Monitoring inland salt-water intrusion with long-electrode ERT

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INTRODUCTION

In coastal regions, but also inland, fresh water supply is threatened by saltwater intrusions. The support of water plants to ensure water supply is of main interest. As the electrical resistivity is mainly influenced by the pore fluid, it is a key parameter for detecting and monitoring saltwater. Results of 2D or 3D electromagnetic surveys or electric resistivity tomography (ERT) give insight into the lithological and hydrological properties of the subsurface. However, most methods show limited investigation depths or are cost-intensive for investigating an area in the catchment scale. As an alternative to classic multi-electrode surveys, long-electrode ERT (LE-ERT) can provide three-dimensional imaging if a sufficient amount of metal-cased boreholes is available. Hence, a cost efficient monitoring is possible as non-recurring costs appear only for the installation procedure.

As the usual point approximation of electrodes is not accurate enough, we use the complete electrode model (CEM) for numerical simulation of the electric field propagation. With this it is possible to model electrodes of arbitrary shape by including two additional equations into the finite element solution of the forward problem, (Rücker and Günther 2011). Changing contact impedances along one electrode does not change the electrical fields significantly. Sensitivity distributions reflect the change of the measured apparent resistivity, if the resistivity of the subsurface is modified. The sensitivity distributions in Figure 1 verify the fact that the patterns are shifted into deeper regions leading to a greater investigation depth caused by the electrode length. The most critical disadvantage is the loss of vertical resolution in the depth range of the boreholes and thus the information content in the near surface region. By mixing surface electrodes with long electrodes an improvement of the resolution can be achieved as shown by a synthetic study (Ronczka et al. 2013).

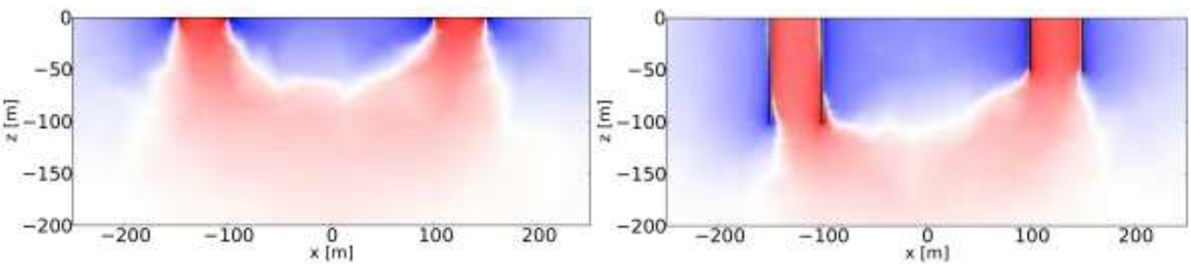

Fig. 1: Sensitivity distributions a for dipole-dipole measurements using surface (left) and long electrodes of different length (right)

TEST SITES

Measurements were conducted on two test sites in south-eastern Brandenburg. A major fault zone and glacial valleys exists that possibly enables vertical fluid transport from salt-domes to surface aquifers. Although it is not completely clear which sources and processes are dominant, a salt water intrusion is present on both locations. First test site is a medium-scale (500x500m) area near Müllrose with 13 boreholes, to which we added 6 point electrodes, and a nearly one-dimensional geological structure. The 40 m thick top layer consists of Pleistocene sands and gravels followed by an approximately 50 m thick Miocene brown coal and silt layer (Voss et al. 2013). The baseline inversion result (Figure 2) shows the main geology and agrees with 2D ERT results. The blue coloured zone indicates conductive parts at a depth of about 35 m. Fluid conductivities (see Figure 1 right side) taken from a multiply filtered ground water well show saline water at about 30 – 40 m depth. The triangle marked curve, taken from the LE-ERT inversion result, at the borehole position agrees well with the fluid samples (circle markers).

