Deltares
Enabling Delta Life

Impacts of climate change on a coastal groundwater system in The Netherlands

Anthropogenic processes and climate change

Gualbert Oude Essink, Esther van Baaren, Perry de Louw
Subsurface and Groundwater Systems
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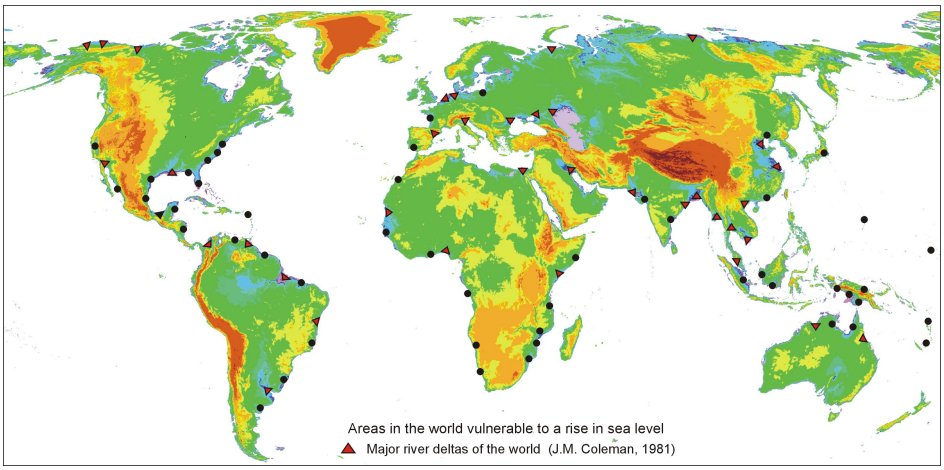
1. Introduction
2. Input 3D saline-fresh model
3. Zone of influence SLR
4. Salinisation and freshening
5. Some measures

Coastal groundwater vulnerable to sea level rise



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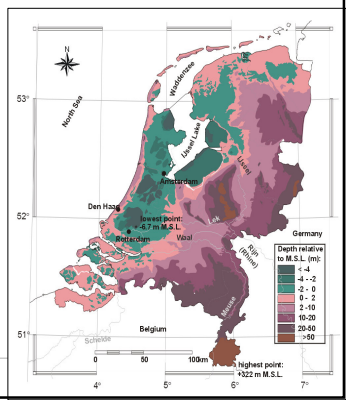
The 'low-lying' lands: Netherlands

River flooding 1995

The facts:

- a deltaic area with 3 rivers: Meuse, Scheldt & Rhine
- ~25% of land surface is lying below mean sea level
- ~65 % would be flooded regularly if there were no dunes and dikes
- ~8 million people would be endangered

The Flooding of 1953



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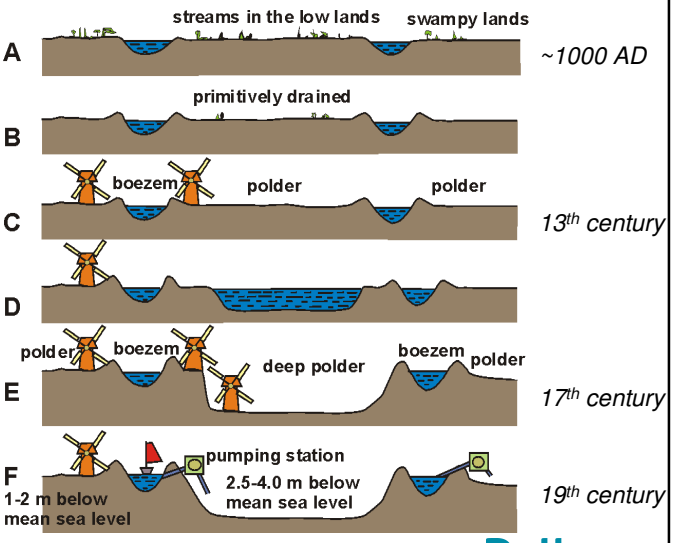
Development of the Dutch 'Polder' Landscape



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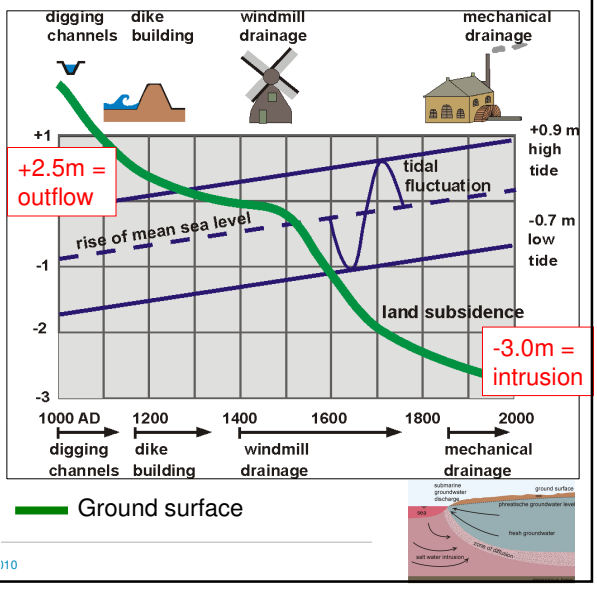
From fresh water outflow to salt water inflow

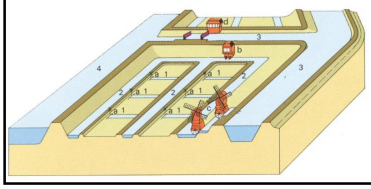
Historical subsidence of the ground surface in Holland

