Long-term Saltwater injection into a confined aquifer: A density-coupled mass-transport model taken to the max?

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N°abstract 2284

25-29th September 2016
Montpellier, France
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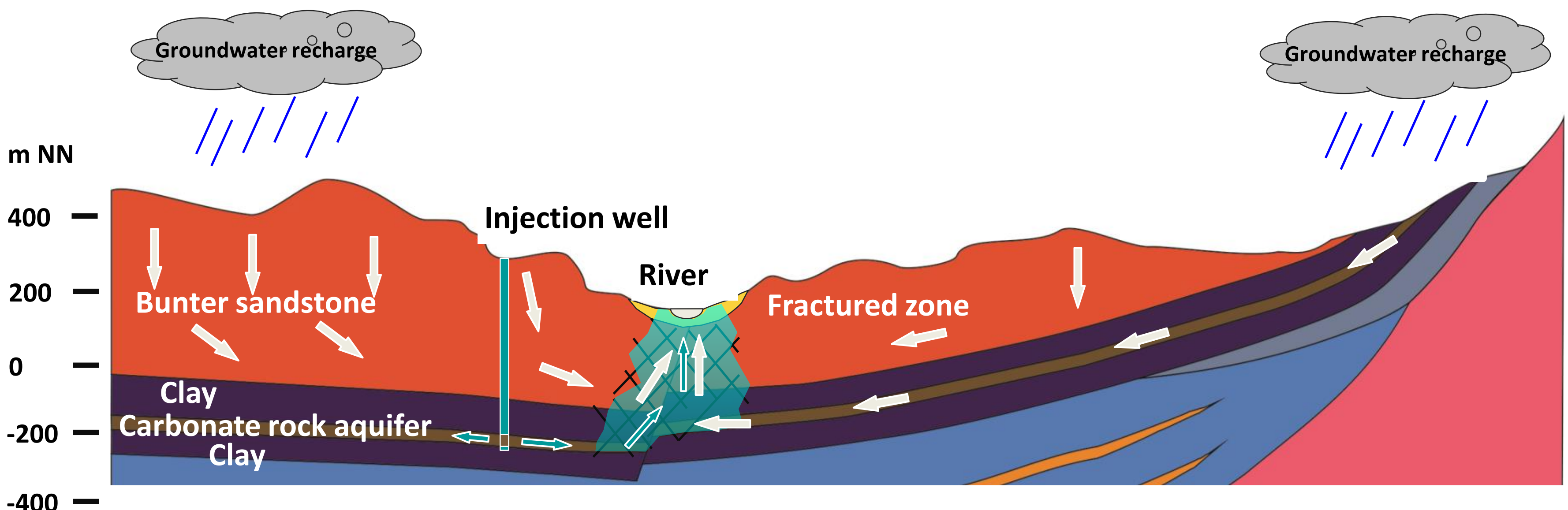
Modelling deep well injection

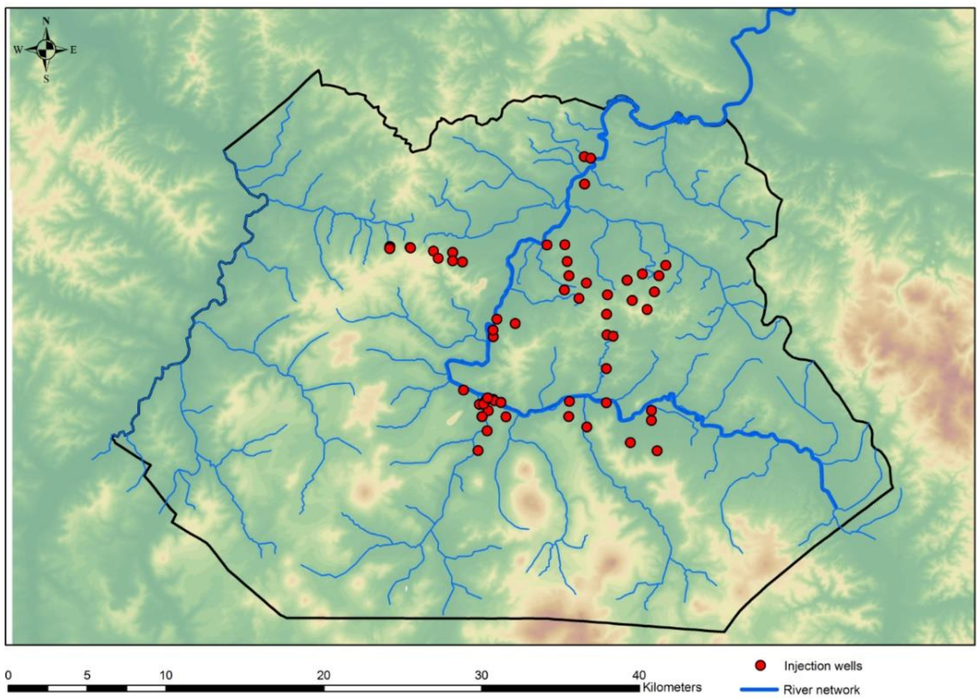
The Project: Modelling of deep well brine injections into a confined aquifer at ~ 500m depth for disposal

The System: a confined carbonate rock aquifer that takes up brine, initial formation water is replaced

