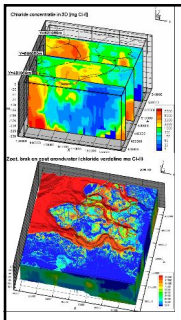
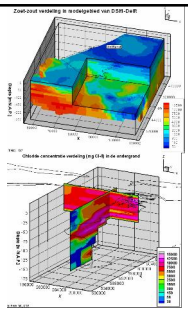


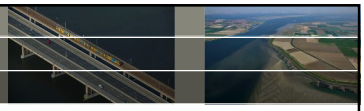


Deltares
Enabling Delta Life

How to determine a 'reliable' 3D fresh-brackish-saline distribution in data-rich coastal groundwater systems

Gualbert Oude Essink
E. Van Baaren, M. Faneca, P. De Louw

Why?



- Groundwater and solute transport are coupled, the density influences grondwater velocities
- To proper estimate the effect of global and climate change (salt loads, fresh water resources, etc.)

A good initial density distribution is essential

Context

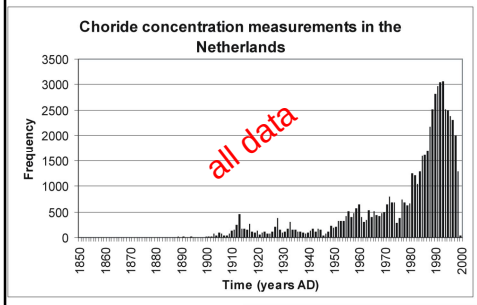
- We have an enormous amount of conc. data
- Still, not enough for a proper initial 3D chloride concentration

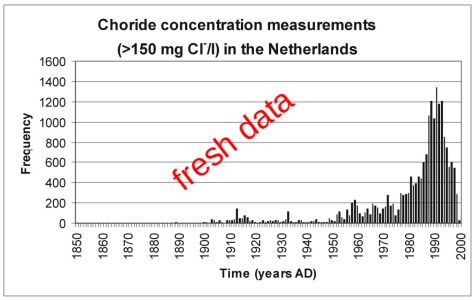
- At SWIM22: preliminary results…, only qualitative comparison
- Approach not yet scientifically sound enough but promising!

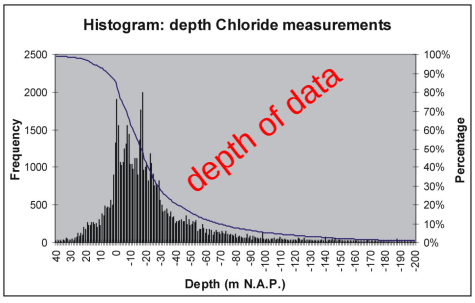
- We want feedback

Deltares

chloride samples per years/per depth







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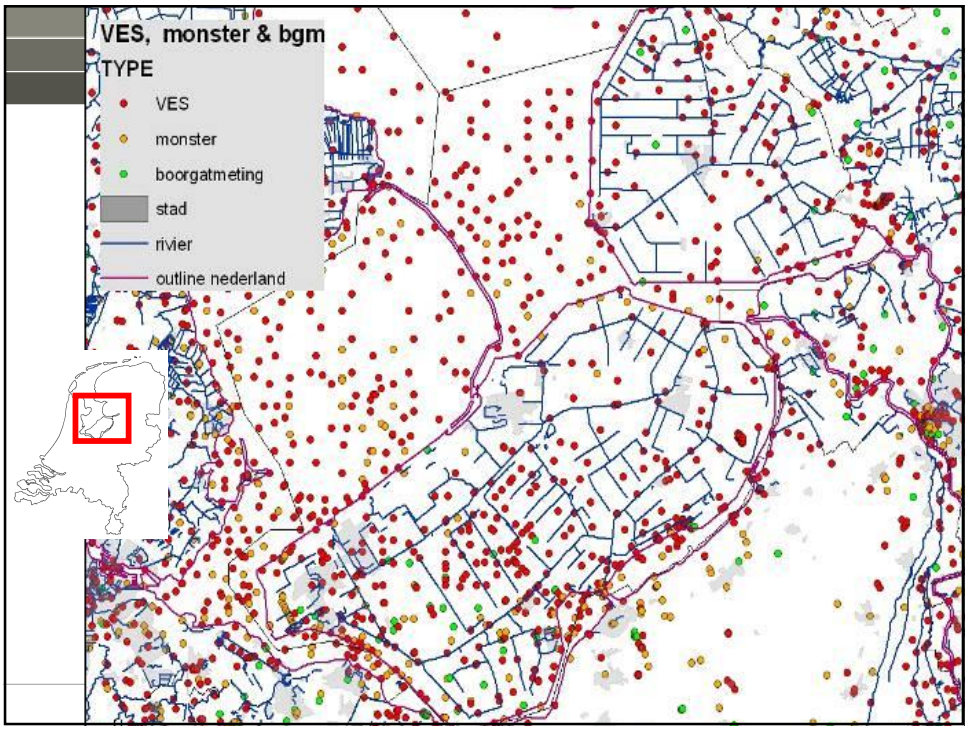
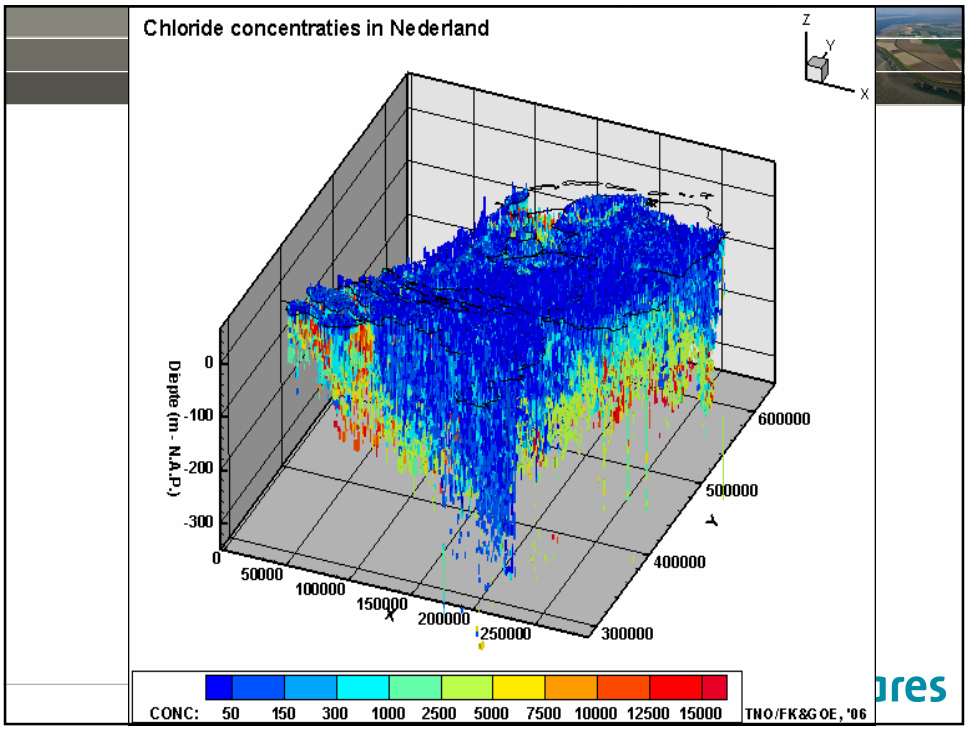

