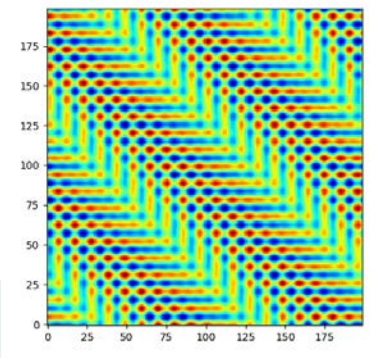
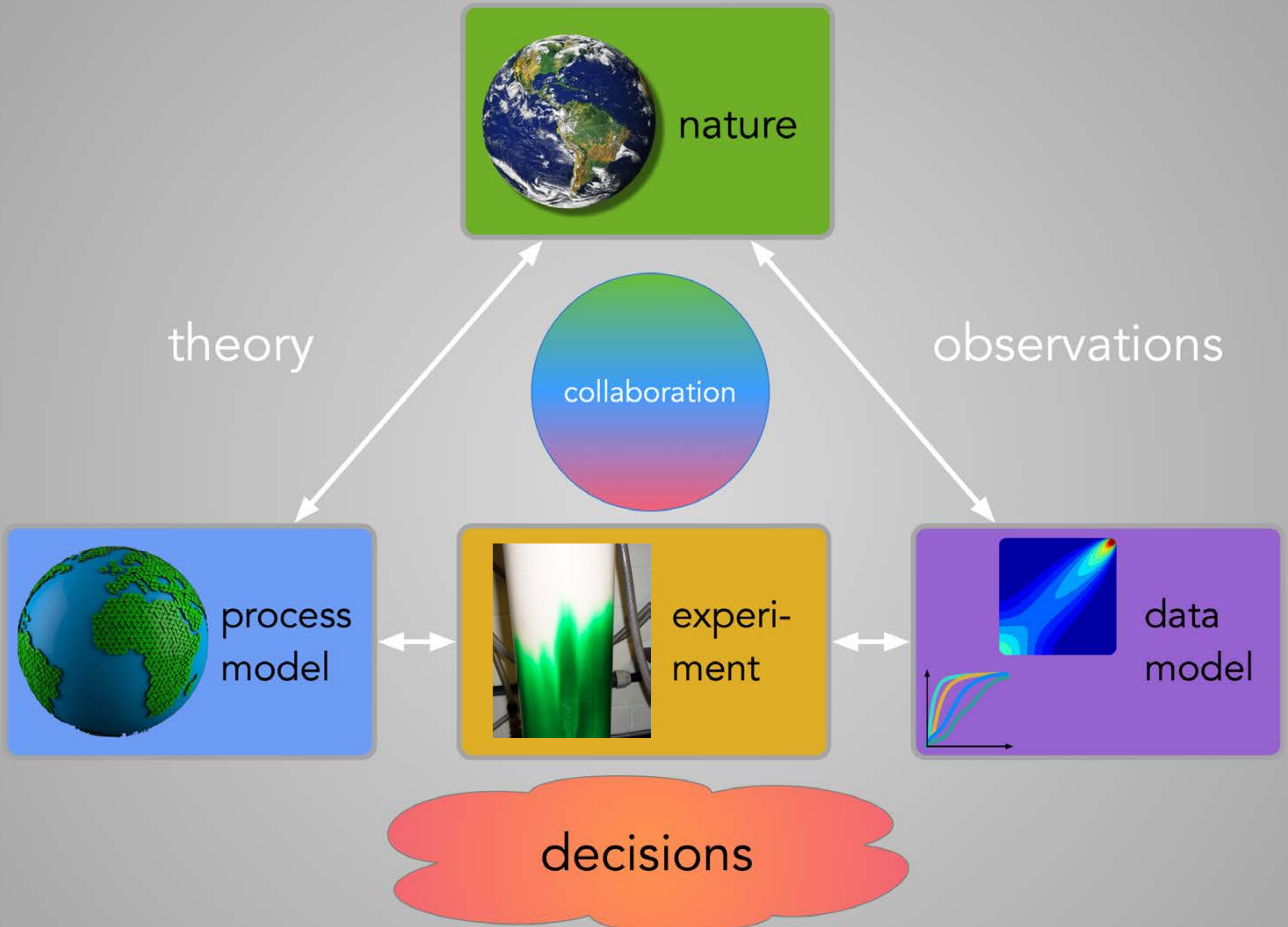


VEGAS

Research Facility for Subsurface Remediation

Research Topics Spring/Summer 2020

PD Dr.-Ing.
Claus Haslauer


nature
theory
collaboration
observations
process model
experi-ment
data model
decisions

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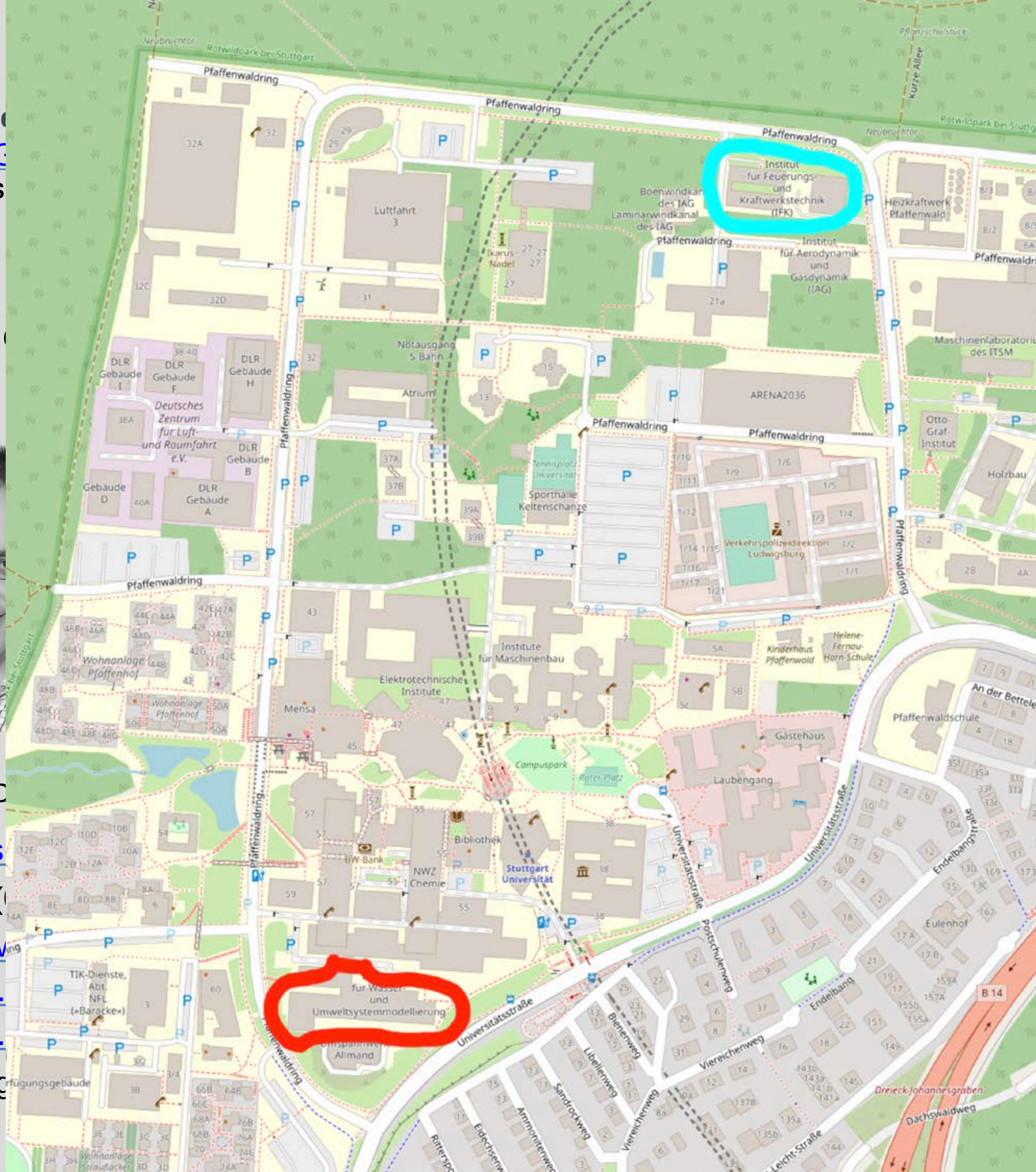

PD D

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URLs www

www.

www.