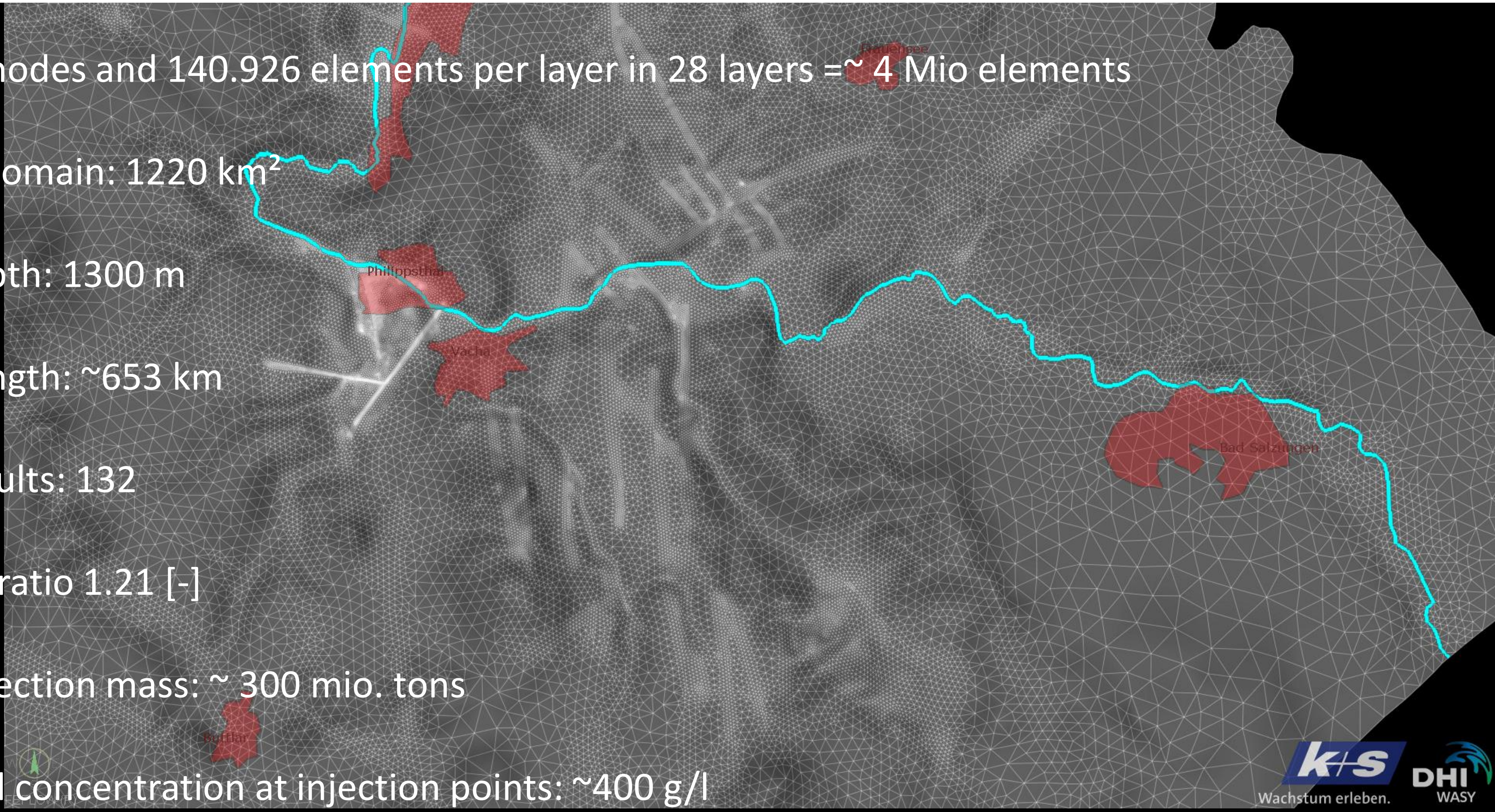


Modeling area and injection wells

- A total of 62 wells were operated since 1925
- Injection regime was highly variable (differing in timing, length of injection period, pumping rate, etc.)
- Groundwater abstraction for anthropogenic use from the upper aquifers had to be considered



Model set-up



- 70.765 nodes and 140.926 elements per layer in 28 layers =~ 4 Mio elements
- Model domain: 1220 km^2
- Max depth: 1300 m
- River length: ~653 km
- No of faults: 132
- Density ratio 1.21 [-]
- Total injection mass: ~ 300 mio. tons
- Maximal concentration at injection points: ~400 g/l
- Number of injection wells: 62 (transient), number of drinking water wells : 67

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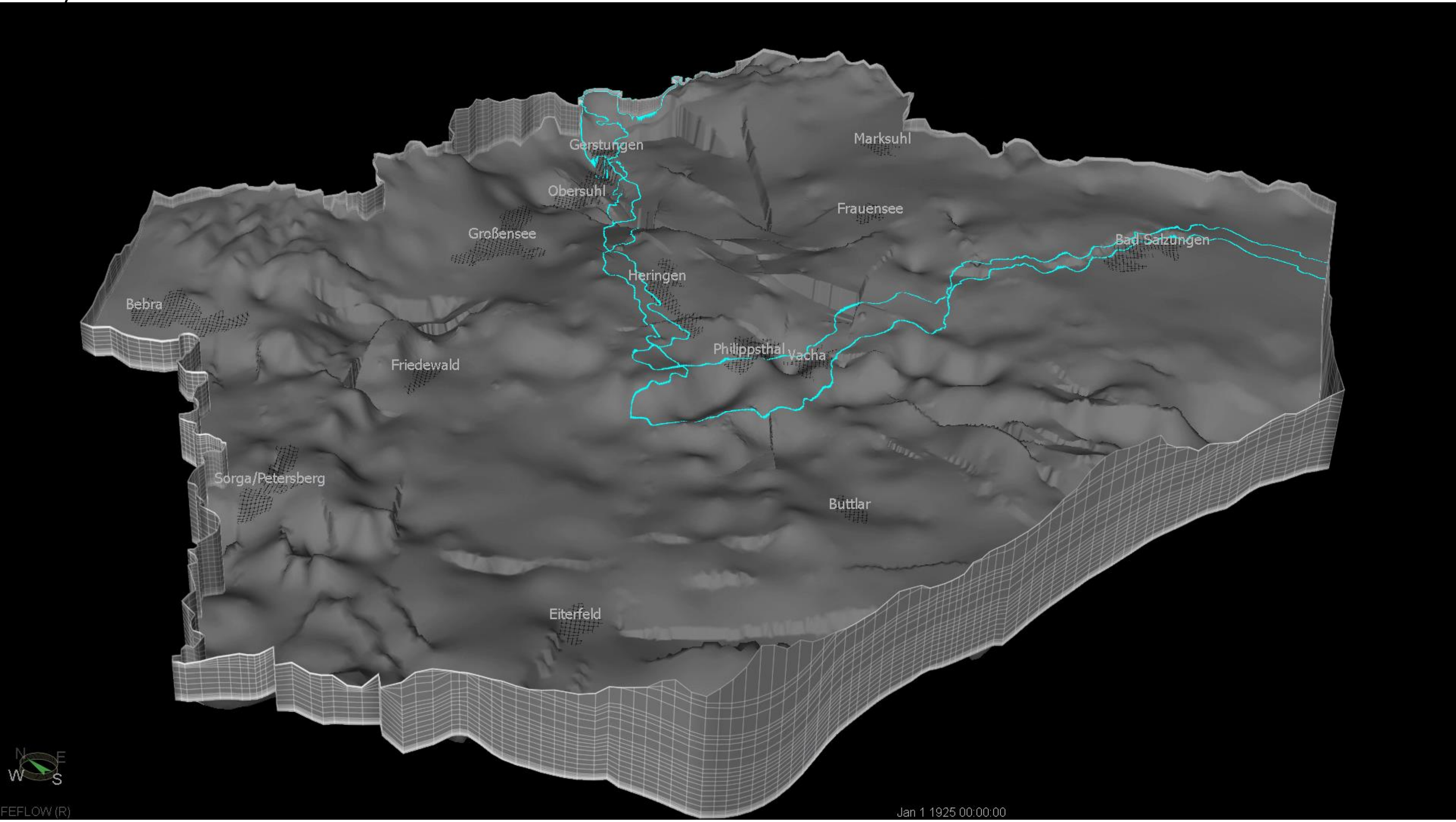
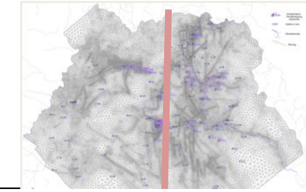
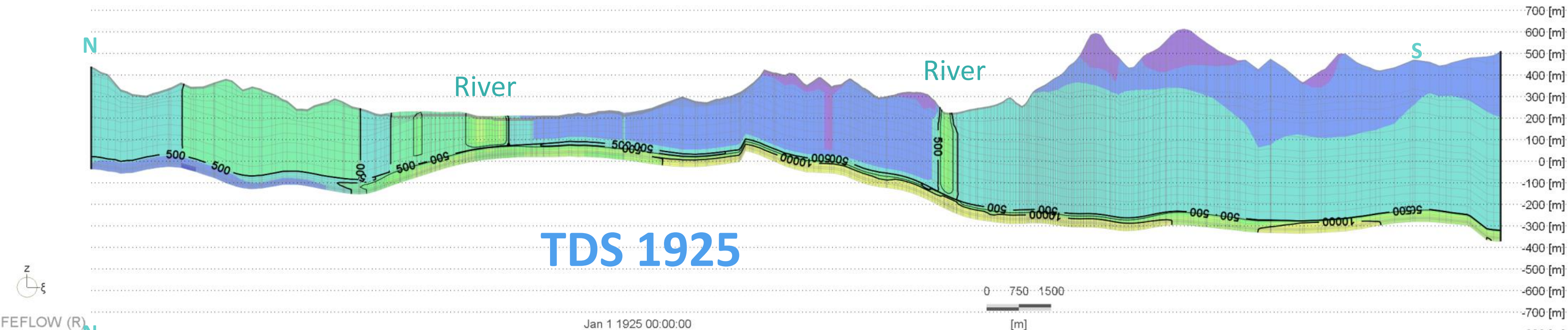
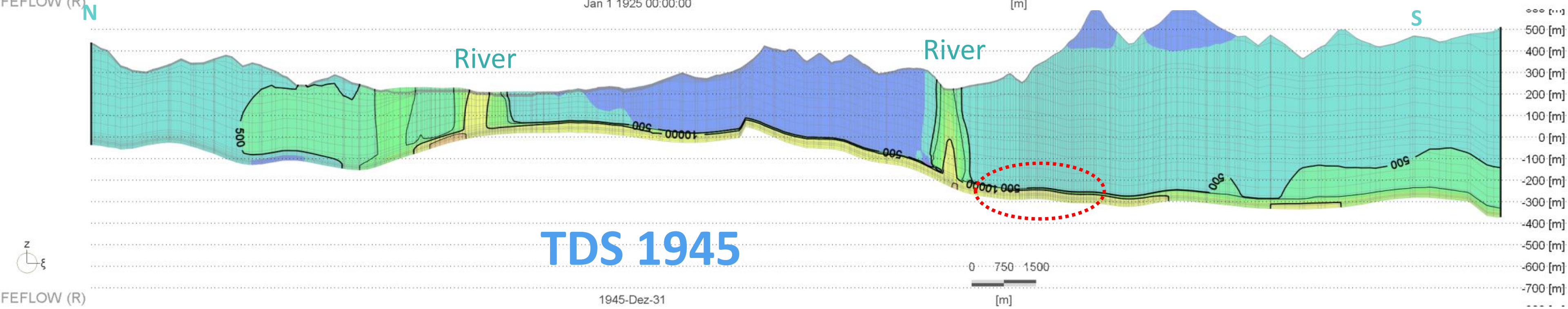
Modeling results