VES, monster & bgm
TYPE
VES
monster
boorgatmeting
stad
rivier
outline nederland


Chloride concentraties in Nederland
Z
Y
X
Depth (m - N.A.P.)
0
-100
-200
-300
0
50000
100000
150000
200000
250000
X
600000
500000
400000
300000
Y
CONC: 50 150 300 1000 2500 5000 7500 10000 12500 15000
TNO/FK&GOE, '06

Methods to determine 3D fresh-saline distribution

Basically, two methods:

1. Use present measurements and inter- and extrapolation
   - Present values are seldom consistent
     - > Different qualities (sample versus VES versus Borehole)
     - > Different measurement dates
   - Never enough data
2. Initial everything is saline (or fresh) and simulate long enough
   - What is 'long' enough?
   - Long computation times
   - Difficult/impossible to implement historical stresses

So, we use a hybride form!

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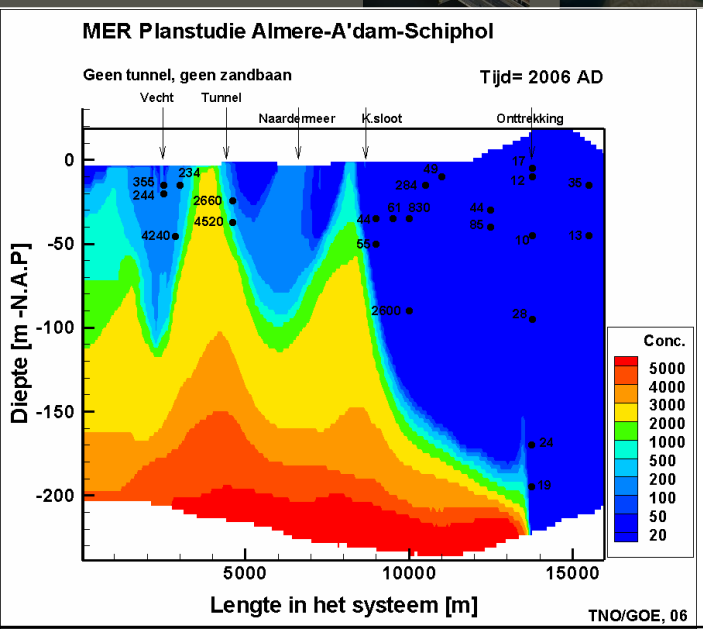
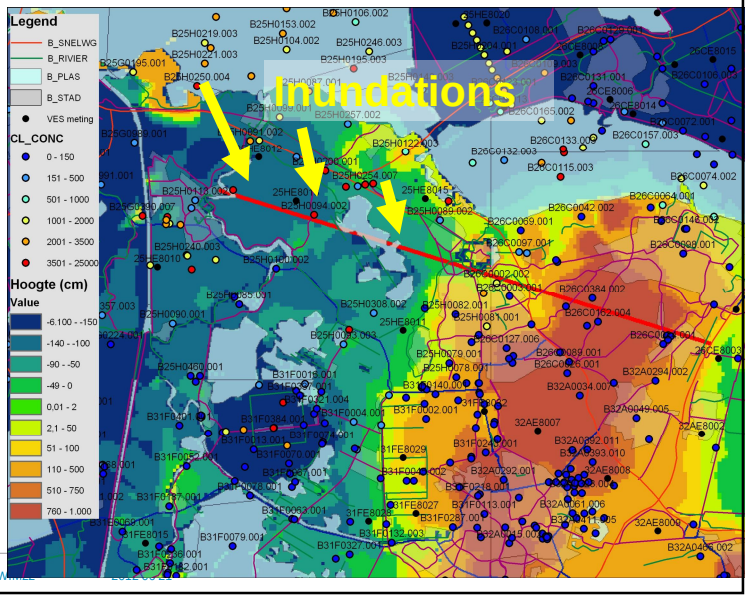
Example Method 1: Case Naardermeer

