Requirements of modeling the freshwater lens of the Island of Sylt

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ABSTRACT

Many islands face the problem of limited fresh water resources. Fresh water lenses are often the only available water reservoirs for the production of drinking water. Those reservoirs are limited and threatened by salt water intrusion. Salt water intrusion will be enforced when the balance between fresh and salt water is disturbed for instance by high abstraction rates.

The Northern German island of Sylt faces the problem of an increasing seasonal drinking water demand and limited water resources. High abstraction rates and other utilizations of the aquifer lead to a hazardous situation. These threats require a sustainable management of the different utilization in order to avoid irreversible damages to the freshwater reservoir. A 3D density dependent groundwater model represents a valuable tool for this task. For this reason the management of the two water companies on the island decided to assign CONSULAQUA to set up, calibrate and test a 3D groundwater model.

The numerical groundwater model is based on a hydrogeological model which is shown in the schematic cross section in Figure 1. The model contains 21 slices respectively 20 layers.

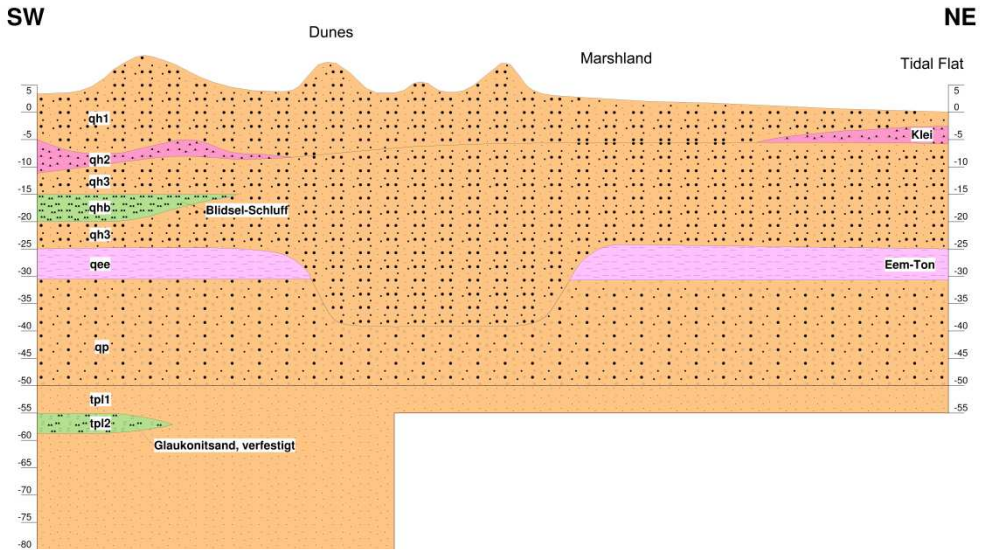

Figure 1: Hydrogeological model for the area under investigation.

