A Decision Support System For Integrated River Basin Management Of The German Elbe

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Keywords: *DSS, River Basin Management; Water Quality; Integrated Modelling.*

EXTENDED ABSTRACT

Water resources management on the river-basin scale as requested by the European Water Framework Directive is a highly complex task: not only the complex network of interdependencies of elements of the natural, ecological and socio-economical systems and their linkage but also the interests of various stakeholder groups must be taken into account. For this purpose a decision support system for integrated river basin management of the German part of the Elbe river basin (Elbe-DSS) has been developed, which involves taking into account water quantity, chemical quality, and ecological status of surface waters.

Starting from identification of user needs by repeated consultation of stakeholders a list of management objectives, measures, and external scenarios turned out, which was taken as the basis for the DSS development. A comprehensive system analysis was carried out to meet the various spatial and temporal scales when dealing with hydrologic, ecologic, economic, and social aspects related to water quantity, quality and ecological status (Matthies *et al.* 2005). The system is build up by integrating only already existing models and data. System and software design are strongly oriented on management tasks: starting from selected management objectives the effects of external scenarios of climate, agro economic and demographic change, and selected measures to achieve the desired state of good water quantity and quality can be investigated. Analysis tools are integrated to assist the user in evaluating the various management options.

The system is implemented by using DSS-generator Geonamica® developed by Research Institute of Knowledge Systems (RIKS) (Hahn and Engelen 2000), which is also used in other DSS projects (Oxley *et al.* 2004).

The implemented measures on catchment scale can be classified into the groups ‘reduction of pollution from urban areas’, ‘modification of agricultural land allocation’, ‘changes in agricultural practices and ‘political and legislative requirements concerning nutrient surplus’.

This paper focuses on water quality related questions on the catchment level. The effects of selected management options on the management objective ‘reduction of nutrient loads’ are presented to demonstrate how the DSS can be used for strategic management tasks as well as for participation and negotiation processes.

The results indicate the different effects of each simulated measure on nitrogen and phosphorus inputs and concentrations in the river system. It could also be shown that efficiency of measures tend to show varying spatial patterns. The same holds for the simulated climate change scenarios where positive or negative effects depend on local and regional conditions.

In the final version tools for economical evaluation of measures will also be implemented to assess cost effectiveness of management options.

1. INTRODUCTION

Integrated river basin management involves all management objectives related to the use, pollution, protection and rehabilitation of water bodies as well as many other impacts on water quantity and quality in a river basin. An integrated approach implies that relations between the abiotic and the biotic part of the various water systems, between ecological and economic factors and between various stakeholder interests are considered in decision making processes. The European Water Framework Directive (EU, 2000) consequently calls for a multidisciplinary approach of river basin management. A decision support system (DSS) for integrated river basin management of the German part of the Elbe river basin (Elbe-DSS) has been developed, which consideres water quantity, chemical quality and ecological state of surface waters.

System analysis of water quality management and design of the Elbe-DSS are presented in Matthies *et al.* (2005). Management objectives, external scenarios, and measures were derived from repeated consultations of stakeholders (international commissions, state agencies, country administrations, non-governmental organizations) and potential end-users. System diagrams were developed for the catchment and river network and appropriate models and databases were selected. Concerning water quality management issues, MONERIS (Behrendt *et al*. 1999) was chosen for the catchment module and GREAT-ER (ECETOC, 1999; Matthies *et al.* 2001) for the river network. The coupling of both models and their integration into the Elbe-DSS is demonstrated in Berlekamp et al. (2005). Rainfall-runoff is simulated by the HBV-D model (Krysanova *et al*. 1999; Lautenbach 2005) and coupled o the above models to simulate the effect of different measures and scenarios on water quantity and water quality.

In this paper, the set of implemented management options (measures and external scenarios) for water quality related questions on the catchment level are explained. Selected simulation results are presented to demonstrate the general suitability of the DSS for integrated management and negotiation processes.

2. CONCEPT OF ELBE-DSS

The Elbe-DSS was designed as a strategic planning instrument, which supports user to analyse different options for environmental management. To meet the various requirements of end-users the concept and realization was done in close cooperation with end-users. Caused by the wide range of issues and the varying spatial scales a hierarchical approach with four linked modules was choosen (Matthies *et al.* 2005): the whole German Elbe river basin (96.900 km^2) is represented by two subsystems, the catchment and river network modules, to allow for better representation of management objectives, scenario development and decision making. The catchment module involves all aspects related to the flow and impact of surface waters, whereas the river network represents the routing and drainage system of the catchment. Two other modules, one of the main stream and one of a small floodplain section in the middle Elbe are also part of the Elbe DSS but not described here (BfG, 2003). They focus on issues of flooding, floodplain ecology and shipping.

