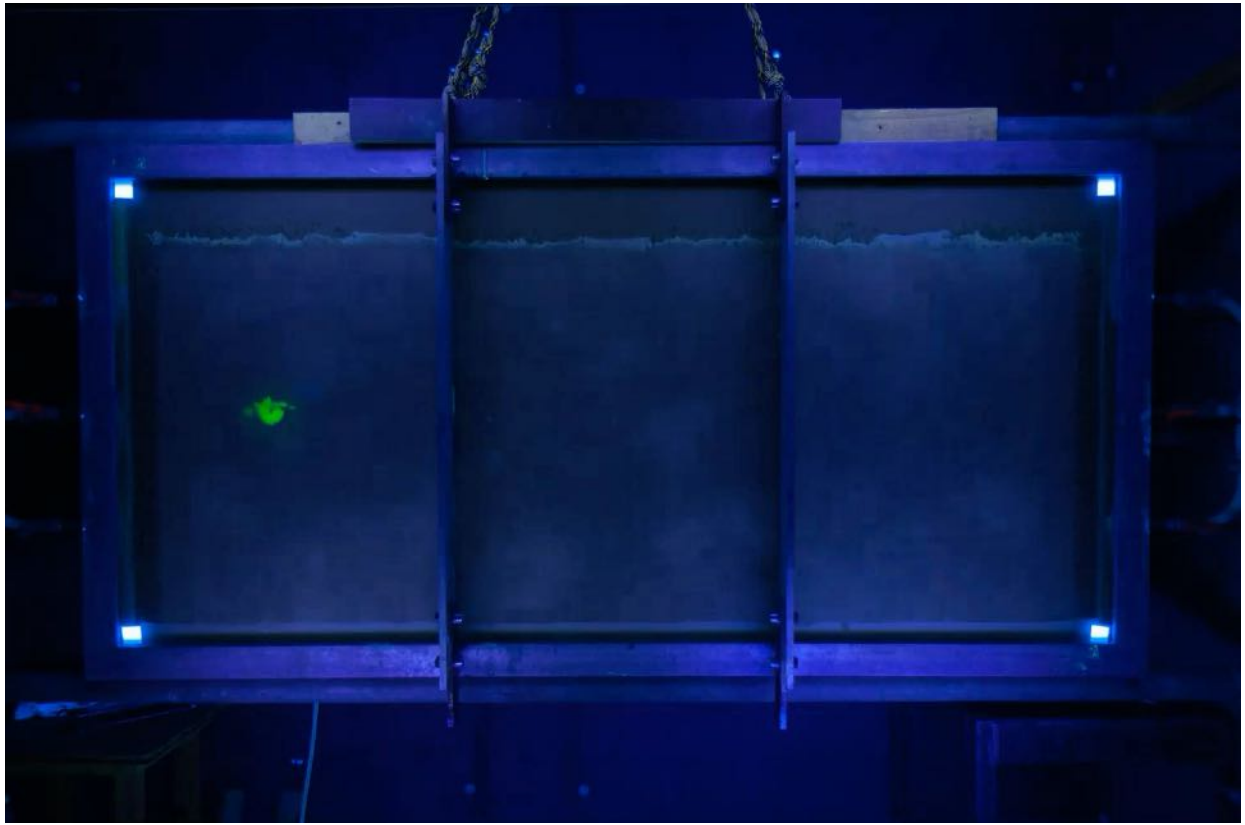




mathematical description
of processes, heterogeneity, prognoses

VEGAS Vision & Strategy

example of basic research: heterogeneity



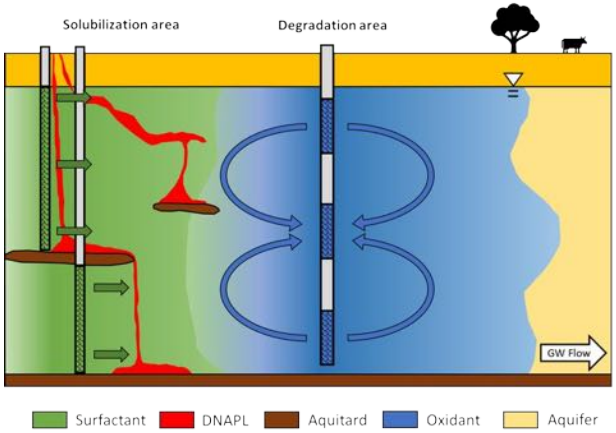
VEGAS Research

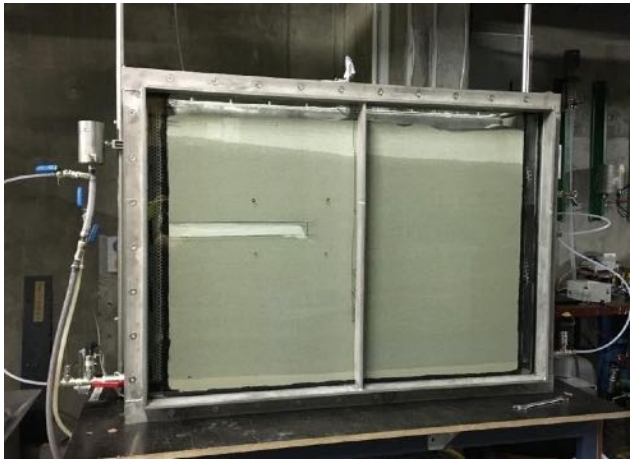
- Fate and Transport of Contaminants
  - all relevant contaminants:
    e.g., CHCs, PAHs, heavy metals, tar oil, PFAS, pesticides, pharmaceutics
  - under various conditions
  - heterogeneity
- Remediation Technologies
  - chemical
    ISCO, ISCR
  - thermal
  - treatment trains
    - electro-nano-bio-remediation

EiCLaR

VEGAS Research: S-ISCO

Surfactant-enhanced In-Situ Chemical Oxidation

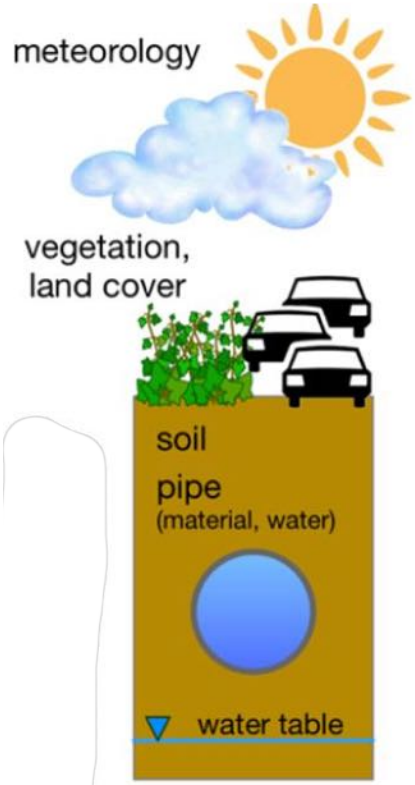


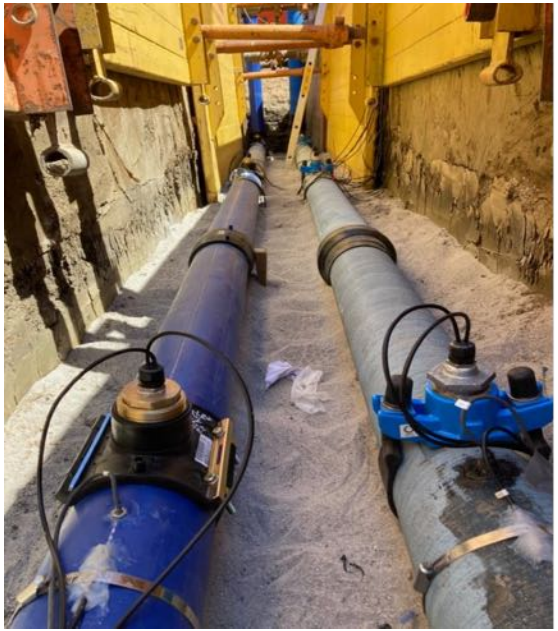


Herzog et al. (2023), JCH, https://doi.org/10.1016/j.jconhyd.2023.104230

VEGAS Research: Heat in the Subsurface

Water quality in drinking water supply networks:
Heat- and water transport driven from atmospheric boundary layer