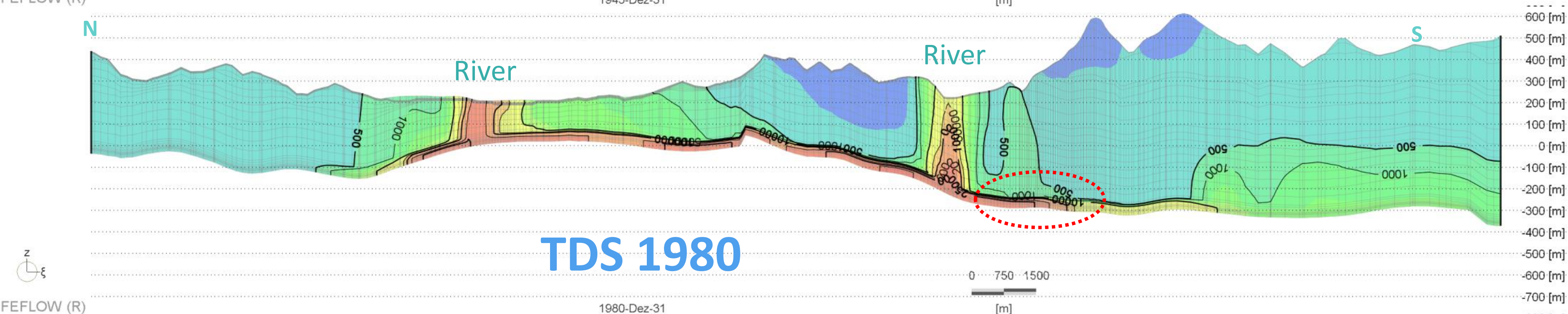


Transient density coupled mass transport 1925 – 2010









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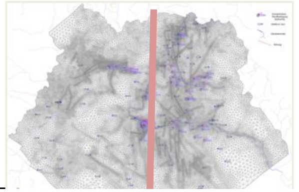
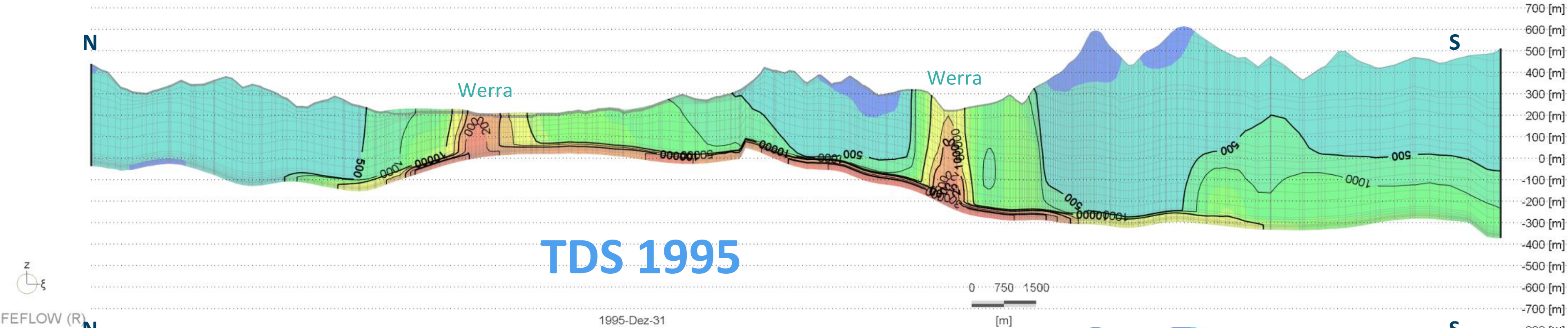
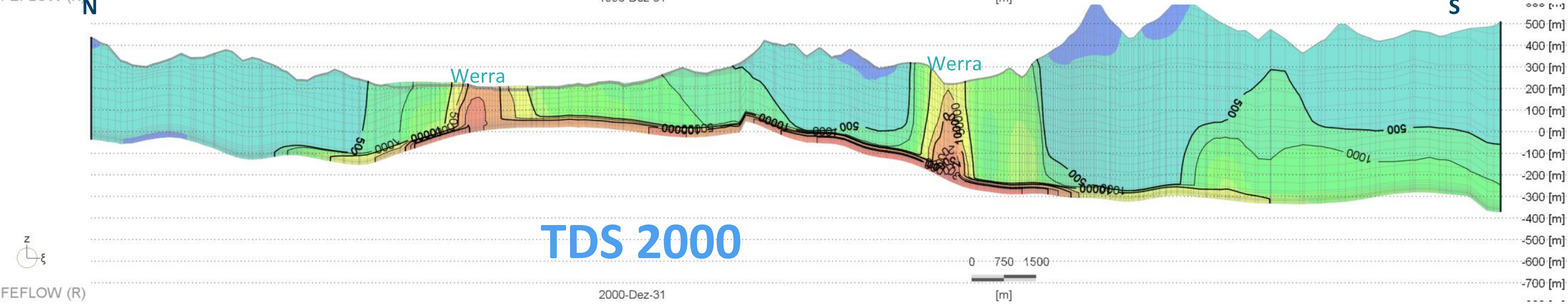
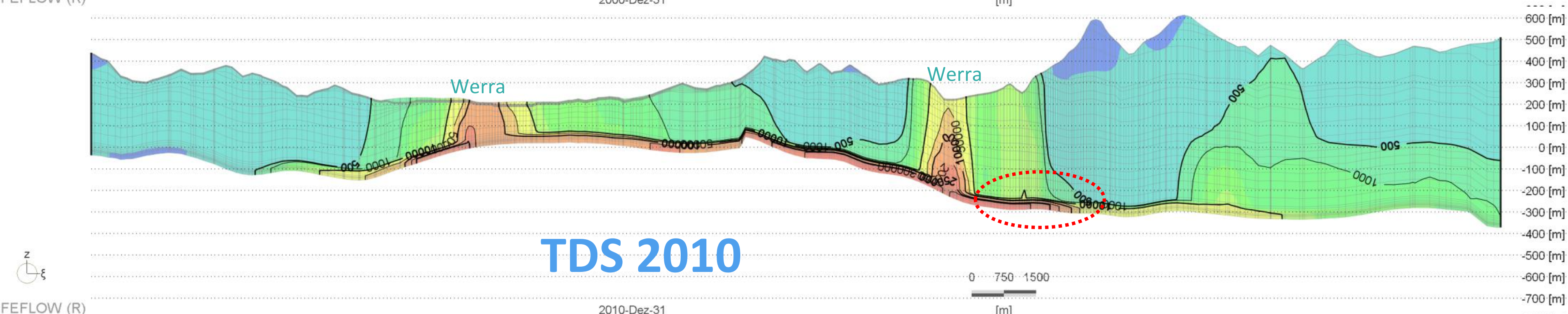
Transient density coupled mass transport 1925 – 2010

