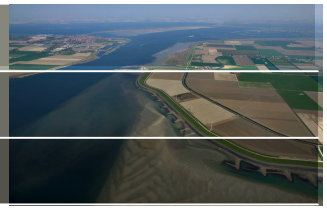
Deltares
Enabling Delta Life

Meten aan (kustnabije) grondwatersystemen

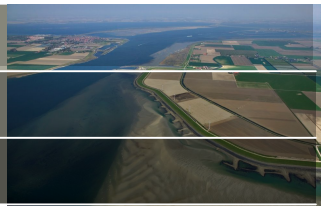
Perry de Louw

Inhoud



- Regionale grondwatersystemen (kwel – infiltratie)
- Lokale grondwatersystemen (interactie grondwater – oppervlaktewater)
- Zoute grondwatersystemen
  - Zoute kwel in Zeeland
  - Meetmethoden (veldwerk kustlab)

Inhoud



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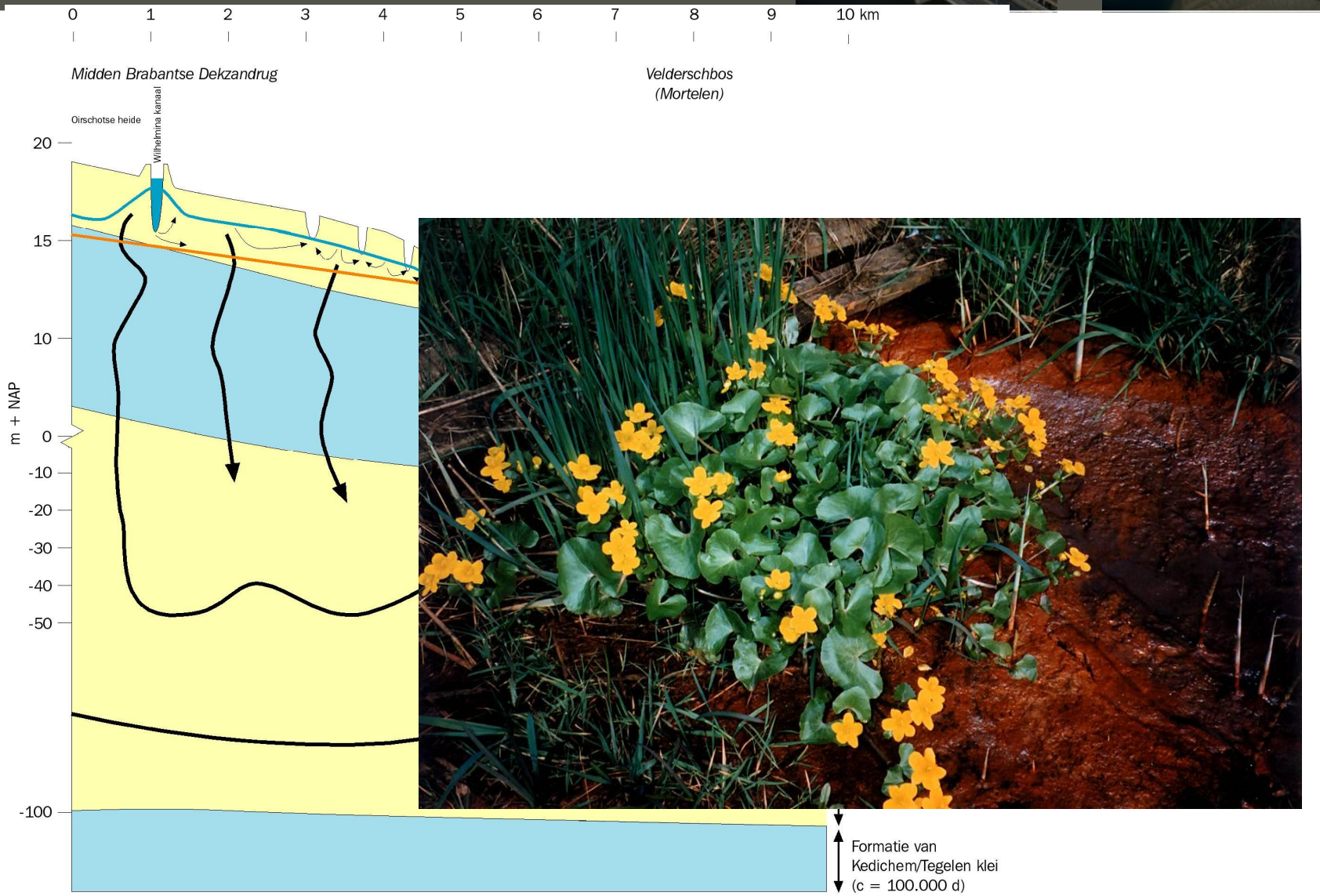
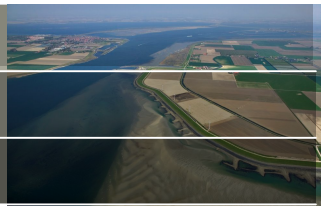
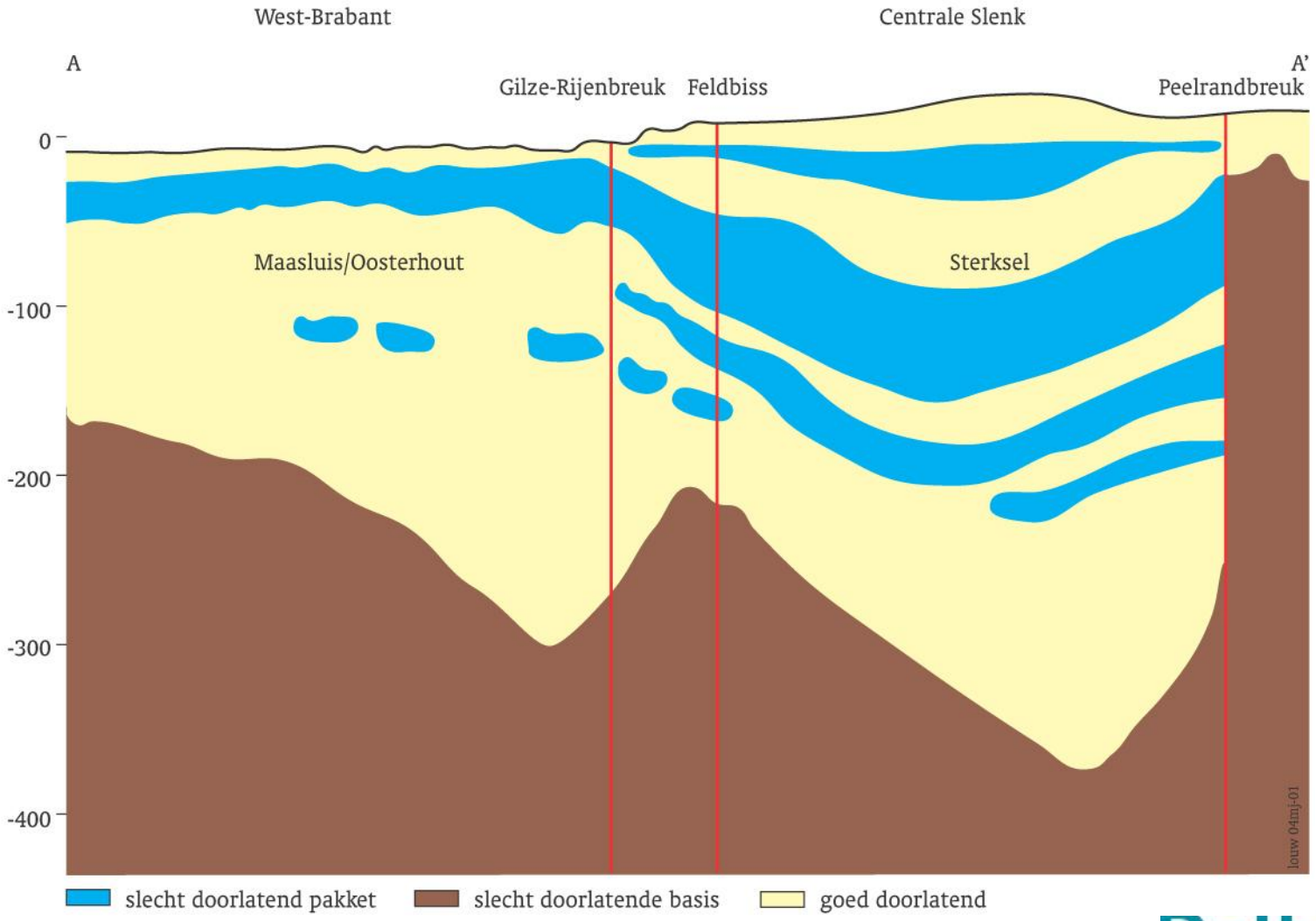
Infiltratie- en kwelgebieden: voorbeeld N-Brabant



Geohydrologische opbouw





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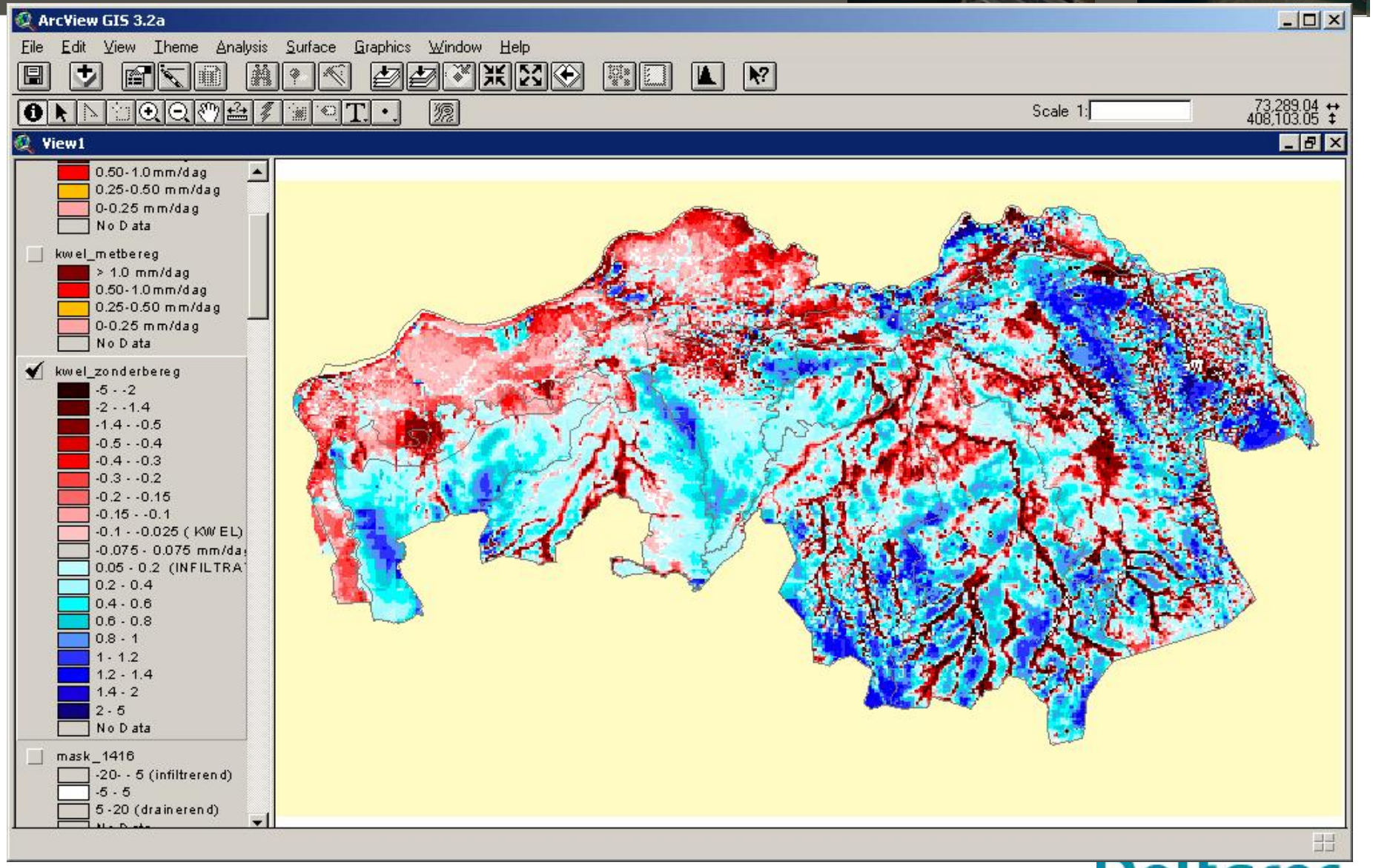
Kwel (rood) en infiltratie (blauw), N-Brabant



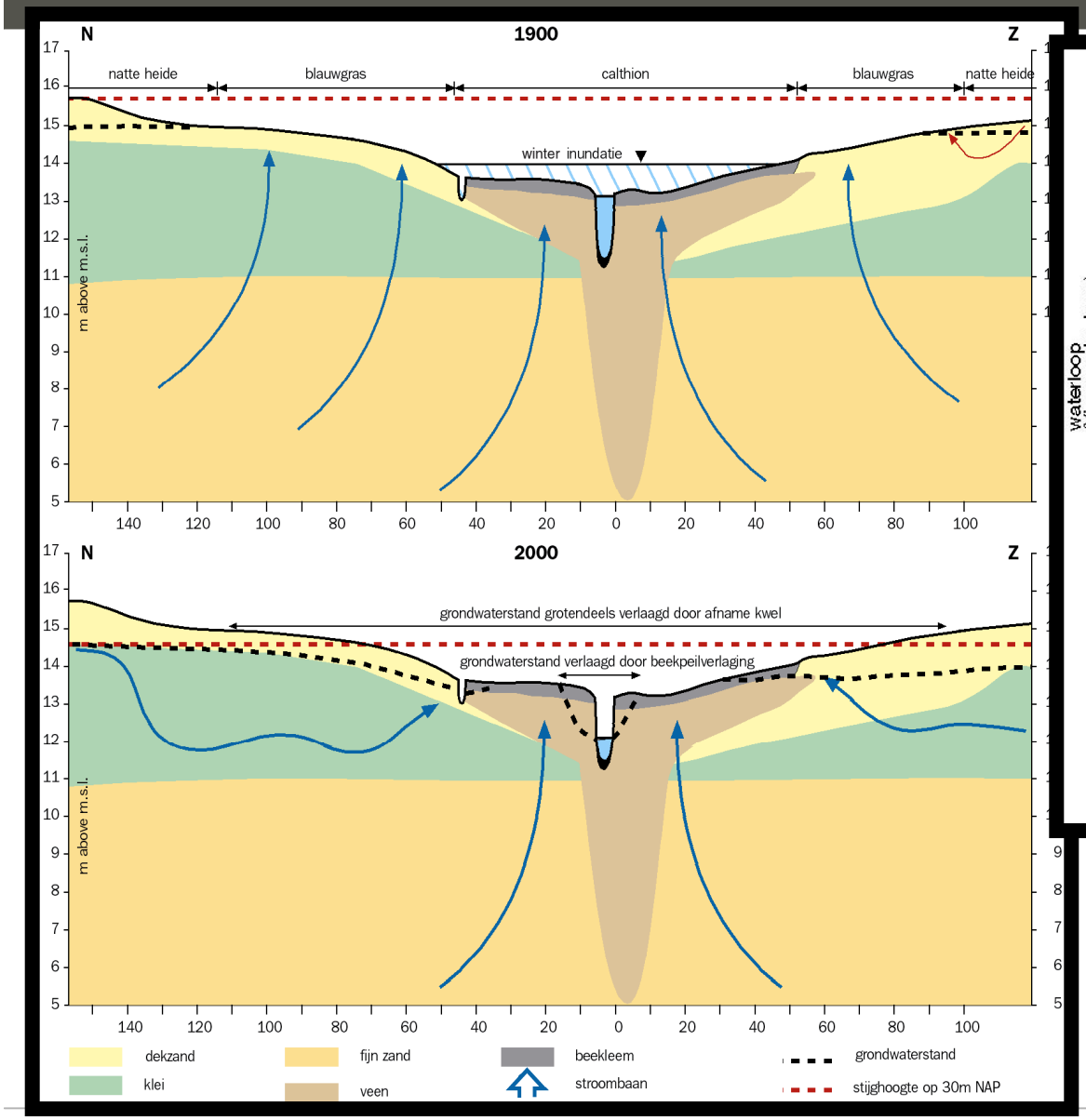
Het Brabantse grondwatersysteen heeft te maken met:

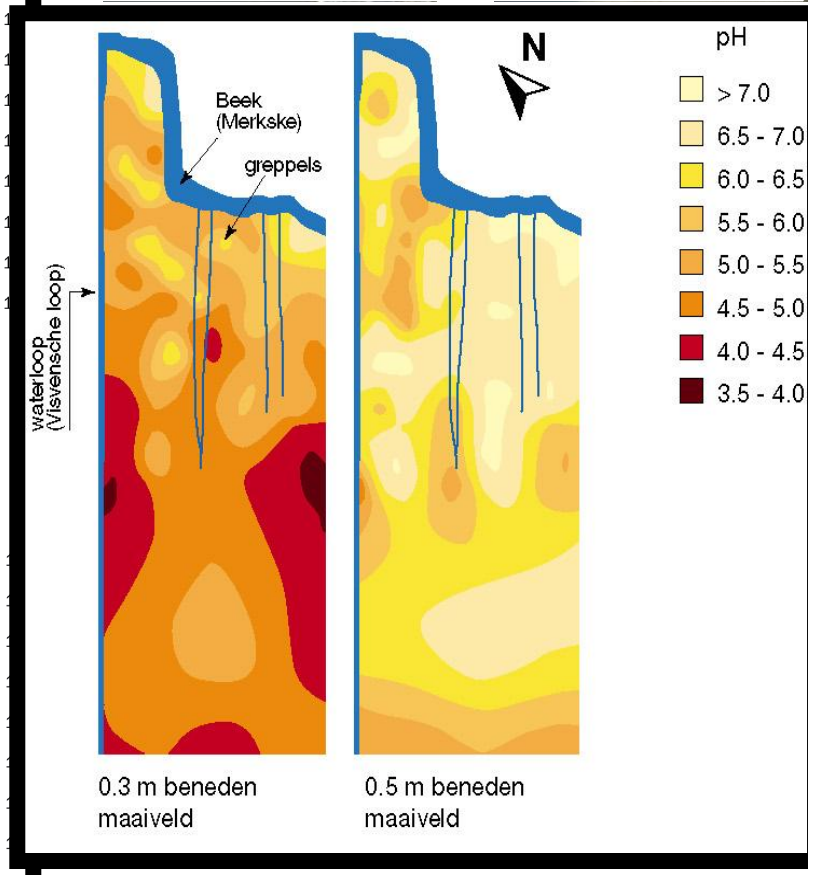
- Verdroging van landbouw- en natuurgebieden (te lage grondwaterstanden, minder of geen kwel)
- Wateroverlast: Water te snel naar de zee (toename van piekafvoeren, lagere basisafvoer)
- Klimaatverandering (intensievere buien, toename droogte)

Oorzaken:

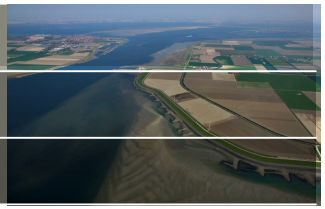
- Intensievere ont- en afwatering (meer en diepere sloten, drainage)
- Verdwijnen vennen
- Toename grondwateronttrekking (drinkwater, industrie, beregening)
- Verstedelijking
- Klimaatverandering

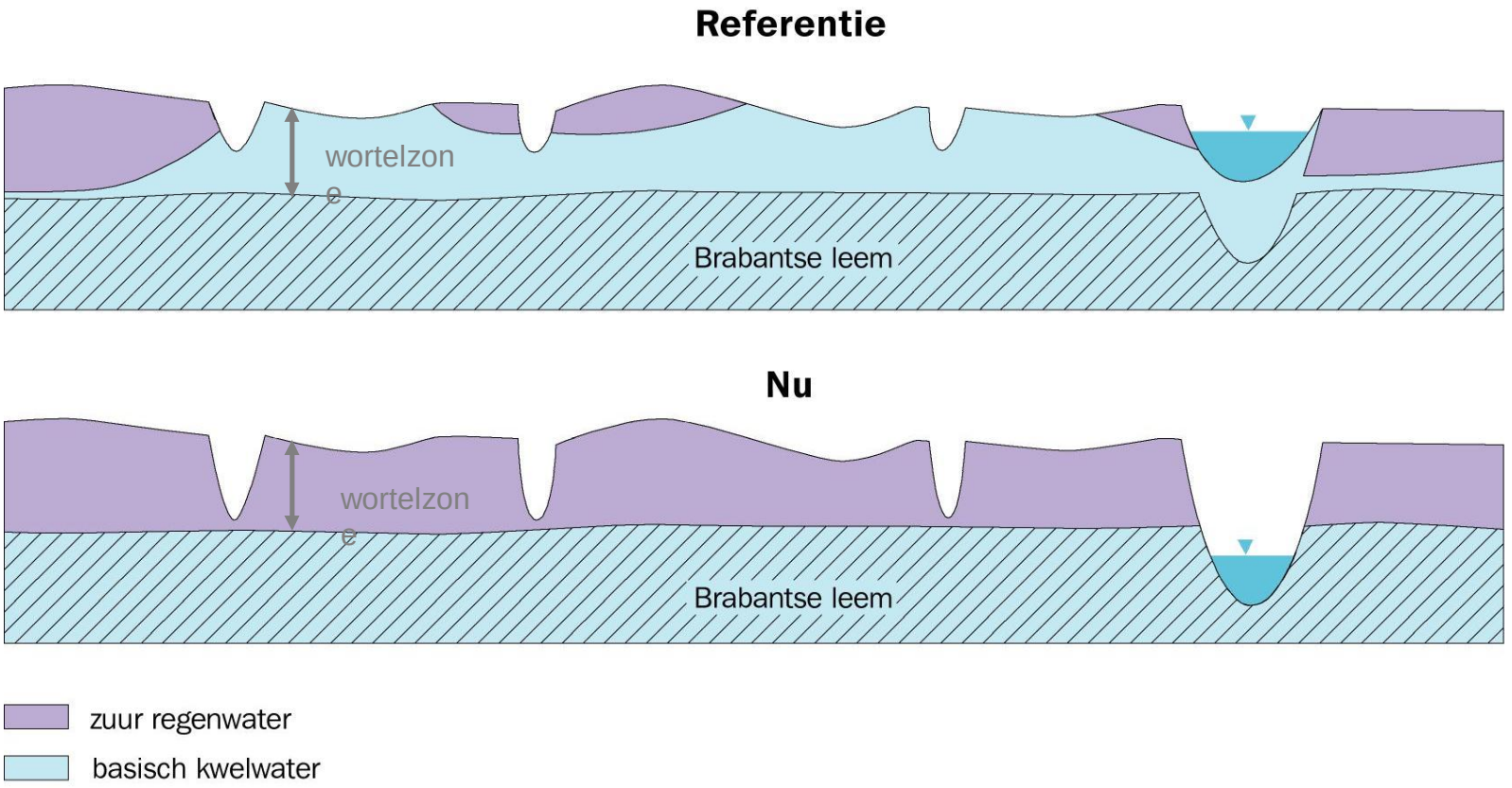
Grondwatersituatie in beekdal 1900 en 2000





Kwel in de wortelzone





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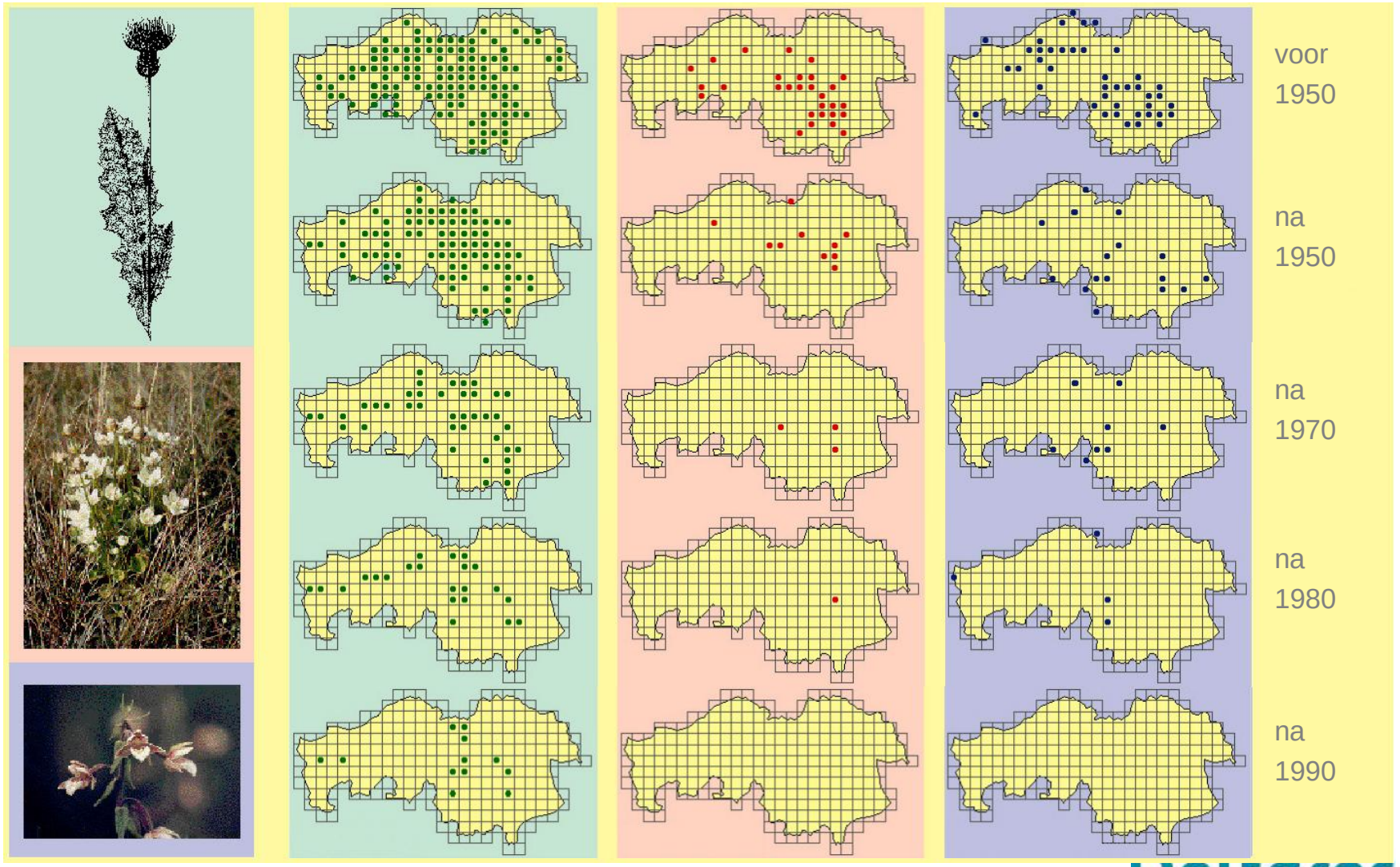
Afname biodiversiteit (grondwaterafhankelijke vegetatie)



Veldproeven

Beregenen uit het oppervlaktewater

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Beregenen uit het grondwater

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Permanente onttrekkingen vs onttrekkingen t.b.v beregening

Op jaarbasis:

- Permanent: 240 miljoen per jaar
- Beregening: 70 miljoen per jaar

Tijdens beregeningsperiode (35 dagen):

- Permanent: 0.66 miljoen per dag
- Beregening: 2.0 miljoen per dag (730 miljoen per jaar)

Tijdelijk ruim 3 keer zoveel grondwater onttrokken voor beregening dan drinkwaterwinningen

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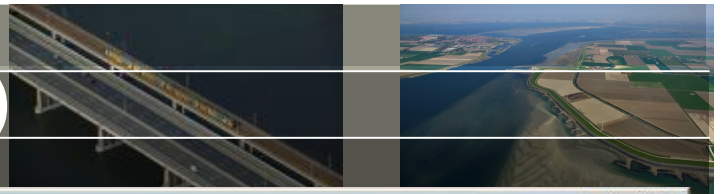
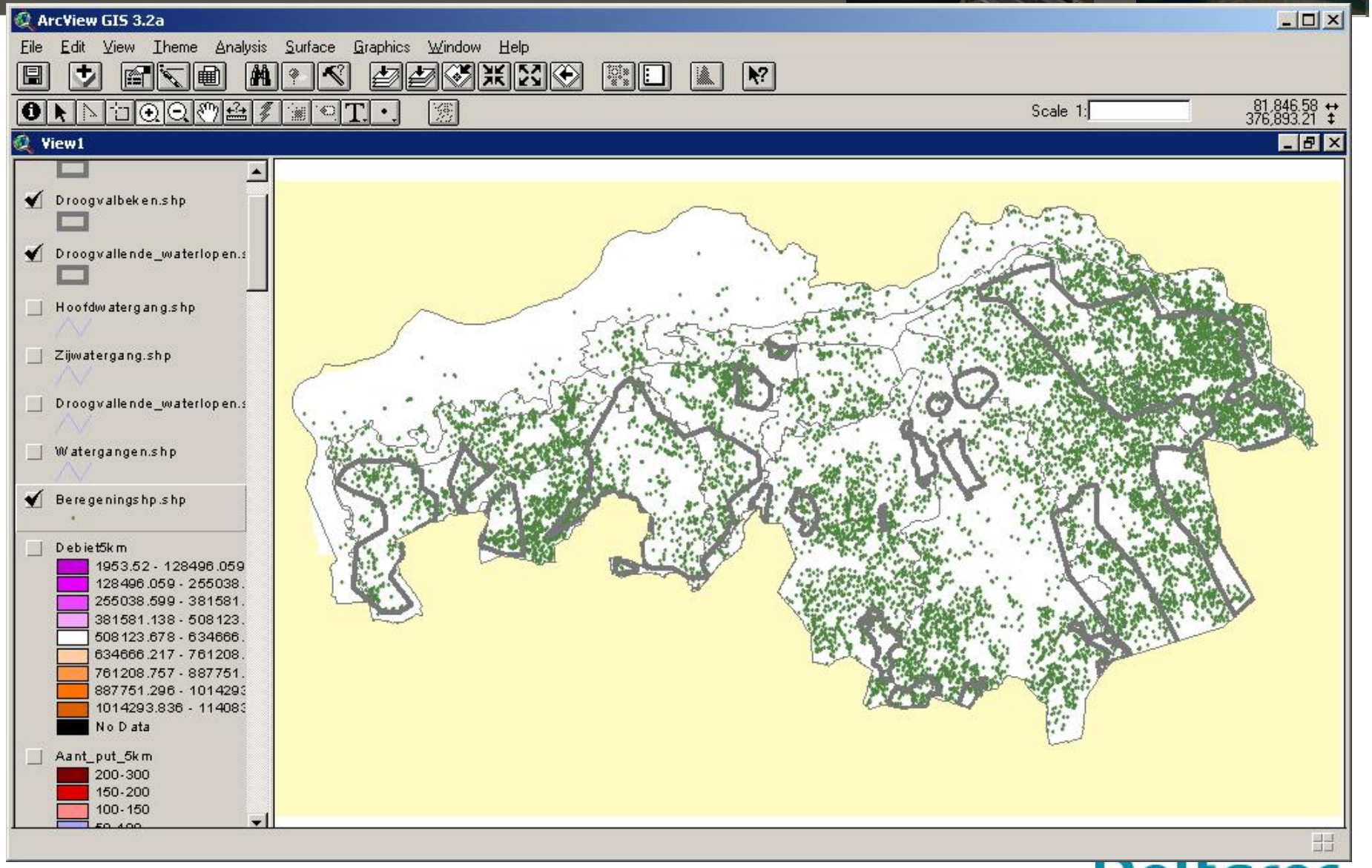
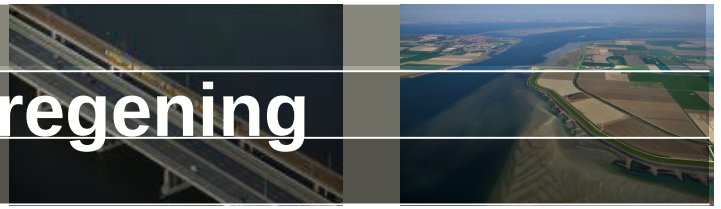
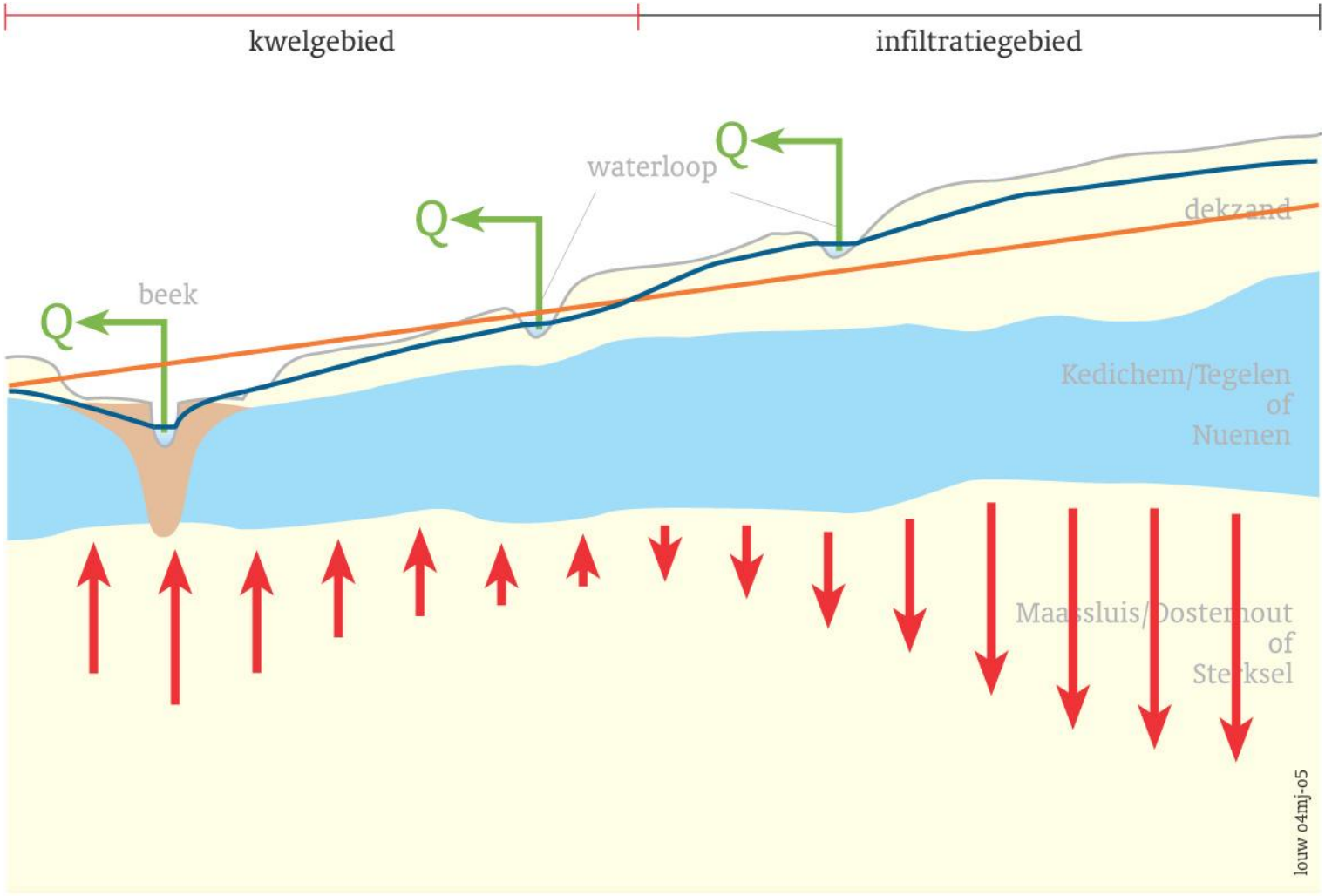
Beregeningsputten (totaal 13.000)