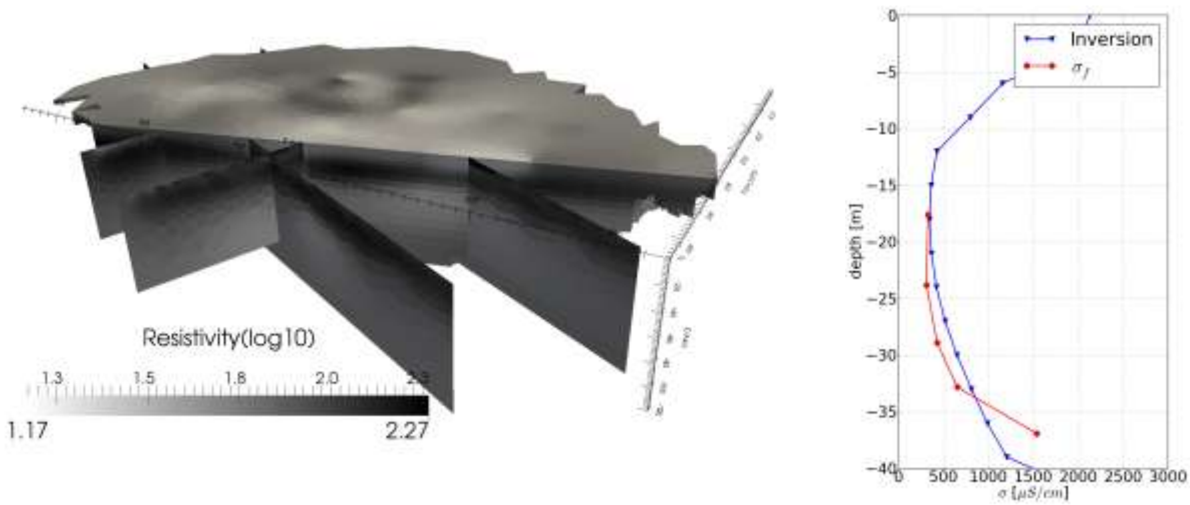

Fig. 2: 3D inversion result of test site Müllrose together with 2D ERT results (left) and measured fluid conductivities together with fluid conductivities derived from the LE-ERT result using a fitted Waxman-Smits equation.

A subsequent permanent installation on this test site allows regular monitoring measurements. As the geology remains constant, resistivity changes are only caused by changes in the pore fluid. Nevertheless, a good baseline model is needed for a successful time-lapse inversion. Four repeated measurements have been carried out within six months. Fluid conductivities were taken from different water wells for every time step. The difference of measurements in June and September is shown in Figure 3. Here, a decreasing resistivity is indicated by the mesh with edges, i.e. increasing fluid salinity and an increasing by the mesh without edges. As expected, the greatest changes can be found near the surface. Although LE-ERT is not that sensitive at shallow depth, these can be interpreted as a dry-out in the unsaturated zone. Nevertheless, interpretations concerning the near surface region had to be treated carefully. More significantly, the increasing resistivity at the bottom of the near-surface aquifer indicates that the before observed increased salinization seems to vanish slightly in time.

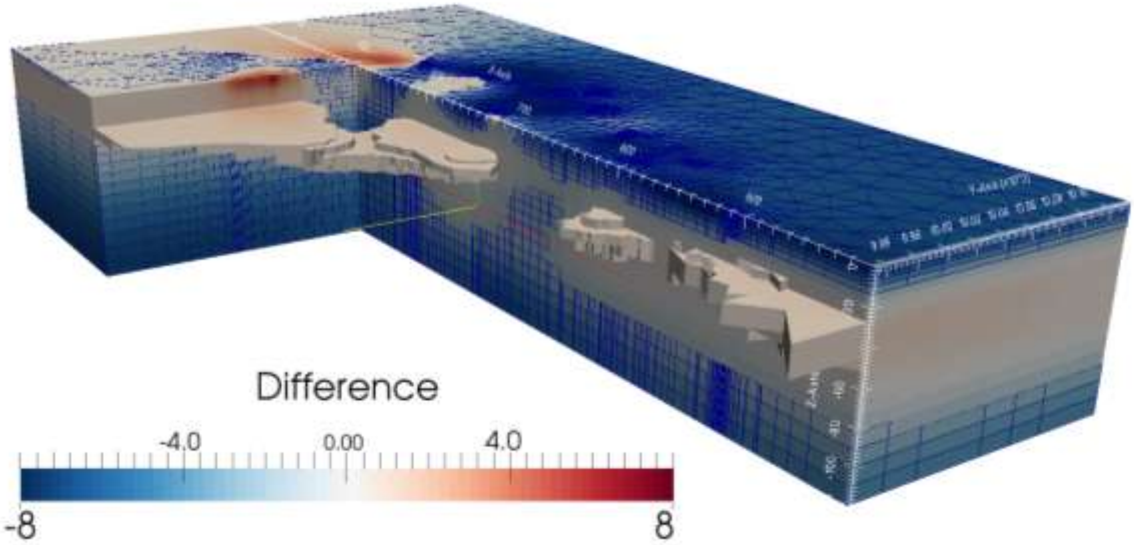

Fig. 3: Difference (in per cent) between two time steps (June and September) from monitoring measurements of the test site Müllrose. Cells with edges indicate decreasing resistivity and the cells without edges denote increasing resistivity.

