Kennis voor Klimaat

Deltares
Enabling Delta Life

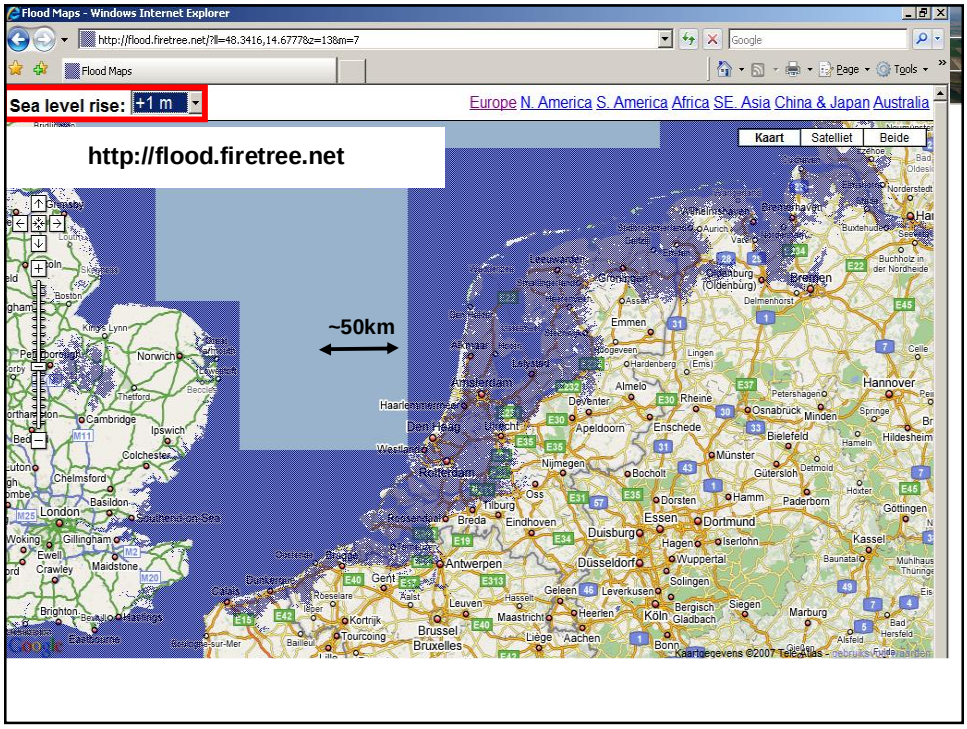
Impacts of climate change on a coastal groundwater system in The Netherlands

Anthropogenic processes and climate change

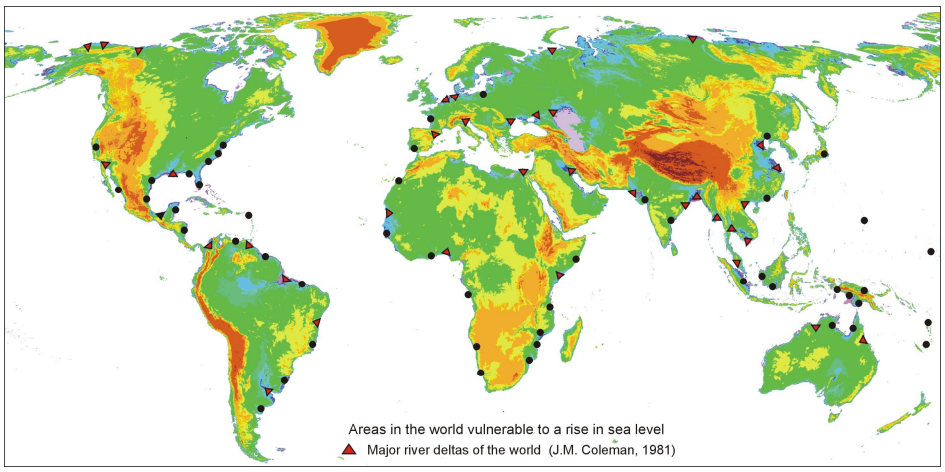
and some sheets for WP2

Gualbert Oude Essink
Esther van Baaren, Perry de Louw
Subsurface and Groundwater Systems
Deltares

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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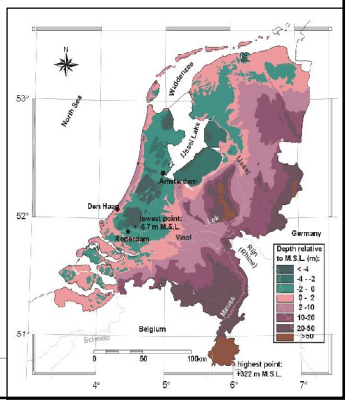
The 'low-lying' lands: Netherlands

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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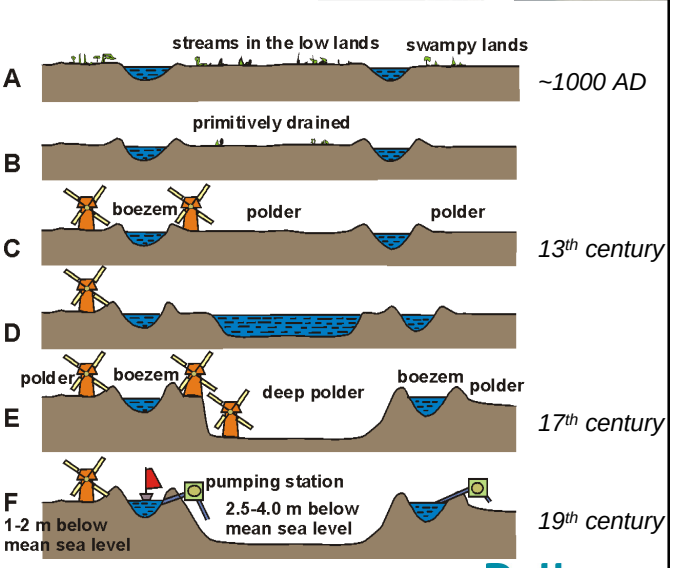
Development of the Dutch 'Polder' Landscape



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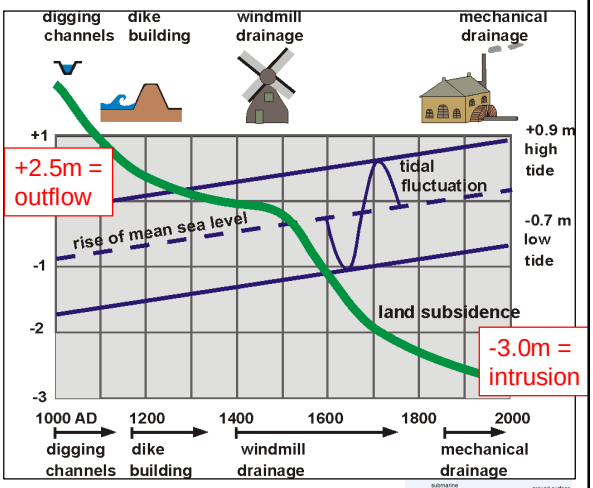
From fresh water outflow to salt water inflow

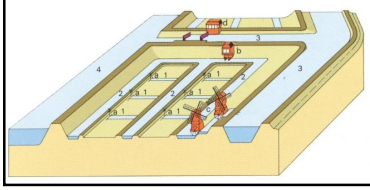
Historical subsidence of the ground surface in Holland

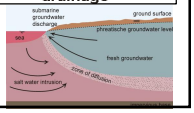
Causes:

Autonomous processes
- Land subsidence
- Abrupt land reclamation

Climate change
- Sea level rise
- Change in net recharge







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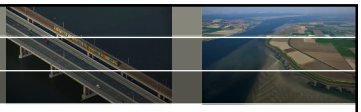

To get an idea about the possible future effects of SLR and climate change in your delta …

evaluate of the past water management in the Dutch delta

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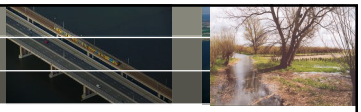

Groundwater in the future

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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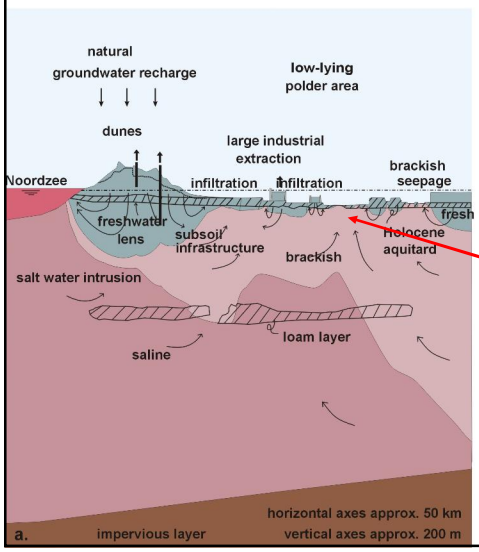
A (Dutch) groundwater system

