Water resources management and water availability in the Elbe river basin under conditions of global change

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Abstract: Global change challenges long-term planning in water management. Practical management requires plausible and consistent scenarios as well as assessments of possible climatic, technological and social developments and their impacts. These problems are subjects of research within the GLOWA Elbe II – project. The project's goal is to develop a water management strategy for possible adaptation to global change in the Elbe river basin (about 150,000 km^2). One important component of the multi-disciplinary project is the analysis of conflicts related to water availability. For that purpose a detailed water management model for the whole Elbe river basin, including the Czech part of the basin, is under development. The model includes the main water uses and management facilities. Special consideration has been given to wetlands as important water "user". The amount of water use is partly determined by modules, which consider economical changes. Also in the model are functions for evaluating the monetary and non-monetary impacts associated with various degrees of fulfillment of the water demands. The simulation software uses the model WBalMo®. The WBalMo Elbe model consists of connected sub-models for major sub-basins, including the sub-model Elbe itself. The water yield is provided by a rainfall-runoff-model, which reflects not only climatic change but also changes in land use, especially by agriculture.

Keywords: water resources management; long-term planning; global change; modeling

1 INTRODUCTION

1.1 Elbe river basin

The Elbe river basin is the 12th largest in Europe. It covers an area of nearly 150,000 km^2 in Central Europe, about 1/3 in the Czech Republic and 2/3 in eastern Germany, with middle mountain ranges in the Czech Republic, the Erzgebirge, Thuringia Forest and Harz in Germany and large areas of hilly terrain or lowlands in the rest of the basin (central, northern and eastern Germany). The basin is representative of semi-humid regions in Central and East Europe, where water availability during the summer months is a limiting factor i.e. for plant growth and crop yields. The water supply of 680 m^3/capita and year is one of the lowest in Europe.

The basin provides a variety of environmental and socio-economic conditions and a number of socio-economic and ecological problems, including water availability and quality problems and water use conflicts. Some of these conflicts are amplified by the political and economic changes connected to the German reunification in 1990. Others are getting more and more into focus with the cooperation between the Czech Republic and Germany in the European Union, especially in the field of water resources management. In the context of climate change water use conflicts are expected to intensify.

1.2 GLOWA-Elbe

The research project GLOWA Elbe has been started to contribute to water resources management planning with special regard to the consequences of global change, against the background of the problems mentioned above. The first phase of GLOWA Elbe (2000 – 2004) was directed towards methodological research and applications in selected sub-basins. The second phase, running since 2004, considers the Elbe river basin as a whole.

One of the important aspects of Global change is climate. In conditions of low water availability water use in the Elbe river basin is vulnerable to changes in temperature and precipitation. Socio-economic changes, particularly in agriculture, commerce and industry, population, energy production and water related technology also a direct influence through policy on water yield and water demand. These changes also affect nutrient and pollutant emissions to surface waters. GLOWA Elbe aims to quantify these changes as influenced by different scenarios of global climate change. Their effects on water quantity and quality can be calculated using appropriate models.

Alternative policy strategies have to be developed for the German part of the Elbe basin. They will be evaluated and selected options for action in different global change scenarios will be recommended to stakeholders. Stakeholders participate in every step of the project, beginning from building the models, through defining current management options, development of alternative options and their evaluation.

The Integrated Methodological Approach (IMA) has been developed to integrate all required research tasks within GLOWA-Elbe aimed at assessing global change effects on the water cycle [Messner et al., 2006]. The IMA combines different methods such as scenario techniques, simulation studies, and multi-criteria validation of effects.

GLOWA-Elbe focuses on management problems in two fields of water related conflicts: surface water availability and surface water quality. The sub-project "surface water availability", which is presented in this paper, has the aim to quantify the effects of climate change and socio-economic development through modeling the process of water use and management in the whole Elbe river basin. Functions are included in the model to calculate water use associated with socio-economic and climate conditions. Also the water demand of large wetlands, an important water use in the lowlands of Elbe river catchment, is calculated by special modules that take into account climate and the management of water. The model also includes assessment functions for evaluating different water resources management strategies. Water yield is provided by a rainfall-runoff model.

