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Aquifer Thermal Energy Storage as an ecosystem service for Brussels, Belgium: investigating iron (hydr)oxide precipitation with reactive transport modeling

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In an evolving energy system it is important that urbanized areas contribute to their own energy demands. To reduce greenhouse gas emissions sustainable energy systems with a high efficiency are required, e.g. using urban aquifers as an ecosystem service.

Here the potential of seasonal aquifer thermal energy storage and recovery (ATES) for the Brussels-Capital Region, Belgium is investigated. An important shallow geologic formation in the Brussels Capital Region is the Brussels Sand formation, a 20-60 m thick phreatic aquifer. The Brussels Sand Formation is known for its potential for ATES systems, but also for its varying redox and hydraulic conditions. Important limiting factors for ATES systems in the Brussels Sand Formation therefore are the hydraulic conductivity and the geochemical composition of the groundwater.

Near the redox boundary iron hydroxide precipitation can negatively influence ATES well performance due to clogging. The interactions between physical processes (e.g. particle transport and clogging in the wider proximity of the ATES well) and chemical processes (e.g. influence of the operation temperatures on precipitation processes) during ATES operation are complex but not well understood.

Therefore we constructed numerical groundwater flow models in MODFLOW to estimate maximum pumping and injection rates of different hydraulic conditions and competing water uses in the Brussels Sand Formation. In further steps the thermal potential for ATES was quantified using MT3DMS and the reactive transport model PHT3D was applied to assess the effects of operating ATES systems near the redox boundary.

Results show that initial mixing plays an important role in the development of iron(hydr)oxide precipitation around the ATES wells, with the highest concentrations around the cold wells. This behavior is enhanced by the temperature effect; temperature differences of $\Delta T \approx 10°C$ already influence the iron (hydr)oxide concentration. The initial injection into the warm well causes both the initial mixing and temperature effects to counteract each other, so that the iron(hydr)oxide concentration at the cold well is lower and closer to those of the warm well.

Avoiding the mixing of oxygen/nitrate rich water with iron rich water remains the best strategy to prevent well clogging. Subsurface planning and feasibility studies for ATES should therefore carefully investigate the vertical distribution of water quality variations and hydraulic conductivity, and use this information to optimize filter screen settings.