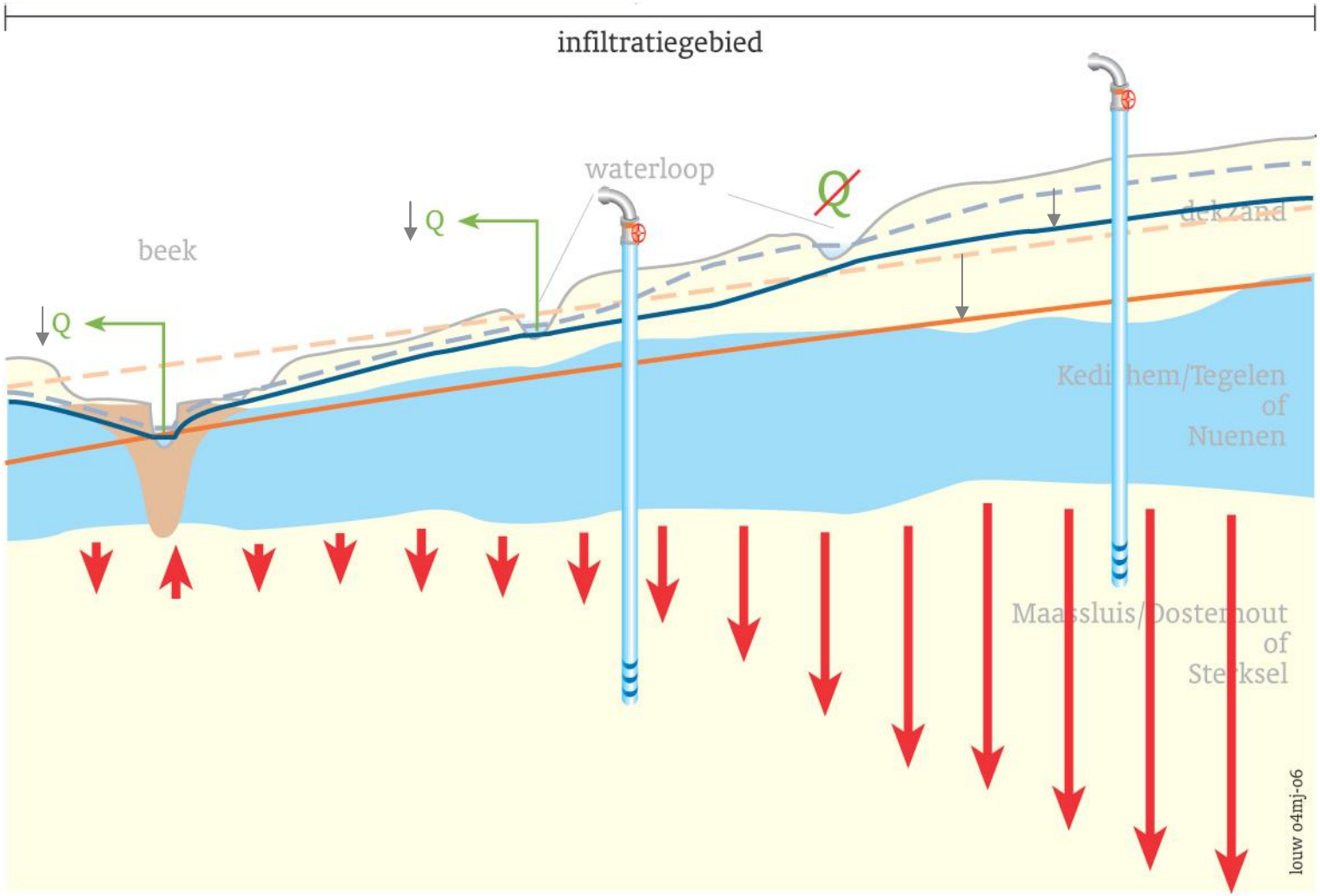


Grondwatersituatie zonder beregening

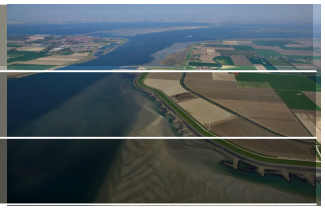


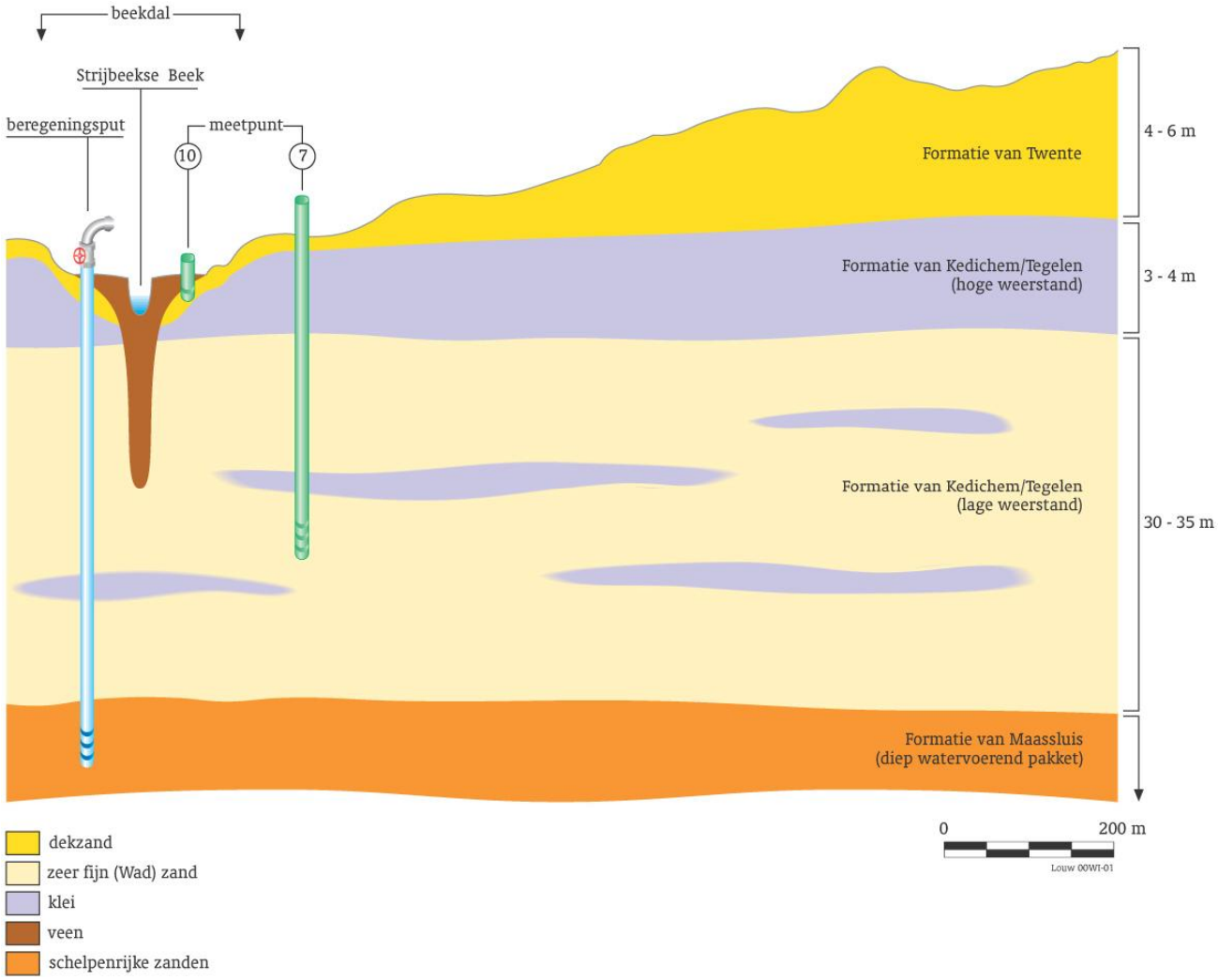


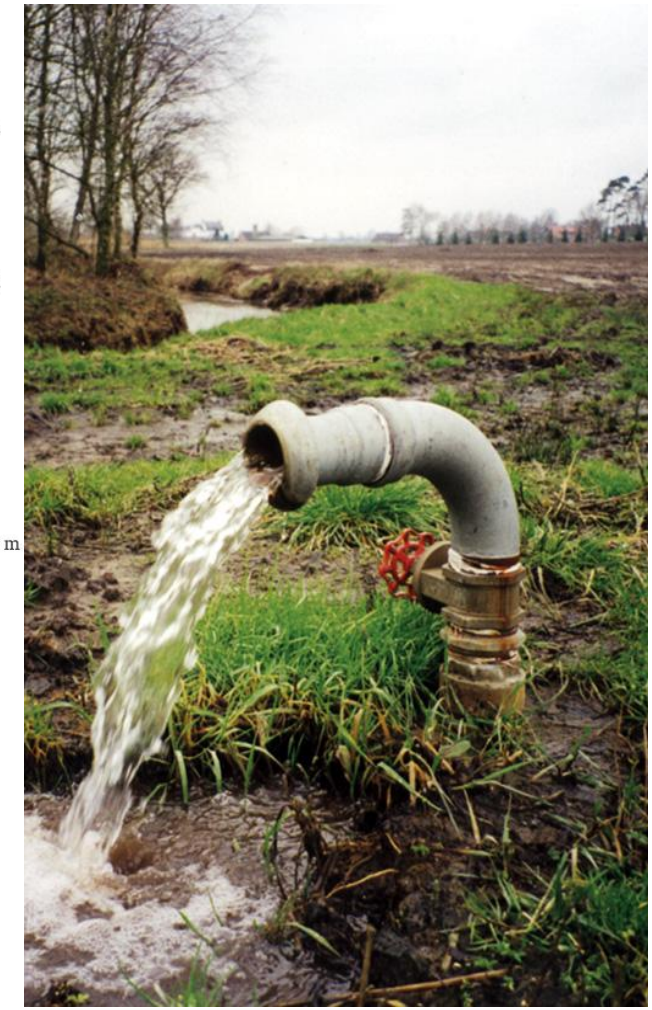
Grondwatersituatie met beregening



Geohydrologische situatie Strijbeek

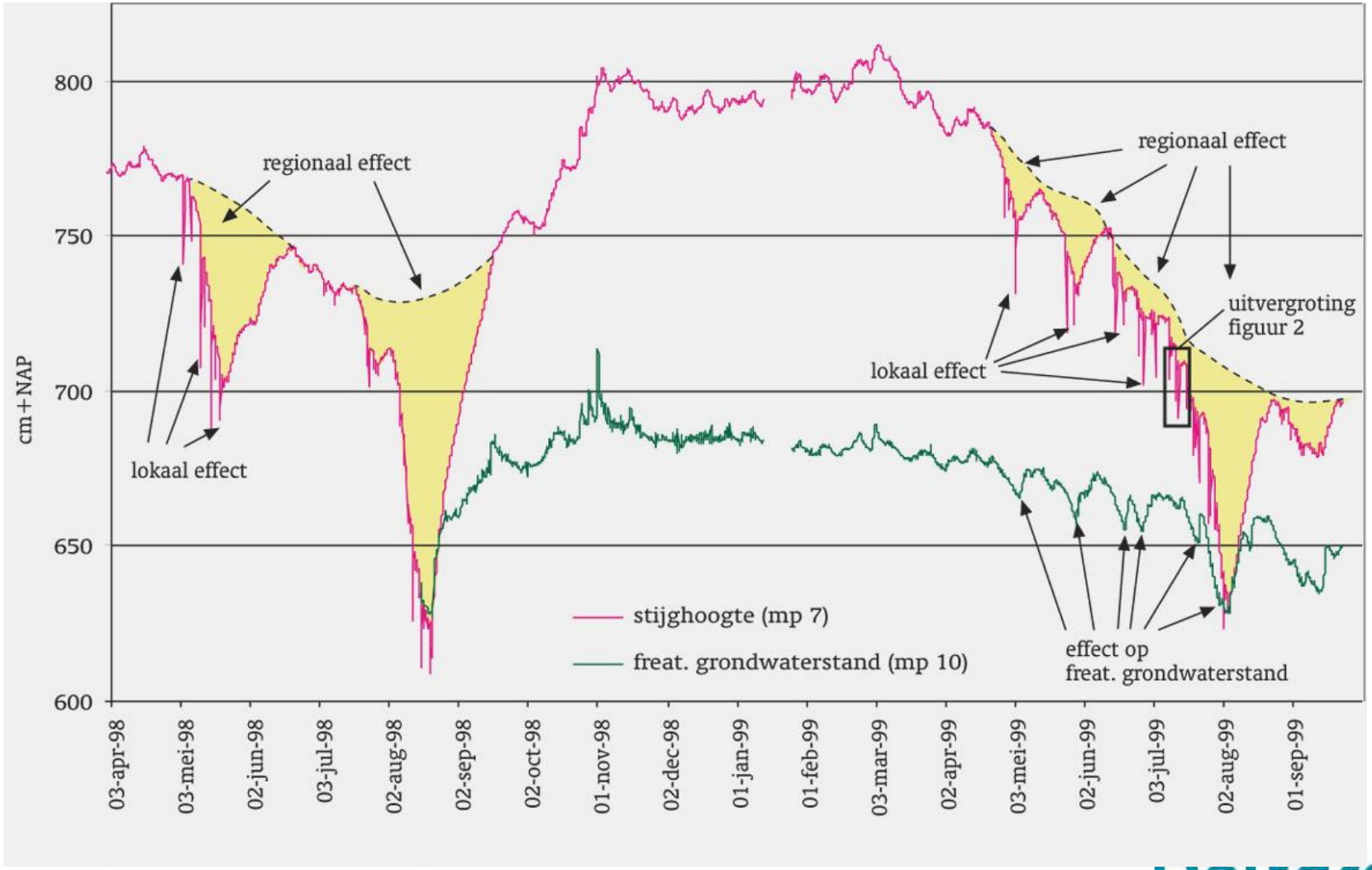




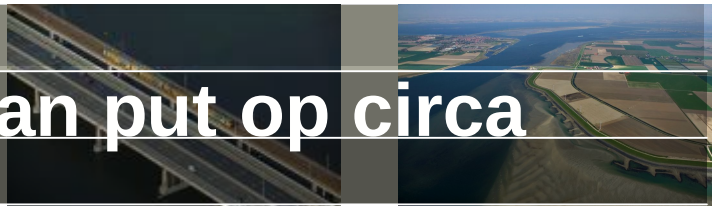


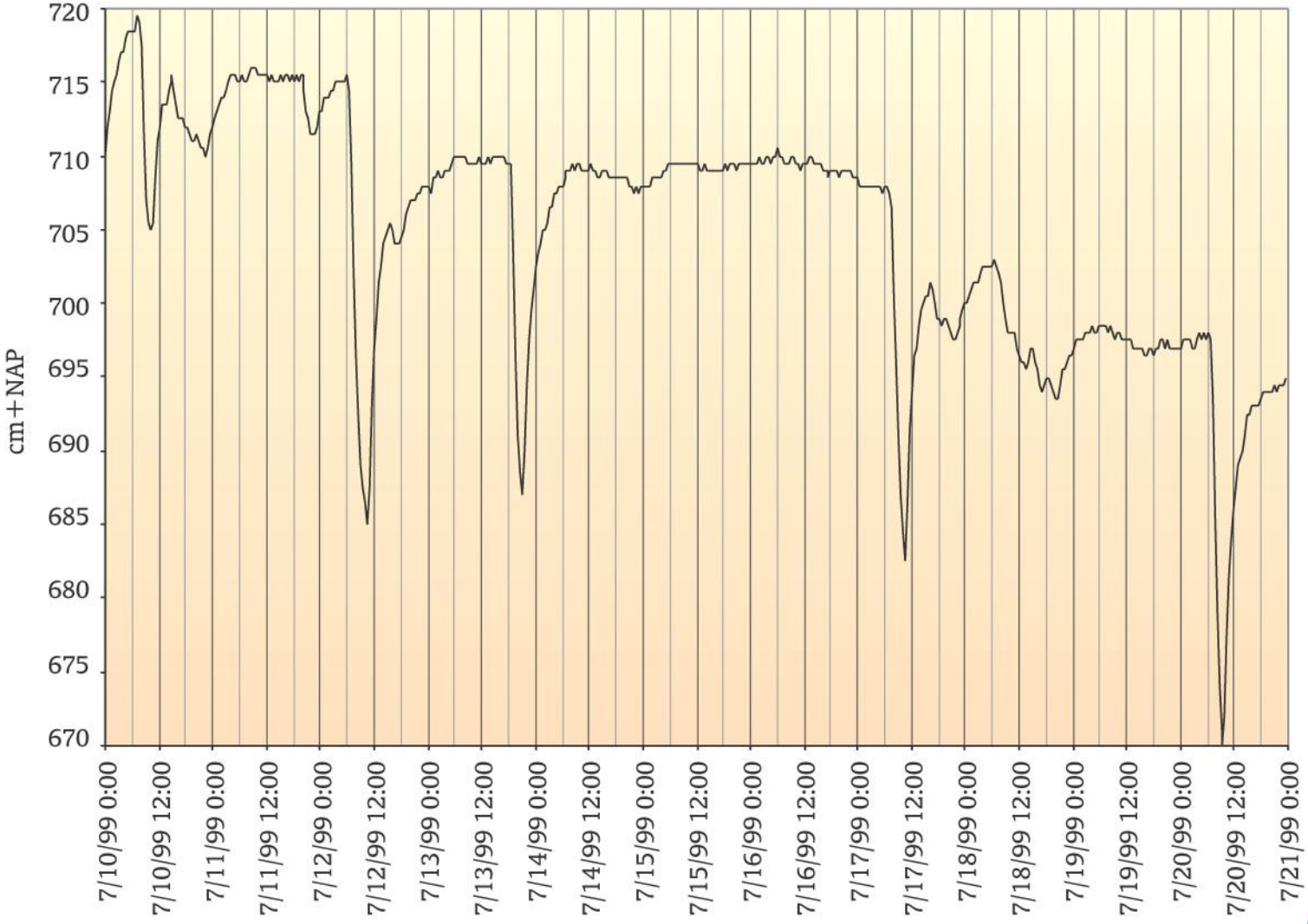
Deltares

Effect op stijghoogte en grondwaterstand

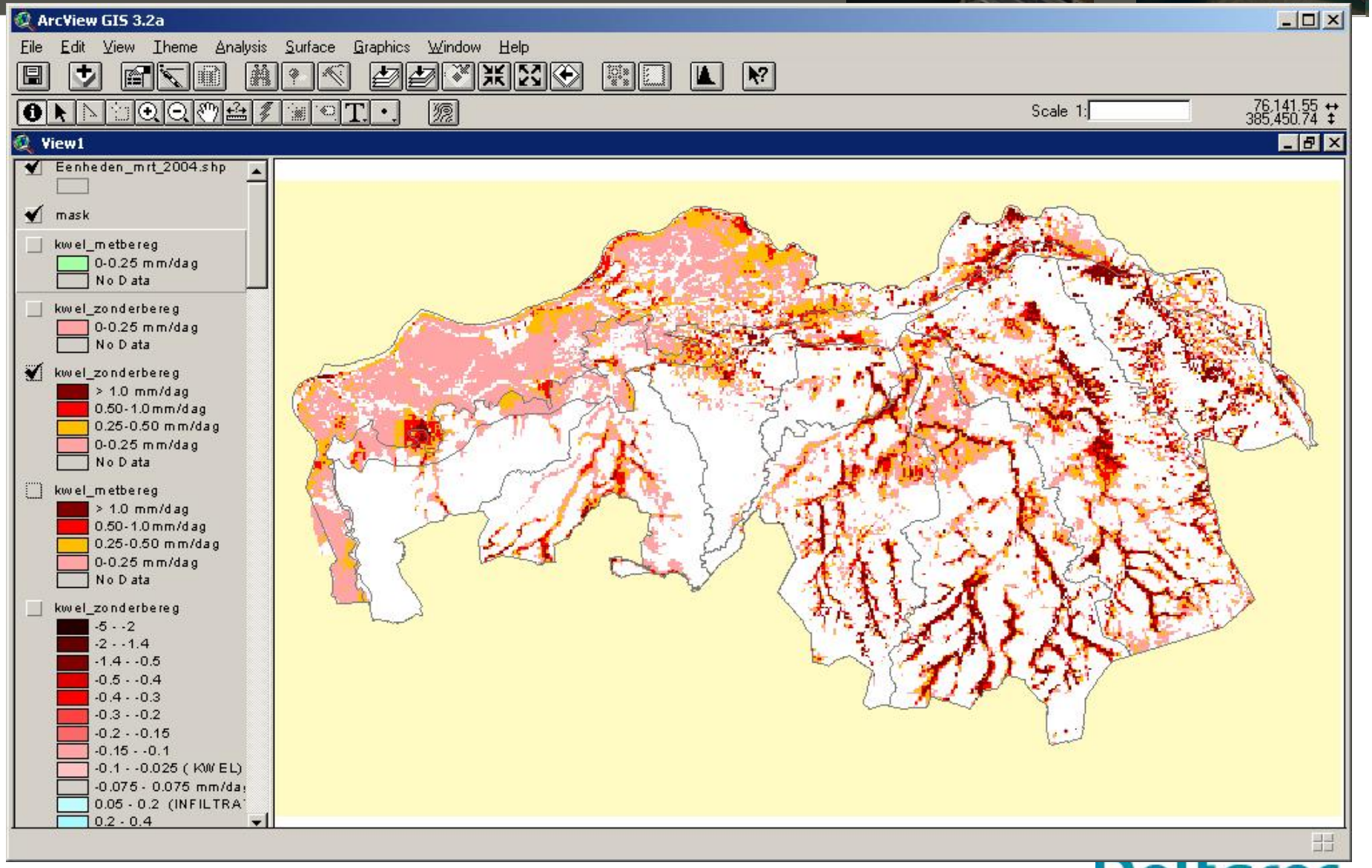


Lokaal effect op stijghoogte van put op circa 200 meter

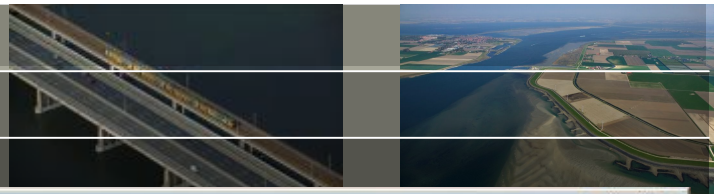


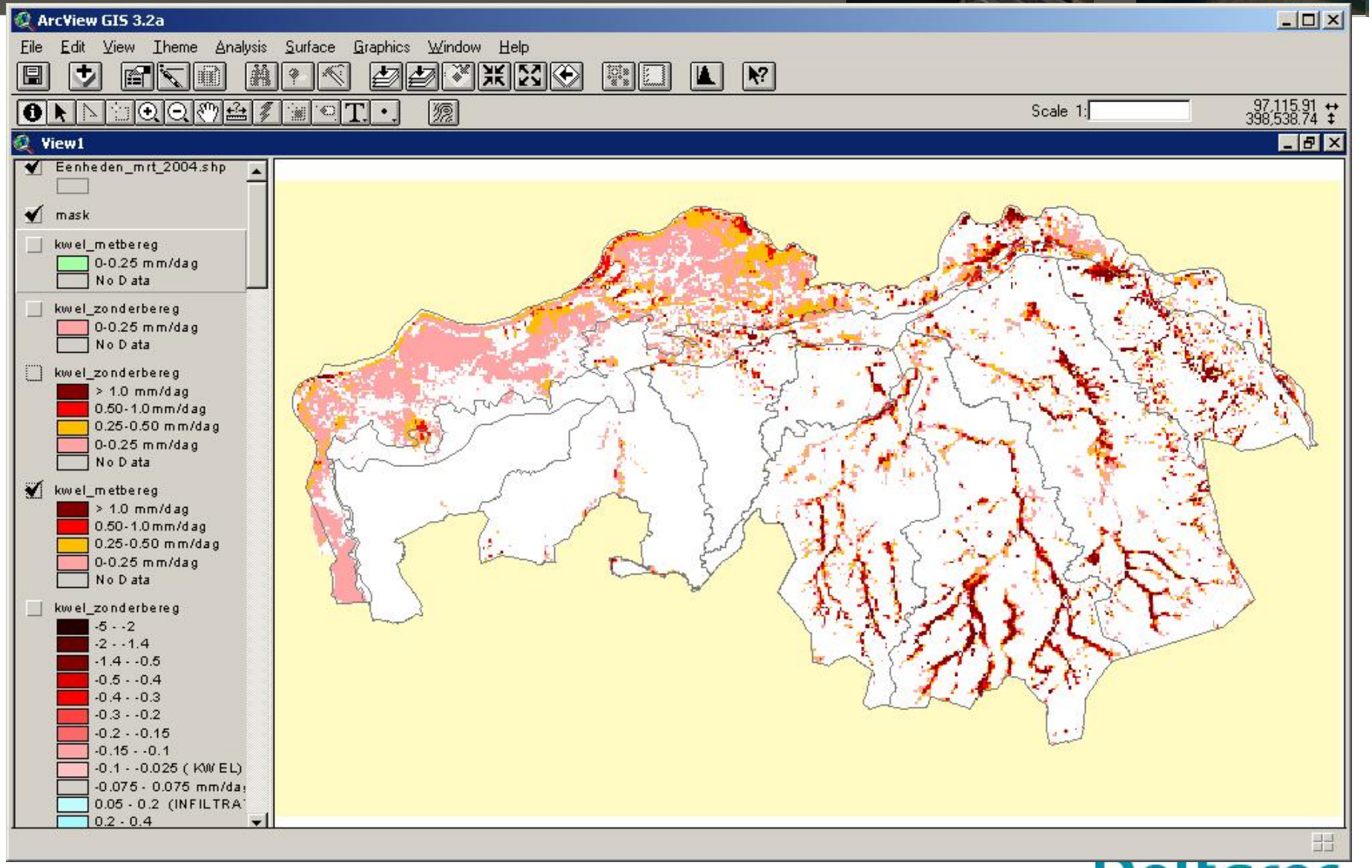


Kwel, zonder beregening

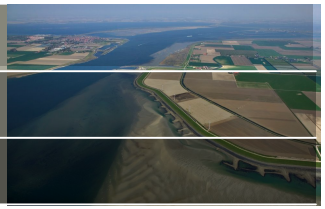


Kwel, met beregening





Inhoud



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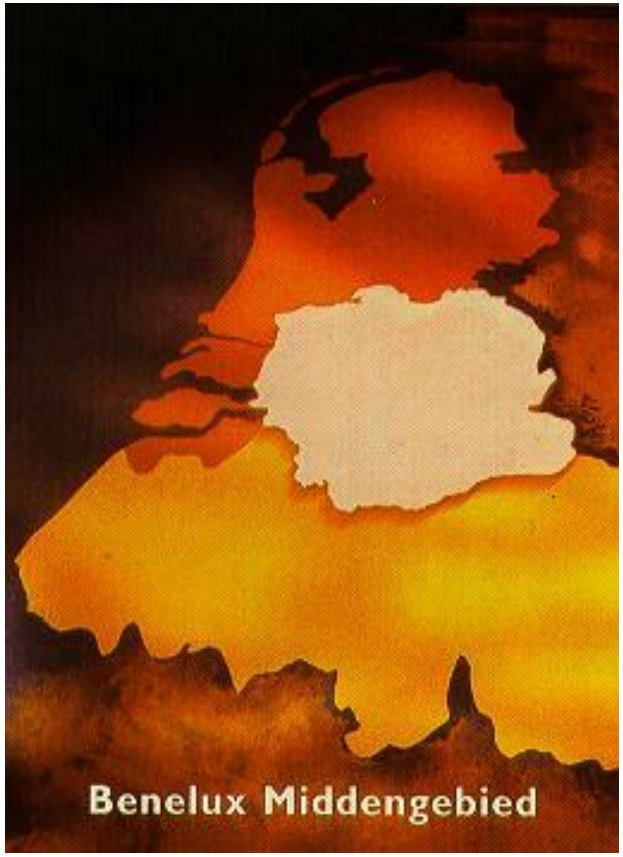
Voorbeeld: Waterconservering in het Benelux-Middengebied

Doelen

- Waterconservering (installatie van 2000 stuwtjes)
- Effecten van waterconservering in beeld brengen
- Best practice of waterconservation

TNO-Onderzoek

- Veldproeven / slootproeven
- Modelberekeningen
- Ontwikkeling van BOS (Reizende Waterconserveringsmaatregel



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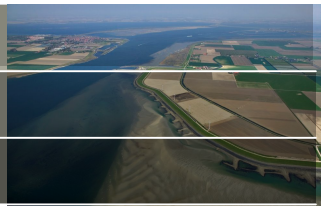
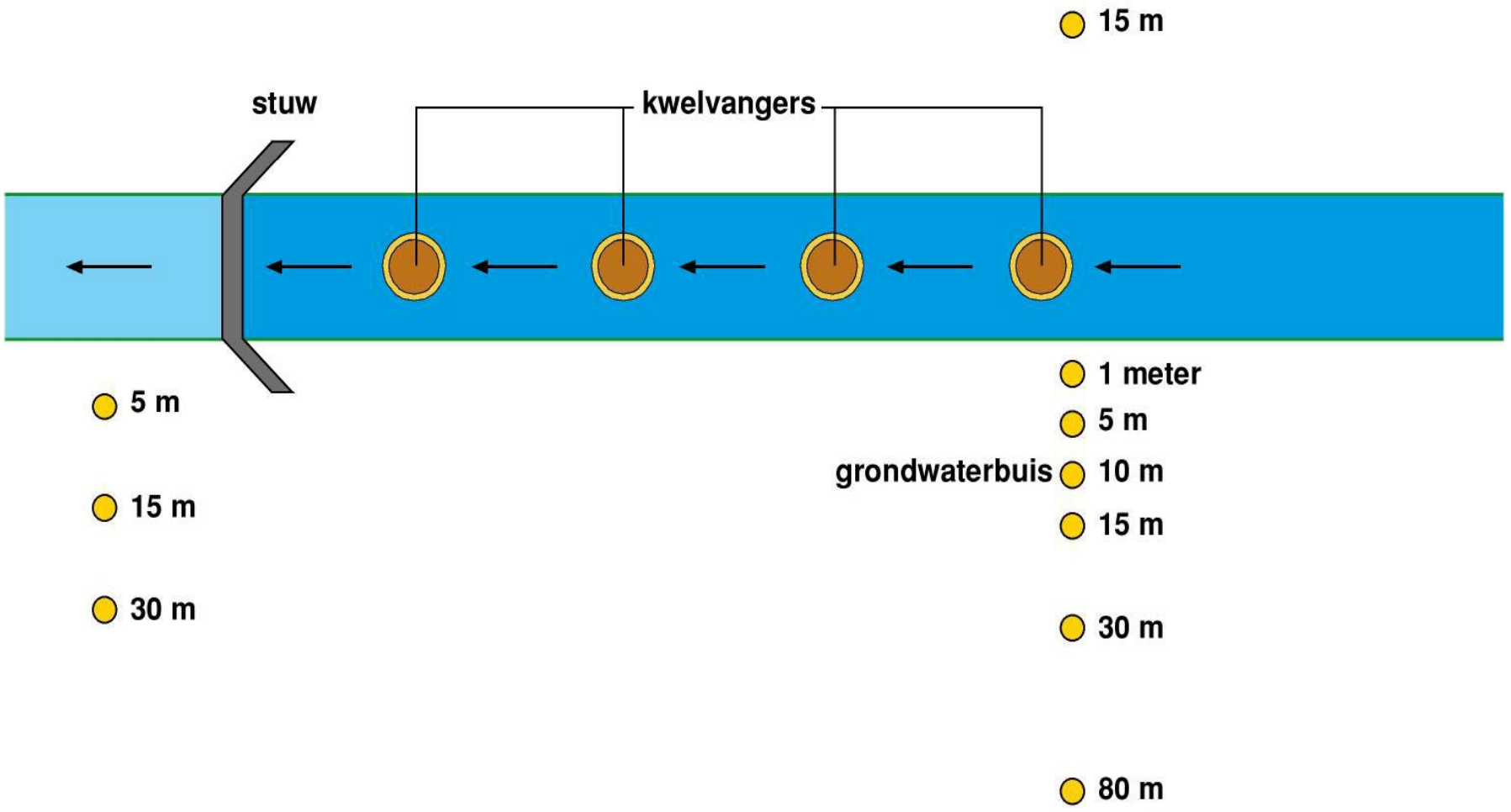
Boer meet grondwaterstand

Beslissen wanneer peil omlaag
of omhoog moet

Deltares

Slootproeven: meetnet

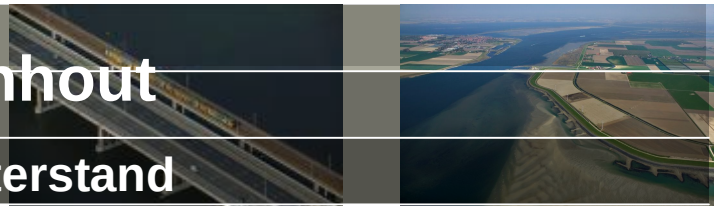


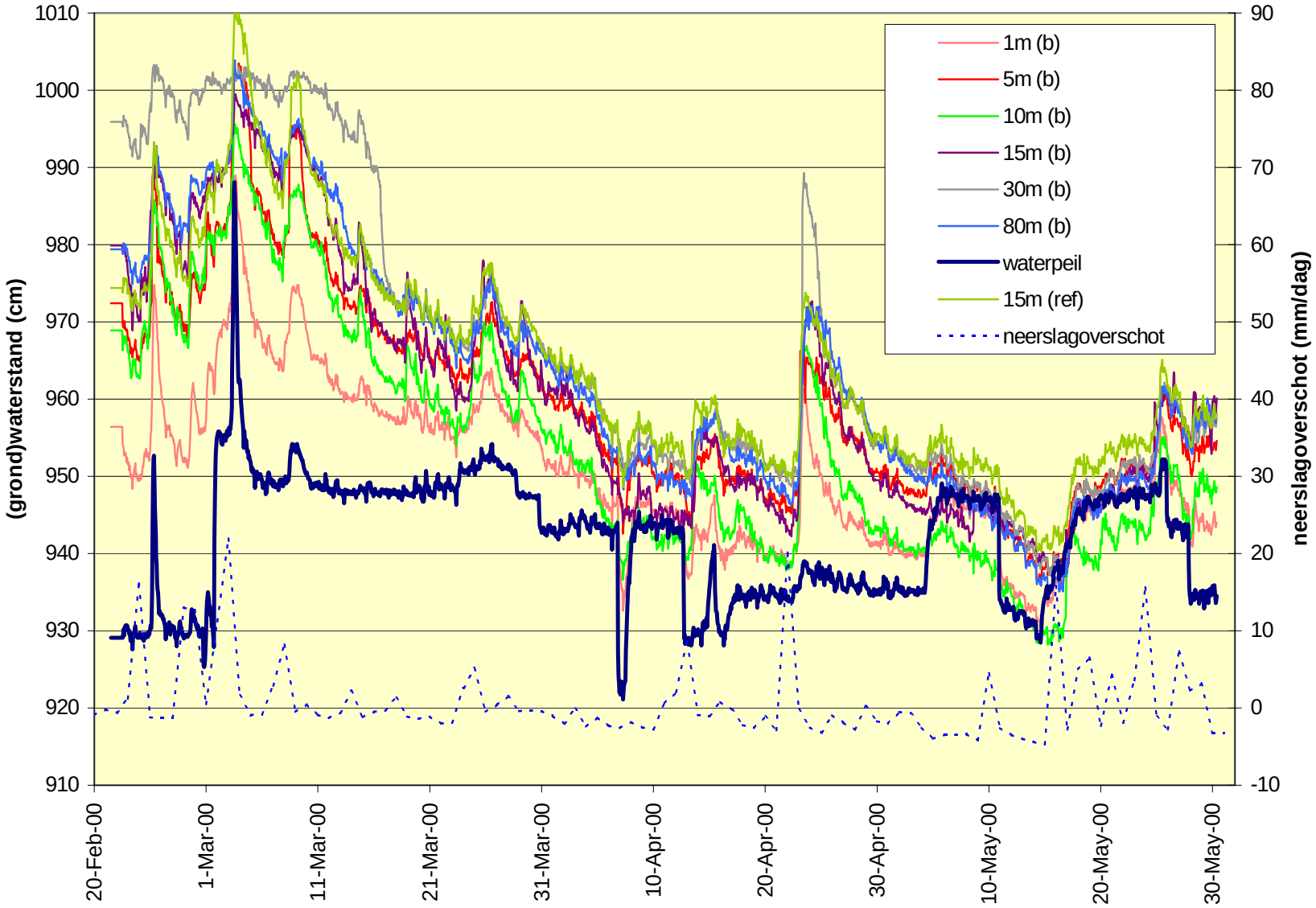


Deltares

Resultaten van slootproeven: Oud-Turnhout

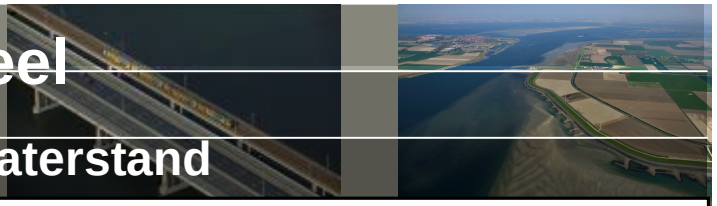
Gemeten effecten of peilveranderingen op grondwaterstand

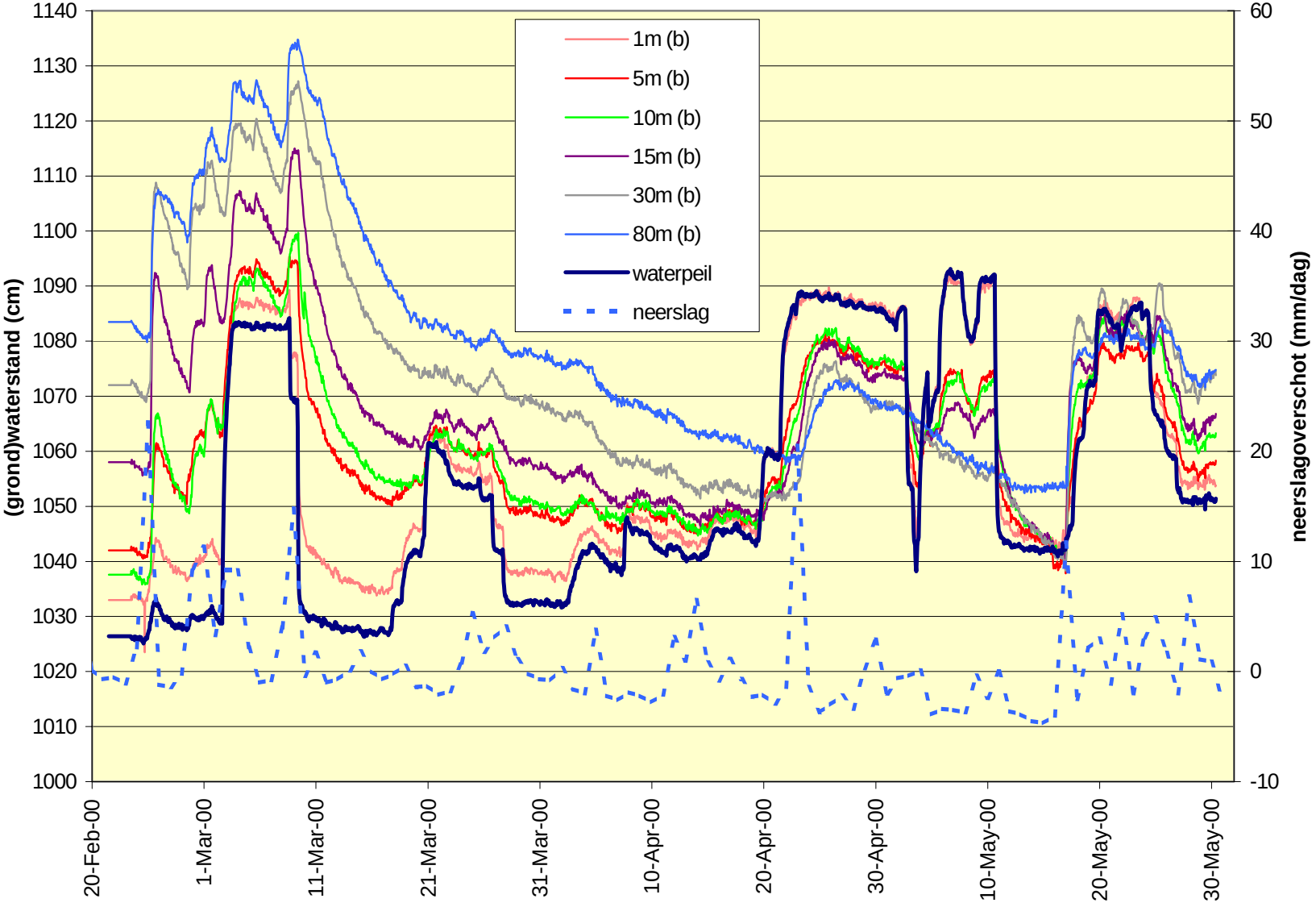




Resultaten van slootproeven: Vredepeel

Gemeten effecten of peilveranderingen op grondwaterstand

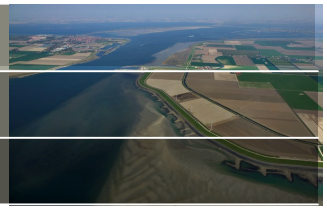




De gemeten effecten op de grondwaterstand van de slootproeven (% van peilverhoging)

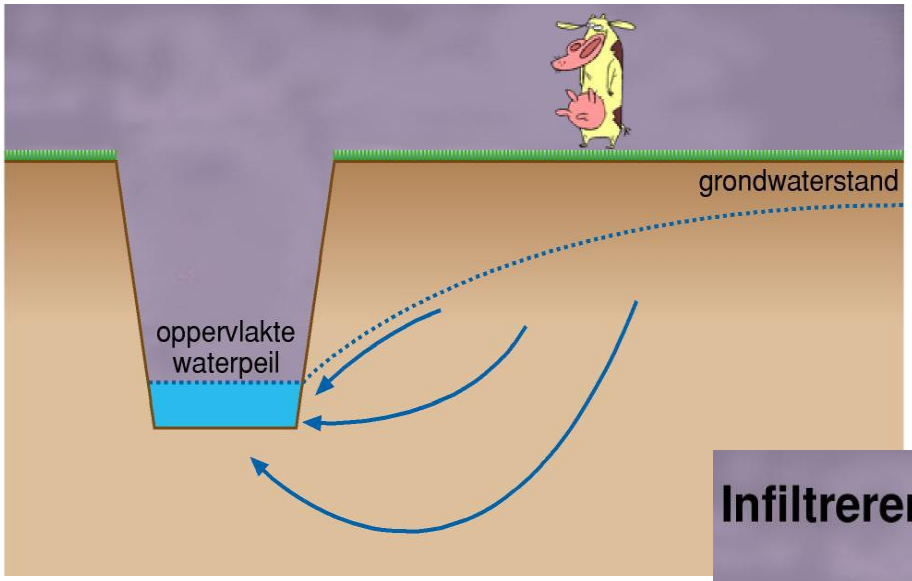
Afstand tot sloot-->	1m	5m	10m	15m	30m	80m
Sprundel	0	0	0	0	0	0
Oud-Turnhout	**41**	**34**	**21**	**12**	**8**	**0**
Overpelt	57	26	1	14	13	0
Spoordonk	86	46	18	9	2	0
Vredepeel	**93**	**54**	**49**	**38**	**15**	**1**

Conclusies slootproeven (1)

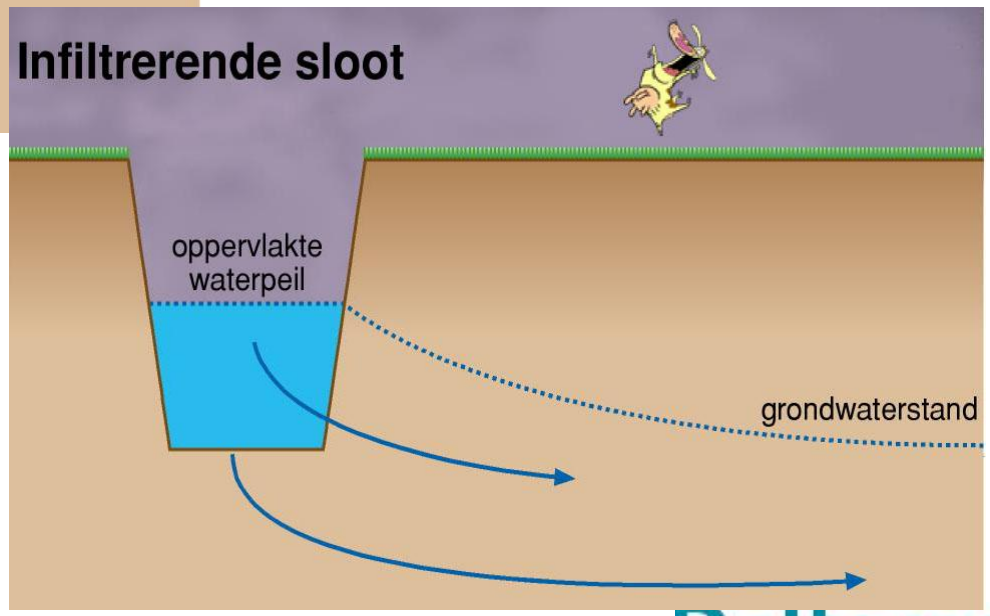


- Gering ruimtelijk effect van peilverhoging (eerste 20 meter)
- Effecten werken relatief snel door voor eerste 20 meter van de sloot, op grotere afstand treedt er een duidelijke vertraging op
- Grotere doorlatendheid geeft groter en sneller effect
- Verlagen van grondwaterstand door peilverlaging veel sneller en sterker dan verhogen door peilverhoging

