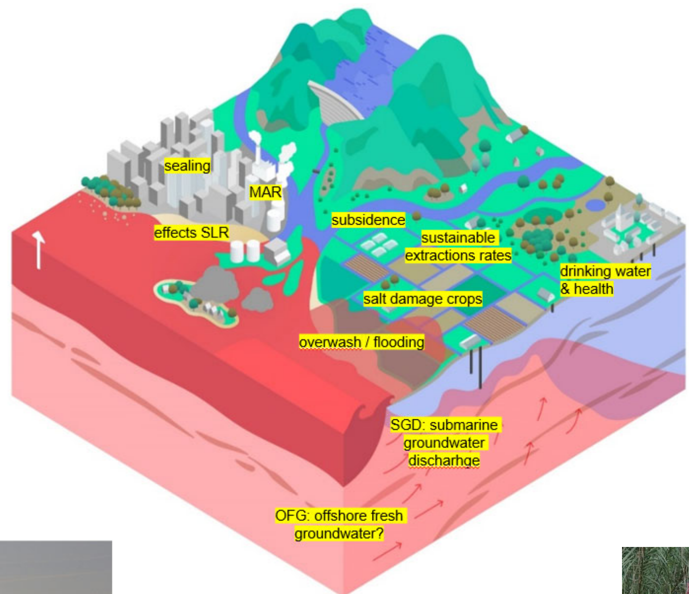
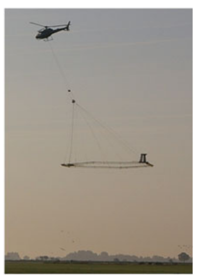
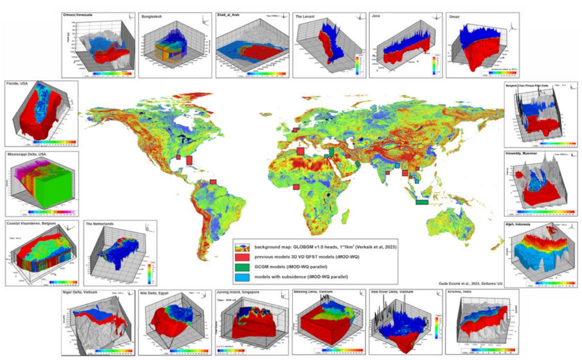
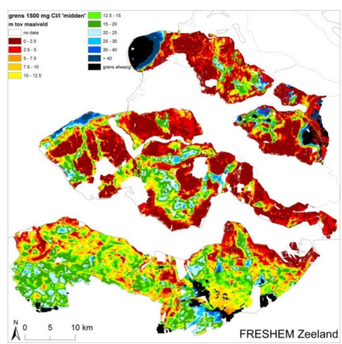








Navigating groundwater salinity in (coastal) groundwater models: insights, challenges, innovations

Gualbert Oude Essink, Daniel Zamrsky, Jude King, Perry de Louw, Joost Delsman, Marc Bierkens and others

gualbert.oudeessink@deltares.nl

This pptx on the wiki http://freshsalt.deltares.nl/ later today

Utrecht University

Deltares

Motivation

- Coastal regions seriously rely on groundwater, but **domestic and agricultural water use** leads to **salinization**, **subsidence**, and **droughts**, **endangering water security**.
- **Climate change** worsens these issues by **altering precipitation patterns** and **raising sea levels**, threatening **food security, public health**, and **ecosystems**.
- **Groundwater models**, integrated with **salt transport** and **local hydrogeological data**, could help **assess these human and climate impacts** on coastal groundwater, and could support **water managers** with **more informed decision making**.
- The **confidence in groundwater salinity models** depends on **understanding** groundwater salinity distribution, which is complex due to its **variability and changing historical conditions**.

Interesting developments in (coastal) groundwater salinity modelling

Data

- **1**: Airborne groundwater salinity mapping
- **2:** Citizen science, using simple monitoring devices for salinity
- **3**: Data mining hydrogeology, using Large Language Models
- **4**: Integrating techniques from 0D/1D/2D data to 3D model input (e.g., groundwater salinity, geology)

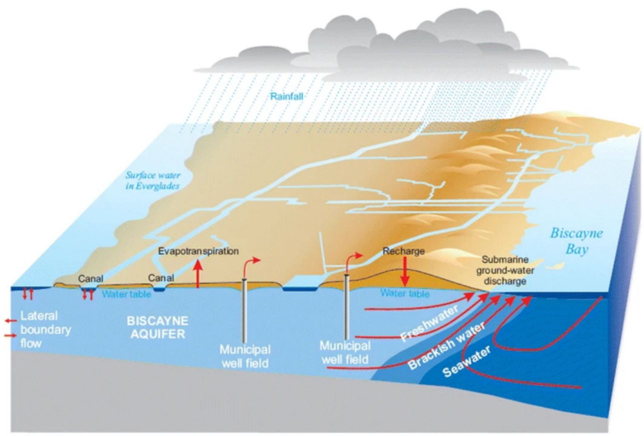
Model

- **5**: Parallel computing plus smart model parameters
- **6:** Paleo-reconstructions groundwater salinity to get better knowledge on salinity distribution
- **7:** Building and running parallel large-scale groundwater salinity models using multiple cores

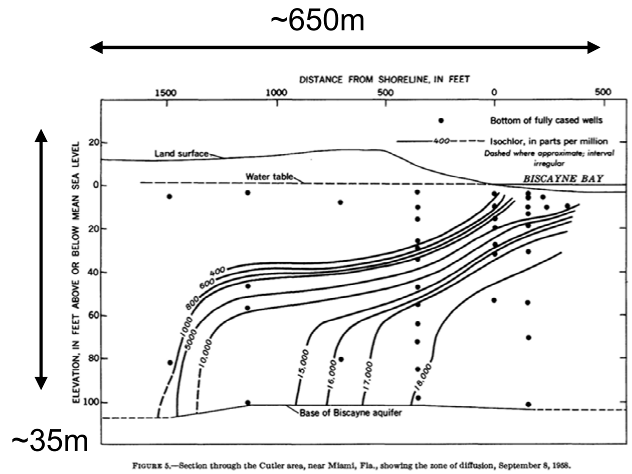
Knowledge sharing

- (Open) python tools, open sources, GitHub, repositories, webportals,

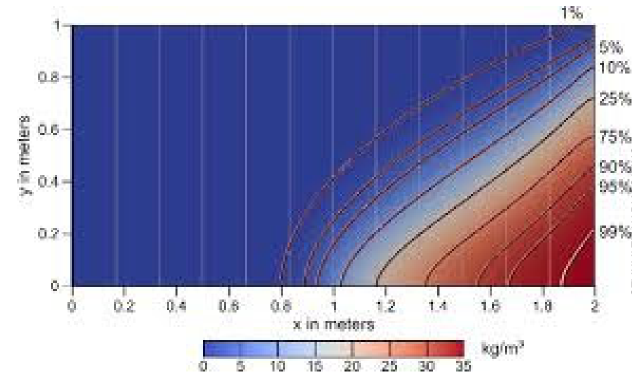
When modeling groundwater salinity, let us move beyond the classical Henry conceptualization to better capture the complexities of fresh-salt groundwater interactions.

