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Geophysical mapping of aquifer properties in infrastructure projects using DCIP and MRS

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Abstract

The derivation of hydrological properties from IP results is a big research topic and target of many investigations. In contrast to just punctual information from selected drilling points, it would enable the mapping of large areas which is crucial for many applications as (e.g.,) groundwater detection and protection, for environmental purposes and for infrastructure projects. So far, the link between IP and permeability resp. hydraulic conductivity has been mainly shown in laboratory investigation. In our study we use DCIP at different field sites and compare the data with the existent hydraulic information won from slug tests or grain size analysis. We also combine DCIP with the magnetic resonance sounding (MRS) since it enables us to get the water content along the profiles and to compare MRS and DCIP with the known hydraulic properties. Our first results reveal a good comparability, depending on the site conditions. Nevertheless, the data processing and interpretation is still ongoing.

Introduction

Information about the groundwater is crucial in order to protect groundwater resources and to avoid structural and environmental problems in infrastructure projects. To determine the hydrogeological properties in an aquifer, usually drillings followed by hydraulic tests are conducted which are reliable but expensive and, in most cases, only give point-scale information. The use of geophysical methods can overcome this problem and help to minimize drillings and therefore provide continuous information while also saving resources, time and budget. It is known that the Induced Polarization (here referred to as DCIP - Direct Current resistivity and time-domain Induced Polarization) can give information about the permeability and thus about the hydraulic conductivity (Revil et al. 2012, Weller et al. 2015). In addition, MRS (Magnetic Resonance Sounding) can provide information about the water content and pore size characteristics and therewith information related to the intrinsic permeability and the hydraulic conductivity (Schirov et al. 1991). By combining both methods and use them in a two- or three-dimensional approach, a more elaborated interpretation of the underground is possible.
To evaluate these methods and to test different site scenarios, we have applied these methods to three different test sites in Sweden that were chosen based on their different geological setting and their electromagnetic noise level.

Test sites & Measurements

Test site 1 is located in the very South of Sweden (Svedala) and characterized by sandy and clayey material, with available hydraulic conductivity test data. Here, several DCIP profiles were measured using the ABEM Terrameter LS2. At this site also 10 MRS soundings were conducted with the Apsu

system (Larsen et al. 2020). The subsurface conditions of test site 2, locate close to Mariestad, consists mainly of glacial clay in varying thicknesses but also an esker structure is present. The electromagnetic noise level was higher compared to test site 1 and mainly caused by houses nearby, buried pipes, power lines and electrical fences. Several DCIP profiles and MRS soundings were performed at test site 2 with the same instrumentation. The third test site is close to Hässleholm and was chosen due to their very low noise level and their esker, sandy moraine, and postglacial sand occurrence. At this site the MRS and DCIP profiles were taken on the same profiles and the interpretation will be supported by drillings and slug tests, determining the hydrological properties along these profiles.
The data processing and inversion is done subsequently. For the DCIP data, a processing after Olsson et al 2016 (e.g., de-noising, drift correction, spike removal, etc.) was carried out before it was auto processed and hand checked to remove outliers and negative data points. The inversion was conducted based on the inversion routine from Fiandaca et al 2021 with a direct inversion for the hydraulic conductivity.
The MRS data were acquired using a steady-state acquisition scheme (Grombacher et al. 2021) and follow a stepwise processing procedure which includes despiking, Wiener filtering with remote reference noise coils, Larmor frequency estimation, and removal of power line signal. Data were subsequently inverted for water content and relaxation parameters related to grain size distribution.

Results & Discussion

In general, the DCIP data quality is good at all test sites. Depending on the expected underground material (sand, clay, esker) the resistivity changes in the different layers. The chargeability values are usually quite small at all profiles. In Figure 1, an example of an DCIP profile in Mariestad on a very clayey site can be seen. The conductivities on top are characterized by high values whereas in depth the conductivity decreases. That can be related to the clay lying above the sand moraine. The known hydraulic conductivity value from that profile (in the middle of the profile) was $2*10^{-5}$ m/s and is in good agreement with the inverted K-value ($10^{-4} – 10^{-5}$ m/s).
The MRS data reveal mostly low water content at test site 1 with some occasional higher contents at the western part. At test site 2 elevated noise was present which affected the MRS data quality considerably. At test site 3, high-quality data were acquired coincident with the DCIP data with high lateral resolution along the 4 lines.