The development of optimal alternative options for water resources management under conditions of scenarios of global change will be the most important outcome of this sub-project.

2 PRINCIPLES OF MODELLING LONG-TERM WATER MANAGEMENT

2.1 Basic methodology

Fig. 1 presents a simplified diagram of water management. It shows that water management is integrated into the hydrological cycle, which is shaped by precipitation and evaporation as the dominant factors in runoff generation, and runoff into the surface waters and into groundwater.

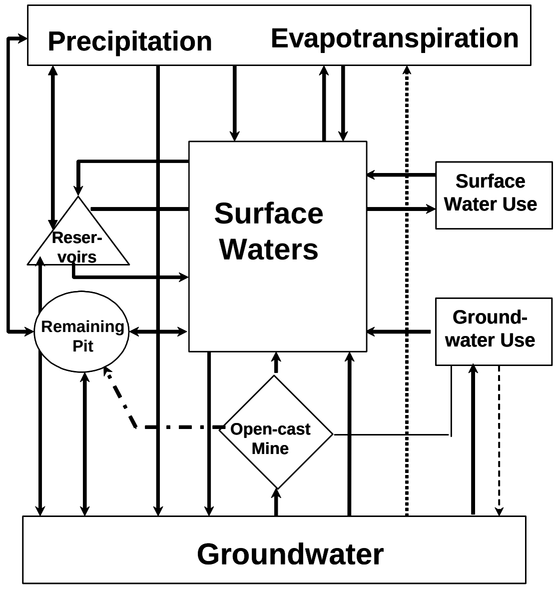

Figure 1. Water management scheme

Superimposed on these natural processes are anthropogenic components, such as use of surface water and groundwater, and water management measures such as reservoir control or water transfers. In mining regions, which are important within the Elbe river basin, both the discharge of mine drainage and the remaining pits have to be considered too.

The goals of water management are, for example, covering the water needs of the users (as municipal water supply, power plants, industry), maintaining minimum discharges (for ecological reasons but also for navigation), and effective protection against floods.

Long-term water management is a stochastic problem. The drainage process itself is a deterministic one, but lack of knowledge of the hydro-meteorological processes driving it, and of the spatial-temporal distribution of runoff generation, forces us to regard the runoff process over the long term as a random process.

Based on the stochastic character of runoff, and thus of water management, the methodology of stochastic long-term management has been developed, mainly for areas characterized by a large demand for water and small available water resources.

The stochastic management models divide the management problem into three parts (Fig. 2):

- Stochastic simulation of meteorological and hydrological processes
- Deterministic simulation of water use processes
- Recording of relevant system states.

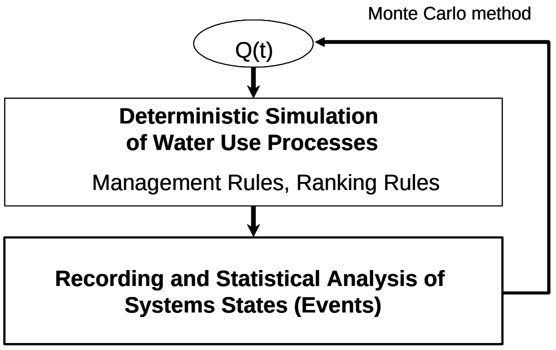

Figure 2. Method of stochastic water resources management modeling

If the month-by-month simulation is passed over sufficiently long periods, a statistical analysis of the recorded system states will give satisfactory approximations to the probability distributions sought, for reservoir levels and discharges for certain water-balance profiles, or safety margins for water provision, for example.

2.2 Simulation of meteorological and hydrological processes and water use

Fig. 3 illustrates the two alternatives for generating time series of runoff. For the simulation and analysis of long-term water resources planning, usually monthly time steps are used.