twitter @veg

mineral oil

chlorinated solvents

BTEX

heavy metals

PAH

dioxin, PCB

Remediation Technologies

restrictions

in-situ methods

relocate

ex-situ methods
- separate / treat
- thermal treatment

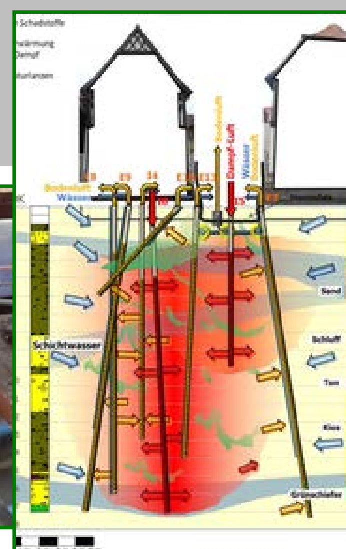
bio-chemical
- MNA
- enhanced MNA
- biologic activated soil flushing

thermal
- air/steam injection
- constant heat source

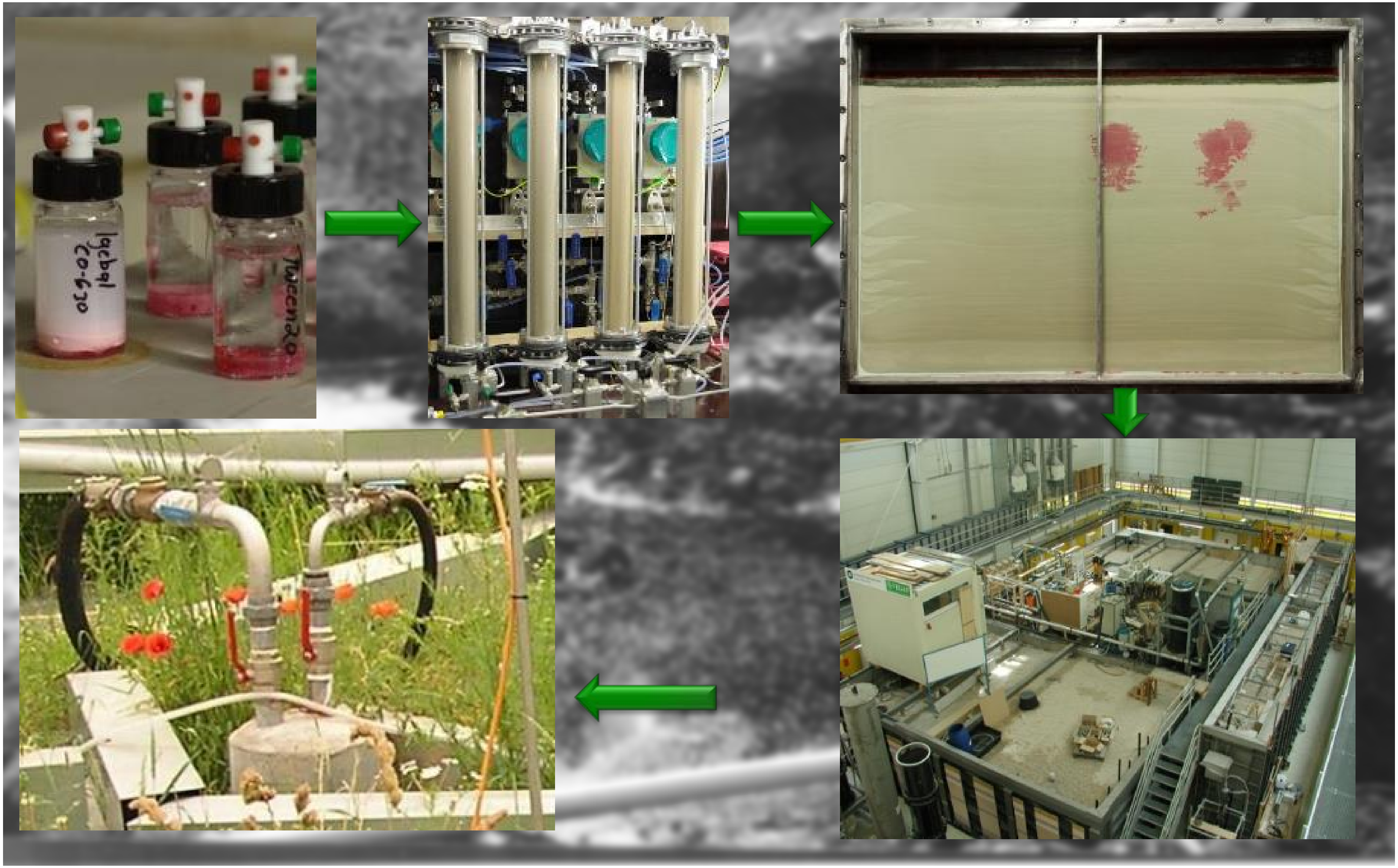
hydraulic
- pump & treat
- scavenging

chemical
- oxidation (ISCO)
  - H_2O_2
  - Fentons reagent (Fe, H2O2, acidic)
  - permanganate
  - persulfate
  - ozone
  - ORC (oxygen release compounds)
- reduction (ISCR)
  - HRC
  - elemental metals (Fe)

Research Facility for Subsurface Remediation



VEGAS – Research Scales



Deutsche Forschungsgemeinschaft DFG

Life

Baden-Württemberg
MINISTERIUM FÜR UMWELT, KLIMA UND ENERGIEWIRTSCHAFT

LUBW

python™

DuMu^{X}

HGS Simulation™

LANDES FORSCHUNGS ZENTRUM GEOTHERMIE

ITVA

altlastenforum
Baden-Württemberg e.V.

DECHEMA
Gesellschaft für Chemische Technik und Biotechnologie e.V.

BOSCH
Technik fürs Leben

CDM Smith
listen. think. deliver.

Fraunhofer
ISE

FUGRO

GAB

GEOsens
Ingenieurgeologie
Umweltgeologie
Messtechnik

STADT OBERURSEL TAUNUS

RiskCom
Optimising Chances

KANTON solothurn

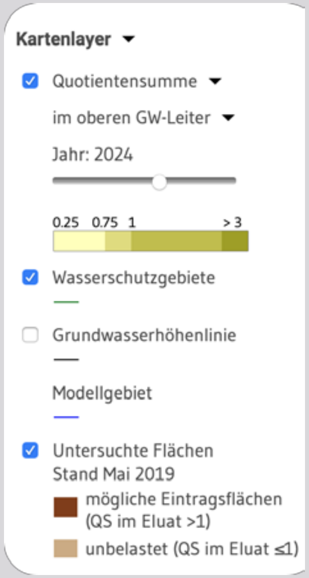
Weber Ingenieure

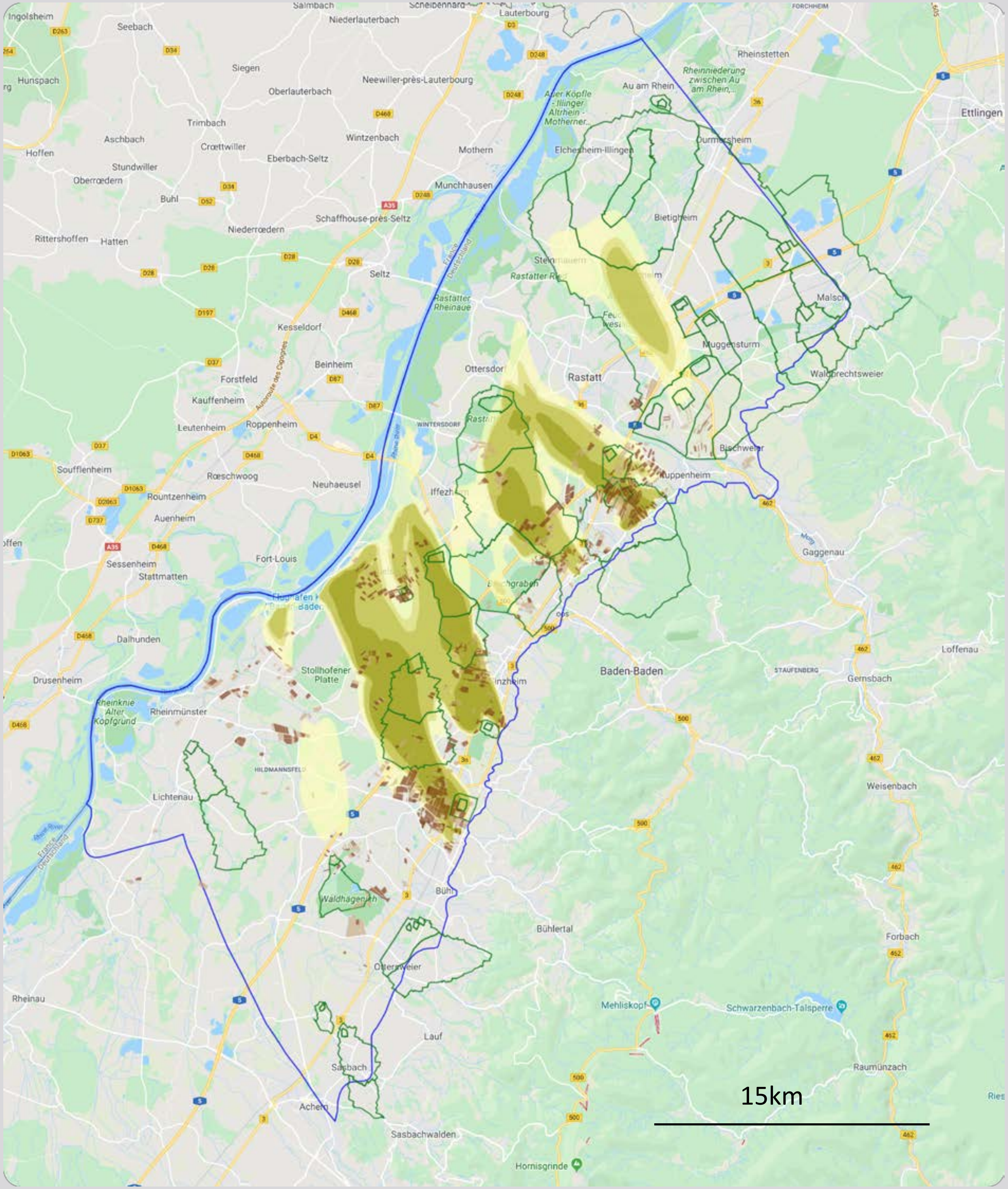
ZÜBLIN

Current Topics

- PFAS (large scale, ubiquitous, chemical and modelling)
- thermal remediation (at large temperatures)
  - heat transport (energy balance) and
  - solute transport (contaminant mass balance)
  - soil moisture sensors
- heat storage in the subsurface
- lindane contamination

