Groundwater modelling

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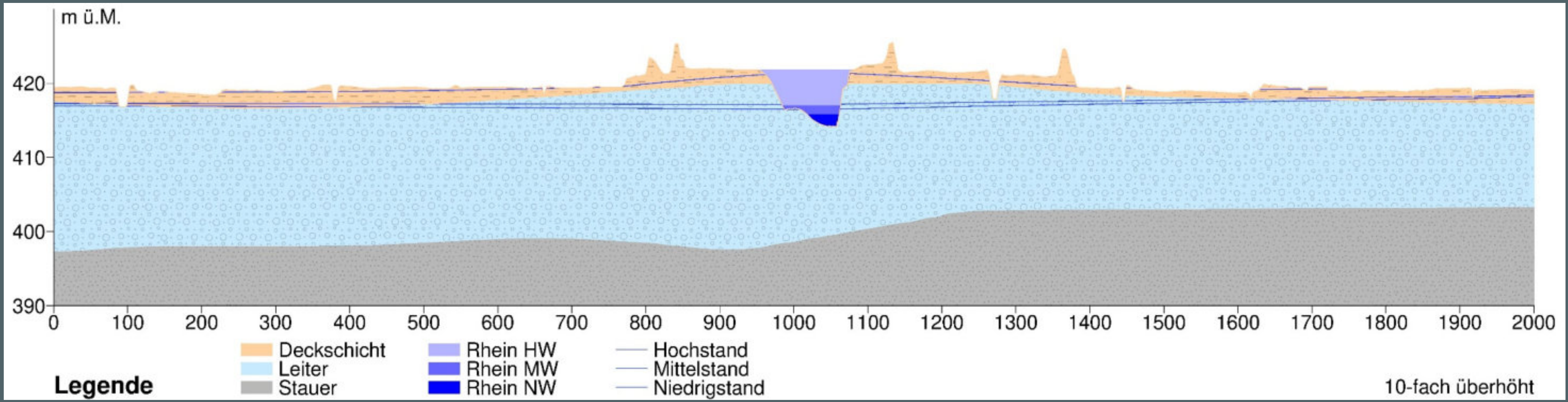
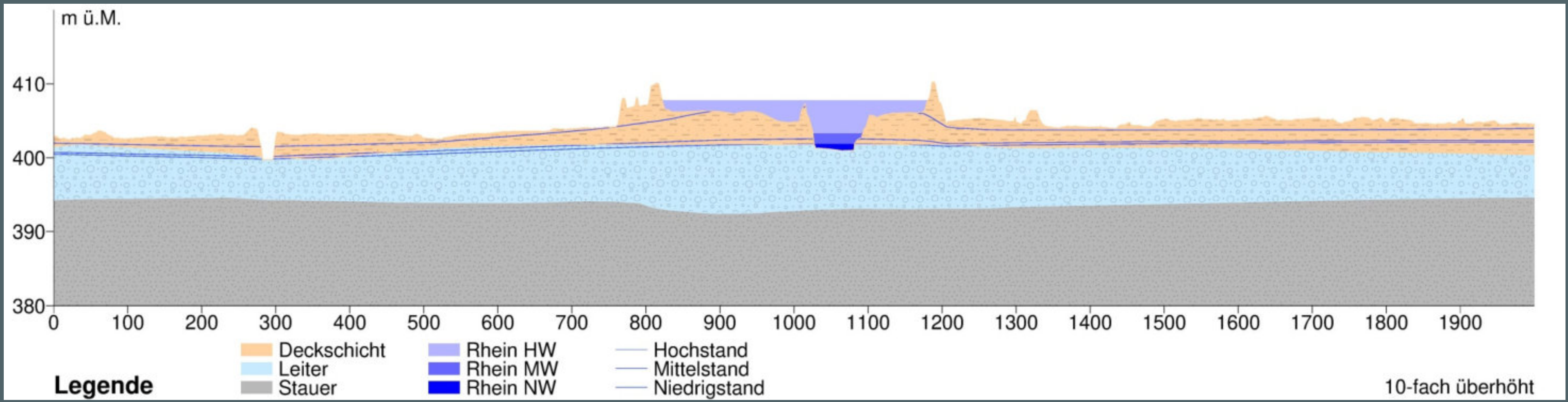
Situation

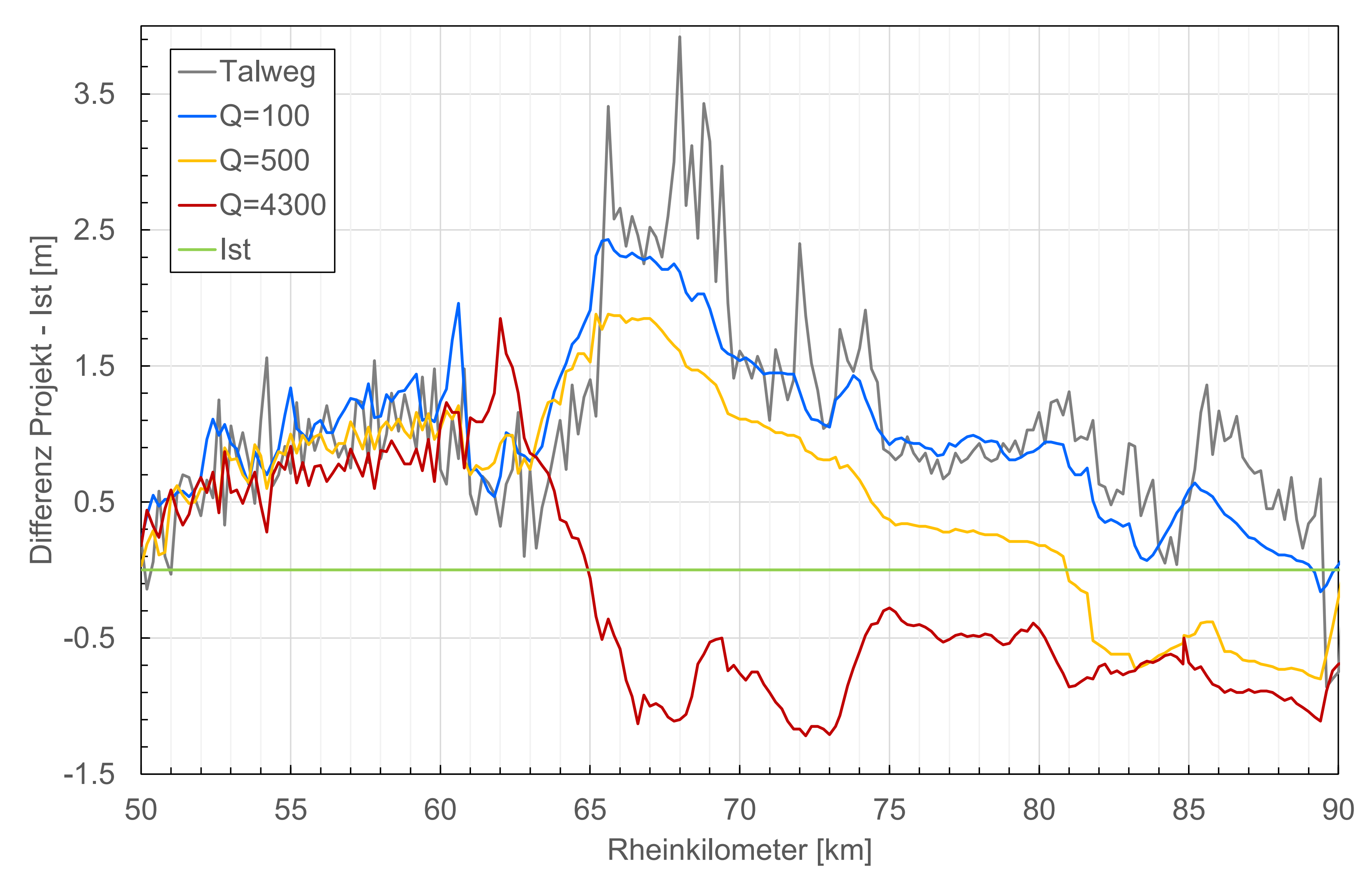
Southern part



Northern part



Changes in the Rhine water level



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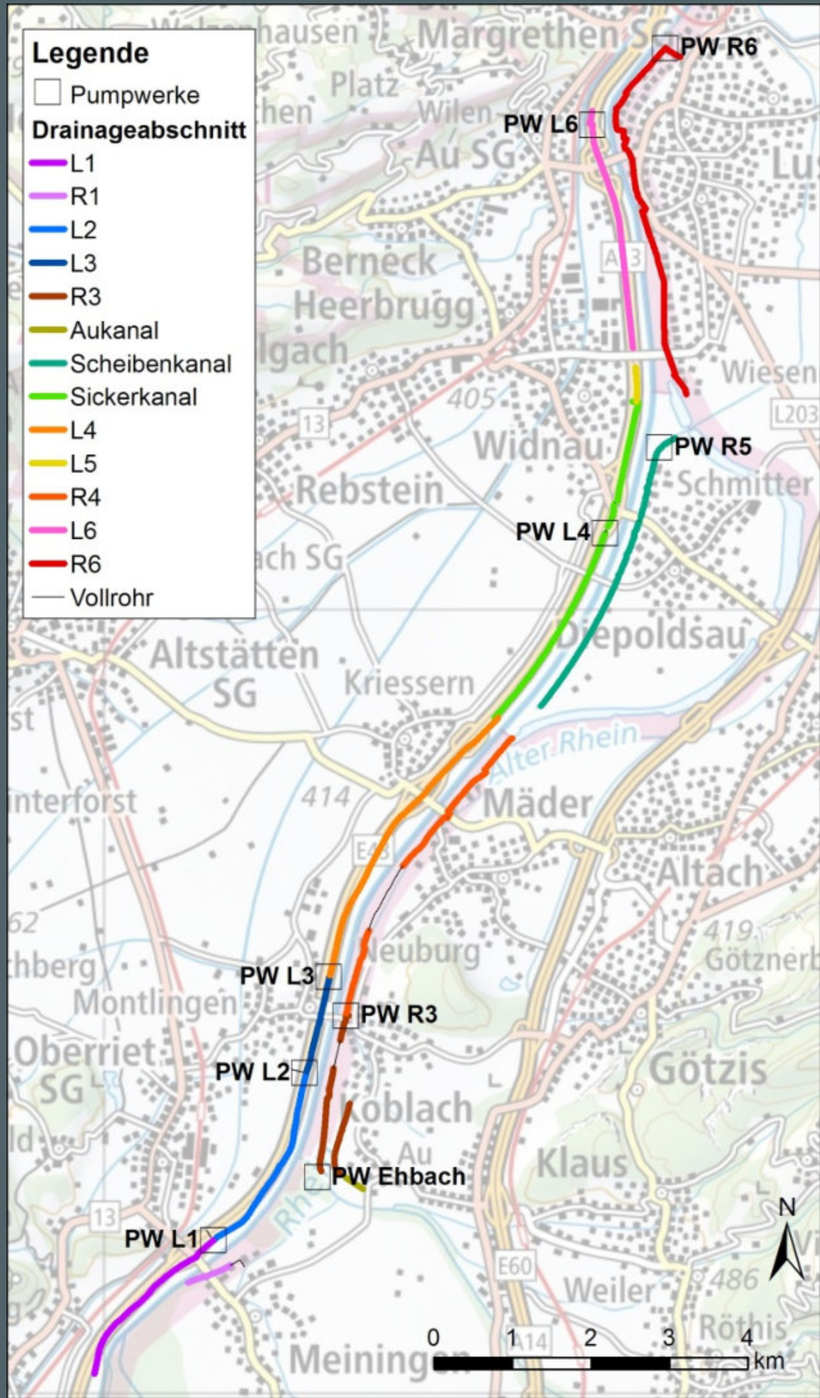
Project

Effects of the project

- The bed of the Rhine will be raised
- The Rhine bed becomes more permeable
- The groundwater table will rise

Measures:

- Drainage located on both sides of the Rhine
- Under normal circumstances, the drainage pipes drain into some small brooks
- In the event of flooding, pumping stations are provided to pump the drained groundwater into the Rhine



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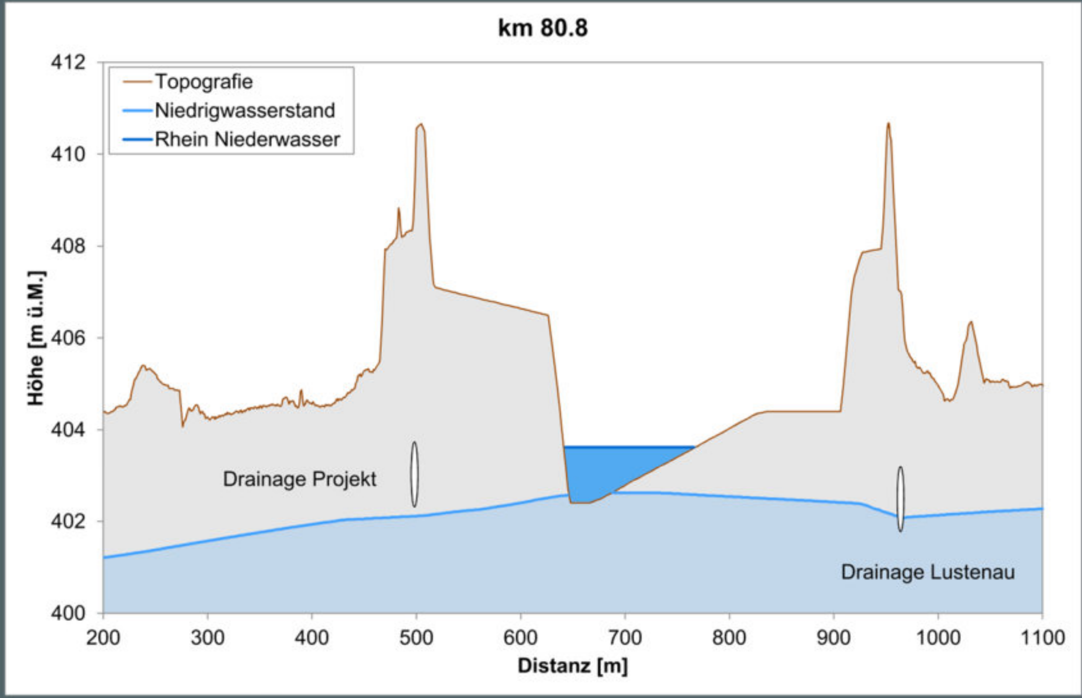
Example

