Design Projects - Case Studies - Detecting DNAPL Source Zones at polluted sites

Use of Design Projects GEM Cables to detect Dense Non-Aqueous Phase Liquids (DNAPL's) Source Zones at polluted sites.

Summary

Electrical Resisitivity Tomography to detect DNAPL's

This project was executed for the Netherlands Centre for Soil Quality Management and Knowledge Transfer (SKB, http://www.skbodem.nl). The project was executed by TNO the Netherlands Institute of Applied Geoscience (project leader), Grontmij Consultants, the City of Utrecht and the Province of Drenthe. The summary is based on the following project report: Goes, B.J.M., J.A.C. Meekes, P.A.A. Verhaagen, H. Booi and M. Stolzenburg (2003). Elektrische weerstandstomografie voor hetopsporen van DNAPL's. SKB-rapport SV-416 (in Dutch).

Background DNAPL pollution and aims of study

In the Netherlands, and elsewhere in industrialised areas, there are many polluted sites that contain Dense Non-Aqueous Phase Liquids (DNAPL's). Most DNAPL's contain highly toxic substances and can, when present in the soil, form a considerable threat to the public health and the environment. DNAPL's are liquids with a density higher than water and a low solubility in water.
Due to these attributes DNAPL's can spread very fast (vertically) in the subsoil. The spreading of DNAPL's usually stops at less permeable layers such as clay or loam. On these less permeable layers so called DNAPL source zones can develop. A well-known example of substances that behave as DNAPL's are chlorinated hydrocarbons.

The detection of source zones with DNAPL's is one of the major bottlenecks in dealing with polluted sites. When the location of the source zones is not known the layout of remediation or control measures can be wrong with as a possible consequence the continuing spreading of pollutants (e.g. PCE and TCE) in the groundwater. Effective mapping of the source zone of groundwater pollution with traditional 1D techniques (samples) is often financially not feasible. Recently new DNAPL detection methods as 'dynamic monitoring' and 'partitioning interwell tracer test' have been studied. In practice these methods are hardly used (in the Netherlands) due to the costs and/or the long duration of these methods. Electrical Resistivity Tomography (ERT; geo-electrical measurements between boreholes) is a new technique that has primarily been developed in the U.S.A. The technique can detect and monitor pure DNAPL's in the subsoil. The application of ERT is based on the high specific electrical resistivity of DNAPL's. The technique has not been applied in the Netherlands before this study.

The aims of the SKB project 'ERT-DNAPL' are:

To demonstrate the applicability of ERT for the detection of DNAPL's under typical Dutch circumstances by executing ERT measurements at two different test sites.

To compare ERT with other DNAPL detection methods.

To determine under which conditions ERT can successfully be applied to map DNAPL source zones.

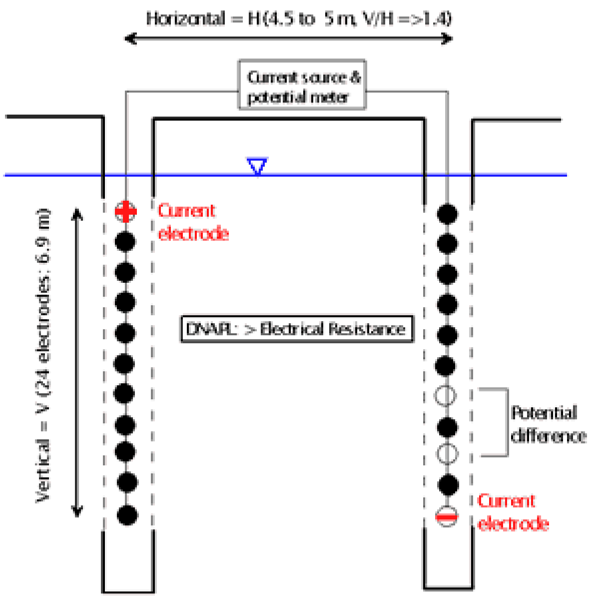
The project had been executed in 4 phases:

- literature study on ERT and modelling with various ERT measurement configurations
- apply ERT at a site in Utrecht
- apply ERT at a site in Drenthe
- compare ERT with other DNAPL detection methods

Background ERT

A geo-electrical measurement is executed by introducing a current into the ground with the aid of a battery and two current electrodes while the potential difference is being measured between two potential electrodes. ERT measurements are geo-electrical measurements between boreholes that contain multi-electrode (24) cables. The figure below presents a 2D profile (x-z) of a schematic ERT layout for the detection of DNAPL's. The figure shows two active current electrodes while at the same time the potential difference is being measured between another pair electrodes. So one ERT measurement uses 4 electrodes: 2 current- and 2 potential electrodes. An ERT measurement schedule is a list with on each line a measurement that follows a certain electrode configuration. The potential difference and the current strength can be recalculated (inverted) into the resistivity of the subsoil. The outcome is a 2D profile with the real electrical resistivity of the subsoil between two boreholes over the depth section at which the electrodes are located.