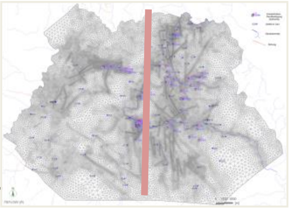




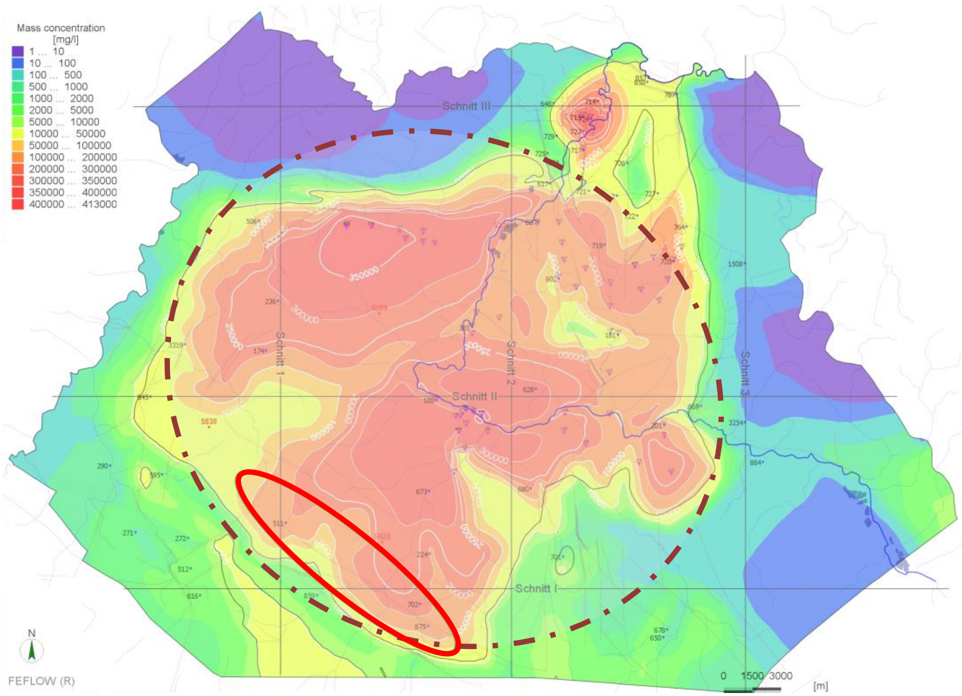




Transient density coupled mass transport: the impact of density

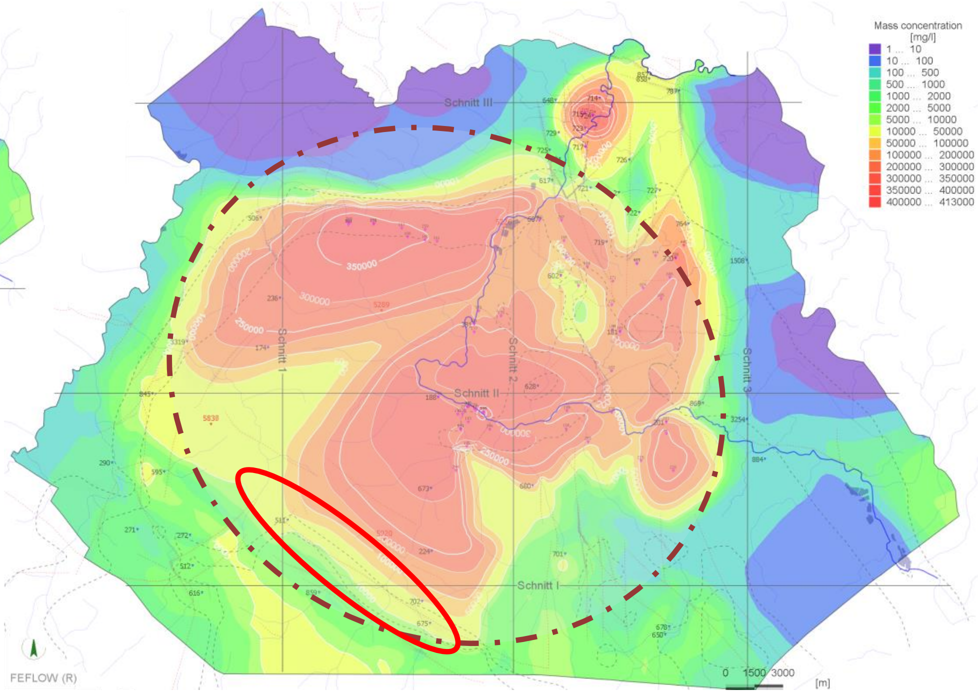


Total dissolved solids, year 2010, carbonate rock aquifer



Simulation with density effects

Simulation not considering density effects



