WINZER: Multi-scale modelling concept for numerical modelling of seasonal thermal energy storage in groundwater-filled underground coal mines

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Extended Abstract

The WINZER project explores the possibilities and challenges associated with seasonal heat storage in flooded underground coal mines. It involves collaboration among scientists and industry professionals focusing on the safe and efficient operation of Aquifer Thermal Energy Storage (ATES) in abandoned coal mines (fig. 1).

Within the project large-volume seasonal heat storage systems in mining infrastructures and the surrounding groundwater bodies will be investigated in order to develop previously unused thermal storage capacities and optimize existing installations.

The aim of the project is the development of a holistic monitoring concept, which will be carried out on an existing aquifer heat storage pilot plant in groundwater-filled mining cavities. The gained measurement data and findings will be used to make qualitative and quantitative statements on the hydrochemical, microbiological, geomechanical and groundwater-ecological properties in cyclic operation.

From this, concepts and technologies for feasibility and optimization, as well as for the safe operation of aquifer heat storage systems in disused coal mines are derived.

This contribution focuses on the development of the thermo-hydraulic simulations used for the evaluation of future sites in order to increase the operational safety and cost-effectiveness of mine heat storage systems. For this purpose, 3 locations with different characteristics are considered in the project: an isolated near-surface site, a deep mine complex connected to the central dewatering system and a disused underground factory with a large volume.

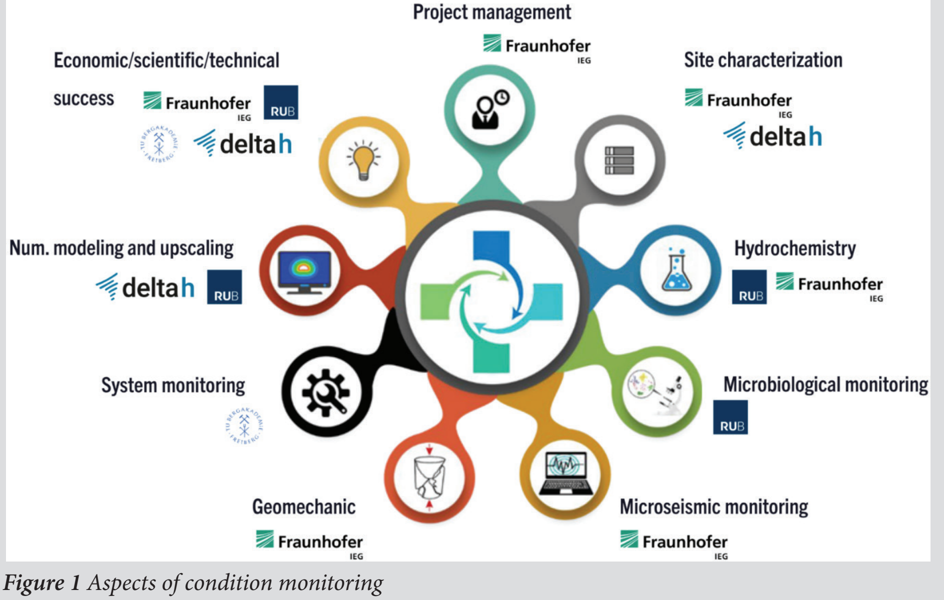

Figure 1 Aspects of condition monitoring

At the time of writing, work on the near-surface location has been nearly completed, while the last two locations are currently being worked on.

The software code chosen for the numerical modelling work is the 3D groundwater flow and transport model SPRING, developed by the delta h, Germany (König et al. 2023). SPRING uses the finite-element approximation to solve the groundwater flow and transport equations. SPRING is able to simulate steady and non-steady flow, contaminant transport, density dependent transport as well as heat transport (heat convection and conduction), in aquifers of irregular dimensions and different model layers with varying thicknesses as well as out-pinching model layers are possible.

Based on the extensive mining situation within the complex geological setting in the Ruhr area of Germany a stepwise modelling concept has been developed (fig. 2). This concept serves as the foundation for comprehending the groundwater occurrence and flow mechanisms of the pilot site, forming the basis for numerical heat transport modelling. The concept encompasses three scales, each providing an increasing level of detail, beginning from a regional scale (>10,000 km²), followed by a site scale of approximately 30 km², and down to a local scale (<1 km²).

Modelling the influence of mine dewatering and flooding on a regional scale as for the Ruhr area presents many challenges including the appropriate discretization of mine voids and the accurate modelling of layered aquifer systems.