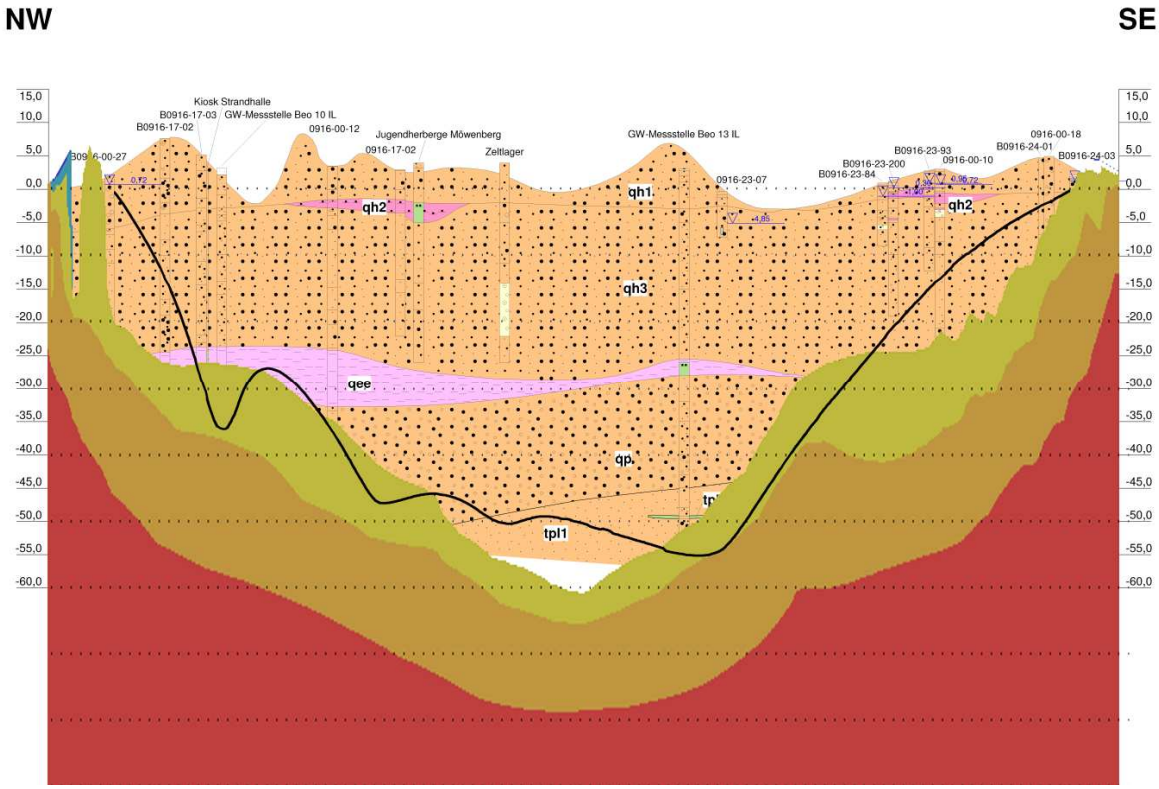

Figure 2: Comparison of the calculated (colored area) and measured (black line) fresh/salt water distribution.

In order to simulate exchange between salt and freshwater in the area of the North Sea in an adequate way, a buffer zone of 1.000 m has been implemented (Figure 3), which does not belong to the mainland, e.g. the Königshafen offshore Listland, and the Ellenbogen spit. The buffer zone enables the freshwater lines to propagate even below seafloor which has been recently observed at freshwater sources on the tidal flats of the Königshafen.

At the outer border of the model area a saltwater piezometric head with 0 mNN (Constant hydraulic head (1st) boundary condition) and a constant mass boundary (Constant mass (1st) boundary condition) with a salt concentration of 35 g/l were assigned to all slices. Additional to the outline mass boundary a constant mass boundary with 35 g/l was applied on the buffer area (North Sea) only on slice 1 (Figure 3). Groundwater recharge was only applied to the core area.

Simulating groundwater of the Wadden Sea islands faces the challenge to find appropriate starting conditions regarding the state of freshwater / saltwater interface development. The question to be answered: Has the aquifer already reached equilibrium conditions.

About 1000 years ago the area of Sylt was still part of the mainland. After several storm floods and other climatic influences the island was separated from the mainland. In this state, it is assumed that the groundwater in the island consisted entirely of fresh water. The intrusion of saltwater into the island's aquifer system started at this point. Therefore the calibration had been done within two steps:

First the process of saltwater intrusion has been modeled for 1000 years (Figure 4). We assume that a quasi-equilibrium state has been reached.

The long term calculation generated the starting condition for the second step of calibration: 50 years under pumping conditions.

Calibration succeeded to reach a good adaption between calculated and measured hydraulic heads respectively saltwater concentrations (Figure 2).

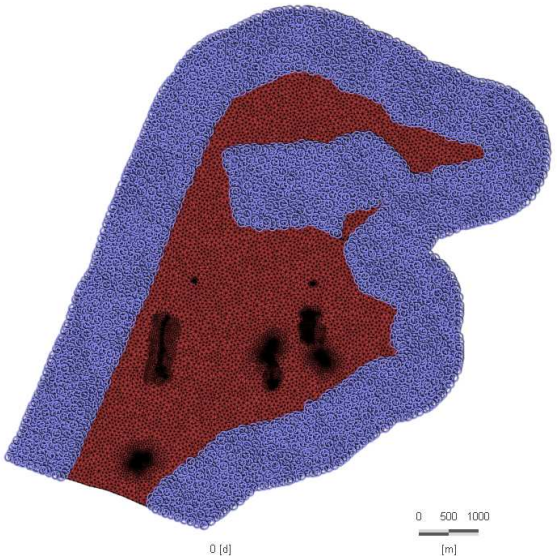

Figure 3: Model area, discretization and constant mass boundary conditions.

