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The role of past and future hydrogeological boundary conditions for groundwater salinization in Northwestern Germany

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DFG Deutsche Forschungsgemeinschaft

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Saltsa

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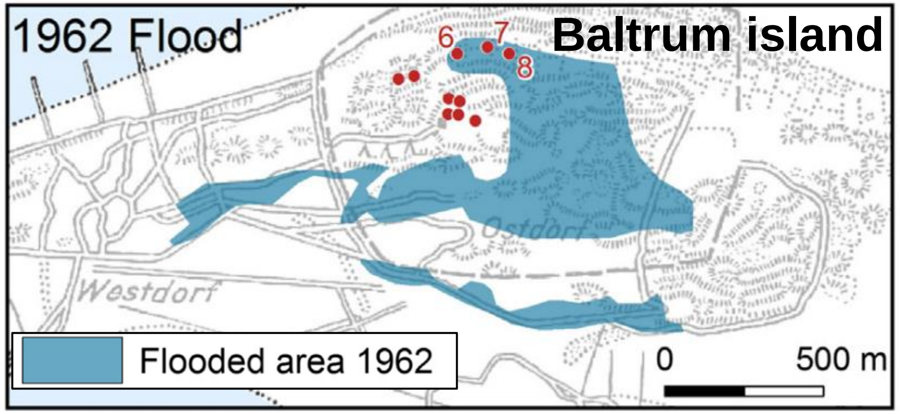
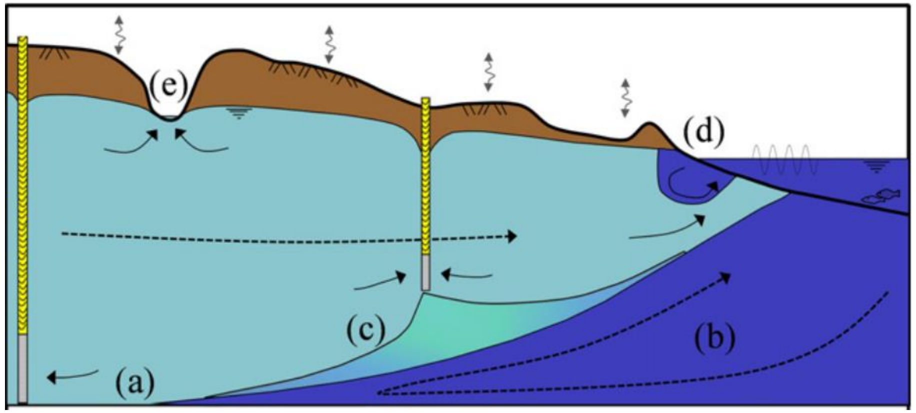
What is “groundwater salinization”?

- Millions of people live in low-lying coastal regions and use fresh groundwater
- Salinization poses a threat to freshwater resources
- Groundwater salinization can occur via:
  (i) seawater flooding or **(ii)** subsurface seawater intrusion
- Process of subsurface seawater intrusion is very slow (years to millennia)



Post and Houben (2017)



Werner et al. (2013)

