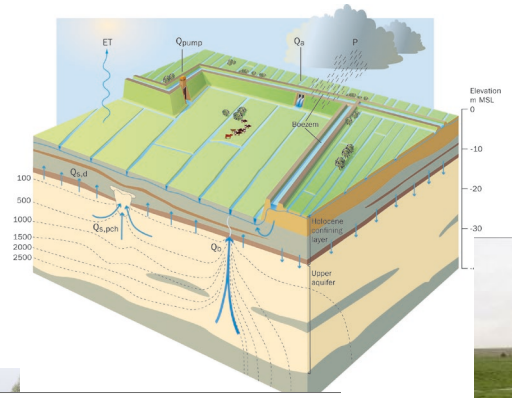
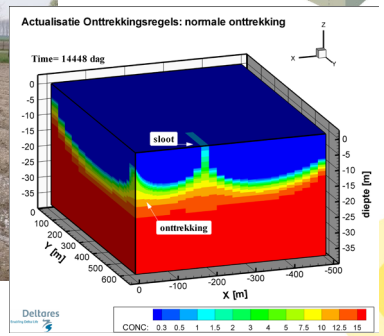


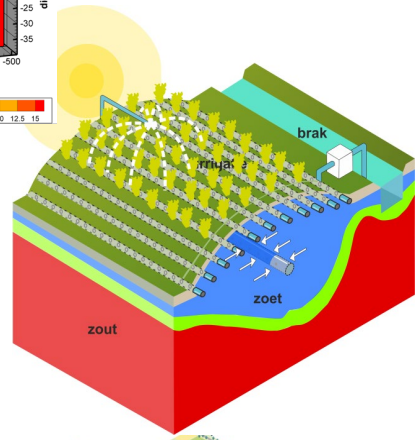


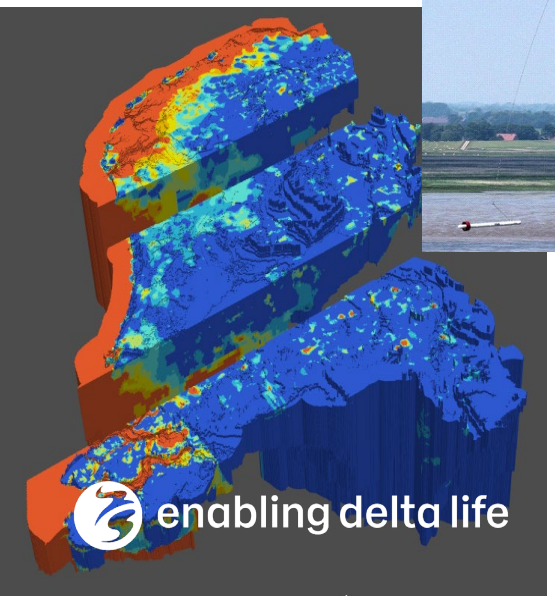


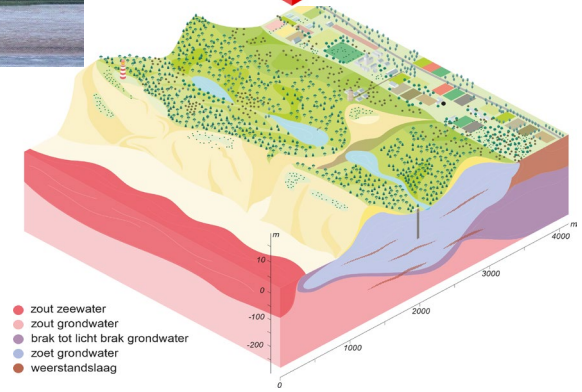












Verzilting en Zoetwaterbeschikbaarheid

- Introductie zoet-brak-zout
- Zoetwaterbalans NL
- Paleo reconstructie zoet-zout
- Effecten zeespiegelstijging op
  - a. verzilting grondwater polders
  - b. zoetwater in de duinen
- Maatregelen
- Meerdere intermezzo's

Nederlandse Kustdagen

Gualbert Oude Essink, en anderen

Wiki: http://freshsalt.deltares.nl/

23-24 September 2026

Deltares

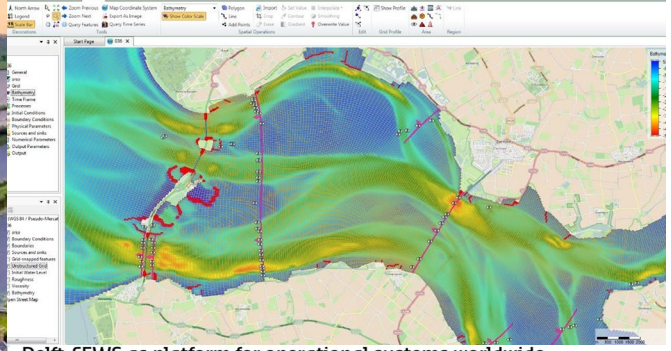
Utrecht University

IHE DELFT

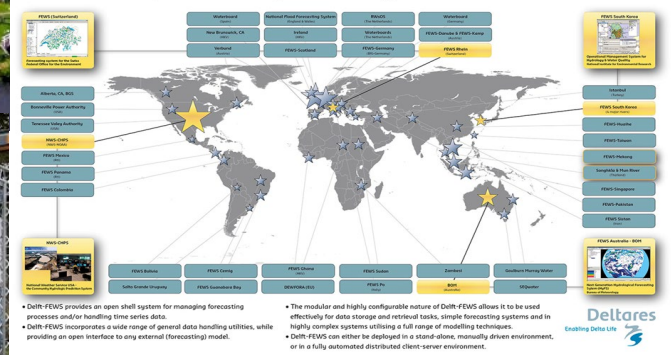
Deltares

- ~850 people, 114 M€ annual turnover
- Legal form: **foundation** under Dutch law (no shareholders)
- Activities targeted at extending our knowlegde (**Not4Profit**)
- Doing **applied research** and specialized consultancy
- Making use of large in-house **research facilities and software**
- Strong links with the academia
- **Open source and software policy**













Sinking salinizing deltas under threat

Rhine / Meuse, NL

>10 million people





Nile delta, Egypt

>50 million people





GBM, Bangladesh

>140 million people





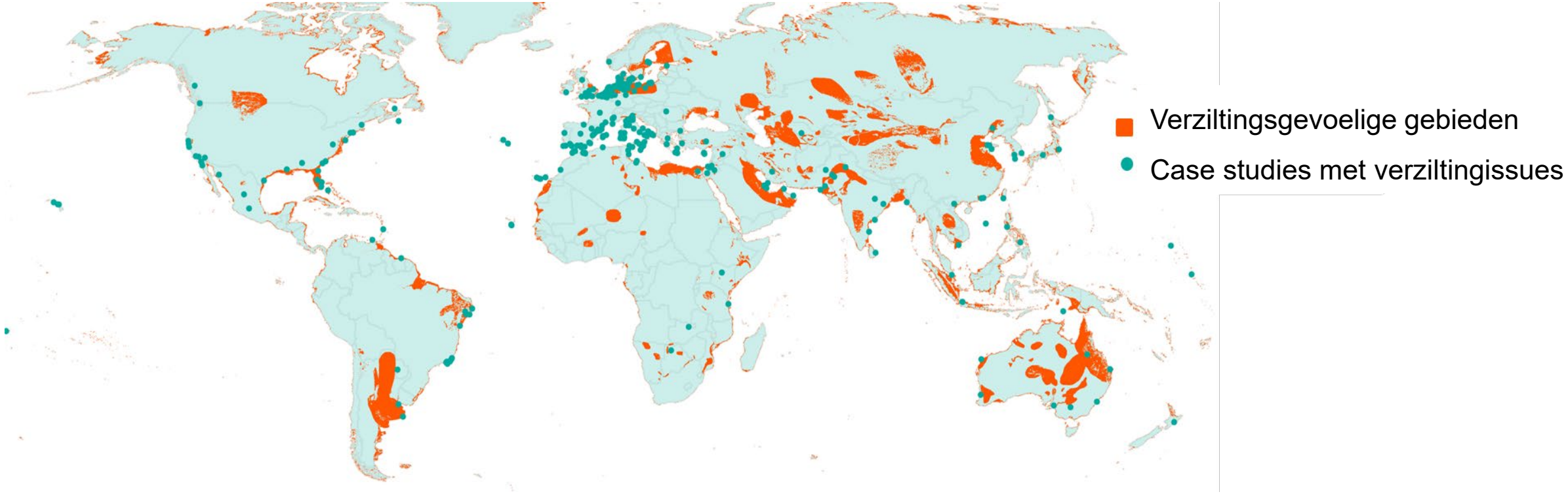
Mekong delta, Vietnam

20 million people



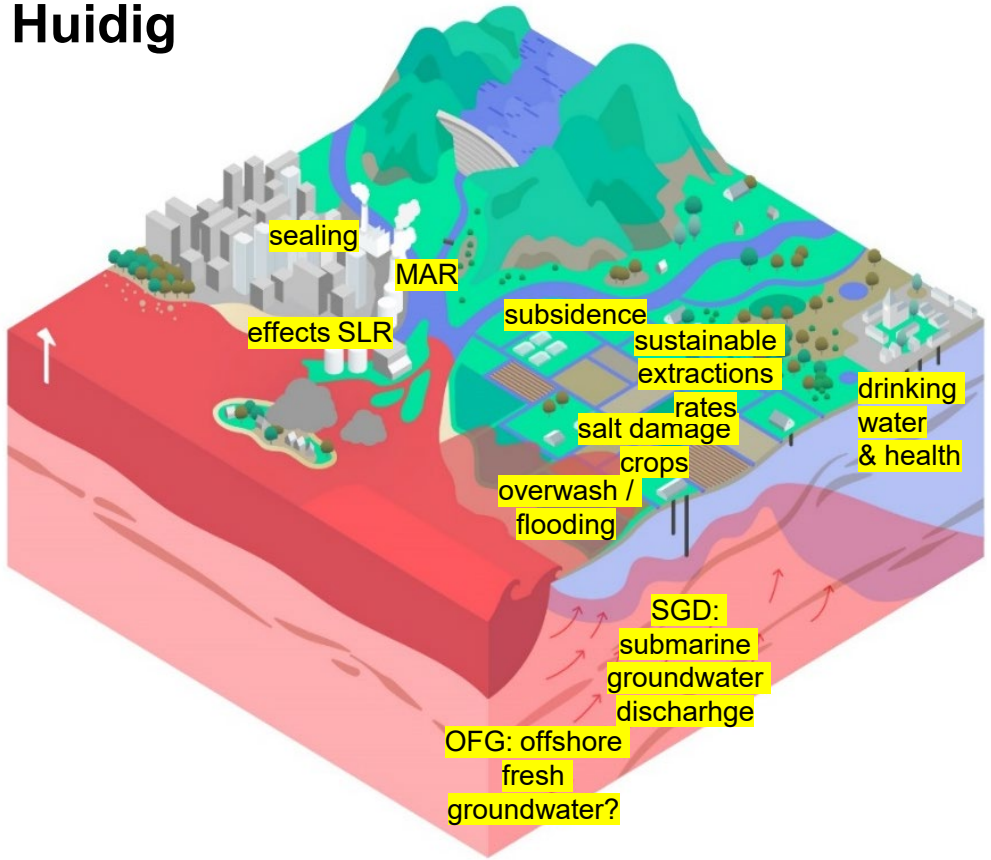


Verzilting is een wereldwijd probleem

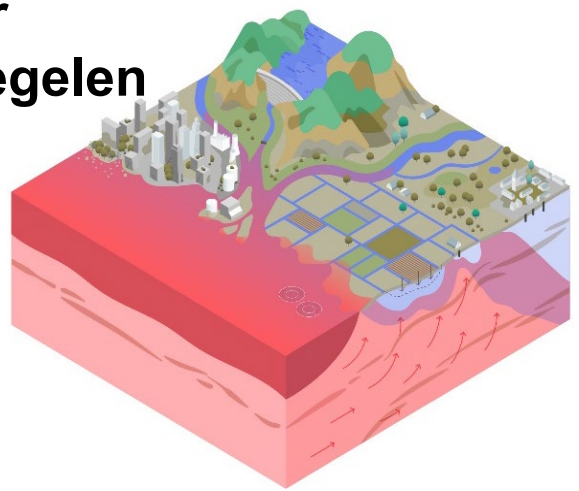


Zoet grondwater beschikbaarheid deltagebieden

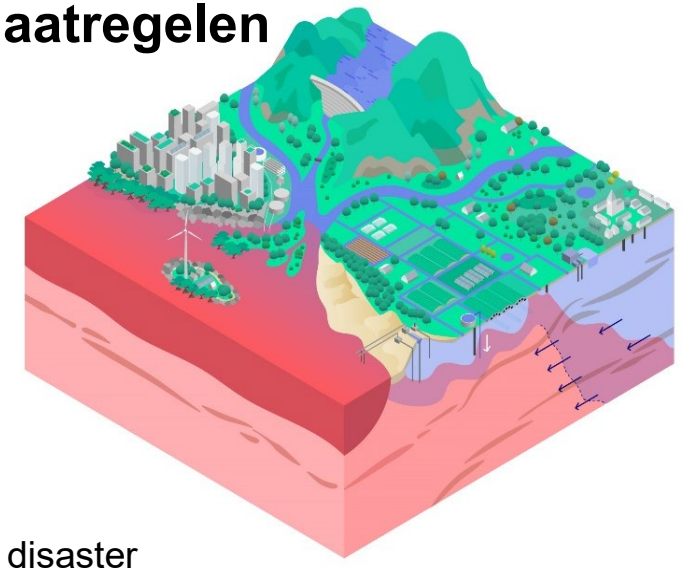
Huidig

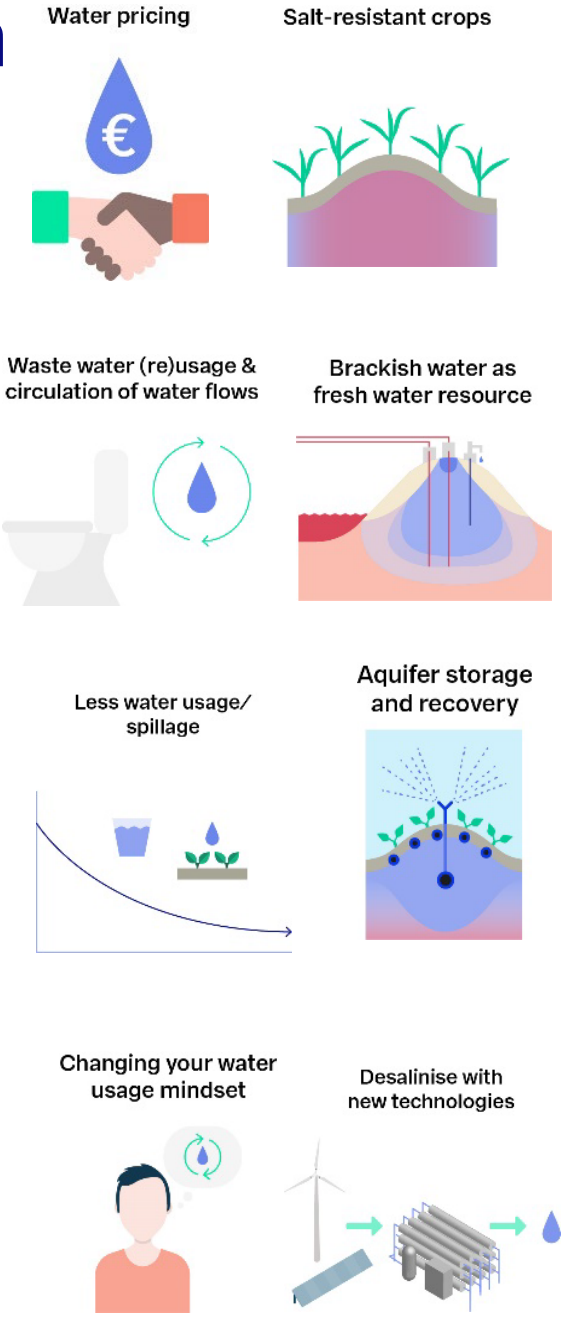


Toekomst zonder maatregelen



Toekomst met maatregelen

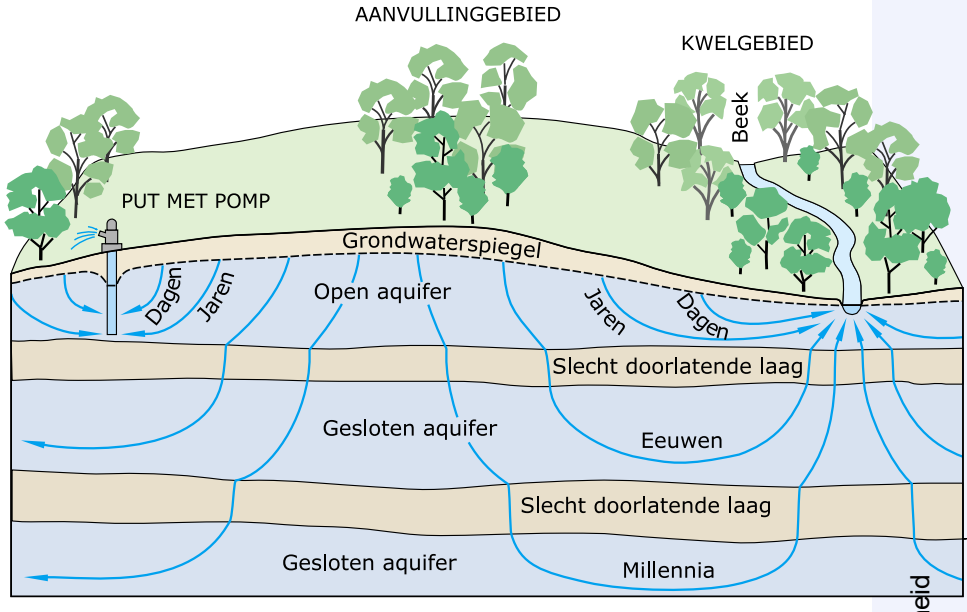


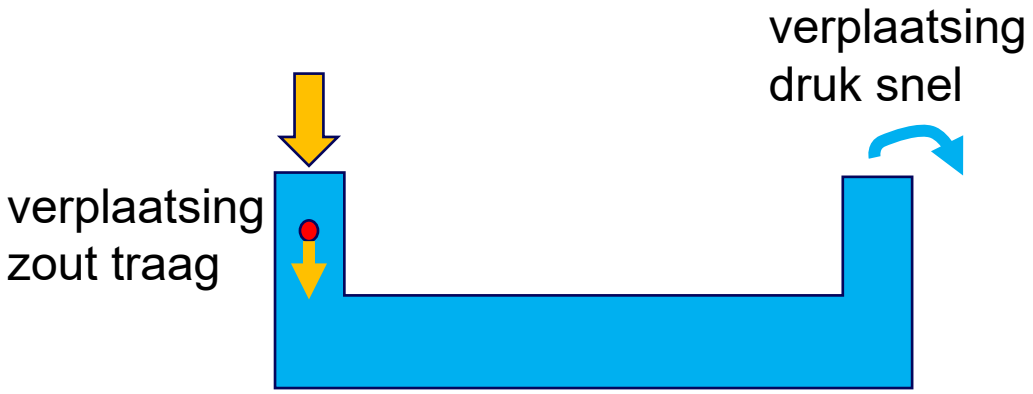


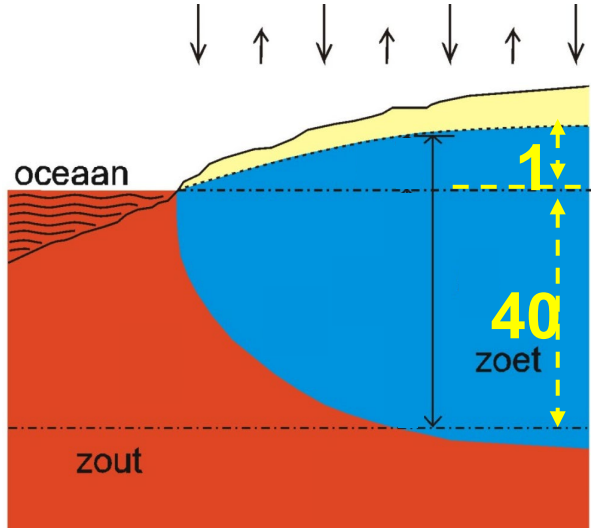
https://deltalife.deltares.nl/september_2022_en/salinisation_the_slow_disaster

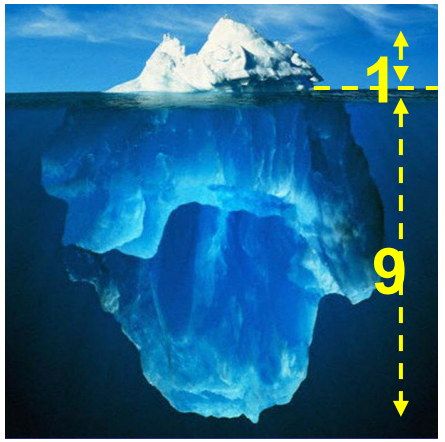
Wat theorie over zoet en zout grondwater

- Grondwater stroomt makkelijk door zand, moeilijk door klei
- Grondwater stroomt erg langzaam (orde meters per jaar)
- Grondwater stroomt van hoge naar lage druk
- Grondwater kan duizenden jaren oud zijn
- Zoet grondwater drijft op zout grondwater door dichtheidsverschillen
- Zout verplaatst door meebewegen met stromend grondwater (dus langzaam)









Zout water is een probleem

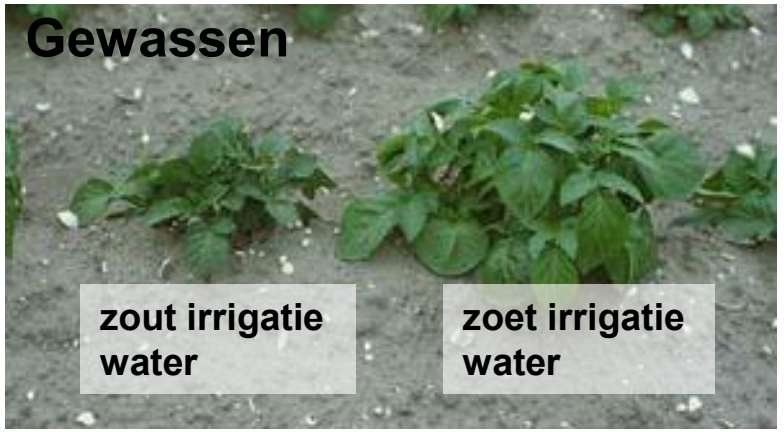
In 1 liter oceanwater zit ongeveer 35.000 mg zout (opgeloste stoffen)
Meng 1 liter zeewater met 100 liter zoet water:

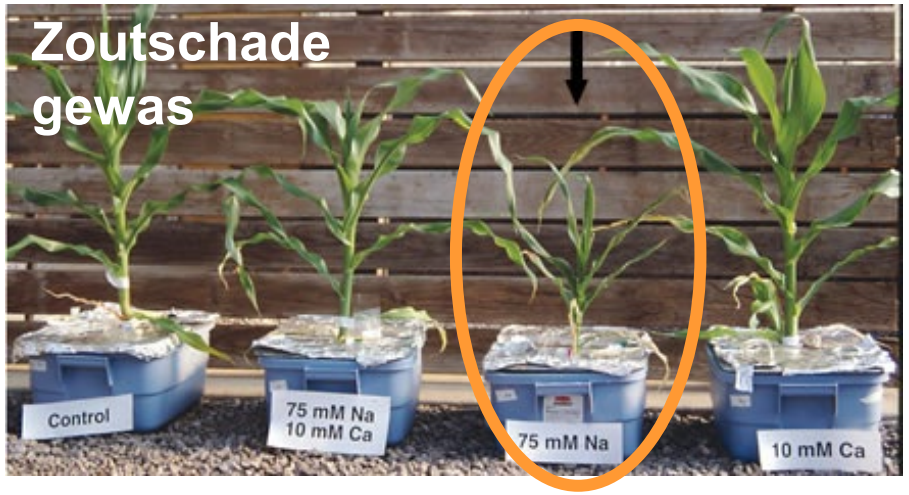
- boven drinkwaternorm (gezondheidseffecten lang termijn)
- zilte smaak
- schade aan sommige gewassen en natuur









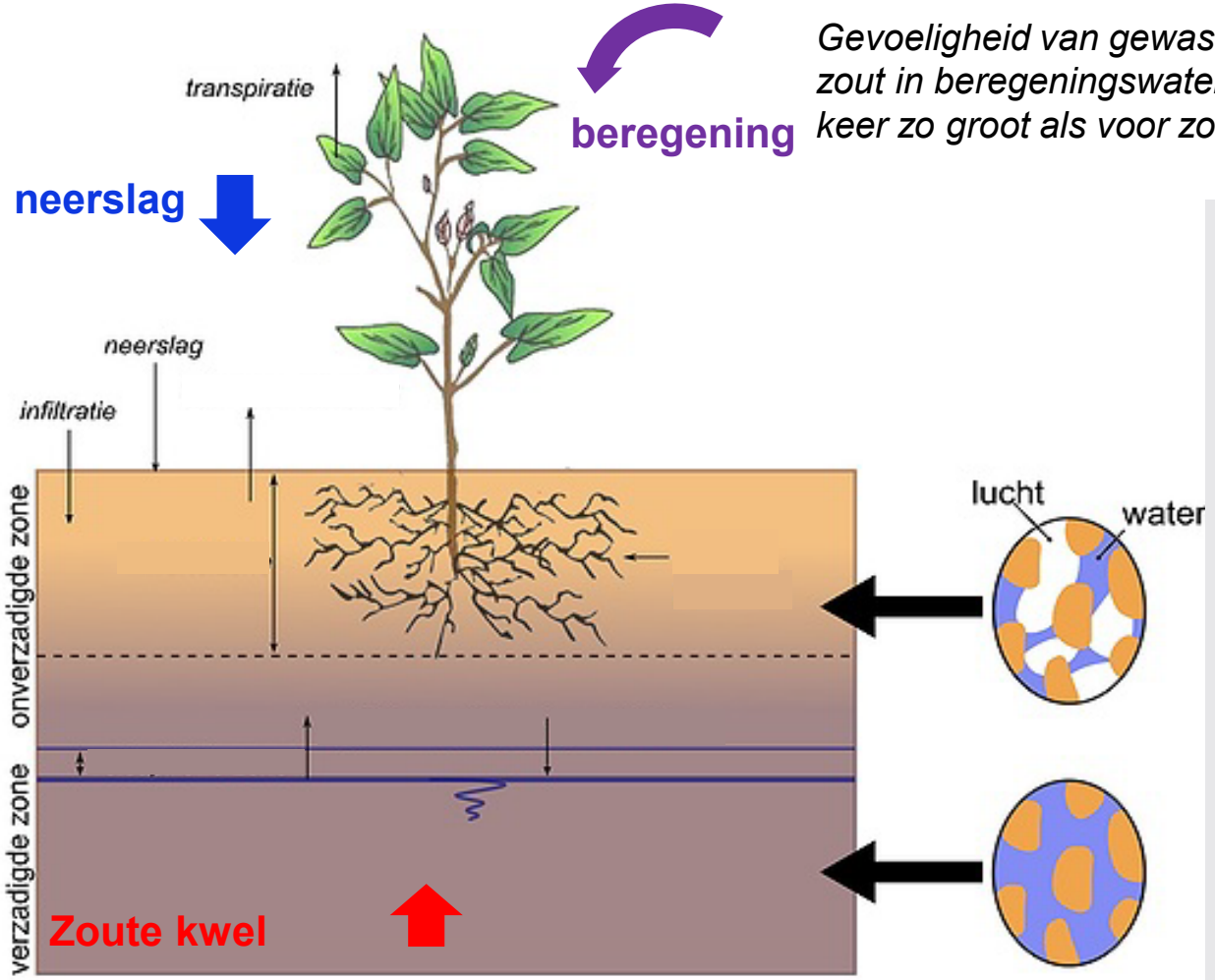




Zouttolerantie gewassen

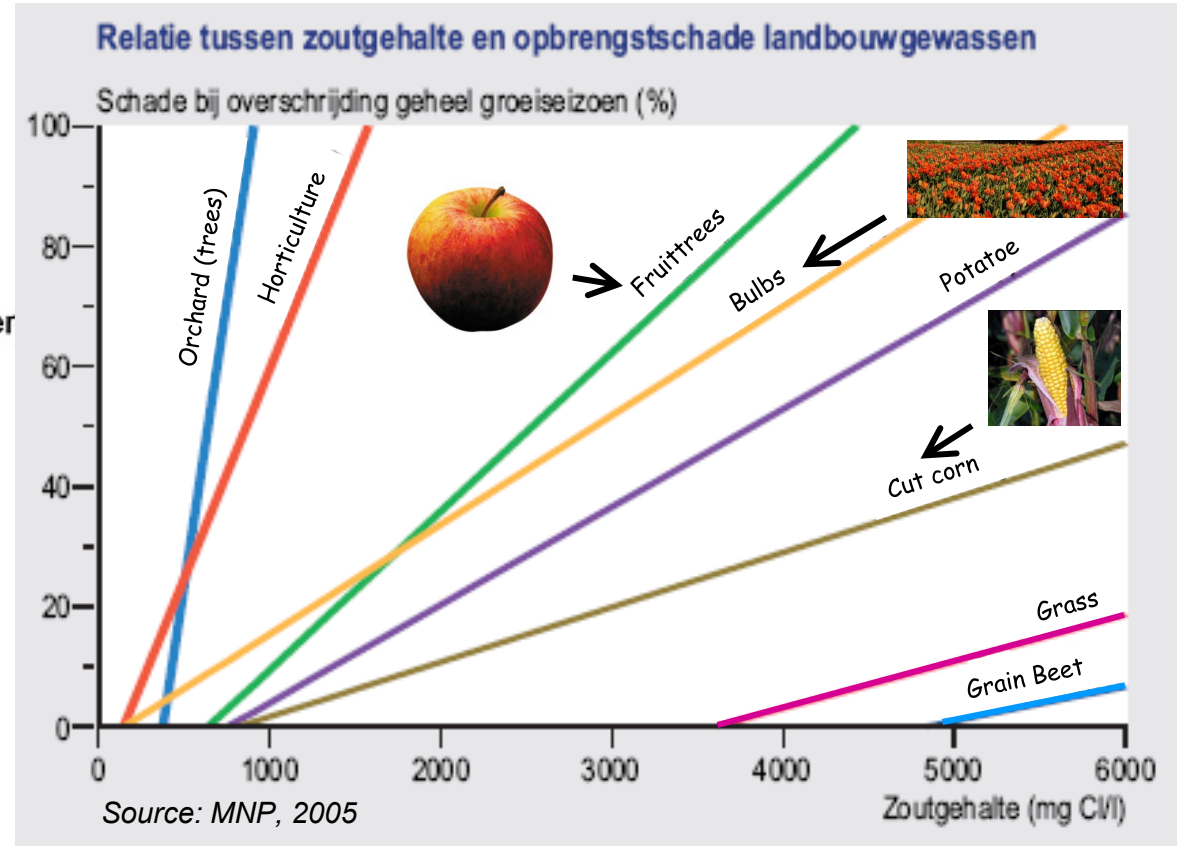
Belangrijke parameters:

- Zoutgehalte concentratie in wortelzone
- Land gebruik
- Gevoeligheid gewassen



Gevoeligheid van gewassen voor zout in beregeningswater is drie keer zo groot als voor zoute kwel.

Gras ≥ 3606 mg Cl-/l
Graan ≥ 4801 mg Cl-/l
Aardappelen ≥ 756 mg Cl-/l
Data gewassen?: bijv. Stuyt et al., 2016, link



Intermezzo Zoetwaterbalans

Wat is de zoetwaterbalans van laag Nederland tijdens droogte en hoe verandert deze bij klimaatopwarming en zeespiegelstijging?

Deltares



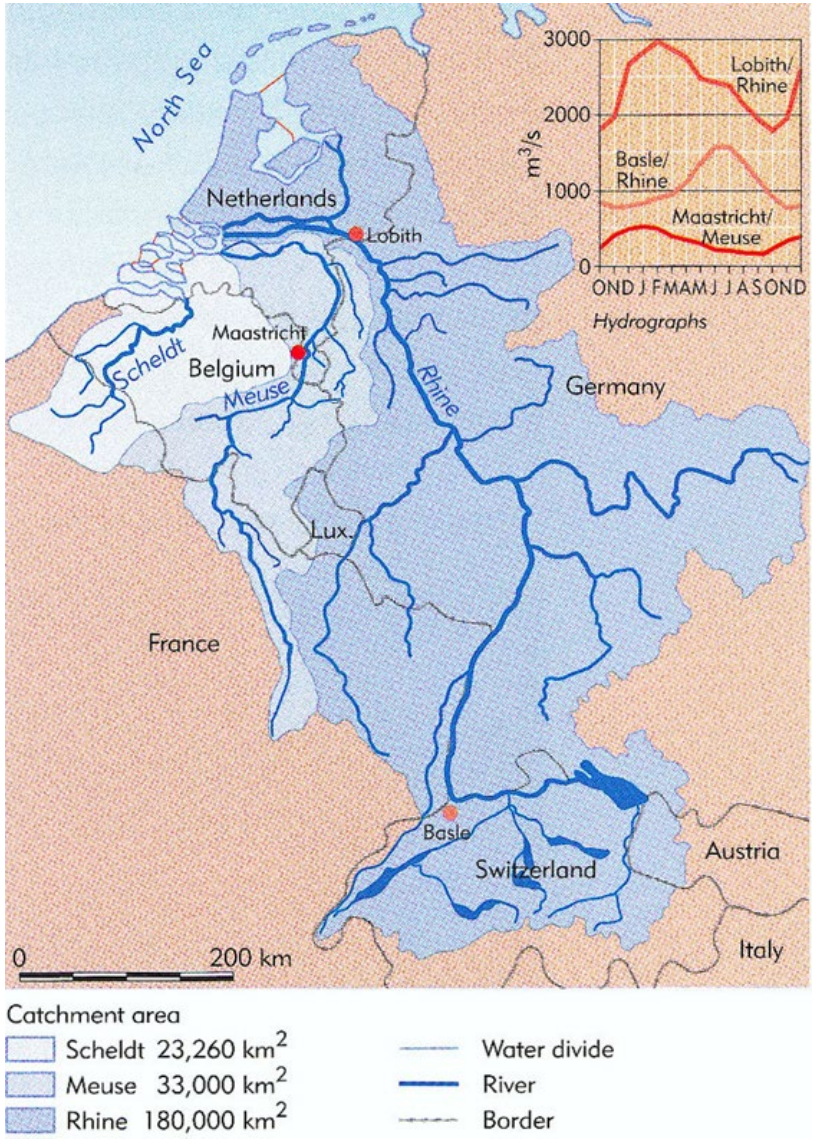
Het gaat om:

- voldoende zoetwater,
- van goede kwaliteit,
- op het juiste moment,
- op de juiste locatie,
- en betaalbaar.

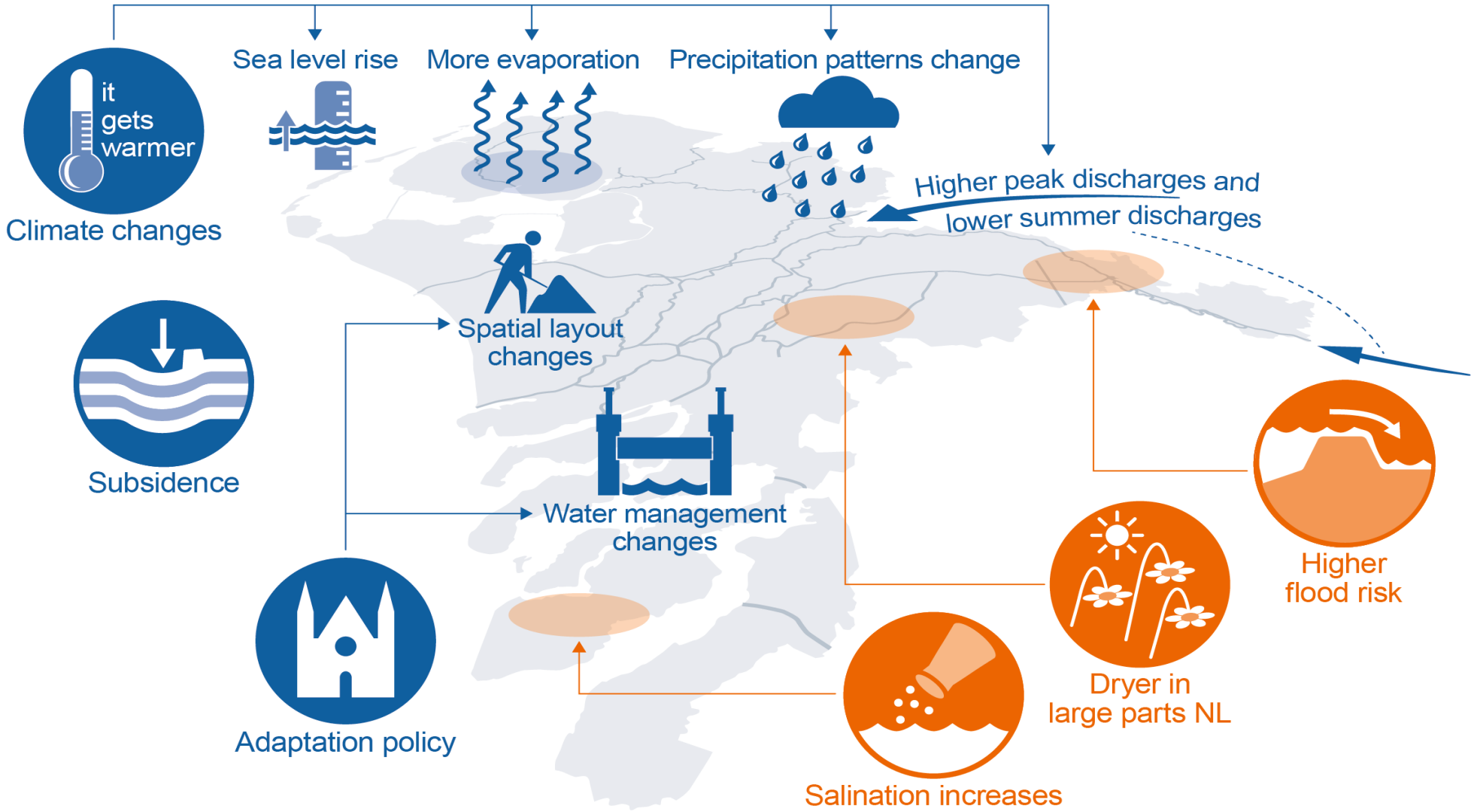
Uit: Mens, M. J. P., Pouwels, J., Weiler, O., Delsman, J. R., & Huismans, Y. (2024). De zoetwaterbalans van laag Nederland in een warmer klimaat. Deltares Report 11210362-000-ZWS-0001, 35.

Wateraanvoer voornamelijk uit de Rijn





Maar de toekomst is onzeker



Kwantificeren zoetwaterbeschikbaarheid met Nationaal Water Model

1. Nationaal Water Model -> Landelijk Hydrologisch Instrumentarium

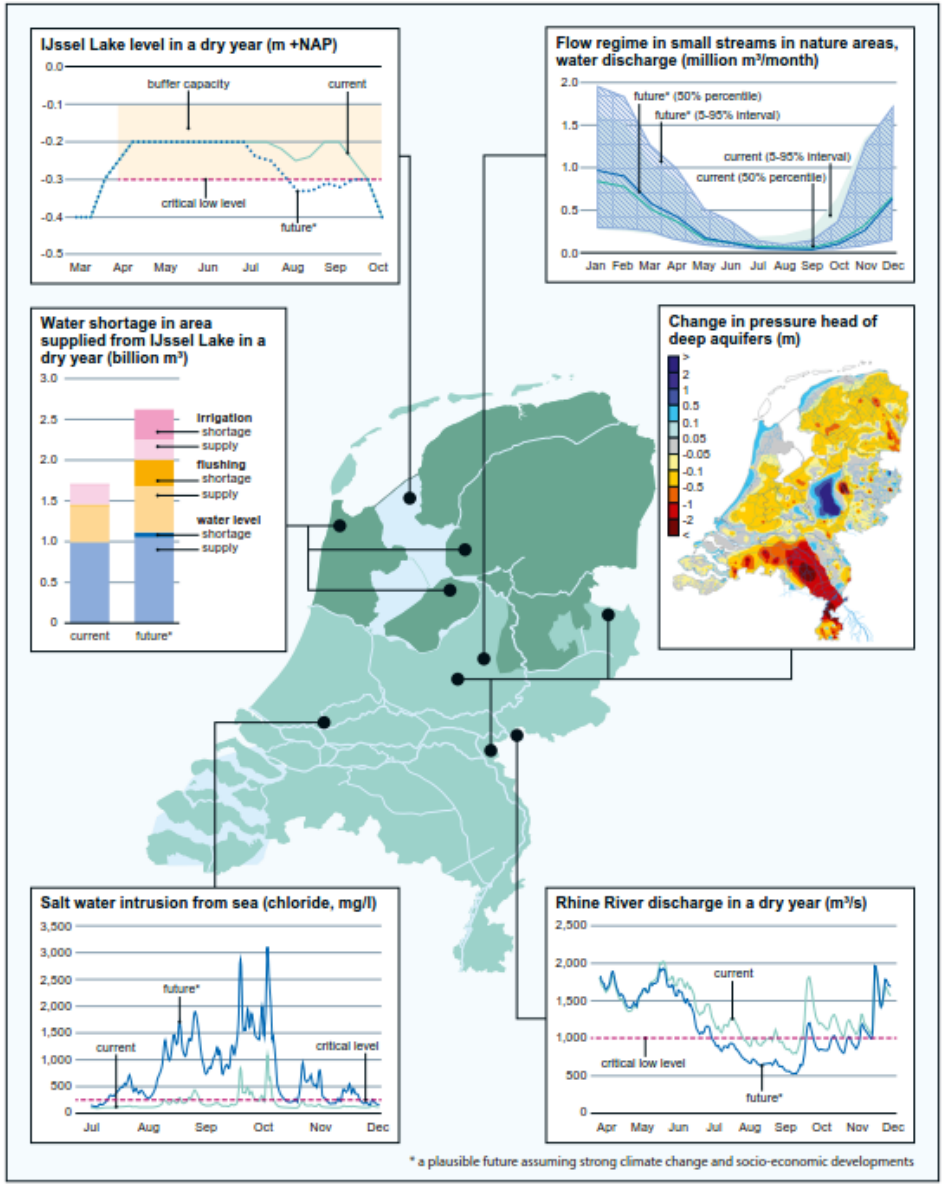
   Ingezet voor Delta programma Zoetwater,

   Kennisprogramma Zeespiegelstijging

2. Regionale modellen, bijv. Zeeland model, voor lokale vraagstukken

   Inzet voor regionale vraagstukken, bijv. evaluatie

   onttrekkingsregels Zeeland



Rijkswaterstaat
Ministry of Infrastructure and the Environment

NHI

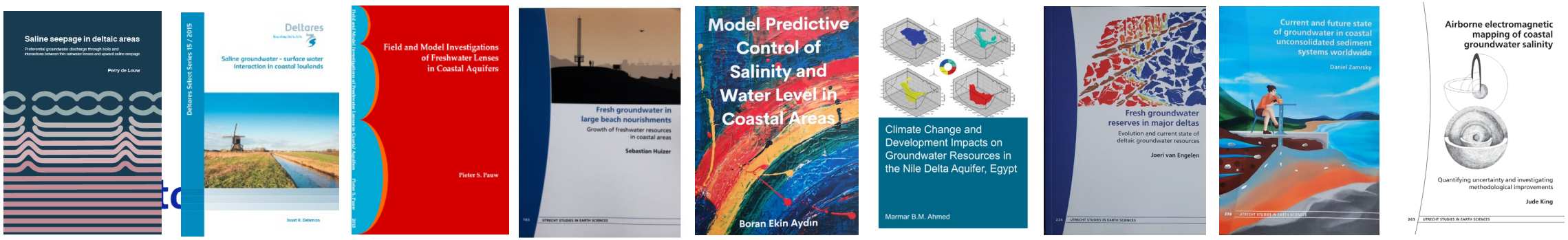
Deltares ARCADIS

Kennisontwikkeling over grondwater processen in het kustgebied

PhD research within research programs and with universities (UU, WUR, VU, TUD):

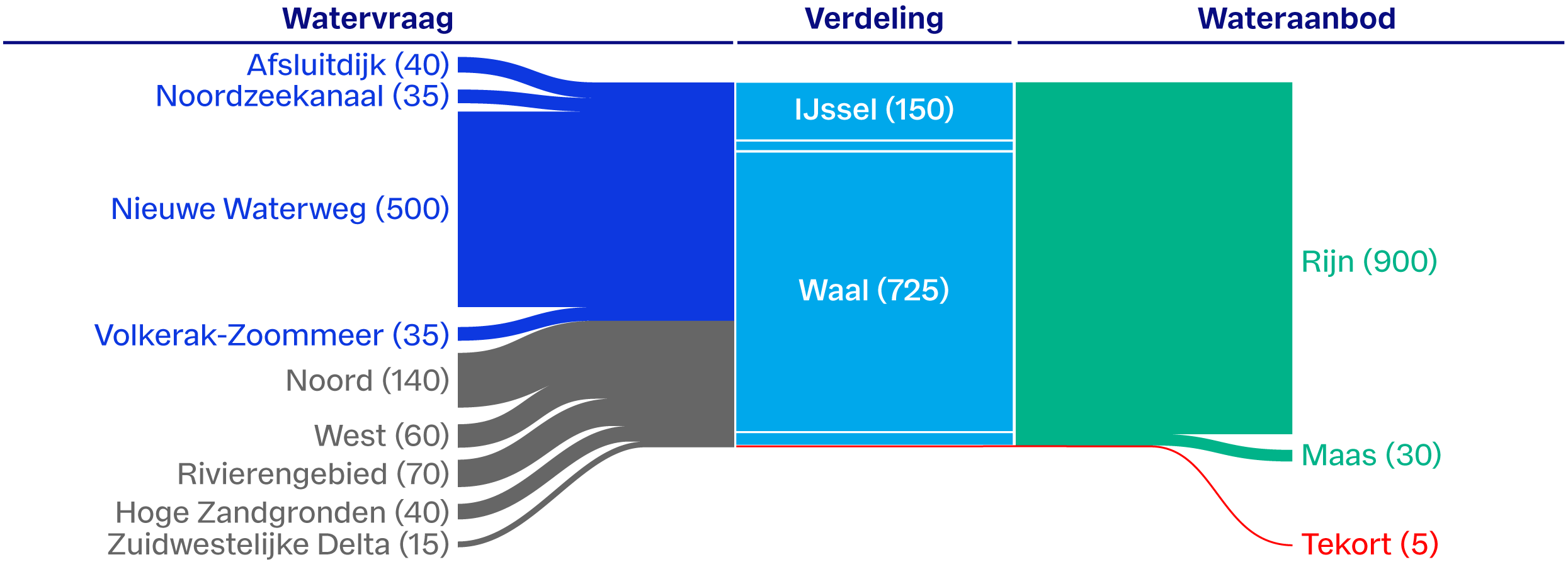
- Salt seepage in deltas; preferential seepage via wells and interactions between thin rainwater lenses and saline seepage (De Louw, 2013)
- Field and model investigations of freshwater lenses in coastal aquifers (Pauw, 2015)
- Interaction of saline groundwater with surface water in low-lying coastal areas (Delsman, 2015)
- Fresh groundwater in large sand nourishments; Growth of freshwater resources in coastal areas (Huizer, 2019)
- Model Predictive Control of Water Level and Salinity in Coastal Areas (Aydin, 2020)
- Climate Change and Development Impacts on Groundwater Resources in the Nile Delta Aquifer, Egypt (Mabrouk, 2020)
- Fresh groundwater reserves in major deltas (Van Engelen, 2020)
- Current and future state of groundwater in coastal unconsolidated sediment systems worldwide (Zamrsky, 2021)
- Airborne electromagnetic mapping of coastal groundwater salinity (King, 2022)