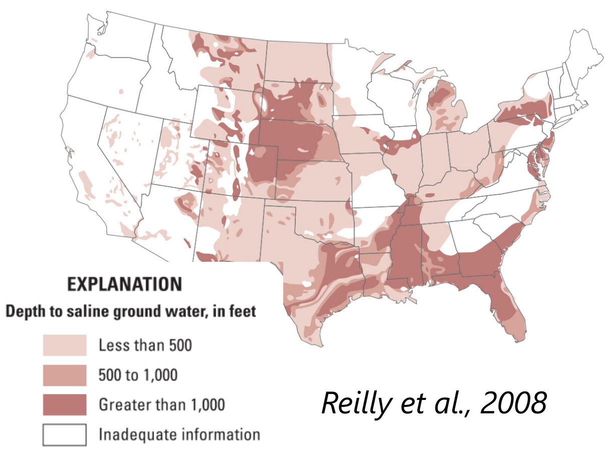


Langevin., 2003

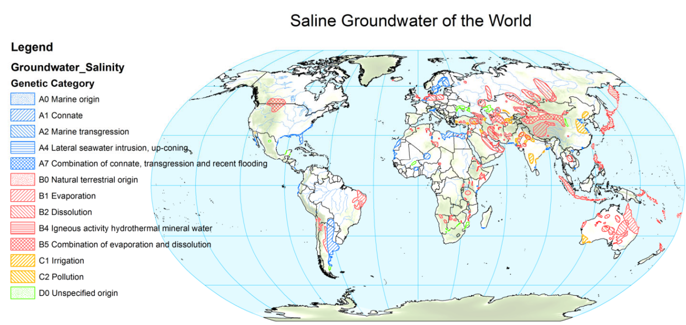


Kohout et al., 1964

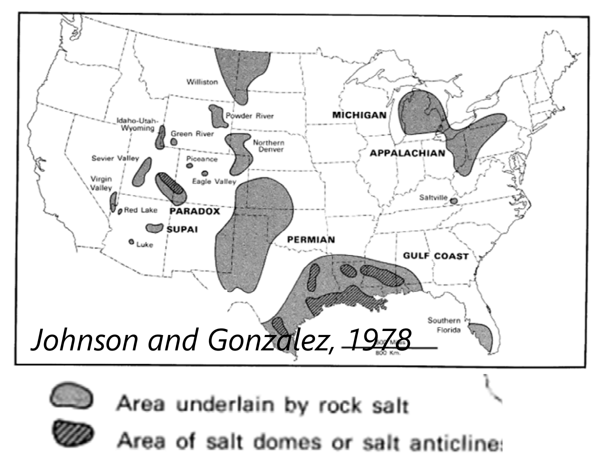




Reilly et al., 2008



Van Weert et al., 2009



Johnson and Gonzalez, 1978

Component 1: Airborne groundwater salinity mapping

Deltares

TNO innovation for life

BGR

Method:

Combination helicopter measurements with knowledge about subsurface and processes in fresh-saline groundwater, and geostatistical mapping via (multiple) indicator kriging.

Results:

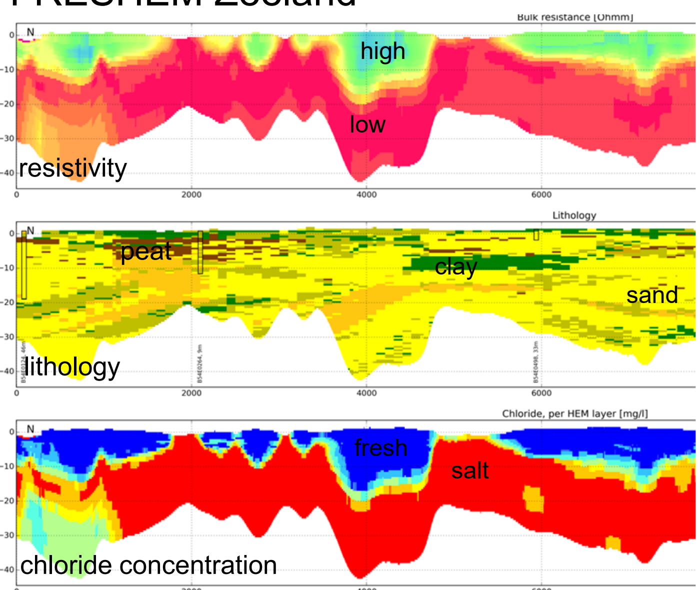
- Mapping of 3D groundwater salinity and clay layers

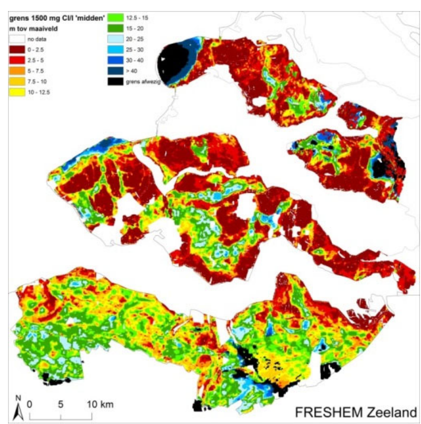
Delsman et al., 2018

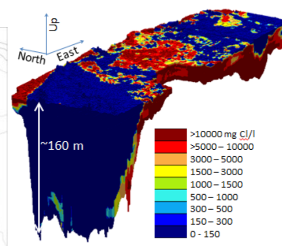
Applications:

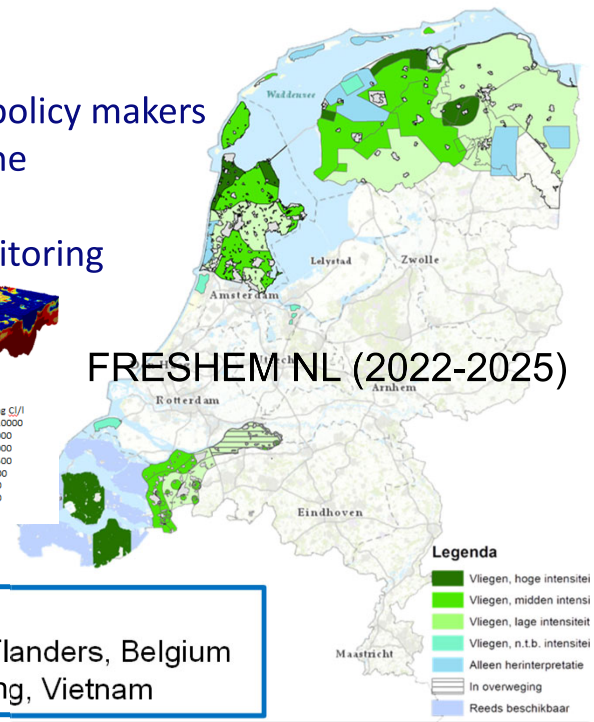
- strategic fresh groundwater users & policy makers
- support ASR (COASTAR) in coastal zone
- identify brackish water potential
- improve groundwater models & monitoring