An evaluation of available models for all relevant processes was carried out to identify appropriate candidates for integration into the DSS. Main model selection criteria considered are appropriateness for the intended purposes, applicability for the whole German Elbe river basin, possibility of linking to other models and application for measures and scenarios as well as acceptable runtime.

The approach of the Elbe-DSS is mainly driven by an user-oriented view to management related issues for large scale river basins. The usage is problem-oriented by focusing on management objectives and the possible effects of measures and scenarios. While measures are understood as direct management options external scenarios, that are also implemented, are given by general development constraints.

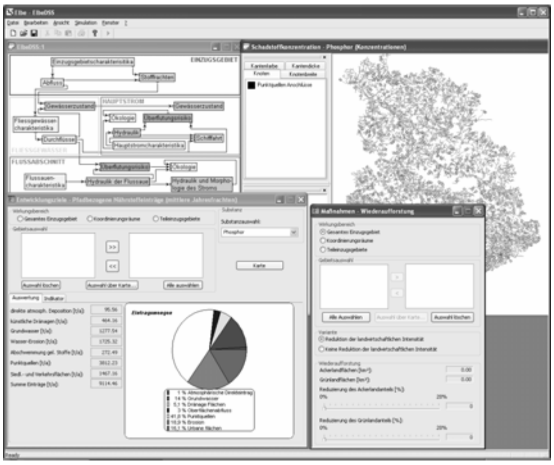

Figure 1. Elbe-DSS user interface.

The software implementation is done by using DSS-generator Geonamica® developed by Research Institute of Knowledge Systems (RIKS) (Hahn and Engelen 2000), which is also used in other DSS projects (Oxley *et al.* 2004). Model runs are performed inside the Geonamica® framework that also ensures the correct scheduling of the different processes. The Elbe-DSS contains a GIS-based user interface, which allows flexible easy-to-use access to pre- and user-defined scenarios (fig. 1). Furthermore, a database management system (DBMS) and a knowledge-based toolbox are integrated under the graphical user interface. Evaluation tools have been provided for various kinds of decision-making, e.g. risk-based for hazardous pollutant concentrations, monetary-based for engineering measures or ecological services for floodplain restoration.

3. IMPLEMENTED MEASURES AND SCENARIOS

From the modelling point of view only those measures that match real representation in model parameters could be implemented. Hence some of the possible measures desired by end-users could not be realised so far.

The following measures are implemented at catchment scale:

1. Reduction of pollution from urban areas
    a. Reduction of impervious areas in urban-industrial areas to favour the infiltration of rainwater.
    b. Increasing fraction of separate sewer to prevent overflow water from treatment plants in case of storm weather.
    c. Increasing fraction of inhabitants connected to sewage treatment plant to reduce the input of raw sewage.
    d. Upgrading of storage volume of sewer water system to prevent overflow water form the treatment plant in the case of storm weather.
    e. Enhancement of treatment plant efficiency to reduce emissions.
2. Modification of agriculture land allocation
    a. Reforestation of arable land or grassland.
    b. Renaturation of drained agriculture land for retrieval of swampland.
    c. Building of riparian buffer zones to prevent input of pollutants from agricultural land.
3. Changes in agricultural practice
    a. Application of soil protection methods like minimal tillage to prevent soil erosion.
    b. Application of different distribution techniques to advance the efficiency of organic fertilizer.
    c. Application of feeding methods to reduce the nutrient concentration in organic fertilizer.
    d. Application of eco-farming methods.
4. Political and legislative requirements concerning nutrient surplus on agriculture land
    a. Taxes on mineral fertilizer.
    b. Standards of maximum allowed amount of fertilizer applied to arable farm land.
    c. Limits of maximum live stocks sizes.

Some of the measures only have an effect on substance inputs and concentrations while others affect both hydrology and substance loads.