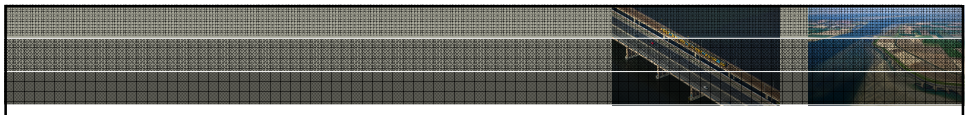
Causes:

Autonomous processes
- Land subsidence
- Abrupt land reclamation

Climate change
- Sea level rise
- Change in net recharge







To get an idea about the possible future effects of SLR and climate change in your delta …

evaluate of the past water management in the Dutch delta

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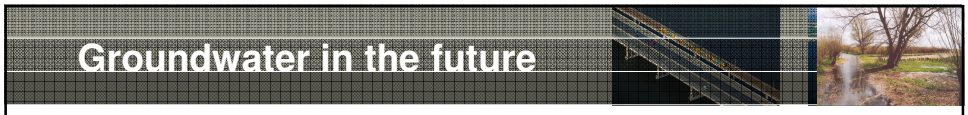

Groundwater in the future

We have to cope which…:

- Climate change
- Groundwater extractions
- Development energy use/production (heat-cold)
- Land subsidence
- Development spatial land use
- Politics, Policy & Watermanagement

Direct anthopogenic influence on groundwater is more important than climate effect

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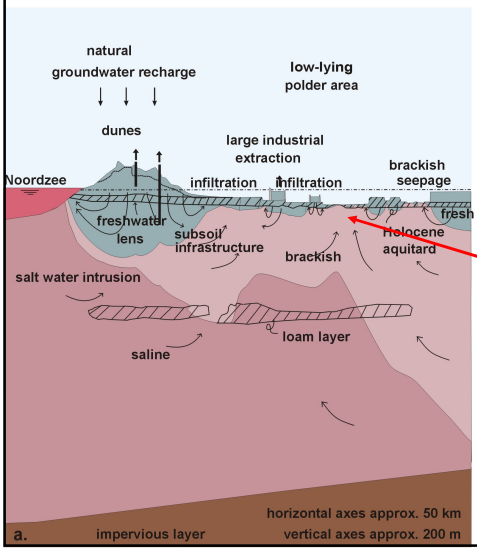
A (Dutch) groundwater system

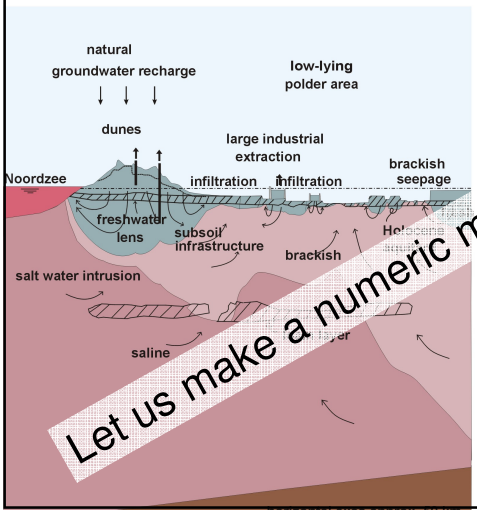
Present processes



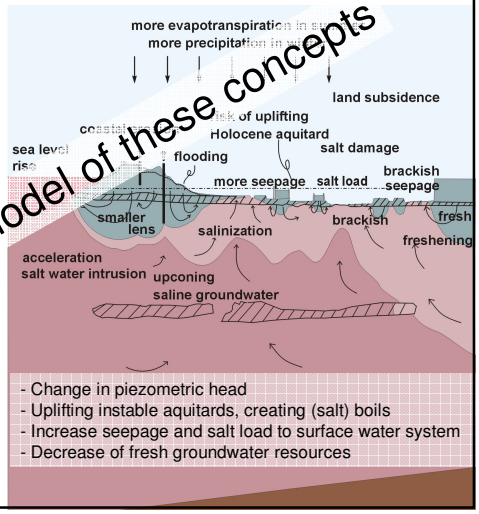
Present saline seepage is from old marine deposits, not from recent Noordzee sea water intrusion

A (Dutch) groundwater system under stress

Present processes

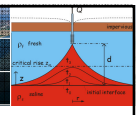


Future changes



Let us make a numeric model of these concepts

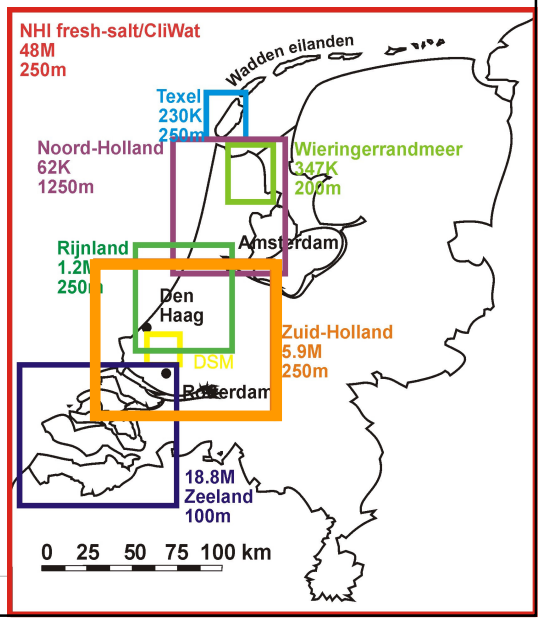
Numerical modelling of salt water intrusion



Characteristics:
- variable-density groundwater
- fresh, brackish and saline
- 3D, non-steady
- coupled solute transport

