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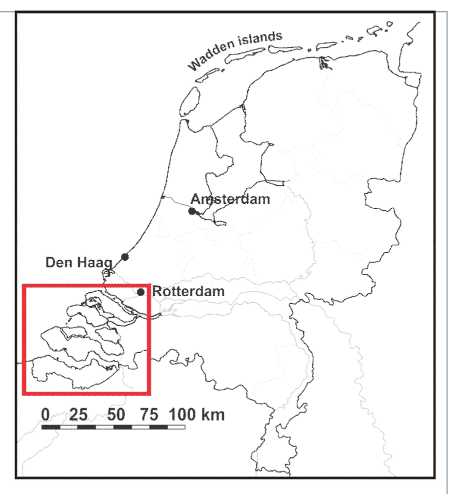
Regional variable-density groundwater flow model: a Dutch case in the southwestern delta



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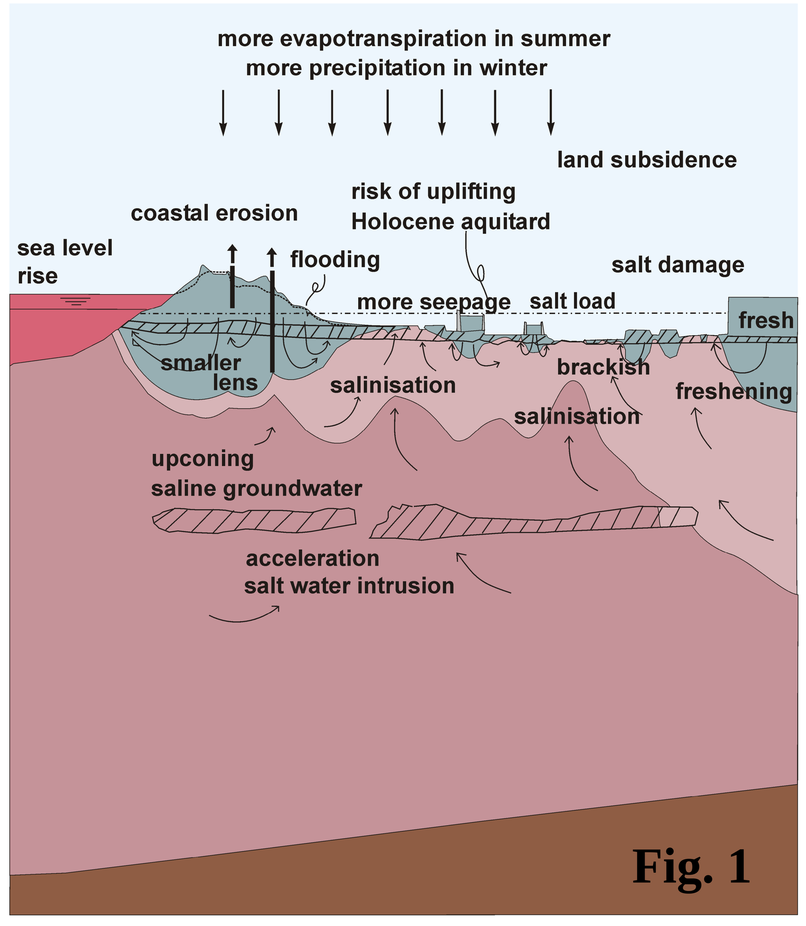


Fig. 1: Concepts of salinisation processes in Dutch coastal areas in case of sea level rise and climate change.

INTRODUCTION

At present, the fresh groundwater resources of the Province of Zeeland are jeopardized by various causes. Floods, droughts, eutrophication and salinisation of ground- and surface waters are some pressing topics. In addition, sea level rise and climate change threaten the fresh groundwater resources even more (Fig. 1, Oude Essink *et al.*, 2010). A 3D-model for density-dependent groundwater flow and coupled solute transport was developed to assess the impact of sea level rise and changing precipitation and evapotranspiration patterns on the freshening and salinisation processes of the shallow Zeeland groundwater system. Special attention is given to the shallow rainwater lenses in agriculture plots (Fig. 2, De Louw *et al.*, 2010). Agricultural crops in this brackish-saline environment depend on these shallow vulnerable water systems. This poster is focused on: a. the characteristics of the 3D numerical model of the region, and b. on the outcome of the climate change scenarios.

