Spatial variation of shallow rainwater lenses on top of saline groundwater: merging model and monitoring results

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ABSTRACT

A sequence of transgressions in the Holocene resulted in a salt to brackish groundwater system in the province of Zeeland, The Netherlands. Saline groundwater with chloride concentration exceeding 10000 mg/l is found within five meters below ground level. Upward seepage of this saline groundwater leads to salinization of surface waters. Fresh groundwater in the region is only present in the form of so-called rainwater lenses floating on top of the denser saline groundwater. These rainwater lenses prevent upward seeping saline groundwater to reach the root zone and make the cultivation of crops possible. Field measurements show a large spatial variation of the characteristics of these lenses (De Louw *et al.*, 2008). We selected a small area with a large gradient concerning the thickness of the rainwater lens to set up a numerical 3D variable density groundwater model. With this detailed groundwater model we tried to reproduce our field measurements and carried out a brief sensitivity analysis.

INTRODUCTION

The study area with a surface area of about 1 km^2 is situated on the Island of Schouwen-Duivenland in the southwest of Zeeland (Figure 1). The area can be divided into two geomorphic distinct units: 1) fossil creek ridge (sand area) and 2) reclaimed salt marsh (clay area). The fossil creek ridge consists of sand and its ground level is situated about 0.5 to 2 meters higher than the reclaimed salt marsh. The upper 3 meter of the reclaimed salt marsh consists of the low permeable sediments clay and peat. The area is in agricultural use and is drained with subsurface drains and ditches.

METHODS

To map the spatial distribution of the thickness of the rainwater lens, we used the following field techniques:

- TEC-probe
- EM31
- CVES
- Groundwater sampling

The TEC probe was used to measure the bulk (soil and water) electrical conductivity (EC) below the groundwater level at 10 cm interval down to a depth of 4.0 m. CVES (Continuous Vertical Electrical Soundings) was carried out along a profile (see Figure 1) which both includes the lower clay and higher sand area. With CVES it was possible to obtain data about the electrical resistivity, and therefore about the salt distribution, down to a depth of 20 meter. EM31 was very useful to get more spatial data about the resistivity of the upper 6 meter for a larger area (Figure 1). At different locations (Figure 1) in the clay and sand area, we sampled groundwater for EC-measurements at different depths (1.0m, 1.3m, 1.6m, 2.0m, 3.0m and 4.0m) (Vermue *et al.*, 2010).

We modeled the spatial variation of the rainwater lens in three dimensions with the variable-density groundwater flow and coupled solute transport model code MOCDENS3D (Oude Essink, 2001). The model area was divided into 202x158 model cells of 5x5 m in xy-direction and 41 layers of 0.3 to 5 m in z-direction. The period of 1990-2010 was simulated with stress periods of 10 days. Recharge was calculated from precipitation and evapotranspiration data from a nearby meteorological station.

