SALT WATER MEETS FRESH WATER – SCIENTIFIC APPROACH MEETS SOCIETAL NEEDS

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ABSTRACT

Groundwater is the preferred source for drinking water and especially in highly populated coastal zones it is one of the most important resource. However, in order to evaluate the resilience of coastal groundwater management related to climate change, groundwater abstraction, drainage, sea level rise and salinization, new strategies to analyze the results of complex model, geodata and governance structures are needed. With that goal in mind, the present work describes a regional coastal groundwater study by considering an area located in the northwestern part of Germany, the Sandelermöns region, which covers an area of about 1,000 km² as an example. This paper presents an appropriate way to fill the gap between process understanding and water resource management by complex physically based modeling, stakeholder analysis and the development of a dialog platform called CAM (Coastal Aquifer Management). The assessment of the freshwater availability is covered by a numerical 3d density-dependent groundwater flow model (d³f++). It is suitable for coastal lowlands and heterogeneous aquifers and has an open interface to the deterministic hydrological water budget model (PANTA RHEI). Main input data are geological model results, groundwater monitoring data and airborne electromagnetic data sets. For the evaluation and presentation of model results, the present paper describes the development and application of the dialog platform CAM (Coastal Aquifer Management) which uses Multi-Criteria Decision Analysis techniques (MCDA) to strengthen transparency and objectivity in decision-making processes and encourage communication between decision-makers.

Keywords: Coastal Aquifer Management, regional density-dependent groundwater model, Groundwater Indicators, Multiple-Criteria Decision Analysis, Hydrological modelling

1 INTRODUCTION

Worldwide groundwater is the preferred source for drinking water due to its mostly outstanding natural quality. Therefore, groundwater reservoirs are of crucial importance in relation to the 'resource-oriented' SDG target 6 of the UN Sustainable Agenda for 2030 to achieve security of water supply. At present, however, groundwater is not adequately expressed with respect to resource sustainability and quality protection. Therefore, new physically based indicators are required in order to define the groundwater status, its risks and trends.

To address these indicators and manage groundwater resources it is essential to fill the gaps in the scientific understanding of complex aquifer systems using hydro(geo)logical models. This is even more challenging for coastal aquifer systems, as they provide encompassing challenges when it comes to the sustainable management of water including the complex hydrological-hydrogeological interface as well as the complex interaction with the bordering sea. An understanding of water flow and solute transport within and across this hydraulic-dynamic transition zones is essential for an effective water resource management. The application of hydro-system models enhances the process understanding and allows for the quantification of the regional water balance – for the current state as well as for changing conditions in the future. Sea level rise, for example, leads to additional pressures by increasing salt water intrusion, increasing the probability of occurrence of flood events. Groundwater abstractions are often restricted by the threat the saltwater-freshwater interface shifting towards inland which is particularly true at the shore-line of the North Sea in North-Western Germany (Feseker 2007). In addition, rising freshwater demands combined with a planned nutrient migration policy reinforces the pressure to act in many coastal regions. Additional overuse of resources due to increasingly dense human occupation deteriorates the freshwater situation (Michael et. al., 2017). The degradation of water resources is often reinforced by a contamination from agricultural sources. Especially nitrate pollution is still one of the most prominent concerns particularly in Germany (Salomon et al. 2016).

The regional groundwater dynamics as a part of the hydrological cycle is inextricably linked to the climate dynamics and thus to the dynamics of the surface hydrology.

Therefore a model concept is needed that integrates a hydrological model and a groundwater flow model as well as the interlinking of both. The application of hydrological models and numerical groundwater models aims

at identifying, quantifying and predicting the development of groundwater indicators for coastal management according to the UN-SDG´s. Another challenge is the identification of interactions between science, practice and policy that needs to be overcome in order to address the continuing water quantity and quality problems in coastal zones (FAO 2016). Safeguarding a sustainable water supply depends not only on the available amount of groundwater, but also on the development of the future water demand and on an effective governance system that ensures the sustainable management of the highly valuable groundwater resource and allows for the adaptation to future changes. This concept is implemented, tested and further developed for several coastal regions in the BMBF funded project go-CAM (Implementing strategic development goals in Coastal Aquifer Management). In this paper we want to present the application of the concept as well as initial results using the example of a coastal case study region in northwestern Germany (Sandelermöns).

2 PROJECT FRAMEWORK

Future developments such as population growth, climate change and drinking water scarcity underlines that a sustainable management of global water resources is one of the biggest challenges of the 21st century. In order to help solve the conflicts arising around the "blue gold", the German Federal Ministry of Education and Research has initiated the "Water as a global Resource" (GRoW) funding measure on the basis of the UN's 2030 Agenda for Sustainable Development. The United Nations' 2030 Agenda for Sustainable Development recognizes the global importance of water resources. Sustainable Development Goal 6 (UN-SDG 6) specifically aims to "ensure availability and sustainable management of water and sanitation for all".

