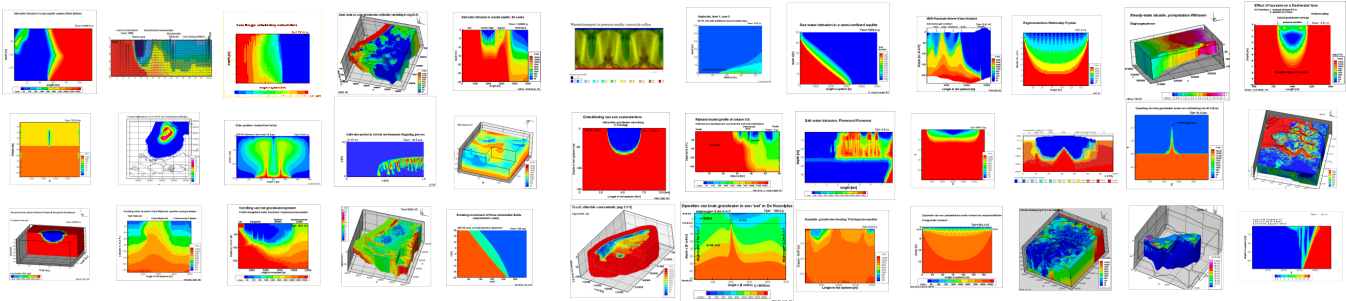
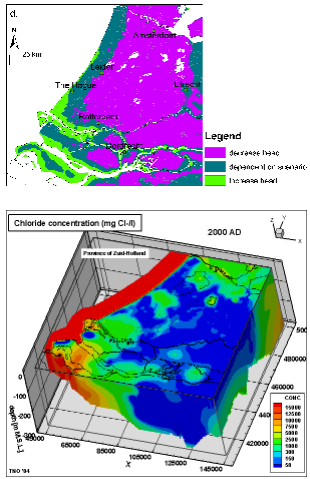
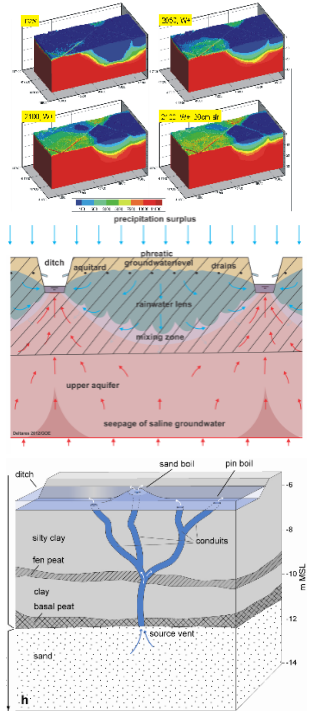


Modelling studies



Type	Project	
National	Netherlands Hydrological modelling Instrument (NHI) The so-called Netherlands Hydrological modelling Instrument (NHI) includes a module to take into account fresh and saline groundwater in the coastal zone. This paper informs you about this NHI fresh-saline groundwater module, which 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. This module is ready to play a role in assessing the effectiveness of mitigation and adaptation strategies to make our water system climate proof. Article: De Lange, W.J., Prinsen, G.F., Hoogewoud, J.C., Veldhuizen, A., Verkaik, J., Oude Essink, G. H.P., van Walsum, P.E.V., Delsman, J.R., Hunink, J.C., Massop, H.T.L., Kroon, T., 2014. An operational, multi-scale, multi-model system for consensus-based, integrated water management and policy analysis: The Netherlands Hydrological Instrument. <i>Environmental Modelling & Software</i> 59, 98–108, doi: 10.1016/j.envsoft.2014.05.009 Poster: Netherlands Hydrological modelling Instrument: fresh and saline groundwater in the Dutch coastal zone More information: Jarno Verkaik, Joost Delsman or Gualbert Oude Essink	Zoet-zout verdeling ondergrond Nederland Legend: - Surface water - Subsidence - Groundwater - Groundwater recharge - Groundwater extraction - Groundwater storage - Groundwater salinity - Groundwater quality - Groundwater quantity - Groundwater dynamics
Regional	Research on salinisation processes in the Province of Zeeland The fresh water resources in the groundwater system of the coastal province of Zeeland are at present jeopardized by various causes. Floods, droughts, eutrophication and salinisation of the ground and surface waters are some pressing topics. Moreover, sea level rise and climate change threaten the groundwater system even more. Water management in the province should anticipate on these changes. The province has initiated a study to get a better insight in the salinisation processes in the top system. The main goal is to analyse what measurements are effective in mitigating the salinisation of the water system. Special attention is given to the so-called rainwater lenses in agriculture plots. Agricultural crops depend on these shallow vulnerable water systems which float upon brackish groundwater and vary over the season in thickness. Poster Salt Water Intrusion Meeting 2010 (Engels): poster Poster Deltas in Times of Climate Change 2010 (Engels): poster	Legend: - Surface water - Subsidence - Groundwater - Groundwater recharge - Groundwater extraction - Groundwater storage - Groundwater salinity - Groundwater quality - Groundwater quantity - Groundwater dynamics