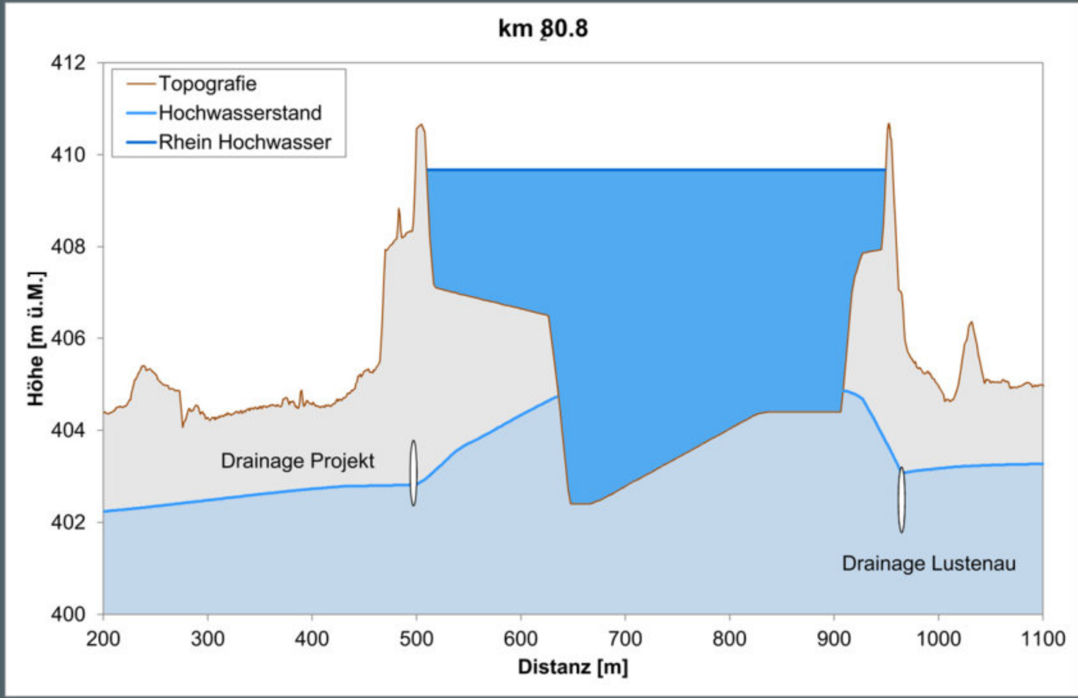
Arrangement:

- Left: new drainage
- Right: existing drainage in Lustenau

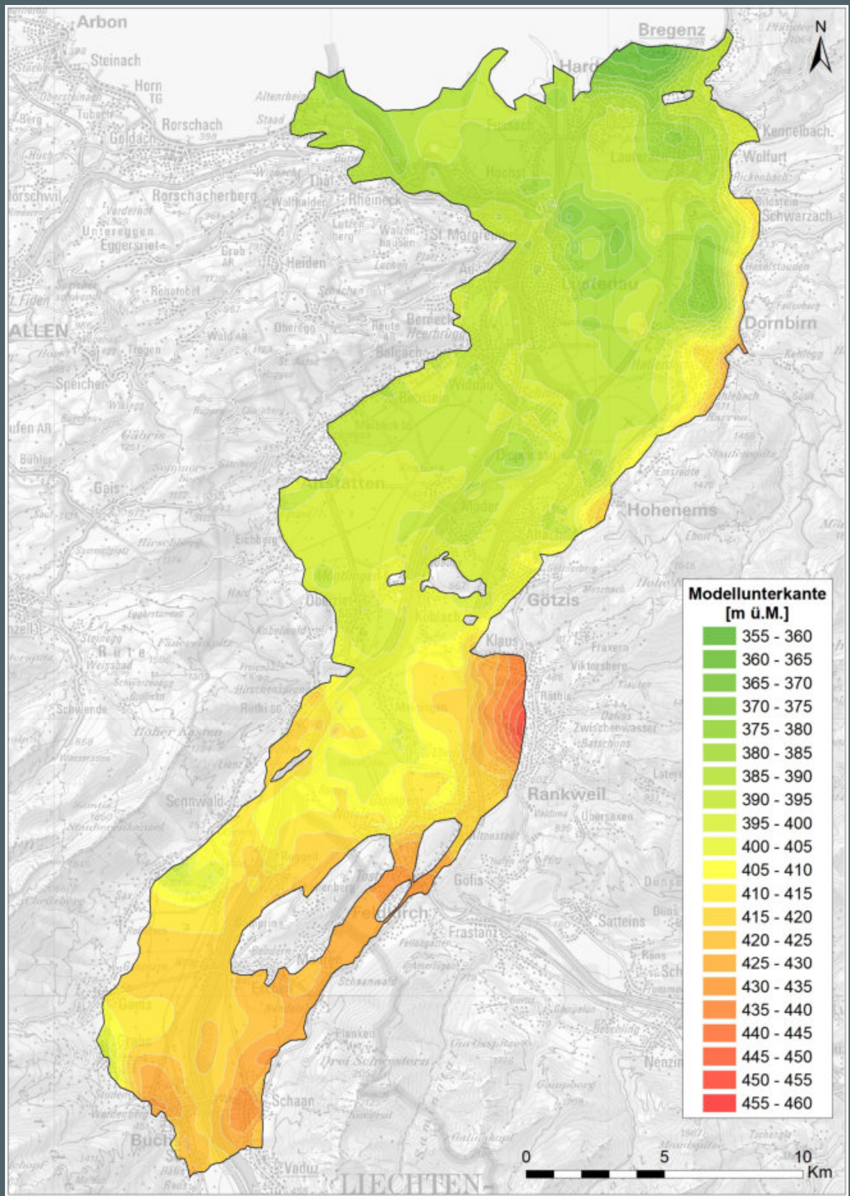
Function:

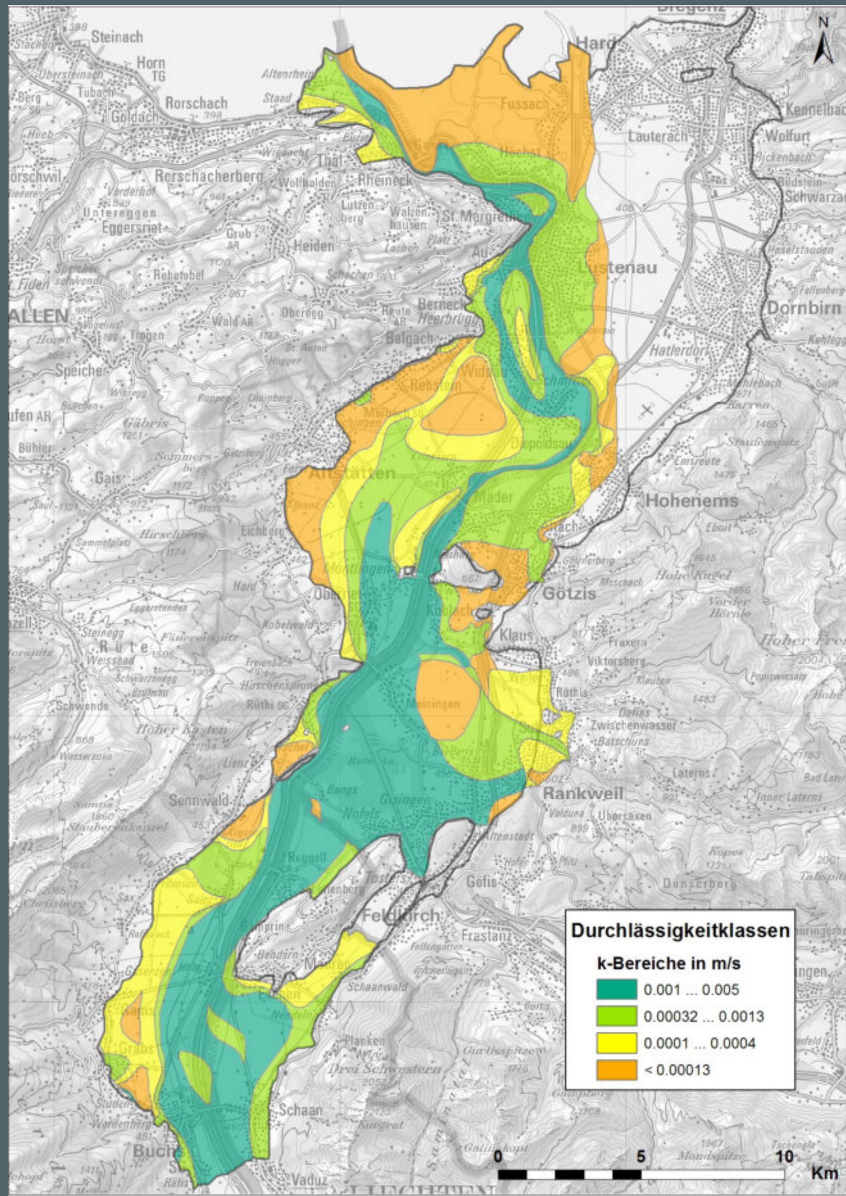
- New drainage only works at groundwater levels > mean water level





Input from the local hydrogeologists





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Model concept

Dimensions

- The aquifer is 44 km long and 10 km wide
- The gravel thickness is 10 - 20 m
- Beneath the gravel are deposits with significantly lower permeability
- A separating intermediate layer is found at a small region only
- A 2D-model with a free groundwater table is appropriate

Time dependence

- The groundwater level fluctuates by several metres in many places
- The impact of the project must be forecast for all groundwater levels
- A flood passage is of particular interest
- The model must be transient

Numerical method

- The requirement for model discretization varies greatly from place to place
- The Finite-Element method is a good choice (FEFLOW)

Data available

Head mesurements

- 320 measuring points
- 600‘000 daily values (2015-2020)

Rivers and drainage channels

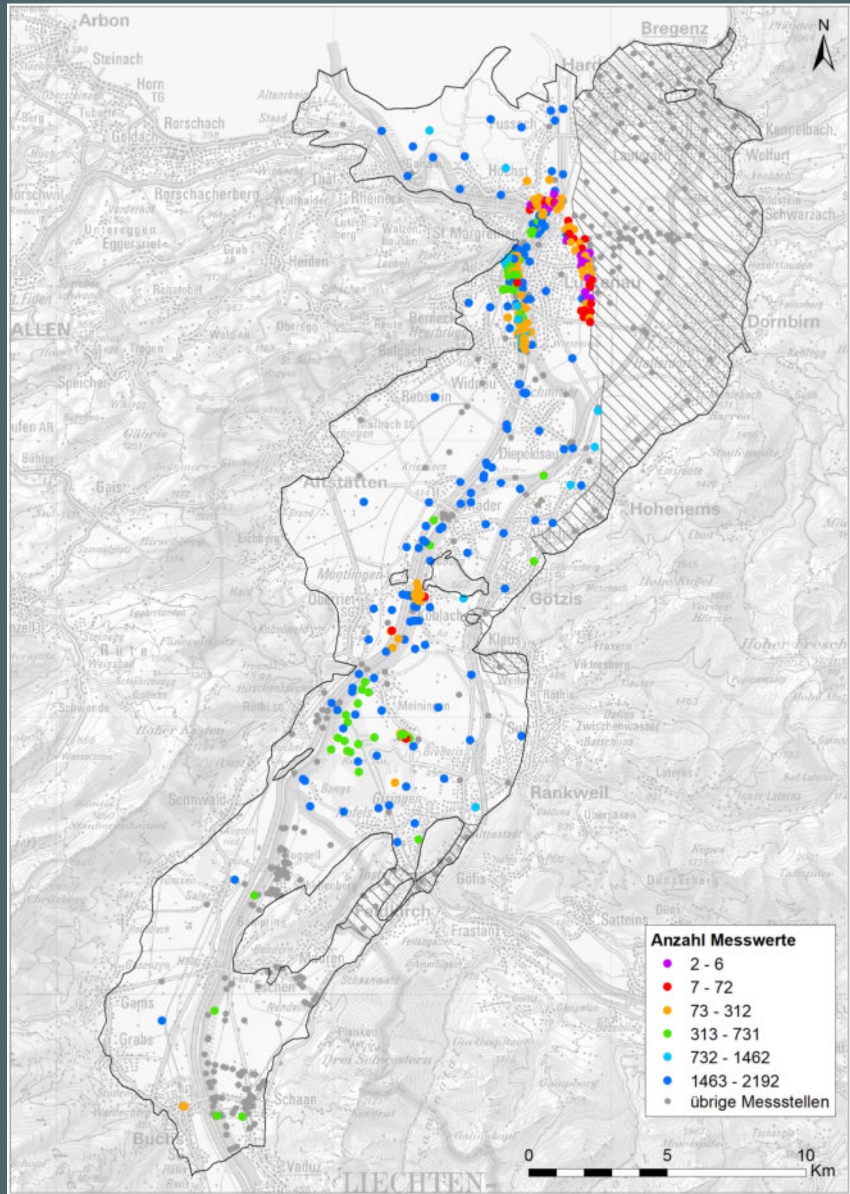
- 10 permanent discharge measuring stations
- Some single measurements

