SALINISATION OF GROUNDWATER RESOURCES IN THE DUCTH DELTAIC AREA: MODELLING, MONITORING, CLIMATE CHANGE AND SOLUTIONS

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ABSTRACT

With increased pressure on fresh water resources in deltaic areas due to increased human activites and climate change, (applied) research on hydrogeological processes has been intensified these last decades. From detection in the nineteenth century of the fresh water lenses due to the analysis of Badon-Ghyben, and via Custodio's hydrogeological water system analysis, we nowadays can combine different disciplines to monitor, understand, model, asses and simulate the relevant phenomena. In this paper different aspects of salinisation of groundwater resources in the Dutch coastal zone will be discussed. This Dutch delta can be considered as a blueprint for other deltas in the future as ground surface is already some meters below mean sea level. We are in the process of combining numerical models with innovative monitoring techniques to better understand the complex subsurface and to assess the impacts of increased anthropogenic and climate pressures. The next step for the coming decades will be to successfully implement measures to adapt to or to mitigate salinisation, based on accurate quantifications of the (future) coastal hydrogological system. This will be done together with stakeholders such as farmers, water boards, provinces, other water knowledge institutes, by starting with pilot studies and via upsaling local successes to regional solutions…all to get to our the final professional goal: enabling delta life!

Keywords. Salt water intrusion, modelling, climate change, water management, measures

INTRODUCTION

For ages, mankind has been attracted to deltaic areas throughout the world because of the availability of an abundance of food (e.g., fisheries and agriculture) and the presence of economic activities (e.g., trade, harbours, ports and infrastructure). Fresh groundwater resources in these deltaic areas are utilized for domestic, agricultural, and industrial purposes. The availability of huge quantities and the high quality (unpolluted), relative to surface water, makes it a popular resource.

For the future, the use of fresh groundwater resources is probably increasing due to population rise, economic growth, intensified agricultural development, and the loss of surface water due to contamination. In addition, the anticipated sea level rise and associated changes in recharge and evapotranspiration pattern will intensity the pressures on the coastal groundwater system.

It is not clear, however, to what extent deltaic areas are threatened, from a groundwater point of view, though conceptually, aquifers will probably become more saline at a greater pace. This could lead to a reduction of fresh groundwater resources. In addition, the present capacity of the discharge systems may be insufficient to cope with the excess of seepage water, especially in those areas which will be below (future) M.S.L. This seepage will probably have a higher salinity than at present. As a result, poor crop yields are produced due to salt damage and indigenous crops might be substituted by more salt-tolerant crops. If even the salt-tolerant crops cannot withstand the high salinities, the population might eventually migrate from the barren land and resettle in more fertile arable territories, which could cause severe social commotions.

On top of the above-mentioned slow processes, very quick processes can also threaten fresh water resources at a much quicker pace. The loss of freshwater after severe floods of low-lying areas after tsunamis caused by underwater earthquakes has been a serious topic after the Sumatra Tsunami December 2004.

In this article, we will quickly pass the problems we are facing in our Dutch delta in terms of fresh water, and move on to a combination of several possible solutions.

In addition, we should not only be pessimistic about future fresh water supply in coastal zone. From a physical point of view, salinisation of the water resources is sometimes accompanied with freshening processes, whereas technical innovations are about to be implemented in showcases. Moreover, stakeholders like farmers and drinkingwater compagnies, universities and knowledge institutes are more and more involved into the topic, and via o.a. governmental funding procedures, the willingness to experiment and implement in climate proof fresh water supply is firm. With (ground)water becoming more precious and expensive, solutions not considered before may become feasible. A number of solutions will be shown in this article.

LEARN TO COPE WITH SALINITY FROM THE DUTCH APPROACH

As the coastal part of The Netherlands (of porous medium composition) are already several below Mean Sea Level, The Dutch already have to cope with salinisation of their freshwater resources: upconing drinking water resources, saline seepage. Basically, where the Dutch are standing now, many low-lying coastal areas will experience similar problems within 20-50-100 years. The way we cope with the threats and the strategies we adopt for adaptation and mitigation can be seen as a blueprint for other deltas in the future. We believe the impact patterns on the Dutch fresh water resources due to future changes are similar to other delta areas worldwide with similar hydrogeological conditions (Figure 1), including the Po, Mississippi, Nile, Mekong, Chinese and Indian deltas and the US Atlantic coast (Custodio and Bruggeman, 1987, Van Weert *et al.*, 2008; Deltares, 2009; Post and Abarca, 2010; Custodio, 2010; Barlow and Reichard, 2010; Oude Essink *et al.*, 2010). Although the characteristics of these delta areas are obviously different, the general picture is that groundwater management in the coastal zone must face serious impact from future stresses (Ranjan et al., 2008).

In addition, within the Delta Programme (Deltacommissie, 2008) but also within research programmes such as the Knowledge for Climate, different adaption and mitigation strategies have been suggested, tested, evaluated and are about to be implemented to make Future Fresh Water Supply in The Netherlands Climate Proof. What we already learned is that a combination of local as well as adaptive strategies is the most effective one, from a robust and flexible point of view, given the uncertainties in the long-term prediction of future climate change effects, and of other relevant socio-economic developments!

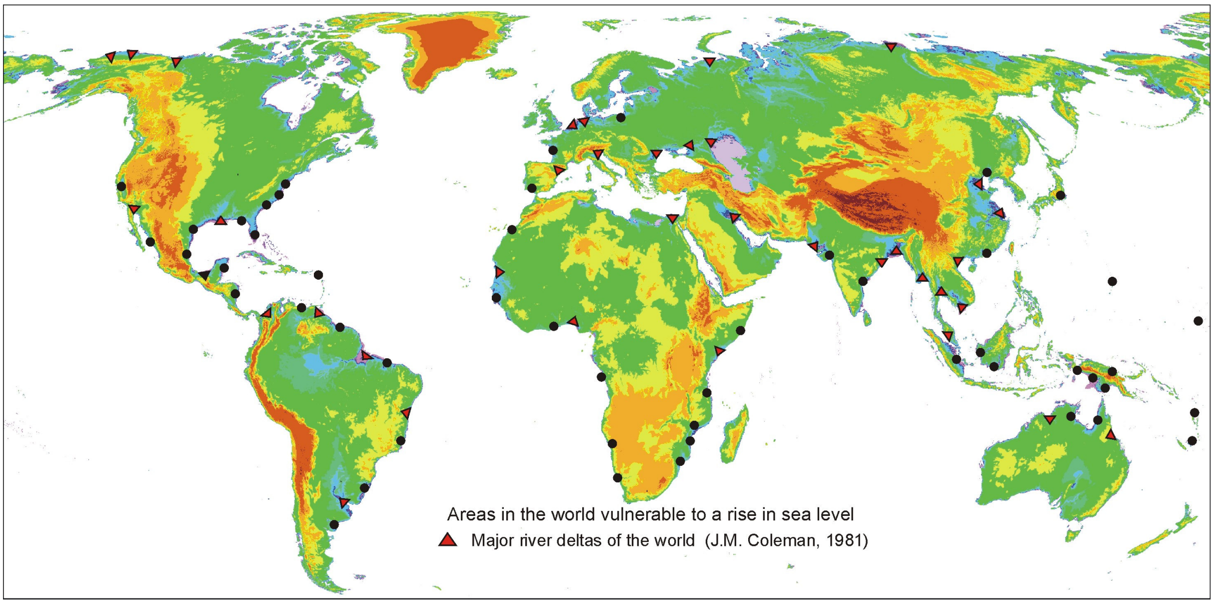


Figure 1*: world map with possible vulnerable coastal deltaic areas suffering salt water intrusion problems, now or in the future (Oude Essink et al., 2011).*

Some of those uncertainties are listed below and place things into perceptive. For instance, what will be the effect on the groundwater system of:

- Land subsidence
- Climate change
- Increased groundwater extractions
- Development energy use/production (heat-cold storage underground)
- Development of land use (land reclamation offshore)
- Politics, policy & water management

SALINISATION IN THE NETHERLANDS

The Netherlands is situated in the deltas of three rivers; the Rhine, the Meuse and the Scheldt. Like in many other deltaic areas, in The Netherlands salinity in groundwater ranges from brackish to saline. This groundwater is mainly old seawater that has been trapped in the ground when the sea transgressed the delta. In a large part of the Netherlands, permanent groundwater drainage keeps the polder areas sustainable. However, this on-going draining resulted in mobilizing and upconing of deeper and more saline groundwater, leading to salinisation of shallow groundwater and surface water (Figure 2). In addition, sandy boils, a localized form of preferential groundwater flow, also increase the salinisation (De Louw *et al.*, 2010) This may pose problems for (drinking) water supply, agricultural production (salt damage) and fresh water ecosystem.