Relatie grondwater – oppervlaktewater

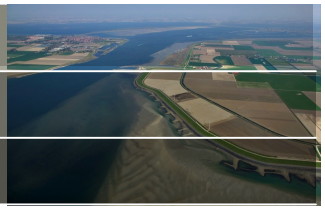


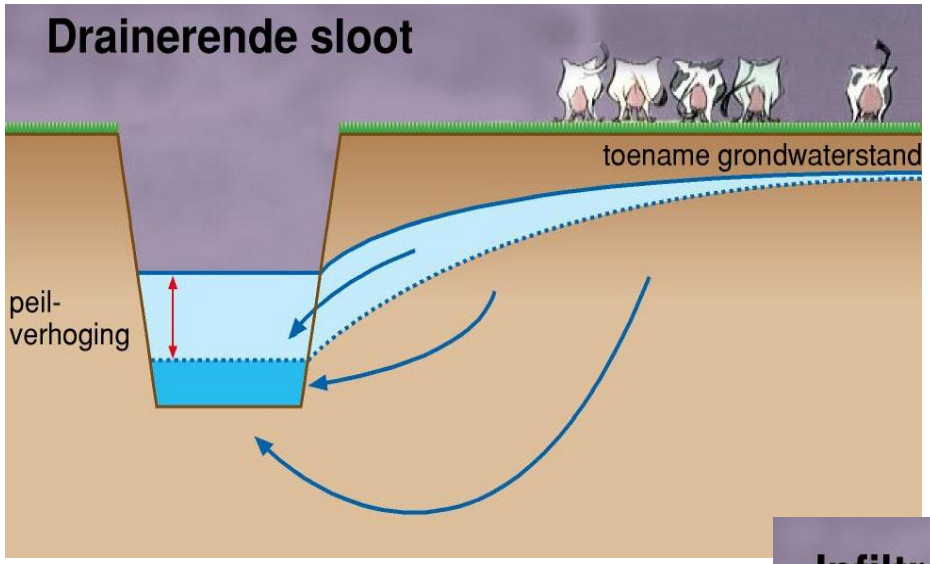
Drainage situatie



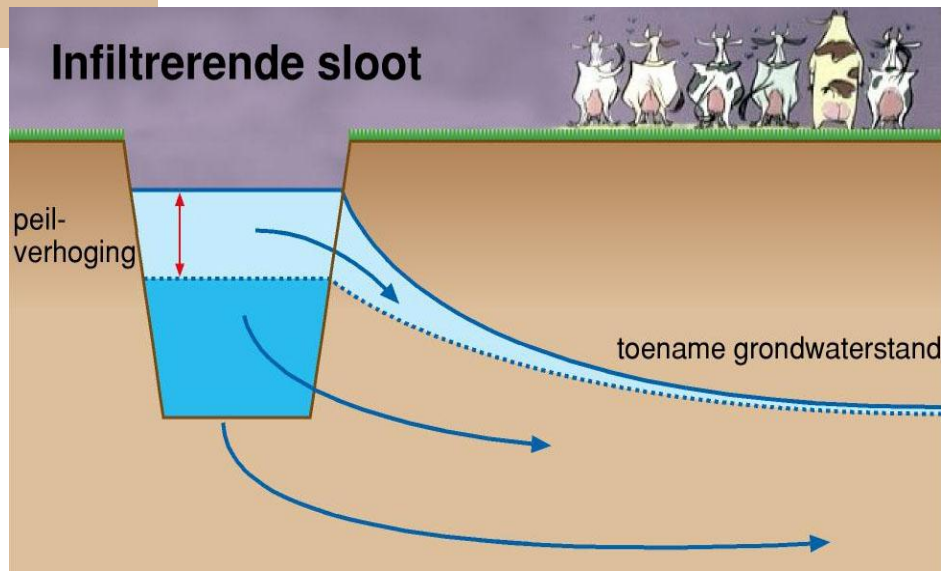
Infiltratie situatie

Waterconservering





Drainage situatie



Infiltratie situatie

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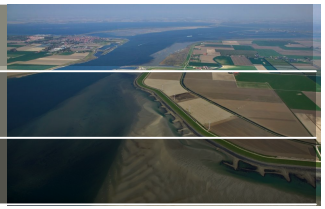
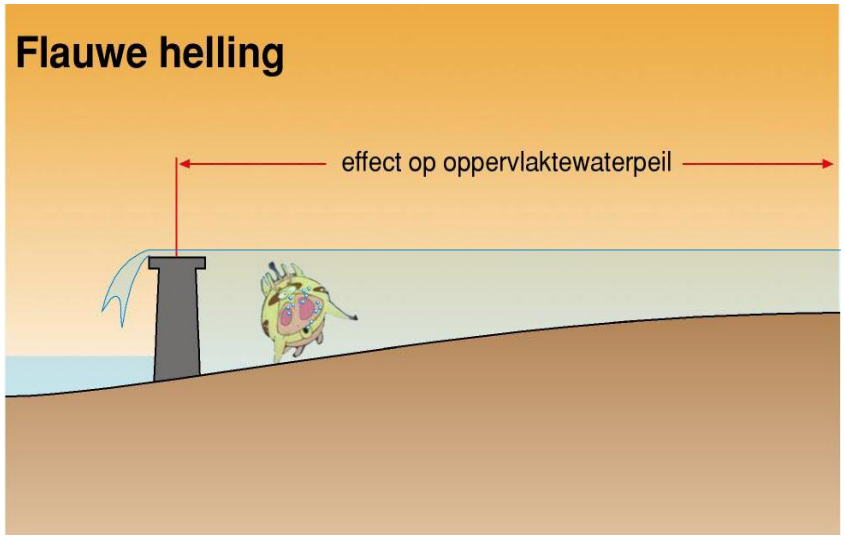
Conclusies Slootproeven (2)

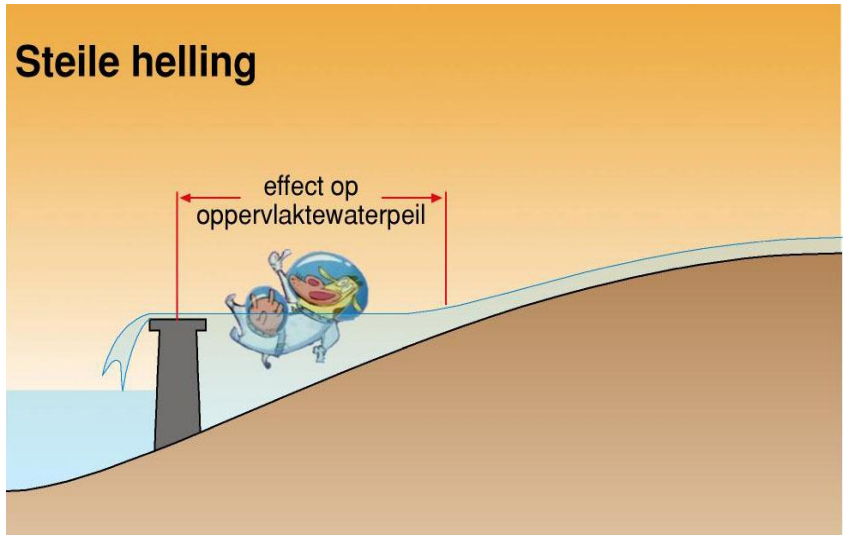


- Natte percelen hoofdzakelijk veroorzaakt door neerslag, in mindere mate door peilverhoging

Grootste waterconserveringseffect van 1 stuw:

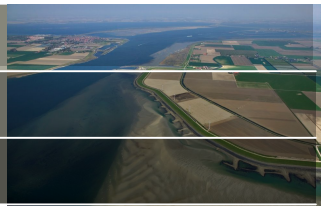
- (1) in sloot met geringe gradient
- (2) in sloot met veel zijsloten die worden beinvloed





Deltares

Inhoud



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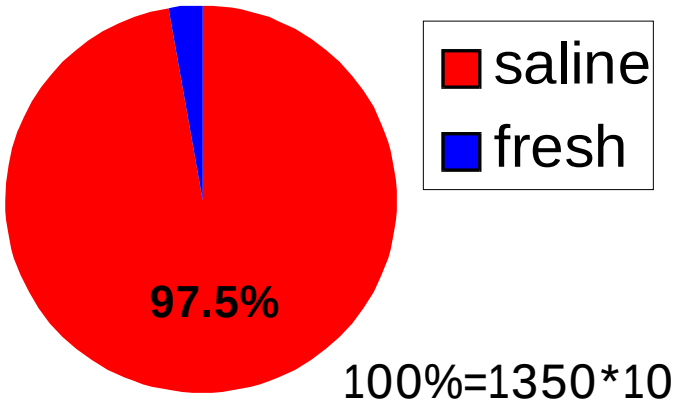
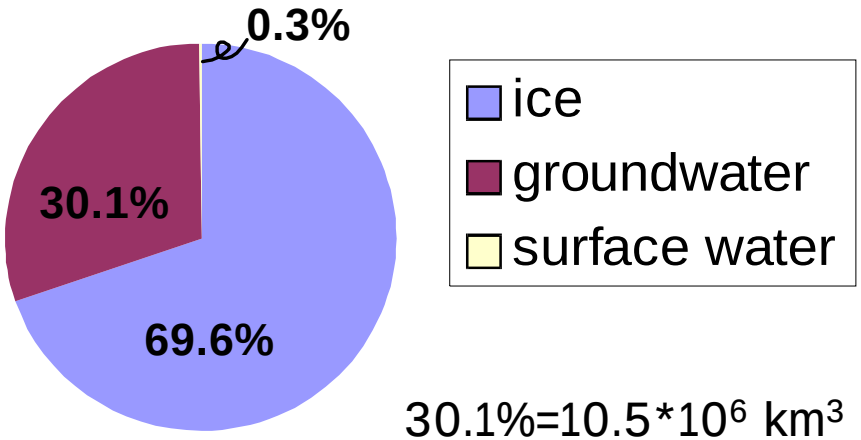
Water on Earth

Total water on Earth



100%=1350*10^6 km^3

Total fresh water on Earth



30.1%=10.5*10^6 km^3

Demand for groundwater (now 30%) increases due to:

- increase world population & economical growth
- loss of surface water due to contamination

Groundwater is available in large quantities and is still unpolluted (relative to surface water)

(Source: Cheng, 1998)

Grondwater-onderzoek in Zeeland door Deltares

Zoet-zout water in Zeeland

- Weinig / geen zoet oppervlaktewater beschikbaar
- Landbouw afhankelijk van regenwaterlenzen en/of zoete grondwatervoorraden (duinen – kreekruggen)

Onderzoek

- Regenwaterlenzen in gebieden met zoute kwel : nu en toekomst
- CLIWAT
- SCALDWIN
- Kennis voor Klimaat (Climate Proof Fresh Water Supply)
- Waterhouderij

Onderzoek met hulp van:

1. Grondwatermodellen (regionaal en lokaal)
2. Veldmetingen
3. Samen met waterschap en boeren

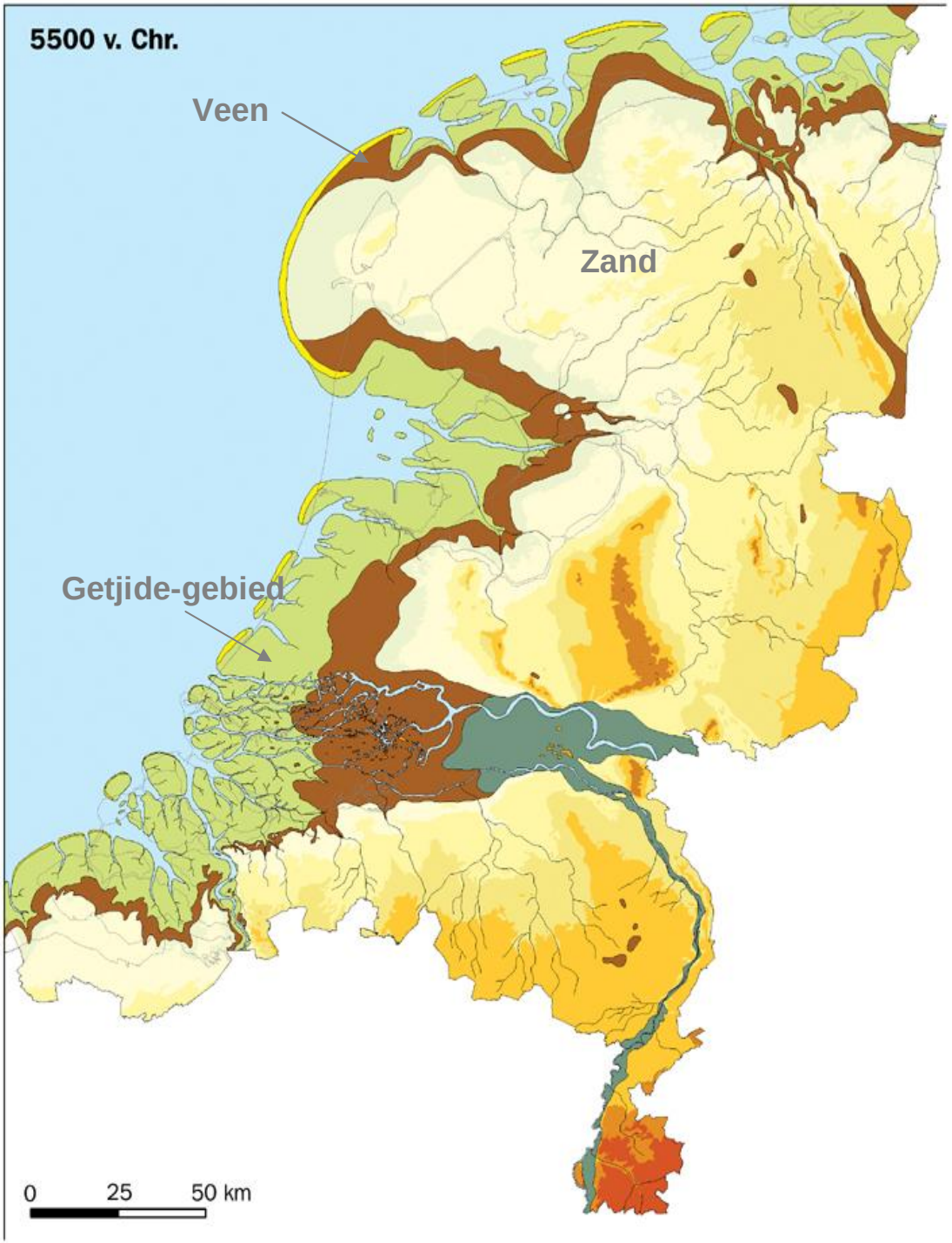
Deltares

The Holocene transgressions

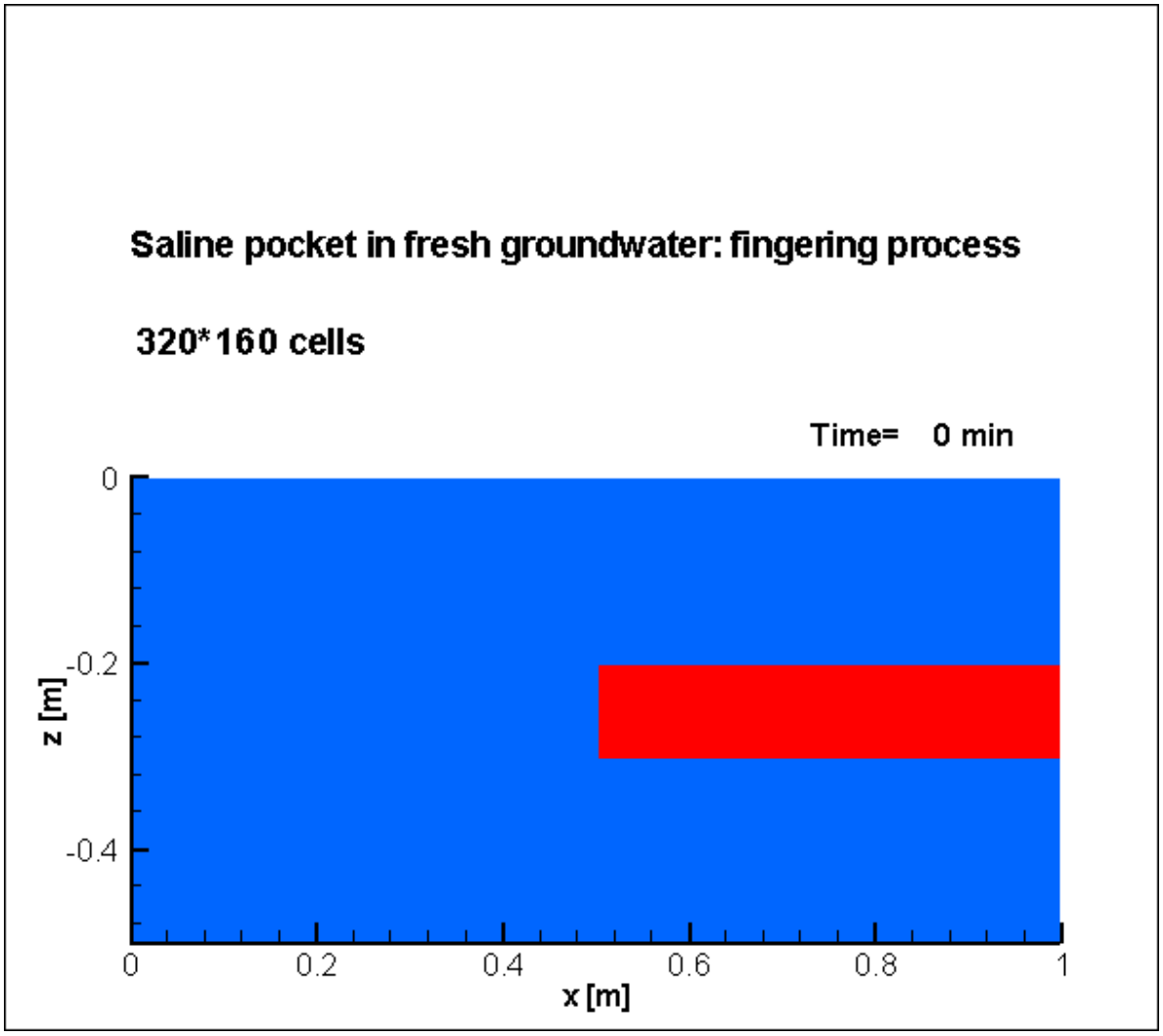
7500 BP

Major impact on present regional saline groundwater systems

SALINIZATION BY FREE CONVECTION

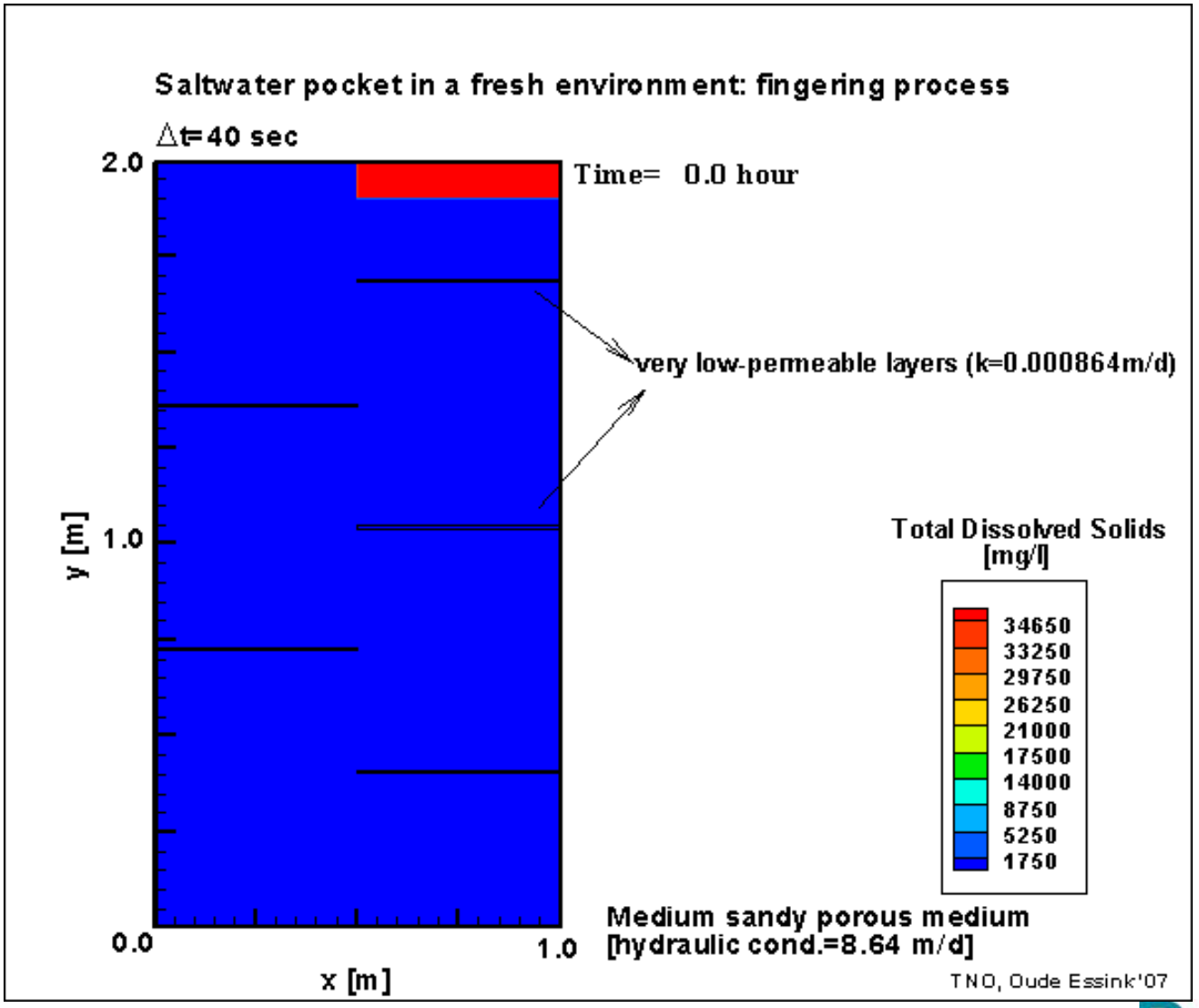


Salt water pocket in a fresh environment (I) (similar to Holocene transgressions)



Deltares

Fingering processes in the subsoil

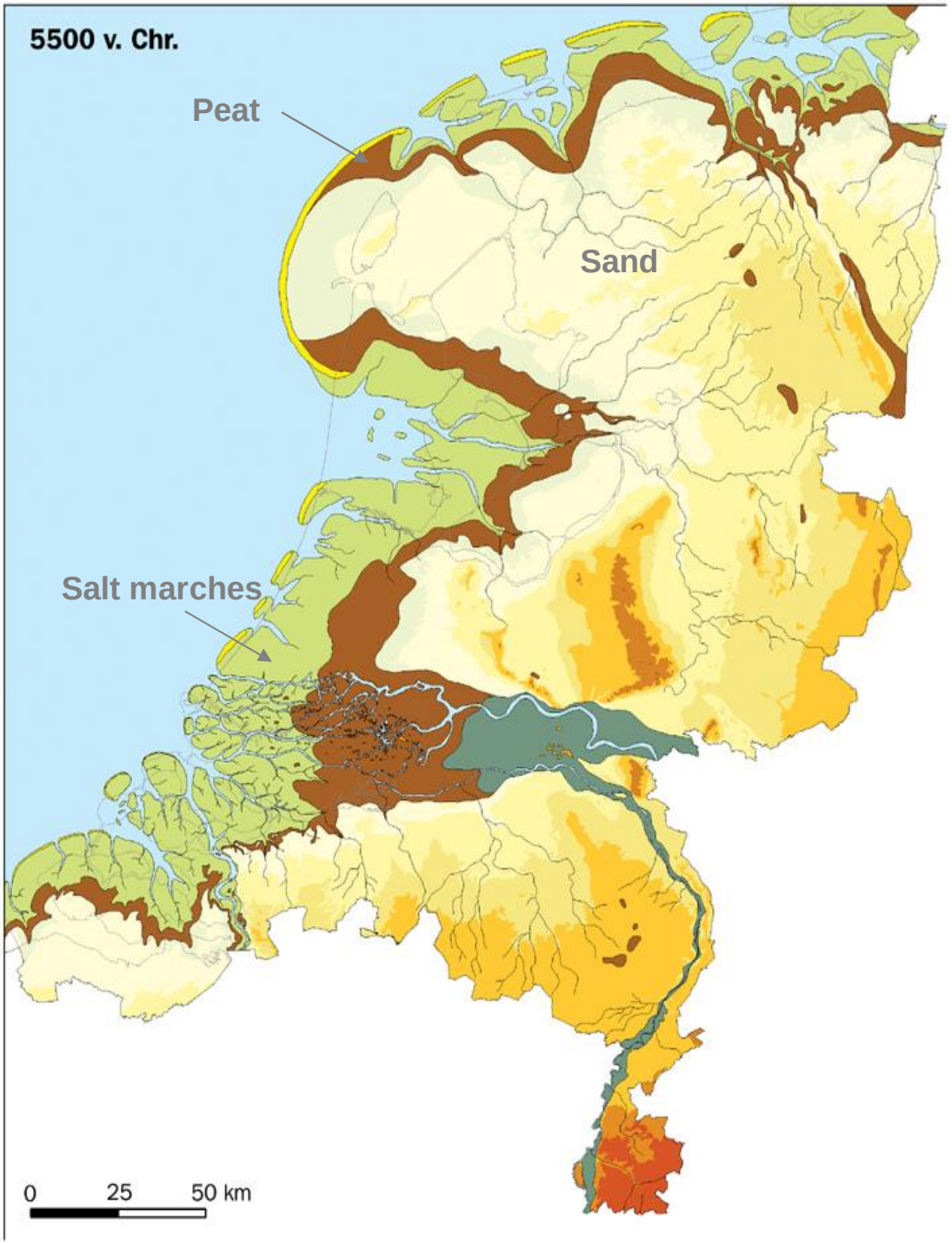


Deltares

The Holocene transgressions

Major impact on present regional saline groundwater systems

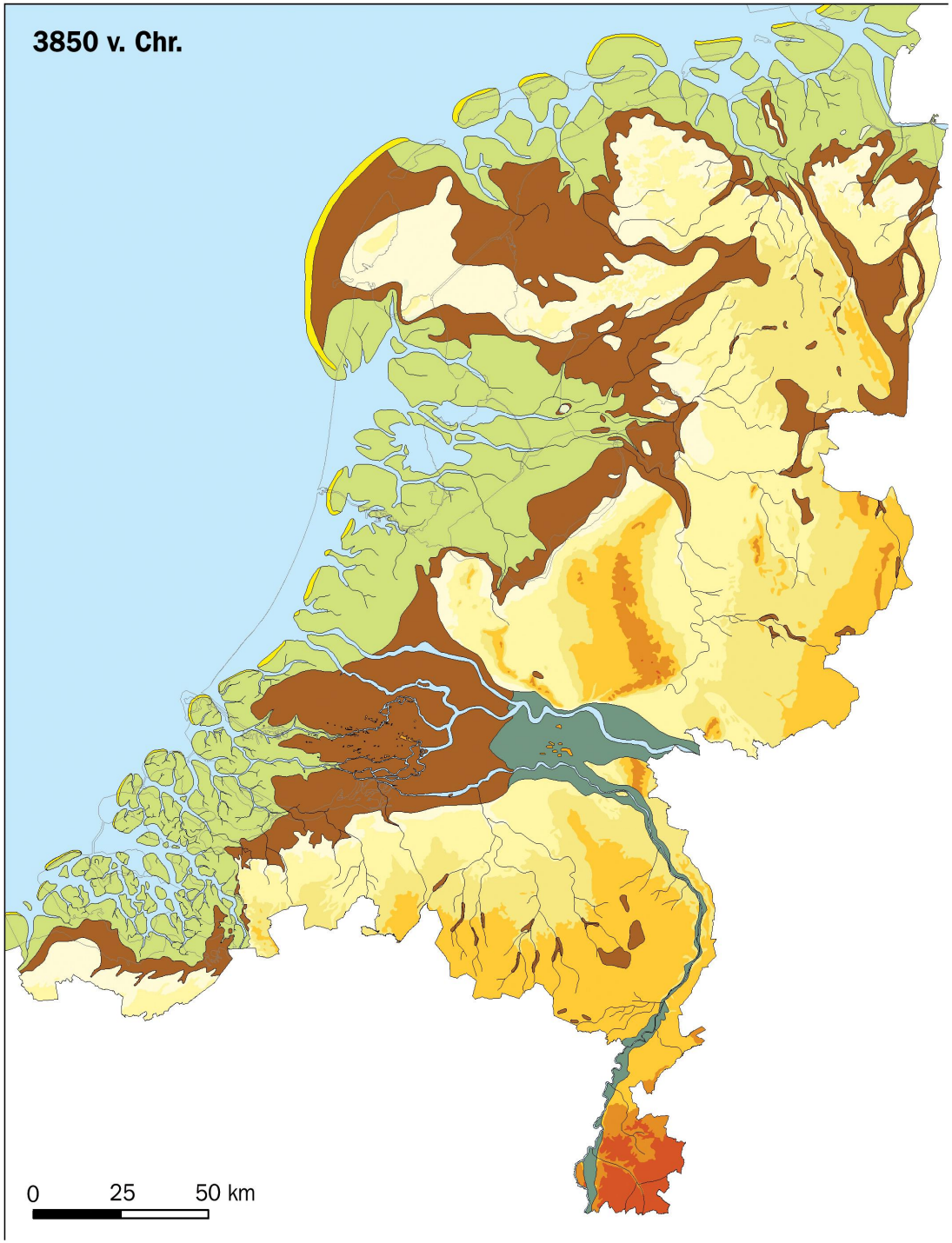
7500 BP



The Holocene transgressions

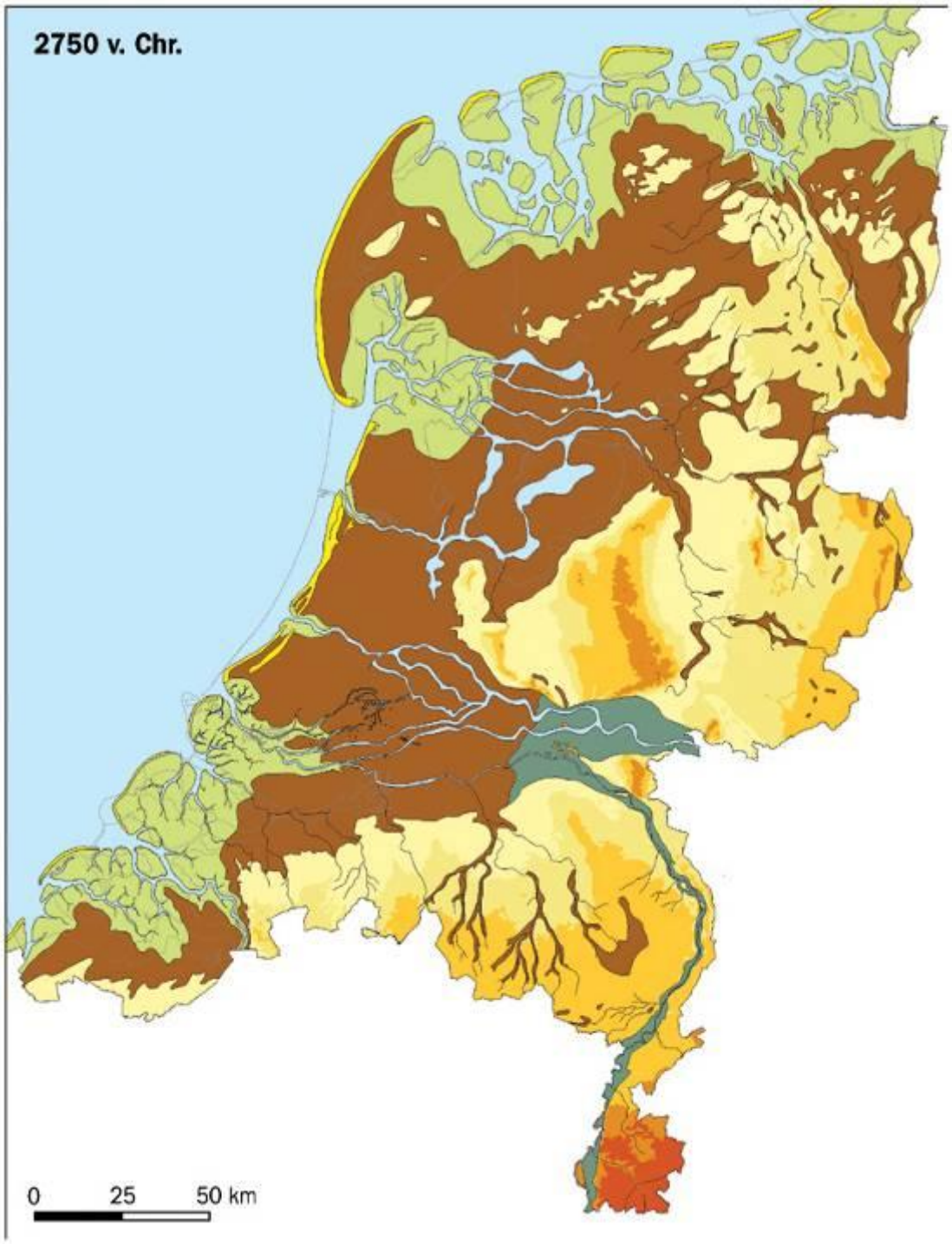
5850 BP

Maximum transgression



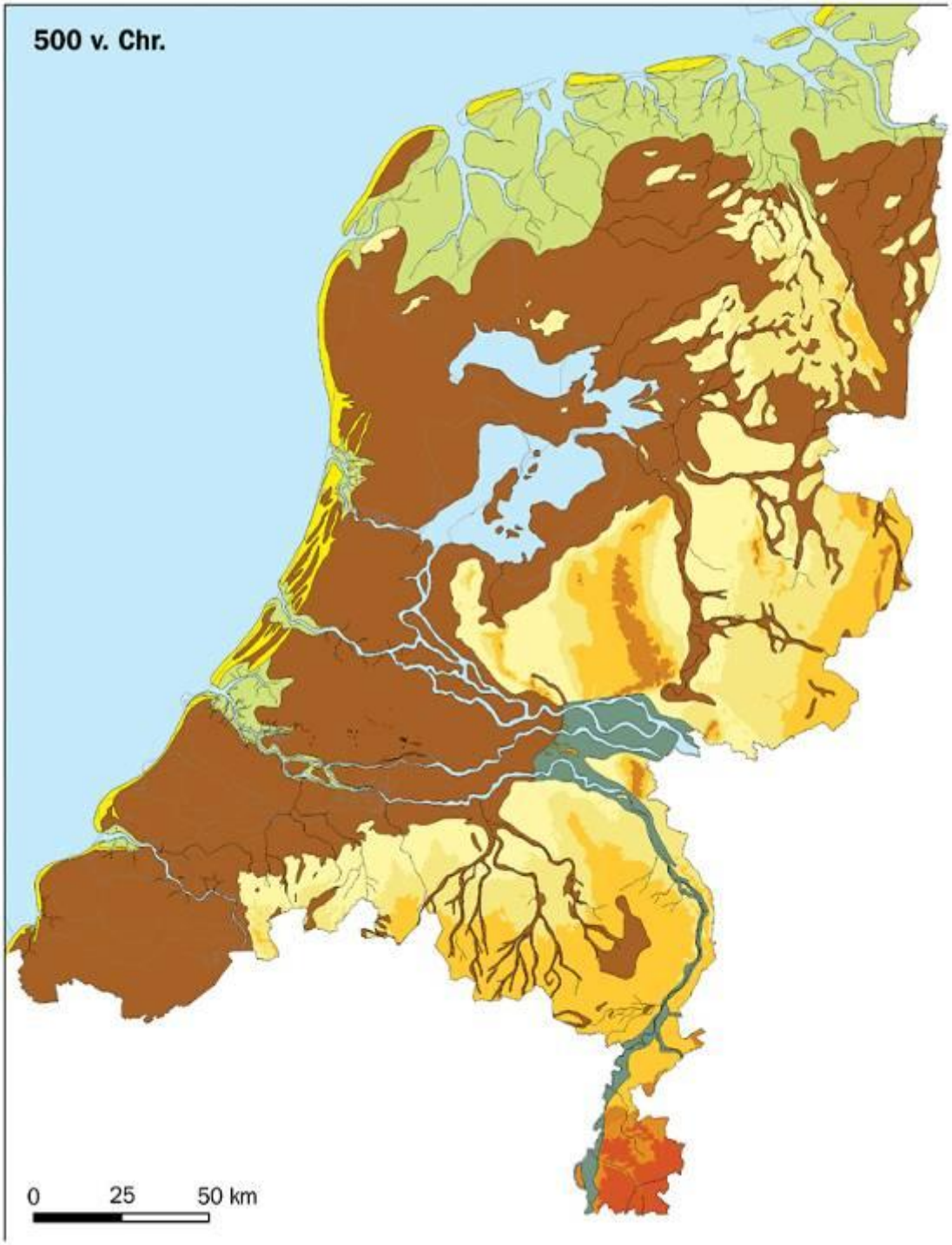
The Holocene transgressions

3350 BP



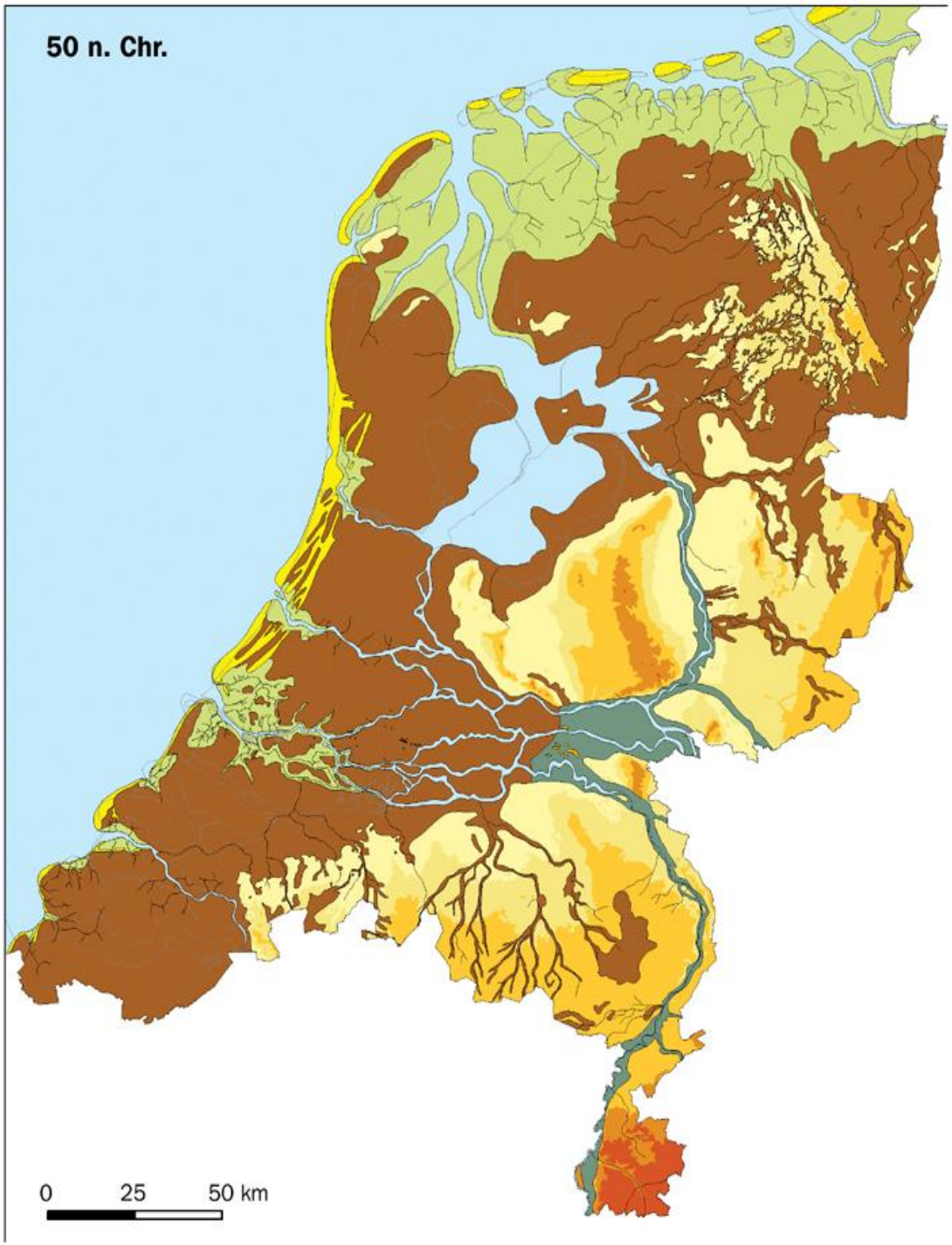
The Holocene transgressions

2500 BP



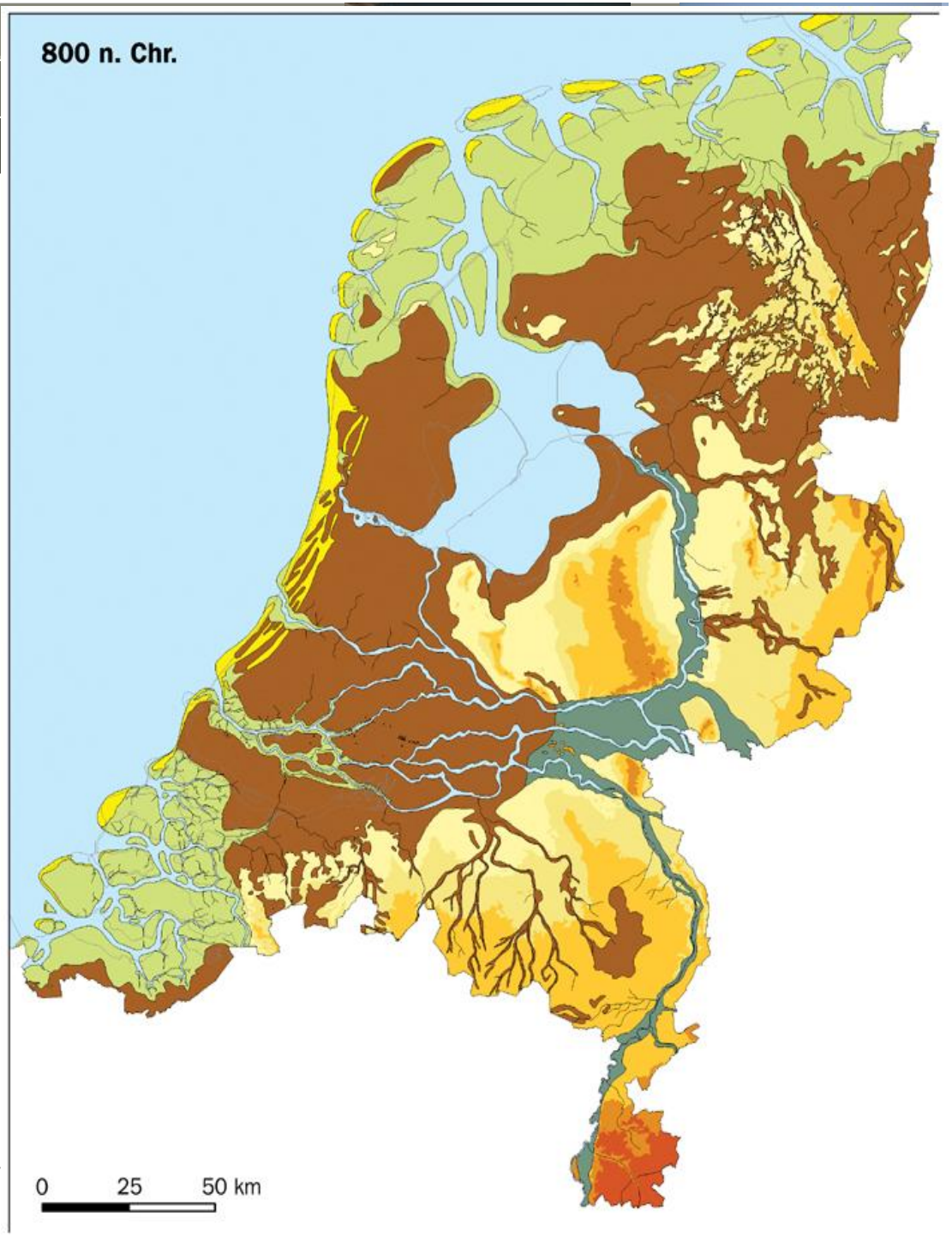
The Holocene transgressions

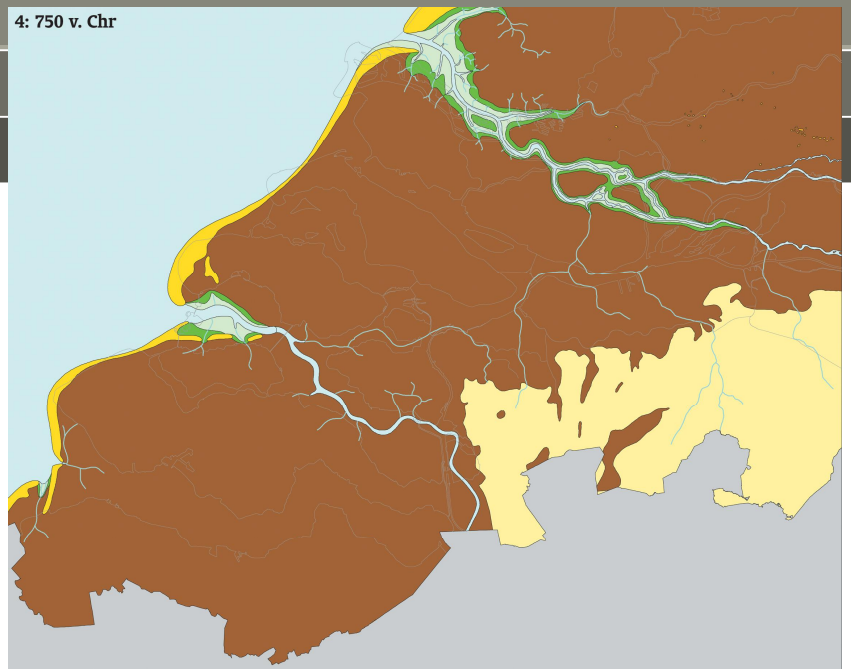
50 AD (Roman time)

