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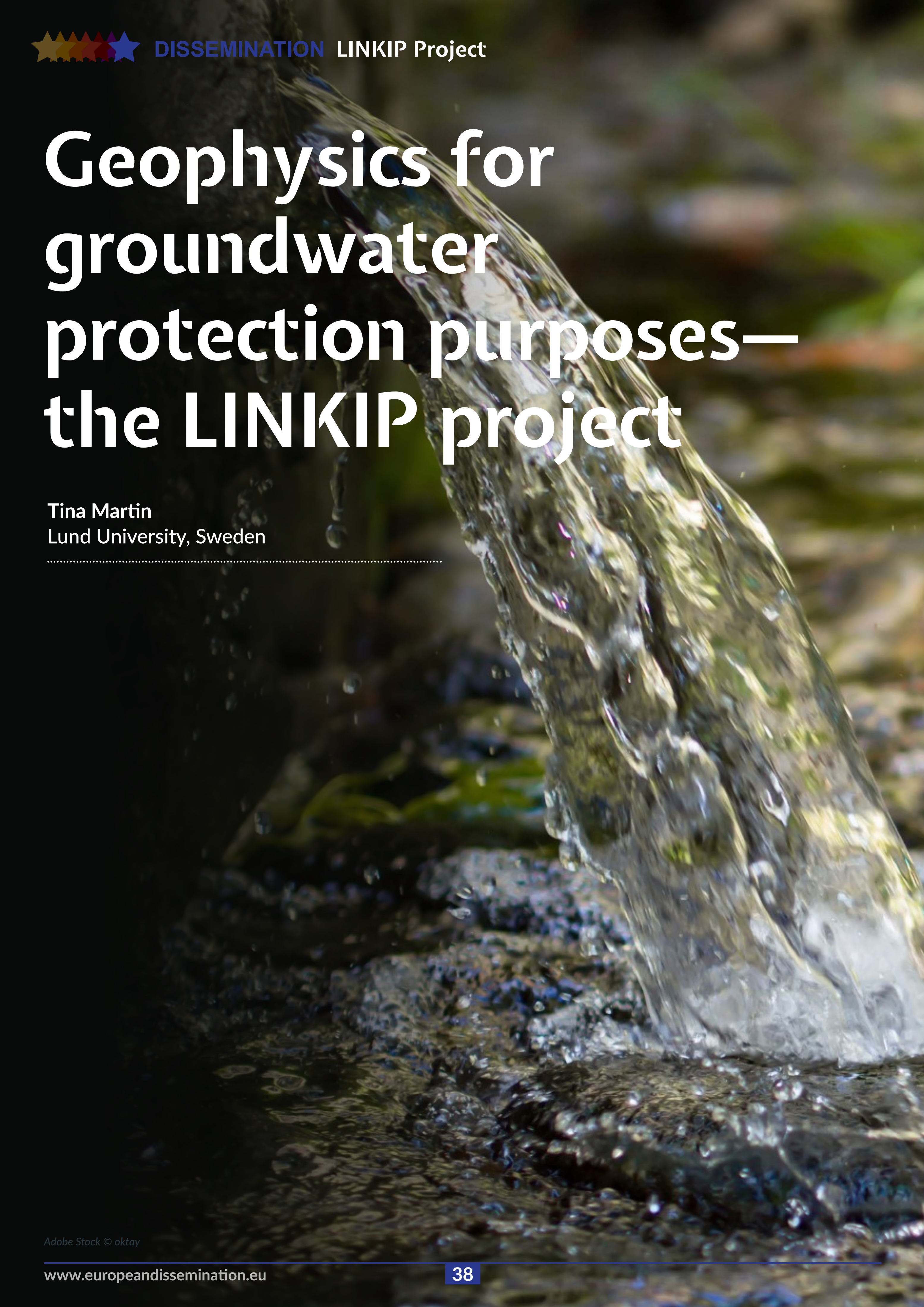

Geophysics for groundwater protection purposes—the LINKIP project

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Access to clean drinking water is a necessary requirement for life. With increasing difficulty in securing safe drinking water from surface waters, it is anticipated that the use of groundwater will increase. There are, however, several threats to the quality of this groundwater, such as the migration of pesticides and nitrates from agricultural applications into the water, waste leachates, and industrial contaminants (chemical industry, gasworks, impregnation plants, dry cleaning, etc.). To plan for protection, mapping of both groundwater resources and potential contaminant sources is needed.