Assess combined effects:
- past land subsidence polders
- sea level rise
- changing recharge pattern
- land subsidence
- changing extraction rates
- adaption measures

Code (MODFLOW family)**:**
MOCDENS3D, similar to SEAWAT



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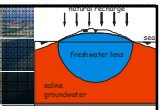
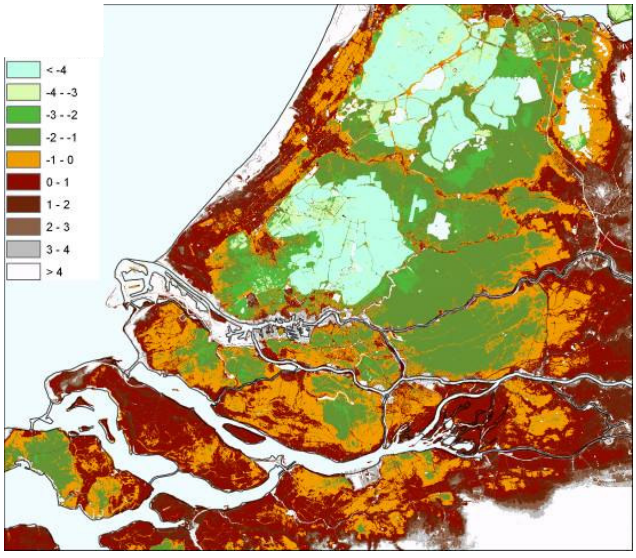
Model input (1/5): Ground surface (m)





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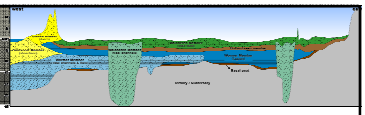
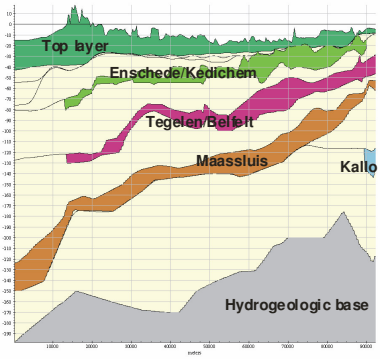
Model input (2/5): Geology

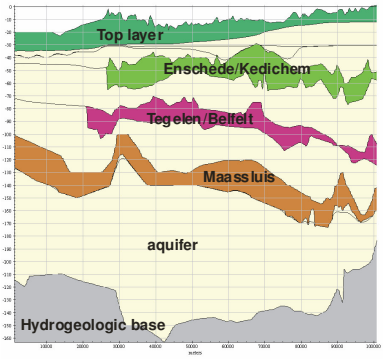


Regional Geohydrological Information System REGIS (TNO)

Profile 1



Profile 2



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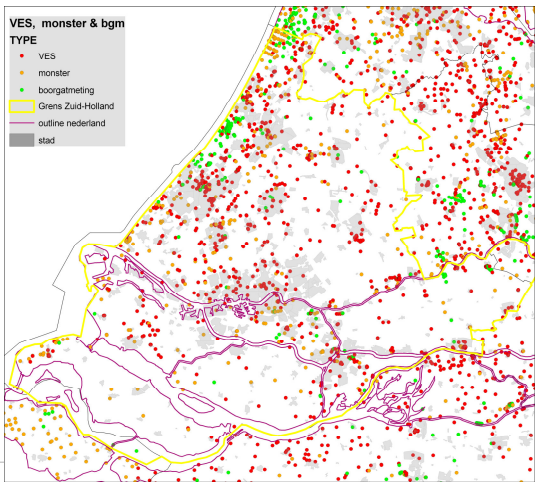
Model input (3/5): initial salinity distribution

- Samples (# = 6000)
- Vertical Electrical Soundings
- Borehole measurements



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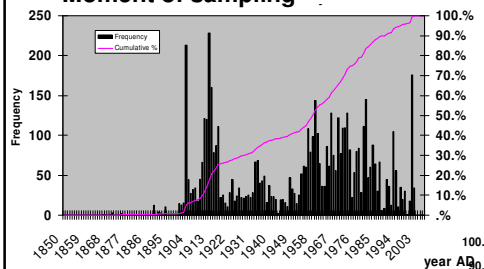
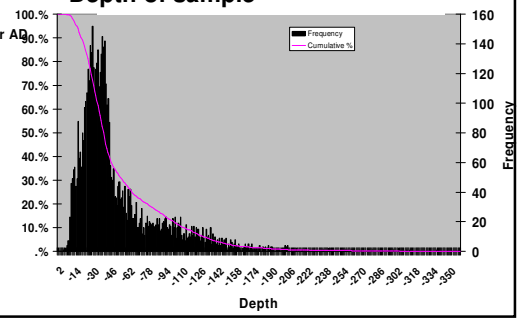
Model input (3/5): initial salinity distribution

- Samples (# = 6000)

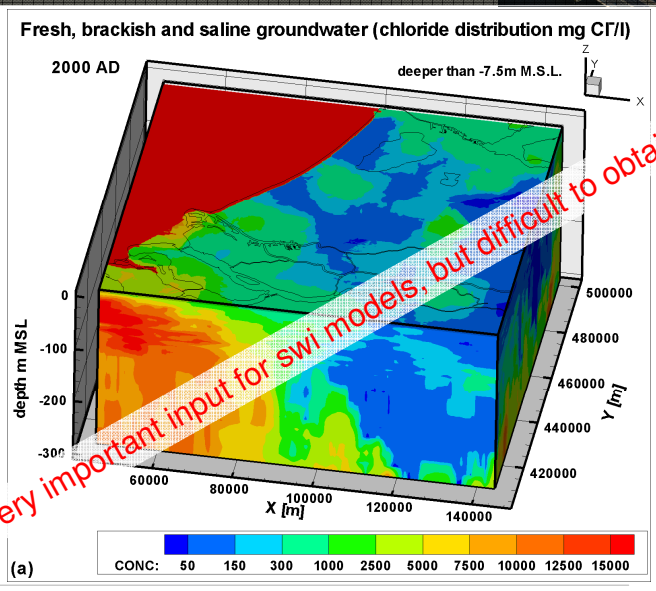
Moment of sampling



Depth of sample



Model input (3/5): initial salinity distribution



Very important input for swi models, but difficult to obtain!