Some measures are too complex or under-determined to implement in only one realization. E.g. changes in agricultural practice might be diverse. For instance, farmers are supported to convert to sustainable or biological farming; European agro economic market might push farmers to decrease or increase live stocks; taxes on mineral fertilizers might reduce nitrogen surplus; methods like preserving tillage, contour farming or strip cropping might be propagated to reduce soil erosion. Thus, each measure can consist of various options to be selected by the user. The range of possible user settings is re-defined to insure realistic values.

In contrast to such measures changes caused by exogenous factors like climate change, agro-economic change or demographic prognosis are represented by a set of *externa*l scenarios.

Regional scenarios for climate change in the Elbe area have been developed for the GLOWA project (PIK 2004) and are being transferred to the Elbe DSS. These climate scenarios describe potential changes in the pattern of distribution of precipitation in the Elbe catchments until 2055.

Globalisation as well as European legislation affect the agro economic sector and thus changes of land use. The Regionalized Agricultural and Environmental Information System RAUMIS (Weingarten 1995) is able to simulate the joint impact of various political and legislative requirements as well as economic developments on agricultural production factors such as land allocation or fertilizer application. Three potential scenarios have been simulated with RAUMIS until 2020 and are incorporated into the DSS (Gömann *et al*. 2004).

Projections of the demographic development are calculated for the Federal Republic of Germany until 2050 and adapted for the six states in Eastern Germany. They are published by the German Federal Statistical Office (2003) and based on different assumed birth and mortality rates as well as immigration quotas. The Federal Office of Architecture and Regional Planning calculated future expansion of urban areas until 2020 for the Elbe region (BBR, 2004). From this data four regionalised alternatives were derived: trend development, growth, efficiency and sustainability development.

4. SIMULATED EFFECTS OF SELECTED MEASURES AND SCENARIOS

The Elbe-DSS can be used to evaluate the effects of implemented measures and external scenarios on a given set of management objectives. Due to the huge number of measures and their (potential) combinations only a selected set can be demonstrated here.

From the user point of view the general practice of analysis is:

1. Select management objective (e.g. reduction of substance loads).
2. Evaluate the reference state.
3. Select measure(s) and/or external scenario (e.g. erosion control).
4. Start simulation.
5. Evaluate the effects of measures/scenarios.

The last step is supported by calculated outputs like:

- tables, charts and maps of model results or indicators.
- concentration profiles (see Figures 3-7).
- comparison of maps (possible by external tool).

As an example of application of the system, the effects of three measures and one external scenario to reach the management objective ‘reduction of substance loads (phosphorus, nitrogen)’ are demonstrated.

4.1. Measures

The selected measures are:

- reforestation of 20 % of arable farm land.
- conversion of traditional farming to eco-farming on an area of 20 % of existing arable land.
- application of erosion control methods (soil protection by preserving tillage, contour farming and strip cropping) for 20 % of existing arable farm land.

Effects of measures can be analysed for substance loads and concentrations in the river network. Concentration profiles for any water course can be used to analyse substance patterns in more detail.

For reforestation the strongest effect on phosphate non-point source discharges can be observed in low mountain ranges of Erzgebirge and Voigtland (south-east border of the Elbe river basin) (Figure. 2a). Other relevant impacts are due to a reduction of drainage, surface run-off and groundwater discharge. Diffuse phosphate emissions are decreased up to 60% for hilly catchments.

An evaluation of changes of P-concentrations in the river network, as compared to the reference situation, show similar results (Figure 2b). High reductions up to 60 % occur in the streams of Erzgebirge and Voigtland. The spatial pattern corresponds to P-emissions because variations, as computed by MONERIS on a sub-catchment scale, are only caused by changes from diffuse sources. Since phosphate load is routed through the river system, a reduction can also be observed along the main tributaries with inputs from the affected areas. The tributaries Mulde and Weiße Elster are mainly affected (Figure 2b).

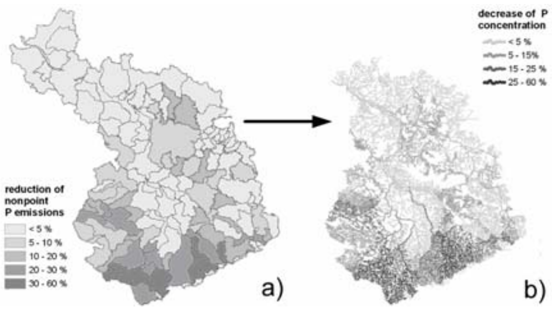

Figure 2. Simulated effects of reforestation on reduction of phosphorus emissions (a) and decrease of P-concentrations in the river network (b).

