Characterization of Local Rainwater Lenses in Agricultural Areas with Upward Saline Seepage: Monitoring Results

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INTRODUCTION

Saline groundwater with chloride concentration exceeding 5000 mg/l is found within five metres below surface level in the southwest of the Netherlands in the province of Zeeland. Upward flowing of this saline groundwater leads to salinization of the surface water and in some cases salinization of the root zone. Infiltrating rainwater forms fresh to brackish water lenses which facilitates agriculture in these areas. Shape, thickness and dynamics of these lenses are determined by seepage velocities, water management (e.g. surface water levels and drainage system) and precipitation surplus. To designate potential risk areas for future salinization with respect to change of water management, climate change and sea level rise, a monitoring campaign and numerical variable density modeling were carried out. Some of the monitoring results are presented in this paper.

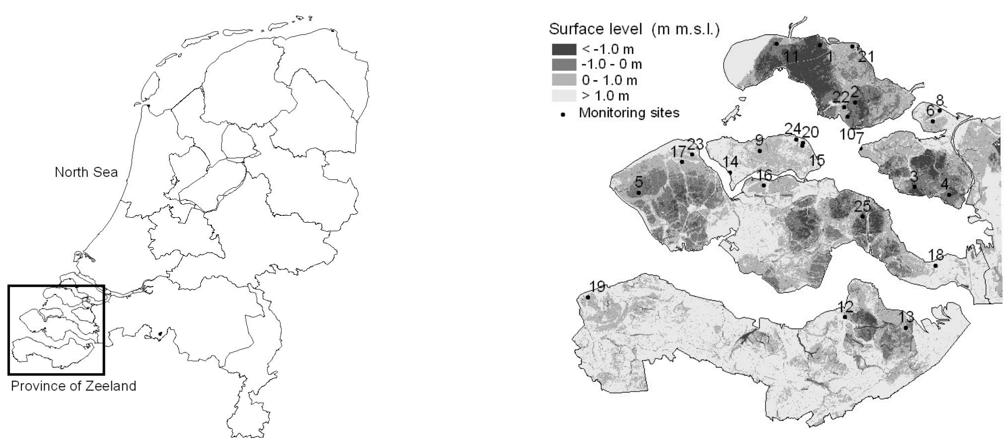

Figure 1. The surface level of the province of Zeeland relative to mean sea level and the location of the 25 monitoring sites

SITE DESCRIPTION

Several transgressions occurred during the Holocene in the province of Zeeland. During these events, seawater could infiltrate and salinize the underlying aquifers. The province of Zeeland can roughly be divided in two different areas, the so-called ‘old’ and ‘new’ land, which relate to the period of reclamation. The ‘old’ land has experienced land subsidence during a longer period and is therefore situated down to two metres below sea level, whereas the ‘new’ land is situated mainly above sea level (Figure 1). Surface water levels are maintained at about 0.5 to 3.0 m below sea level. Groundwater seepage from the first aquifer takes place into almost all ditches and in the ‘old’ land also in the parcels between the ditches. In about 70% of the province the brackish-salt interface is found within five metres depth.

METHODS

The monitoring campaign was carried out using a T-EC probe and CVES to measure the salt distribution in the shallow subsoil at 25 different agricultural parcels (Figure 1). A typical agricultural parcel in Zeeland is drained by ditches (ditch distance of 50 to 200 m) and drain tubes at about 1 m below the surface. The field measurements were carried out from ditch to ditch between the drain tubes.

T-EC probe

The T-EC probe is constructed for the 1D in-situ measurement of temperature and electrical conductivity of soft soils like peat and clayey soils. In the ditch and at different distances from the ditch the T-EC probe was used to measure the temperature and the bulk (soil and water) electrical conductivity (EC) below the groundwater level at 10 cm interval down to a depth of 4.0 m. Detailed soil descriptions were carried out for estimation of the Formation Factor which is needed to convert the bulk-EC into the EC of the groundwater. Chemical analyses on local groundwater samples showed that chloride is the dominant anion and that EC-values could be converted into Cl-concentration using an established empirical EC-Cl relation.

CVES

2D geo-electrical measurements, or Continuous Vertical Electrical Soundings (CVES), have been carried along several profiles at eight agricultural sites to map the spatial variation of thin fresh/brackish water lenses within a parcel. The CVES measurements have been done with an AbemSAS4000 connected to four multi-electrode cables with an electrode spacing of 1 m. The measured electrical resistivity data have been recalculated (inverted) into real soil resistivities with a computer program (SensInv2D). Based on an empirical relation it is estimated that a water resistivity of 1.2 Ohm-m corresponds with a chloride concentration of ~3000 mg/l. Given a dominant soil type of clayey sand (Formation Factor 2.5), a water saturated soil resistivity of ~2.5 Ohm-m represents a chloride concentration of ~3000 mg/l.