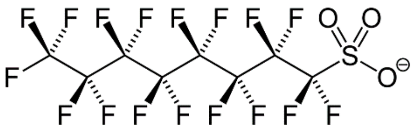




https://www.lubw.baden-wuerttemberg.de/wasser/pfc-karten-online

Experiments with PFAS-contaminated soils



- PFAS: per- and polyfluoroalkyl substances (> 4000 substances)
  - surfactant properties: hydropobic and lipophobic
  - persistent in the environment

- Problem:
  - approximately 800 ha of agricultural land has been contaminated with PFASs (→ groundwater)
  - lack of knowledge: precursors and transformation processes

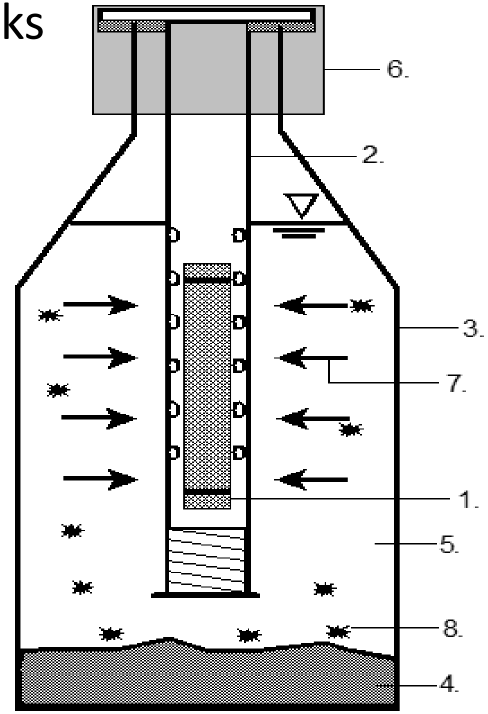
- Remediation strategy „Immobilization“:
  - in situ
  - on-site

  - How to evaluate/validate immobilization?
    - Experiments on different scales and under different conditions
    - Numerical Modelling

„Infinite Sink“-Experiments

Batch experiments

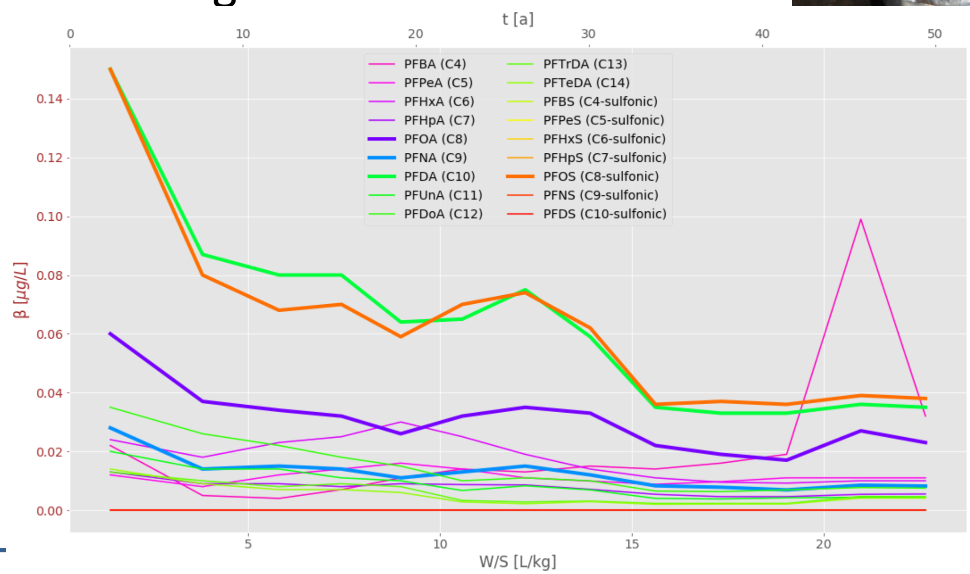
- Maximum desorption rate
  - Sorbent material: activated carbon
- Shaking test with sampling in intervals (sorbent material and water phase)
- Duration: ≈ 4 – 8 weeks



Column Experiments

Column experiments (saturated conditions)

- Evaluation of effluent concentrations
  - → desorption dynamics of contaminants
  - → long-term behaviour
- Fixed flow rate → retention time
- Sampling of eluate in regular intervals
- Duration:
  ≈ 4 – 8 weeks

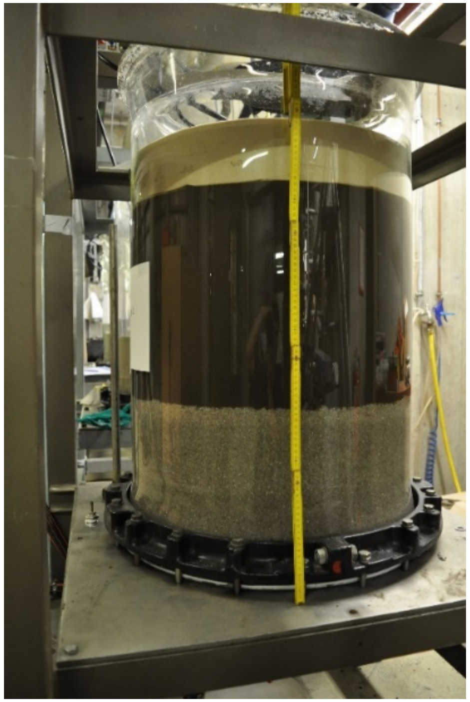


Lysimeter Experiments

Lysimeter experiments (unsaturated conditions)

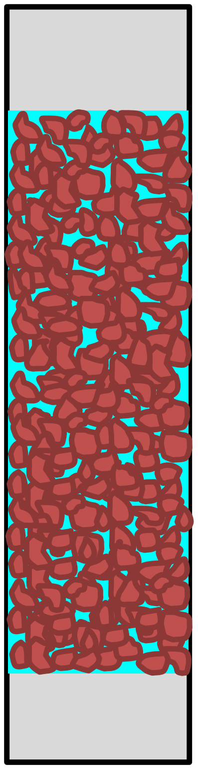
- Percolation conditions close to „real“ conditions
- Flow rate similar to real groundwater recharge
  - Irrigation: ≈ 1L/d

- Duration: 1 year (!)

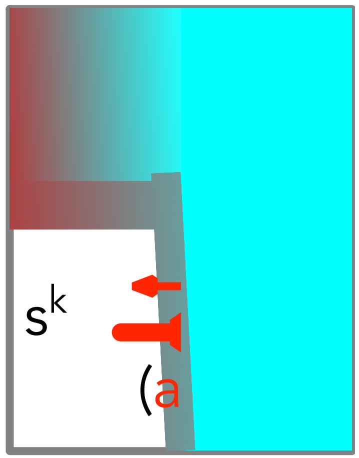


Numerical Modelling

→ tailed BTC



PFAS aqueous-phase concentrations (c [µg/L]); in eq. with s^e.



