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Netherlands Hydrological modelling Instrument
fresh and saline groundwater in the Dutch coastal zone

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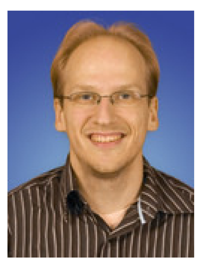
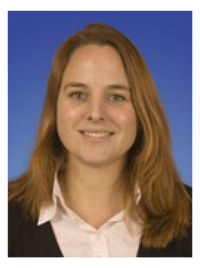
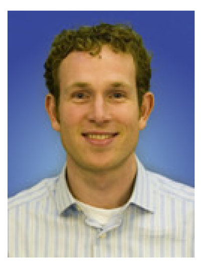


INTRODUCTION

One of the major water issues in the National Water Plan is to make fresh water supply in The Netherlands climate change proof for the coming century. To assist water managers in their choices to make our country ready for future stresses such as flooding, drought, land subsidence and salinisation, a modeling framework called The Netherlands Hydrological modelling Instrument (NHI) has been set up. As in the Dutch coastal zone brackish to saline groundwater is The Driver for salinisation of surface water systems (Fig. 1), NHI is extended with a fresh-saline groundwater module. The fresh-salt groundwater module assesses on a national level the effect on groundwater in the Dutch coastal zone of the following physical processes: 1. the autonomous salinisation due to past head differences in the top system (e.g. sea level relative to low-lying polder water levels), 2. sea level rise, 3. changes in precipitation and evapotranspiration, 4. land subsidence, 5. increasing groundwater extractions, and 5. water level variation in the large fresh water lake IJsselmeer.

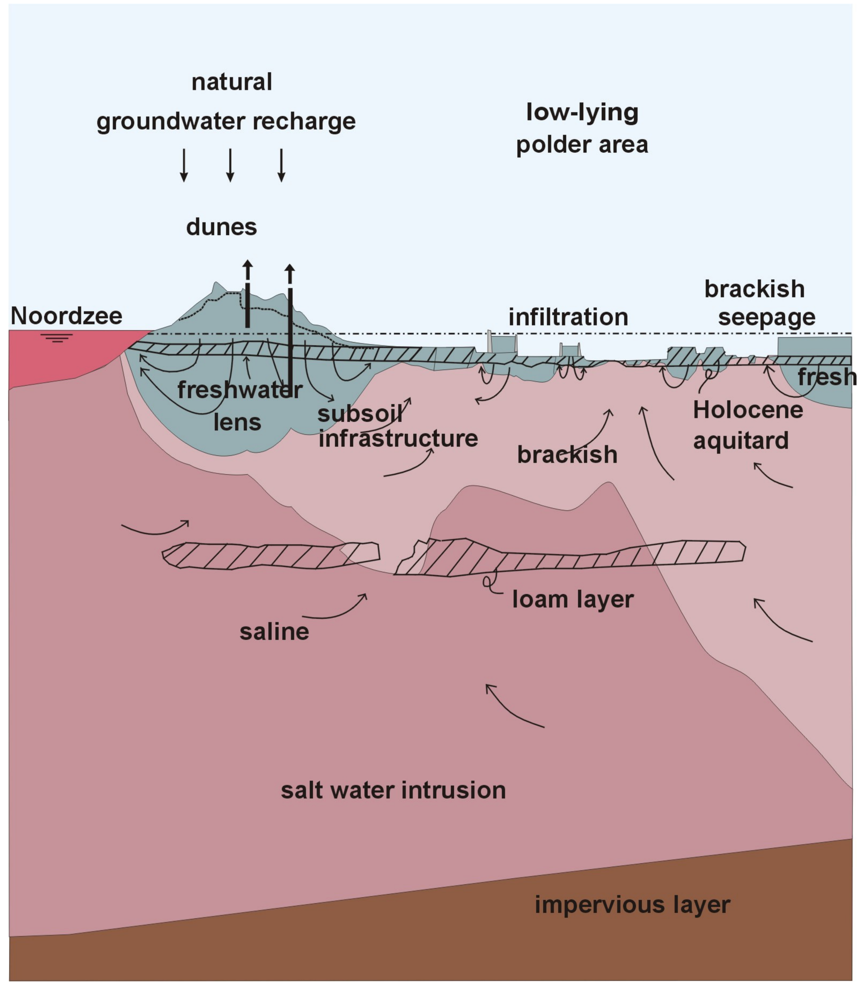

Fig. 1: Salinisation processes in Dutch coastal areas in case of sea level rise and climate change.