Pumping rates

- Pumping rates at 172 wells

Clima

- Rainfall at 19 climate stations
- Full climate data at 2 stations



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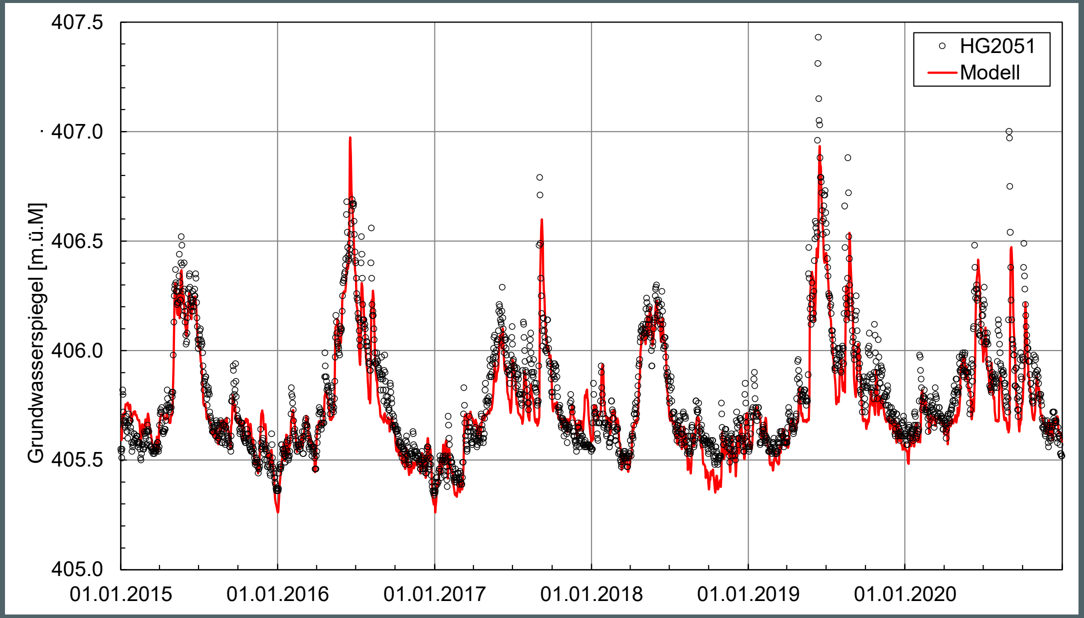
Calibration method

Manual and automatic calibration in a loop

- The informations given by the hydrogeologists were rather detailed
- A zonal calibration was therefore choosen
- Before and after an automatic calibration step, a manual step was done
- The correlation matrix and the sensitivity of the parameters resulting from PEST was used to better choose the parameter zones and ranges
- Time period 2015-2017

Calibration measures

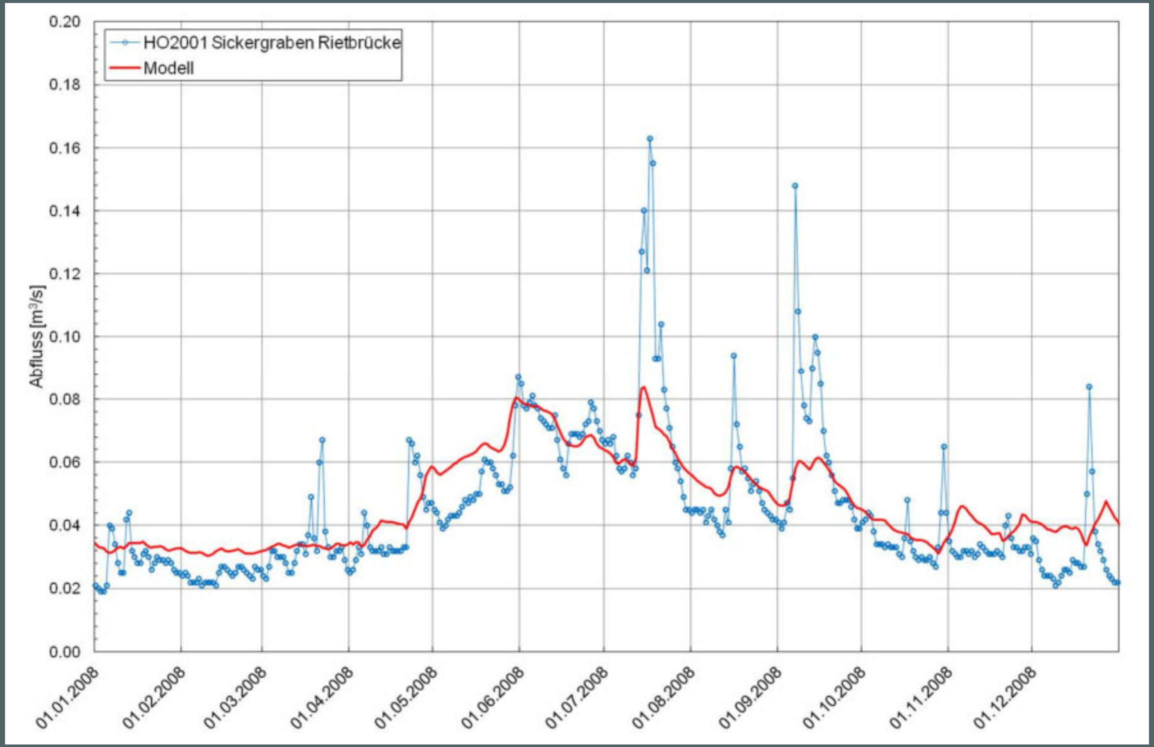
- Root mean square error
- Average deviation
- Median of deviation
- Visual check of the most important measuring points



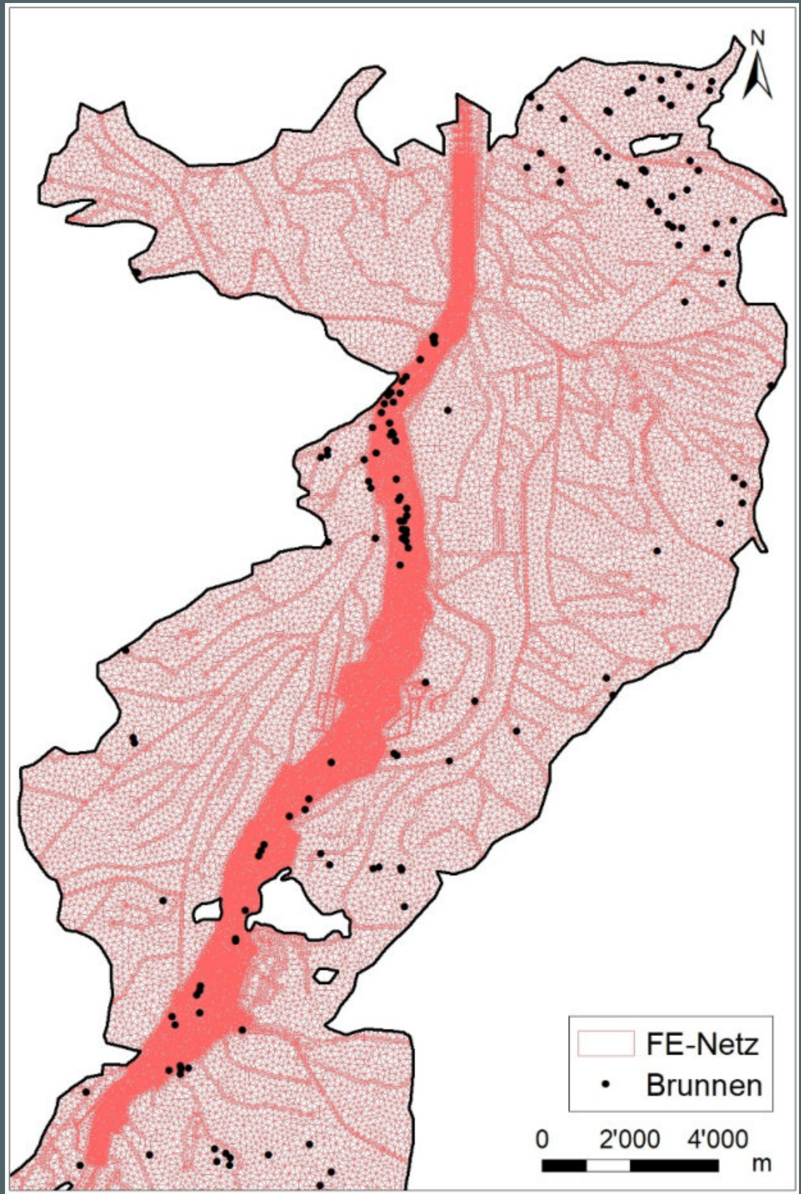
Validation

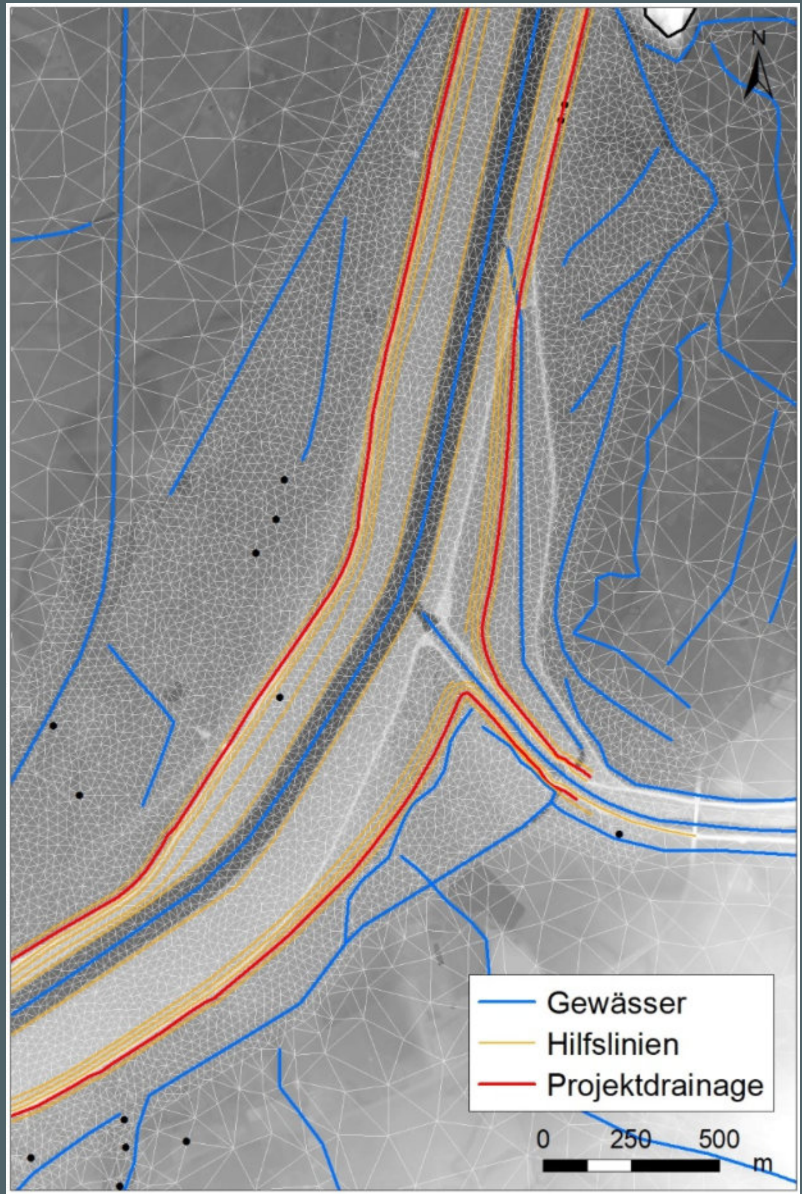
Validation is crucial for a predictive model

- Time period 2018 – 2020
- Discharge of the drainage channels
- Pumping tests at nearly all drinking water wells
- Transport calculations:
  - electrical conductivity
  - oxygen-Isotopes
- Tracer tests
- Lysimeter measurements



Finite-element mesh





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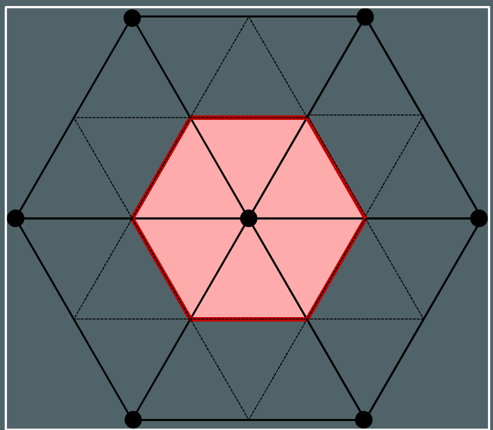
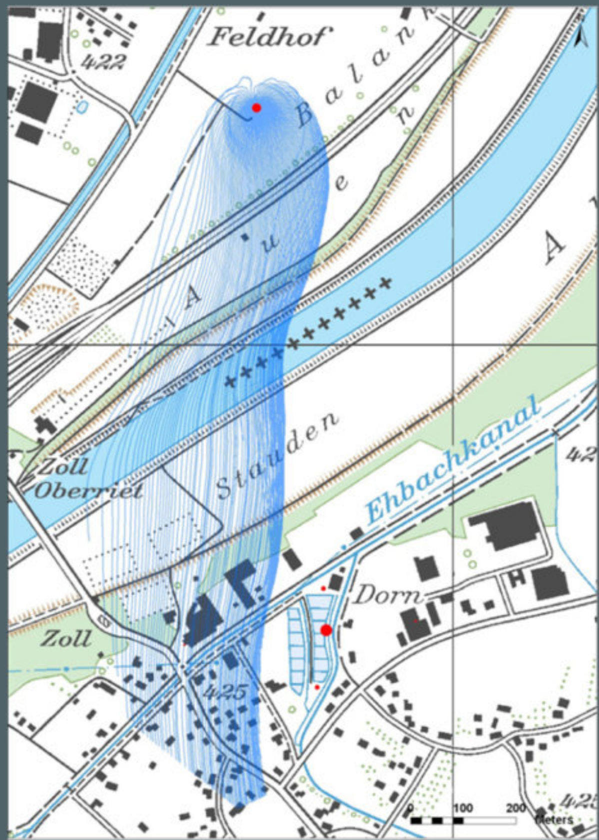
Extensions to FEFLOW

