Saltwater Intrusion Monitoring with the SAMOS System as a Basis for Groundwater Management of Coastal Aquifers

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Summary

Saltwater intrusions are a major problem for the freshwater supply in coastal regions. The project go-CAM is part of a research initiative to develop a platform for groundwater quality assessments. The main objective of the presented study is the monitoring of the freshwater/saltwater interface with the vertical electrode chain SAMOS in the vicinity of the North Sea. The first system was installed in December 2018 near Jever in the Sandelermöns region, where ongoing chloride monitoring detected an increasing chloride concentration at 50 m depth. ERT and HEM surveys provide an overview about the resistivity distribution in the investigated region and are used to find other SAMOS locations. The data are influenced by the drilling process indicating that the equilibrium is still not reached after four months of monitoring. An inversion procedure separates drilling effects from undisturbed conditions. First results show that the transition zone towards saline groundwater starts at approximately 40 m depth and reaches a minimum resistivity of 25 Ωm at 50 m depth.
Introduction

A major problem for the freshwater supply of coastal regions is the intrusion of seawater into aquifers, which is a natural process (e.g., Michael et al. 2017). Due to extensive extraction of freshwater to suffice increasing drinking water demands and/or periods of reduced groundwater recharge, the equilibrium state is disturbed. The result is a movement of the fresh-saline groundwater interface towards inland, which reduces local drinking water resources at coastal regions or islands. Observing the transition zone between freshwater and saltwater is often difficult as common sensors for chloride monitoring provide only point information. A solution is given by the geoelectrical monitoring system SAMOS, which is a vertical electrode chain that is installed in an open borehole (no casing), which is filled afterwards. Meaning that the electrode part cannot be removed anymore and is thus lost, once installed. A prototype of this system has proven to be a reliable monitoring system in coastal regions (Grinat et al. 2018). In cooperation with the water supply company OOWV and Solexperts (Switzerland), a new SAMOS version was developed and installed on a test site near Jever in northern Germany. First inversion results of single timesteps could image the fresh-saline transitions zone.

Method

The currently used SAMOS consists of an electrode part with 80 ring electrodes and 11 temperature sensors. Every ring electrode has a diameter of $d = 5$ cm and a height of $h = 2$ cm. With an electrode spacing of 25 cm, it is possible to monitor along a 20 m depth interval. However, it is possible to either increase the number of electrodes or to increase the electrode spacing to monitor thicker targets. The installation at the surface mainly consists of a “4point light 10 W” (LGM Lippmann) and a solar panel to recharge the battery used for power supply.

The general approach to find the correct SAMOS position is to combine geological information, airborne electromagnetic surveys (HEM) and surface electrical resistivity tomography (ERT) measurements. The final depth localization prior to the installation is done by borehole geophysics (electro log, gamma ray and NMR logs). The test area where the two SAMOS systems are to be installed is within the Sandelermöns region of the go-CAM project in northern Germany near Jever. The whole region is covered by a HEM survey that was conducted in 2015 in the project D-AERO (Siemon et al. 2018). According to chloride monitoring data provided by the local water supply company (OOWV), a site near the Ems-Jade canal was chosen for the first SAMOS location. Parts of several HEM flight lines have been inverted and re-interpreted to get an overview about the electrical resistivity distribution in the area and as a basis for planning the ERT survey. Results from both data sets (HEM and ERT) are shown in Figure 1 along with a location map.

![Figure 1](image_url)
The resistivity distribution in Figure 1 shows a decreasing trend towards south and east. ERT Profile 1 and the flight line Tie 12 are partly intersecting and cross the chloride monitoring position at about $x = 150$ m (white dot in Figure 1 right). The more detailed view in Figure 2 shows a transition zone from $300 \, \Omega m$ down to $15 \, \Omega m$ between 30 m and 50 m depth. The monitoring sensor at 50 m depth indicates an increasing chloride concentration during the last years.

![Figure 2](image2.png)

*Figure 2 Detailed view on the inversion result of ERT profile 1 (top) and HEM Tie 12 (bottom).*

However, the freshwater aquifer with resistivities up to $300 \, \Omega m$ between 5 m and 30 m depth gets thinner towards along $x$ direction (east) and vanishes at $x \approx 900$ m. The increased chloride concentration at 50 m depth lead to the decision that the first SAMOS system was installed at the marked position at $x = 150$ m and in the depth range of $35 \, m - 55 \, m$ directly on top of a clay layer. The dashed line at $x \approx 850$ m marks another possible SAMOS location. Currently, the monitoring is running with one measurement per day using a Wenner-α (1027 data points) and a dipole-dipole (2141 data points) array. The first four separations $a = [0.25, 0.5, 0.75, 1]$ m for a Wenner-α configuration are shown in Figure 3 together with the geologic information obtained from the drilling.

![Figure 3](image3.png)

*Figure 3 ERT raw data of the SAMOS system for the first four separations with $a = [0.25, 0.5, 0.75, 1]$ m for the Wenner-α configuration together with geologic information. Points at the same depth represent measurements at different times from grey (installation) to black ($x$ months later).*
The first separation in Figure 3 (left) shows large resistivity variations because it is mostly influenced by the drilling process. As the investigation depth radial to the borehole increases with the separation “a”, the effect due to the drilling and the decreasing resistivity trend down to \( z = -50 \) m becomes clear. For data inversion, we generated a cylinder-symmetrical finite element mesh because the electrodes are placed in a full-space. To achieve that, we set the same marker to all cells within a depth slice, so that only one parameter (i.e. resistivity) is assigned to that slice. To account for resistivity variations radial to the electrode chain, several vertical cylindrical slices with increasing radii were merged, keeping the cell marker (inversion region) homogeneous within every vertical slice. The mesh is shown in Figure 4 (left). Ring electrodes were incorporated using CEM (Complete Electrode Model) after Rücker & Günther (2011). It allows arbitrary electrode shapes, which is necessary because the electrode chain is an electrical insulator and therefore included as a hole-cylinder.

The inversion is done with pyGIMLi/pyBERT packages for Python (Rücker et al. 2017). Figure 4 (right) shows an inversion result for a Wenner-\( \alpha \) data. The resistivity distribution indicates freshwater with about 125 \( \Omega \)m down to 40 m depth, which decreases to 25 \( \Omega \)m at 55 m depth where an increased chloride concentration is known. Quite significant resistivity changes appear near the borehole, which can also be seen in the raw data (Figure 3 left) and is caused by the drilling process. The low resistivity near the borehole at 44 m depth arises from a clay layer, which was confirmed by borehole geophysics. However, the inversion result as well as the raw data cannot resolve this layer for larger distances from the borehole. It has to be noted that thin structures perpendicular to a resistivity measurement can only be poorly resolved. Nevertheless, we assume that the clay lens has a very small lateral extension, because it does not appear in lithological logs of a borehole approx. 10 m afar.

**Conclusions**

We successfully installed a SAMOS system in December 2018 for monitoring the fresh-saline groundwater interface at a test site near Jever in northern Germany. To find the best monitoring location, we used geologic information, HEM and surface ERT surveys. The depth interval for the final SAMOS positioning should be set according to borehole geophysical logging. However, we could save the
borehole logging as chloride monitoring was already running at our test site. The raw data are still influenced by the drilling process. Thus, resistivity changes occur that show the way back to equilibrium. The data inversion by pyGIMLi/pyBERT could image the transition zone between freshwater and saltwater. Larger resistivity variations and some compensation artefacts near the electrode chain indicate that disturbed part can be separated from the undisturbed by the inversion. Hence, it is not necessary to wait with the data interpretation for the equilibrium state after drilling.

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References