PFAS solid-phase concentrations (sorbed) (s^k [µg/kg])

$$\frac{\partial \theta c}{\partial t}+\rho\frac{\partial s^{e}}{\partial t}+\rho\frac{\partial s^{k}}{\partial t}=\frac{\partial}{\partial z}\left(\theta D\frac{\partial c}{\partial z}\right)-\frac{\partial qc}{\partial z}-\phi$$

$$s^{e}=f_{e}K_{d}c$$

$$\rho\frac{\partial s^{k}}{\partial t}=\alpha_{k}\rho\left(s_{e}^{k}-s^{k}\right)-\phi_{k}$$

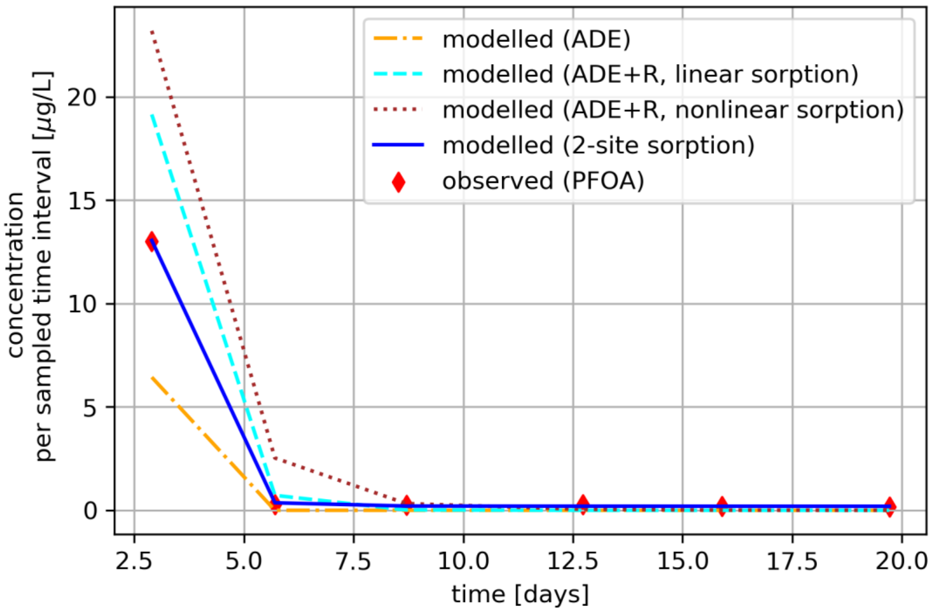
$$s_{e}^{k}=\left(1-f_{e}\right)K_{d}c$$

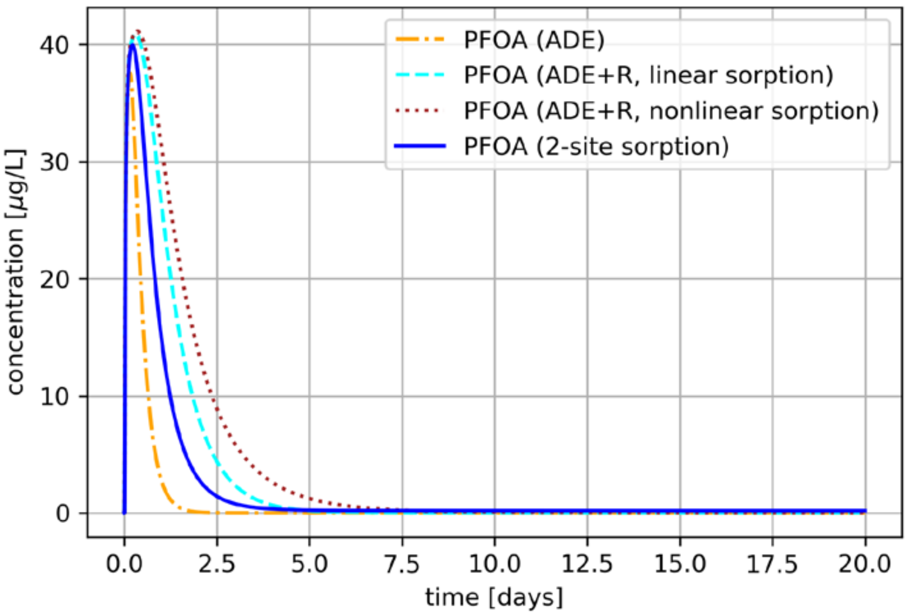
The two-site sorption model allows consideration of nonequilibrium sorption-desorption reactions (hence, sorption hysteresis)!

Physical equilibrium:
Uniform flow

Chemical nonequilibrium:
Two-site sorption model

Modelling PFOA





	ADE	ADE+R, linear	ADE+R, nonlinear	2-site sorption
C_0 [μg/L] (meas =9.71)	42.5	42.5	42.5	42.5
S_0 [μg/kg] (meas=32)	-	-	-	32 (s_k only)
RMSE	2.689	2.520	4.261	0.054

Available Master Theses

Several experimental topics available involving

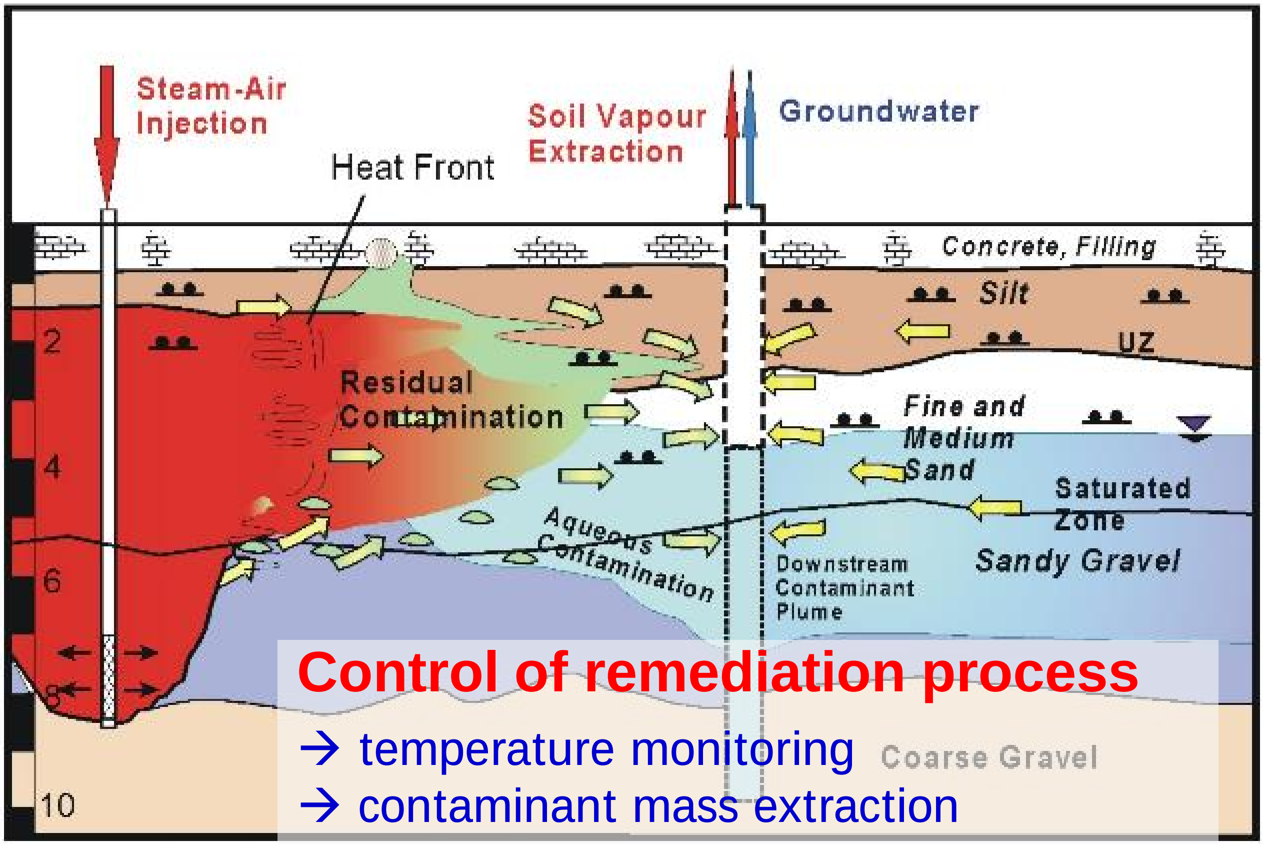
- Literature review
- Set-up of experiments
- Operation
- Sampling (lab work)
- Data Evaluation and visualization
- Additional studies: tracer tests, determination of p_c-s_w-relations…

Topics related to Numerical Modelling:

- Programming: Python
- Set-up of models
- Reproduction of experimental results
- Comparison of different models
- Sensitivity analysis

Steam-Air Injection: Remediation Principles

Contaminant source zone remediation by steam-air injection in saturated zone for organic contaminants (b.p. < 200°C)



Control of remediation process

→ temperature monitoring

→ contaminant mass extraction

Design of Steam-Air Injection

steam-air injection

specific power
0.1 – 0.2 kW/m³ soil

Air prevents
accumulation of NAPL

SVE:

specific discharge
0.1 – 0.2 m³/(m³ x h)

GW-pumping
(cooling water)

depends on aquifer

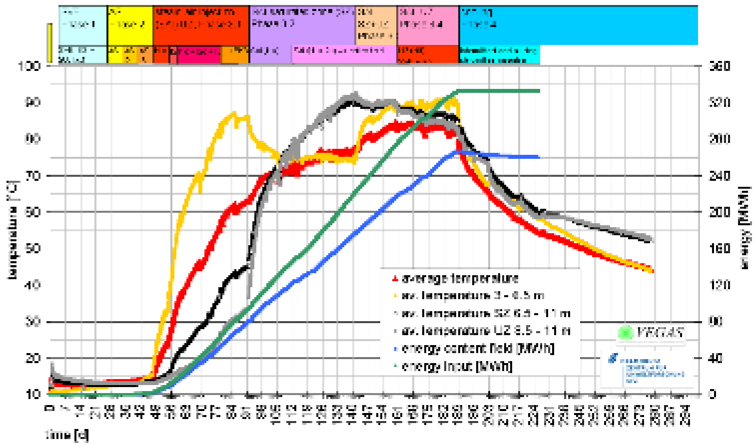
Field Site „Zeitz“ with 1.600 m³ soil volume and 120 kW injection power

