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# Application of the Elbe-DSS to Water Quality Issues

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**Abstract:** The Decision Support System for the Elbe river basin (Elbe-DSS) was developed as a tool to assist water managers. A user can select various measures and compare them to evaluate their relative effectiveness in achieving a good ecological and chemical status of the Elbe and its tributaries. Two subsystems, the catchment and the river network, represent the whole German Elbe river basin (96.900 km$^2$). This approach allows for better representation of management objectives, scenario development and decision-making. The implemented measures 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 surpluses'. Simulation models for the calculation of nutrient and pollutant loads from point- and non-point sources are integrated under a user-friendly graphical interface. These models may be used to assess the impact of measures such as reforestation, changes of agro-practices or efficiency of wastewater treatment plants on a set of management objectives. External scenarios of climate change, demographic development, and agro-economic projections can be considered simultaneously with specific measures. The user can evaluate pollution of water bodies from single river stretches up to larger watersheds and river basins. Examples of concentration profiles in river waters are displayed as colour coded maps to facilitate the assessment. Tools for economic evaluation of measures are also implemented, providing an avenue to assess cost-effectiveness of management options. We demonstrate the applicability and effectiveness of the Elbe-DSS with selected measures on such diverse topics such as improvement of sewage treatment, erosion control, eco-farming, and reforestation as well as climate change scenario.



***Keywords:*** Integrated river basin management; Measures; Modelling; Water Quality


## 1. INTRODUCTION

The Decision Support System for the Elbe river basin (Elbe-DSS) was developed as a tool to assist water managers. Water quality issues are still a major problem for most Elbe tributaries and the main channel. The Hamburg harbour is contaminated with many pollutants originating from upstream sources. The coastal areas of the North Sea are among the most vulnerable marine ecosystems worldwide. The EU-Water Framework Directive (EU-WFD) calls for an integrated system approach of water quality management on a basin wide scale (EU, 2000).
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 and quality (Matthies *et al.* 2006). Stakeholder interests were identified by oral interviews with representatives from the international (International Commission for the Protection of the Elbe), national (German Hydrological Institute), regional (state agencies) and local authorities (district administrations) (BfG, 2003). Potential end users have been routinely consulted to provide their goals and requirements. As a result of this repeated consultations, a list of management objectives, measures, and external scenarios emerged and was taken as the basis for the DSS development. This paper describes the application of the Elbe-DSS to water quality issues. Other objectives concerning navigability, flood protection, and floodplain ecology are not described here (see BfG, 2003).

## 2. ELBE-DSS

The Elbe-DSS was designed as a strategic planning instrument, which supports users by analysing different options for environmental management. It was developed and realized in close cooperation with end-users and stakeholders. Due to the wide range of issues and the varying spatial scales under consideration, a hierarchical approach with four linked modules was chosen (Matthies *et al.* 2006). The whole German Elbe river basin (96.900 $km^2$) is represented by two subsystems, the catchment and river network modules. This allows 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 part of the Elbe-DSS but are 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. Four models have been integrated in the catchment and river network modules (Figure 1). For the rainfall-runoff simulation, HBV-D was selected (Krysanova et al., 1999). It is an enhanced distributed version of the conceptual hydrological model HBV, which has been calibrated for 19 catchments, which were spilt into 118 sub-catchments for the German part of the Elbe (Lautenbach, 2005). Concerning water quality management issues, MONERIS (Behrendt et al., 1999) was chosen for the catchment module and GREAT-ER (ECETOC, 1999a; Matthies et al., 2001) for the river network (Berlekamp et al., 2006). LFBilanz calculates spatial explicit nutrient inputs from agronomic statistics (Bach et al., 1998).

The approach of the Elbe-DSS is mainly driven by a user-oriented view to manage water quality and quantity related issues for large scale river basins. The decision making process is problem-oriented, focusing on management objectives and the possible effects of measures and scenarios. While measures are understood as direct management options, external scenarios such as climate and demographic changes are implemented as pre-calculated external driving forces.