Nowadays, one of the major water issues in the low-lying Netherlands is to make The Netherlands climate proof for the coming century. Second to safety against flooding, climate proof fresh water supply is a top priority in the Delta Programme and in the National Water Plan. When water related problems (flooding, drought, salinisation, land subsidence) seem to get worse, possibilities to be part of solutions to these problems seem to be more than ever: sharing knowledge via internet and meetings, advanced data-collections (satellite, AEM), combing modelling and monitoring, increasing computer capacities, and finally, the sense of urgency with stakeholders such as water boards, provinces and the national government.

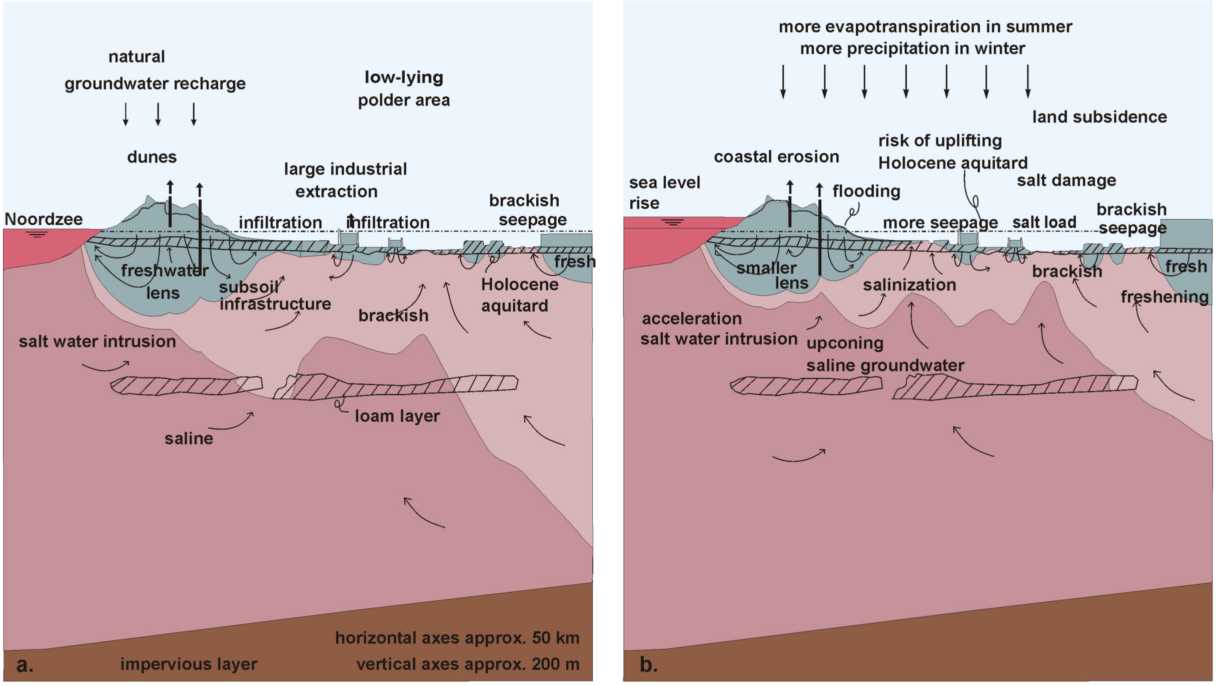


***Figure 2**: Schematization of the groundwater system in the Dutch deltaic area; possible processes which occur in case of climate and global change.*

NUMERICAL MODELLING

In contrast with 10-15 years ago, numerical modelling of variable-density dependent groundwater and coupled solute transport on a large regional to national scale is now technical feasible (e.g. see Figure 3 for the situation in The Netherlands and Oude Essink, 1996; 2003b). With the developments in computer capacity due to the increase in speed of processors but especially the additional extended and hard drive memory storage, 3D models with many tens of millions model cells simulating 100 years is not special any more. However, these 3D models still have coarse model cells (e.g. 250*250m^2), and can therefore not be used for small phenomena such as shallow freshwater lenses or saline seepage () from sand boils (Louw *et al.*, 2010). New innovative techniques, from parallelisation to graphical cards, to make large-scale numerical models with small grid cells possible for the near future.

In-house hydro(geo)logical databases with high resolutions, numerical modelling techniques, monitoring results are available to thoroughly investigate salinisation issues. Since 1996, only the data problem is still existing: viz. not enough hydrogeological data available, especially not in data-poor countries.

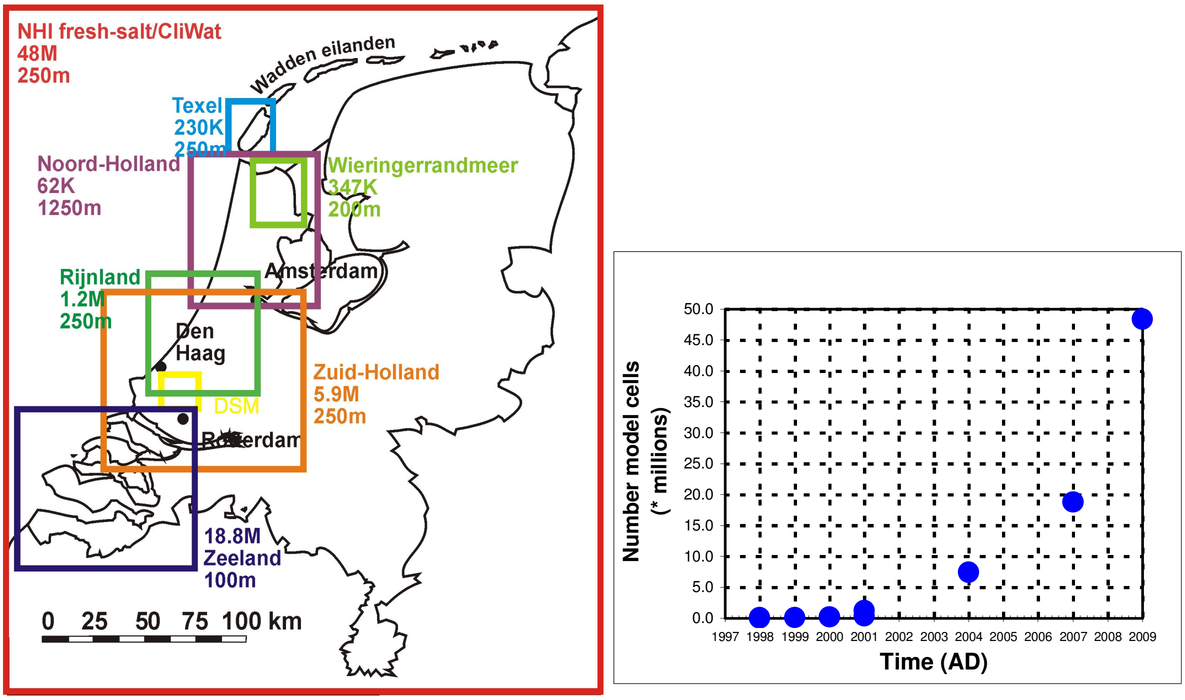


Figure 3: *a. Difficult 3D numerical models for variable-density and coupled solute transport on a regional and national scale: name, number of model cell and size of squared model cell in the horizontal plane, b. Number of model cells of every case versus the date of the creation of the model: the shape is correlated to the capacity in extended memory as well as hard disk.*

IMPACT OF CLIMATE CHANGE ON COASTAL GROUNDWATER

Since quite some years now, the impact of climate change and sea level rise on coastal groundwater resources has been investigated. Various articles have been published on this topic, whereas during meetings such as the SWIM or AGU spend sessions on this topic (e.g. Meisler et al., 1984; Navoy, 1991; Jelgersma *et al.*, 1993, Oude Essink, 1996, 1997, 1999, 2001a, 2001c, 2003a; Klein *et al.*, 1998; Sherif and Singh, 1999; Bobba, 2002, Ranjan et al., 2006, 2008; Masterson and Garabedian, 2007; Vandenbohede, 2008; Werner and Simmons, 2009; Oude Essink et al., 2010). In addition, the UNESCO initiative GRAPHIC Groundwater Resources Assessment under the Pressures of Humanity and Climate Change has been set up to improve our understanding of how groundwater interacts within the global water cycle under pressures of human activity and climate change. Basically, the mean focus on most articles is focussed on the direct impact of a sea level rise on lateral salt water intrusion (Figure 4). However, in deltaic areas, upward saline seepage may be a more important issue (Figure 2).