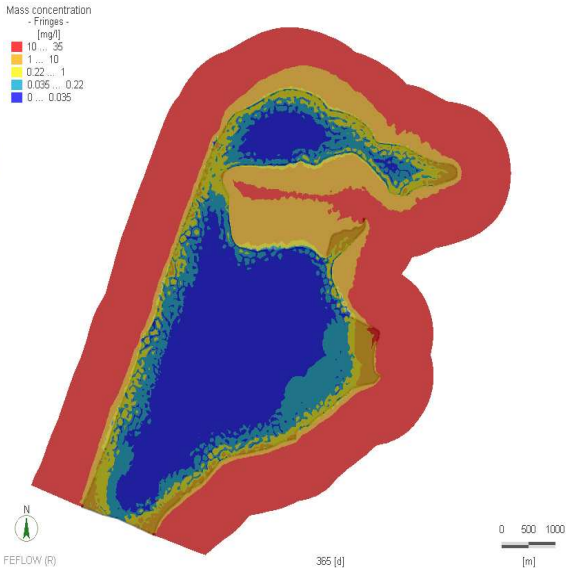

Figure 4: Calibrated fresh and saltwater distribution.

After the successful calibration, a transient model test was performed. For the testing of the model, we used piezometric heads from 05/01/2010 to 05/01/2011 recorded at observation points spread over the island. Two piezometers were installed at each observation point in order to record the level of surface water heads as well as groundwater heads. Data of some water gauges revealed a linear correlation between groundwater dynamics and fluctuation of surface water level. For the transient calculation the varying groundwater recharge was calculated after Grossmann using the daily rainfall statistic from the German Weather Service for the station “List” and the evaporation by Haude. By varying the specific storage coefficients in the upper layers a good match between measured and calculated hydrographs could not be achieved. These discrepancies have been detected for all observation wells and occurred only in during winter.

The winter 2010/2011 was characterized by snowfall events and periods with soil temperatures below freezing point. In the days with snowfall and low soil temperatures no groundwater recharge could occur. After the freezing period, the snow melted and infiltrated into the aquifer. The ‘frozen water’ (snow) and the low soil temperature lead to a delay of recharge. After ordering and analyzing the records of the German Weather Service for measured snowfall and temperature the recharge was adapted to the new situation. Every 10 cm of snow were converted in equivalent recharge values and applied to the recharge value of the following day, when temperatures rose above zero degrees. With this adaption it was possible to reproduce the measured hydrographs (Figure 5, Figure 6).