A comparison of effects of the three selected measures on concentrations is given for the main Elbe river (Figure 3). Eco-farming has nearly no effect on phosphorus concentrations in Elbe river up to the mouth of Mulde and Saale river. Downstream the reduction reaches 1 % relative to the reference state. Erosion control shows a reduction effect up to 3 % of reference state downstream of the mouth of Saale and Mulde river where erosion is one of the main sources for phosphorus loads. The highest effects on phosphorus concentrations can be observed for reforestation. In the upstream part of the Elbe river a reduction of up to 4 % occurs and rises up to nearly 8 % in relation to the reference state. The concentration profile corresponds to the emission pattern (see Figure 2) which shows most effects in mountain ranges with high relief energy resulting in high soil erosion mainly from arable farm land. Only a minor part of the effects are caused by changed hydrology (data not shown). The simulated discharges indicate that reforestation locally causes a 20 % reduction of surface runoff but the effect is overtopped by reduced particle erosion, drainage, groundwater flow and input from impervious urban areas respectively.

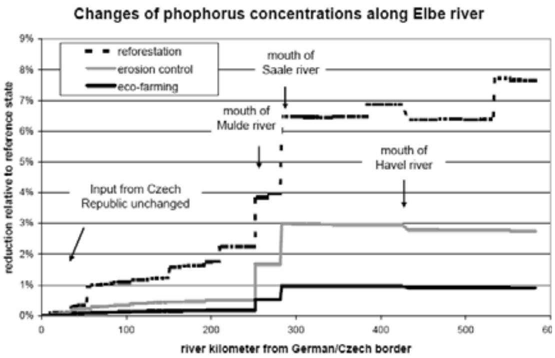

Figure 3. Effects of selected measures on phosphorus concentrations in the Elbe river. Changes are given in relative reduction to reference state.

The effects on nitrogen concentrations show similar concentration profiles (Figure 4). Reforestation leads to major effects and the reduction compared to reference state reaches the same amount of up to 7-8 %. Erosion control and eco-farming lead to a contrary result compared to phosphorus. Erosion control has a negligible effect while eco-farming reduces the nitrogen concentration in downstream Elbe river up to 3 %.

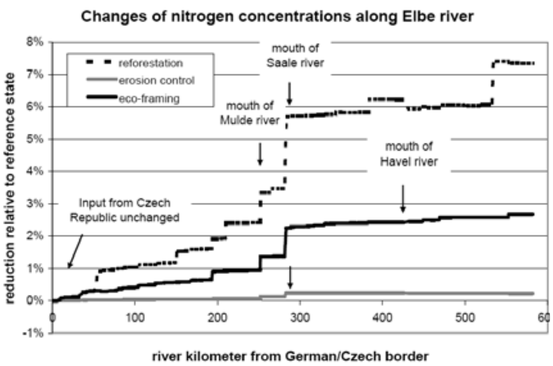

Figure 4. Effects of selected measures on nitrogen concentrations in the Elbe river. Changes are given in relative reduction to reference state.

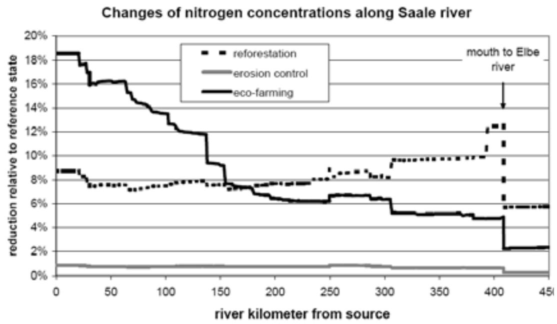

Figure 5. Effects of selected measures on nitrogen concentrations in the Saale river. Changes are given in relative reduction to reference state.

Results for Saale river show that the highest effect of eco-farming on nitrogen concentration can be observed upstream (19 %) while the effect reduces down to 5 % near the mouth to Elbe river. In contrast to the effects of eco-farming, the effects of reforestation stay more or less constant over the whole river profile. Erosion control has only a minor reduction effect of about 1% relative to the reference state.

4.2. External scenarios

Climate change as an external scenario is calculated for three realizations of the used regionalized climate model (Gerstengarbe and Werner 2004): a most probable scenario (realisation 032), a scenario without precipitation trend (realisation 054) and scenario with precipitation trend (realisation 058).

