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Prediction of hydraulic parameters at test-site Schillerslage using SIP field and lab measurements

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Objective

Hydraulic investigations are mostly still based on point information by pumping-tests, boreholes etc. Spectral Induced Polarisation (SIP), related to hydraulic parameters, can provide unique and cost-efficient information about aquifers and their transport properties.
In this study, an aquifer characterisation using SIP profiling, sounding and lab data is done. These results will be verified by different standard kf estimation. The final aim is to image porosity and permeability on field scale.

Geology and measurements at Schillerslage

As typical in N-Germany, two sandy aquifers are separated by a fine-grained till layer. These quaternary sediments are overlaying cretaceous marls. Some thin peat layers are detected in the first aquifer.

A 2D SIP profile with 21 electrodes and 2m electrode spacing and a SIP Schlumberger sounding, from AB/2=1.5m up to AB/2=150m, at the borehole location are measured (Fig.1). From the material of the core sample, SIP lab measurements, kf measurements at the 1m-liner and at soil sample rings are done. Here, a single frequency analysis (0.366 Hz for 1D and lab measurements and 0.625Hz for field measurements) is presented.

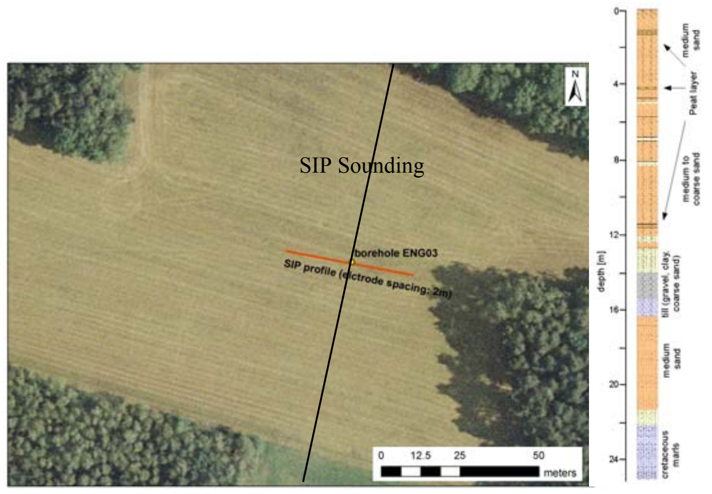

Fig.1: Test-site Schillerslage: measurements and geology

Comparison of 1D, 2D and lab SIP results

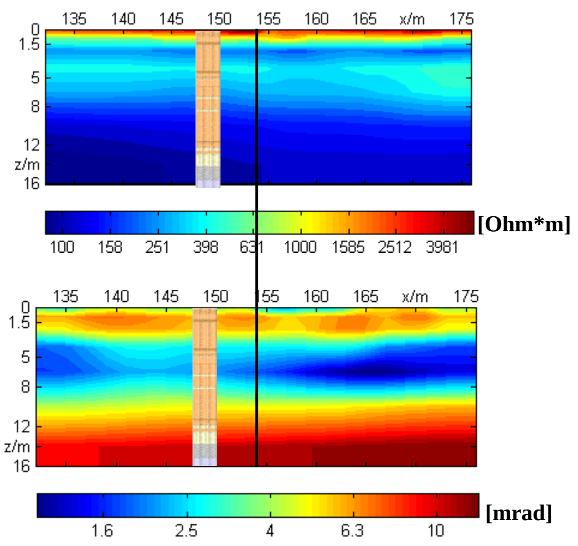

Fig.2: Inverted resistivity (top) and phase (bottom) model

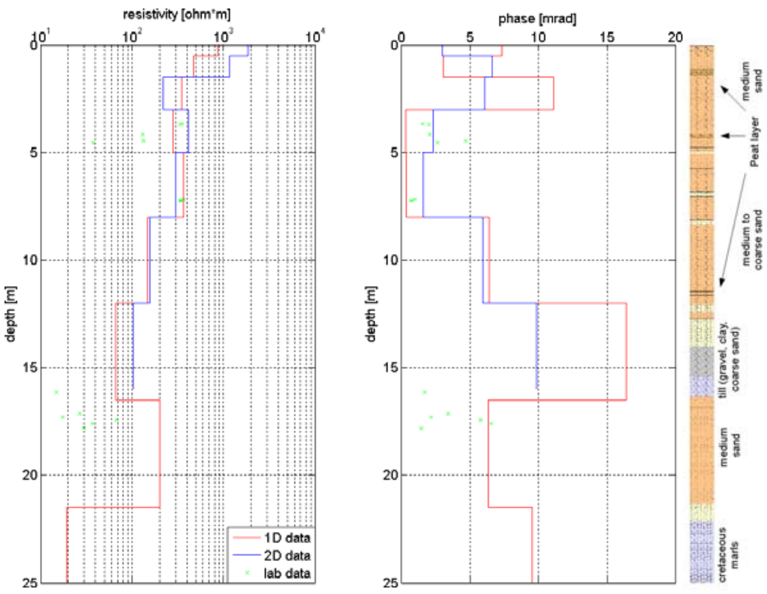

Fig.3: Comparison of 1D, 2D and lab data. Resistivity (left) and phase (right)

For comparison, the intersection from x=154m from the SIP profile is plotted with 1D data and lab data from the same location.