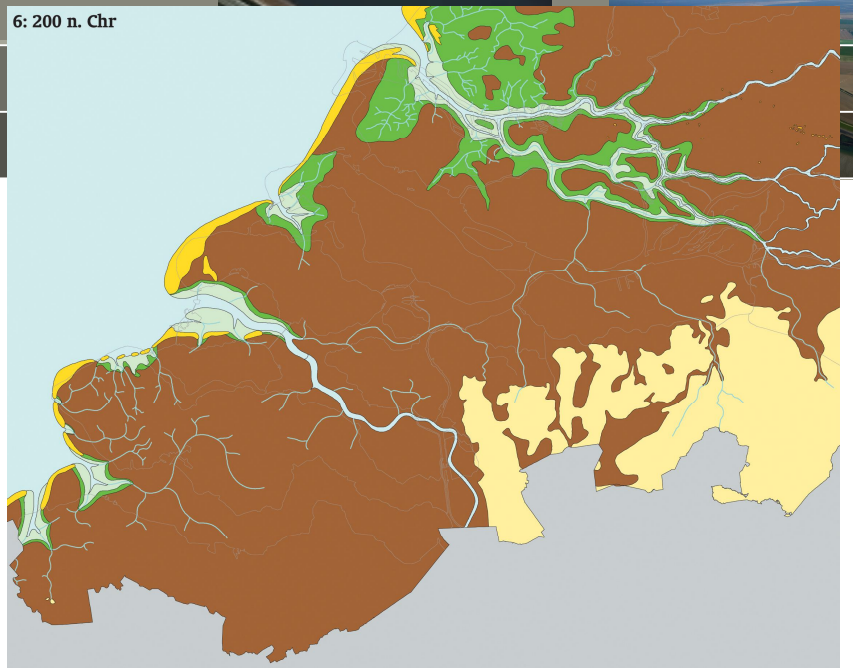


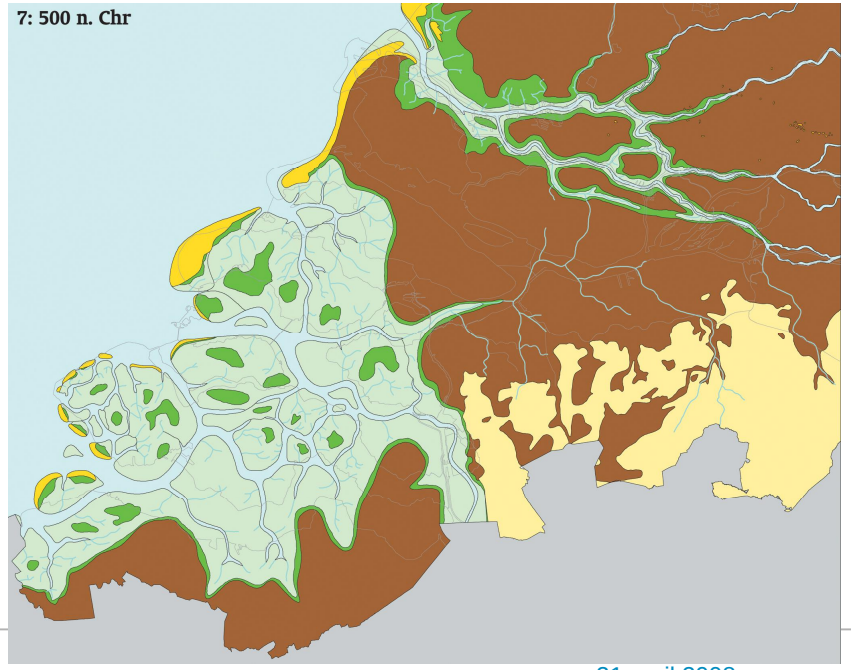
The Holocene transgressions

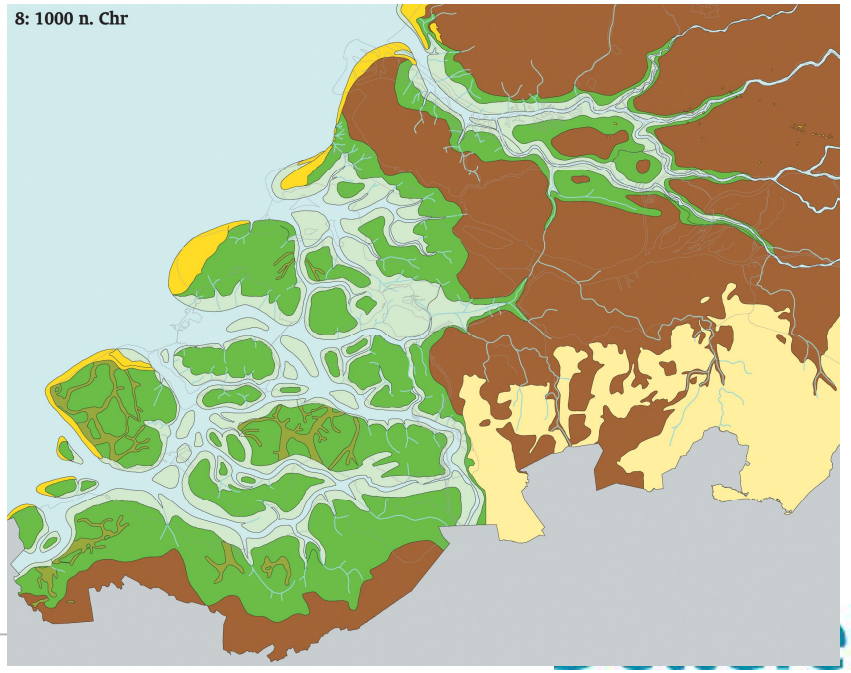
800 AD

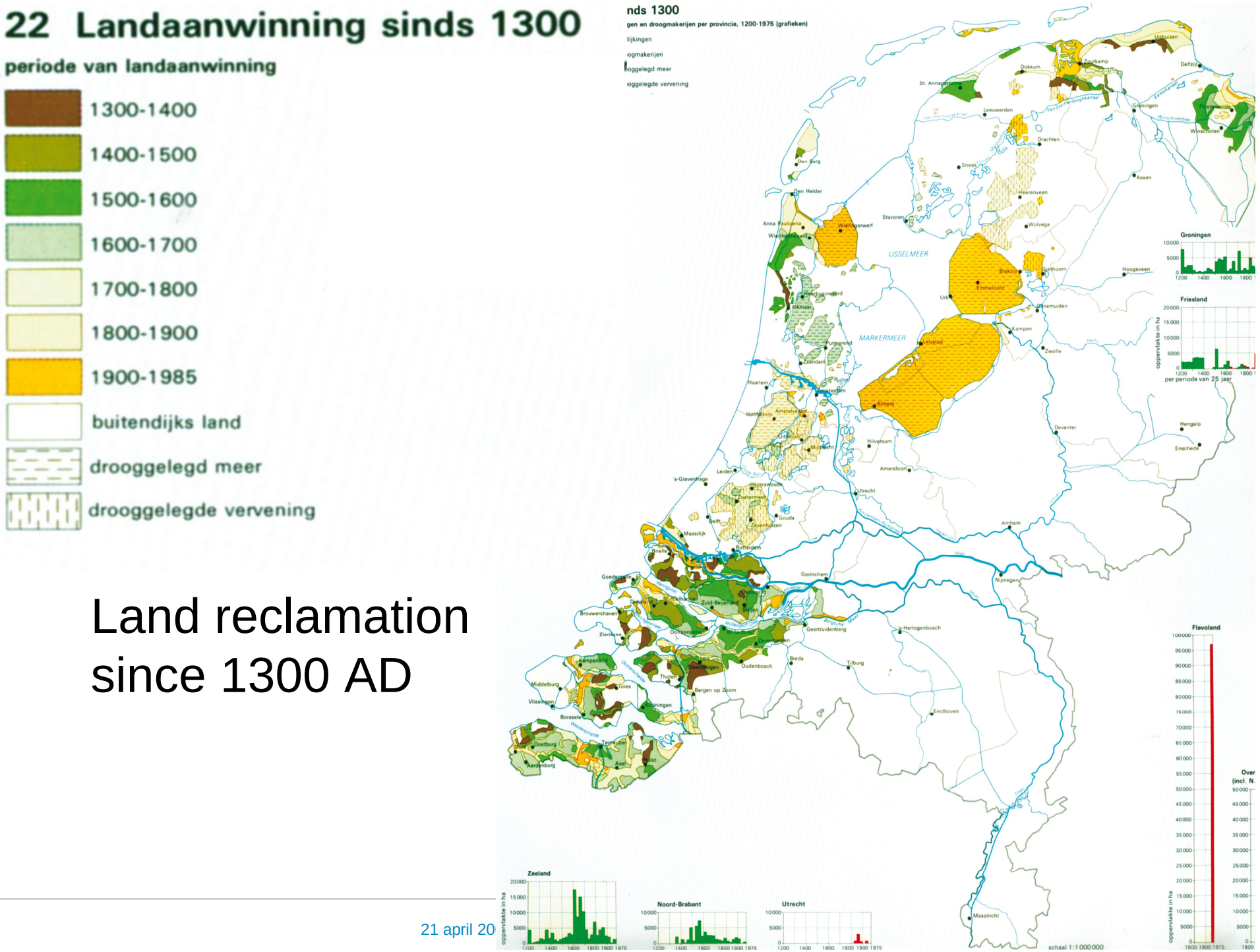



4: 750 v. Chr


6: 200 n. Chr

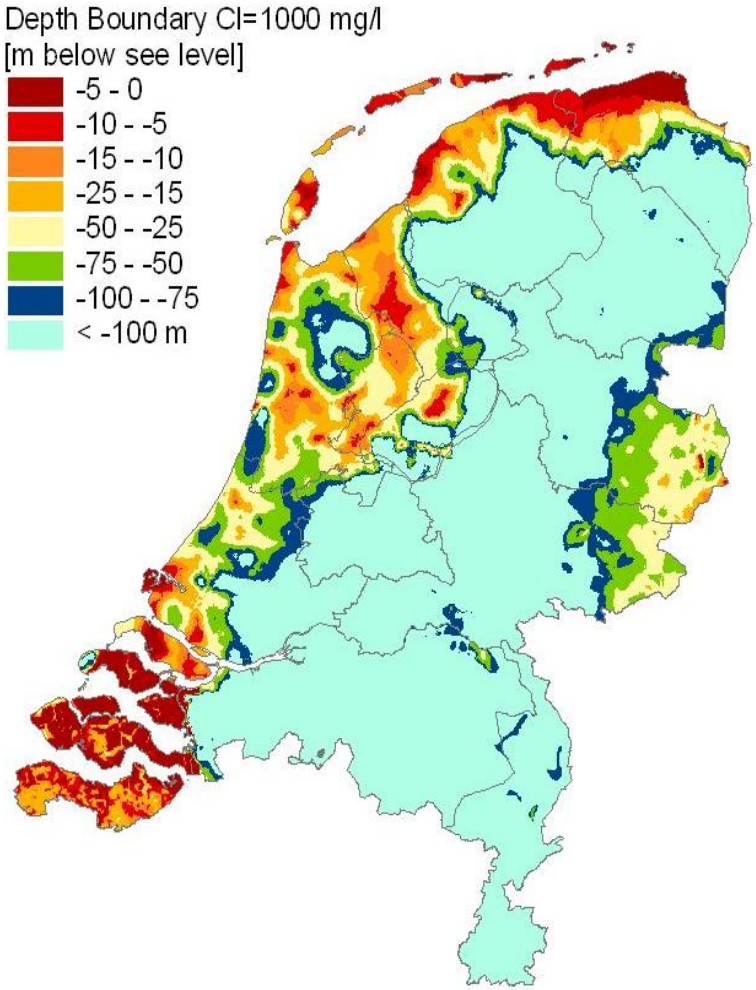

7: 500 n. Chr

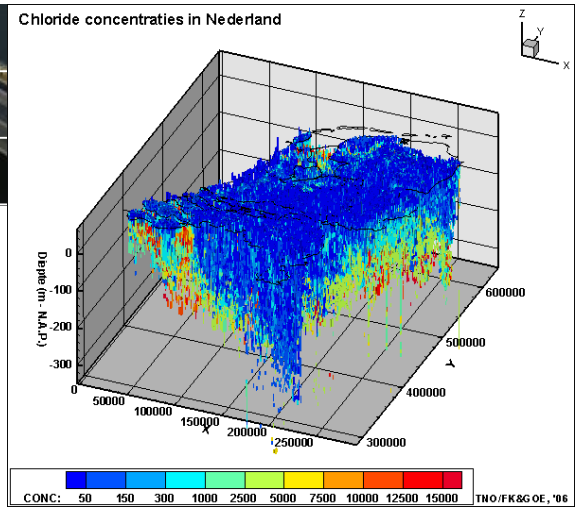

8: 1000 n. Chr

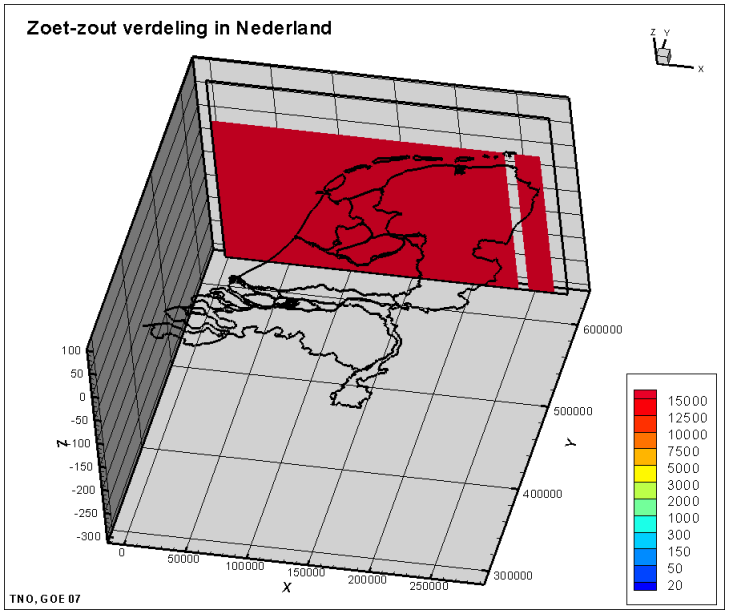


Land reclamation since 1300 AD

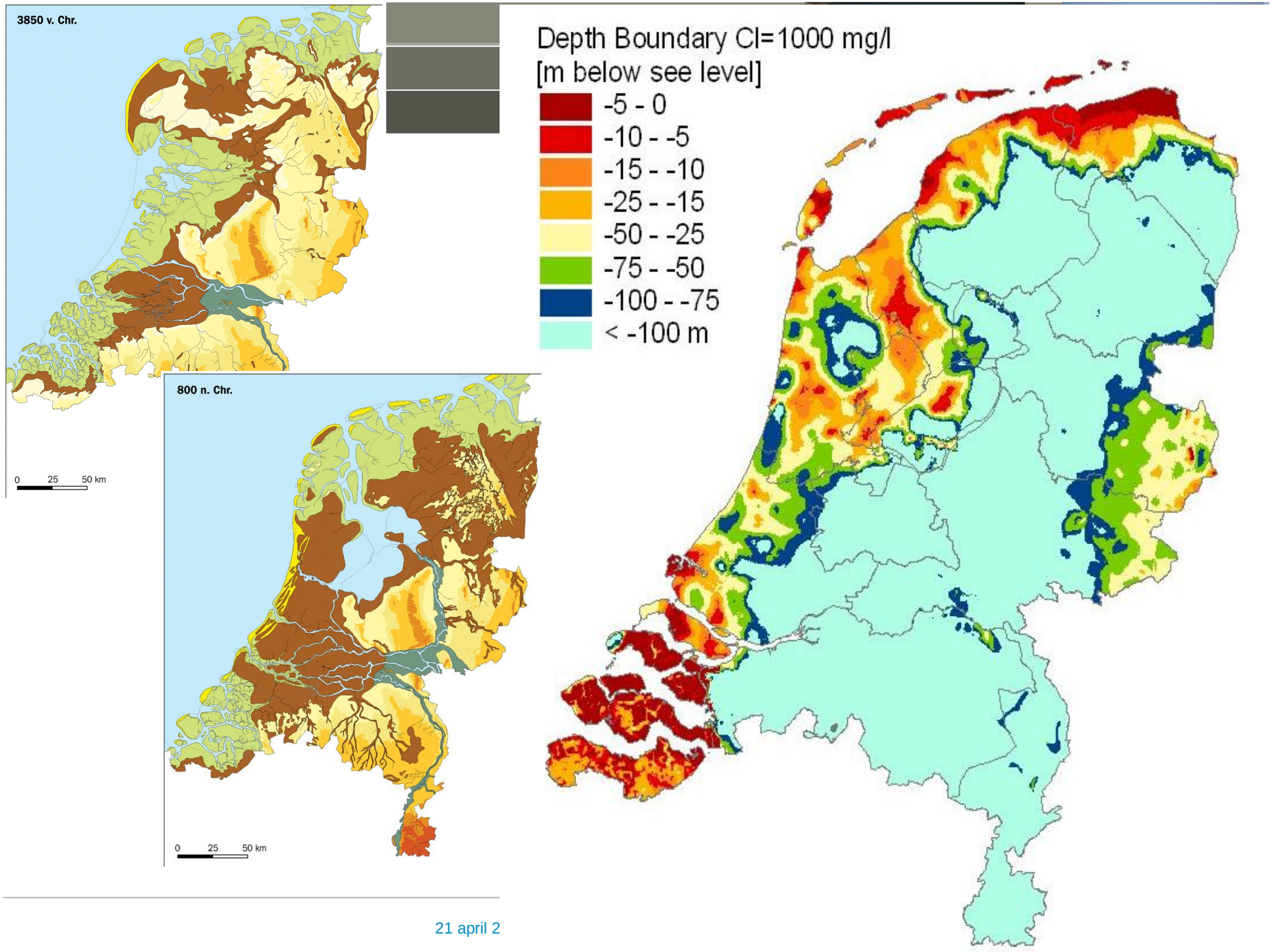
Grensvlak zoet-brak grondwater







Based on:
Analyses, VES and Borehole meas.


3850 v. Chr.
0 25 50 km
800 n. Chr.
0 25 50 km
Depth Boundary Cl=1000 mg/l
[m below see level]
-5 - 0
-10 - -5
-15 - -10
-25 - -15
-50 - -25
-75 - -50
-100 - -75
< -100 m

Five regions : saline groundwater systems

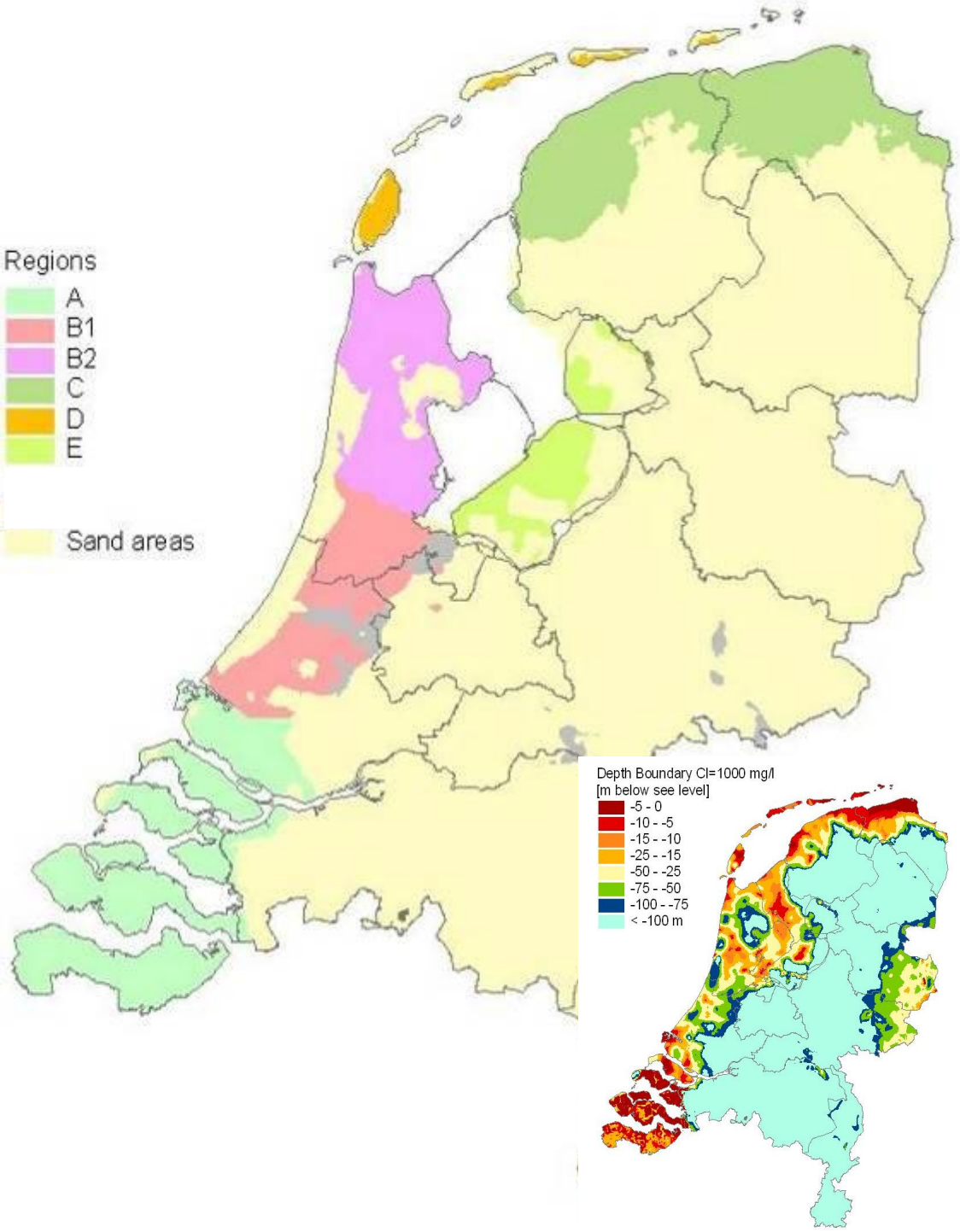
A: Zeeland

B: Western Netherlands

C: Friesland-Groningen

D: Islands of Wadden sea

E: Lake IJssel Polders



A: Important features for local groundwatersystems

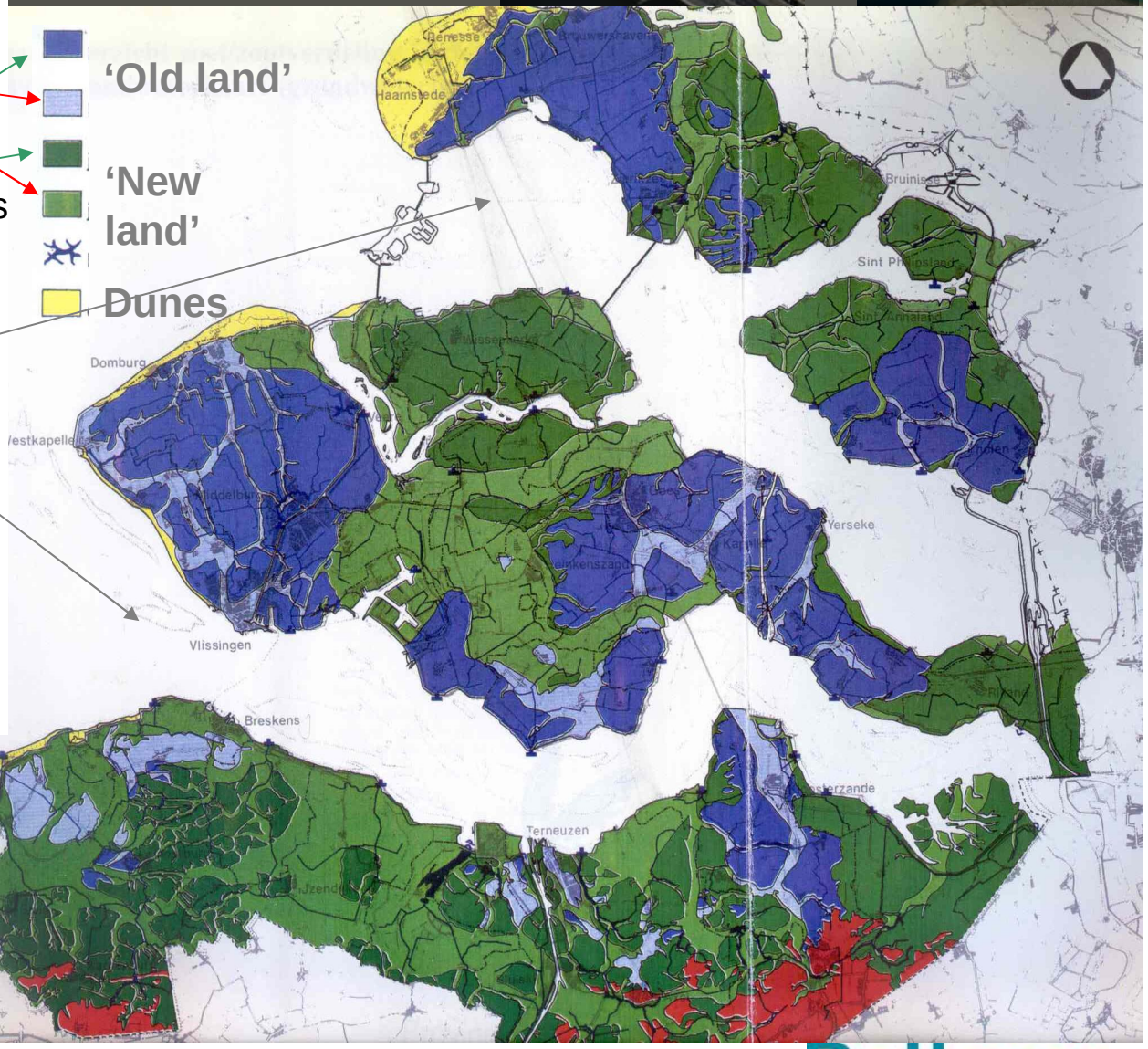
Creek deposits: infiltration, fresh rainwater lens 1-10m

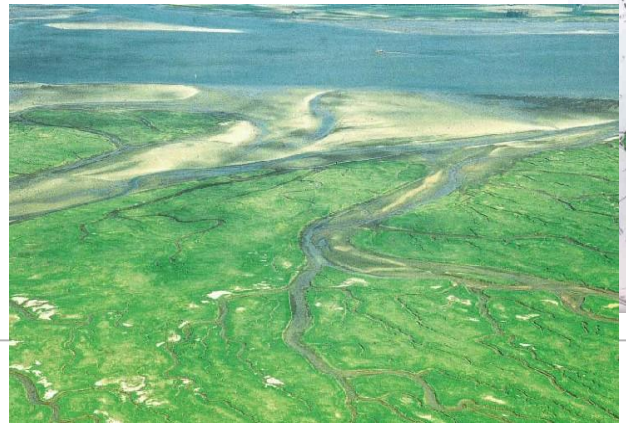
Reclaimed salt marches: exfiltration, fresh rainwater lens 0-1m

Infiltration from fresh or salt estuaries

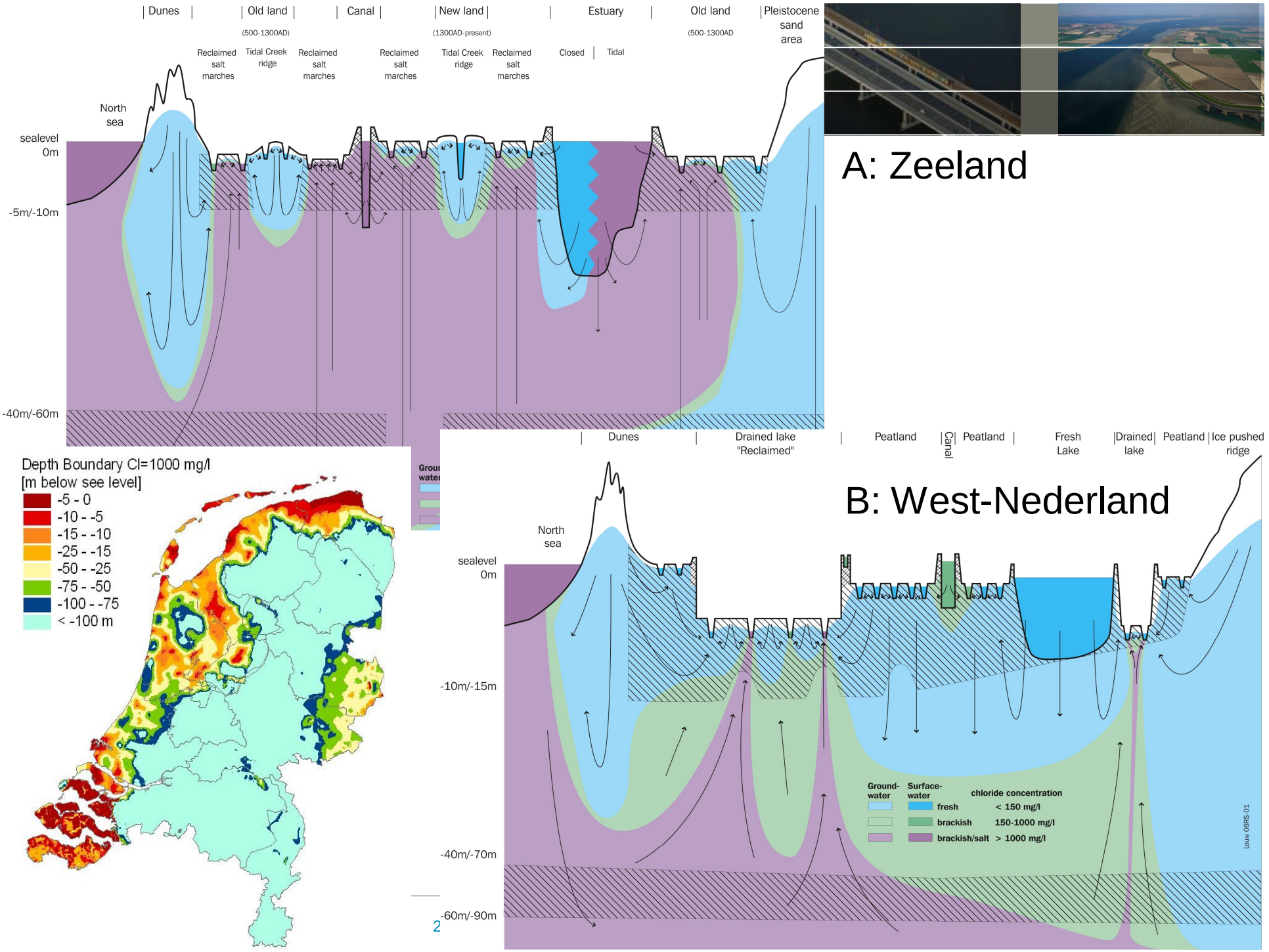
Infiltration from canals

Dune system

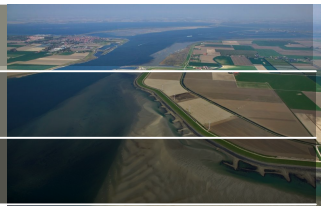


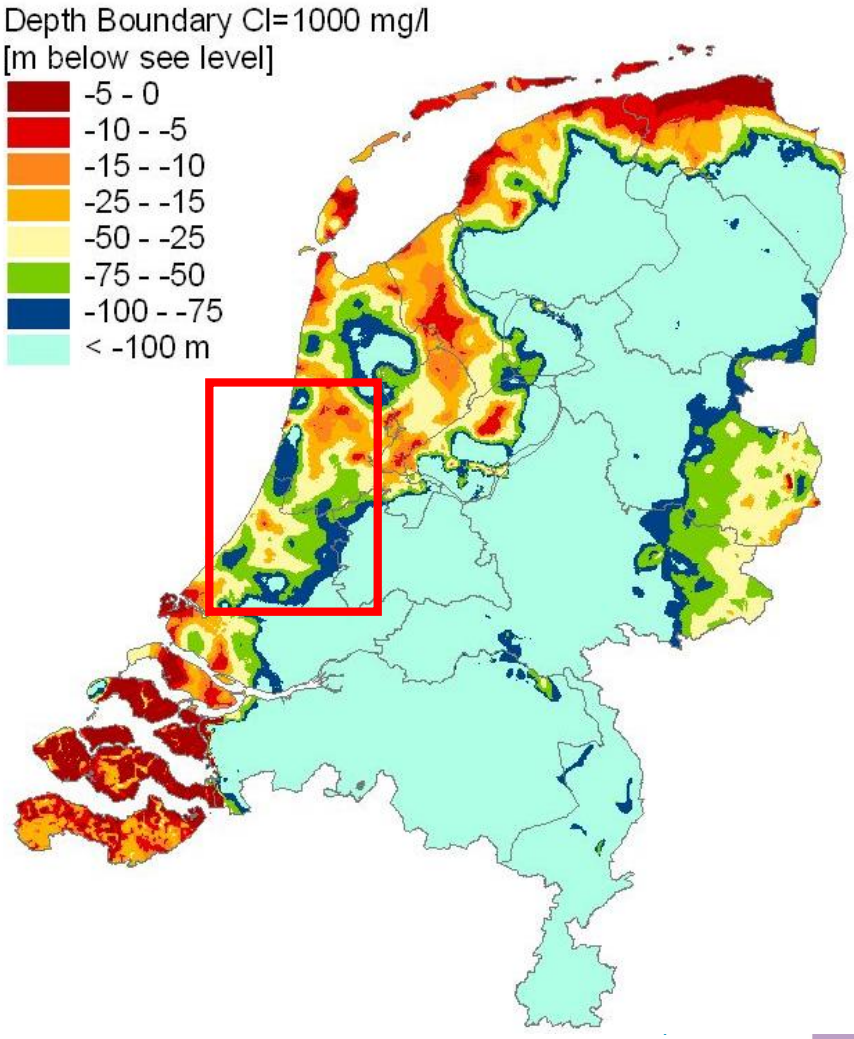


Deltares

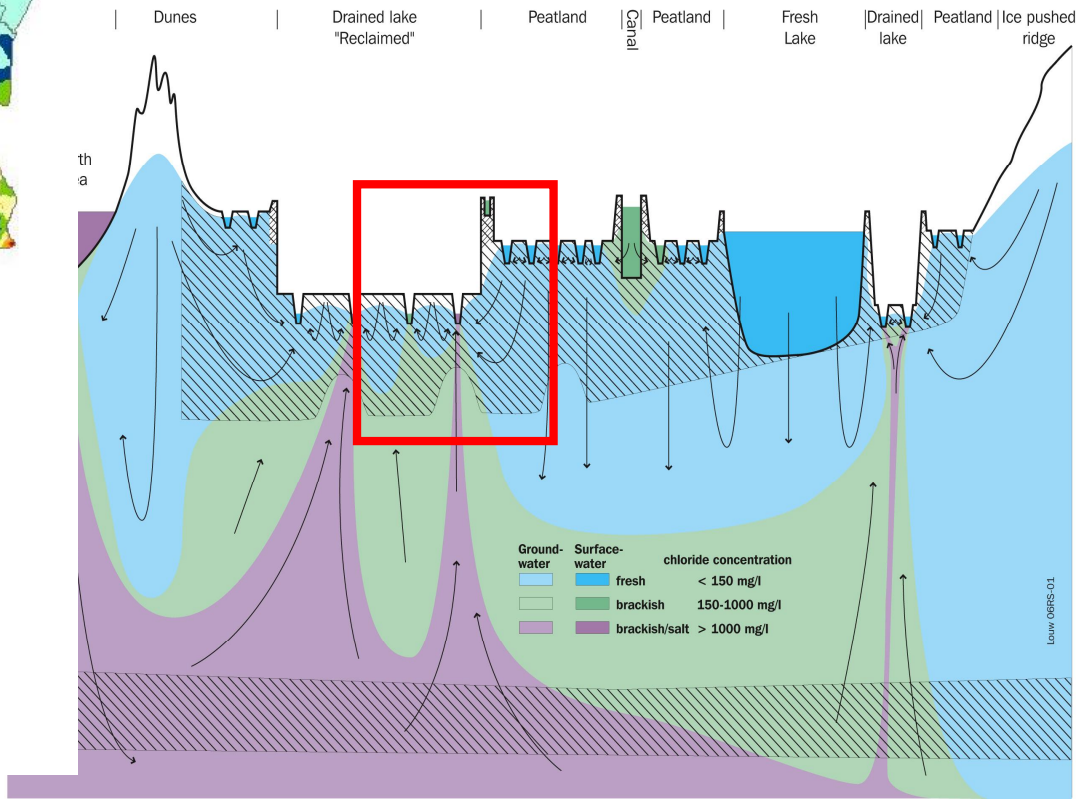

Dunes
Old land
(500-1300AD)
Canal
New land
(1300AD-present)
Estuary
Old land
(500-1300AD
Pleistocene sand area
Reclaimed salt marches
Tidal Creek ridge
Reclaimed salt marches
Reclaimed salt marches
Tidal Creek ridge
Reclaimed salt marches
Closed
Tidal
North sea
sealevel 0m
-5m/-10m
-40m/-60m
A: Zeeland
Depth Boundary Cl=1000 mg/l
[m below see level]
-5 - 0
-10 - -5
-15 - -10
-25 - -15
-50 - -25
-75 - -50
-100 - -75
< -100 m
Dunes
Drained lake "Reclaimed"
Peatland
Canal
Peatland
Fresh Lake
Drained lake
Peatland
Ice pushed ridge
B: West-Nederland
North sea
sealevel 0m
-10m/-15m
-40m/-70m
-60m/-90m
Ground-water
Surface-water
chloride concentration
fresh
< 150 mg/l
brackish
150-1000 mg/l
brackish/salt
> 1000 mg/l
Louw 06RS-01

