Salinisation and freshening of phreatic groundwaters in Zeeland, The Netherlands: a modeling study

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ABSTRACT
For the Province of Zeeland in the Netherlands, a 3D-model for density-dependent groundwater flow and coupled solute transport is developed to assess the impact of sea level rise and changing precipitation and evapotranspiration patterns on the freshening and salinisation processes of shallow groundwater systems. The model is used to determine feasible and robust adaptation or mitigation measures in the water system to secure the vulnerable fresh water resources in this low-lying coastal zone. We will present the building of the complex 3D numerical model (15 million model cells), and with the focus on the determination of the initial chloride distribution. For this different types of (geophysical) techniques are combined with groundwater sampling data.

INTRODUCTION
At present, the fresh water resources in the groundwater system of the Province of Zeeland are jeopardized by various causes. Floods, droughts, eutrophication and salinisation of ground and surface waters are some pressing topics. Moreover, sea level rise and climate change threaten the groundwater system even more (Figure 1). This study is initiated to get a better insight in the salinisation and freshening processes in the top of the water system. The main goal is to analyse what measures can be effective to make the fresh water supply in this area climate proof. Special attention is given to the shallow rainwater lenses in agriculture plots (De Louw *et al.*, 2008; Oude Essink *et al.*, 2009). Agricultural crops in this brackish-saline environment depend on these shallow vulnerable water systems. In this paper, the emphasis is focused on the development of the large 3D numerical model of the region, and on the determination of the initial chloride distribution.

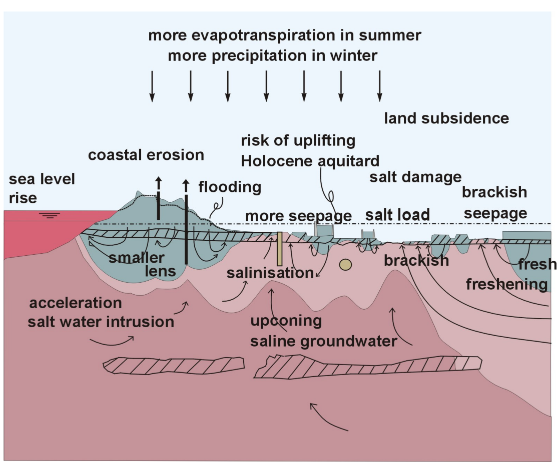

Figure 1 Concepts of salinisation processes in Dutch coastal areas in case of sea level rise and climate change.

METHODS
A 3D numerical regional model is constructed with the code MOCDENS3D (Oude Essink, 1999) to consider fresh, brackish and saline groundwater. With a 64 bit compiler,

a large number of model cells can be used to merge two necessary features: a. to simulate details in the top groundwater system (necessary to get enough detailed information for salt damage to crops) and b. to determine changes on a regional provincial scale. The dimension of the model is 70 km by 67 km by 142 m thick, whereas over 15 million model cells ($100*100m^2$) were used in 40 model layers. The latest results of geological modeling was implemented, using very detailed information of the Holocene lithology (Figure 2). Common hydrogeological parameters for these low-lying areas were used, e.g. small longitudinal dispersivities of 5 cm. The model is calibrated with measures head corrected to freshwater heads. As we are interested in the salinity at the top system, we modeled this top part of the system with very thin model cells (viz. 10 model layers have model cells of 0.5 m thickness), which causes relatively long computation times to simulate 100 years. Moreover, one of the most difficult parts of modeling variable density groundwater flow and coupled solute transport on this regional scale is the determination of the initial fresh-brackish-saline distribution. Here, we were able to combine various (geophysical) techniques, such as groundwater samples, geo-electrical borehole logs, electrical CPT, Vertical Electrical Soundings (VES), EM31, EM34, groundwater extractions, CVES and TEC probe data, to improve the first estimate of the distribution.

SOME PRELIMINARY RESULTS

Up to now the following steps were executed to determine the initial fresh-brackish-saline distribution (Goes *et al.*, 2009): 1. 3D interpolation of analyses, VES and borehole measures via geostatistical procedures (Figure 3a); 2. penetrating this 3D distribution with a mapped brackish-saline interface (of 1000mg Cl^-/l), (Figure 3b); 3. implementing salinity values of open surface water, and 4. implementing shallow low-lying rainwater lenses areas via empirical relation (De Louw et al, 2010, see this SWIM21). Figure 4 shows the first three steps and figure 5 shows the result in various profiles. In addition, for the near future, helicopter-borne geophysical systems will also be implemented to improve this distribution (using data from the Interreg IV-B CLIWAT project).