FRESHEM Zeeland





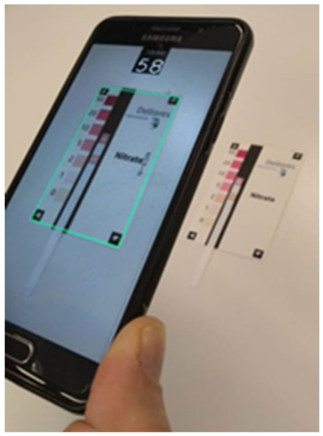


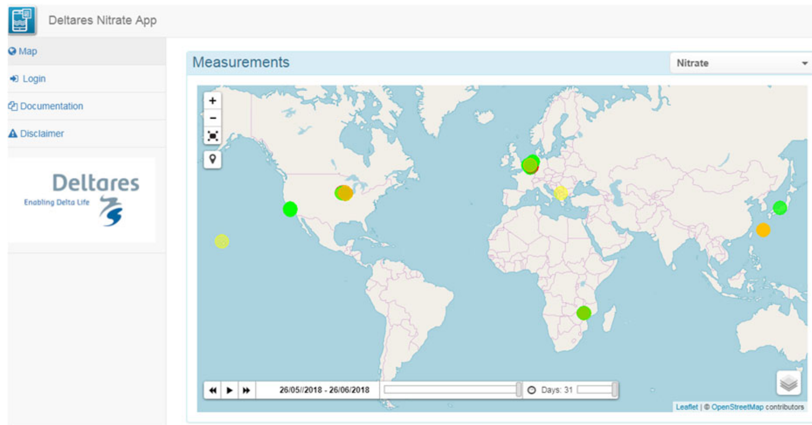


International:

- Project in Flanders, Belgium
- Pilot Mekong, Vietnam

Component 2: Citizen science, using simple monitoring devices for salinity, especially in data-poor areas



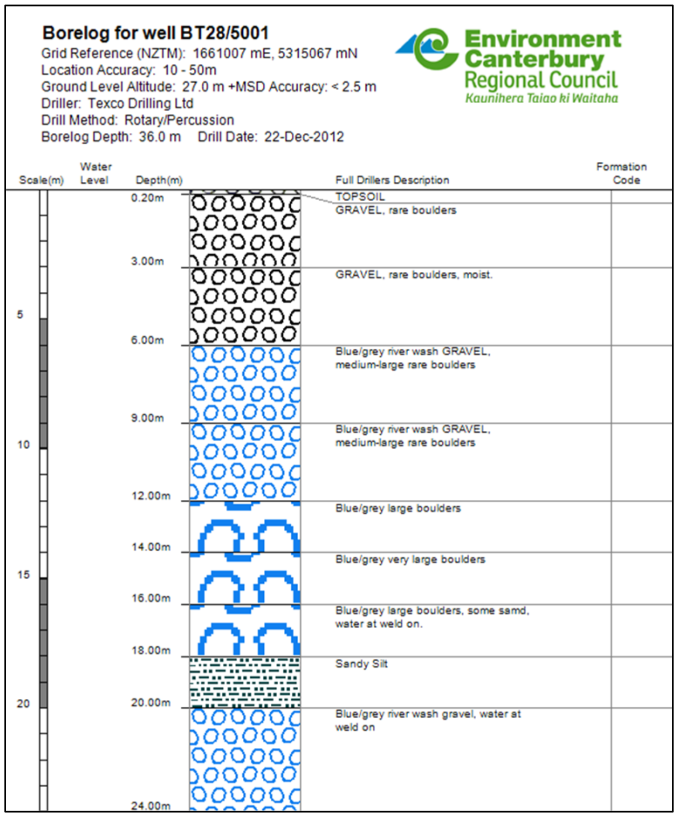


e.g., Aquality App

Component 3: Data mining hydrogeology, using Large Language Models

Structured data from images

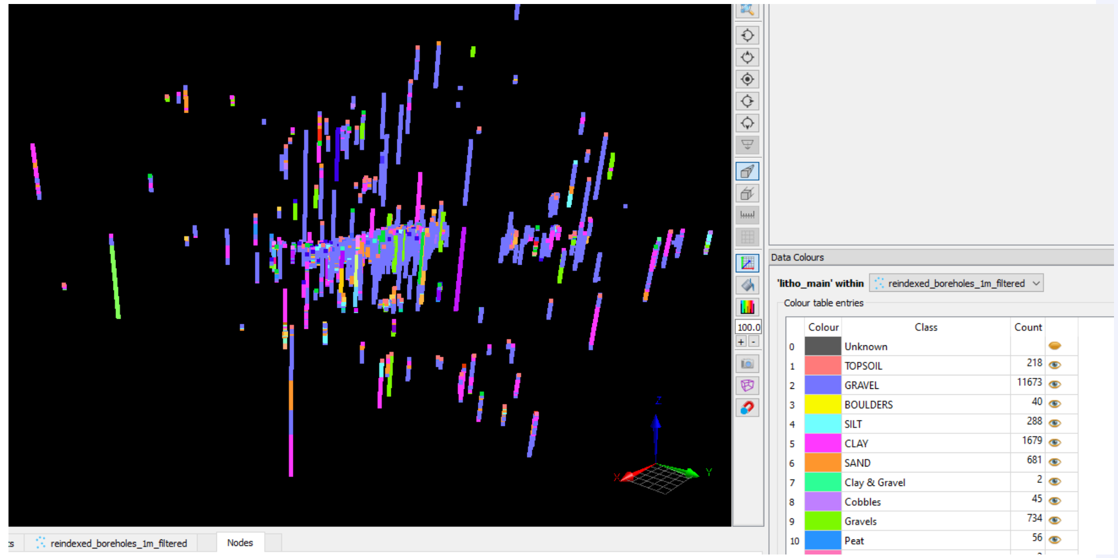
Tested on ~500 borehole images from New Zealand, provided by Utrecht University