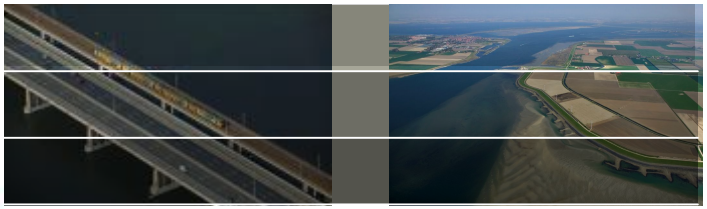
Saline seepage in deep polders



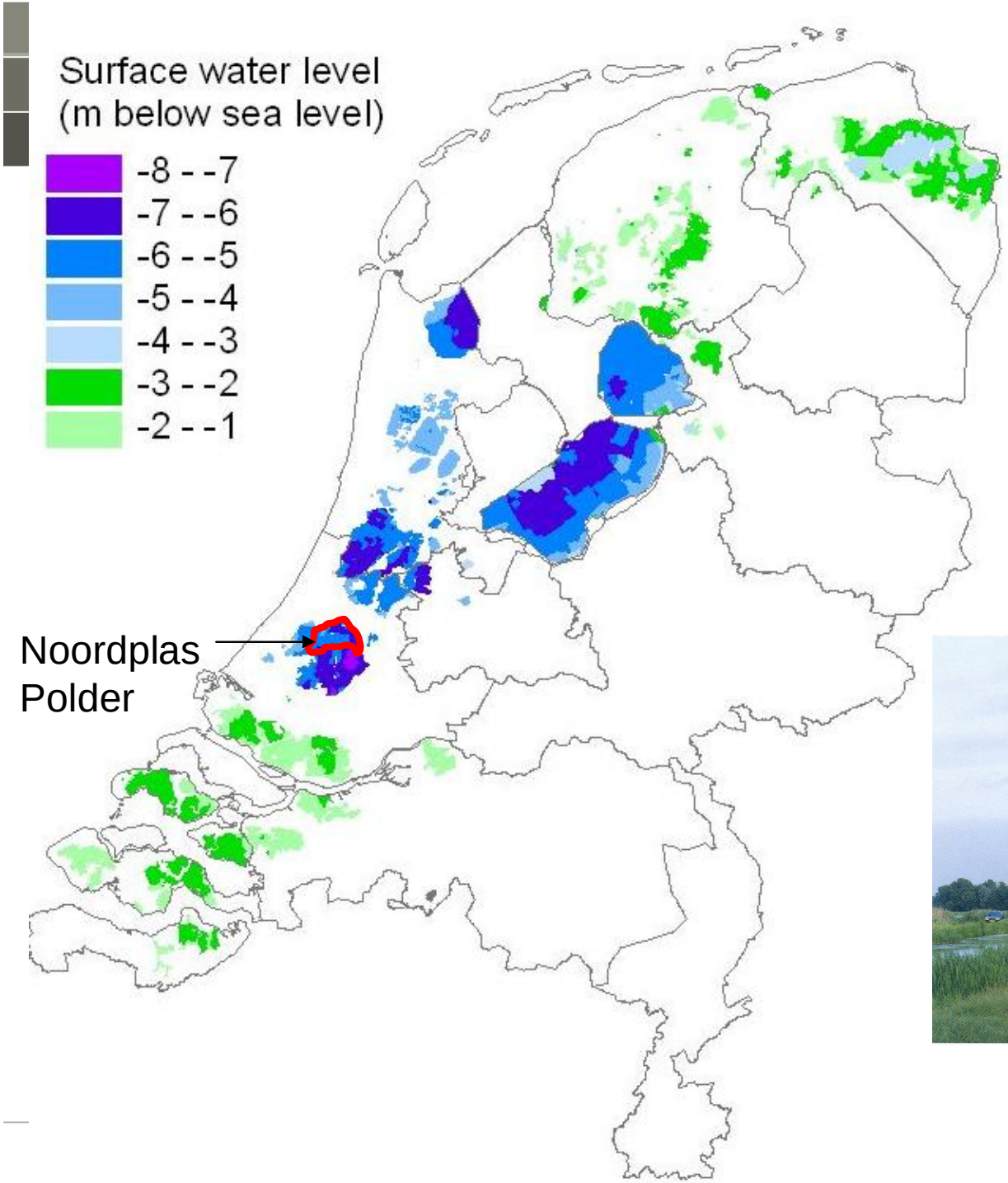


B: Western Netherlands



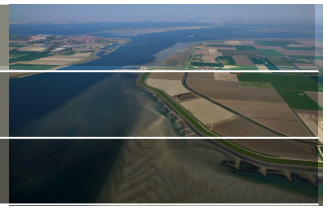


Deep polders in the Netherlands

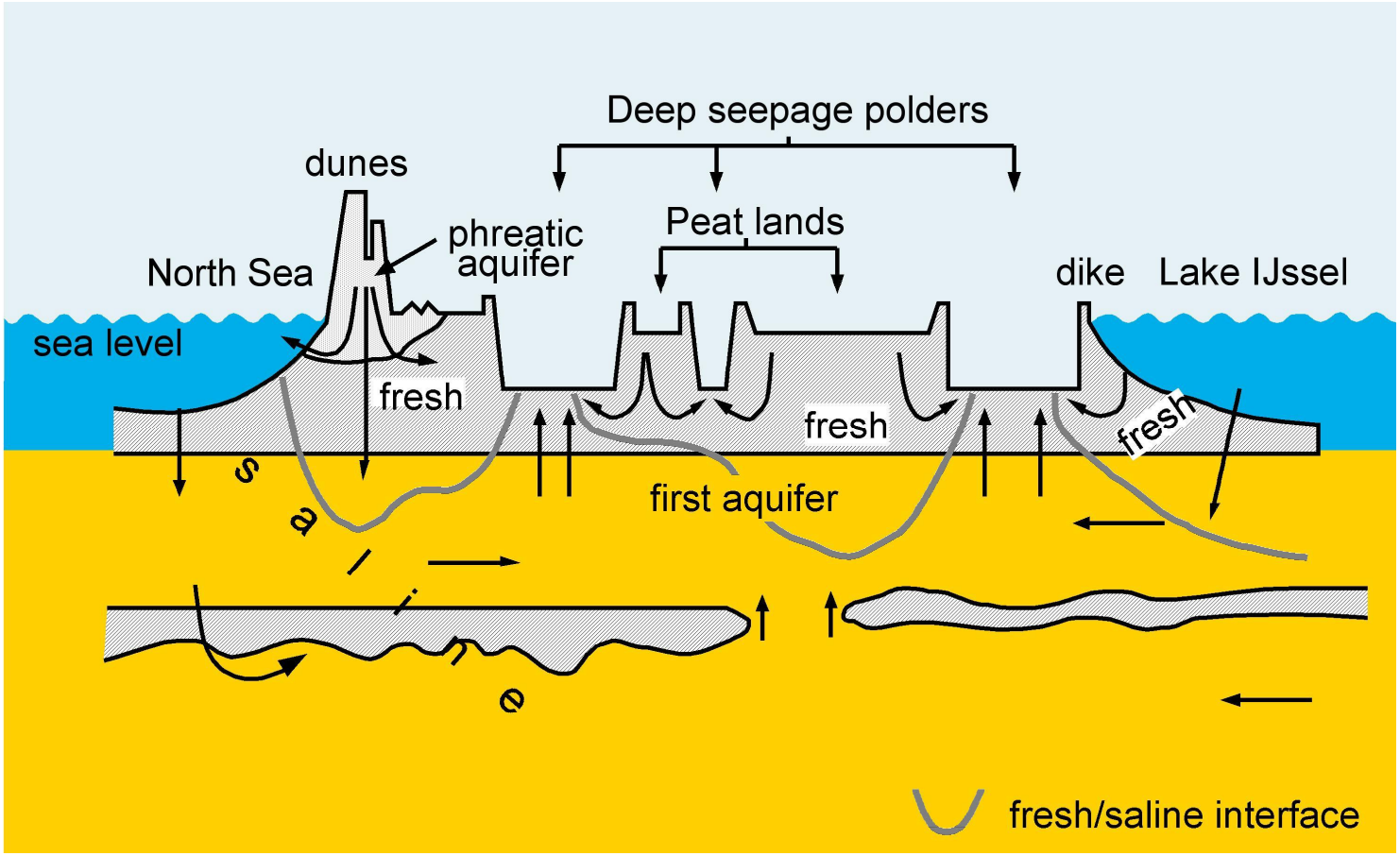


Deltares

Probleem

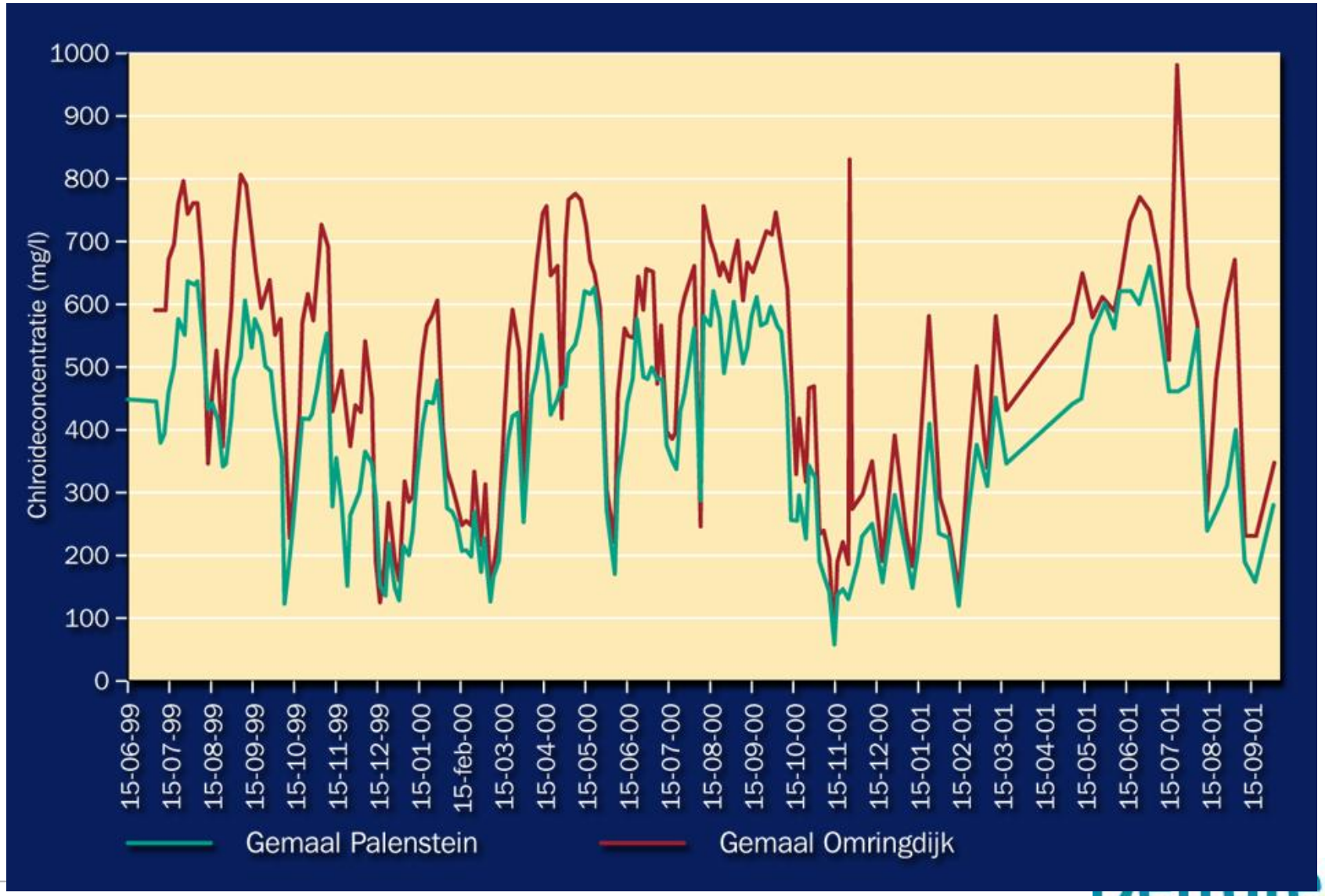


- Zoute kwel leidt tot verzilting van het oppervlaktewater in diepe polders



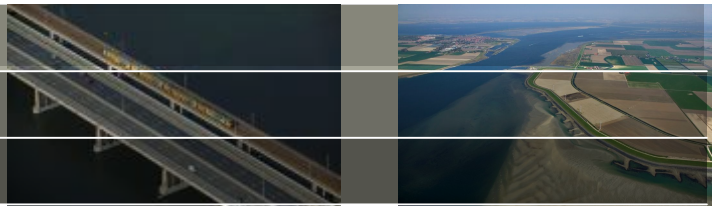
Deltares

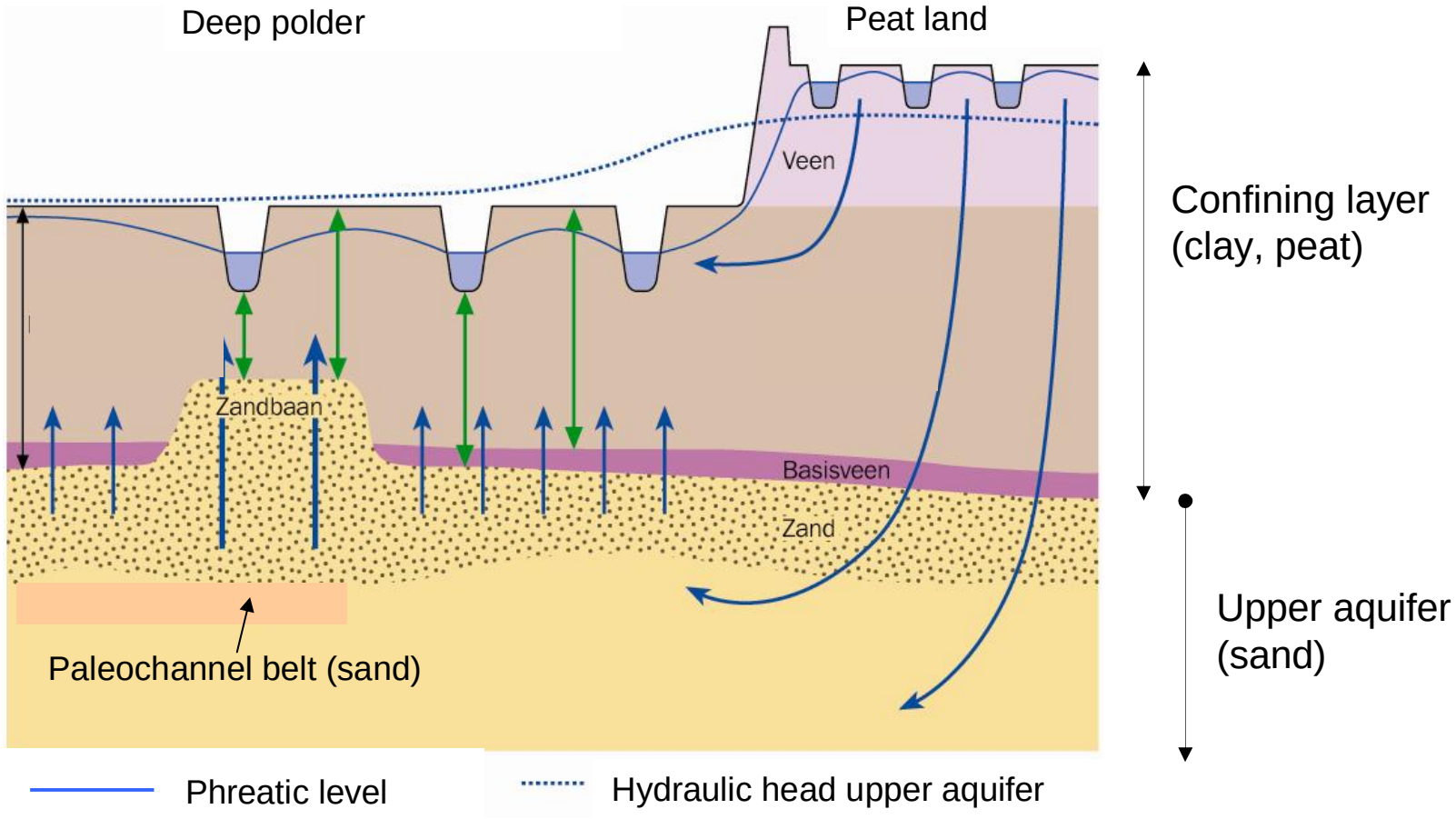
Chloride concentratie van uitgemalen polderwater Polder de Noordplas



40 ton keukenzout per dag wordt uitgemalen

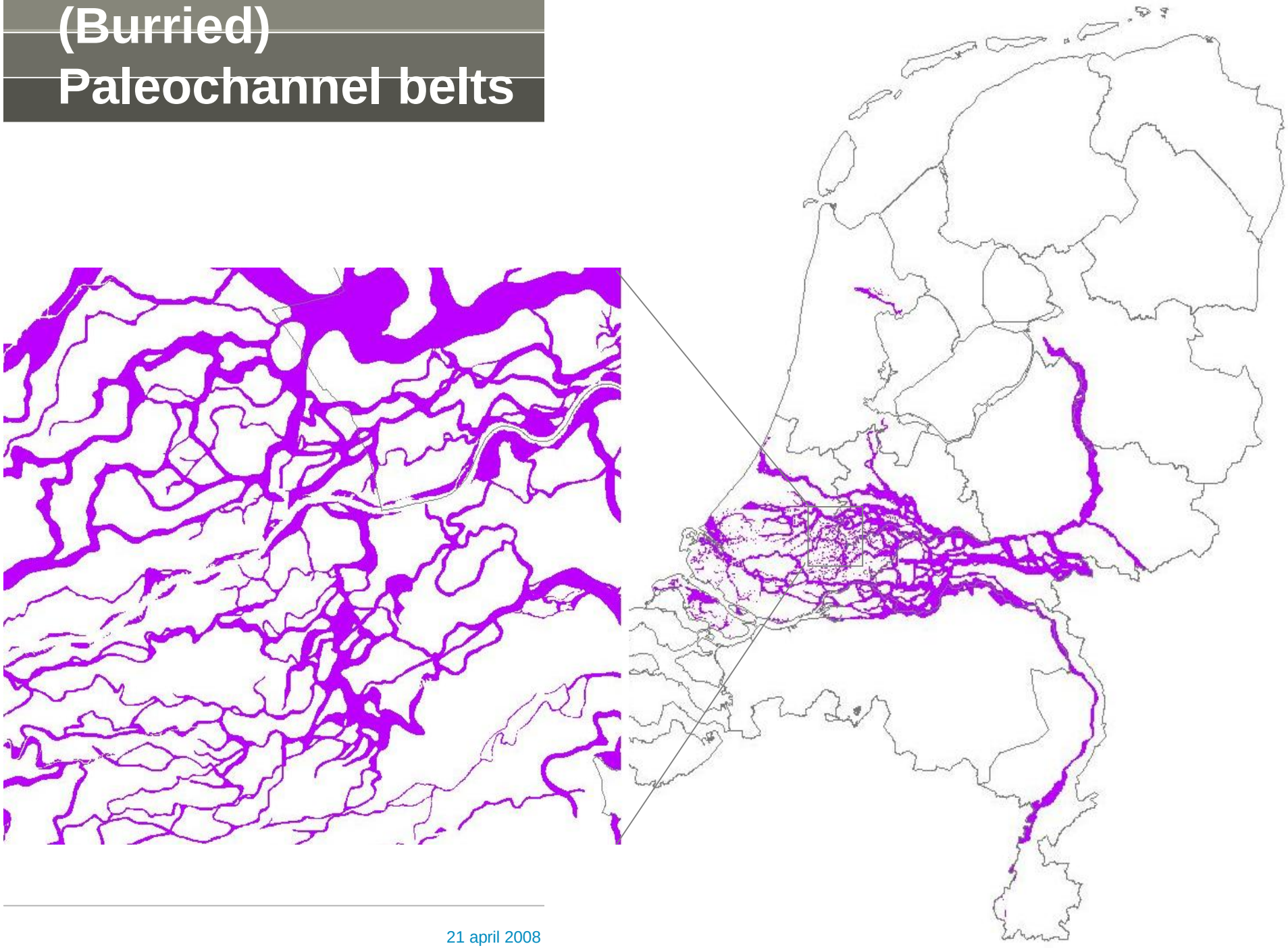
Typen kwel in diepe polders



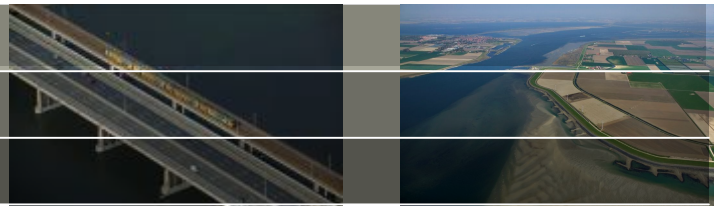


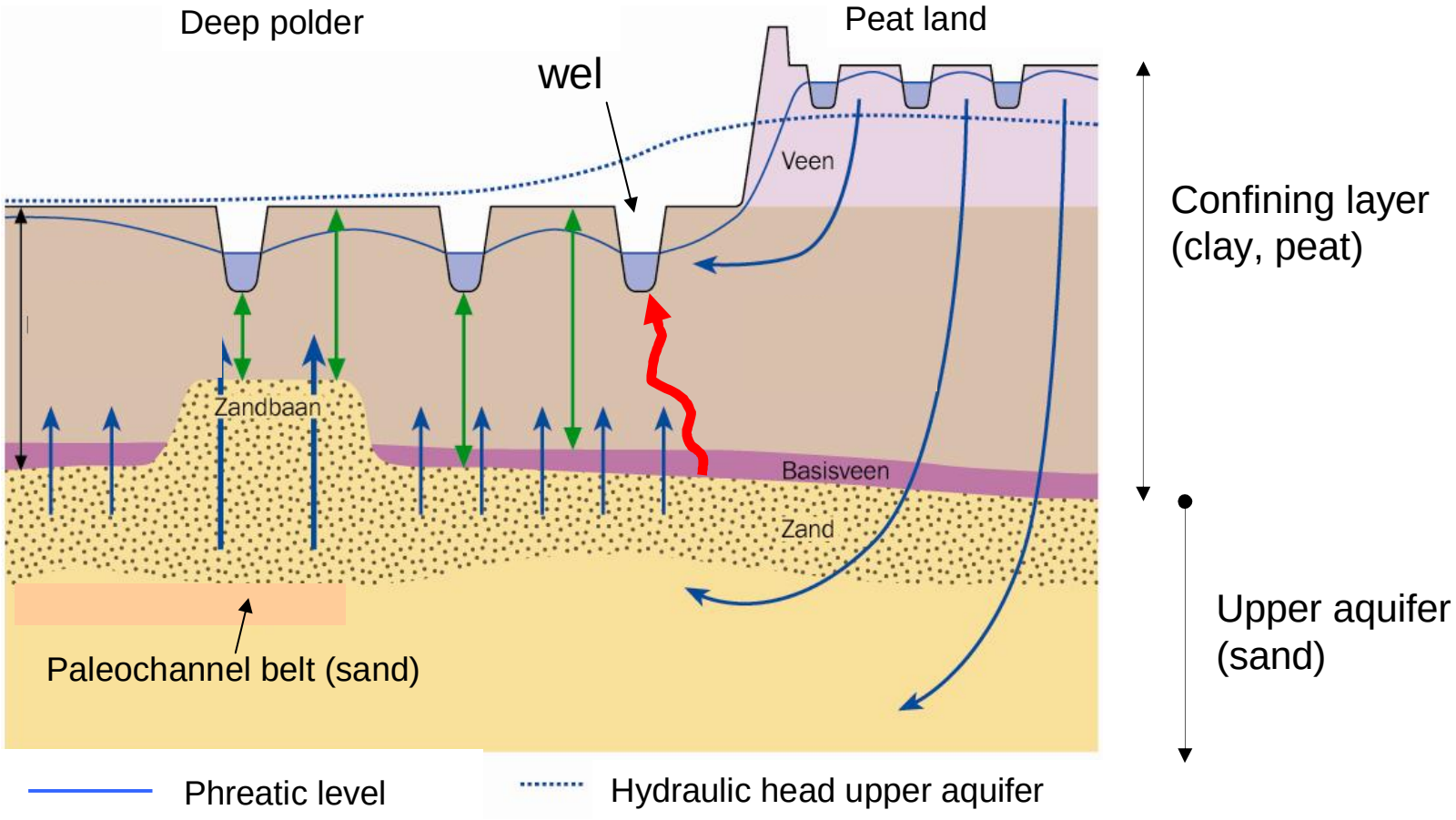
Deltares

(Burried) Paleochannel belts



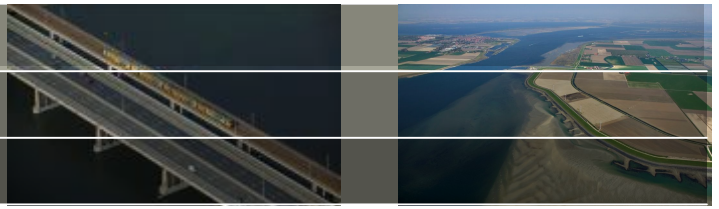
Preferente kwel via wellen

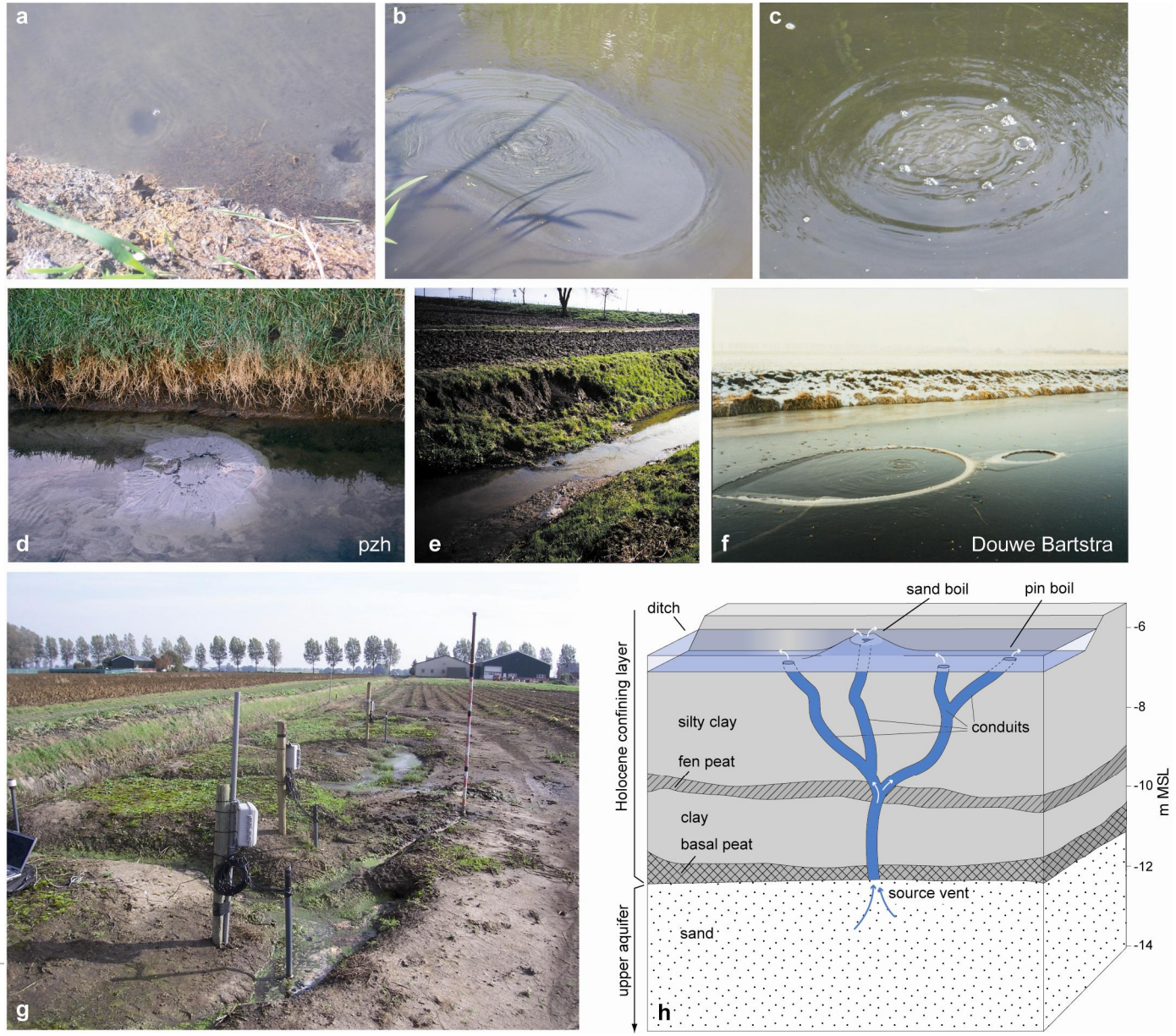




Deltares

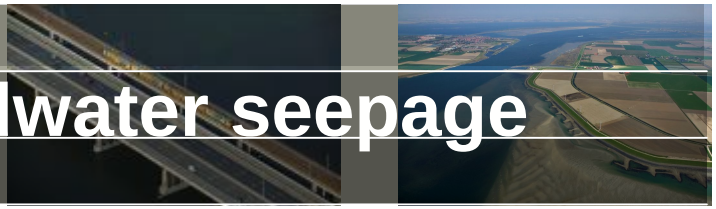
Wellen (boils)

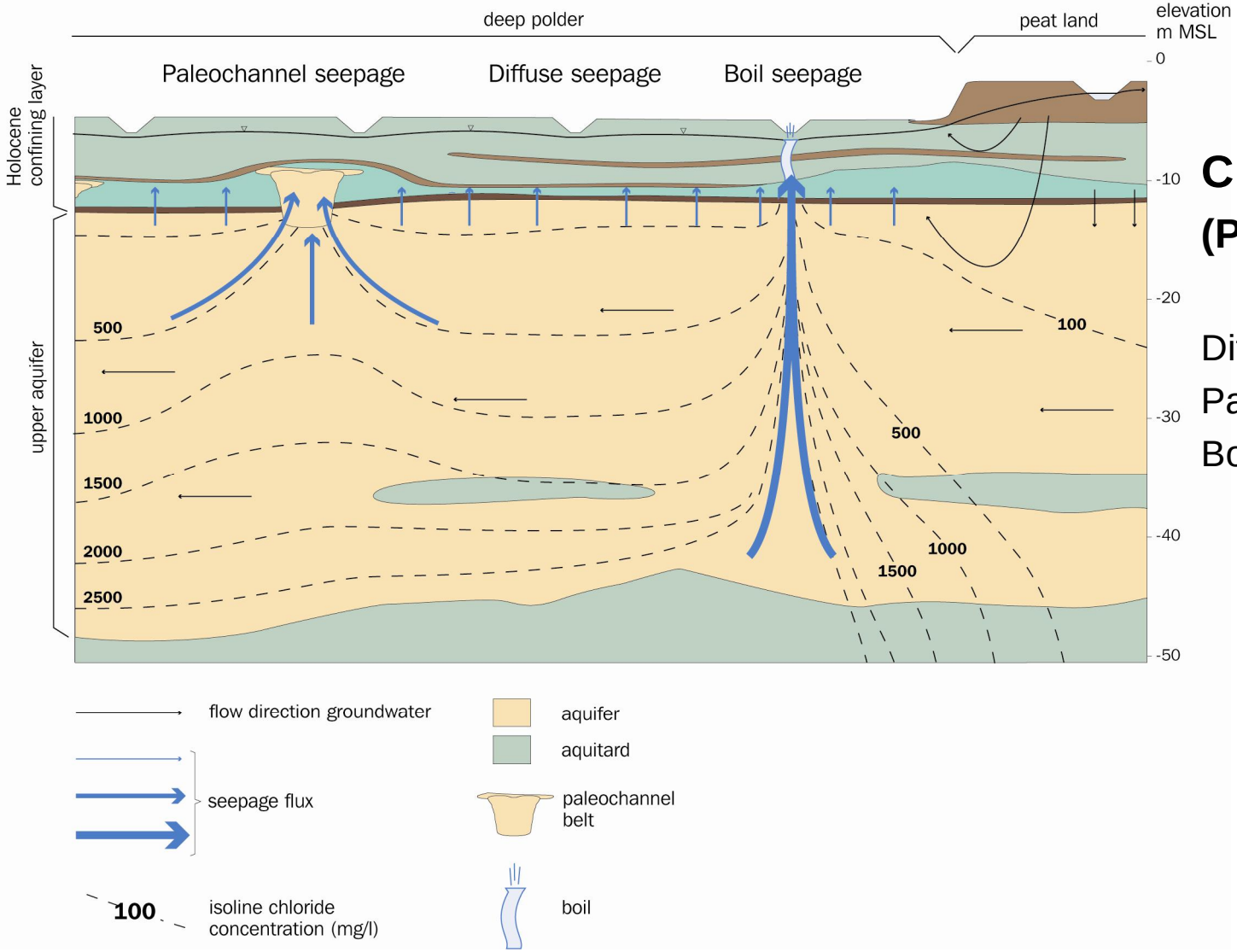




Deltares

Three types of upward groundwater seepage





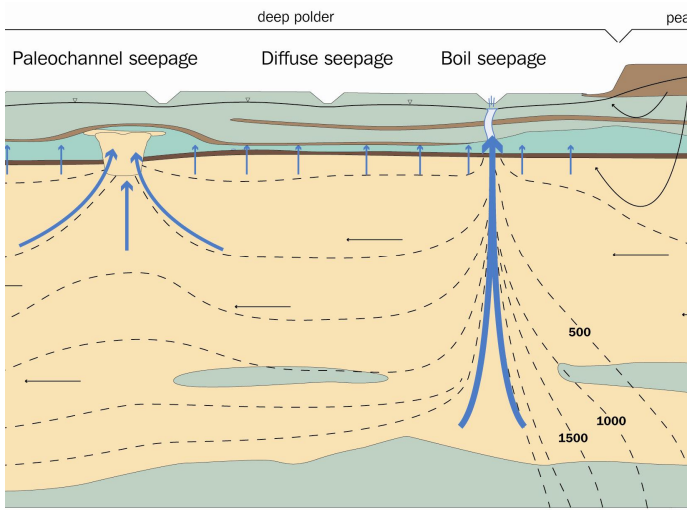
Cl-conc seepage:
(Polder Noordplas)

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

Deltares

Preferential seepage as dominant mechanism of salinization in deep polders

	Area	Contribution % (± stdev.) to:	
		Polder water Discharge	Total salt load
Diffuse seepage	31 km^2	**7 %** *(± 1.8)*	**4 %** *(± 1.7)*
Paleochannel seepage	6 km^2	**9 %** *(± 2.5)*	**19 %** *(± 6.2)*
Boil seepage	< 0.001 km^2	**13 %** *(± 4.7)*	**64 %** *(± 7.7)*

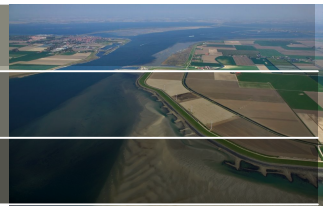


We conclude from the Noordplas data and modeling that :

Preferential seepage contribute more than **<u>80%</u>** to the total salt load in Noordplas Polder and that **boils** are dominant.

Deltares

Zoute kwel in Zeeland



Ondiep zout grondwater

Zoute kwel leidt tot:

- Verzilting en eutrofiering van oppervlaktewater
- Verzilting van wortelzone

Hoofdvragen:

- Ruimtelijke variatie van regenwaterlenzen – zoute kwel
- Dynamics of saline seepage - rainwater lens

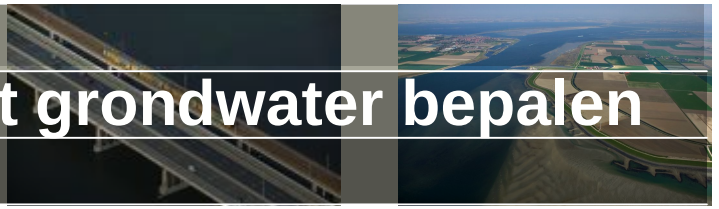
} huidig

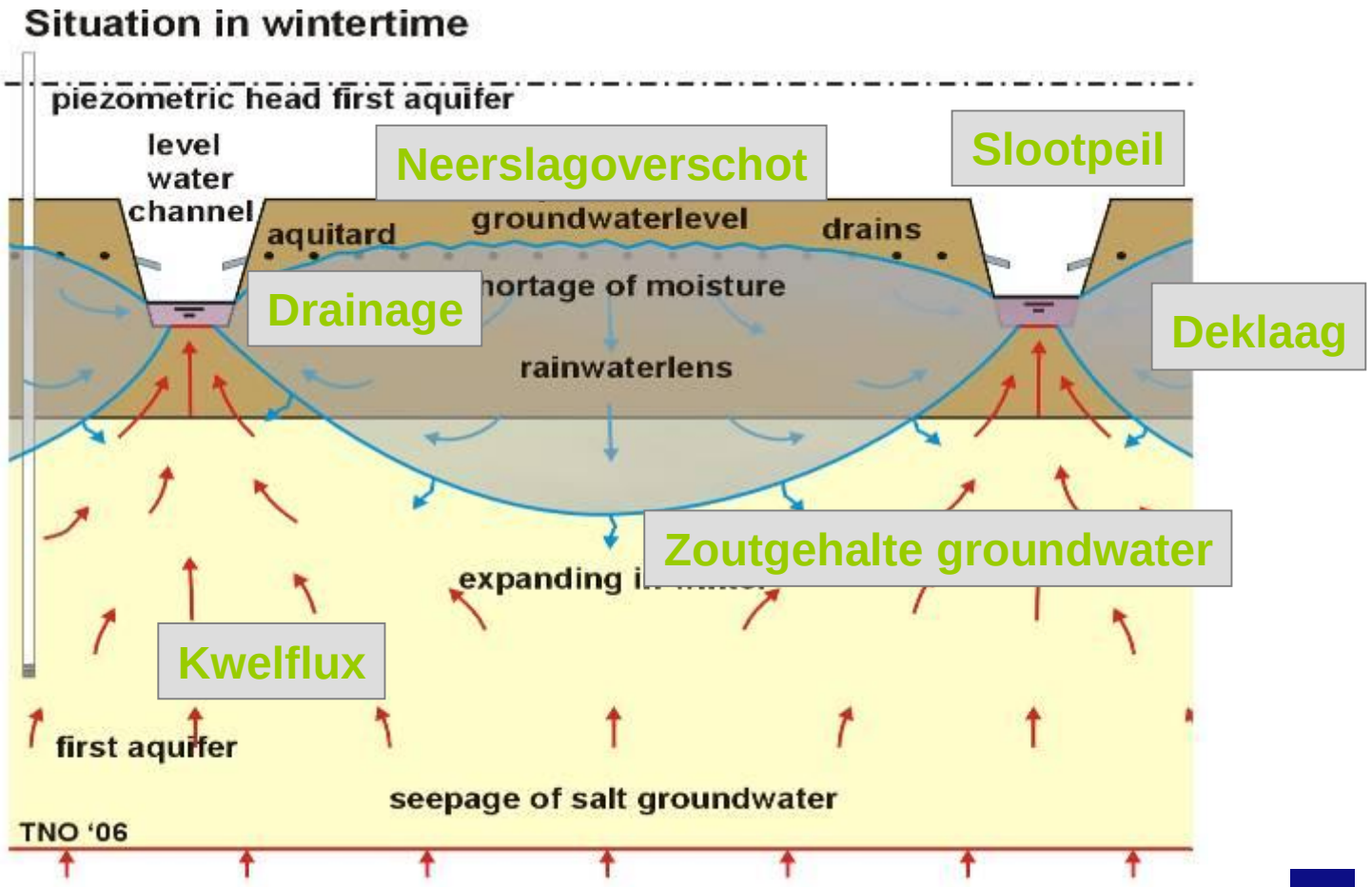
- Effecten van zeespiegelstijging en klimaatverandering

} toekomst

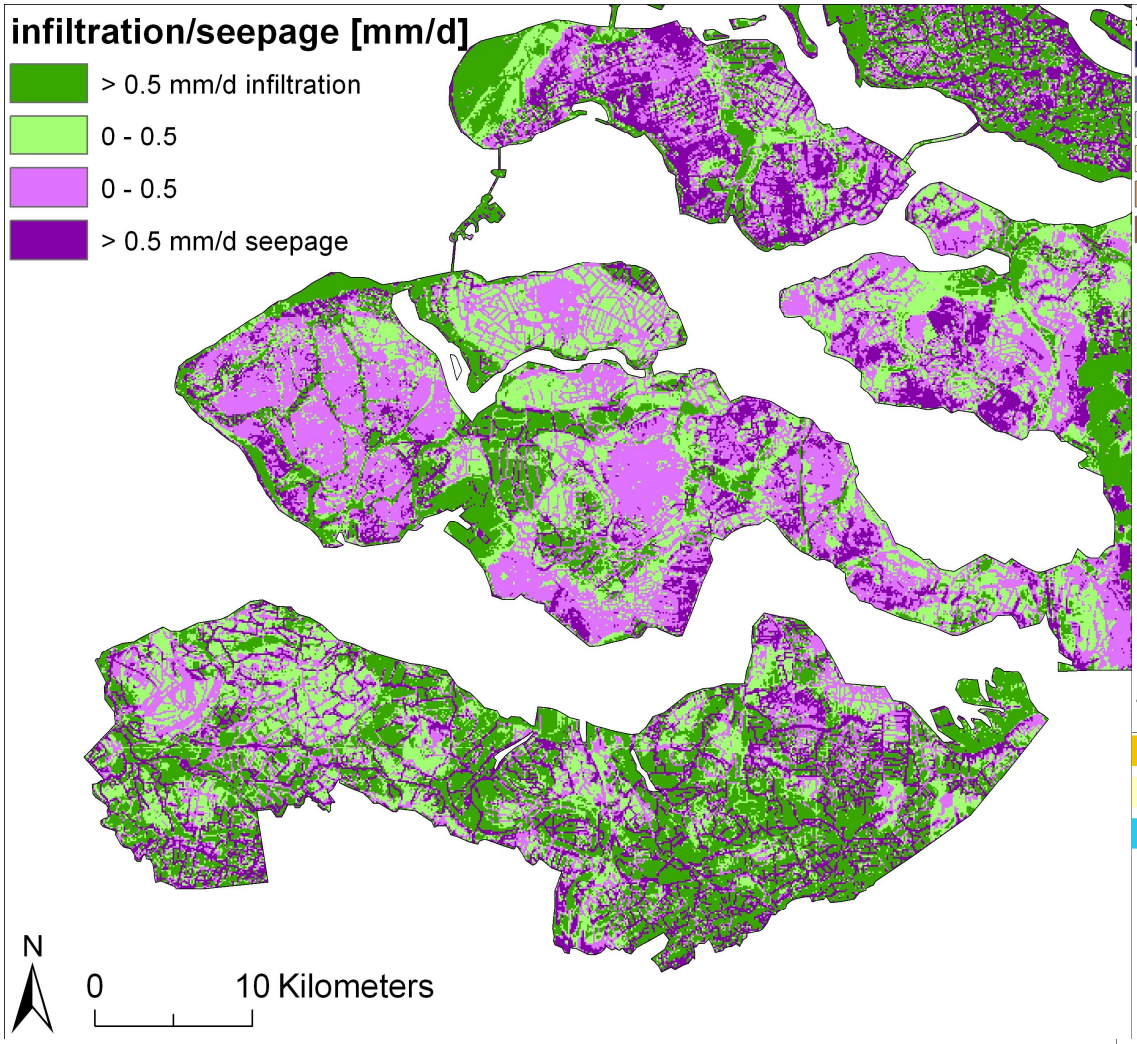
Deltares

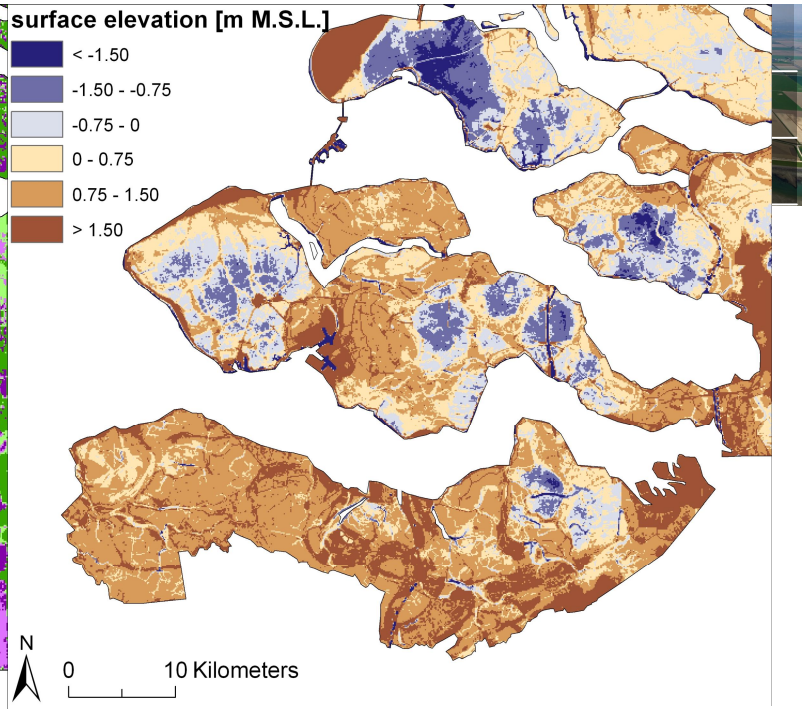
Factoren die regenwaterlens op zout grondwater bepalen