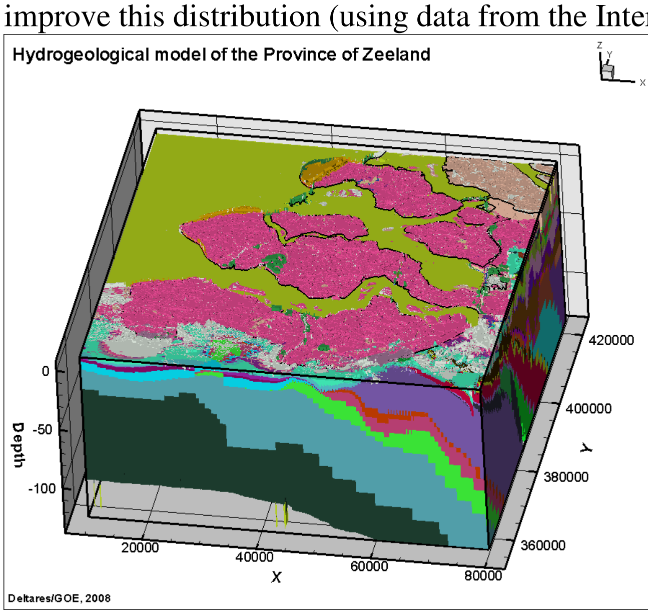

Figure 2: Geological model of the area: detailed information of the geology is implemented in the (Holocene) top of the system.

CONCLUSIONS

A modeling tool has been developed ready to start assessing the impacts of climate change (changes in precipitation and evapotranspiration, and indirect sea level rise) on the fresh-brackish-saline distribution on a regional scale, but with enough detail to transfer these modeling output to local circumstances (e.g. for input to salt damage calculations of agricultural plots). In addition, a procedure has been set up to combine different techniques to get a more reliable fresh-brackish-saline distribution: from various types of (indirect) geophysical techniques using geostatistical procedures, via groundwater sampling, to numerical modeling.

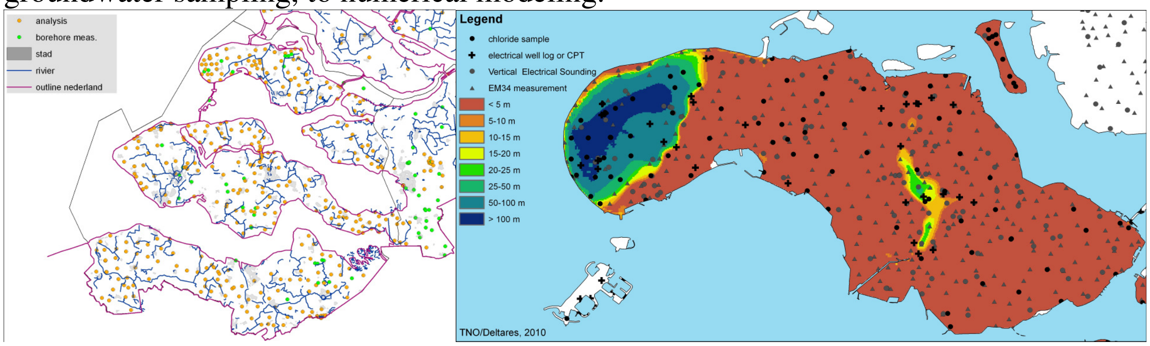

Figure 3: a. Analyses and Borehole measures in the study area, b. mapped brackish-saline interface in a part of the study area (viz. Schouwen-Duiveland).

