Saltwater intrusion in porous aquifers in Northern Germany

Helga Wiederhold[1], Reinhard Kirsch[2], Bernhard Siemon[3]
[1]Leibniz Institute for Applied Geophysics (LIAG), Hannover, Germany
[2]Agency for Agriculture, Environment and Rural Areas Schleswig-Holstein (LLUR), Flintbek, Germany
[3]Federal Institute for Geosciences and Natural Resources (BGR), Hannover, Germany

BACKGROUND

In Northern Germany the primary source for drinking water supply is groundwater from porous Quaternary and Tertiary aquifers. After Grube (2000) around 25% of North German aquifers show inland salinization (upconing deeper saltwaters and salt diapir dilution) and about 5% seawater intrusion. The latter is expected to become more important in future due to climatic and demographic change. About 500 km coastal region (roughly measured) at the North Sea are concerned plus several barrier islands but also the metropolitan area of Hamburg.

INTRODUCTION

Availability of freshwater (in coastal areas) has been a challenge for long time. In the beginning of the settlement of the German coast water was collected in cisterns. Since the beginning of tourism and increasing of bather in the seaside resorts a more sustainable water supply has been necessary. That was the time when Herzberg made his studies on freshwater lenses on top of saltwater saturated sediments on the island of Norderney (Herzberg 1901). International discussion on groundwater salinization resulted in the first Salt Water Intrusion Meeting SWIM in Hannover (1968). Efforts were made to develop and apply geophysical methods to identify salinization. At the 6th SWIM first results of locating the freshwater/saltwater interface on the German North Sea island of Spiekeroog by airborne electromagnetic resistivity mapping were presented by Sengpiel and Meiser (1981). Since 2000 these airborne techniques have been applied to larger coastal regions also having in mind to create a reference data set as basis for monitoring climate or anthropogenic induced changes of the freshwater/saltwater interface at the German North Sea coast (Siemon et al. 2014a). Recently, several projects were dealing with saltwater intrusion and groundwater modelling, e.g., CLIWAT, KLIMZUG-NORD, KLIFF, NAWAK.

The objective of this paper is to summarize recent research activities on seawater intrusion in Northern Germany.

GEOLOGY

The hydrogeological situation of the upper 300 meter in northwestern Germany that is part of the North German Basin is dominated by Tertiary and Quaternary coarse grained, sandy sediments (aquifer) and fine grained, clayey strata (confining layer). Due to salt tectonics as well as glacial erosion and glacial tectonics the geological situation is very complex. In the coastal areas and where saltdomes are close to the surface aquifer salinization is an issue.

The southern North Sea coast developed after the last glaciations in the Holocene. Today the German North Sea coastal area is dominated by low-lying marshland and higher elevated Geest ridges, estuaries of the rivers Ems, Weser, Elbe and Eider, the East Frisian barrier

islands and the North Frisian Geest core islands. Beside natural processes dike construction, land reclamation and water catchment affect the freshwater/saltwater environment.

GEOPHYSICAL METHODS

For geophysical methods to recognize salt water intrusion see Kirsch and Wiederhold (2014).

RESULTS / PROJECTS

Since 2000 the research borehole Cuxhaven Lüdingworth is focal point of coastal research and the basis of a "coastal aquifer test field" established by Leibniz Institute for Applied Geophysics (e.g., Wiederhold et al. 2005; Noell and Panteleit 2004). An airborne geophysical survey enabled a unique and large-area view to coastal seawater intrusions and freshwater aquifers as well as offshore freshwater springs (Siemon et al. 2004). Recognition of buried glacial valleys in these data provides the basis for the EU-project BurVal, where methods for mapping structures under the aspect of groundwater supply are developed and applied in pilot areas (BURVAL Working Group 2006). Building on these results and knowledge a general airborne survey of the German North Sea coastal area has been projected and started in 2008. Emphasis is placed on the mapping of freshwater/saltwater interfaces, saltwater intrusions and the evaluation of the coastal aquifers as well as on the mapping of submarine freshwater discharges (Siemon et al. 2014a). An example is given in Figure 1. With the mapping also a basis for monitoring should be set up. Interpretation strategies for airborne electromagnetic data are given, e.g., by Klimke et al. (2013), Siemon et al. (2014b).

With the EU-project CLIWAT groundwater dynamics came into focus as well as the effects of climate change on coastal groundwater systems and through this on surface water and water supply. Corresponding pilot areas for numerical groundwater modelling were the German North Sea islands Borkum (Sulzbacher et al. 2012) and Föhr (Scheer et al. 2014; Wiederhold et al. 2012). Also, to investigate the dynamics of the freshwater/saltwater transition zone at the North Sea island Borkum two vertical electrode systems of about 20 m length were installed in two water catchment areas in depths between 44 m and 65 m, i.e. in the freshwater/saltwater transition zone below the pumps. Data are transferred to LIAG in 5-hour rhythm (Grinat et al. 2014).