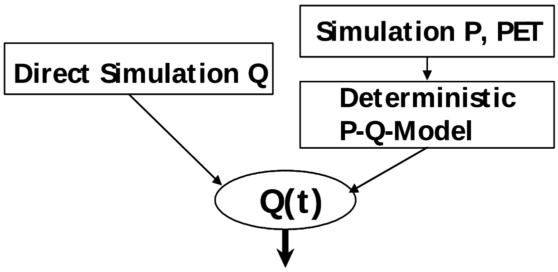

Figure 3. Runoff generation

Obviously, by employing adequate stochastic simulation models one can generate different realizations of precipitation and other climate variables. Resulting runoff time series are estimated with a precipitation-runoff model.

The user demands, on the other hand, are deterministic in time and space from the planner's point of view. For each time step of the investigated planning horizon and each cross section of the river network in the planning area the simulation of water use can described as follows. First, the available water resources have to be calculated on the base of natural water yield and relevant water management options. Second, the resulting water resources are balanced for each balance profile with water demand. Water demand often depends on:

- time,
- meteorological variables,
- socio-economic development.

The ordering of the water balancing process depends on the location of the water uses along the flow direction and of the priority given to each of them without regard to flow direction.

As a result approximate probability distributions are available at selected river profiles for values such as reservoir capacity, water supply deficiency for individual water users or for flow. Due to this, the quality of a selected management strategy can be assessed for the investigated river basin and a gradual improvement of this strategy can then be achieved with well-aimed scenario analysis.

Finally water resources planning results in management measures as the construction or operation of reservoirs, depending on water resources availability and user demand in the future. Fig. 4 summarizes the aspects discussed above.

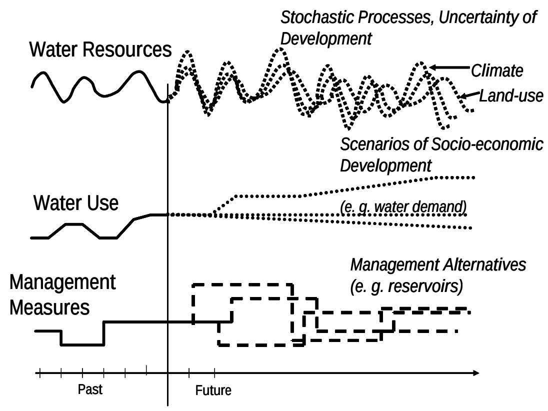

Figure 4. Aspects of water resources planning

2.3 Implementation into simulation software

Based on the general methodology described above a series of models, the so-called long-term planning models, have been developed in the last decades. The first generalized model – GRM - of this type was developed in the 1980s [Kozerski, 1981]. In the 1990s, the model was further improved by the WASY GmbH, Institute for Water Resources Planning and Systems Research and new hard- and software technologies adopted. A major step was the introduction of an ArcView user interface beginning from ArcGRM 1.0. The most recent simulation system is known as WBalMo 3.0 with the possibility to model even very large river basins (over 100 000 km^2).

Other important capabilities are:

- consideration of variable boundary conditions (climate change affecting water yield, socio-economic developments),
- incorporation of user defined algorithms as standard model objects,
- balancing by priority instead of flow direction,
- modularization of large models.

3 SIMULATION OF LONG-TERM WATER MANAGEMENT AND ITS ASSESSMENT IN THE GLOWA-ELBE II PROJECT

3.1 Scenario development

The starting point of the development of scenarios is the storylines, underlying the IPCC-scenario families (IPCC = Intergovernmental Panel on Climate Change) A1 and B2 [IPCC 2002]. A1-scenarios belong to a group of scenarios characterized by very high economic growth and significant globalization. In B2-Scenarios the development of society and economy takes place on a more regional basis, which results, among other things, in lower economic growth. These storylines are in a first step described in more detail for the Elbe river catchment. On the next level regional politics are derived for every water dependent sector, significant for the regionalization of global change. On this basis quantities are defined, which serve as input values and parameters for water demand functions. In doing so, a huge set of scenarios is obtained. Obviously this high number of scenarios cannot be used for calculation of their effects and of the effects of adopted water resources management. Therefore an important step on this working stage is to choose typical scenarios, which covers the principal development in a wide range of grouped scenarios. It is necessary to point out that all scenarios have an equal probability of occurrence and that none of them can be selected as a reference in terms of what will happen if actual developments will stay unchanged.