Nissler et al. (2023), VZJ, http://dx.doi.org/10.1002/vzj2.20286

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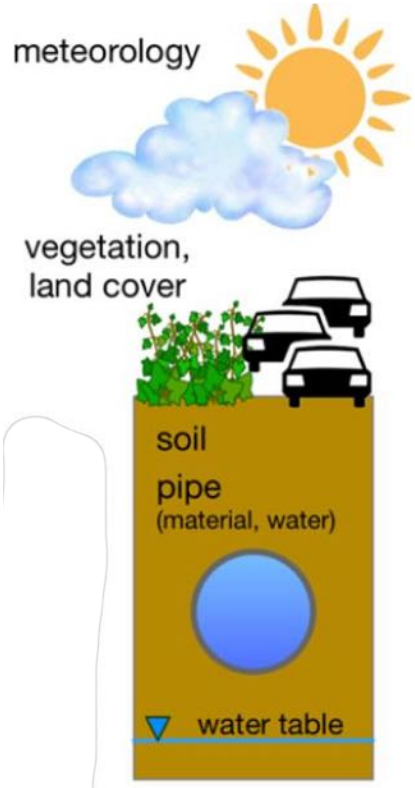
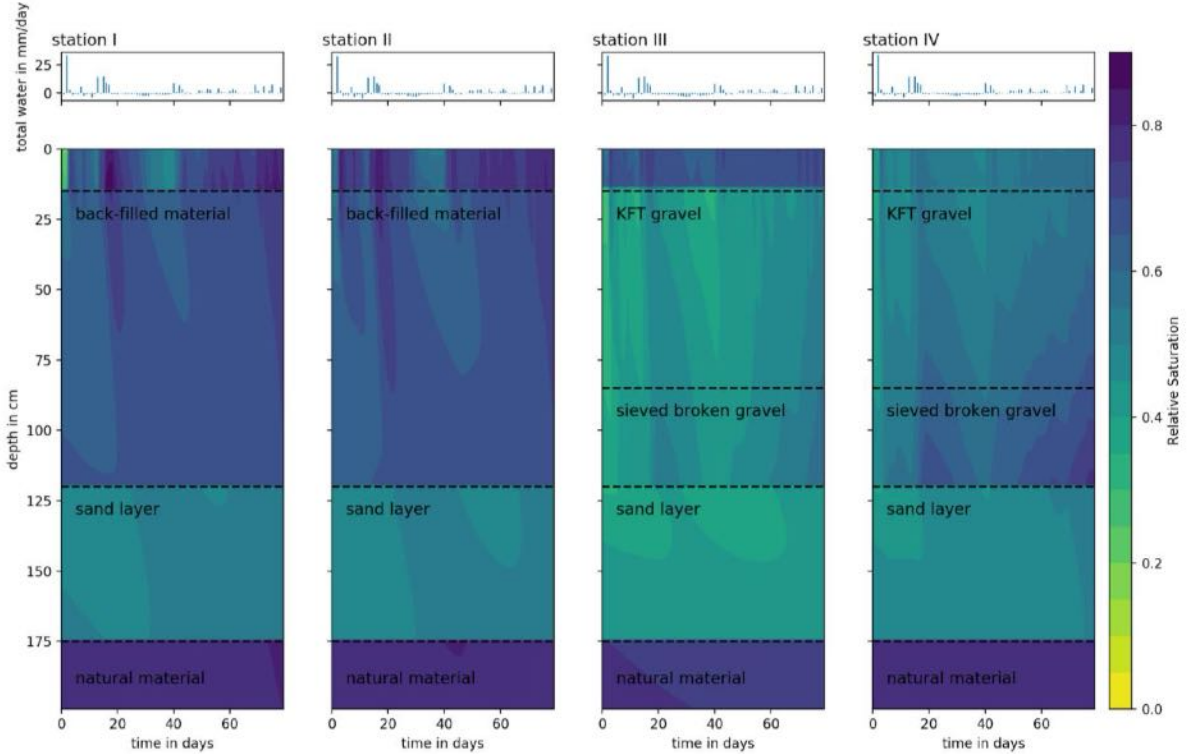


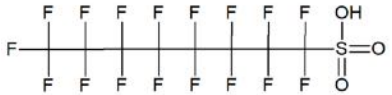


Nissler et al. (2023), VZJ, http://dx.doi.org/10.1002/vzj2.20286

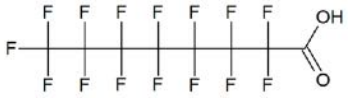
PFAS

What are they and why should we care?

- per- and polyfluoroalkyl substances



PFOS

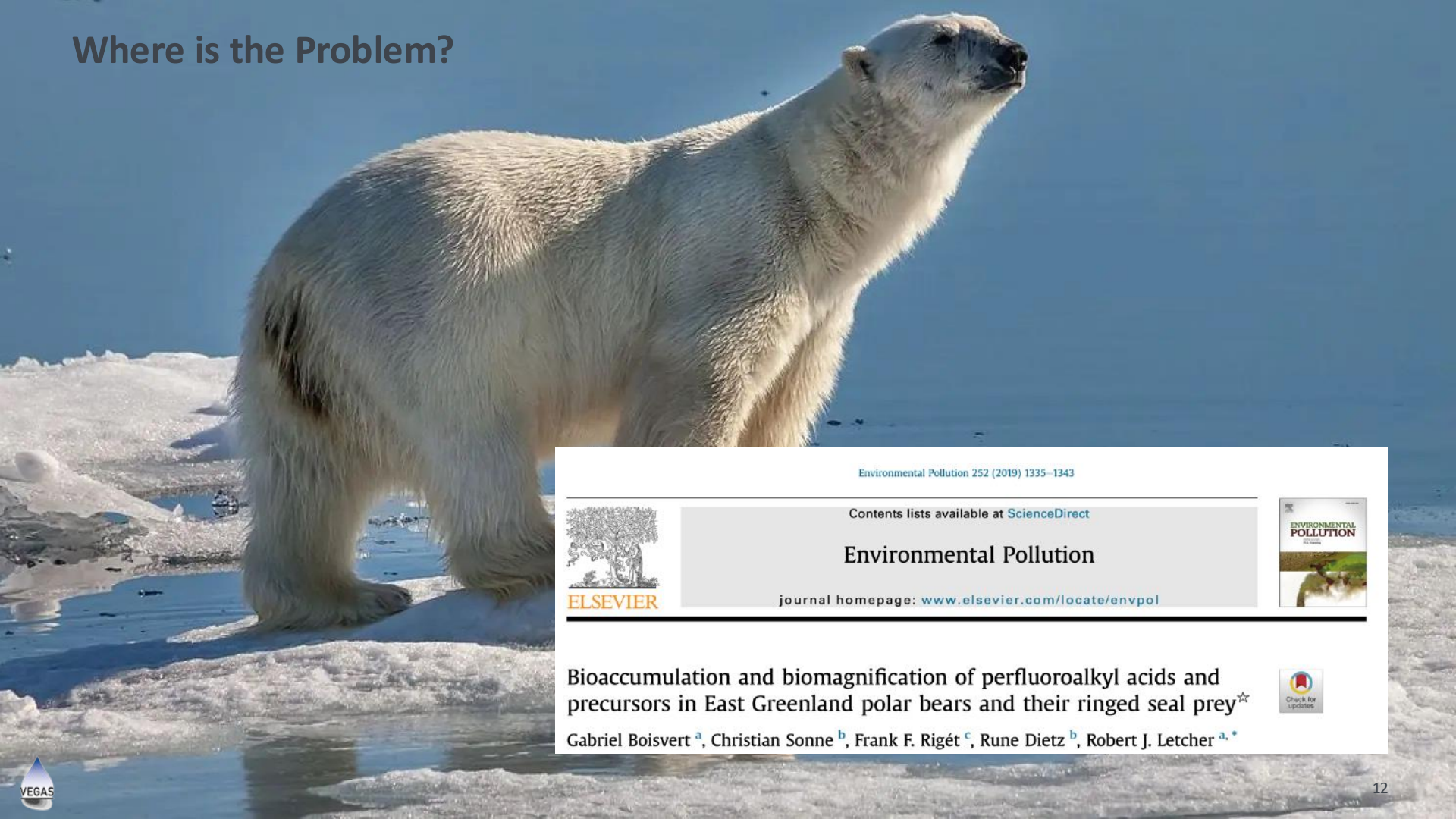


PFOA

- do not occur naturally
- high water and oil repellency
- persistent, ubiquitous,
  → “forever chemicals”
- thousands of different substances[1]
  - limited analytical standards

[1] https://comptox.epa.gov/dashboard/chemical-lists/pfasmaster; Graph: https://pinellas.gov/per-and-polyfluoroalkyl-substances-pfas/

Where is the Problem?