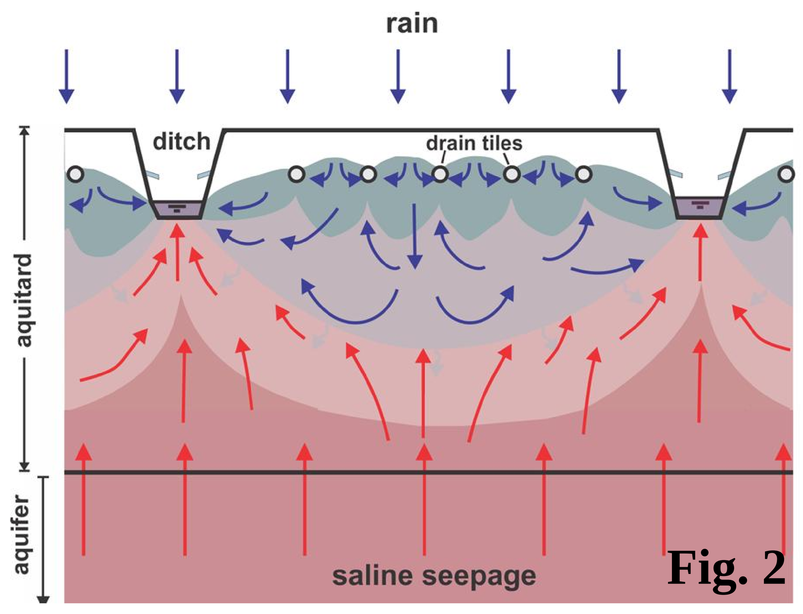


Fig. 2: Fresh water lens in summer and winter, along with ditches containing salt water (De Louw et al., 2011)

METHODS

The 3D numerical regional model is constructed with the code MOCDENS3D (Oude Essink, 1999) to consider fresh, brackish and saline groundwater. With a 64 bits compiler, 16.9 million model cells is used to merge two necessary features:

- simulate details in the top groundwater system (to get enough detailed information for salt damage to crops)
- determine changes in the grounmdwater system on a regional scale.

See table 1 for details of the numerical geometry. The latest results of geological modeling was implemented, using very detailed information of the Holocene lithology (GEOTOP Zeeland). The model is calibrated with measured head corrected to freshwater heads. 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 make the first estimate of the distribution (Fig. 3a).

Zeeland: some model and subsoil parameters	
total land surface [km^2]	4690 km^2
modelled area, L_x*L_y [km]	L_x=70 km, L_y=67 km
horizontal cell size [m^2]	100*100
grid size, total # active cells	700*670*40 model layers = ~16.9 million
vertical cell size [m]	1x4m, 10x0.5m, 10x1m, 11x4m, 8x10m
# particles/cell, total number particles	4, ~68 million
porosity	0.3
convergence head criterion	10^{-4} m
total time [yr]	100 yr
longitudinal dispersivity α_L [m]	0.05 m

Table 1: numerical geometry of the 3D model.