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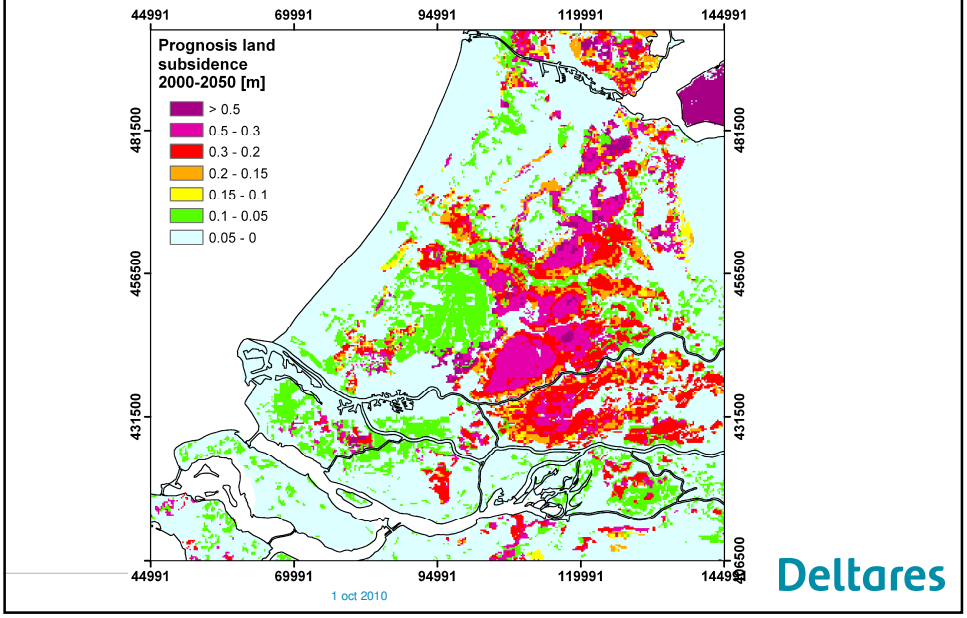
Model input (4/5): land subsidence



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Model input (5/5): climate scenarios (KNMI06)

2100		G	G+	W	W+	C	C+
Worldwide temperature rise in 2050		+1 °C	+1 °C	+2 °C	+2 °C	+3 °C	+3 °C
Worldwide temperature rise in 2100		+2 °C	+2 °C	+4 °C	+4 °C	+6 °C	+6 °C
Change airstream pattern Western Europa		no	yes	no	yes	no	yes
Winter	Average temperature	+1,8 °C	+2,3 °C	+3,6 °C	+4,6 °C	+5,4 °C	+6,9 °C
	Coldest winter day each year	+2,1 °C	+2,9 °C	+4,2 °C	+5,8 °C	+6,3 °C	+7,8 °C
	Average precipitation	7%	14%	14%	28%	21%	42%
Summer	Average temperature	+1,7 °C	+2,8 °C	+3,4 °C	+5,6 °C	+5,1 °C	+8,4 °C
	Hottest summer day each year	+2,1 °C	+3,8 °C	+4,2 °C	+7,6 °C	+6,3 °C	+11,4 °C
	Average precipitation	6%	-19%	12%	-38%	18%	-57%
Sea level rise	Absolute rise (cm)	35-60	35-60	40-85	40-85	45-110	45-110

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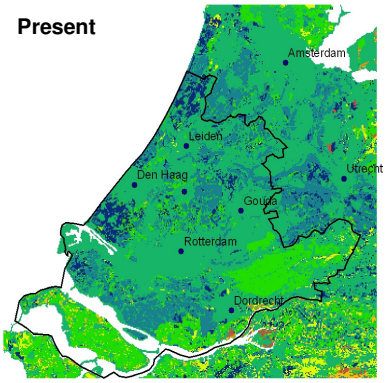
Model input (5/5): Change in groundwater recharge

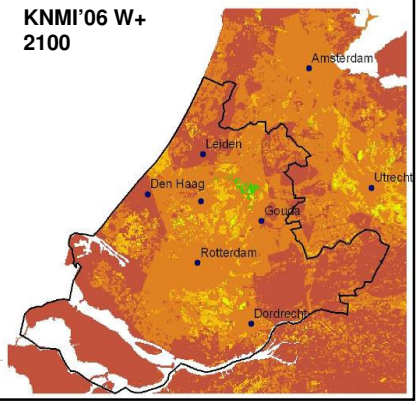
Present



GW recharge mm/day

- 0 - 0,4
- 0,4 - 0,5
- 0,5 - 0,6
- 0,6 - 0,7
- 0,7 - 0,8
- 0,8 - 0,9
- 0,9 - 1
- > 1