3.2 Implementation of climate change an land use

Climate change is expressed through simulation of climate variables with the model STAR [Gerstengarbe and Werner, 2004]. A fundamental underlying assumption is a trend of temperature of 1.4 °K from 2001 until 2055. For the simulation of other climate variables and their spatial and temporal distributions statistical approaches are used, parameterized by observed values. In order to get the opportunity to apply simulated climate variables in models based on the Monte Carlo method. For that, with the model STAR 100 realizations for all climate variables have been generated, each of them 55 years long. This time horizon is the investigation period for the water management model.

The required realizations of runoff are calculated with the rainfall-runoff model SWIM [Hattermann et al., 2002]. As input values the STAR-model output is used. The spatial structure of the SWIM-model is defined by the structure of the water management model. That means that the hydrological structuring of the water management model into sub basins has to be used as a minimum of spatial resolution in the SWIM-model. The hydrological structure of the water management model is an outcome of defining so called balance profiles. They are defined at river cross-sections, where water extraction or discharge takes place, or water management facilities are located. The hydrological structure, defined according to the water management model WBalMo Elbe, is shown in Fig. 5.

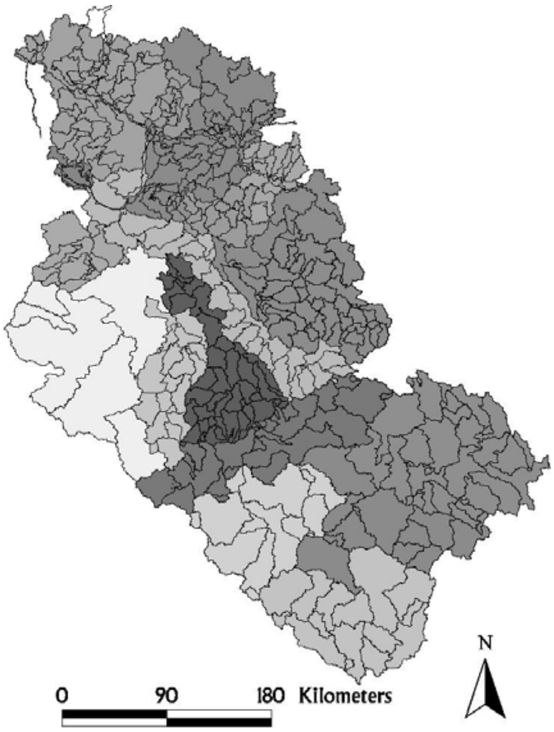

Figure 5. Hydrological structure of the water management model WBalMo Elbe

The use of a rainfall-runoff model also provides the opportunity to incorporate changes in land use.

These changes are determined by special models, transforming scenarios of agricultural world market and of other factors significant for food production into changes of land use of the Elbe river catchment.

Special regard is given to the water consumption of wetlands. To investigate their impact on water availability, large partly irrigated wetlands were chosen for modeling. The drainage (or consumption) of water is not modeled by SWIM but by a special wetland model called WABI [Dietrich et al., 1996]. WABI calculates the water demand or the water drainage considering the precipitation-evapotranspiration balance with regard to groundwater level, soil type and land use and on the operation of weirs given target groundwater levels. To evaluate the water balance between water yield and water demand of wetlands again the WBalMo model is used for modeling the water management process in time and space. For this purpose the algorithms of WABI-model are linked to the WBalMo model.

3.3 Implementation of socio-economic influence on water use and its assessment

Socio-economic developments are considered when calculating the water demand of the water users. The relationships between the water management model WBalMo and several other activities within the GLOWA-Elbe project are shown in figure 6.