Climate change first of all affects the hydrological flow components. All 134 single sub-catchments show varying increase to decrease effects caused by rainfall pattern, local morphological and geo-hydrological conditions. The overall discharge for realisation 032 is reduced on average by 22 % for all sub-catchments compared to the reference state (data not shown). For realisation 054 and 058 the averaged reduction is lower (-8 % and -1 %, respectively).

In general all realisations cause reductions of nitrogen and phosphorus inputs (data not shown). Because substance concentrations are affected both by discharge flow and substance load they may show specific spatial patterns.

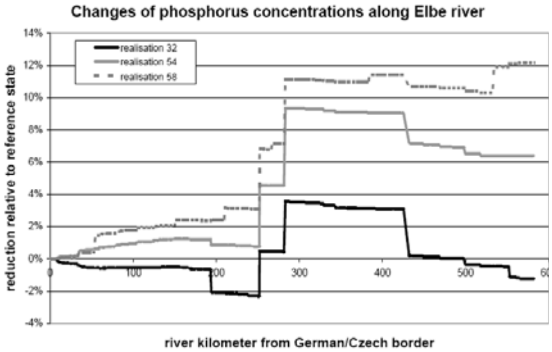

Figure 6. Effects of climate scenarios on phosphorus concentrations along Elbe river. Changes are given in relative reduction to reference state.

Fig. 6 indicates that the highest effects of climate change on phosphorus concentrations along Elbe river can be observed downstream of the mouth of tributaries Mulde and Saale (river kilometer 300-580) due to reduced surface runoff and erosion. While realisation 058 (scenario with precipitation trend) gives an averaged reduction of around 11 % relative to reference state for the downstream Elbe river this effect is reduced for realisation 054 and much more for realisation 032 where a slightly increase of phosphorus concentrations can be observed downstream from river kilometer 500 (Figure 6).

Climate change scenarios show different results on nitrogen concentrations in Elbe river compared to phosphorus (Fig. 7). The trend scenario (realisation 032) indicates a relative increase up to 5 % downstream. The highest gradient can be observed at inflow from Havel river and is caused by a simulated reduction of discharge of more than 20 % but this effect is uncertain due to catchment characteristics and data situation.

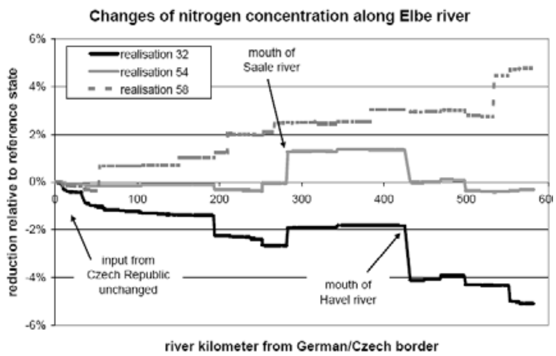

Figure 7. Effects of climate scenarios on nitrogen concentrations along Elbe river. Changes are given as relative reduction to reference state.

Taking into account predicted precipitation trends (realisation 058) nitrogen concentrations decrease up to 5 % at river kilometer 570. Without precipitation trend effects can only be observed between Saale and Havel river.

5. CONCLUSIONS

The generally good agreement between model results and monitoring data (Berlekamp et al., 2005) indicate that the integrated system response reasonably matches the present situation. This allows us to investigate the effects of management measures and external scenarios. However, since the uncertainty of the estimates increases if extrapolation beyond observations occurs, management scenarios are restricted to moderate deviations from observed parameter values.

The comparison of three measures shows the specific differences in effects between these measures and scenarios. Differences between the selected concentration profiles indicate the spatial heterogeneity of resulting effects.

Not only the ecological effects but also economic evaluations of implemented measures are of major interest. This part is not demonstrated here because of late implementation but will be included in the final version.

Software like Elbe-DSS can not produce management options by themselves. In fact the intention was to use it as an instrument to explore effects of possible measures and scenarios and to use it as a tool for discussion and negotiation processes. Because of the easy-to-use interface and the user-oriented approach Elbe-DSS could become an accepted instrument for supporting sustainable water management.

6. ACKNOWLEDGMENTS

The authors wish to thank the DSS development team for their kind collaboration, Bundesanstalt für Gewässerkunde (German Federal Institute for Hydrology), Federal Minister for Education and Research and Federal Environmental Protection Agency for their financial support and data supply.

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