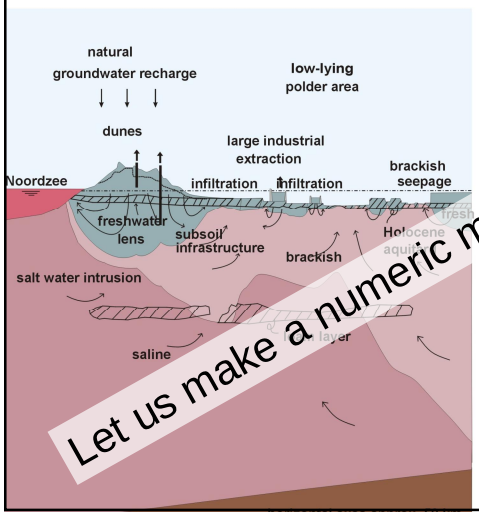
Present processes



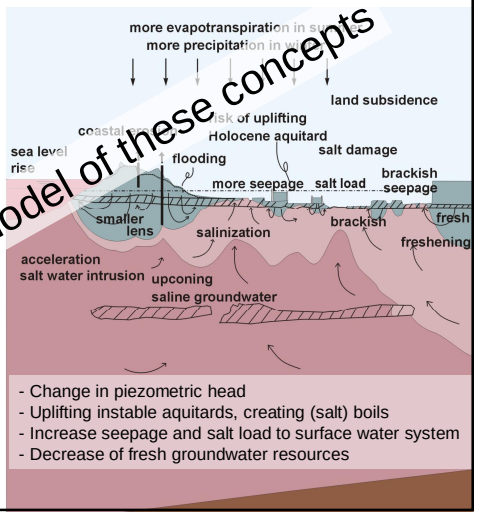
Present saline seepage is from old marine deposits, not from recent Noordzee sea water intrusion

A (Dutch) groundwater system under stress

Present processes



Future changes

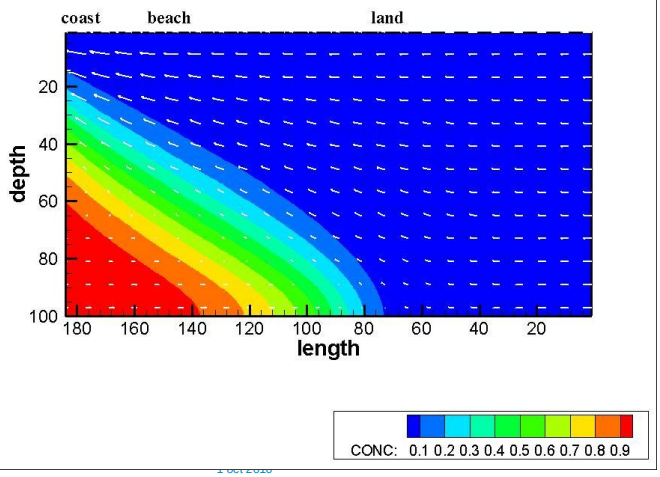


- Change in piezometric head
- Uplifting instable aquitards, creating (salt) boils
- Increase seepage and salt load to surface water system
- Decrease of fresh groundwater resources

Let us make a numeric model of these concepts

Definition of salt water intrusion

Numerical model: Henry's case



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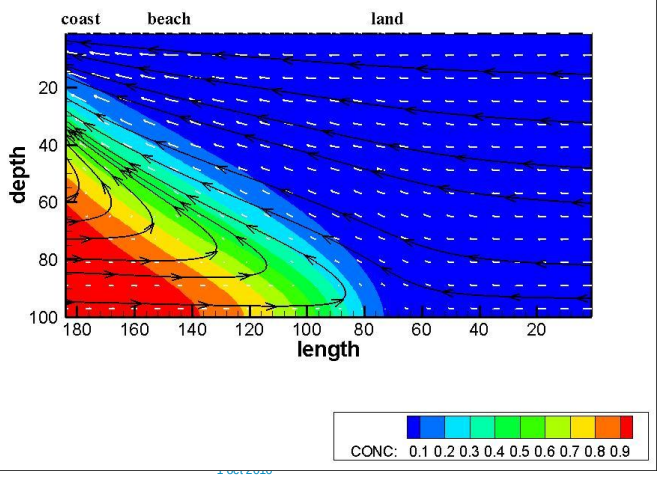
Definition of salt water intrusion

Numerical model: Henry's case



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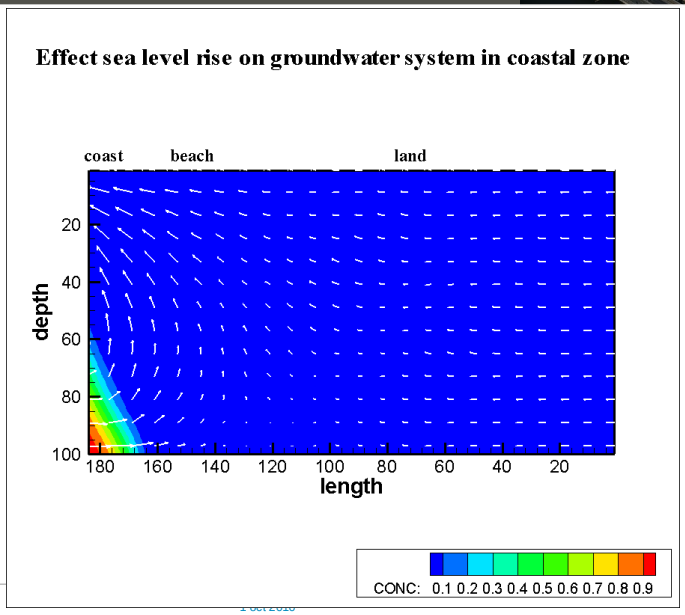
Sea level rise and salt water intrusion



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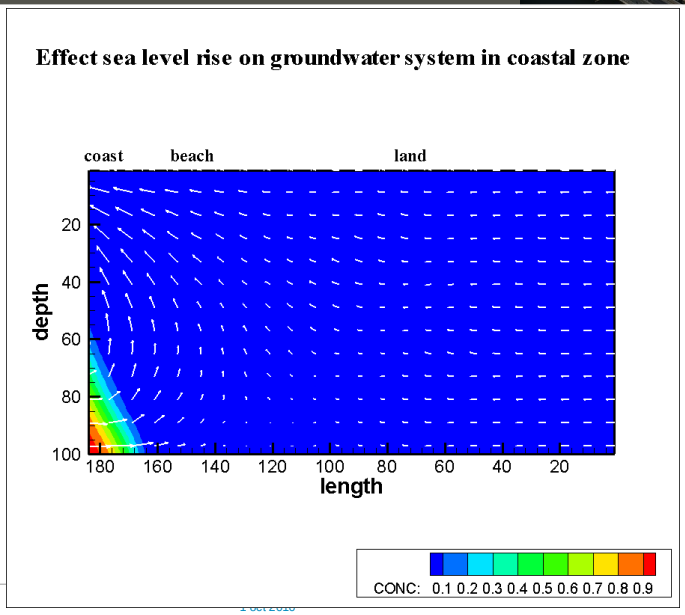
Sea level rise and salt water intrusion



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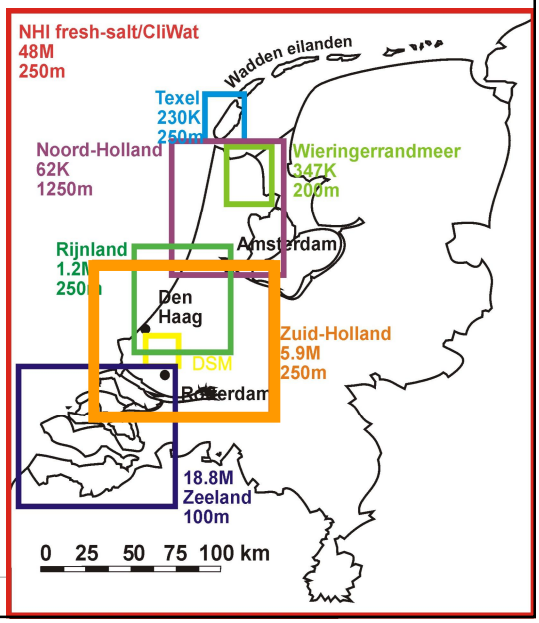
Numerical modelling of salt water intrusion

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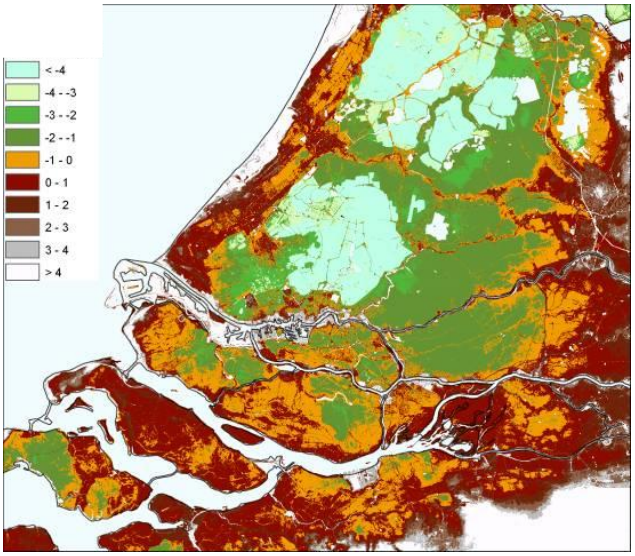
Model input (1/5): Ground surface (m)