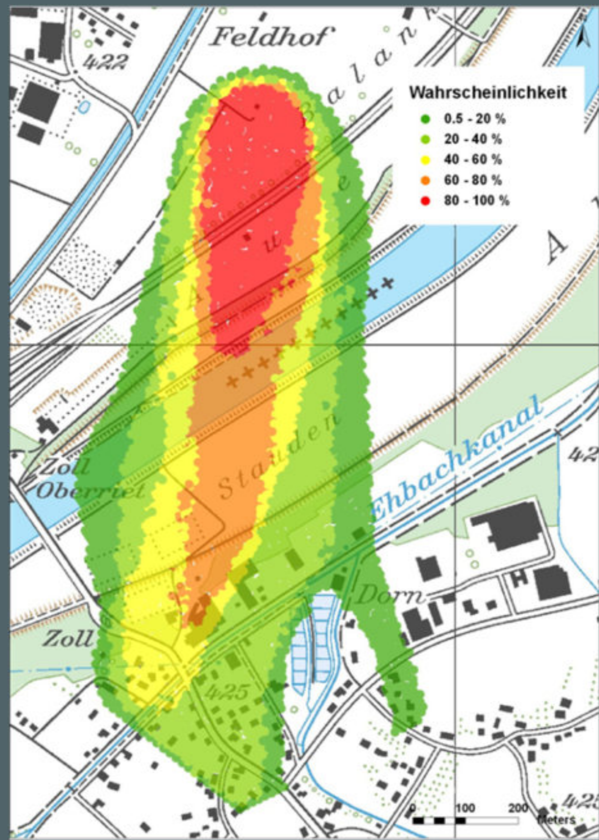
Flow path routine in a continuous flow field

- According to Cordes and Kinzelbach (water resources research 1992)
- Allows for calculating the water balance along the flow paths
- Statistics of flow times
- Origin probability



Patch for water balance

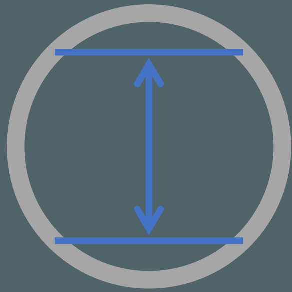




Extensions to FEFLOW (python)

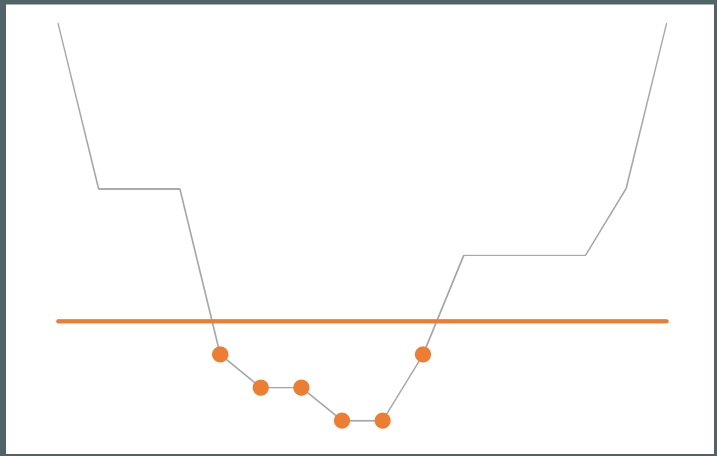
Pipe hydraulics

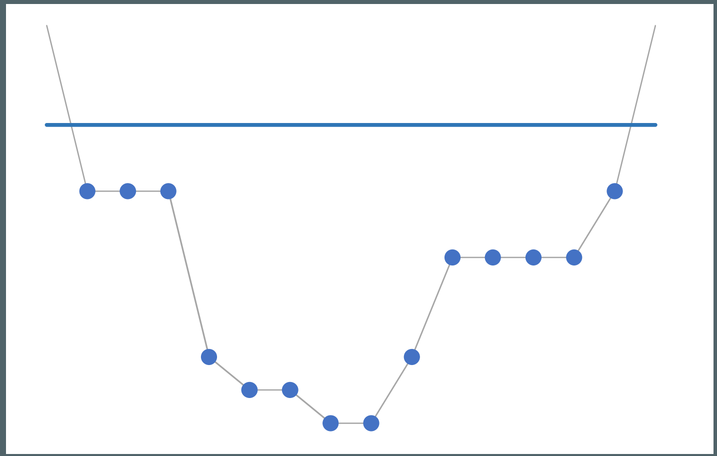
- To drain the groundwater at high dscharge in the Rhine pipes up to 2.20 m diameter are nesessary. The water level in the pipes is therefore relevant
- The water level is calculated at every time step by analytical formulas along the pipe



Wetting of the river bed

- The cauchy boundary condition is switched on and off according to the water level in the Rhine river





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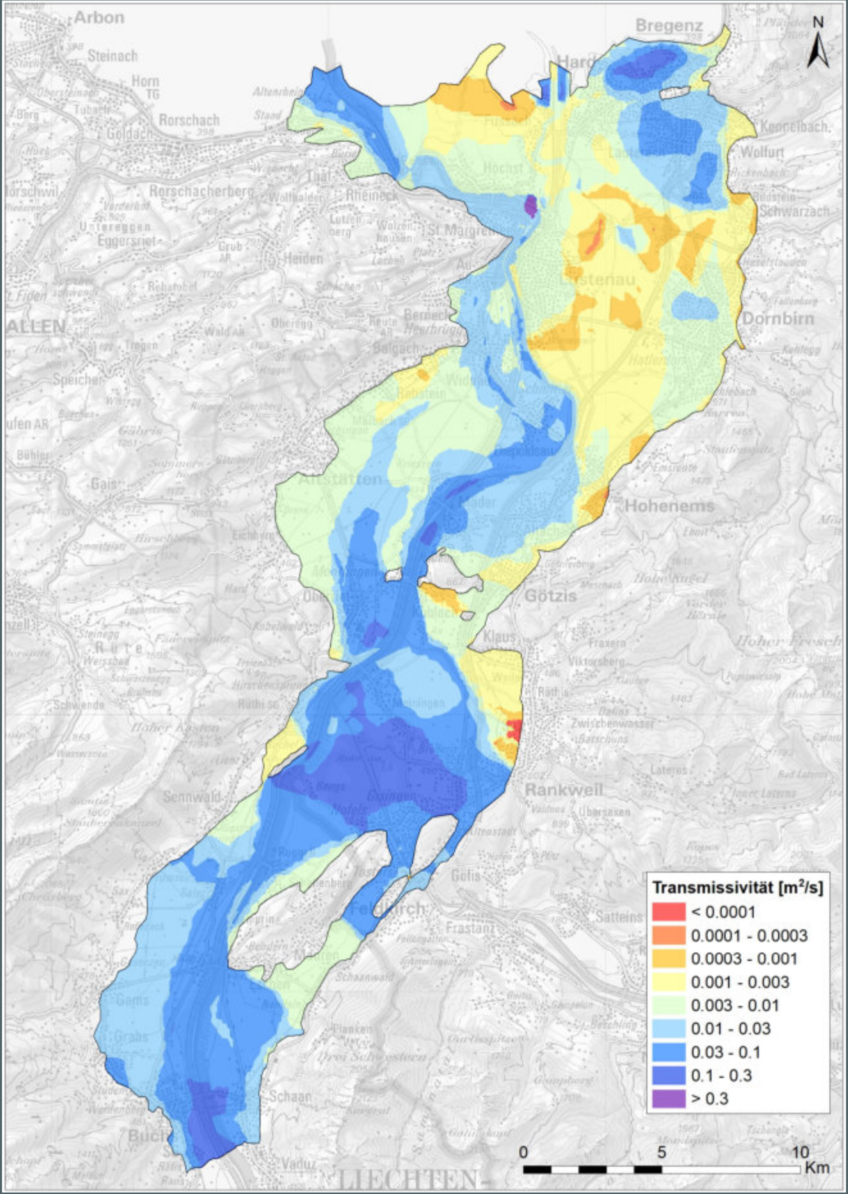
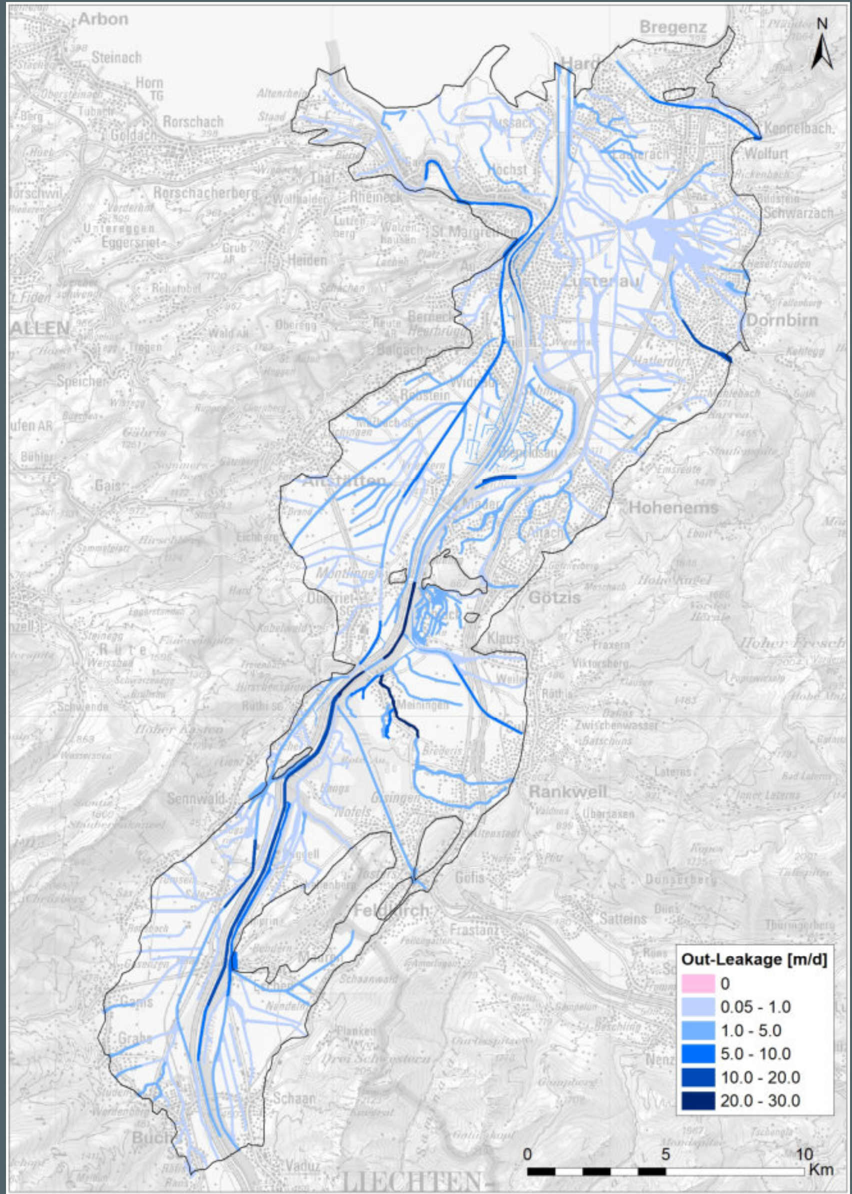
Resulting model