The software was developed by Research Institute of Knowledge Systems (RIKS) (Hahn and Engelen, 2000) and implemented by using DSS-generator Geonamica®, which is also used in other DSS projects (Oxley et al., 2004). Model runs are performed inside the Geonamica® framework. Figure 2 shows the Elbe-DSS user interface with the system diagrams of the catchment and river network modules. The interactive system diagram is the main user interface component – model runs, measure and scenario settings are all accessed by the system diagram.

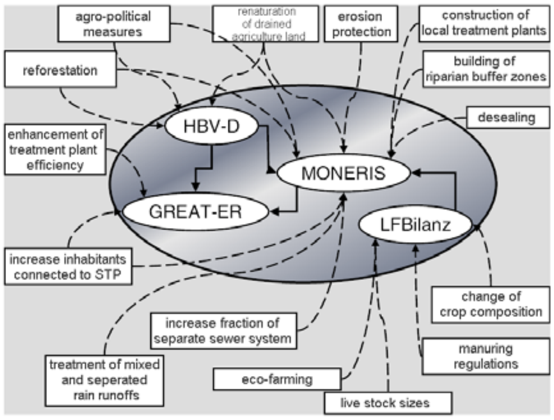


**Figure 1.** Integrated models and implemented measures (see Berlekamp et al., 2006).

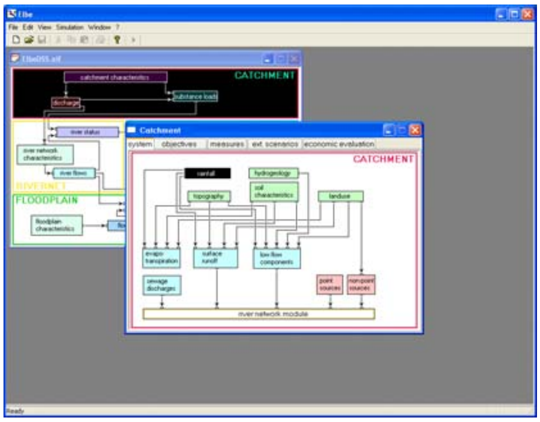

**Figure 2**. Elbe-DSS user interface.

## 2. IMPLEMENTED MEASURES AND EXTERNAL SCENARIOS

Four management objectives, which are related to water quality issues in the whole Elbe River basin, have been identified: ‘reduction of pollution from urban areas’, ‘modification of agricultural land allocation’, ‘changes in agricultural practices and ‘political and legislative requirements concerning nutrient surpluses’. Figure 1 shows the integrated models together with the selected measures. The following measures are implemented at catchment scale:

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

Some of the measures have an effect on substance inputs and concentrations only, while others affect both hydrology and substance loads. Some measures are rather diverse and thus are split up into sub-measures. For instance, farmers are financially supported to convert to sustainable or biological farming; European agro-economic markets 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 restricted to ensure 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 *external* scenarios. Regional scenarios for climate change in the Elbe area have been developed for the GLOWA project (PIK 2004) and 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 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.

## 3. SIMULATED EFFECTS OF SELECTED MEASURES AND EXTERNAL 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. A typical session has the following sequence:

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;
- comparison of maps (external tool).

As an example application, the effects of various measures to reach the management objective ‘reduction of substance loads (phosphorus, nitrogen)’ are demonstrated below.

### 4.1. Measures

The selected measures and external scenario to demonstrate the application of the Elbe-DSS are:

- Improvement of sewage treatment.
- Erosion control, reforestation and eco-farming.
- Climate change scenario.

Obviously, there are many more options for the user than these few. Elbe-DSS offers various sub-measures for the improvement of sewage treatment: separate sewer system, population connected to STP, enhancement of STP efficiency, and storage volume of sewer system. Here, we select the enhancement of sewage treatment efficiency as an example (Figure 3). The user can investigate the effect of better treatment technology on phosphate and nitrogen elimination, e.g. activated sludge instead of trickling filter or mechanical treatment. Moreover, chemical phosphate elimination and P-flocculation filtration as well as nitrogen elimination can be considered. These technical improvements might be more effective for larger than for smaller STPs, which is indicated by the number of inhabitants connected to the STP. The user can apply each measure easily to the whole catchment as well as to some of the EU-WFD coordination areas or even a set of smaller sub-catchments.