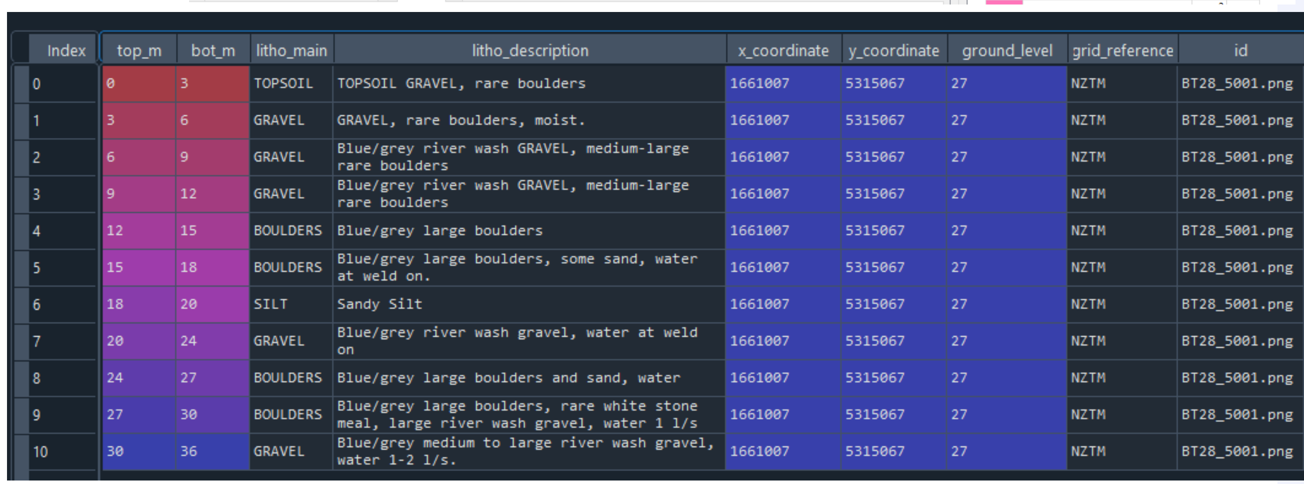


Borelog for well BT28/5001
Grid Reference (NZTM): 1661007 mE, 5315067 mN
Location Accuracy: 10 - 50m
Ground Level Altitude: 27.0 m +MSD Accuracy: < 2.5 m
Driller: Texco Drilling Ltd
Drill Method: Rotary/Percussion
Borelog Depth: 36.0 m Drill Date: 22-Dec-2012

Environment Canterbury Regional Council
Kaunihera Taiao ki Waitaha

Scale(m)	Water Level	Depth(m)	Full Drillers Description	Formation Code
		0.20m	TOPSOIL	
			GRAVEL, rare boulders	
		3.00m	GRAVEL, rare boulders, moist.	
5		6.00m	Blue/grey river wash GRAVEL, medium-large rare boulders	
		9.00m	Blue/grey river wash GRAVEL, medium-large rare boulders	
10		12.00m	Blue/grey large boulders	
		14.00m	Blue/grey very large boulders	
15		16.00m	Blue/grey large boulders, some samd, water at weld on.	
		18.00m	Sandy Silt	
20		20.00m	Blue/grey river wash gravel, water at weld on	
		24.00m		





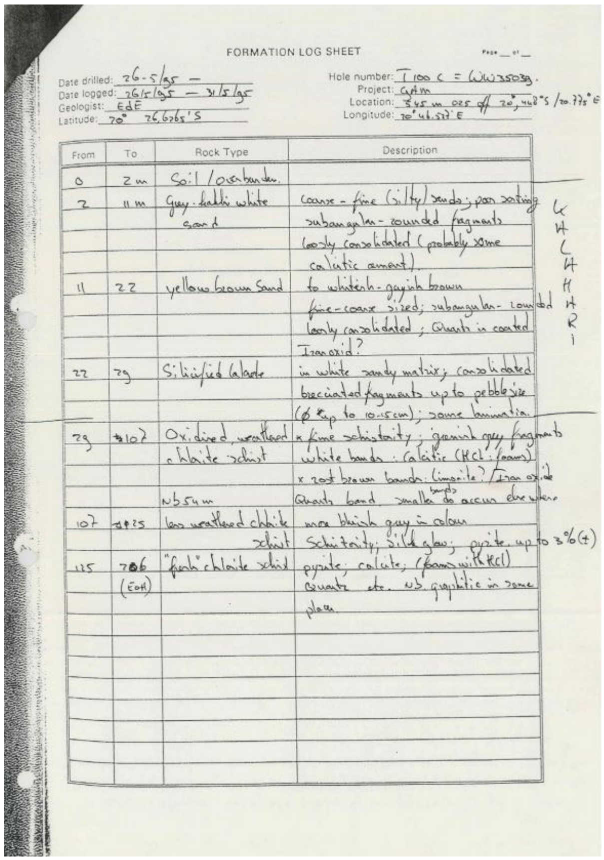
Index	top_m	bot_m	litho_main	litho_description	x_coordinate	y_coordinate	ground_level	grid_reference	id
0	0	3	TOPSOIL	TOPSOIL GRAVEL, rare boulders	1661007	5315067	27	NZTM	BT28_5001.png
1	3	6	GRAVEL	GRAVEL, rare boulders, moist.	1661007	5315067	27	NZTM	BT28_5001.png
2	6	9	GRAVEL	Blue/grey river wash GRAVEL, medium-large rare boulders	1661007	5315067	27	NZTM	BT28_5001.png
3	9	12	GRAVEL	Blue/grey river wash GRAVEL, medium-large rare boulders	1661007	5315067	27	NZTM	BT28_5001.png
4	12	15	BOULDERS	Blue/grey large boulders	1661007	5315067	27	NZTM	BT28_5001.png
5	15	18	BOULDERS	Blue/grey large boulders, some sand, water at weld on.	1661007	5315067	27	NZTM	BT28_5001.png
6	18	20	SILT	Sandy Silt	1661007	5315067	27	NZTM	BT28_5001.png
7	20	24	GRAVEL	Blue/grey river wash gravel, water at weld on	1661007	5315067	27	NZTM	BT28_5001.png
8	24	27	BOULDERS	Blue/grey large boulders and sand, water	1661007	5315067	27	NZTM	BT28_5001.png
9	27	30	BOULDERS	Blue/grey large boulders, rare white stone meal, large river wash gravel, water 1 1/s	1661007	5315067	27	NZTM	BT28_5001.png
10	30	36	GRAVEL	Blue/grey medium to large river wash gravel, water 1-2 1/s.	1661007	5315067	27	NZTM	BT28_5001.png

Component 3: Data mining hydrogeology, using Large Language Models

Structured data from images

Handles handwritten data, also in other languages

work in progress


FORMATION LOG SHEET
Date drilled:
Date logged:
Geologist:
Latitude:
Hole number:
Project:
Location:
Longitude:

From	To	Rock Type	Description

top_m	bot_m	litho_main	litho_description
0	2	Soil/Organic	Coarse-fine (silty) sands, poor sorting
2	11	Grey silt with some sand	Subangular to rounded fragments, poorly consolidated (possibly some volcanic glass)
11	22	Yellow/brown Sand	Coarse to fine grain brown, ferroan coated,…
22	29	Silicified (Lahar	White sandy matrix (poorly sorted, bimodal)…
29	102	Oxidised weathered basalt	Some scoriacity, general clay fragments, wh…
102	125	Basalt	Fresh basalt, small to medium olivine phenocrysts, black glassy groundmass
125	126	Frank chlorite schist	Epidote, calcite (HCL), quartz, schistosity, silty, (possibly up to 30 (Gt))