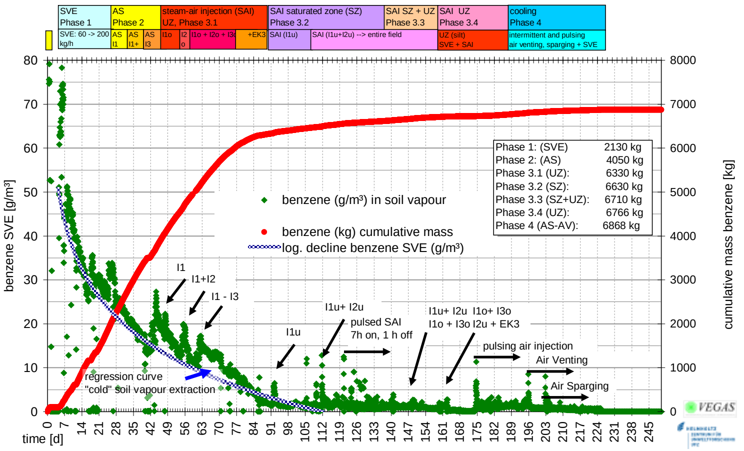
➔ Theoretical Energy demand: ca. 300 MWh

➔ Theoretical time demand: ca. 80 days

➔ Energy demand:
335 MWh → analytical solution of tool fits reality

➔ Time demand:
Remedy: 140 days → analytical solution underestimates reality





Design of Steam-Air Injection

Flume experiments in VEGAS: experimental work

➔ Variation of soil types and carbon content
➔ Determination of removal time vs.
carbon content, soil type, flow regime, diffusion coefficient
➔ Definition of mass removal coefficient

DLI-Tool: Visual Studio Software to implement mass removal coefficient

➔ Implementation of GUI to select mass removal coefficient
➔ Implementation of parameters in analytical solution (Excel spreadsheet)

Numerical Solution: simulation to predict mass removal coefficient

➔ Implementation of a numerical model (multi-phase flow and thermodynamics) of flume
➔ Parameter sensitivity tests to define mass removal coefficient

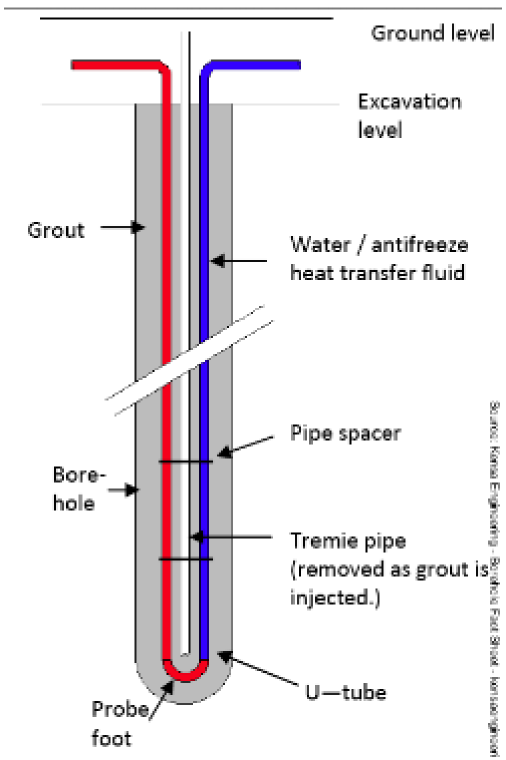
Design of Steam-Air Injection, Validation of Tool

Sensors - Development

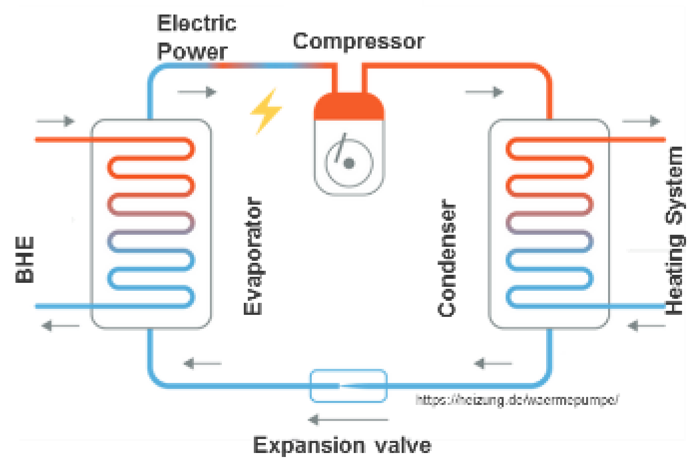
Storage and Use of Thermal Energy in the Subsurface

Research Topic: Geothermal Energy

- **Shallow Geothermal Energy:** clean and competitive heating for buildings and industry
- **Borehole Heat Exchanger (BHE):** a well-controlled vertical **closed system** is the most frequent geothermal application



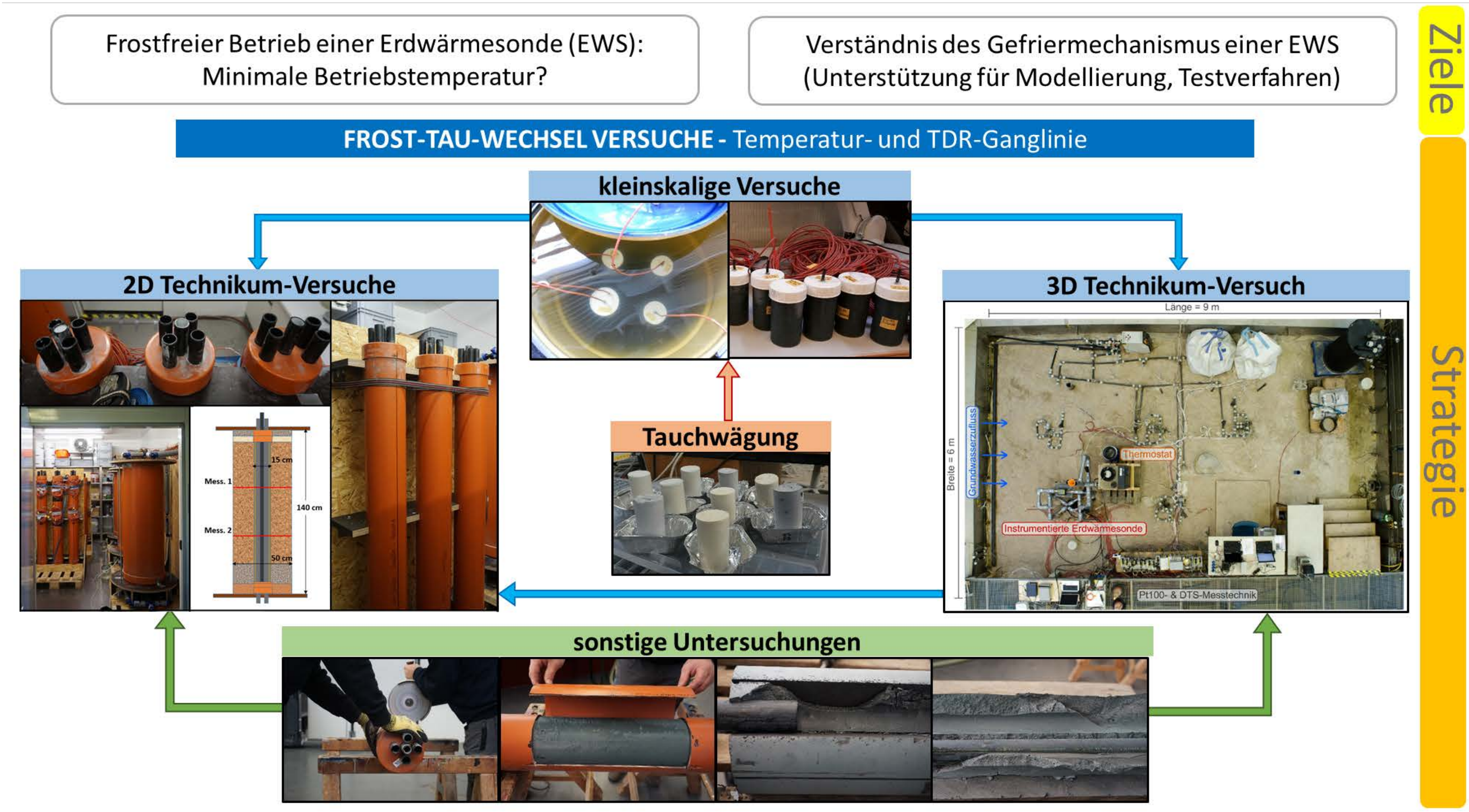
Sketch of a BHE



B

- Sketch of a shallow geothermal system: BHE + heat pump + house heating system (A)
- Detailed sketch of all the components of a heat pump (B)