KNMI'06 W+ 2100



Based in NHI

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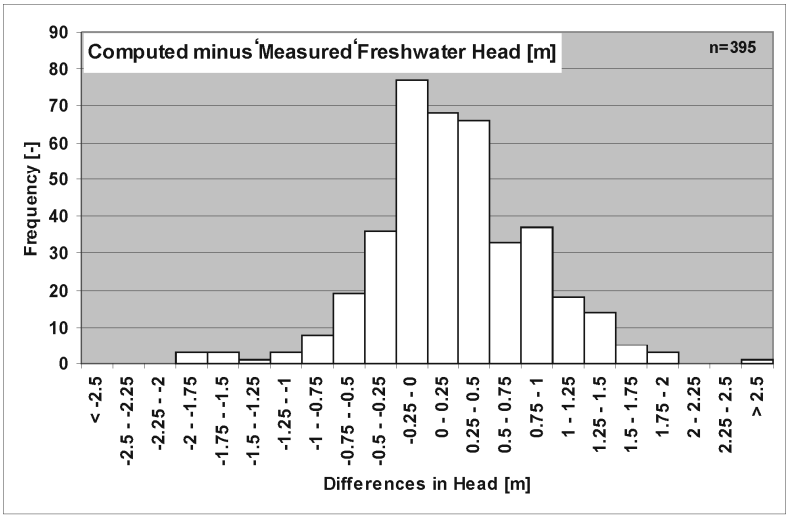
Calibration



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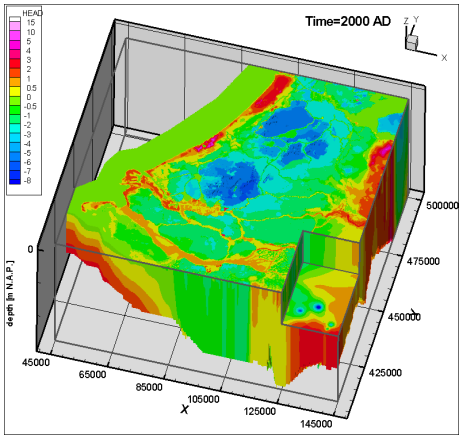
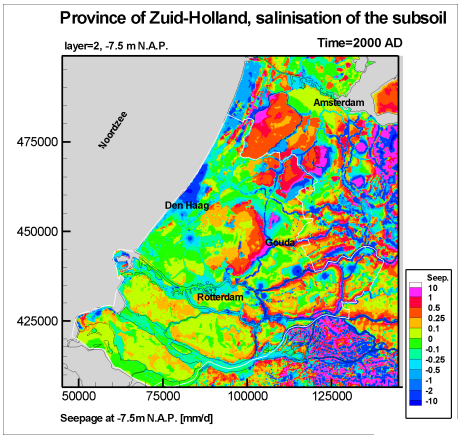
Results

Freshwater heads



Seepage or infiltration



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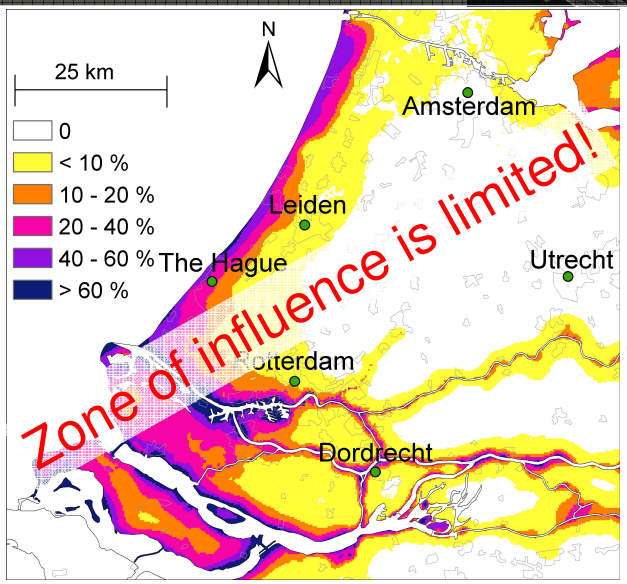
Zone of influence of sea level rise



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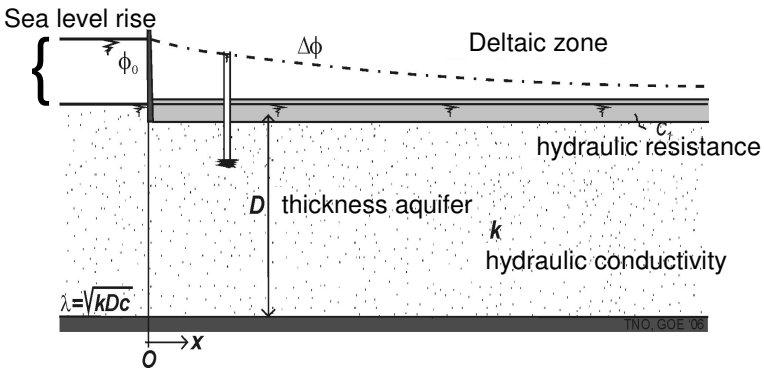
Explanation limited zone of influence sea level rise
Simple analytical approach for zone of influence in deltaic areas



$$\Delta\phi(x) = \phi_0 e^{-x/\lambda}$$

$$\lambda = \sqrt{kDc}$$

Zone of influence λ is equal to √(kDc)
At x=3λ, only 5% of sea level rise is detectable