Proefschriften hier te vinden: http://freshsalt.deltares.nl/



Waterbalans in droge zomer in huidige klimaat

Deltares



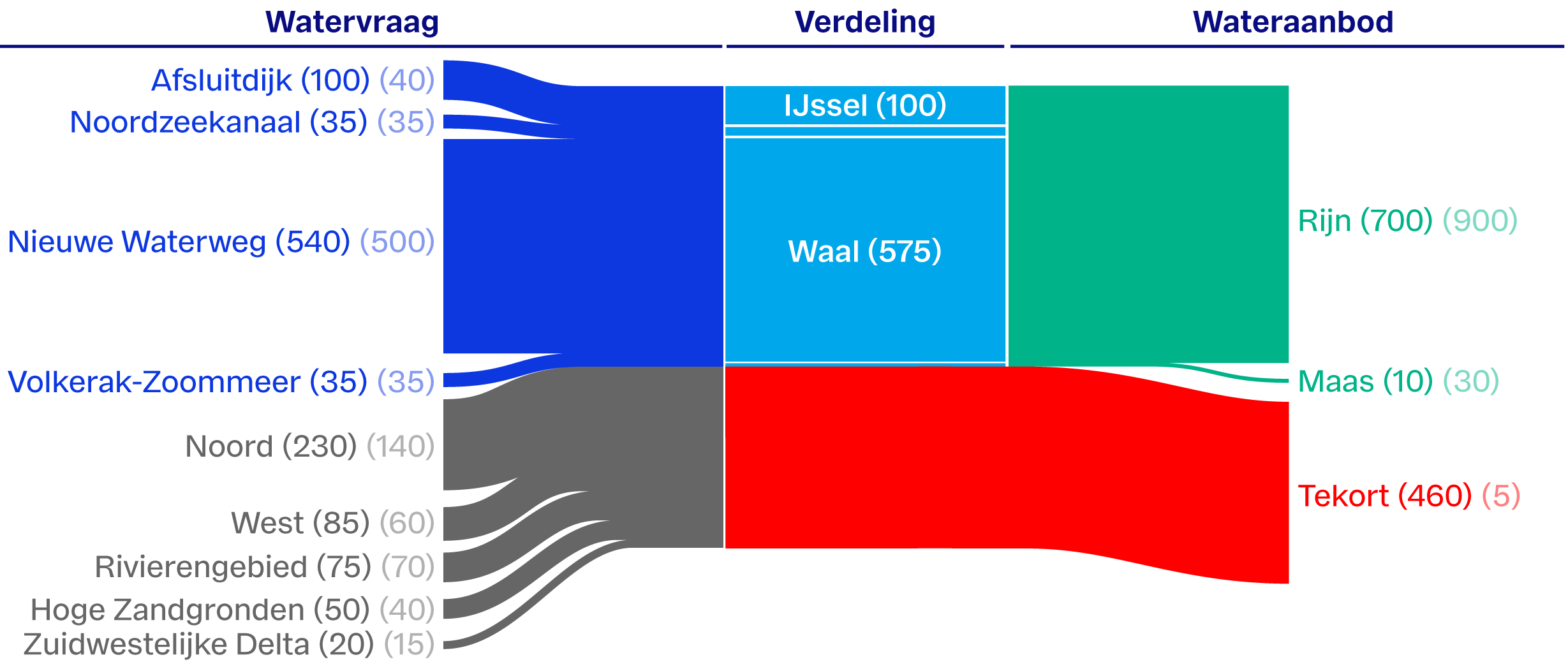
Sommige termen in de waterbalans zijn zeer onzeker en vragen om nader onderzoek

(Mens et al., 2024)

Alle getallen zijn in m^3/s gemiddeld over een droge zomermaand

Waterbalans bij 2º opwarming en 0,4 m zeespiegelstijging

Deltares



Sommige termen in de waterbalans zijn zeer onzeker en vragen om nader onderzoek

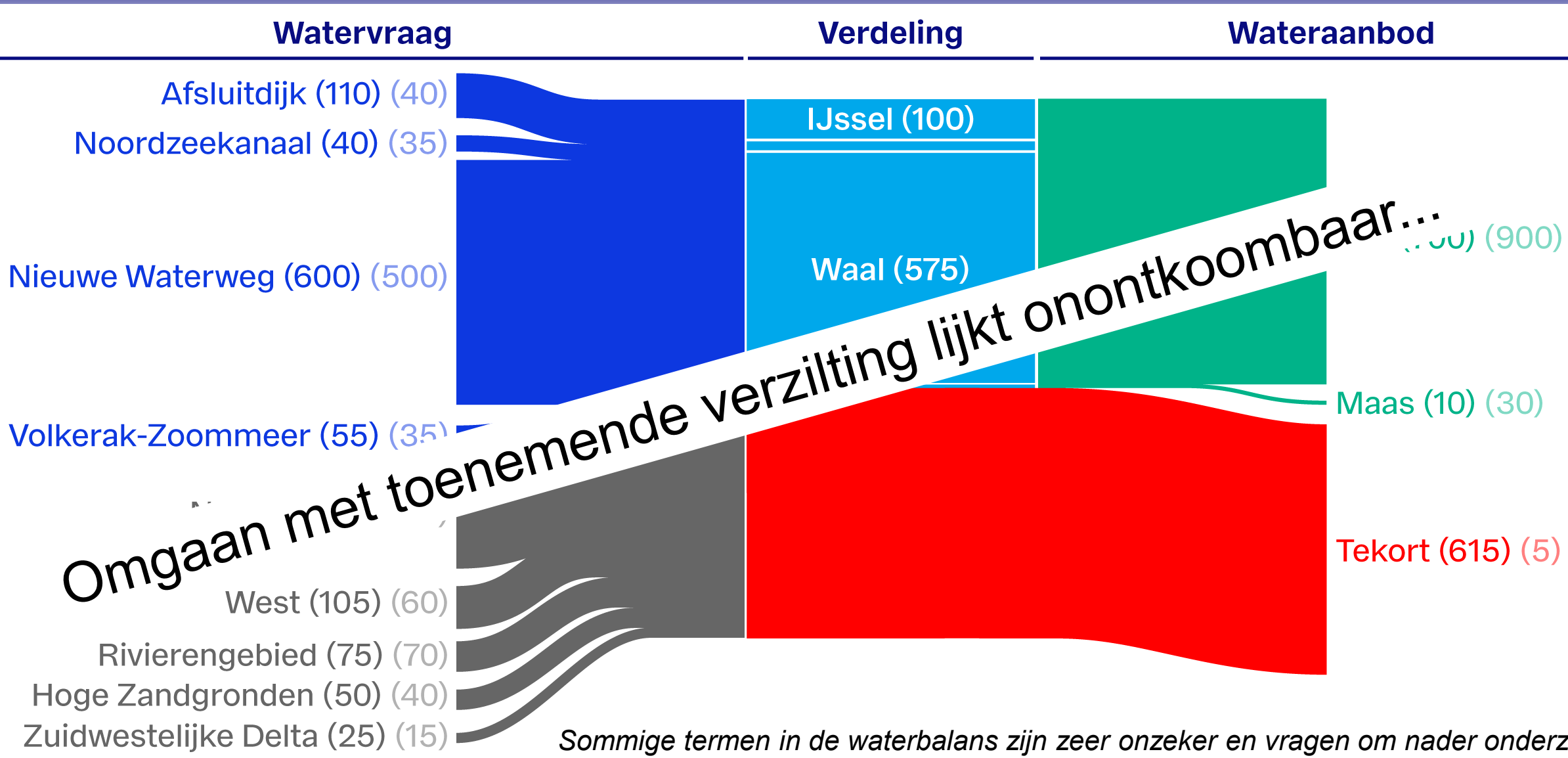
(Mens et al., 2024)

Huidige waarden in lichte kleuren

Alle getallen zijn in m^3/s gemiddeld over een droge zomermaand

Waterbalans bij 2º opwarming en 1 m zeespiegelstijging

Deltares



Sommige termen in de waterbalans zijn zeer onzeker en vragen om nader onderzoek

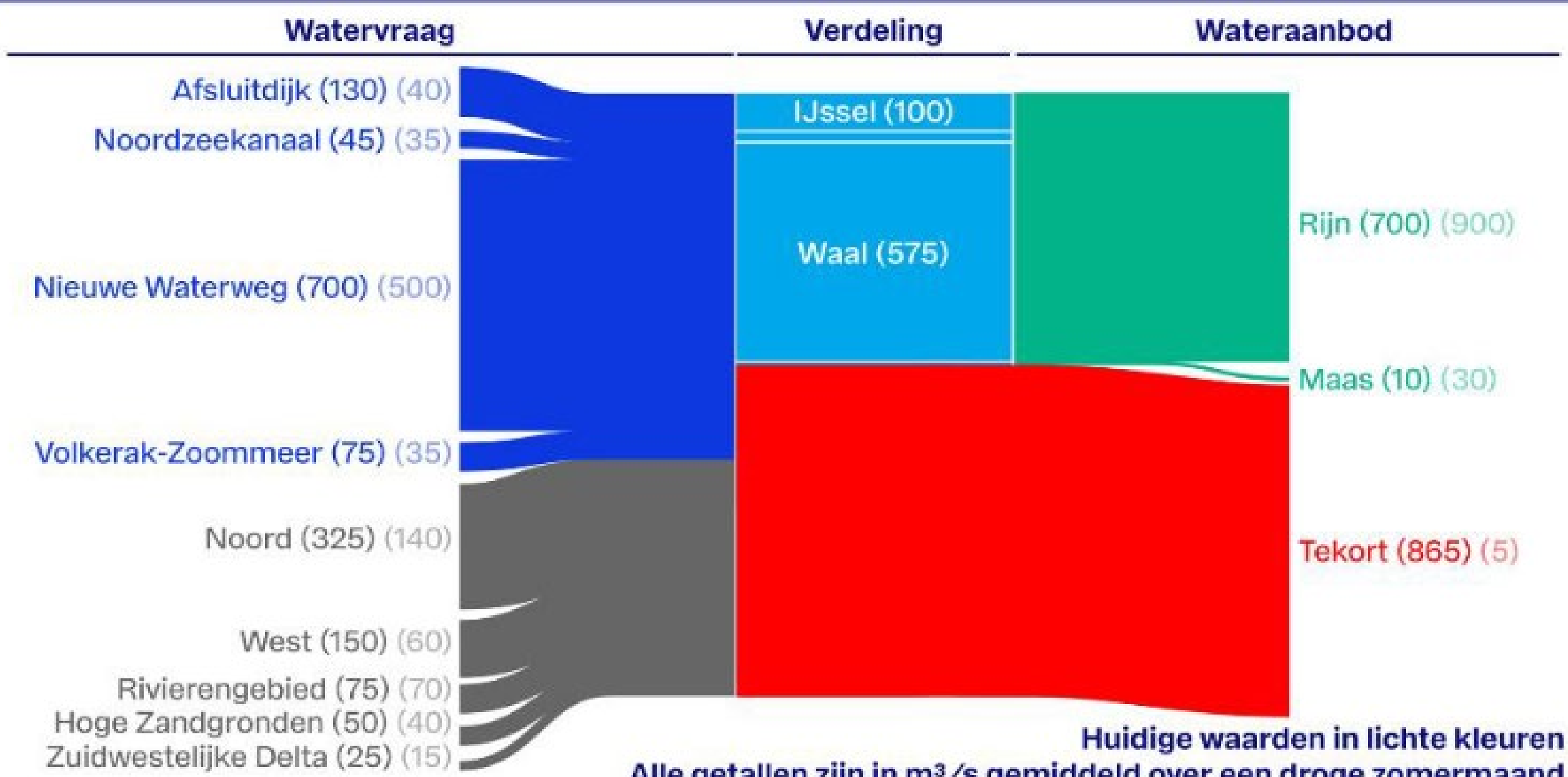
(Mens et al., 2024)

Huidige waarden in lichte kleuren

Alle getallen zijn in m^3/s gemiddeld over een droge zomermaand

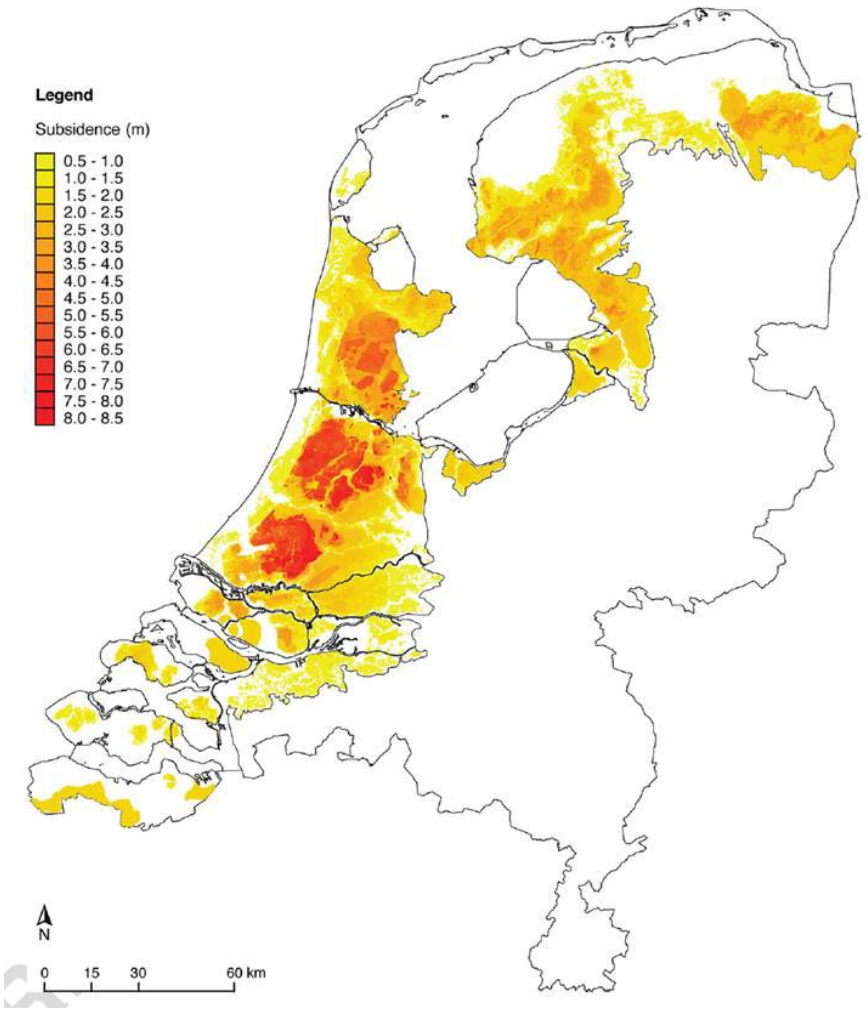
Waterbalans bij 2º opwarming en 2 m zeespiegelstijging

Deltares

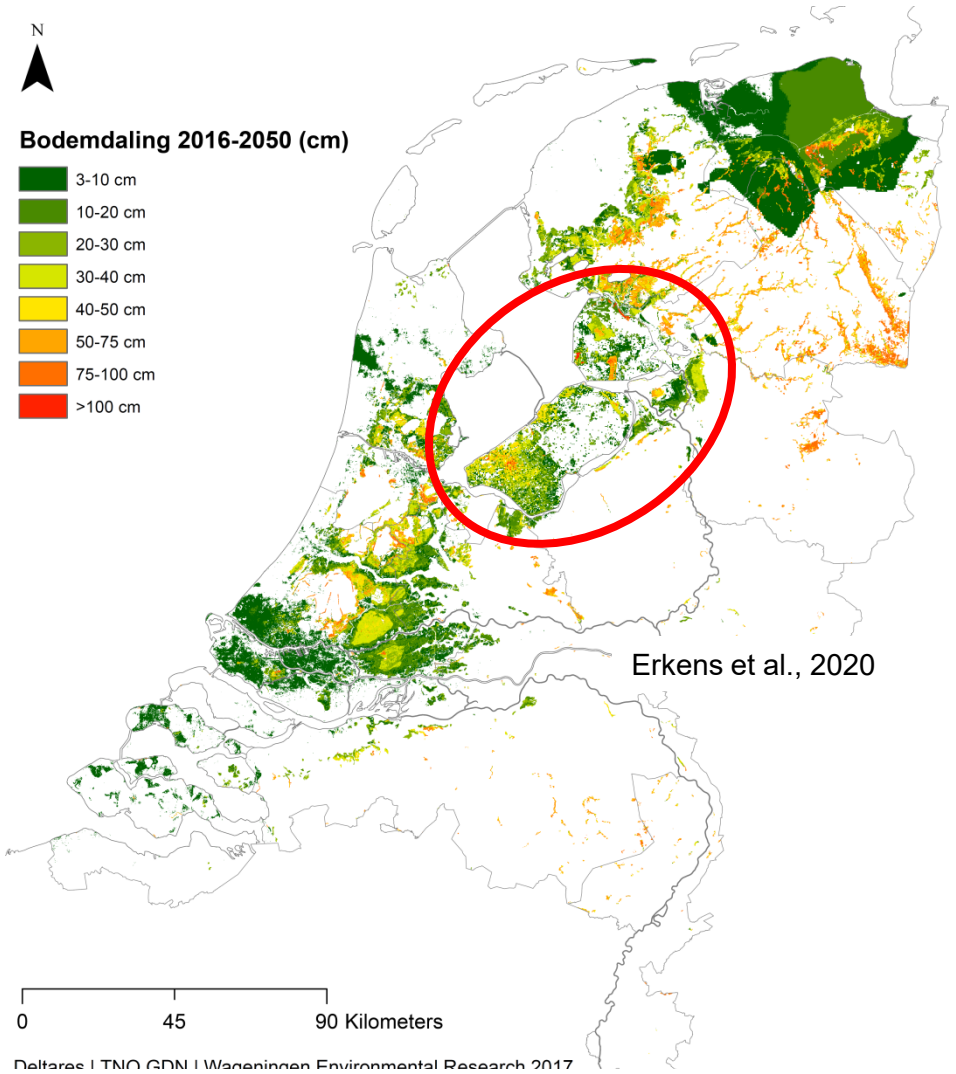


Bodemdaling:
het gaat niet vanzelf weg en vraagt om zoet water….

AFGELOPEN 1000 JAAR



KOMENDE DECENNIA



Erkens et al., 2020



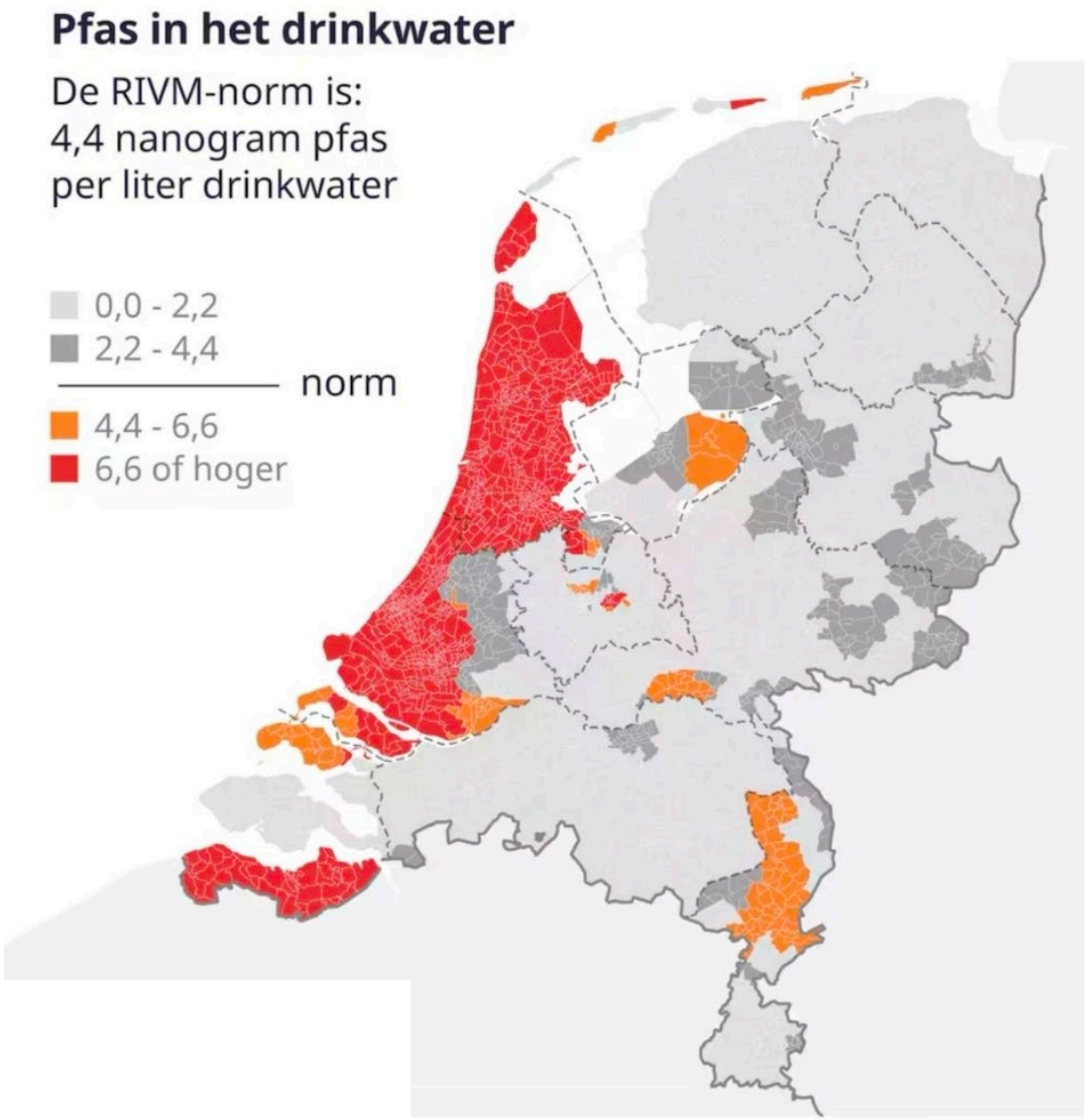




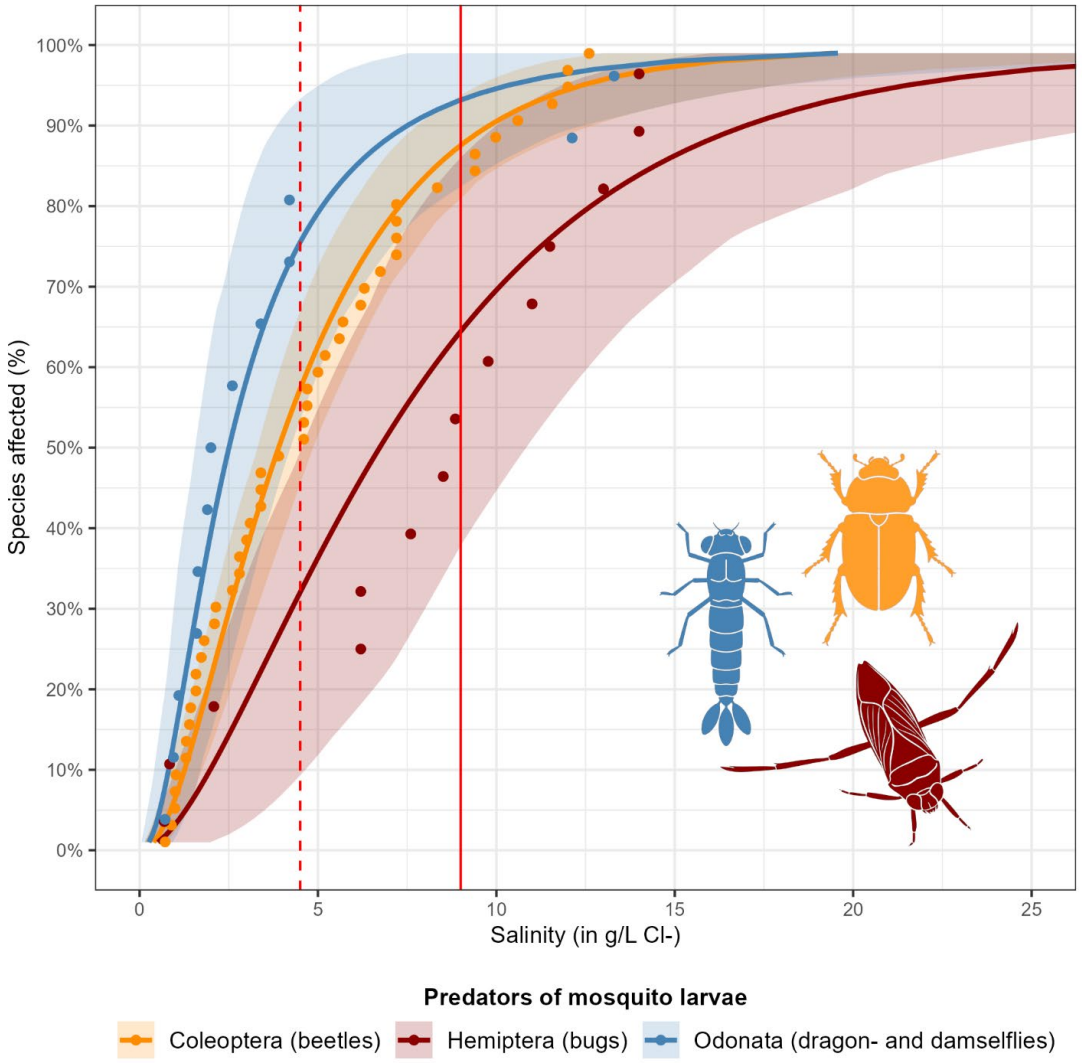


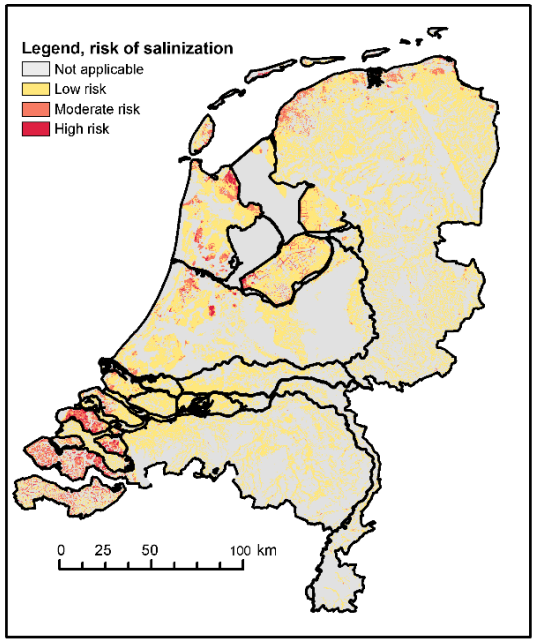
Hunink, J.C., Schasfoort, F., Pouwels, J., Mens, M.J.P., 2021. Het effect van onderwaterdrainage en passieve peilstijging in veenweidegebieden op knelpunten in de zoetwatervoorziening. Deltares Rapport. 11205271-007-ZWS-0001. link

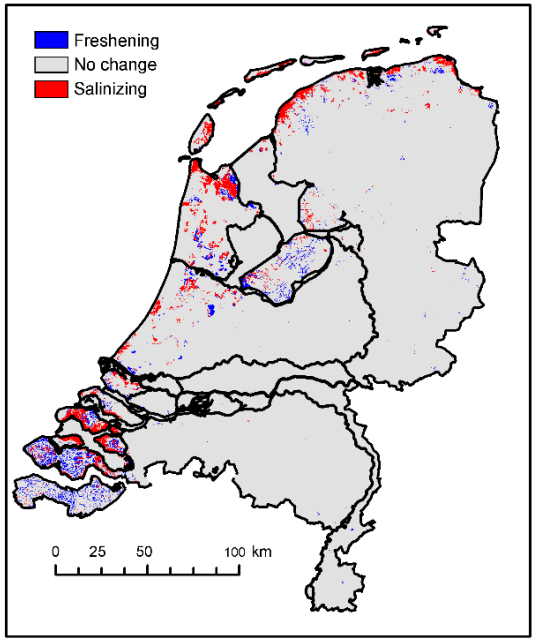
Verontreinigingen



Verzilting beïnvloedt het risico op door muggen overgedragen ziekten.

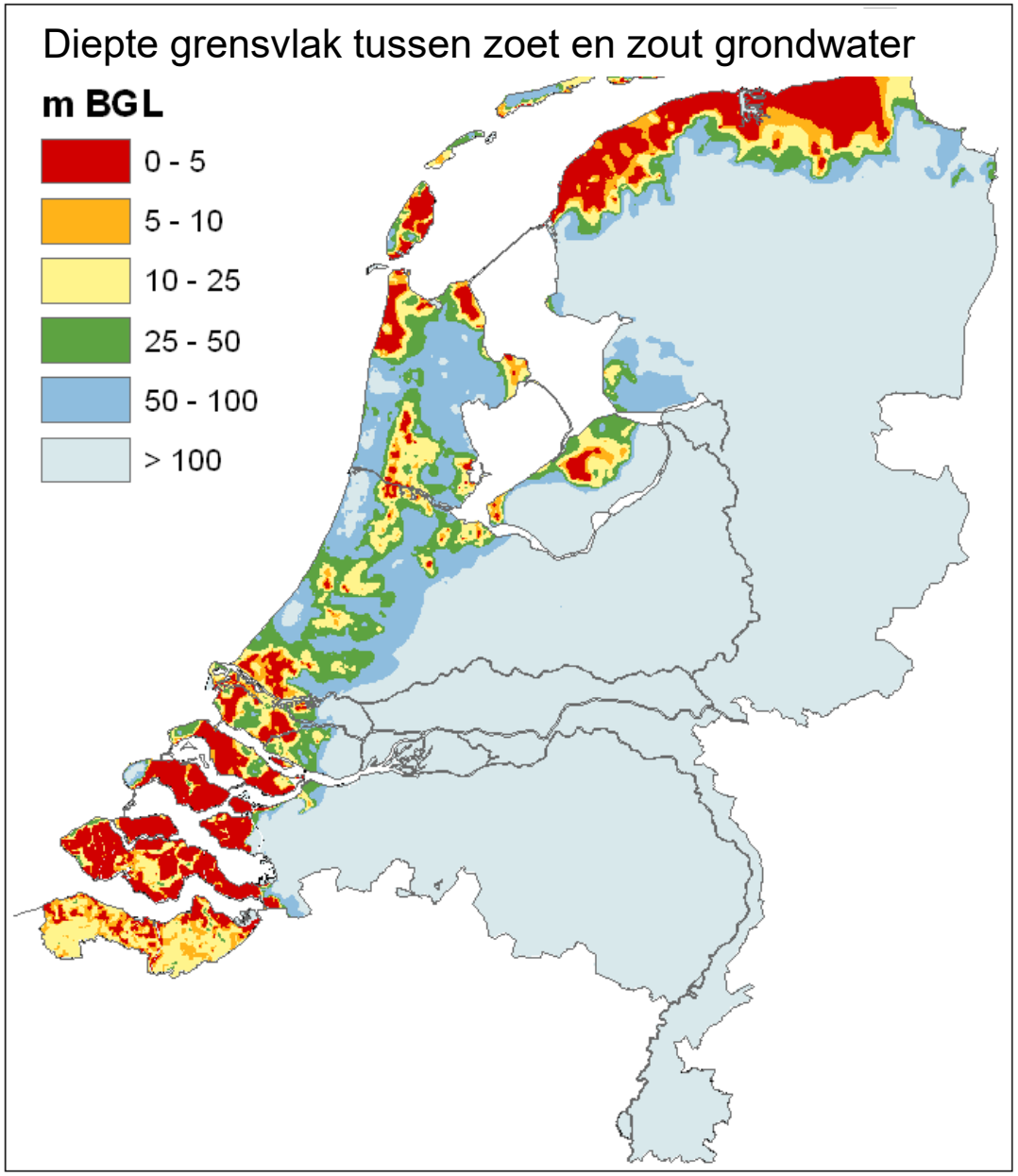


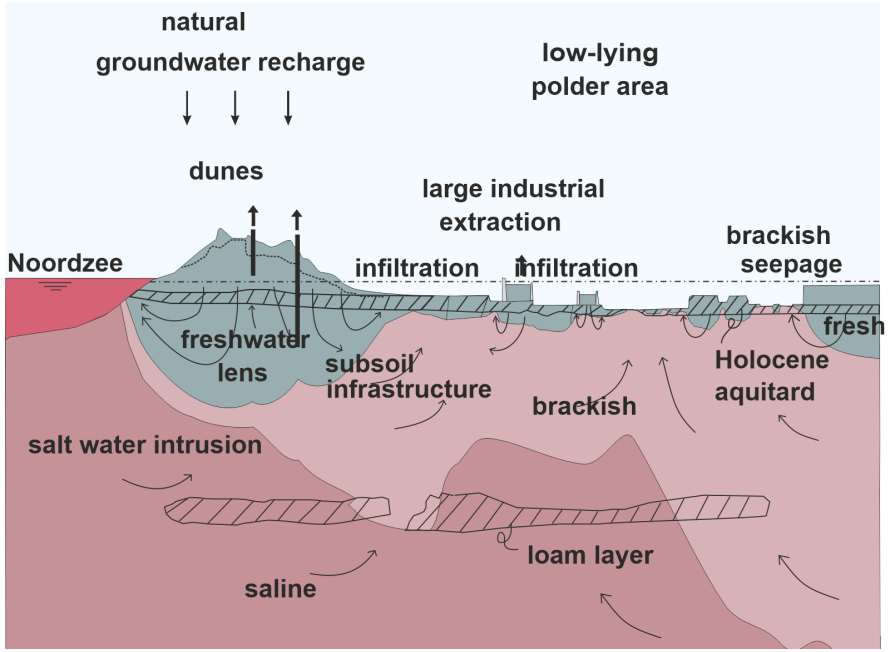


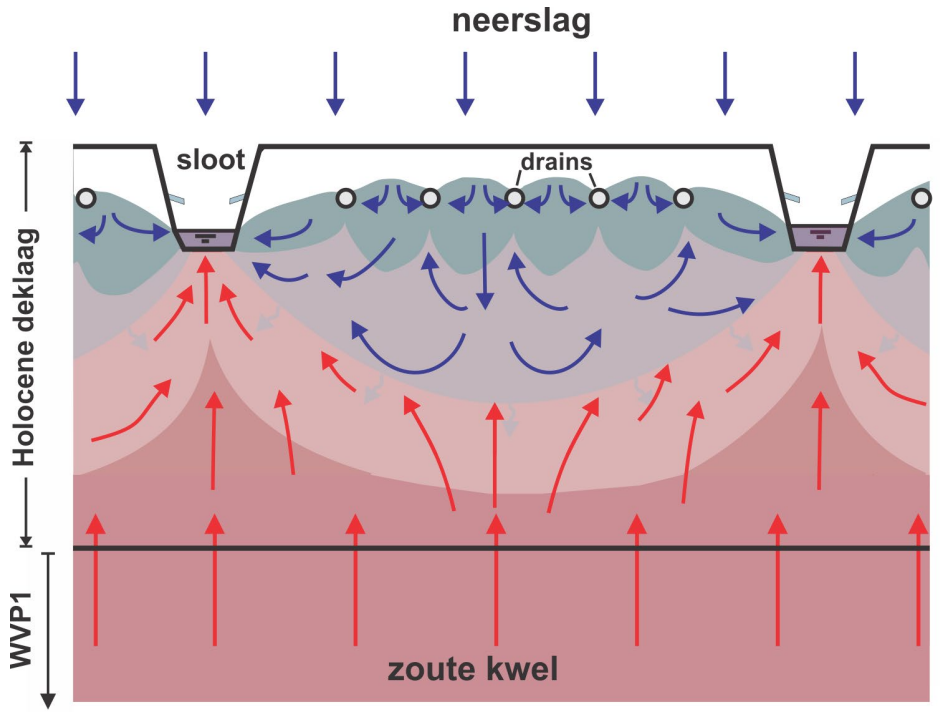


Soortgevoeligheidsverdelingen voor 3 belangrijke groepen van muggenpredatoren, gebaseerd op hun bovengrens voor zouttolerantie zoals afgeleid uit veldwaarnemingen in de kustprovincies van Nederland.

Kans op grondwaterverzilting in kustgebied



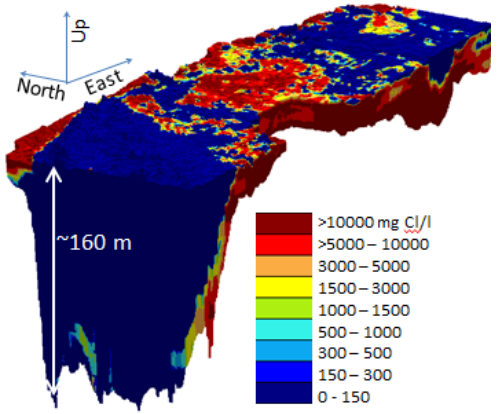


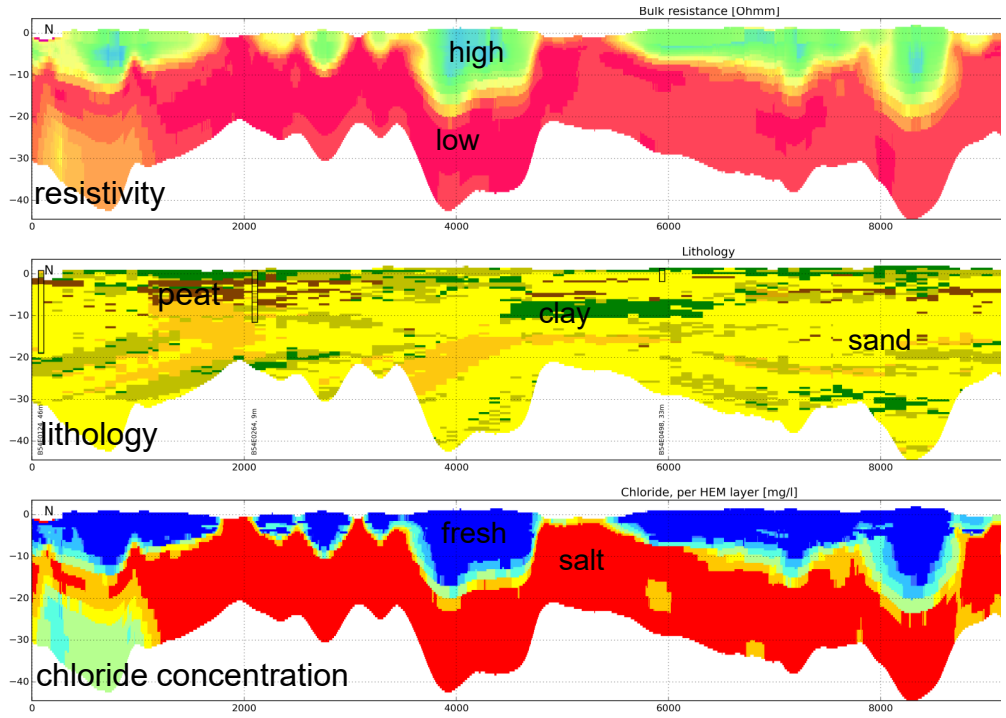


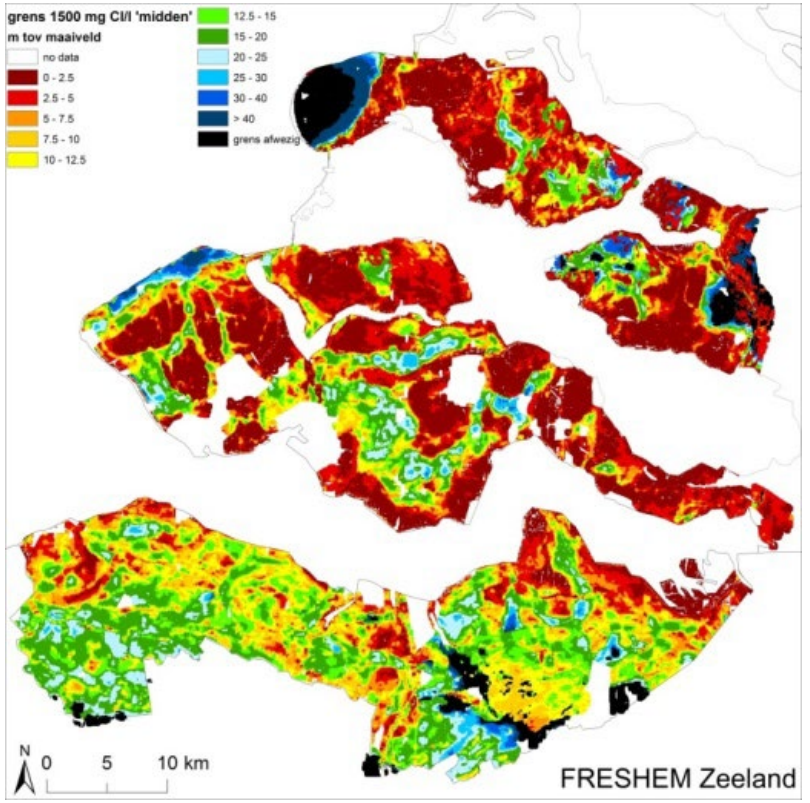
Karteren zoet-zout grondwater: FRESHEM Zeeland, en NL in-spe

Link naar de kaarten! https://kaarten.zeeland.nl/map/freshem#







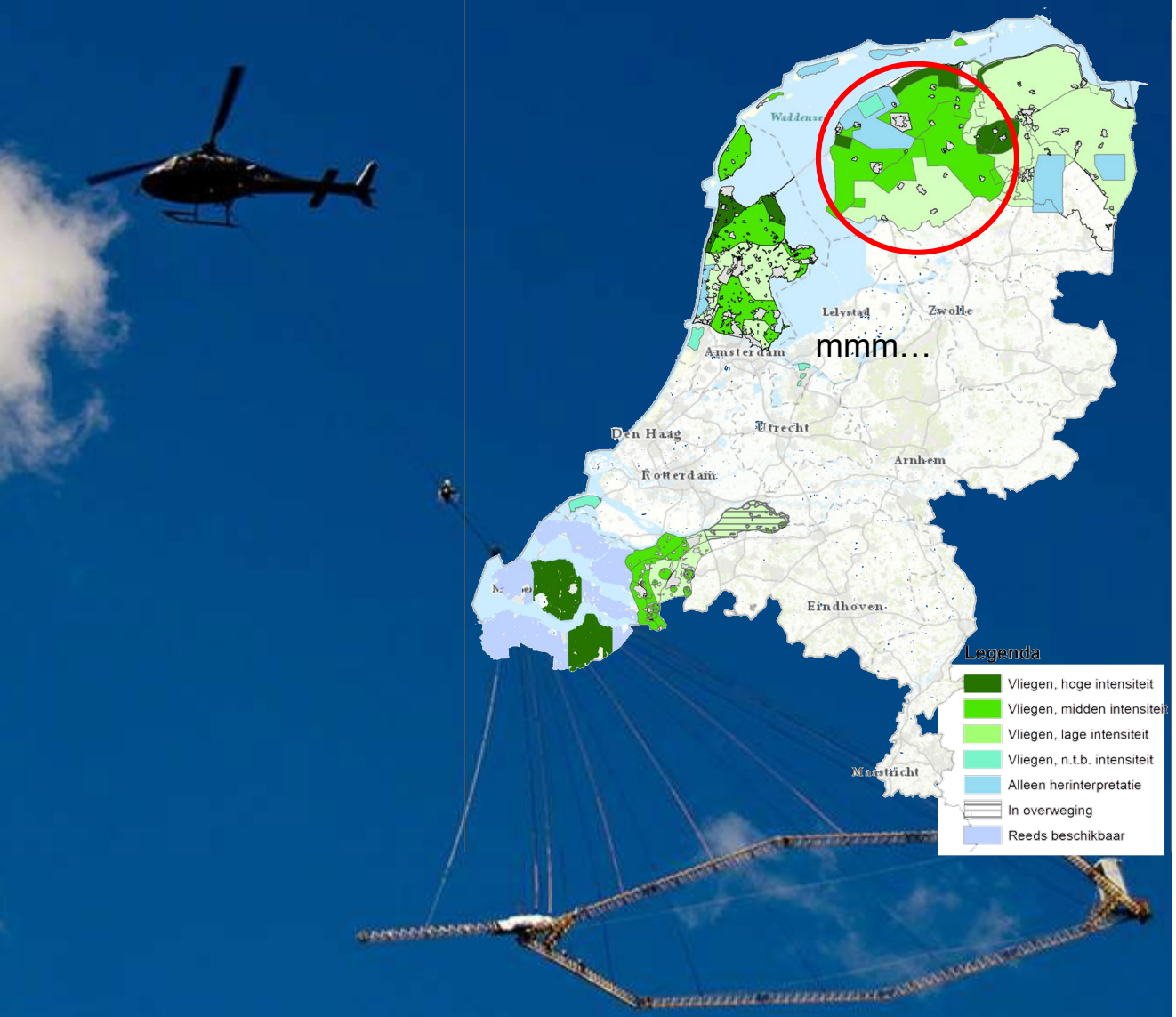






Delsman, et al., 2018. Large-scale, probabilistic salinity mapping using airborne electromagnetics for groundwater management in Zeeland, the Netherlands. Environ. Res. Lett. 13, 13. https://doi.org/10.1088/1748-9326/aad19e

TNO innovation for life BGR Deltares



FRESHEM

3D kartering van zoutgehalte grondwater

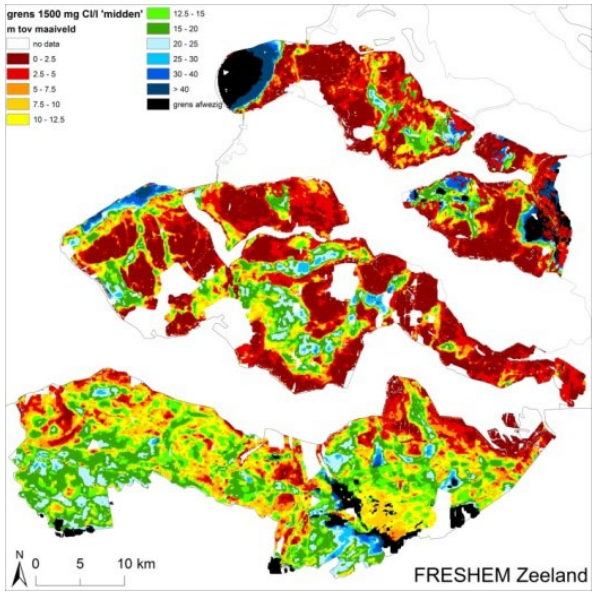
Methode:
Combinatie van helicoptermetingen met data en kennis over ondergrond en processen in zoet/zout grondwater

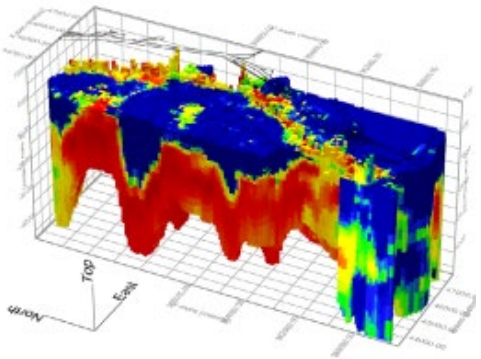
Tweeledig doel kartering

- Gedetailleerd 3-D beeld van zoutgehalte grondwater
- Geologie (scheidende lagen) in zoete gebieden

Succesvol toegepast in Zeeland en Vlaanderen

Opzetten nationale toepassing:
Kartering van grote delen laag Nederland met provincies, waterschappen, drinkwaterbedrijven, TNO & financiering Deltafonds





IOP Publishing Environ. Res. Lett. 13 (2018) 084011 https://doi.org/10.1088/1748-9326/aad19e

Environmental Research Letters

LETTER

Large-scale, probabilistic salinity mapping using airborne electromagnetics for groundwater management in Zeeland, the Netherlands

Joost R Delsman[1,6], Esther S van Baaren[1], Bernhard Siemon[2], Willem Dabekaussen[3], Marios C Karaoulis[1], Pieter S Pauw[1], Tommer Vermaas[1], Huite Bootsma[1], Perry G B de Louw[1], Jan L Gunnink[3], C Wim Dubelaar[3], Armin Menkovic[3], Annika Steuer[2], Uwe Meyer[2], André Revil[4] and Gualbert H P Oude Essink[1,5]

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Keywords: airborne electromagnetics, groundwater salinity, fresh groundwater management, uncertainty

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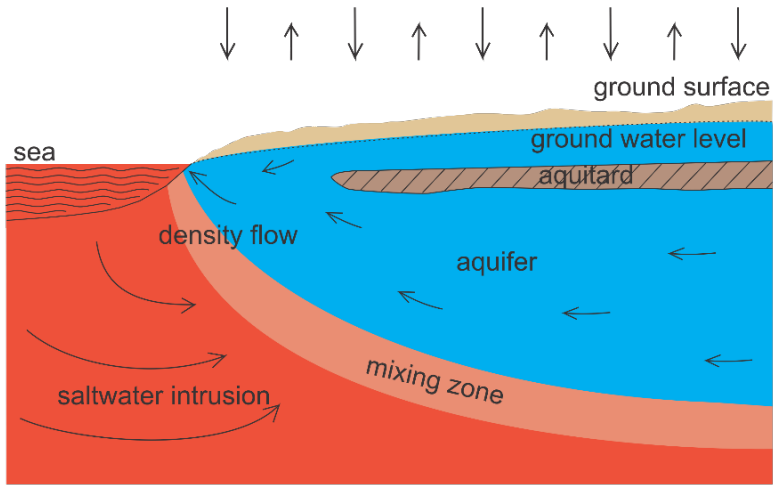
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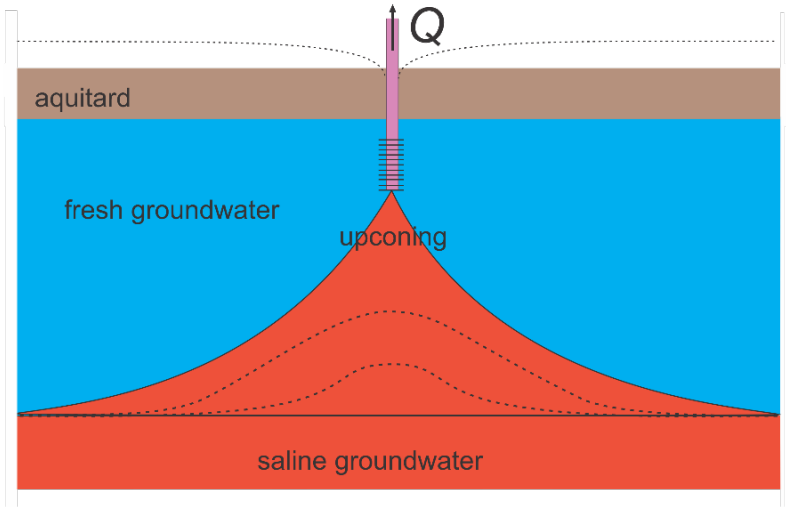
Any further distribution