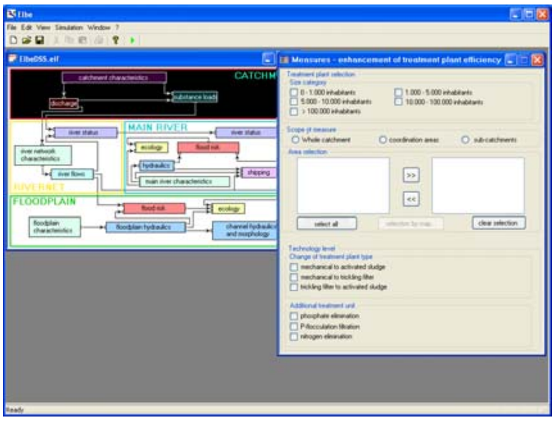


**Figure 3**. Screenshot for the measure “Enhancement of treatment plant efficiency”.

Effects of measures can be analysed for substance loads and concentrations in the river network. Concentration profiles for a selected river course offer more details about the spatial substance patterns. Figure 4 shows the colour-coded map of phosphate concentrations in the whole Elbe catchment after the simulation of the measure. The user can select a specific river course out of the whole river network for closer inspection. He or she also has the option to display the concentration pattern before and after application of the measure for the specific river course (Figure 5). The plot demonstrates the remarkable reduction of phosphate concentrations in the upper Saale (until river km 120). After the confluence with the main river, this positive effect almost completely vanishes. The Elbe shows only marginal reduction of phosphate compared to the reference state, which is mainly due to the upstream discharges from the Czech Republic. This holds also for other pollutants such as personal care products (musk fragrances) or human pharmaceutical (diclofenac, paracetamol).

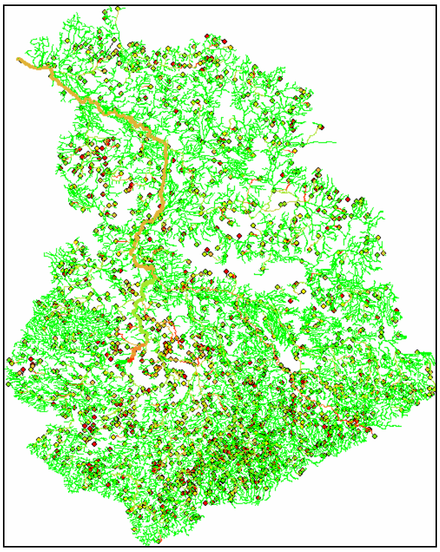

**Figure 4**. Screenshot of the Elbe catchment with mean phosphate concentrations in selected river course (thick line) from upper Saale to downstream Elbe.

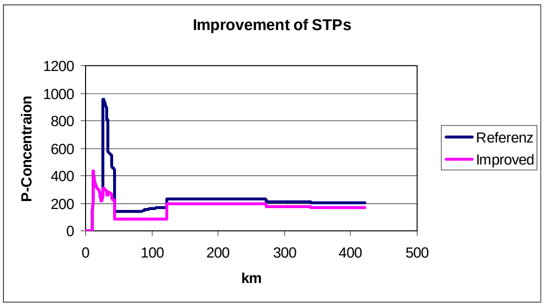


**Figure 5**. Phosphate concentration in river course of Figure 4 for reference state and STP improvement measure.

Berlekamp et al. (2005) had already shown that reforestation have the strongest effect on phosphate non-point source discharges in low mountain ranges of Erzgebirge and Voigtland (south-east border of the Elbe river basin). They compared various measures, which reduce the diffuse inputs. Figure 6 shows the relative effect of eco-farming, erosion control and reforestation on the nitrogen concentrations in the Elbe. It is interesting to note that eco-farming has much less effect than the other two measures. Other relevant impacts are due to a reduction of drainage, surface runoff and groundwater discharge. Diffuse phosphate emissions are decreased up to 60% for hilly catchments.