The joint project go-CAM is one of 12 collaborative projects which aims to ensure the supply of fresh water in coastal areas, even under increasing stress. The project integrates the coastal study areas North-West Germany (Sandelermöns and Großenkneten, Lower Saxony), South Africa (Eastern Cape), North-Eastern Brazil and Turkey (Antalya). All case study areas are vulnerable to future changes (climate change, socio-economic change e.g. increasing tourism) and are located in heavy agriculturally used environments or the affected by saltwater intrusion. For all case study areas it is essential to evaluate and discuss the water management situation with focus on water stress and water scarcity and the development of future management practices. The group of international project partners include water agencies, water supply companies and local universities.

3 METHODS

The concept of go-CAM project relies on the integration of hydrological and hydrogeological investigations based on watershed modelling, groundwater models, geophysical surveys and hydrogeological models (see fig. 1). The requirements and the focus of these modelling approaches will be indirectly determined by groundwater indicators that are defined by regional stakeholders. This part of analyzing the groundwater availability is highly influenced by water demand, climate conditions and the sea level. All model results will be transferred to the CAM-dialog platform (Coastal Aquifers Management) using the software CAMup. The objective of CAMup is to convert input data from different sources (e.g. models and geodata) into consistent indicator data grids. In the CAM-dialog platform the model results are evaluated with the help of a Multi-Criteria Decision Analysis (MCDA) with related target functions defined by the stakeholders. This concept is introduced in the present article taking the case study area Sandelermöns, located in North-Western Germany, as an example.
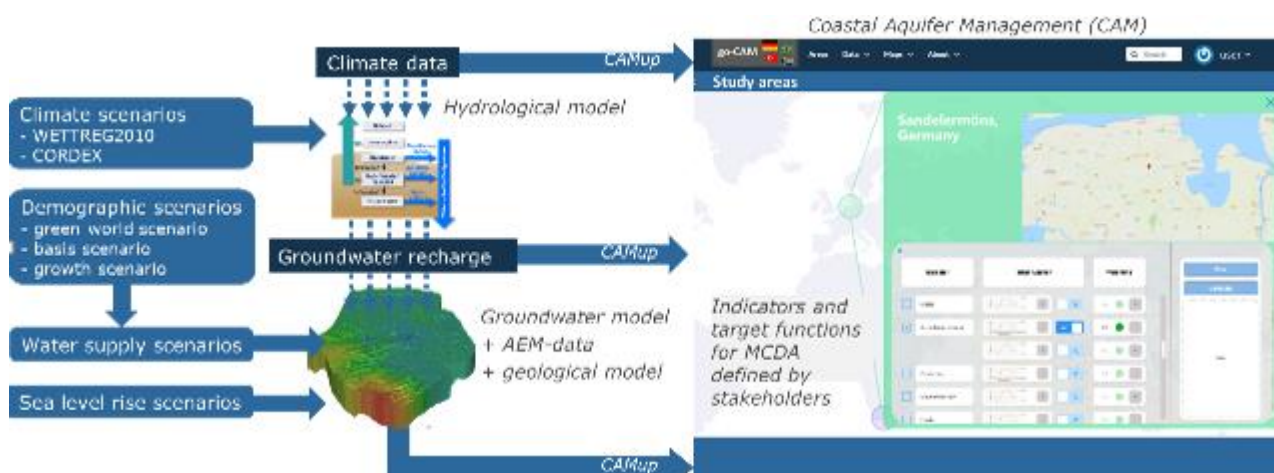
Figure 1. Concept of the go-CAM-Project with hydrological modelling, groundwater modelling with related airborne electromagnetic data (AEM) and geological model, input of scenario data and the transfer of model data to the Coastal Aquifer Management platform (CAM) via CAMup