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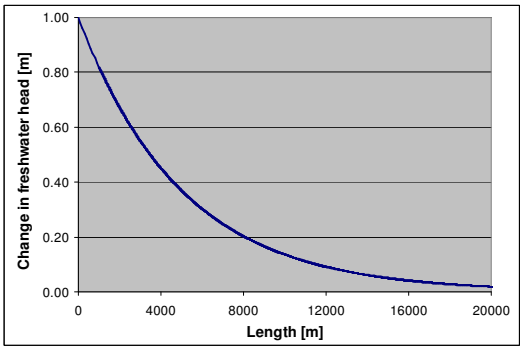
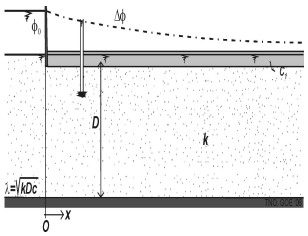
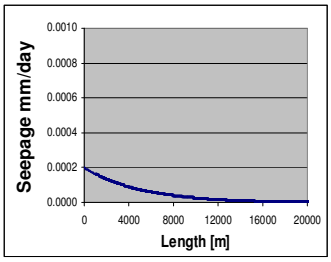
Zone of influence of sea level rise:
Case 1 with Dutch subsoil parameters

kD = 5000 m2/day
c = 5000 day
λ = 5000 m







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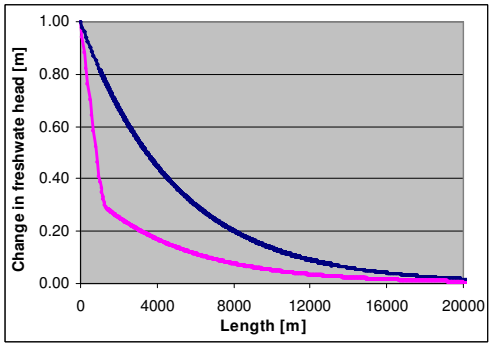
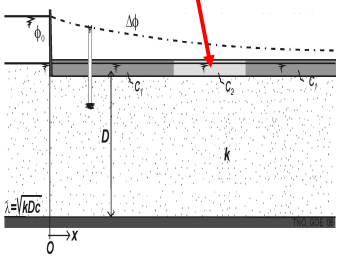
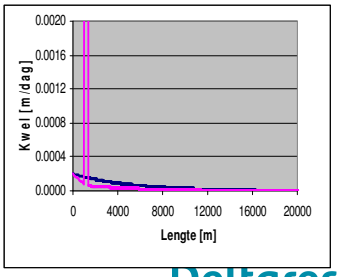
Zone of influence of sea level rise: Case 2 with Dutch subsoil parameters

good permeable aquitard

kD = 5000 m2/dag
c1 = 5000 dag c2 = 50 dag







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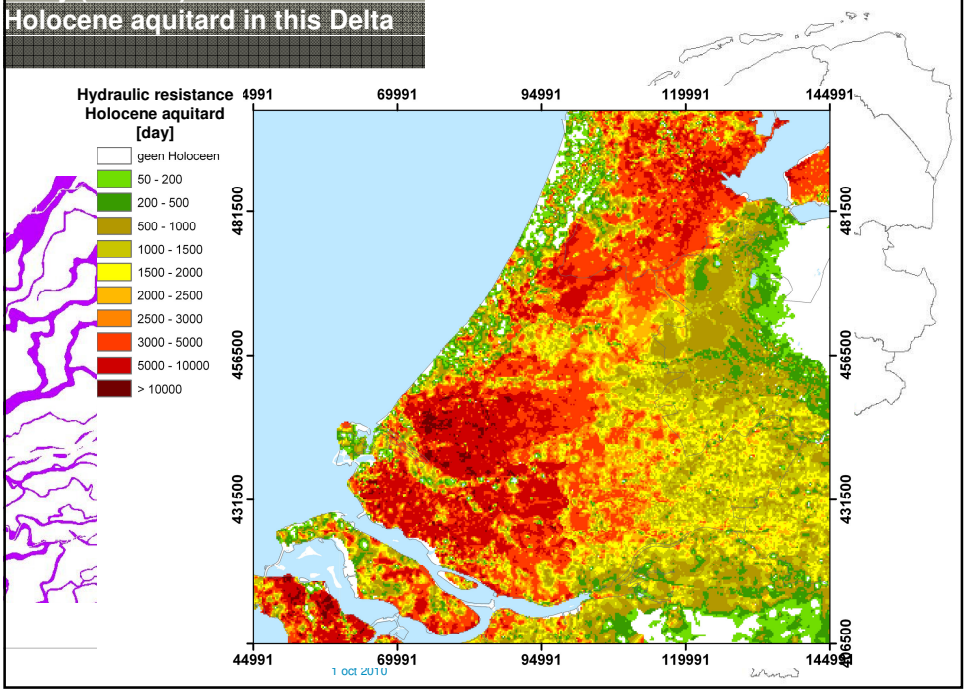
Many (burried) creeks cross the Holocene aquitard in this Delta



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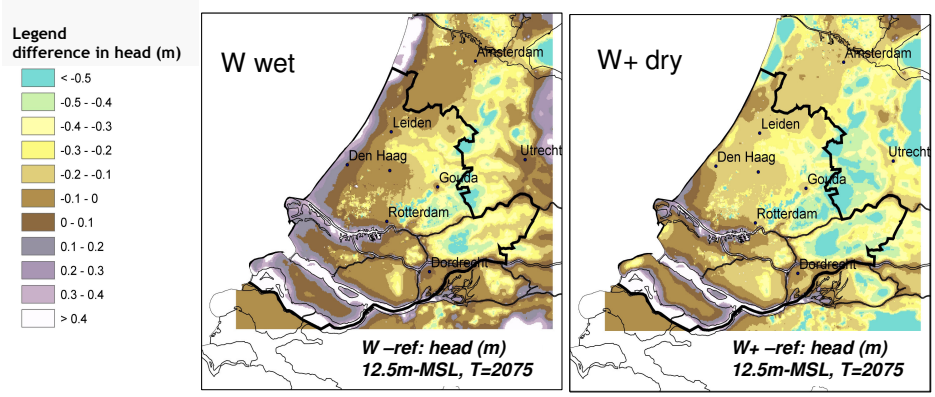
Combined effect SLR, land subsidence & change groundwater recharge