NHI: some model and subsoil parameters	
total surface model [km^2]	97500 km^2
modelled area, L_x*L_y [km]	L_x=300 km, L_y=325 km
horizontal cell size [m^2]	250*250 m^2
grid size, total # active cells	1300*1200*31 model layers=~20.6 million
vertical cell size [m]	2x5m, 10x2m, 8x5m, 11x20m
# particles/cell, total number particles	4, ~63 million
porosity	0.3
convergence head criterion	10^{-3} m
total time [yr]	100 yr
longitudinal dispersivity α_L [m]	0.10 m

Table 1 shows some model and subsoil parameters. The module is constructed with the code MOCDENS3D (Oude Essink, 1999). The thickness of the groundwater system is 290 m thick. To characterize the vertical distribution of fresh-brackish-saline groundwater with enough detail, 31 model layers are used. A 64 bit compiler is used to make the simulation of this large number of model cells possible.

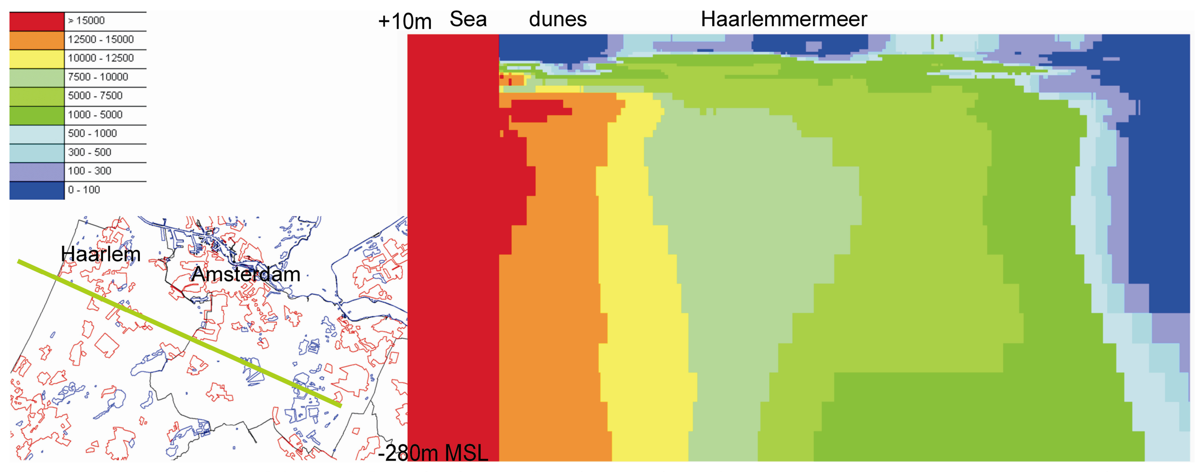

Fig. 2: 2D profile of fresh-brackish and saline groundwater over the western coastal part of The Netherlands.

METHODS

National databases are used to set up the 3D module for the simulation of variable-density groundwater flow and coupled salt transport:

- Hydrology (surface water system, precipitation, evapotranspiration, drain and water channels characteristics)
- Fresh-brackish-salt distribution (3D interpolation via geostatistical procedures of chloride concentration analyses, Vertical Electrical Soundings (VES) and borehole measurements in combination with the mapped brackish-saline interface of 1000 mg Cl$^-$/l within the ZZREGIS database), see Figs 2 and 3.
- Topography (Digital Elevation Map)
- Geology (REGIS)
- Geohydrology (groundwater extraction rates)

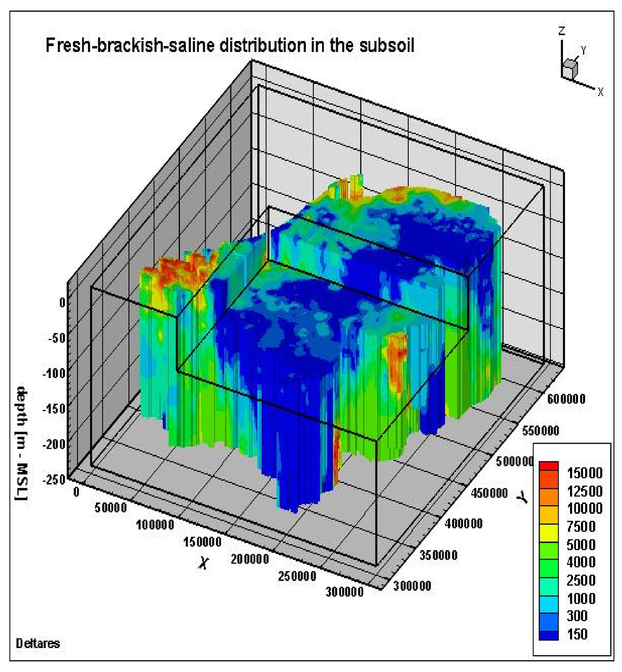

Fig. 3: 3D chloride distribution in the Netherlands.