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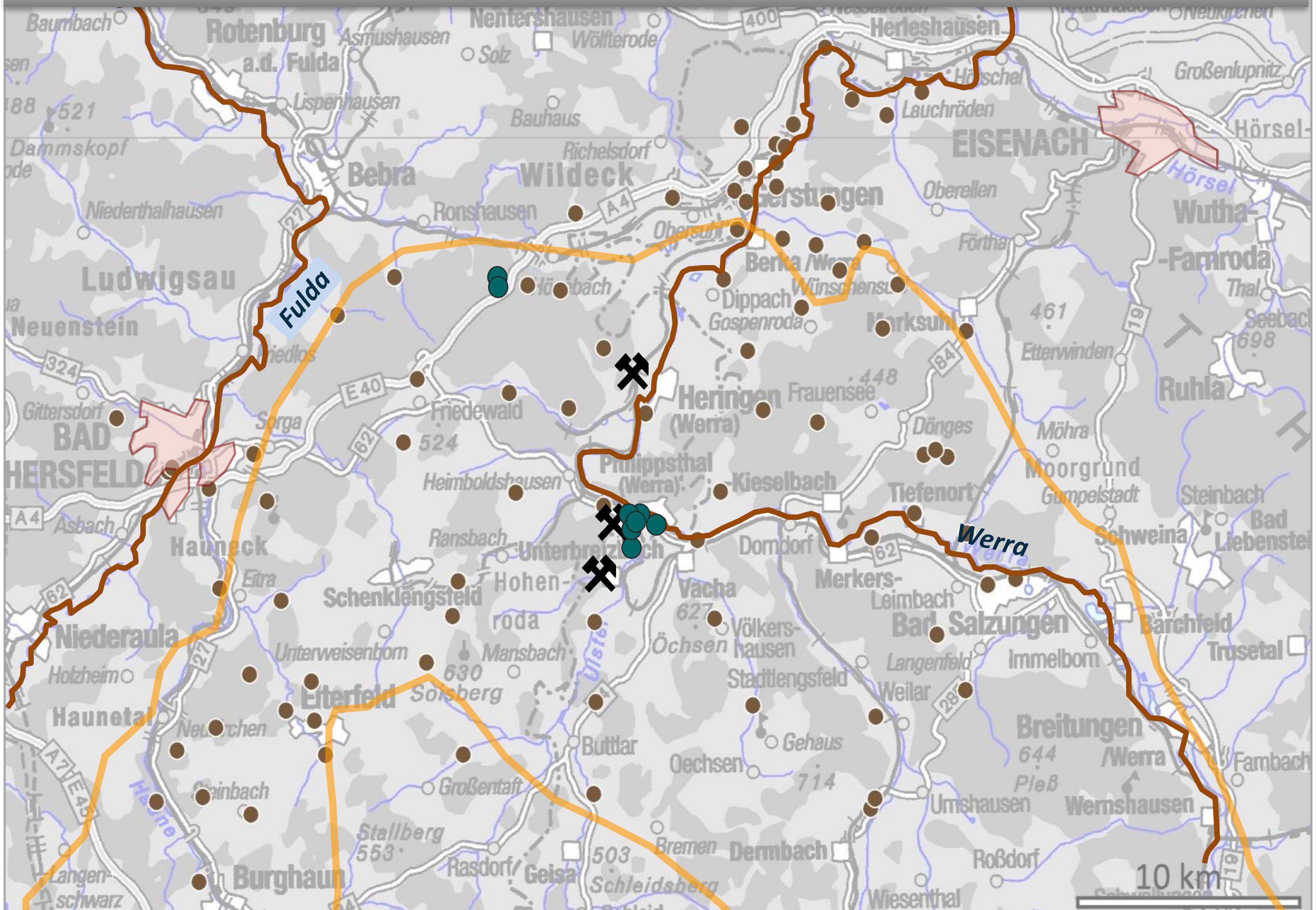
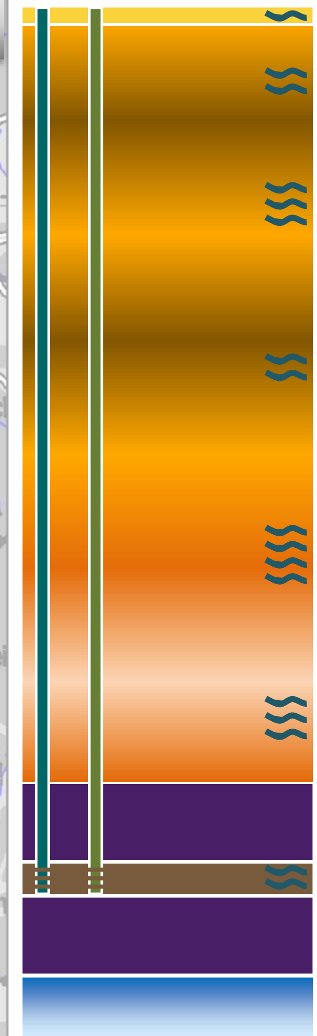
Calibration and verification data base: groundwater monitoring

96 monitoring wells in the confined carbonate rock aquifer





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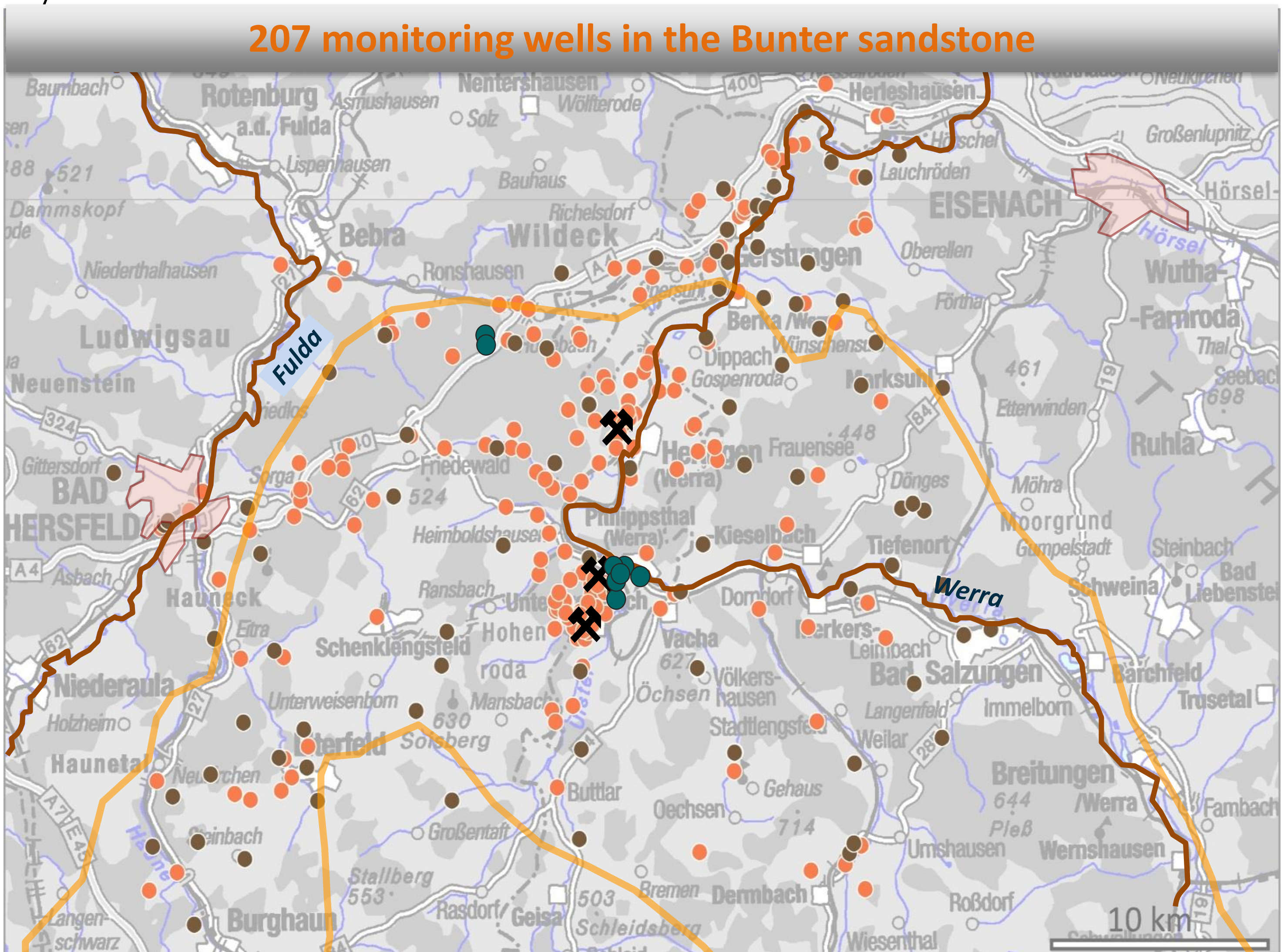

