Evaluating hydraulic barriers for reducing and controlling saltwater intrusion in a changing climate

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ABSTRACT

Groundwater abstraction from coastal aquifers is vulnerable to sea level rise, increasing groundwater abstraction and drainage because they may potentially impact saltwater intrusion and hence groundwater quality depending on the hydrogeological setting. In the present study the impacts of sea level rise, drainage systems and changes in groundwater abstraction are quantified for an island located in the Western Baltic Sea using the modeling packages MODFLOW/MT3DMS/SEAWAT. Increasing chloride concentrations have been observed in several abstraction wells indicating that saltwater intrusion is ongoing. The water resources on the island are abstracted from a confined chalk aquifer. In order to prevent saltwater intrusion a hydraulic barrier is established. The effectiveness of the barrier consisting of injection wells is examined for a projected climate change scenario using variable density modeling.

INTRODUCTION

Groundwater abstracted from coastal aquifers is at risk of increased saltwater intrusion as an effect of the projected climate changes. This problem is studied for an area located in the southeastern part of Denmark on the island of Falster in the Baltic Sea (Figure 1). The local waterworks abstract groundwater from a shallow chalk aquifer. Part of the aquifer is located near the coast where an increasing chloride concentration has been monitored in groundwater abstraction wells over the last decades (Rasmussen et al. 2013).

In some coastal areas where saltwater intrusion has been threatening groundwater well fields, injection wells have been installed to generate a hydraulic barrier that prevents further saltwater intrusion, e.g. in Spain and USA. Climate changes might cause, among other things, sea level rise and changes in groundwater recharge. The objective of the present study is to conduct a model analysis of the effect of injecting freshwater into the groundwater aquifer to act as a hydraulic barrier to prevent further saltwater intrusion in a climate change scenario with increasing sea level and reduced groundwater recharge.

METHODS

The groundwater abstraction wells in focus are located on a barrier island between the Baltic Sea to the east and a low laying drained area to the west (Figure 1). A previous model study has examined possibly effects of increasing sea level, changes groundwater recharge, and canal stage on groundwater quality (Rasmussen et al. 2013). The model area of 44km^2 is discretized using a grid size of 50m by 50m, and 32 model layers varying in thickness from 2m to 12m down to a depth of -200m.a.s.l. The main aquifer consists of fractured and crushed calk overlain by up to 45m of clayey till and sand.

In order to model the historical changes the study area has undergone from an area with saltwater lagoon and barrier islands to reclaimed and drained land with groundwater abstraction, a modeling period of more than 3000 years were carried out in order to reach a steady-state situation for the freshwater-saltwater distribution. From 1960 groundwater abstraction was implemented in the model. The modeling packages MODFLOW/MT3DMS/ SEAWAT were used for the variable density modeling.

Eight combinations of sea level rise (0.5m, 0,75m, and 1m), changed groundwater recharge (decrease of 15%, increase of 15%), and changed canal stage (-30cm, +30cm) were analyzed. The climate change effects of sea level rise and changed recharge was gradually implemented in the model form 2010 to 2100. The model simulations were continued for additionally 200 years to year 2300.

It was found that the most severe scenario concerning the chloride concentration in groundwater abstraction wells were the scenario with a 0.75m sea level rise and a decrease in groundwater recharge of 15%. This “worst case” scenario has been used for the present study.