Case Study Area Sandelermöns

The case study area is located on the East Frisian peninsula in Northern Germany and includes the cities of Wilhelmshaven, Wittmund and Jever (see fig. 2). It has a size of approx. 1,000 km² and borders on the North Sea in the North, to the Jade Bight in the East and the southern and western sides are bound by watersheds. The case study area comprises of two different landforms, the higher and sandy geest in the southwestern part and the marsh with heavy soils and terrain heights slightly above sea level in the northeastern part of the model area. The geest as well as the marsh are under intensive agriculture with pastureland dominating over cropland in the marsh and vice versa. It is belonging to the oceanic climate zone (Cfb, Peel et al. 2007). The average annual temperature is 8.7 °C and the average precipitation amounts to around 830 mm/yr with an even distribution over the year.
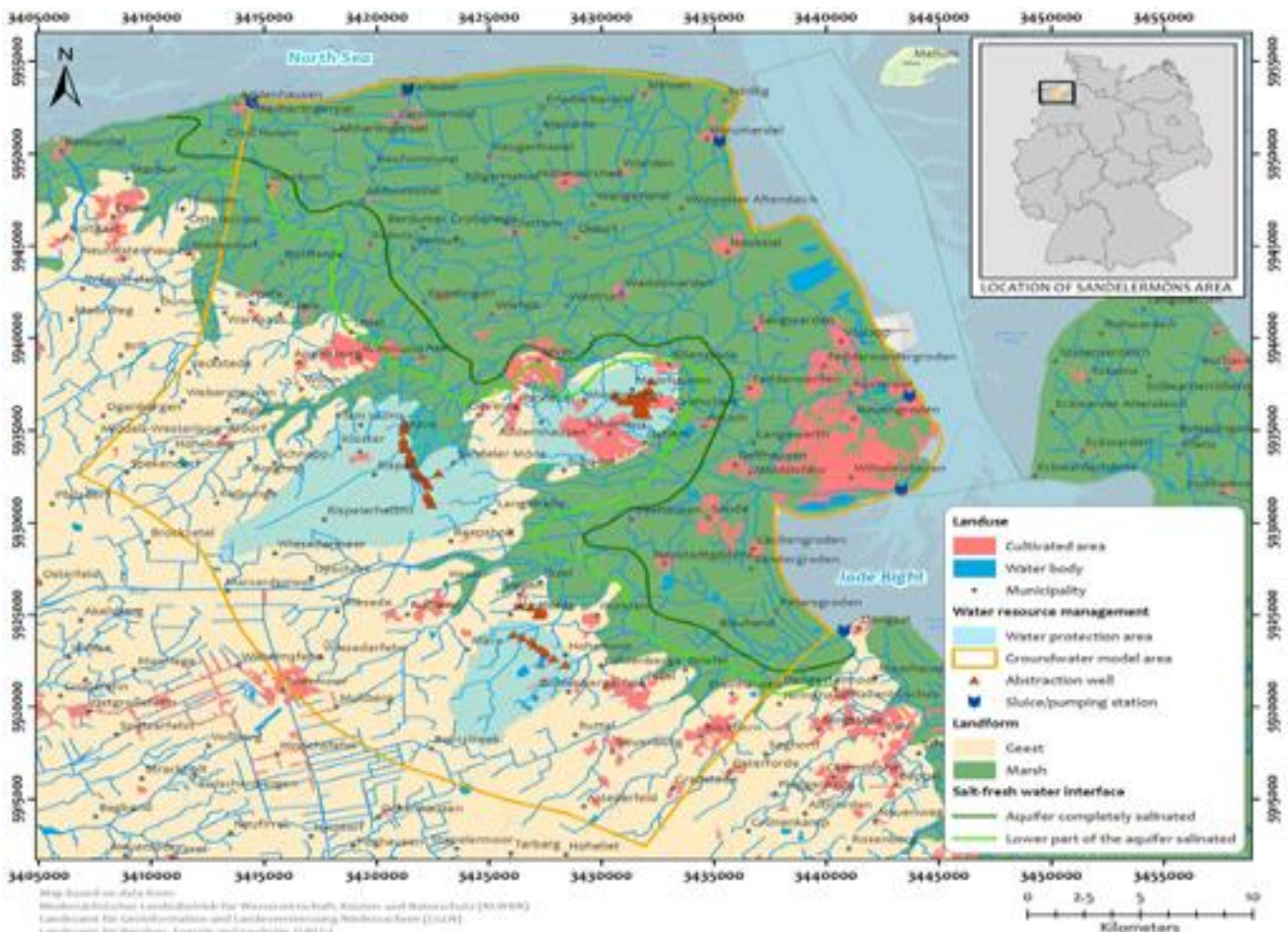
Figure 2. The model area Sandelermöns is separated in the landforms geest and marsh and includes three water protection areas for public drinking water supply. It is located at the German North Sea coast.

In respect to hydrology, the marsh is characterized by a dense net of small draining ditches and rivers conducting water to the coastal pumping stations in the dikes in order to keep the groundwater level below land surface. This drainage is crucial for the hydrologic-hydraulic regime, just as the drawdown around the groundwater pumping stations. Large parts of the surface waterbodies and groundwater in the marsh landscape are salinated with chloride concentrations above 250 mg/l. The course of the salt-fresh water interface is very similar to the border of geest and marsh landscape.

Three waterworks for the public drinking water supply are installed in the geest landscape with an annual production volume of approx. 16 million cubic meters. In addition, there are many water rights of private households, farms and industry.

The hydrogeological subsurface system consists of six formations of mainly (glacio-)fluviatile sediments dating to the tertiary and quaternary with a total thickness of around 135 m. A thick layer of fluviatile sands at the bottom is superimposed by small fields of Tergast clay and a continuous layer of melt-water sands. The top of the model consists of thin layers of Lauenburg clay, dune sands and silty materials.

Indicators of Coastal Aquifer Management (CAM)

The main objective of go-CAM is the development and application of the dialog platform CAM (Coastal Aquifer Management) which uses Multi-Criteria Decision Analysis techniques (MCDA) to strengthen

transparency and objectivity in decision-making processes and encourage communication between decision-makers.

The requirements for this coastal aquifer management platform were determined as part of a participation process. Stakeholders from the sectors of agriculture, economic development, nature conservation, water supply, administration and water management were represented. The main objective is to derive evaluation variables that should be implemented into the Coastal Aquifer Management. Tab. 1 summarizes the assessment parameters with high relevance given to changing climatic and socio-economic conditions in the region. The main impacts would be a shift of the salt-freshwater interface, changing groundwater recharge, increased irrigation requirements and a changing water balance with a focus on discharges at the sluices and pumping stations. To calculate the assessment parameters, indicators were defined which could be calculated from the results of the hydrological model, the groundwater transport model or climate data.