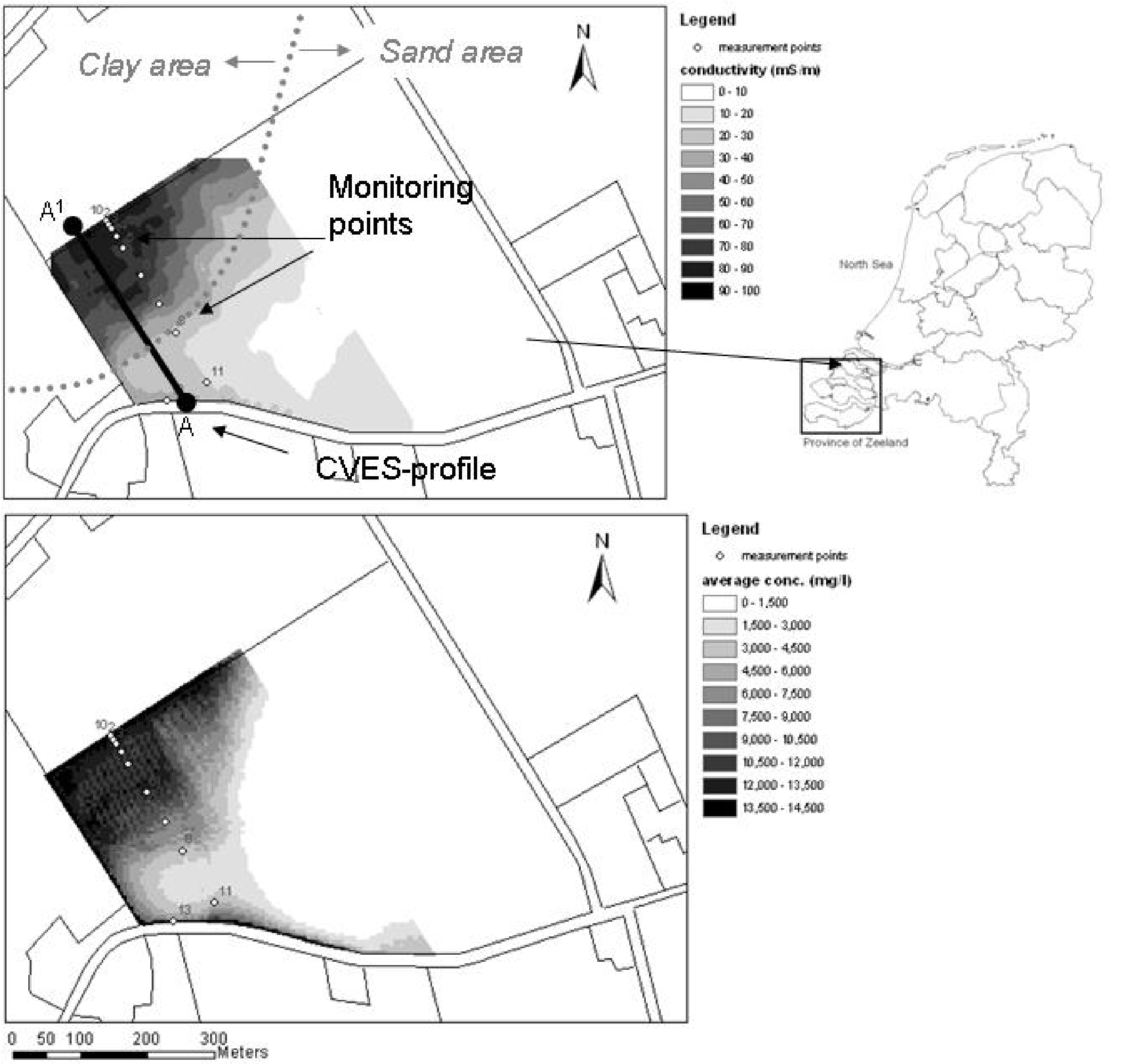

Figure 1. EM31-conductivity values for the upper 6m (top). Modeled average chloride concentration of the upper 6m (bottom). CVES-line and monitoring point are indicated in the top-picture.

