# Decision Support System for the Elbe River Water Quality Management

**M. Matthies[a], J. Berlekamp[a], S. Lautenbach[a], N. Graf[a] and S. Reimer[b]**

[a]Institute of Environmental Systems Research, University of Osnabrueck and [b]Intevation GmbH
Osnabrueck, Germany

**Abstract:** A decision support system (DSS) for integrated river basin management of the German part of the Elbe river basin is currently under development, which involves taking account water quantity, chemical quality and ecological state of surface waters. The Elbe is one of the largest river basins in middle Europe having multiple land and water use demands. A hierarchical approach was developed to meet the various spatial and temporal scales when dealing with hydrologic, ecologic, economic and social aspects related to water systems. Four subsystems were defined: catchment, river network, main channel and floodplain. For each module, a system diagram was worked out which describes the properties, processes and data influencing the water flow and substance load. The modules are connected by water and substance flow, which guarantee the interactions between the different scales and consequences of measures on all subsystems. In close collaboration with the users, management objectives, scenarios and measures were defined. The DSS integrates models, spatial and non-spatial data and analysis tools under a user-friendly GIS-based interface, which confronts the decision maker with possible measures as well as multiple management objectives. Three conceptual models were selected and coupled to meet the user requirements. A model for the calculation of the long-term nutrient discharges in 130 sub-catchments from non-point and point sources, a simulation model of the waste water pathways (point-sources) and the aquatic fate assessment was coupled with a GIS-based discrete digitized river network of the Elbe. For the precipitation-runoff simulation, a distributed conceptual hydrological model was selected and calibrated for the same sub-catchments. Long-term discharge time series from gauging stations are being used to calibrate the hydrological discharges. A transport and elimination model describes the downstream fate of the chemical. Temporal concentration distributions of chemicals in each river stretch can be calculated from variable and uncertain input data. With the example of phosphate attached to eroded soil particles the applicability of the Elbe DSS to support decisions for the improvement of the water quality is demonstrated.

***Keywords:*** *River basin; Water quality; Modelling; Decision Support System*

## 1. INTRODUCTION

Integrated river basin management involves all management issues related to the supply, use, pollution, protection, rehabilitation and many others in a river basin. Integrated implies that relations between the abiotic and the biotic part of the various water systems, between the ecological and economic factors and between the various stakeholder interests are taken into consideration in decision process. Over the last decades river basin management has become increasingly complex. Increasing demands of society regarding ecological and chemical quality of river reaches, use and protection of water bodies and pollution with many different substances lead to new views and strategies towards policy making for river basin management (BfG 2002). So the new European Water Framework Directive 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) is currently under development, which involves taking account of the chemical quality and ecological state of surface waters. Moreover, protection against flood and floodplain inundation and the improvement of navigability are also part of the Elbe-DSS (BfG, 2001).

## 2. CHARACTERIZATION OF THE ELBE RIVER BASIN

### 2.1. Introduction

The Elbe is one of the largest river basins in Middle Europe having a length of approximately 1,100 km and catchment area of 148,000 km² from which about two third belong to Germany (Fig. 1). The mean annual discharge into the North Sea is 877 m³/s. The catchment area can be divided in three main natural regions: The Pleistocene lowlands, the loess region and the mountain area. The hydrogeology is dominated by bedrock aquifers (mountains mainly in the southwest) and porous


**Figure 1.** Elbe river basin

sediment aquifers (lowland). Almost 25 million people live in the river basin. Chemical and others industries, coal (lignite) and ore mining, manufacturing, and agriculture are located in the river basin. Point as well as non-point sources discharge nutrients, heavy metals, pesticides, persistent and many other industrial, agricultural and household chemicals into the stretches. In particular after the reunion of Western and Eastern Germany, various measures and the collapse of the industry had positive effects on the water quality. However, the Elbe and its tributaries are still far from being in a good chemical and ecological state. Although up to 80% of the original floodplains are lost due to embankment, the Elbe riverscape still has many reaches in near natural state. In 1997 UNESCO included the middle Elbe into the list of biosphere reserves. In August 2002 the highest flood of the Elbe since many years occurred with an estimated damage of approximately 9.2 billion EURO only in Germany. High waters resuspended a lot of sediments and transported it to the inundation areas. Sediment particles are associated with microorganisms and toxic chemicals, such as heavy metals and persistent organic pollutants, leading to the contamination of large areas.