In the coming sub-sections, some examples of numerical modelling studies in the Dutch deltaic setting will be shown.

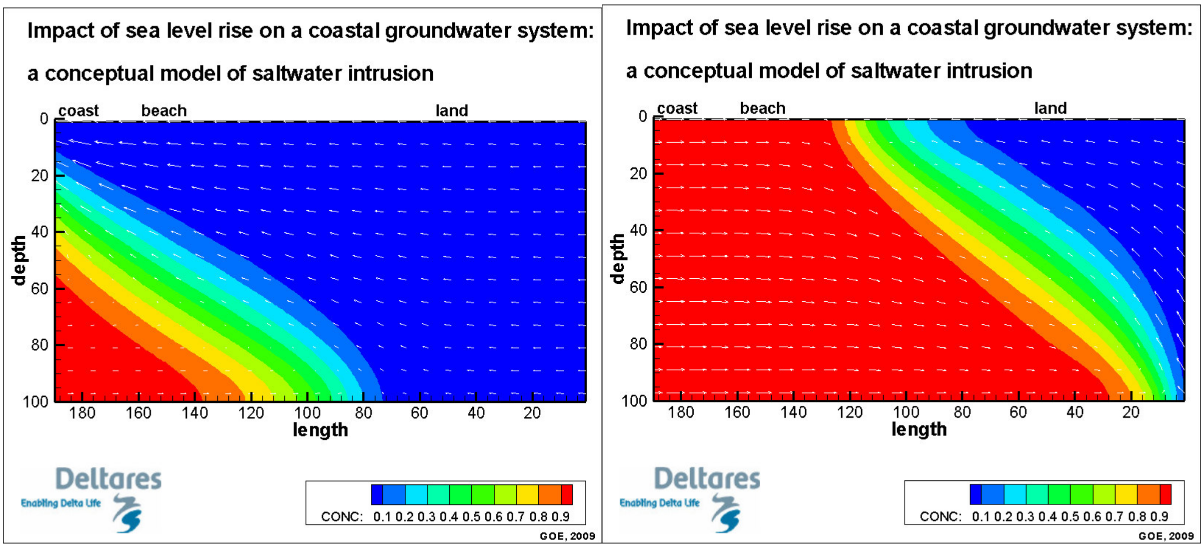


Figure 4: *Conceptual approach of the impact of sea level rise on coastal aquifers: a. the basic Henry solution: lateral salt water intrusion, circulation, mixing and outflow of fresh water, b. the same case with a sea level rise: as a effect of overpressure at the coastal side, salt water will intrude more inland.*

Netherlands Hydrological modelling Instrument (NHI)

To assist water managers in their choices to make our country ready for future stresses such as flooding, drought, land subsidence and salinisation, a modelling framework has been set up. The so-called Netherlands Hydrological modelling Instrument (NHI) includes a module to take into account fresh and saline groundwater in the coastal zone. This NHI fresh-saline groundwater module assesses on a national scale the impact of stresses such as sea level rise, land subsidence, increasing groundwater extraction and changes in natural groundwater recharge on groundwater in the Dutch coastal zone. Modelling results show that the water system significantly becomes more saline these coming 50-100 years, and that water courses need to be flushed more intensively if water boards want to maintain the water quality in the surface water system.

National databases on topography, geology (REGIS), chloride concentration (combining Vertical Electrical Soundings (VES), borehole measurements and analyses with the brackish-saline interface within the ZZREGIS database), geohydrology (extraction rates) and hydrology (surface water system, precipitation, evapotranspiration, drain and water channels characteristics) are used to set up the 3D module for the simulation of variable-density groundwater flow and coupled salt transport. The initial chloride distribution is determined with 3D interpolation of analyses, VES and borehole measures via geostatistical procedures and a mapped brackish-saline interface of 1000 mg Cl^-/L (taking into account the geological set-up of the groundwater system). The dimension of the covered area is 325 km by 300 km by 290 m thick, whereas over 20.6 million active model cells of 250*250m^2 were used in 31 model layers (the top layers are thinner than the lower ones) to characterize the vertical distribution of fresh-brackish and saline groundwater with enough detail. Figure 5b shows a result of a 100 years modelling of groundwater flow in the Dutch coastal area: salinisation as well as freshening of the system is taking place.

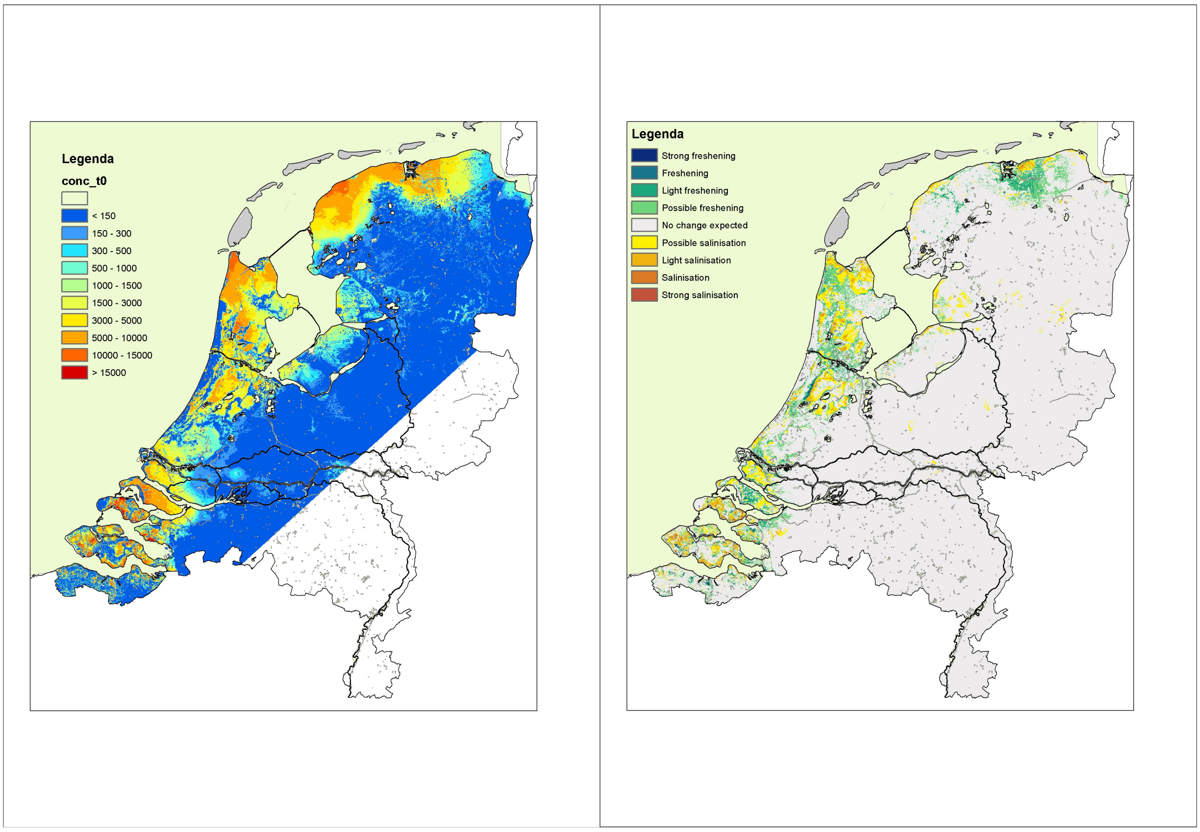


Figure 5: *a. The present chloride distribution (mg Cl-/L) at the bottom of the Holocene aquitard, b. Change in chloride concentration in relative terms due to autonomous development (caused by past lowering in polder water levels).*

Zeeland: regional model

For the Province of Zeeland in the Netherlands, a 3D-model for density-dependent groundwater flow and coupled solute transport has been developed to assess the impact of sea level rise and changing precipitation and evapotranspiration patterns on the freshening and salinisation processes of shallow groundwater systems. The model is used to determine feasible and robust adaptation or mitigation measures in the water system to secure the vulnerable fresh water resources in this low-lying coastal zone. In the building of the complex 3D numerical model (15 million model cells) the focus was on the determination of the initial chloride distribution (Goes, 2009). For this, different types of (geophysical) techniques are combined with groundwater sampling data (Figures 6b and 7).