Similar groundwater modelling studies were performed for the Elbe estuary in the BMBF (Federal Ministry of Education and Research)-project KLIMZUG-NORD (www.klimzug-nord.de) or for the Weser estuary in the MWK-Niedersachsen (Ministry of Economy and Culture of the State of Lower Saxony)-project KLIFF (www.kliff-niedersachsen.de). For further studies on barrier islands see the BGR-project FLIN (e.g., Houben et al. 2014; Costabel et al. 2014).

Currently, the State Authority for Mining, Energy and Geology (LBEG) plans to generate a statewide "salt water map" for Lower Saxony (Deus et al. 2014). For actual maps see NIBIS® MAPSERVER.

A planning tool for coastal aquifers at the German North Sea Coast is under development in the project NAWAK. This tool takes into account the hydrodynamic and hydrochemical evolution of the aquifer as well as groundwater recharge and hydrological impacts of open drainages. Also specified targets and options of the regional water suppliers and other stakeholders are included (Eley et al. 2014).

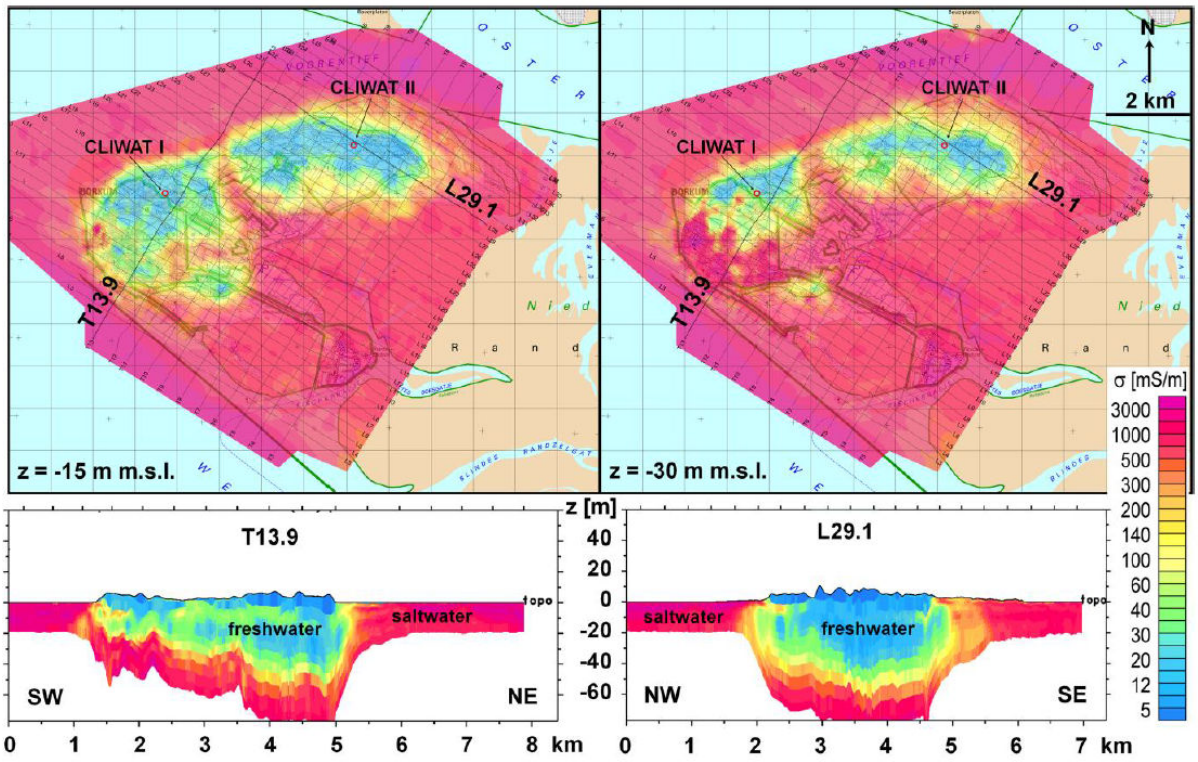

Figure 1. Top panel: Electrical conductivity (σ) maps for the North Sea island Borkum at different depths derived from helicopter-borne electromagnetic survey (saltwater saturated = high conductivity, freshwater saturated = low conductivity), bottom panel: cross sectional view along transects T13.9 and L29.1 (from Sulzbacher et al. 2012).

REFERENCES

BURVAL Working Group. 2006. Groundwater Resources in Buried Valleys - A Challenge for Geosciences. Leibniz Institute for Applied Geophysics, 314 pp., 190 figs, Hannover:LIAG.