Fig. 01



Geo-electrical detection of DNAPL's is done on the basis of the increase of the specific electrical resistivity of the soil when pure DNAPL's are present. The thickness of the

DNAPL layers that need to be detected can vary from several cm's to several dm's. The DNAPL source zones are possibly located on low permeable clay layers that have a low electrical resistivity. So the clay has a kind of counter-effect on the measured electrical resistivity of the DNAPL source zone. DNAPL related groundwater pollution (e.g. PCE and TCE) will not be visible in 2D electrical resistivity images because this pollution does not, as far as known, lead to a significant change of the electrical resistivity. Degradation products of DNAPL's can lead to a local reduction in the electrical resistivity. These degradation products are namely partly ionic soluble in water.

In the main report the following attributes of ERT measurements are discussed:

The mutual distance between the electrodes of the especially for this project made tomography cables. The chosen distance is relatively small (0.30 m) in order to achieve a high resolution.

The ratio between the length of the section of the borehole that contains the electrodes (vertical=V) and the distance between the boreholes (horizontal=H). From literature, modelling and the field measurements it was concluded that this ratio should be at least ~1.4 in order to provide a good image of the electrical resistivity between the boreholes.

The mutual positions of the 5 ERT borehole at the two test sites. A trapezium shape was chosen.

The inversion or calculation method to calculate the real resistivity of the subsoil from the apparent resistivities. The two inversion methods that have been tried in this study gave strongly comparable results.

Different electrode configurations (see below)

According to the geophysical literature the 'best' measurement schedule (a list of four-electrode positions to be addressed by the resistivity meter) remains a poorly resolved problem. For this reason much attention has been paid to the comparison of various electrode configurations during the modelling exercise and the two field measurements. In the end it was concluded that three electrode configurations are useful:

The especially for this project developed 'Meekes' electrode configuration provided the best results at both field sites. In this configuration both current electrodes are positioned in such a way that the current has to flow very oblique through the plane between the boreholes. The idea behind this configuration is that the more vertical the current electrodes are positioned the stronger the current flow lines are influenced when horizontal DNAPL source zones (high electrical resistivity) are present between the boreholes.

The in case studies from literature much used 'circulating dipole-dipole' electrode configuration provided fairly good results at test site Drenthe. Still, in the middle between the boreholes the resolution clearly decreases. At test site Utrecht the results with this configuration were disappointing.

The ERT 'well log' electrode configuration. The well log ERT measurements proved to be useful for the verification of the through inversion obtained electrical resistivities from the subsoil near the borehole. The resistivities obtained with the ERT 'well log' table represent namely directly, without an inversion, the resistivity of the subsoil.

Demonstration measurements at sites Utrecht and Drenthe

The first figure below presents, for the Utrecht site, the outcome of the ERT profiles (4 out of 7) from which groundwater samples have been taken. In the ERT profiles one large and one small zone with an increased electrical resistivity have been found. Groundwater samples show that the large zone is caused by DNAPL's (PER=PCE). The smaller resistivity anomaly has a different cause; probably coarser sediment. The DNAPL is not located, as was expected beforehand, on the low permeable clay/peat layer but under this layer in a generally permeable sand layer. These data have been used to plan the layout of remediation system. The bottom figure presents a semi-3D resistivity image of all the 7 ERT planes.