Verziltingsprocessen in het grondwater systeem

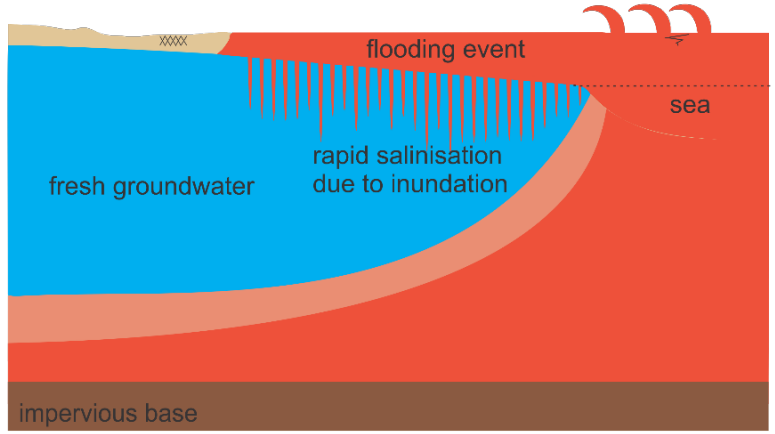
Zoutwaterintrusie



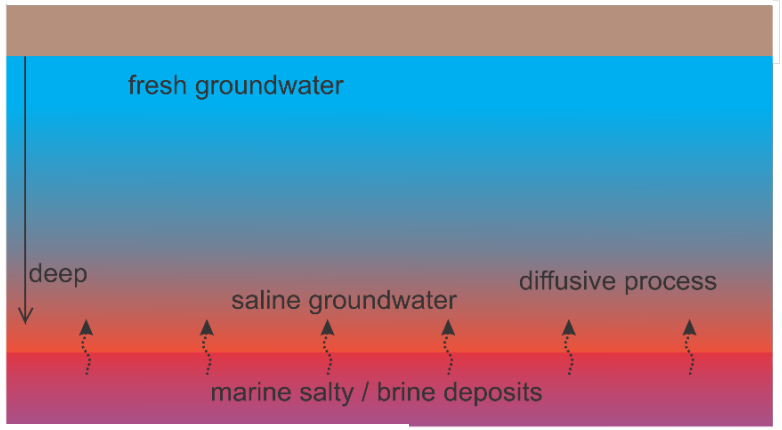
Opkegeling onder onttrekking



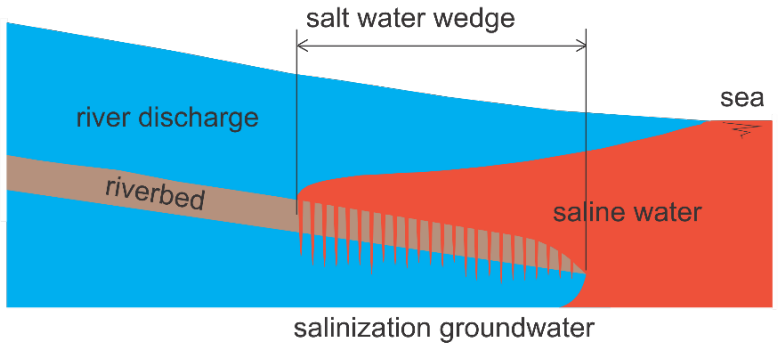
Inundatie zeewater bij overstroming



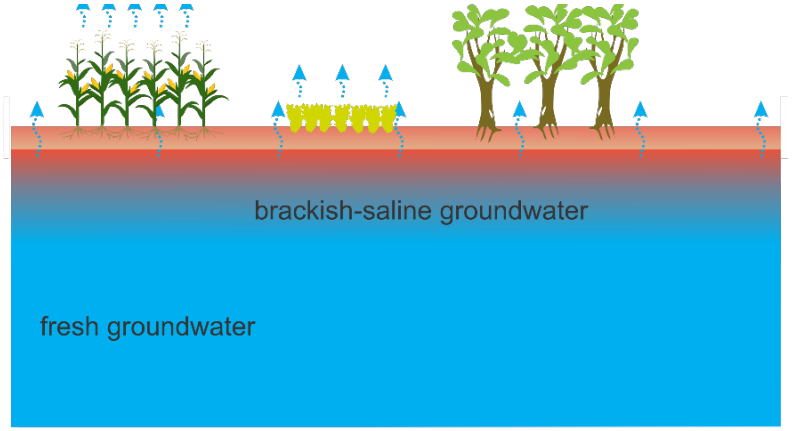
Verzilting door marine afzettingen



Zoutwater intrusie oppervlaktewater

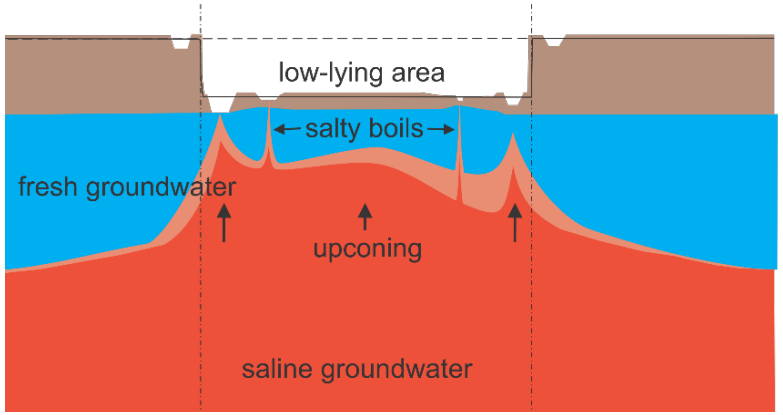


Zoutophoping door verdamping

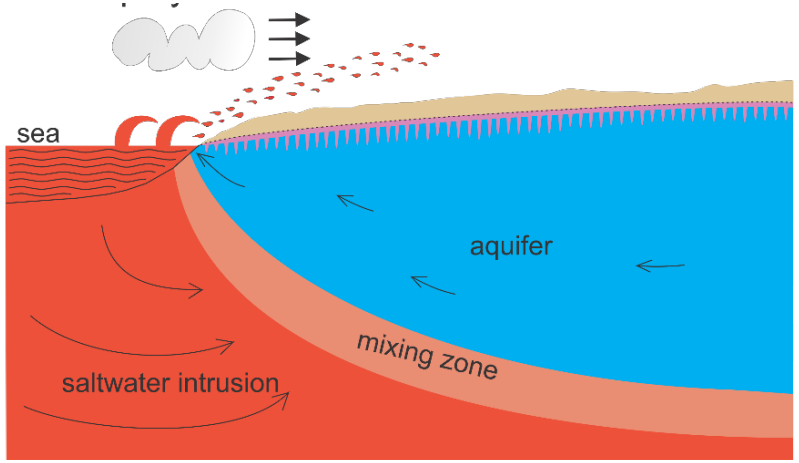


Verziltingsprocessen in het grondwater systeem

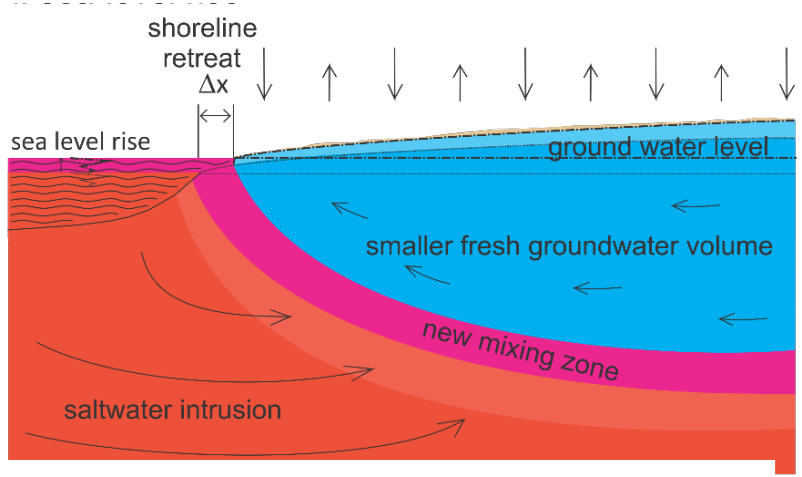
Opkegeling zout onder polders



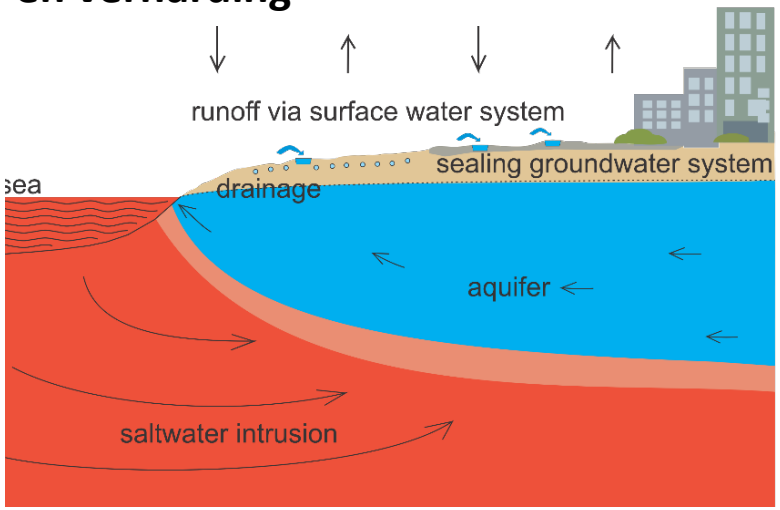
Sea spray



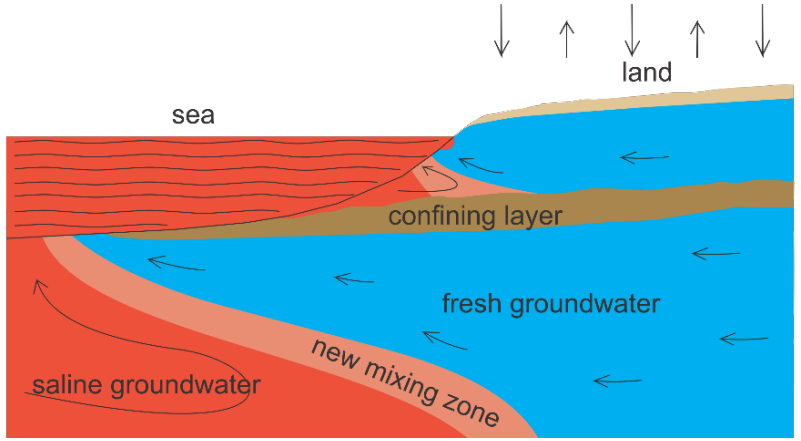
Zeespiegelstijging



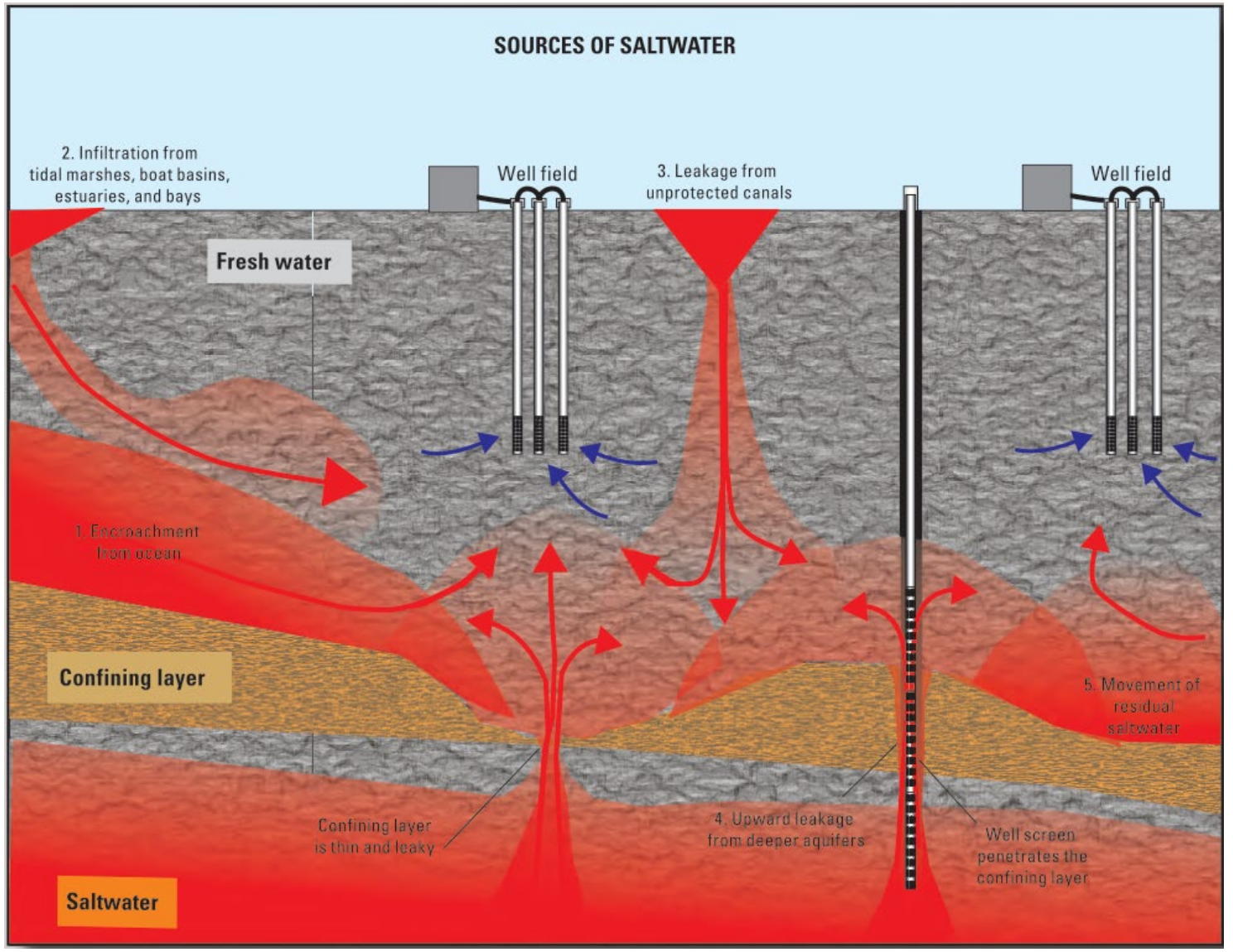
Afname grondwateraanvulling en verharding



Submarine Groundwater Recharge

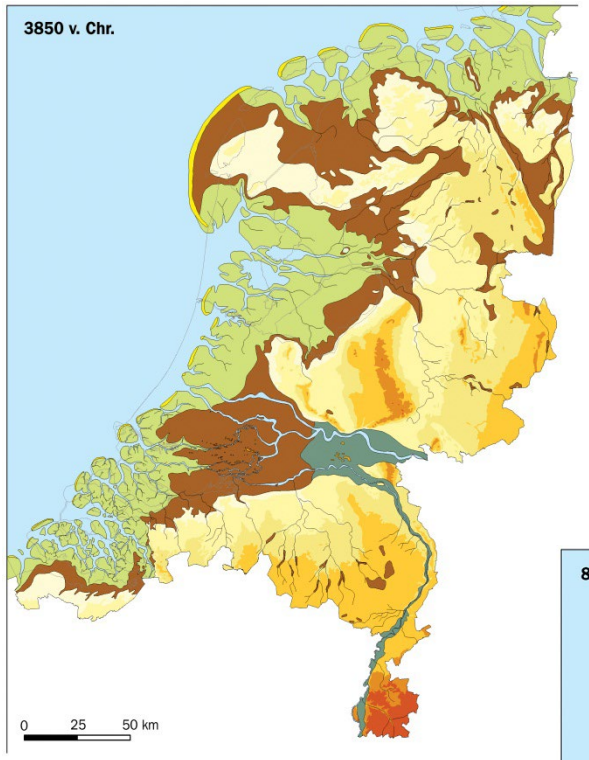


De praktijk: waar komt het zout vandaan?

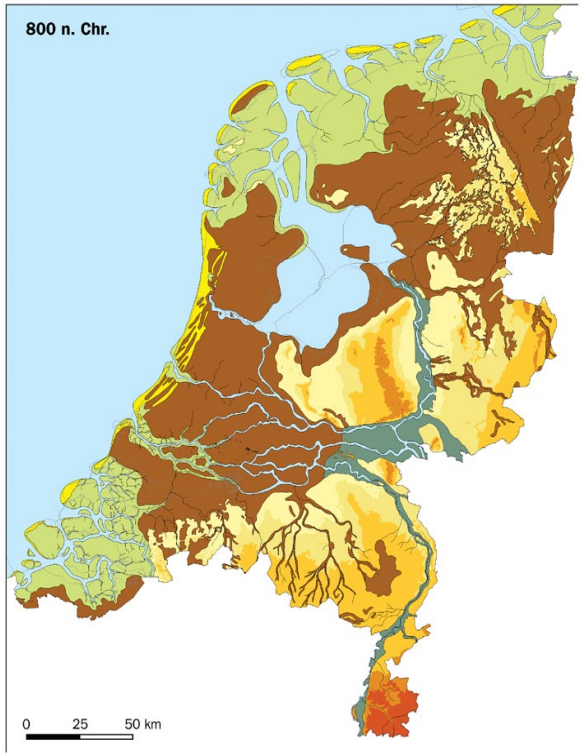


Bron: Prinos, S.T., 2013. USGS, Report 2013–1088.

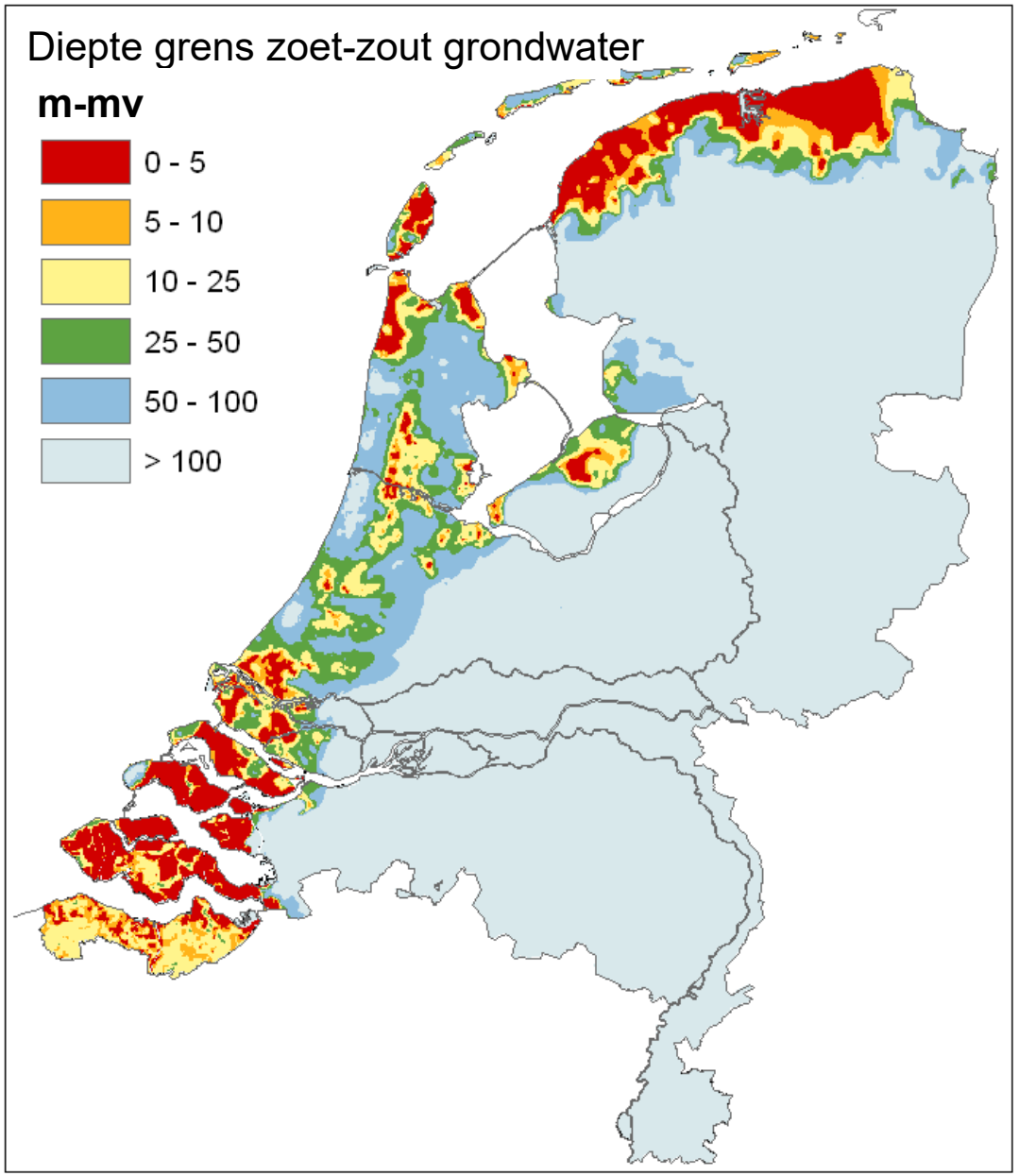
Waar komt het zout vandaan?



5500 jaar geleden
Maximale zee-invloed



1200 jaar geleden
Meeste recente zeeinvloed



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Hydrol. Earth Syst. Sci., 18, 3891–3905, 2014
www.hydrol-earth-syst-sci.net/18/3891/2014/
doi:10.5194/hess-18-3891-2014
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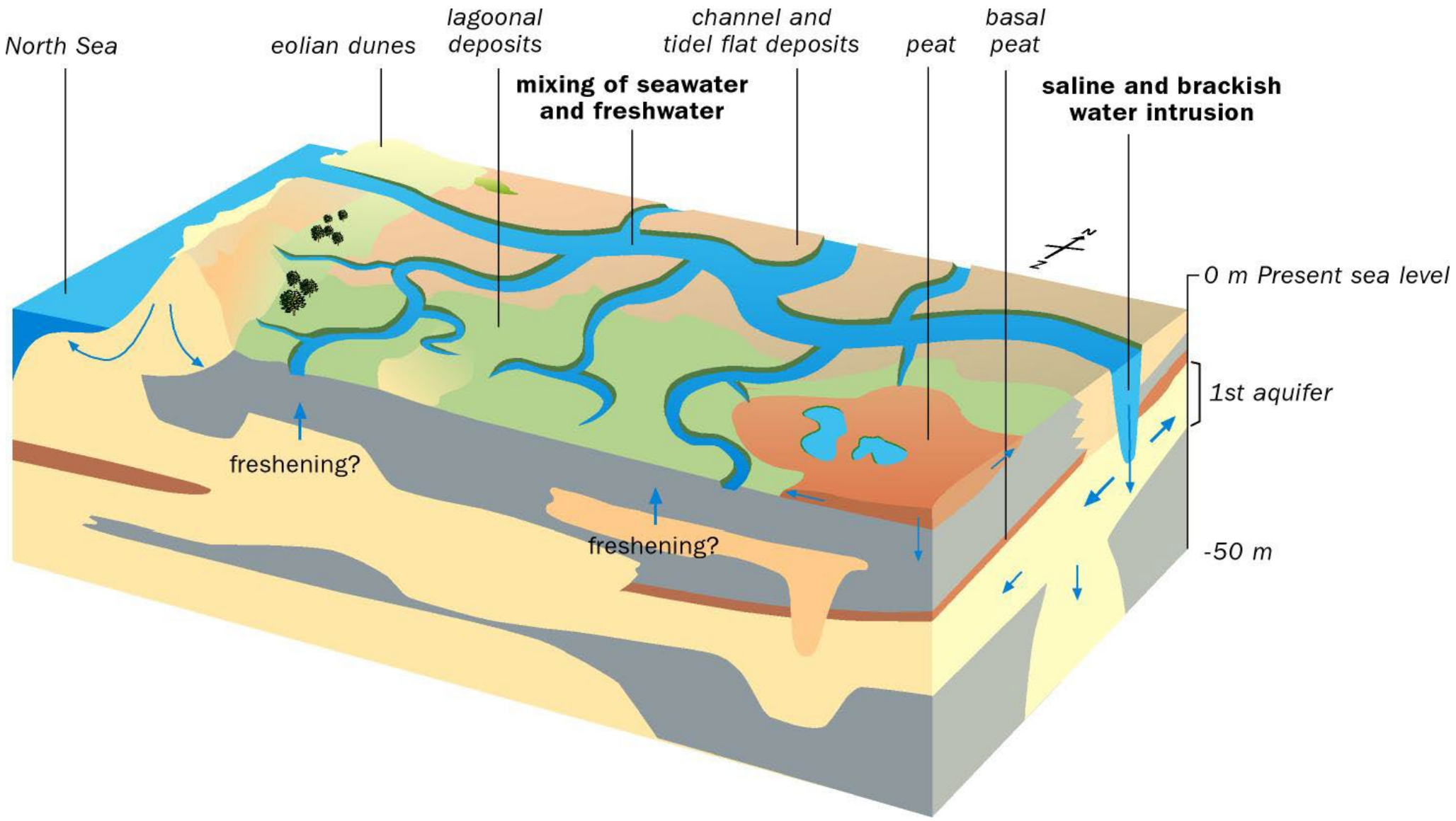
Paleo-modeling of coastal saltwater intrusion during the Holocene: an application to the Netherlands

J. R. Delsman[1,2], K. R. M. Hu-a-ng[1,3,*], P. C. Vos[1], P. G. B. de Louw[1], G. H. P. Oude Essink[1,3], P. J. Stuyfzand[2,4], and M. F. P. Bierkens[1,3]

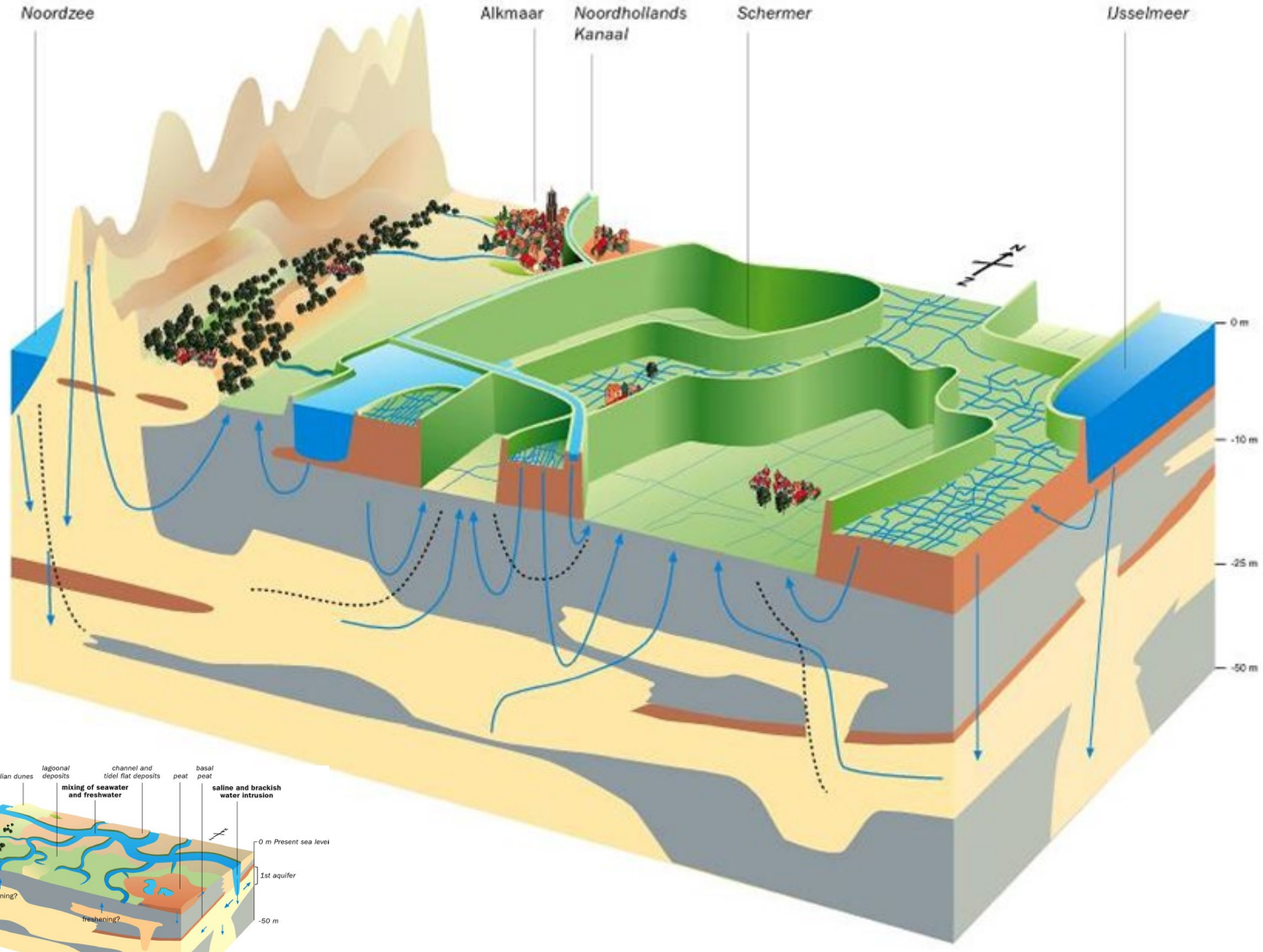
[1]Unit Subsurface and Groundwater Systems, Deltares, P.O. Box 85467, 3508 AL Utrecht, the Netherlands
[2]Critical Zone Hydrology Group, Department of Earth Sciences, VU University Amsterdam, De Boelelaan 1085, 1081 HV Amsterdam, the Netherlands
[3]Department of Physical Geography, Utrecht University, P.O. Box 80.115, 3508 TC Utrecht, the Netherlands
[4]KWR Watercycle Research Institute, P.O. Box 1072, 3430 BB Nieuwegein, the Netherlands
[*]now at: Acacia Water, Jan van Beaumontstraat 1, 2805 RN Gouda, the Netherlands

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Nederland in verleden, vóór menselijke invloeden (~4000 vChr.)



Het huidige grondwatersysteem in Nederland



Peilverlagingen in het verleden hebben grondwaterstromingen richting binnenland veroorzaakt

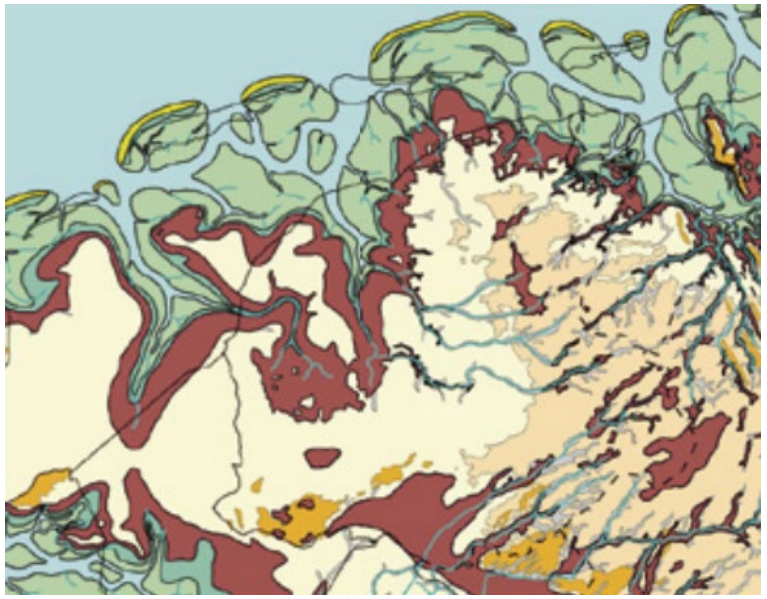
Historie (palaeohydrogeologie) belangrijk: grondwaterstroming is een traag proces

Het verleden heeft nog steeds invloed op de verdeling van zoet-brak-zout grondwater

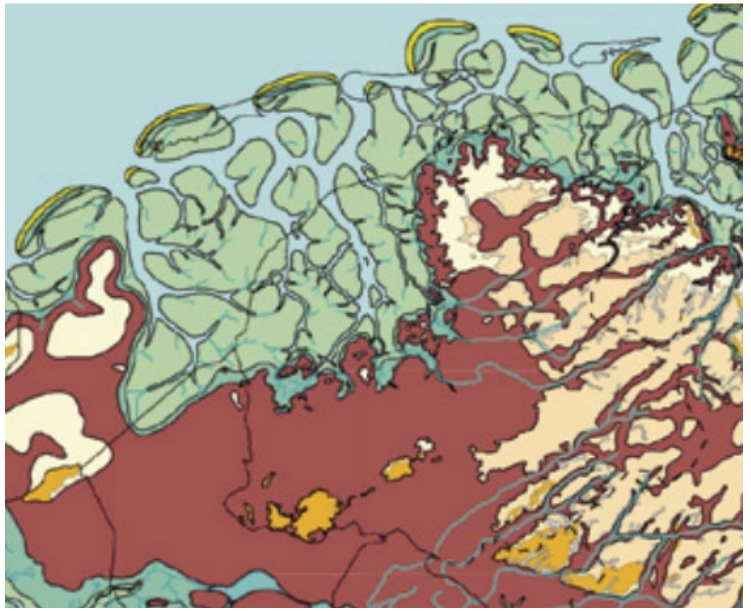
Zoet-zout verdeling kan op korte afstand sterk variëren

Uitleg en video op: https://www.nemokennislink.nl/publicaties/oud-zout-rukt-op/

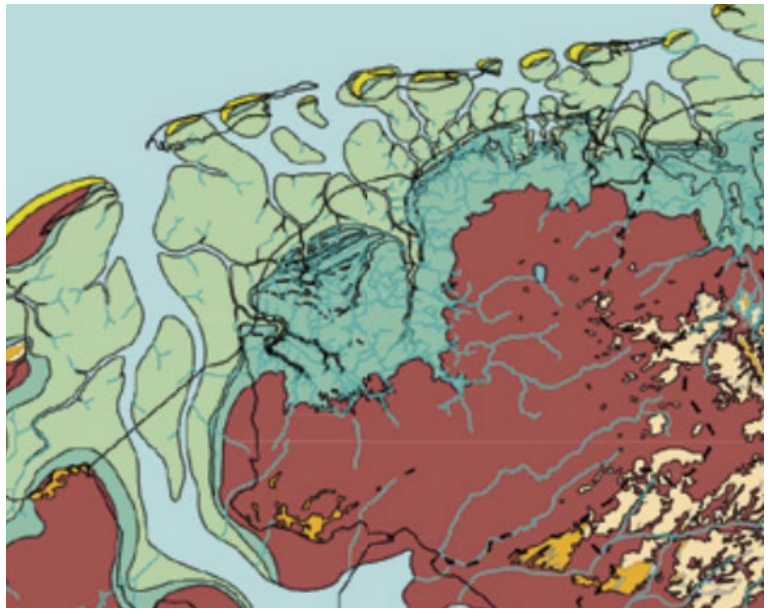
Landschappelijke ontwikkeling over de laatste ~6000 jaar



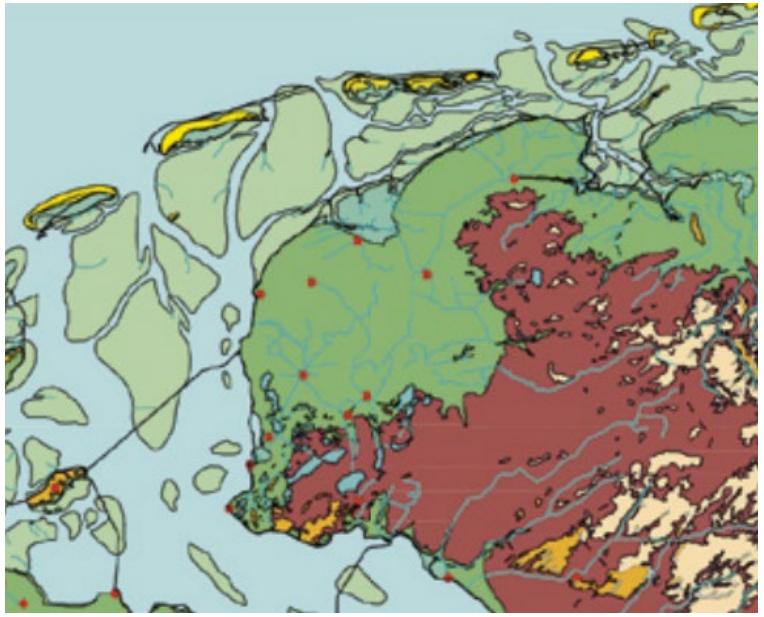
3850 BC



2750 BC



100 AD

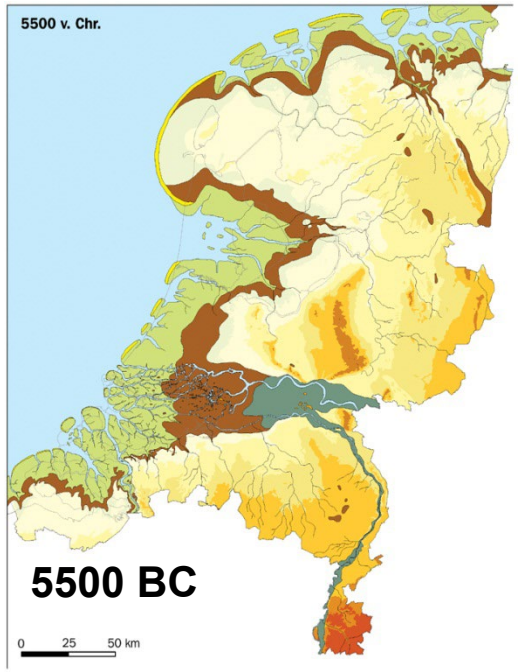


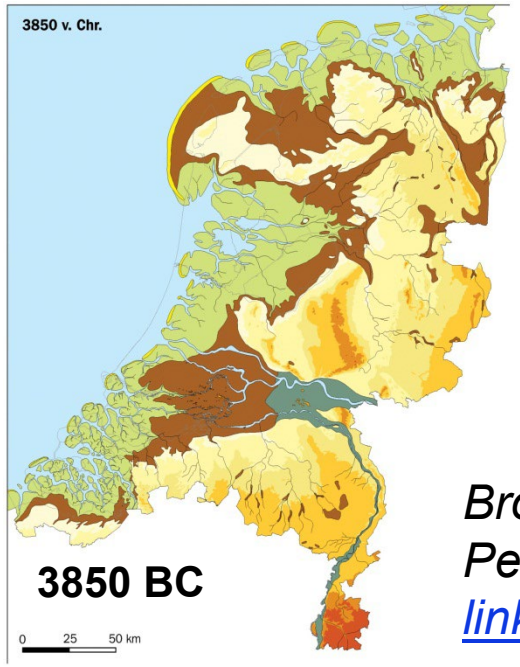
1500 AD

Bron:
Peter Vos, 2015,
link

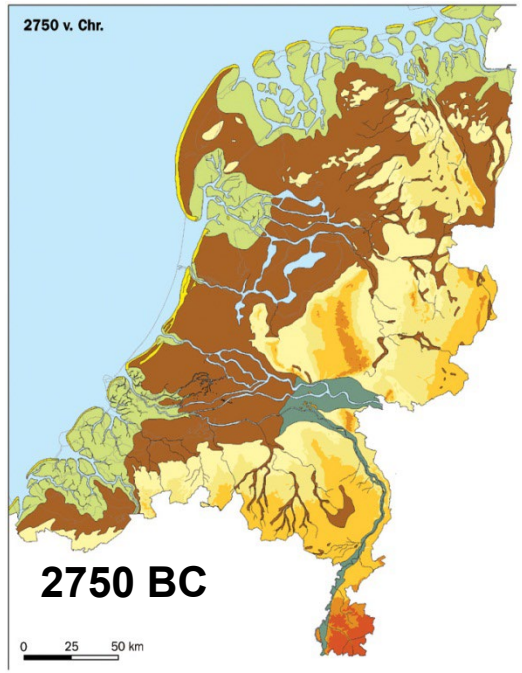


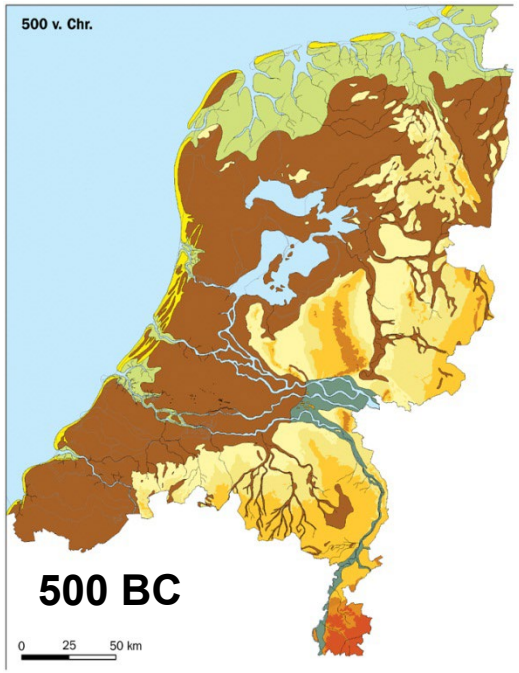
Kunnen we de huidige zoutverdeling in het grondwater voorspellen met behulp van een paleo-hydrogeografische reconstructie?