Table 1. Evaluation parameters and related indicators for the coastal aquifer management (CAM-Tool).

Evaluation parameter	Indicator
Chloride concentration [mg/l]	Location of salt-freshwater interface in three depths (isolines of chloride concentration of 250 mg/l according to the drinking water ordinance): d³f++ calculation
Distance of salt-freshwater interface [m]	Distance of pumping wells to the salt-freshwater interface in three depths: d³f++-calculation
Groundwater recharge [mm/yr]	Trend of groundwater recharge for sub catchments differentiated in geest and marsh landscape: PANTA RHEI calculation
Groundwater head [m a. s. l.]	Trend of the water table in the geest and marsh landscape: d³f++ calculation Trend of the groundwater head in the geest and marsh landscape: d³f++ calculation
Drought Index [-]	Decreasing or increasing of dry days based on a drought index (Martonne 1926)
Water budget [mm/yr]	Positive or negative balance in the model area and groundwater abstraction area: PANTA RHEI and d³f++ calculation
Discharge [m³/s]	Increasing or decreasing discharge at the sluices and pumping stations at the coast: PANTA RHEI calculation

CAMup

To enable an indicator based evaluation, all model results will be transferred to the dialog platform CAM by using an interface tool called CAMup, a stand-alone application written in Java. CAMup is a support tool for the dialog platform CAM and interacts with it via file based network communication using a NextCloud Server. The aim of CAMup is to convert input data from different sources into consistent indicator data grids. These grids form the basis for the MCDA part of the CAM dialog platform. In network based interaction with CAM, the CAMup tool ensures that the indicator grids meet the requirements of the MCDA. These requirements includes an uniform and consistent naming of scenarios and indicators as well as a homogeneous spatial distribution and resolution of the MCDA grids. CAMup provides various interfaces for common GIS file formats and for selected simulation models, which were applied within the go-CAM project. Local files containing indicator data can be loaded into CAMup, where they are assigned to a project area, a scenario and a set of indicators. Based on the project area settings obtained from CAM, the data is transformed into multiple indicator grids and then uploaded into the CAM data pool to be integrated into the MCDA.

CAM online dialog platform

The architecture of the CAM dialog platform is based on the open source GeoNode, a Web-based application and platform for developing a geospatial information system. GeoNode builds upon the useful and already developed open source software and combines them in order to take advantage of their functionalities. GeoNode is a web application developed in Django, a popular Python web framework, which provides a spatial data server (based on GeoServer), a spatial database (based on PostgreSQL and PostGIS) and a catalogue (based on pycsw, the default option, or GeoNetwork OpenSource). A data model has been designed to extend the database in order to accomplish the platform needs, including the study areas, scenarios, indicators, target functions, weighting, valuations and the result of the calculations. For each study area, one or more scenarios can be chosen and every scenario can be composed of different indicators. And for every indicator, more than one target function can be implemented with a specific weighting value.

A website design has been built using the software Adobe XD, to represent the program workflow with its planned functionalities. The start page contains the description of the project, the available tools, study areas and the contacts. On this page, the user can create an account and manage it. After registration, a study area can be selected in order to get more information about it. Furthermore, the user has the possibility to create a new valuation for the selected study area as well as explore saved valuations and saved calculations. Each study area provides an explanation and all related information besides the layers, documents and images. After the selection of a study area, the user can select a "MCDA-Valuation", which uses different methods (e.g. Composite programming). For different scenario combinations (e.g. climate and pumping), the user can choose indicators, which are presented as a table of raster indicators and for every chosen indicator, it is possible to select more than one target function. These target functions are customizable. Also, there is a possibility to put a specific weighting value for the indicator with colored identification. These calculations can be saved for comparison purpose. Moreover, by using the dialog button, two users can login and explore the saved calculations. The view of this dialog will be either two windows side by side or one window with a swipe tool.

The integrated concept of hydrological models, density dependent groundwater models and geophysical investigations is described in the following chapters in order to get the underlying information for an indicator based evaluation of coastal aquifer management.

Hydrological Modelling (PANTA RHEI)

The software system PANTA RHEI (LWI-HYWAG & IfW 2017) was used for the quantification of the regional water balance. PANTA RHEI is a deterministic, semi-distributed hydrological model system. It allows for the treatment of hydrological and water management issues and tasks, such as the temporally and spatially highly resolved water budget modeling for climate impact research. Other fields of application are the planning and designing of flood protection concepts and operational flood forecasting (Hölscher 2012).