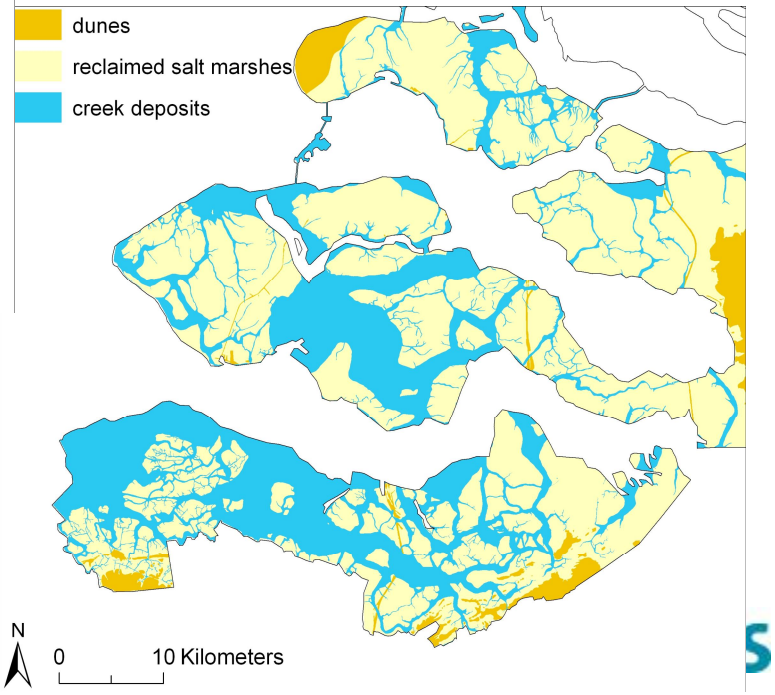




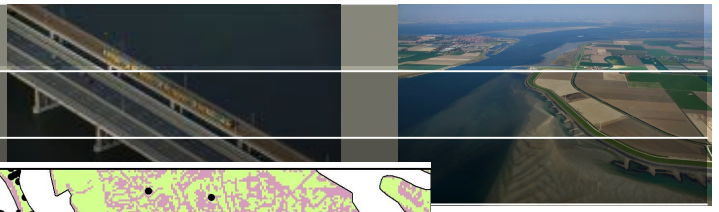
Deltares

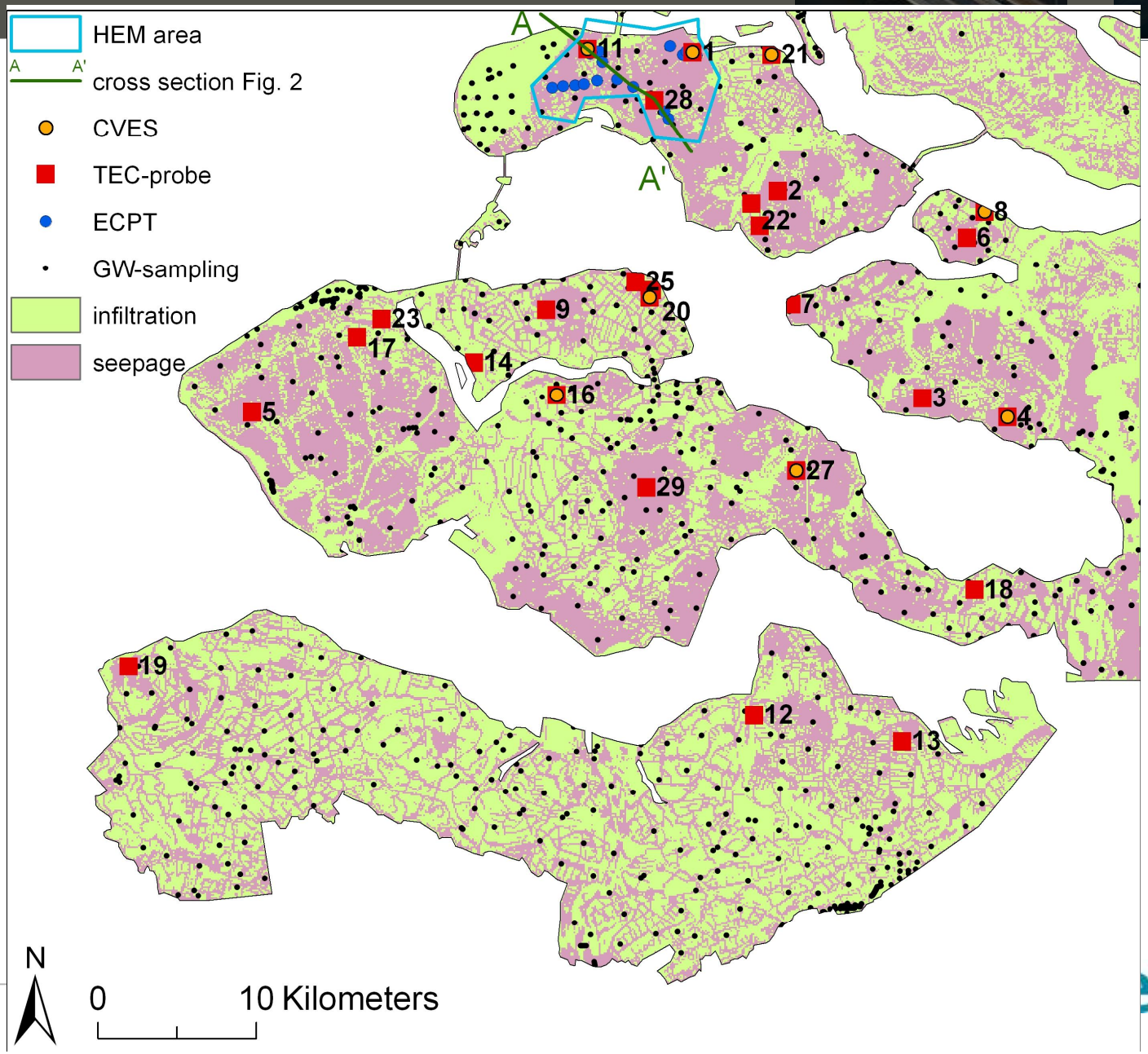

infiltration/seepage [mm/d]
> 0.5 mm/d infiltration
0 - 0.5
0 - 0.5
> 0.5 mm/d seepage
N
0
10 Kilometers

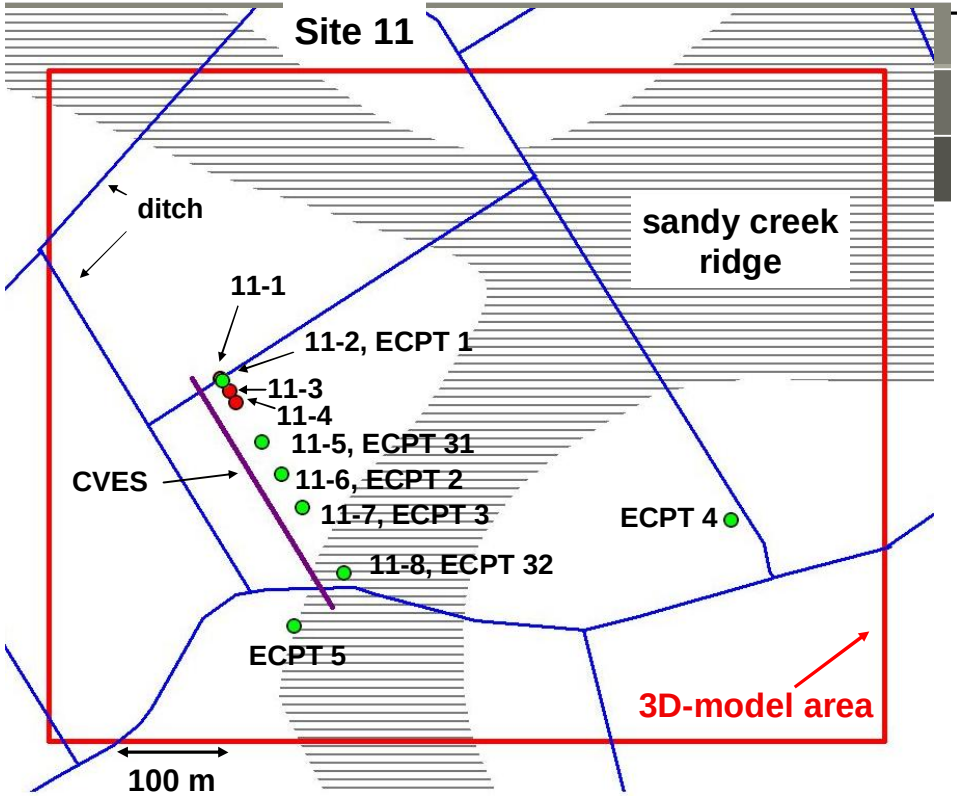

surface elevation [m M.S.L.]
< -1.50
-1.50 - -0.75
-0.75 - 0
0 - 0.75
0.75 - 1.50
> 1.50
N
0
10 Kilometers

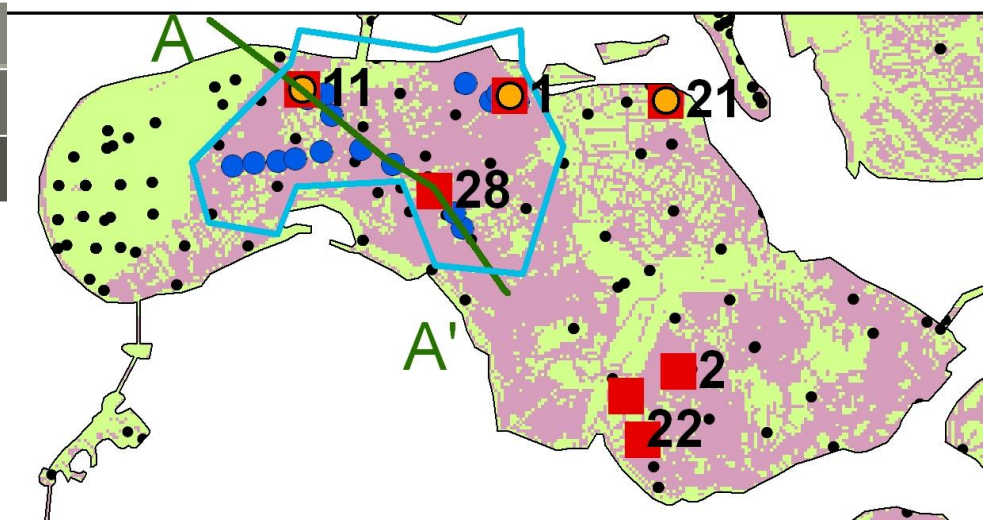

dunes
reclaimed salt marshes
creek deposits
N
0
10 Kilometers

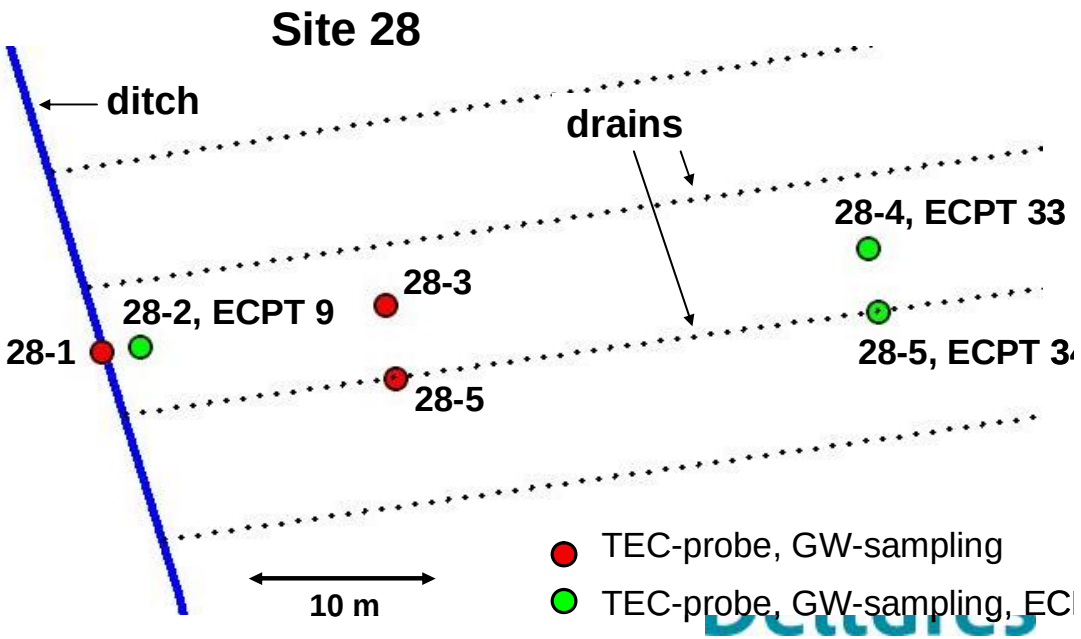
Meetnet




HEM area
A A'
cross section Fig. 2
CVES
TEC-probe
ECPT
GW-sampling
infiltration
seepage
A
A'
11
1
21
28
2
22
8
6
25
20
9
23
17
14
7
16
5
3
4
27
29
18
19
12
13
N
0
10 Kilometers


Site 11
ditch
sandy creek ridge
11-1
11-2, ECPT 1
11-3
11-4
11-5, ECPT 31
CVES
11-6, ECPT 2
11-7, ECPT 3
ECPT 4
11-8, ECPT 32
ECPT 5
3D-model area
100 m

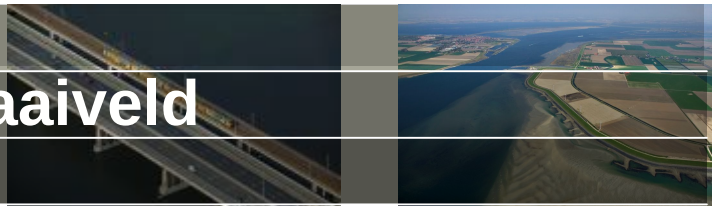

A
A'
11
1
21
28
2
22

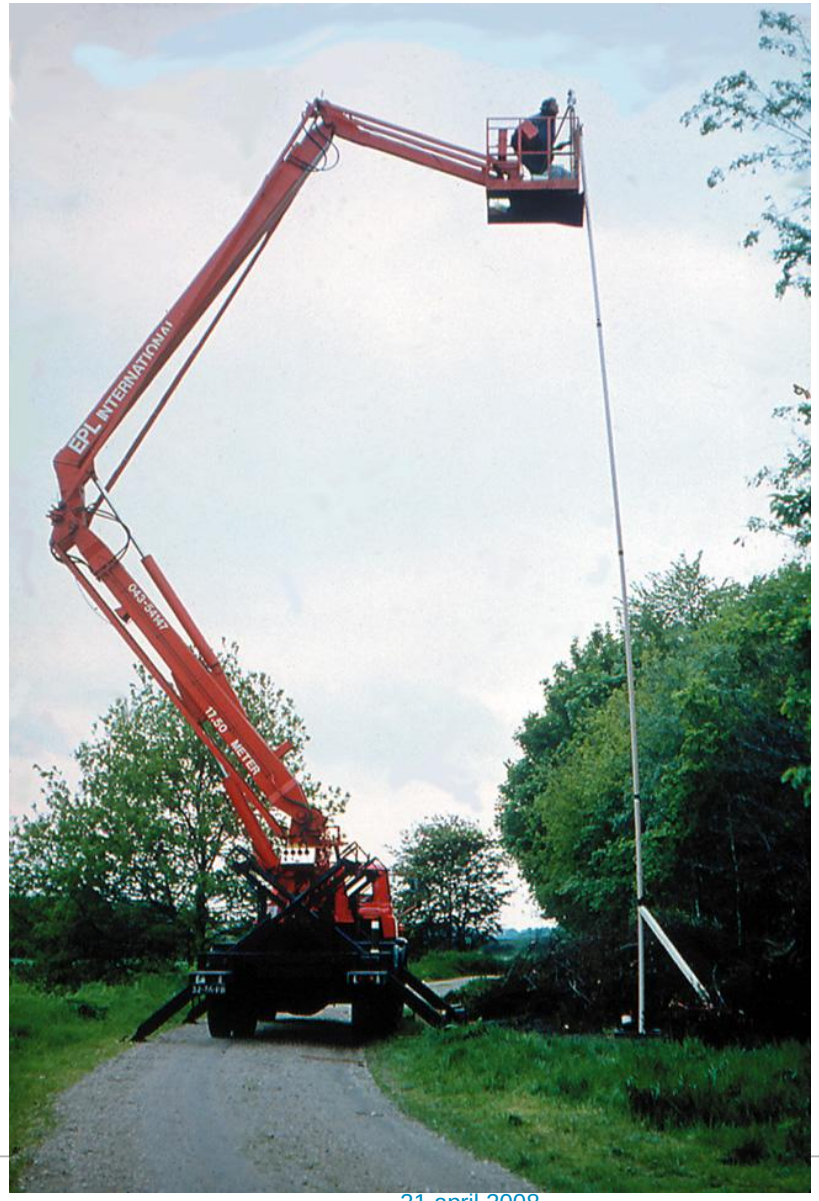

Site 28
ditch
drains
28-4, ECPT 33
28-3
28-2, ECPT 9
28-1
28-5, ECPT 3
28-5
10 m
TEC-probe, GW-sampling
TEC-probe, GW-sampling, EC

Meetmethode 1: grondwaterstand / stijghoogte

- Grondwaterstanden meet je in een peilbuis.
- Filterlengte peilbuis: 0.5 tot 1.0 m
- Filterdiepte belangrijk: grondwaterstand vs stijghoogte

Stijghoogte soms meters boven maaiveld (Limburg)





Deltares

Meetmethode 1: grondwaterstand / stijghoogte

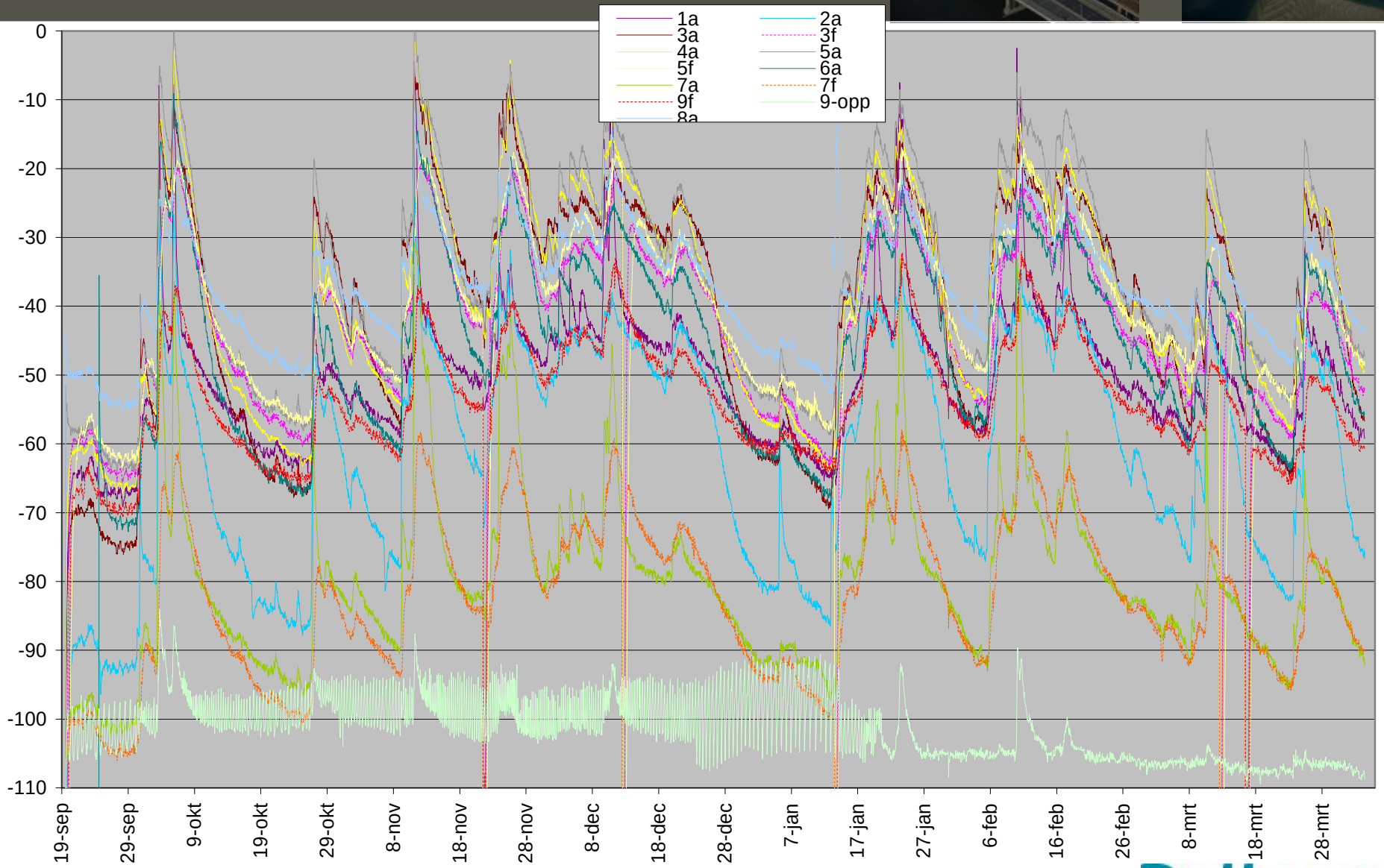
- Grondwaterstanden meet je in een peilbuis.
- Filterlengte peilbuis: 0.5 tot 1.0 m
- Filterdiepte belangrijk: grondwaterstand vs stijghoogte
- Bepaal lithologische samenstelling van ondergrond

Grondwaterstand meet je:

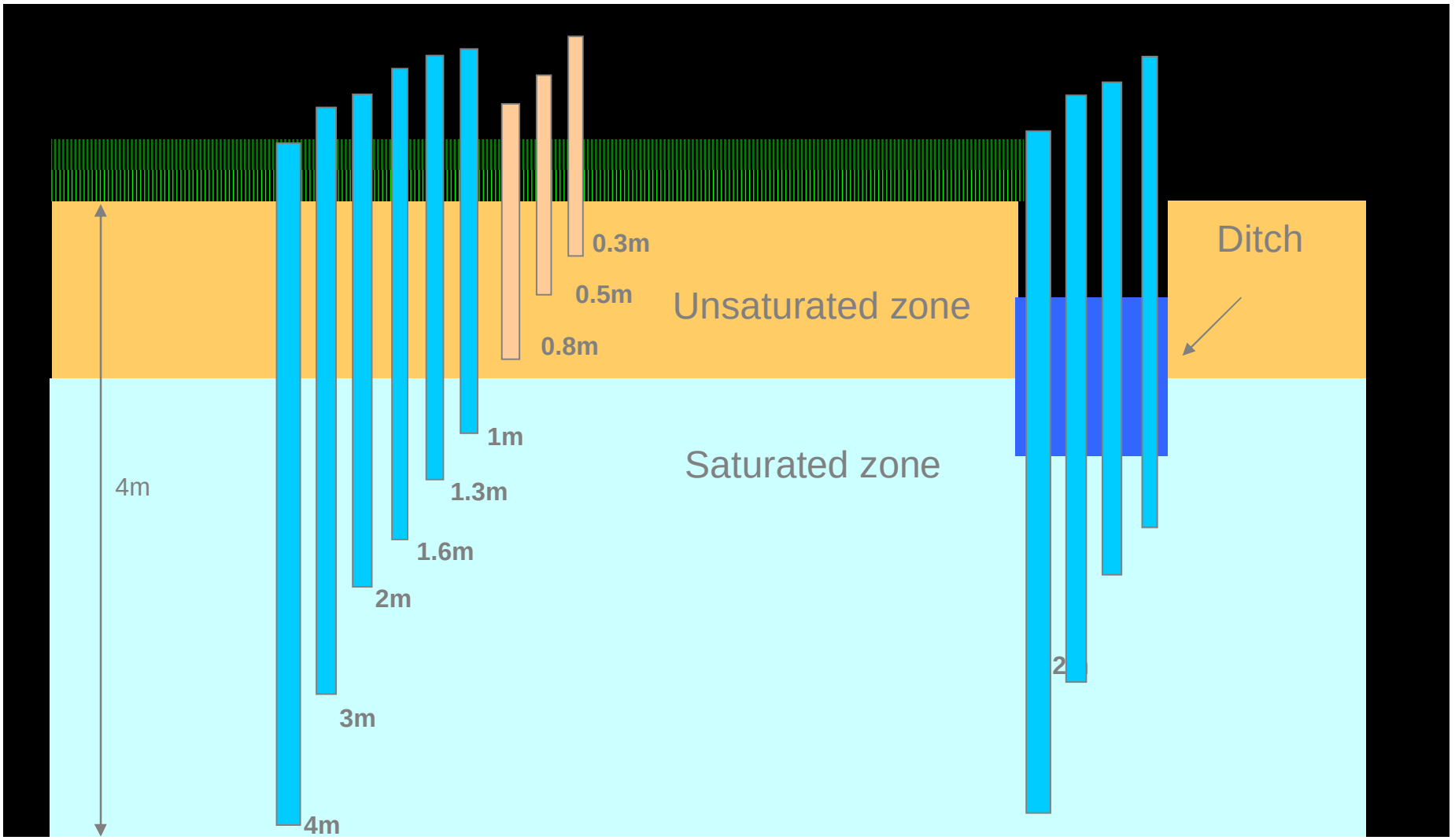
- handmatig (bijv. met plopper)
- automatisch met bijv. divers (corrigeren voor barometrische druk)

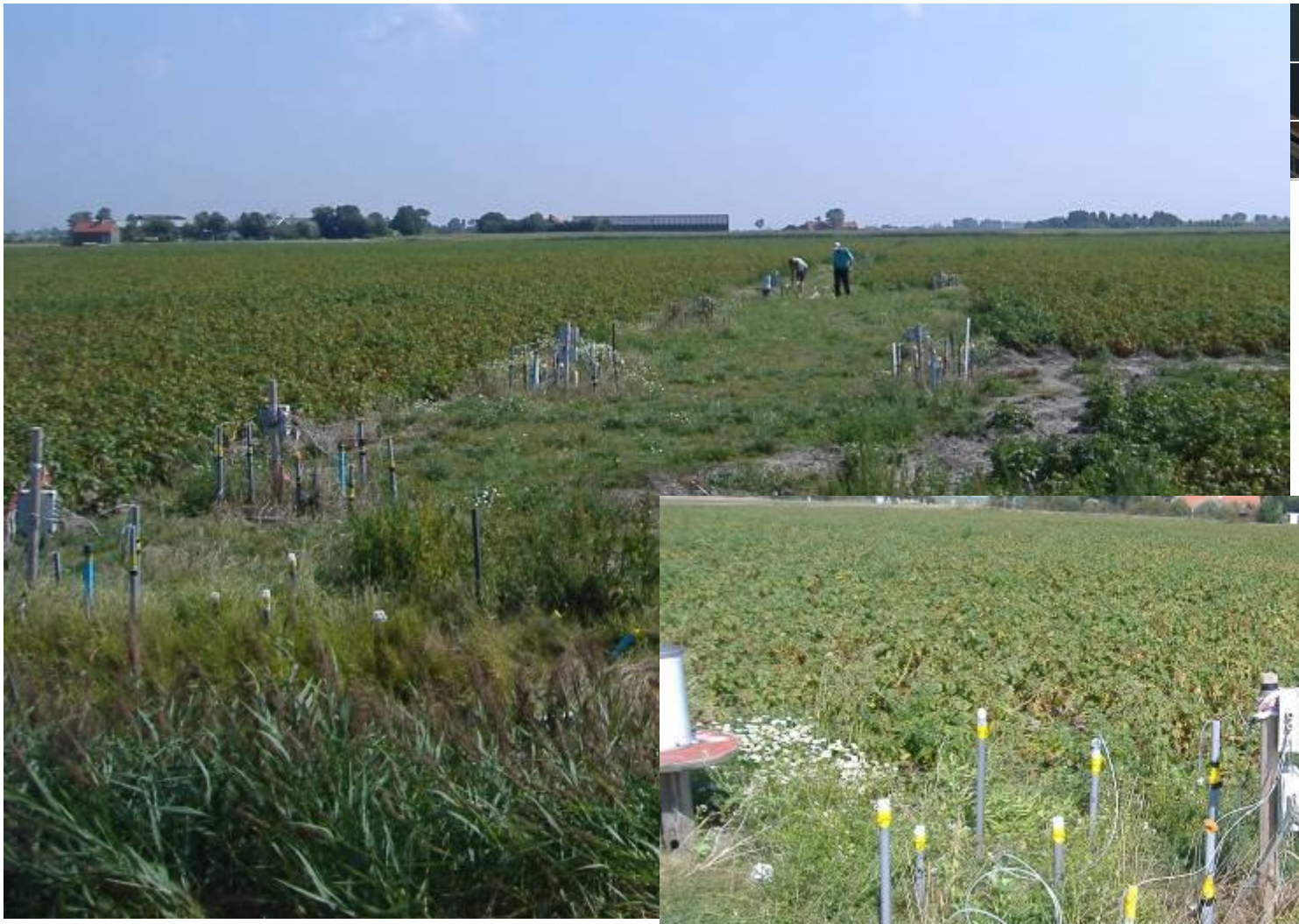
Deltares

Groundwaterstand fluctuatie (cm beneden mv)

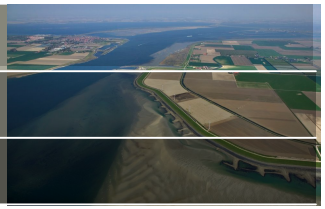


Meetmethode 2: Meten van zoutgehalte grondwater: monitoring regenwater lens





Elektrische Geleidingsvermogen (EGV)



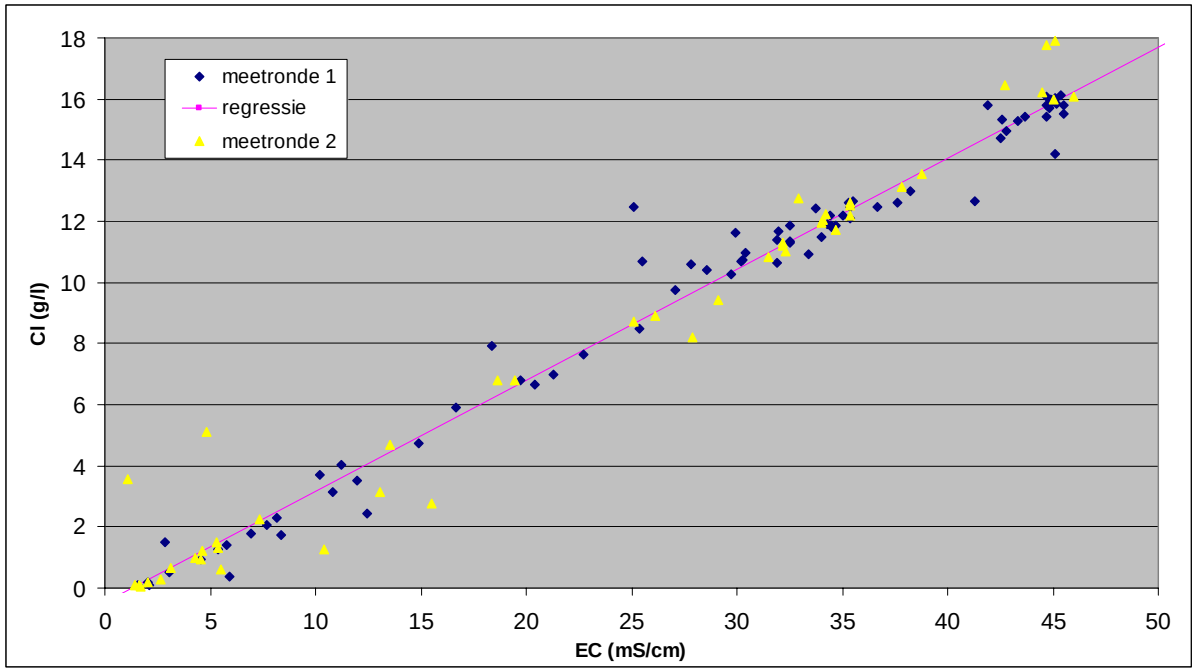
Electrical Conductivity (EC) gemeten in µS/cm mS/cm (siemens)

Noordzee heeft een EGV van ongeveer 45-48 mS/cm (varieert langs de kust agv bjimenging met rivierwater) en een chloride-gehalte van ongeveer 17 g/l. Oceaanwater is zouter, 19.4 g/l.

EGV van 10 mS/cm in het grondwater meten dan hebben we te maken 10/48 zeewater, dus ongeveer 20% zeewater.

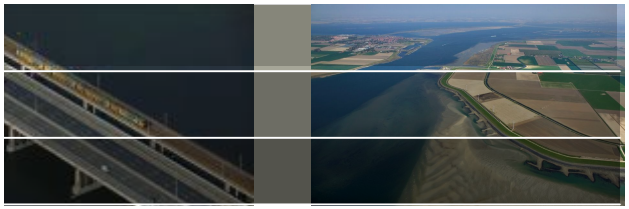
Chloride vs EC: samenstelling zeewater

	g/l
NaCl	24
MgCl2	5
Na2SO4	4
CaCl2	0.7
MgBr2	0.8
	34.5

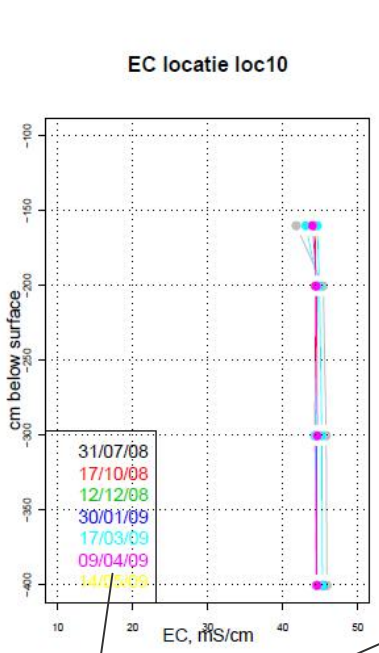


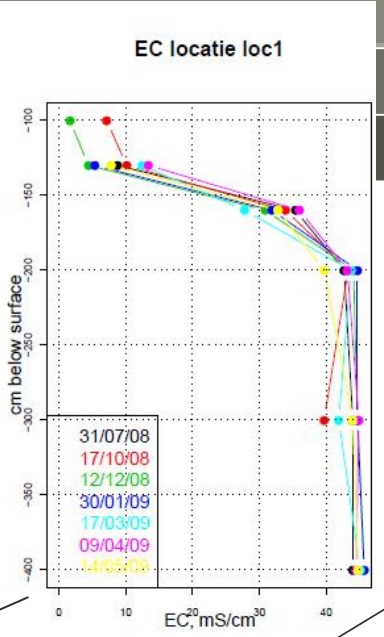
		g/mol	lading	mgr/l zeewater	%kat/an	meq/l	**% of EC**
kationen	Na	23	1	10.7	87	467	**79**
	Mg	24.3	2	1.4	11	114	**19**
	Ca	40.1	2	0.3	2	13	**2**
anionen	Cl	35.5	1	18.7	85	528	**89**
	Br	79.9	1	0.7	3	9	**1**
	SO4	96.1	2	2.7	12	56	**9**
			TOT	34.5			

