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Impact of streambed hydraulic conductivity estimates from induced polarization on the predictive uncertainty of a groundwater flow model

Peter Radvanyi (1), Philipp Hoehn (1), Adrián Flores Orozco (2), and Thilo Hofmann (1)

(1) Department of Environmental Geosciences, University of Vienna, Vienna, Austria, (2) Department of Geodesy and Geoinformation, TU-Wien, Vienna, Austria

Numerical modelling is the go-to tool for sustainable groundwater resources management for drinking water production and other purposes. Reducing post-calibration predictive uncertainty is essential for increasing the utility of numerical groundwater models and thus providing more robust predictions. This can potentially be achieved by constraining parameter ranges during regularized model calibration, using related information derived from field measurements. Quantifying water exchange rates in heterogeneous stream-aquifer systems remains a particular challenge affecting model results, especially in case of hydraulic heads being the only type of observation.

Spectral induced polarization (SIP) measurements were computed for 133 profiles along the streambed of a subalpine headwater stream. At a selected stream reach, 325 depth-discrete transient slug tests were performed, to yield streambed hydraulic conductivity (K). Here, 5 additional SIP measurements were performed at 5 frequencies in the range between 7.5 and 75 Hz. Both the raw data and the inverted images revealed the strongest IP response at 7.5 Hz. Extracted pixel values of the inverted phase-shift (φ) at this frequency were used to investigate the relationship with K values derived from the slug tests. The log-linear regression analysis between the two parameters revealed a positive correlation (coefficient of determination of 0.39). Based on the linear correlation, the K distribution along the 133 profiles was estimated using the φ images (at 7.5 Hz) pixelwise. The resulting streambed K dataset covered a total extent of 1607 m (61% of the total stream length under investigation). The pixel data of streambed K was then used to constrain the range of allowed leakage coefficients of a Cauchy-type boundary condition during parameter estimation of a steady-state numerical flow model of the interacting groundwater system at the site. A null-space Monte Carlo (NSMC) approach was used to come up with 200 equally-likely realizations from the same set of hydraulic head state observations for the constrained model, as well as for an unconstrained reference model. Predictive uncertainty was quantified in terms of the standard deviation of the total stream-aquifer exchange rates throughout the 200 realizations for each of the two cases. It was found to be smaller after the incorporation of the SIP-derived streambed K estimates as constraining information. The results indicate that supporting groundwater models at stream-aquifer boundaries with SIP measurements and applying them as parameter constraints, can reduce predictive uncertainty and help to bring about more robust forecasts.