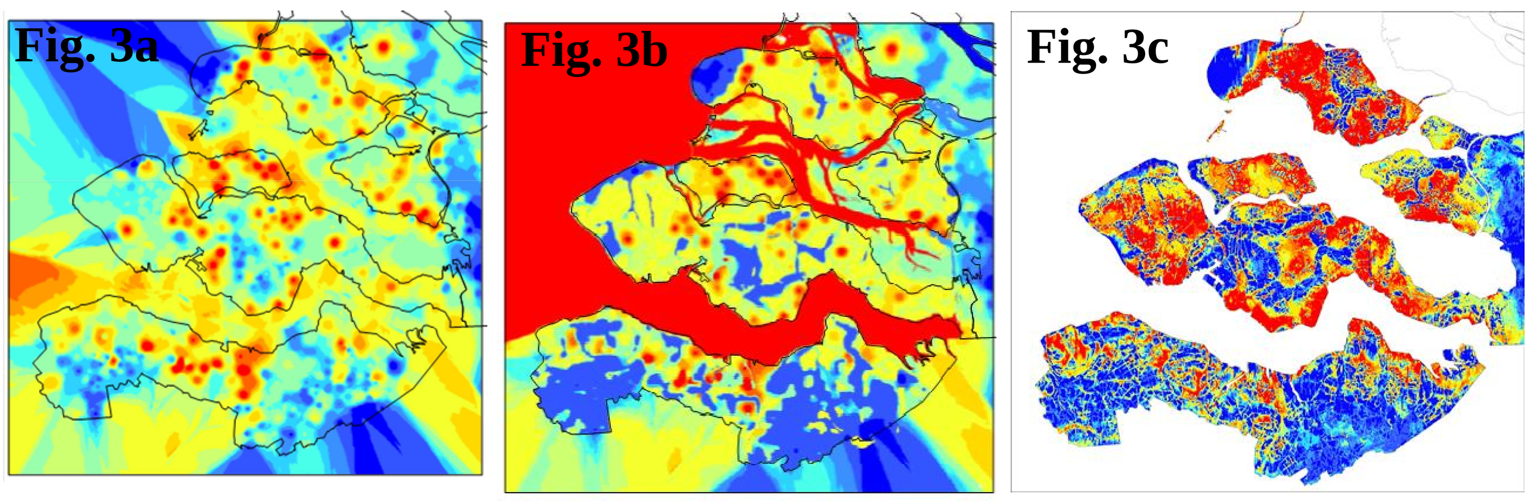


Fig. 3: Three steps in the chloride distribution determination: a. interpolating data, b. including mapped brackish-saline interface; c. model as interpolator.

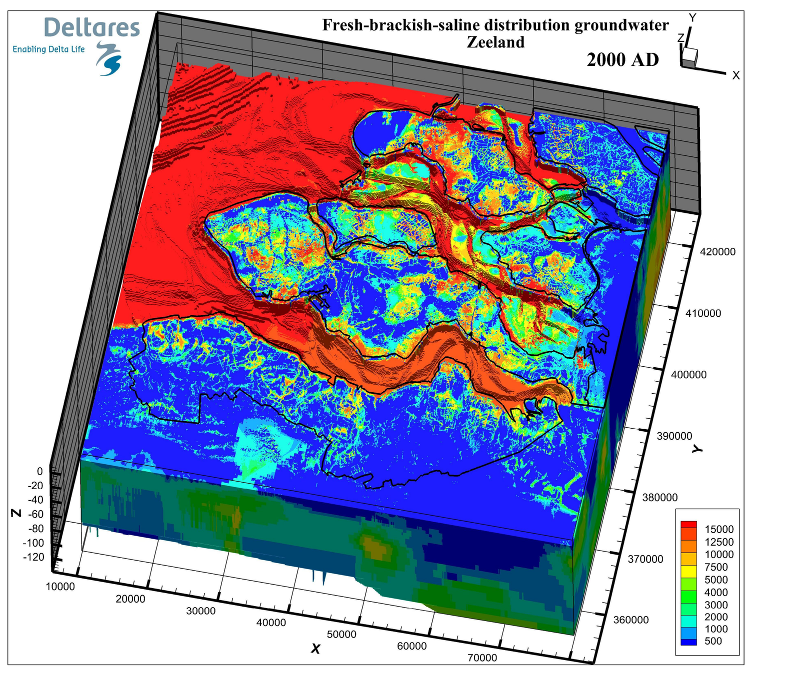


Fig. 4: Modelled versus measured freshwater head.