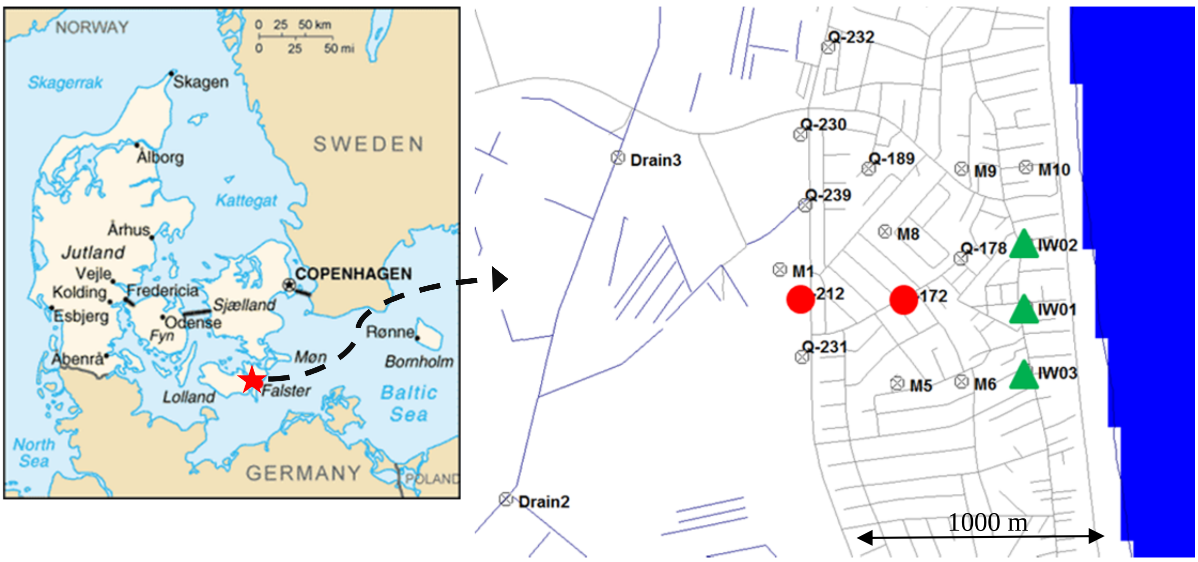

Figure 1. Location of study area (red star on left panel). Right panel shows part of the study area with two abstraction wells (red dots) and three injection wells (green triangles).

Three injection wells were added in the area between the well field and the cost line (Figure 1). The injection wells were located so far from the coast that they were not penetrating the saltwater wedge. The wells were screened in the upper fractured chalk from an elevation of -12m to -30m. The injection rates were the same as the average abstraction rates for the waterworks wells, 68 m^3/d. The injection wells are located 300m from the coast with spacing of 250m. The abstraction wells of interest for this study, Q-172 and Q-212, are located 750m and 1150m, respectively, from the coastline (Figure 1).

The injection of water in the three injections wells was started in year 2300 and the simulation was continued for additional 100 years. The salinity concentrations were monitored in the two abstraction wells, Q-172 and Q-212 (Figure 1).

RESULTS

100 years of freshwater injection has a significant effect on the extension of the freshwater lens in both horizontal and vertical direction. Figure 2 upper panels show the freshwater-saltwater distribution in the year 2300 before start of the injection. Figure 2 lower panels show the freshwater-saltwater distribution after 100 years of freshwater injection.

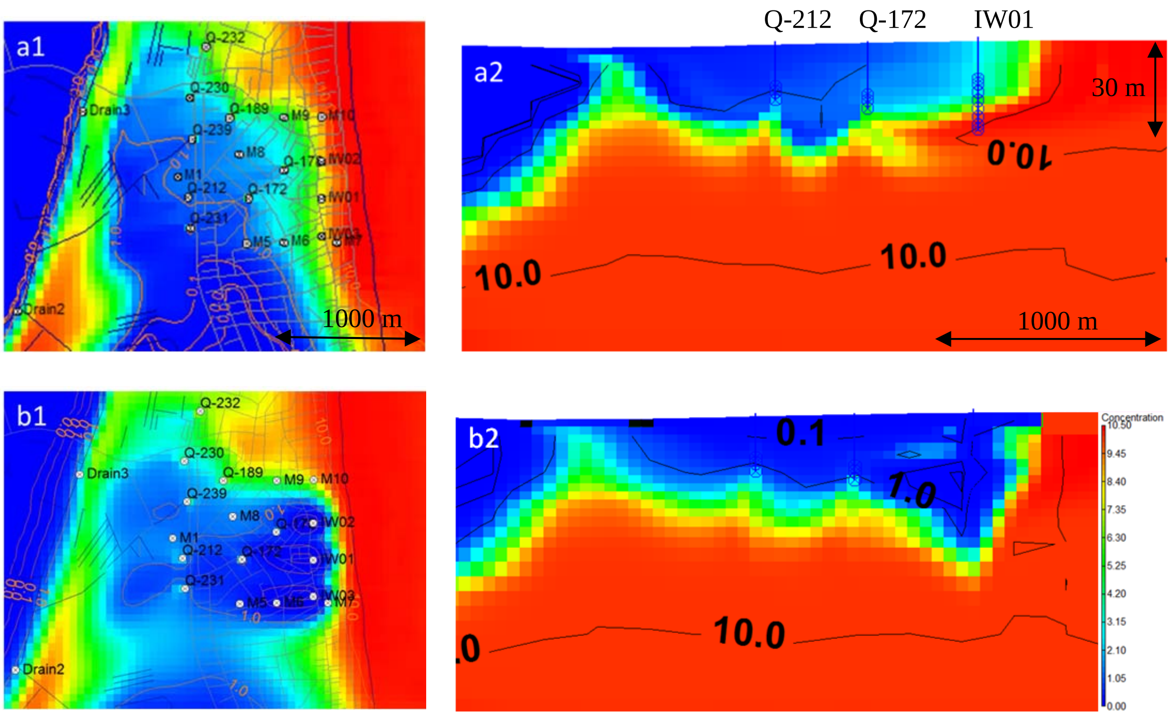

Figure 2. Saltwater distribution, plan view and cross section. Plan view: model layer 8, elevation -22m. Cross sections through wells Q-212, Q-172, and IW01. Panel a1 and a2: before injection. Panel b1 and b2: after 100 years injection. Contours: TDS (g/l).