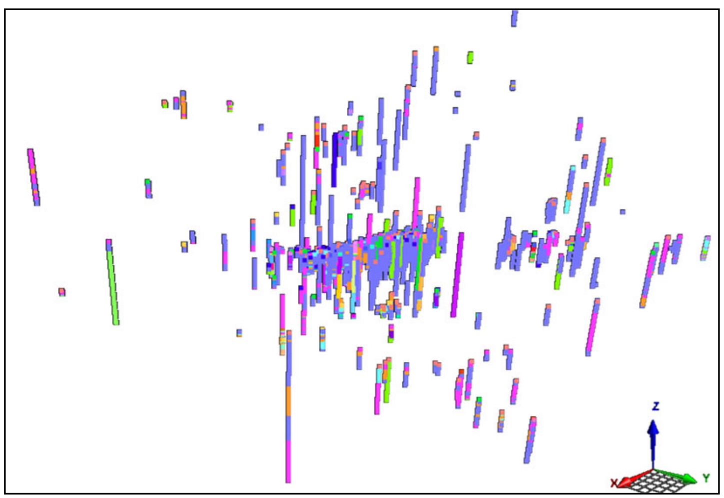
Component 4: Integrating techniques from 0D/1D/2 data to 3D model input

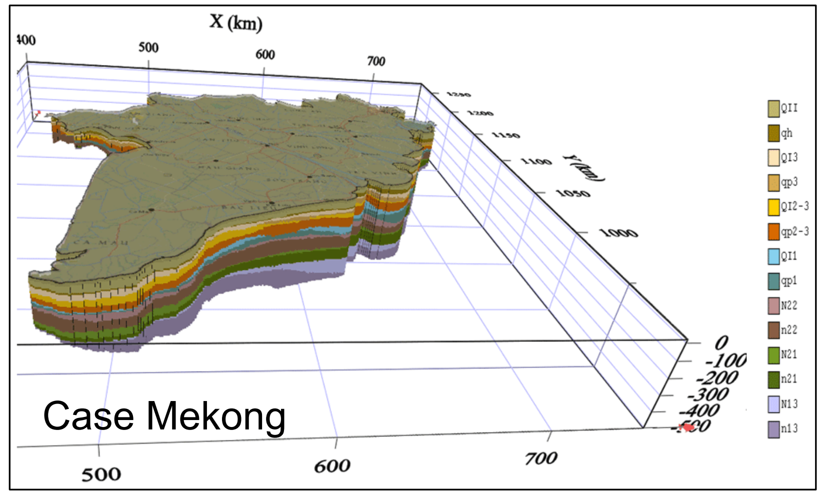
Data to construct large-scale hydrogeological models

Now, models can (mainly) parameterised in two ways with data-mining:

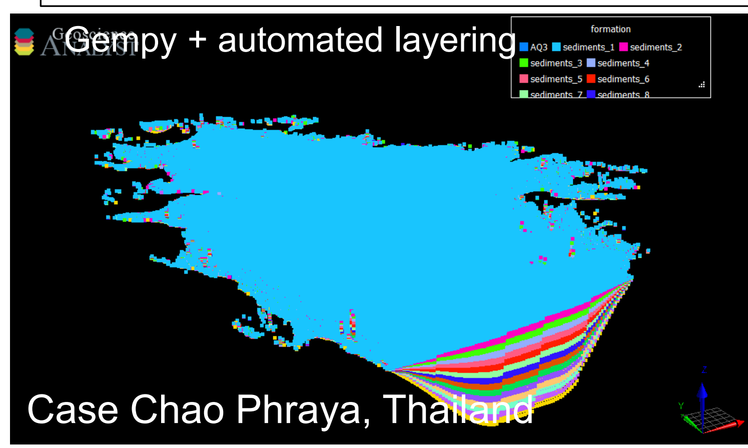
1. Hydrogeological properties
2. Initial salinity distributions

