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Imaging of groundwater flow paths in an active river channel using 3D ERT monitoring of a salt tracer injection

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Inferring groundwater flow paths in heterogeneous alluvial sediments is a difficult task for which the use of stand-alone conventional hydrological tools may be insufficient. Our field site at the Thur River in northeastern Switzerland was developed and instrumented to investigate the hydrological, ecological and biochemical effects of river restoration. The subsurface hydrology was first investigated using hydrological logging time series and various hydrological tests based on a few piezometers. Unfortunately, the groundwater flow paths could not be clearly determined on the basis of this analysis. This led to non-optimal siting of subsequent piezometers that were designed to be located along specific flow lines. Surface-based 3D ground penetrating radar (GPR) and electrical resistance tomography (ERT) surveys at the site detected zones with different physical characteristics, but these results could not be directly related to groundwater movement. Since surface-based ERT monitoring is a useful technique for tracking electrical resistivity changes due to the movement of a saline tracer, we investigate here the extent to which this technique can be used to constrain the actual flow paths at the site.

During 20 minutes, we injected 500 l of saline tracer over the entire thickness of the 6 m thick alluvial aquifer through a borehole located 10 m from the river. The salinity of the injected fluid (36 g NaCl per liter) was similar to seawater, corresponding to a 100 times higher electrical conductivity than the groundwater. Although hydrological state variables (electrical conductivity, temperature and pressure) were logged in five piezometers 5 – 30 m downstream of the injection borehole only two of the loggers at 5 m distance from the injection borehole detected the tracer. The ERT monitoring was performed using 144 electrodes distributed on a 2D surface grid, with an electrode spacing of 4 m parallel and 6 m perpendicular to the expected flow direction. Starting at hourly intervals, a total of 27 time-lapse data sets were recorded in the 50 hours following the tracer injection. Each data set comprised a total of 3888 measurements made with dipole-dipole (inline and equatorial) and gradient-type configurations in the two directions of the electrode grid. The time-lapse ERT data were inverted using a difference-type inversion with respect to a background data set recorded prior to tracer injection. The ERT finite-element mesh included surface topography as well as undulations in aquifer thickness determined from the 3D GPR data. The inverted time-lapse ERT models imaged the tracer plume for the 50 hours following injection, during which parts of the tracer moved about 30 m. While the entire plume moved without much spreading during the first 6 hours, only parts of the tracer moved in preferential flow paths located at approximately 4 m depth during later times. We found that the plume by-passed the array of piezometers by only a few metres.

To test hydrological hypotheses about the hydrostratigraphy and to investigate the resolution capability of the ERT experiment, we used the hydrological modeling codes MODFLOW and SEAWAT together with ERT forward modeling to create synthetic time-lapse ERT data for different hydrological models. The hydrological models were used to investigate the importance of (i) the density effect on the salt tracer movement, (ii) different hydraulic conductivity zones inferred from static GPR and ERT and (iii) the effect of dispersion (spreading) related to small-scale heterogeneity.