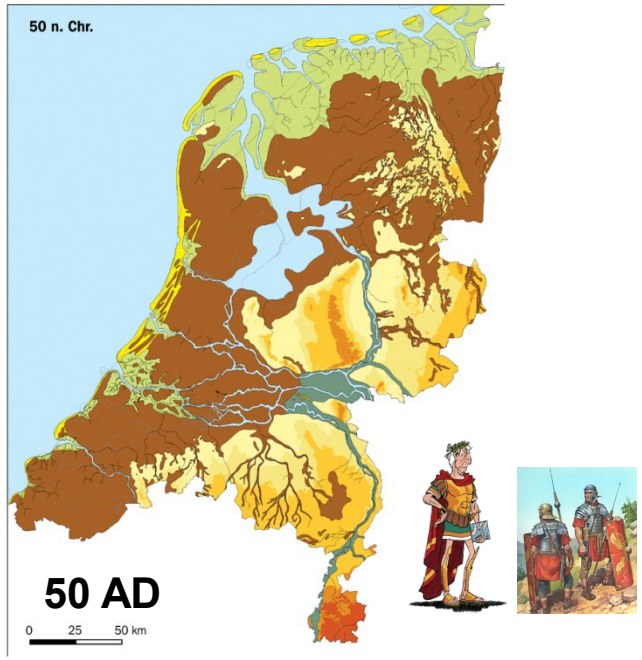


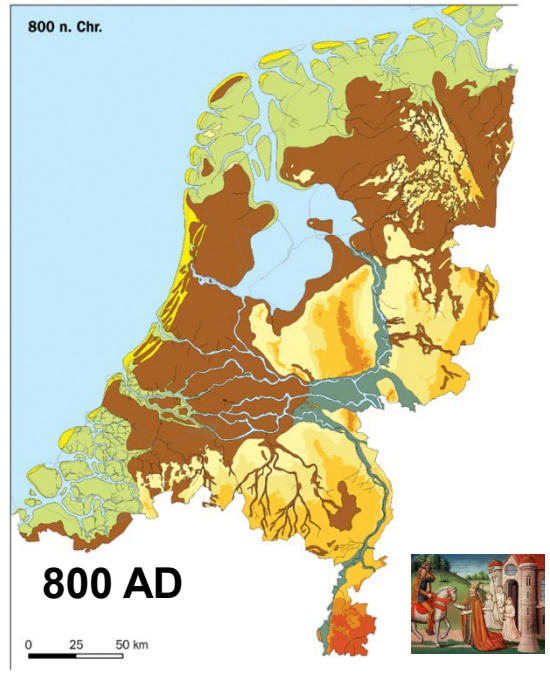


Bron:
Peter Vos, 2015,
link



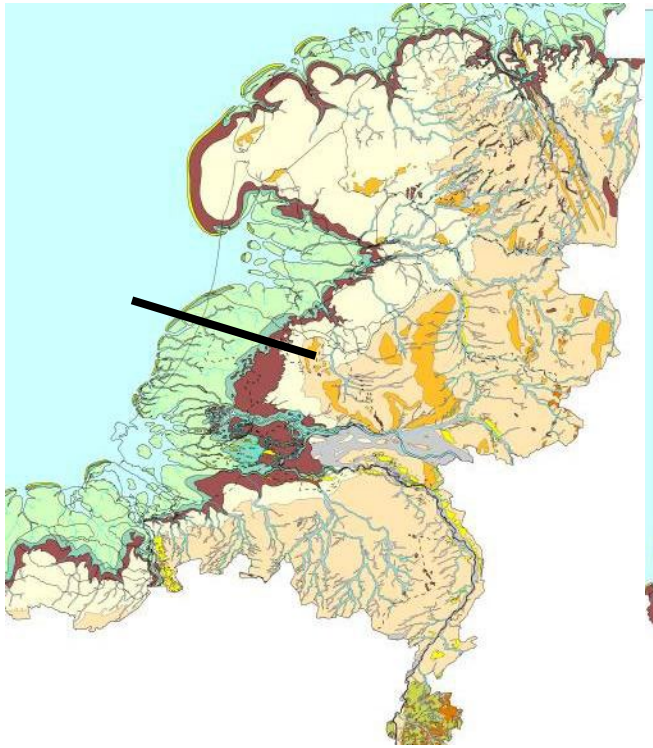






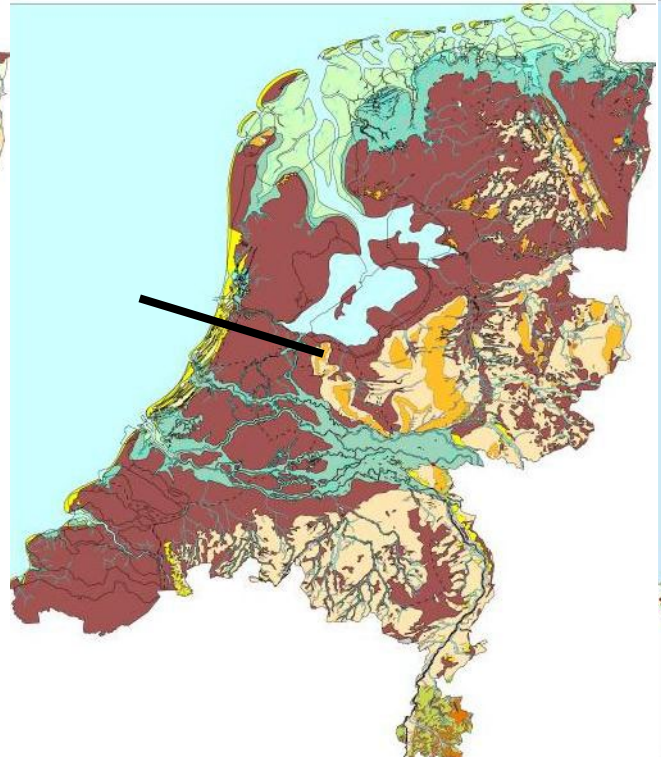
Paleohydrogeografische reconstructies

5500 BC



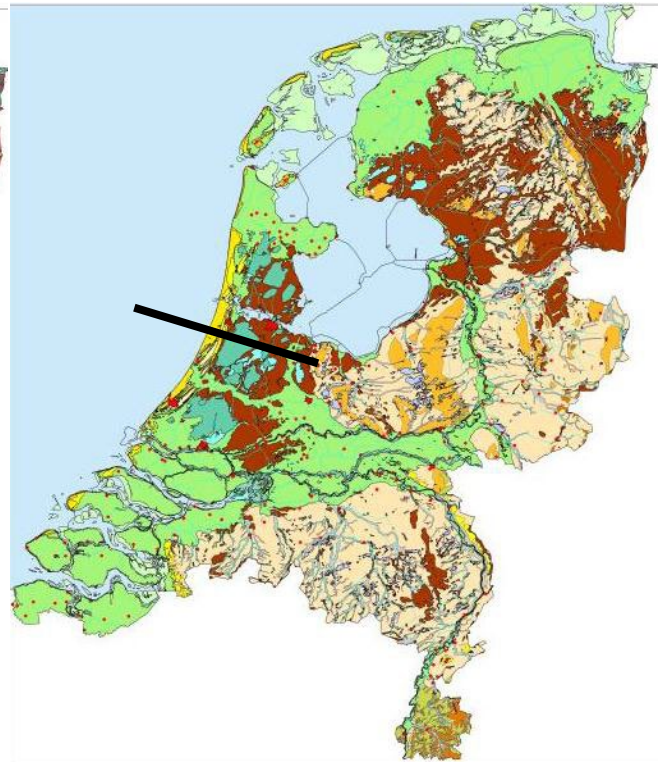
Maximal transgression

100 AD



Peat development

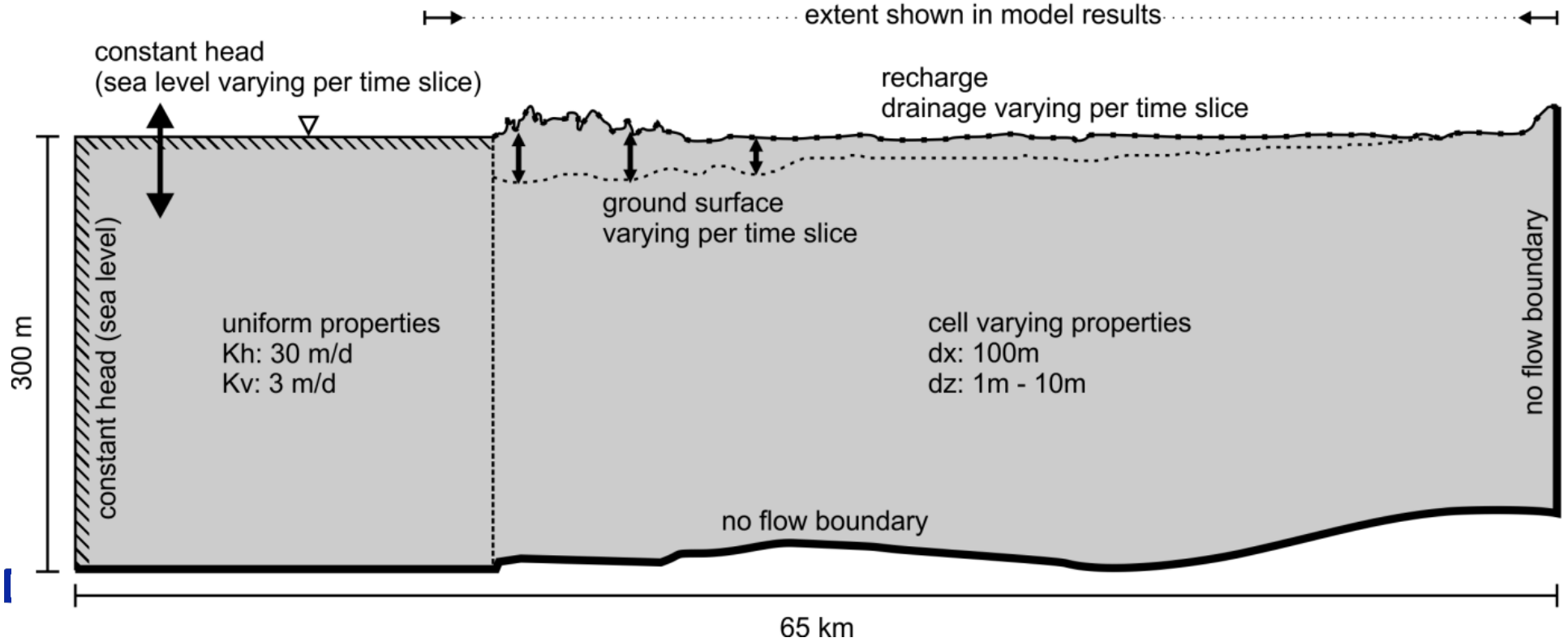
1850 AD



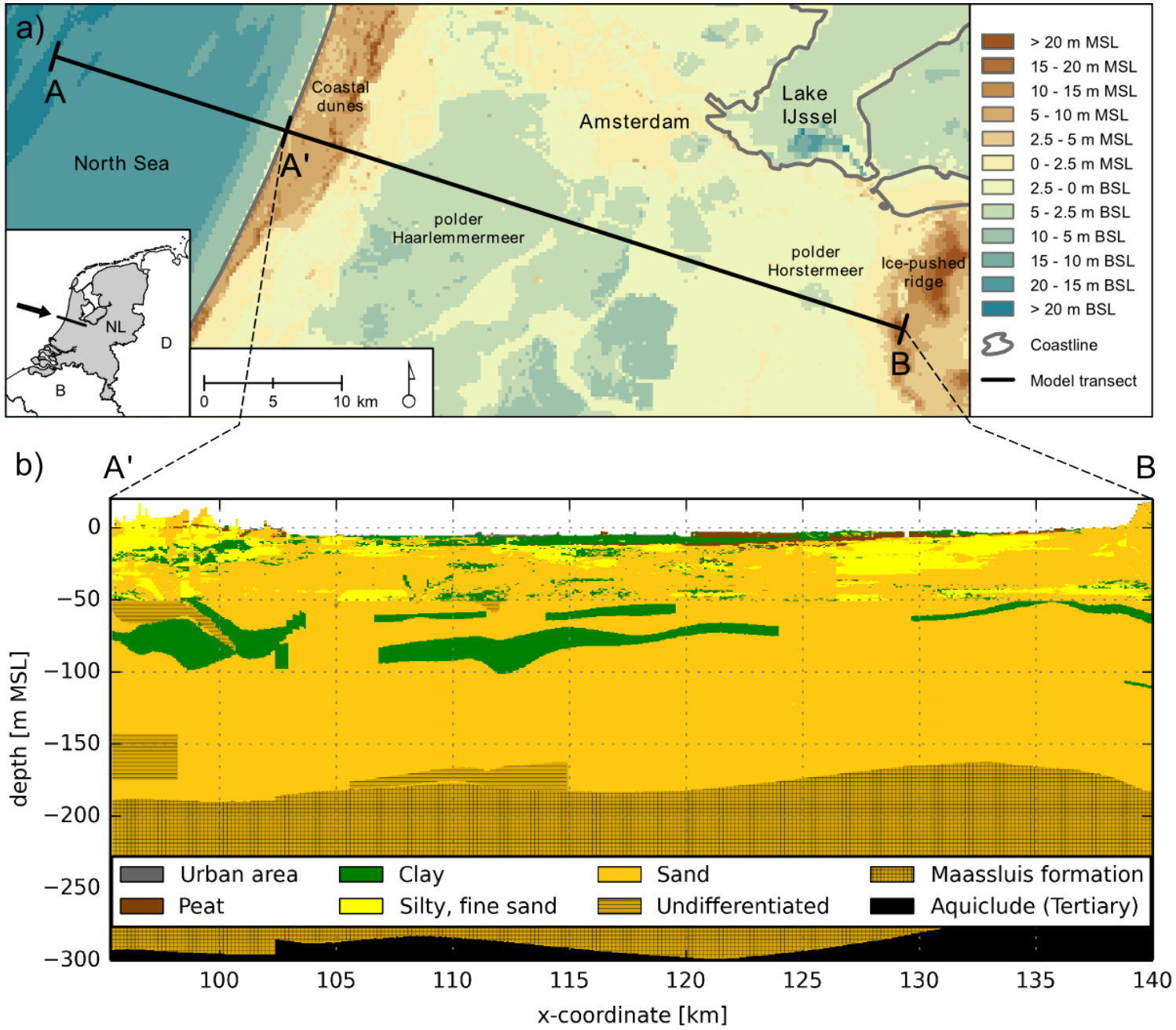
Reclaimed land, polder

Occurrence of salt under the polder Haarlemmermeer

- Model profile Zandvoort - Hoofddorp – Hilversum
- Palaeogeographical development (Vos et al, 2011)
- 6500 BC - 2010 AD
- marine transgression
- Peat development, peat degradation, drainage, reclamation

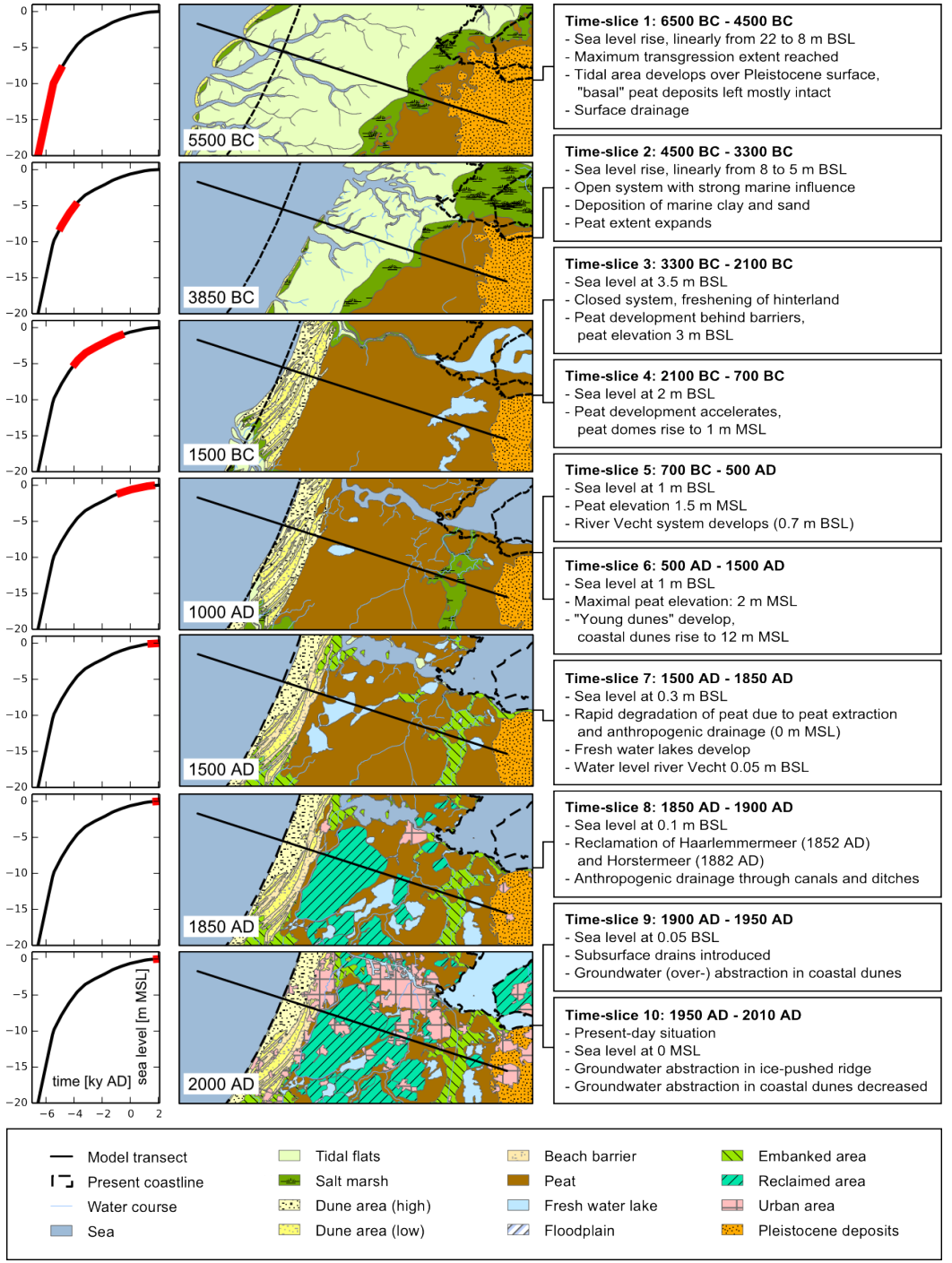


Geologie

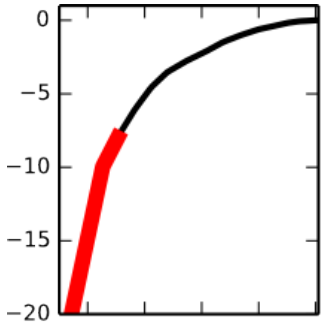


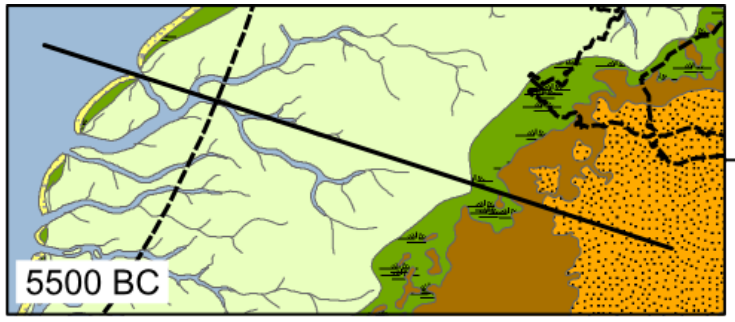
Deltares

Randvoorwaarden over de tijd

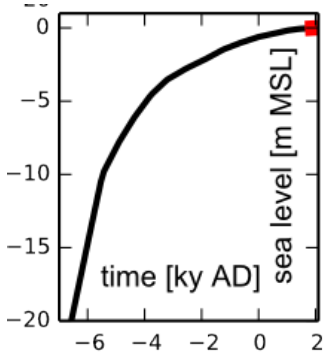


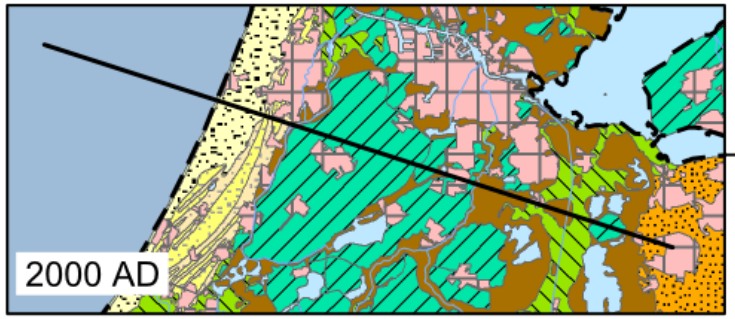
Deltares





Time-slice 1: 6500 BC - 4500 BC
- Sea level rise, linearly from 22 to 8 m BSL
- Maximum transgression extent reached
- Tidal area develops over Pleistocene surface, "basal" peat deposits left mostly intact
- Surface drainage





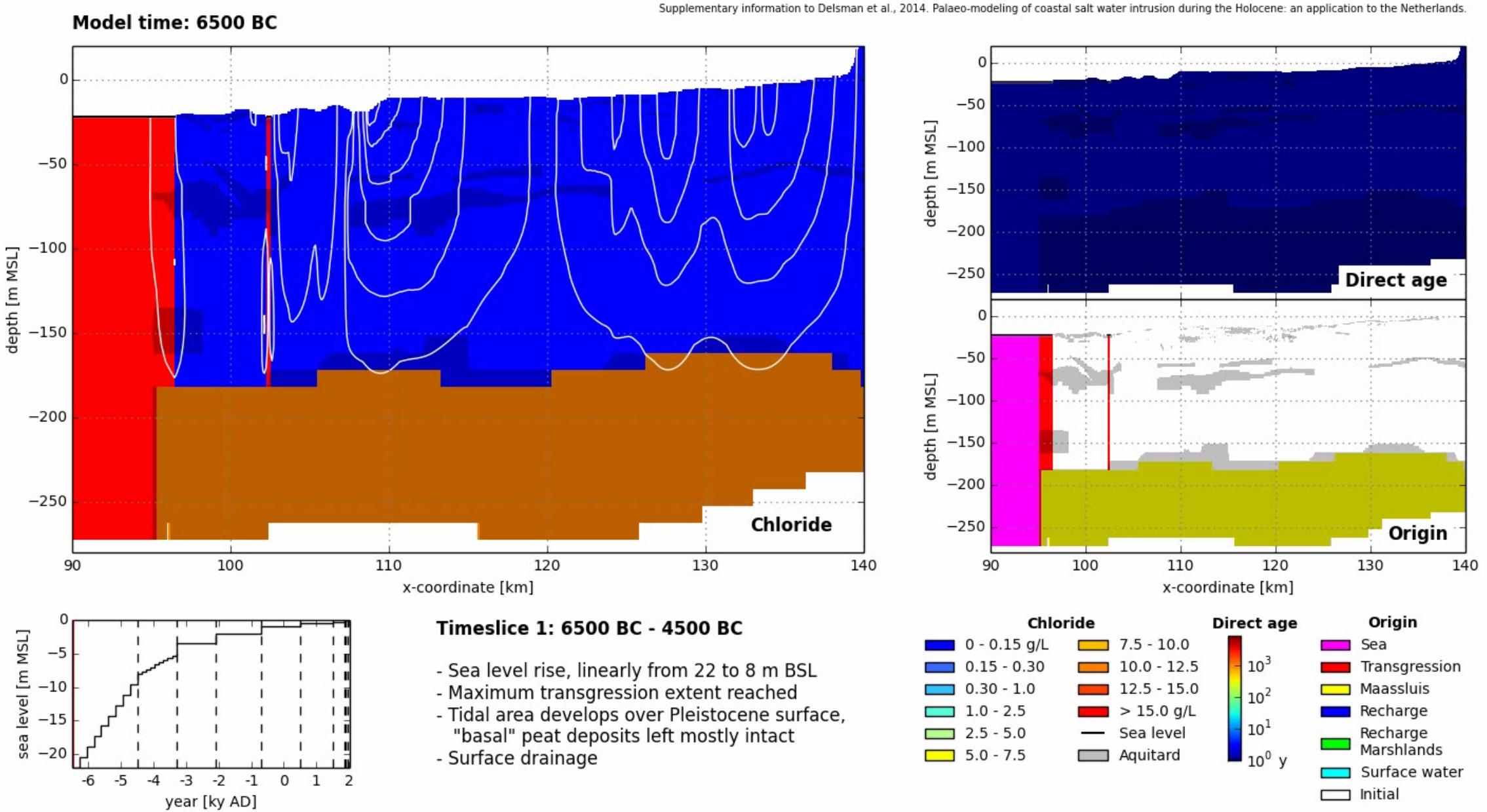
Time-slice 10: 1950 AD - 2010 AD
- Present-day situation
- Sea level at 0 MSL
- Groundwater abstraction in ice-pushed ridge
- Groundwater abstraction in coastal dunes decreased

Model transect
Present coastline
Water course
Sea
Tidal flats
Salt marsh
Dune area (high)
Dune area (low)
Beach barrier
Peat
Fresh water lake
Floodplain
Embanked area
Reclaimed area
Urban area
Pleistocene deposits

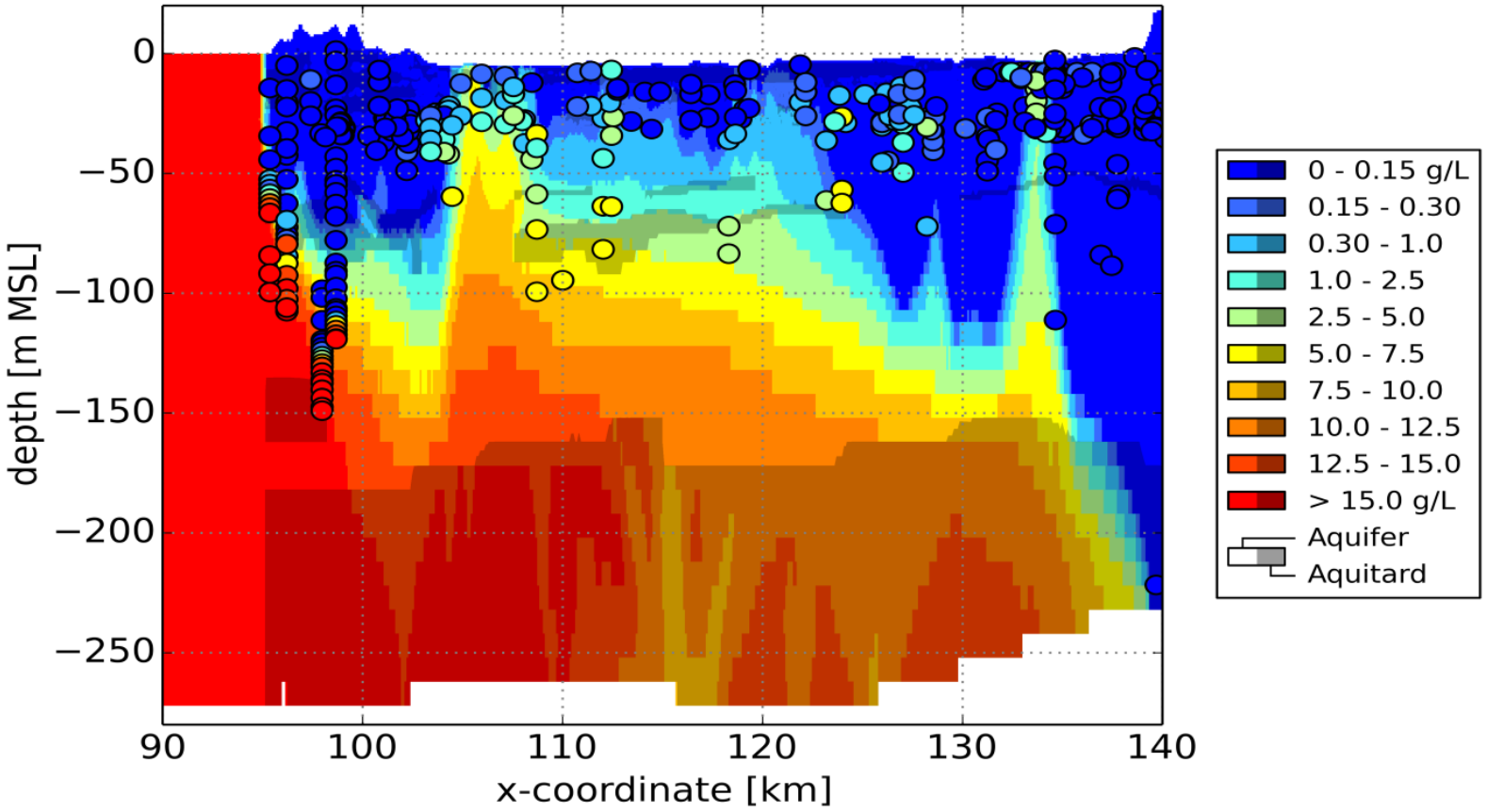
Ontwikkeling zoet-brak-zout verdeling gedurende het Holoceen

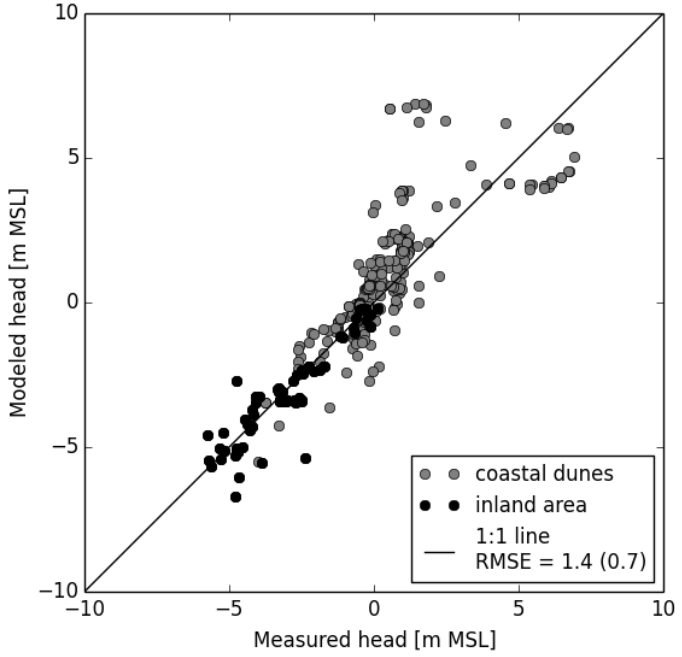
https://www.youtube.com/watch?v=BUfSIVfxxvY

animatie laatste 8500 jaar



Modelresultaat versus zoet-zout metingen

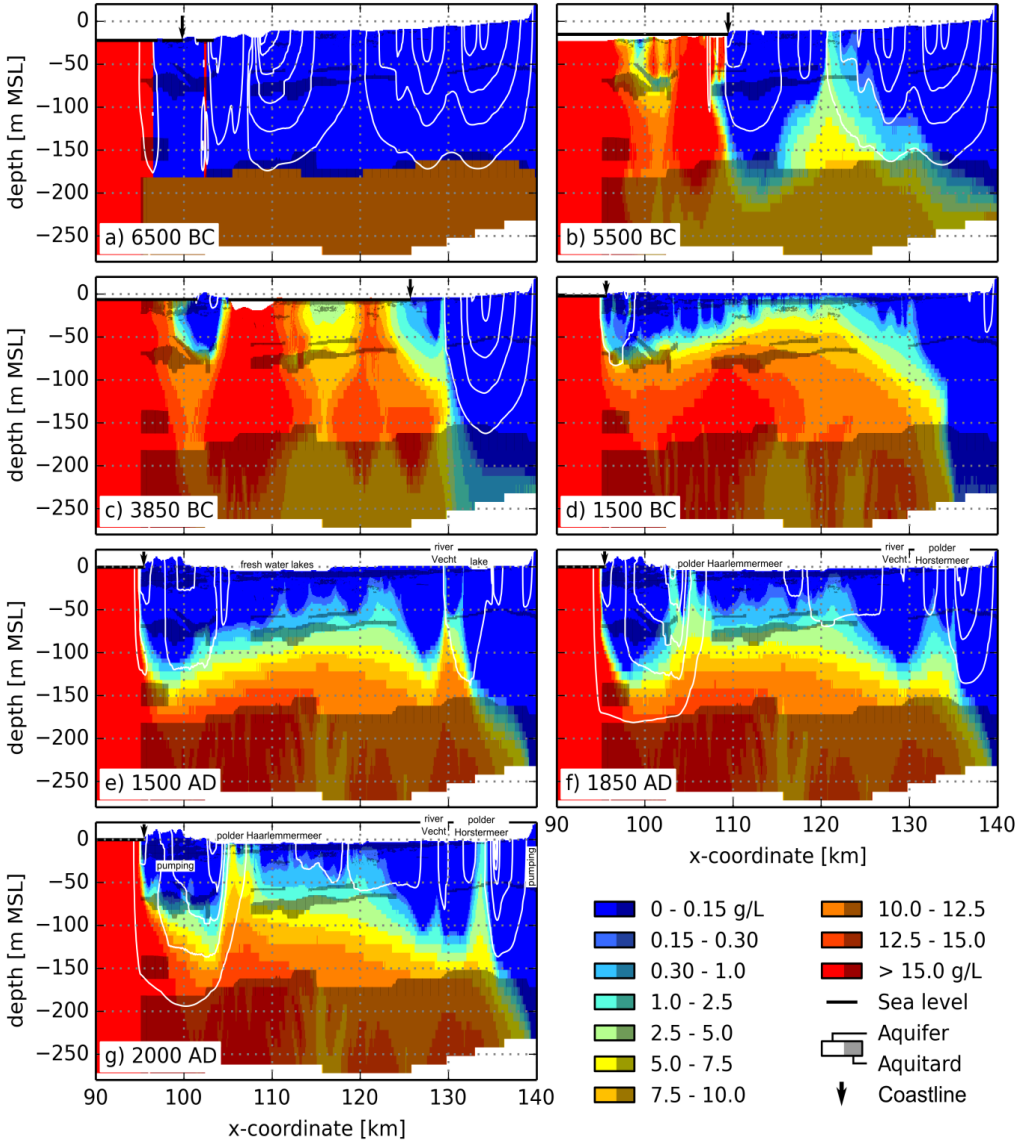




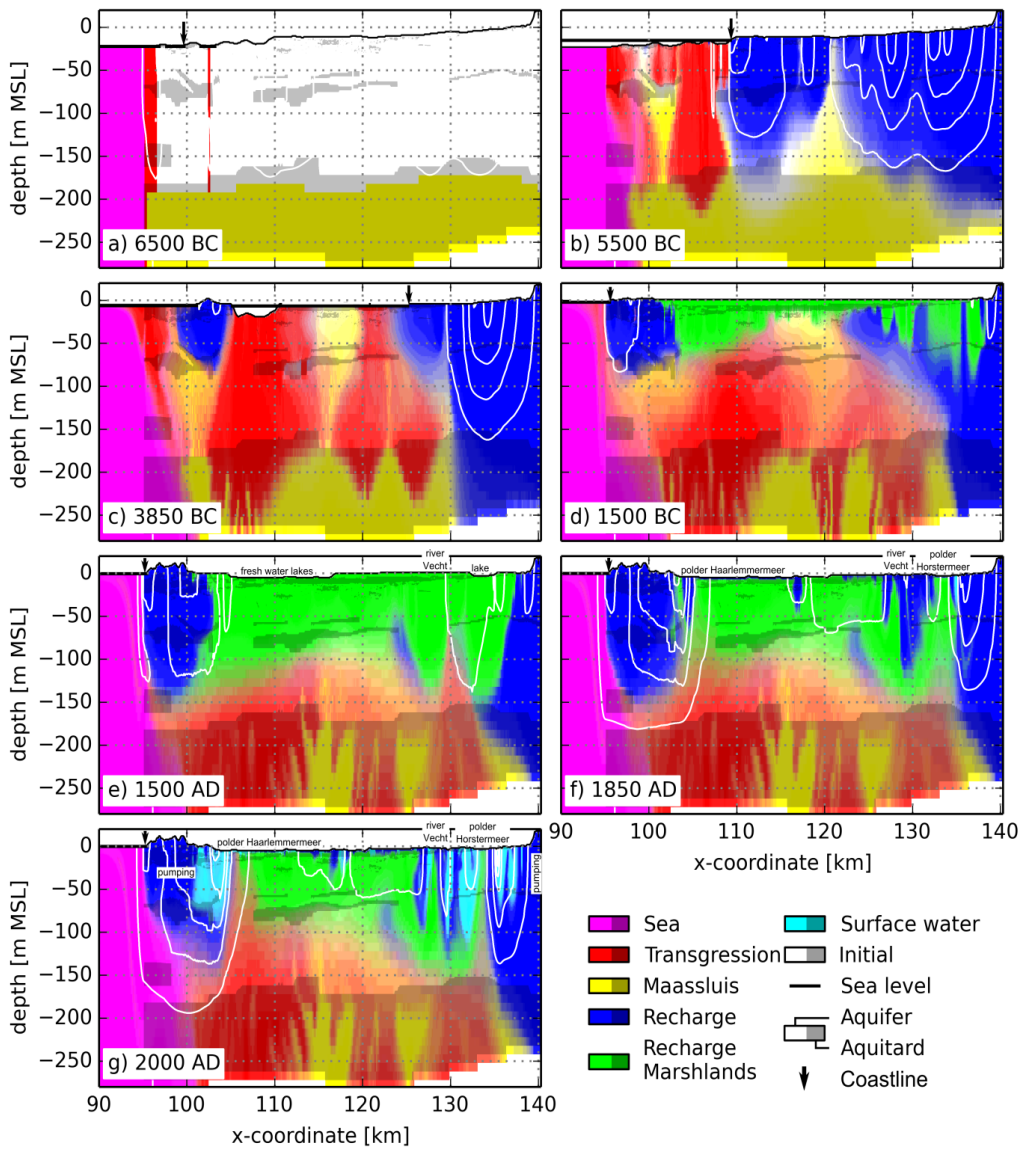
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Paleo-hydrogeografische reconstructie zoet-zout grondwater

Zoet-zout verdeling over de tijd

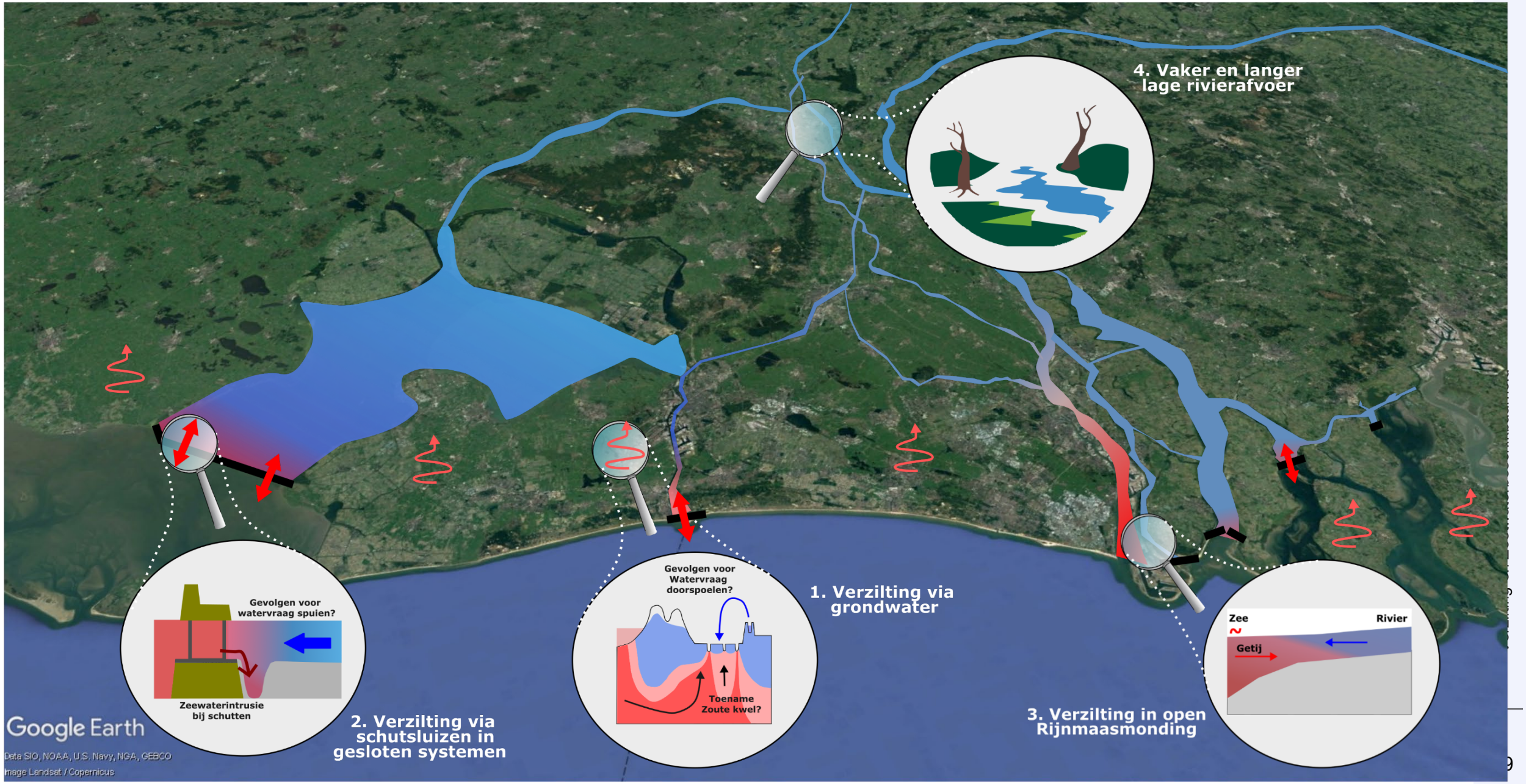


Waar komt het water vandaan?:



- paars is vanuit de zee
- rood is door trangressie, van boven
- geel is vanuit de ondergrond (‘oud zout’)
- groen is infiltratie vanuit veengebied (nutientenrijk)
- blauw is ‘gewone’ grondwateraanvulling
- lichtblauw is vanuit kunstmatige infiltratieplassen

Hoe beïnvloedt zeespiegelstijging de zoetwaterbeschikbaarheid van Nederland?



Twee recente rapportages



Link naar rapport: hier



Contact personen: Jantine Hoekstra, Quirijn Lodder

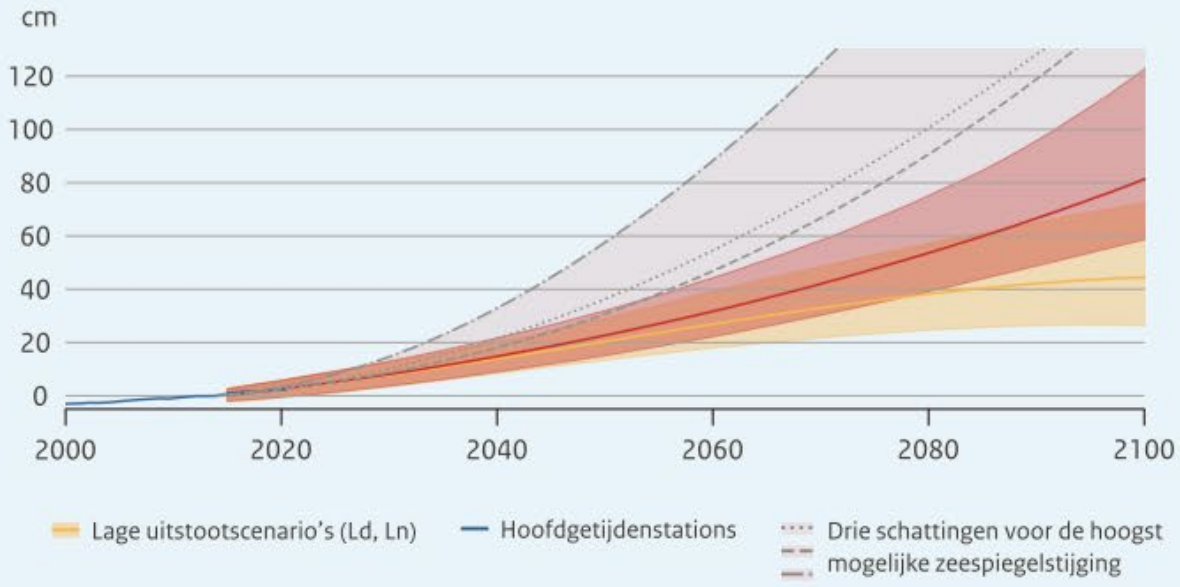
Zeespiegelstijging...



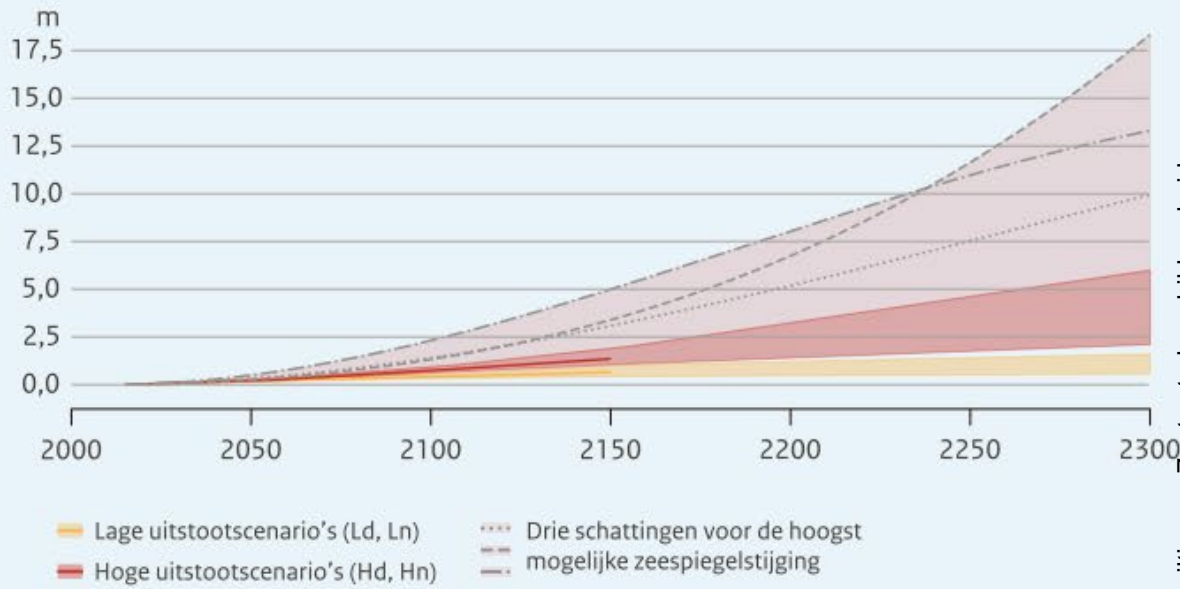


Zeespiegel bij Nederland

Scenario's tot 2100



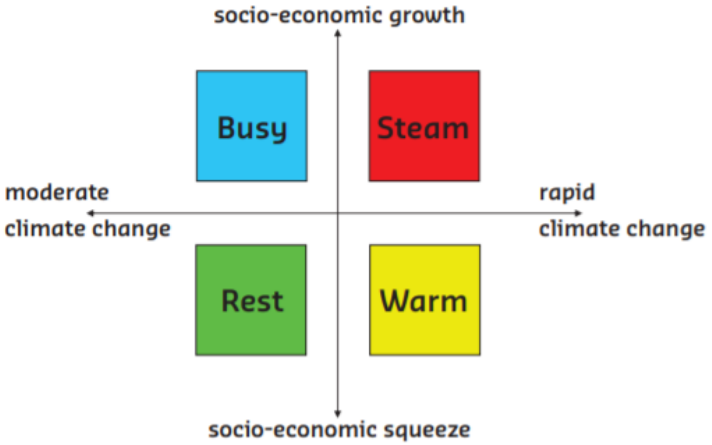
Scenario's tot 2300



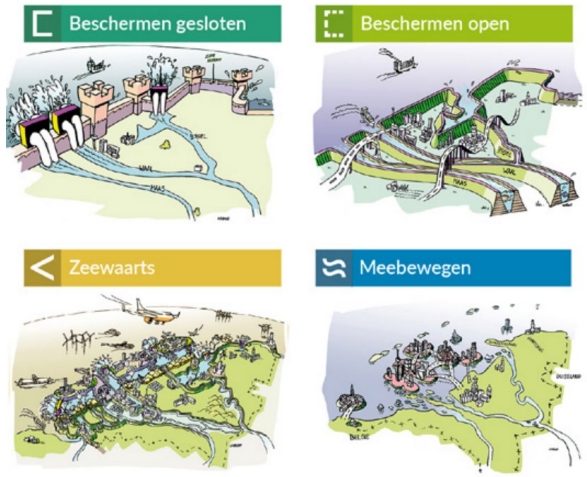
... zelfs in lage uitstootscenario in 2150 wrs. meer dan 1 m zeespiegelstijging ...

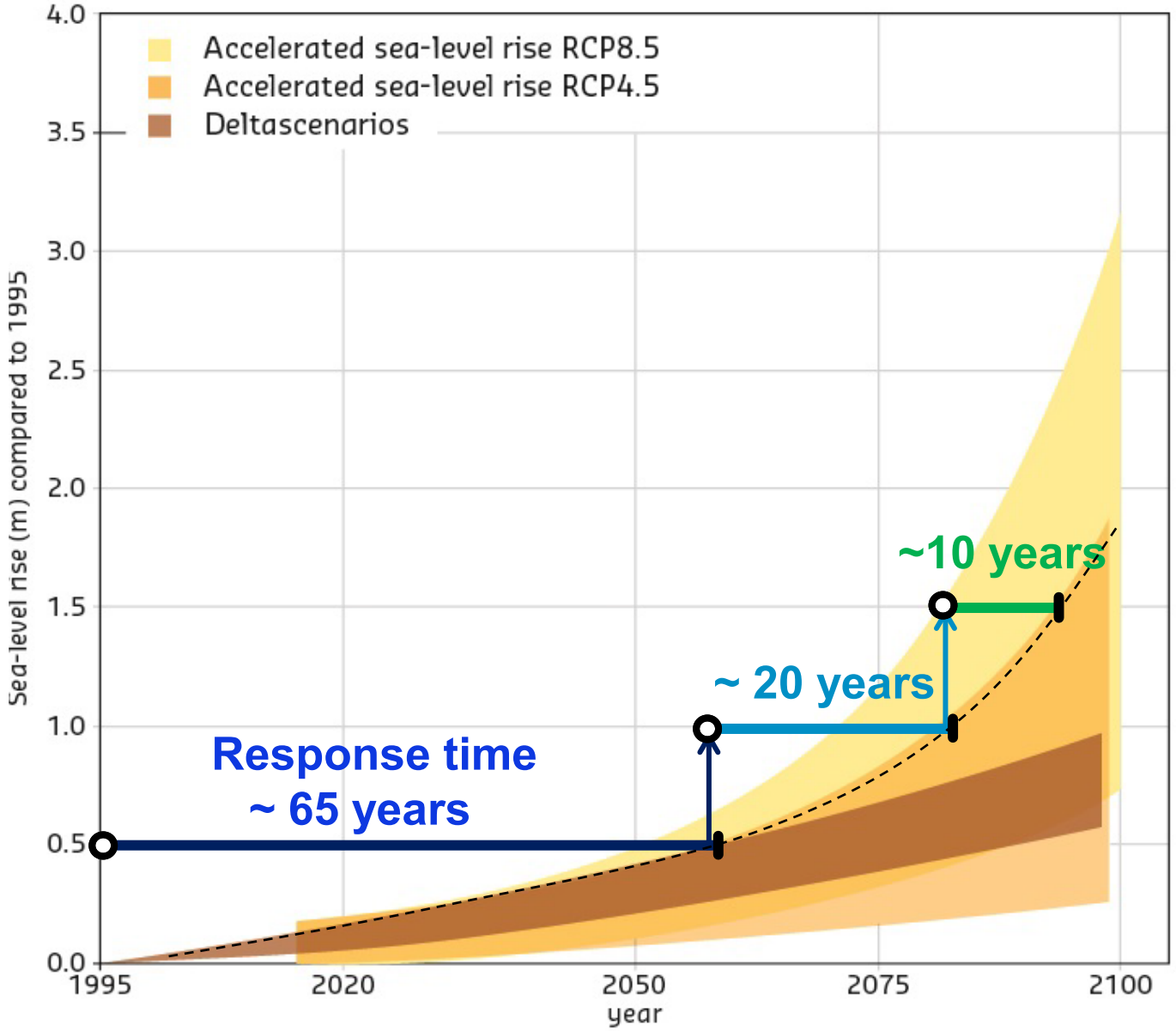
... bovengrens: 2.5 m in 2100 (als ijskappen Antarctica instabiel) ...