To predict the environmental impacts of both the historic mining activities and future operations, a detailed conceptual model of the aquifer systems and a 3-dimensional model of the mining areas were incorporated into a numerical groundwater model (fig. 3).

This model was used to simulate the dewatering and post-closure rebound of the water tables in the vicinity of the mine. The largest model scale comprises the regional geological setting, aquifer systems, mining areas grouped into water provinces and their interconnections. Calibration of mine water levels is based on historical dewatering rates and mine water levels.

Regional modelling provides the boundary conditions for the site scale taking into consideration the influence of mine dewatering. This approach reduces the size of the site scale model and enables the geometrically discrete representation of the mine and shaft geometry as well as a more complex geological domain. To maintain the fluid mass balance coupling between the two domains is established via fluxes (Neumann boundary condition). This representation is crucial for variable-density flow and heat transport modelling of the system (fig. 4).

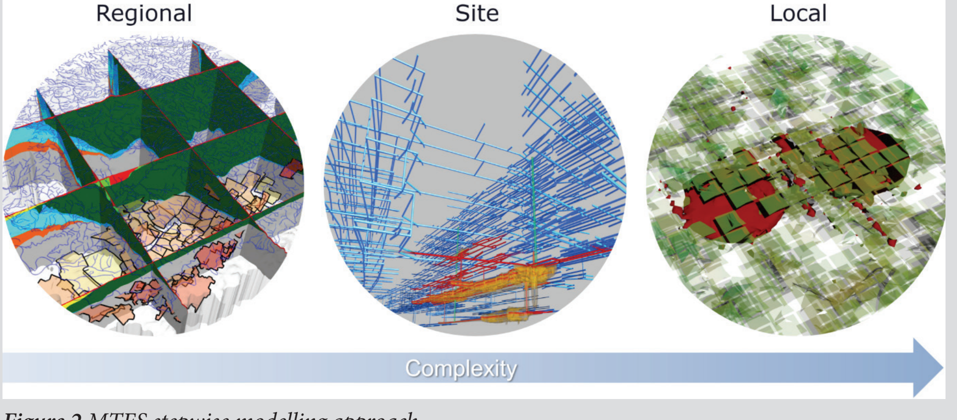

***Figure 2** MTES stepwise modelling approach*

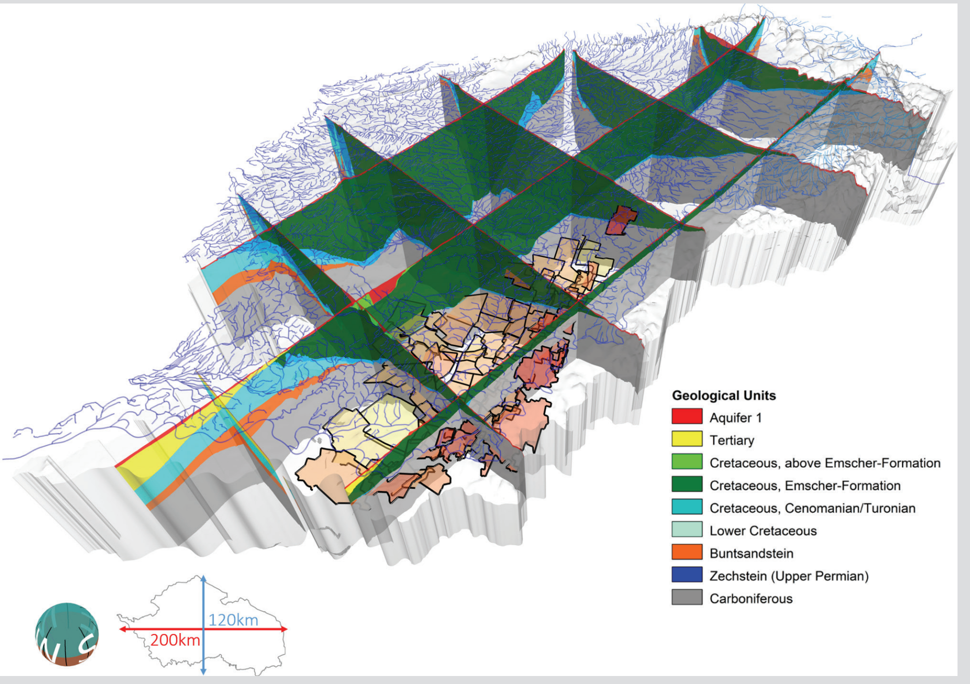

Figure 3 The largest model scale comprises the regional geological setting, aquifer systems, and mining areas grouped into water provinces (horizontal surfaces colored according to water level from yellow = low to red = high)