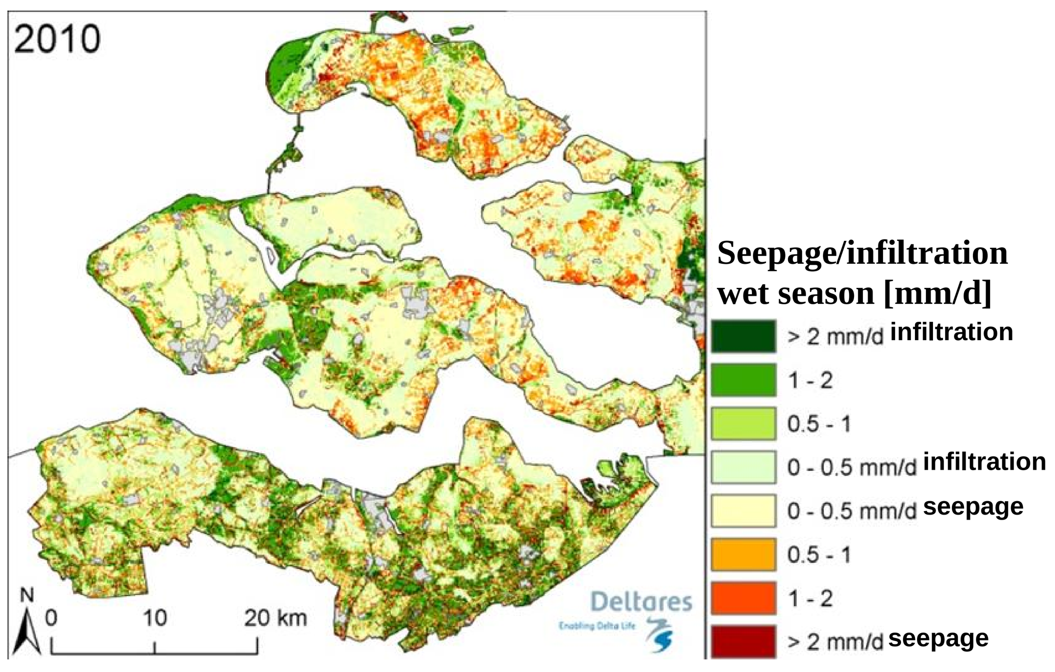
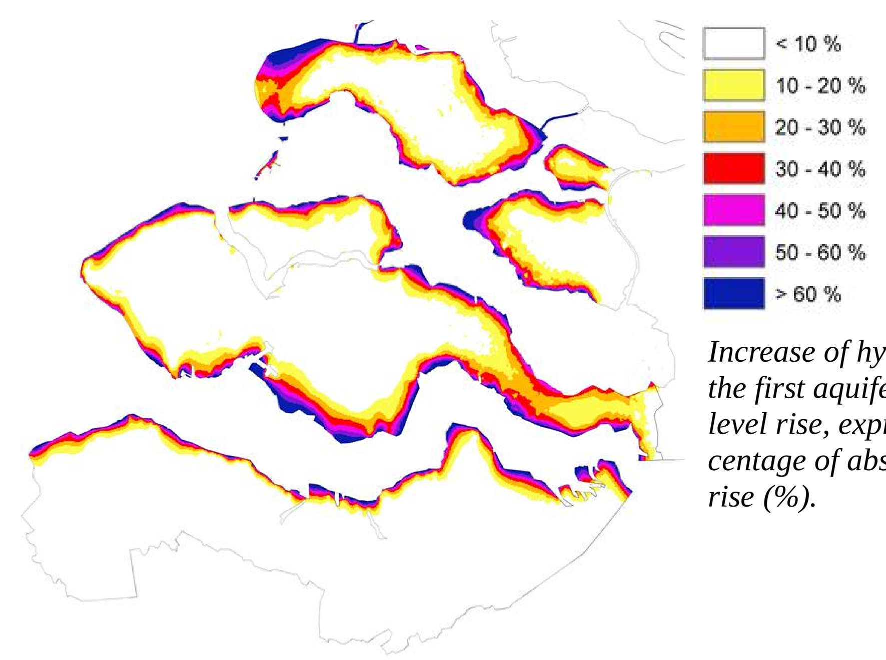


Fig. 5: 3D fresh/brackish/saline chloride distribution.



Increase of hydraulic heads in the first aquifer caused by sea level rise, expressed in percentage of absolute sea level rise (%).