Environmental Pollution 252 (2019) 1335–1343

Contents lists available at ScienceDirect

Environmental Pollution

journal homepage: www.elsevier.com/locate/envpol

Bioaccumulation and biomagnification of perfluoroalkyl acids and precursors in East Greenland polar bears and their ringed seal prey☆

Gabriel Boisvert [a], Christian Sonne [b], Frank F. Rigét [c], Rune Dietz [b], Robert J. Letcher [a, *]

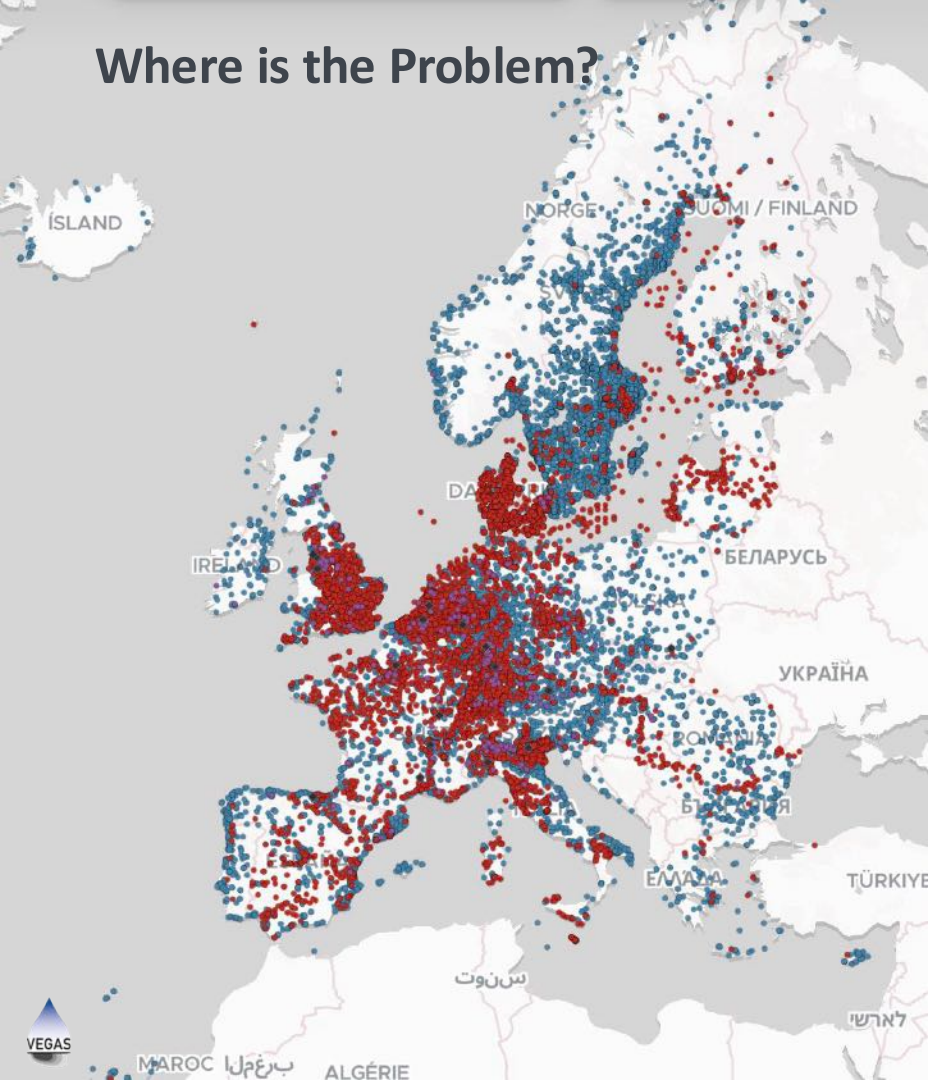
Where is the Problem?

The Netherlands warn: don’t touch Sea-Foam

“North Sea foam contains poisonous substances”

https://www.kreiszeitung.de/welt/niederlande-belgien-nordsee-schwimmen-verbot-pfas-meerschaum-algen-92738106.html

Where is the Problem?



the FPP identified **22,934 known contamination sites**, including 20 PFAS manufacturing facilities, and 21,426 "presumptive contamination sites", including 13,745 sites presumably contaminated with fluorinated aqueous film-forming foam (AFFF) discharge, 2911 industrial facilities, and 4752 sites related to PFAS-containing waste.

Environmental Science & Technology

pubs.acs.org/est Article

PFAS Contamination in Europe: Generating Knowledge and Mapping Known and Likely Contamination with "Expert-Reviewed" Journalism

Alissa Cordner, Phil Brown, Ian T. Cousins, Martin Scheringer, Luc Martinon, Gary Dagorn, Raphaëlle Aubert, Leana Hosea, Rachel Salvidge, Catharina Felke, Nadja Tausche, Daniel Drepper, Gianluca Liva, Ana Tudela, Antonio Delgado, Derrick Salvatore, Sarah Pilz, and Stéphane Horel*

Cite This: *Environ. Sci. Technol.* 2024, 58, 6616–6627 Read Online

https://www.lemonde.fr/en/les-decodeurs/article/2023/02/23/forever-pollution-explore-the-map-of-europe-s-pfas-contamination_6016905_8.html

"The costs for remediating some cases of contamination run to many millions of EUR. Total costs at the European level are expected to be in the hundreds of millions
of EUR as a minimum"

- cancer causing
- DNA altering
- accumulating

http://norden.diva-portal.org/smash/get/diva2:1295959/FULLTEXT01.pdf

The costs for remediating some
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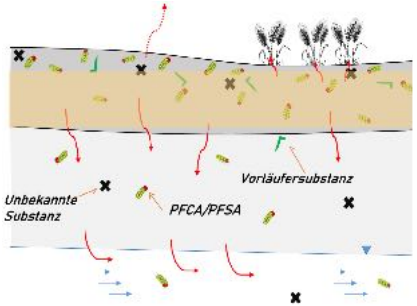
Table 1: Estimates of annual health impact-related costs (of exposure to PFAS)

Exposure level	"Exposed" population and source	Health endpoint	Nordic countries		All EEA countries	
			Population at risk	Annual costs	Population at risk	Annual costs
Occupational (high)	Workers at chemical production plants or manufacturing sites	Kidney cancer	n.a.	n.a.	84,000–273,000	EUR 12.7–41.4 million
Elevated (medium)	Communities near chemical plants, etc. with PFAS in drinking water	All-cause mortality	621,000	EUR 2.1– 2.4 billion	12.5 million	EUR 41–49 billion
		Low birth weight	8,843 births	136 births of low weight	156,344 births	3,354 births of low weight
		Infection	45,000 children	84,000 additional days of fever	785,000 children	1,500,000 additional days of fever
Background (low)	Adults in general population (exposed via consumer products, background levels)	Hypertension	10.3 million	EUR 0.7– 2.2 billion	207.8 million	EUR 10.7–35 billion
Totals			*Nordic countries*	*EUR 2.8–4.6 billion*	*All EEA countries*	*EUR 52–84 billion*

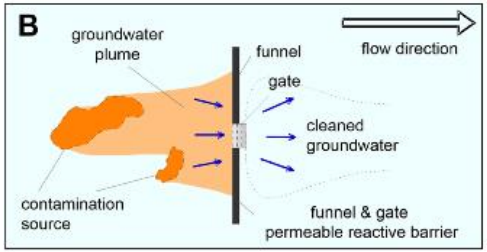
http://norden.diva-portal.org/smash/get/diva2:1295959/FULLTEXT01.pdf

immobilisation



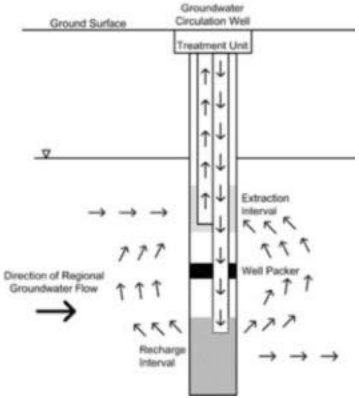
pilot site Hügelsheim,
variably saturated