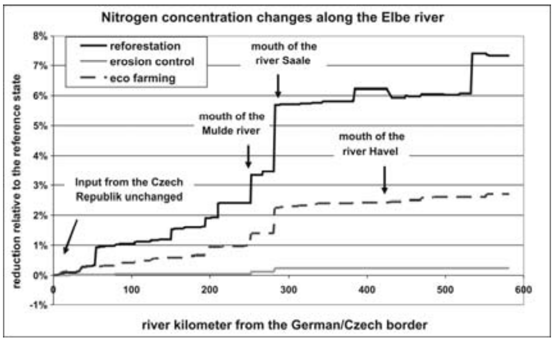


**Figure 6.** Effect of various measures on nitrogen concentration in the River Elbe.

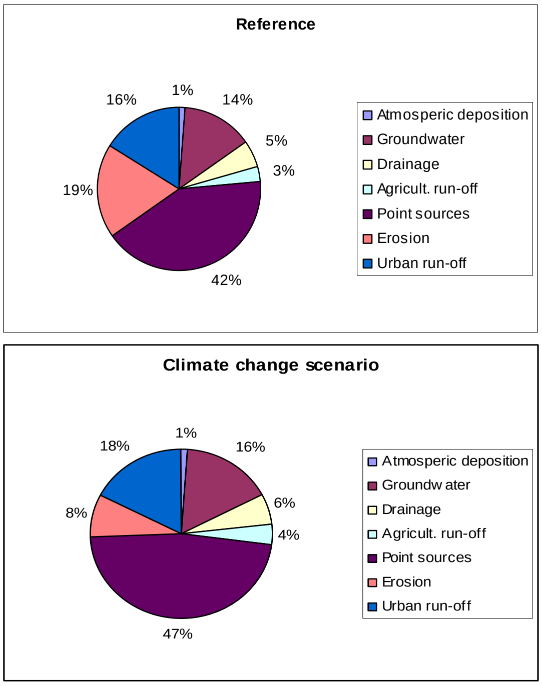


**Figure 7.** Effect of climate change scenario on phosphate loads in the whole Elbe river basin.

## 4.1. External Scenarios

In addition to measures, external scenarios for climate, agro-economic and demographic change may be simulated. Precipitation pattern, runoff, evapotranspiration and other hydrologic processes are recalculated by HBV-D according to the predicted climate development. Figure 7 shows the effects of the climate change scenario with precipitation trend (Gerstengarbe and Werner, 2004) on the phosphate loads from various pathways in the whole Elbe river basin. Climate change affects all pathways differently. The largest reduction in P-loads is with water erosion. However, effects are quite heterogeneously distributed over the various subcatchments. This is shown in Figure 8. Some of them display an increase of P-loads, while others exhibit almost no effect.

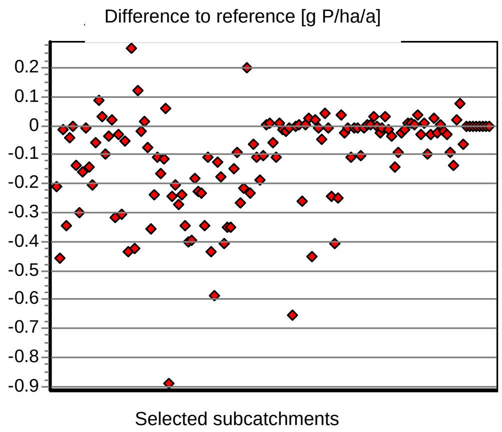


**Figure 8.** Differences of phosphate loads in selected catchments between climate change and reference scenario.

The Elbe-DSS has many more options, variants and scenarios, which cannot be demonstrated here. End-users, stakeholders and interested persons can now investigate and analyse single measures, a combination of measures, or even a combination of measures and scenarios. The development of the whole Elbe-DSS needed approximately 16 person-years. The software is available free of charge from http://elise.bafg.de/servlet/is/3283/ (only in German; English version in preparation).

## 6. ACKNOWLEDGEMENTS

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