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Hydraulic characterization of aquifers by thermal response testing

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Temperature as a major physical quantity of the subsurface, and naturally occurring thermal anomalies are recognized as promising passive tracers to characterize the subsurface. Accelerated by the increasing popularity of geothermal energy, also active thermal field experiments have gained interest in hydrogeology. Such experiments involve artificial local ground heating or cooling. Among these, the thermal response test (TRT) is one of the most established field investigation techniques in shallow geothermal applications. It is a common method to investigate important subsurface heat transport parameters to design sustainable ground-source heat pump (GSHP) systems. During the test, the borehole heat exchanger (BHE) is heated up with a defined amount of energy by circulating a heat carrier fluid. By comparing temperature change between BHE inlet and outlet, the ability of the BHE to transfer heat or cold to the ambient ground is assessed. However, standard interpretation does not provide any insight into the governing processes of in-situ heat transfer. We utilize a groundwater advection sensitive TRT evaluation approach based on the analytical moving line source equation. It is shown that the TRT as a classical geothermal field test can also be used as a hydrogeological field test. Our approach benefits from the fact that thermal properties, such as thermal conductivity, of natural aquifers typically are much less variable than hydraulic properties, such as hydraulic conductivity. It is possible to determine a relatively small hydraulic conductivity range with our TRT evaluation approach, given realistic ranges for thermal conductivity, volumetric heat capacity, thermal dispersivity and thermal borehole resistance. The method is successfully tested on a large-scale geothermal laboratory experiment (9 m $\times$ 6 m $\times$ 4.5 m) and with a commercially performed TRT in the field scale. The laboratory experiment consists of a layered artificial aquifer, which is penetrated by a short BHE. This BHE is used to record a groundwater influenced TRT dataset. The performed field TRT is measured at a BHE located in the Upper Rhine Valley in South-West Germany, which penetrates a 68 m thick gravel aquifer with significant horizontal groundwater flow. At both sites, the derived hydraulic conductivity ranges obtained from TRT evaluation are shown to be within the ranges obtained from classical hydrogeological methods such as sieve analysis and pumping tests. This confirms that the temperature signal recorded during thermal response tests can be employed as a thermal tracer and that the evaluation of such a signal can be applied to estimate aquifer hydraulic conductivities.