Result Method 1: present measurements and inter- and extrapolation



Method 2: simulate transgression



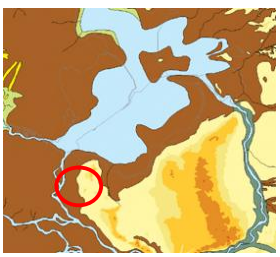
Method 2: simulate transgression

Various inundations

Co-authors:
Dagmar Mooi, Paul Schot

50 AD

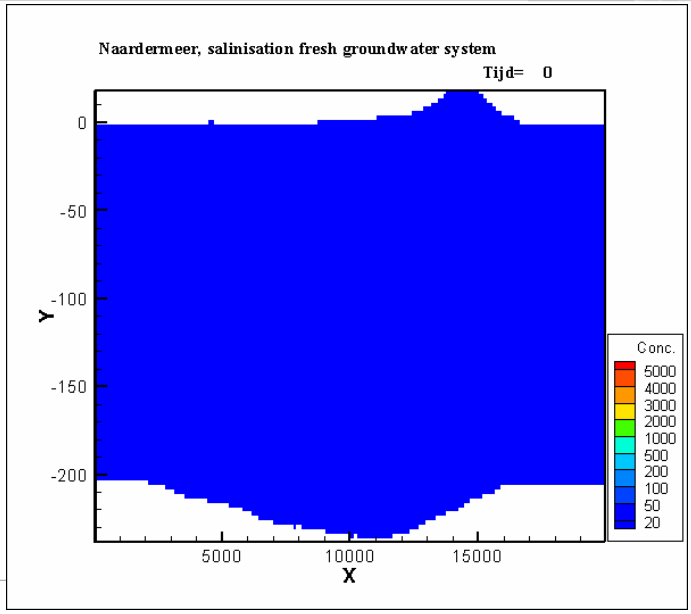
800 AD



1200 AD

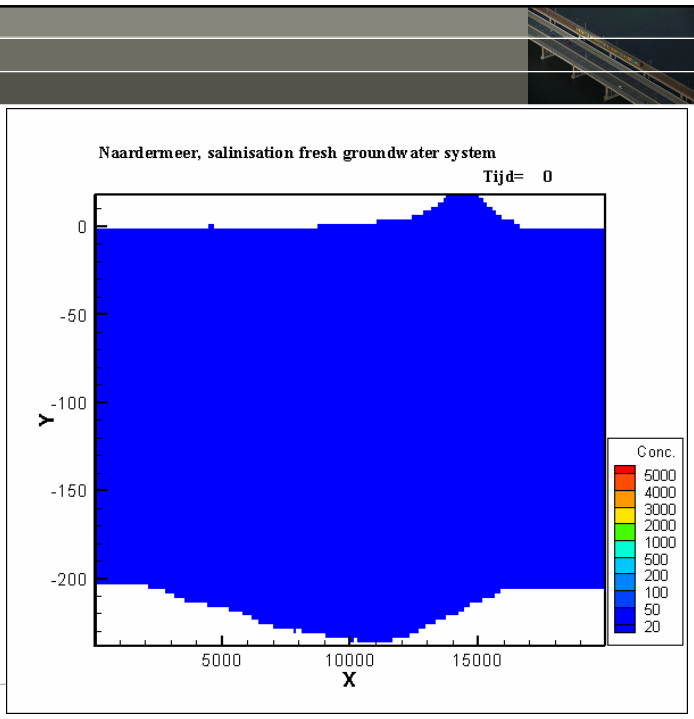
Deltares

Various inundations over 600 years

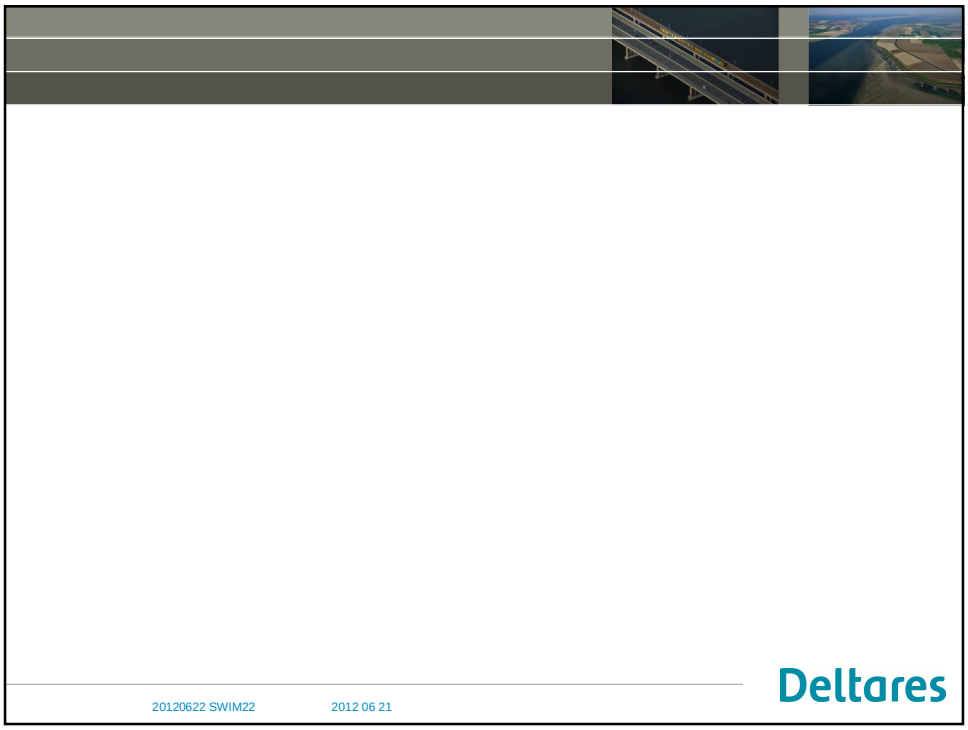


First results

Deltares

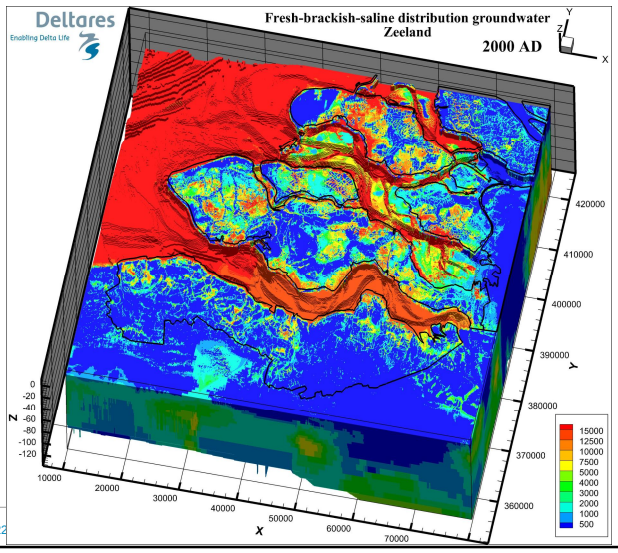


Deltares

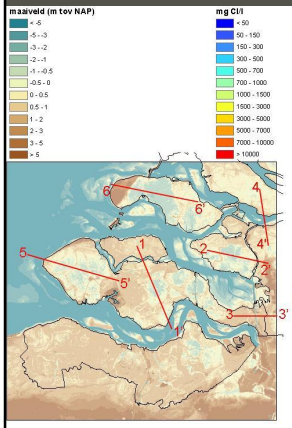


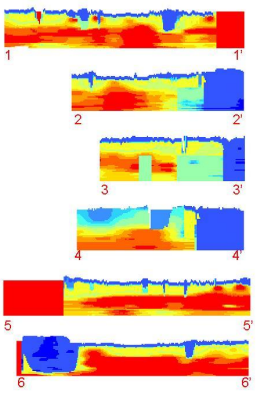
Deltares

Case Zeeland

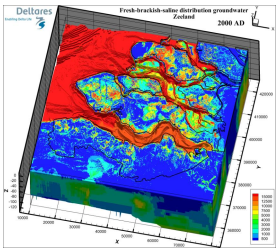


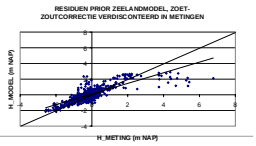
Case Zeeland

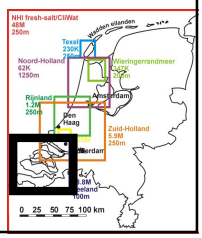




- Cels 100*100 m^2
- Top modellayers 0.5 m thickness
- Calibrated
- Improved 3D initial fresh saline field







Procedure to derive initial 3D chloride distribution

Step 1: interpolation all values of analyses, VES and BGM
via geostatistical procedure (weighted spatial interpolation, Inverse Distance)
> Rule 1: Better old data then nothing
> Rule 2: Better VES then nothing

Step 2: implement base knowledge
- Sea = salt, unless submarine groundwater discharge
- Inland = fresh

Step 3: mapping brackish-saline interface (1000mg Cl-/l)
Goes, Oude Essink, Vernes, Sergi, 2009, Estimating the depth of fresh and brackish groundwater in a predominantly saline region using geophysical and hydrological methods, Zeeland, the Netherlands. NSG 401-412

Step 4: using density-dependent flow model to smooth out artifacts

verification
iteration

Later:

Step 5: implementing knowledge and data from local studies
- rainwaterlenses via empirical relation (data Perry de Louw)
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Step 6: implementing AEM HEM data and compare