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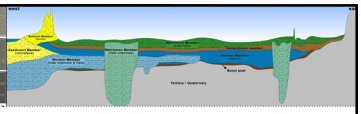
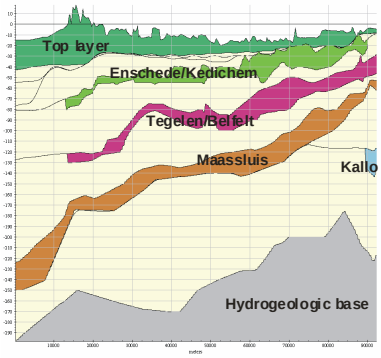
Model input (2/5): Geology

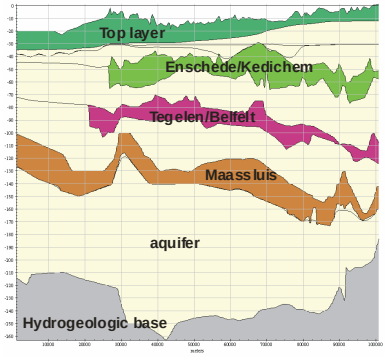


Regional Geohydrological Information System REGIS (TNO)

Profile 1



Profile 2



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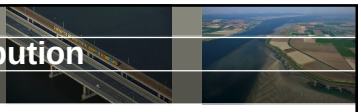
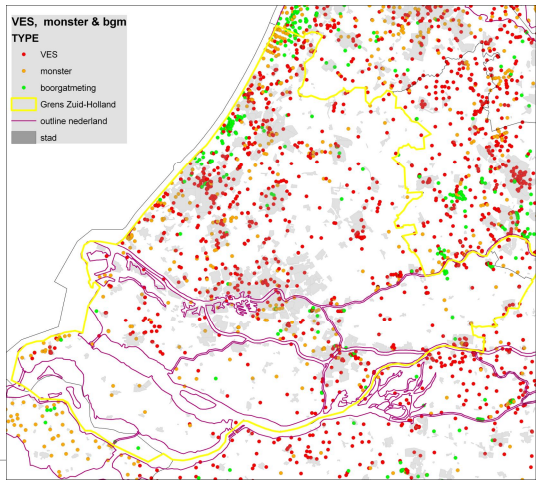
Model input (3/5): initial salinity distribution



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



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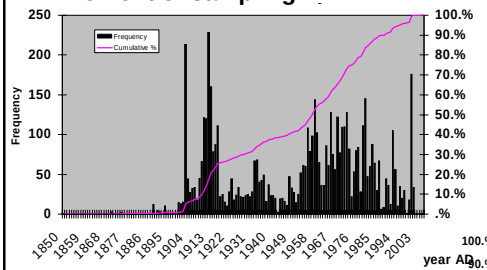
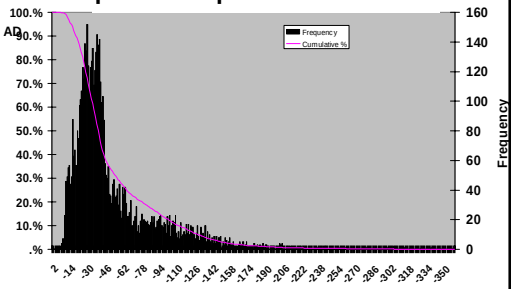
Model input (3/5): initial salinity distribution

- Samples (# = 6000)

Moment of sampling



Depth of sample



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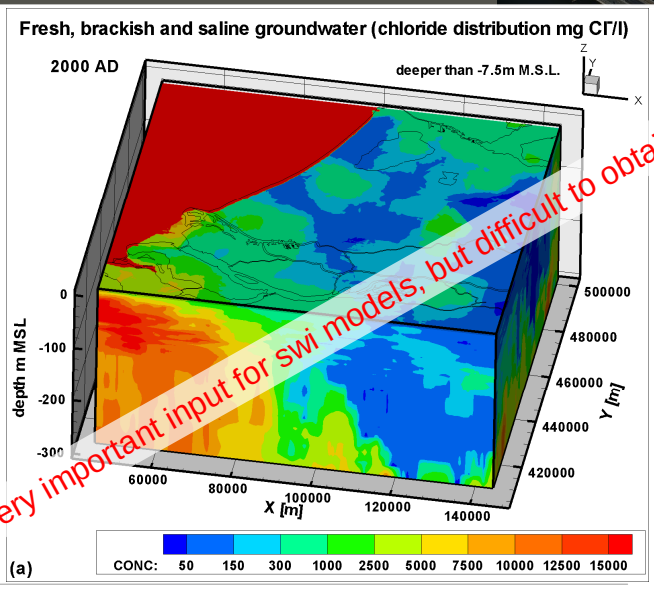
Model input (3/5): initial salinity distribution



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

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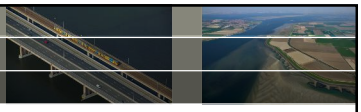

Intermezzo

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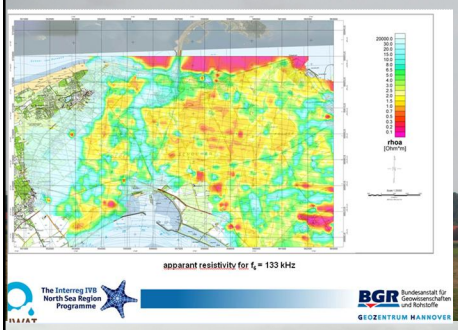
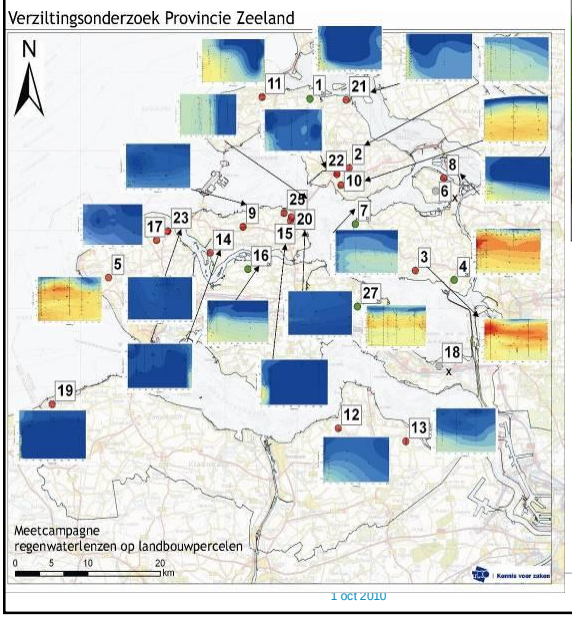
Innovations: Airborne EM (HEM/Sky-TEM)