Therefore, the aim of the LINKIP (**link** **i**nduced **p**olarisation) project was the improvement of the geophysical induced polarisation (IP) method to characterise the underground and to provide a better understanding of the subsurface and mapping properties which are essential for a long-term sustainable management of groundwater resources. For that, we compared the two different approaches on how to measure IP to develop more practical approaches for field data acquisition. Furthermore, we wanted to find out how to link them to hydrological parameters such as the permeability, which describes the ability of a porous material to allow water (or other fluids) to pass through it.

The IP method is an extension of the geoelectrical direct current (DC) method, where electrical current is injected into the underground, and the resulting voltage potential is gathered at different positions on the surface. By using Ohm's law and a geometrical factor (depending on the positions of the current transmission and voltage measurement), the resistivity can be calculated. That parameter quantifies how strongly a material resists electric current, and it can be used to characterise different soil and rock materials. In addition to that, IP also measures the polarisability (also called 'chargeability'), which characterises the capacitive properties of a material. By measuring both quantities (resistivity and polarisability), it is possible to get information about the spatial distribution of these quantities in the underground.

In general, IP can be measured in time domain (TD) or frequency domain (FD). In theory, time-domain data can be converted into the frequency range and vice versa. Practically, it is much more complicated due to instrumental limitations and noise from various sources such as power grid systems, railroads, etc. In the LINKIP project, we focused on the comparison between both measurement domains and the possible link to hydraulic parameters. For that, we have conducted many experiments in the laboratory and in the field.

Together with our colleagues at St. Petersburg State University, we carried out laboratory experiments where we used two different measurement instruments. One measures IP in time domain, the other one in frequency domain. The aim was to investigate differences in the data information content and to find out how they can be linked respectively and transformed into each other. For that, we first created a computed model to compare both domain measurements. This is done to see if it also works in theory. After that, we used different test circuits ('perfect samples'), which model various resistive and capacitive properties. That means that we already know what the results of the measurements should be, and we can make statements about possible differences between the expected and the measured results.

Finally, we also measured on real samples. For that, we used (inter alia) sandstone samples that are well documented from other researches. Our results show that both types of measurement, in time and frequency domain, are equivalent and reveal similar spectral 'information'. An example can be seen in Figure 1. Here, a sandstone sample was measured over a broad time (in TD) respectively frequency (in FD) range. Then, the measured spectra were fitted to a model to get a so-called *relaxation time distribution*. This distribution describes the time that the charges (e.g. the ions) need to get into equilibrium again after they were moved by the external current field. This characteristic can then give information about the material and the fluid in the material. In the example in Figure 1 it is obvious that it does not matter how we measure, we get almost identical distributions. However, we could observe that the data quality has a big impact on the comparability. The poorer the data quality, the worse the fit to the model—thereby the agreement between the measurement modes. In particular, for TD measurements, the required very good data quality is not always easy to reach, and great attention must be paid to it.

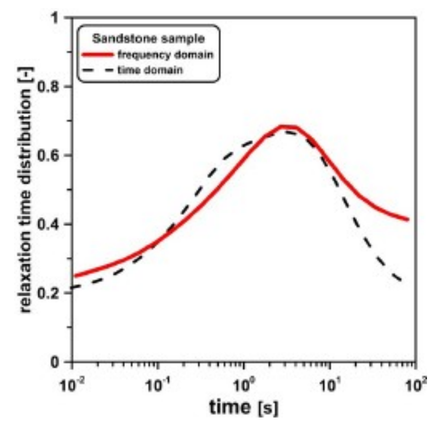


Figure 1: Example of a comparison between IP data, measured in time and frequency domain for a sandstone sample. Both relaxation time distributions are in good agreement. Differences between both curves occur often (inter alia) due to the measured data quality.

We also tested both methods in the field. In cooperation with German and Austrian colleagues, we measured at three different field sites in Sweden and Germany. Besides a comparison of the methods and instruments, we were also looking for the best settings of field measurements and for variation regarding the underground geology. So, it is generally more difficult to measure at test sites with a sandy top layer instead of a loamy layer because the first one is often drier, which leads to higher contact resistance and that complicates the current injections. Hence, this can result in worse data quality. Another point is the varying polarisability of the underground. Naturally, it is easier to measure high polarisation effects than small effects because the latter ones can be overlaid by noise and cannot be separated from the intrinsic IP signal.