PANTA RHEI was developed by the HYWAG department at the Leichtweiss-Institute for Hydraulic Engineering and Water Resources of the University of Braunschweig - Institute of Technology in cooperation with the IfW GmbH. The model system is based on the spatial discretization of the model area in sub-basins that are linked by the flow relationship of the surface waters. The HRUs (hydrologic response units; areas with similar hydrological properties), which are generated by the intersection of land use, soil properties, a digital elevation model and sub-basins, are the basis of the calculations. At the hydrotope level, the processes of runoff formation are calculated. These include snow accumulation and melting, evapotranspiration, interception, infiltration, percolation and groundwater recharge. The discharge concentration and the discharge routing are calculated at the level of the sub-basins. The modular structure of PANTA RHEI allows for a selection of needed procedures in order to calculate the hydrological sub-processes.

The hydrological model of the Sandelermöns region encompasses a total area of 1,080 km² that is further divided into six catchment areas, 147 sub-catchments and 7,797 hydrotopes. The number of catchments complies with the number of outlet structures that ensure the drainage of the basins.

For the calculation of the water balance, the physically oriented soil module DYVESOM (Dynamic Vegetation Soil Model) (Kreye & Meon 2016) is applied. It is characterized by an accurate and detailed simulation of the soil water balance and groundwater recharge. This is especially helpful, as within the go-CAM project, the main output of the hydrological model is the spatially and temporarily discretized groundwater recharge rate.

The vertical water exchange in the unsaturated zone, which is affected by the processes of infiltration, percolation, capillary rise and groundwater recharge, is realized by the use of the matrix potential-dependent Darcy-Buckingham relationship (see e.g. Jury and Horton, 2004). A distinction is made between three horizontal soil reservoirs, whereby the condition of the uppermost soil layer is decisive for the infiltration rate. The parameterization of the soil model is not done by an effective parameter set, but considers the natural spatial subgrid variability by several parallel soil models with different parameter sets (Kreye and Meon, 2016).

The potential evapotranspiration is calculated using the Penman-Monteith approach (Penman, 1948, Monteith, 1965). Discharge routing is carried out by calculating translation and retention. For the translation of flowing waters, the flow velocity is determined using the Manning-Strickler flow formula. Due to the separation of the discharge into river bed and foreland, the retention is calculated separately with two single linear accumulators.

Climate data, required by the model are date wise precipitation, air temperature, solar radiation, wind speed and relative humidity. For this study, all the meteorological inputs required for model calibration and validation were obtained from a total of 20 precipitation stations and six climate stations. Model calibration and validation are performed for the period 1971-2011 based on water monitoring data obtained from gauging stations within the study area. The calibration is based on the comparison of measured and simulated runoff at the gauging stations, sluices, and pumping stations. To have an additional calibration variable, a comparison of the levels in the lowest storage in the DYVESOM model with measured groundwater levels is taken into account. For a first calibration of the model, an automatic lexicographic optimization method is used (Gelleszun et al., 2017). Unfortunately, only little information is available about the water levels of the receiving streams in the Sandelermöns region as well as the pumping rates of the coastal pumping stations. Missing information was

replaced by reasonable and careful assumptions to meet the natural hydraulic regime by a careful calibration process.

For the evaluation of the impact of climate scenarios on the water balance and thus on the indicators of groundwater recharge and water balance, data of the statistical downscaling method WETTREG2010 (Spekat et al., 2007; Kreienkamp et al., 2010) for SRES scenarios (Special Report on Emissions Scenarios) A1B, B1 and A2 are used (Tab. 1). Within the framework of further projects for climate impact research in Northern Germany, good results could be achieved with WETTREG, e.g. in Hölscher (2012). The calculation results of the water balance as well as the development of groundwater recharge on the basis of WETTREG-data are exemplarily shown in chapter 5.

Airborne electromagnetics (AEM)

For 3d density-driven groundwater flow simulations the salt concentration of the aquifer is an essential initial condition. Due to the correlation of total dissolved solids concentration of water and specific conductance geoelectrical and electromagnetic methods are suitable techniques to detect corresponding characteristics of subsurface formations. Especially aero-electromagnetic (AEM) methods provide area wide distribution of bulk conductivity or resistivity (fig. 3). To translate this parameter into salt concentration, a statistical analysis is applied. First, borehole lithology and resistivity (inverse of conductivity) depth models are linked. In case of the project area Sandelermöns 1,430 boreholes were analyzed. Second, from the distribution of resistivity for clay, silt and sand intervals a resistivity threshold for sand with saline affected groundwater is derived. Third, transformation of 3d AEM resistivity data into salt fraction by linear transfer function from 5 Ωm (salt fraction is 0) to 0.3 Ωm (salt fraction of 1).
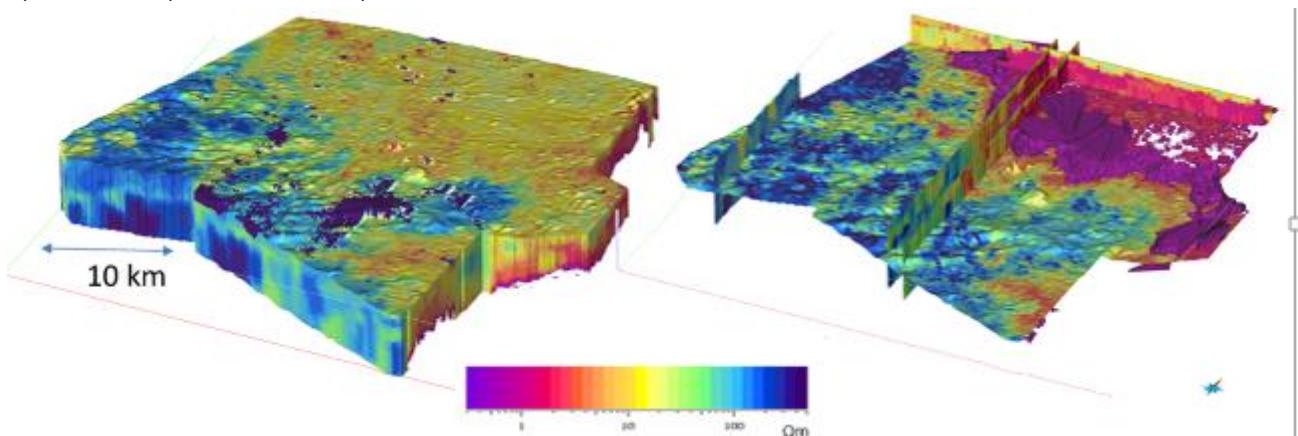
Figure 3. left: 3d resistivity data from AEM survey for the project basin Sandelermöns (vertical exaggeration: 50), right: view into the data (35 m depth slice, 3 N-S sections, 1E-W section) with interpretation of fresh-saline groundwater interface (purple surface corresponding to 3 Ωm isoline).

