EGU22-856
https://doi.org/10.5194/egusphere-egu22-856
EGU General Assembly 2022

Modelling environmental interactions of large-scale, closed seasonal thermal energy storage systems

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Efficient thermal energy storage concepts are key for achieving the ambitious international climate targets. Implemented in thermal energy networks with a high contribution made by volatile renewable energy sources, large-scale applications for sensible heat and cold storage are favourable. They compensate for short-term fluctuations in the energy demand profiles, and they enable solar energy harvested in summer to be recovered for use in winter. Especially when pre-existing infrastructure facilities (e.g., basin installations from disused industrial, water treatment, and stormwater retention facilities) are reused as framework structures for thermal energy storage devices, environmental boundary conditions are often adverse. This is, for example, due to interference with near-subsurface aquifers or due to a suboptimal geometry of the given storage structure. For identifying strengths and weaknesses of a storage facility, and for technological optimization, simulation of thermal processes is vital. By this, the role of subsurface heterogeneity and slowly evolving transient thermal conditions in the storage device as well as in the ambient ground can be analysed. Thus, different degrees of utilisation, potential lateral energy losses or gains, and ultimately the economic viabilities of potential solutions can be evaluated. Most of the existing modelling applications do not address these issues in full detail. In fact, previous studies revealed that originally predicted efficiencies and amortization periods are often not achieved. This can be attributed to insufficiently represented boundary conditions (e.g., steady and uniform ambient temperatures at all exterior storage interfaces) or to rigorous simplifications by symmetric modelling techniques (no possibility to implement asymmetric processes, e.g., groundwater flow in surrounding subsurface).

In our study, we use a new numerical model to represent hydrogeological processes around ground-based thermal storage devices at high resolution and in different respects. In a series of generic scenarios, we focus on fundamental parameters of groundwater and environmental conditions, such as different groundwater levels and flow velocities, and we inspect the influence of various thermophysical (thermal conductivity/storage capacity) and hydraulic material parameters (e.g., porosity, permeability). With these, we analyse effects on storage utilisation rates, thermal losses, and temperature conditions in the surrounding area. Finally, we provide insight into previously neglected influencing factors and offer improvement strategies for the planning and implementation of large-scale, closed, seasonal thermal energy storage systems.