“enhanced sorption”

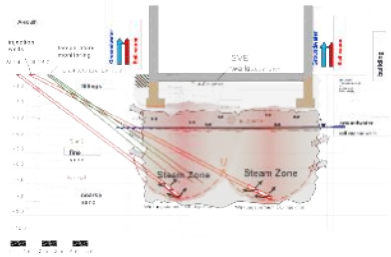


pilot site Reilingen,
AFFF, aquifer

mobilisation



thermal desorption

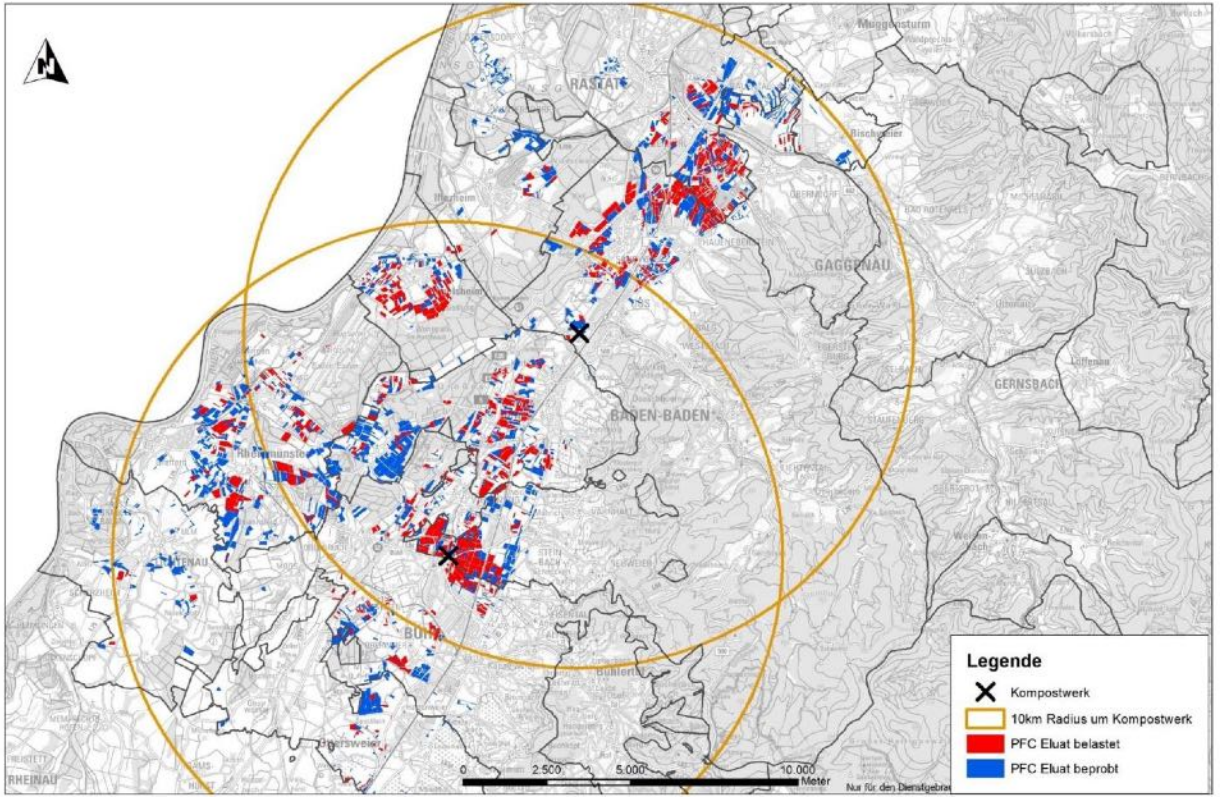


exploratory;
lab- & technicum


Esbjerg
Odense
Kiel
Rostock
Hamburg
Wilhelmshaven
Bremen
Hannover
Berlin
Dortmund
Düsseldorf
Cologne
Leipzig
Dresden
Frankfurt am Main
Prague
Nuremberg
Stuttgart
Strasbourg
Munich
Salzburg
Zurich

Test-Site 1: Rhine Valley – Hügelsheim

Non-point, ”biosolid”



- Geobasisdaten © LGL, www.lgl-bw.de
- Geodaten © LRA-RA, www.landkreis-rastatt.de

LANDKREIS RASTATT

Test-Site 1: Rhine Valley – Hügelsheim

application of ”biosolids”

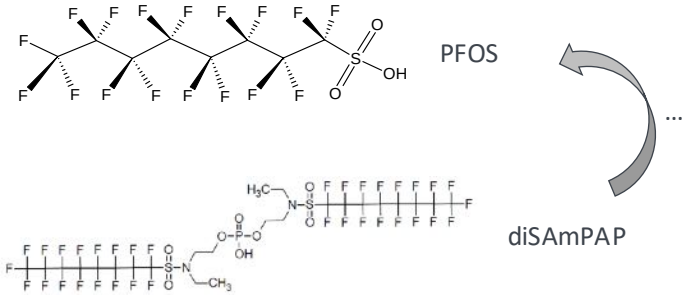
VEGAS

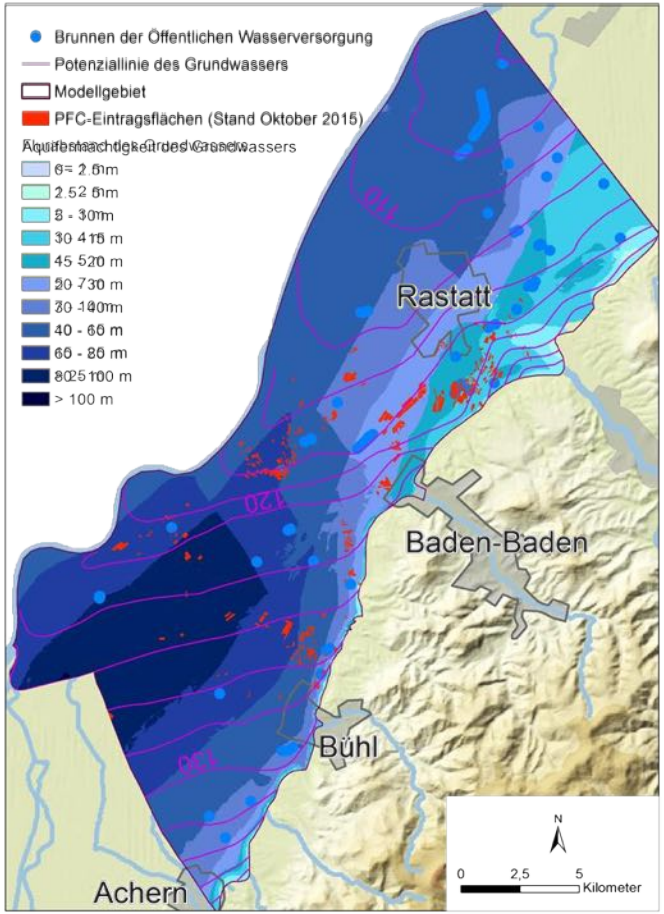
LANDKREIS RASTATT

Test-Site 1: Rhine Valley – Hügelsheim

non-point, ”biosolid”

- mainly agricultural land-use
- large area known contaminated (>1200 ha with >1 mg/kg PFAS measured in topsoil)
- “compost” from paper industry (2005 - 2008)
- complex infiltration processes (sorption, transformations)





LANDKREIS RASTATT

Schweiz 20.09.2024

Grosse Sorgen wegen Giftfleisch

Bild: ar.ch

Weil ihre Böden mit giftigen Chemikalien verseucht sind, dürfen fünf Bauernbetriebe im Rheintal das Fleisch ihrer Tiere nicht mehr verkaufen. Es ist ein Thema für den ganzen Kanton.