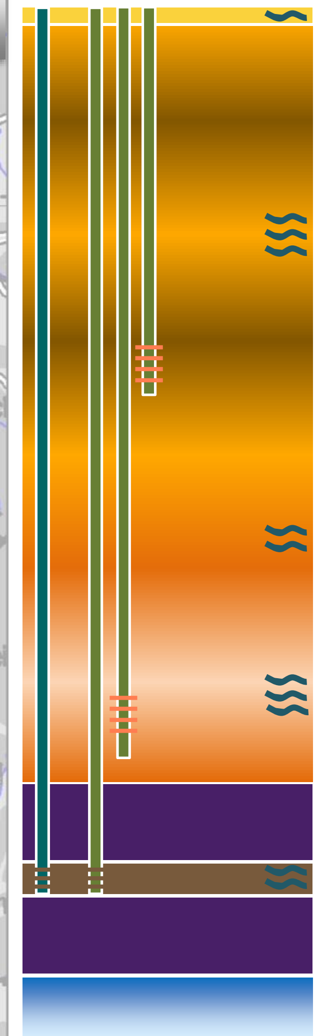

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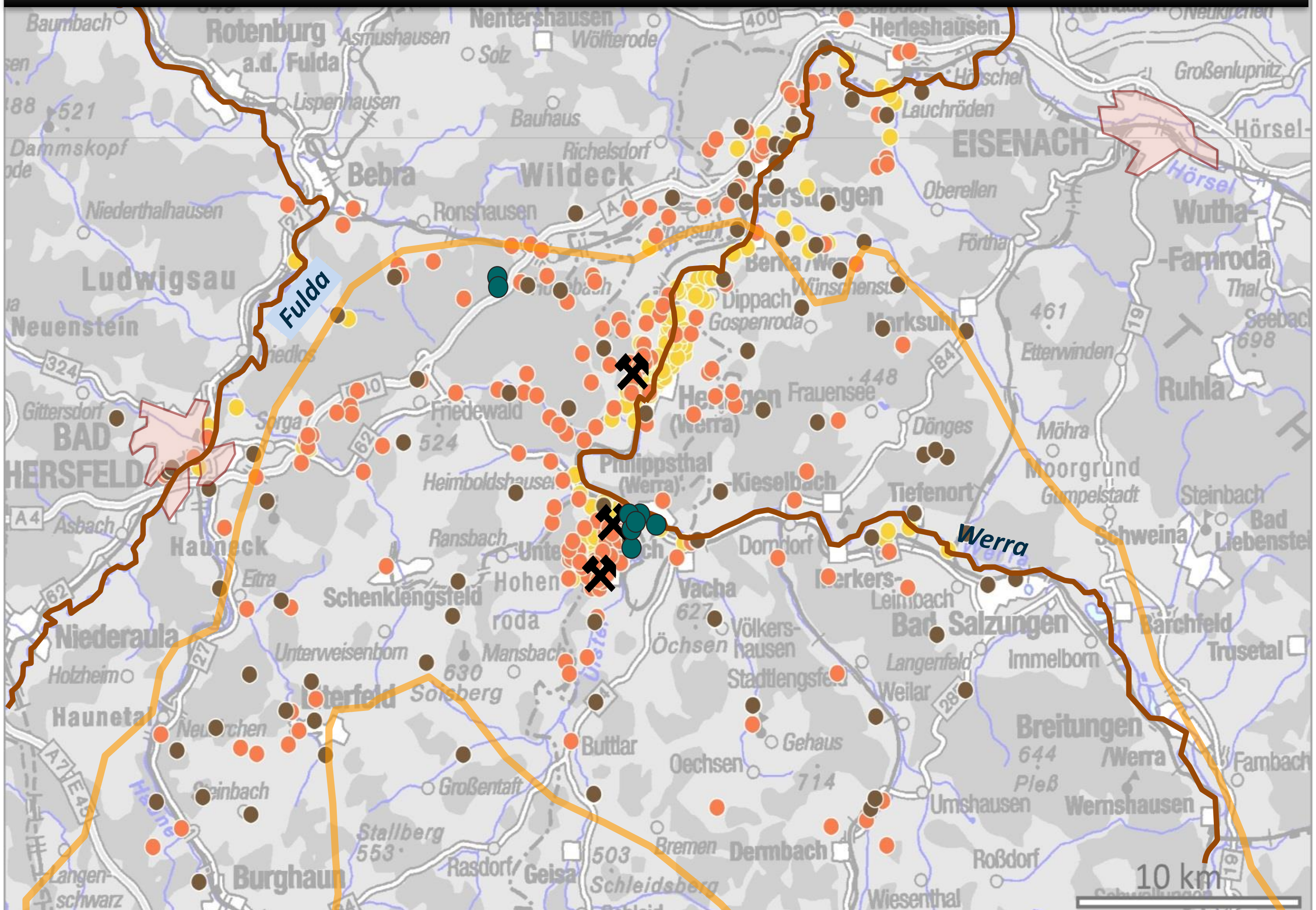
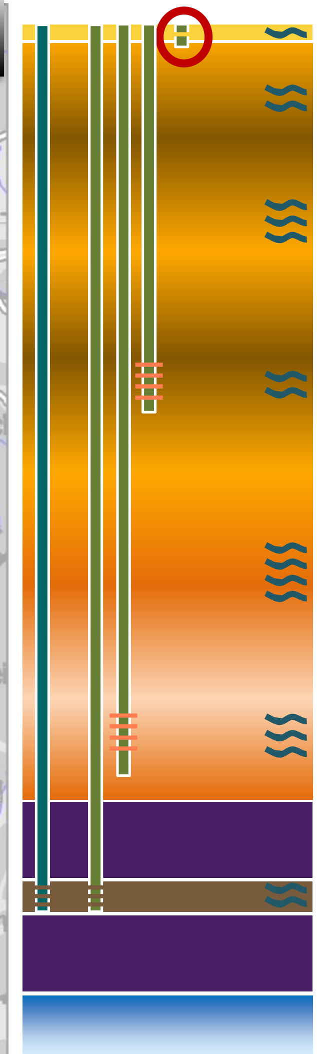
Calibration and verification data base: groundwater monitoring