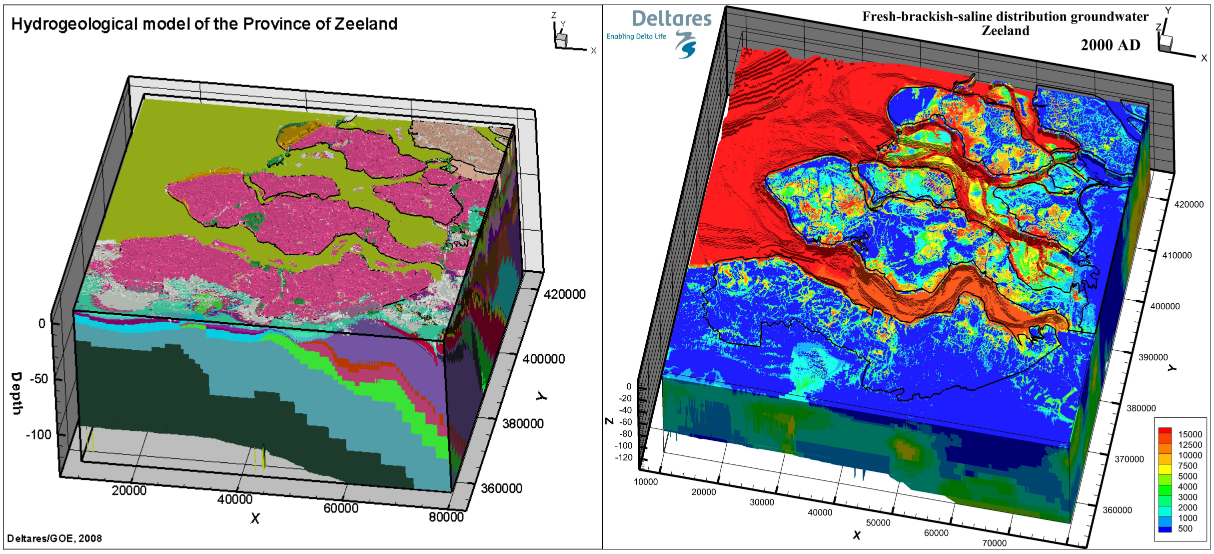


Figure 6: a. *Geological model of the area: detailed information of the geology is implemented in the (Holocene) top of the system, b. Initial fresh-brackish-saline distribution in the Zeeland groundwater system.*

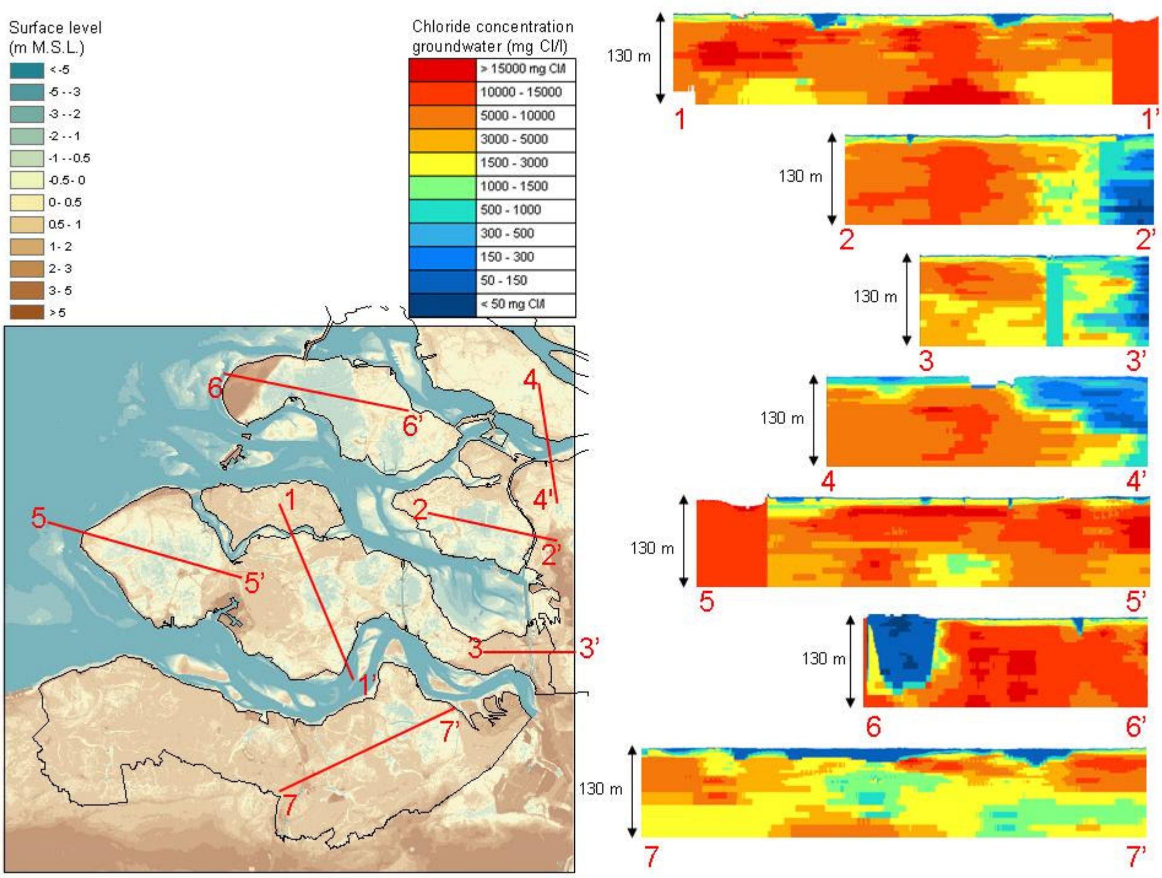


Figure 7: *a. Groundwater surface and b. fresh/brackish/saline profiles through the 3D chloride distribution.*

Province of Zuid-Holland

Large parts of the Province Zuid-Holland, the Netherlands, are situated several metres below mean sea level. Saline groundwater from the North Sea and from deep marine finegrained deposits intrudes the upper aquifers (Oude Essink et al., 2010). Natural processes and anthropogenic events of land surface settling, that have been going on for nearly a millennium, cause the salinisation of the subsoil. In addition, future sea level rise and land subsidence are expected to jeopardise the groundwater system even more. Water managers are concerned about the future state of this dynamic groundwater system during the coming 100 years. A 3-dimensional model was constructed to quantify changes in the groundwater system. The model predicts that past land subsidence and sea level rise lead to an accelerated inflow of saline groundwater towards the coastal groundwater system in the next centuries. The groundwater system, especially the upper part, will contain more saline groundwater. The salt load to low-lying areas will increase, which will seriously affect surface water management in these lower parts of the Netherlands (Table 1).

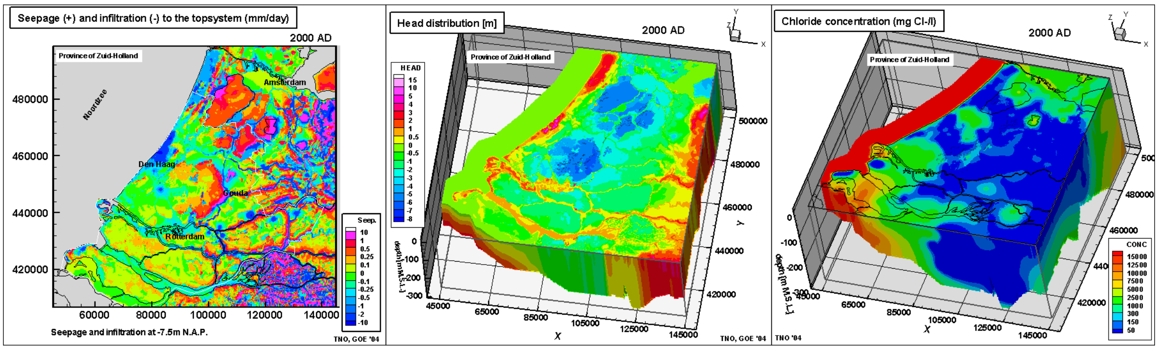


Figure 10: *Calculated with the 3D model: a. seepage and infiltration to the top system; b. head distribution in the groundwater system; and c. chloride concentration.*

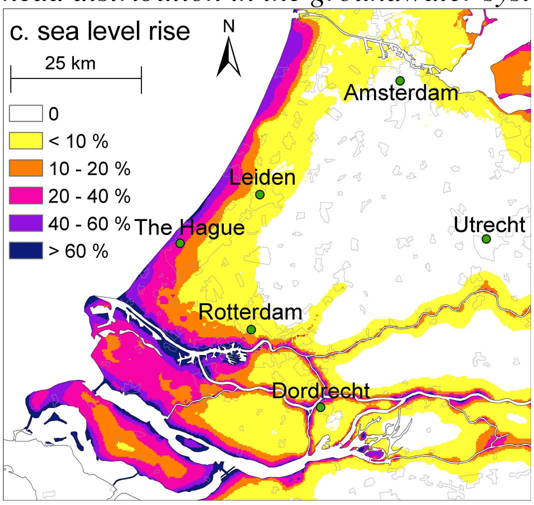


Figure 11: a. *Zone of influence of a sea level in the central part of the Netherlands. The figure shows the difference in head at -12.5m M.S.L. between 2000AD and 2050AD: e.g. 20% means 20% of the sea level rise at the sea itself.*