RESULTS

T-EC probe measurements

Eeman et. al. (2008) characterized the shape of modeled rainwater lenses using spatial moments of chloride concentration change with depth, where the centre of mass (1^{st} moment) indicates the centre, the variance (2^{th} moment) the width and the skewness (3^{th} moment) the symmetry of the transition zone. However, the measured chloride profiles show a S-shaped curve (figure 2) and the measurements show too much variation to apply the statistical moments method. Therefore comparable characteristics are used which are determined graphically as shown in figure 2. Parameter *b* represents the depth of the centre of the transition zone where salt change with depth is at its maximum and *c* is the corresponding chloride concentration. The distance from this point to the depth where the chloride concentration (*e*) becomes more or less constant is characterized by parameter *d* and it represents the width of the lower half transition zone. At almost all surveyed sites chloride concentrations of the groundwater at phreatic level (parameter *a*) has significantly higher values than fresh rainwater. This implies that the top of the transition zone is located in the unsaturated zone and could not be determined with the T-EC probe that can only be applied in the saturated zone.

For 15 of the 25 sites an S-shaped chloride profile (figure 2) was found and the characteristics of the rainwater lens could be determined (table 1). In general, the measurements at relatively saline sites show a wider transition zone with its centre at shallower depth. These sites are situated in the lowest parts of Zeeland, in the 'old land' with highest seepage rates. At the other sites not mentioned in table 1, no salt groundwater was found and showed a relatively fresh profile (average Cl of 400 mg/l) with only slightly increasing salt content with depth. These sites are all located in the higher parts of Zeeland where no seepage or little seepage into the parcel takes place. However, seepage of saline groundwater into ditches happens almost everywhere (figure 2) because surface water levels are maintained at 0.5m below sea level or lower.