Nederland Later



(Haasnoot et al., 2020, 2019, 2018)

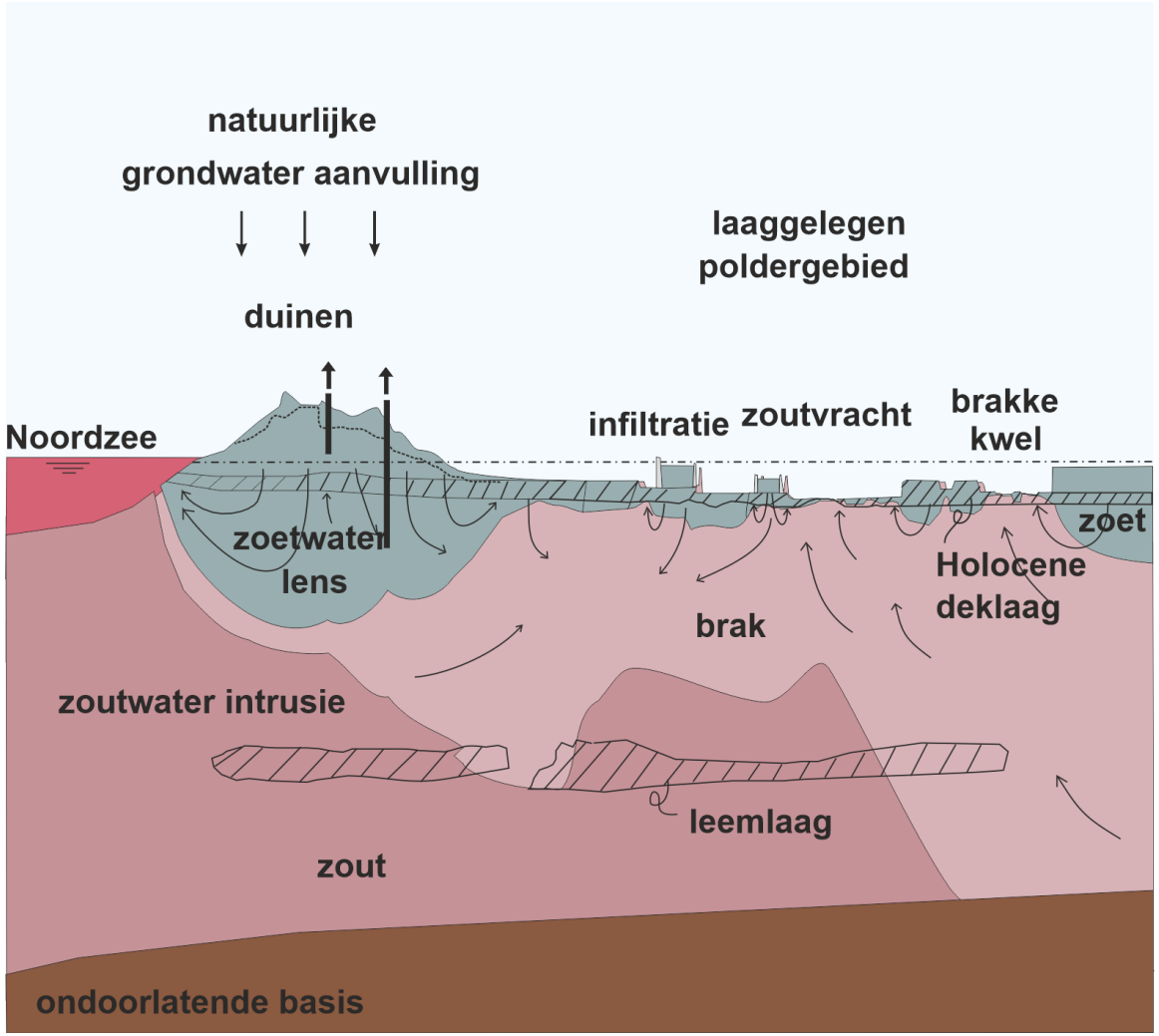




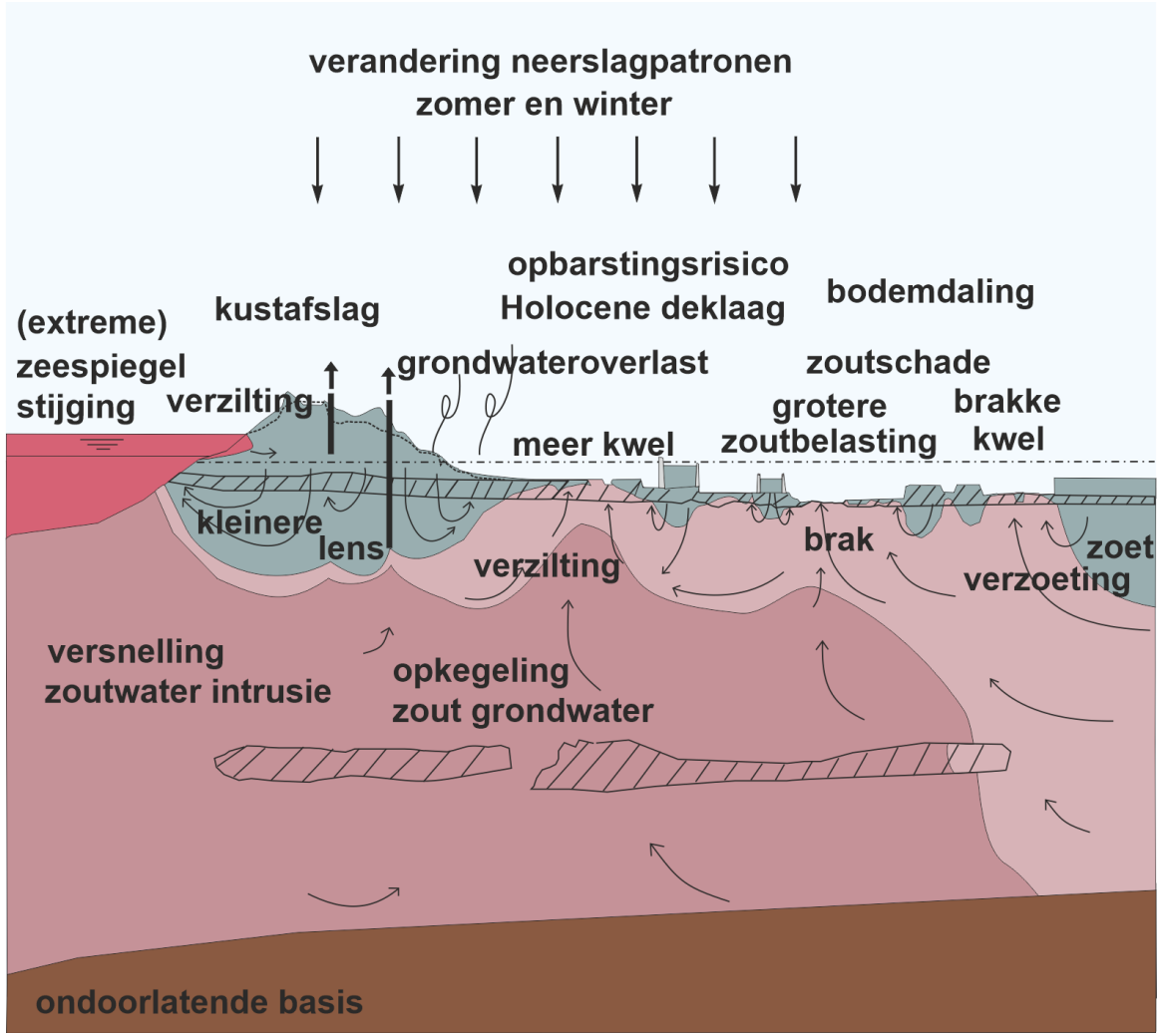
Haasnoot et al., 2019. Strategieën voor adaptatie aan hoge en versnelde zeespiegelstijging. Een verkenning. 1–65.
Haasnoot et al., 2018. Mogelijke gevolgen van versnelde zeespiegelstijging voor het Deltaprogramma. Een verkenning, Deltares rapport 11202230-005-0002.
Deconto, R.M., Pollard, D., 2016. Contribution of Antarctica to past and future sea-level rise. Nature 531, 591–597. https://doi.org/10.1038/nature17145

Effect zeespiegelstijging op grondwater

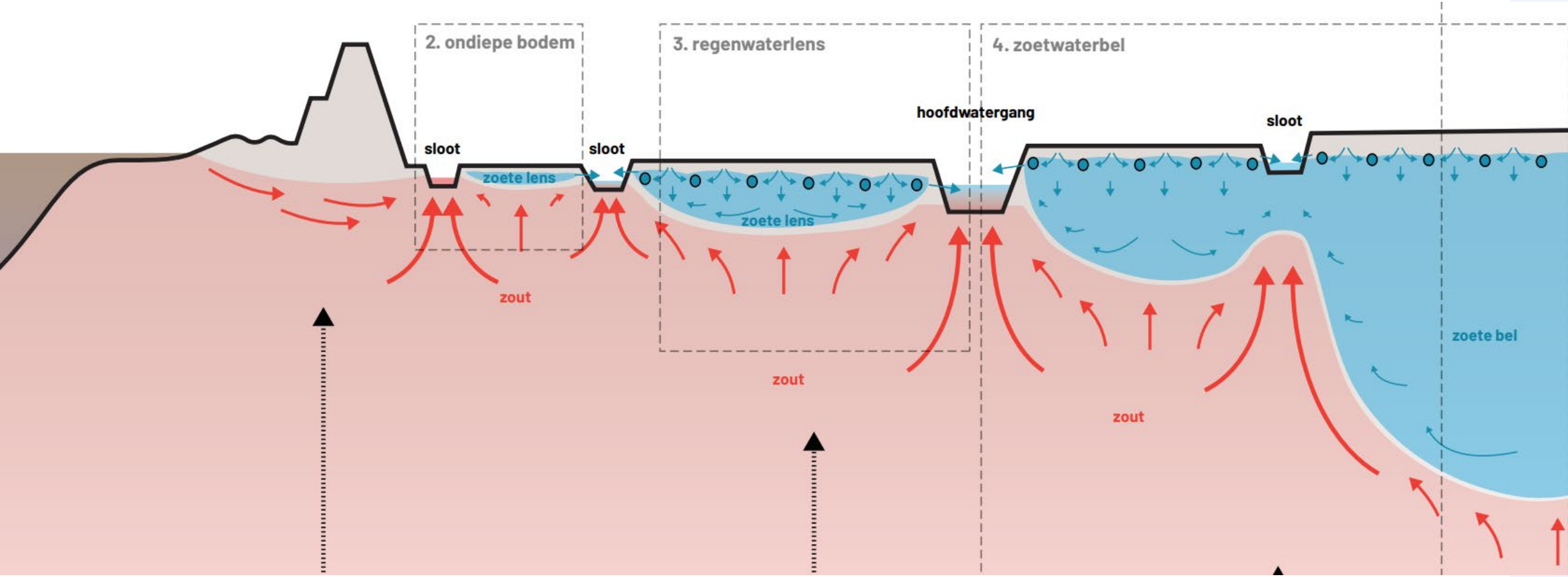
nu



toekomst



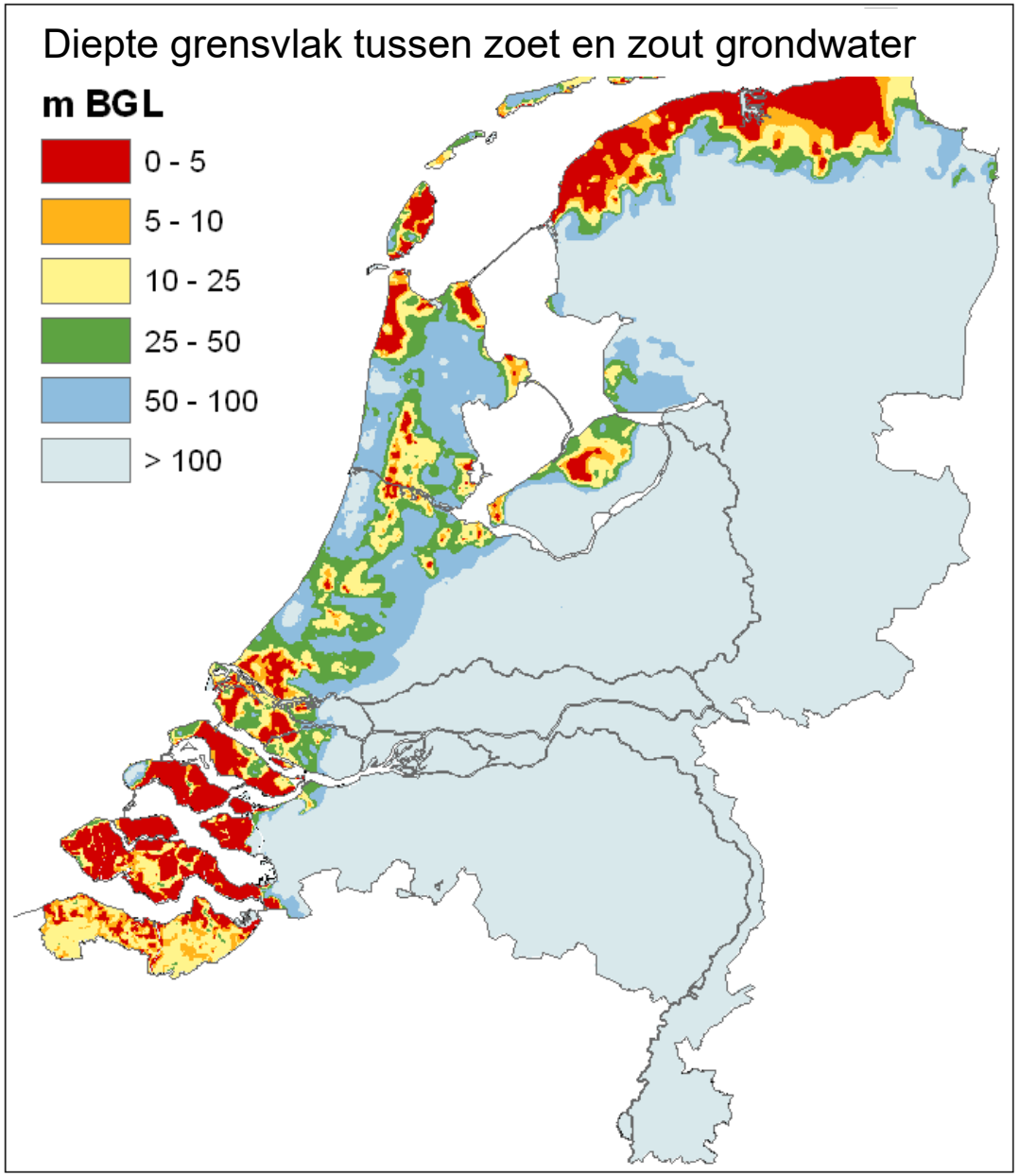
Zoetwaterbellen en regenwaterlenzen, case Zeeland

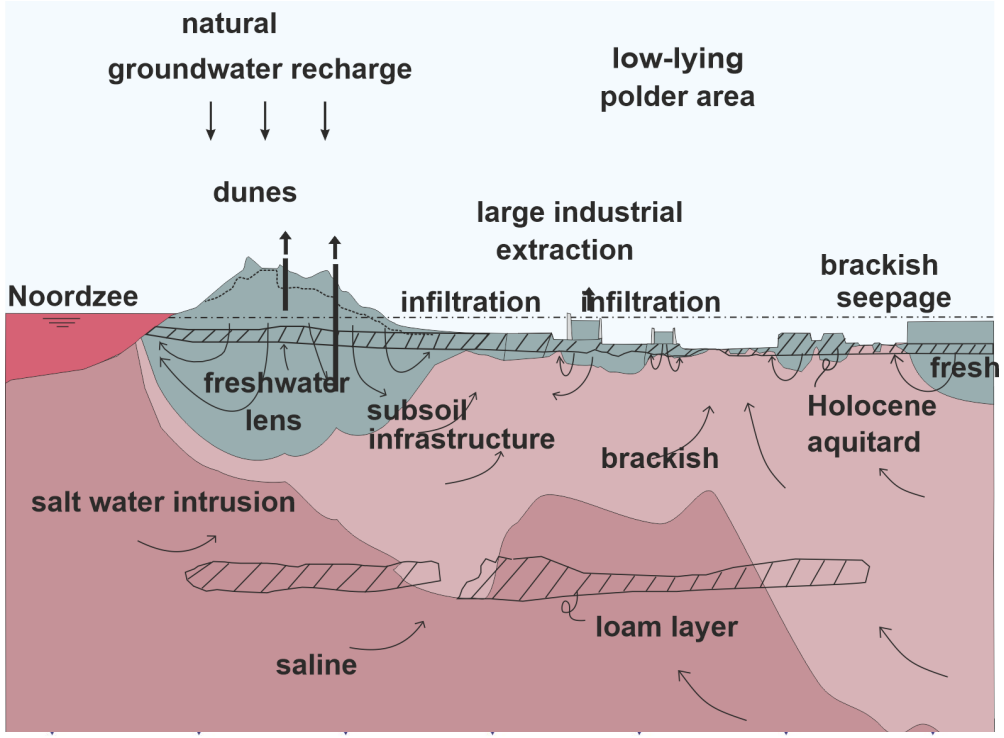


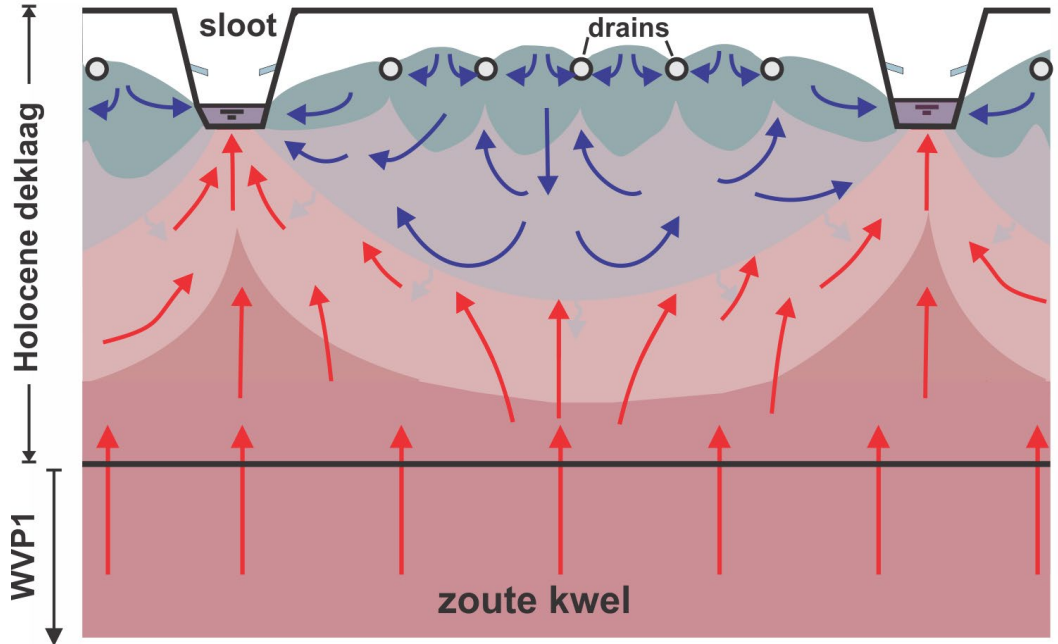
Zoetwaterlenzen Zeeland:

1. Onder duinen
2. Onder kreekruggen
3. In percelen

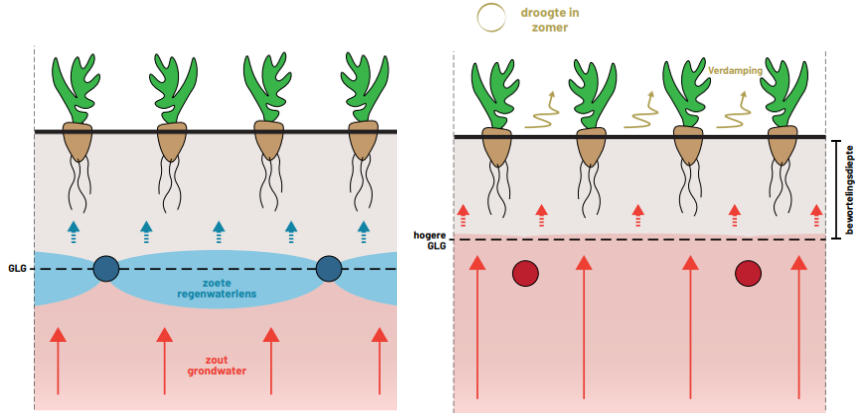
Zoet grondwater beschikbaarheid

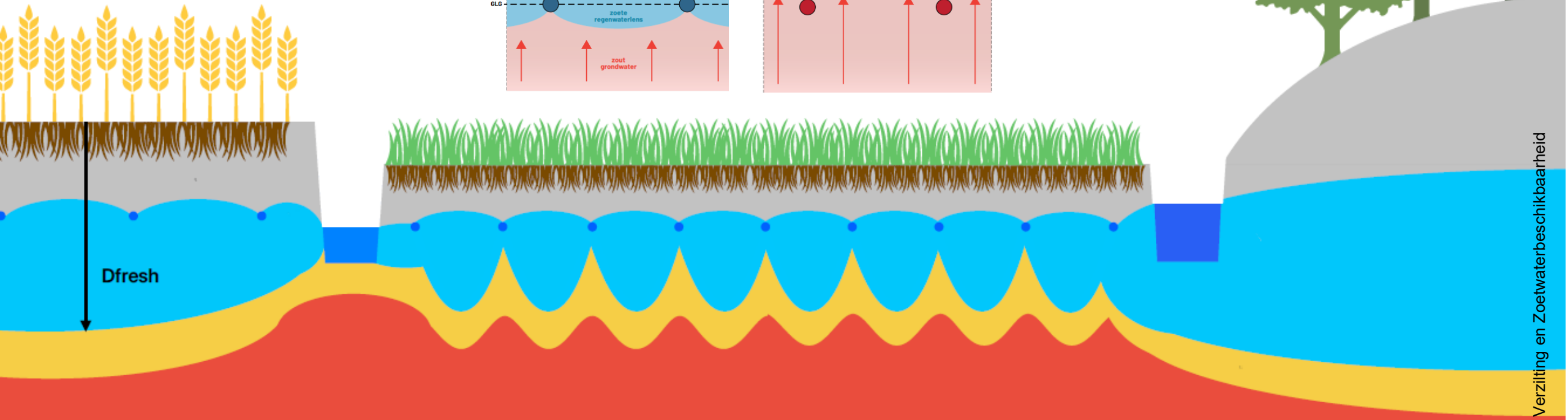




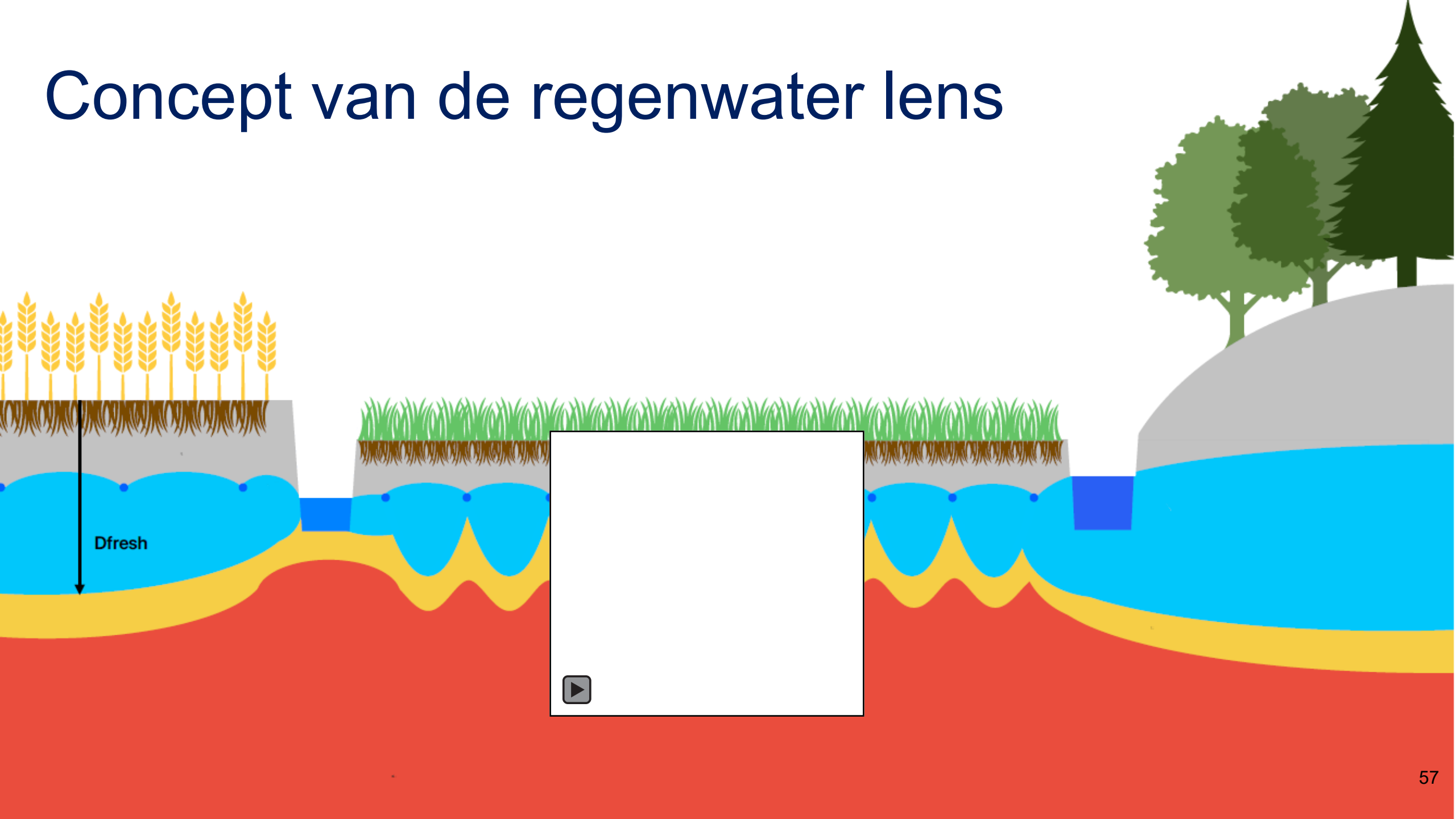


Effect klimaatverandering en droogte

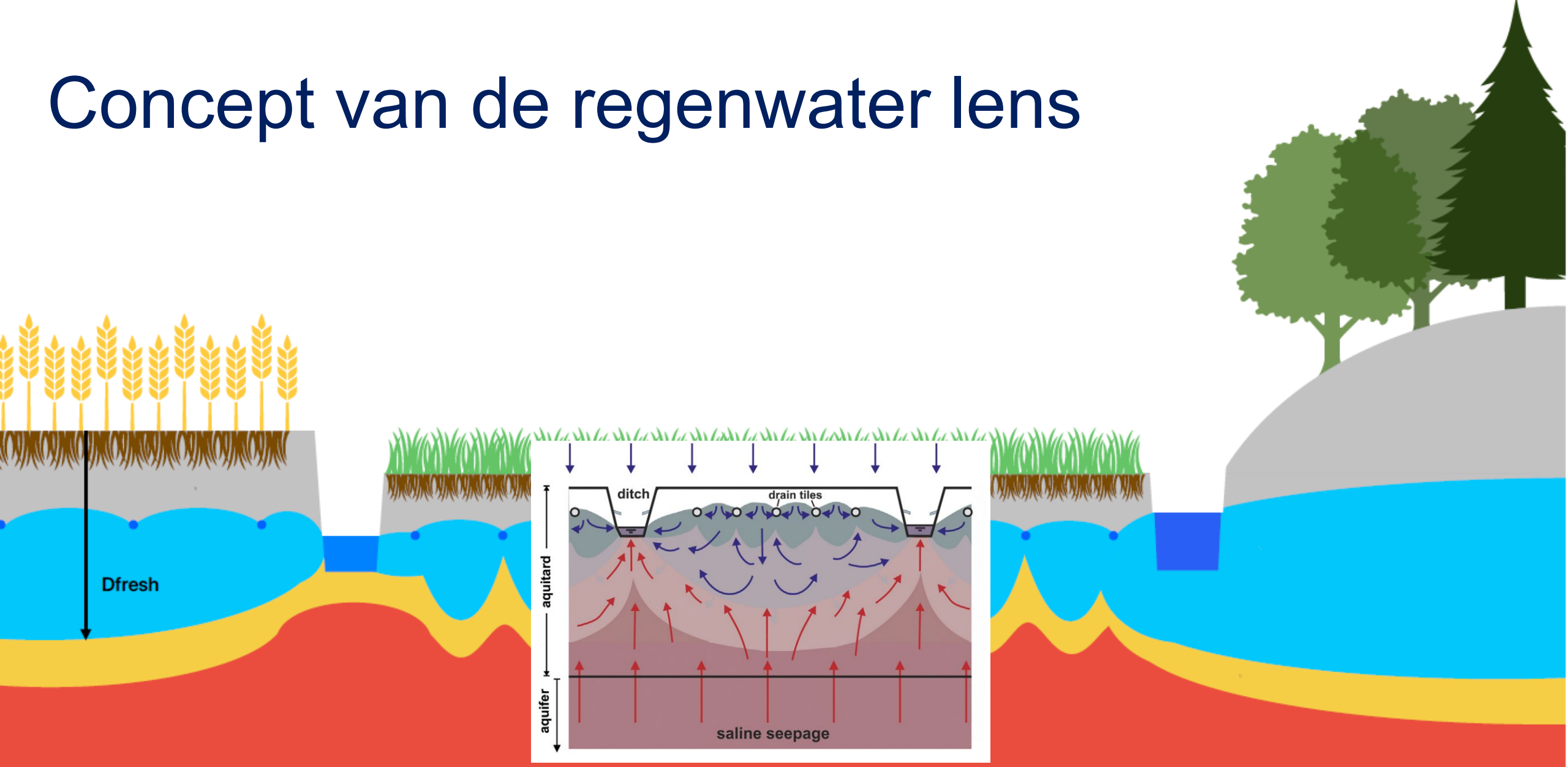




Concept van de regenwater lens

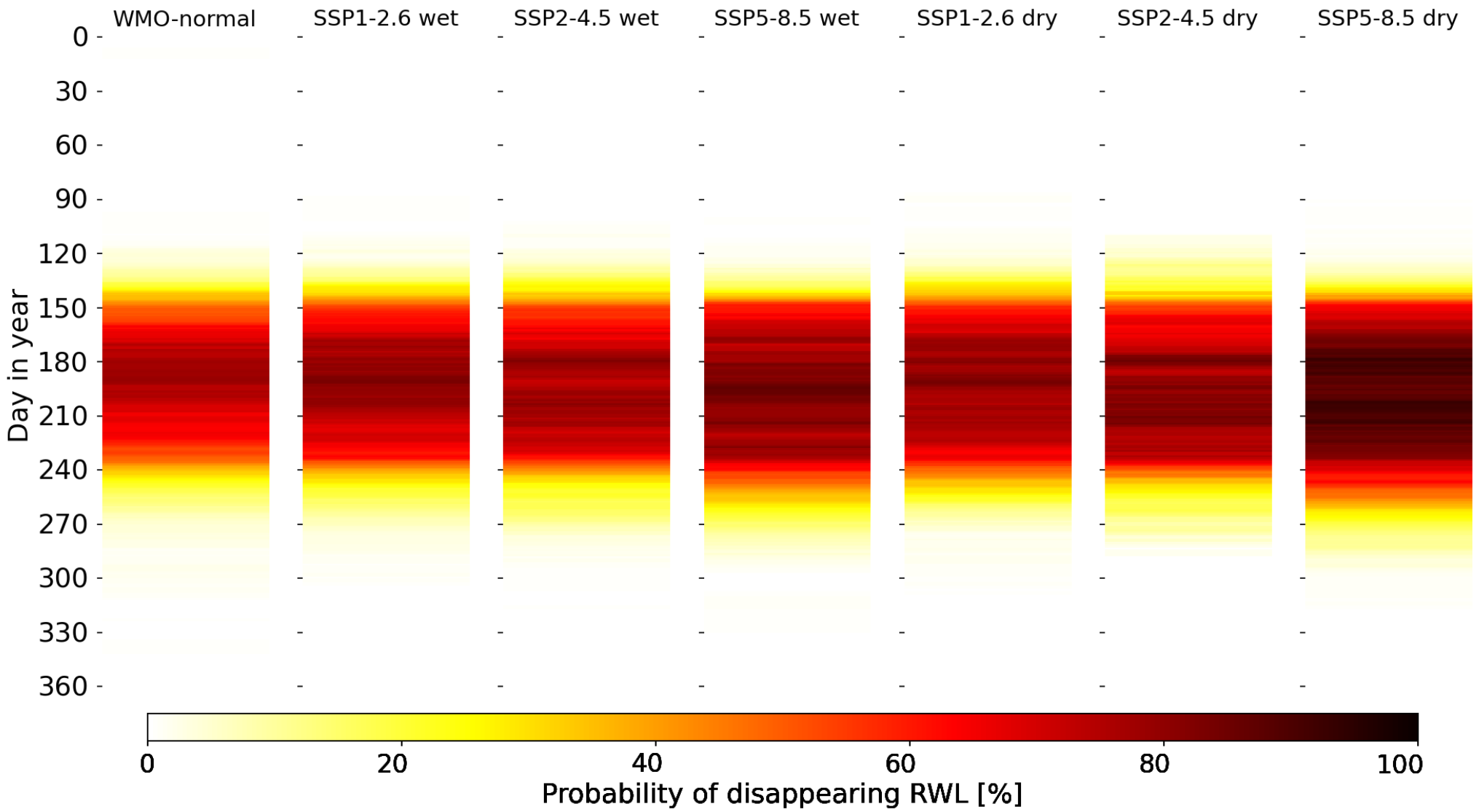


Concept van de regenwater lens

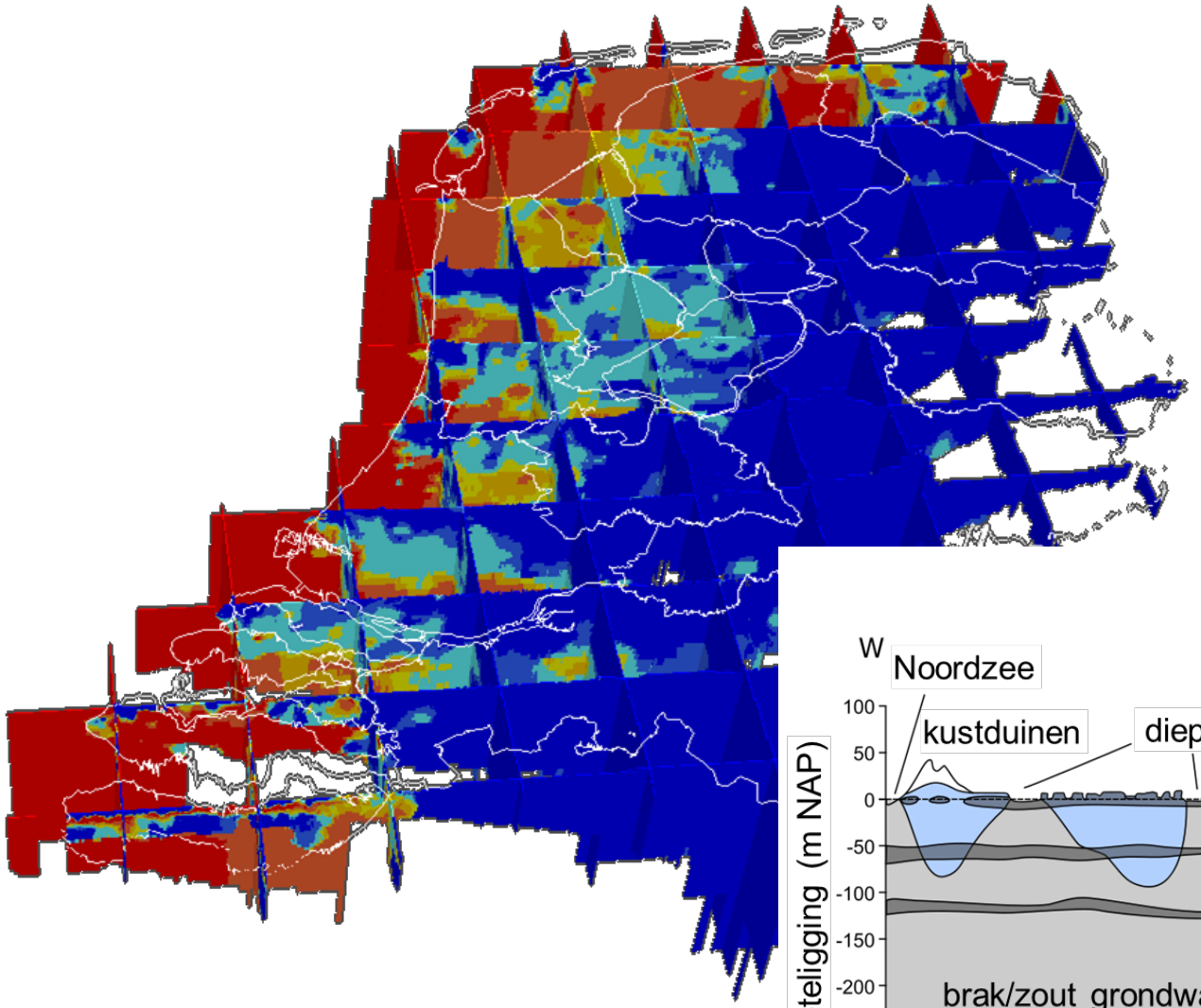


de Louw et al. (2013)

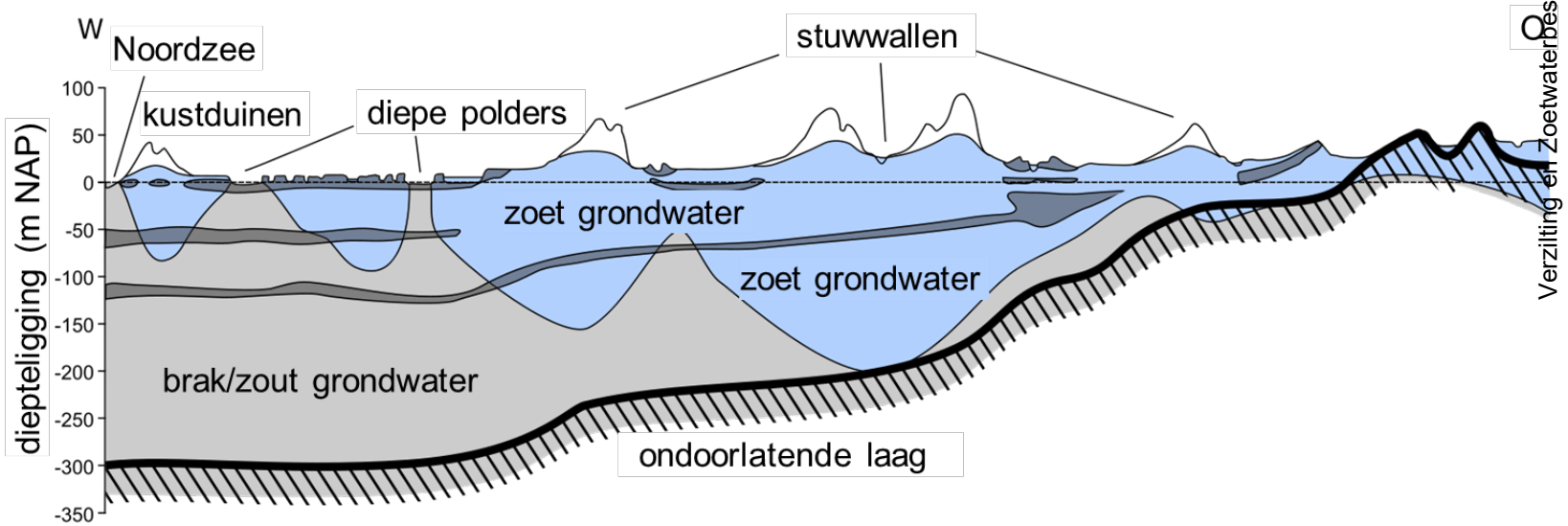
Klimaat effect op regenwaterlenzen



Brak-zout grondwater in Nederland



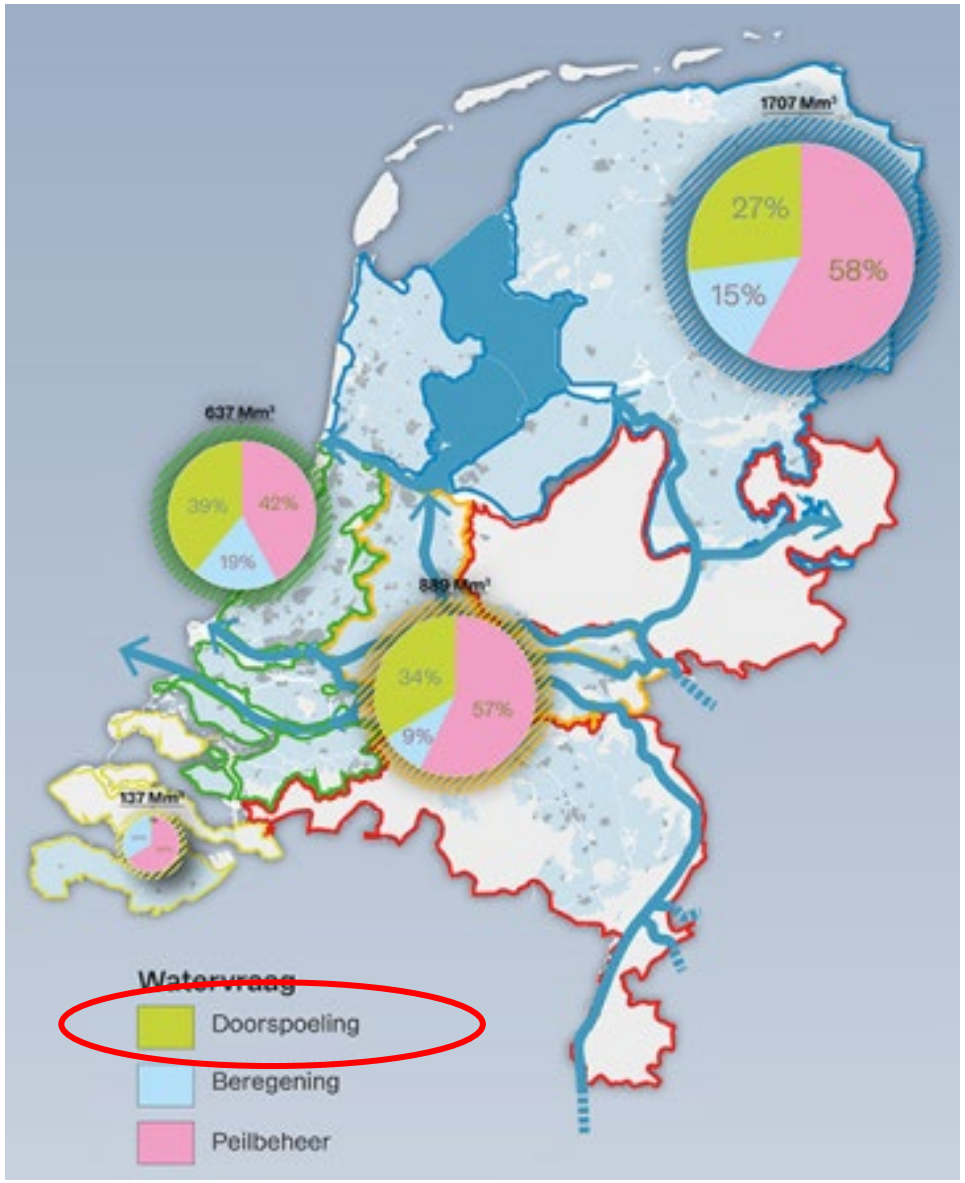




Deltares

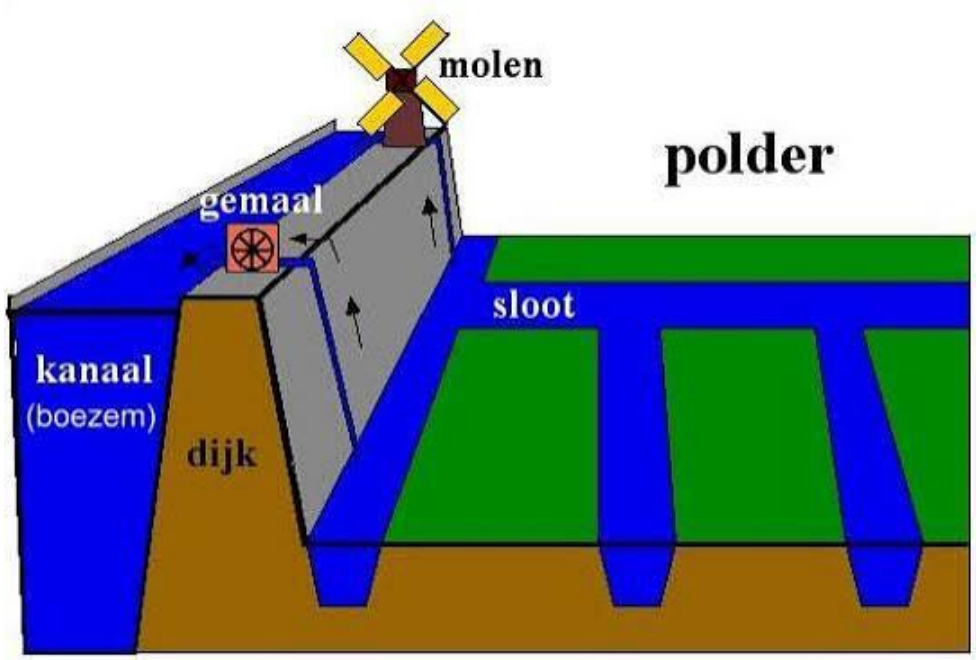
Zoetwaterbeschikbaarheid en grondwater verzilting