The spacing between the three injection wells is seen to be sufficiently close to preventing saltwater intrusion between the injection wells.

Figure 3 shows the effect of the freshwater injection on TDS concentration in the two abstraction wells, Q-172 and Q-212. In the left panel the effects of the climate scenario implemented from year 2011 to 2300 is shown. The right panel shows the effect on TDS concentrations during 100 years of water injection starting in the year 2300. The effect of the injection well is first observed in the abstraction well closest to the injection wells and the coast, Q-172, after 25 years. In the abstraction well located further from the injection wells and the coast, Q-212, the effect is seen after 50 years. In well Q-172 a significant reduction in TDS concentration is found through the rest of the injection period. After 100 years of injection, the TDS concentrations are reduced to a level that is close to the concentrations found before the effects of the climate changes commenced.

However, the negative effects of climate changes could have been avoided if the injection wells had been installed before the onset of sea level rise and reduction in groundwater recharge.

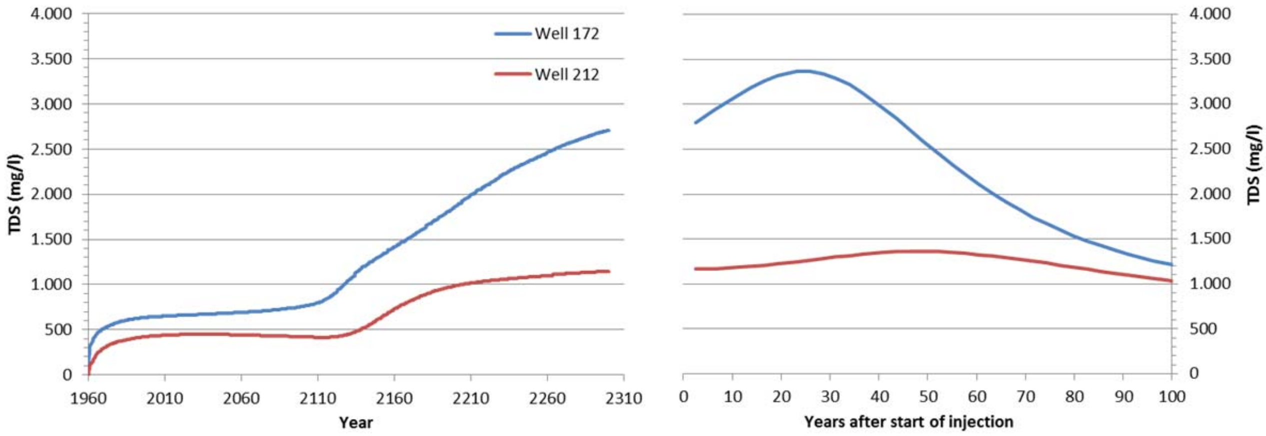

Figure 3. Effect of injection wells on TDS concentration in two groundwater abstraction wells. Location of wells, see figure 1. Left panel shows effects of a climate scenario implemented from year 2011. Right panel shows effect on TDS concentrations of 100 years water injection starting in the year 2300.

DISCUSSION AND CONCLUSIONS

Injection wells are tested as a hydraulic barrier to alleviate increased saltwater intrusion into coastal aquifers due to effects of projected climate change effects. Variable density modeling studies shows that fresh water injected into a coastal aquifer can prevent further increase in chloride concentrations in abstracted groundwater. The effectiveness of the hydraulic barrier in reversing the increasing trend in chloride concentrations in groundwater abstraction wells depends among other things on the timing of the injection scheme installation relative to the timing of climate changes.

Further studies in the area are planned to characterize the variation in hydraulic conductivity by calibrating the variable density model against available data on hydraulic head and chloride concentration using the pilot points method. Results from an airborne electromagnetic survey (SkyTEM) will be used to estimate the chloride concentration in the aquifers and it will be tested if these data can be used as targets in the calibration process. Also different designs of the hydraulic barrier including the number of injection wells, the injection rate and the location and orientation of the wells will be examined.

REFERENCES

P. Rasmussen, T. O. Sonnenborg, and K. Hinsby. 2013. Assessing impacts of climate change, sea level rise, and drainage canals on saltwater intrusion to coastal aquifer. Hydrol. Earth Syst. Sci., 17, 421–443, 2013. www.hydrol-earth-syst-sci.net/17/421/2013/. doi:10.5194/hess-17-421-2013.

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