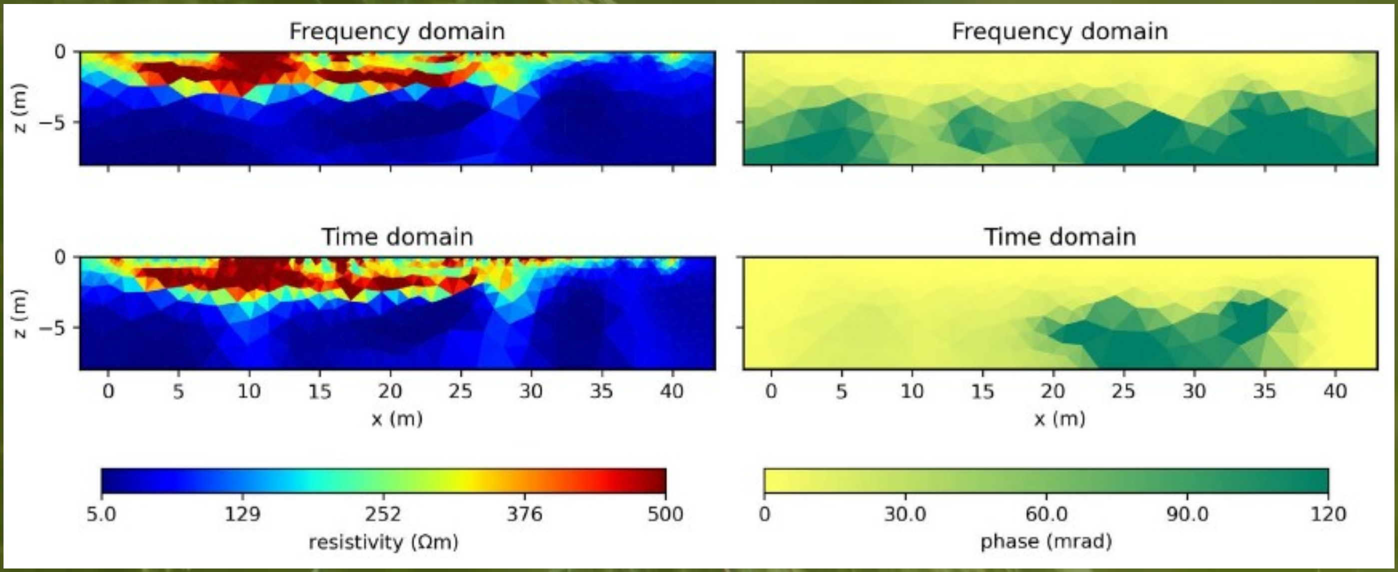


Figure 2: Comparison between IP measurements in time domain (bottom) and frequency domain (top). The resistivity (left) is almost identical whereas the phase (right) shows higher variation, in particular at the left side of the profile.

Therefore, we have chosen three different test sites with varying polarisable underground to reflect different conditions. The measurement settings also play an important role when it comes to data quality or the size of the aimed structures in the underground. For example, the use of two cables (separate cables for current transmission and voltage measurement) instead of one, can reduce noise caused by coupling inside the cables which also contaminates the IP signal. This is even more important when the expected IP signals are very small.

IP can be measured in a wide range of scales, and it is essential to know which structure, in terms of the dimensions, that is to be investigated. To establish this, often, a preliminary geological conceptual model is created based on available information. So, is it possible to measure small structures (decimetre range, for example, buried objects) but also geological layers acting as groundwater-bearing horizons (aquifers). Only if the right spacing between the electrodes for current transmission and voltage difference measurement is chosen, reliable data can be received. In general, it applies that a smaller electrode distance enables higher resolution (means to find small structures in the underground) but limits the depth of investigation (we cannot reach great depth).

The results from our three field trips show that we were able to get similar results for measurements in TD and FD when it comes to resistivity and polarisability. The phase is also a measure for the size of the polarisability and is defined as the phase shift between the current transmission and the voltage signal. In Figure 2 both results, resistivity and phase, are shown. It can be clearly seen that the resistivity results are almost identical, whereas the variation in the phase is significantly larger. The differences are more problematic when the underground provides only small polarisation effects. Furthermore, we could also observe discrepancies in the TD data

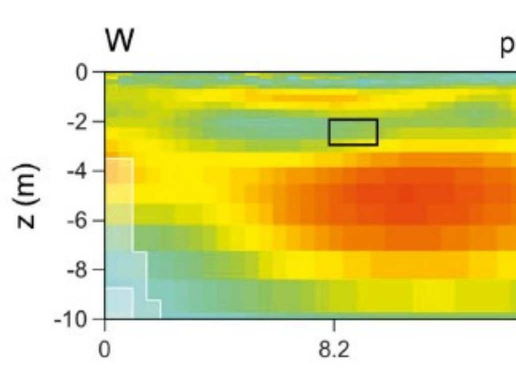


Figure 3: Calculation of the permeability from time-domain
in agreement with the IP results.