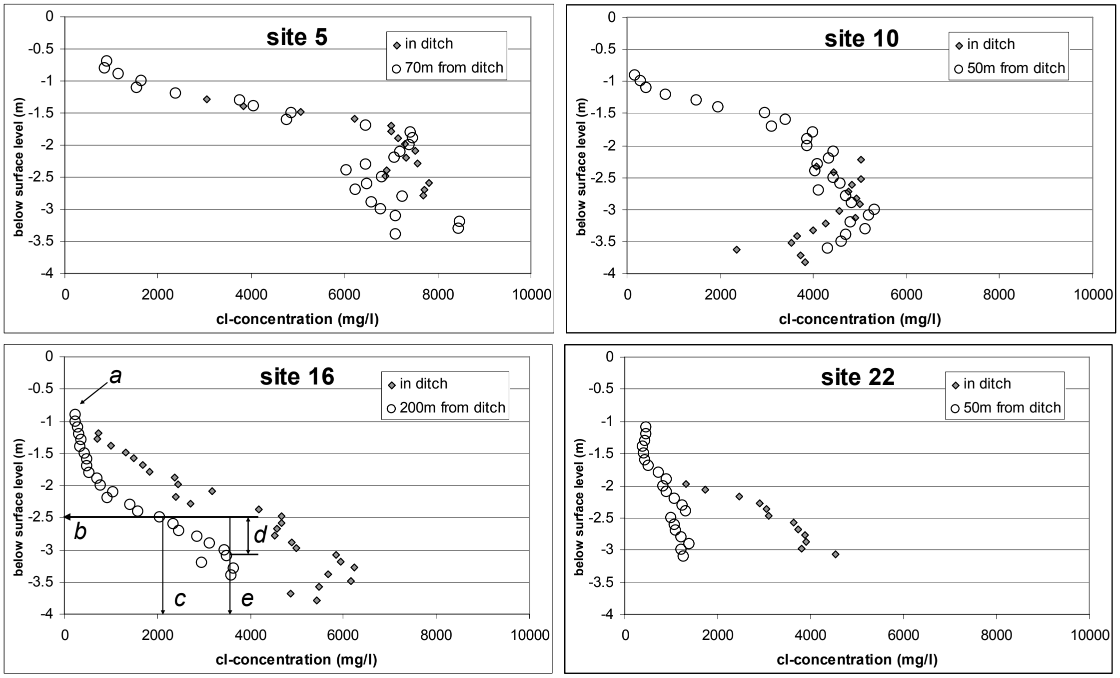

Figure 2. Cl-profiles based on T-EC probe measurements in ditch and parcel

	a	b	c	d	e			a	b	c	d	e
	cl-conc	depth	cl-conc	width	cl-conc			cl-conc	depth	cl-conc	width	cl-conc
site nr.	*mg/l*	*m*	*mg/l*	*m*	*mg/l*		site nr.	*mg/l*	*m*	*mg/l*	*m*	*mg/l*
2	500	2.0	1900	1.5	3000		12	400	2.1	1000	0.4	1700
3	960	0.7	5000	1.1	9000		13	500	2.4	2000	0.9	3800
4	600	0.9	3300	1.1	6200		16	250	2.5	2100	0.6	3600
5	900	1.3	3800	0.9	7000		21	370	1.3	1500	0.7	2800
7	470	1.5	1600	1.0	2400		22	470	2.1	900	0.6	1300
9	300	2.0	750	0.5	1000		24	1400	1.3	3000	0.4	4000
10	170	1.4	2200	1.2	4500		25	380	0.9	2500	0.8	5000
11	550	1.6	4000	1.8	7000							

Figure 3. Rainwater lens parameters *a,b,c,d* and *e* based on T-EC measurements for different monitoring sites (see figure 2 for explanation parameters)

CVES measurements

In the figure 3 an example CVES profile is shown. At the left side of the profile (x-position: 40 to 100 m) there is a relatively thick saturated zone (2 to 8 m thick) with an estimated chloride concentration of less than 3000 mg/l. At the right side of the profile (x-position: 120 to 240 m) the zone with a lower chloride concentration is much thinner (~2 m). Below these brackish zones the soil resistivity is very low (<2.5 Ohm-m) which indicates saline groundwater and/or clay. No major lithological differences have been observed along the profile. The relatively thick brackish water lens at the left side of the profile can be explained by the fact that the agricultural drainage pipes are situated at a higher level than at the other side of the profile causing higher groundwater levels and therefore lower seepage rates and probably even infiltration for most part of the year.

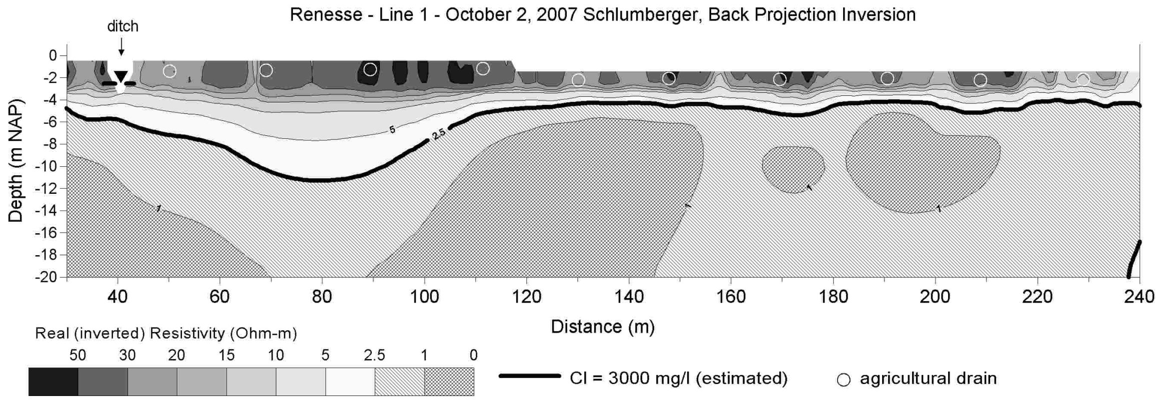

Figure 3. CVES profile for site 11

DISCUSSION AND CONCLUSIONS

The combination of T-EC probe (up to 4m depth) and 2D geo-electrical measurements (up to 20m depth) have proven to be a useful tool to visualize and characterize lateral variations of local rainwater lenses floating on saline groundwater. The monitoring results showed there is no sharp boundary between infiltrating fresh rainwater en saline seepage groundwater but there is a gradual transition zone with an average width of 2.0 m. At sites with high seepage rates no fresh groundwater was found and the transition zone already begins in the unsaturated zone with its centre at shallow depth (0.5-1.5m).

Little is known about the dynamics of these local rainwater lens caused by changes of precipitation surplus and seepage rates. Therefore an intensive monitoring network will be installed at two parcels this coming year where salt distribution of groundwater, soil moisture, drainage and surface water will be measured every hour for at least two years.

REFERENCES

Eeman, S. A. Leijnse, S.E.A.T.M. van der Zee. (2008). Modeling fresh water lenses on saline groundwater (in prep).

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