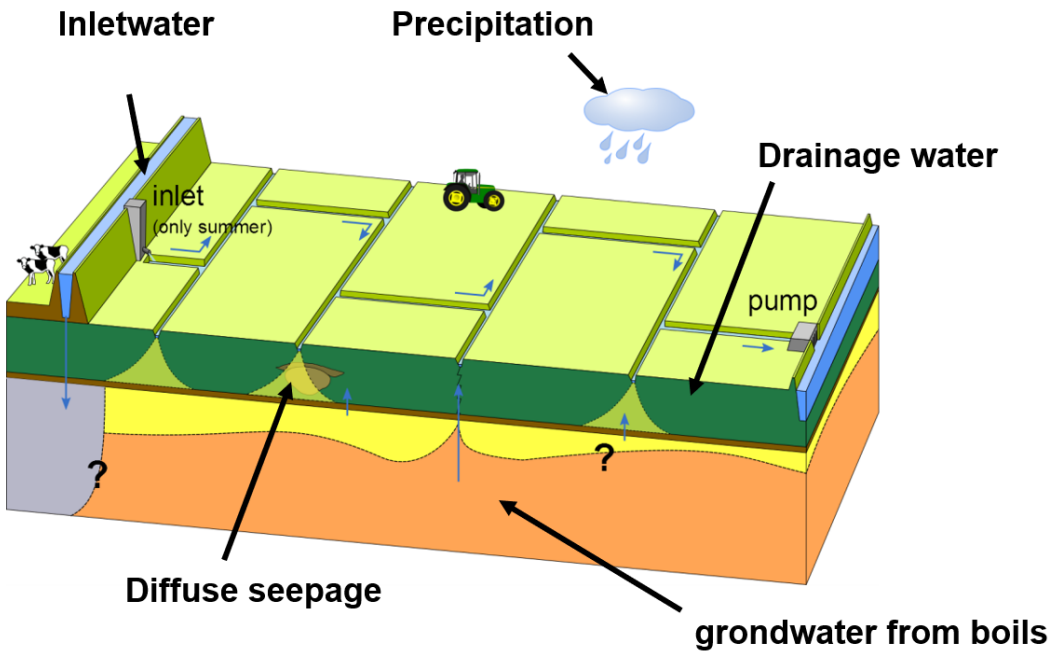


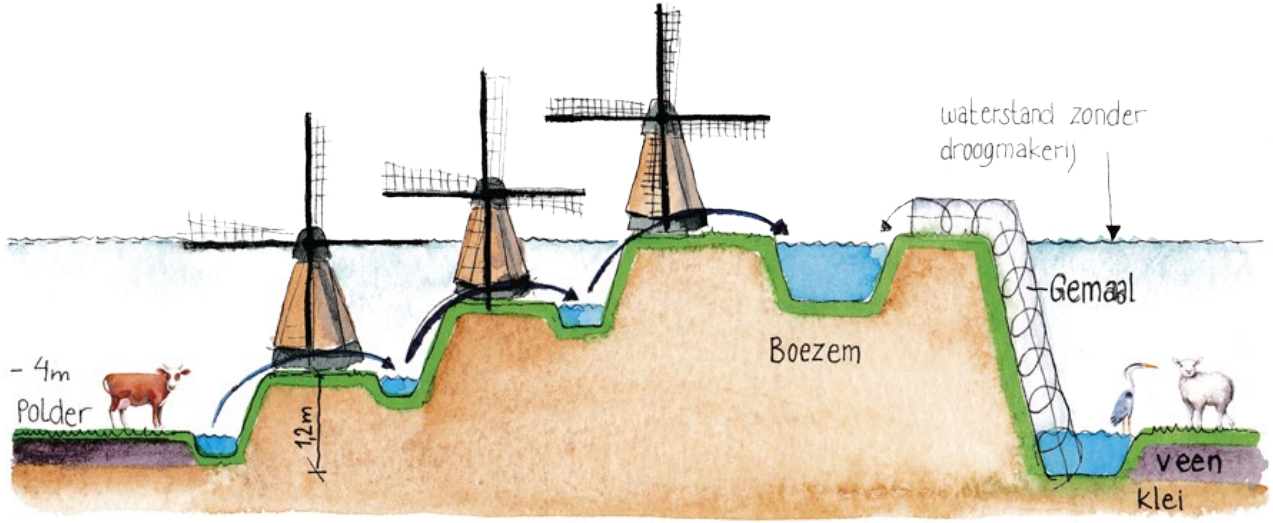


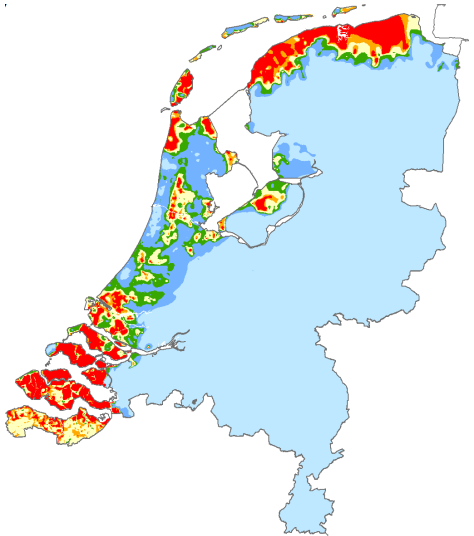
Deltares

Intermezzo 2: doorspoelen van polders met brakke kwel



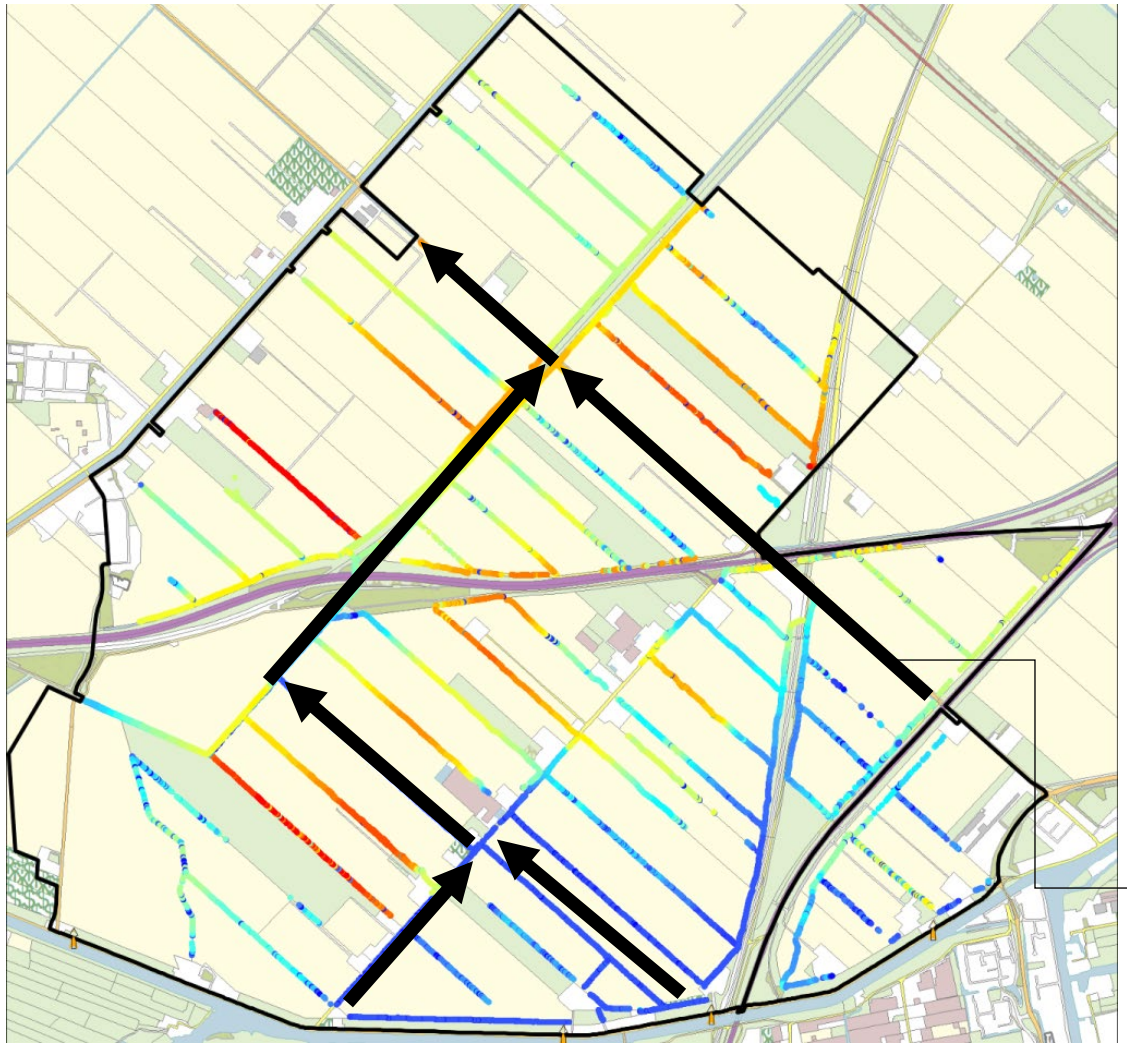






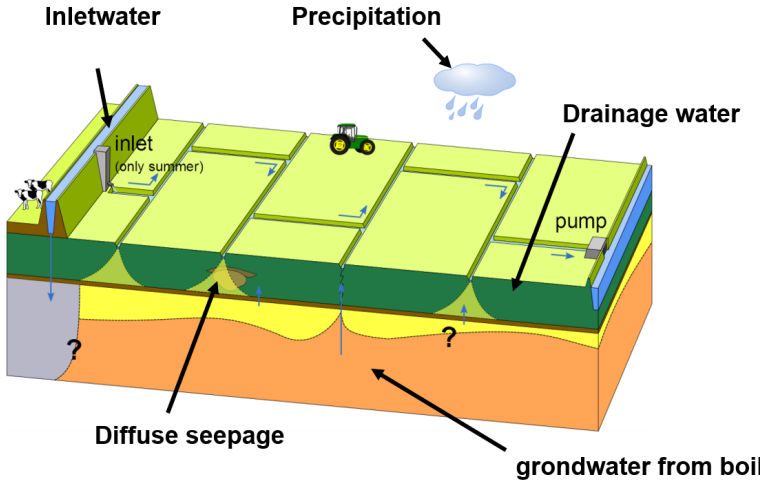
Intermezzo 2: doorspoelen van polders met brakke kwel

Ruimtelijke verdeling zout in waterlopen zuidelijk Haarlemmermeerpolder



Meting zout concentratie
- mei 2011 (droog weer)
- 70 km waterlopen…

Legenda
- blauw: ~150 mg Cl-/l
- oranje: ~1500 mg Cl-/l
- rood: > 3000 mg Cl-/l



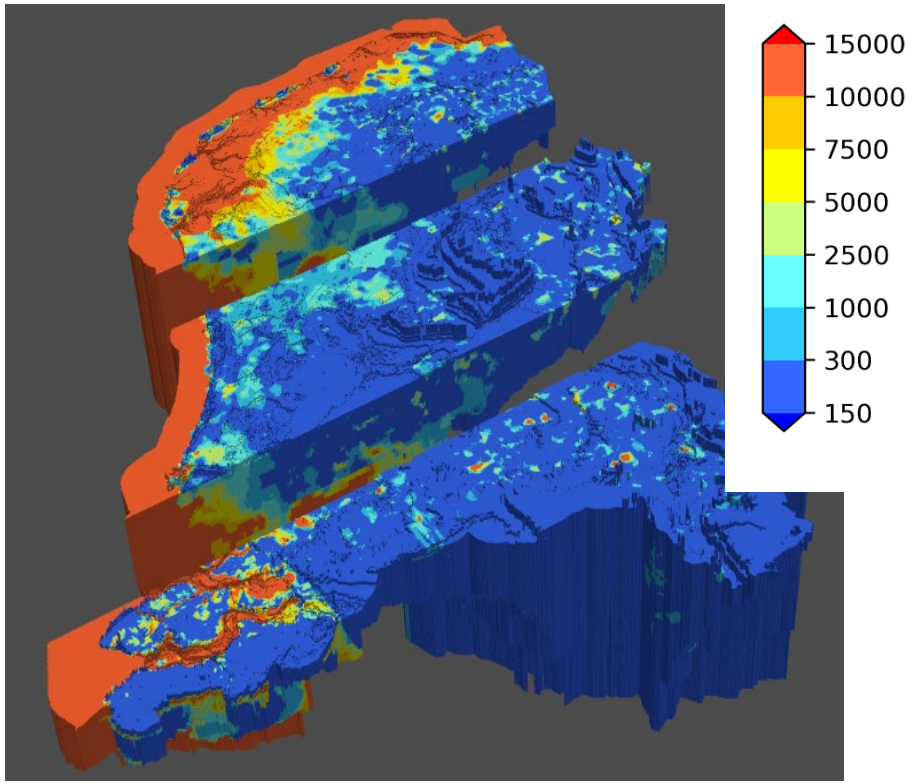
- Het zoutgehalte in sloten in diepe polders is het resultaat van mengen van zoet rivierwater (dat tijdens het groeiseizoen wordt ingelaten) met (brak) grondwater dat via drainage of rechtstreeks in de sloten uittreedt.
- Doorspoelen niet overal even effectief is om verzilting tegen te gaan; deze metingen laten zien dat binnen een km de concentratie al te zout is voor veel gewassen.

Stromingsrichting van oppervlaktewater

Delsman, 2015, link

Waar zoet-zout grondwater?

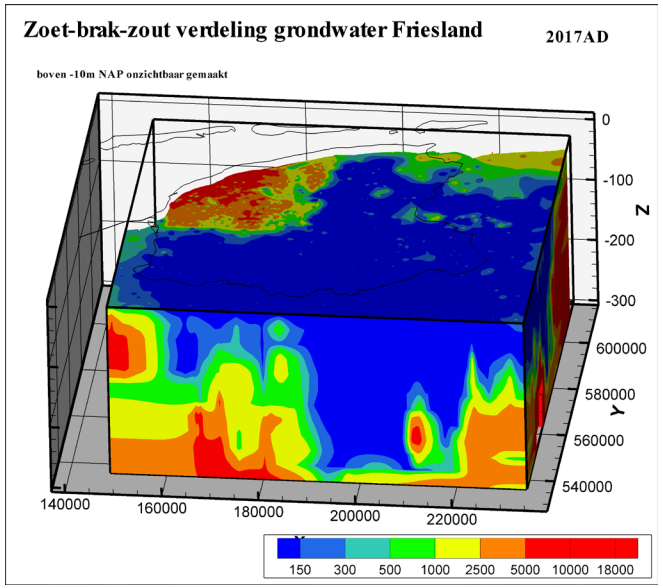
- Volume zoet grondwater Nederland: ~1100km^3
- Er wordt in Nederland per jaar 1.5km^3 grondwater onttrokken
- Het regent orde 30 km^3/jaar
- (toch is door verzilting ~20% van de winputten afgesloten)

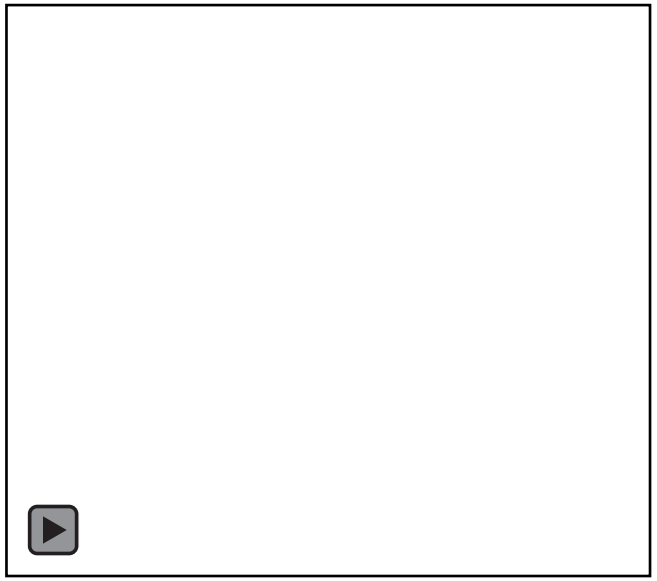


Geïnterpoleerde 3D zoet-zout verdeling (mg Cl$^-$/L)

Delsman, J.R., Oude Essink, G.H.P., Huizer, S., Bootsma, H., Mulder, T., Zitman, P., Romero Verastegui, B., 2020. Actualisatie zout in het NHI - Toolbox NHI zoet-zout modellering en landelijk model, Deltares rapport 11205261-003-BGS-0001. Utrecht. link

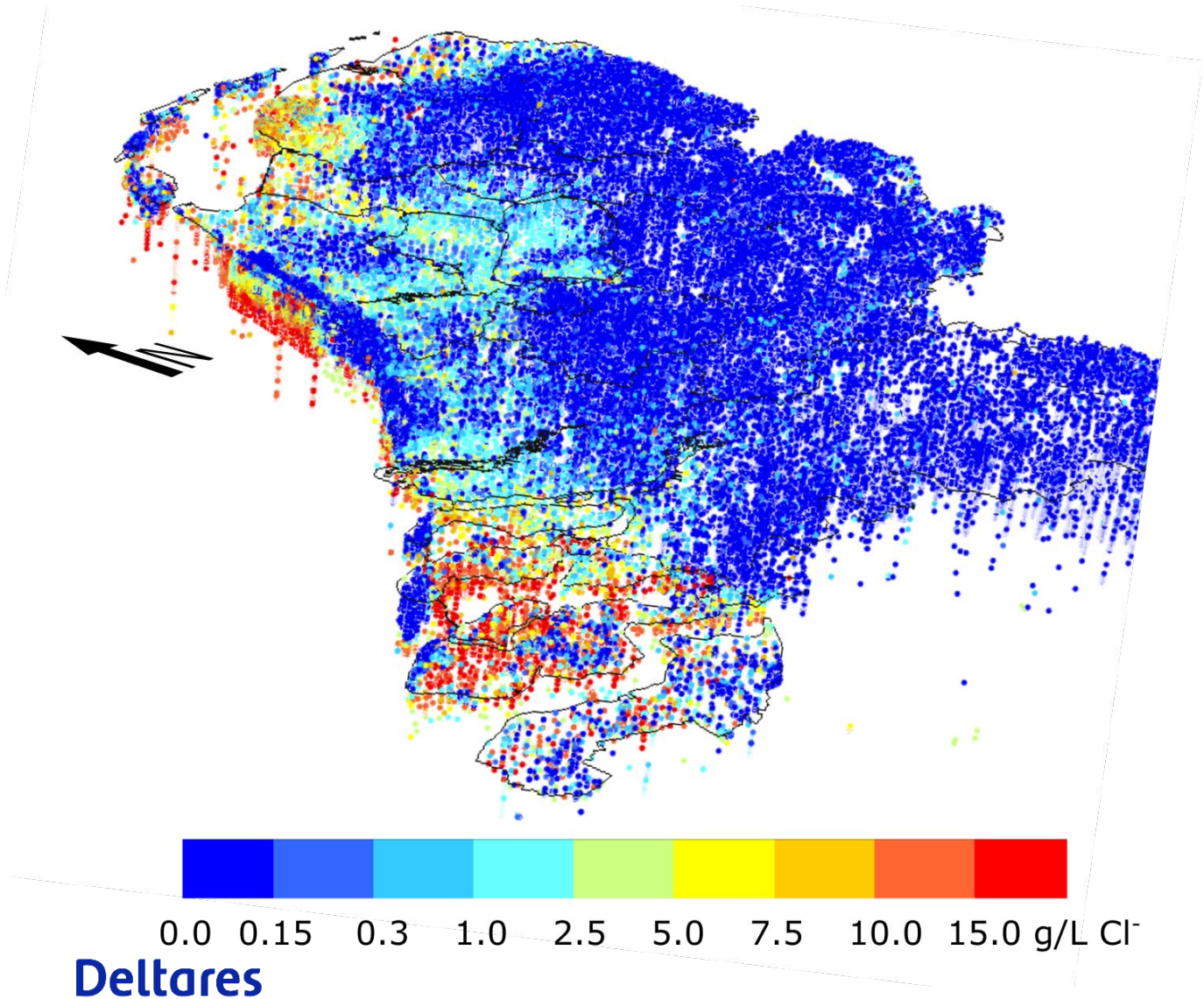


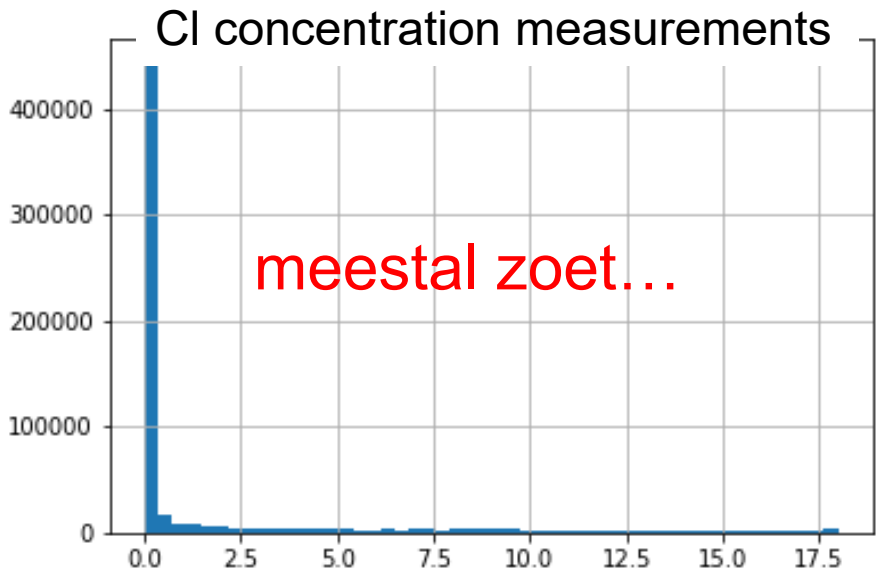


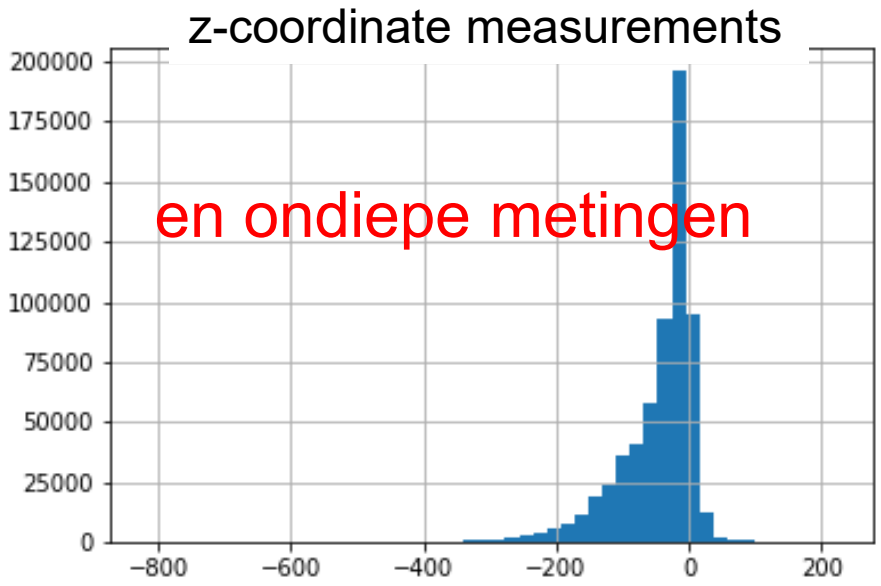


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Huidig zoet-brak-zout grondwater verdeling

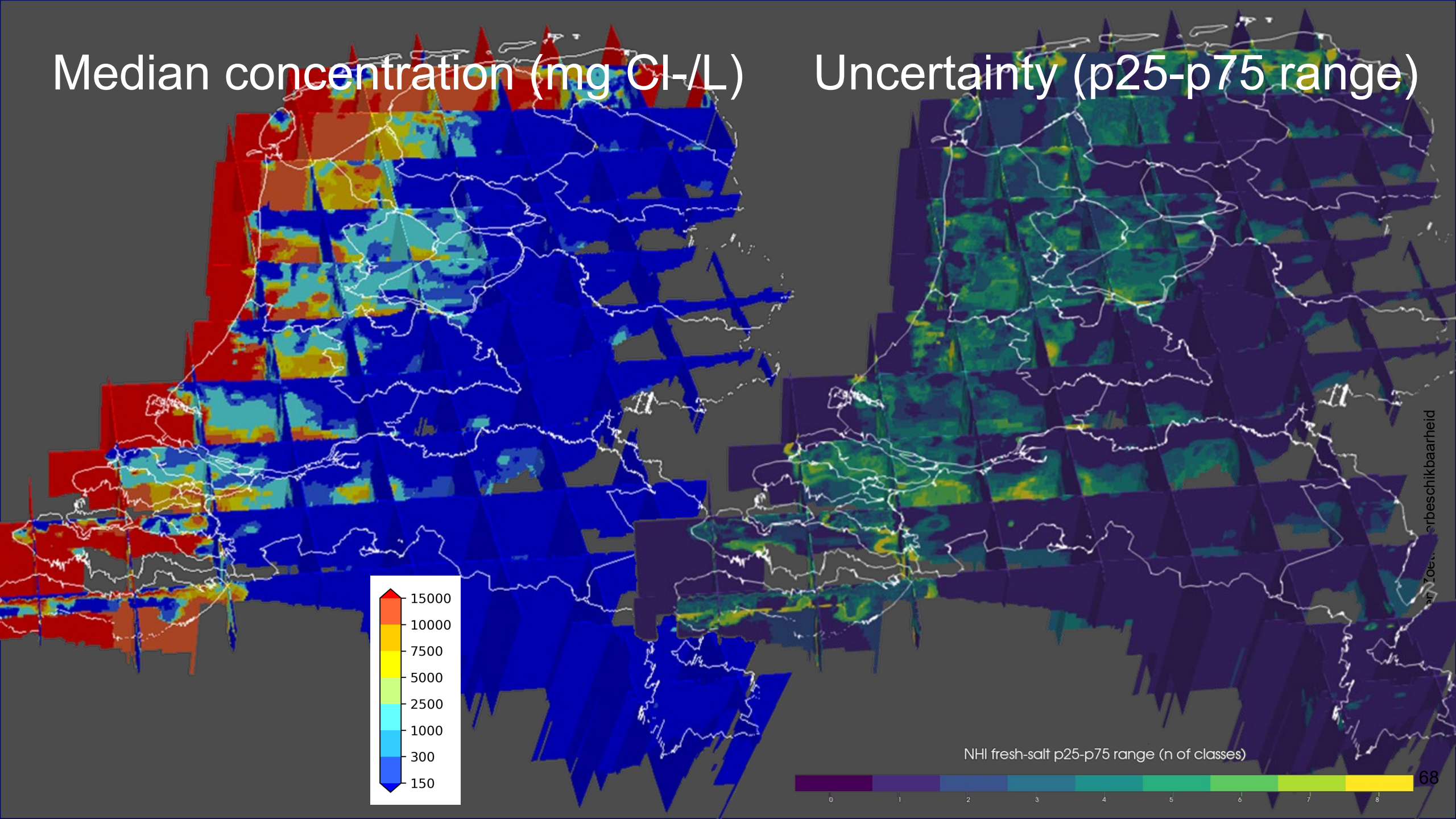






Deltares

Median concentration (mg Cl-/L)



Uncertainty (p25-p75 range)

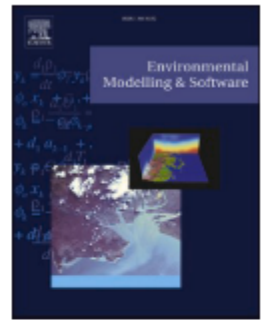
Environmental Modelling and Software 164 (2023) 105683



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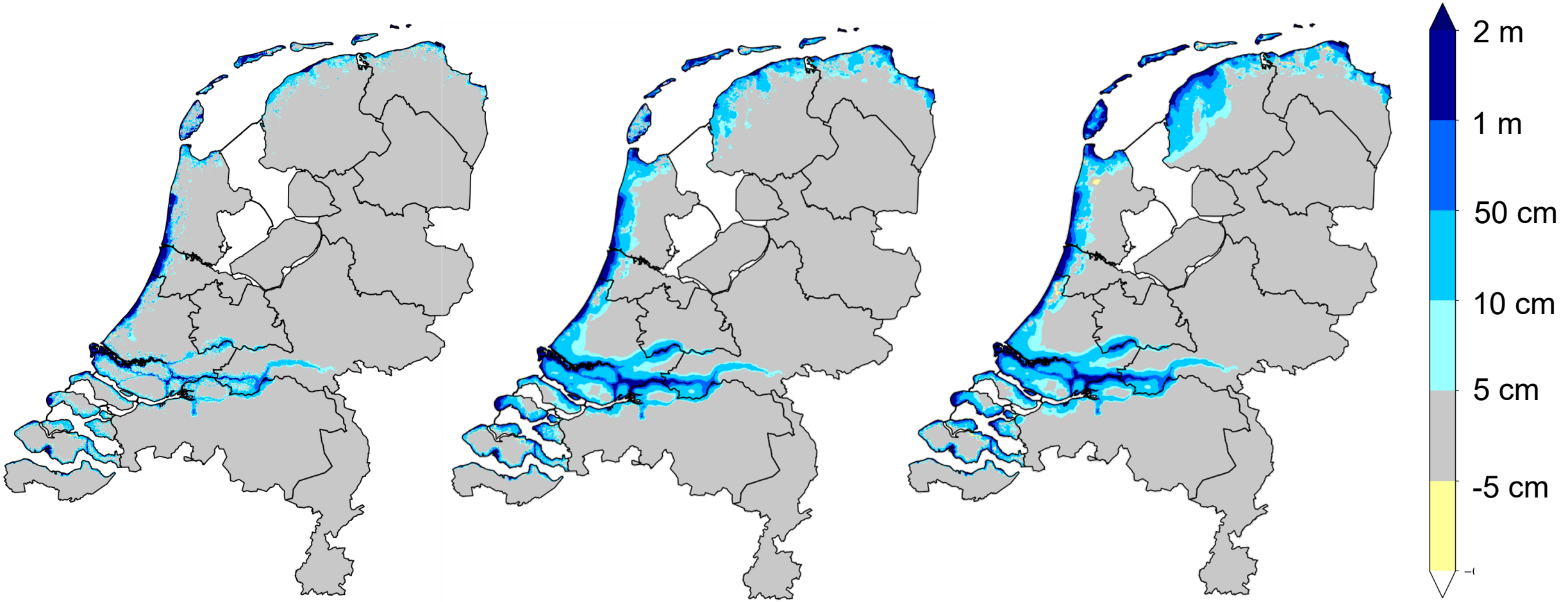


Reproducible construction of a high-resolution national variable-density groundwater salinity model for the Netherlands

Joost R. Delsman [a,*], Tobias Mulder [a,1], Betsy Romero Verastegui [a], Huite Bootsma [a], Pieter Zitman [a,2], Sebastian Huizer [b], Gualbert H.P. Oude Essink [a,c]

[a] *Deltares, Unit Subsurface and Groundwater Systems, Utrecht, the Netherlands*
[b] *Arcadis, Department Land & Watermanagement, Arnhem, the Netherlands*
[c] *Utrecht University, Department of Physical Geography, Utrecht, the Netherlands*

Effect zeespiegelstijging merkbaar tot zo'n 10 km van kustlijn en open wateren



grondwaterstand

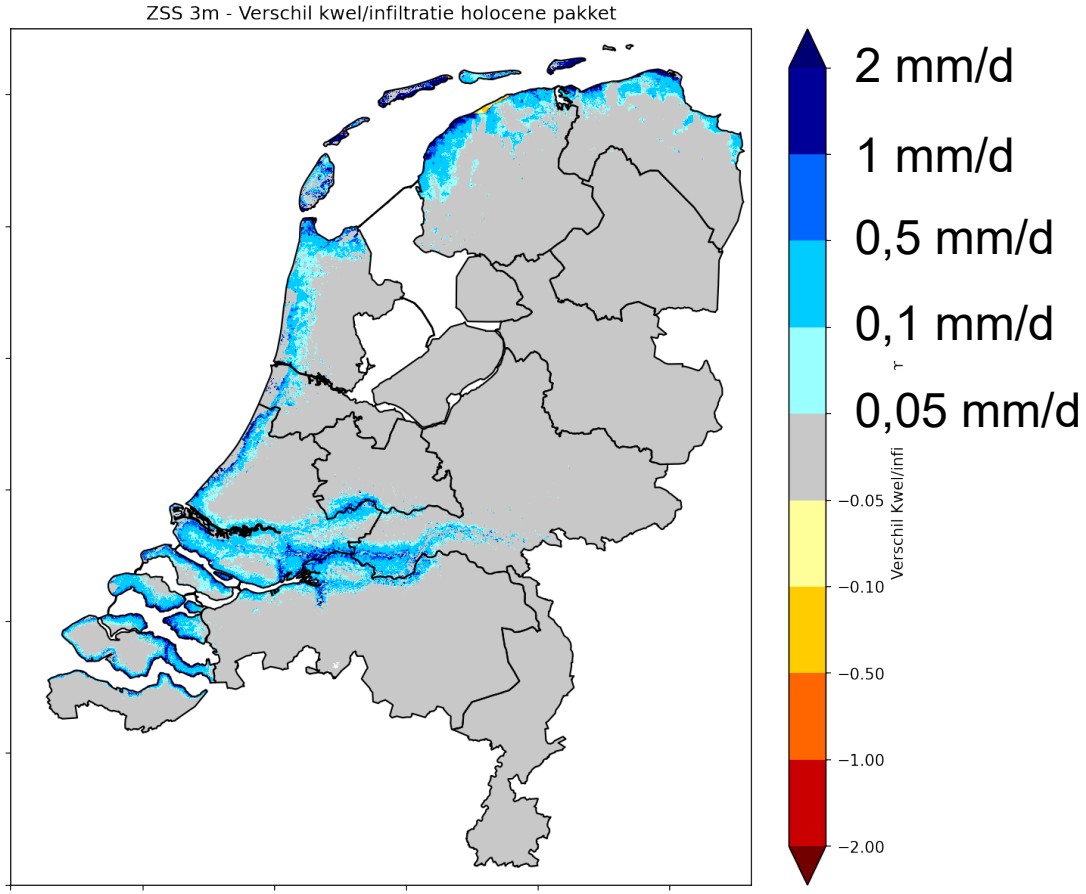
watervoerend pakket 1

watervoerend pakket 2

Deltares

"Verschil stijghoogte ZSS 3 m ten opzichte van autonoom"

Kweldruk neemt toe, kwelbezwaar niet alarmerend



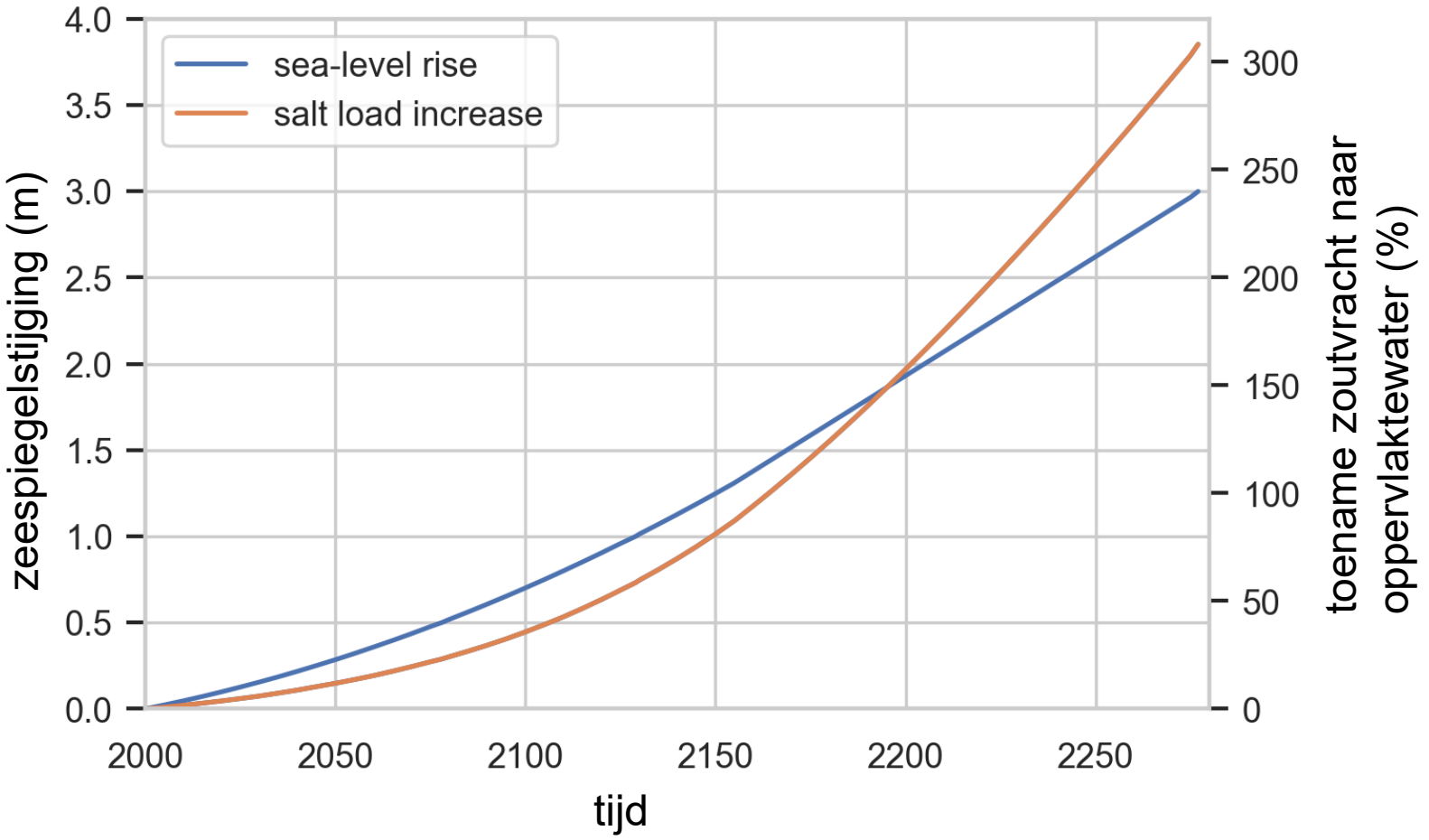


piekbui van 35 mm versus 2 mm…

voor bemalingscapaciteit is meteorologie leidend

“Verschil kwel ZSS 3m ten opzichte van autonoom”

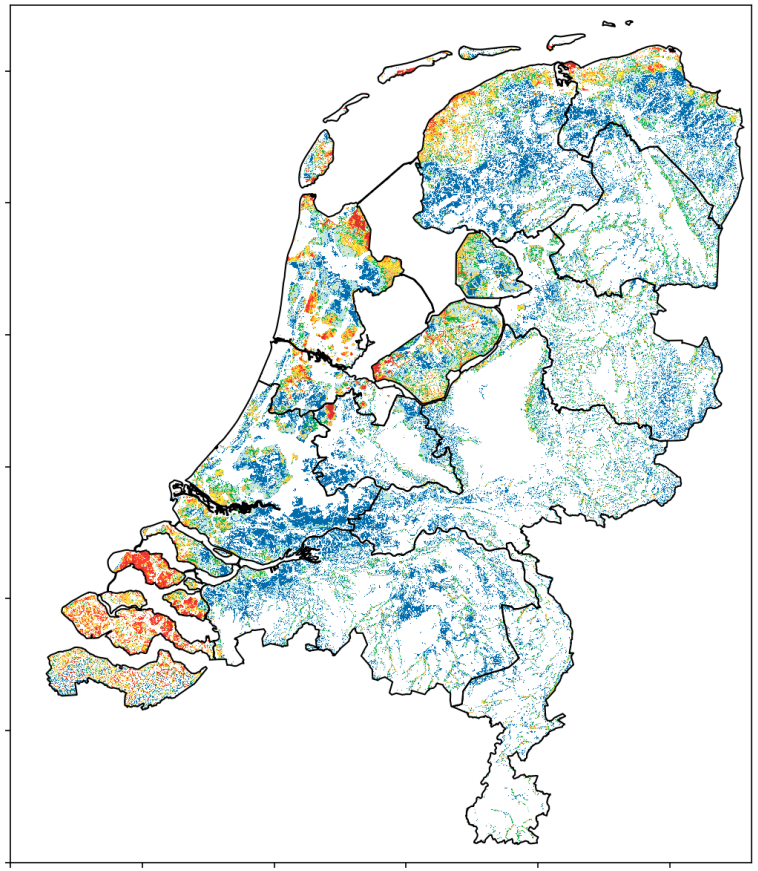
Zoutvracht naar oppervlaktewater neemt toe met ZSS



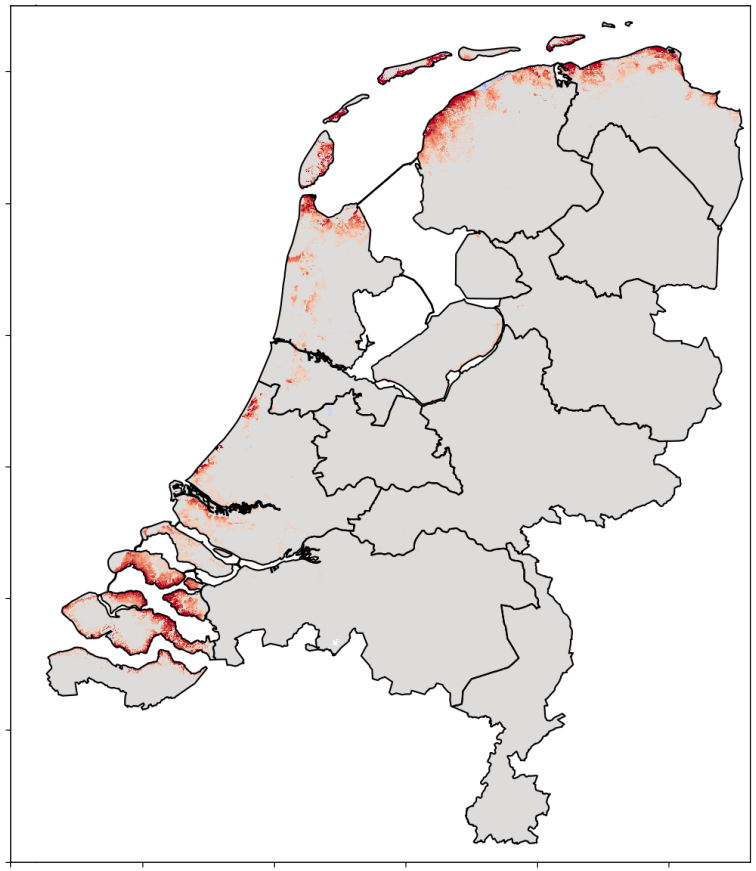
Tot ~2100: min of meer lineair met zeespiegelstijging, versnelling door langzame grondwaterstroming

Zoutlast neemt toe, ook in ‘nieuwe’ gebieden

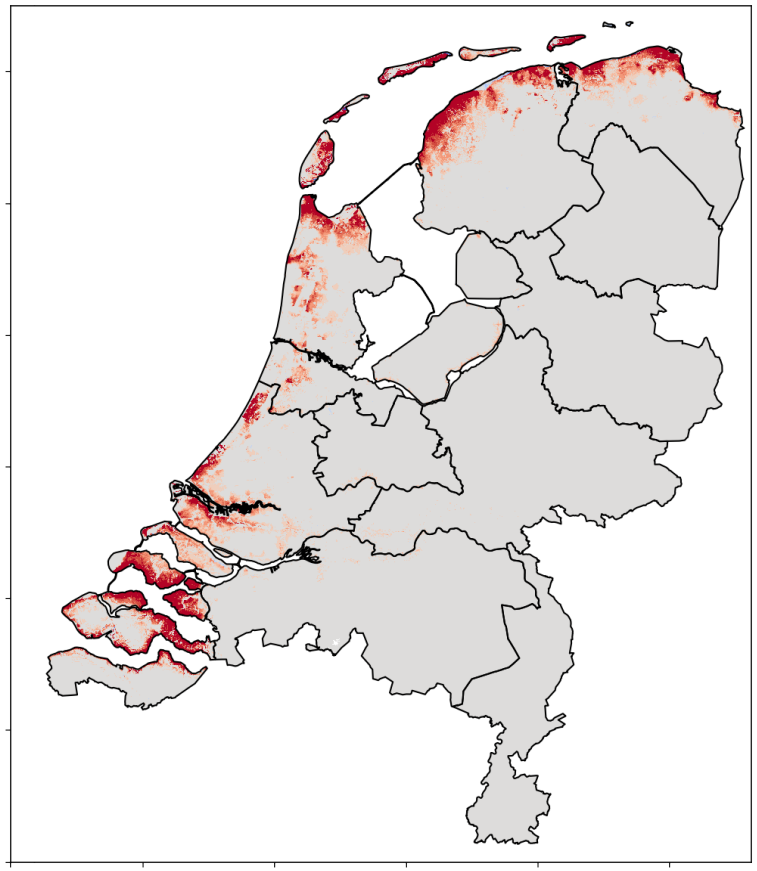
zoutlast huidig

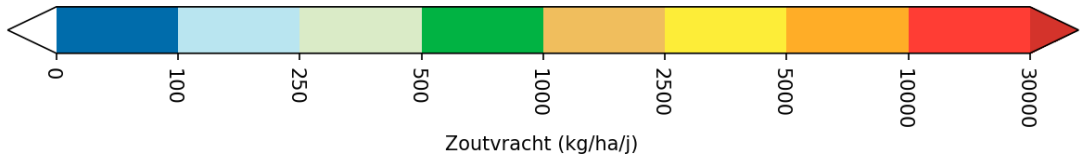


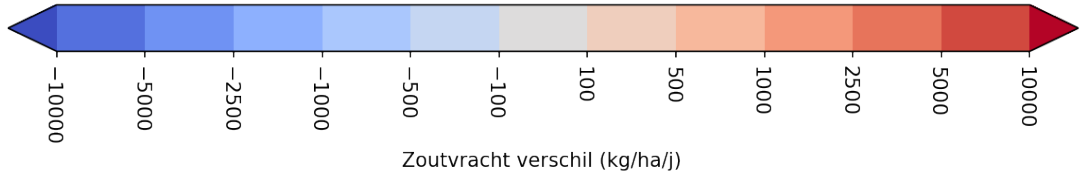
zoutlast toename 1m ZSS



zoutlast toename 3m ZSS

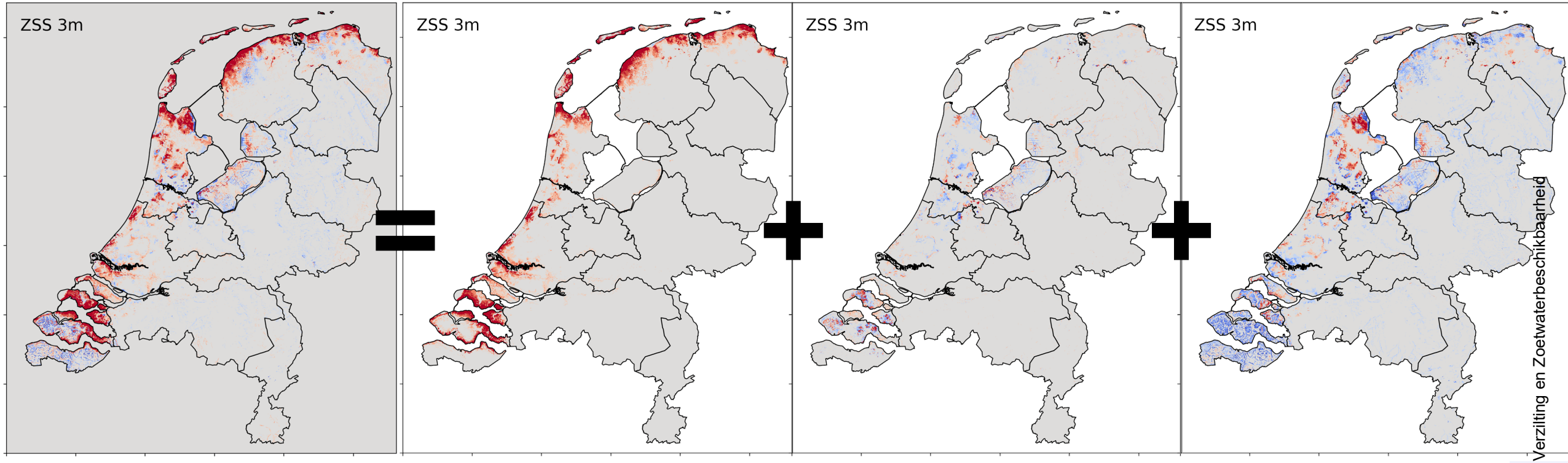






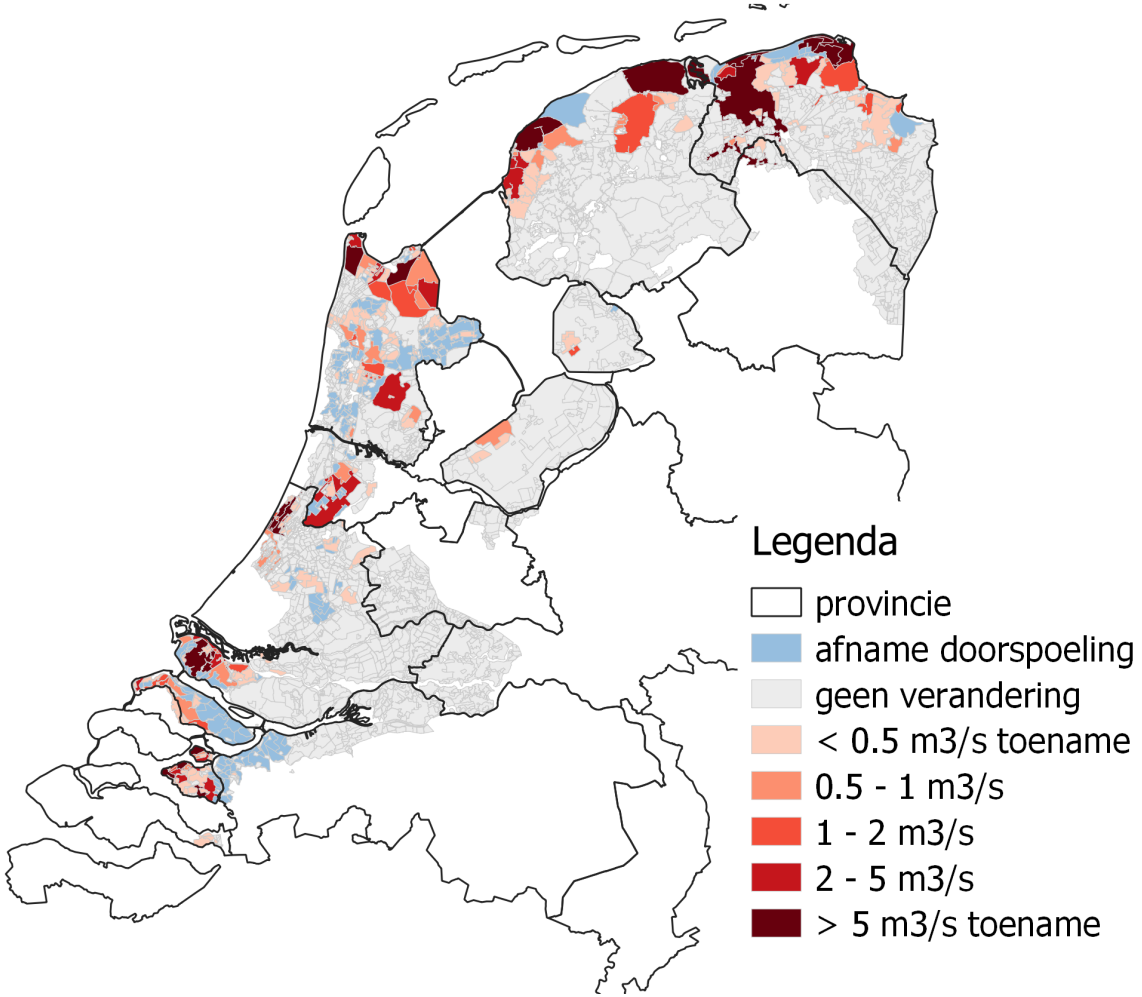
Zeespiegelstijging is dominant in toename zoutvracht