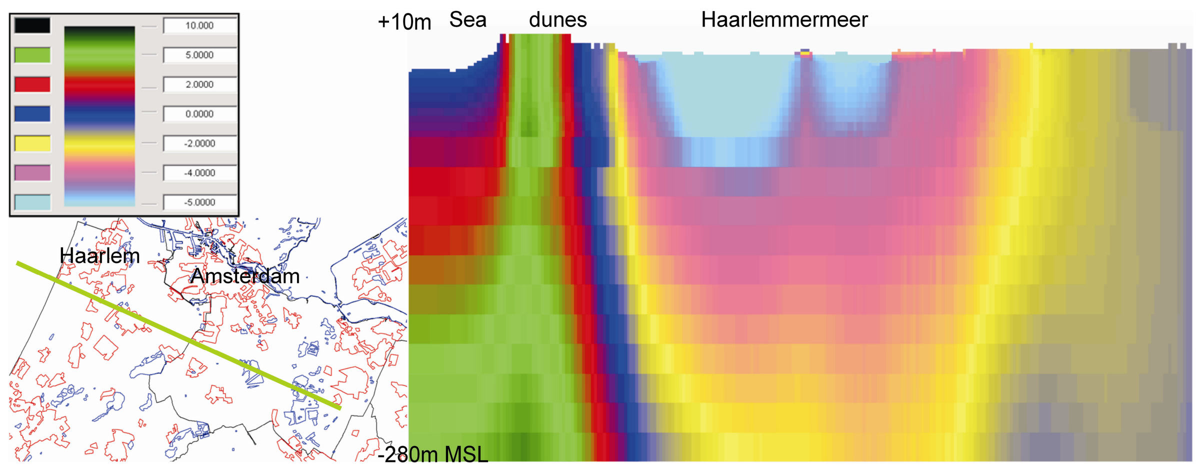

Fig. 4: 2D freshwater head profile over the Dutch coastal zone.

PRELIMINARY RESULTS:
fresh-brackish-saline

Figs. 2 and 3 show snap-shots of the 3D chloride distribution. The distribution of fresh, brackish and saline groundwater is closely related to the Holocene transgressions when saline water could easily and rapidly infiltrate the aquifers via free convection. In the hinterland, old marine evaporate deposits also contributes to high chloride concentrations. It can be seen that the groundwater system in the coastal zone is brackish to saline within some tens of meters, and that inversions of saline-fresh groundwater occur in the top system. Salt load to the surface water system (Fig. 5) is severe in the low-lying polders where seepage values are large and the chloride concentration is brackish to saline (Fig. 6).