Groundwater modelling (d³f++)

For the simulation of the dynamics of the aquifer in the Sandelermöns region a numerical groundwater model was developed using the code d³f++. The aquifer is represented by a three-dimensional finite volume grid, consisting of 4.6 million nodes and 18,000 prismatic elements of variable size. d³f++ is a modern tool for modeling density-driven flow and pollutant transport in porous and fractured media, including heat transport as well as free surface flow on large model domains with complex hydrogeological structures (Schneider 2016). d³f++ is based on the open-source software package (Vogel et al. 2014). The use of modern numerical methods such as geometric and algebraic multigrid methods and their parallelization enables simulations over long time periods with feasible computational effort. The thermohaline groundwater flow in porous media is modelled by a coupled system of nonlinear, time-dependent differential equations representing balance equations for mass, brine and heat.

For spatial discretization, the finite volume method is used, ensuring mass conservation. d³f++ solves the complete, nonlinear coupled equation system without simplifications such as the Boussinesq approximation. The time dependent system is discretized by an implicit Euler algorithm, as this method enables the use of large time steps. The nonlinearity is solved by a modified Newton algorithm. Geometric and algebraic multigrid methods are used as the most effective solvers of large linear equation systems. d³f++ can not only be run on desktop but also on massively parallel computers, it also may make use of modern multicore and hybrid computer structures (Heppner et al. 2013). The time dependent position of the groundwater table is computed using level set methods (Frolkovič 2012). Using level set functions implicates some restrictions to this part of the model boundary: regarding the pressure, the boundary condition p=0 is set directly by numerical discretization and cannot be changed. This means that groundwater recharge as well as discharge may not be treated as boundary conditions, as both effects have to be modelled as factors directly influencing the normal velocity of the groundwater surface.

The groundwater model comprises six model layers with a total thickness of 135 m that were derived from a hydrogeological structure model set up by the Oldenburg-Ostfrisian Water Board (OOWV). In this model six formations are distinguished depending on the geological setting as described in the case study area description. The model's boundary conditions were determined from the (geo)hydraulic properties in the area. The south-western boundary of the model is located on the border of a watershed and therefore assumed to be impermeable. The salt concentration is set to zero. The north-western and south-eastern boundaries are chosen to be perpendicular to the water table isohypses and therefore, they are also regarded as impermeable for the flow. The eastern border of the model concurs with the shoreline of the North Sea and the Jade Bight. This coastal boundary is equipped with a hydrostatic pressure for seawater and a salt concentration of 34 kg/kg (35 g/l). The bottom of the model is also assumed to be impermeable. On the upper boundary, a Dirichlet boundary condition $p = 0$ has to be chosen for the pressure prescribed by the level set method. The concentration is also set to zero. The north-eastern region of the model domain is characterized by a dense net of small draining ditches and rivers conducting water to the coastal pumping stations in the dikes to keep the groundwater level below land surface. This drainage plays a crucial role in the hydraulic regime and had to be incorporated in the model. Because an explicit mapping of all ditches in a regional model is impossible, only the rivers of first and second orders were integrated.

To find an appropriate initial condition for the free groundwater table the data of 284 groundwater observation wells were averaged over the year 2011 and interpolated. The initial condition for the salt concentration is based on aero-electromagnetic data provided by the Leibniz Institute for Applied Geophysics (LIAG). Furthermore, the 51 pumping wells of the waterworks were included into the model and additionally, 36 private wells are regarded. Time-dependent groundwater recharge rates for the three climate scenarios WETTREG2010 B1 (moderate), WETTREG2010 A1B (long-term dry) and WETTREG2010 A2 (dry) for the period 2011 to 2050 were calculated using the hydrological model PANTA RHEI. A sea-level rise of 0.25 m was assumed for this period. For 2050 three different socio-economic scenarios influencing the water demand were investigated by the OOWV, a basic scenario, a green world scenario and a growth scenario. The resulting time-dependent pumping rates were used in the scenario-simulations by d³f++.