Difference in freshwater head (future-now) on op -12.5 N.A.P.: W scenarios



Sea level rise is 85 cm

Including change in natural groundwater recharge and land subsidence

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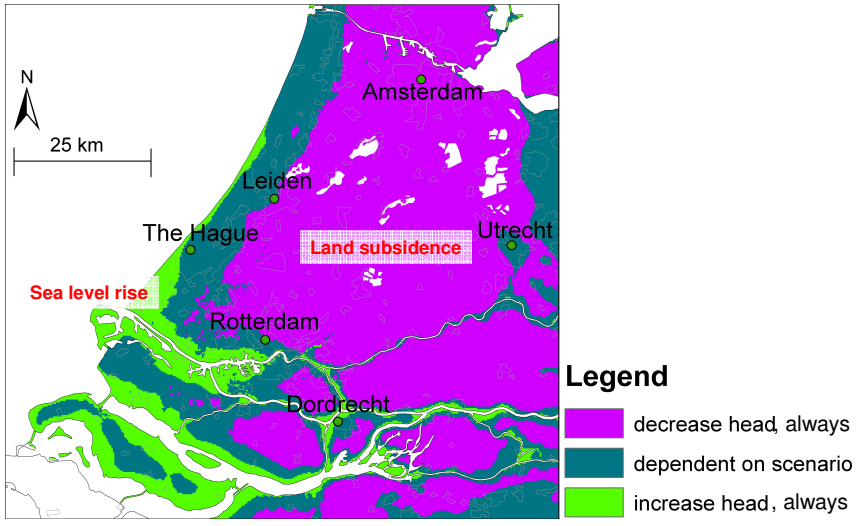
Combining effect of KNMI climate scenarios in 2075 on freshwater head



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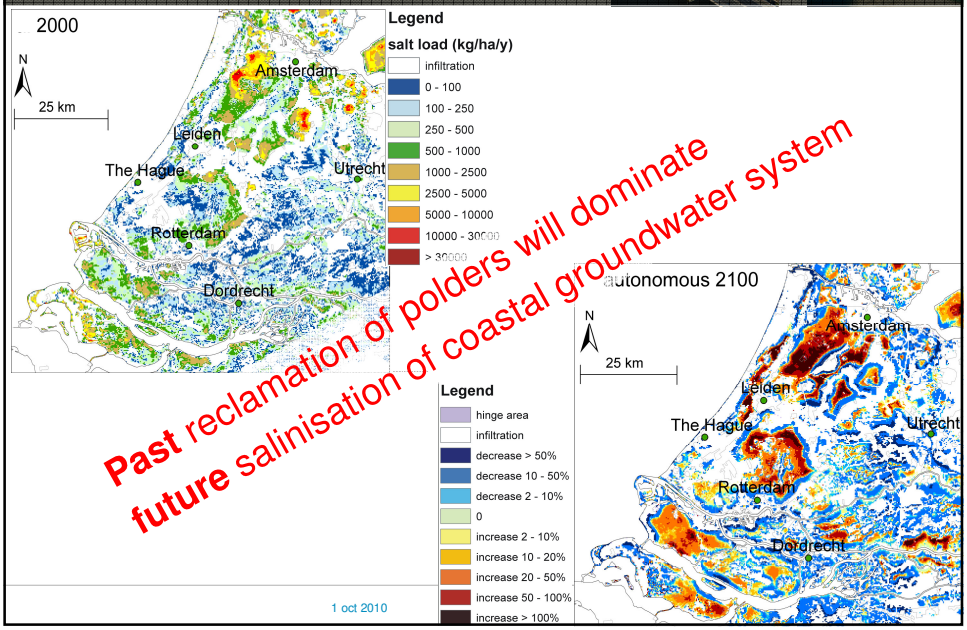
Salinisation and freshening in case BaU



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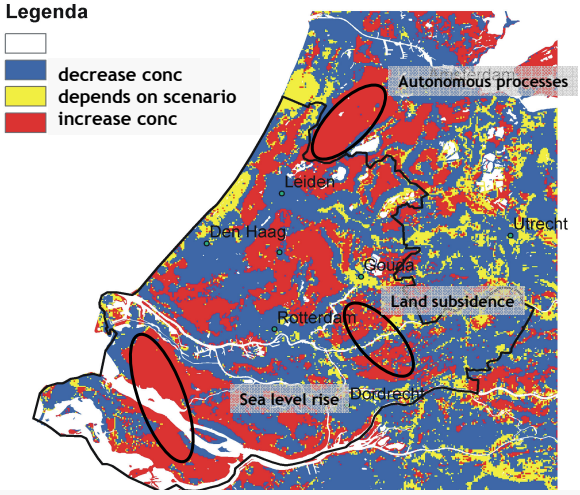
Effect climate scenarios in 2075 on salinity



Increase or decrease concentration for all climate scenarios G, G+, W, W+

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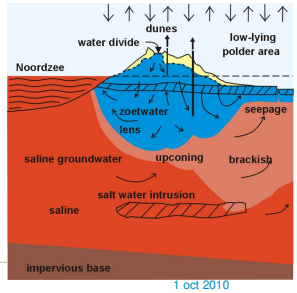
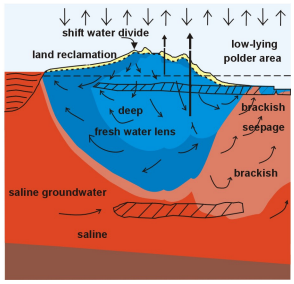
Are regional measures effective to stop salinisation?

