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Brine migration resulting from pressure increases in a layered subsurface system

Jens-Olaf Delfs, Johannes Nordbeck, and Sebastian Bauer
CAU Kiel, Kiel, Germany (jod@gpi.uni-kiel.de)

Brine originating from the deep subsurface impairs parts of the freshwater resources in the North German Basin. Some of the deep porous formations (esp. Trias and Jurassic) exhibit considerable storage capacities for waste fluids (CO_2, brine from oil production or cavern leaching), raising concerns among water providers that this type of deep subsurface utilization might impair drinking water supplies. On the one hand, overpressures induced by fluid injections and the geothermal gradient support brine migration from deep into shallow formations. On the other hand, the rising brine is denser than the surrounding less-saline formation waters and, therefore, tends to settle down. Aim of this work is to investigate the conditions under which pressurized formation brine from deep formations can reach shallow freshwater resources. Especially, the role of intermediate porous formations between the storage formation and the groundwater is studied. For this, complex thermohaline simulations using a coupled numerical process model are necessary and performed in this study, in which fluid density depends on fluid pressure, temperature and salt content and the governing partial differential equations are coupled.

The model setup is 2D and contains a hypothetic series of aquifers and barriers, each with a thickness of 200 m. Formation pressure is increased at depths of about 2000 m in proximity to a salt wall and a permeable fault. The domain size reaches up to tens of kilometers horizontally to the salt wall. The fault connects the injection formation and the freshwater aquifer such that conditions can be considered as extremely favorable for induced brine migration (worst case scenarios). Brine, heat, and salt fluxes are quantified with reference to hydraulic permeabilities, storage capacities (in terms of domain size), initial salt and heat distribution, and operation pressures.

The simulations reveal the development of a stagnation point in the fault region in each intermediate aquifer above the injection formation, where brine settles down and flows from the fault zone into the aquifer. This effect changes buoyancy so that lower density brine from the upper aquifers can rise higher and at larger fluxes compared to the case when no intermediary aquifers are present. In general, uplift of brine originating from the intermediary aquifers is mainly restricted to the next overlying two to three permeable aquifers (200m-1000m) or even only to the next aquifer if injection pressures are lower than about 10 bar. If injection induced over-pressures are high, brine from the injection reservoir can dominate inflow into the freshwater reservoir at late times (tens of years). An extensive parameter variation shows the effects of individual parameters. It is found, e.g., that no brine enters the freshwater aquifer if fault permeability is lower than about 10^{-14} m^2.

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