Fig. 02

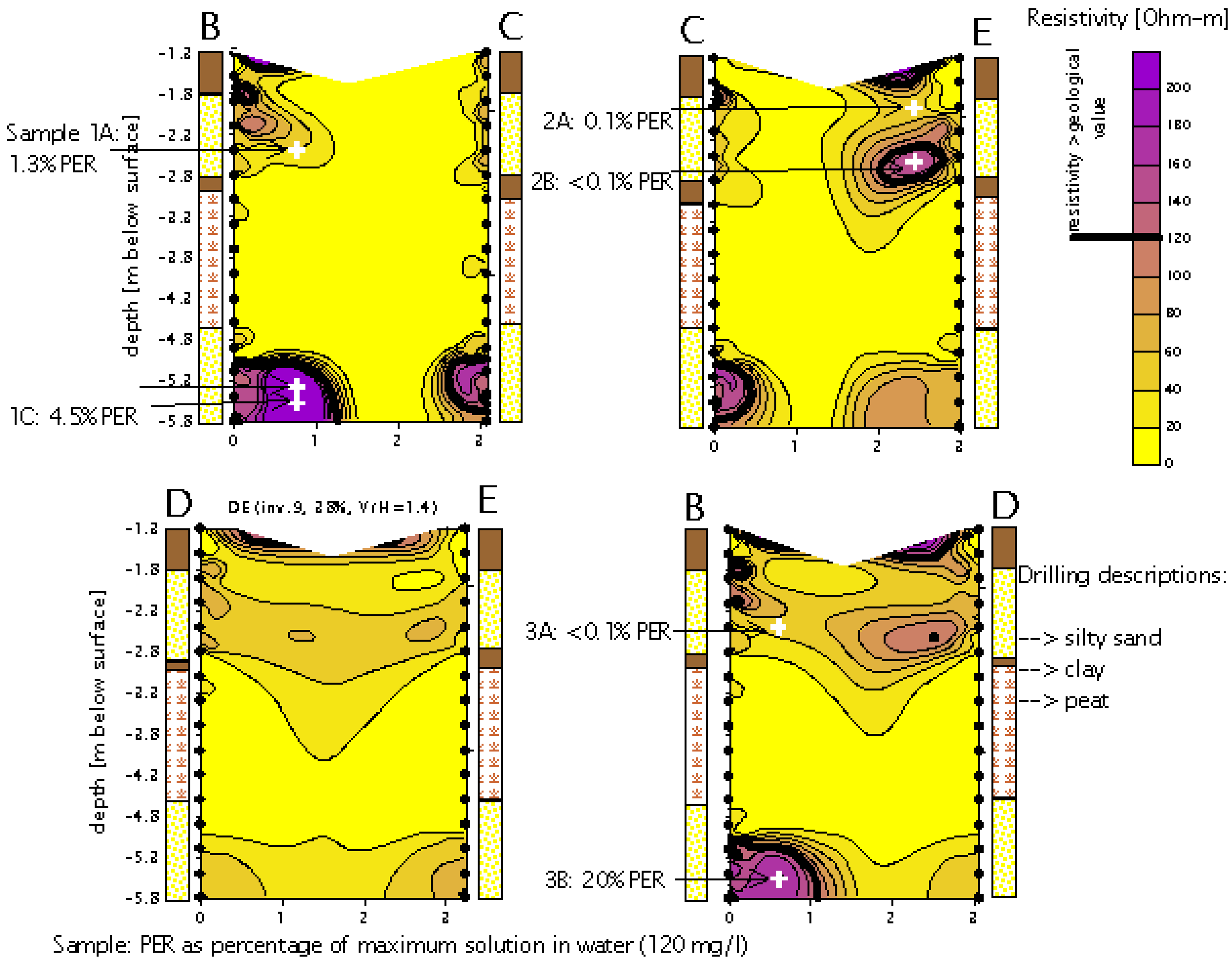
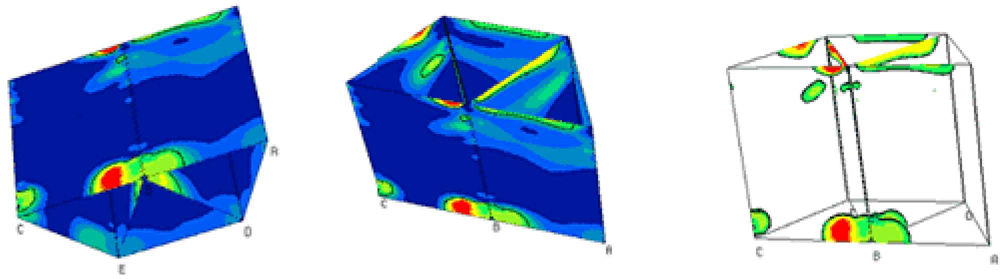


Fig. 03



The first figure below presents, for the Drenthe site, the outcome of the ERT profiles from which groundwater samples have been taken. In the shallow (2.55-9.45 m-bs) ERT profiles two large and one small zone with an increased electrical resistivity have been detected. DNAPL source zones were expected at this depth (0-10 m-bs) but the location of the source zones was unknown. All groundwater samples, including the reference samples, have high PCE (PER) percentages (15 to 166%) that indicate the proximity of DNAPL source layers. Three out of four groundwater samples with an extreme high PCE percentage (117-150%) originate from each of the three zones with an increased electrical resistivity. So these zones represent DNAPL source zones.

The sample with the highest PCE percentage (166%) is taken from half a meter below one of the high resistivity zones. Still, it is very likely that this extreme PCE groundwater pollution has been fed by the DNAPL source zone located above because of the low resistivity of the subsoil at the location of the sample. The bottom figure presents a semi-3D resistivity image of all the 7 ERT planes. The fact that higher resistivity anomalies have been observed in Drenthe (150-400 Ohm-m) than in Utrecht (120-250 Ohm-m) is in accordance with the much higher PCE saturation percentages in the groundwater at the Drenthe site (>100%) than at the Utrecht site (5-20%).

At the Drenthe site the deep ERT resistivity profiles (17.2-24.1 m-bs) do not, in contradiction to the expectation, show indications for DNAPL source zones.