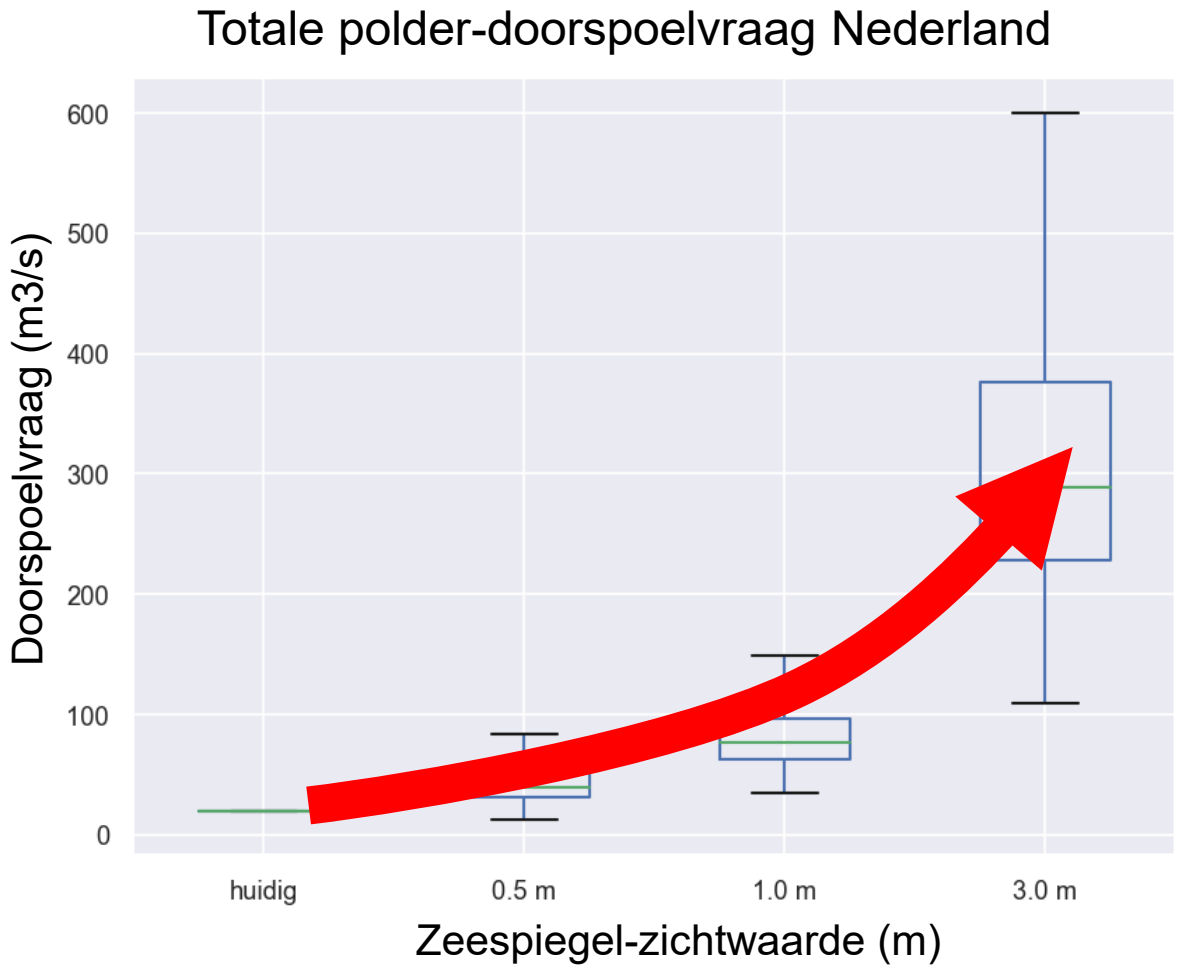
Totaal = ZSS + bodemdaling + autonoom (+ inspelen)



Doorspoelbehoefte bij gelijk beheer neemt sterk toe

Absolute verandering doorspoeling polders bij ZSS 3m (m3/s)

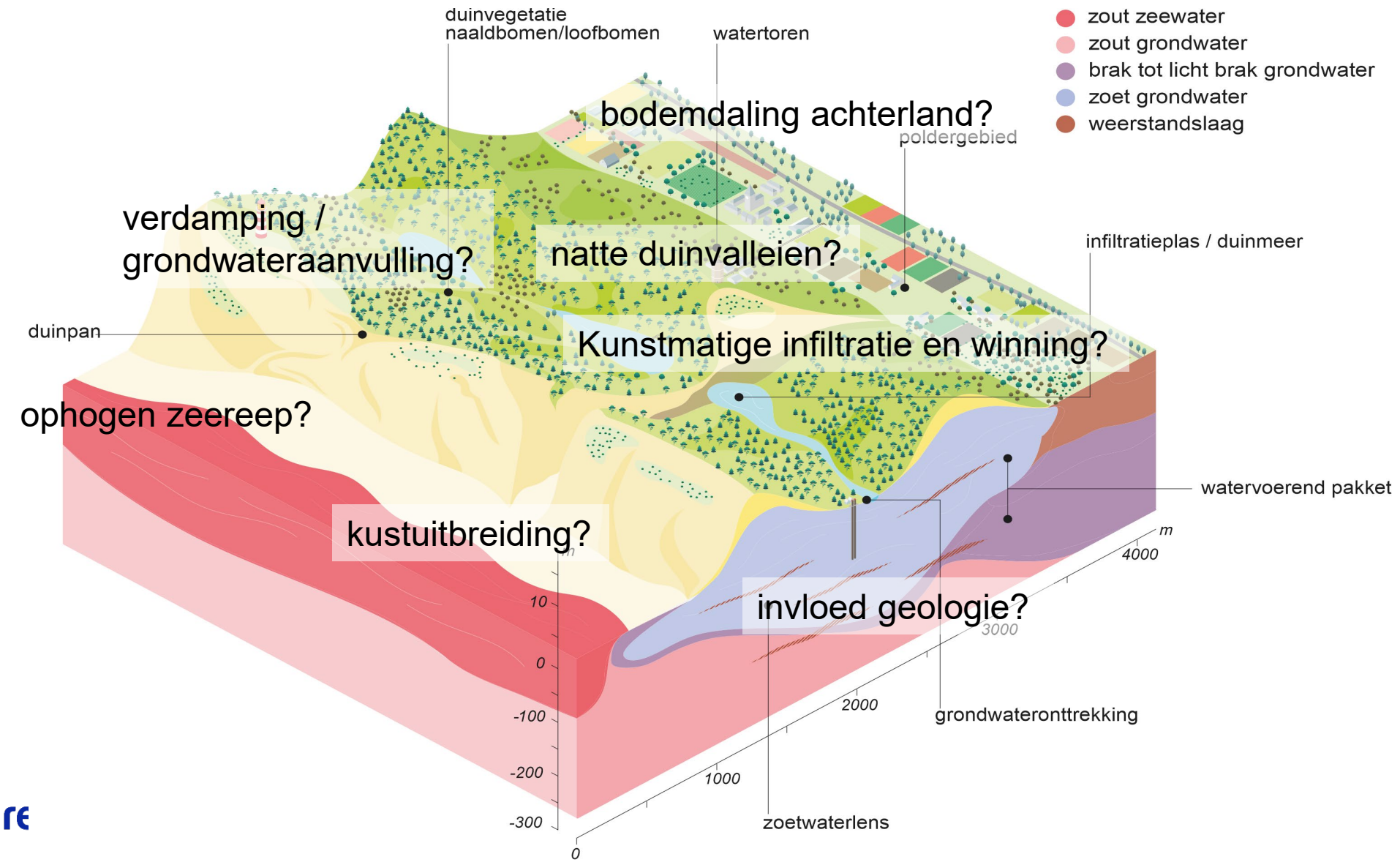




<u>Uitgangspunt: handhaven huidige concentratie in sloot</u>

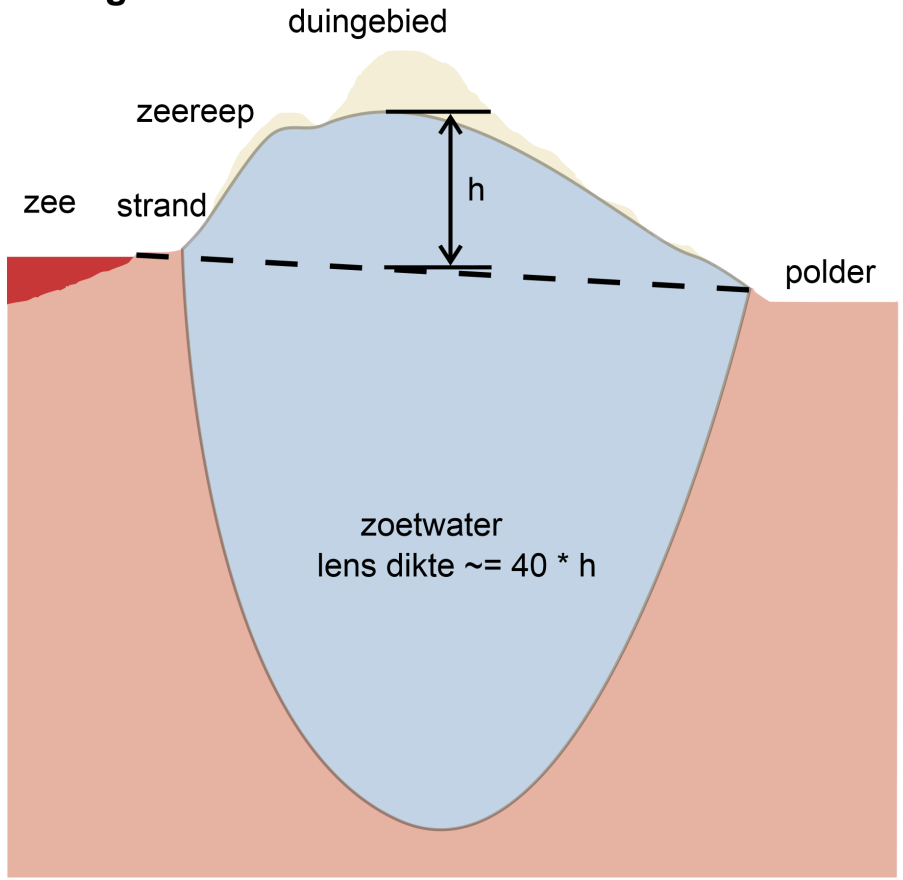
Effecten zeespiegelstijging op zoetwater in de Nederlandse duinen

Processen die zoete grondwatervoorraden in de duinen beïnvloeden

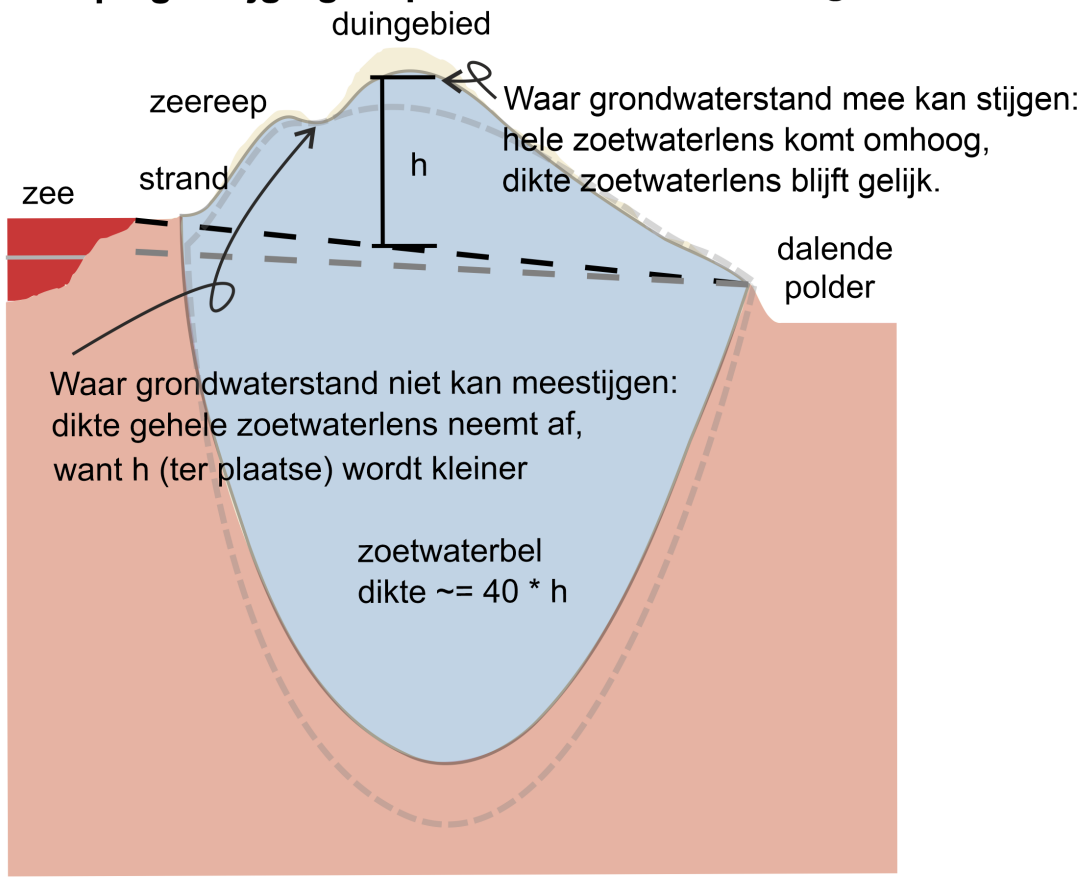


Effect maaiveld in het duingebied

Huidige situatie

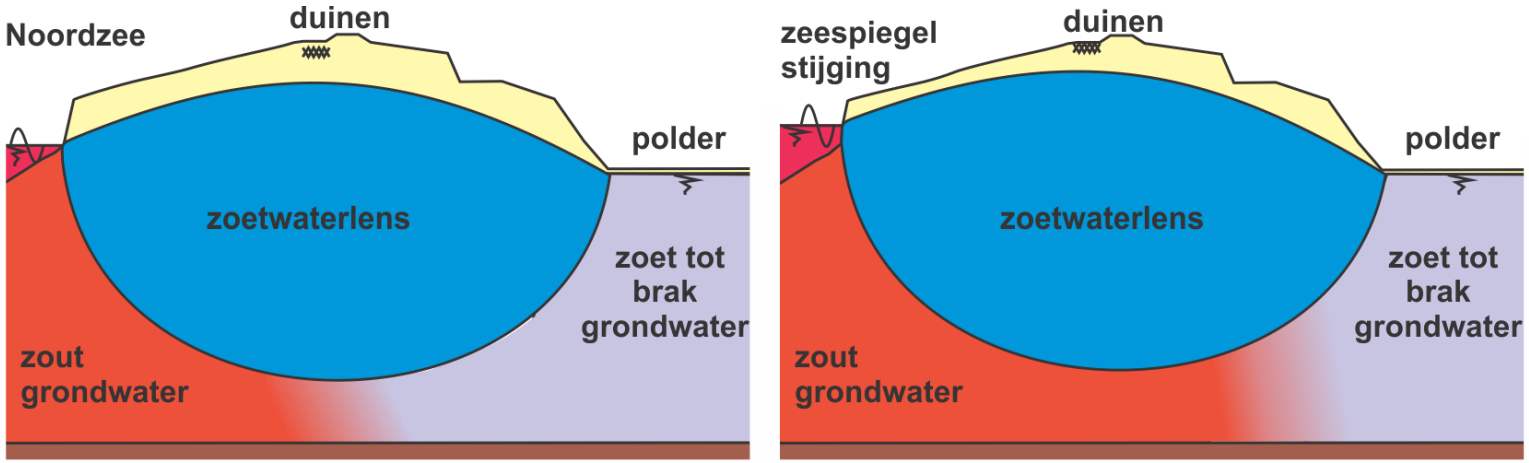


Zeespiegelstijging en polder met bodemdaling

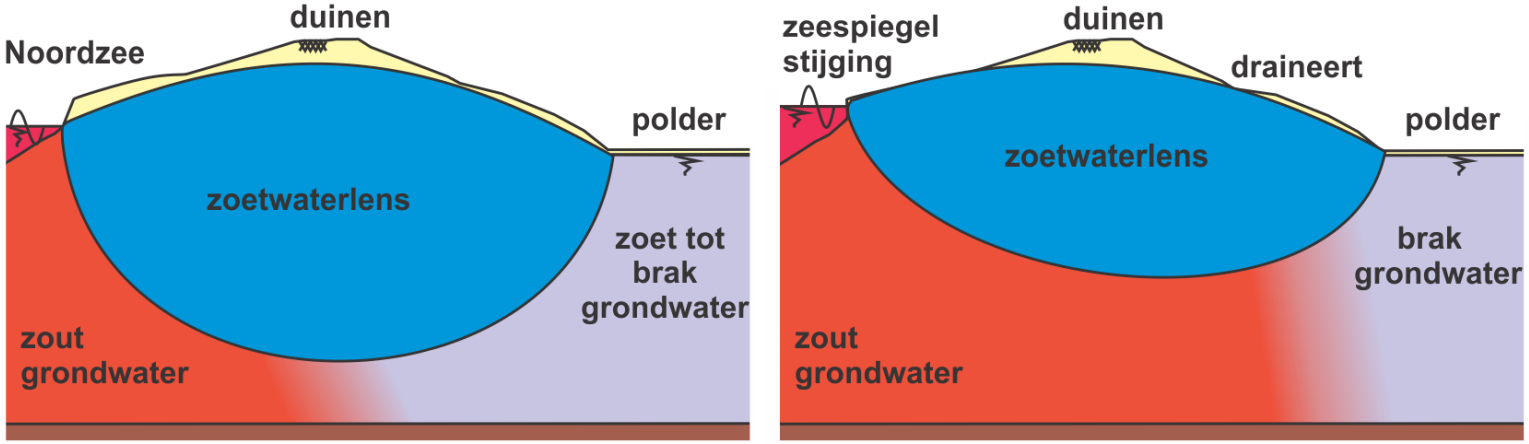


Effect maaiveld op zoet grondwater in duinen

Maaiveld hoog



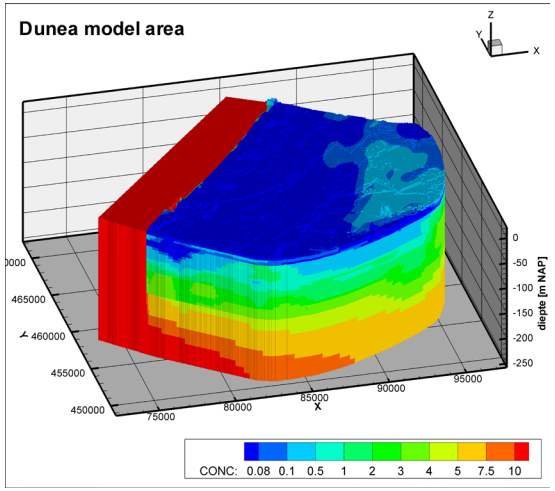
Maaiveld laag

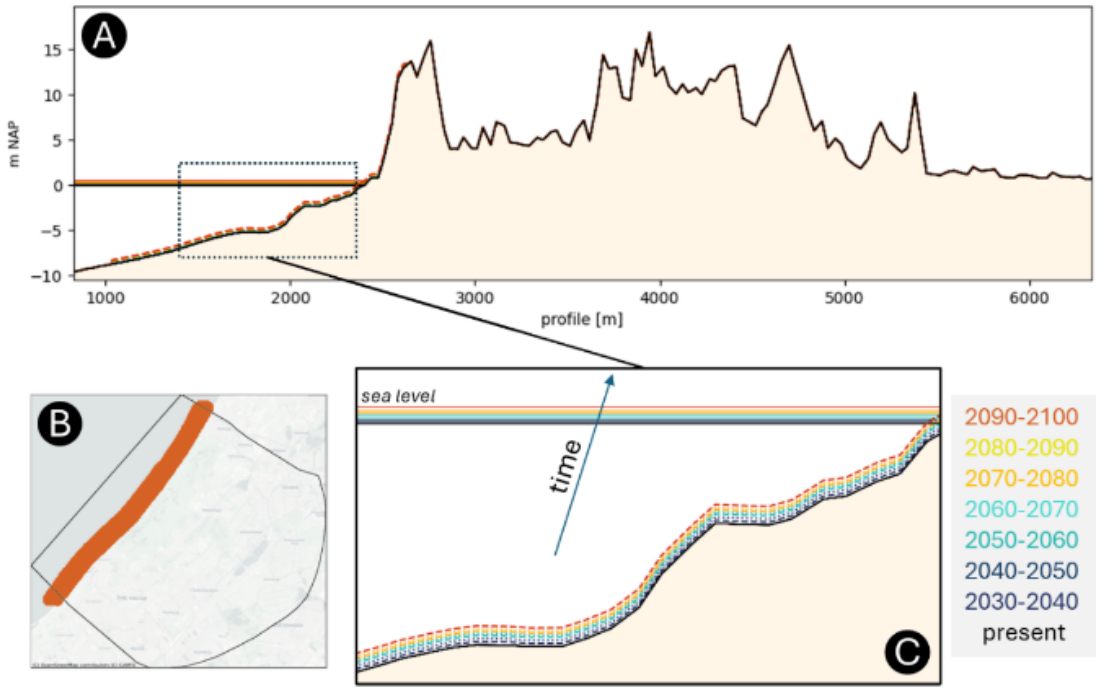


Deltares

Modelaanpak

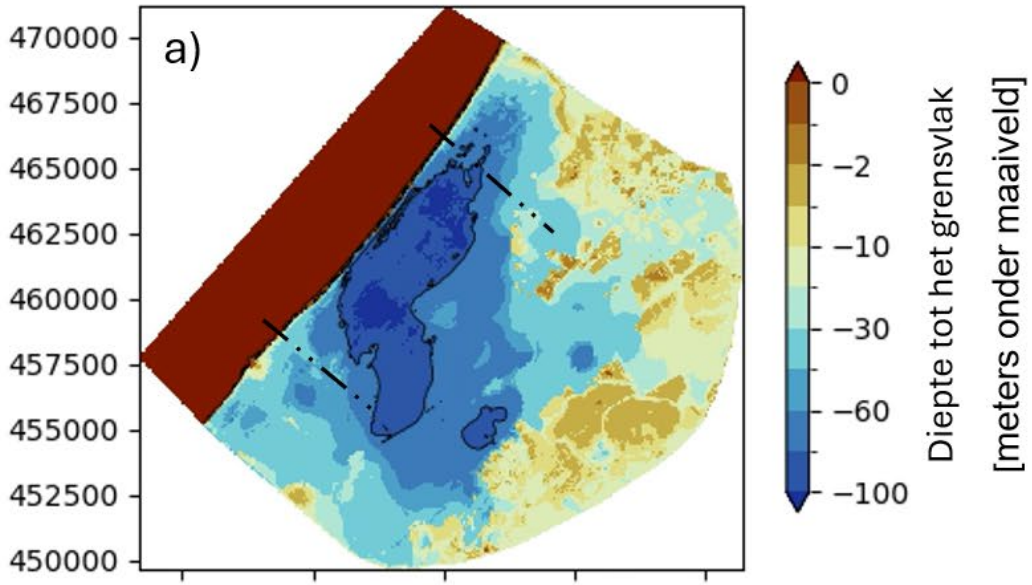
1. 3D zoet-zout gekalibreerd grondwatermodel duingebied Dunea (Den Haag – Meijendel - Berkheide)
   - ZSS 2100: 0 m, 0.5 m, 1.0 m
   - ZSS 2150: 3 m
   - Zandsuppleties
   - Bodemdaling
   - Klimaat: grondwateraanvulling +3%, -3%, -8%
   - Effecten onzekerheid geologie
   - Combinatiescenario's

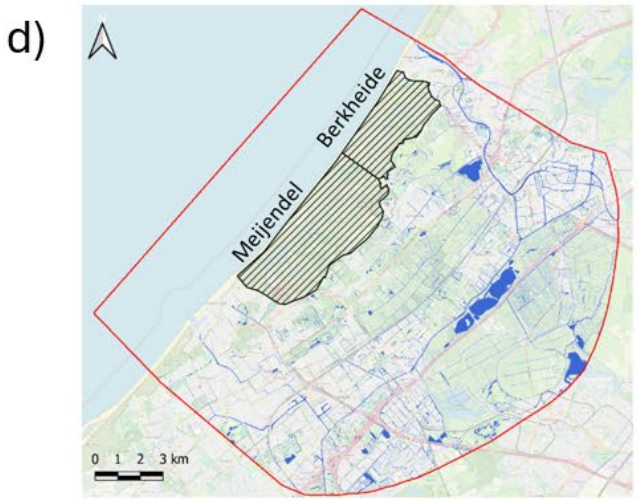


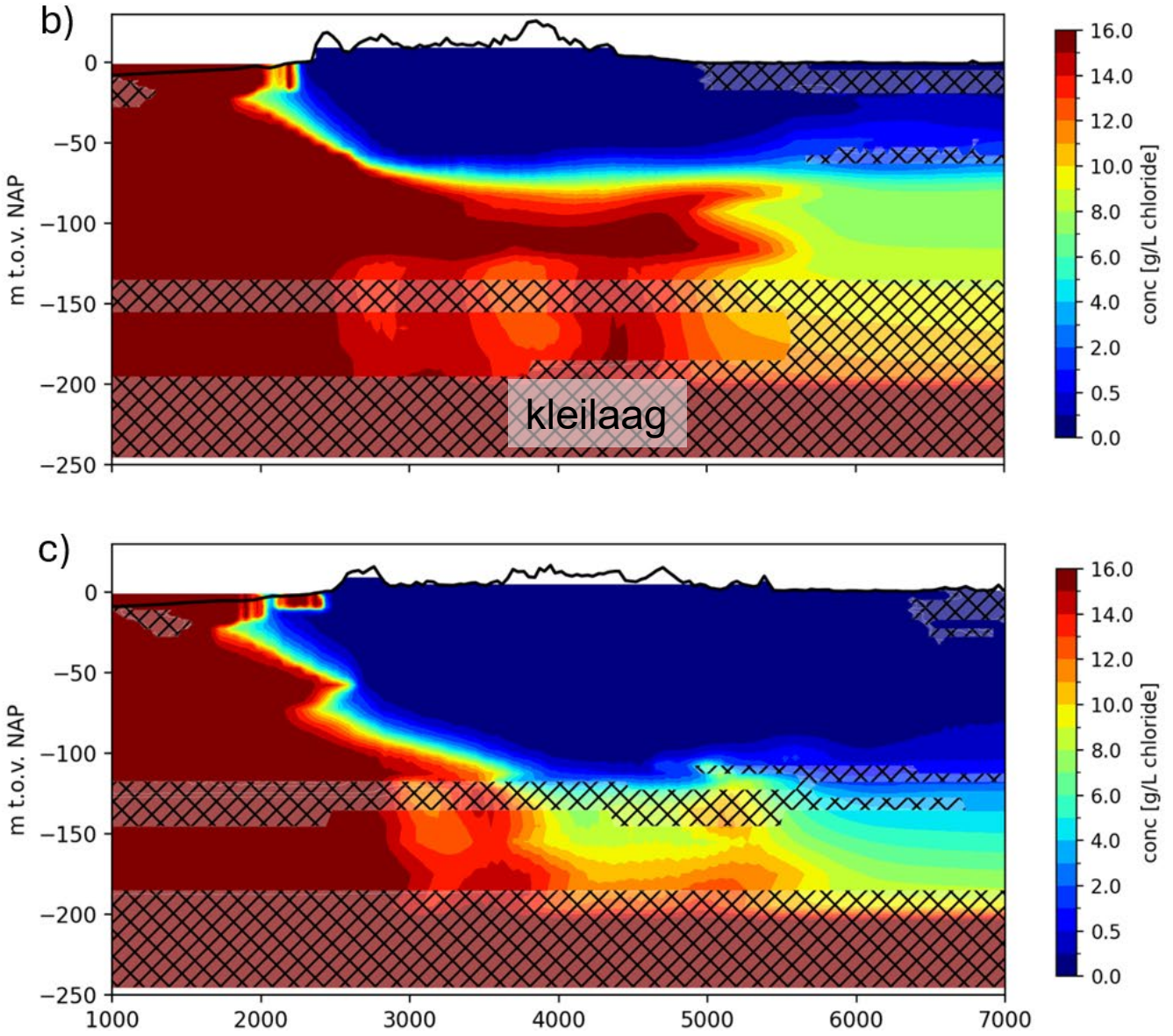


2. 2D profielen op 9 locaties langs de Hollandse kust + Wadden
   - ZSS 2150: 3m (1.35m in 2100)

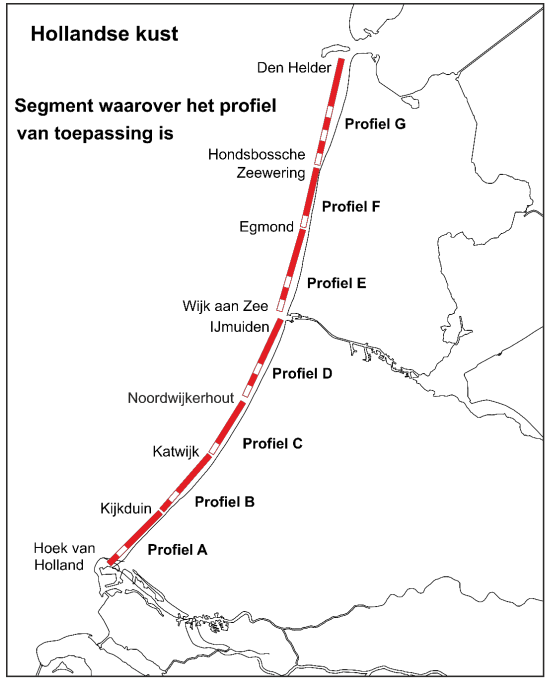
3D zoet-zout grondwatermodel duingebied Dunea

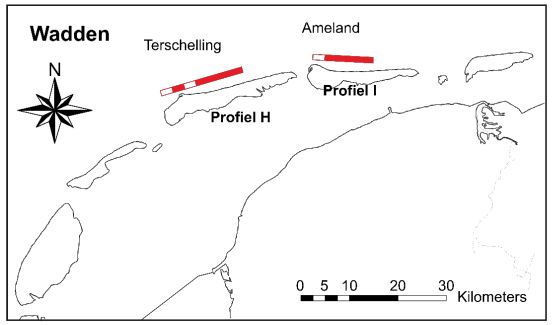


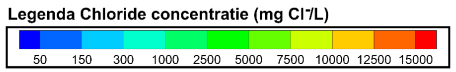


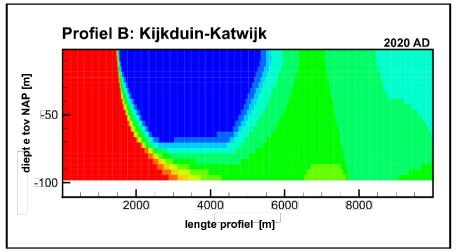


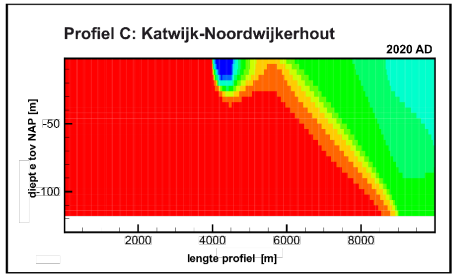
2D profielen op 9 locaties langs de Hollandse kust + Wadden

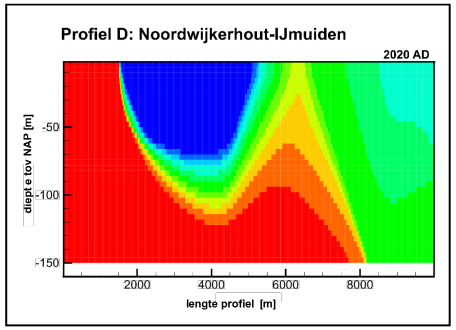


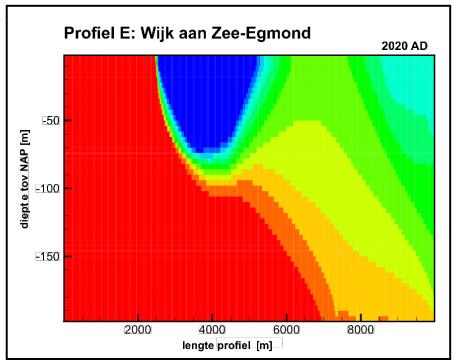


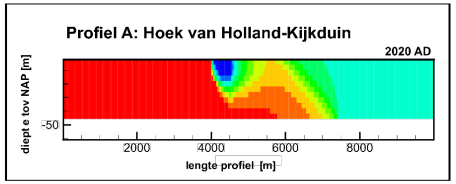


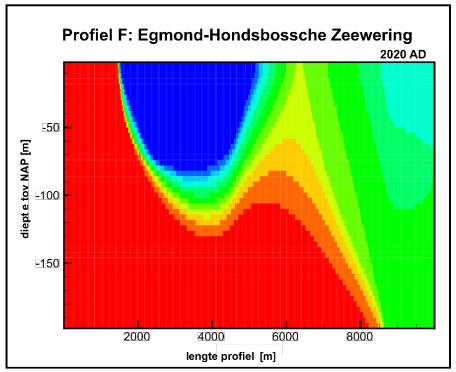


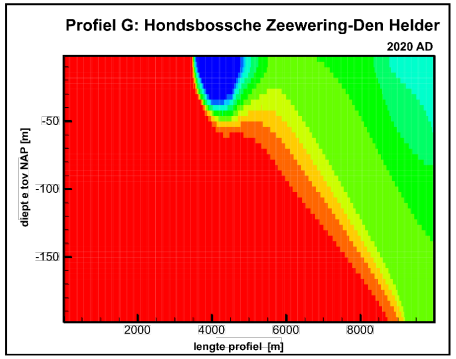


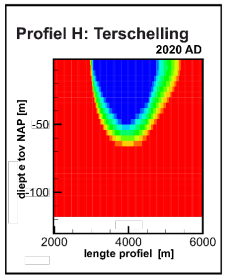


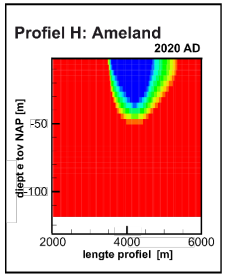






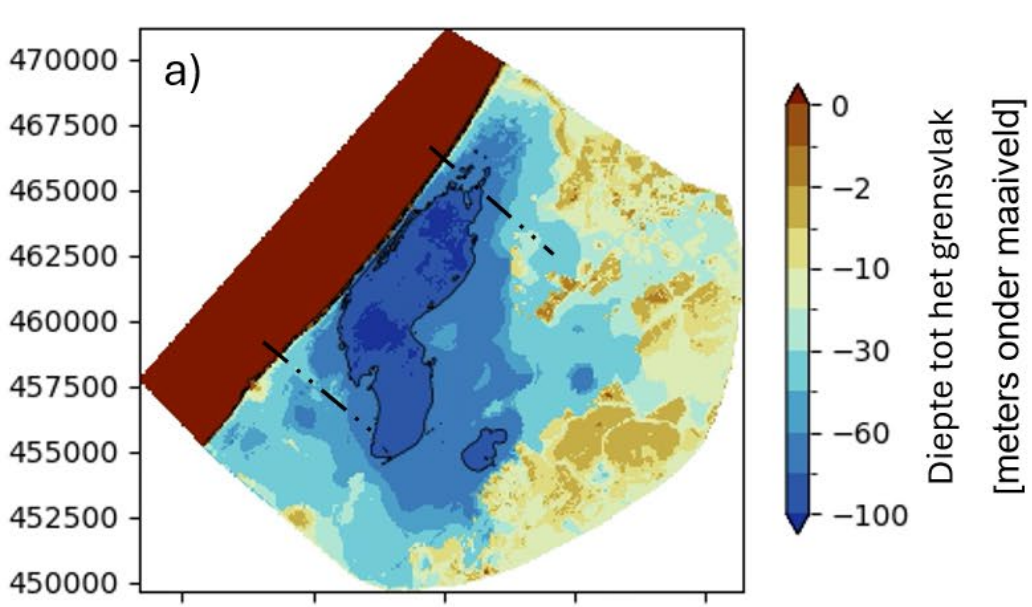


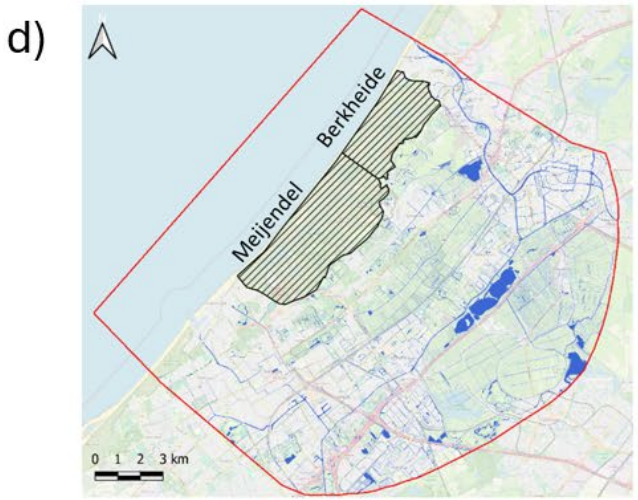


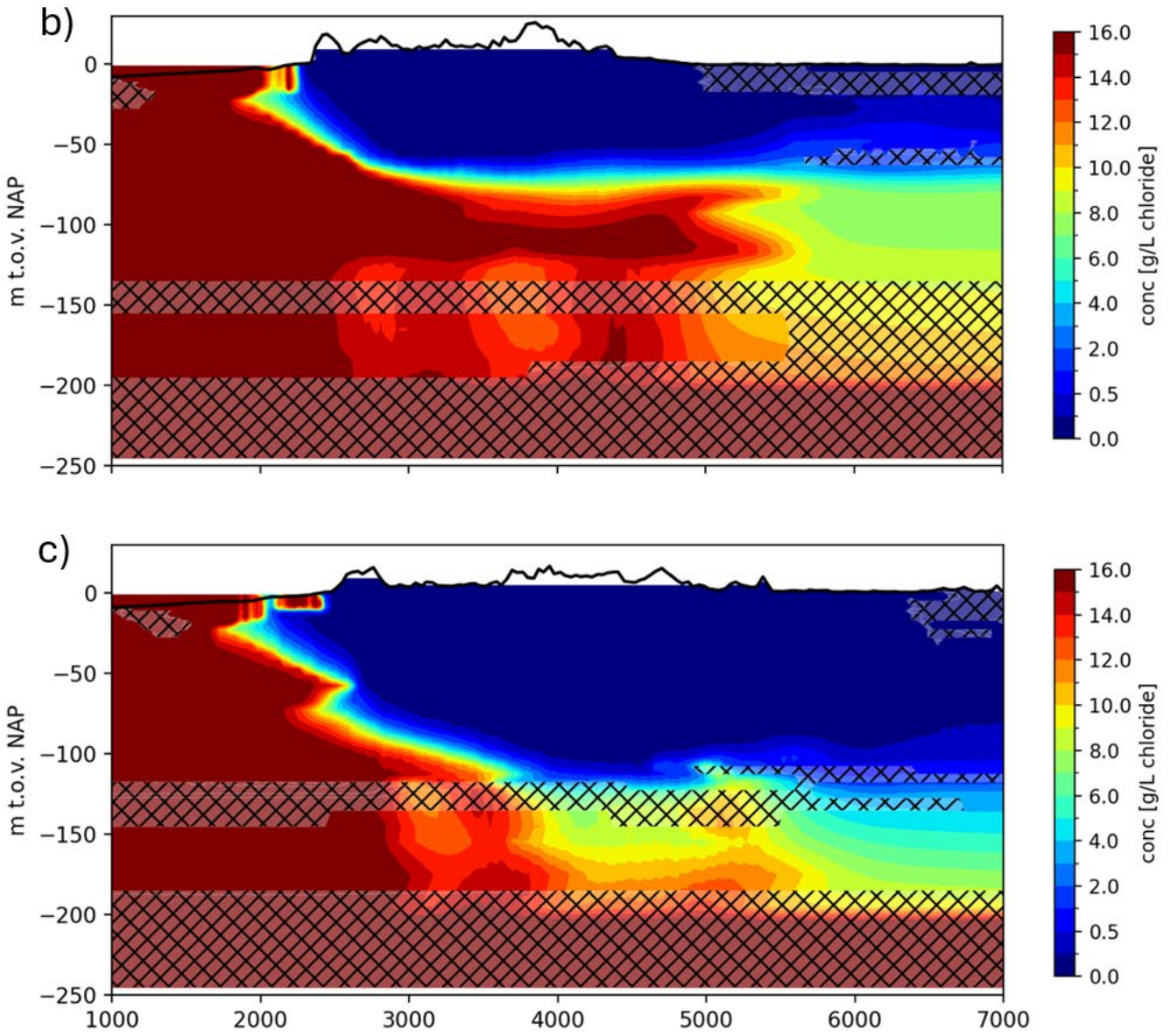


Deltares

3D zoet-zout grondwatermodel duingebied Dunea



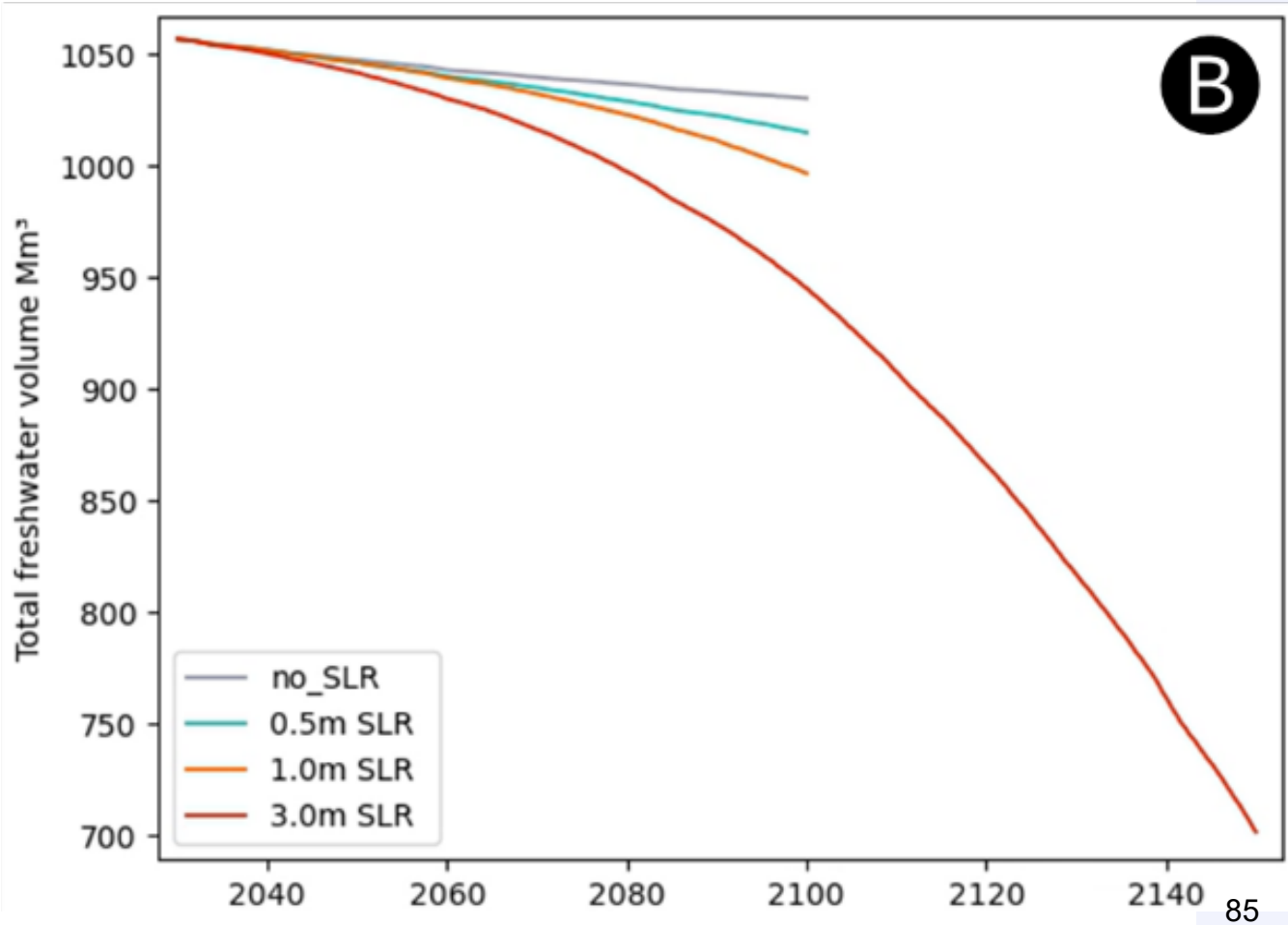




Resultaten 3D zoet-zout grondwatermodel

- Zeespiegelstijging (SLR)

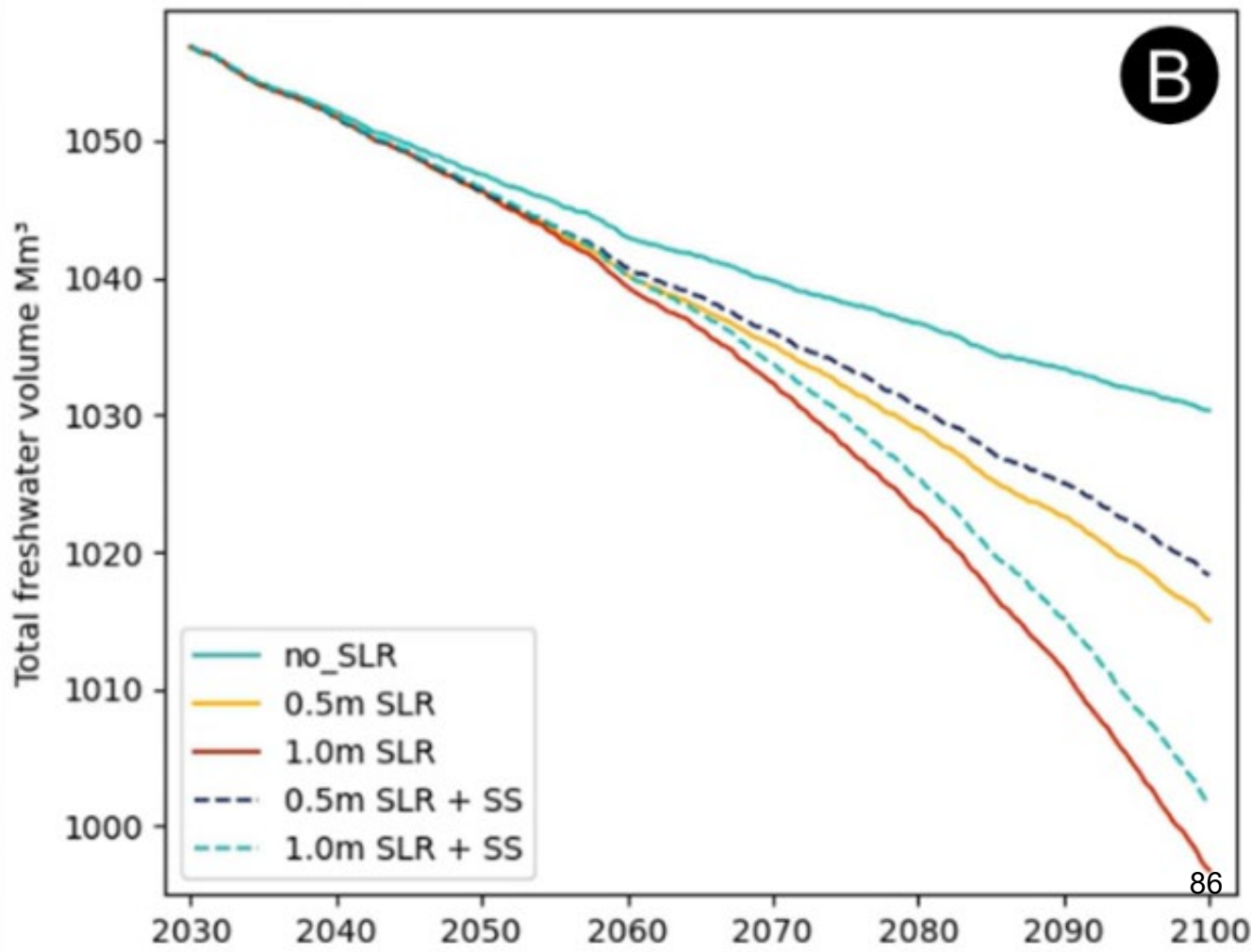
Scenario	Laatste simulatiejaar	Zoetwatervolume [Mm³]	Verandering (t.o.v. referentie)
Referentiesituatie	2020	1057.0	
no_SLR	2100	1030.3	-2.5%
0.5m SLR	2100	1015.0	-4.0%
1.0m SLR	2100	996.8	-5.7%
3.0m SLR	2150	701.7	-33.6%



Resultaten 3D zoet-zout grondwatermodel

- Zeespiegelstijging (SLR)
- Zandsuppletie (SS)
- Zeespiegelstijging (SLR) + Zandsuppletie (SS)

Scenario	Laatste simulatiejaar	Zoetwatervolume [Mm³]	Verandering (t.o.v. referentie)
Referentiesituatie	2020	1057.0	
no_SLR + SS	2100	1033.4	-2.2%
0.5m SLR	2100	1015.0	-4.0%
0.5m SLR + SS	2100	1018.3	-3.7%
1.0m SLR	2100	996.8	-5.7%
1.0m SLR + SS	2100	1001.7	-5.2%

