On the use of complex resistivity imaging to estimate in-situ hydraulic conductivity

Kemna A.[1], Huisman J.A.[2], Zimmermann E.[2], Martin R.[1], Flores Orozco A.[1], Vereecken H.[2]

[1]Geodynamics/Geophysics, University of Bonn, Germany
kemna@geo.uni-bonn.de, rmartin@geo.uni-bonn.de, flores@geo.uni-bonn.de

[2]Agrosphere (IBG-3), Forschungszentrum Jülich, Germany
s.huisman@fz-juelich.de, e.zimmermann@fz-juelich.de, h.vereecken@fz-juelich.de

Over the past years, several studies have proven the potential of the induced polarization (IP) method for the hydraulic characterization of the subsurface. In particular for frequency-domain IP (i.e., complex resistivity) measurements, various relationships with textural and hydraulic properties have been established for different soil and rock types. These relationships are either based on a single-frequency measurement of IP, typically in terms of imaginary conductivity at some frequency, or on a quantity describing the spectral IP (SIP) response, for instance in terms of a characteristic relaxation time. Few studies have demonstrated the general value of such relationships for the estimation of hydraulic conductivity in field-scale imaging applications, where the relationships are applied to IP inversion results. However, convincing validation of this methodological approach based on independent SIP and hydraulic measurements on samples from the considered site (allowing site-specific calibration of the used relationship), or by comparing the inferred hydraulic conductivity image with the independently observed hydraulic flow field, for instance in the course of a solute tracer experiment, is still lacking. In particular the applicability of a fully spectral approach in an imaging framework under field conditions, involving electromagnetic coupling effects in the data acquisition and effects due to varying image resolution (sensitivity) in the inversion – both leading to systematic distortions of the 'true' SIP response –, is still an open question. We here investigate and discuss the potential and limitations of complex resistivity imaging to determine hydraulic conductivity for cross-borehole data collected at the Krauthausen test site, Germany, which presents a heterogeneous aquifer with four orders of magnitude variation in (saturated) hydraulic conductivity. Laboratory measurements on drilling samples from the site, well representing the vertical lithological variation, show a strong correlation in form of a power-law relationship between saturated hydraulic conductivity (K_s) and a representative SIP relaxation time (τ), while the correlation of imaginary conductivity (σ'') with K_s is less strong and only exists for higher measurement frequencies. We quantify and compare the virtual distortion of both relationships (K_s-τ and K_s-σ'') under the imaging process in numerical simulations mimicking the field survey. The simulations reveal a strong dependence of the recovered σ'' value upon image sensitivity (and resolution), strongly impacting the estimation of K_s, while K_s-τ turns out to be relatively invariant across the image plane. Furthermore, we compare the K_s images inferred from the field data using different K_s-(S)IP relationships, in particular also with the actual flow pattern as previously observed in solute tracer experiments by means of time-lapse electrical resistivity tomography (ERT) (Müller et al., 2010). The latter comparison represents an important validation of the IP methodology for K_s estimation at the imaging scale, since the flow patterns delineated by ERT-imaged tracer breakthrough should directly correspond with the IP-derived image of K_s if hydraulic gradient variations are negligible.

Müller, K., Vanderborght, J., Englert, A., Kemna, A., Huisman, J.A., Rings, J., and Vereecken, H., 2010. Imaging and characterization of solute transport during two tracer tests in a shallow aquifer using electrical resistivity tomography and multilevel groundwater samplers: Water Resources Res., 46, W03502, doi: 10.1029/2008WR007595.