Demonstration of 3D interpolation for hydrogeological properties





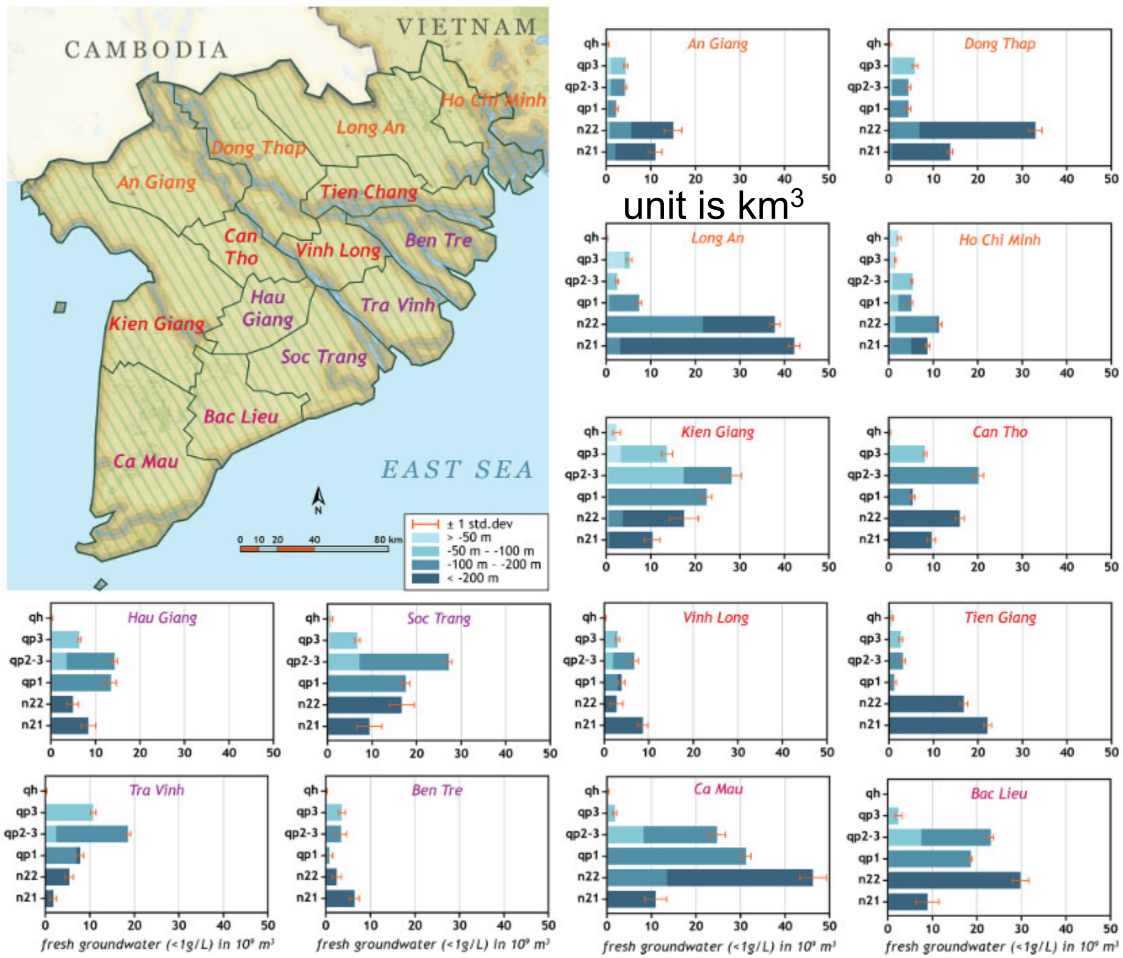
Case Mekong



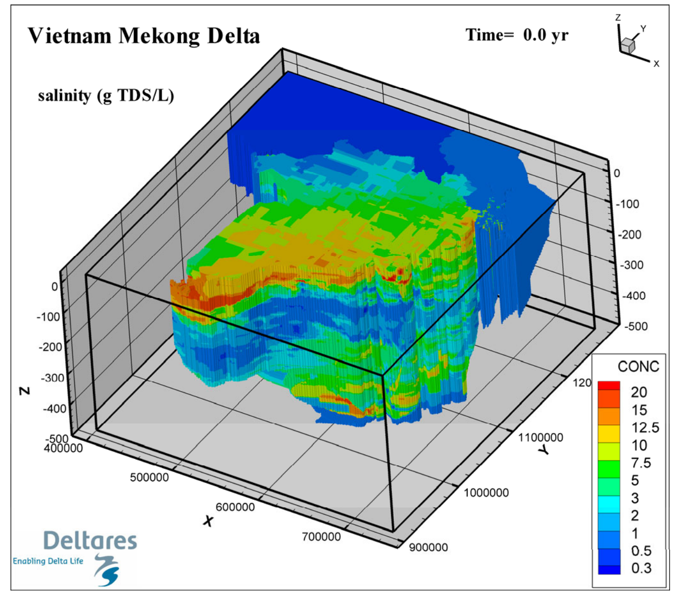
Case Chao Phraya, Thailand

Component 4: Integrating techniques from 0D/1D/2 data to 3D model input

Example Mekong delta: based on measurements, we estimated the volume of fresh groundwater (km^3) per province per aquifer



unit is km^3



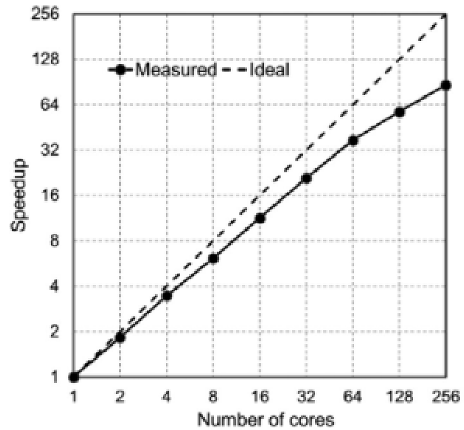
(total: some 830 to 900 km^3 fresh groundwater)

ref:

Gunnink, J.L., Pham, V.H., Oude Essink, G.H.P., Bierkens, M.F.P. 2021 The 3D groundwater salinity distribution and fresh groundwater volumes in the Mekong Delta, Vietnam, inferred from geostatistical analyses. Earth Syst. Sci. Data 13, 3297–3319. https://doi.org/10.5194/essd-13-3297-2021

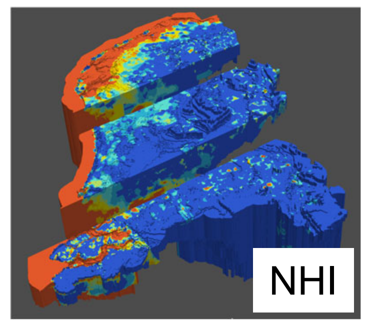
Component 5: parallel computing plus smart model parameters

- Split into (tens of) partitions, leading to a significant reduction in computation time
- Speed-ups of at least 10 up to 100 times, depending on cores, solver iterations and data exchange efficiencies

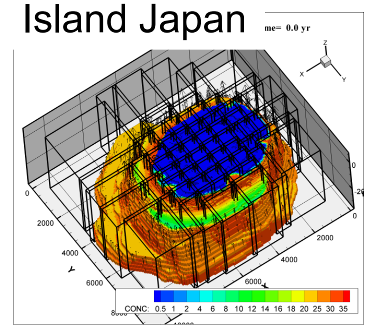


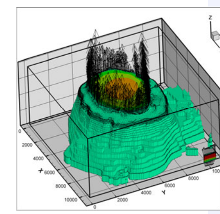
Three examples of speed-ups:

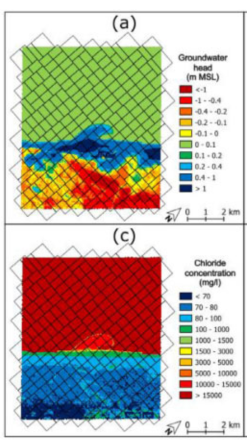
1. Sand Engine: from 1hr 47min 55sec -> 2min 40sec: factor **40***
2. NHI fresh-salt: from ~30 days to ~2days: **15***
3. Island Japan: from 5d0h36m to 5m59s: **1209***

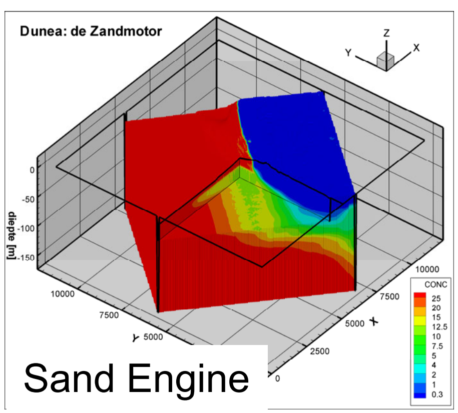


Island Japan

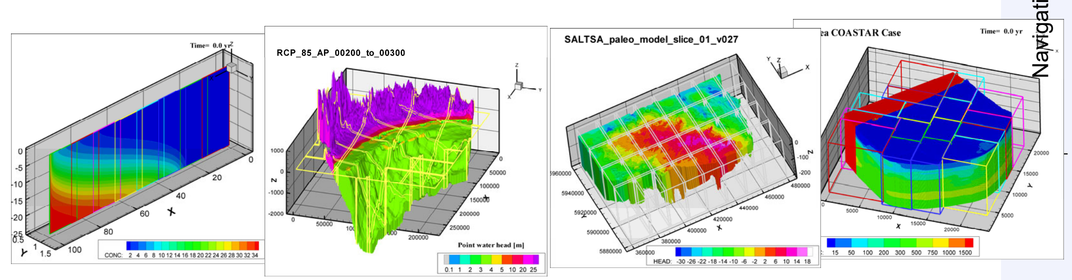








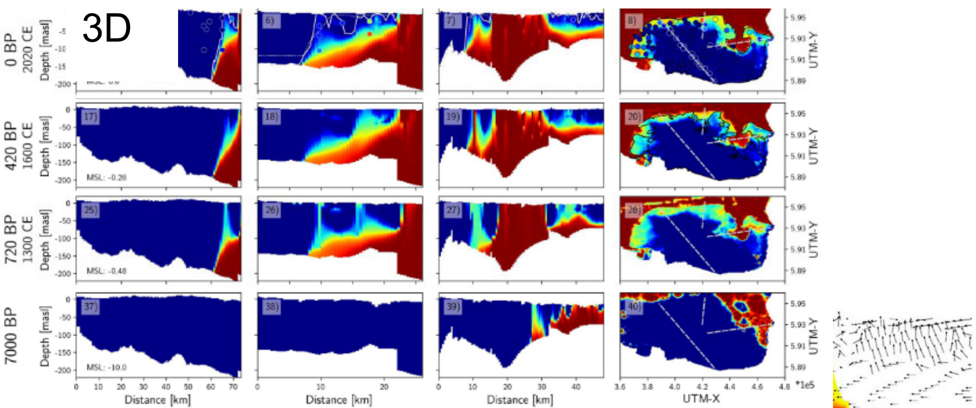
Verkaik, J. et al., 2021. Adv. Water Resources



Component 6: Paleo-reconstructions groundwater salinity

Parallel computer power is utilised to simulate 3D reconstructions of past hydrological conditions (in data-poor areas), improving understanding of present groundwater salinity.