1 grain of sugar = 625.000 ng


1 grain of salt = 58.500 ng

US EPA Lifetime Health Advisory Limits (HALs): PFOA: 0,004 ng/L

https://www.eurofinsus.com/environment-testing/pfas-testing/pfas-resources/recent-pfas-news/epa-publishes-revised-lifetime-health-advisory-limits-hals-for-pfas-compounds/

PFOS: 0,02 ng/L

limits in drinking water

100 ng/L starting 12.1.2026 (PFAS-20, TrinkwV)

20 ng/L starting 12.1.2026 (PFAS-4: PFOA, PFNA, PFHxS, PFOS), TrinkwV)

2 ng/L PFAS-4 since 2021, Danish EPA

background concentrations (LUBW): 200 ng/L … 700 ng/L

https://pd.lubw.de/10215

porewater concentrations in Hügelsheim: 10.000 ng/L

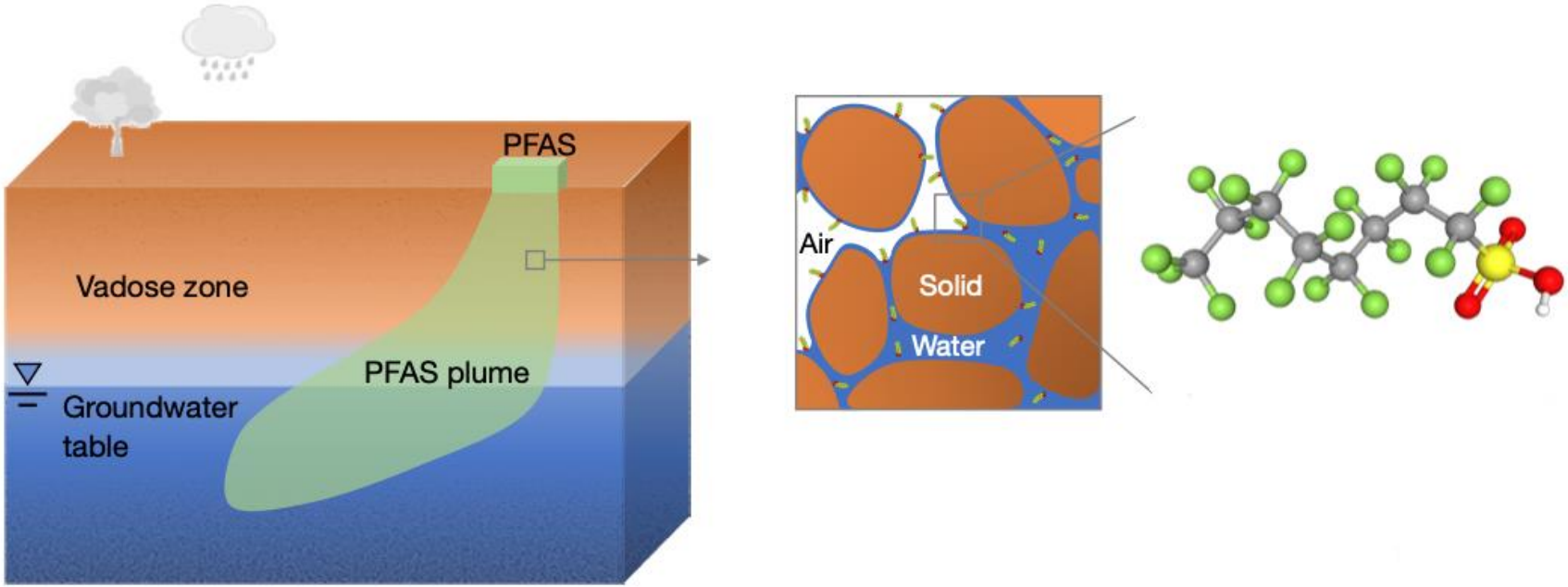
eluate from contaminated soil (30-60cm, Hügelsheim) 80.000 ng/L
(2:1 shaking, 24h, with water)

No limits

- WWTPs
- Industrial wastewater
- soil (GFS)

PFAS Transport in the Unsaturated Zone

air-water interfaces, transformation processes



PFAS Transport in the Unsaturated Zone

air-water interfaces, transformation processes

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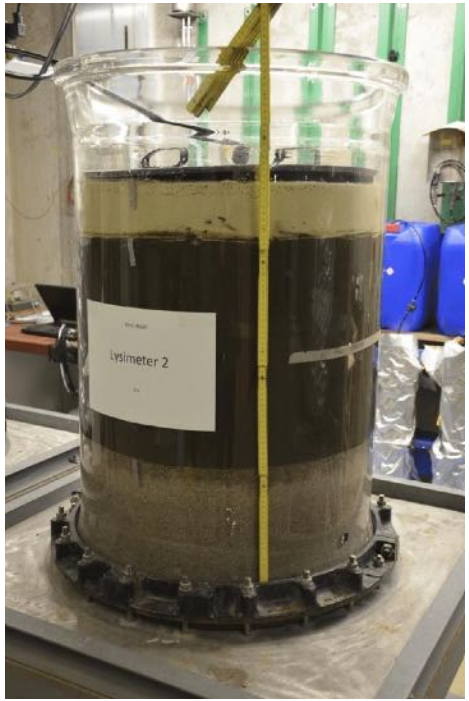
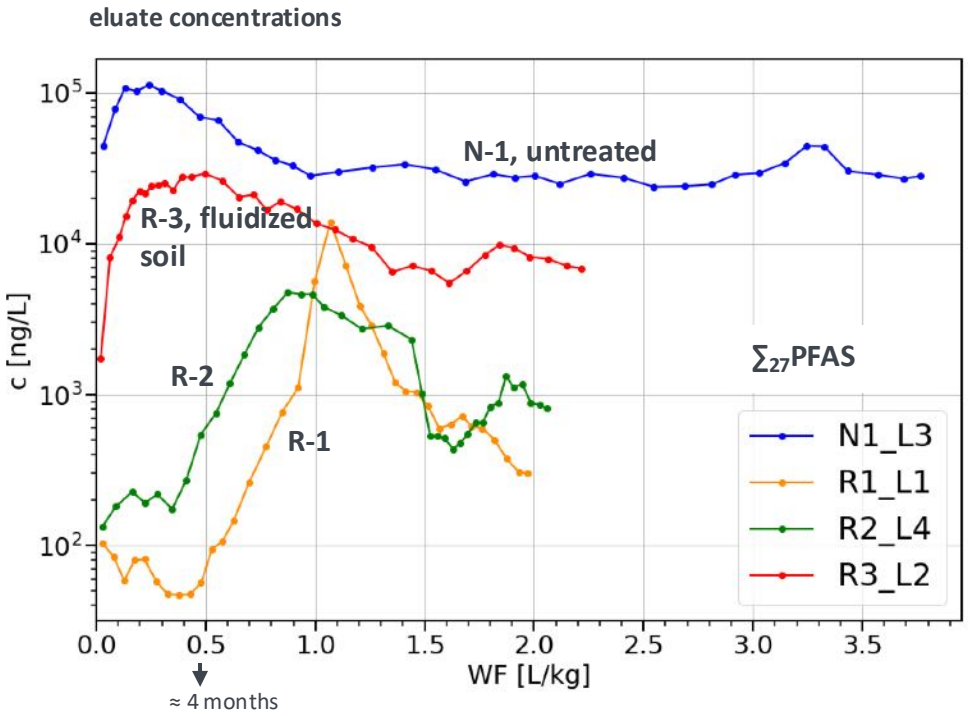
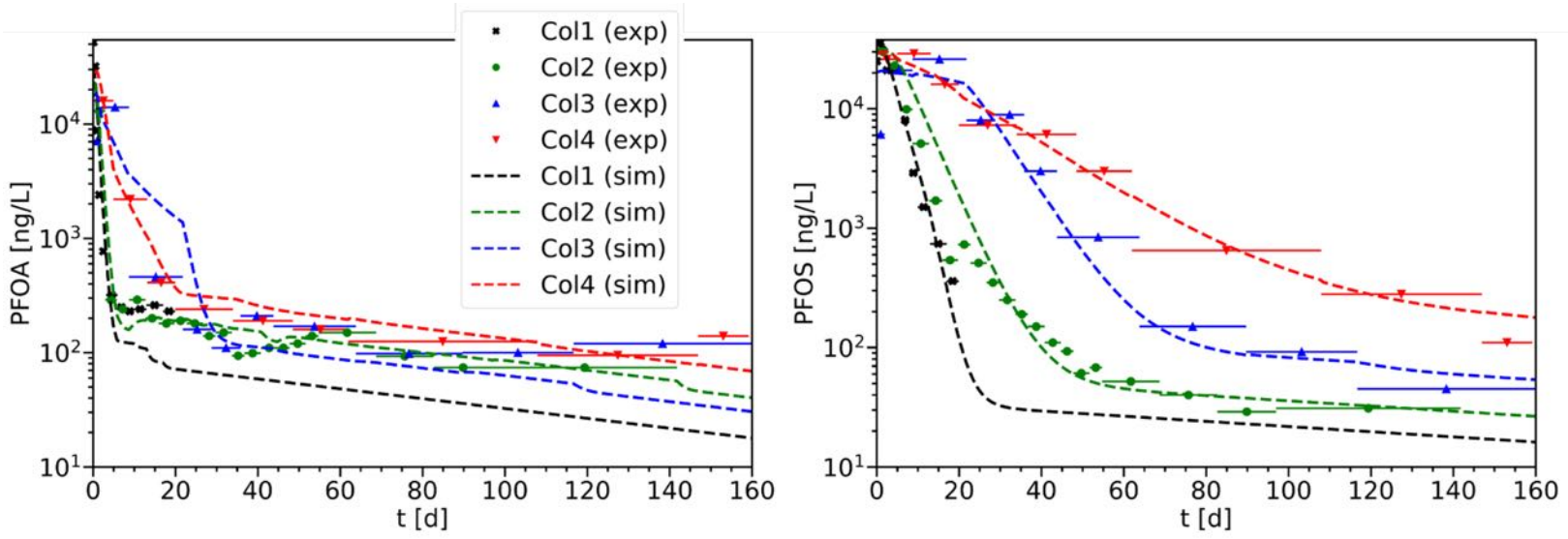




