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Numerical investigation of induced thermal impacts from high-temperature thermal energy storage in porous aquifers

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High-temperature aquifer thermal energy storage (HT-ATES) in the geological subsurface will affect the temperature distribution in and close to the storage site, with potential impacts on groundwater flow and biogeochemistry. Quantification of the subsurface space affected by a HT-ATES operation is thus required as one basis for urban subsurface space planning, which would allow to address potential competitive and conflicting uses of the urban subsurface. Therefore, this study shows a quantitative evaluation of induced thermal impacts and subsurface space required for a synthetic ATES operated at varying temperature levels.

A hypothetic seasonal HT-ATES operation is simulated using the coupled groundwater flow and heat transport code OpenGeoSys. A well doublet system consisting of fully screened “warm” and “cold” wells 500 m apart is used for the storage operation. A sandy aquifer typical for the North German Basin at a depth of 110 m and with a thickness of 20 m in between two confining impermeable layers is used as storage formation. Seasonal cyclic storage is simulated for 20 years, assuming charging and discharging for six months each. During charging, water with the aquifer background temperature of 13°C is extracted at the "cold" well, heated to 70°C and reinjected at the “warm” well using a pumping rate of 30 m^3/h. During discharging, the stored hot water is retrieved at the "warm" well using the same pumping rate and reinjected at the “cold” well after heat extraction at aquifer background temperature.

The simulation results show that during a single storage cycle using a storage temperature of 70°C 7.51 GWh of thermal energy is injected, of which 4.79 GWh can be retrieved. This corresponds to a thermal recovery factor of 63.8% and thus an effective storage capacity of 0.43 kWh/m^3/K can be deduced in relation to the heat capacity of the storage medium. For storage temperatures of 18°C, 30°C and 50°C, the effective storage capacity is 0.56 kWh/m^3/K, 0.55 kWh/m^3/K and 0.49 kWh/m^3/K, respectively. By delineating the subsurface volume with a temperature increase larger than 1°C, the subsurface space used for and affected by the storage operation at the storage temperature of 70 °C is determined to be 10.56 million m^3. In relation to the retrieved thermal energy, a subsurface volume of 2.2 m^3 is thus required to retrieve one kWh of heat energy at 70 °C injection temperature. At lower temperatures of 18°C, 30°C and 50°C, the subsurface space required is 1.77 m^3/kWh, 1.54 m^3/kWh and 1.76 m^3/kWh, respectively. The lower effective storage capacity and the relatively larger required space, which correspond to a lower thermal recovery factor, are caused by induced thermal convection and higher heat losses by conduction at higher

temperatures.