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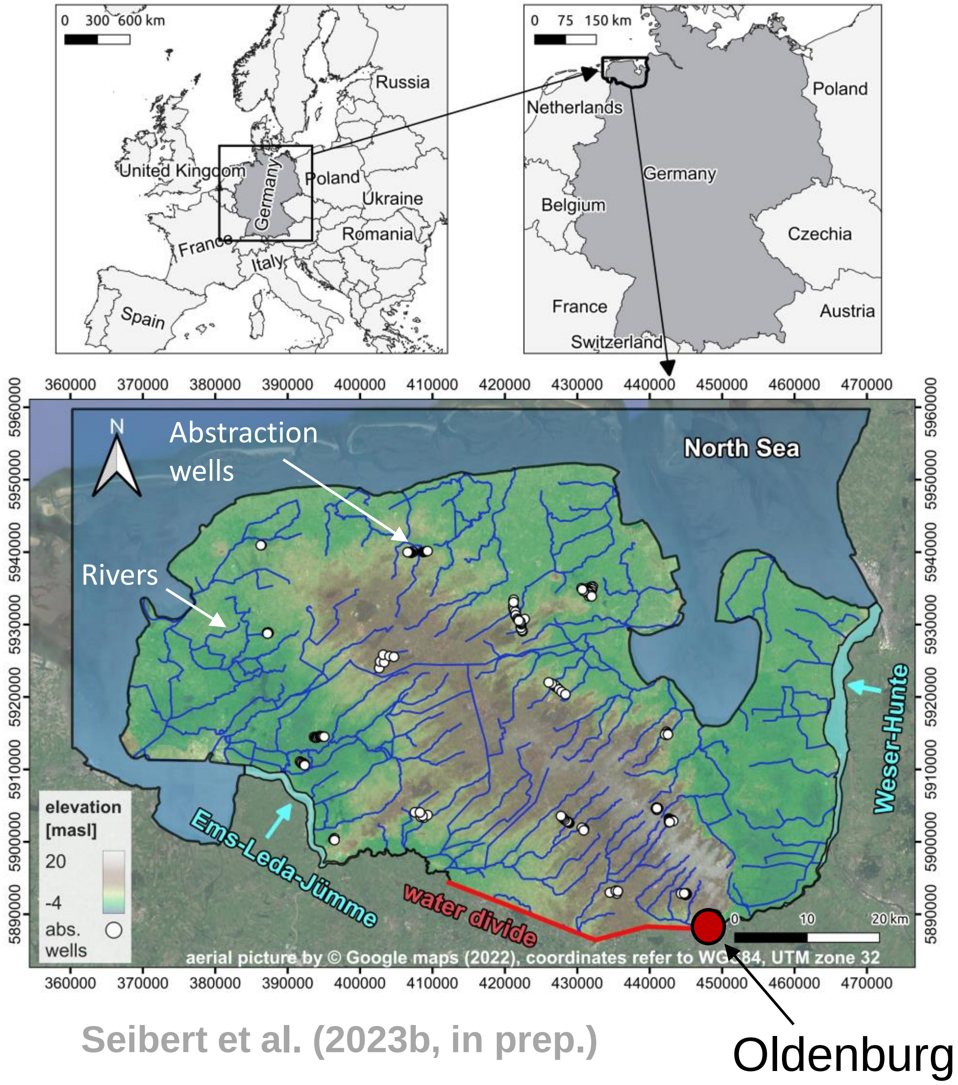
Background of the SALTSA project

- SALTSA project was part of SPP SeaLevel Phase 1 (WP B/C)
- Duration: 2016-2020
- Institutes: Ecological Economics & Hydrogeology Group (Uni Oldenburg)
- Study region: Northwestern Germany (Ems-Weser region)
- Project aims:
  - Understanding the physical behaviour of coastal groundwater salinization (model reconstruction and projection of groundwater salinization)
  - Assessment of the socioeconomic consequences of groundwater salinization and development of possible mitigation strategies with stakeholders

SALTSA project study region

- ❑ Marsh (~ 0 masl) and geest (<20 masl)
- ❑ ~1 million inhabitants
- ❑ Agricultural activities in marsh areas
- ❑ Coastline protected by dikes
- ❑ Region delineated by rivers Ems and Weser
- ❑ Rivers, sluices and a drainage network control the hydro(geo)logic system



Seibert et al. (2023b, in prep.)

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Objectives of hydrogeological modeling

“What is driving coastal groundwater salinization?”

- ❑ Which processes shaped the present-day salinity distribution?
- ❑ What are the roles of Holocene sea-level rise, paleogeography and land cultivation?
- ❑ Which boundary conditions will drive the salinization processes in the future?
- ❑ What are the implications for water end-users? Which counter measures exist?