PFAS Transport in the Unsaturated Zone

air-water interfaces, transformation processes

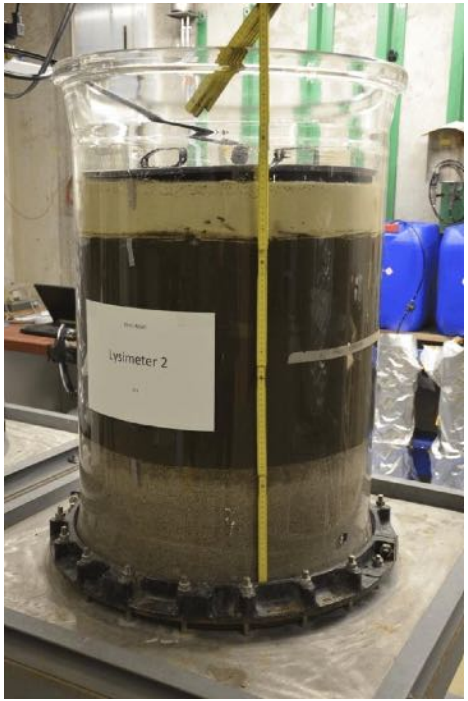


- The long tailing can not be represented using **non-linear sorption isotherms but in combination with kinetic sortpion**
- K_d from f_{oc} **not** sufficient

Bierbaum et al. (2023), EnvScPolRes, https://doi.org/10.1007/s11356-023-30811-2

PFAS Transport in the Unsaturated Zone

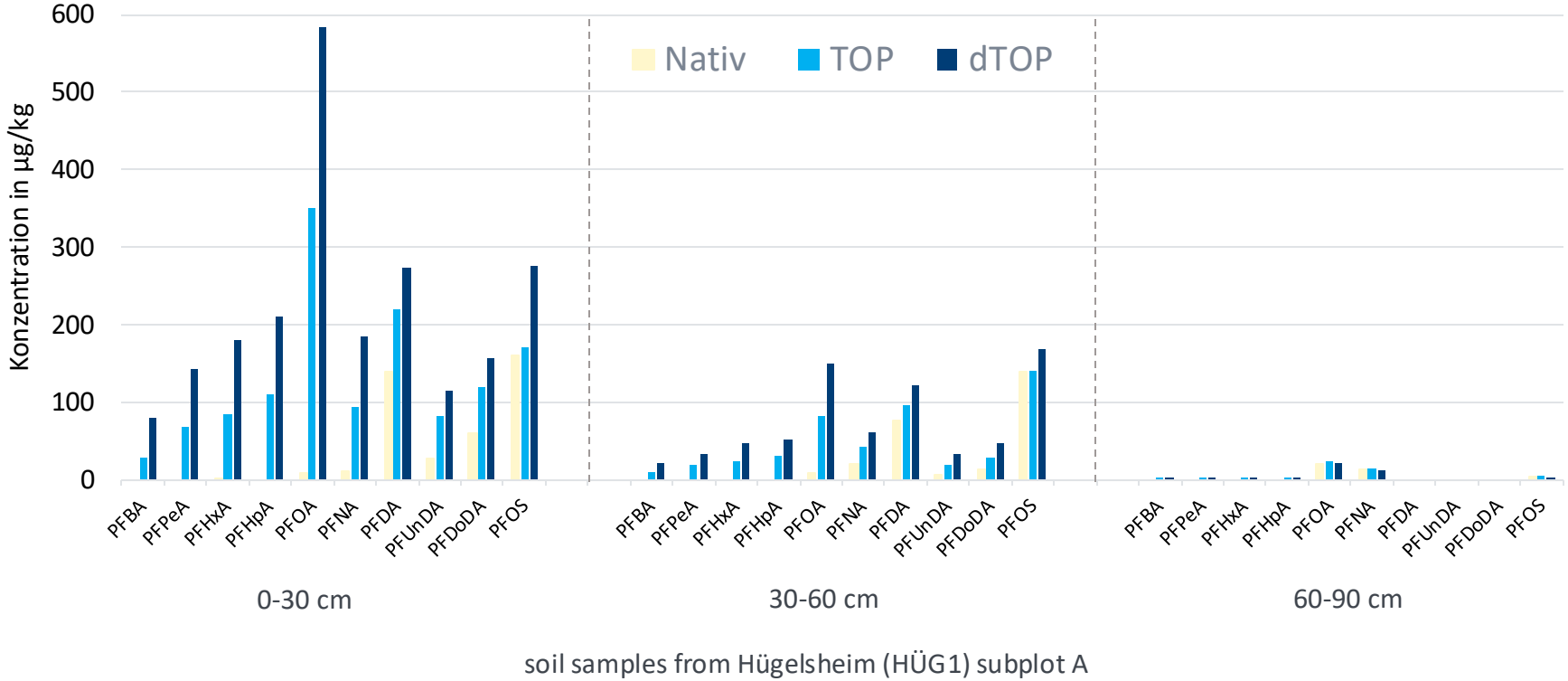
air-water interfaces, transformation processes



- field
- laboratory with controlled
  - water input,
  - transformations,
  - AC
- modelling