## 3. DESIGN OF ELBE-DSS

A DSS is an interactive, flexible, and adaptable computer based information system specially developed for supporting the recognition and solution of a complex, poorly structured or unstructured, strategic management problem for improved decision making. It uses data and models, provides an easy, user-friendly interface, and can incorporate the decision's makers own insights. In addition, a DSS is built by an interactive process (often by end-users), supports one or more phases of decision making and may include a knowledge component (Delden 2000, modified from Turban and Aronson, 1998). Originally developed to support business managers in a company DSS has attended much interest in the environmental management. The consideration of environmental and ecological aspects for the sustainable management of land and water use in cities, regions or whole countries requires the development of appropriate instruments for policy making (BfG, 2000). Up to now, most DSS were developed for specific purposes such as flood protection, floodplain ecology or management of estuaries (RIKS, 2003).

The Elbe-DSS is the first project, which covers strategic water policy issues of different spatial and temporal scale for a large river basin. Therefore, a feasibility study was performed to elaborate the most prominent issues for the Elbe river management (BfG, 2001). User needs were identified by repeated discussion with representatives from the international, national, regional and local authorities. Since many projects were carried out in the Elbe river basin after the German reunion in 1990, a lot of results, simulation models and data sets were already available. Thus the development of the Elbe DSS could build on a large and current data and knowledge base, which are to be integrated in a flexible, user-friendly system. A preliminary system design was derived in the feasibility study and stepwise refined. Scenarios and measures for various identified management objectives were defined. Appropriate models were selected which deliver indicators to compare the impacts of specific measures and to support decisions to meet user requirements. Data sets of the catchment and river network were collected to support the model calculations. The Elbe-DSS will be implemented using the DSS-generator software Geonamica developed by RIKS (Hahn and Engelen, 2000). It will consist of a GIS-based user interface, which allows flexible easy-to-use access to pre- and user-defined scenarios. A data base management system (DBMS), model base management system (MBMS) and a knowledge-based tool box are integrated under the graphical user interface.

### 3.1. Spatial scale and hierarchical approach

Management issues often depend on a specific temporal and spatial scale. For instance, substance discharge into the North Sea is determined by the discharges in the whole catchment, whereas protection against flood damage in a city requires local constructions such as dikes or polders. Also the decision makers have different responsibilities in water management, making an overall systems view difficult. On the other hand, decisions on the catchment scale influence local situations and vice versa. Therefore, the whole river basin was divided into four subsystems, called modules, to allow for better representation of management objectives and scenario development. The modules are connected by water and substance flow, which guarantee the interactions between the different scales and consequences of measures on all subsystems. The four modules are: catchment, river network, main channel and floodplain. A hierarchical approach was developed for the stepwise refinement of the DSS design (Fig. 2).

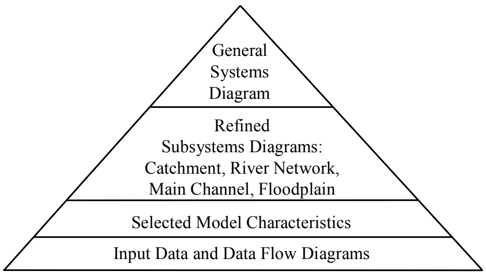


**Figure 2.** Hierarchical approach

The general systems diagram depicts the relations between the four modules (top level). In a second level all processes of the water flow and quality in each subsystem are laid down. Management objectives are related to the modules and scenarios and measures are defined (second level). In the third level, selected models and their coupling are characterized according to their spatial and temporal scale. Finally, in the bottom level all input data are discovered and their flow through the subsystem is described with data flow diagrams. This hierarchical approach ascertains that the users of the DSS are not lost in a too complex software environment.