Fig. 6: Zone of sea level rise in the first aquifer system

RESULTS

Up to now the following steps were executed to determine the initial fresh-brackish-saline distribution (Goes *et al.*, 2009): a. 3D interpolation of analyses, VES and borehole measurements via geostatistical procedures (Fig. 3a); b. penetrating this 3D distribution with a mapped brackish-saline interface (of 1000mg Cl^-/l), (Fig. 3b); c. using the model as a interpolator. Figs. 5-7 show some results of the modeling: seepage and infiltration areas (Fig. 5); zone of influence of sea level rise (Fig. 6); and change in chloride concentration at the bottom of the Holocene aquitard (around 4-10 m below ground surface), (Fig. 7).

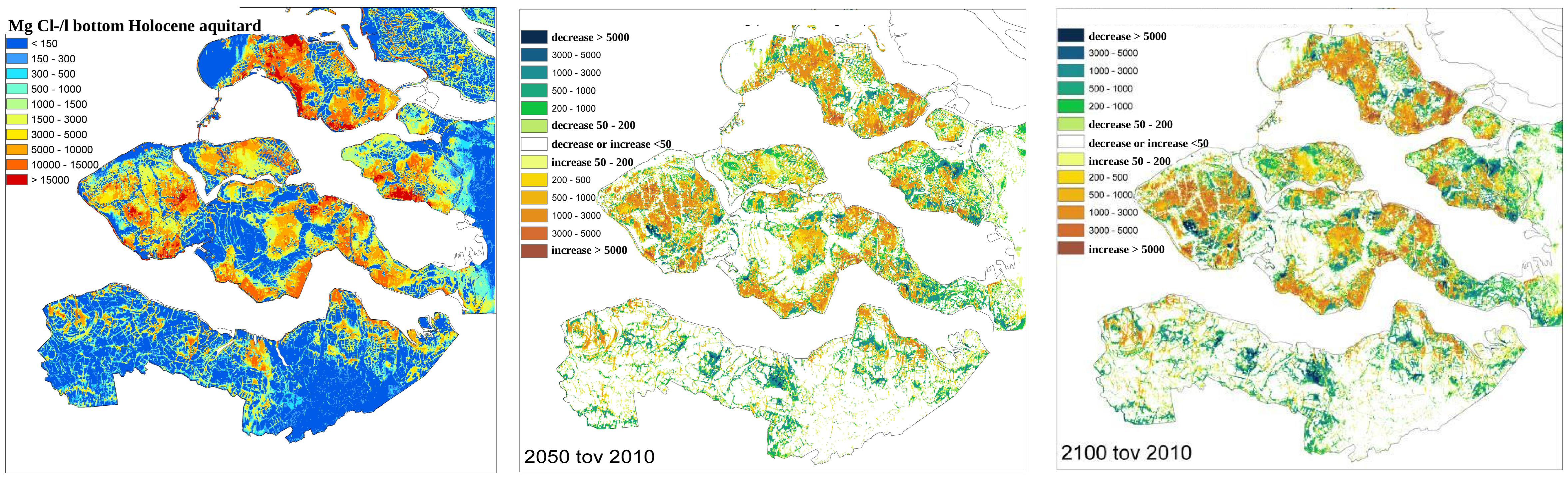


Fig. 7: Chloride concentration at bottom Holocene aquitard, and the salinsation and freshening after 40 and 90 years, resp.

References:

- Goes, B.J.M., Oude Essink, G.H.P., Vernes, R.W. and Sergi, F. 2009. Estimating the depth of fresh and brackish groundwater in a predominantly saline region using geophysical and hydrological methods, Zeeland, the Netherlands, *Near Surface Geophysics 401-412*.
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- Oude Essink, G.H.P., van Baaren, E.S., de Louw, P.G.B., 2010. Effects of climate change on coastal groundwater systems: A modeling study in the Netherlands. *Water Resources Research* 46, 1–16.

CONCLUSION

A modeling tool has been developed which was used to assess the impacts of climate change (changes in precipitation and evapotranspiration, and sea level rise) on the fresh-brackish-saline distribution on a regional scale, with enough detail to transfer these modeling output to sub-regional circumstances (for input to salt damage calculations on 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.

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