Test-Site 1: PFAS in the Soil

optimizing chemical extraction for PFAS residuum



soil samples from Hügelsheim (HÜG1) subplot A

Test-Site 1: Rhine Valley – Hügelsheim

Immobilisation

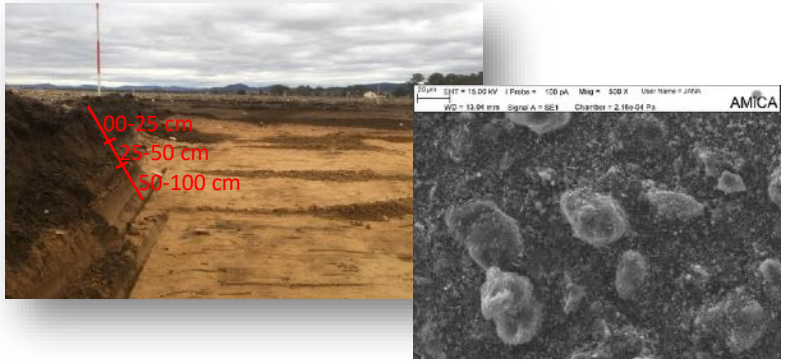


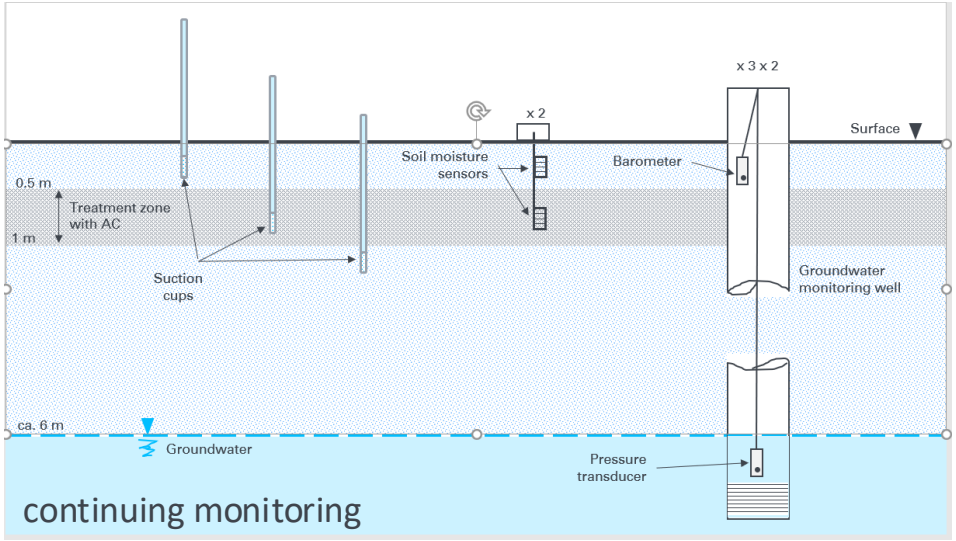
- GAC with high sorption capcacity
- „filter carpet“, well-mixed GAC
- detailed monitoring
  (groundwater, pore water, soil)

DVGW TZW Technologiezentrum Wasser VEGAS geiger WIRTGEN LANDKREIS RASTATT PFClean

Test-Site 1: Rhine Valley – Hügelsheim

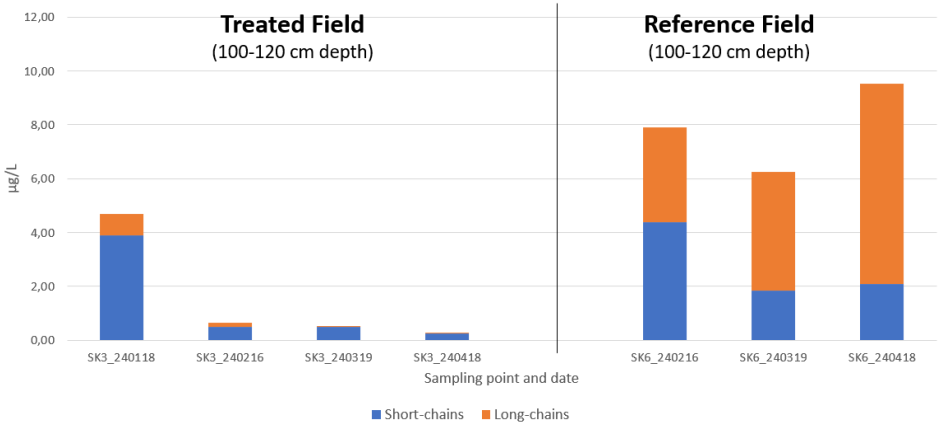
Immobilisation



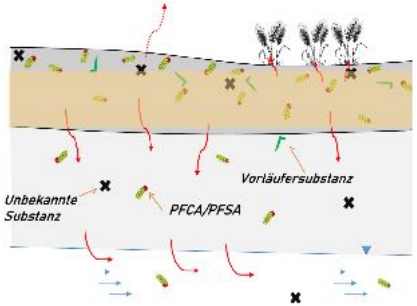


continuing monitoring

preliminary results

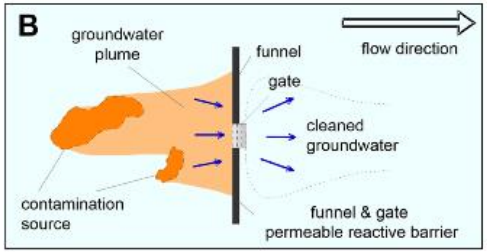


immobilisation



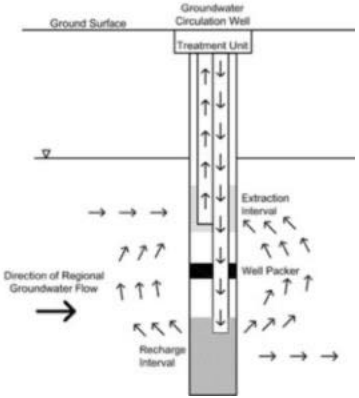
pilot site Hügelsheim,
variably saturated

“enhanced sorption”