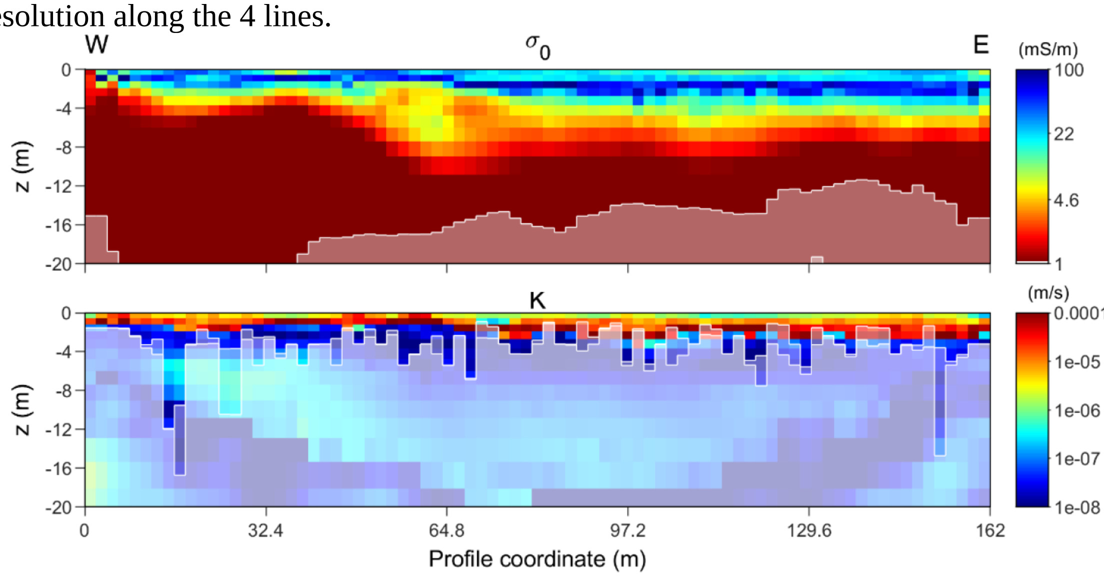

Figure 1: DCIP Inversion results for one profile at the second test site in Mariestad. The inversion is inverting for the electrical conductivity (σ_0) with a known fluid conductivity (σ_w) of 140 mS/cm.

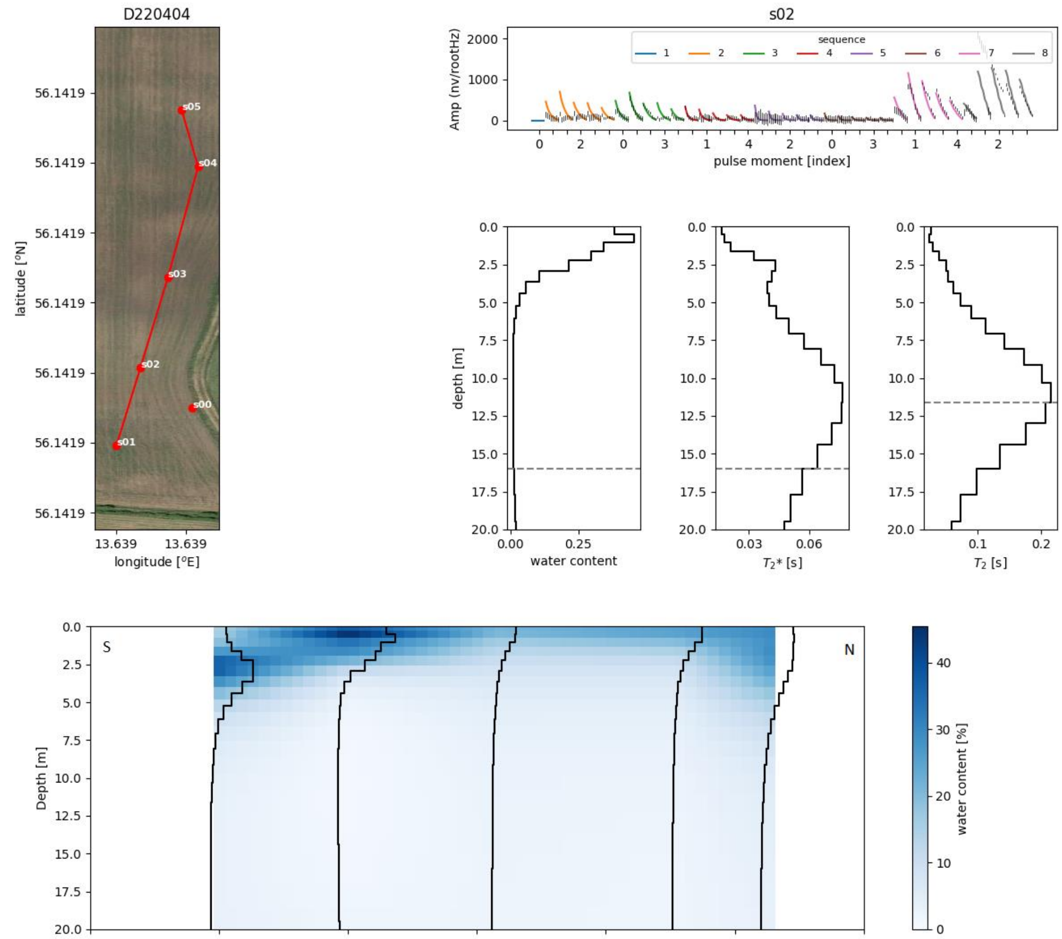

Figure 2: MRS inversion results for one line of soundings at Site 3: Hässleholm. The top left panel shows a map of the sounding centres, while the top right sets show the data fit and inverted models for site S02. Dashed line indicates a conservative depth of investigation estimation. The bottom panel shows a transect of water content from south to north along the line.

Conclusions and Outlook

So far, the DCIP measurement at all test sites shows some layered underground structure with varying resistivities. The IP signals response is quite small but for some profiles significant. The MRS data quality depends a lot on the test site. While the Mariestad site had too high noise level for accurate interpretation, at Hässleholm it provided excellent data quality and laterally varying water content levels as high as 40+% in some locations.

The first correlation of the DCIP measurements with the known hydraulic conductivity values are promising but a deeper analysis and interpretation is needed. The next steps in the project are to finalize the processing and inversion and to interpret the results from both methods. Subsequently, the data will be compared then with the available hydrogeological information based on slug or pump tests. For that, also drillings with the hydraulic profiling tool (HPT) and further slug test will be conducted. In addition, laboratory measurements are planned on samples, taken from the three test sites.

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