Potential Consequences of Saltwater Intrusion at the German North Sea Coast for the water supply

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ABSTRACT

In order to assess possible impairments of the water resources at the coastal zone, an intensive analysis of possible degradation of water quantity and quality triggered by climatic and demographic change is necessary. For the coastal groundwater systems monitoring and protection of the water quality of freshwater reservoir are fundamental parts of the economic and social security and enhancements. An analysis of possible impairments helps to plan future investments in the water supply infrastructure and to guarantee a sustainable water supply for the near future.

The project NAWAK has started in 2013 and aims at examining the effects of climatic and demographic change on the coastal water supply, show impairments on both the supply and demand side of water systems for several pilot areas at the German North Sea coast in order to develop customized adaptation strategies for water supply companies. The expected project output is a planning tool based on a deterministic semi-distributed hydrological model (PANTA RHEI) coupled with a density-driven groundwater flow model (d^3f).

In the pilot areas where geophysical data are available they will be used to build up the geological model. For the modeling of the surface and groundwater hydrology the focus lies on the definition and derivation of the hydraulic and hydrologic boundaries like recharged water, drainage of wet lands and marsh and the spatial freshwater-saltwater boundary in the subsurface. Recharge of freshwater to the coastal groundwater system increase groundwater levels and hence hydraulically controls the movement of the freshwater-saltwater interface. In other words: groundwater recharge is acting as a hydraulic barrier towards saltwater intrusion. If the freshwater is drained from the area by the network of canals and ditches this barrier is impaired. This submarine groundwater discharge (SGD) is important to the coastal environment from a hydrological as well as environmental point of view. The applications of both project models shall provide the freshwater component of SGD and appropriately simulate the flow in the part of the coastal aquifer upstream of the saltwater intrusion area. In this contribution the project NAWAK is presented with focus on strategy for modeling of surface and groundwater hydrology and on possible options to mitigate sea water intrusions, e.g. by adapting groundwater withdrawal, e.g. by shifting of sensitive pumping wells, changing the delivery depth as well as increasing groundwater recharge by the means of rainwater collection basins and reduction of drainage of surface water.

1 INTRODUCTION

The development of an effective planning tool of the coastal aquifers at the German North Sea coast requires the use of two physical based hydrological models to assess present and alternative exploitation scenarios, taking into account not only technical aspects but also economic, legal and political ones. While the d^3f-code simulates the hydrodynamic and hydrochemical evolution of the regional aquifer, the semi-distributed surface hydrology program PANTA RHEI calculates the groundwater recharge from actual infiltrated precipitation water and the hydrological impacts of open drainage canal network. The dense network of drainage canal networks has been observed to have a significant quantitative effect on the fresh water balance respectively the freshwater recharge. Otherwise this network of watercourses is necessary to drain the agricultural basin. The management tools works with specified targets and options of the regional water suppliers and other stakeholders (for example the mentioned requirements on the drainage networks). These targets and options provide important inputs to the computed scenarios and generate finally the decision matrix within the planning tool.

2 METHODS

2.1 Hydrogeological modeling

The geological models introduced here were developed by processing geologists using the integrative software GSI3D© (since 2014: SubsurfaceViewer MX©). The GSI3D© methodology is based on the construction of close-meshed geological cross-sections and the definition of distribution boundaries for all model units found in the sections (Sobisch, 2000).

With the help of this software, all significant surface and subsurface data capable of being digitalized and geo-referenced such as boreholes, geophysical and geochemical investigations, geological (among other) maps, isoline maps and digital terrain data could be integrated in the course of iterative cross-section construction. In addition, the emerging models were complemented with old analogue hand-drawn sections and in some cases with already existing 3D data such as gOcad-TINs, ESRI-, Surfer- and GeoObject-Grids (ascii) etc. All input data are for the first time be interpreted in a three-dimensional context and tested for plausibility before being processed into the hydrogeological model.

On the basis of the constructed cross-sections and the associated layer distribution boundaries a 3D subsurface model was developed with a total area of 1,014 km^2. This model is based on a consistent network of 222 (so far) individual geological cross-sections for which in total more than 11,000 boreholes and geoelectric measurements were available.