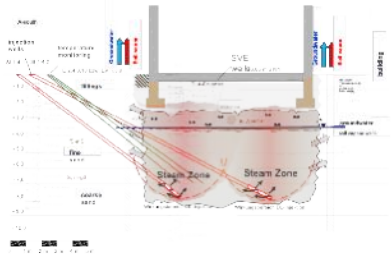


pilot site Reilingen,
AFFF, aquifer

mobilisation

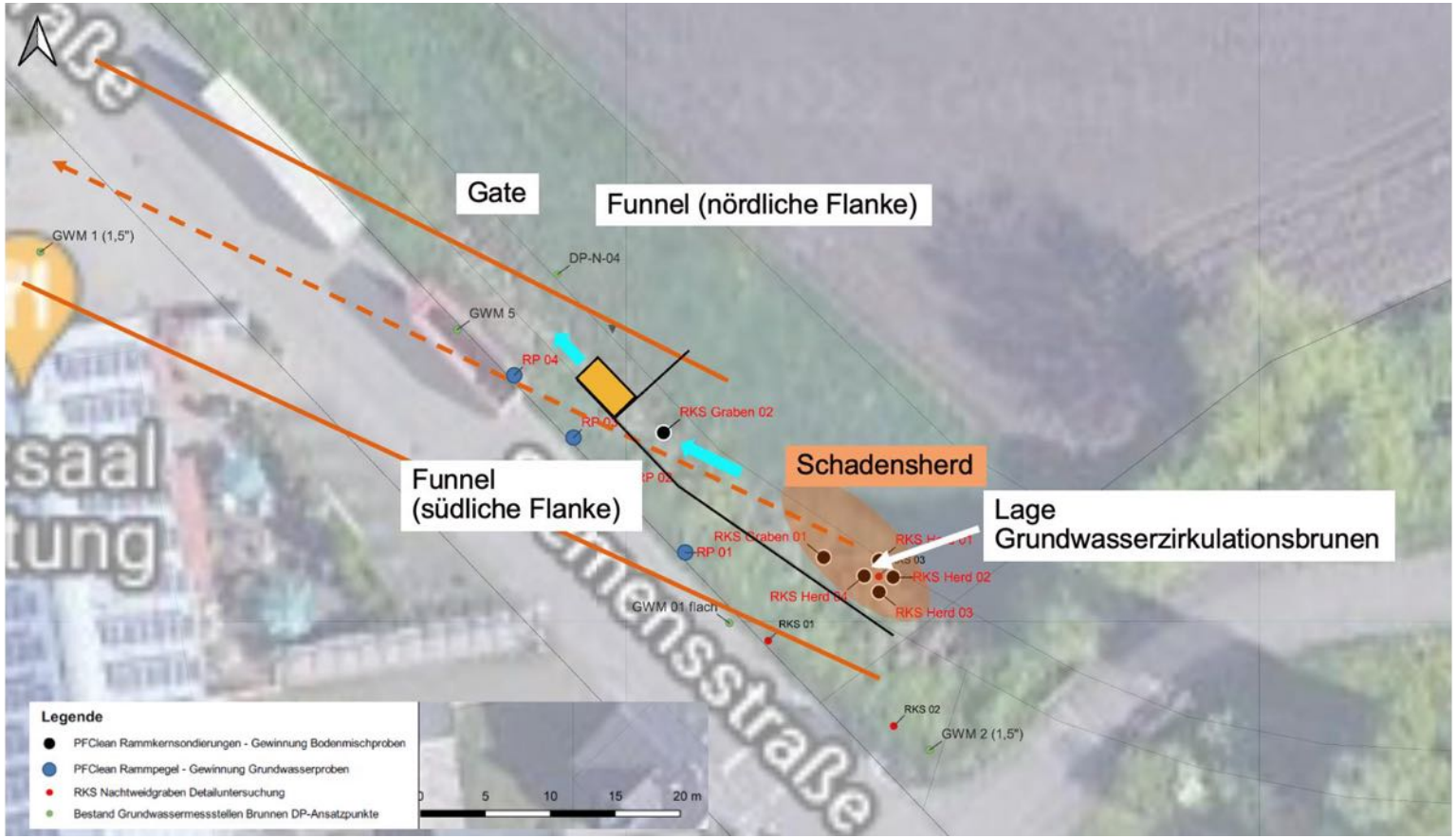


thermal desorption



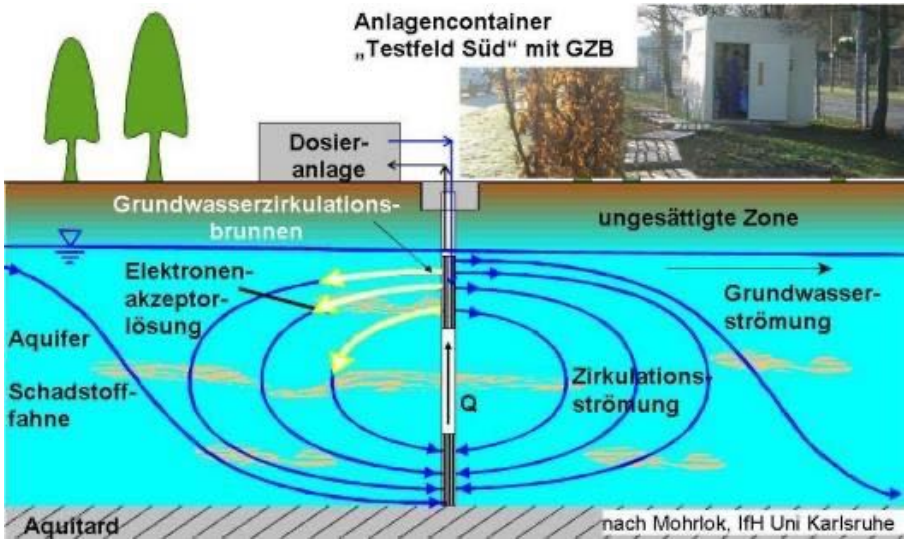
exploratory;
lab- & technicum

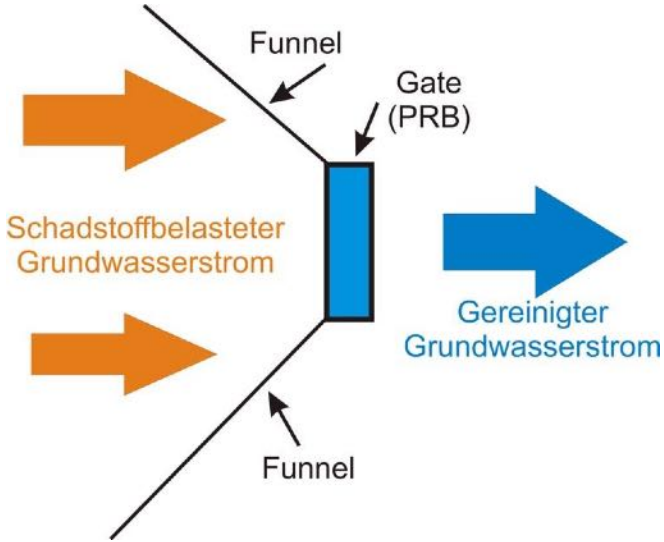
Test-Site 2: Reilingen
AFFF



Funnel & Gate; Groundwater Circulation Well (GCW)

Elektrically polarised transformation; forced transformations

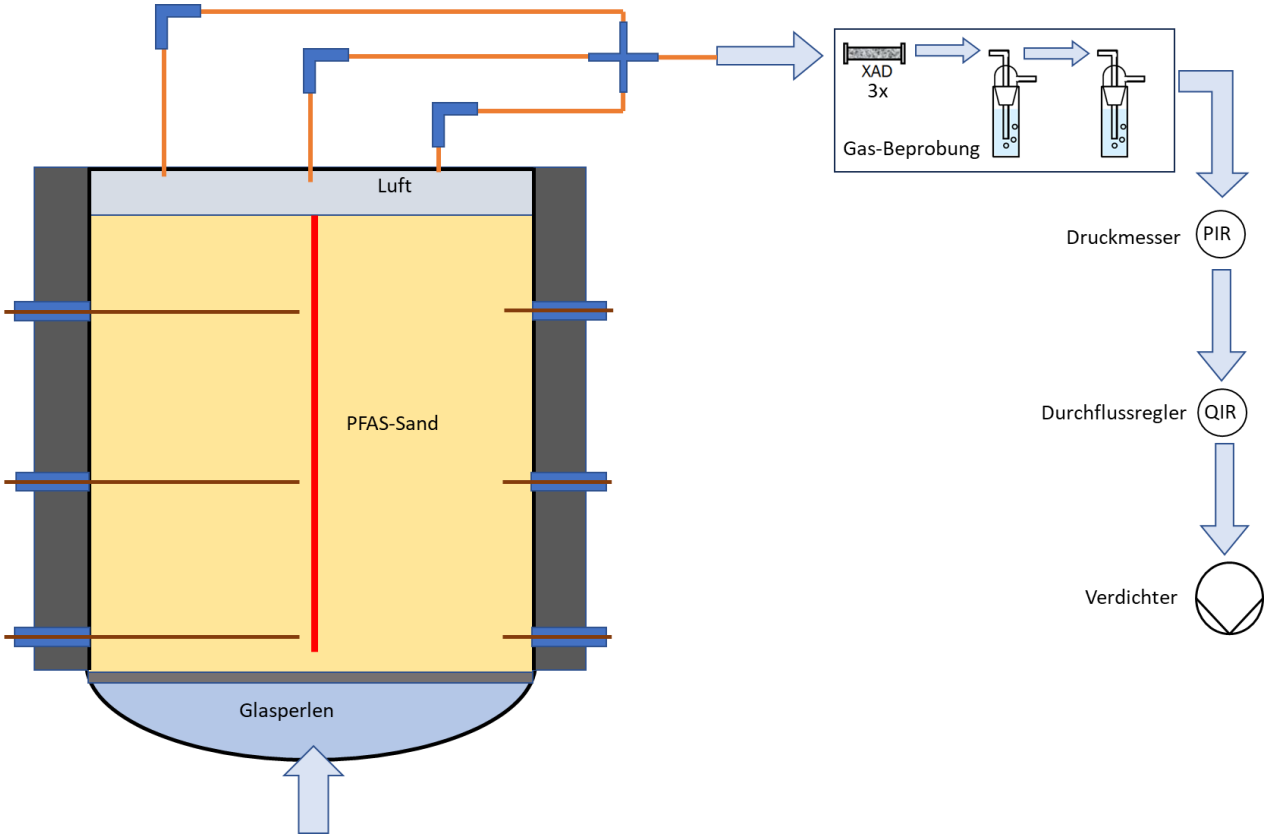




Groundwater Circulation Well (GCW)

Thermal Desorption

at technicum-scale



Thermal Desorption

at technicum-scale

ARCADIS

Michael Reinhard

EBERHARD KARLS
UNIVERSITÄT
TÜBINGEN

Christian Zwiener

LANDKREIS
RASTATT

Reiner Söhlmann

VEGAS
Versuchseinrichtung
zur Grundwasser- und
Altlastensanierung

Claus Haslauer

geiger
Entsorgung

Martin Haberstock

IEG ®

Marc Sick

SAX+KLEE

Werner Bock

DVGW | TZW
Technologiezentrum
Wasser

Frank Thomas Lange

VEGAS

University of Stuttgart
Institute for Modelling Hydraulic and Environmental Systems
Research Facility for Subsurface Remediation

Thank you!

Claus Haslauer

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https://mathstodon.xyz/@**planetwater**
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