Regional	Research on salinisation processes in the 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 fine-grained deposits intrudes the upper aquifers. 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. Article: Oude Essink, G.H.P., E.S. van Baaren, and P.G.B. de Louw. 2010. Effects of climate change on coastal groundwater systems: A modeling study in the Netherlands, <i>Water Resour. Res.</i>, 46, W00F04, doi: 10.1029/2009WR008719. Presentation:: Oude Essink G.H.P, Van Baaren E.S., De Louw P.G.B., 2010, Effects climate change on coastal groundwater systems, focus on the Rhine Delta, Proceedings Deltas in Times of Climate Change, Rotterdam, The Netherlands, Sept-Oct. 2010 download	 The figure consists of two parts. The top part is a map of the Rhine Delta region, showing the coastline and major water bodies. A legend indicates three categories: 'No saline lens' (white), 'Saline lens' (yellow), and 'Saline lens' (green). The bottom part is a 3D model showing chloride concentration (mg Cl/l) in the groundwater system. The model is a rectangular prism with axes for X, Y, and Z. A color scale on the right indicates chloride concentration from 0 to 40000 mg Cl/l. The model shows a high concentration of chloride in the coastal area, which decreases towards the inland.
Local	Local phenomena: saline boils and rainwater lenses Saline boils Louw, P.G.B., de, van der Velde, Y., and van der Zee, S.E.A.T.M. 2011. Quantifying water and salt fluxes in a lowland polder catchment dominated by boil seepage: a probabilistic end-member mixing approach, <i>Hydrol. Earth Syst. Sci.</i>, 15, 2101-2117 link to HESS Louw, P.G.B., de, Oude Essink, G.H.P., Stuyfzand, P.J., Zee, van der, S.E.A.T.M., 2010, Upward groundwater flow in boils as the dominant mechanism of salinization in deep polders, The Netherlands, <i>J. Hydrol.</i> 394, 494-506. download Shallow rainwater lenses Louw, P.G.B., de, Eeman, S., Siemon, B., Voortman, B.R., Gunnink, J., van Baaren, E.S., and Oude Essink, G.H.P., 2011, Shallow rainwater lenses in deltaic areas with saline seepage, <i>Hydrol. Earth Syst. Sci.</i>, 15, 3659-3678. link to HESS	 The figure contains two main diagrams. The top diagram shows four 3D models of groundwater flow and salinity distribution under different scenarios: '100%', '50%', '25%', and '12.5%'. Each model shows a cross-section of the ground with a color scale for salinity. The bottom diagram is a schematic cross-section of a polder. It shows the 'precipitation surplus' (blue arrows) entering the ground. Below the surface, it shows 'phreatic' water, 'groundwater level', 'drains', 'relating zone', 'upper aquifer', and 'seepage of saline groundwater' (red arrows). The bottom part of the diagram shows a cross-section of the ground with layers: 'ditch', 'silty clay', 'fen peat', 'clay', 'basal peat', 'sand', and 'source vent'. It also shows 'sand boil' and 'pin boil' features.

