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Utilizing time-lapse hydraulic tomography to characterize the subsurface changes during methane and heat injection experiments

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Storage options for the energy storage in the subsurface includes the injection and storage of the "energy gas" (e.g., methane, hydrogen, compressed air) or thermal water into the underground formations. The heterogeneous structure of the storage formations could play a crucial role on the potential storage capacity, as well as the formulation of post treatment strategy. Hence, innovative techniques are required for characterizing the high-resolution formation heterogeneity and monitoring the gas or heat plume distribution in the subsurface after their injections. Previous studies have shown that flow properties can vary as the gas or thermal water being injected into the aquifer. In this study, we propose a time-lapse hydraulic tomography (HT) method for characterizing the baseline hydraulic information and depicting the hydraulic property changes through a series of cross-well pumping tests. These tests were implemented in two pilot sites for methane and hot water injection tests at Wittstock, Germany. In order to generate a three-dimensional tomographical configuration, each pumping test was conducted at certain depth in a testing well, accompanying with multiple observation points at other wells. Depth-variant pumping and observation segments were formed by the double-packer system. As a result, we achieved 198 and 135 baseline drawdown curves for the methane and heat sites, respectively. For these measured data, we initially evaluated the effective hydraulic conductivity and specific storage of the aquifer according to certain analytical fitting methods. Furthermore, the vertical anisotropy of the hydraulic conductivity was also estimated. Sequentially, the fitted hydraulic parameters and analytical drawdown curves were utilized for correcting the well skin effects on hydraulic traveltimes and attenuations, as they have an unneglectable impact on them. The corrected hydraulic traveltimes and attenuations were used for the inversion of the baseline hydraulic diffusivity and specific storage, respectively. Hydraulic conductivity distribution was then estimated through these two parameters. After we achieved the baseline information, HT was executed again by repeating the tomographical pumping tests after methane and hot water injections. The same data processing and inversion techniques were applied to the drawdown curves derived from the post-injection period. Inverted hydraulic diffusivity, specific storage, and hydraulic conductivity were compared to the baseline inversion results. Changes on these hydraulic properties could provide the information of the spatial distribution of methane or heat plume.