Deltares

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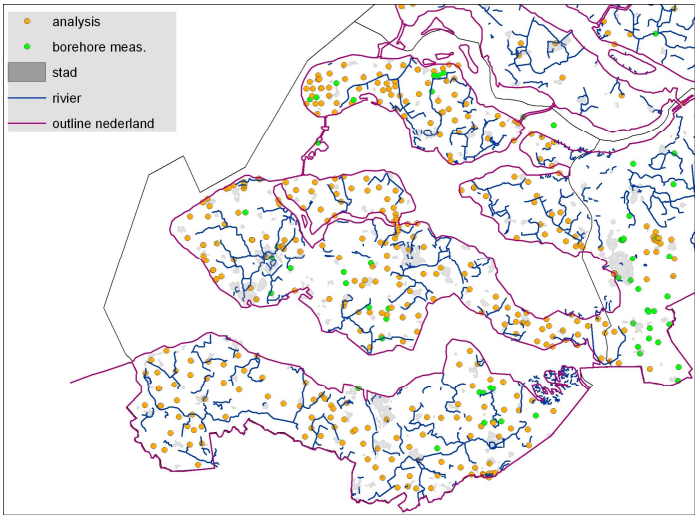
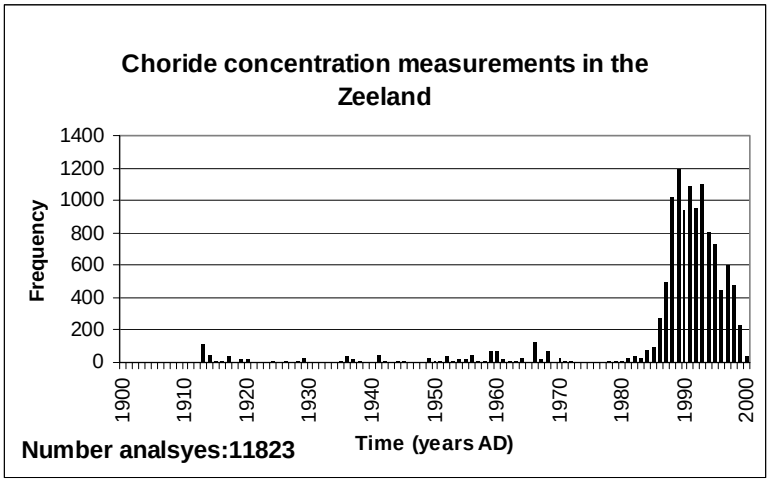
Step 1: interpolated values analyses, BGM



Deltares

Step 1: interpolated values analyses, VES, BGM

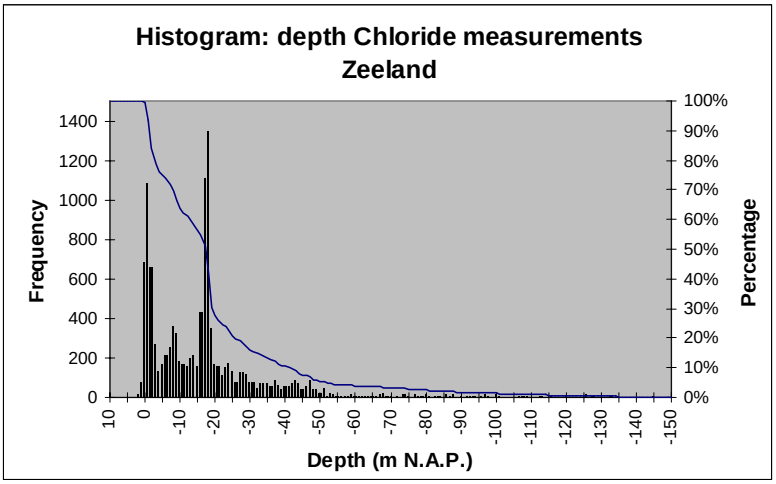
When measured? Recently!



Deltares

Step 1: interpolated values analyses, VES, BGM

Depth of measurements? Shallow!



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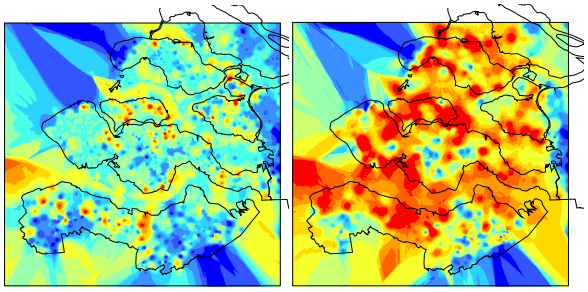
Results after step 1 (interpolation analyses)

-2.25 MSL

-11.5 MSL



Step 1

Legenda

mg Cl/l

- < 50
- 50 - 150
- 150 - 300
- 300 - 500
- 500 - 700
- 700 - 1000
- 1000 - 1500
- 1500 - 3000
- 3000 - 5000
- 5000 - 7000
- 7000 - 10000
- > 10000

Deltares

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Step 3: Mapping brackish-saline interface

Combining different types of data sources:

Data type	Characteristics of measurement	# Data	Determined	Accuracy depth of interfaces
Groundwater Samples	0D in situ	721	Chloride concentration	Depends on positions of screens
Geo-electrical borehole logs	1D in situ	149	1D chloride profile, Depth fresh-brackish and brackish-saline interface, Inversions.	±1 m
Electrical CPT	1D in situ (max. depth 50 m)	71	Borehole log	±1 m
VES	1D from surface	1113	Depth brackish-saline interface, Major inversions, (1D chloride profile).	±20% of depth
EM34	1D from surface	3251	Depth brackish-saline interface	ranges of 7.5, 15 or 30 m (accuracy decreases with depth)
Groundwater Abstractions	0D in situ	716	Depth brackish-saline interface	a range depending on screen depth
Unique locations		**6021**		

