Groundwater salinity patterns at the land-ocean boundary of the Netherlands

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INTRODUCTION

Understanding the land-ocean boundary of coastal aquifers is of key importance to investigate submarine groundwater discharge and salt water intrusion. The characterization and specification of boundary conditions at the coast is also a critical step in constructing groundwater flow models. While many previous studies have significantly improved our understanding of the land-ocean boundary of unconfined aquifers, relatively few studies have focused on confined systems. For confined aquifers, the land-ocean boundary essentially differs from a phreatic aquifer, as fresh groundwater flow continues below the seabed instead of terminating at the shore (Figure 1).

Because direct observation in the offshore more difficult, more expensive and considered less relevant compared to onshore investigations, much less is known about the interaction between groundwater and coastal waters in confined systems than in unconfined systems. In particular, relatively little documented cases of these systems have been described in literature.

The objective of our study was to expand the number of documented cases of confined aquifer systems with data from the Netherlands. We have investigated groundwater salinity patterns at the land-ocean boundary along the North Sea coast using electrical resistivity cone penetration test (ER-CPT) measurements. With this method, a probe with a conical tip is pushed into the ground which measures penetration resistance, friction, pore water pressure and the electrical resistivity of the subsurface. In this paper, we illustrate two ER-CPT measurements that were taken in the intertidal area.

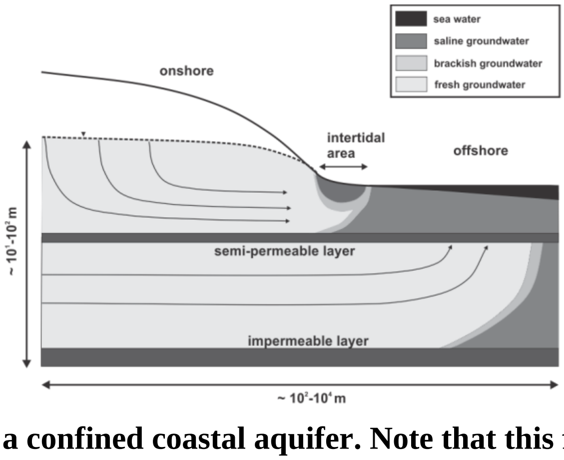

Figure 1. Concept of a confined coastal aquifer. Note that this figure is not at scale and that the freshwater tongue may extend much further below the seabed.

METHODS

During an electrical resistivity cone penetration test (ER-CPT), a 3.6 – 4.4 cm diameter probe is pushed into the subsurface by a heavy truck (Figure 2). The tip of the probe consists of a cone where the cone resistance (*qc*) is measured. Just after the cone, at the sides of the probe, the sleeve friction (*fs*) is measured. The ratio of *qc* and *fs*, the friction ratio (R_f), is often used to in combination with *qc* to estimate the lithology:

(1) $$R_f = \frac{fs}{qc} \cdot 100\%$$

High values of R_f in combination with low values of *qc* indicate fine grained and clayey materials, whereas the opposite combination is characteristic for sands (Lunne, 1997). In addition to the cone resistance and the sleeve friction, the pore water pressure (*u*) can be measured. In low-permeable sediments *u* is usually different than in aquifers. More detailed information about the measurement of *qc*, *fs* and *u*, including soil classification based upon these data, can be found in Lunne (1997).

Within a few decimeters from the cone, the electrical resistivity of the subsurface (ρ_s) is measured using two or four electrodes. In clay-free sediments, ρ_s can be related to the electrical resistivity of the fluid (ρ_f) using Archie's Law (Archie, 1942). ρ_f can be used to estimate the salinity.

Figure 2. ER-CPT measurement in the intertidal area.

RESULTS

Figure 3 shows the results of two ER-CPTs. 73H was taken in the higher part of the intertidal area. The *Rf* and *u* values indicate multiple low-permeable layers. The ρ_s values indicate that fresh groundwater is present until -40 m mean sea level (msl). 71H was taken in the lower part of the intertidal area (i.e., below msl). Here, the *Rf* and *u* values also indicate multiple low-permeable layers. The ρ_s values indicate that from the surface to -17 m msl, the groundwater is saline to brackish. Fresh groundwater is present between -17 to -30 m msl, and is likely confined by a low-permeable layer. Below -30 m msl the groundwater salinity increases again.

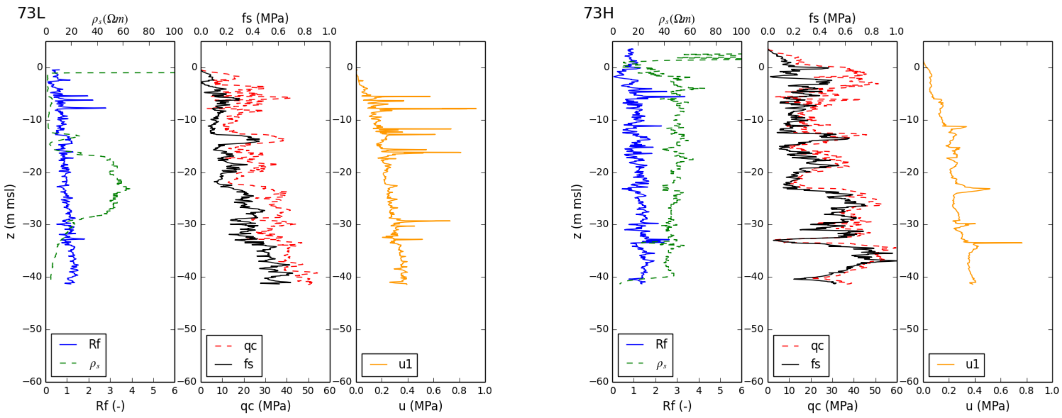

Figure 3: ER-CPT measurements in the intertidal area near Zandvoort.

These observations illustrate the complex heterogeneity and salinity patterns below the intertidal area near Zandvoort aan Zee, which raises questions about the governing groundwater flow processes but also gives valuable information for constructing a groundwater flow model. The section of fresh groundwater indicated in 73L may be part of an offshore discharge component of the fresh coastal dune groundwater flow system, or paleowater (i.e., not the result of the current hydrological boundary conditions). In all other ER-CPT measurements that were taken along the coast of the Netherlands in this study (not shown here), we observed a fresh water tongue in the lower part of the intertidal area. This suggests that in similar heterogeneous aquifer systems, fresh water tongues extending some distance below the seabed are rule rather than exception.

REFERENCES

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