Assessing The Underworld
An Integrated Performance Model of City Infrastructures
4D ERT monitoring of water pipe leakage during a controlled field experiment

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Introduction
Detecting leaking pipes and delineating the spread of leaking fluids is an important task for civil engineers dealing with vulnerable pipelines infrastructure. 3D and 4D Electrical Resistivity Tomography (ERT) allows changes in bulk resistivity at an entire subsurface volume to be mapped at high spatial and temporal resolution in a minimally invasive manner. It is therefore a promising tool to supplement conventional point measurement techniques to monitor subsurface flow processes (e.g. Rubin and Hubbard 2000).

The goal of the presented project is to assess the effectiveness and ability of ERT to detect and monitor pipe leakage, so to this, a controlled field experiment with a leaking pipe in the vicinity zone was carried out. The geophysical monitoring was validated using laser point measurements, which allowed ERT derived bulk resistivities to be related to direct measurements of changing hydrogeological properties.

Method (4D ERT)
ERT maps spatial and temporal changes in bulk resistivity. In the vicinity zone they are primarily sensitive to water content variations. Other influences include variations in temperature and in concentration of the pore fluid.

Data acquisition
The field data is sampled on a rectangular grid of buried electrodes (‘sensors’). The RES2012 (Resistivity Imaging and Solution) system was used for data acquisition. By conducting a set of measurements with varying electrode combinations the total volume below the electrode array can be interrogated. Temporal resolution is obtained by repeating an identical set of measurements several times (Kunze et al., 2016).

Data processing
The final ground resistivities are obtained indirectly through a 4D inversion process, in which the observed data are matched to those calculated for a specific subsurface electrical model. The process is constrained by assuming smooth spatial and temporal resistivity changes (software: Res2012 v. 1.09, Luke 2014)

Results and discussion

In figure 4 in the first time window after leak activation a 10% decrease in bulk resistivity already indicates an increased volumetric water content below the leak location. In the following time steps a predominately horizontal spread of decreasing resistivity values defines the emergence of the leak-fluid. Only 1.25 hours after closing the leak the volume defined by a 10% decrease varies indicating drying out. In the vertical time-slices a surprising additional resistivity increase emerges during the leakage, it might correspond to a washing out of fine clay particles from the disturbed trench refill.

Figure 5 shows that the ERT data is in very good accordance with the point measurements. The increased bulk resistivity of the post-leak state compared to pre-leak conditions opposes the increased volumetric water content. This reinforces the assumption that compositional changes of the disturbed refill took place, at depth the decrease in resistivity due to the rainfall event occurs too early compared to the BGC data. This might be caused due to the high temporal and spatial smoothing. Or might be caused due to the very low conductivity layer (infiltration) at the near surface.

ERT – Conclusions
- Leakage and wetting front development were successfully detected.
- The movement and cessation of leakage was correctly resolved within the ERT measurement sequence.
- Temperature changes after rainfall were limited (especially during rain event).
- Artificially disturbed soil washing out of the materials can significantly influence the bulk resistivity (supporting e.g. VWC measurements required in order to understand the “null probe”)
- The resistivity pattern due to rain events can be clearly distinguished from point leakage.

What next?
- Data acquisition: using optimised electrode arrays to improve image resolution.
- Processing: incorporate time of each four-point ERT measurement (instead of time per measurement well).