Fig. 04

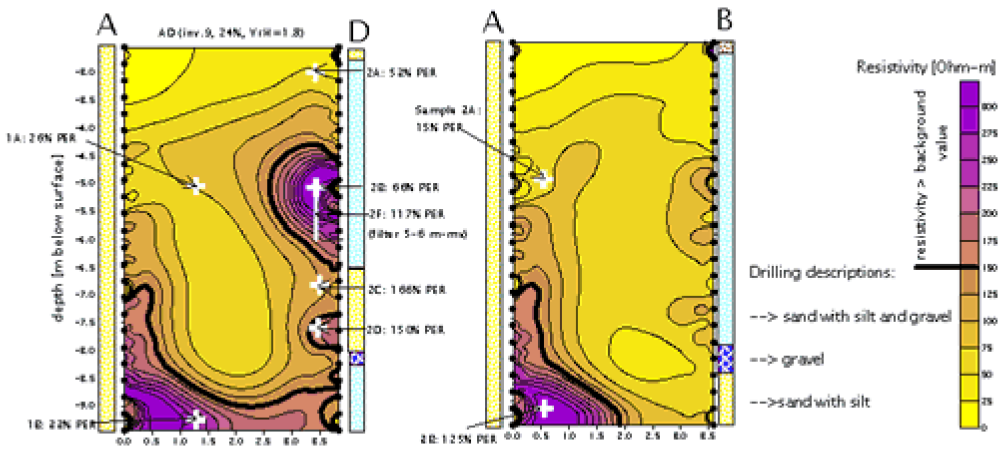
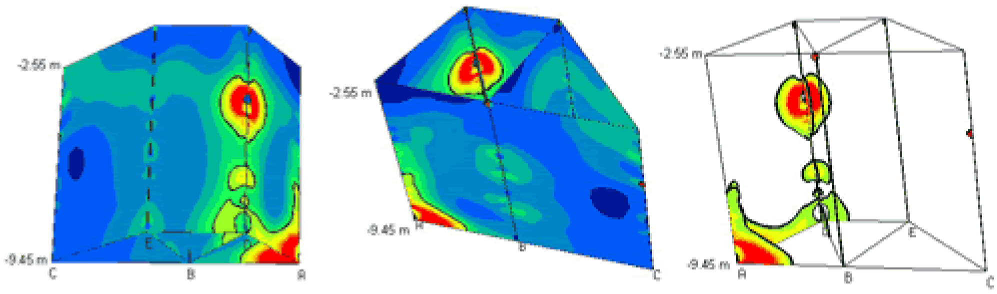


Fig 05



Conclusions and recommendations

It has been demonstrated that ERT is able to detect DNAPL's in common Dutch soil types (water saturated: sand, silt, clay, peat and sand with little bit of gravel). ERT also functions well at polluted sites with a lot of underground infrastructure (cables, pipes, concrete, cellars, etc). ERT will not perform well in detecting DNAPL's at sites with sediment that has a high electrical resistivity (e.g. gravel) or contain antropogenic objects (e.g. barrels) at the depth of the electrode cables. With a mutual electrode distance of 0.3 m the resolution varies from ~0.15 m near the boreholes to ~0.5 m in the middle between the boreholes. The outcome of the ERT measurements has proven useful for the planning of the remediation measures at both test sites.

According to the expert meeting, of the considered semi-3D techniques ERT is the only technique that has prospects to be used at a larger scale. This conclusion is based on the high spatial resolution, the relatively short measurement time and the possibility to reduce the costs of the technique. Presently, especially for a shallow pollution (< ~10 m-bs), ERT can not compete financially with traditional soil studies that have the aim to determine the rough extension of a pollution. This should also not be the target because then often the conclusion will be that ERT does not have an added value (no DNAPL's present). ERT will become interesting when it was shown in earlier studies that there is a need to remediate and that DNAPL's may be present. Comparing the costs for ERT with the achieved reduction in remediation costs can show the usefulness of ERT. The added value of ERT is especially large at sites where DNAPL's can easily spread vertically. At sites with heterogeneous subsoil, for example the Utrecht demonstration site, ERT can also have an added value.

To reduce the ERT measurement time in the field it would be useful to execute more geo-electrical measurements at the same time; this can be done with so called multi-channel measurements. With geo-electrical multi-channel measurements the potential difference is measured over several electrode pairs at the same time while current is being transmitted into the ground over another pair of electrodes.

APPENDIX 1

PICTURES OF ERT FIELDWORK UTRECHT (MARCH 2002)

Pic. 01

Pic. 02

Pic. 03

Pic. 04

APPENDIX B

PICTURES OF ERT FIELDWORK COEVORDEN, DRENTHE (JUNE 2002)

Pic. 01

Pic. 02

Pic. 03