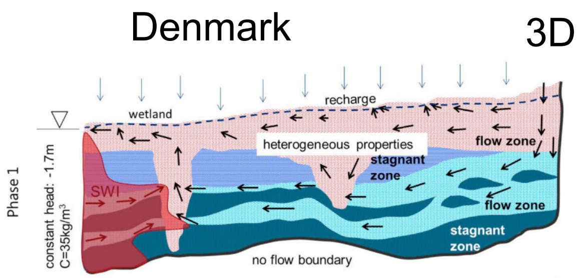
Northwest Germany



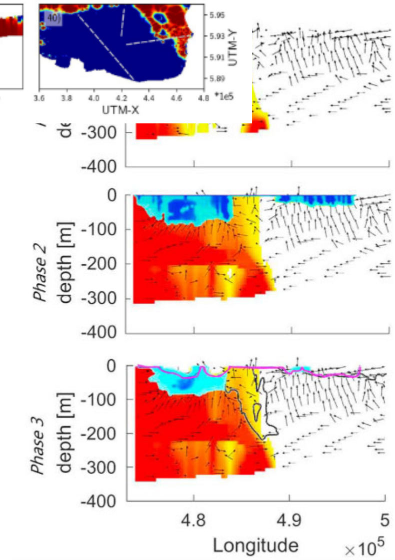
Seibert et al., 2023 WRR

Origin of sources and ~age dating

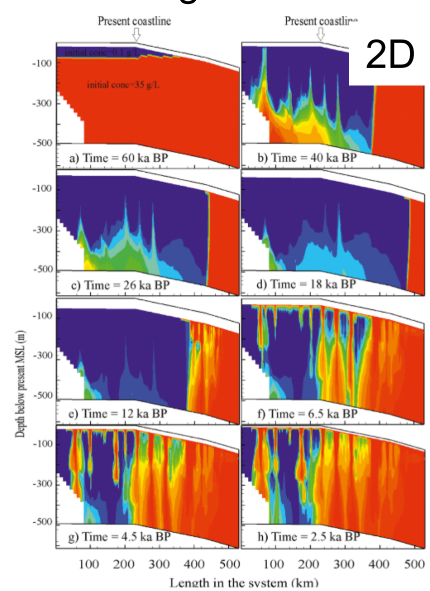
Denmark



Meyer, et al., 2019

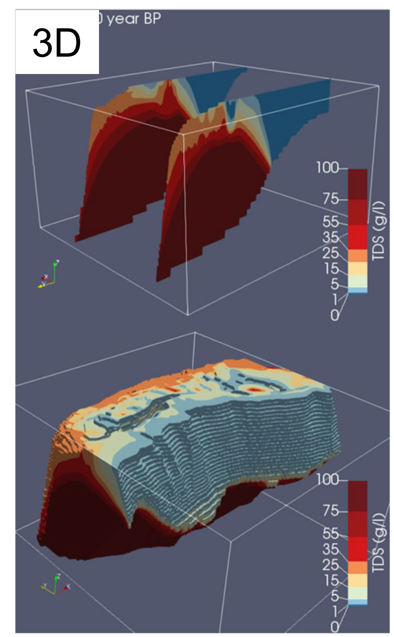


Mekong delta



Hung et al., 2019 JoH, RS

Nile delta

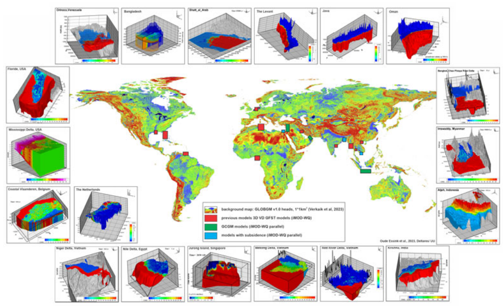


Van Engelen et al., 2019. HESS

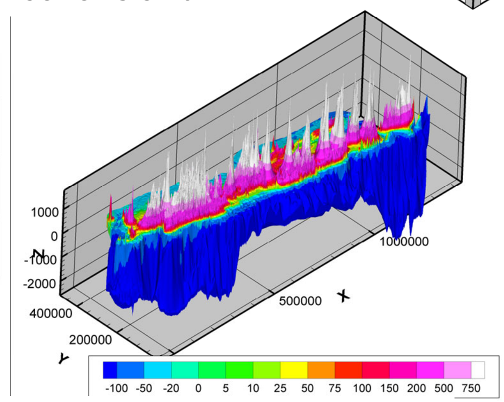
Component 7: Building and running large-scale groundwater salinity models, based on global and local (LLM) data using multiple cores

Components:

- iMOD-WQ (SEAWAT parallel)
- later shift to MODFLOW6
- incl. subsidence
- multiple model layers
- open-source (python) tools
- global datasets
- high-performance computing
- LLMs for local data