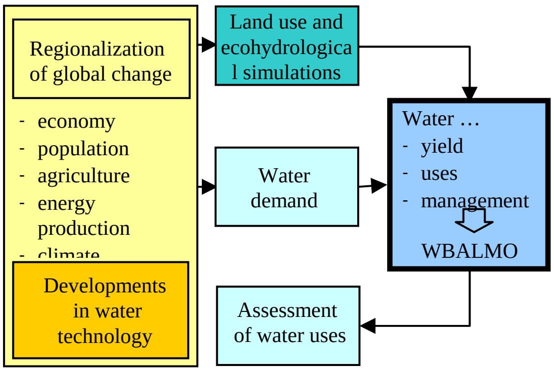

Figure 6. Interrelationships of water management model WBalMo to socio-economic aspects

For the following sectors of water use water demand modules are developed:

- wetlands,
- municipality (households etc.),
- industry,
- energy production and mining,
- agriculture and irrigation.
- navigation.

Input variables of these modules are the regionalized socio-economic developments and water availability calculated by WBalMo Elbe. As output the water demand for the respective time step of the WBalMo-model is calculated.

In each time step the calculated water supply is assessed by a specialized module. This module is incorporated in the model in the same way as other user defined algorithms. The assessment procedure has to be called at the end of the balancing process in each time step, because only at that point are the flow states in the river systems the real ones. Based on the real water supply and the assessment function, i.e. using cost-benefit analysis, the indicator defined for the respective water user is calculated. In the same manner as for the built-in indicators, the time series of quantities of these socio-economic indicators can be used for statistical analysis. Indicators in general are defined in the discussions with the cooperating stakeholders of the Elbe river basin.

3.4 Implementation of options for action

As a first step the present and planned management options of regional politics are merged together in a so called “reference” strategy. It is important to consider that the particular options of action can be based on inconsistent perspectives about future developments. In contrast, the frameworks of development associated with the reference strategy will be consistent in terms of different aspects of global change. WBalMo Elbe will calculate the effects on water availability of the resulting scenarios. These results will be discussed with important water user and with stakeholders from local and federal water authorities and others, trying to maintain the objectives of society and economy, formulated by stakeholders.

4 RESULTS

In the second phase of GLOWA Elbe the main focus is the water availability in the whole Elbe river basin. That means that the main effects in the Elbe River itself will be assessed. So far results for important sub basins are available.

One of the hot spots is the water scarcity in the Spree river basin. It is caused by a significant reduction of extensive lignite mining. On the one hand exist a large-area groundwater lowering, infiltration losses in river network and decreased groundwater transfer from open mine pits into the Spree river. On the other hand the fulfillment of established water demand has to be guaranteed, while at the same time a large number of remaining pit lakes need to be filled up with surface water, in order to avoid their acidification by chemical processes in the groundwater.

Against this background the effects of the following scenarios were investigated:

- *reference scenario*: The recent water resources management has been retained unchanged, while all mining activities phase out until 2040 and the climate of the past 50 years will continue.
- *climate scenario*: Same as reference scenario with inclusion of a climate change scenario with a warming of 1.4 K until 2050.
- *scenario prior_filling*: Same as climate scenario with higher priority of the water demand for the filling of remaining pit lakes (in short *prior filling*). The risk of the emergence of these lakes filled with a greater fraction of acidic groundwater should been decreased.

The planning period ranges from 2003 until 2052. It is divided into ten 5-year-periods. Within the periods the water management system is assumed as unchanged from a statistical point of view.

Next figures show the results of the WBalMo-Model for the Spree river basin. Values for the indicators were calculated for a fixed probability of exceedance. The probability was chosen accordingly to moderate water scarcity conditions.

The expected discharge at inflow gauge to Berlin (Grosse Tränke/Spree River) is shown in Fig. 7 for a dry summer in July over the planning period from 2003 until 2052.

