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Evaluation of a thermal tracer test in a porous aquifer

T. Li (1), C. Leven (2), P. Dietrich (2), P. Grathwohl (1), and P. Blum (1)

(1) Center for Applied Geoscience (ZAG), Universitiy of Tübingen, Tübingen, Germany (tao.li@student.uni-tuebingen.de),
(2) Helmholtz – Centre for Environmental Research (UFZ), Leipzig, Germany (carsten.leven@ufz.de)

In the early 1960s, attention was called to the potential for using heat as a tracer to estimate hydraulic parameters. Due to the fact that geothermal energy is being increasingly considered as an alternative source of energy for fossil fuels, recent studies have also been carried out on using temperature to estimate thermal parameters. In this study, the feasibility of using temperature data to derive hydraulic and thermal parameters of an aquifer is evaluated using a field-scale thermal tracer test in a porous aquifer. The field experiments were carried in a groundwater protection area at the well-equipped "Lauswiesen" test site, which is located close to the city of Tübingen, Germany. During the test, an amount (16 m^3) of warm water (22˚C) was injected constantly into the unconfined aquifer, where the average groundwater temperature is 11˚C. The resulting temperature changes in different observation wells along the groundwater flow direction were measured using submerged thermometers (PT100 chains). The scale of observations in the performed experiment was approximately 10 m from the injection well. In the current study, the observed temperature data is discussed and applied to calibrate an analytical and a numerical model. The analytical model enabled the determination of average values for hydraulic parameters such as porosity, hydraulic conductivity, and longitudinal dispersivity as well as for thermal parameters such as the thermal conductivity. A finite-element model (with FEFLOW) was used to determine their spatial variations. The results of the sensitivity analysis with the analytical model demonstrate that the heat transport processes in the aquifer are highly dependent on the aforementioned hydraulic parameters; whereas thermal conductivity in this circumstance might have minor influence, due to relatively homogeneous composition of the porous media (sand and gravel). Furthermore, parameters such as hydraulic conductivity and longitudinal dispersivity were compared with previous site-specific and non site-specific studies. Within the current framework, the derived average hydraulic conductivity is 0.003 m/s, while the longitudinal dispersivity has an average value of 0.6 m. These derived hydraulic parameters from the performed thermal tracer test are comparable to the results from other previous studies with pumping, flowmeter and dyed-tracer tests. Therefore, we conclude that thermal tracer tests could be generally used as a standard field technique for hydrogeological investigations. Interestingly, in the current study the derived longitudinal dispersivity shows no significant scale-dependency in comparison to the results from previous studies on solute transport, which typically indicate a scale-dependency. Hence, further studies need to be performed to test the hypothesis that the thermal longitudinal dispersivity might differ from the solute longitudinal dispersivity in terms of scale-dependency, as well as on other possible aspects.