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Waterborne spectral induced polarization imaging to investigate stream-aquifer exchange

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Detailed information about the geometrical and hydraulic properties of a streambed's colmation layer is critical for accurate numerical modelling of stream-aquifer exchange, which in turn is of pivotal importance for adequate groundwater management at bank filtration sites. Inverse methods in numerical groundwater modeling tend to bear high spatial uncertainty and existing methods are limited, e.g. fiber-optic distributed temperature sensing (FO-DTS) by its unidirectional sensitivity towards groundwater discharge. To overcome such deficiencies we propose the application of high resolution spectral induced polarization (SIP) imaging. The objective was to elucidate its capability to provide spatial estimates of parameters of a Cauchy-type boundary condition in groundwater flow modeling, namely hydraulic conductivity and thickness of potentially colmated substream sediment as well as stream stage.

SIP measurements were collected along selected reaches of a losing-disconnected subalpine stream in a broad frequency bandwidth (0.063-225 Hz) using an array of 32 electrodes (at 1 m spacing), which was fully submerged at the stream bottom, while the equipment was mounted on a stationary-positioned inflatable rubber boat. A total of 32 transient infiltration tests, using an open-bottom standpipe (4.2 cm inner diameter), were performed to determine vertical hydraulic conductivity (k_v) of the streambed at discrete positions along the electrical arrays. Imaging results of the real component of the complex electrical conductivity (σ') permitted to delineate stream stage and the general substream architecture; whereas the imaginary component (σ") revealed larger variability within the substream sediment, likely related to changes in the textural parameters. The k_v dataset confirms the textural variability with values varying between $3 \cdot 10^{-2}$ and $5 \cdot 10^{-7}$ ms^{-1}. The electrical imaging results exhibit the strongest polarization response at 75 Hz, suggesting that fine grains, as the dominating length scale, are enhancing the polarization response. The relationship between σ" and k_v reveals an inverse linear relationship, in accordance with laboratory studies, with higher correlation observed at 75 Hz. Yet, the σ"-k_v correlation is rather weak, likely due to (i) the differences in the volume of investigation considering the given 4-electrode array in the SIP data (3m) and the punctual k_v measurements (0.042 m) and (ii) sample disturbance when installing standpipes in streambed sediment. Nevertheless, in the frequency range around 75 Hz, patterns of the first derivatives of σ" as a function of depth suggest the possibility to extract the distribution of stream stage in agreement with measured values. Furthermore, SIP imaging results permitted to delineate the 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 underlying aquifer material. Our results demonstrate the potential of SIP images to improve groundwater flow modeling by providing necessary estimates for Cauchy-type boundary conditions at longer stream-aquifer interfaces; yet, the quantification of hydraulic conductivity based on SIP images at the field scale remains an open area of research.