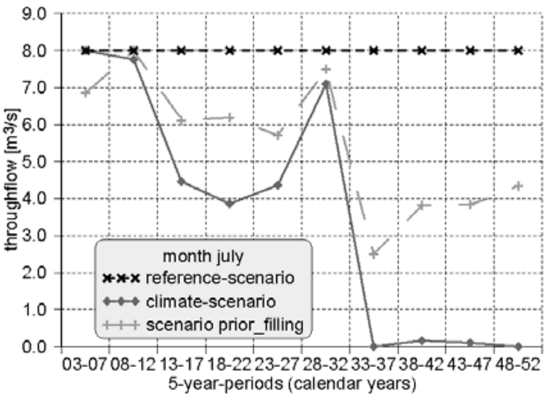

Figure 7. Discharge at inflow gauge to Berlin (Grosse Tränke/Spree River)

For the reference scenario the required inflow of 8 m^3/s can be maintained. For the other two scenarios this is not the case. One reason is the reduction of water yield because of climate warming. In these conditions the water dams and reservoirs can not compensate the decreasing groundwater transfer from the open pit mines to the Spree river. After the first phase of mine closure around 2020 the required level of 8 m^3/s is achieved by beginning of operating of the water reservoirs Lohsa II and Baerwalde. When all pits are closed after 2040, in dry summers the discharge can drop to zero. In scenario prior_filling the inflow to Berlin can be maintained on a level of about 4 m^3/s after closure of all mines. This was achieved by giving the highest priority to the minimum required discharges in this scenario.

While mine closure is the main reason for the decreasing inflow to Berlin, until 2020 the management of water reservoirs Bautzen and Quitzdorf contribute to this problem. They are used until this time partly for the supply of water for filling of the future so called Lusation lake chain, instead to support the minimum inflow to Berlin. The amount of water, used for pit lakes in dry years, is shown in Fig. 8.

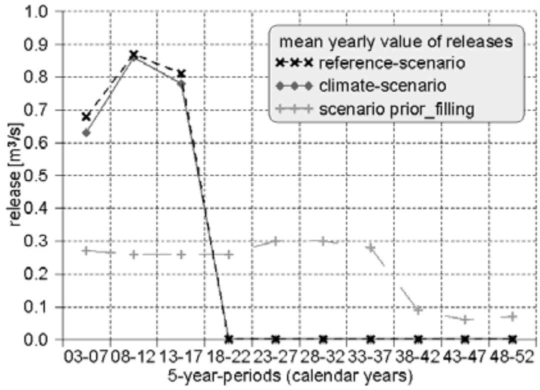

Figure 8. Water releases from the reservoirs Bautzen and Quitzdorf for filling of mining pits

In scenario prior_filling the management of water reservoirs Bautzen and Quitzdorf was changed. They support not only the filling of Lusation lake chain, but also of all other pit lakes. Nevertheless the amount of water is generally lower, because water yield from the catchment area is used to fill up pit lakes instead of supporting other water uses.

To exemplify the connection of the WBalMo-model with socio-economic functions, the profit of the tourism at pit lakes is shown (Fig. 9).

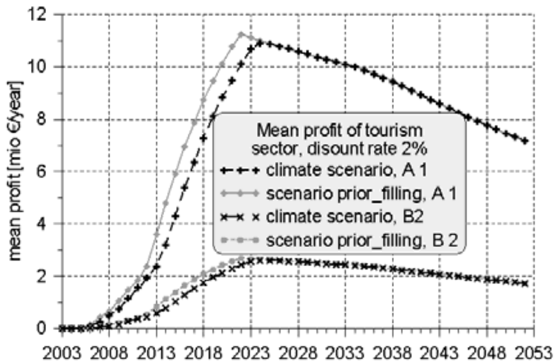

Figure 9. Mean profit of the sector tourism at mining lakes, discount rate 2 %

One of the conclusions is, that socio-economic implications, derived for the frame of developments A1 and B2 [IPCC 2002], have much more influence on mean profit than changes in water resources.

The progress in getting results for the scenarios, derived for GLOWA Elbe II, can be viewed on the projects web site www.glowa-elbe.de.

5 ACKNOWLEDGEMENTS

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