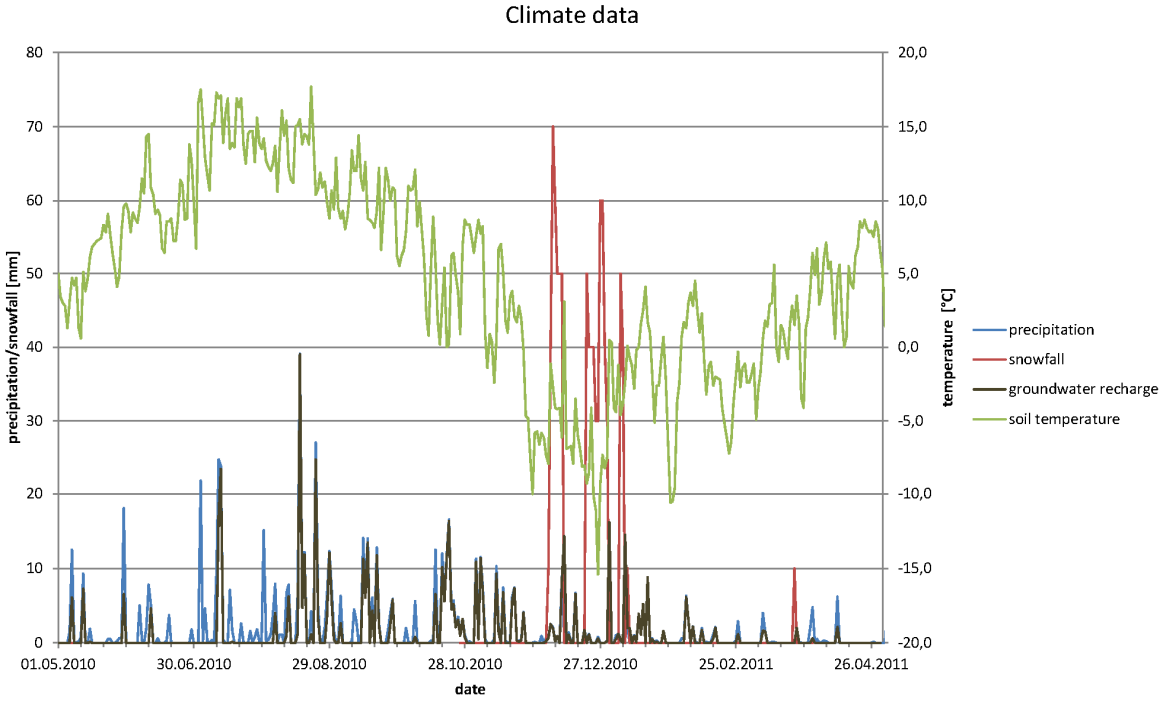

Figure 5: Climate data of the climate station "List" for the year 05/2010 - 05/2011.

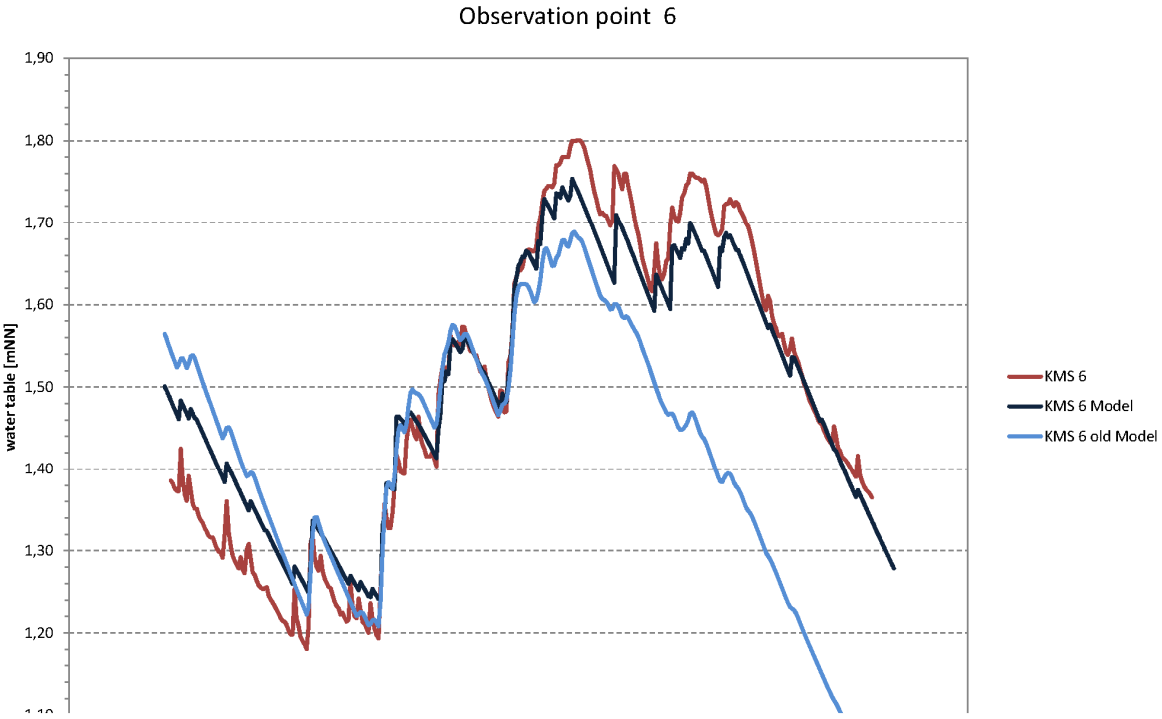

Figure 6: Groundwater hydrographs of observation point 6 (red = measured; black = calibration; blue = before adaption of recharge).

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