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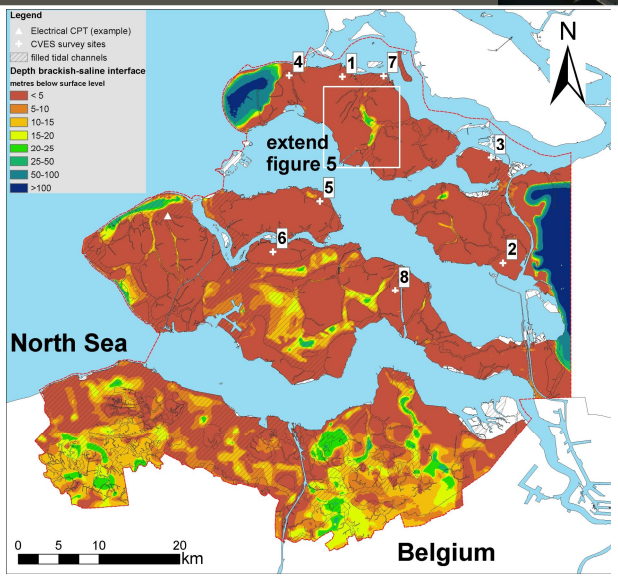
Step 3: Mapping brackish-saline interface

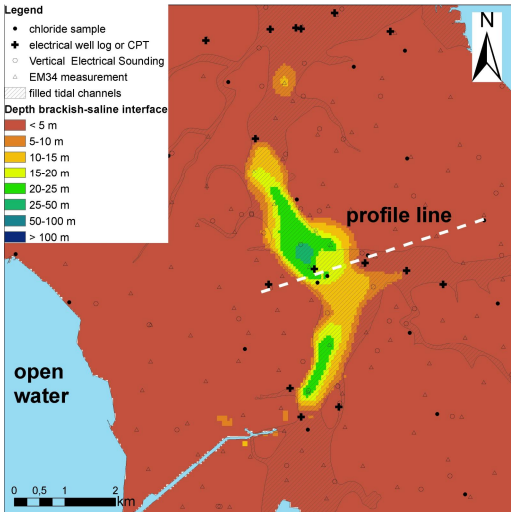


Goes et al, 2009

Deltares

Step 3: Mapping brackish-saline interface

Combining different types of data sources



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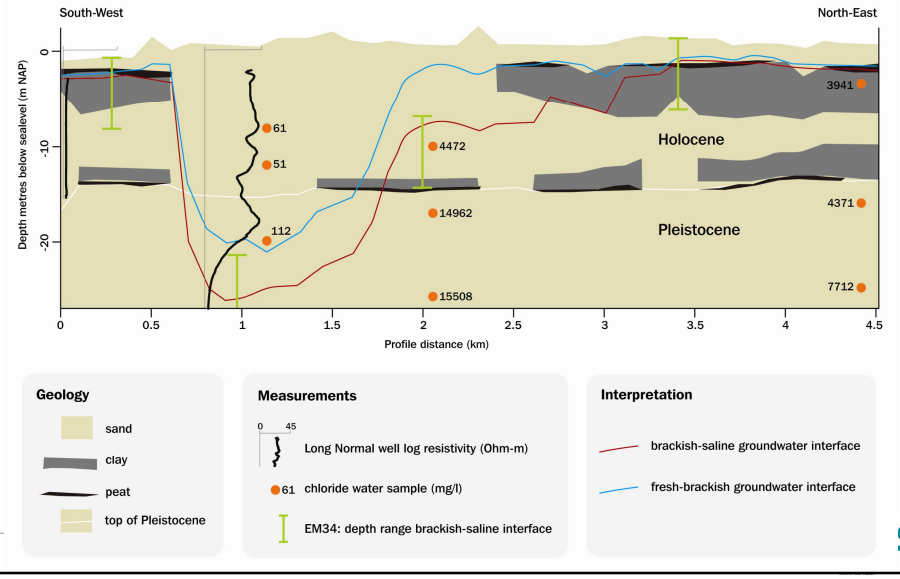
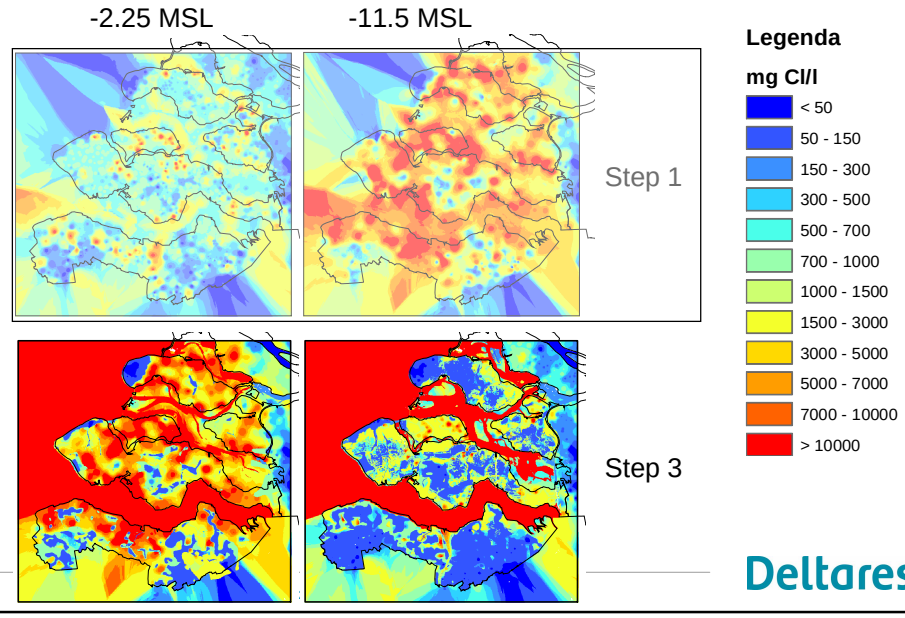
Combining different types of data sources