5 Results

The results presented here are intermediate insights from hydrogeological and hydrological modelling and main indicators for our online dialog platform CAM. The main findings are the annual water balances with their system-relevant components for different climatic and socio-economic scenarios (Tab. 2). The results of selected hydrological scenarios are the mean values of 10 realizations of WETTREG2010 scenarios in combination with social-economic scenarios based on studies of the local water board. The main focus is on the availability of freshwater, especially in the case of threats from saltwater intrusion due to rising sea levels and/or falling groundwater recharge due to extreme precipitation and rising air temperatures (intensification of the earth's water cycle, increasing evaporation).

Also the agricultural use generates a further water component with a bidirectional groundwater interaction (Tab. 1). In the groundwater abstraction areas, the average annual runoff from the drained agricultural land partly exceeds the groundwater abstractions. The volume fraction of groundwater bodies influenced by sea water is approximately 48 % (aquifer partly or completely salinated). For three scenarios, the fresh-saltwater interface (250 mg/l) is shown at a depth of 60 below surface, the level where the production well filters are usually located and the groundwater inflow is well developed. For different scenarios there is a change of the saltwater distribution, but the interface is not approaching the abstraction wells (tab. 2).
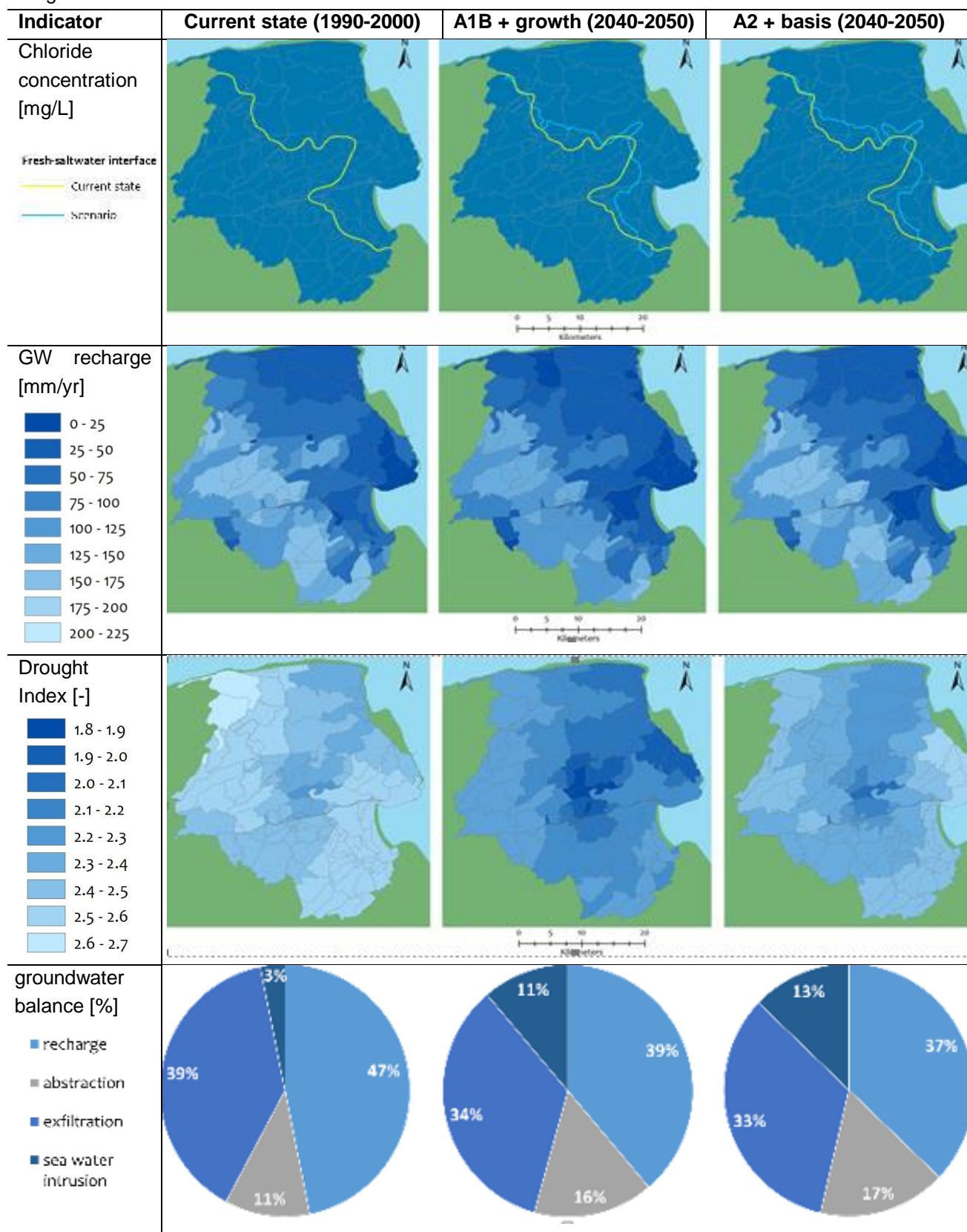
The groundwater recharge will be indicated by the water balance model for three calculations at approximately 150 mm/yr, with lower values for the marsh landscape (10-125 mm/yr) and significantly higher values for the geest landscape (up to 225 mm/yr). In the combination of scenarios in relation to the current state you can see a decrease of groundwater recharge of about 40-50 mm/yr. The available freshwater quantity in our coastal groundwater resource is estimated with approximately 14 billion cubic meters for the current state.