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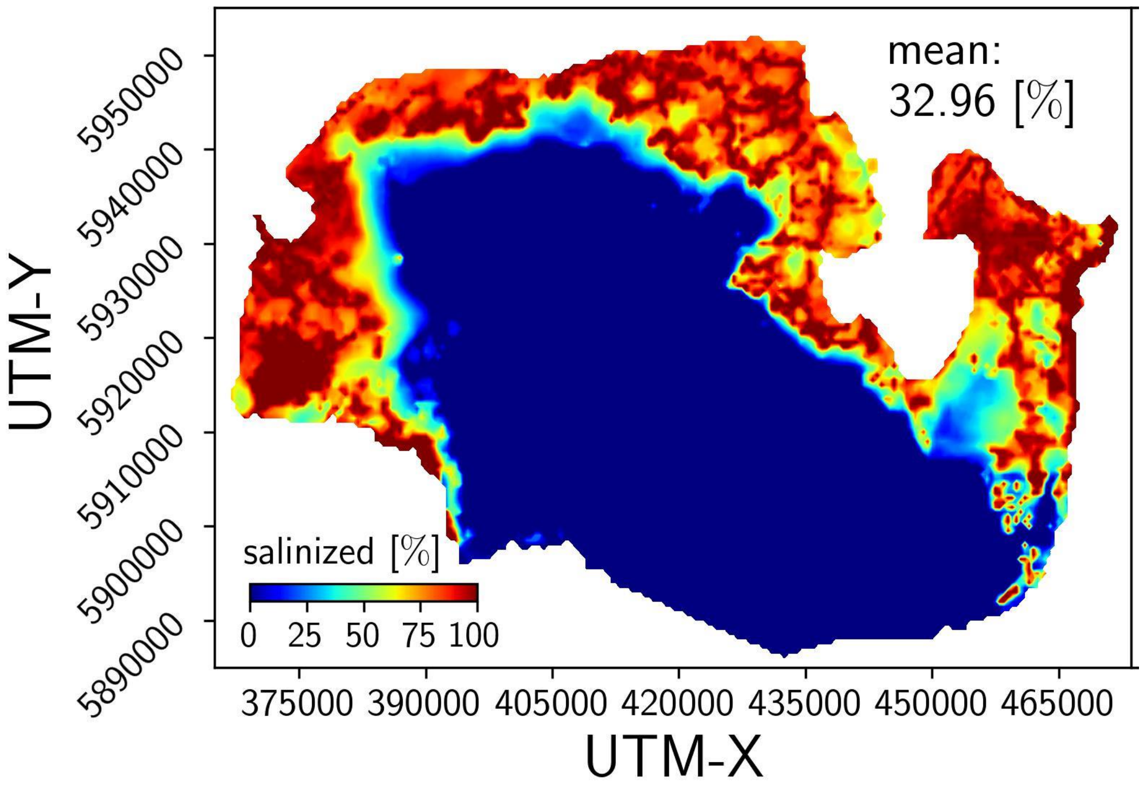
Methodology of hydrogeological modeling

- ❑ 3-D variable-density groundwater flow and salt transport modeling
- ❑ Software packages: SEAWAT (Langevin et al., 2008), iMOD-WQ (Verkaik et al., 2021) and iMOD-Python (Visser & Bootsma, 2019)
- ❑ Development of site-specific (conceptual) models (e.g., geology, coastline, hydrology)
- ❑ **Historic groundwater salinization**: 9,000 BP until today
- ❑ **Future groundwater salinization**: today until 2100 CE

Historic groundwater salinization

Resulting salinization situation after 9,000 years simulation time at 2020 CE



Seibert et al. (2023b, in prep.)

- Coastline ~400 km to the north at the end of the Pleistocene
- Sea-level ca. -30 masl at 9,000 BP
- Sea-level rise dominant salinization driver until ~1300 CE
- Dike construction, land cultivation and drainage important salinization drivers afterwards

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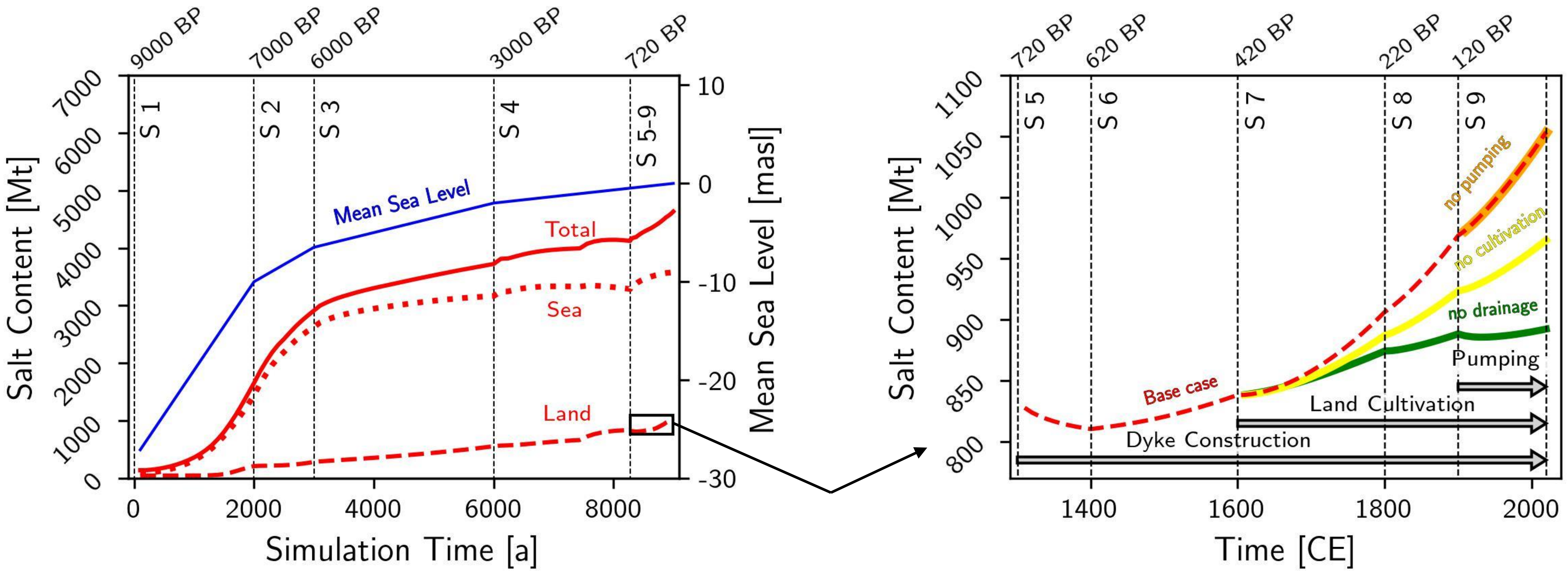
Historic groundwater salinization



