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Effects of brine displacement on pressure and salinity increases in a regional freshwater aquifer complex with respect to CO_2 storage in saline subsurface formations

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The geological storage of CO_2 in deep saline aquifers may cause upward migration of displaced brines along leakage pathways such as highly-transmissive faults due to an increasing pore pressure in the storage formation. Besides the risk of CO_2 leakage, the protection of the shallow freshwater reservoirs from upward migrating brine is a requirement with regard to environmental compatibility of future CCS projects.

In the present study, the regional impact of pressure build-up and salinity increases in a freshwater reservoir induced by brine displacement due to CO_2 injection into saline subsurface formations was investigated. A multi-layered aquifer-aquitard system of Triassic to Cenozoic age was used as a framework to ensure that realistic hydrodynamic and hydrochemical conditions were applied in this assessment. The prospective storage horizon corresponding to a Lower Triassic sandstone aquifer is located in a broad anticlinal structure at the southeastern margin of the Northeast German Basin. This intracontinental basin is not only characterised by large salinity gradients but also by hydrogeologically significant fault zones and glacial erosional structures that may act as migration pathways for saline formation water into Cenozoic freshwater reservoirs.

In a first step, a detailed three-dimensional geological model was implemented. The model has a horizontal extent of 73 km (N-S) $\times$ 85 km (E-W) and a vertical extent of 2.4 km. In a second step, the geological model was transferred into a hydrogeological model by discretisation and parameterisation using data obtained from borehole measurements, field observations and geological maps. The modelling was performed using the FEFLOW FMH3® code. Long-term transport simulations with NaCl as a tracer were conducted to comprehend the natural freshwater-saltwater distribution of the regional aquifer system. Based on these initial conditions, simulations of possible upward brine migration into a freshwater aquifer complex induced by CO_2 injection into a saline storage formation were carried out.
The brine displacement out of the storage formation along transmissive fault zones induced by the injection of 1.7 Mt CO_2/year over a time span of 20 years was calculated by use of a regional-scale model with the multi-phase flow simulator TOUGH2-MP/EC02N. The simulation results of different fault leakage scenarios from the reservoir model served as input data for modelling the impact of upward brine migration on pressure and salinity increases in the overlying freshwater aquifers. This was achieved by implementing an influx of saline formation water that corresponds to the calculated flow rates in the adjacent transmissive fault zones dissecting the caprock of the reservoir formation.

The sensitivity analysis illustrates the influence of brine displacement on pressure and salinity development in a multi-layered freshwater reservoir: Depending on the geological settings, moderate pressure elevations were found at the base of the Cenozoic freshwater aquifers. However, the impact of upward brine migration and the related salinity increase in the freshwater reservoirs is negligibly small.