CLIWAT
CLIMATE & WATER

TEC-probe results



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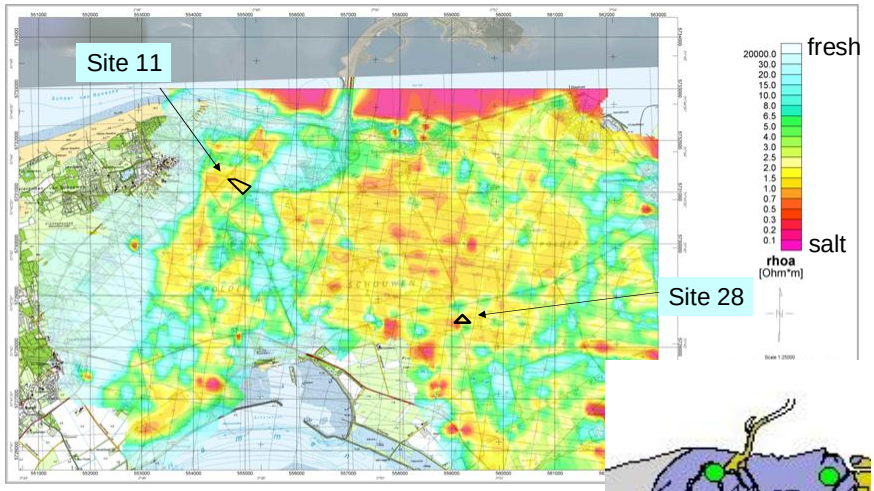
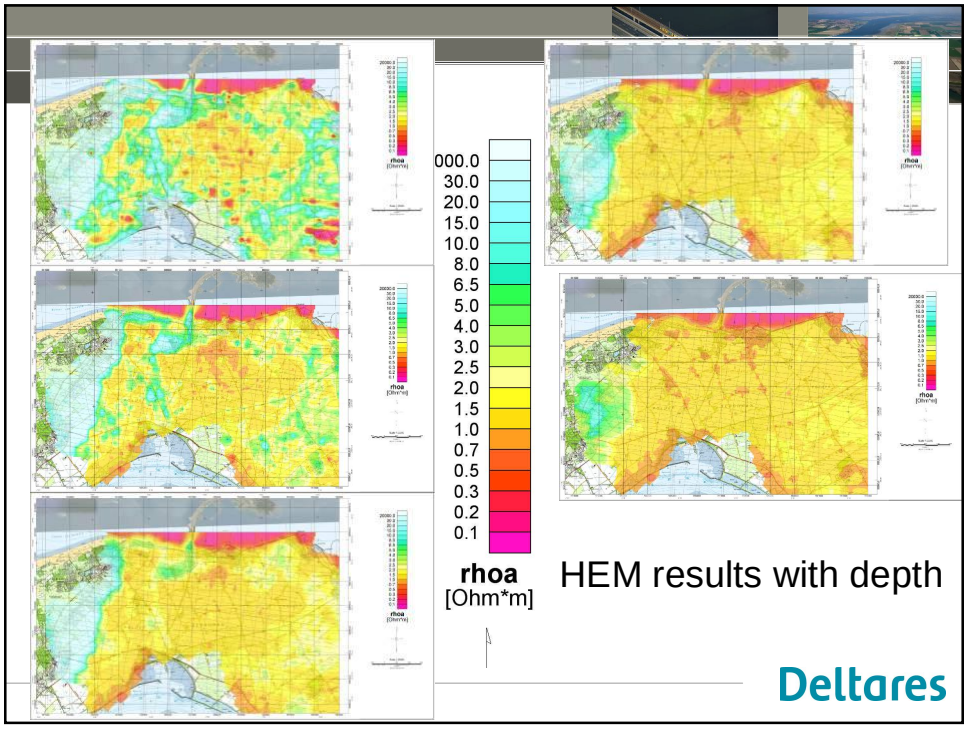
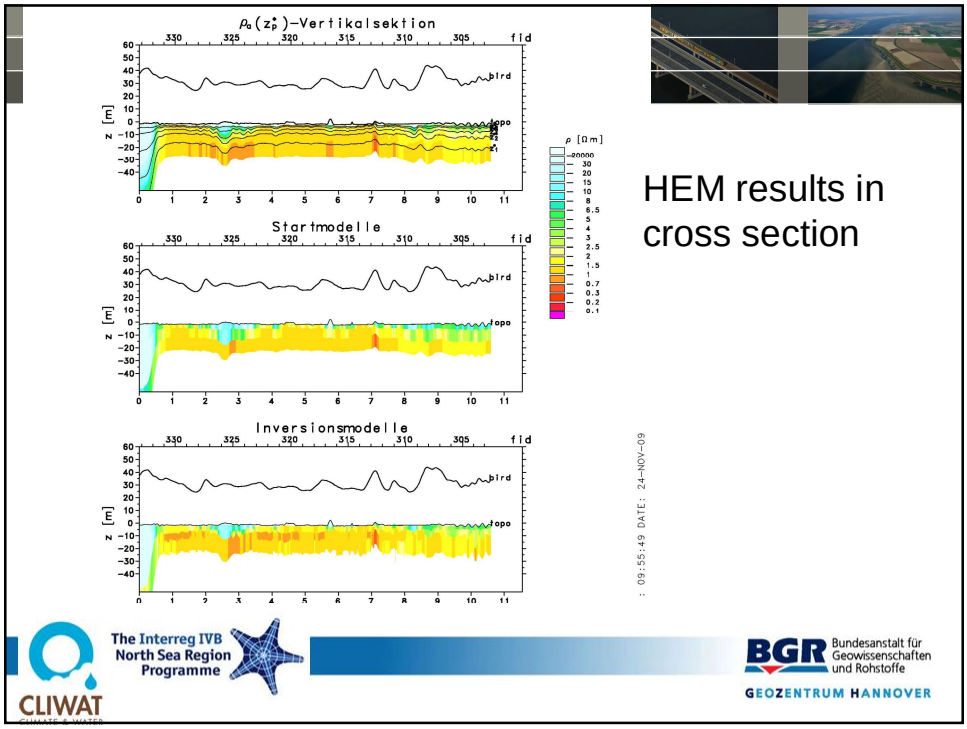
HEM results

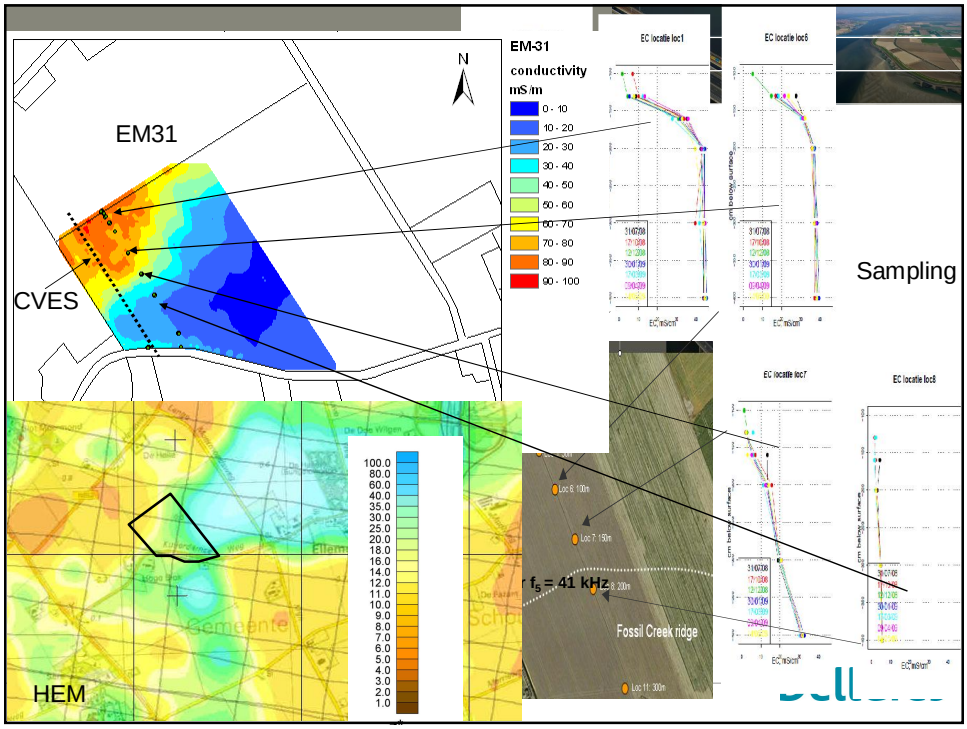


The Interreg IVB North Sea Region Programme

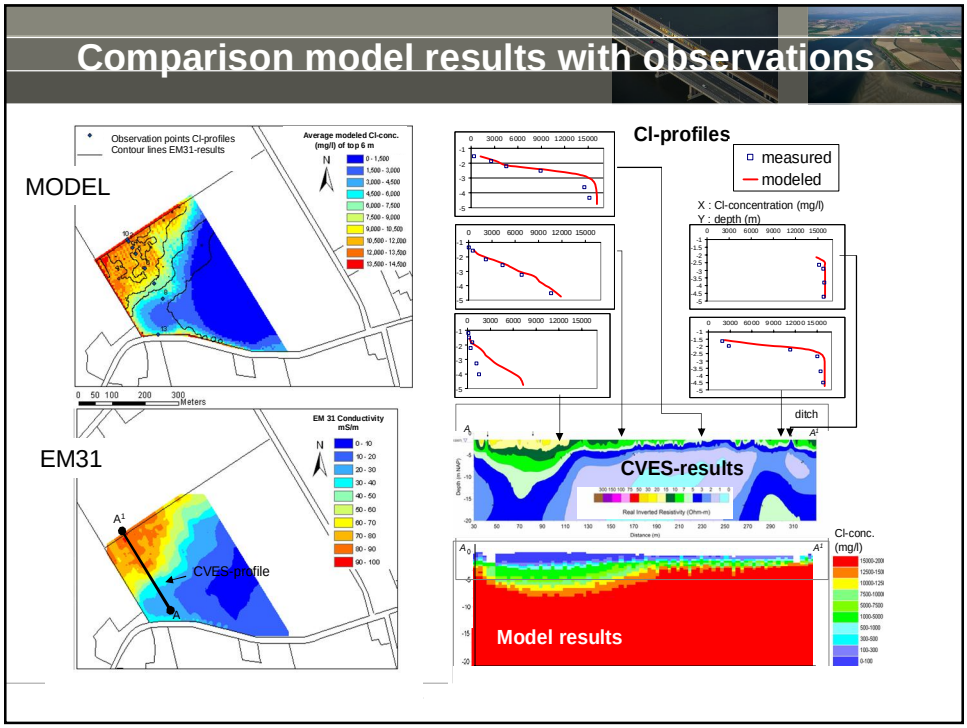
GEOZENTRUM HANNOVER


000.0
30.0
20.0
15.0
10.0
8.0
6.5
5.0
4.0
3.0
2.5
2.0
1.5
1.0
0.7
0.5
0.3
0.2
0.1
rhoa
[Ohm*m]
HEM results with depth
Deltares