Topics Geothermal Energy

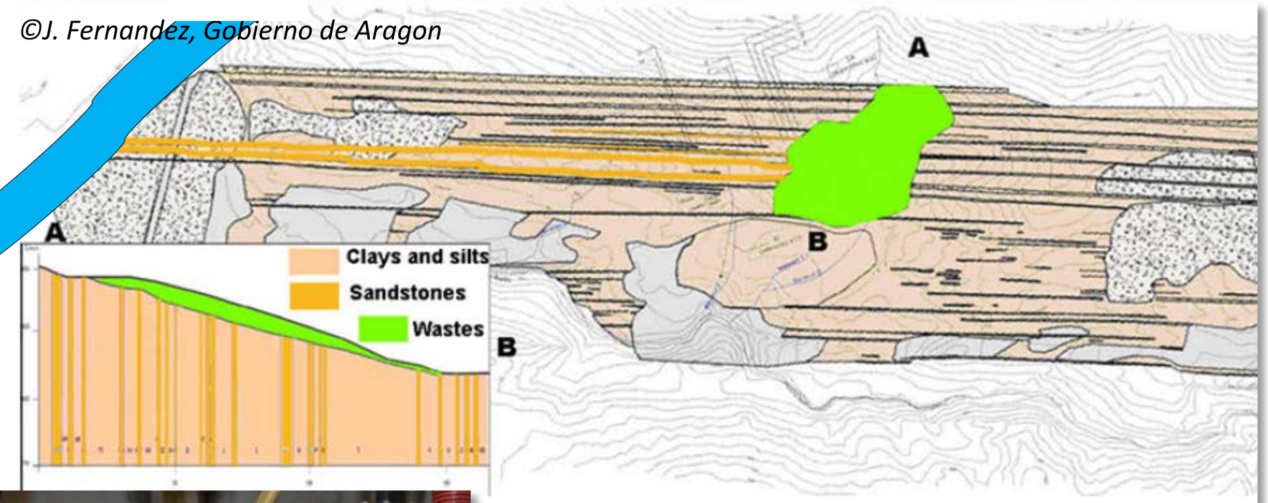


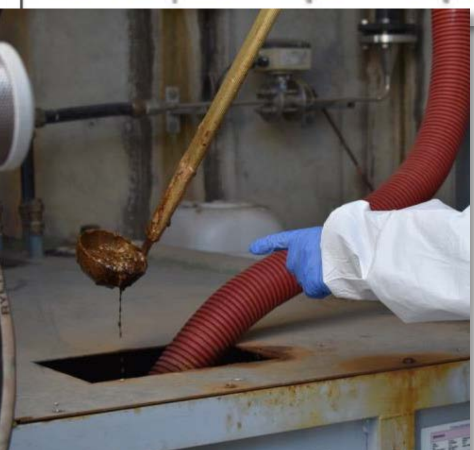
Surfactant enhanced chemical oxidation

EU environmental project:

„SURFactant enhanced chemical oxidation for remediatING DNAPL"

©J. Fernandez, Gobierno de Aragon



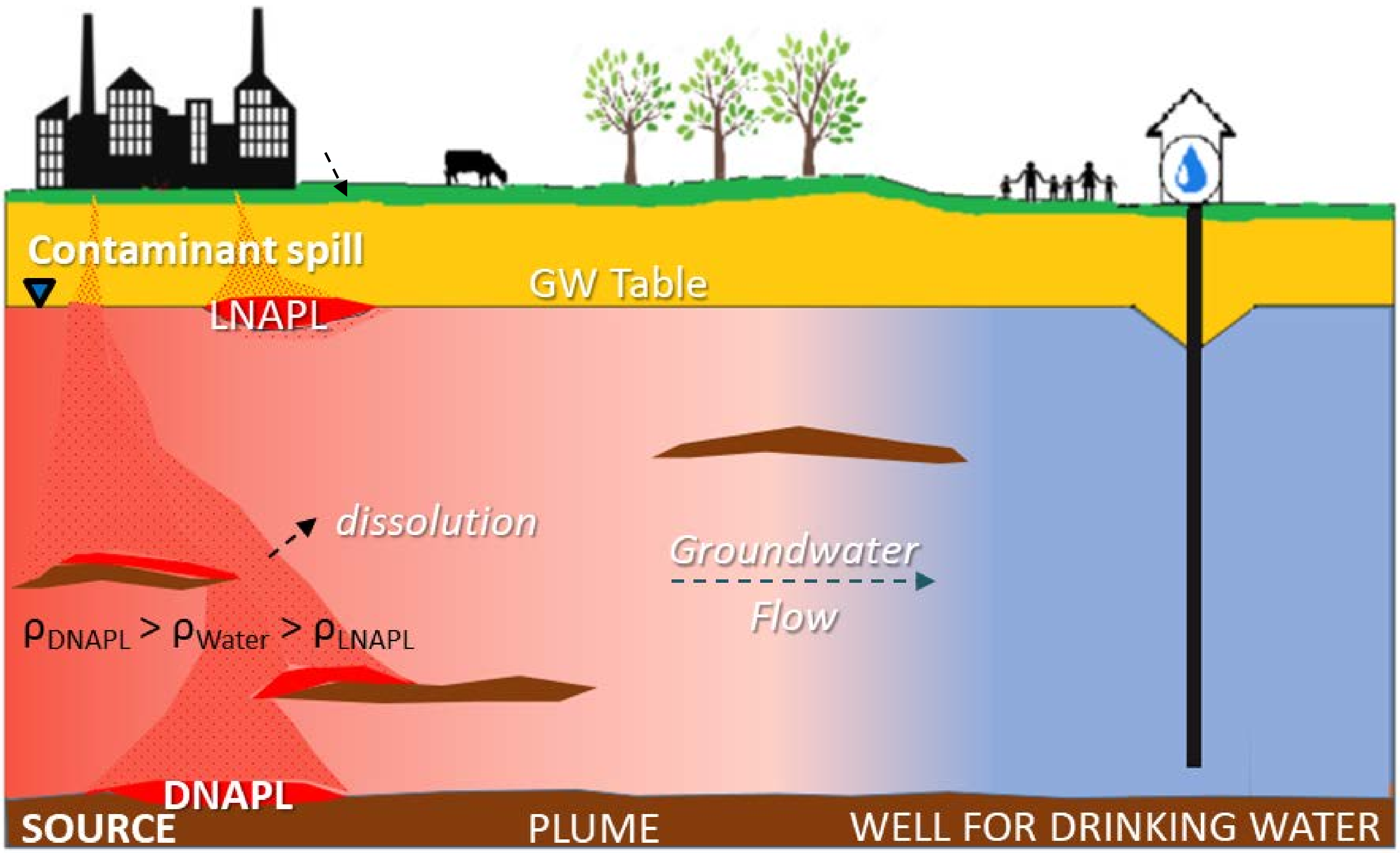


- Liquid wastes from insecticide production were dumped on a landfill
- Contaminants penetrated into the subsurface and groundwater
- Permeable sandstone layer led to entry of pollutants into the river

→ **Closing of a drinking water plant 60 km downstream**

Surfactant enhanced chemical oxidation

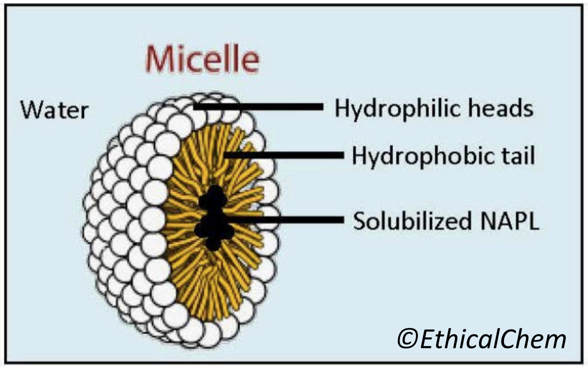
- **Problem: N**on-**A**queous **P**hase **L**iquids(NAPLs) cause longterm damage by slowly dissolving into Groundwater



Surfactant enhanced chemical oxidation

- **Concept:** Source remediation by surfactant enhanced In situ chemical oxidation (**S-ISCO**)

Surfactant



Increasing solubility of NAPLs, desorption from soil matrix

Oxidant

$C_{10}H_8 + 24H_2O_2 \rightarrow 10CO_2 + 28H_2O$

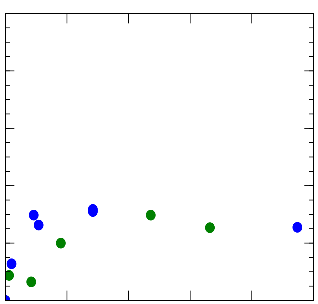
Oxidative degradation of contaminants

- Injection of mixture in concerned aquifer via wells
- Possible without big affect on ground surface (remediation under buildings, no treatment aboveground necessary)
- Biodegradable surfactants ensure sustainibility of procedure
- Fast and effective (when applied correctly)

