MULTI-PHASE FLOW SIMULATIONS OF METHANE GAS LEAKAGE IN AN UNCONFINED AQUIFER: REVEALING THE IMPORTANCE OF HYDROGEOLOGIC CONDITIONS ON GPR AND ERT SIGNATURES

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Methane gas was injected into an unconfined sandy aquifer at Canadian Forces Base (CFB) Borden, Canada, over a 72-day period to better understand the evolution of the free-gas plume. Time-lapse electrical resistivity tomography (ERT) and ground-penetrating radar (GPR) revealed a highly transient gas-phase exhibiting multiple oscillatory lateral migration events. We examined the nature of these geophysically based observations using a multi-phase flow model (CompFlow Bio) through a series of simplified hydrogeologic scenarios, designed to evaluate the impacts of macro-heterogeneity, anisotropy, groundwater velocity, air-entry pressure, layer discontinuity, and injection rate history on the evolution of the free-gas plume. Forward ERT and GPR simulations were conducted on select groundwater flow models to evaluate geophysical sensitivity to pore-water desaturation during the simulated injection period. Results show >25% increase in the volume of gas retained within the aquifer during the active injection period with the introduction of a low-permeable layer above the injectors. Gas was shown to preferentially spread along the base of the layer as layer permeability decreased (from 1 x kaqifer to 0.03 x kaquifer). Lateral gas spreading was enhanced by increasing groundwater velocity (from 0 to 10 cm/day) and layer gas-entry pressure (2.22 kPa to 2.99 kPa). Although the volume of gas retained in the aquifer was similar for unadjusted and adjusted gas entry pressures, higher layer entry-pressures led to the formation of a well-defined gas lens that extended in both the up and downgradient directions. GPR was most sensitive to the formation of gas lenses along the base of lower permeable layers while the ERT was most sensitive to changes in spatially distributed desaturation. The strongest GPR response occurred beneath a low-permeability layer with increased entry pressure. Multi-phase flow simulations confirm the formation of a laterally extensive free-gas plume in the unconfined aquifer, which is consistent with experimental observations.