### 3.2. System Diagrams

*General Systems Diagram (Fig. 3):* In the general systems diagram only the main systems elements are indicated with their interactions. Both water quantity issues, e.g. provision with enough water for various users, as well as quality issues, e.g. clean drinking water are considered. Each of the four subsystems is described by its geometrical, environmental, hydrological and other characteristics. They determine the discharges in the catchment and the chemical substance flow from the catchment to the river network and further downstream. The whole river network is

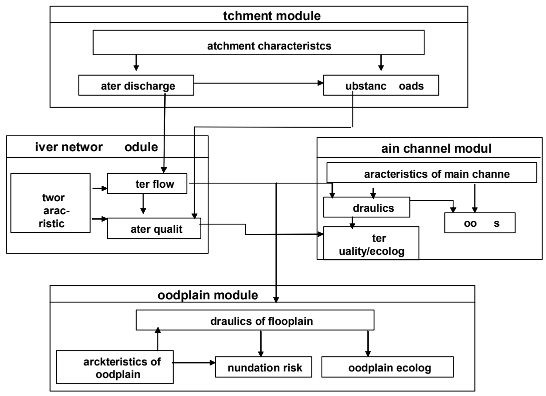


**Figure 3.** General systems diagram

*Catchment module (Fig 4):* The system diagram of the catchment depicts all system elements and their relations in more detail. Important catchment characteristics are the topography, soil properties, precipitation, land-use and hydrogeology. The quantity of discharges is determined by the various hydrological processes such as evapotranspiration, infiltration and surface run-off. The infiltrated water moves by interflow and groundwater flow into the river network. Also discharges from treated and untreated sewage water are considered. The third block describes the quality of discharges into the river network, which are driven by substance run-off from land (non-point sources of agrochemicals) as well as from point sources.

*River network module (Fig. 5):* The river network receives the discharges from the catchment. A digital geo-referenced river network is attributed with the locations of the point sources. The long-term historical time series from