→ **Research needed for wide approach in the field**

Surfactant enhanced chemical oxidation

Batch experiments for optimizing degradation conditions of S-ISCO applications

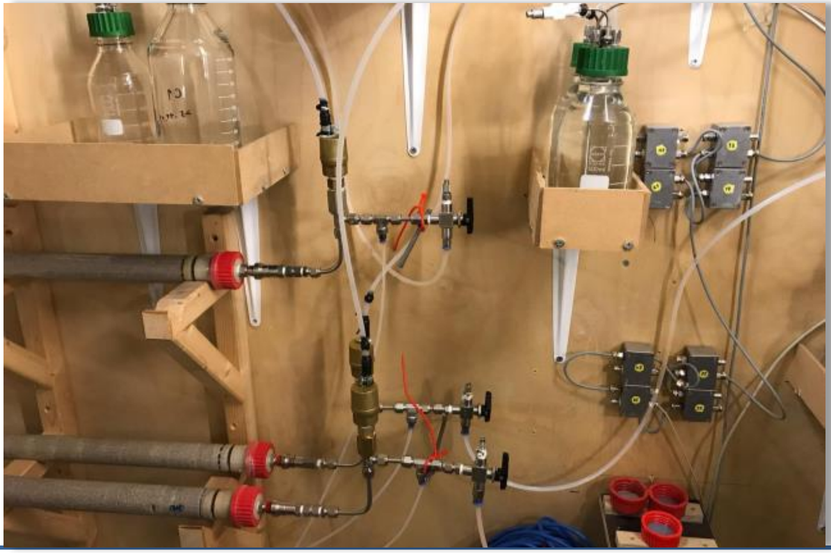


time in h

- Development of analytical lab methods to determine relevant parameters
- Solubility experiments with different contaminants in surfactant solution
- Investigation of competing reactions between oxidant, surfactant and contaminants
- Behaviour of activating agents for enhancing the degradation process
- Assessment on efficiency of S-ISCO treatment from chemical point of view

Surfactant enhanced chemical oxidation

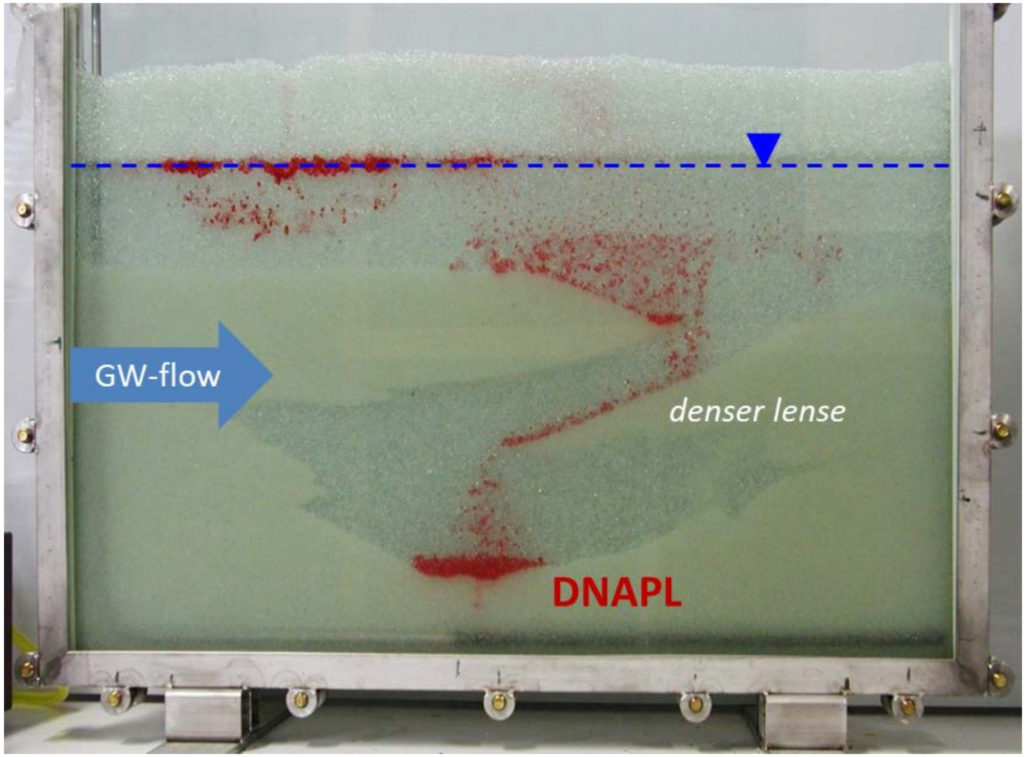
Column experiments for investigating degradation and desorption processes of S-ISCO applications



- Injection of surfactant-oxidant mixture into columns filled with contaminated soil
- Assessment of the remediation efficiency based on intensive monitoring of relevant parameters
- Consideration of fluid mechanical aspects
- Process engineering

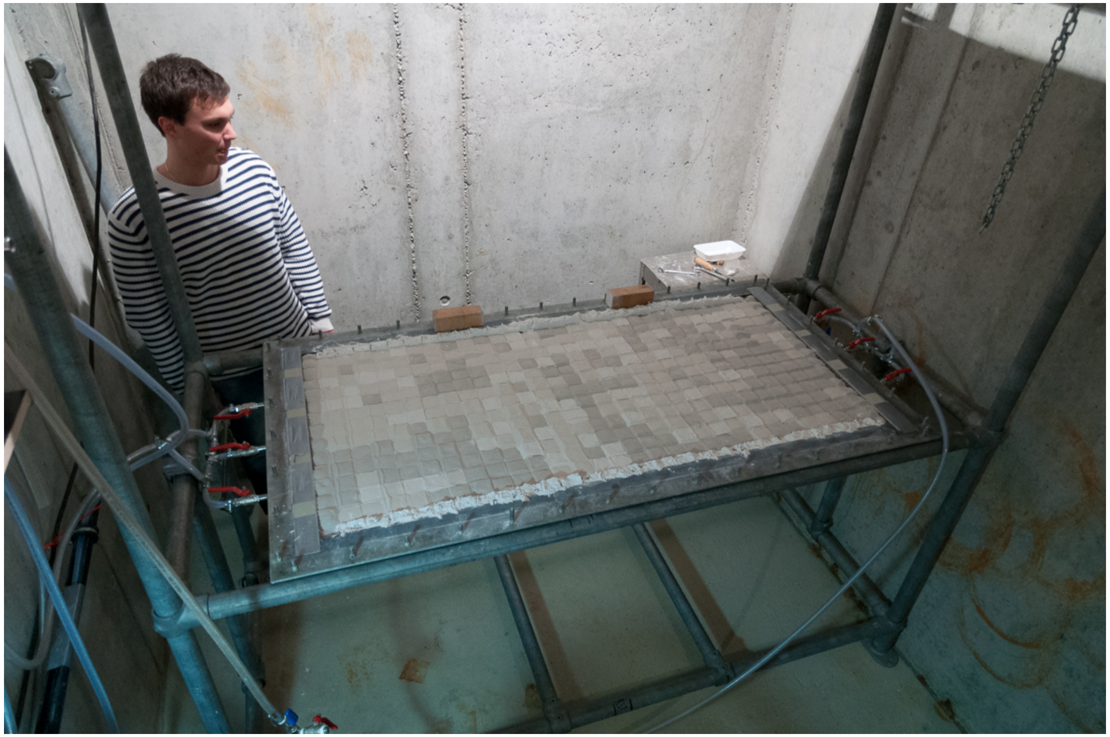
Surfactant enhanced chemical oxidation

Research on behaviour of contaminants during S-ISCO remediation in the subsurface with cuvette experiments



- 2D-observation of processes during S-ISCO remediation in subsurface, on top of sampling and measurements
- Impact of soil heterogeneities
- Investigation on possible vertical mobilization of DNAPLs caused by lower interfacial tension *(surfactants!)*