Transmissivity



Leakage values

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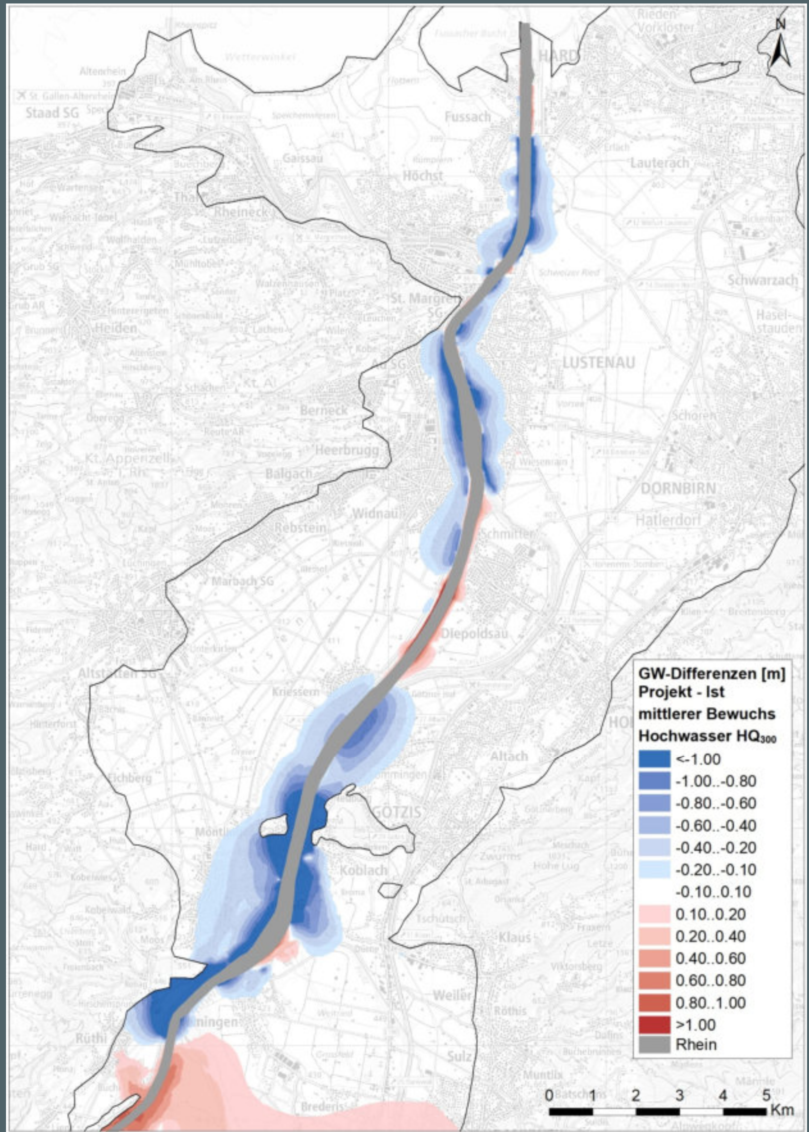
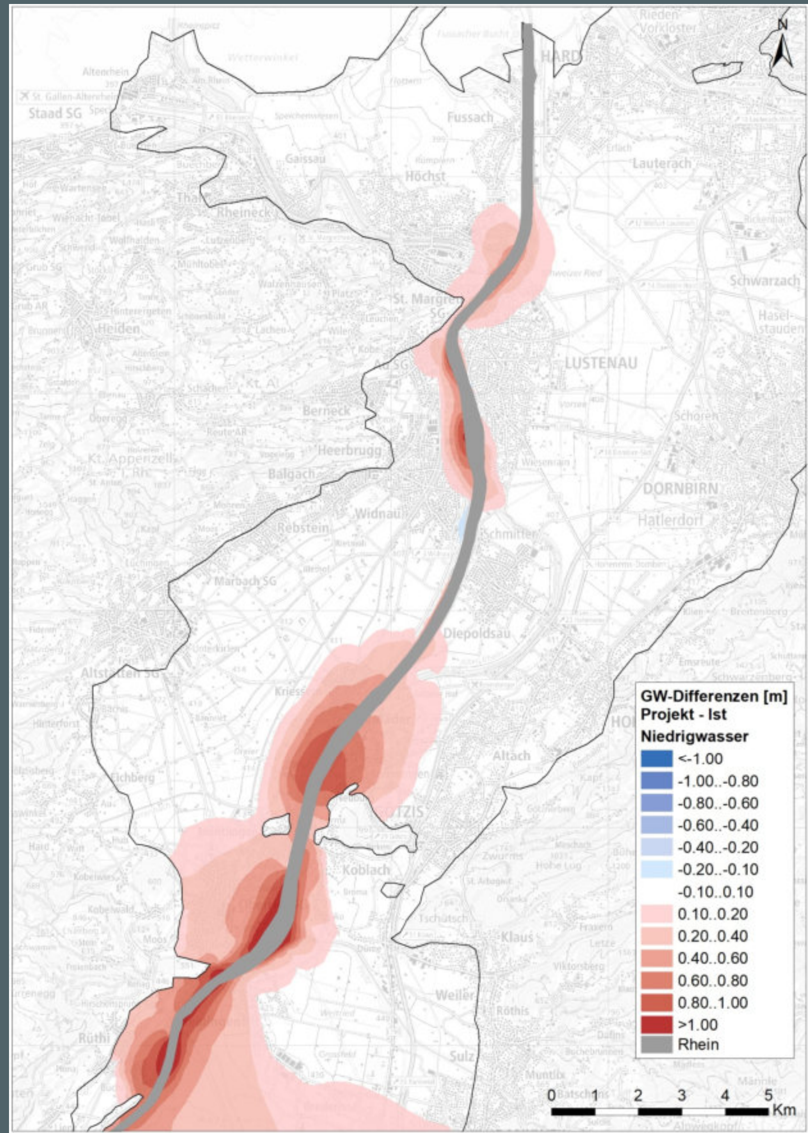
Predictions of the target state in 2099

Impacts at high Rhine discharge



Target state – actual state

Impacts at low Rhine discharge



Target state – actual state

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Decolmation test

Motivation and goals

Importance

- In order to protect the densely populated Rhine valley from flooding, the Rhine channel will be widened
- 24 drinking water wells must be temporarily taken out of operation during the construction works
- Due to the expected higher bed permeability, drainage channels will be constructed on both sides of the Rhine

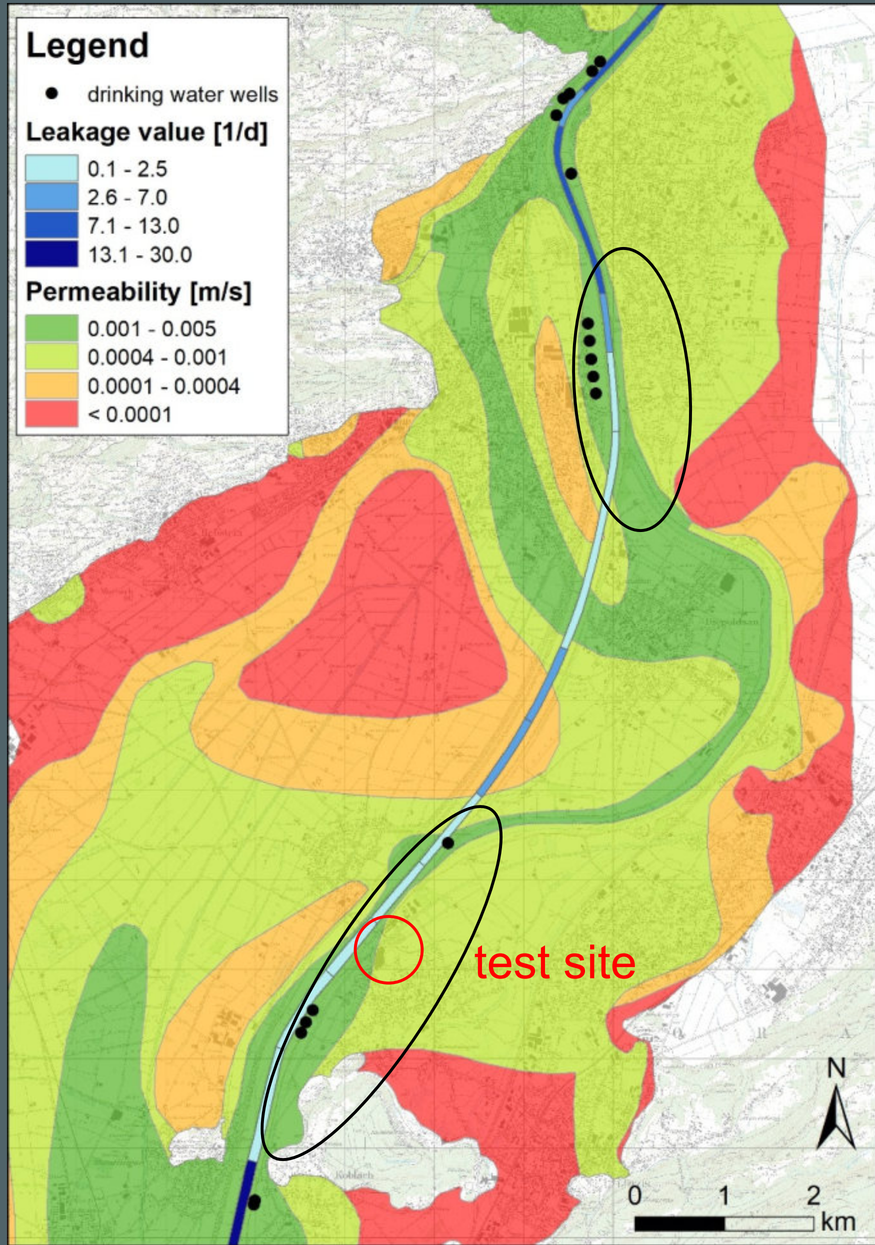
Questions arising

- How much will the riverbed permeability increase during construction?
- Will the quality of the infiltrating groundwater change?
- How long will it take to colmatise the riverbed again?
- How long will it take until groundwater quality is good enough again?

Test site evaluation

Site requirements

- Representative for existing drinking water catchments
- High permeable aquifer
- Heavily colmated Rhine bed
- Infiltration zone (all season)
- No risk for drinking water wells



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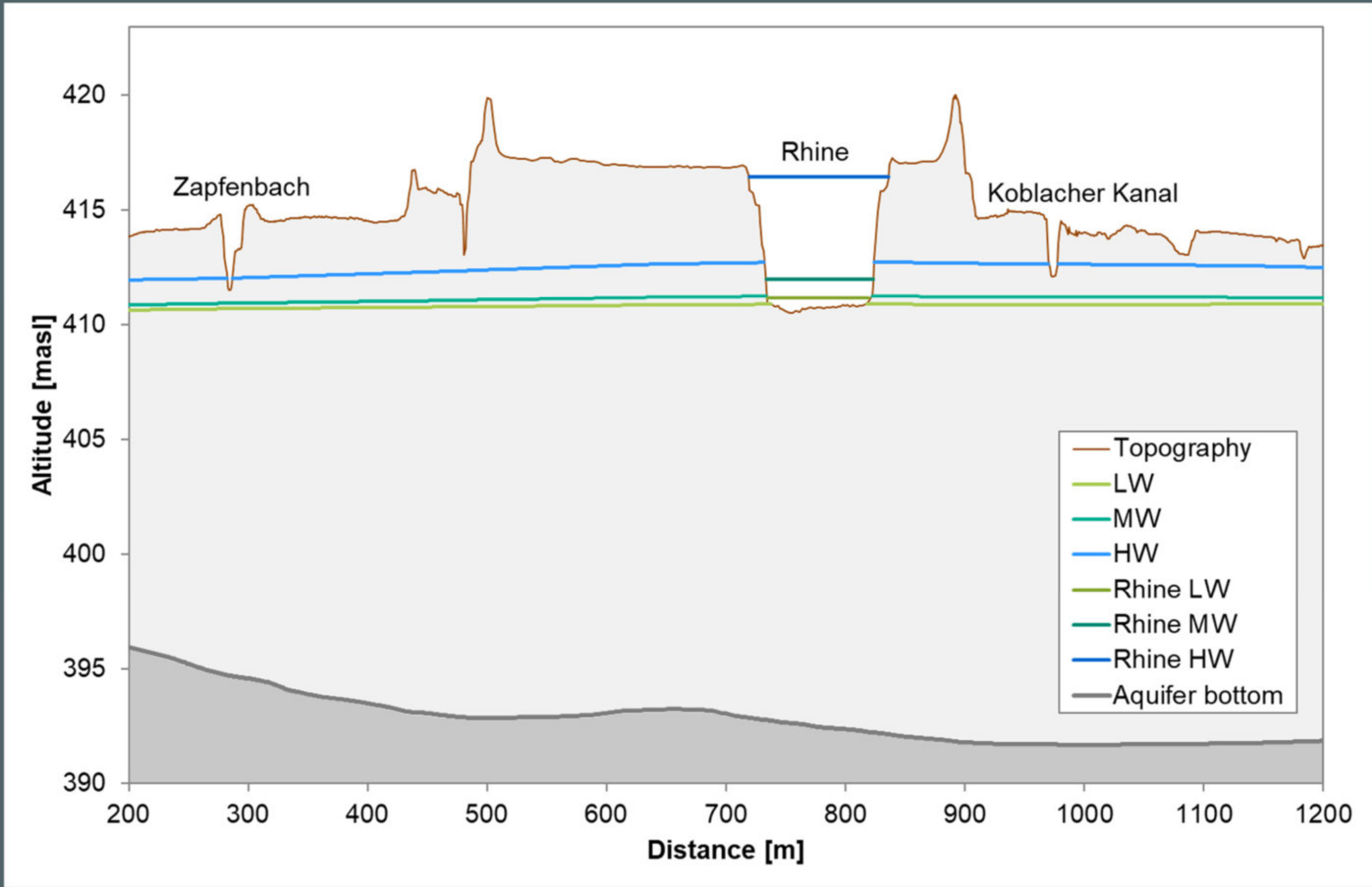
Position of the groundwater table



Experimental setup

Pumping well

- force the flow direction to slightly inwards

Monitoring wells

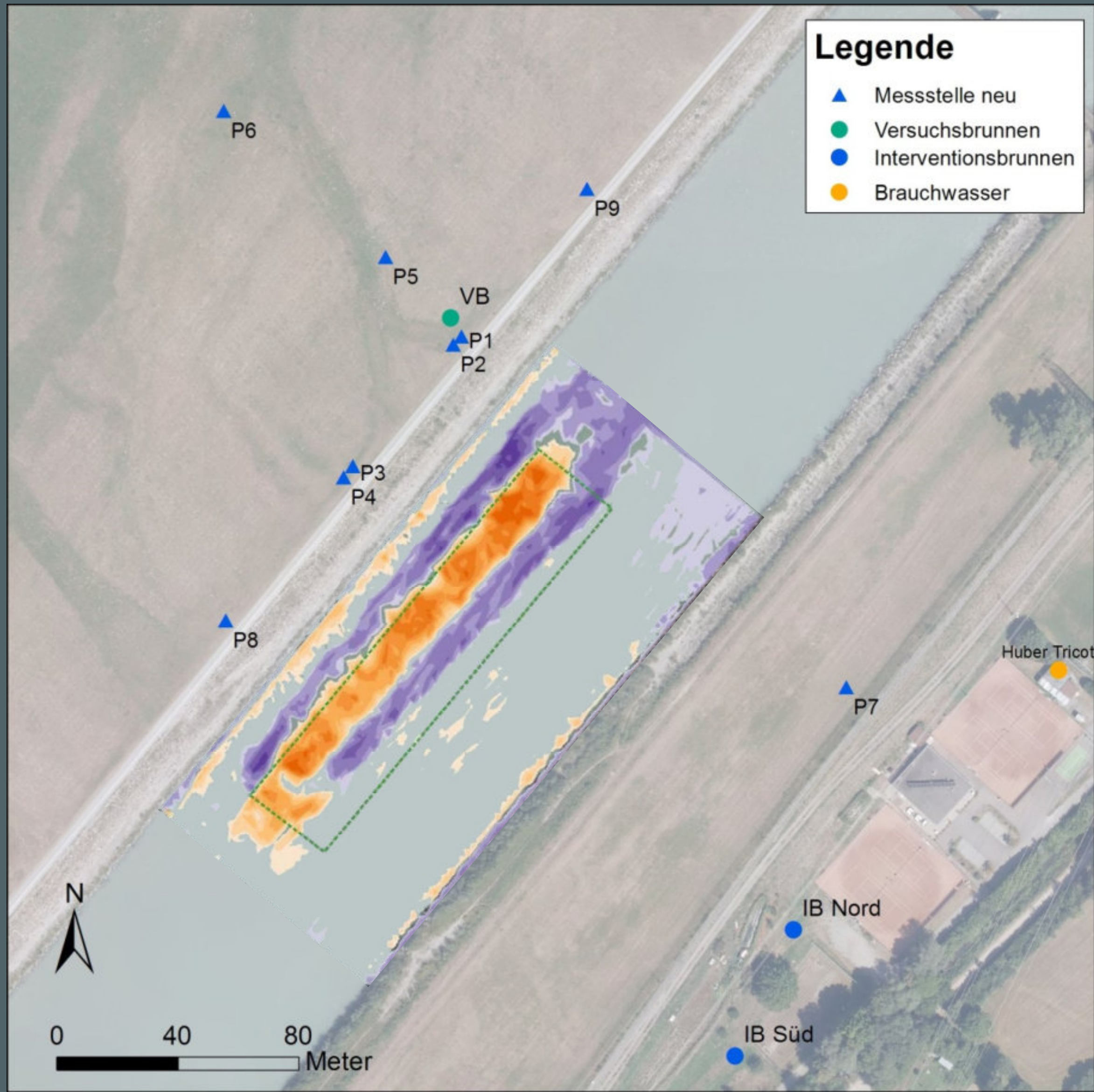
- along the riverbank
- perpendicular to the riverbank
- In two depth levels