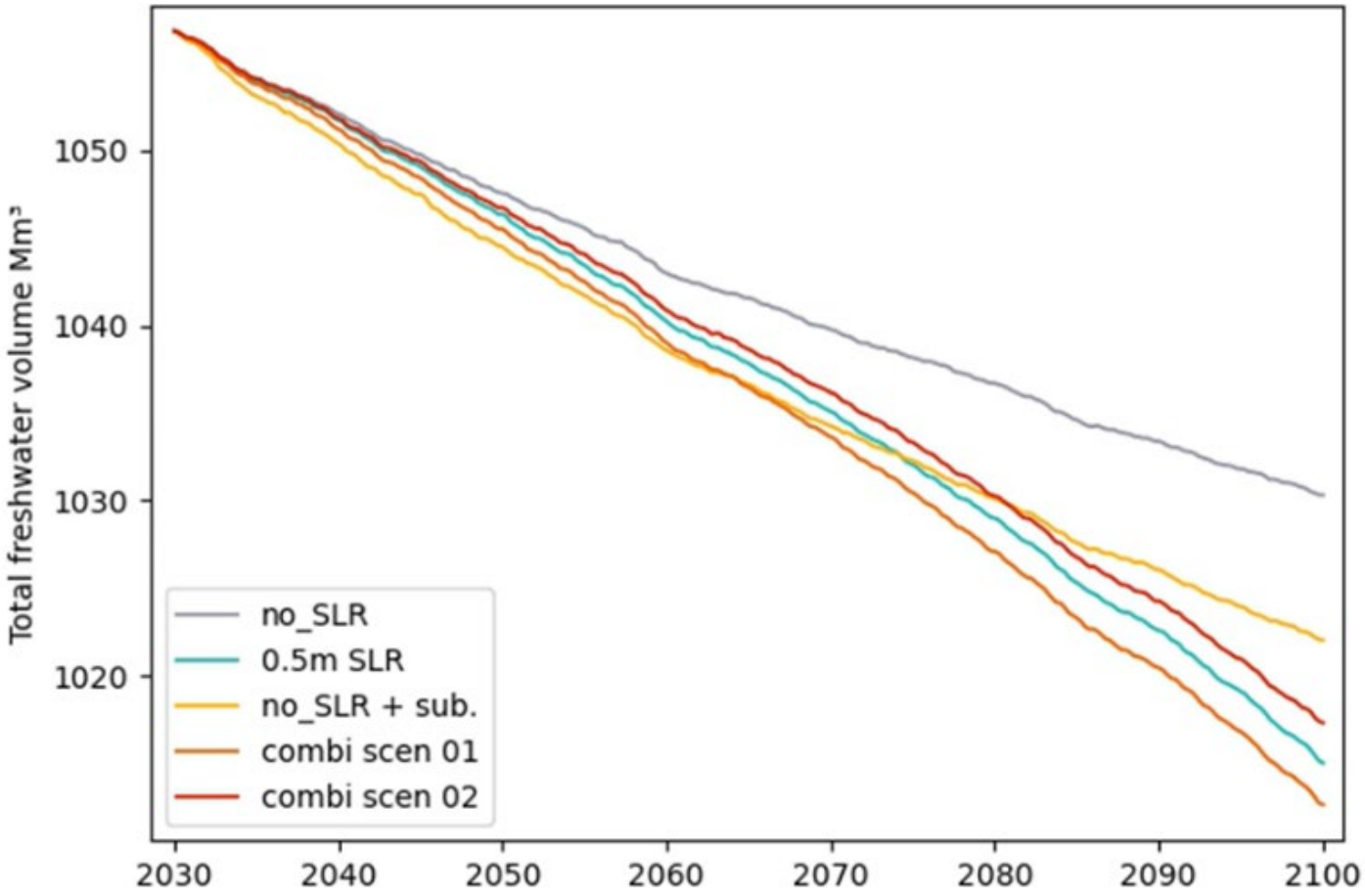


Deltares

Resultaten 3D zoet-zout grondwatermodel

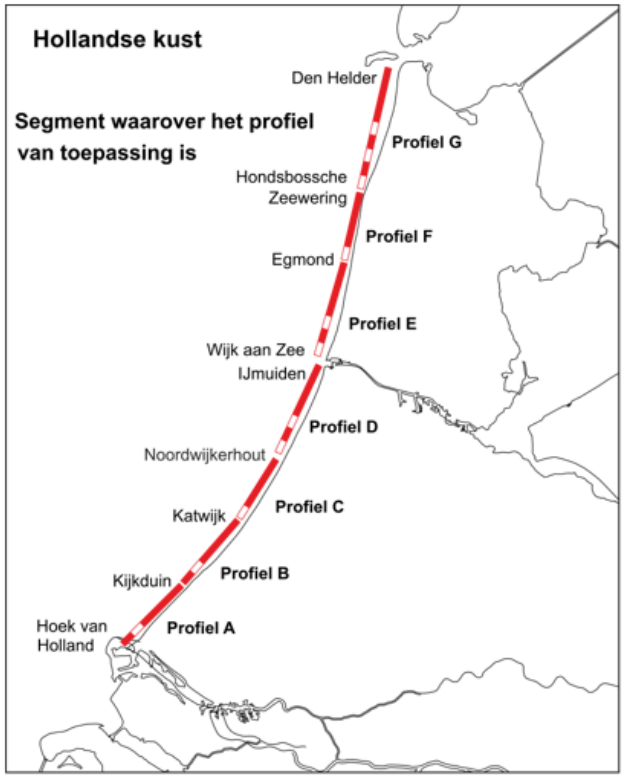
- Zeespiegelstijging (SLR)
- Bodemdaling (subs.)
- Zeespiegelstijging + Bodemdaling + Grondwateraanvulling (GWR)

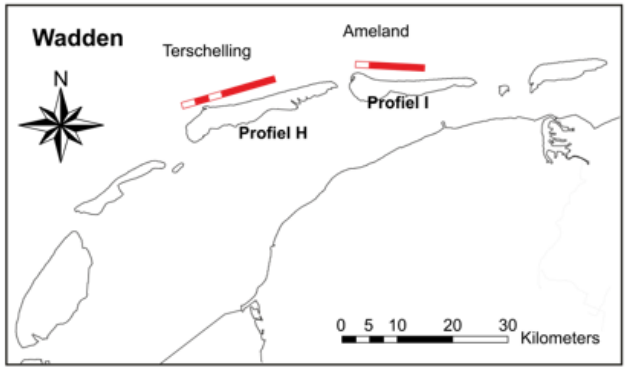
Scenario	Laatste simulatiejaar	Zoetwatervolume [Mm³]	Verandering (t.o.v. referentie)
Referentiesituatie	2020	1057.0	
0.5m SLR	2100	1015.0	-4.0%
no_SLR + subs. (bodemdaling)	2100	1022.0	-3.3%
combi scen 01 (-3% GWR)	2100	1012.6	-4.2%
combi scen 02 (+3% GWR)	2100	1017.3	-3.8%



Deltares

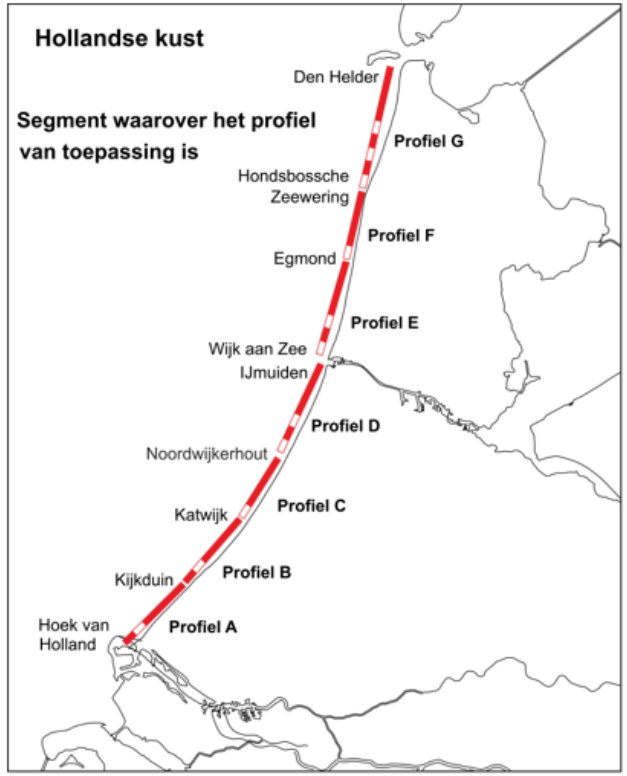
Resultaten 2D zoet-zout profielen

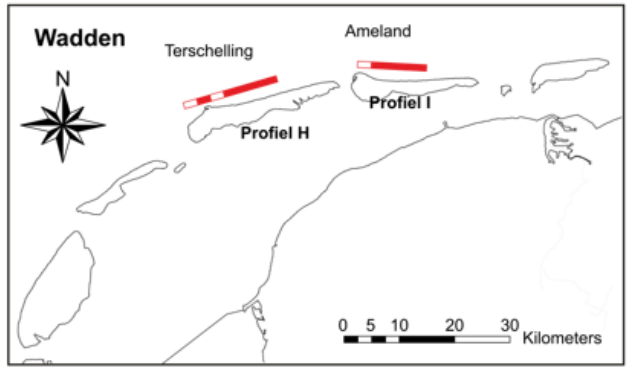


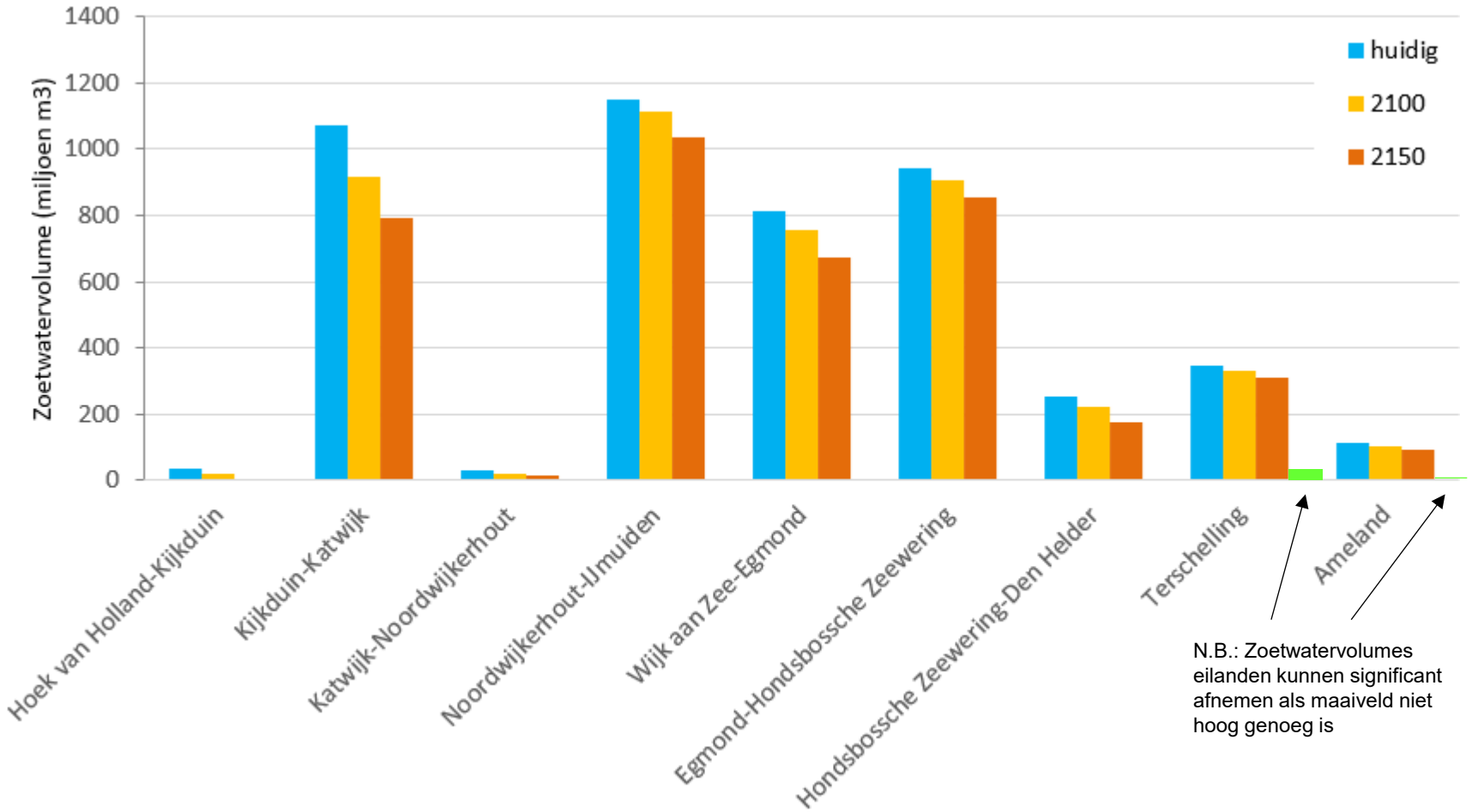


Segment langs de Nederlandse kust	Lengte profiel langs de kust (km)	Grove schatting huidig zoetwater volume (Mm^3)	Overgebleven volume, in 2100 (%)	Overgebleven volume, in 2150 (%)
A. Hoek van Holland-Kijkduin	15.0	35	63%	6%
B. Kijkduin-Katwijk	15.0	1070	86%	74%
C. Katwijk-Noordwijkerhout	12.5	30	77%	45%
D. Noordwijkerhout-IJmuiden	17.5	1150	97%	90%
E. Wijk aan Zee-Egmond	17.5	810	93%	83%
F. Egmond-Hondsbossche Zeewering	12.5	945	96%	90%
G. Hondsbossche Zeewering-Den Helder	22.5	250	87%	70%
H. Terschelling	17.5	350	95%	89-11%
I. Ameland	12.5	115	91%	83-0%

Resultaten 2D zoet-zout profielen



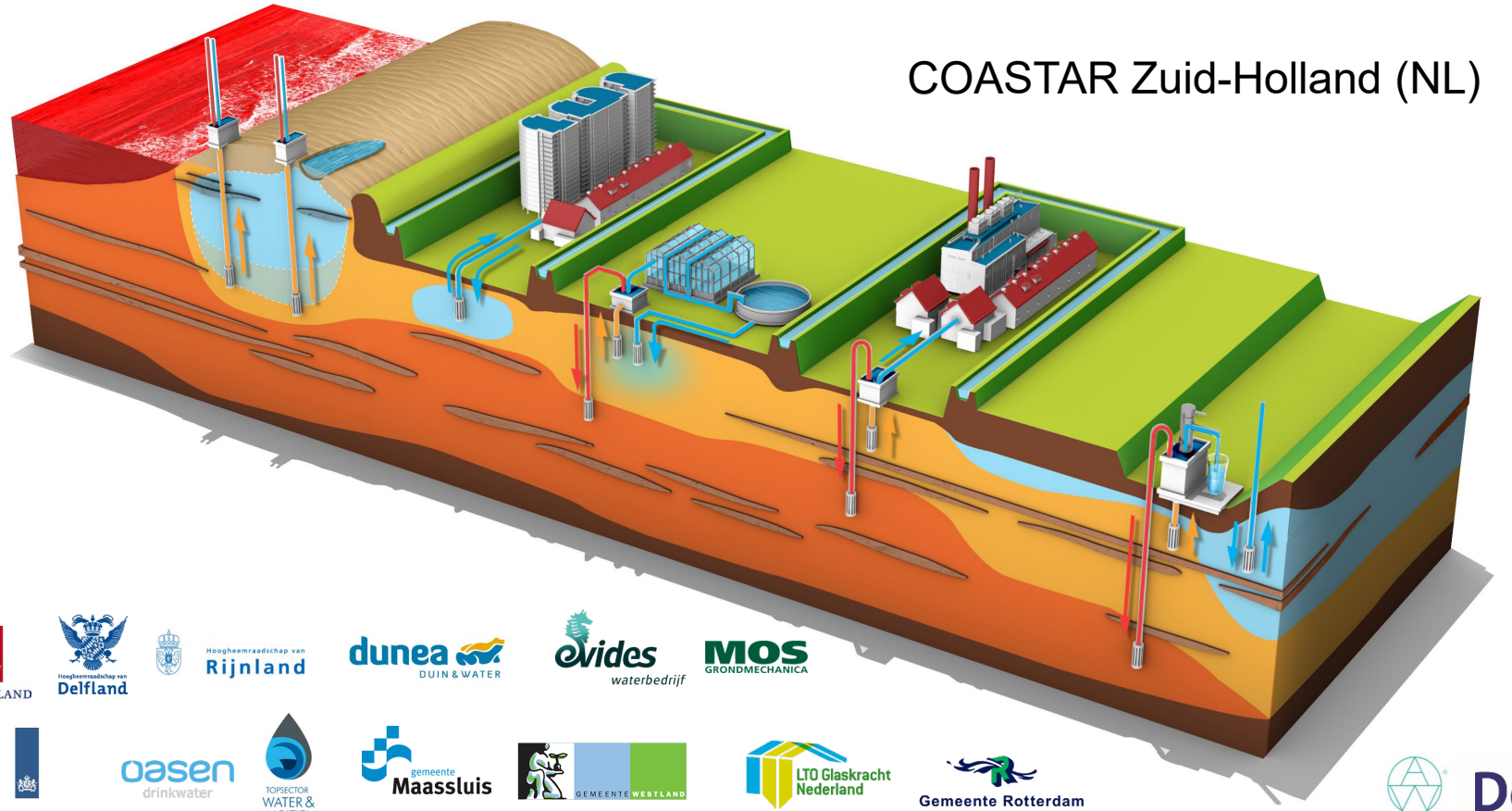




N.B.: Zoetwatervolumes eilanden kunnen significant afnemen als maaiveld niet hoog genoeg is

Regionaal: grootschalig gebruik van de ondergrond voor een robuuste watervoorziening en waterbeheer door:

- het dichten van het gat tussen watervraag en wateraanbod over tijd en ruimte
- vóórkomen van verzilting door brak grondwater te gebruiken voor de zoetwaterproductie

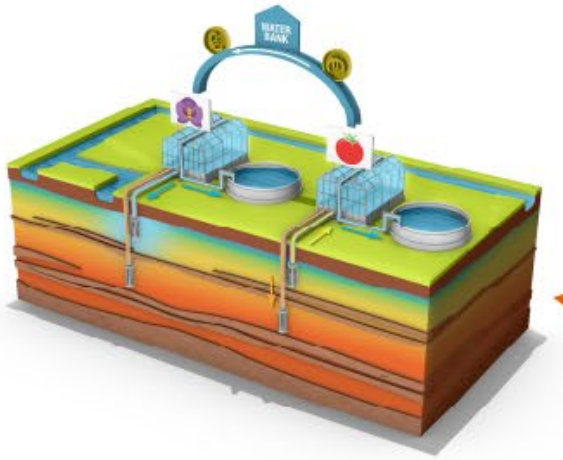


COASTAR Zuid-Holland (NL)

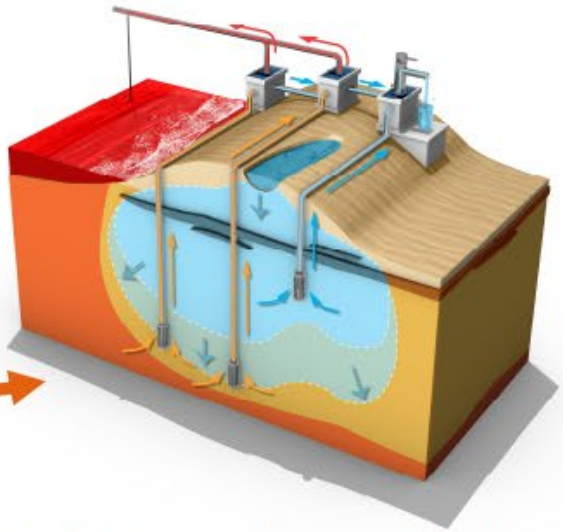
www.coastar.nl

COASTAR solutions in the Netherlands - Cases

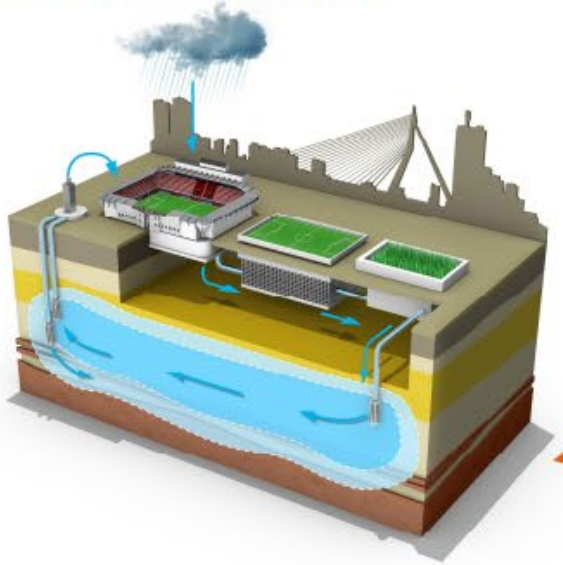
1. Waterbank Westland



2. Brackish water extraction dunes

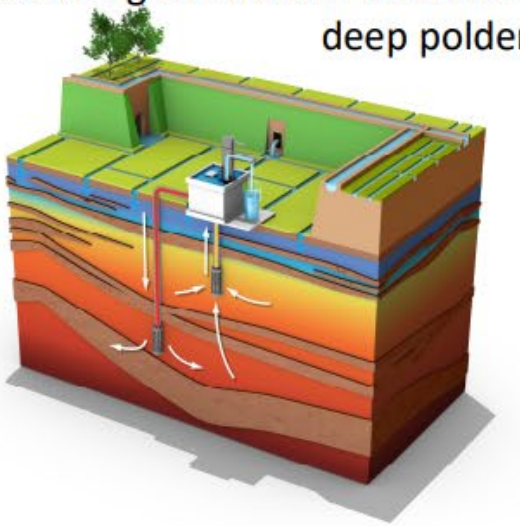


4. Urban Water Buffers





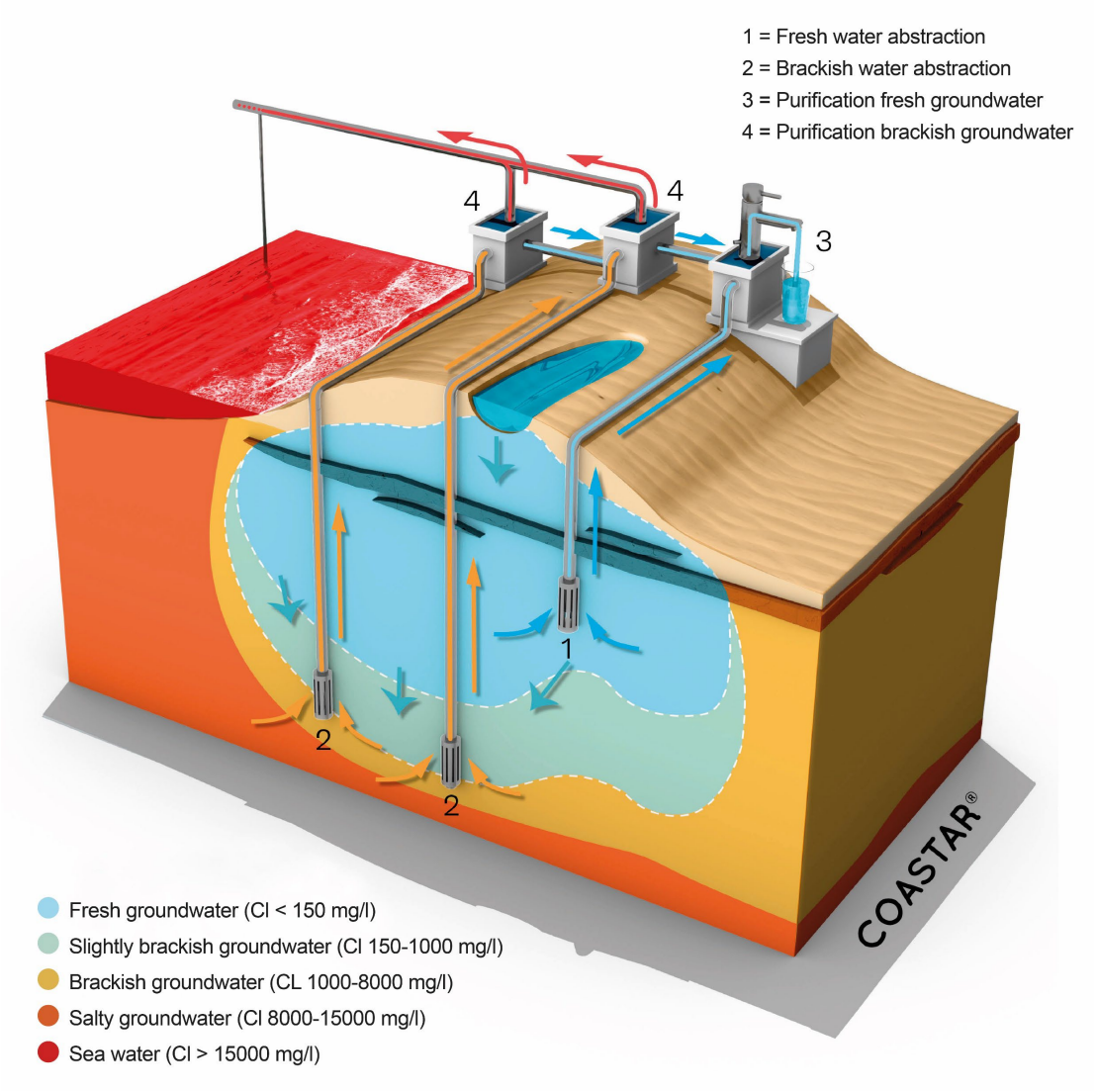
3. Brackish groundwater extraction deep polders

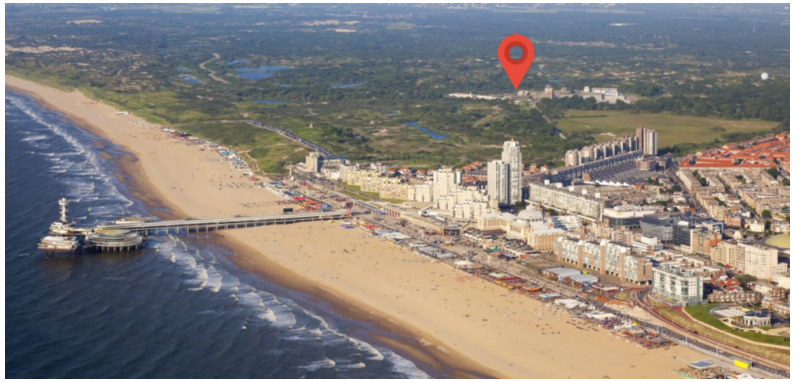


Verzilting en Zoetwaterbeschikbaarheid

Intermezzo: brak grondwater onttrekken, case Dunea







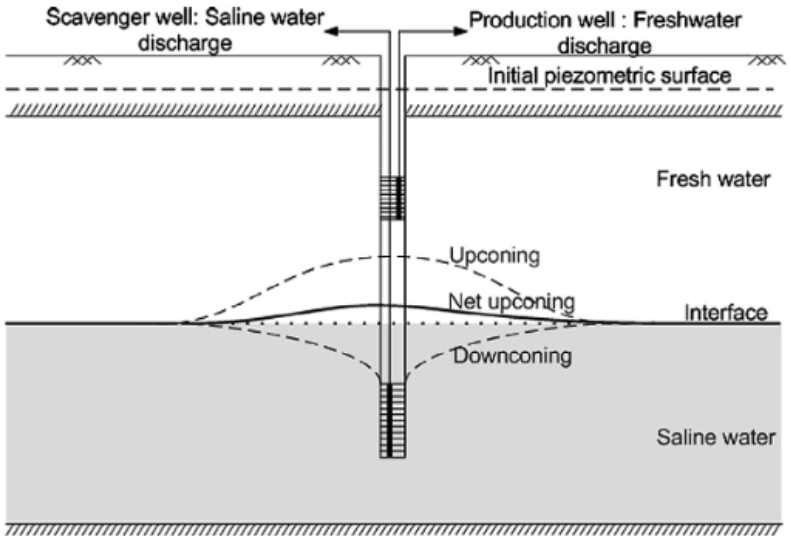
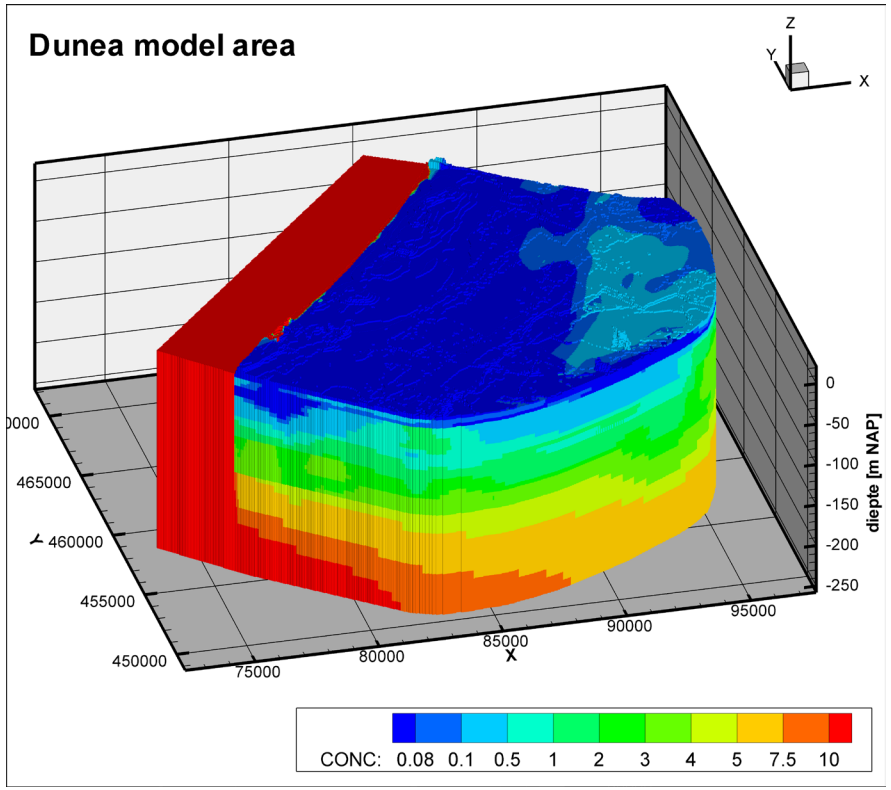


Fig. 1. Upconing under scavenger well.

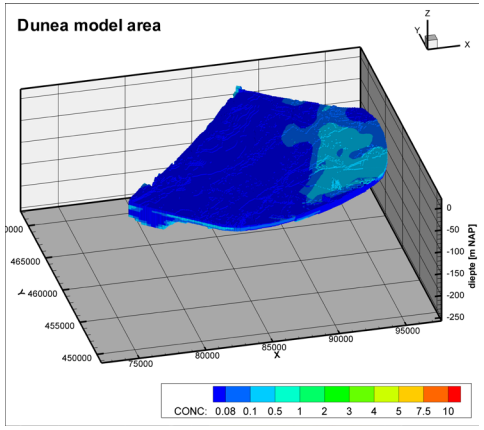
Intermezzo: brak grondwater onttrekken, case Dunea, PhD onderzoek

Brackish groundwater is the new fresh

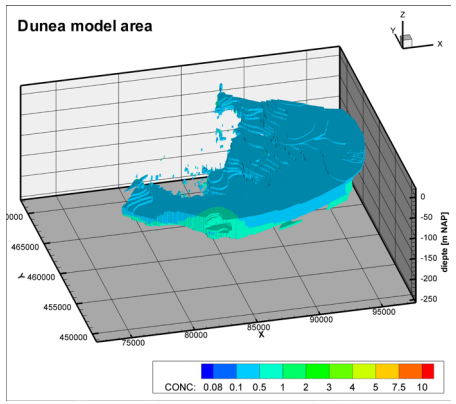
Volume in km³ (porositeit=0.3)	Gehele Dunea gebied	Ondieper dan -150m	Ondieper dan -100m
< 150 mg/l (zoet)	3.0	3.0	3.0
150-1000 mg/l (licht brak)	2.1	2.1	2.1
1000-5000 mg/l (brak)	9.9	4.7	2.2
5000-10.000 mg/l (zeer brak)	3.9	1.4	0.4
> 10.000 mg/l (zout)	5.4	3.4	2.1



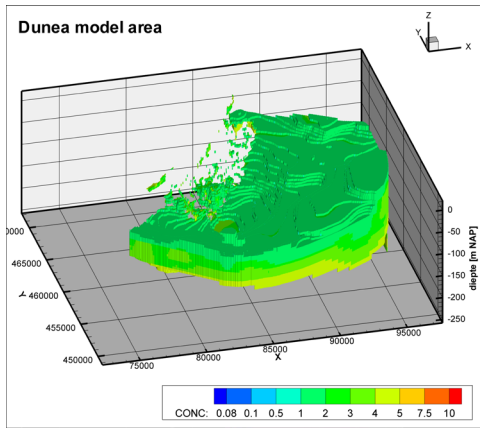
< 150 mg/l (fresh)

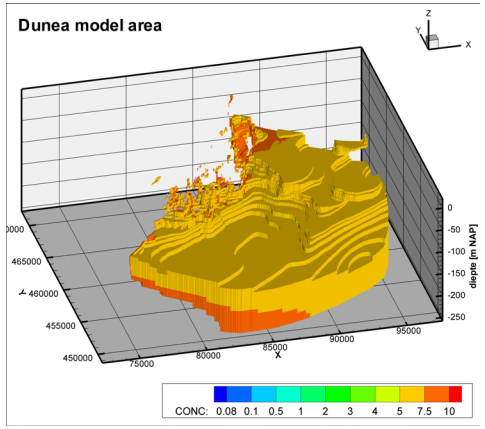


150-1000 mg/l (light brackish)

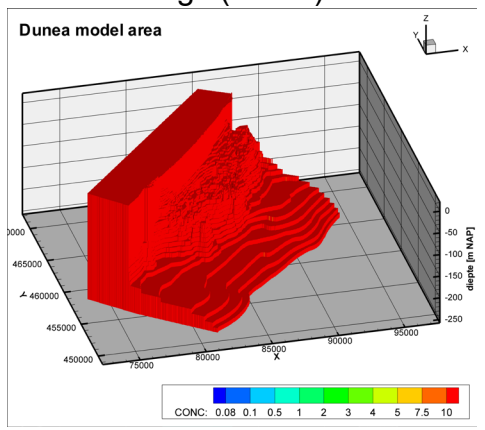


1000-5000 mg/l (brackish)





> 10.000 mg/l (saline)



Intermezzo: brak grondwater onttrekken, case Dunea

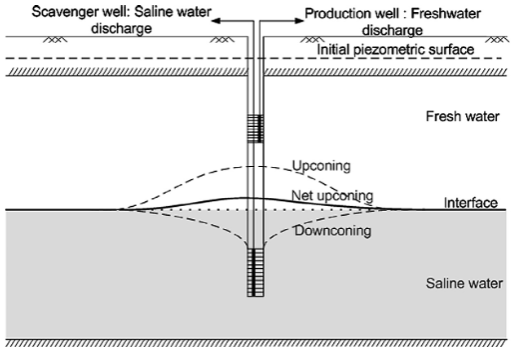
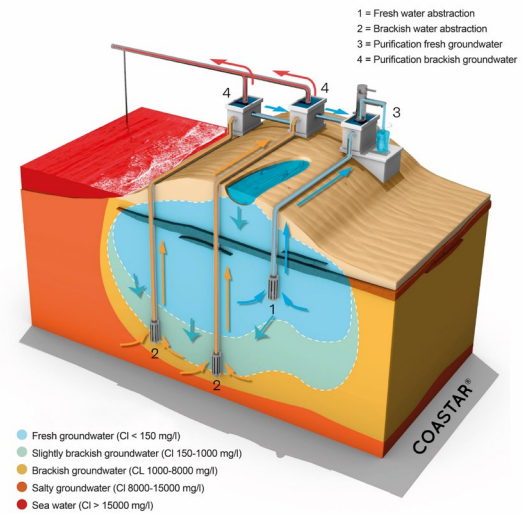
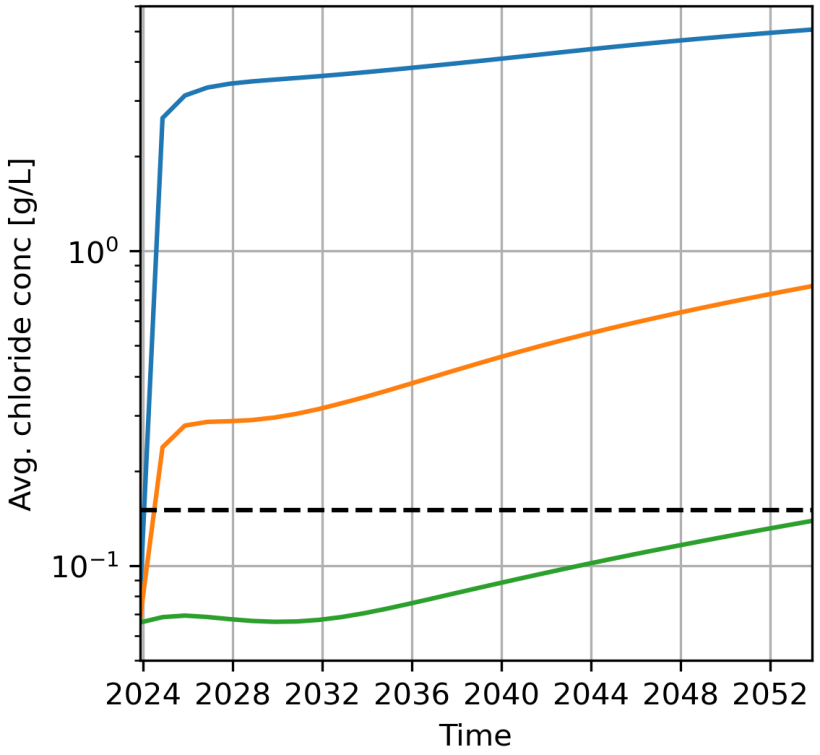


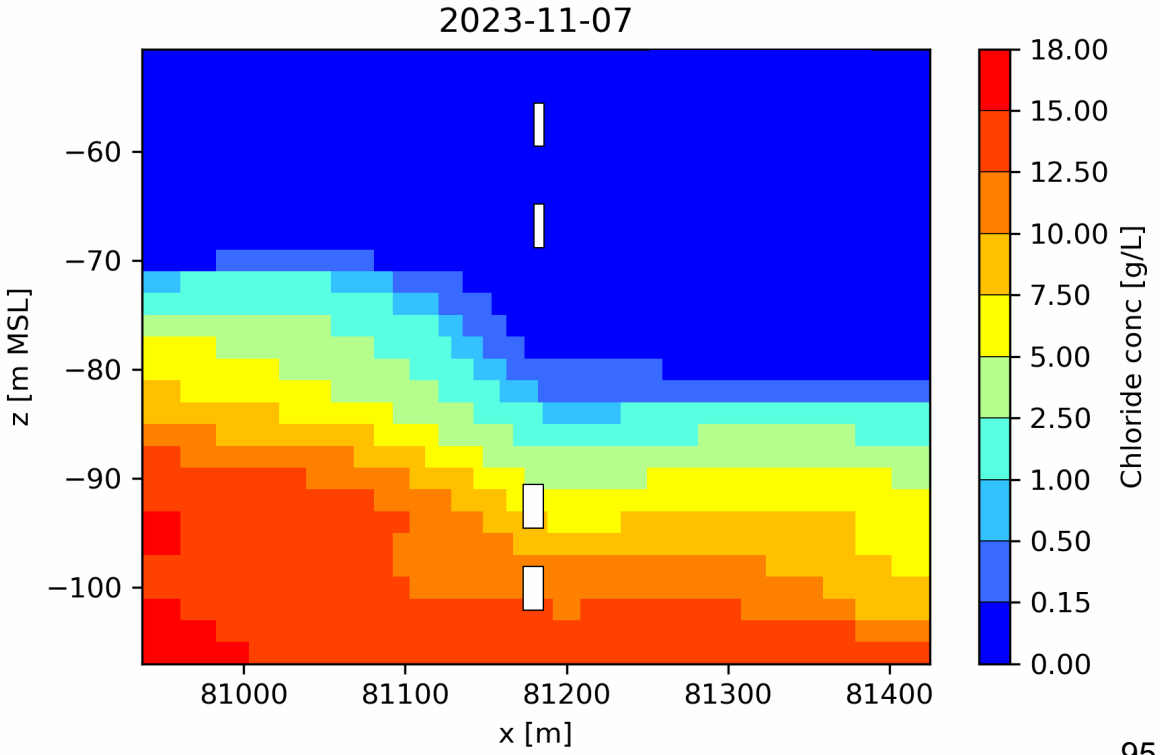
Fig. 1. Upconing under scavenger well.





grondwateronttrekking

Zoet	Brak
zoet [$m^3\ h^{-1}$]	**zout** [$m^3\ h^{-1}$]
50	**0**



Samenvattend werk Kennisprogramma Zeespiegelstijging

Effecten zeespiegelstijging op verzilting grondwater:

- Invloedssfeer zeespiegelstijging max zo'n 10 km van de kust, invloed geohydrologie
- Zeespiegelstijging geeft sterke toename zoutvracht, versnelt door langzame toestroming brak grondwater
- Huidig waterbeheer loopt tegen knikpunten aan bij sterke zeespiegelstijging (doorspoelvraag, kustnabije landbouwgebieden)
- LET OP: effect zeespiegelstijging is geïsoleerd bekeken, veranderingen in meteorologie / beheer / beleid NIET onderzocht

Effecten zeespiegelstijging op zoetwater in de Nederlandse duinen

1. ZSS heeft een negatief effect op de zoetwatervoorraden in de Duinen.
   - In Meijendel/Berkheide ook zonder zeespiegelstijging een afname in de zoetwatervoorraad (autonome processen)
   - Bij 0.5 m ZSS 4% afname, bij 1 m ZSS 6 % afname en bij 3 m ZSS tot bijna 34%
   - De kleinere zoetwaterlenzen langs de Hollandse Kust (Hoek van Holland – Kijkduin, Kijkduin – Katwijk en in mindere mate Hondsbossche Zeewering – Den Helder) zullen richting 2150 met 3 m ZSS grotendeels verdwijnen
2. Andere factoren welke een effect hebben op de zoetwatervoorraden in de Duinen
   - Zandsuppleties aan de kust zeer beperkt positief effect
   - (kunstmatige) Grondwateraanvulling zeer beperkt positief als negatief (beperkt door o.a. kunstmatige infiltratie)
   - Bodemdaling in het binnenland (licht) negatief effect

Dank u voor de aandacht!

Vragen?

Nederlandse Kustdagen

- **Zorgen voor een robuuste en toekomstbestendige kennisbasis.**
- **Effectiviteit van maatregelen onder verschillende omstandigheden testen en optimaliseren.**
- **Het gedrag en de keuzes van watergebruikers meenemen in het waterbeheer.**
- **Anticiperen op nieuwe uitdagingen, waaronder PFAS en andere verontreinigingen.**

Since 1957 in the Netherlands: large-scale Managed Aquifer Recharge for drinking water

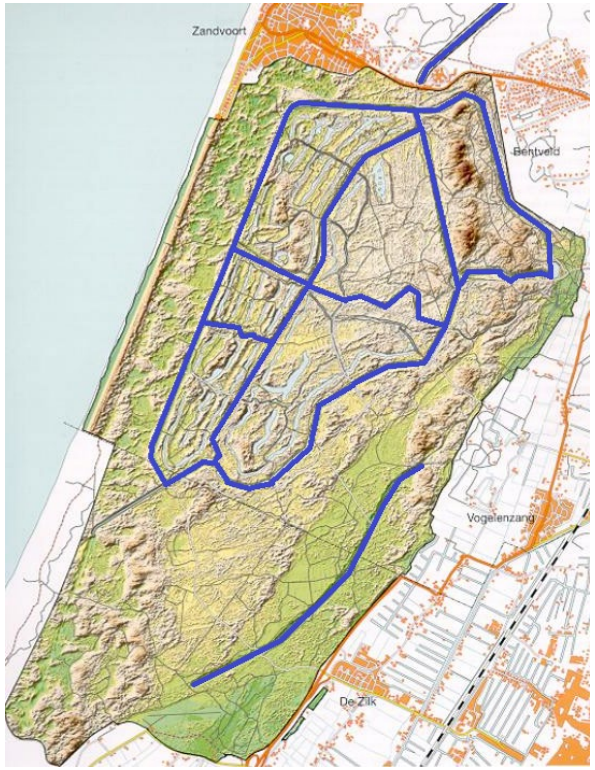
Dune water supply for Amsterdam:

- Artificial infiltration of river water from Rhine River started in 1957
- 40 km of abstraction canals
- 9 km of drains
- 40 recharge ponds (86 ha)
- 65 Mm^3/year
- 60% Amsterdam water supply

- Groundwater is a very reliable source for water supply, but is likely not renewable and should be used sustainable.
- Extractions must be managed and monitored systematically.
- We apply conjunctive use of surface as well as groundwater. Feasible tested technologies include river bank infiltration, gallery, and infiltration basin.



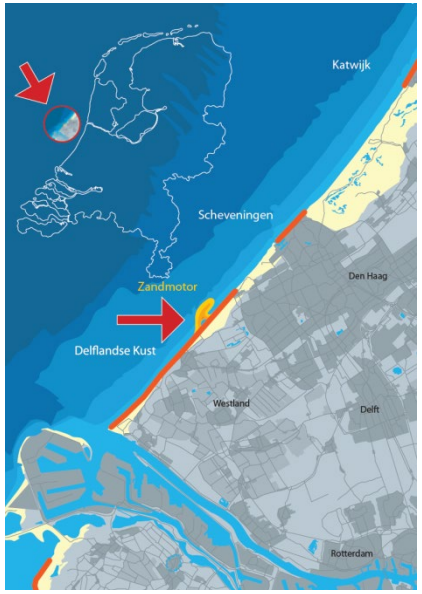




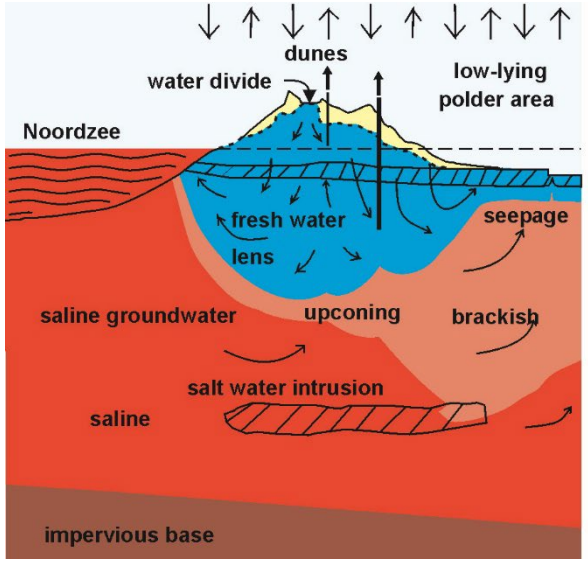
Increase strategic freshwater reservoirs in the coastal zone

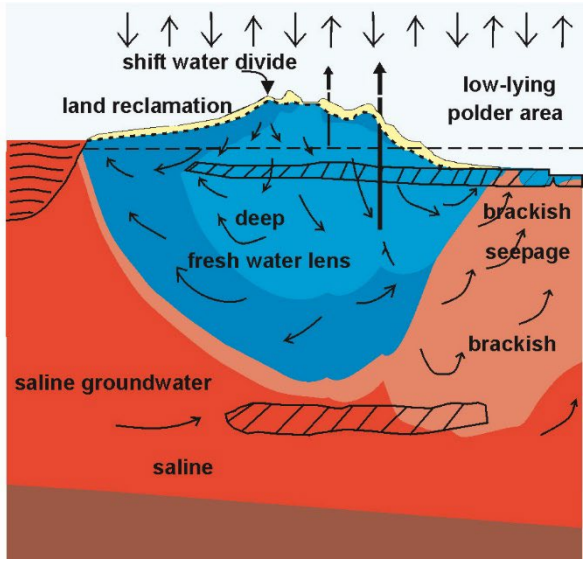
NatureCoast, Building with Nature, De Zandmotor

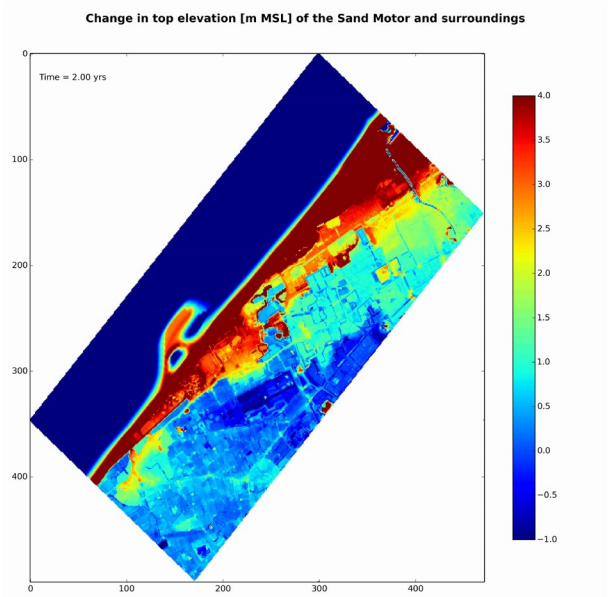




200m width sand suppletion at the Dutch Coast will on the long run to a built-up of ~1000 million m3 fresh groundwater







Development of the Sand Motor