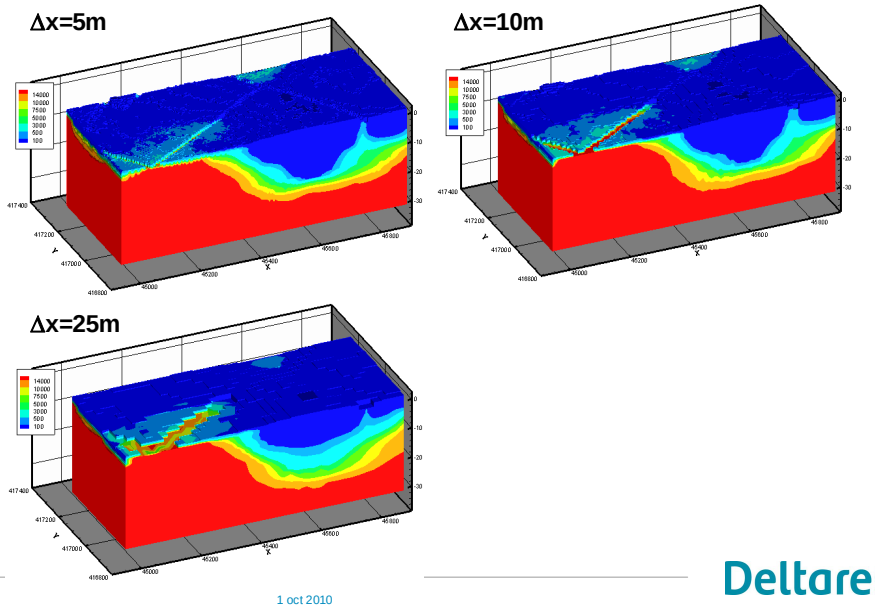

Vertikalsektion
Startmodelle
Inversionsmodelle
HEM results in cross section
The Interreg IVB North Sea Region Programme
CLIWAT
BGR Bundesanstalt für Geowissenschaften und Rohstoffe
GEOZENTRUM HANNOVER



Comparison model results with observations



Voorbeeld schaal modelcel, 3D lokaal zz model



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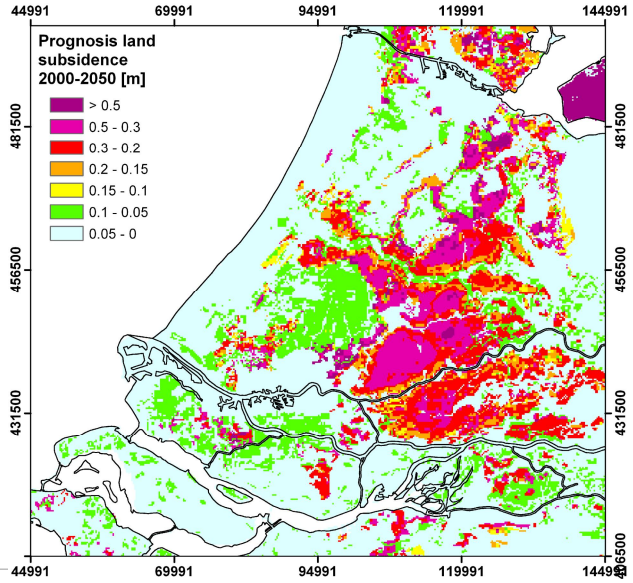
Model input (4/5): land subsidence



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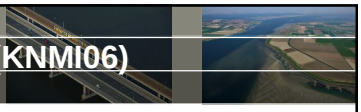
Model input (5/5): climate scenarios (KNMI06)



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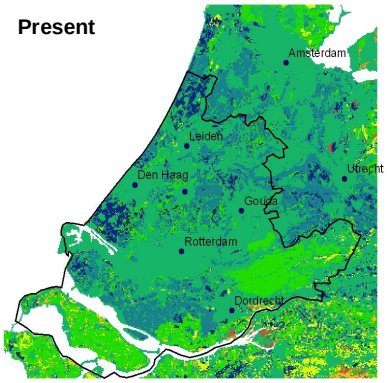
Model input (5/5): Change in groundwater recharge

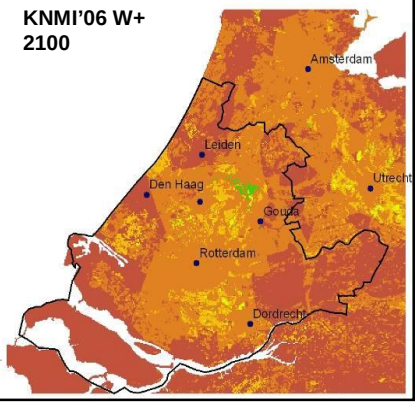
Present



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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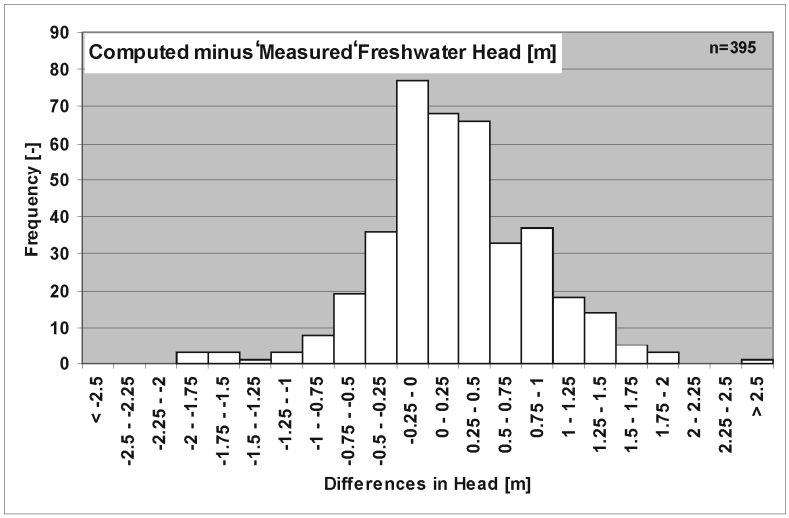
Calibration



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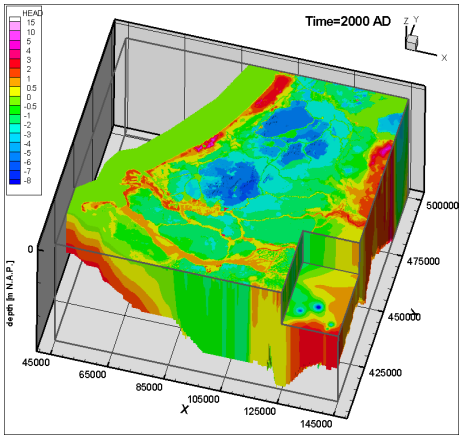
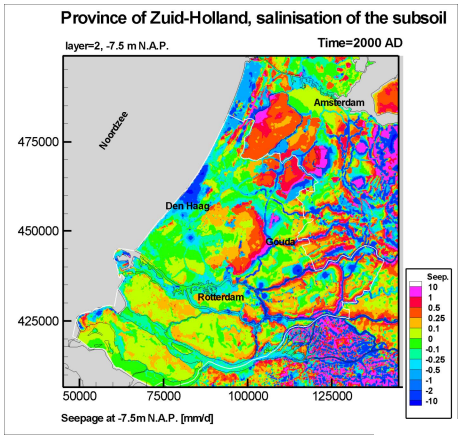
Results

Freshwater heads



Seepage or infiltration



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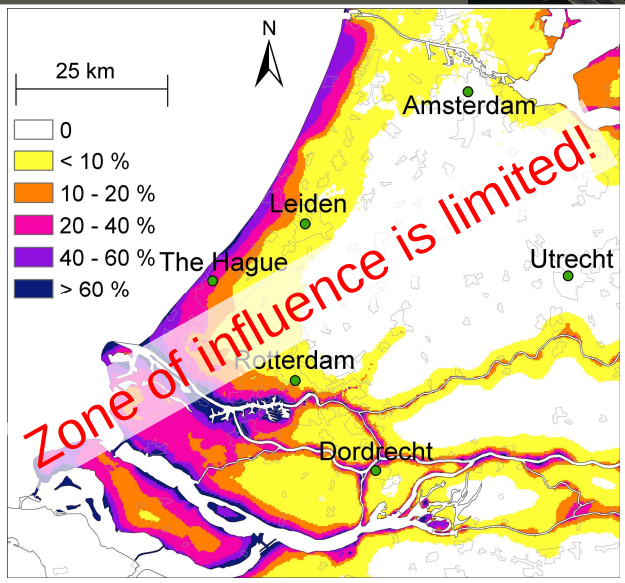
Zone of influence of sea level rise



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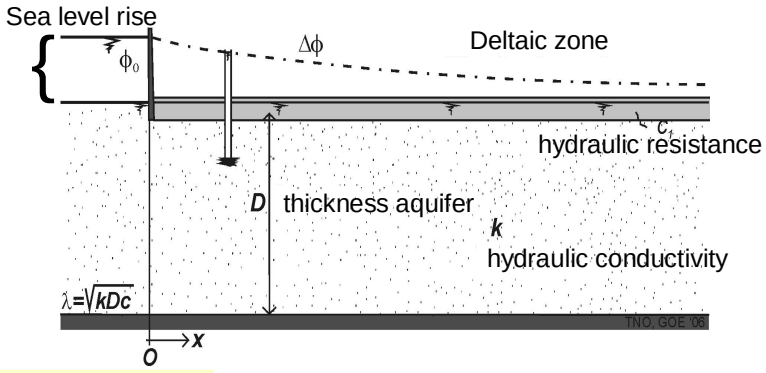
Explanation limited zone of influence sea level rise