Results after step 3



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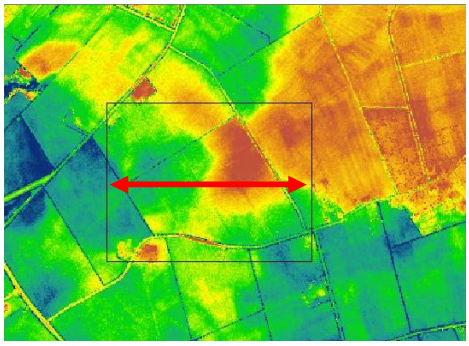
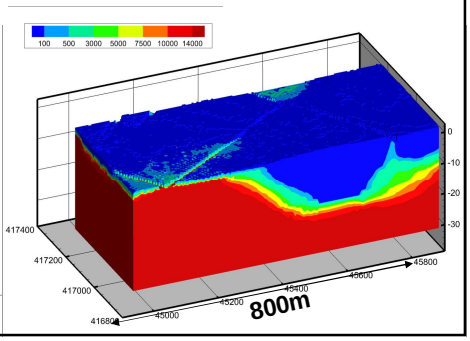
Deltares

Step 4 density-dependent flow modelling

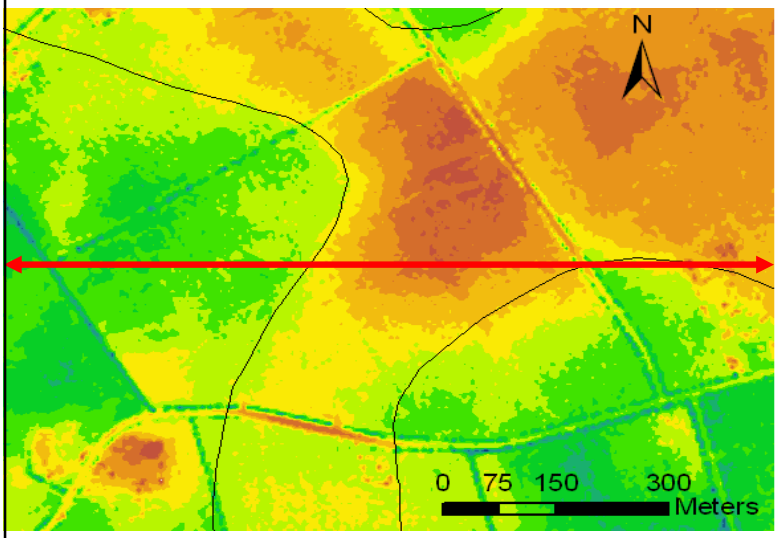
Why?

• variation in ground surface directly affects fresh-saline disribution





Step 4 density-dependent flow modelling



Legend

AHN (m NAP)

- 0.75 - 1.00
- 0.50 - 0.75
- 0.25 - 0.50
- 0.00 - 0.25
- -0.25 - 0.00
- -0.50 - -0.25
- -0.75 - -0.50
- -1.00 - -0.75
- -1.25 - -1.00
- -1.50 - -1.25
- -1.75 - -1.50
- -2.00 - -1.75