1. Land reclamation in front of the coast
2. Inundation of low-lying polders
3. Injection of fresh surface water
4. Extraction of saline/brackish groundwater
5. Creating physical barriers

Ad a.





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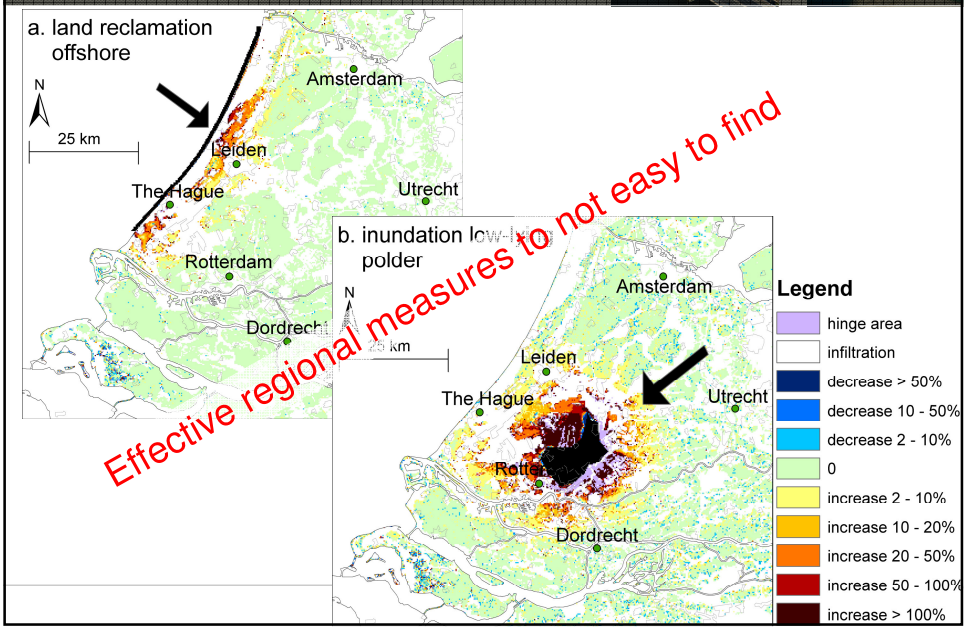
a. land reclamaton and b. inundation polders



Effective regional measures to not easy to find

Main conclusions

Zone of influnce SLR:

- Zone of influence of sea level rise is rather limited, due to geological 'shortcuts'

Salt load to surface water:

- Past reclamation of polders will dominate future salinisation and freshening of coastal groundwater system

Future plans:

- Assess the (un)feasibility of regional measures to stop salinisation
- Incorporate local processes into regional models, such as preferential saline seepage through boils

Article in Water Resources Research (from half oct. 2010):
Oude Essink, G.H.P., Baaren, E.S., van, De Louw, P.G.B., Effects of climate change on coastal groundwater systems: a modeling study in the Netherlands

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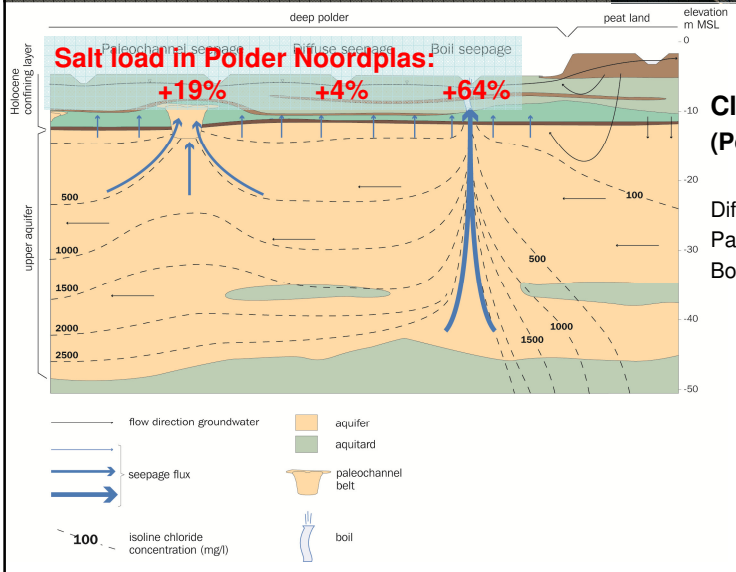
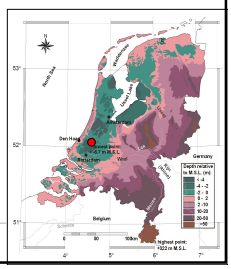
Three types of upward groundwater seepage



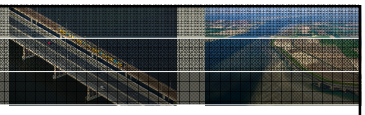
Cl-conc seepage:
(Polder Noordplas)

Diffuse : 100 mg/l
Paleochannel : 600 mg/l
Boils : 1100 mg/l



From: De Louw et al., 2010, J. Hydrology

Main conclusions



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- Incorporate local processes into regional models, such as preferential saline seepage through boils

Article in Water Resources Research (from half oct. 2010):
Oude Essink, G.H.P., Baaren, E.S., van, De Louw, P.G.B., Effects of climate change on coastal groundwater systems: a modeling study in the Netherlands

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