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 $\sqrt{(kDc)}$

At x=3λ, only 5% of sea level rise is detectable

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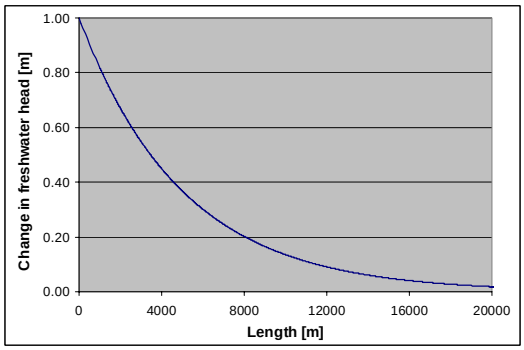
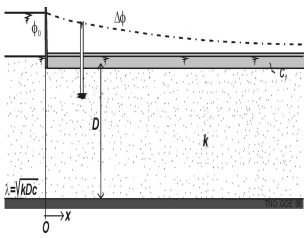
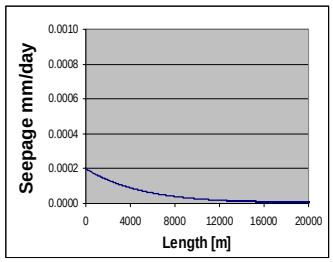
Zone of influence of sea level rise:

Case 1 with Dutch subsoil parameters

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







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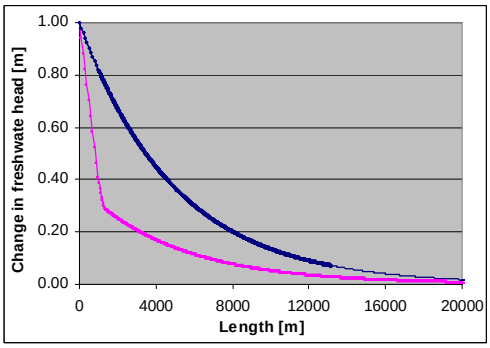
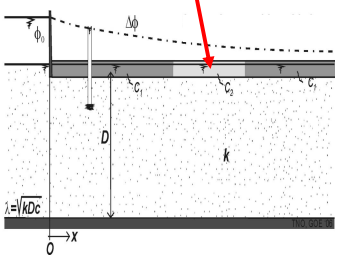
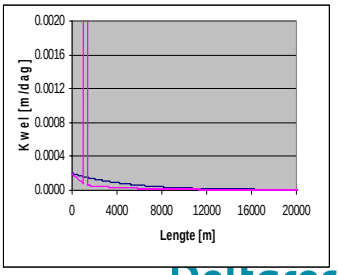
Zone of influence of sea level rise: Case 2 with Dutch subsoil parameters

good permeable aquitard

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







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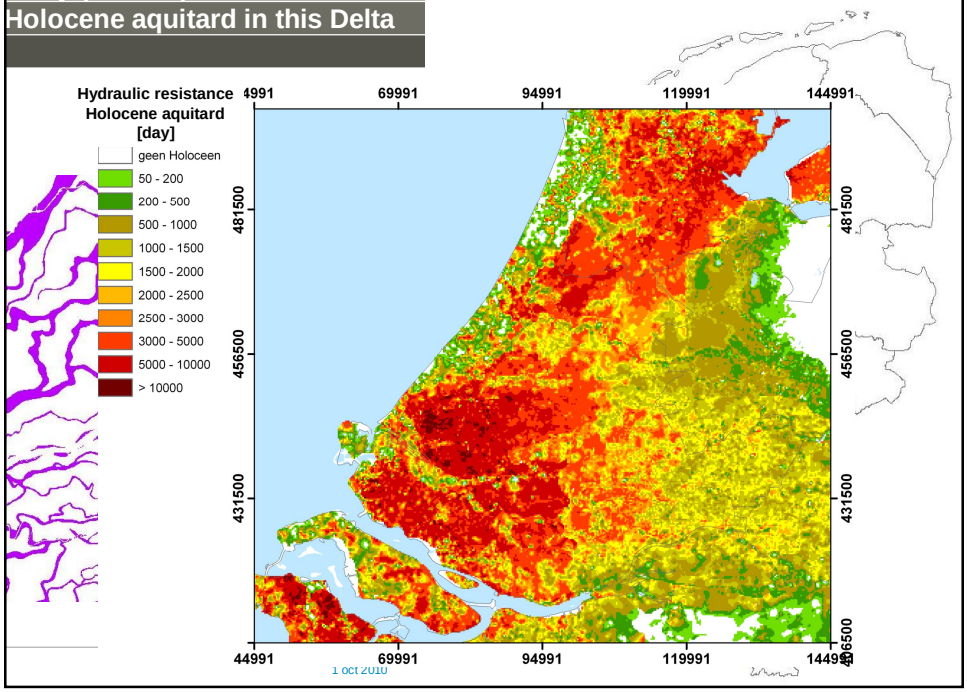
Many (burried) creeks cross the Holocene aquitard in this Delta



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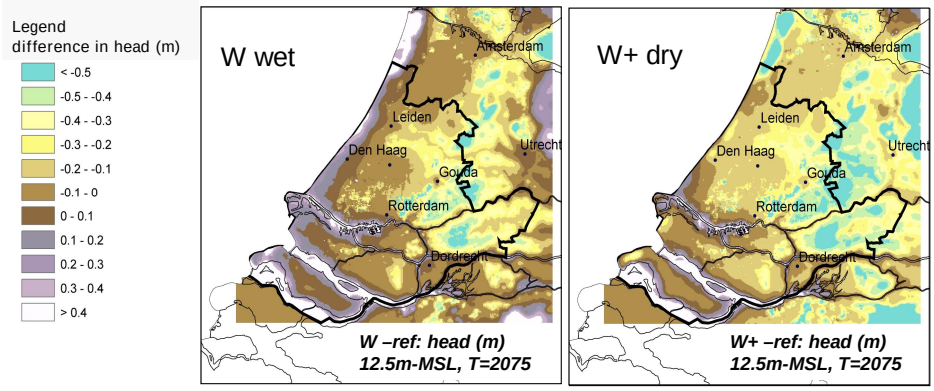
Combined effect SLR, land subsidence & change groundwater recharge

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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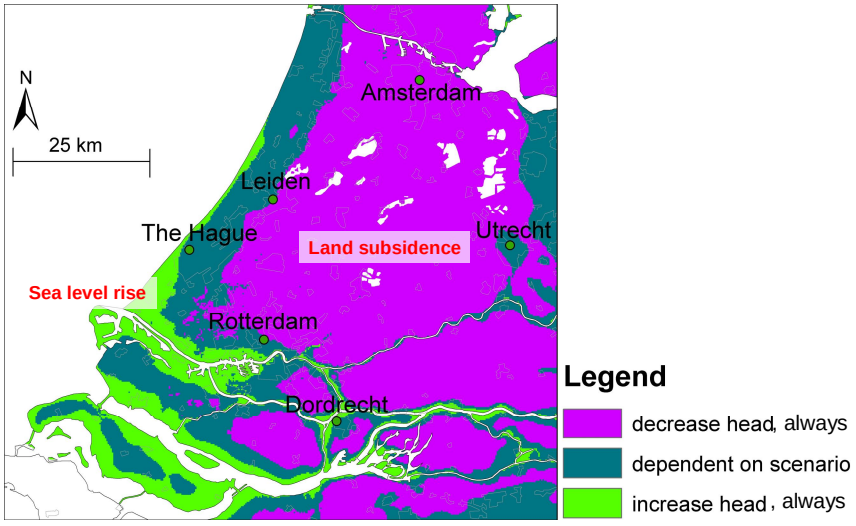
Combining effect of KNMI climate scenarios in 2075 on freshwater head