Intervention wells

- prevent high ground-water levels

Excavation

- Area: 15 x 150 m
- Depth: 1 m



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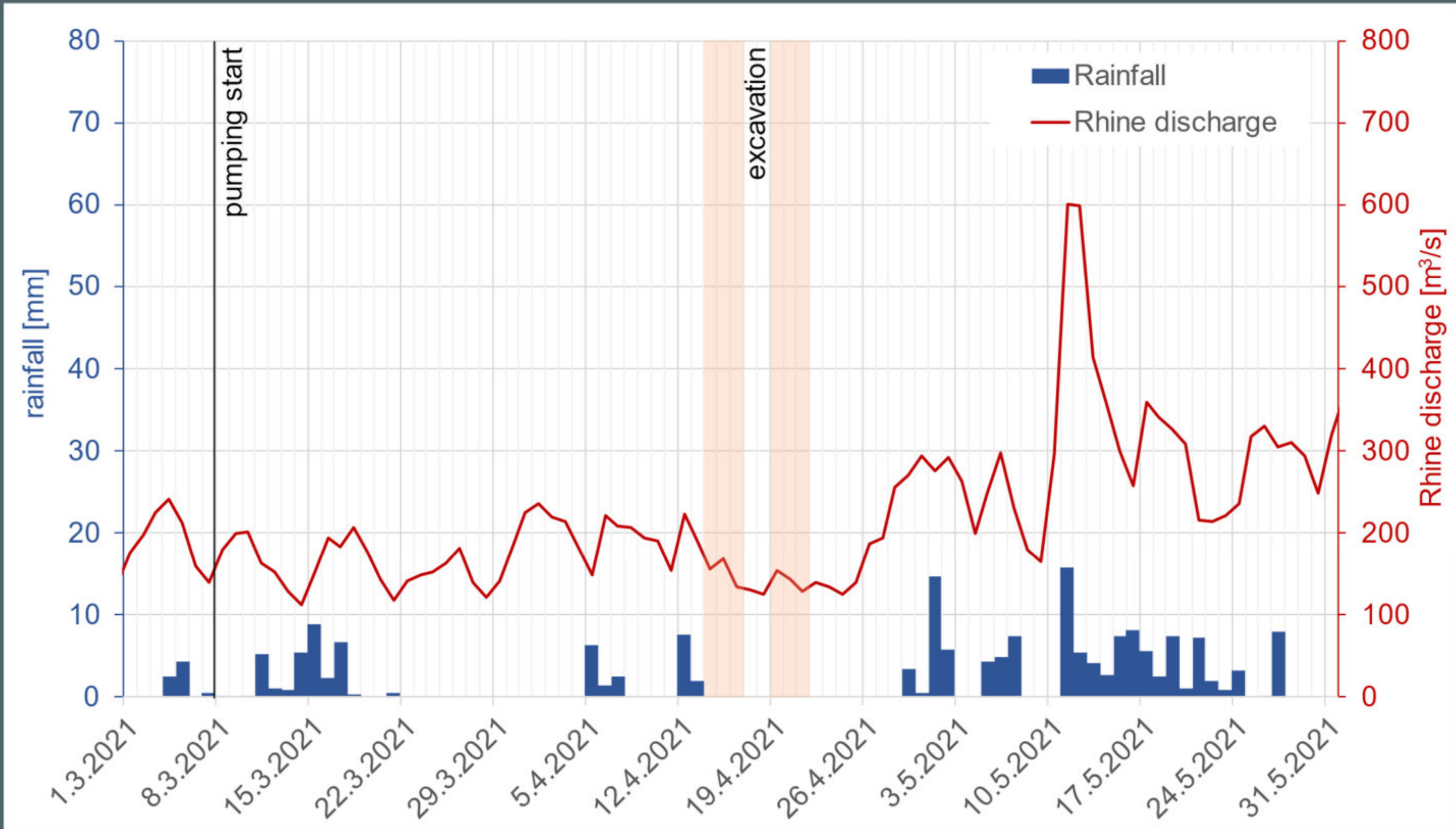
Test period

- No heavy rainfall before and after excavation
- Rhine discharge low and constant



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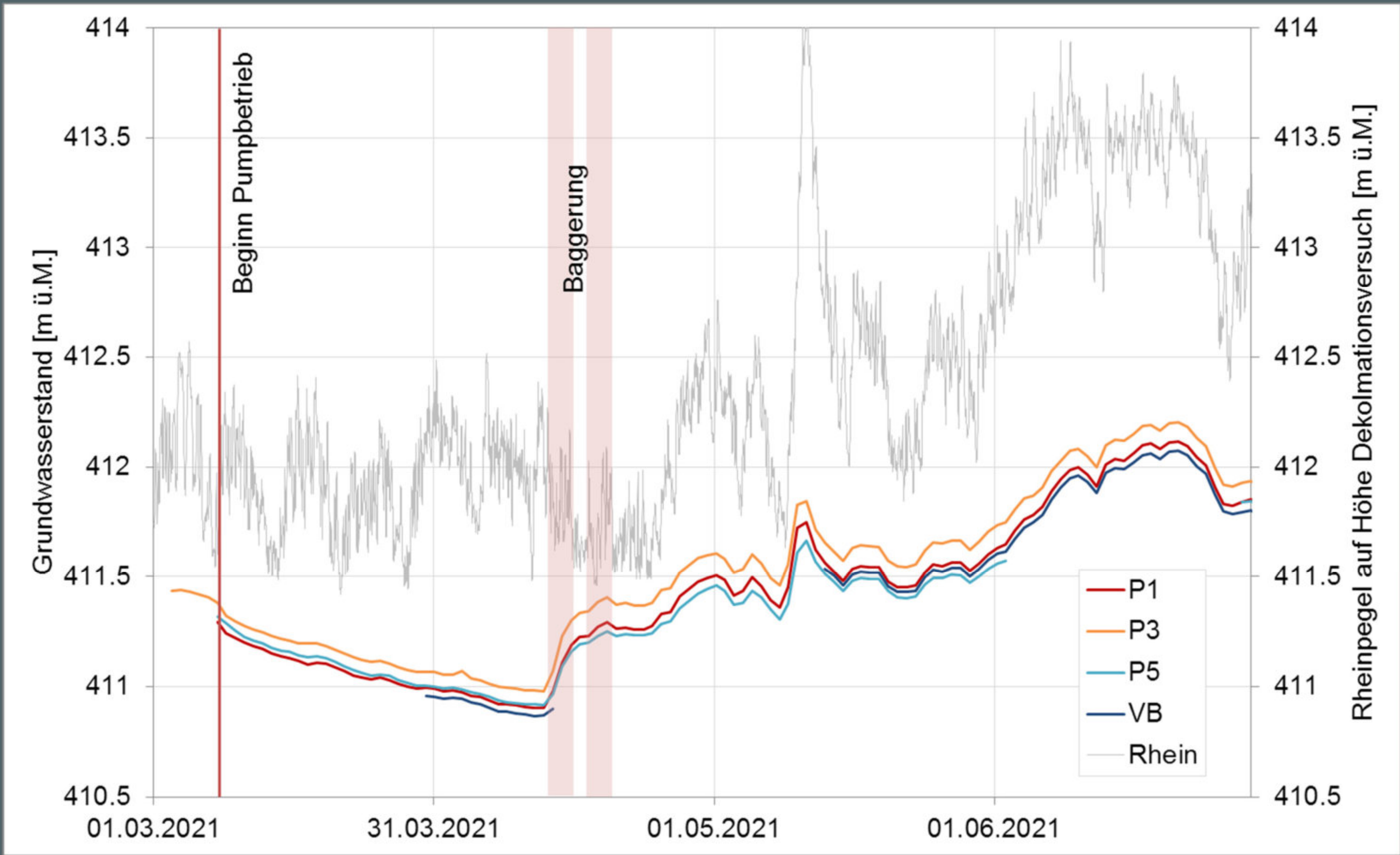
Excavation and Freeze-Cores

Freeze-cores

Reaction of the groundwater table



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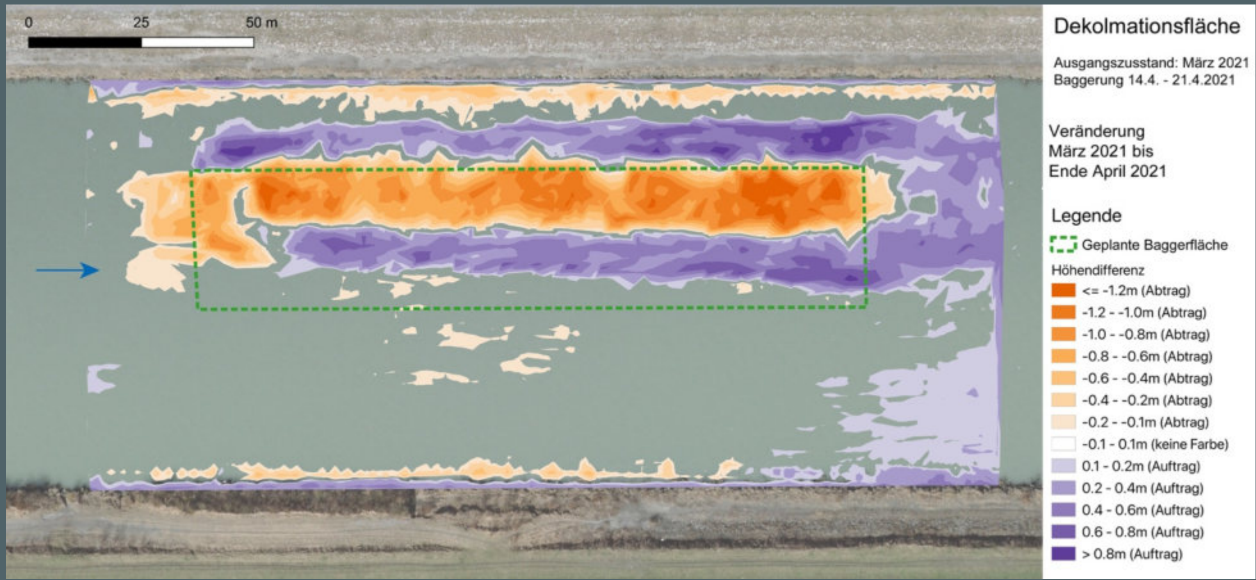
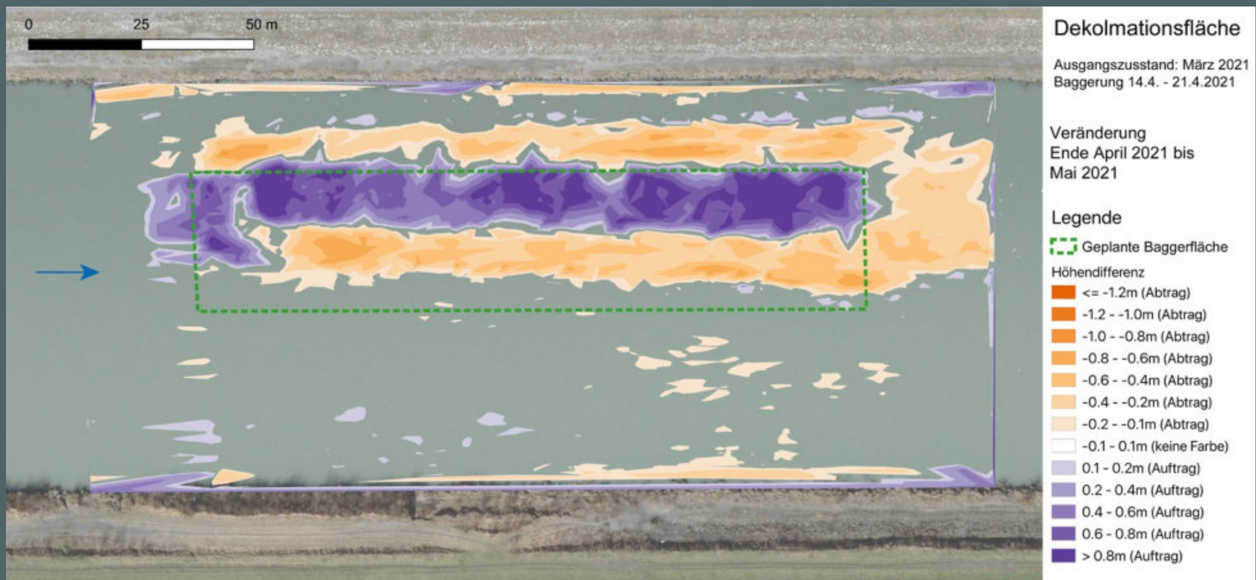
Survey of the Rhine bed