Island of Texel

Salt water intrusion is investigated at Texel, which is a Wadden island in the northern part of The Netherlands with a surface area of approximately 130 km^2 (Oude Essink, 2003a). In this coastal groundwater system of Quatenary deposits, salinisation of the upper layers is taking place. At present, brackish water already occurs close to the surface of the low-lying polder areas at the eastern part of the island. Freshwater occurs up to –50 m M.S.L. in the sand-dune area at the western part. Groundwater flow and salt transport was simulated for the coming centuries. The salinity in the top layer as well as the salt load at the surface of the polders will increase substantially during the next centuries. In addition, a relative sea level rise of 0.75 meter per century definitely intensifies the salinisation process, causing a further increase in salt load in the polders (Table 1). As such, the increased salinisation of the top layer will affect the surface water system from an ecological as well as a socio-economical point of view.

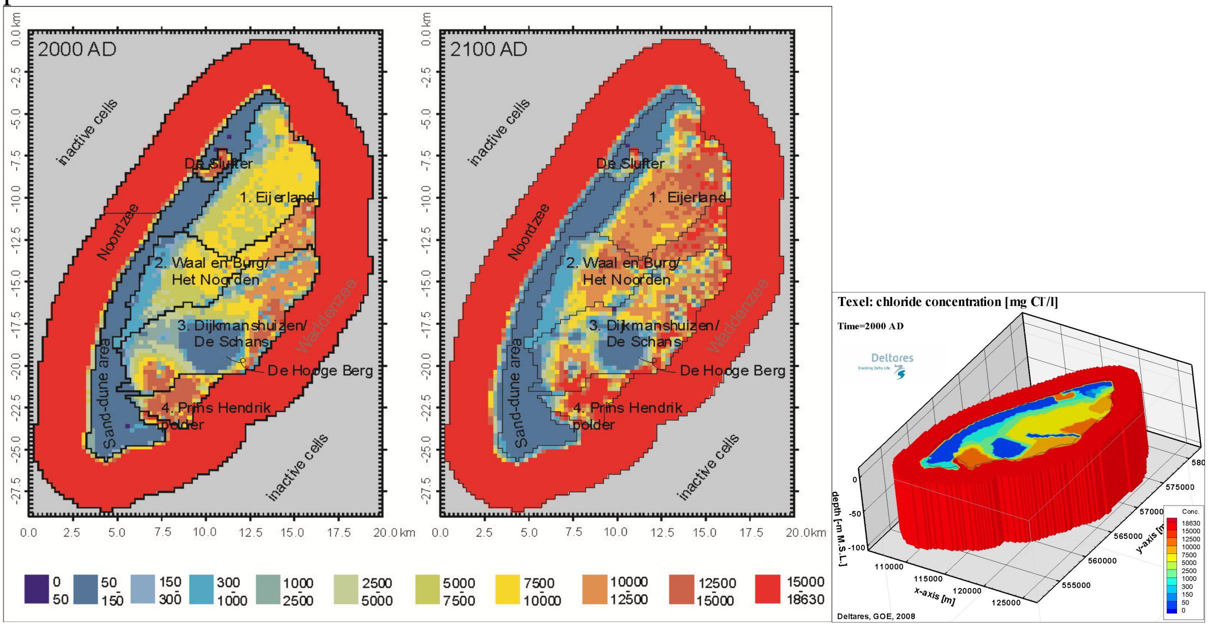


Figure 12: *a. and b.: Chloride concentration distribution to the top system at 2000AD and 2100AD of the island of Texel. The figure shows an increase of concentration, especially at the polder areas with low water levels; c. initial chloride distribution in Texel.*

Table 1: *Change in seepage and salt load at the bottom of the Holocene aquitard in the two groundwater systems over a period of 100 years. Areas from infiltration to seepage, the so-called hinge areas are also quantified (these areas are vulnerable from an ecological point of view).*

Studied area	**Texel**	**Provincie Zuid-Holland**
Change in seepage (%)	+22	+4
Change in salt load (%)	+46	+34
Hinge area (from infiltration to seepage) (%)	+3	+5

SCALING ISSUES

These last five years, 3D coupled groundwater-surface water models have been constructed for Climate Proof Fresh Water Supply In The Netherlands, called the Netherlands Hydrological Instrument (www.nhi.nu). The scale of these models 250 even up to 1 km, depending on the questions.

On this scale, some phenomena that are probably relevant for national water management policy within the framework of climate and anthropogenic change cannot be modelled accurately. For instance, the interaction between surface water and groundwater and shallow or saline seepage though sand boils (Louw *et al.*, 2010) demand a much finer resolution. N addition, the Figures 8 and 9 show a another scaling case: the effect of different model cell sizes on the freshwater volumes in a shallow freshwater lens. In incorporate these local phenomena, sophisticated up- and downscaling techniques must be developed to couple these different hydrogeological scale. This field of applied research is still open for new ideas.

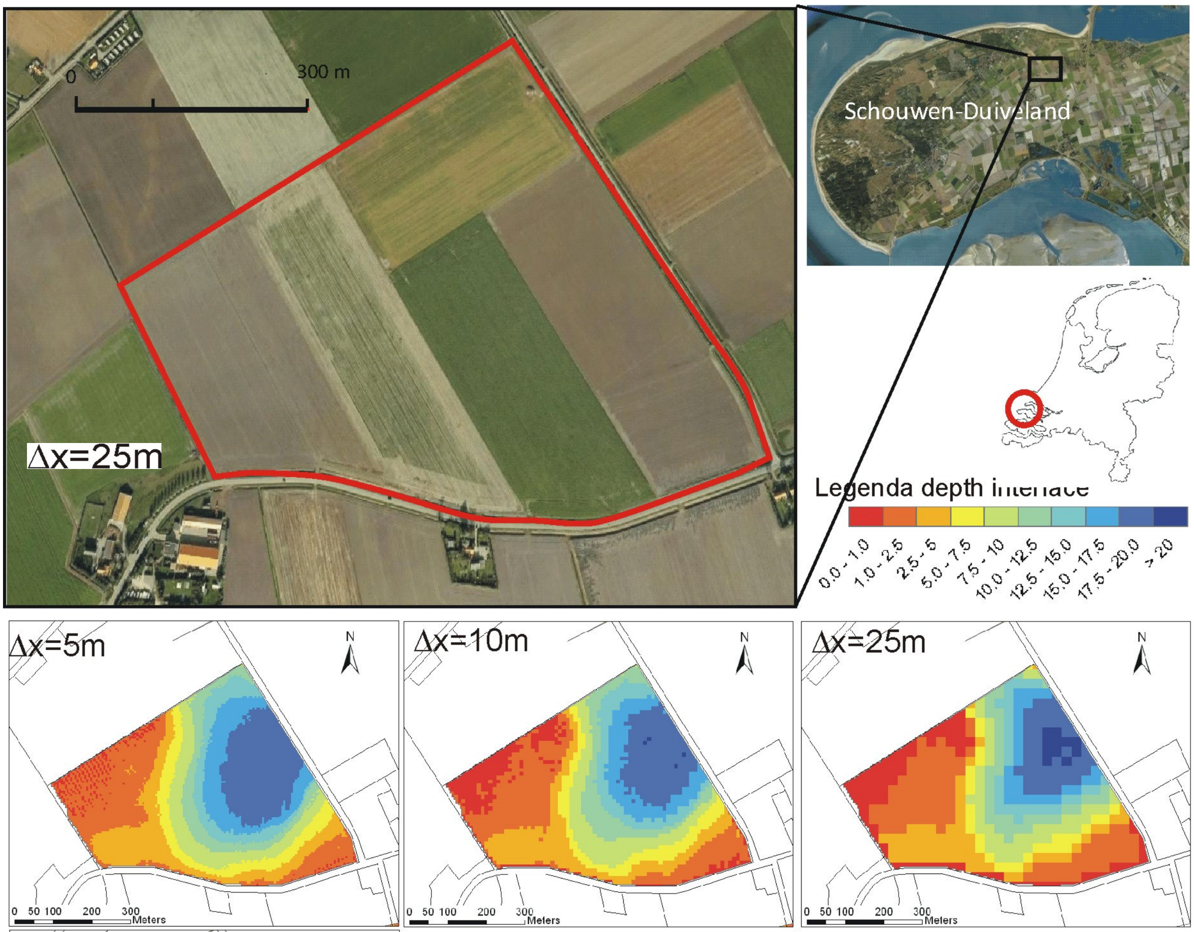


Figure 8: *Depth of the brackish-saline interface of a shallow freshwater lens (3000 mg Cl⁻/L) on different model cell scales (5m, 10m, 25m, resp.).*