Sounding (red): able to image the geological structure (high phase and low resistivities in till and marl)
High phase value around 2m due to peat layers
Too high phases in 2nd aquifer due to inversions problems caused by sourrounding layers

2D data (blue): in general similar to 1D data
Low resolution of the first 3m due to 2m electrode spacing
Too low depth of penetration causes to low phases and too high resistivities of the till layer

Lab data (green): accurate phase information, but too low resistivities due to different fluid conductivity and temperature effects

Derivation of hydraulic parameters

Porosity is calculated from SIP data by using a modified Archie law (Börner et al., 1996): $\Phi = 1 / F^{1/1.3}$,
$F = \sigma_w/(\mathrm{Re}(\sigma) - \mathrm{Im}(\sigma)/0.1)$,

kf values are derived by a Kozeny-type equation (Pape et al., 1982): $kf = 0.00475/(F*S_{por}^{3.1})$ $S_{por}=86*\mathrm{Im}(\sigma)*1000$;
and after Slater and Lesmes (2002):
$kf = 2.3e\text{-}4/(\mathrm{Im}(\sigma)*1e6)^{0.9}$

Porosity from 2 to 8m and from 16 to 21m is more or less realistic, values in the deeper part of the first aquifer are too high. Pretended extreme high porosity in the two clayey layers is caused by surface conductivity of clay minerals.

kf values calculated after Börner show a wide range. Extreme high kf values between 3 and 8m depth are produced by phase values around 0. The results after Slater and Lesmes show slightly too low values, while the range between 3 and 8m correlates well with lab data.

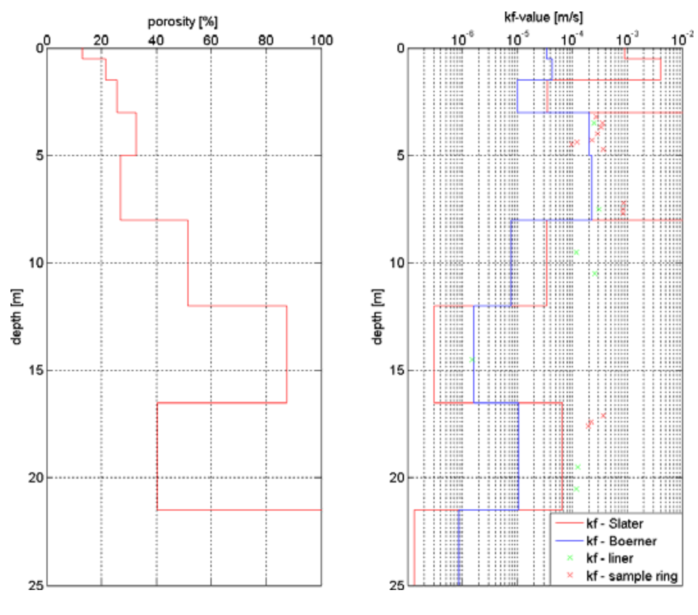

Fig.4: Porosity and kf estimates from 1D SIP data compared to lab kf data. SIP data derived from Fig.3

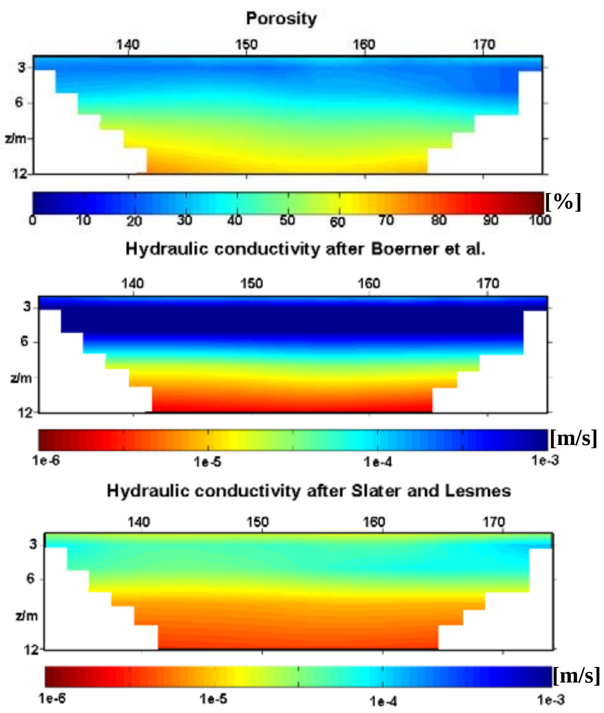

Fig.5: Porosity and kf estimates from SIP 2D data, derived from Fig.2

Conclusions

1D and 2D SIP data are useful for aquifer characterisation in the field scale. Both used approaches for calculating kf-values still show uncertainties. While the Börner et al. (1996) approach was not stable in all parts of the studied aquifers, the Slater and Lesmes (2002) approach yields slightly too low results, probably due to the tight validity range of this empirical relation.

Derived Porosity values by 1d and 2D SIP data are in general coherent, but for detailed aquifer characterisation still too unconfident.

SIP Lab results seem to be adequate additional information, but fluid conductivity and temperature effect have to be quantified accurately.

Ongoing work

Pumping tests, hydraulic tomography and further lab measurements to assess reliable hydraulic properties will be done to get a substantial estimation of these presented results.

The main focus will be on the spectral analysis of all data type. Aim is, to find relations between chargeability and grainsize and consequently hydraulic parameters.

For more precise porosity values, the constants in the used empirical equation have to be quantified thorough. Other approaches, including clayey sediments, will be applied, too.

References

Börner, F.D., Schopper J.R. and A. Weller, 1996: Evaluation of transport and storage properties in the soil and groundwater zone from induced polarization measurements. Geophysical Prospecting 44, 583-601.

Pape, H., Riepe, L. and J.R. Schopper, 1982: A pigeon-hole model for relating permeability to specific surface. Log Analyst. 22., 5-13.

Slater, L and D.P. Lesmes, 2002: Electrical-hydraulic relationships observed for unconsolidated sediments. Water Resources Research 38, 31-1 to 31-13.