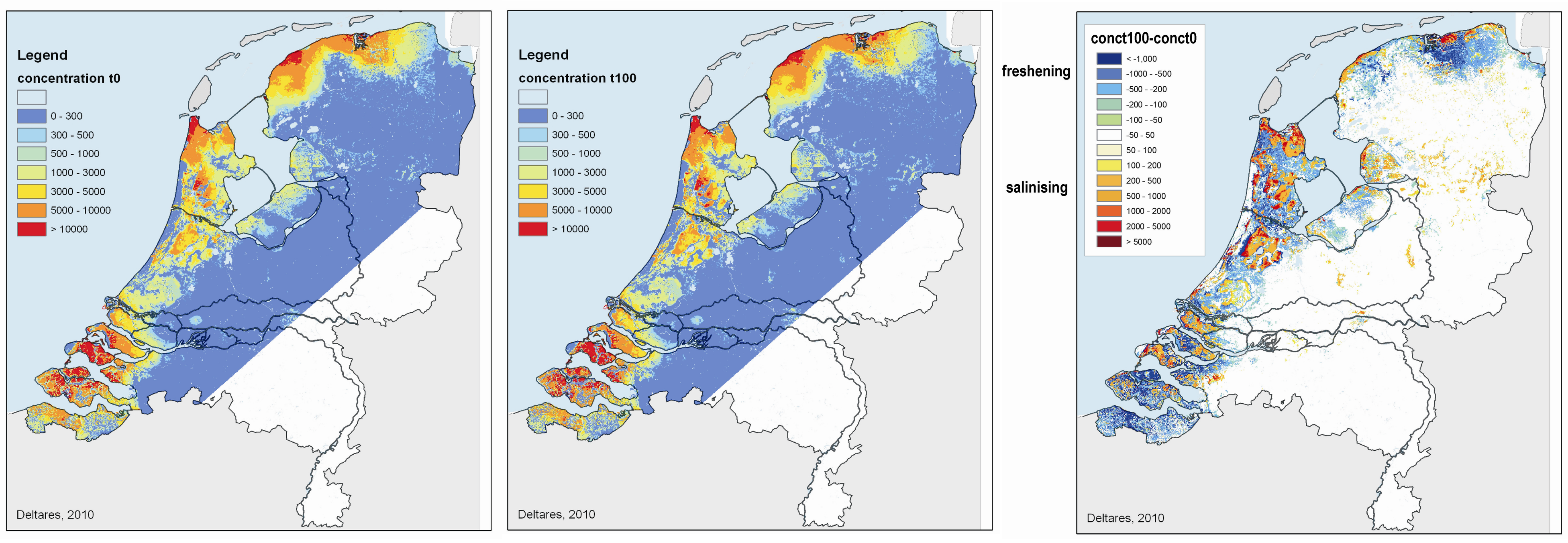

Fig. 4: Chloride distribution now (a.) and after 100 years (b.); increase and decrease in salinity over 100 years (c.).

PRELIMINARY RESULTS: freshwater head

Figs. 4 and 7 show the freshwater head in a 2D profile; the increase in freshwater head at the no-flow sea-side boundary is obvious. The zone of influence is surprisingly limited: it can only be detected within 10 km of the coastline and the main rivers (Fig. 8). The reason is that the increased head in the first aquifer coast can easily be released through the highly perforated Holocene confining layer (e.g. by sandy layers and/or boils).

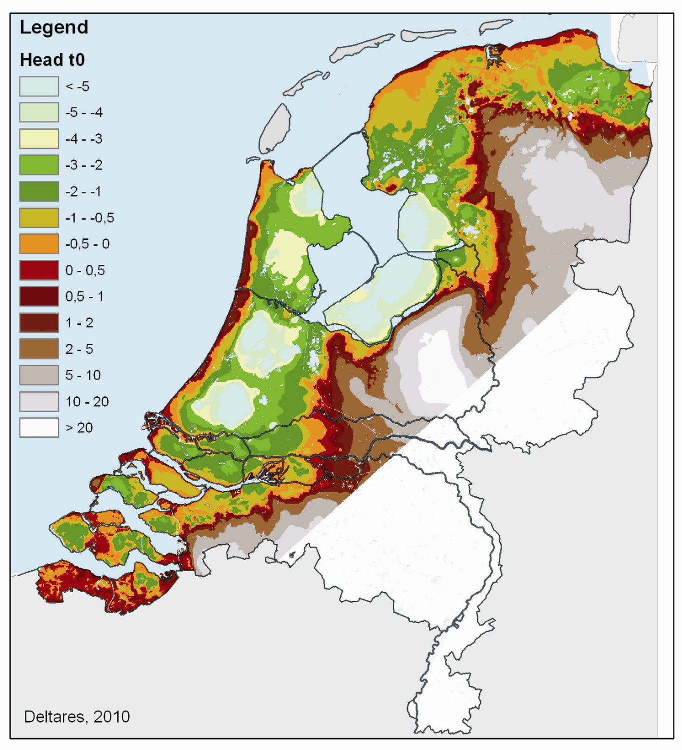

Fig. 7: Freshwater head [m] in the first aquifer.