152 monitoring wells in the Quarternary





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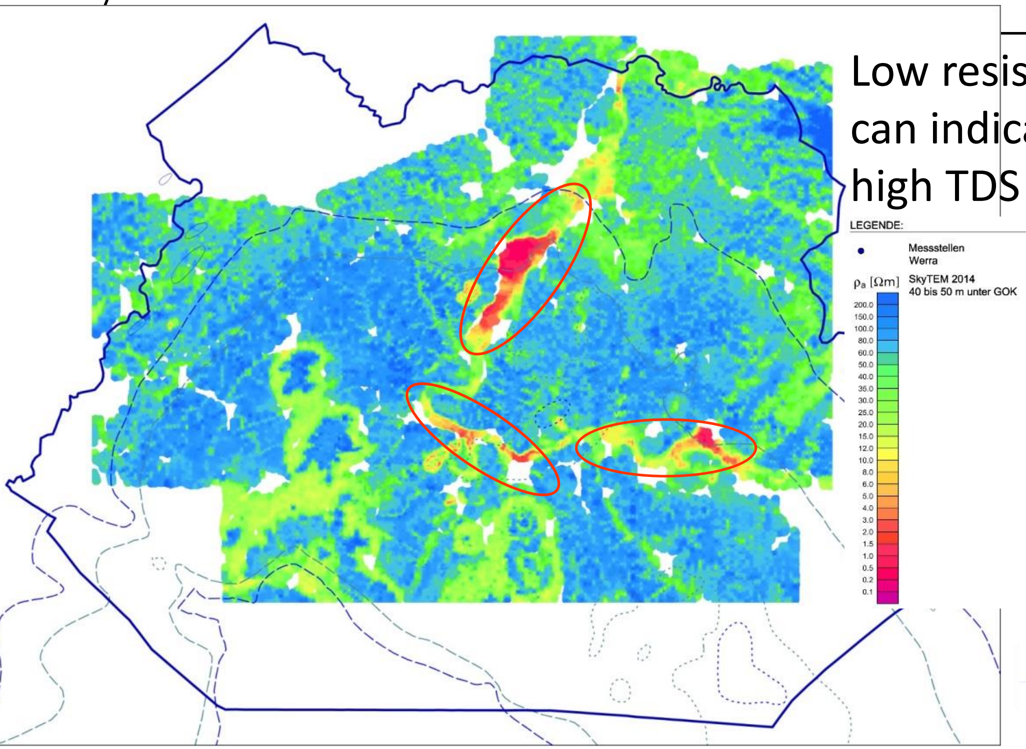
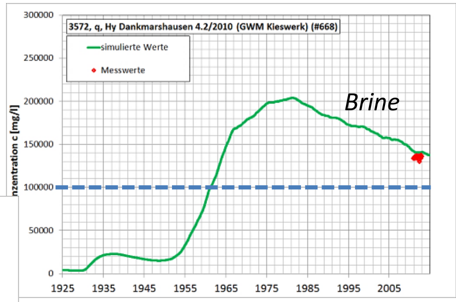
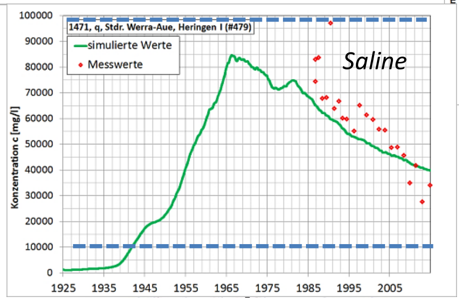
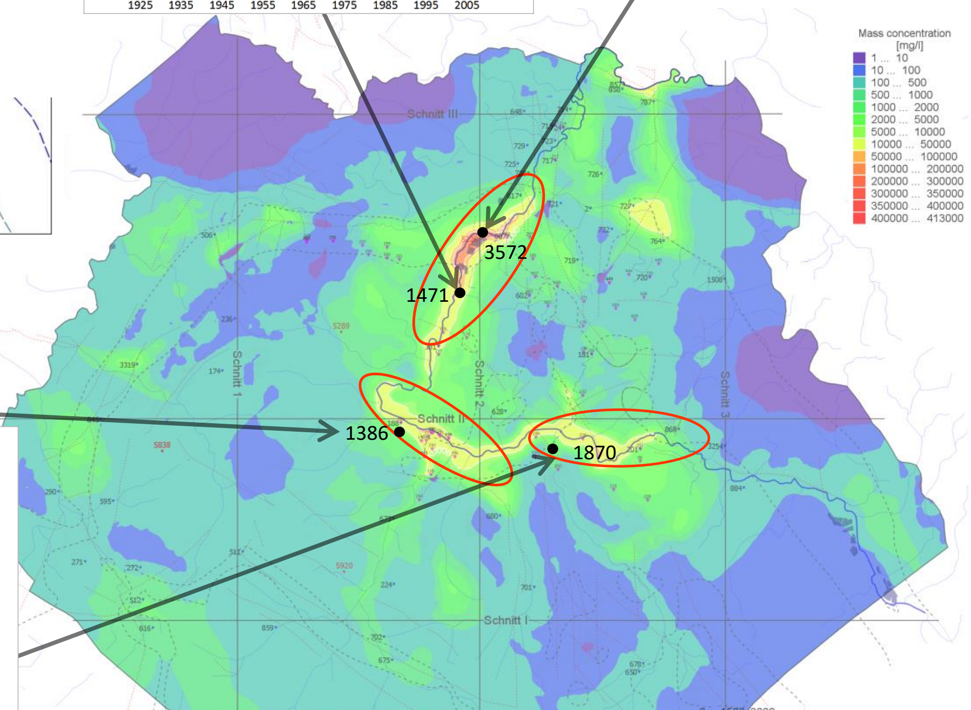
Transient density coupled mass transport, verification with airborne electromagnetics (AEM)



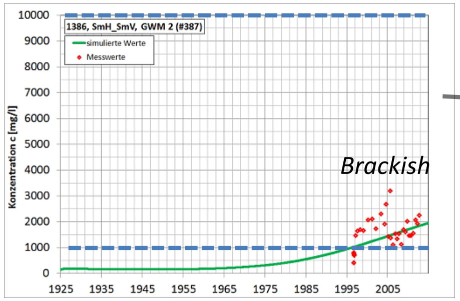
Low resistivity of AEM signal can indicate presence of high TDS content