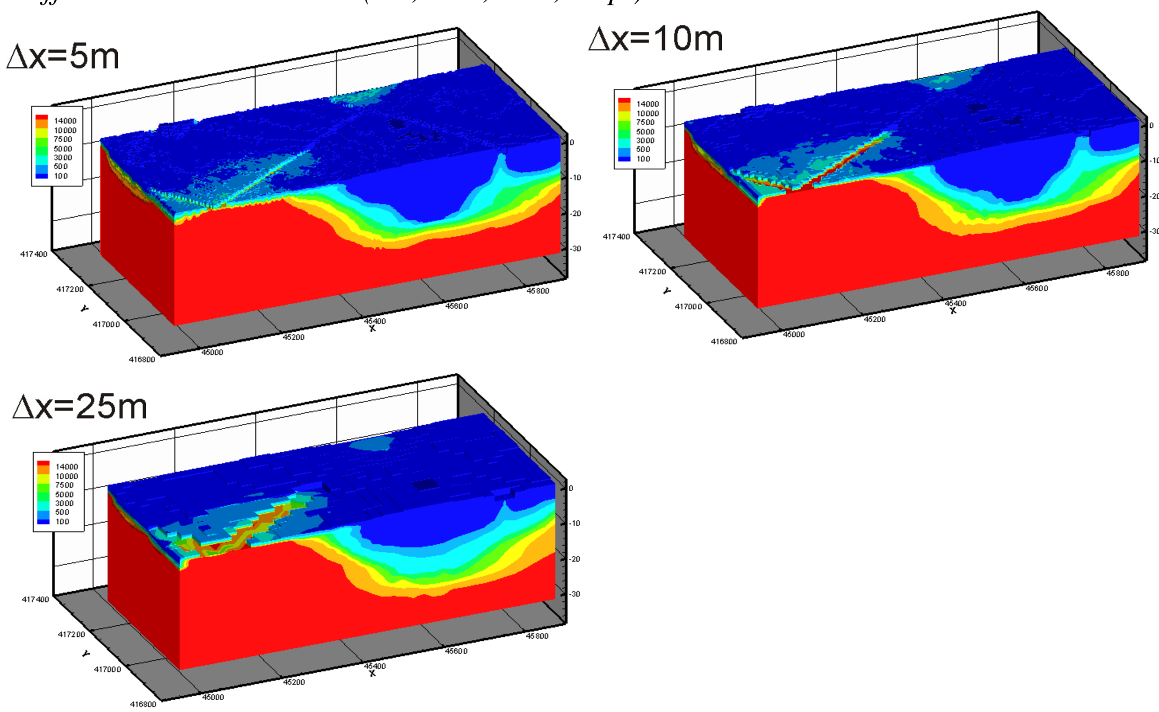


Figure 9: *Modelling chloride concentration in groundwater at different model cell scales: (Dx=5m, 10m, 25m, resp.). The coarser the model cell, the thinner the fresh water lens is modelled; in addition, the salt load to the surface water system is also quantified differently.*

USING A RELIABLE 3D DISTRIBUTION OF FRESH-SALINE GROUNDWATER

Data scarcity often limits sustainable management of these groundwater systems worldwide. Mapping and monitoring the current spatial extent of fresh groundwater resources normally requires detailed in-situ information of large areas, which is seldom available. As an alternative, remotely sensed data are a cheap way of collecting data and cover large areas in a short time span. For instance, Airborne Electromagnetic (AEM) geophysical methods can be exploited.

AEM methods are especially suited for detecting the salinity of groundwater due to the impact of salinity on the conductivity for electrical currents used in EM. Complicating factors include the effect of man-made infrastructure that transports electrical currents (power lines, railways, etc.) and the effects of the underlying geological structure. Both salinity and lithology influence the response of the EM system and it is therefore important to be able to unravel the combined effect of these two factors.

Though Fitterman (1998) already successfully used AEM in fresh-saline groundwater environments (South-Florida, USA) during the 1990s, it is within the framework of the Interreg IV-B project CliWat (www.cliwat.eu) that Deltares, TNO, BGR and Aarhus Geophysics work together to make these AEM methods suitable and accessible for several stakeholders for mapping fresh groundwater resources over large areas (Figure 10). Pilot studies in The Netherlands, Denmark and Germany have been set up to combine Airborne EM results with detailed 3D geological models to get a much better insight in the spatial distribution of saline groundwater as well as in the geological setting.

Subsequently, 3D variable-density groundwater and coupled salt transport numerical models use these salinity data to more accurately predict the possible effects of climate change, sea level rise and human activities on the availability of fresh groundwater resources. Adaptive strategies will be more effective (and cheaper) to limit the impact of negative future stresses. We think that incorporating this technique with traditional (geophysical) techniques such as TEC, CVES, EM31 and sampling groundwater will, in the end, lead to a more sustainable water management (Goldman and Kafri, 2006).

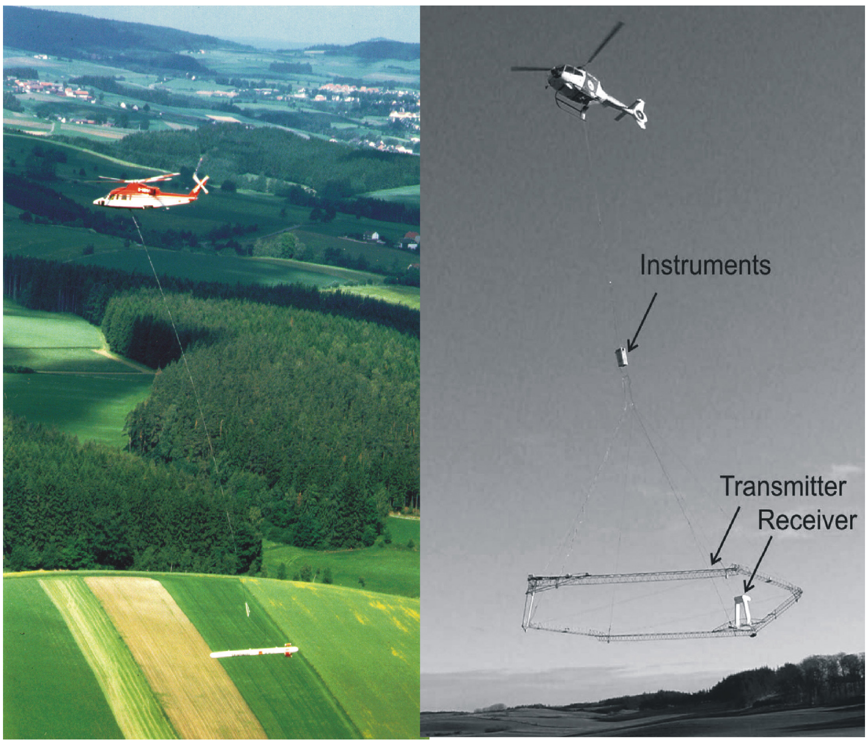
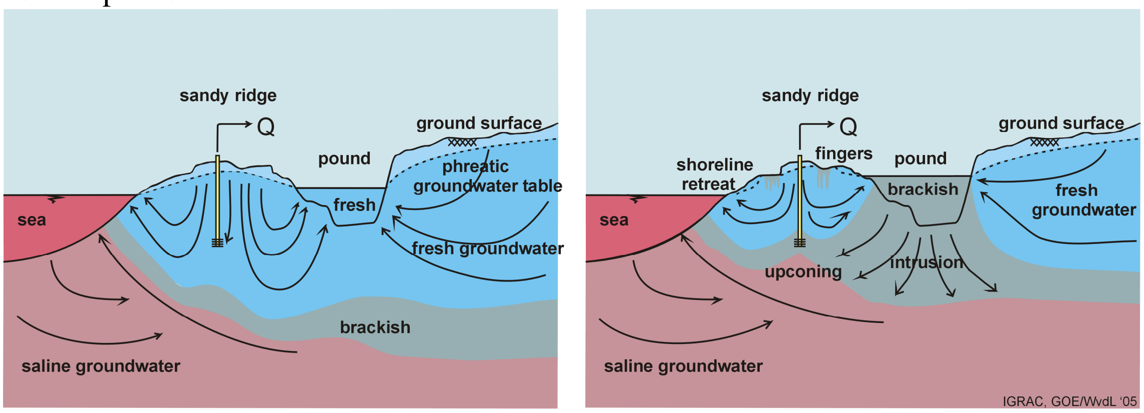


Figure 10: *Helicopter borne geophysical systems: a. left: BGR system recording simultaneously frequency-domain electromagnetic, magnetic and radiometric data, b. right: SkyTEM system recording time domain electromagnetic data.*

VULNERABILITY OF FRESH GROUNDWATER RESOURCES TO DISASTERS

Mapping and monitoring existing coastal fresh groundwater resources is an important activity that should be high on the agenda of water related institutes worldwide. The following example shows that a known safe fresh water resource is important for the survivors in case of disasters.