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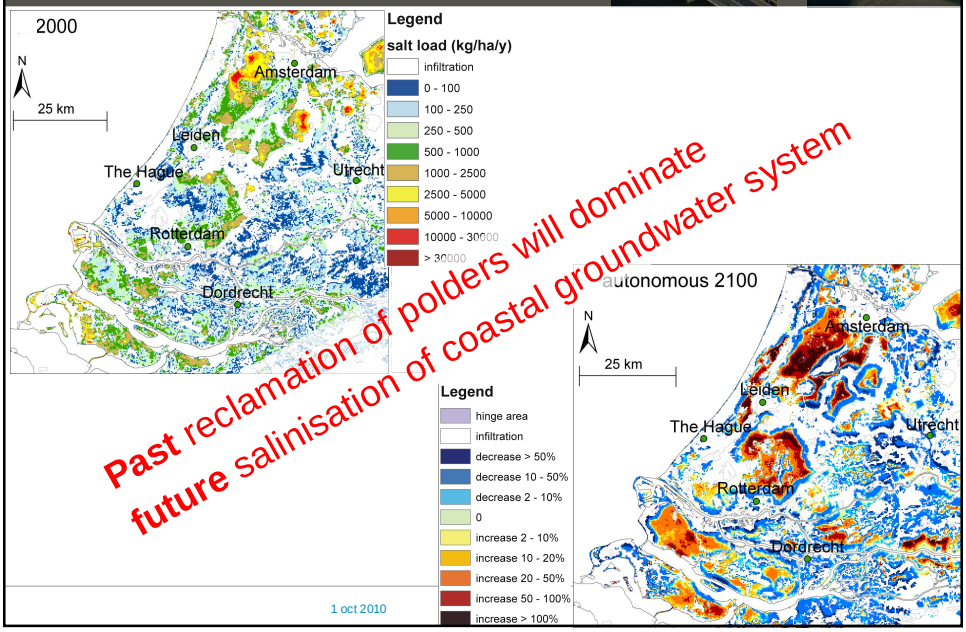
Salinisation and freshening in case BaU



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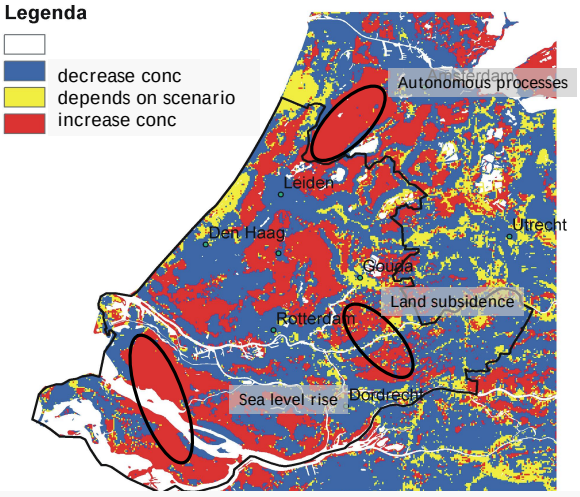
Effect climate scenarios in 2075 on salinity



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

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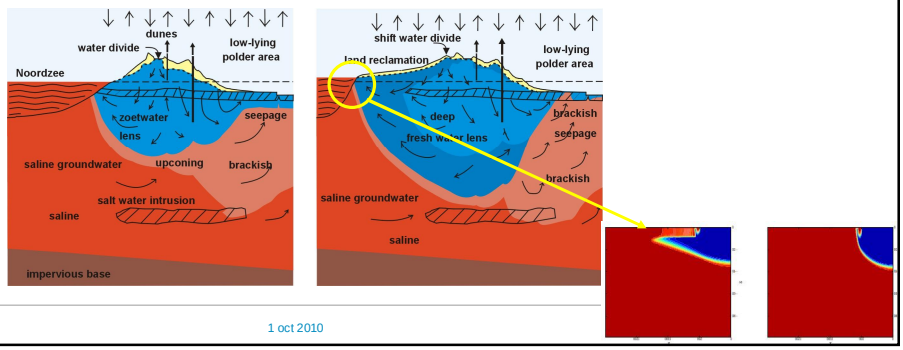
Are regional measures effective to stop salinisation?

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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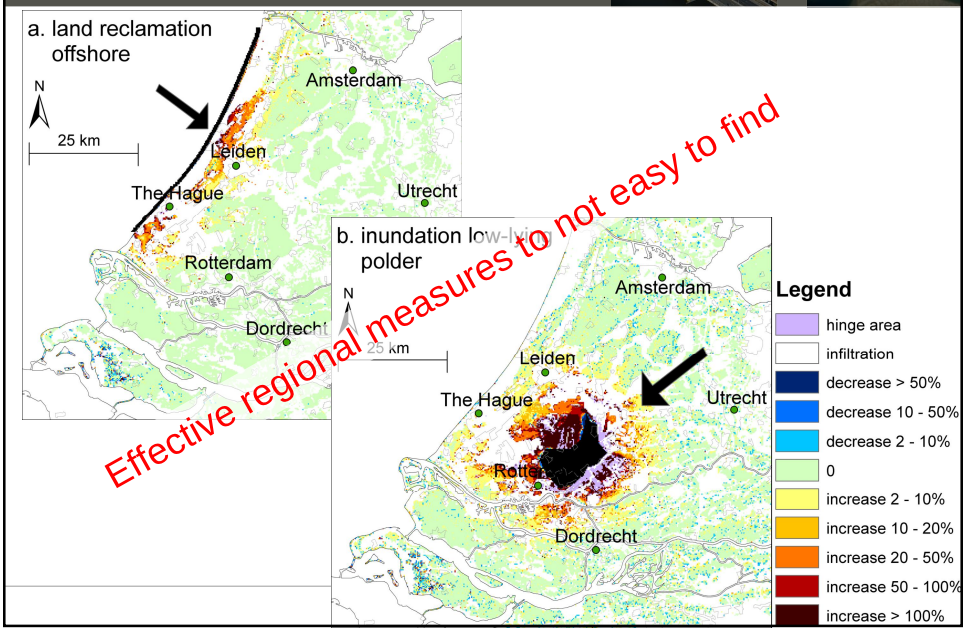
a. land reclamaton and b. inundation polders



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

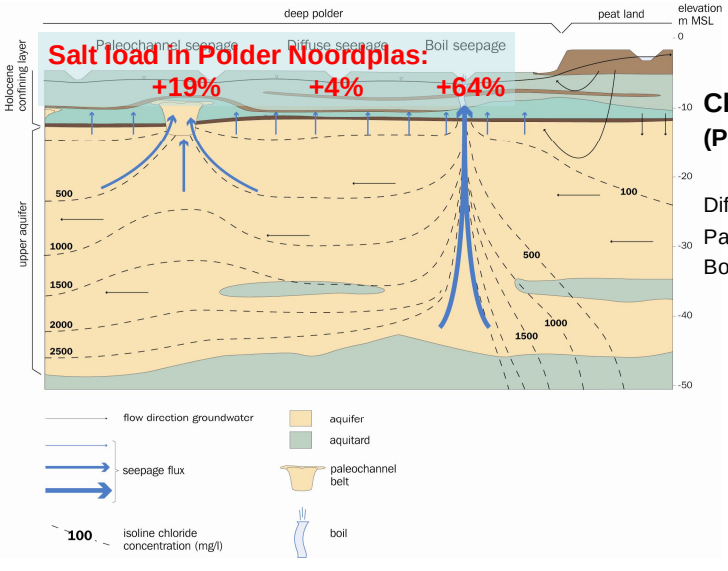
Future plans:

- 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:
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

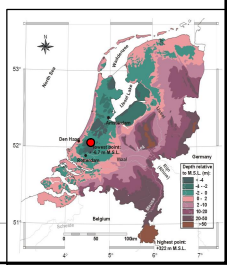
Deltares

Onderzoek zoute wellen en verzilting OW

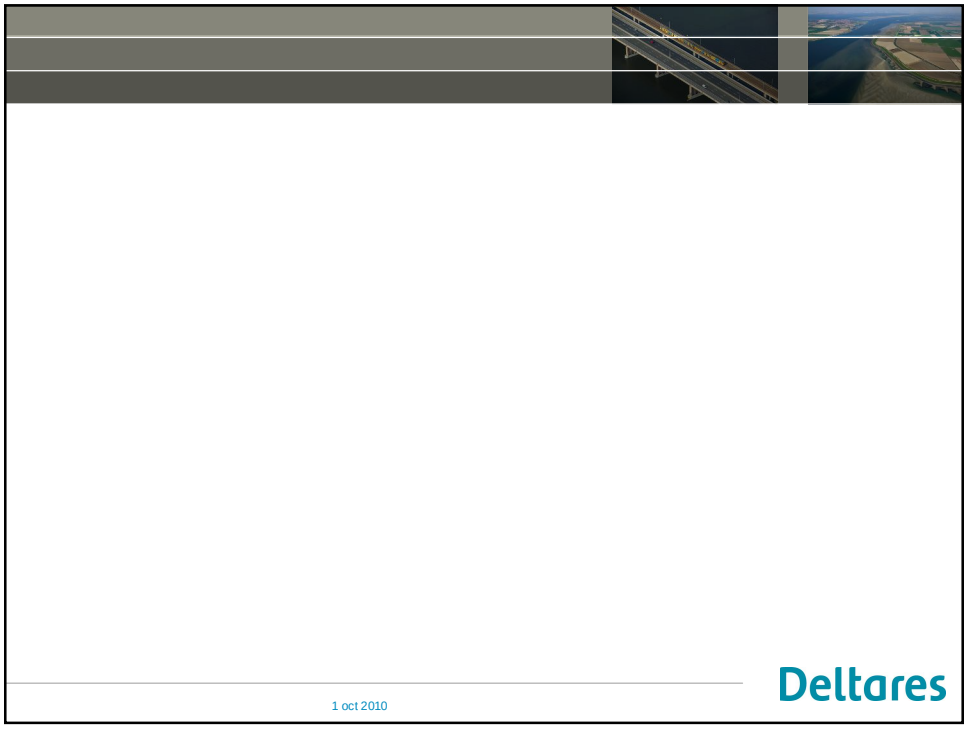


Cl-conc seepage: (Polder Noordplas)

