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3D modelling of subsurface methane leakage through unconsolidated sedimentary aquifers; implications for environmental monitoring

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Human underground activity related to oil & gas production can result in unintended connections between shallow groundwater and deep reservoirs, causing upward gas leakage. This may impair groundwater quality, contribute to anthropogenic greenhouse gas emissions, and can cause explosion hazard. Typically, leakage is detected by measuring methane emissions at the soil surface, or methane concentrations in shallow groundwater. The extent to which such leaks may result in elevated methane concentrations in groundwater and methane emissions at surface level is expected to depend on a range of factors. Besides the gas leakage rate, it is also affected by the degree of dissolution of the gas and dispersion in intermediate aquifers during its upward migration. Such losses may be particularly large in thick unconsolidated sedimentary systems, under the influence of lateral groundwater flow.
To investigate how these various factors affect subsurface methane gas leaks, a 3D numerical model was constructed using DuMux, to simulate two-phase (liquid & gas) and two-component (H_2O & CH4) behaviour for variations of typical sedimentary aquifer conditions. Then, a sensitivity analysis was carried out to determine the most influential parameters by varying porous medium properties, two-phase flow parameters, regional groundwater flow velocities and leakage flux. The results show that for typically observed leakage fluxes significant proportions of gas may be dissolved and/or dispersed laterally during upward migration, making it effectively undetectable at surface level or only after long time periods (decades to centuries). Under such conditions, measurements at surface are inadequate for determining subsurface gas leakage rates.