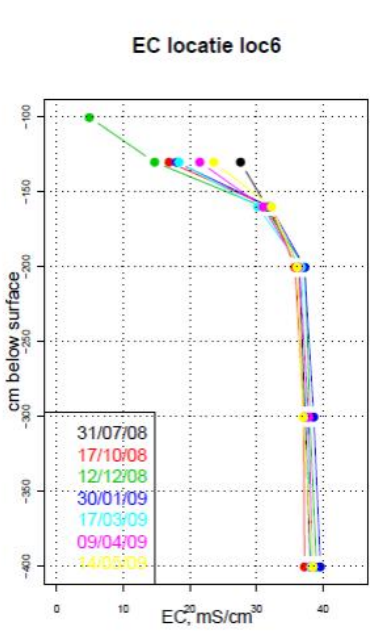
Deltares

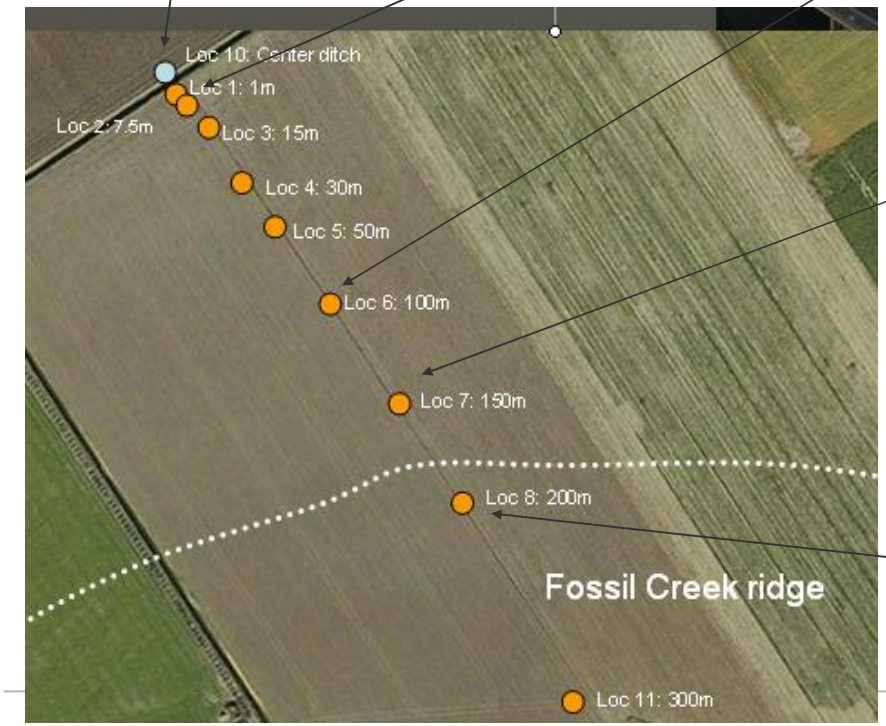


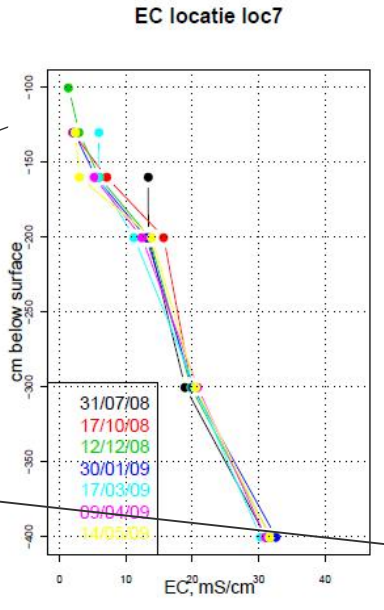
Variatie zoutprofiel in de tijd

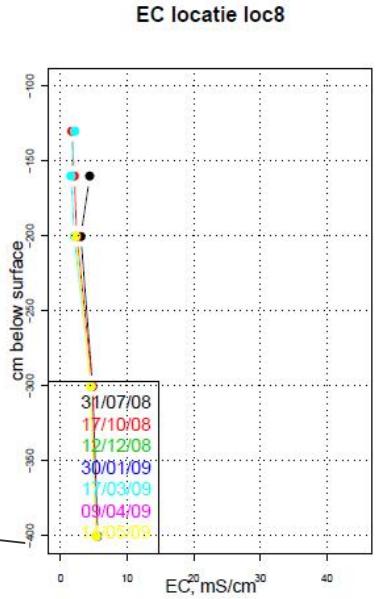




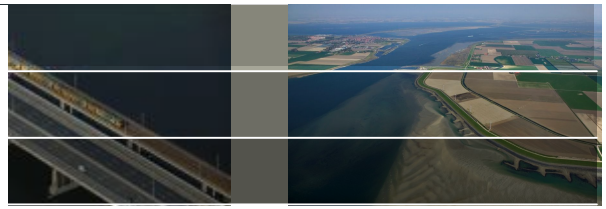


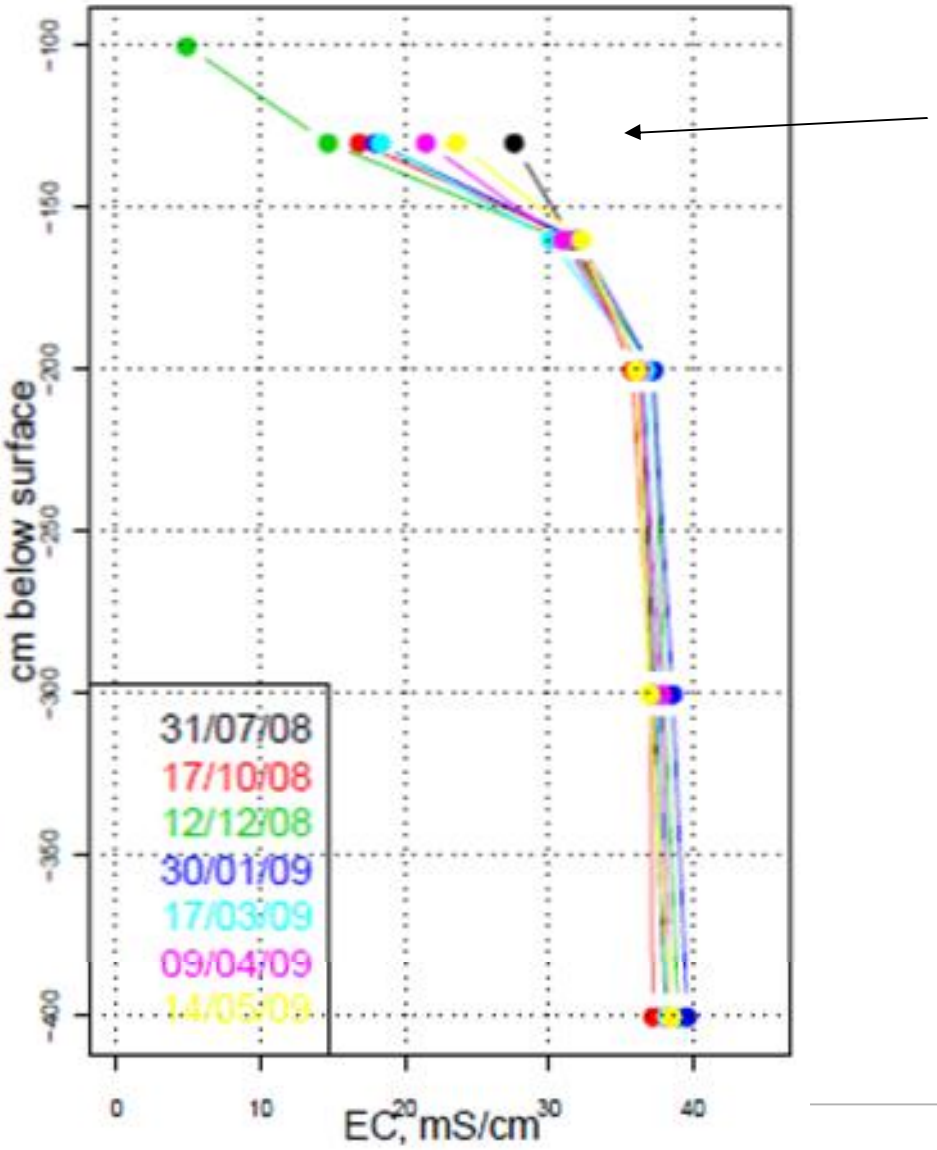






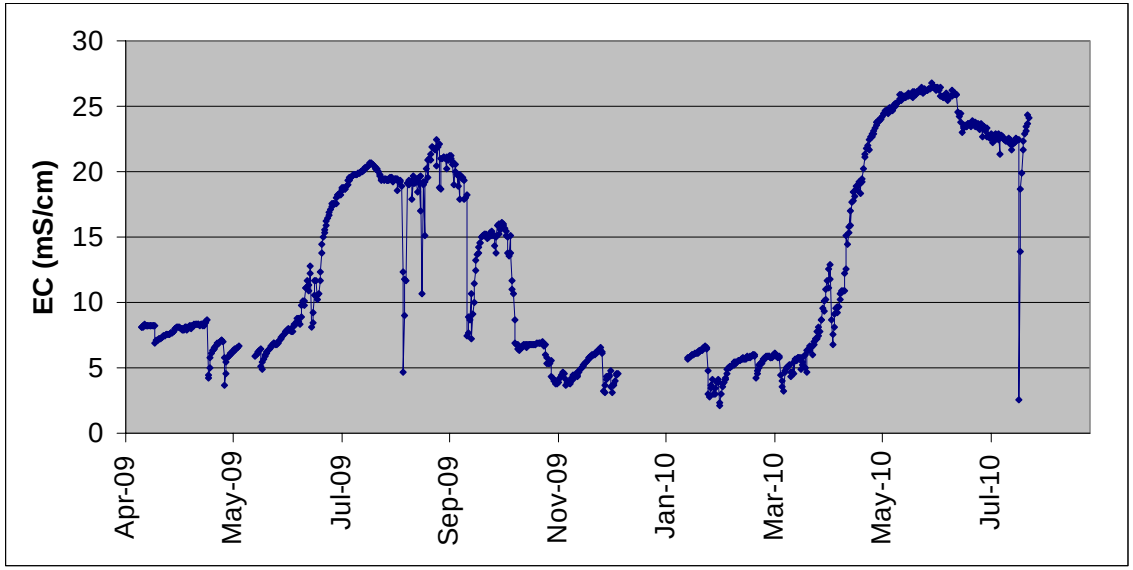
EC locatie loc6





Deltares

Meetmethode 3: Continue registratie van het zoutgehalte met CTD-diver (hier van drainage-afvoer)

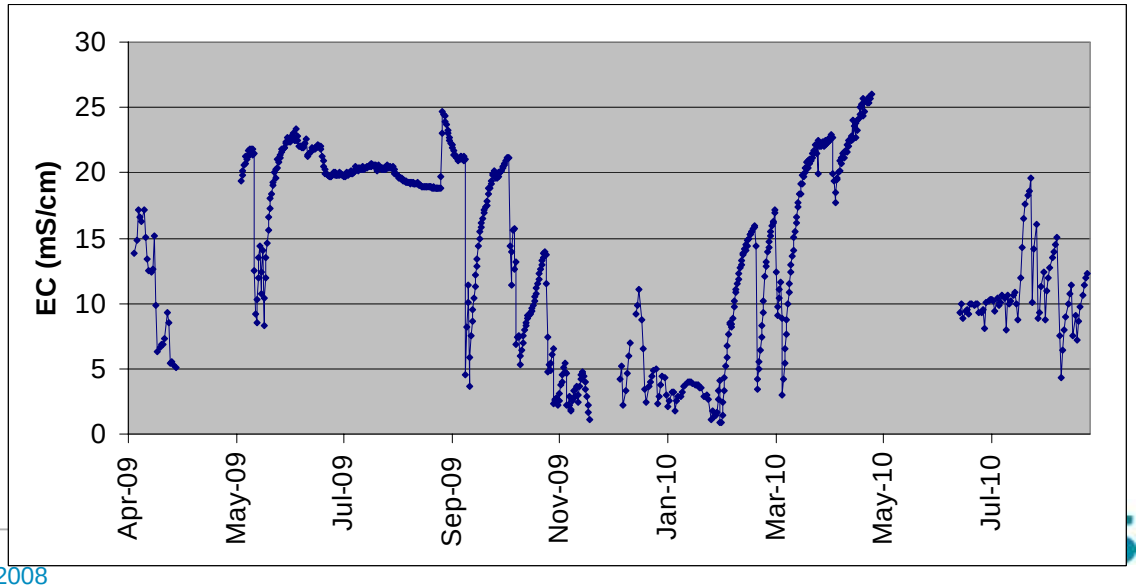


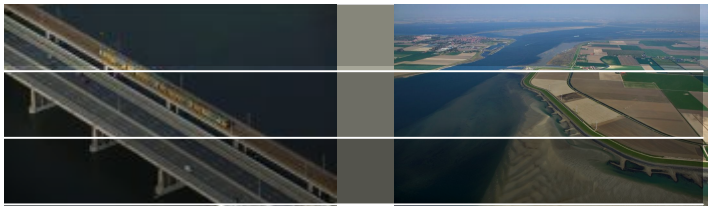
Location 11

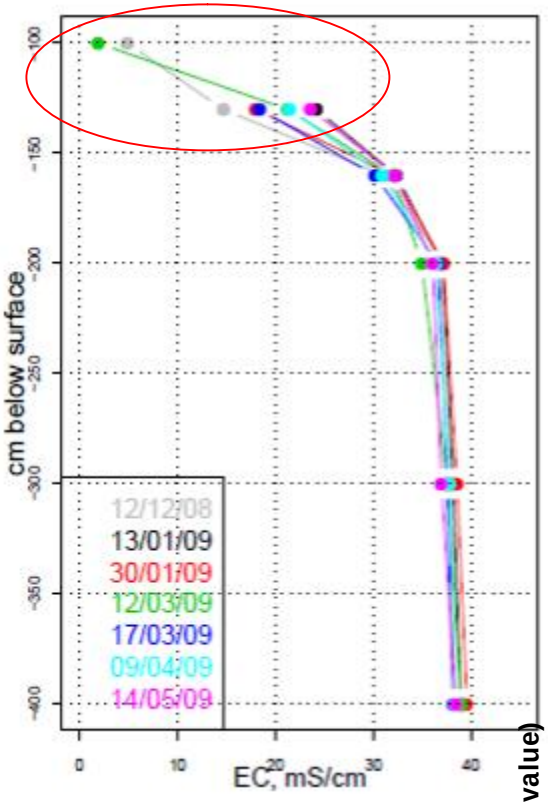
EC kwel = 45 mS/cm

Location 28

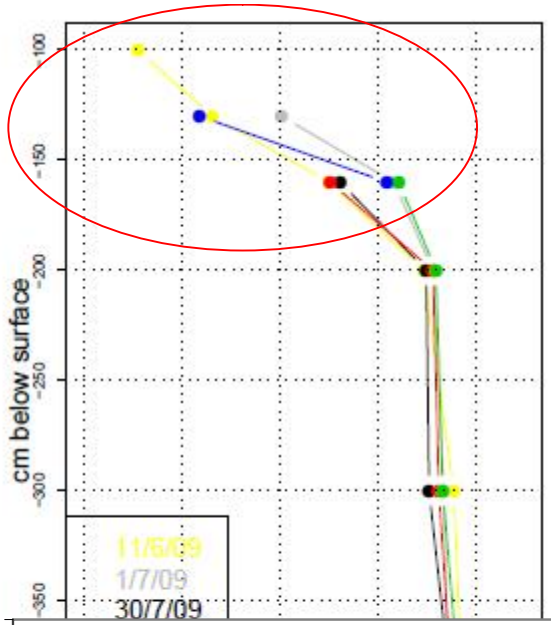
EC kwel = 35 mS/cm



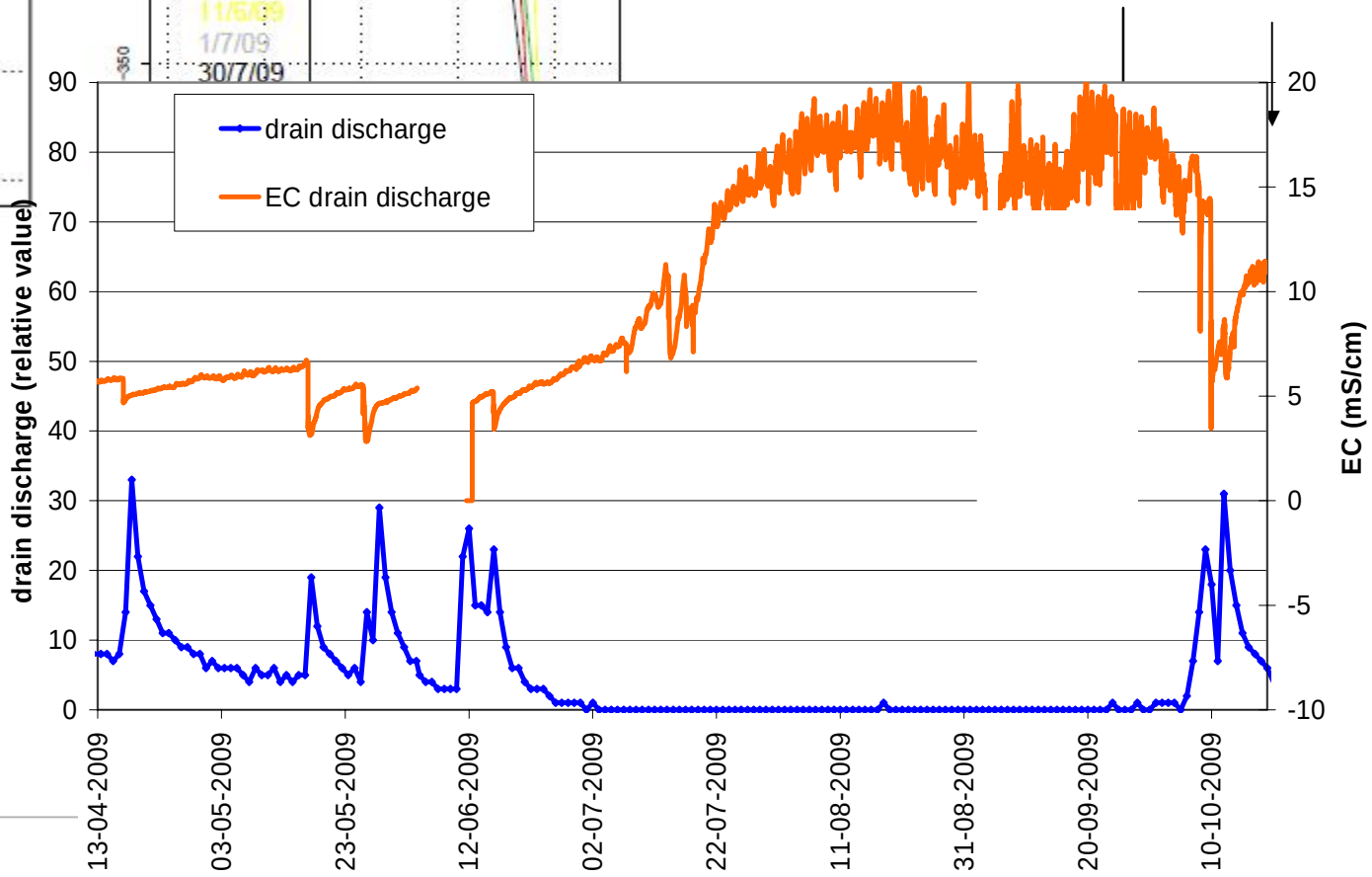




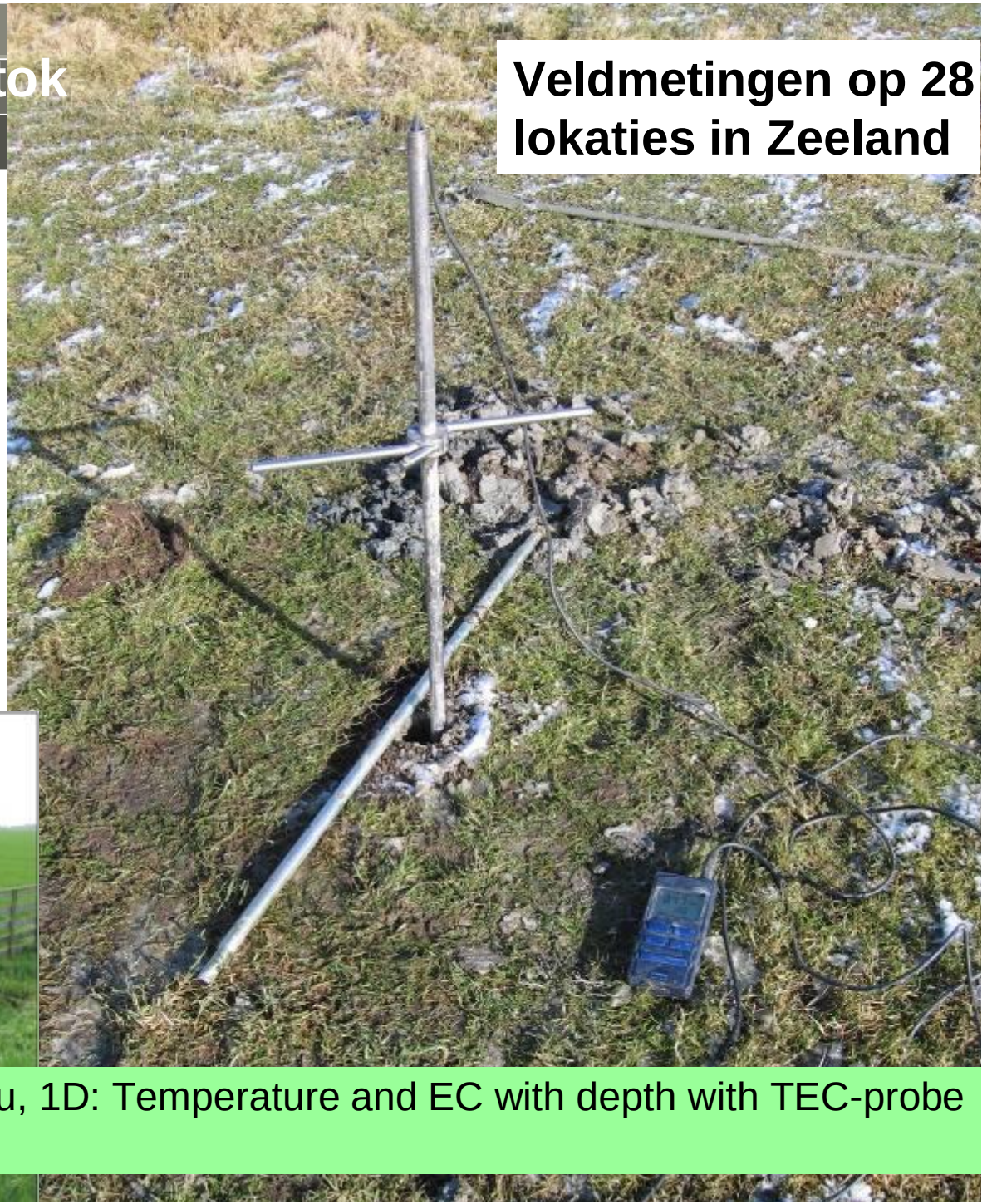
winter-spring 2009



Summer 2009



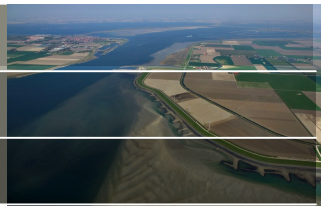
Meetmethode 4: prikstok TEC-probe



Veldmetingen op 28 lokaties in Zeeland

In-situ, 1D: Temperature and EC with depth with TEC-probe

TEC-probe (prikstok)



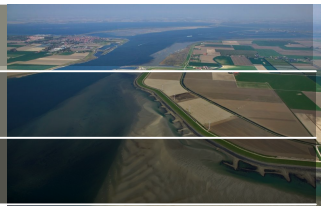
- Meet geleidbaarheid van zowel bodem en water.
- Bodem geeft extra weerstand t.o.v. water.
- Voor EC-water dient voor de weerstand van de bodem te worden gecorrigeerd: formatie factor

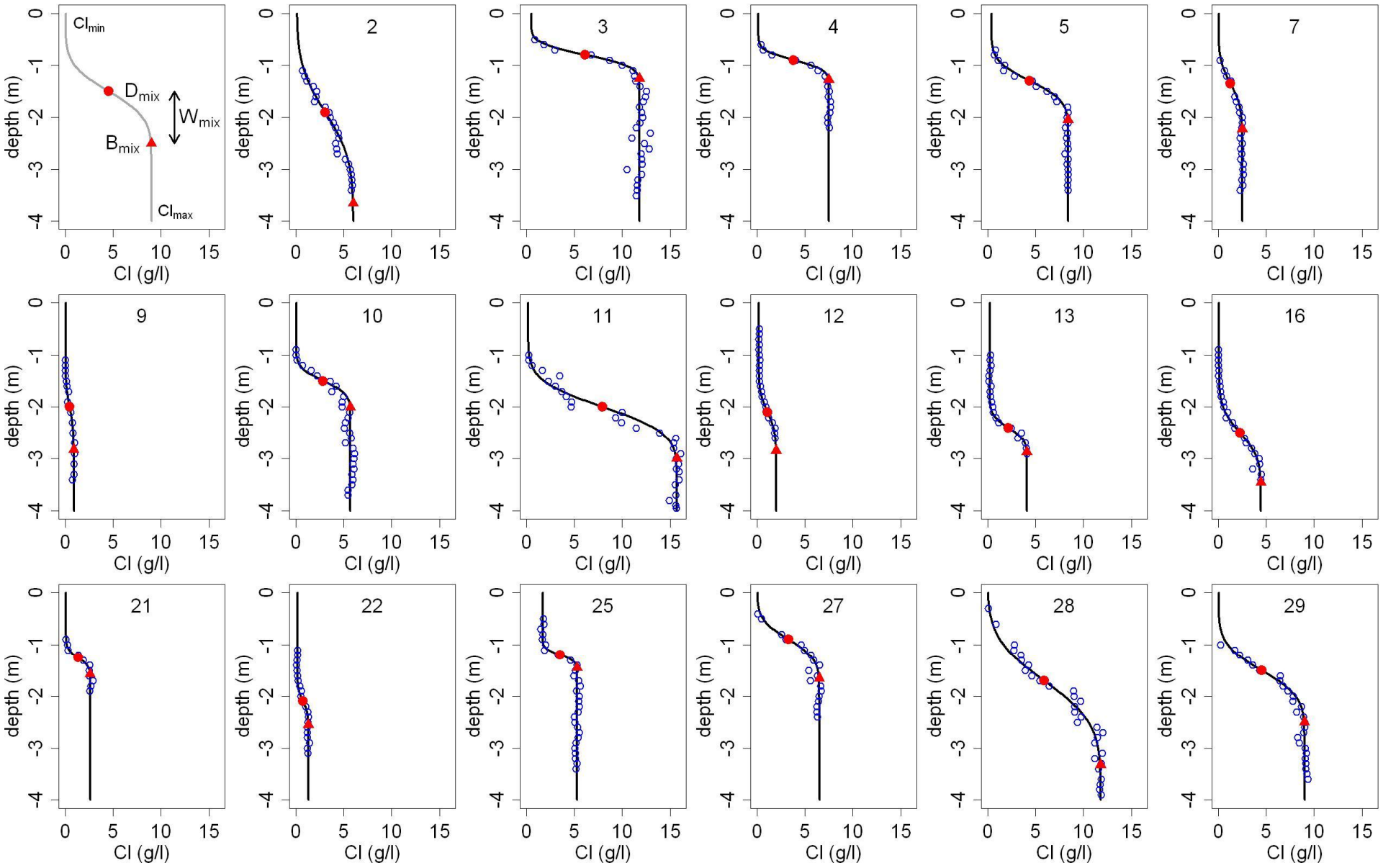
- $EC_w = FF * EC_{soil}$

Formatie-Factor (FF) voor verschillende lithologie

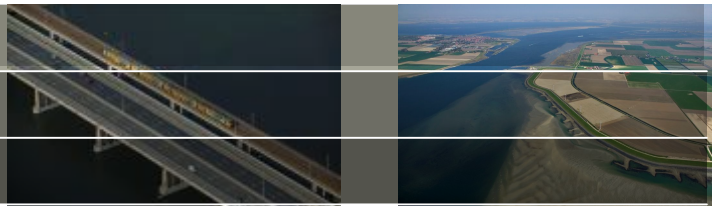
Lithology	Average FF	Std	Nr. of samples
Peat	2.1	0.7	41
Clay	2.5	0.6	192
Sandy clay / clayey sand	2.8	0.8	52
(Clayey) fine sand	3.2	0.4	299
Medium coarse sand	4*		
Coarse sand	5*		
Sand with gravel	6-7*		

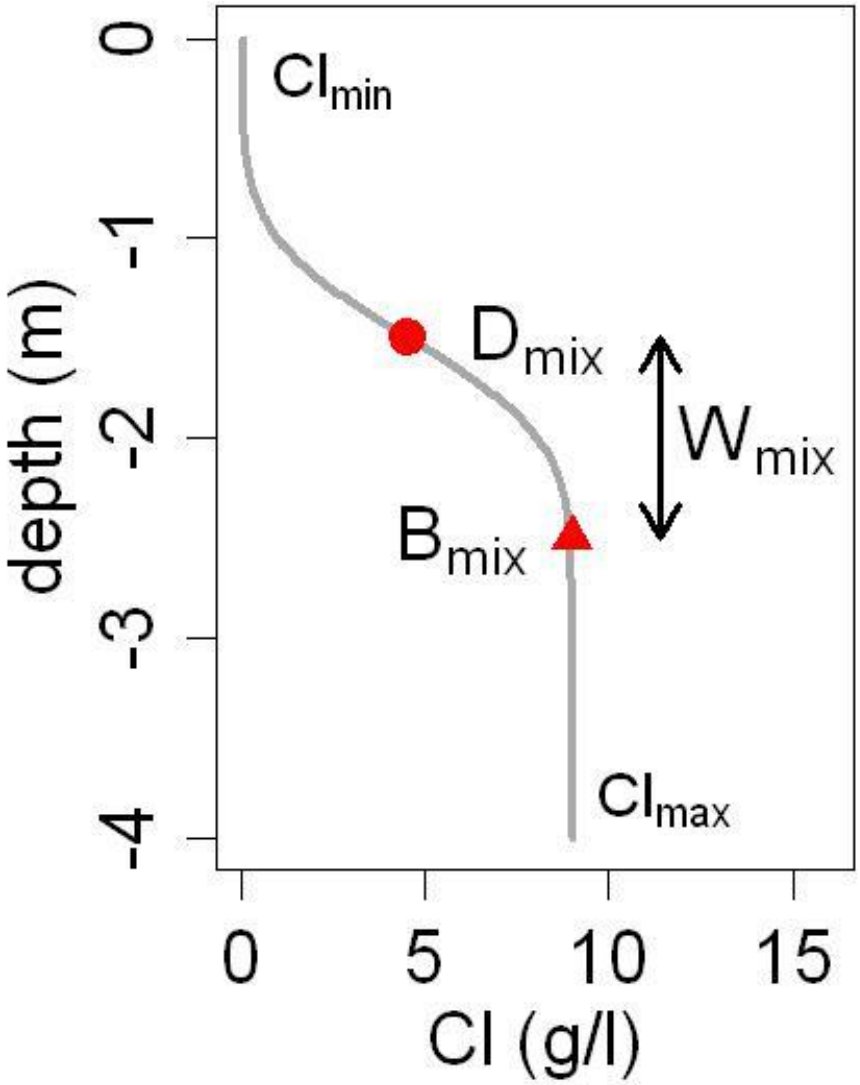
TEC-probe results

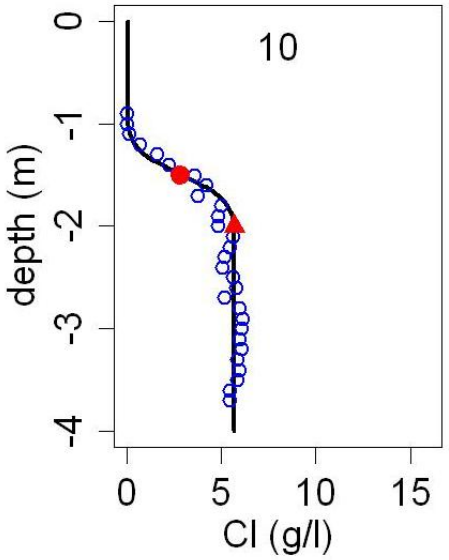


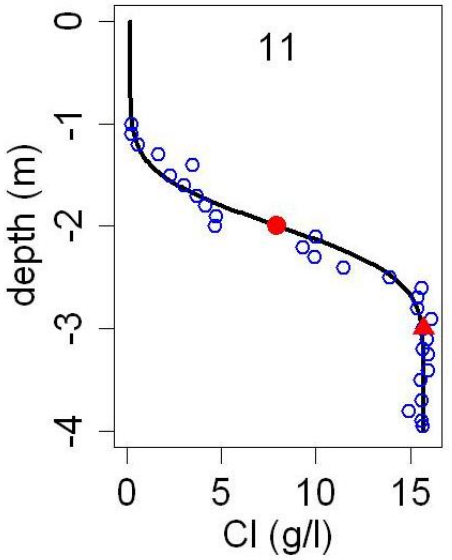


Lens characteristics



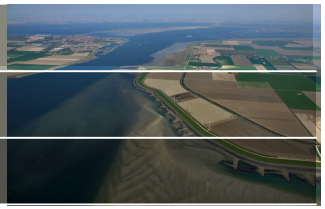






Deltares

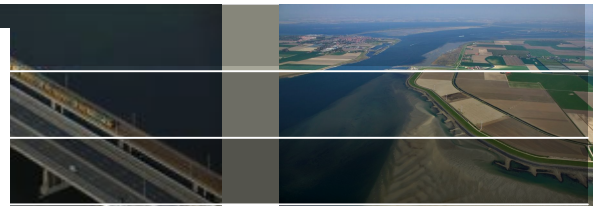
Meetmethode 5: (elektr.) sonderingen

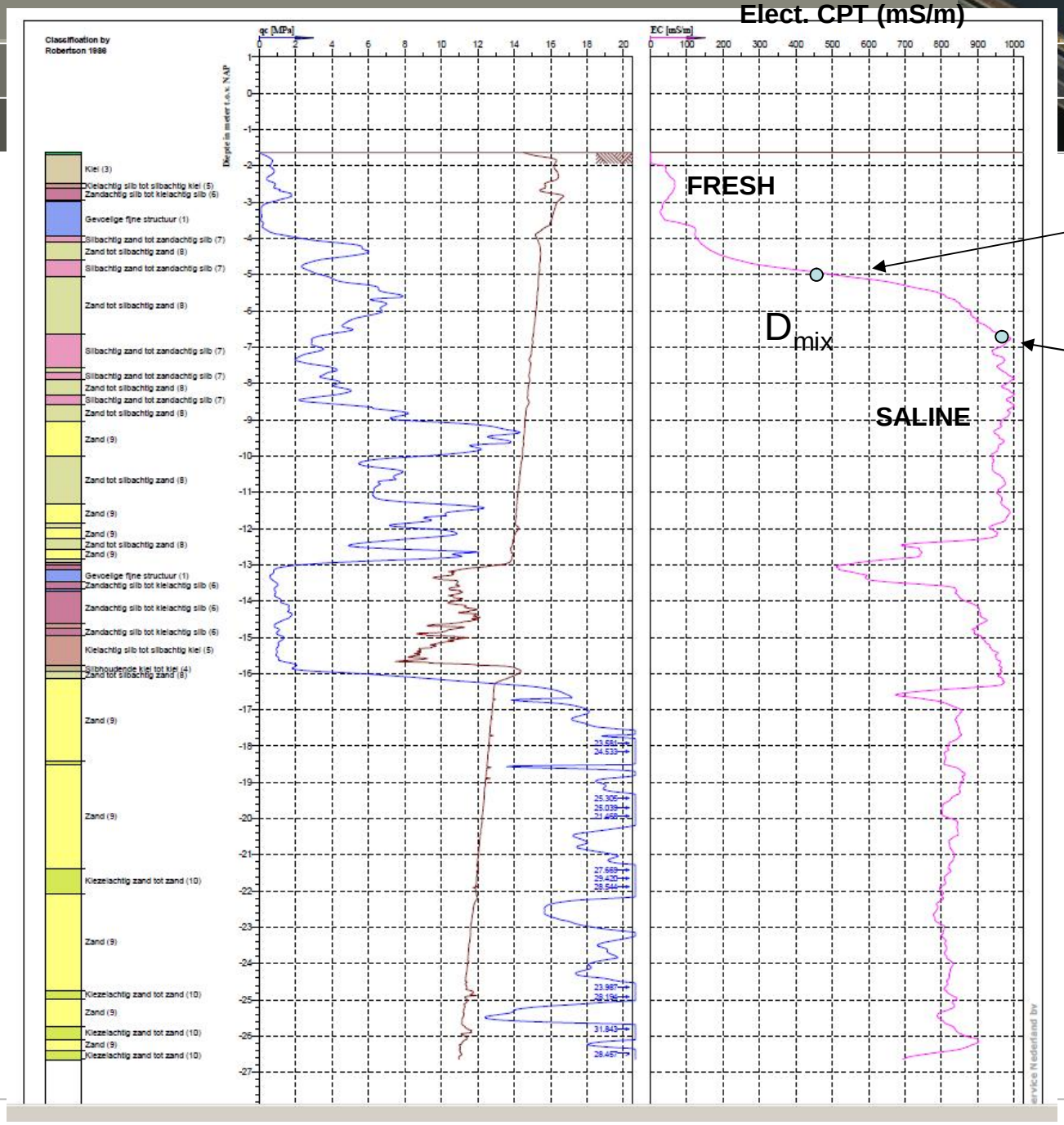


(Electrical) Groundwater Penentration Test.

Zelfde principe als prikstokmeting alleen dan machinaal
+ kleef en wrijving wordt gemeten -> lithologie

Deltares



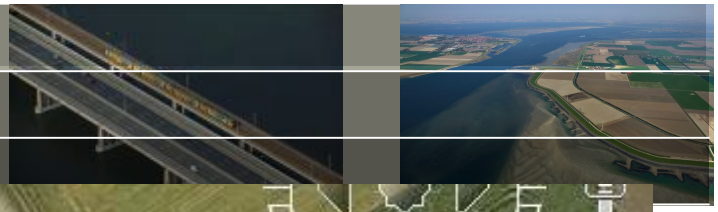


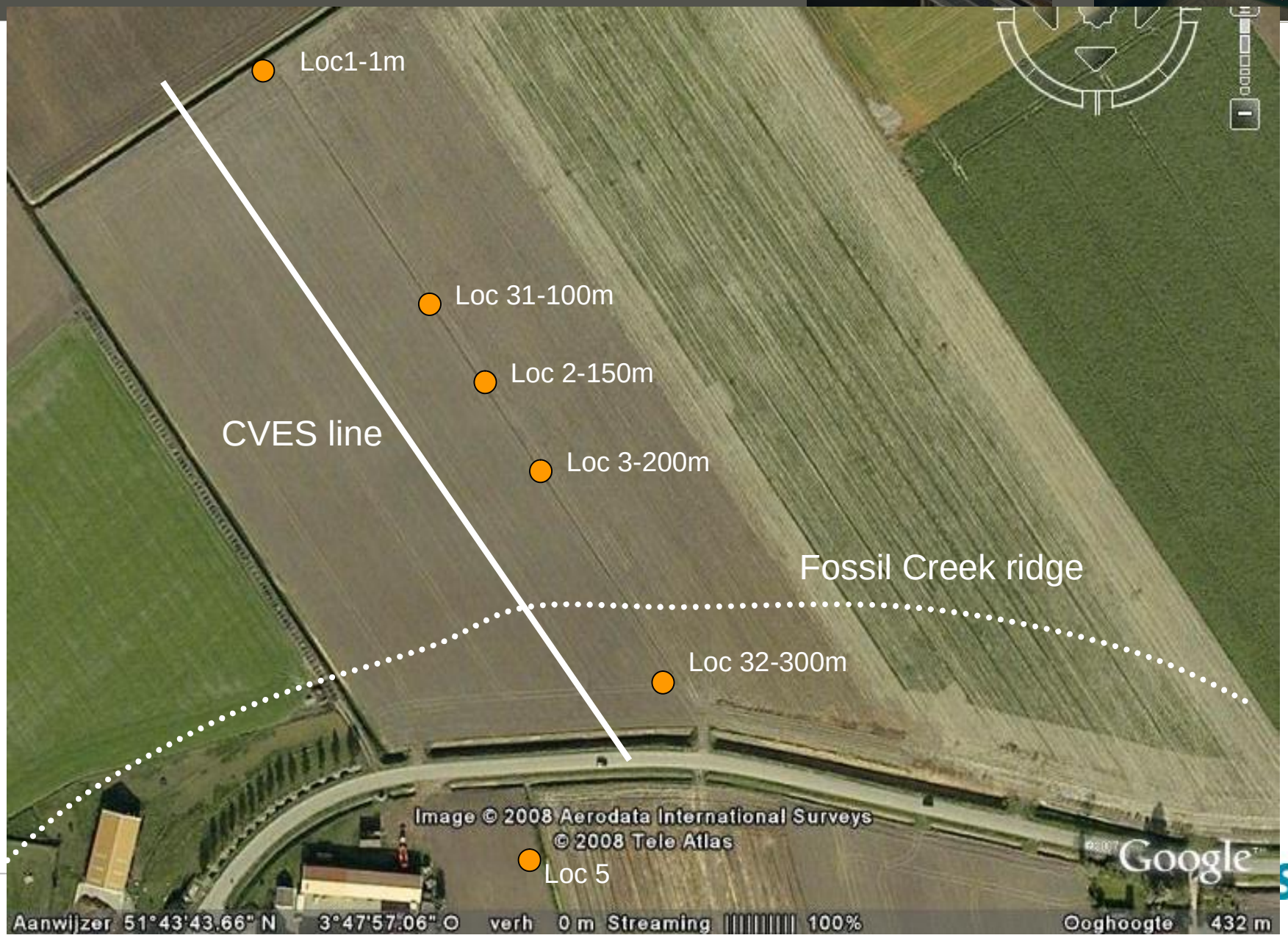
a) Depth of transition, D_{mix}, zone between 2 types of groundwater (fresh-saline)

b) Start of transition, S_{mix},

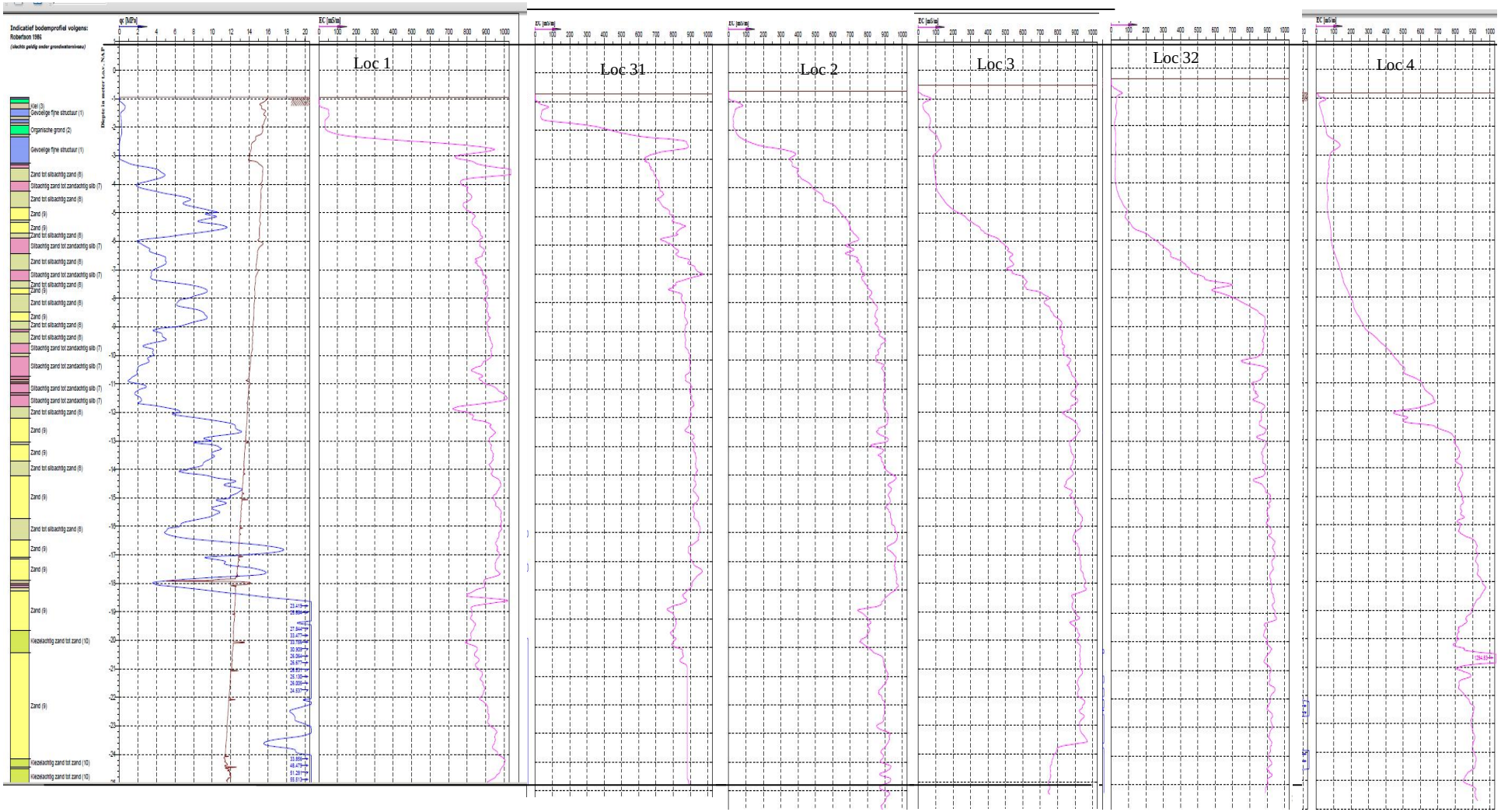
Deltares

Site 11

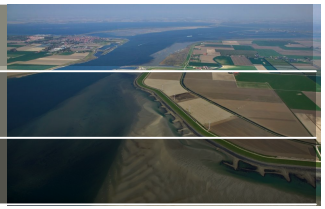



Loc1-1m
Loc 31-100m
Loc 2-150m
CVES line
Loc 3-200m
Fossil Creek ridge
Loc 32-300m
Image © 2008 Aerodata International Surveys
© 2008 Tele Atlas
Loc 5
Google
Aanwijzer 51°43'43.66" N 3°47'57.06" O verh 0 m Streaming 100%
Ooghoogte 432 m