Deltares

Step 4 density-dependent flow modelling

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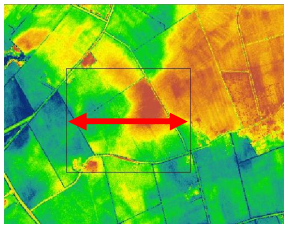
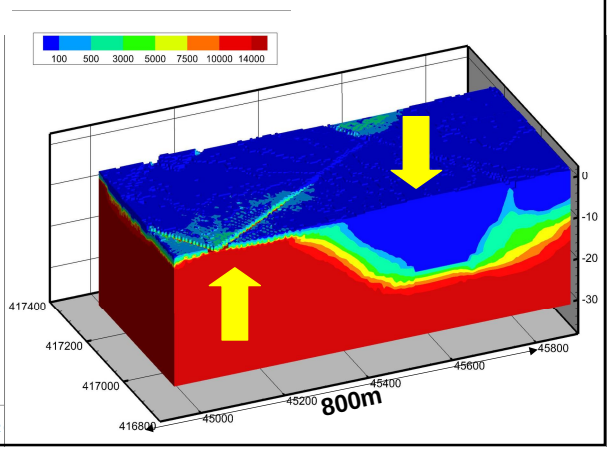
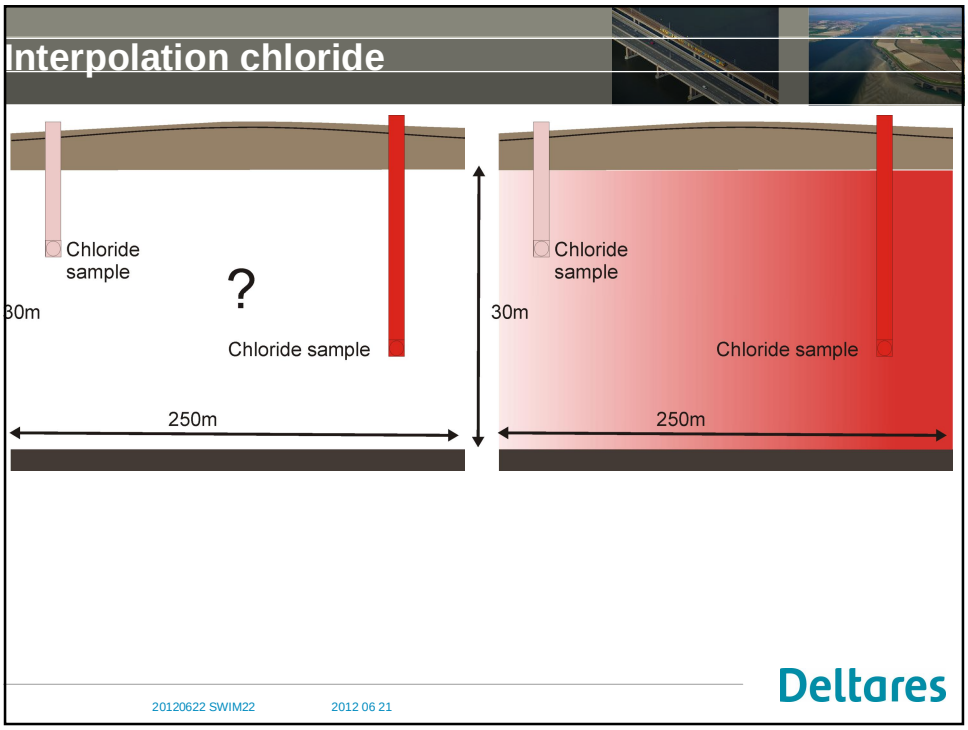
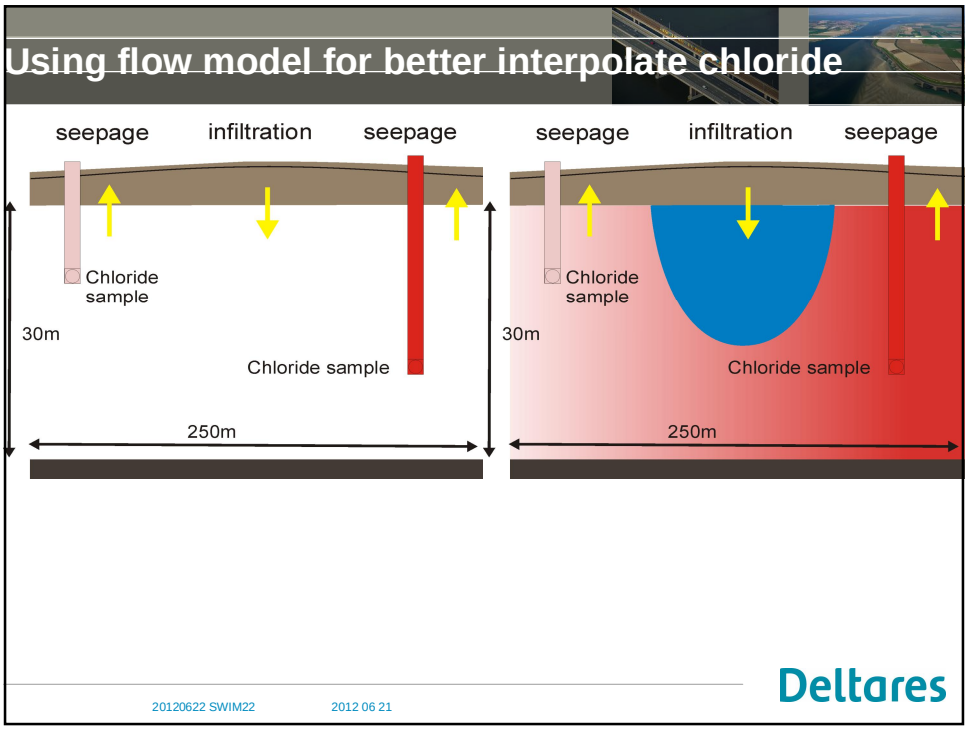





Interpolation chloride
Chloride sample
?
30m
Chloride sample
250m
Chloride sample
30m
Chloride sample
250m
20120622 SWIM22
2012 06 21
Deltares


Using flow model for better interpolate chloride
seepage
infiltration
seepage
seepage
infiltration
seepage
Chloride sample
30m
Chloride sample
250m
Chloride sample
30m
Chloride sample
250m
20120622 SWIM22
2012 06 21
Deltares

Take home messages

Take home messages

- Numerous measurements are necessary to get an acceptable 3D density matrix
- Hydride method looks promising, but scientifcally not sound yet

Next activities:

- Step 5: implementing knowledge and data from local studies
- Step 6: Implementing AEM data and quantification result
- Other areas, o.a. area Rijnland/Waternet
- PhD on paleohydrogeography and density distributions

Thank you for your time