The seawater intrusion for both future scenarios increases from 10 mm/yr to about 12-16 mm/yr. Related to the distribution of saltwater you can see that there must be also a high drainage of salinated groundwater from the marsh landscape. The drought index (De Martonne 1926) indicates an increase of drought risk for the decade 1940-1950 compared to the current state.

The hydrological model shows the spatial and temporal sensitivity of groundwater recharge and the changes caused by the effects of climate change. The performance of the PANTA RHEI program package provides satisfactory simulation results even for long time series.

It has been shown that it is essential for the validation and calibration of our groundwater model calculations to have a 3d hydrostratigraphic and a 3d AEM resistivity data model with which a calculation of the regional hydraulic interactions between the sea-, and groundwater body and the rivers respectively drainage ditches can be realistically simulated. Crucial in connection with density-dependent groundwater modelling is the derivation of initial and boundary conditions of salt water transport (Fig. 3). The preliminary results show the need for integrated groundwater management that takes adequate account of the interests of stakeholders from agriculture (artificial drainage), water supply and environmental protection.

Table 2. Example of water indicators, as they presented in the CAM dialogue platform. Our proposed indicators are based on data received by measuring, monitoring and modeling. All indicators show the current state and the climate scenarios A1B and A2 (WETTREG2010) in combination with socio-economic scenarios "growth" and "basis". Shown is a line of equal chloride concentration (250 mg/l), groundwater recharge, drought index and groundwater balance.

Indicator	Current state (1990-2000)	A1B + growth (2040-2050)	A2 + basis (2040-2050)
Chloride concentration [mg/L]			
GW recharge [mm/yr]			
Drought Index [-]			
groundwater balance [%]			

6 CONCLUSIONS

At the current stage of the project, we have presented the hydrological and water management findings from the modelling, that – expressed as sustainability indicators for groundwater and surface water resources – serve as the data fundament for the CAM dialogue platform. Calculated water/groundwater indicators referring to the UN-SDG 6 form the basis for decision-making and good groundwater governance. The latter is the basis for effective and sustainable groundwater management not only in coastal areas. Groundwater sustainability is defined as developing and using ground water in a way that can be maintained for an indefinite time without causing unacceptable environmental, economic, or social consequences. The dialogue platform CAM is intended to serve this concept.

Regarding the quantification of the regional water budget our first calculations on water availability and groundwater indicators for our coastal watershed in Northwest Germany show that progressive salt-water intrusions are not expected for all three climate scenarios presented here (see Tab. 1). From the modelling results we can also conclude that there will be no water stress in the future, as the annual groundwater renewal exceeds the groundwater abstraction by far. With our modelling work in progress we found out that the dense network of ditches ensuring the drainage in the marsh with its highly artificial discharge regime is an outstanding and difficult to model peculiarity of the case study area. This is contrasted by a lack of discharge measurements at the coastal sluices and pumping stations controlling the drainage of the whole area. A fortification of the discharge monitoring network appeared to be indispensable and was meanwhile initiated in cooperation with local auteurs (water boards) by installing new measuring devices at the sluices. This additional data fills existing gaps in our knowledge of regional water flows and must be considered as an elementary contribution to better calibrate the hydrological model.

From our first results we can conclude that the highly dynamic water turnover in coastal regions can only be understood and quantified with physically based modelling approaches that have the power to essentially contribute to the data base for managing water resources. In order to generate reliable answers on the availability of fresh water in these coastal regions as well, the methodological approach of the go-CAM project proved to be eligible and convincing and thus will be retained and further developed.

The methodology applied in the go-CAM project is used to identify and specify further groundwater and surface water indicators which are suitable to express and assess the current situation. In the same manner these indicators need to be sensitive to the impact of changes on ground water use originating from the future dynamics in the broader economy as well as the social and ecological dimension.

The final step in the project is to start the process of planning and management, beginning with priority aquifer bodies or surface water where pressures are high and interests large. Once the regional actors, e.g. from the water sector and agriculture, have been identified, the exchange and discussion on the basis of the dialogue platform CAM should start. For future publications, it is planned to present findings from case studies from the CAM coastal regions to explain the indicator evaluation and derived measures carried out with the help of the dialogue platform CAM.

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