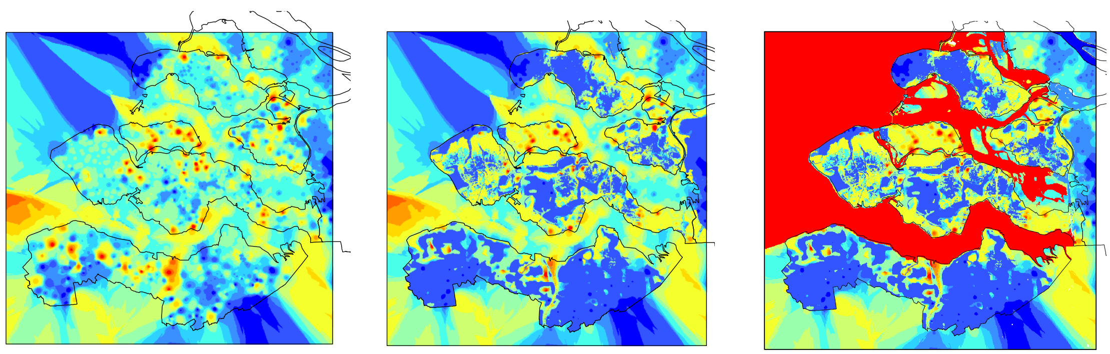

Figure 4. Three steps in the chloride distribution determination: 1. interpolating data, 2. including mapped brackish-saline interface; 3. including surface water.

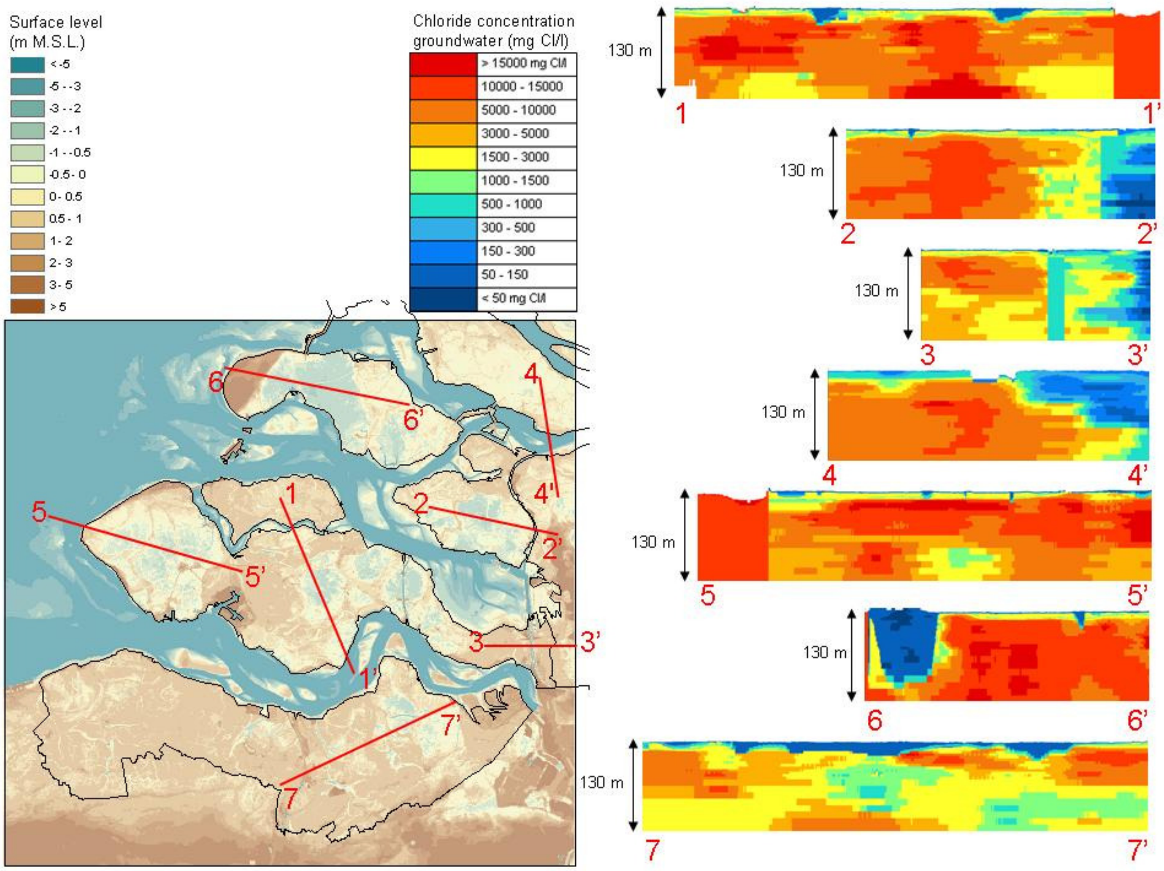

Figure 5: a. Groundwater surface and b. fresh/brackish/saline profiles through the 3D chloride distribution.

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