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



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



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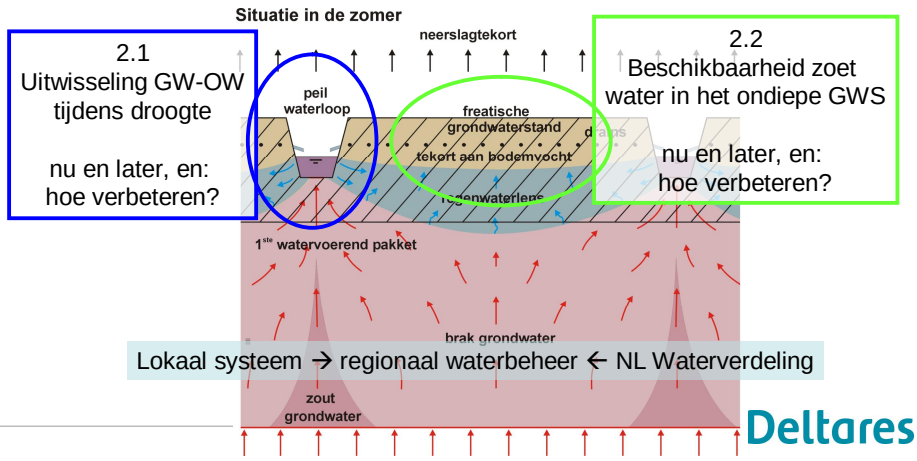
WP2: Adapting fresh water supply and buffering capacity to a changing climate

Hoofddoel:

Welke maatregelen zijn toe te passen om systeem-eigen zoetwaterbeschikbaarheid te optimaliseren, gegeven klimaatverandering?



2.1
Uitwisseling GW-OW tijdens droogte

nu en later, en:
hoe verbeteren?

2.2
Beschikbaarheid zoet water in het ondiepe GWS

nu en later, en:
hoe verbeteren?

Lokaal systeem → regionaal waterbeheer ← NL Waterverdeling

Deltares

Gekoppeld Grondwater – Oppervlaktewater

Oppervlaktewater onder zoute en droge omstandigheden voor het vinden van een klimaatrobuuste regionale zoetwatervoorziening

Vraagstelling:

- Polders in laaggelegen deltagebieden: problemen met zoetwaterbeschikbaarheid
- Detailprocessen (als wellen, drains) GW-OW invloed op grotere schaal
- 'Waar blijft het inlaatwater in polders?'
- Voor toekomst- en maatregelscenario's is kwantitatief instrumentarium nodig

Aanpak onderzoek

- Opbouw analyseraamwerk regionaal waterbeheer voor droge perioden
- Inzicht uitwisseling OW-GW in combinatie met verzilting (en nutriënten): meten
- Inzicht werking doorspoeling op slootniveau: meten
- Doorrekenen klimaatreeksen op de hydro(geo)logie van het watersysteem
- Onderzoeken maatregelstrategieën: op locale schaal en op regionale schaal
- Lokaal systeem → regionaal waterbeheer ← NL Waterverdeling

Cases:

Case Groene Ruggengraat (Rijnland)
Case Haaglanden: generieke kennis
Case Zuidwestelijke Delta

Joost Delsman
Deltares

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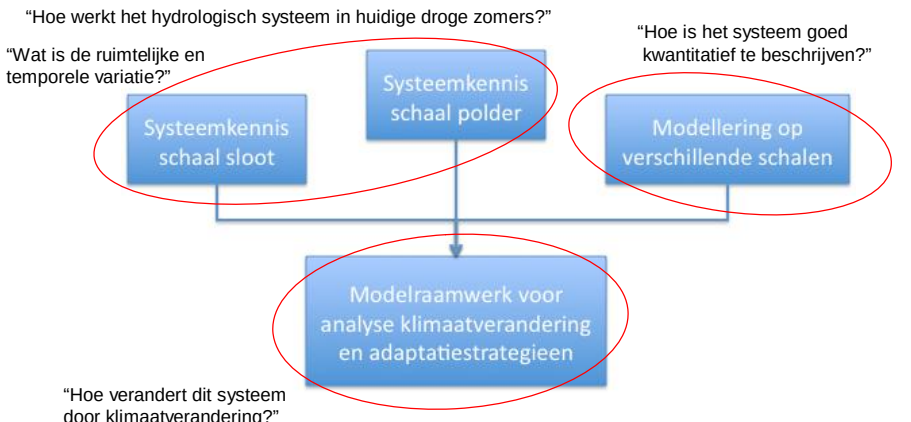
Onderzoek interactie GW-OW: droog en zout



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Zoetwatervoorraad in zoetwaterlenzen

Zoetwatervoorraad in neerslaglenzen onder druk van klimaatverandering

laten toenemen van de lokale beschikbaarheid van zoet water door het creëren van een robuust en flexibel buffersysteem om zoet water in de ondergrond in regenwaterlenzen op lokale schaal te bergen.

1. ***kleine lenzen op landbouwpercelen***
2. ***medium lenzen op kreekruggen***
3. ***grote lenzen onder duingebieden***

Cases:
Zuidwestelijke Delta: vervolg Zeeland studie Provincie Zeeland
Haaglanden

Pieter Pauw
Deltares

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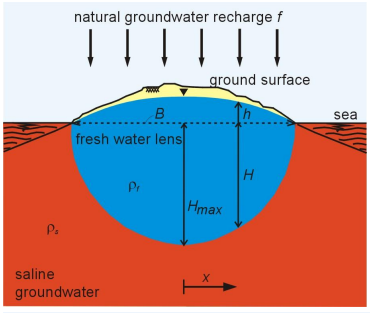
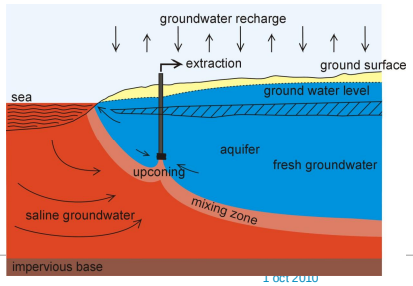
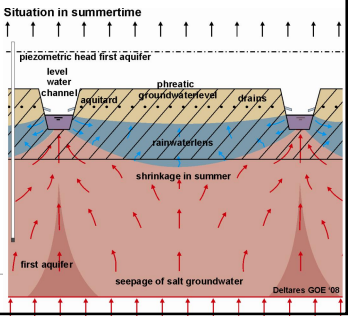
Onderzoek kwetsbaarheid regenwaterlenzen







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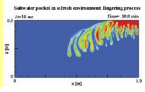
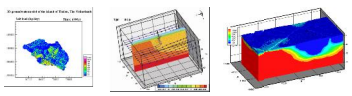
Different model cell sizes to consider several phenomena

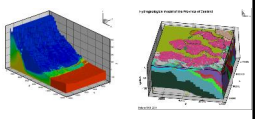
Sub-local: fingering, salty sand boils
Sri Lanka (Tsunami 2004), Zandmotor
cell size=1cm-1m



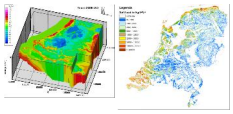
Local: rainwaterlenses, heat-cold
Tholen, Schouwen-Duiveland
cell size=5-25m



Regional:
Zeeland, Gujarat/India, Philippines
cell size=100m



National: salt load
Zuid-Holland, NHI
cell size=250m-1km



Goal:
To take largest cell size possible to accurately model relevant salinisation processes

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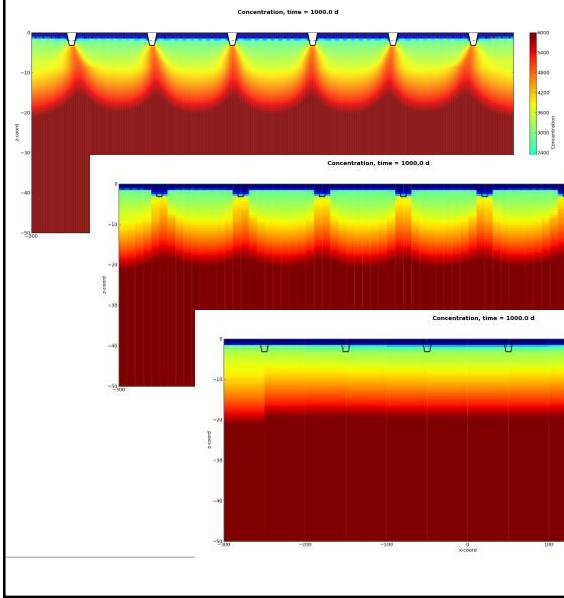
Modelmatig opschalen



Celgrootte: 0,5m
Zoutvracht: 3000 kg/d

Celgrootte: 10m
Zoutvracht: 1750 kg/d

Celgrootte: 50m
Zoutvracht: 2000 kg/d

α_L=0.01m

Deltares