2.2 Groundwater recharge

PANTA RHEI is a conceptual water balance model that describes the hydrological processes in a deterministic way. Furthermore, some sub-processes such as soil water and the snow module can be calculated physically-based. The model is the result of many years of development of hydrological models at the Institut für Wassermanagement GmbH and the Leichtweiß-Institut für Wasserbau of the TU Braunschweig (Meon et al. 2012).

PANTA RHEI is based on the assumption of nearly hydrologically similar units that result from the intersection of soil properties, land use and the surface watersheds. The meteorological input variables such as effective precipitation, solar radiation, wind and temperature are regionalized by a grid-method. The runoff generation is divided in three storages (see fig. 1). The upper two storages are influenced by root water uptake and evapotranspiration. The third storage is unaffected, so the outflow can be interpreted as groundwater recharge (Kreye et al. 2012, Eley 2013). The groundwater recharge is calculated with a time discretization of one hour for each part area and represents an essential input parameter for the groundwater model (see 2.3). In the module of runoff concentration the temporal extending is calculated in four storages without interactions. All storages are treated as single linear reservoirs. For model calibration, the total outflow is fitted to the measured values at the basin level. In addition to runoff calibration then the model should be calibrated via a transfer function to the ground water levels.

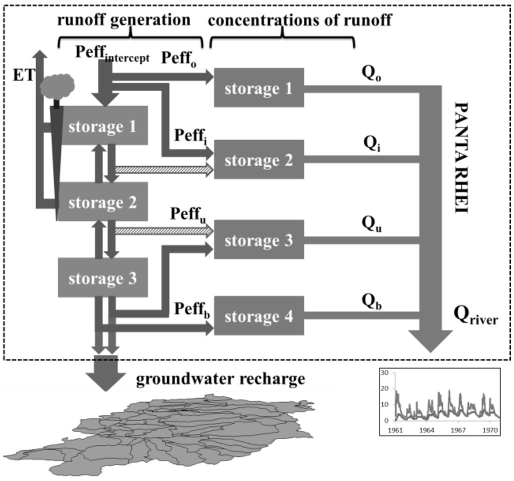

Figure 1. Structure of the conceptual model PANTA RHEI based on single linear storages with runoff generation and concentration of runoff (P_{eff}: precipitation, Q: runoff, ET: evapotranspiration) (changed according to Kreye et al. 2012).

2.3 Density-driven flow modeling

The finite volume code d³f (distributed density driven flow) has been developed with a view to the modelling of large, complex, density-influenced aquifer systems (Fein 1999, Schneider 2012). The use of cutting-edge numerical methods and their parallelisation enable simulations over long time periods with feasible computational effort.

Based on the hydrogeological model (see 2.1) a regional 3d density-driven flow model will be set up, including pumping wells of the waterworks and groundwater recharge provided by PANTA RHEI (2.2.). Scenarios to be simulated are sea-level elevation as a consequence of climate change, shifts of the seasonal distribution of precipitation and changes in the fresh water demand caused by demographic and economic factors.

For now, a 2d vertical cross section is extracted and adapted for d³f. Simulations are started with the objective of getting acquainted with the hydraulic processes in the model domain as well as testing the interaction of the various features and instruments.

2.4 Airborne electromagnetics

The geological model will be verified using geophysical data (Kirsch and Wiederhold 2014). Especially airborne electromagnetic data deliver a good database for locating the saltwater-freshwater boundary and for interpolation between boreholes. Siemon et al. (2014) give an example of clay mapping and thus mapping of low permeable layers. Deus and Elbracht (2014) show the freshwater-saltwater mapping and thus mapping of paleohydrological structures. Both works are close to the project areas of NAWAK. To overcome misinterpretations detailed data analysis and constrained inversion of the electromagnetic data is necessary and planned (Burschil et al. 2012).

3 OUTLOOK

The project NAWAK is in progress. The goal is an exactly replica of spatial and temporal dynamic of the density driven saltwater transport and the development of a planning tool based on a generated (computed) decision matrix. Innovative is the haunted modeling concept as the kernel of the planning instrument. That is the basis for every scenarios of climate change with impact of sea-level rise and groundwater recharge. The results are adaption strategies for the regional water utilities and the water management, e.g. the relocation of wells, adaption of pumping rates, shifting of filter sections, changing of land use and adaption of drainage management.

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