(spatial structure) K
→ solute transport properties



dimensions

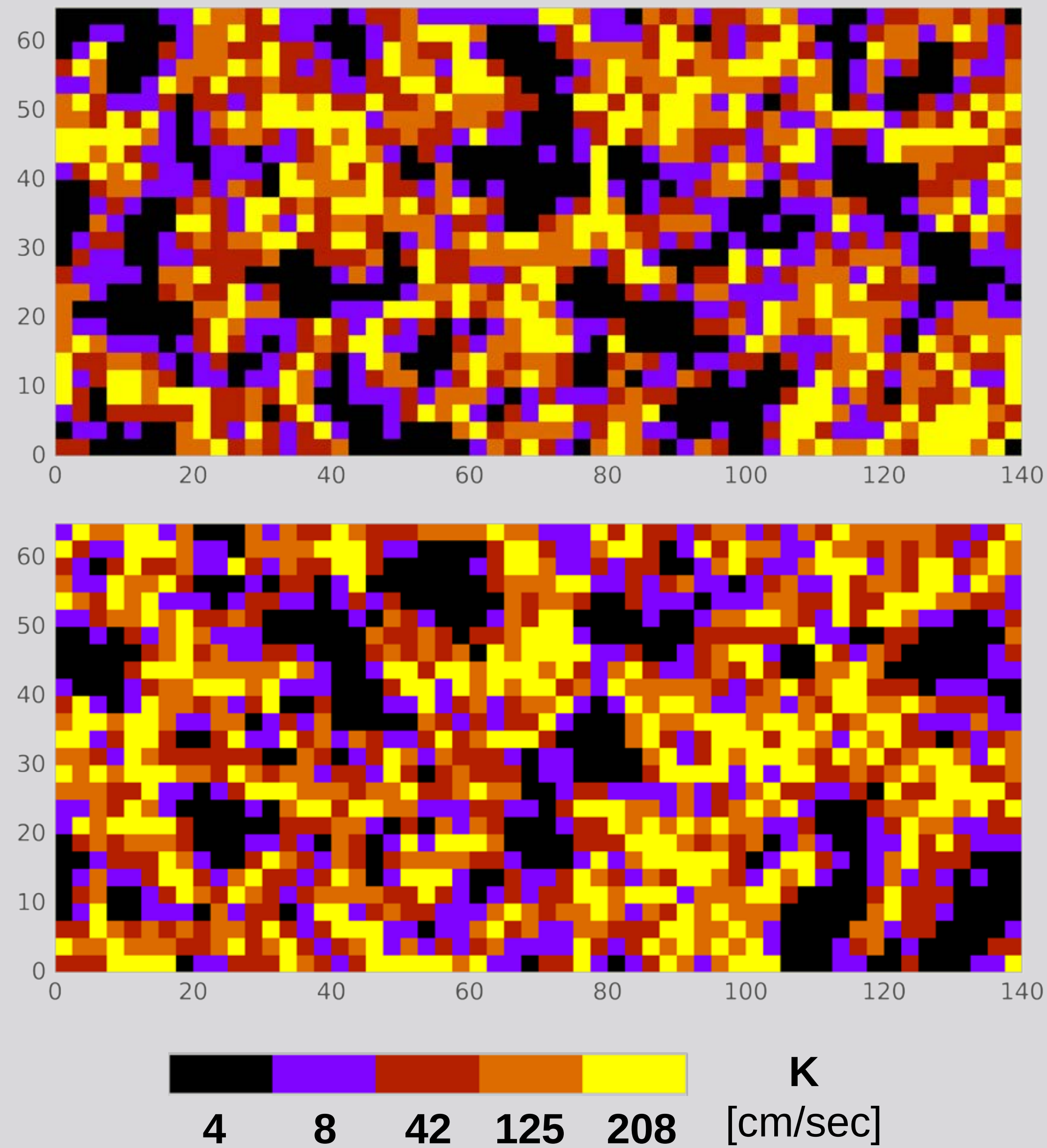
- box: 140cm × 70cm
- cubes: 0,5cm × 0,5cm

5 different sands corresponding to a realistic continuous distribution

covariance structure
1.0 Mat(1.5)^2.0

limited number of experiments possible → choose the ensemble smartly

- the one that is most different (antithetic, ARF)
- “flipped”

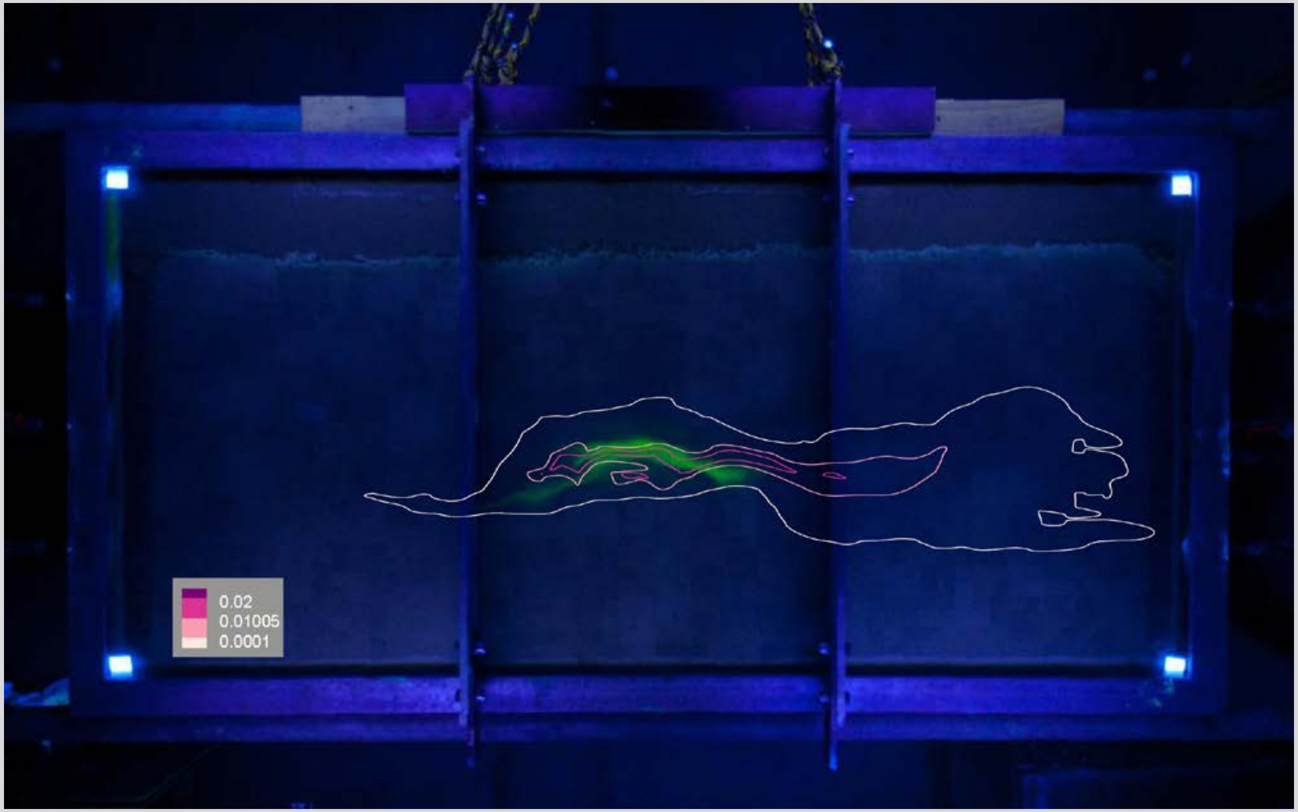


Numerical Modelling of Stochastic Tracer Experiment

calibration

- tank is completely filled with two different, known concentrations
- 10 different concentrations at 5 different locations

the observations can be reconstructed



https://www.iws.uni-stuttgart.de/vegas/lehre-und-weiterbildung_0001/

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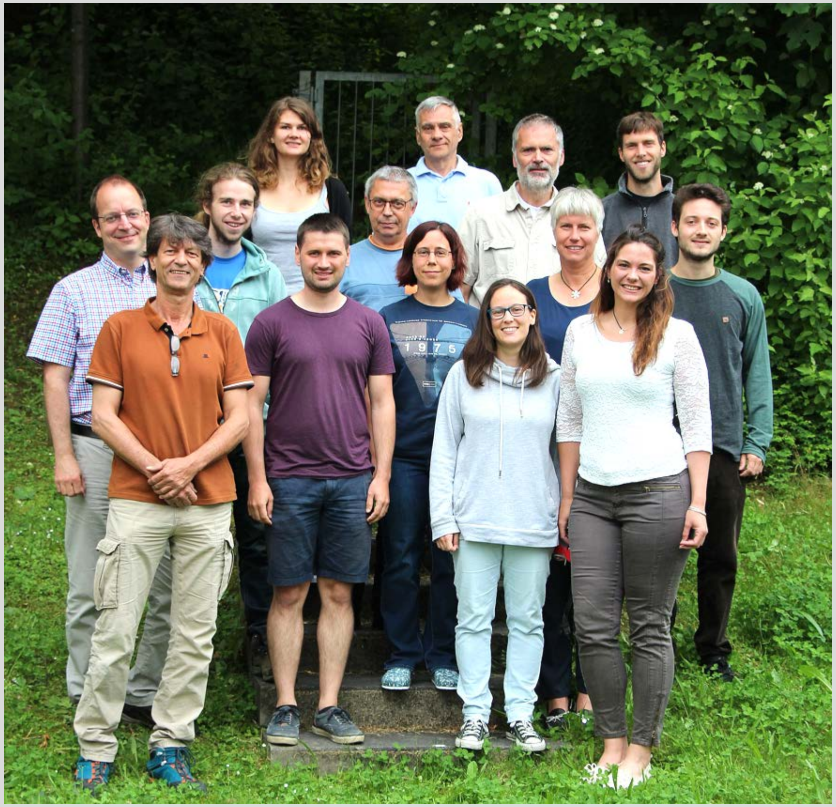
VEGAS

Research Facility for Subsurface Remediation

Contact us!



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