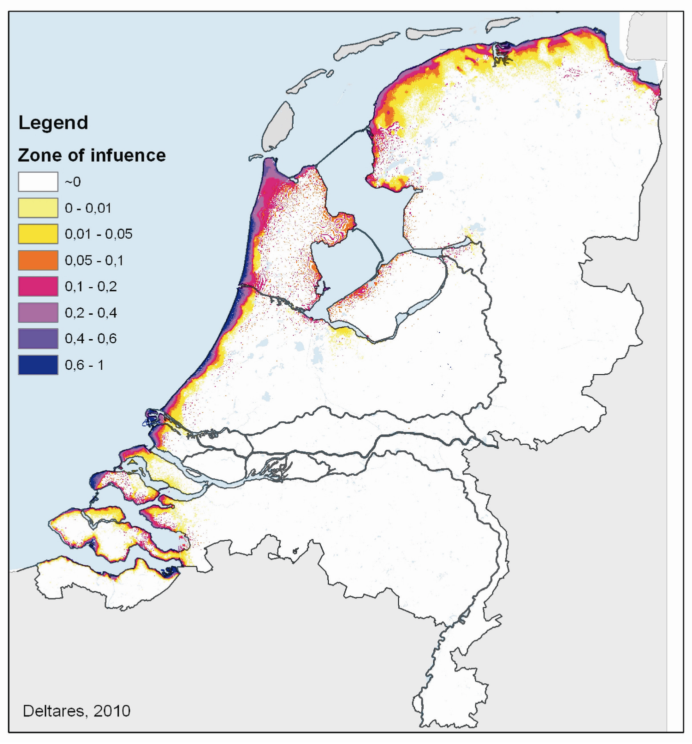

Fig. 8: Increase in freshwater head [m]: zone of influence of sea level rise (rise in North Sea is 1m).

Reference:
Oude Essink, G.H.P. 1999. Simulating 3D density dependent groundwater flow: the adapted MOC3D. *Proc. 15th Salt Water Intrusion Meeting*, Ghent, Belgium: 69-79.

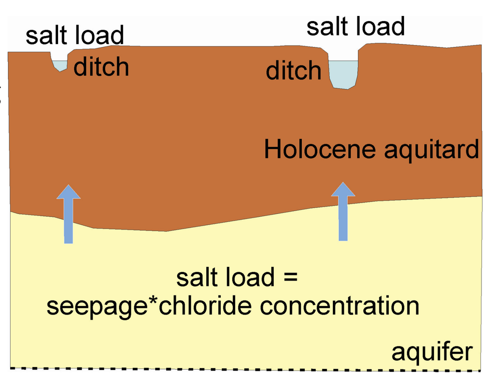

Fig. 5: concept of salt load to the surface water system.

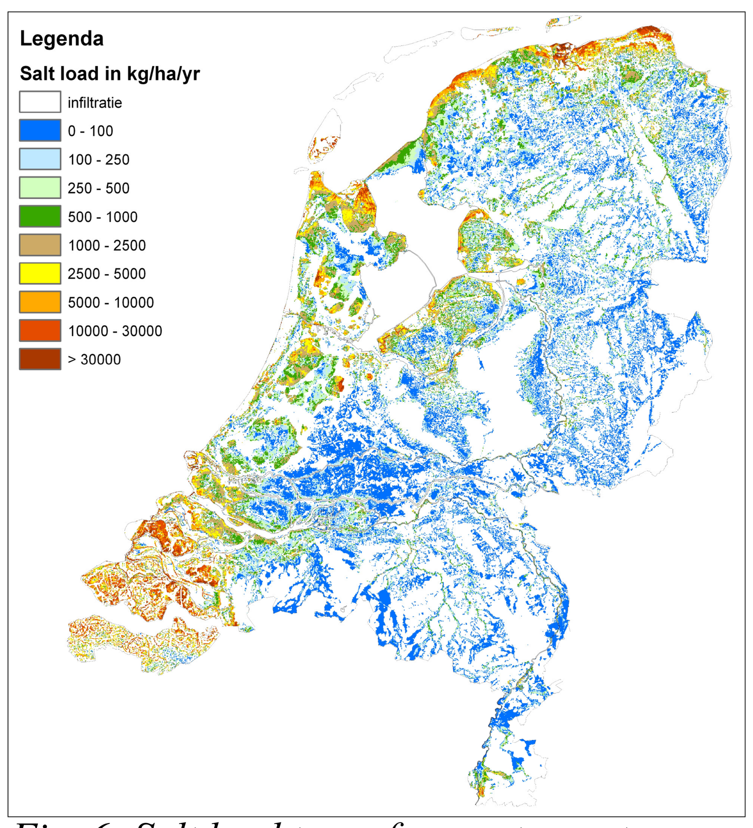

Fig. 6: Salt load to surface water system.

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CONCLUSIONS

- We can construct a 3D variable density groundwater flow and coupled salt transport module (on a national scale with 250*250m^2 cells) to analyze the effects of water management strategies on climate change proof fresh water supply within acceptable computation run times.
- In the Dutch delta, complex salinity and geology distributions ask for the variable-density approach
- Zone of influence of sea level rise is limited
- The coastal ground and surface water system significantly becomes more saline these coming 50-100 years