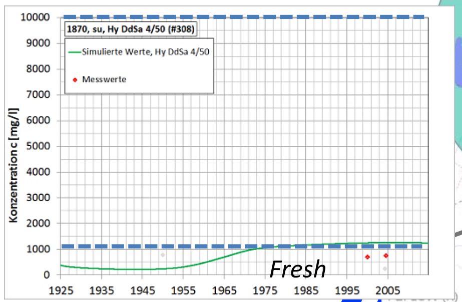






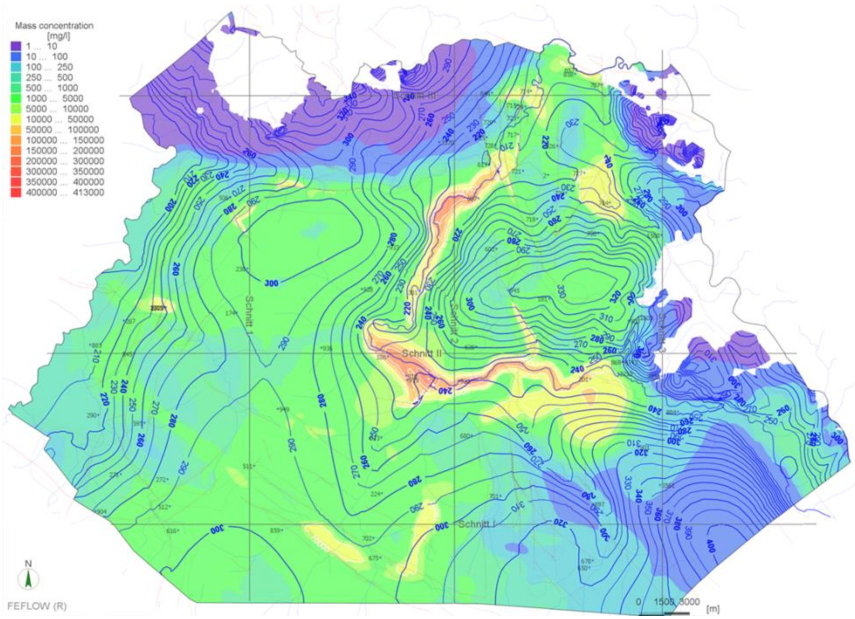
overburden

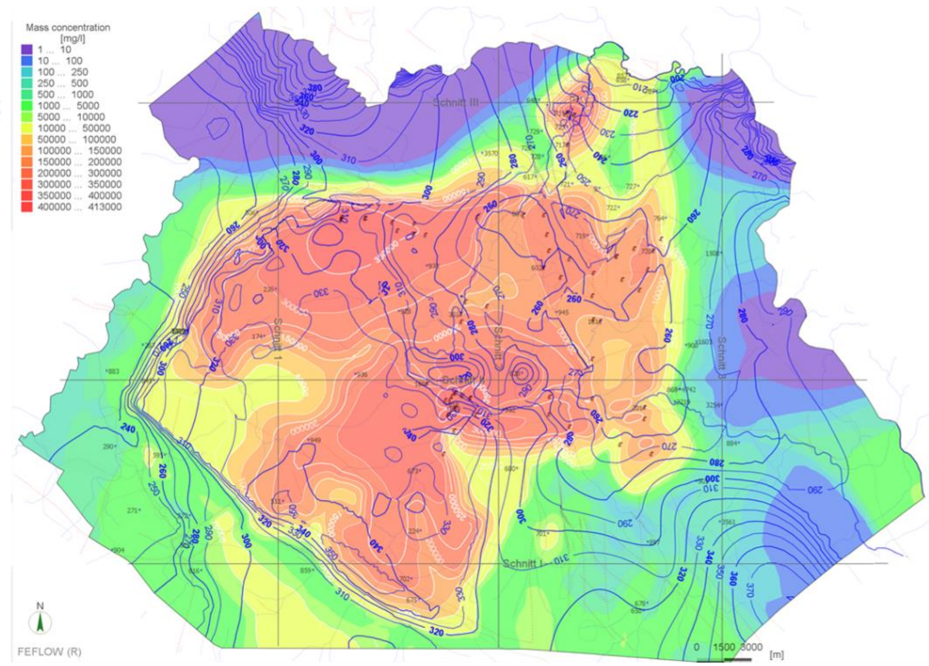




Plausible description of the regional groundwater flow pattern

Heads and TDS in the lowest overburden layer and injection layer





Summary

Reality	*Model*
• Groundwater salinity is relatively high and varies substantially regionally as well as with depth • The initial state is poorly known as injection began as early as 1925	→ *A (stable) initial state had to be calculated based on the stationary water balance and rough estimates from very limited well data*
• Injection was carried out over a long time (1925-2016)	→ *Leading to a long simulation period*
• Injection wells were operated non-uniformly, alternating duration, location, timing and pumping rates	→ *Leading to a long calibration period*

Summary

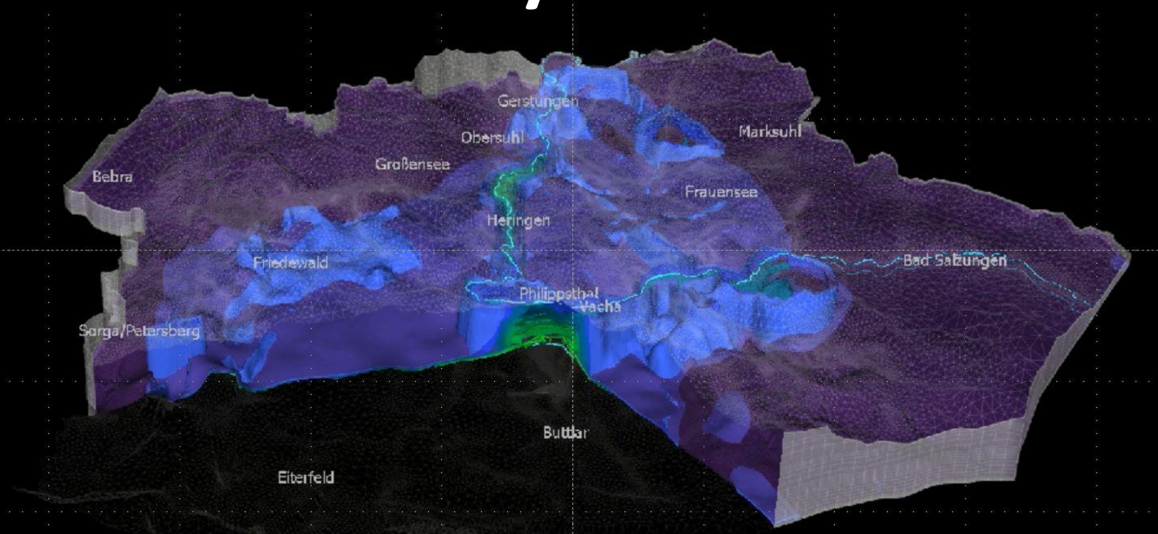
Reality	***Model***
• The overburden is quite heterogeneous with variations in hydraulic conductivity both spatially as with depth	→ *Modelling of the unsaturated zone as well as aquifers and aquitards with a more homogeneous representation of hydrogeologic conditions*
• Seasonal variations in groundwater recharge and streamflow; many (small scale) groundwater wells…	→ *Due to the complexity of the modeled system, additional dynamics had to be reduced as much as possible (e.g. use long-term average groundwater recharge)* → *Exact modelling of the unsaturated zone and perched aquifers is limited*

Conclusions

The model has proven to be an indispensable tool in modelling the impact of 90 years of deep well injection:

- It has confirmed and improved the understanding of the long-term processes related to brine injection
- Already during calibration status it was used to verify theories on regional hydrologic and local well conditions
- It offers the possibility to test different injection management strategies now and for the future
- With new field data, the model is updated to become successively better along the way
- Yet, modelling results should always be used in combination with field measurements for a correct interpretation of the system behaviour especially when used to answering smaller scale questions

Thank you!



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Protection areas