Carboniferous rock at the site is highly fractured. Groundwater flow takes place in the fracture network where advection and gravity forces are the dominant processes. For characterizing the flow and transport phenomena in the fractured rock on a local scale, it is necessary to model a discrete fracture matrix system (König 1998). At this scale different parts of the system can be modelled in high detail (fig. 5). It is used to estimate local effects like the influence of fractures on the heat transition in the system (fractured rock aquifer with low permeability), different (residual) mine void volumes

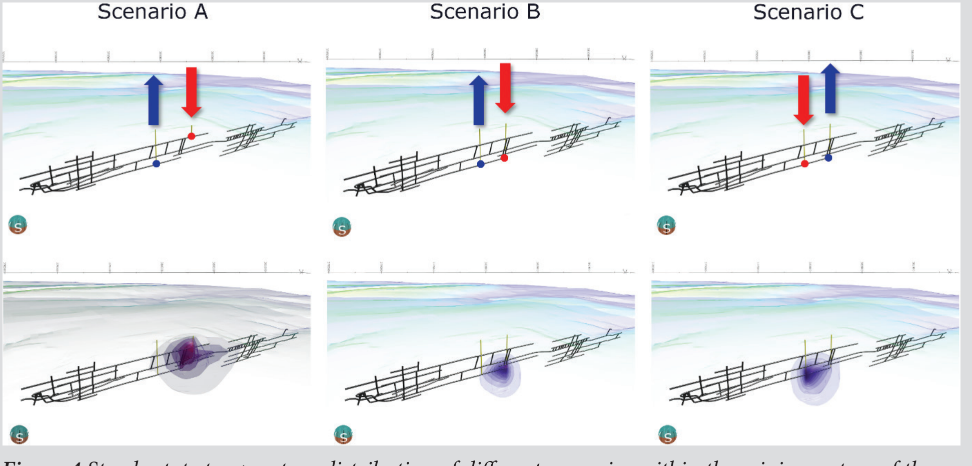

Figure 4 Steady state temperature distribution of different scenarios within the mining system of the near surface-site (black), arrows indicate the location of injection (red) and production (blue)

and operation modes. Once the influencing parameters have been determined, they can be transferred to the site model.

The step-by-step approach enables easy transfer of the concept which has since been rolled out to other mining locations in the Ruhr area.

Keywords: Mine, thermal, energy, storage, numerical modelling, SPRING

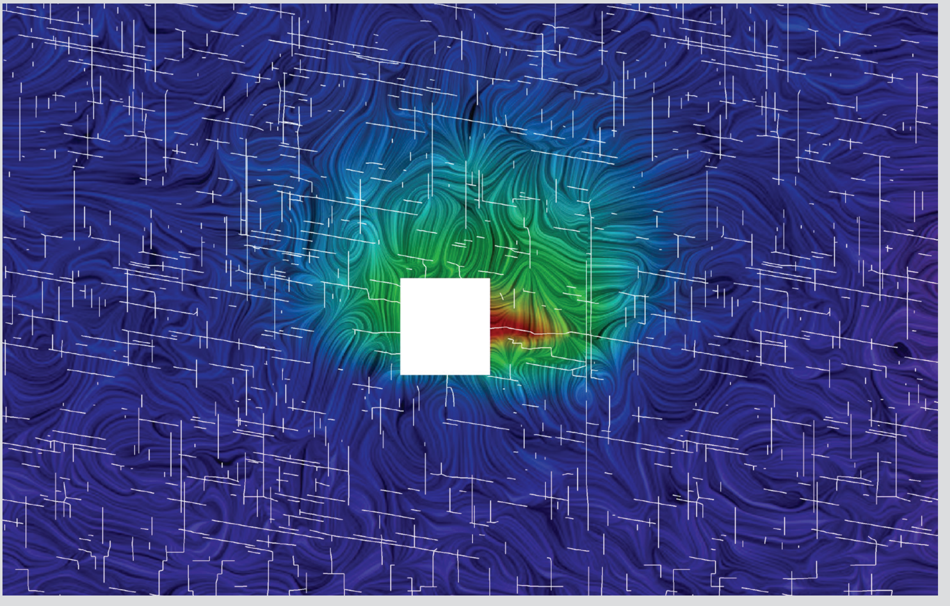

Figure 5 *Detailed 2D vertical model perpendicular to a mining cavity (white rectangle) to estimate the local effects of a discrete fracture matrix system (white lines) on the temperature distribution close to the mine*

Acknowledgements

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References

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