Investigating stream-aquifer exchange using waterborne spectral induced polarization imaging

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Analyzing stream-aquifer exchange for the management of bank filtration sites requires detailed information on the geometrical and hydraulic streambed properties. Inverse methods in numerical groundwater modeling tend to bear high spatial uncertainty. To reduce these uncertainties fiber-optic distributed temperature sensing (FO-DTS) can be applied but is limited by its unidirectional sensitivity towards groundwater discharge. To gain information with high spatial information, we investigate here the applicability of spectral induced polarization (SIP) imaging, a geophysical method, that provides information about the distribution of the low frequency electrical properties of subsurface materials. In particular, the objective of the study was to evaluate the capability of SIP imaging results to provide spatial estimates of parameters of a Cauchy-type boundary condition, namely hydraulic conductivity and thickness of potentially colmated substream sediment as well as stream stage, as required to improve numerical groundwater models. Hence, SIP measurements were collected with high spatial density using an array of 32 electrodes (at 0.5 m spacing) along a selected reach of a losing-disconnected subalpine stream in a broad frequency bandwidth (0.5-225 Hz). The array was fully submerged at the stream bottom, while the equipment was mounted on a stationary-positioned inflatable rubber boat. The electrical measurements were complemented with hydraulic tests. A total of over 300 depth-discrete transient infiltration tests, using temporarily installed steel piezometers with 10 cm screen length, were performed and analyzed to determine horizontal hydraulic conductivity (k) of the streambed at various depths and positions along the electrical arrays. SIP imaging results expressed in terms of the frequency dependence of the complex conductivity (σ^*) have provided two main observations: i) the real component (σ') shows only consistency to the main lithological units, permitting to delineate stream stage and the general substream architecture; whereas the imaginary component (σ'') has revealed a large spatial variability, which in turn is consistent with the variability observed in hydraulic conductivity measurements. Moreover, the correlation between σ'' and hydraulic conductivity values increases with increasing the acquisition frequency, suggesting that fine grains, as the dominating length scale, are enhancing the polarization response. Patterns of the first derivatives of σ'' as a function of depth suggest variable geometry of an immediate sub-stream layer, associated to the strongest polarization effect, as expected of a streambed colmation layer, commonly related to lower hydraulic conductivity compared to the surrounding armor layer and aquifer material. Our results demonstrate the potential of SIP images to assist groundwater flow modeling by providing necessary estimates for Cauchy-type boundary conditions at longer stream-aquifer interfaces. Particularly, the potential improvement of groundwater model predictive accuracy when embedding these estimates into a parameter estimation framework is still open to investigation.