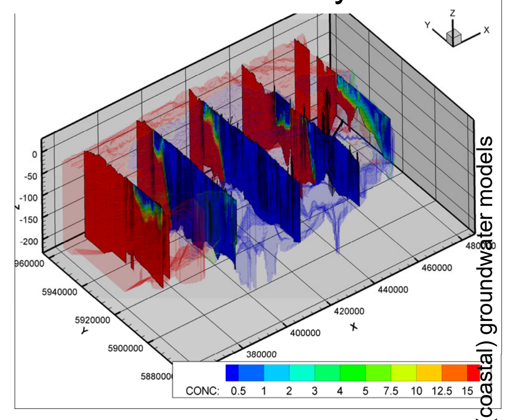


Java island

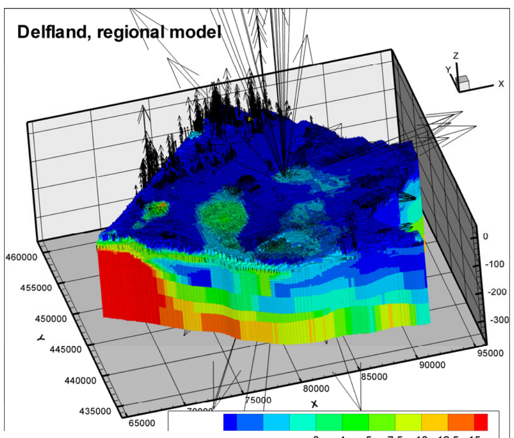


Wahdan Achmad Syaehuddin

North-west Germany

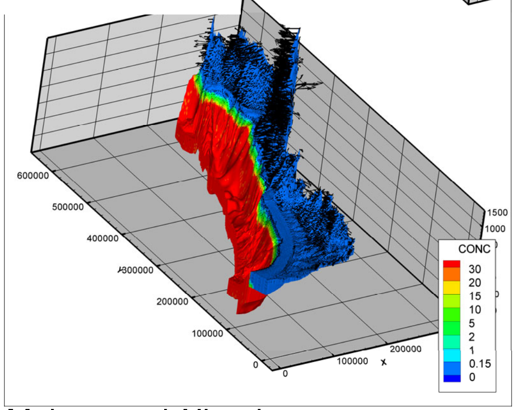


Seibert et al. WRR. 10.1029/2022WR033151



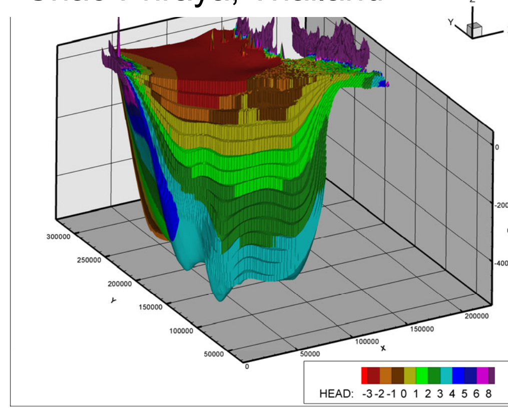
coastal part NL

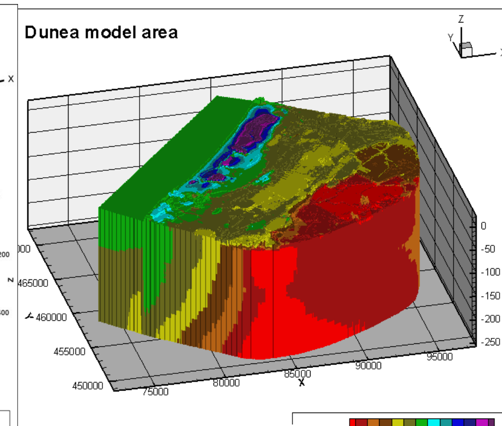
The Levant



Mohammed Alkurd

Chao Phraya, Thailand





coastal part NL

Navigating groundwater salinity in (coastal) groundwater models

Conclusions

1. By integrating diverse data sources (airborne groundwater salinity mapping, citizen science, and LLM data mining) with advanced modeling techniques (parallel computing and paleo-reconstructions), we now can improve the accuracy of large-scale groundwater salinity models.
2. These models are crucial for understanding complex salinity groundwater systems over time under climate and human stressors, useful for water managers.
3. The use of open-source tools ensures that this knowledge is shared and accessible, fostering innovation, enabling practical applications, and contributing to more effective management of fresh groundwater resources.

NATIONAAL DELTAPROGRAMMA > Documenten >

Grondwaterverzilting en watervraag bij een stijgende zeespiegel

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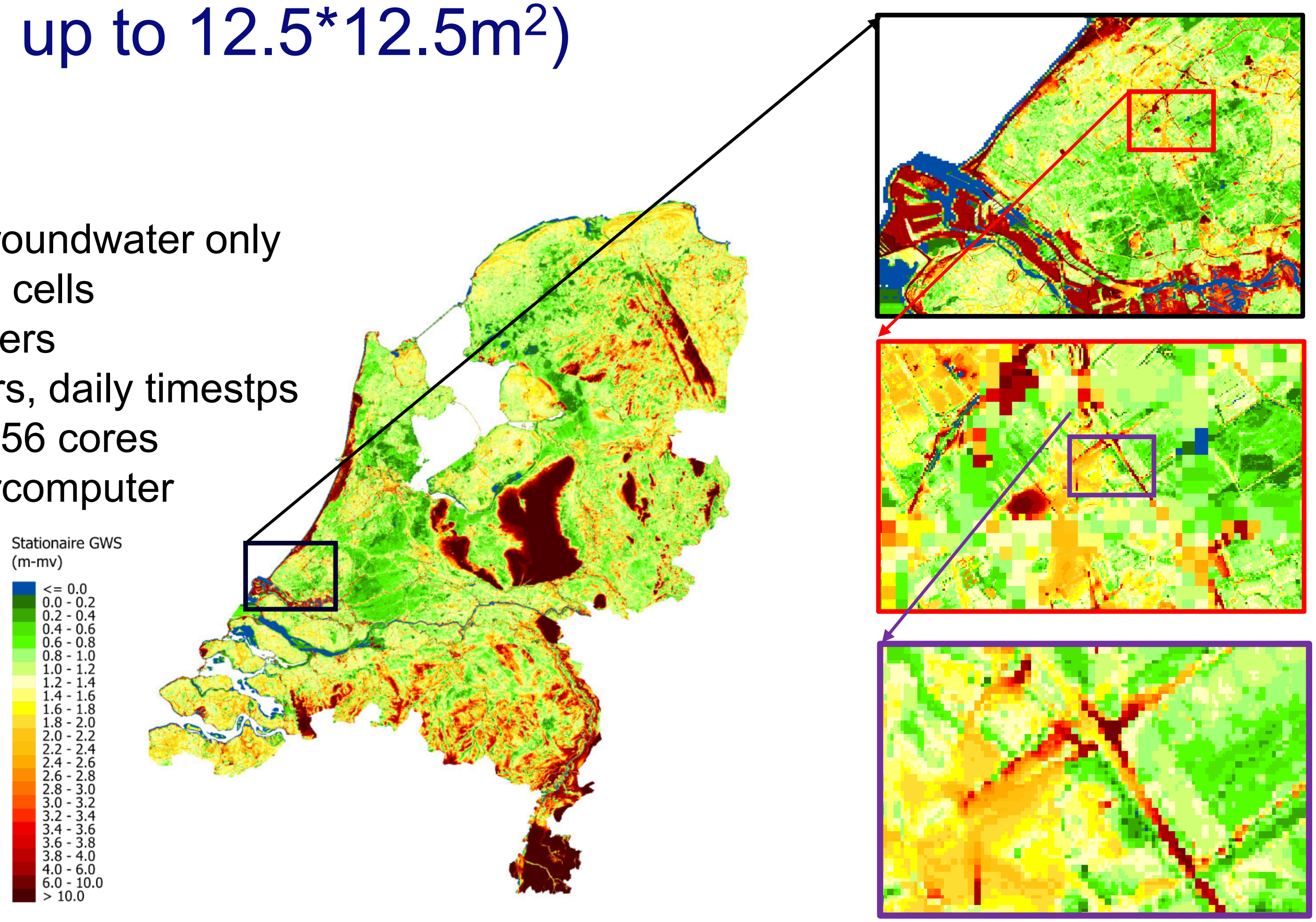
Hyperresolution quantitative groundwater modelling (national: up to 12.5*12.5m^2)

Components:
- MODFLOW6
- quantitative groundwater only
- 1 billion active cells
- 125 model layers
- Simu time 8 yrs, daily timestps
- testing up to 256 cores
- Snellius supercomputer



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