Difference before (March) and after (April 21) the excavation

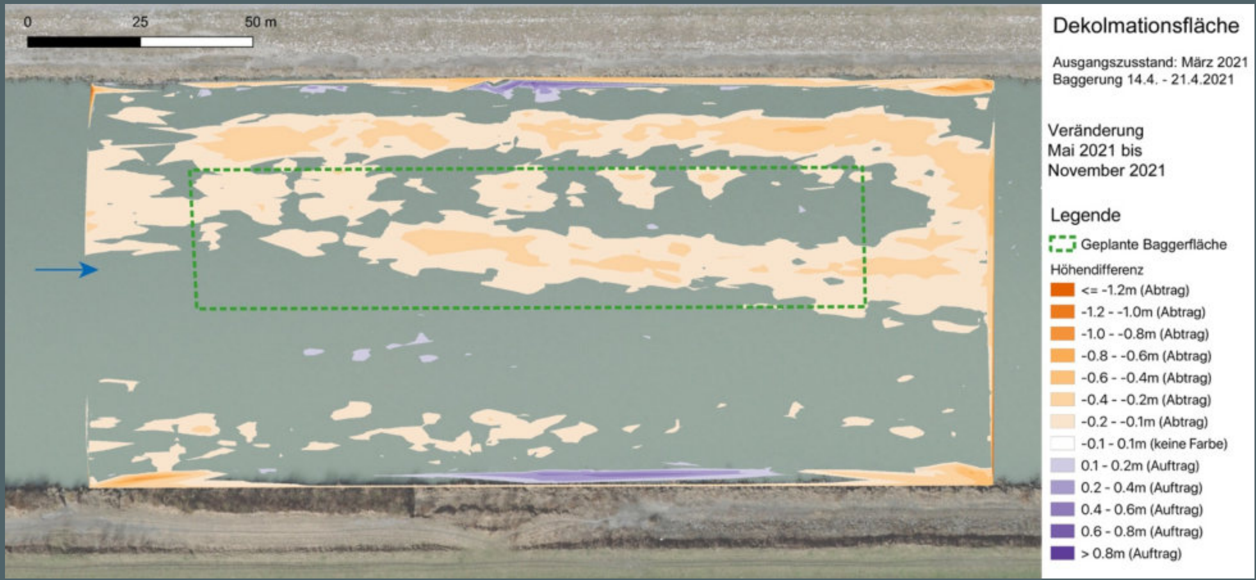
orange: lower

violet: higher



Development after the excavation until May 18

Survey of the Rhine bed

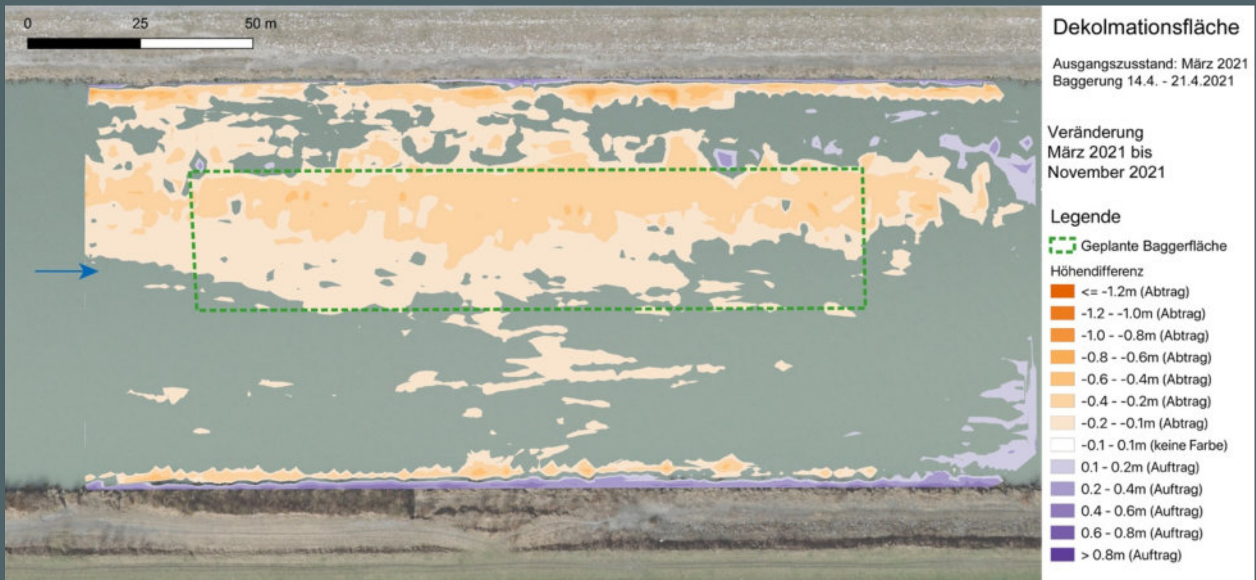


Further development

Mai – Nov. 21

orange: lower

violett: higher

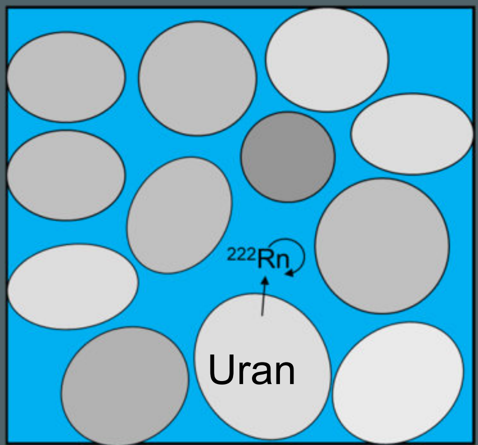


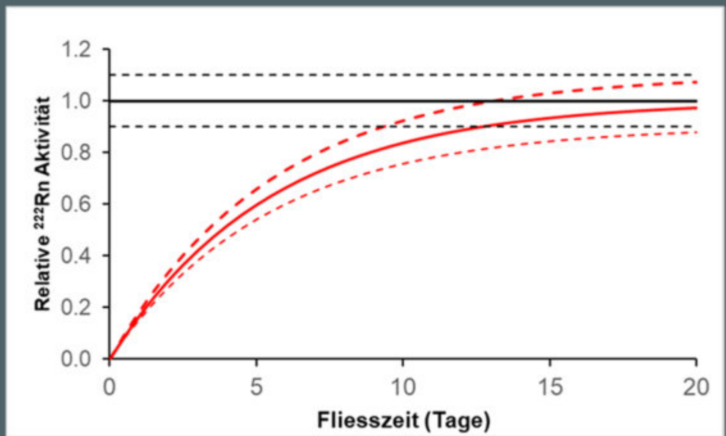
Difference between the original state and the survey of Nov.

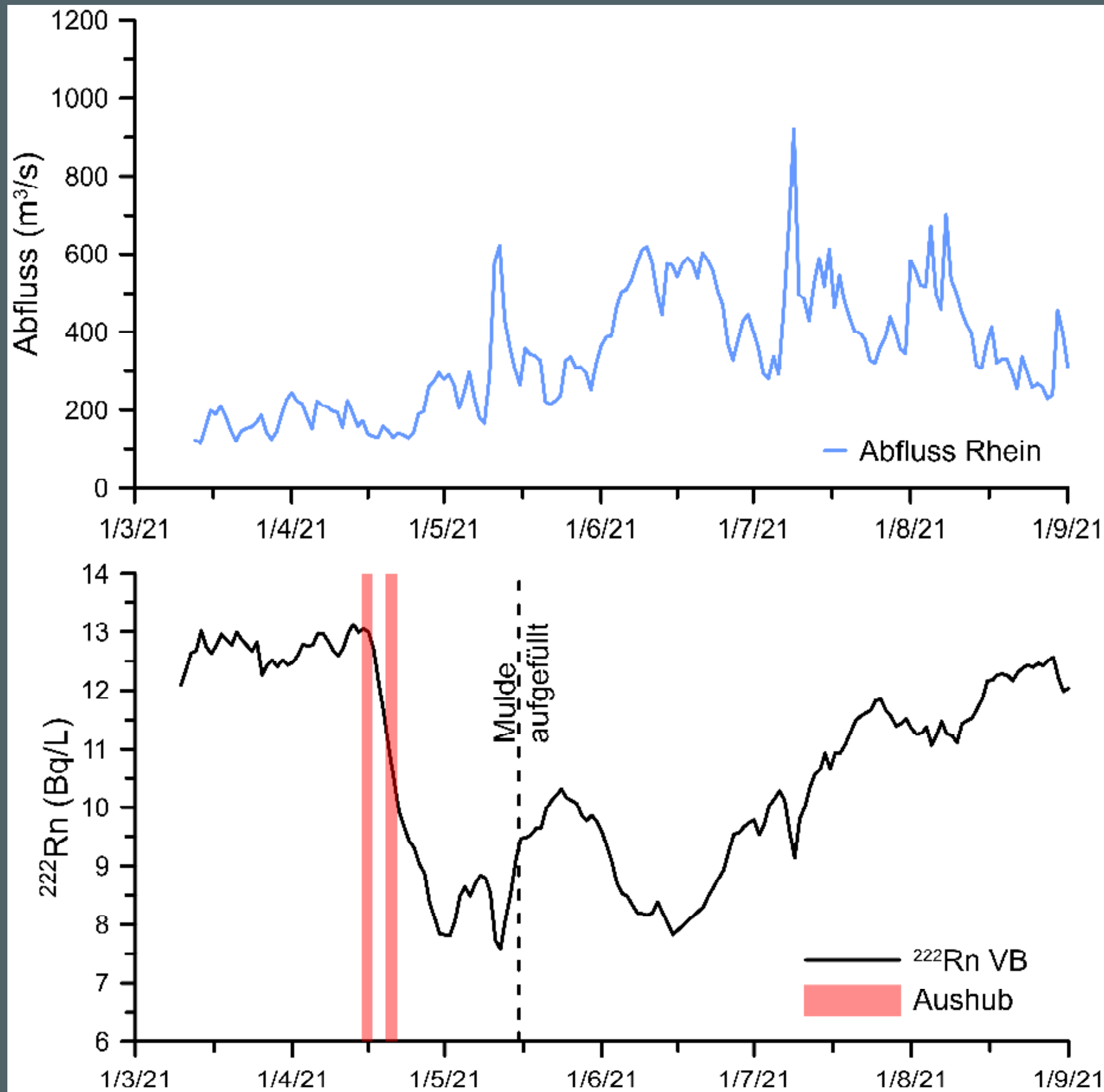
Change in flow time from the Rhine

^{222}Rn method:

- No ^{222}Rn in the Rhine water
- Saturation hal-life time 3.8 d

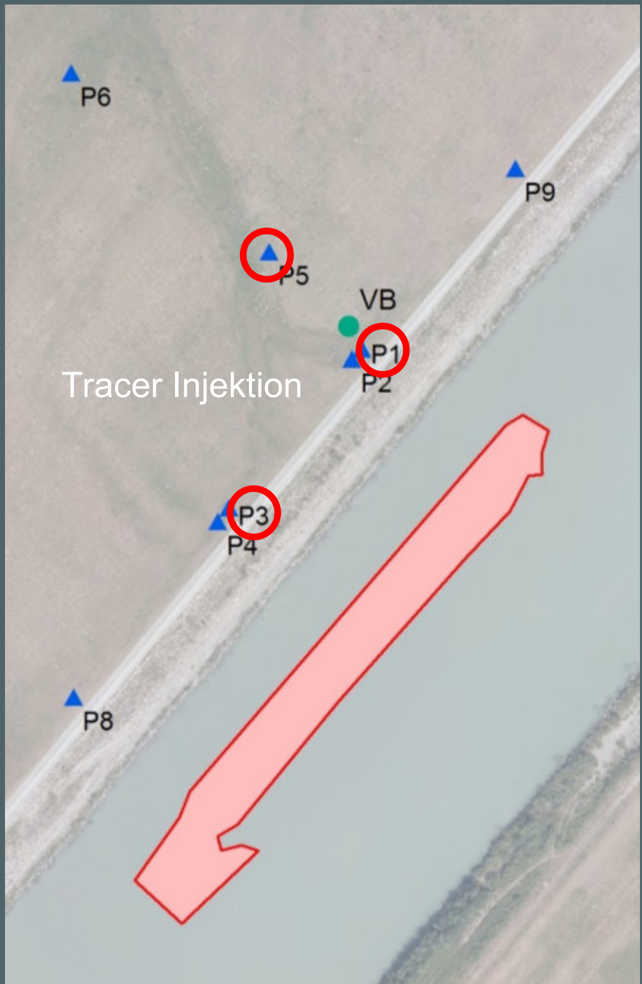


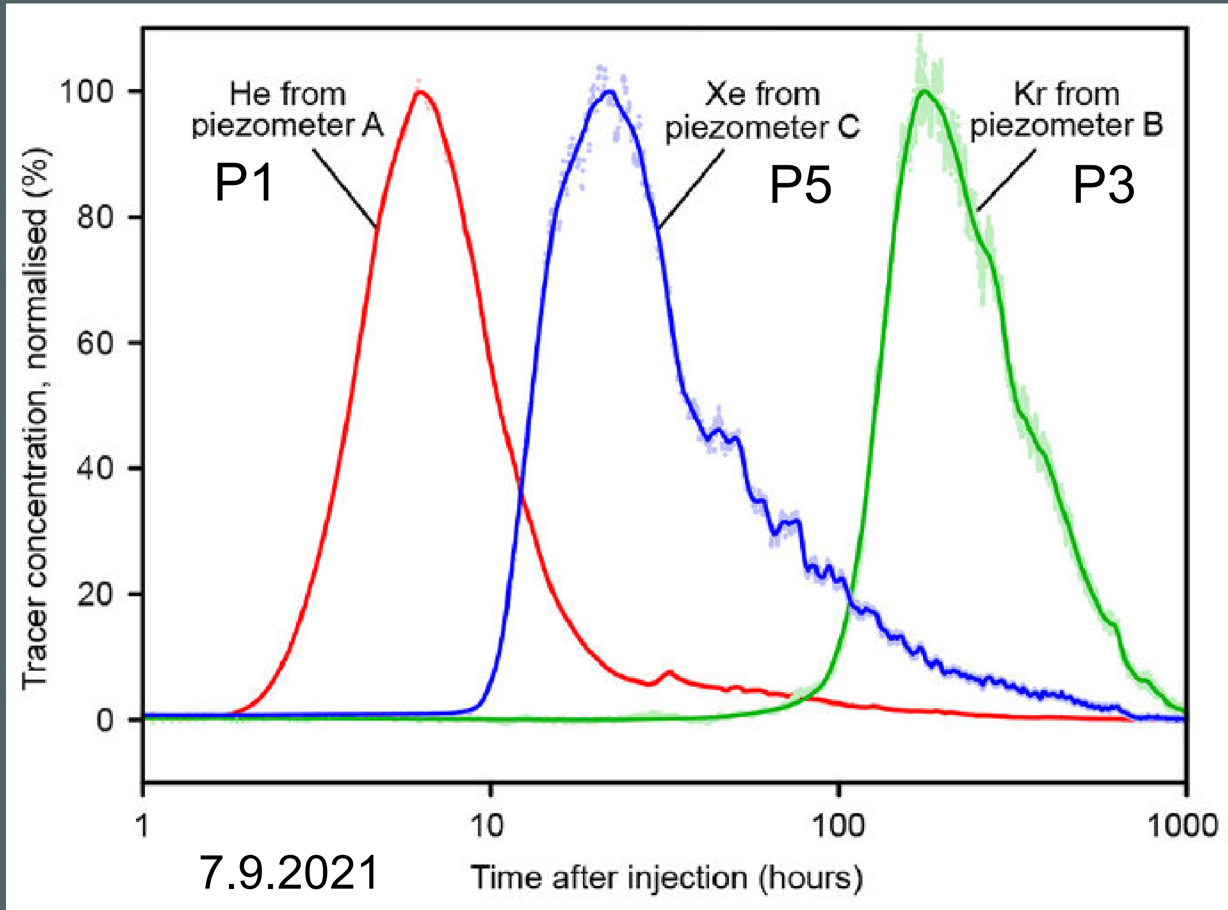




Rhine flow rate and ^{222}Rn activity at the test well

Tracer-tests with nobel gases





Ref. Brennwald et al, 2022. Frontiers in Water.

Break-through-curves

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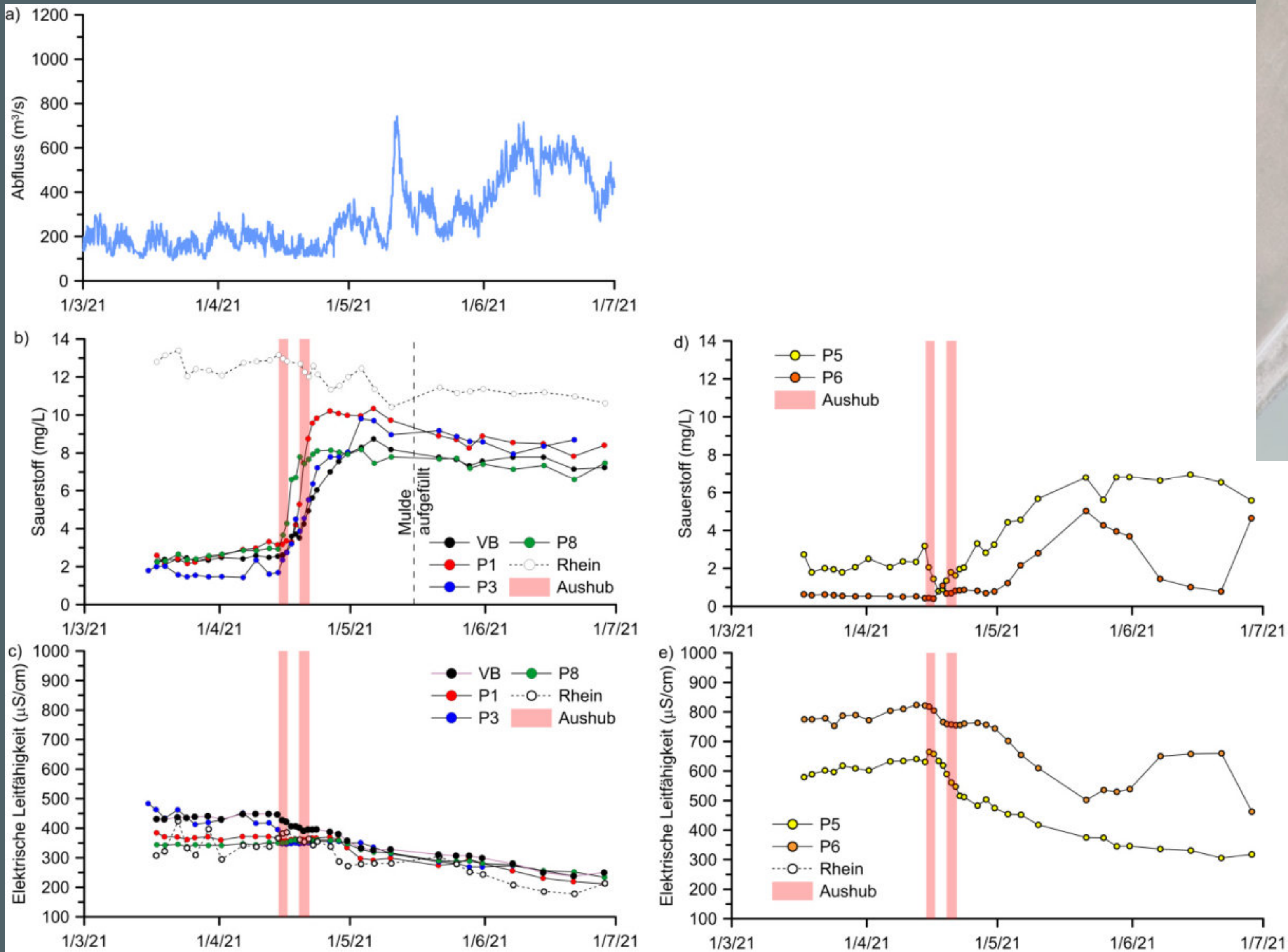
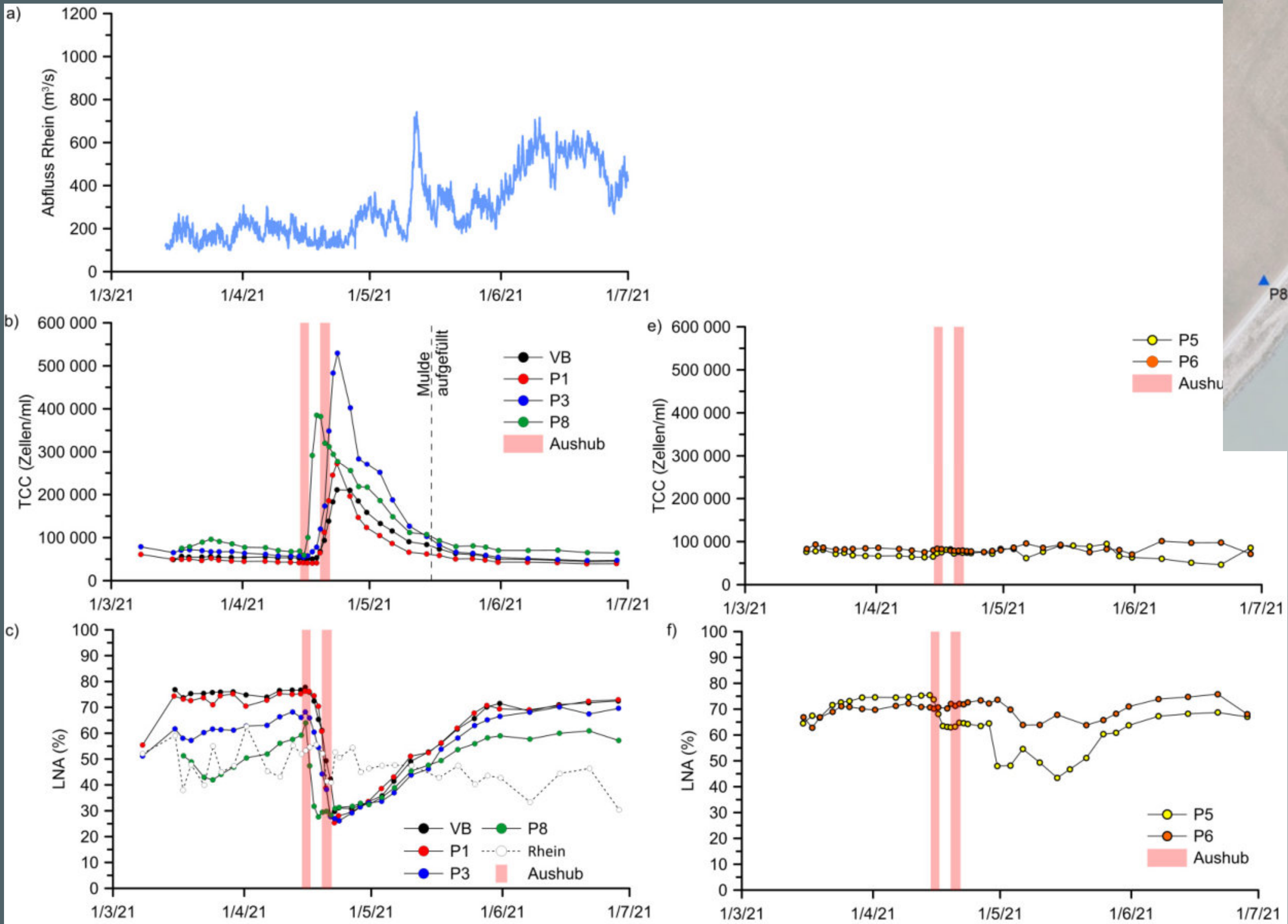
Chemische Wasserqualität



Sauerstoff und elektrische Leitfähigkeit

Mikrobielle Wasserqualität



Gesamtzellzahl und Anteil LNA (Low DNA)

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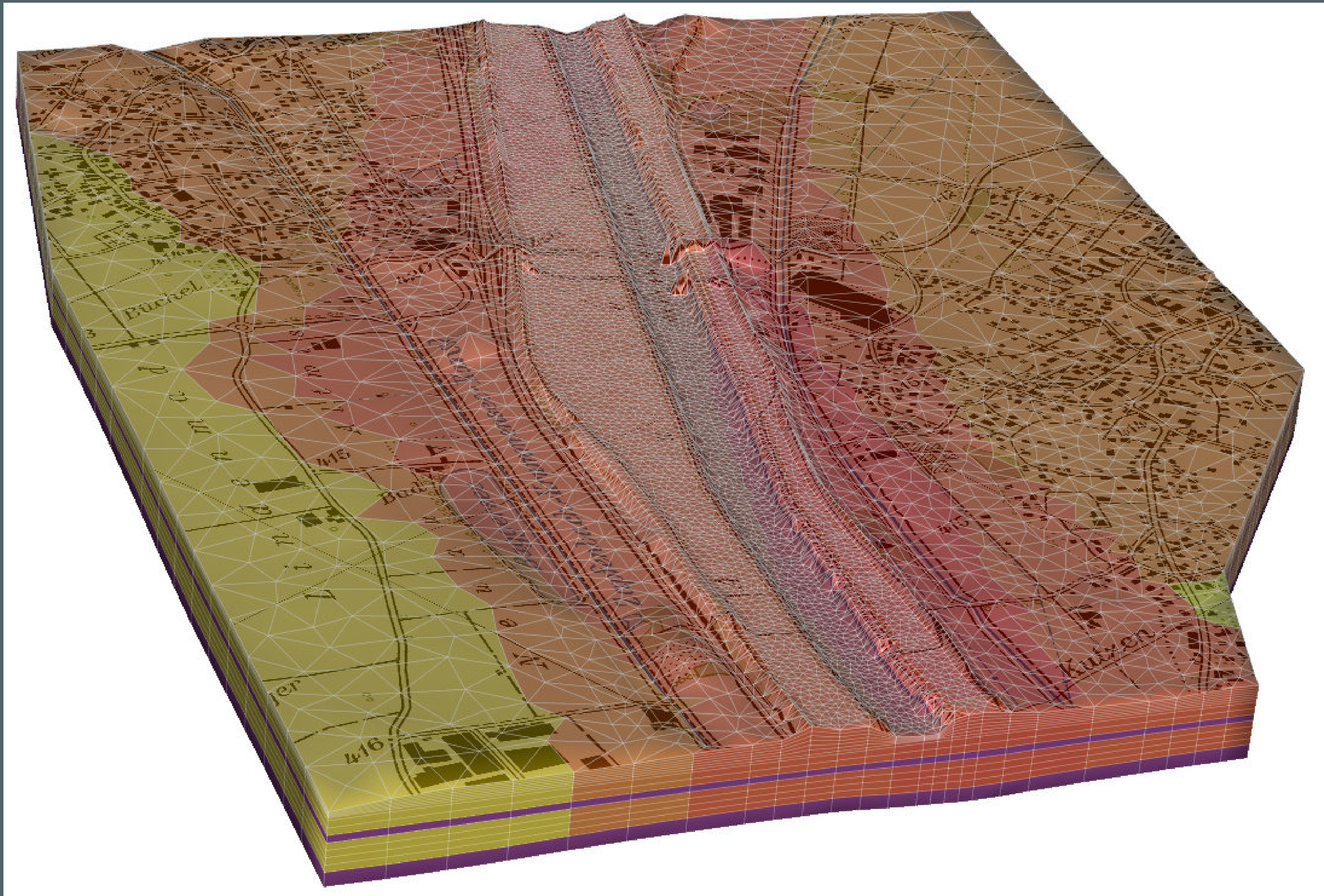
Model interpretation - tomorrow



Thanks for your attention
Questions?

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