In this case, the impact of the 26-12-2004 Sumatra Tsunami on freshwater resources on islands is shown. Figure 11 gives a sketch of possible impacts on freshwater resources in coastal aquifers. Questions can be asked about how serious the impacts of the floods on fresh groundwater resources are; about how harmful they are from a drinking water point of view; and about how long it takes before the contaminated freshwater resources are clean again for consumption.



Before the Tsunami After the Tsunami

Figure 11: *Schematic representation of the possible effects of the Sumatra Tsunami on coastal groundwater systems: upconing of brackish groundwater under abstraction wells, intrusion of brackish or saline water from ponds, fingering of brackish water from pools, reduction in freshwater volume due to shoreline retreat, etc…*

By analyzing several possible situations in the subsoil that may have occurred, it is tried to describe the relevant processes of salt water intrusion in the coastal aquifers by means of conceptual models (Figure 12b and 12c). The main hypothesis is that sea water that flooded the land may have intruded into the subsoil, causing density driven flow through salt water fingers (Figure 13). Factors of importance are:

- Disturbance and reduction of the freshwater lens by the subsurface pressure wave.
- Local geometry of the inundated areas.
- Duration of sea water standing on the land.
- Leaching of salts from the soil.
- Local weather conditions during the coming months.

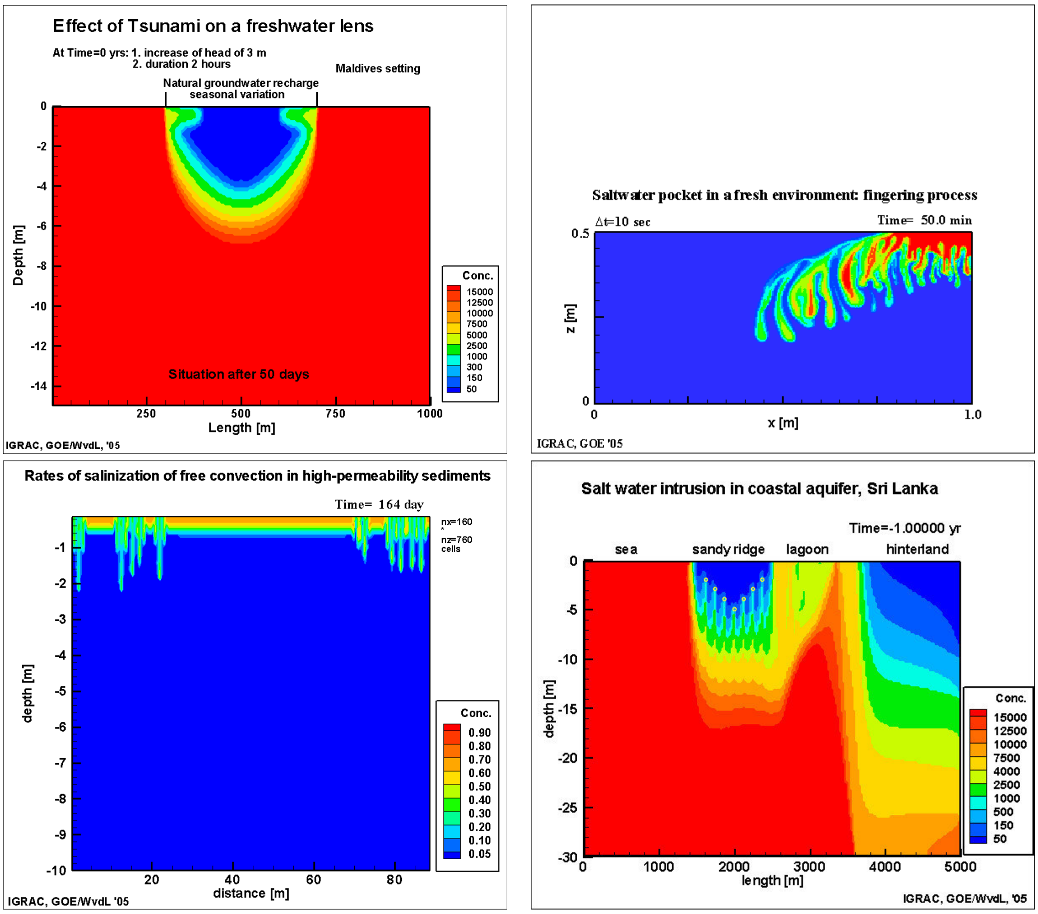


Figure 12: *Conceptual models are used to analyse the impact of the Tsunami on groundwater resources: Concept 1: evolution of a freshwater lens after flooding by sea water, Concept 2: fingering processes in the subsoil, Concept 3: salinisation due to flow caused by density differences (free convection), Concept 4: freshwater lens in a coastal aquifer with a brackish lagoon.*

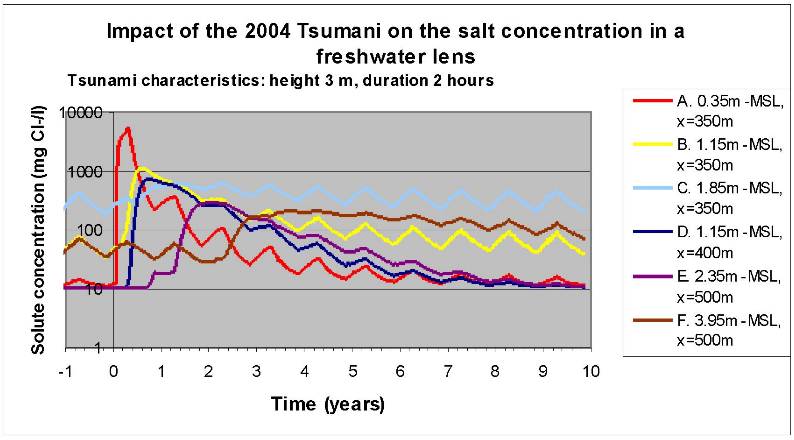


Figure 13: *Chloride concentration as a function of time at various depths and at various positions in the freshwater lens. Flooding with seawater occurs at year 0. Seasonal variation in concentration is mainly caused by seasonal variation in recharge.*

RESPONSES/SOLUTIONS

The modelling tools are used to assess the future changes in the groundwater system. With this information, measures can be modelled and evaluated. The next step is normally showing the effectiveness of successful measures in pilot studies and showcases. Some adaptation measures give results quickly on a local level, though on a regional scale it will take a long time before freshening of aquifers will be observed, since groundwater flow is a slow process (e.g. Oude Essink, 2001c).

Basically, there are two mean strategies to cope with salinity: adapt or mitigate/resist. Within several studies, these two concepts are worked out into details (e.g. De Vries *et al.*, 2009), whereas future water management policy will be developed along these two lines. Here some technical solutions to stop salinisation of coastal freshwater resources will be shown (Figure 15):

- 'The Freshmaker': scavenger wells to stop upconing of saline groundwater. By both extracting fresh and saline groundwater;
- Land reclamation in front of the coast, thus creating a foreland where a freshwater body can develop which could delay the inflow of saline groundwater. This is actually happening in front of the coast in Zuid-Holland, The Netherlands, where sand suppletion ('The Sand Engine') creates a foreland to better protect the low-lying hinterland against flooding, see also Figure 14;
- Freshwater injection barriers through injection or (deep-well) infiltration of fresh (purified sewage) water near the shoreline;
- Extraction of saline and/or brackish groundwater (and desalinisation of this extracted water);
- Increase of (artificial) recharge in upland areas to enlarge the outflow of fresh groundwater through the coastal aquifer, and thus, to reduce the length of the salt water wedge;
- Modifying pumping practice through reduction of withdrawal rates or adequate relocation of extraction wells;
- Creating physical barriers, such as sheet piles, clay trenches and injection of chemicals (chrystallisation or biosealing). This solution is applicable in shallow aquifers and probably at high costs.