The second test site (Briesen water works) is an area of 4x3km in the catchment of a water supplier where artificial recharge with river water is done. Borehole measurements lead to the conclusion that an extensive use of the water plant lead to a salt water intrusion into a shallow aquiver. Some water wells were contaminated by saltwater and had to be disabled. A two-week field campaign was conducted with a high-voltage transmitter and eight self-developed data loggers using 28 boreholes and two additional surface electrodes at regions of low coverage. Prior to the field measurements we used resolution analysis methods optimizing the survey to find out which measurements provide the best information content of the subsurface. With this optimized measurements we conducted a 3D long electrode ERT survey (LEERT) in order to locate possible saltwater intrusions. Readings from 40 current injections generated a data set of about 700 data points. A first inversion result is shown in Figure 4.

The transition to a highly conductive zone at about 200 m depth is associated with a saltwater contamination as supported by resistivity logs in several boreholes. The highly resistive layer at about 70 m depth can be seen in some borehole logs as well. As the hydrogeological situation seems to be quite complicated, a further interpretation has to be done including ground water flow information to verify where the salinization comes from and which layers are affected. Even the borehole logs are very heterogeneous in this region.

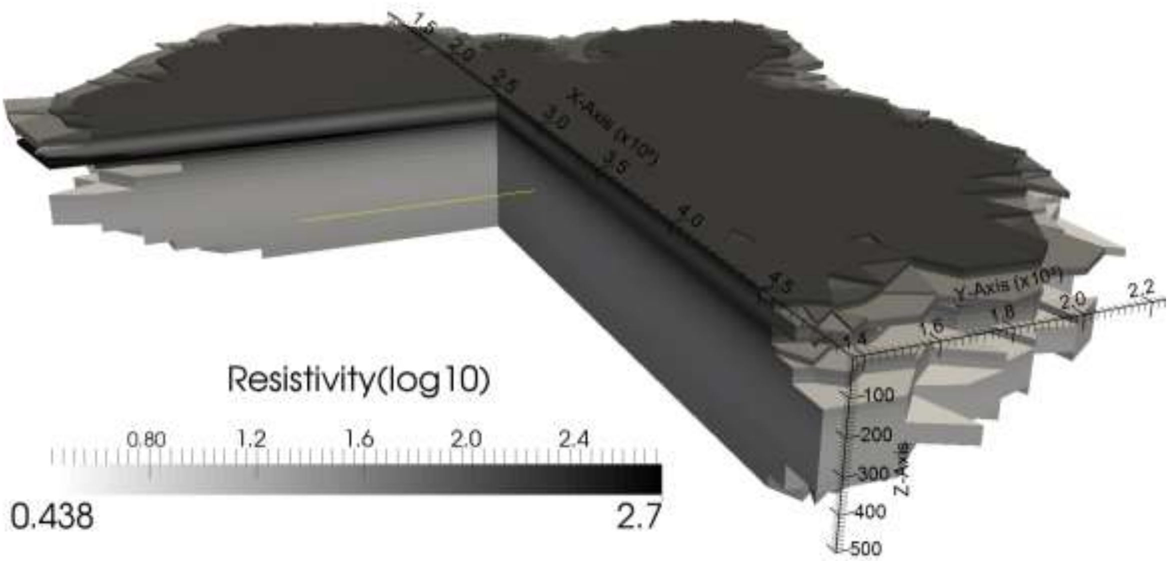

Fig. 4: Inversion result of the LE-ERT survey at the second test site (Briesen).

CONCLUSIONS

It could be shown that LE-ERT provides reasonable resistivity distributions compared to electro-logs from borehole measurements and surface ERT measurements. Furthermore, comparison with fluid samples demonstrates that salinity can be reliably retrieved. As real 3D measurements these surveys can cover large areas about several square kilometers, assuming a sufficient borehole density. Thus it represents a low-cost method for monitoring saltwater intrusion in the catchment scale.

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