Seibert et al. (2023a, Water Resources Research)

- ❑ Sea-level rise dominant salinization driver until ~1300 CE
- ❑ Dike construction, land cultivation and drainage important salinization afterwards

Future groundwater salinization

- Model runs until 2100 CE, applying constant present-day boundary conditions, show that groundwater salinization will increase in the future due to non-equilibrium of the hydro(geo)logic system
- Groundwater salinization will increase particularly in marsh areas
- Model runs until 2100 CE, applying sea-level rise scenarios and changing inland groundwater heads, demonstrate that sea-level rise is a major driver of future groundwater salinization
- The lifting of drain levels, i.e., re-wetting of the marsh areas, presents an effective measure to counteract salinization in the future
- Variations of groundwater recharge and groundwater abstraction have comparatively low and/or local impact on future salinization

Preliminary results from Seibert et al. (2023b, in prep.)

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Outlook

- ❑ Holocene sea-level rise and paleogeography were dominant drivers for historic salinization
- ❑ Dike construction, land cultivation and drainage have become important drivers during last centuries
- ❑ "Autonomous" groundwater salinization will continue in the future (due to non-equilibrium with present-day boundary conditions)
- ❑ Sea-level rise and inland groundwater levels have strong impact on overall salinization
- ❑ Low-lying marsh region strongly affected by salinization
- ❑ Higher groundwater levels in marsh could be effective salinization mitigation measure

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Thank you for your attention!

Further questions are very welcome, either here on site or via e-mail to:

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leena.karrasch@uol.de (socioeconomic research)

Recent publications of SALTSA project:

Karrasch et al. (2023). *Groundwater salinization in northwestern Germany: A case of anticipatory governance in the field of climate adaptation? Earth System Governance, 17. https://doi.org/10.1016/j.esg.2023.100179*

Seibert et al. (2023). *Paleo-Hydrogeological Modeling to Understand Present-Day Groundwater Salinities in a Low-Lying Coastal Groundwater System (Northwestern Germany), Water Resources Research, 59(4), https://doi.org/10.1029/2022WR033151*

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Langevin, C. D. et al. (2008). SEAWAT version 4: a computer program for simulation of multi-species solute and heat transport (No. 6-A22). Geological Survey (US).

Post & Houben (2017). Density-driven vertical transport of saltwater through the freshwater lens on the island of Baltrum (Germany) following the 1962 storm flood. Journal of Hydrology, 551, pp.689-702. https://doi.org/10.1016/j.jhydrol.2017.02.007

Seibert et al. (2023a). Paleo-Hydrogeological Modeling to Understand Present-Day Groundwater Salinities in a Low-Lying Coastal Groundwater System (Northwestern Germany), Water Resources Research, 59(4), https://doi.org/10.1029/2022WR033151

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Verkaik, J. et al. (2021). Distributed memory parallel groundwater modeling for the Netherlands Hydrological Instrument. Environmental Modelling & Software, 143, p.105092. https://doi.org/10.1016/j.envsoft.2021.105092

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Werner et al. (2013). Seawater intrusion processes, investigation and management: recent advances and future challenges. Advances in water resources, 51, pp.3-26. https://doi.org/10.1016/j.advwatres.2012.03.004