Peer-reviewed articles fresh-saline modelling case-studies

Delsman, J.R., Hu-a-ng, K.R.M., Vos, P.C., de Louw, P.G.B., Oude Essink, G.H.P., Stuyfzand, P.J., & Bierkens, M.F.P. 2014. Paleo-modeling of coastal saltwater intrusion during the Holocene: an application to the Netherlands. *Hydrology and Earth System Sciences*, 18(10), 3891–3905, doi: [10.5194/hess-18-3891-2014](https://doi.org/10.5194/hess-18-3891-2014)
[link to paper](#) [link to animation](#)

Faneca Sánchez, M., Gunnink, J., van Baaren, E.S., Oude Essink, G.H.P., Elderhorst, W., de Louw, P.G.B., Siemon, B., Auken, E. 2012. Modelling climate change effects on a Dutch coastal groundwater system using airborne Electro Magnetic measurements, *Hydrol. Earth Syst. Sci.*, 16, 4499-4516, doi: [10.5194/hess-16-4499-2012](https://doi.org/10.5194/hess-16-4499-2012).
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Pauw, P.S., Louw, P.G.B., de, Oude Essink, G.H.P. 2012. Groundwater salinization in the Wadden Sea area of the Netherlands; quantifying the effects of climate change, sea level rise and anthropogenic interferences, *Netherlands Journal of Geosciences* 91-3, 373-383.
[link to NJG](#)

Oude Essink, G.H.P. and Kooi, H. 2012. Land-subsidence and sea-level rise threaten fresh water resources in the coastal groundwater system of the Rijnland water board, The Netherlands, p. 227-248, Chapter 13 in: *Climate Change Effects on Groundwater Resources: A Global Synthesis of Findings and Recommendations*, Treidel, H., Martin-Bordes, J.L. and Gurdak, J.J. (Eds), 401 p.
[link to Book](#)

Oude Essink, G.H.P., E.S. van Baaren, and P.G.B. de Louw 2010, Effects of climate change on coastal groundwater systems: A modeling study in the Netherlands, *Water Resour. Res.*, 46, W00F04, [doi:10.1029/2009WR008719](#).
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Oude Essink, G.H.P. 2001. Salt Water Intrusion in a Three-dimensional Groundwater System in The Netherlands: a Numerical Study, *Transport in Porous Media* 43(1): 137-158, doi: [10.1023/A:1010625913251](#)
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Oude Essink, G.H.P. 2001. Saltwater intrusion in 3D large-scale aquifers: a Dutch case, *Phys. & Chem. of the Earth* 26(4): 337-344, doi: [10.1016/S1464-1909\(01\)00016-8](#)
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User Manuel MOCDENS3D

Vandenbohede, A. 2008, Ghent University, Visual MOCDENS3D: Visualisation and processing software for MOCDENS3D, a 3D density dependent groundwater flow and solute transport model.
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Reports, proceedings 3D fresh-saline modelling

Oude Essink, G.H.P. 2001. Density dependent groundwater flow at the island of Texel, The Netherlands. Proc. 16th Salt Water Intrusion Meeting, Miedzyzdroje-Wolin Island, Poland: 47-54.
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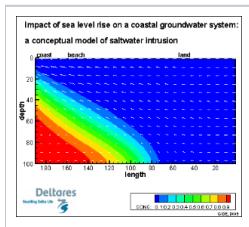
Oude Essink, G.H.P. 1999. Simulating 3D density dependent groundwater flow: the adapted MOC3D. Proc. 15th Salt Water Intrusion Meeting, Ghent, Belgium: 69-79.
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Oude Essink, G.H.P. 1998. MOC3D adapted to simulate 3D density-dependent groundwater flow. In: Proc.MODFLOW'98 Conference, October 4-8, 1998, Golden, Colorado, USA, Vol. I, 291-303.
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Animations: examples

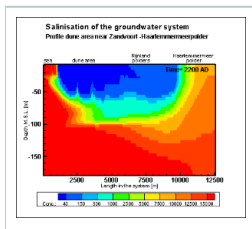
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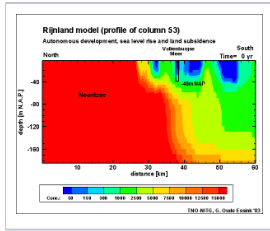
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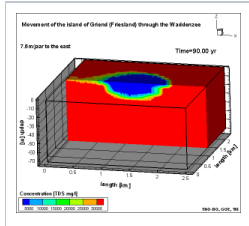
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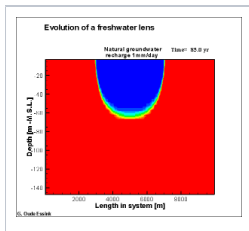
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Oude Essink, G.H.P. 2001. Density dependent groundwater flow at the island of Texel, The Netherlands. Proc. 16th Salt Water Intrusion Meeting, Miedzyzdroje-Wolin Island, Poland: 47-54.

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