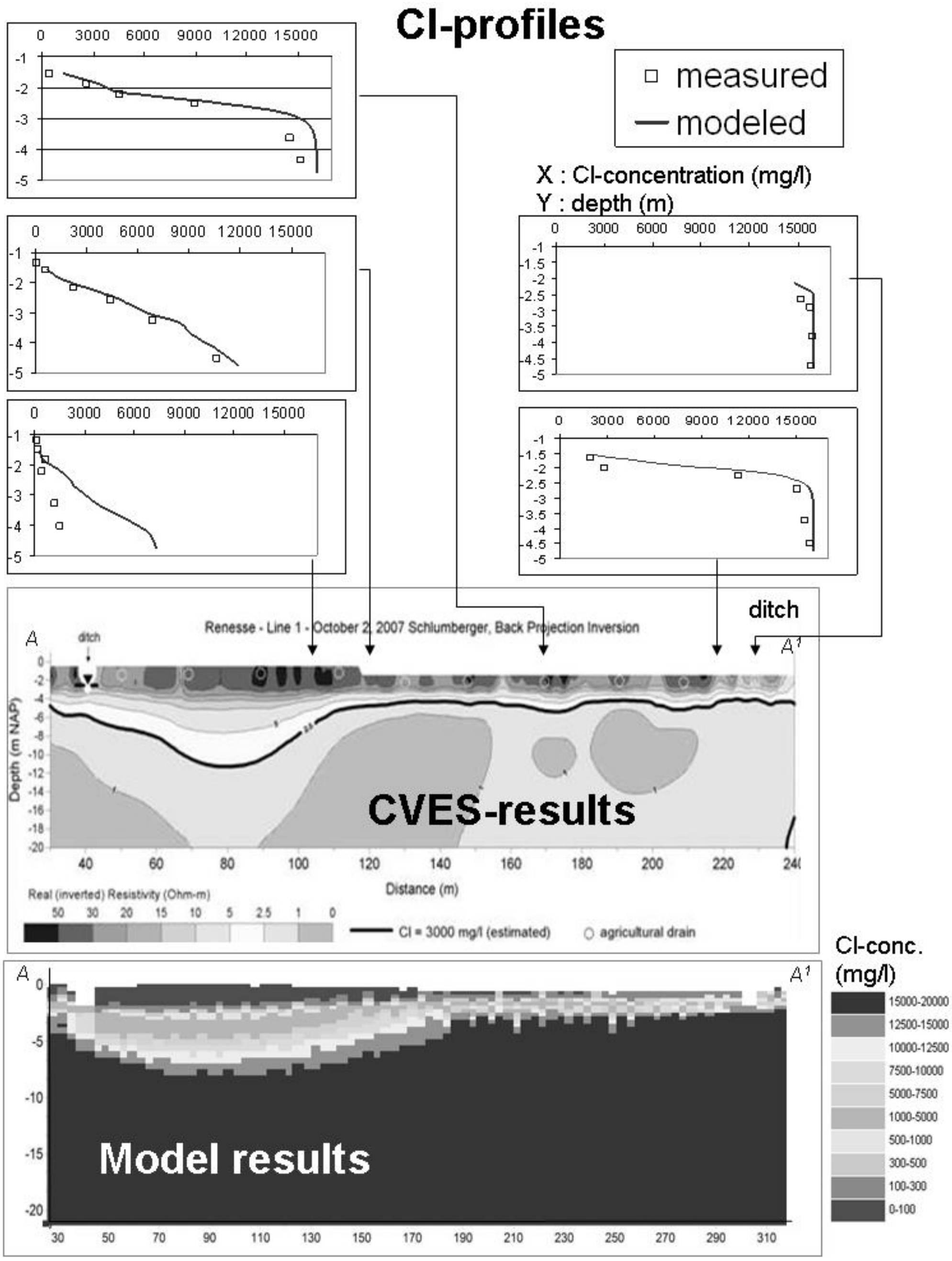

Figure 2. Top: Modeled and observed chloride profiles. Center: CVES-results in cross-section A-A[1] (from De louw *et al.*, 2008). Bottom: Modeled chloride concentration in cross-section A-A[1].

RESULTS

Comparing field data with model results

Figure 2 shows the observed and simulated chloride distribution of groundwater for the upper 4 meter at different locations. The modelled chloride profiles for the clay area correspond well with the monitoring results. A relatively constant salt profile is found for depths > 2.0m with chloride concentration of about 16000 mg/l. Saline seepage is mixed with fresh rainwater in the upper 2 meter of the soil and the observed mixing zone is modelled well (Figure 2). In the direction of the sandy fossil creek, the rainwater lens becomes much thicker. When comparing the CVES-results with the modelling results, it can be seen from figure 2 that the shape and thickness of the rainwater lens of the sand area is well simulated could be simulated well. The thick rainwater lens (3 to 10 meter) at the higher situated sand area is caused by the absence of seepage. Therefore rainwater lenses are able to develop to greater depth, similar to fresh water lenses in the dune area. The spatial EM31-data correspond nicely with the modelled average chloride concentration of the upper 6 m (Figure 1).

Sensitivity analysis

A brief sensitivity analysis was carried out with the constructed 3D-density dependent groundwater model. The results show that the drainage characteristics drainage level and resistance are the most important factors which control the thickness of the rainwater lens in the clay area. More detailed results of the sensitivity analysis will be shown at our poster during the SWIM2010.

CONCLUSIONS

We used different field techniques and a density dependent groundwater model to increase our knowledge about the spatial variation of rainwater lenses in areas with shallow saline groundwater. We were able to reproduce our field data concerning the spatial variation of the rainwater lens and the detailed chloride distribution in the mixing zone with a numerical density dependent groundwater model.

Acknowledgement: We would like to thank Esther van Baaren (Deltares), Jarno Verkaik (Deltares) and Paul Schot (UU) for their contribution to the modeling activities and Sara Eeman (WUR), Esther Vermue (WUR) and Bart Goes for their help with the monitoring campaign.

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