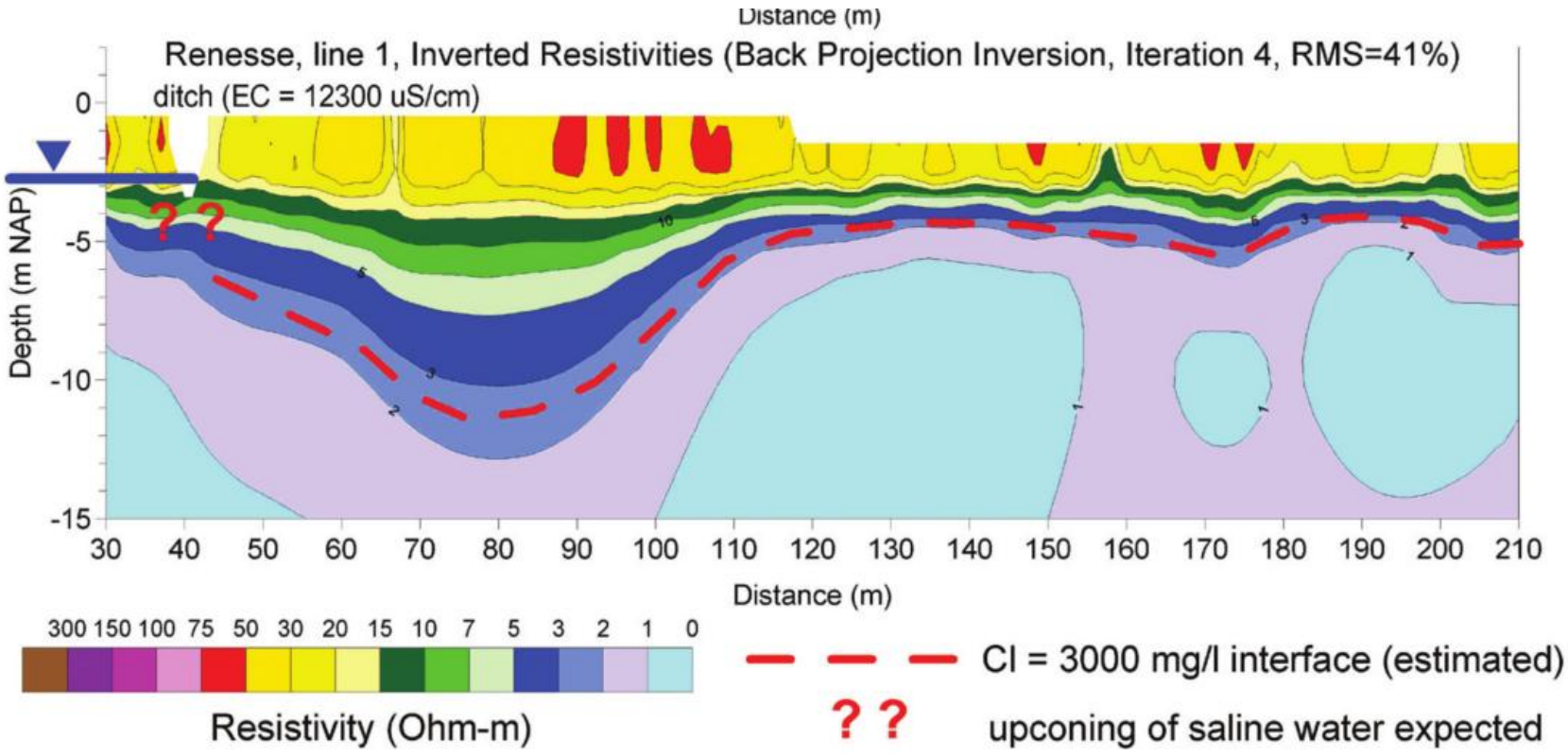
Resultaat van ECPT’s (sonderingen)



Meetmethode 6: CVES

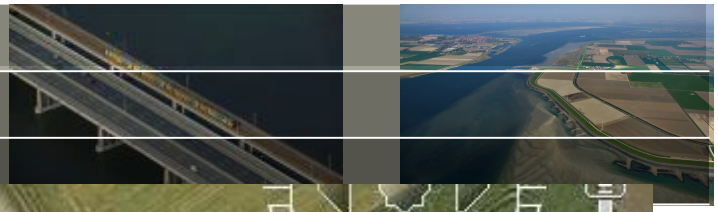


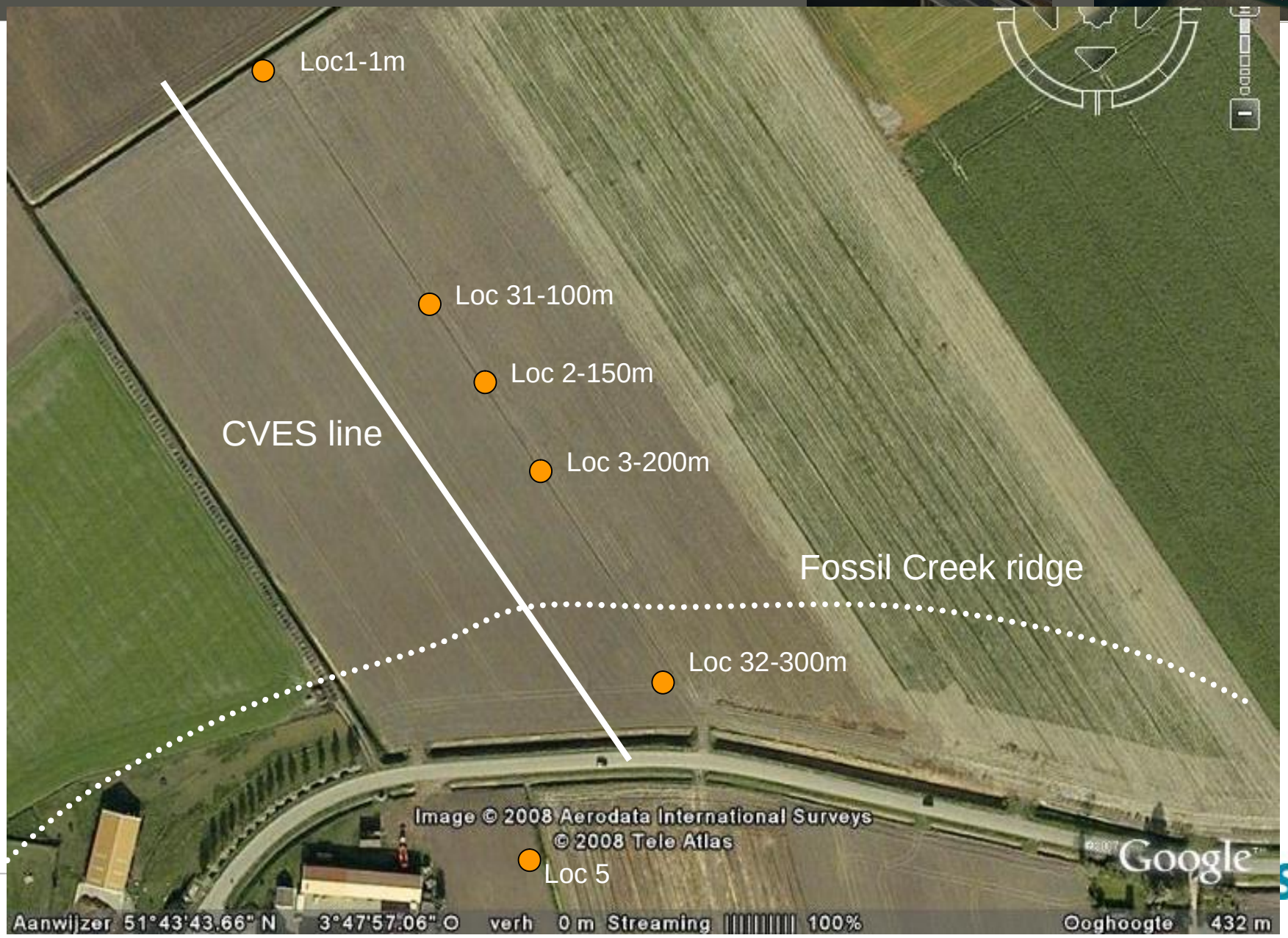
CVES: continuous vertical eletrical sounding



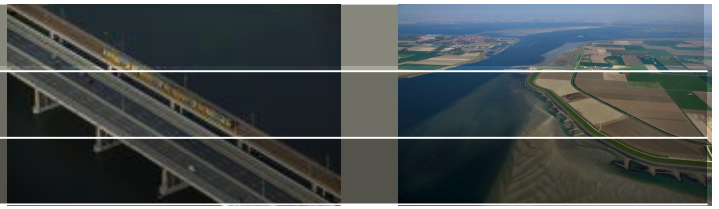
Deltares

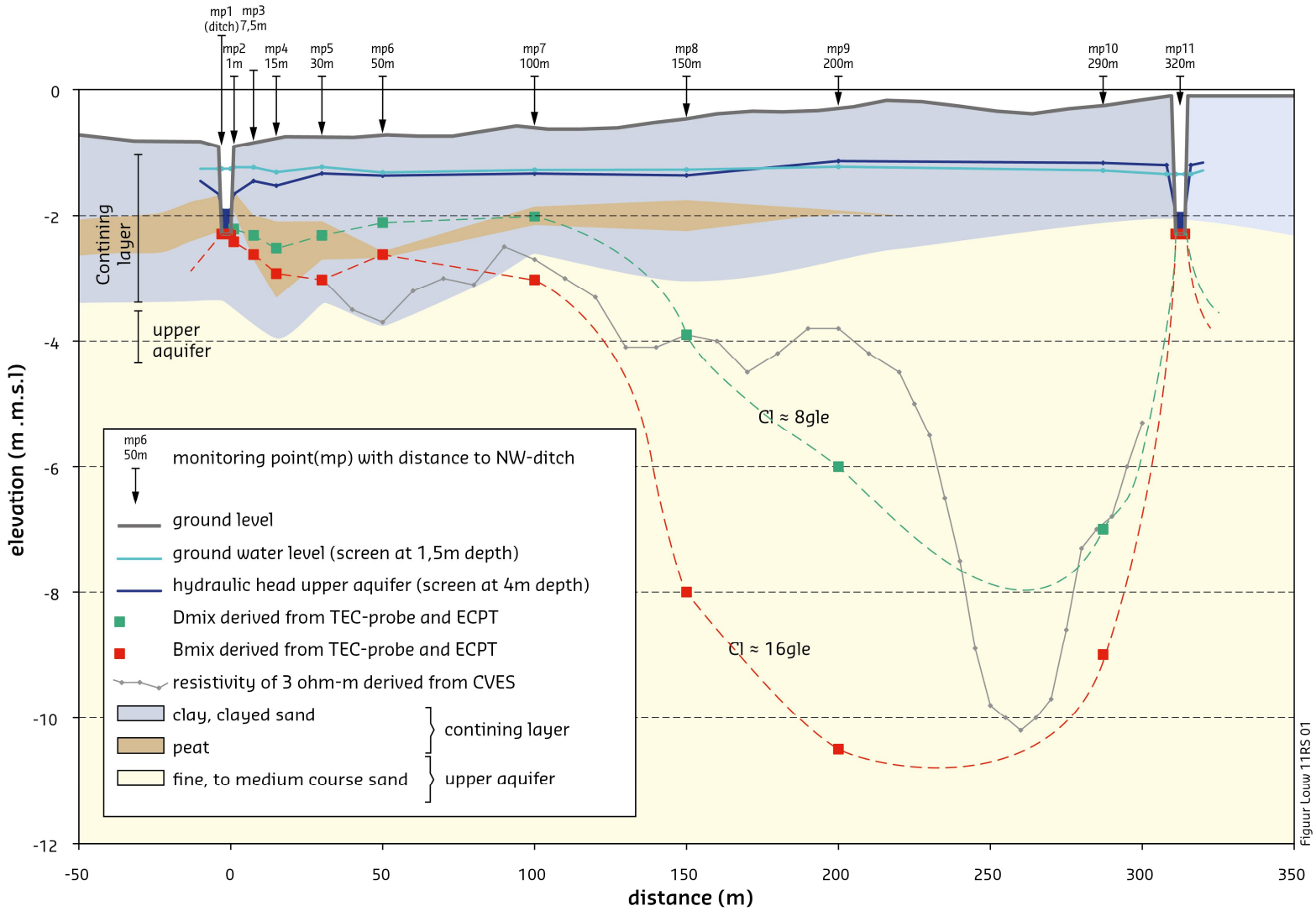
Site 11




Loc1-1m
Loc 31-100m
Loc 2-150m
CVES line
Loc 3-200m
Fossil Creek ridge
Loc 32-300m
Image © 2008 Aerodata International Surveys
© 2008 Tele Atlas
Loc 5
Google
Aanwijzer 51°43'43.66" N 3°47'57.06" O verh 0 m Streaming 100%
Ooghoogte 432 m

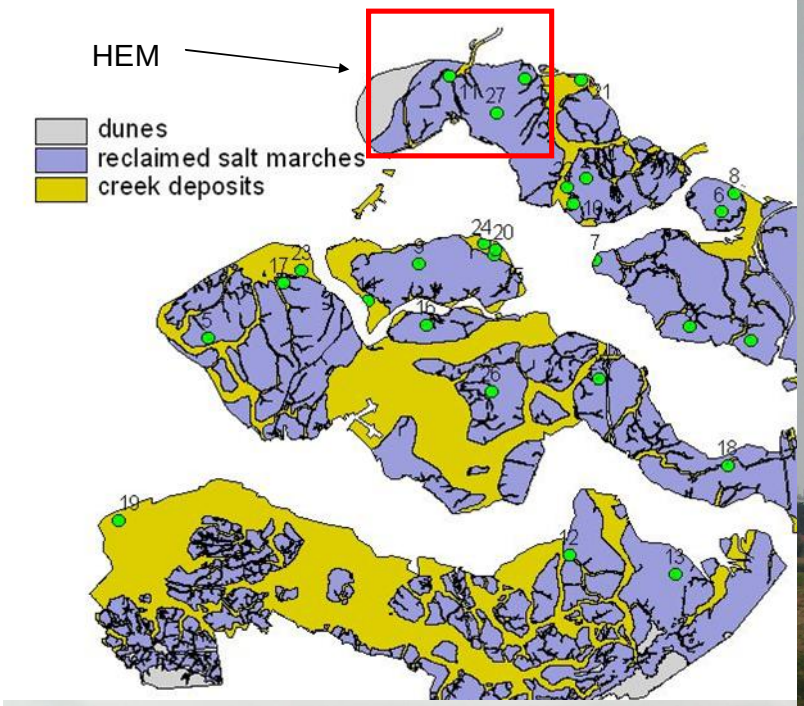
Alle metingen gecombineerd





Deltares

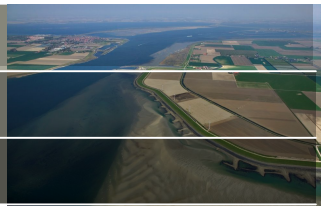
Helicopter-EM measurements to map fresh-saline interface (BGR)

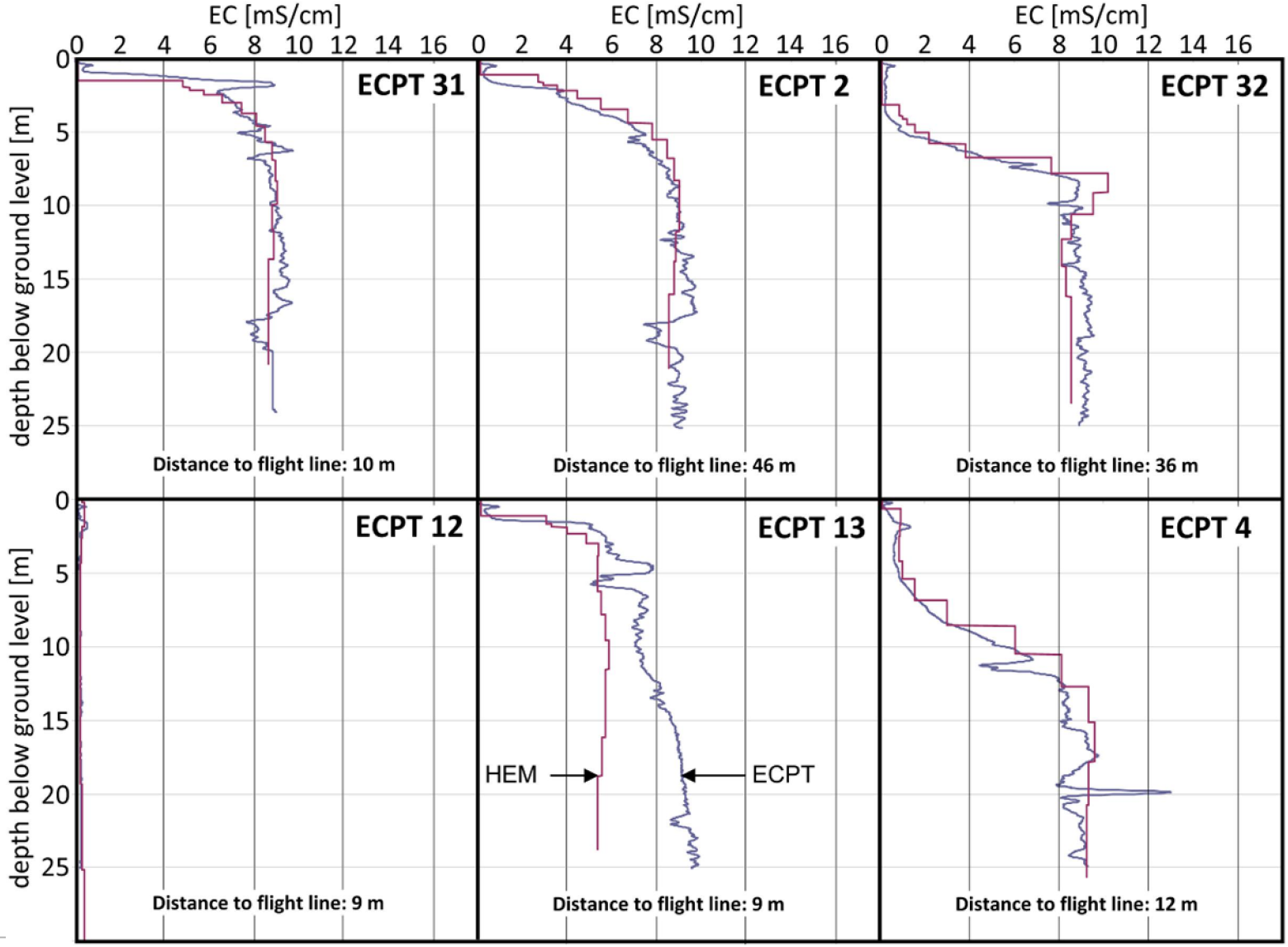


Interreg project

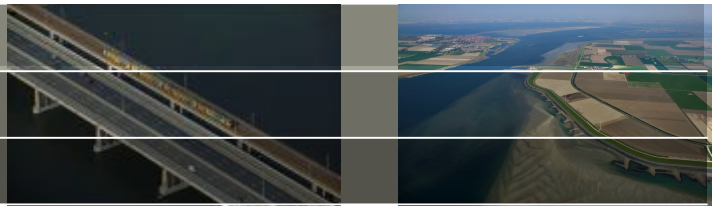
CLIWAT
CLIMATE & WATER

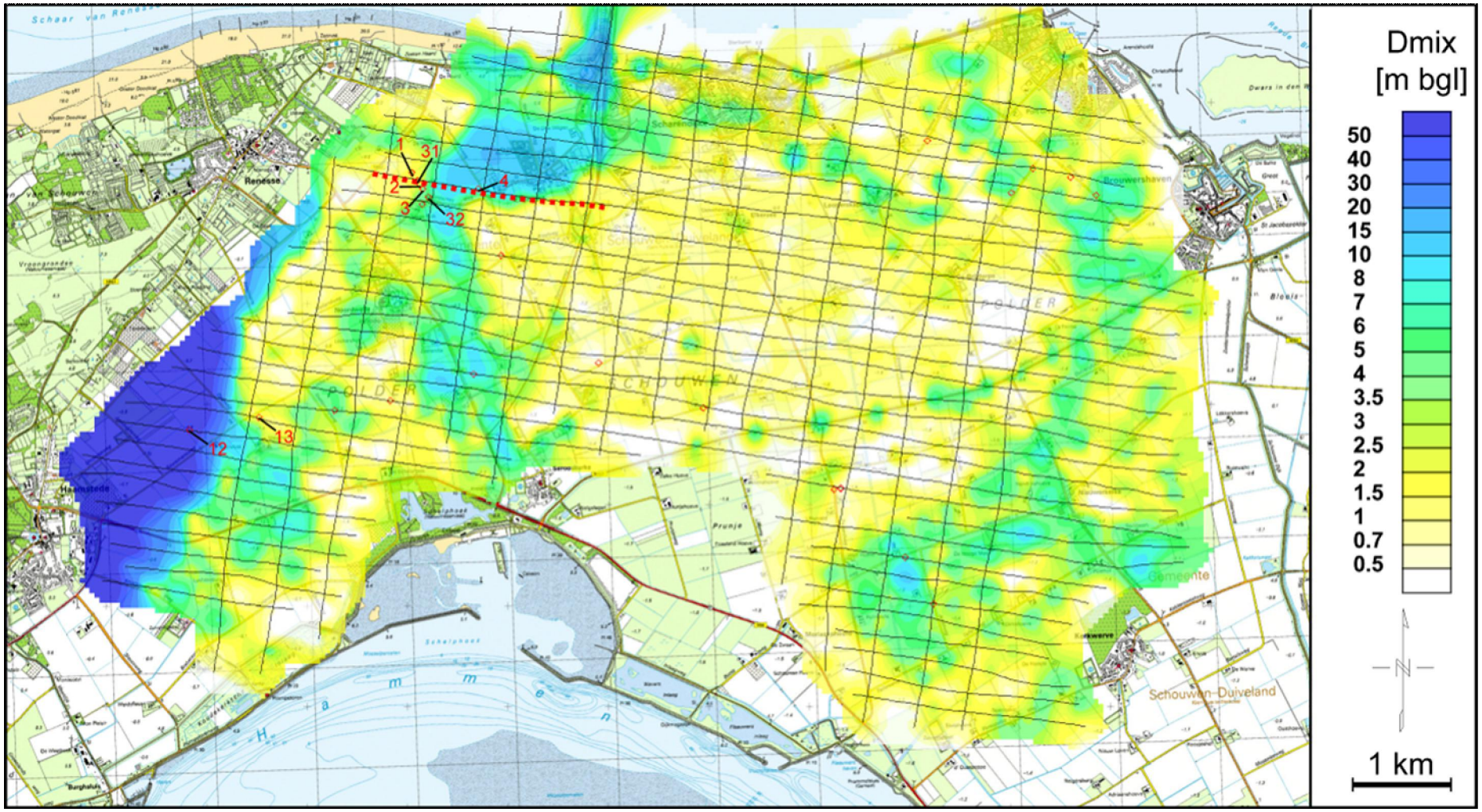
Vergelijking HEM - ECPT





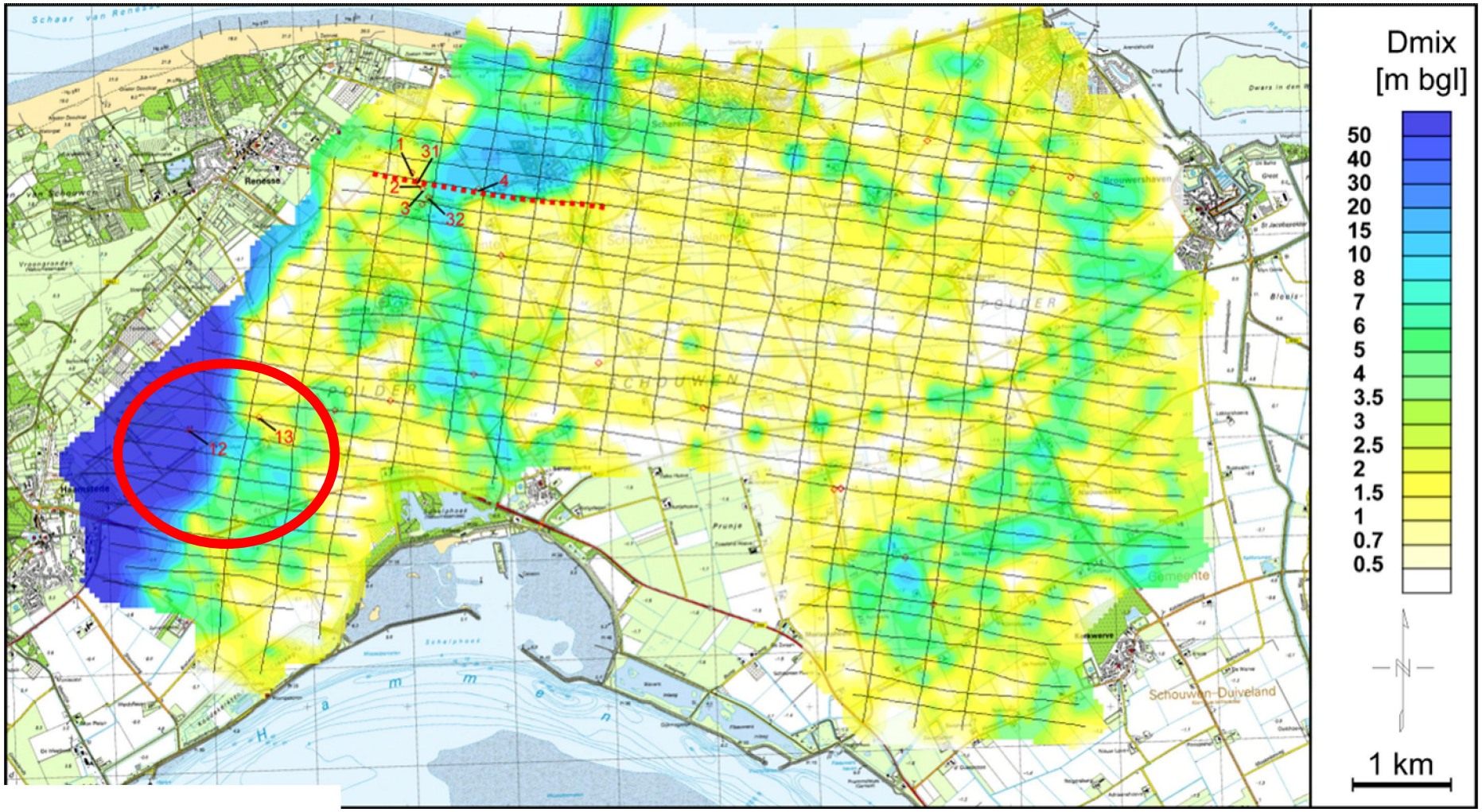
Dikte regenwaterlens (D_{mix})



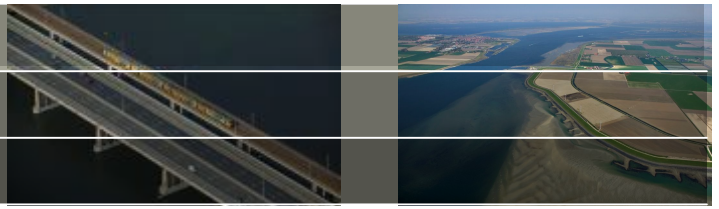


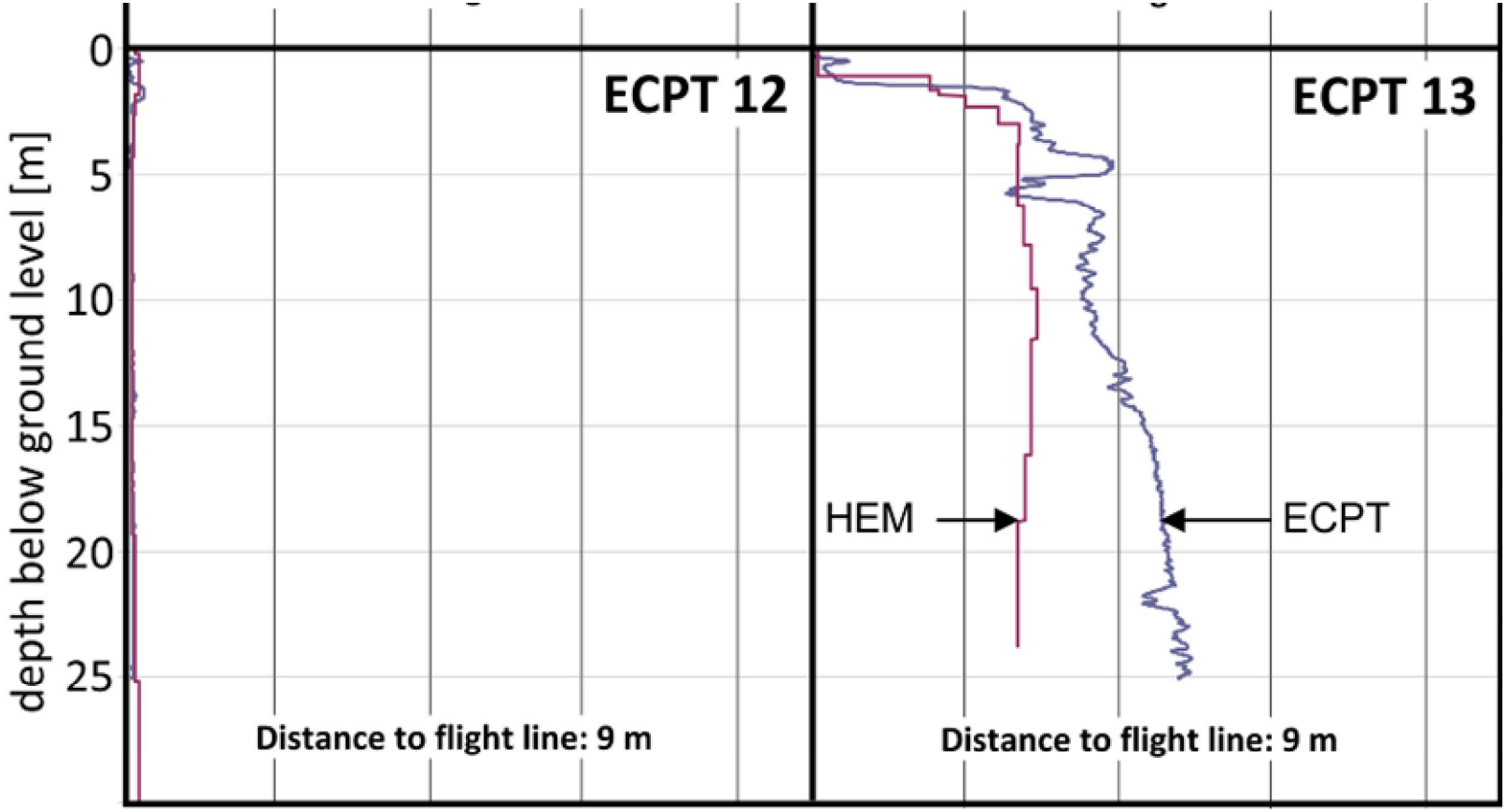
Deltares

Rainwater lens thickness (D_{mix}= average position mixing zone) mapped with HEM



Comparison HEM – ECPT



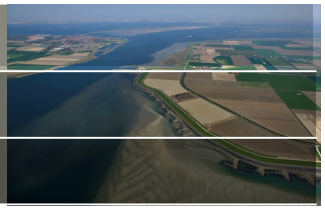


BGR Bundesanstalt für Geowissenschaften und Rohstoffe

GEOZENTRUM HANNOVER

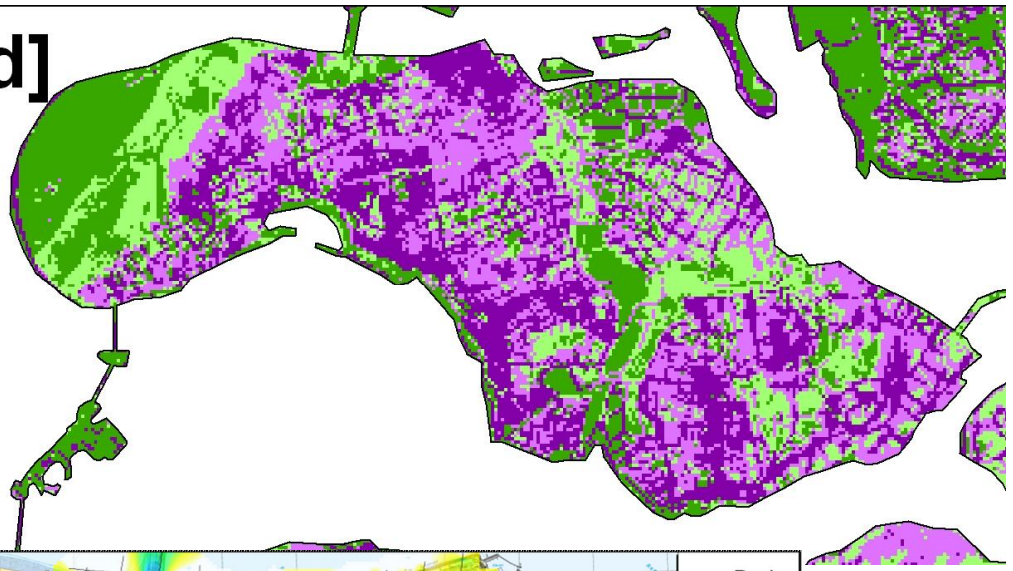
Deltares

Kwel-Infiltratie: model results

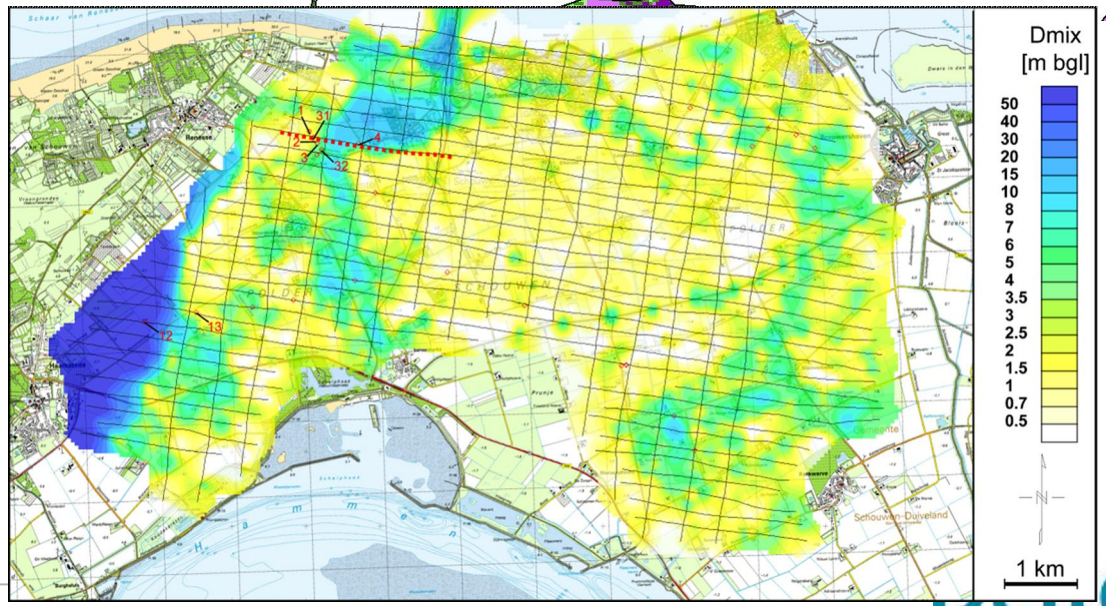


infiltration/seepage [mm/d]

- > 0.5 mm/d infiltration
- 0 - 0.5
- 0 - 0.5
- > 0.5 mm/d seepage



HEM →



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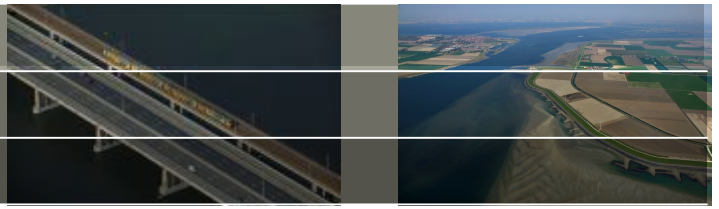
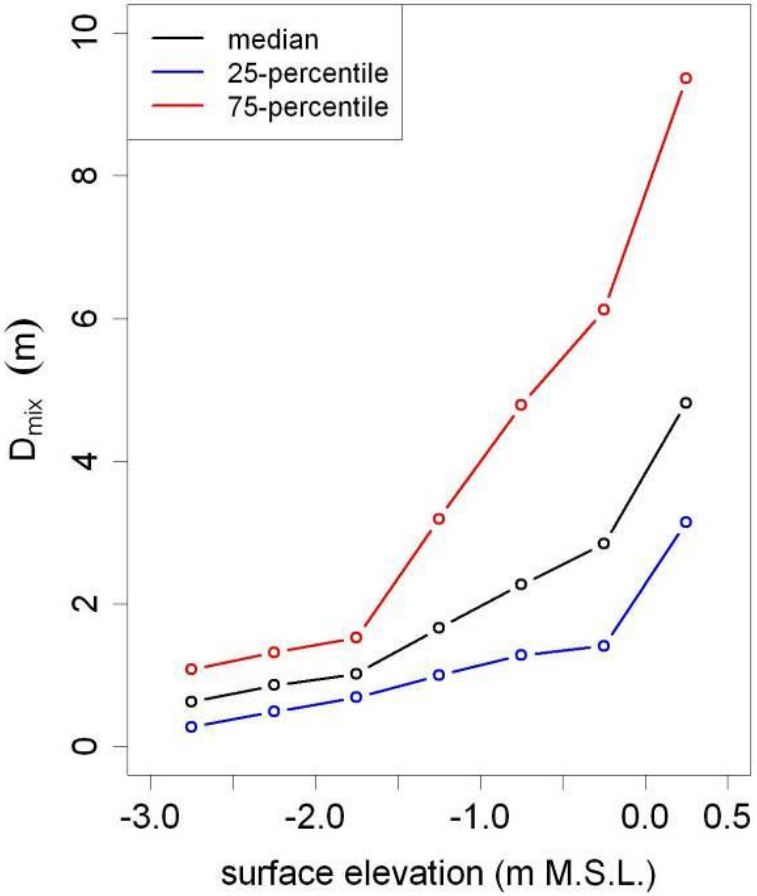
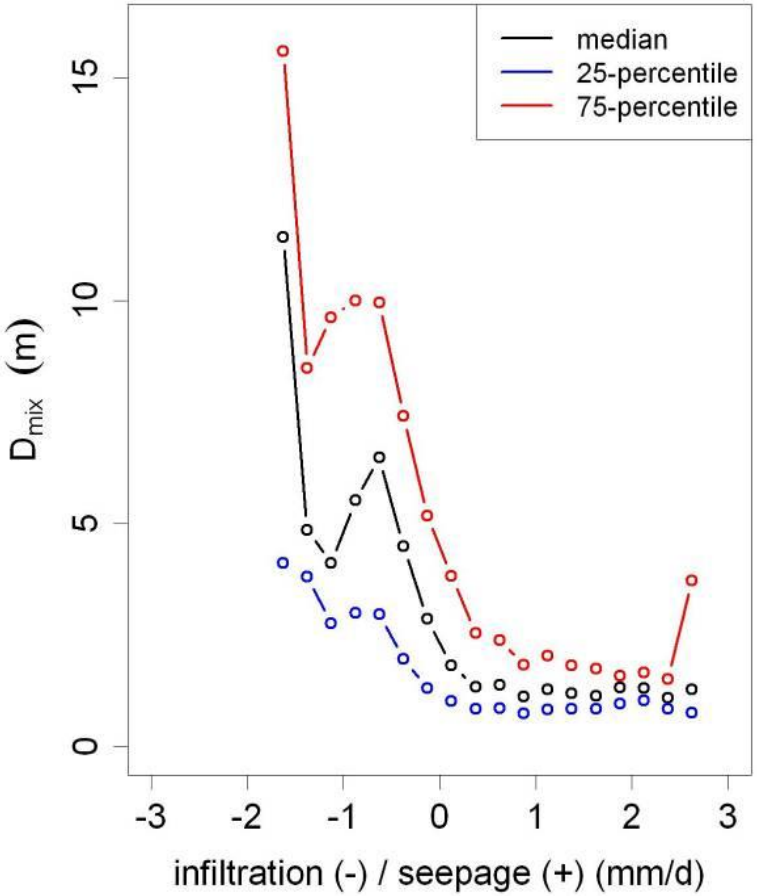
Dikte regenwaterlens (D_{mix}) versus maaiveld en kwel / infiltratie







Deltares