Costabel, S., U. Noell, T. Günther, G. Houben, and W. Voß. 2014. Geophysical investigation of a managed freshwater lens on the North Sea island of Langeoog. In Proceedings of the 23rd Salt Water Intrusion Meeting, Husum, Germany.

Deus, N. and J. Elbracht. 2014. 3D-Modelling of the salt-/fresh water interface in coastal aquifers of Lower Saxony (Germany) based on airborne electromagnetic measurements (HEM). In Proceedings of the 23rd Salt Water Intrusion Meeting, Husum, Germany.

Eley, M., M. Howahr, A. Schneider, H.M. Schöniger, A. Ullmann, J. Wolf, and G. Meon. 2014. Potential Consequences of Saltwater Intrusion at the German North Sea Coast for the water supply. In Proceedings of the 23rd Salt Water Intrusion Meeting, Husum, Germany.

Grinat, M., W. Südekum, D. Epping, and R. Meyer. 2014. Measurements with an automated electrical resistivity tomography system in a freshwater/saltwater transition zone. In Proceedings of the 23rd Salt Water Intrusion Meeting, Husum, Germany.

Grube, A. 2010. Widespread geogenic salt water occurrence in North Germany - demonstrated on the basis of a generalized map. In Proceedings of the 16th Salt Water Intrusion Meeting, Wolin Island, Poland.

Herzberg, B. 1901. Die Wasserversorgung einiger Nordseebäder. J. Gasbel. Wasservers., 44: 815–819.

Houben, G., P. Koeniger, and J. Sültenfuß. 2014. Freshwater lenses as archives for climate history and hydrochemical evolution - insights from depth-specific age dating and stable water isotope analysis, Langeoog Island, Germany. In Proceedings of the 23rd Salt Water Intrusion Meeting, Husum, Germany.

Kirsch, R. and H. Wiederhold. 2014. Saltwater intrusions - a challenge for geophysics. In Proceedings of the 23rd Salt Water Intrusion Meeting, Husum, Germany.

Klimke, J., H. Wiederhold, J. Winsemann, G. Ertl, and J. Elbracht. 2013. Three-dimensional mapping of Quaternary sediments improved by airborne electromagnetics. Z. dt. Ges. Geowiss., 164: 369-384.

NIBIS® MAPSERVER (http://nibis.lbeg.de/cardomap3)

Noell, U. and B. Panteleit. 2004. Geophysical detection and hydrochemical analysis of an isolated shallow salt water body near Cuxhaven, Lower Saxony, Germany. In Proceedings of the 18th Salt Water Intrusion Meeting, Cartagena, Spain.

Scheer, W., B. Nommensen, and B. König. 2014. The fresh-saltwater distribution of the Island of Föhr - assembling of a data base for the assessment of climate change impact. In Proceedings of the 23rd Salt Water Intrusion Meeting, Husum, Germany.

Sengpiel, K.-P. and P. Meiser. 1981. Locating the freshwater/saltwater interface on the Island of Spiekeroog by airborne EM resistivity/depth mapping. Geologisches Jahrbuch C29: 255-271. Hannover: BGR.

Siemon, B., D.G. Eberle, and F. Binot. 2004. Helicopter-borne electromagnetic investigation of coastal aquifers in North-West Germany. Z. geol. Wissen 32: 385-395.

Siemon, B., H. Wiederhold, A. Steuer, M.P. Miensopust, W. Voß, M. Ibs-von Seht, and U. Meyer. 2014a. Helicopter-borne electromagnetic surveys in Northern Germany. In Proceedings of the 23rd Salt Water Intrusion Meeting, Husum, Germany.

Siemon, B., W. Voß, J. Elbracht, N. Deus and H. Wiederhold. 2014b. Airborne clay mapping at the East Frisian coast. In Proceedings of the 23rd Salt Water Intrusion Meeting, Husum, Germany.

Sulzbacher, H., H. Wiederhold, B. Siemon, M. Grinat, J. Igel, T. Burschil, T. Günther, and K. Hinsby. 2012. Numerical modelling of climate change impacts on freshwater lenses on the North Sea Island of Borkum using hydrological and geophysical methods. Hydrology and Earth System Sciences 16: 3621-3663.

Wiederhold, H., F. Binot, and W. Kessels. 2005. The Cuxhaven research borehole and the “Coastal Aquifer Test Field (CAT-Field)” – a test field for applied geoscientific research. Zeitschrift für Angewandte Geologie 51(1): 3-6.

Wiederhold, H., W. Scheer, R. Kirsch, T. Burschil, and M. Lilienfein. 2012. Effects of climate change to the groundwater body of the German North Sea Island of Föhr. In Proceedings of the 22nd Salt Water Intrusion Meeting, Armacao dos Buzios, Brazil.

Contact Information: Helga Wiederhold, Leibniz Institute for Applied Geophysics, Stilleweg 2, 30655 Hannover, Germany, Email: helga.wiederhold@liag-hannover.de