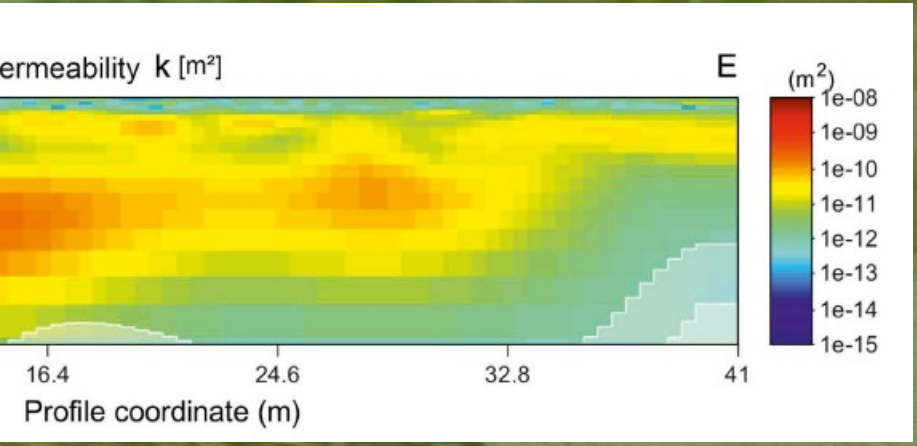
for different settings which need to be investigated further and affect an objective comparison between TD and FD in the field.

One way to clean contaminated groundwater is the use of bacteria that degrade contamination. The IP method has the potential to monitor that cleaning process in the underground from the surface since the degradation process changes the electrical properties and the bacteria themselves give rise to IP effects. Therefore, it is necessary to know the influence of the bacteria on the IP signal, which was the motivation for doing laboratory measurements with bacteria-sand mixtures at different bacteria concentrations in cooperation with the MIRACHL project at Lund University (www.mirachl.com). Our results show that bacteria have a significant influence on our IP data. An increasing bacteria concentration rises the IP signal. Nevertheless, the effects are quite small and challenging to measure in the field.

Another experiment comprised IP measurements in the field to compare the permeability which we calculated from our IP data and the permeability data which were gathered from hydraulic tests in different boreholes in that area (so-called slug tests). Together with our partners from the Hydrogeophysics Group at Aarhus University Denmark, we used the IP data measured in time domain and could show that the calculated permeability values are in the same range as the measured permeability data from the tests in the boreholes (see Figure 3).

The results suggest that instead of doing a lot of drillings and hydraulic tests in an area to get information about the water-bearing layers, which can become expensive, it can be possible to use mainly the IP method to get similar information in a faster and more cost-efficient manner. For verification purposes, that can then be supplemented by a limited number of in-situ test in boreholes, in representative points selected based on these results.

By the end of the LINKIP project, many research questions could be answered, and the results are very promising. Others still remain unanswered and new research questions and fields of applications arose. Most of all, using IP in biogeophysical issues is a new, worthwhile, and extremely exciting research field. Further on, the IP method can still make important contributions to answering current and new hydrogeological research questions in future.



IP data. Results from borehole tests (within the black rectangle) reveal values of 2*10-11 m^2 which are

PROJECT SUMMARY

LINKIP assesses how enhanced spectral resolution in geophysical IP data characterise the subsurface, for groundwater management and protection purposes, by linking IP data to groundwater properties. This can be also used for further applications, e.g. contaminations, landfill, mineral exploration.

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PROJECT LEAD

Dr Tina Martin studied geophysics at Free University Berlin and is a Marie Skłodowska-Curie fellow at Lund University, Division of Engineering Geology. Her research interests are the geophysical induced polarisation method and how it can be used in different field applications such as geological (rocks), biological (wood, trees, bacteria) and anthropogenic investigations (waste/mining dumps).

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