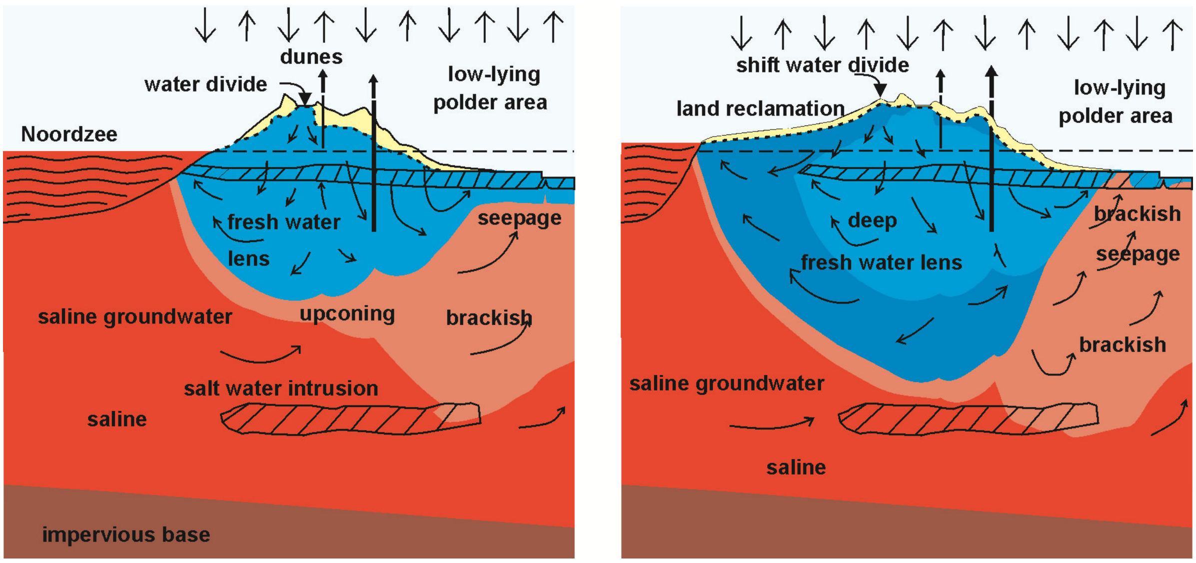


***Figure 14**: Effect of land reclamation on the freshwater lens under the coastal dunes: the lens becomes deeper and wider.*

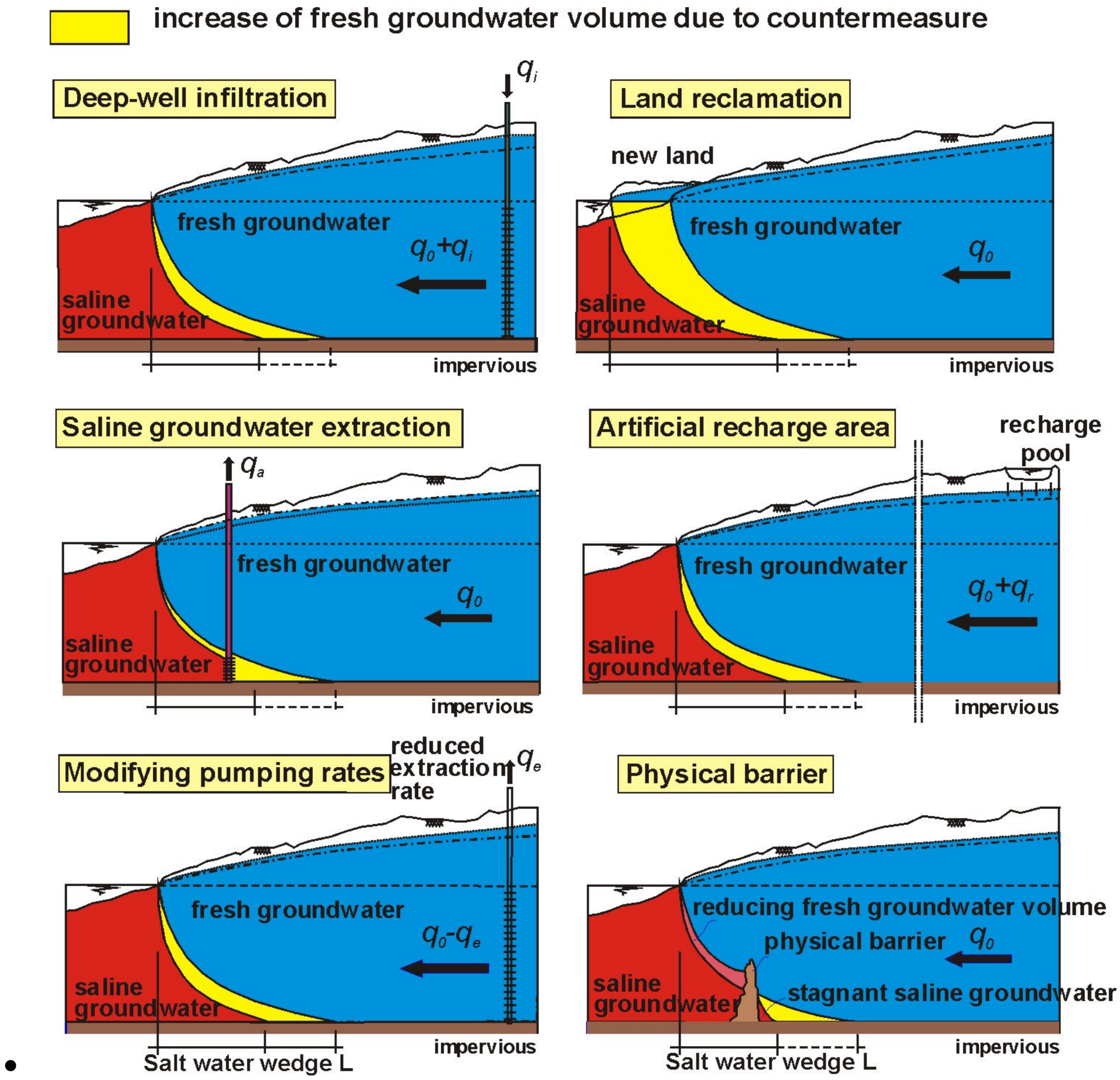


Figure 15: *Some countermeasures to control salt water intrusion (Oude Essink, 2001b).*

SCIENTIFIC CHALLENGES FOR THE NEXT DECADE

- Improve the 3D density and chloride concentration matrix, e.g. by using different types (geophysical) measurements
- Optimise groundwater management in coastal aquifers by using 3D variable-density flow models and innovative monitoring techniques
- Improve calibration of 3D models by using transient data of solute concentrations, as well as fluxes instead of alone piezometric heads
- Incorporate reactive multicomponent solute transport in double-diffusive convection density-driven (heat and solute) groundwater flow: use PHT3D!
- Facilitate platforms and knowledge exchange of numerical innovations, viz. parallelisation, graphical cards, 64 bits-computer, improved visualization techniques, complex computer codes (e.g. PHT3D), integrating groundwater-surface water

CHALLENGES FOR THE NEXT DECADE(S)

When focussing on coastal lowlands:

- Export the knowledge retrieved of complex phenomena to data-poor countries such as submarine groundwater discharge, shallow freshwater lenses and sand boils (Louw *et al.*, 2010)
- Collect data in data-poor areas, e.g. with Airborne Electro-Magnetic, as demonstrated in the EU-funded INTERREG IV-B project www.cliwat.eu
- Implement effect of climate change and sea level rise on coastal aquifers, maps vulnerable areas, test compensating measures in pilot studies/showcases and upscale the successful showcases to the whole regional system
- Share knowledge via web-sites, internet communities, international meetings, lectures, exchange of students and personnel
- Set up a UN programme to (financially) facilitate excellent students worldwide to participate in existing salinisation projects
- Create maps of fresh groundwater resources vulnerable to disasters such tsunami's or extreme future drought
- Create showcases of successful measures to mitigate salinisation of fresh water resources or to adapt to a climate proof fresh water supply, and communicate successtories worldwide. Examples of adaptive and mitigative measures to stop salinization of the coastal groundwater system are the fresh keeper, the coastal collectors, the water farm, special drainage systems and freshwater storage underground
- Incorporate stakeholders to solution of salinity problems. They need to be part implement of innovative solutions for a robust climate proof fresh water supply in their coastal zone.

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