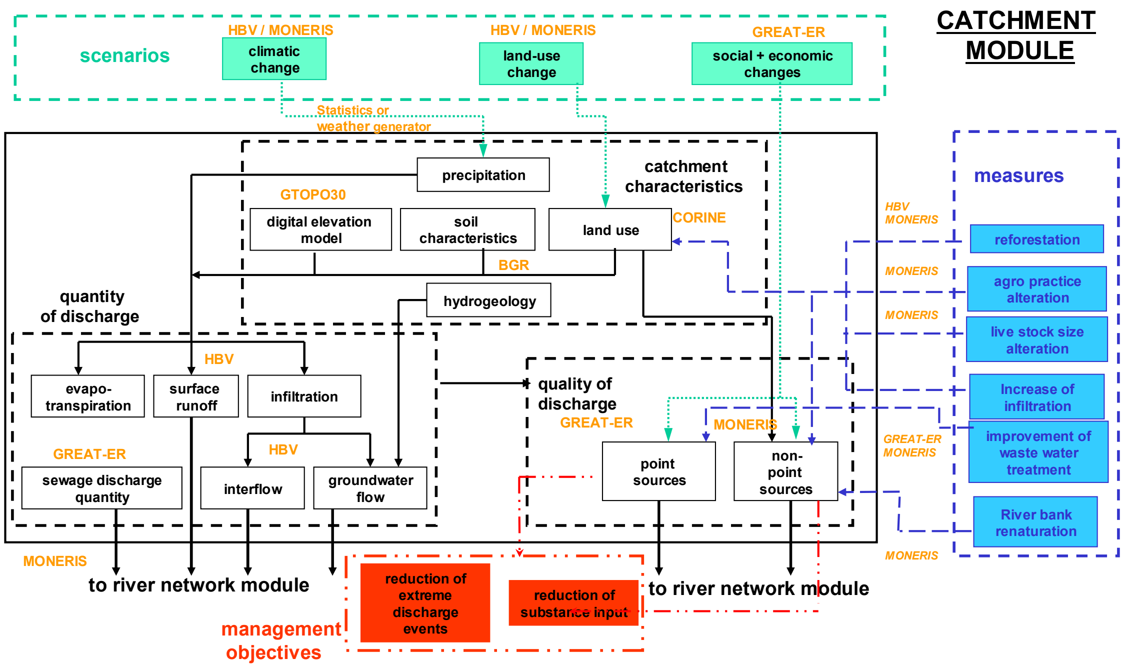


**Figure 4.** System diagram of the catchment module

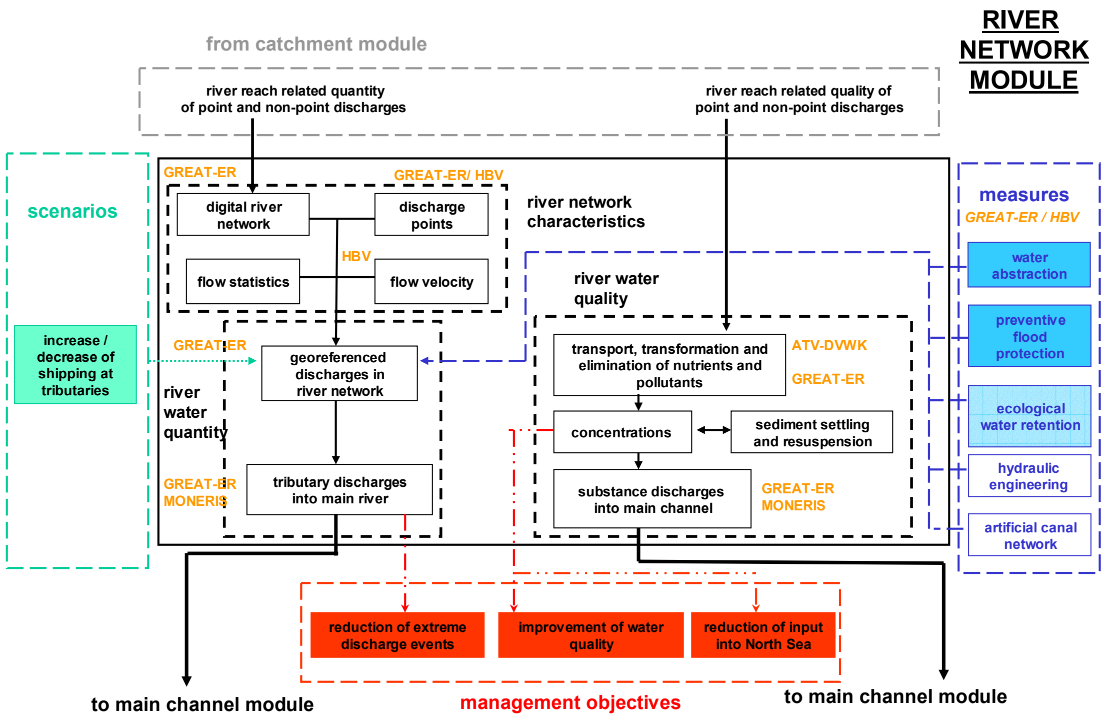


**Figure 5.** System diagram of the river network module

gauging stations are statistically analyzed to derive mean and variability of the discharges. Moreover, with a rainfall-runoff model daily discharges can be calculated. Water quality is determined with a transport, elimination and transformation model to deliver substance loads as well as concentration patterns along the river net.

### 3.3. Management objectives, scenarios and measures

Around the system diagrams in Fig. 4 and 5, management objectives, scenarios and measures are indicated. They are defined as follows:

- A management objective describes the state, which should be achieved to meet legislative or other goals.

- A scenario is a pathway into future determined by climate, hydrological, economic, ecological and/or social changes in the catchment.

- A measure is an action taken to achieve the objective.

Please note that scenario is differently defined than in the usual way.

*Catchment module (Fig. 4):* Indicated at the bottom of Fig. 4 are the management objectives of water quantity and quality management, namely the reduction of substance input into water systems. Three sets of pre-defined scenarios (top of the diagram) can be investigated: climate change, land-use change and socioeconomic change, e.g. demographic growth or decline. They influence the land-use, water cycle and substance impact on water systems. Moreover, various measures are indicated at the right hand side, which the water manager can select to reduce nutrient or other substance discharge. Point as well as diffuse sources can be investigated. Typical measures are local or regional change of agricultural practices to minimize nutrient input (see 4.), deforestation or soil degradation.

*River network module (Fig. 5):* There are three management objectives in Fig. 5, namely the improvement of the water quality, the reduction of extreme flow events (high water and low water) and the reduction of substance into the estuaries of the North Sea. They can be achieved by various measures indicated at the left hand side. The scenario of increased shipping on the tributaries Saale and Havel was skipped after the flood in August 2002.

### 3.4. Model selection and coupling

Figs. 4 and 5 also indicate the selected models to calculate indicators, which are used to support the decision making for a specific management objective. Only calibrated and validated models were included in Elbe-DSS. For the precipitation-runoff simulation, HBV-D was selected (Krysanova et al., 1999). HBV-D is a distributed conceptual hydrological model, which is being calibrated for 132 sub-catchments of the German part of the Elbe. It delivers daily discharges as well as any other time-period. Also long-term flow statistics can be created. Besides that, historical time series from 196 gauging stations are used to cover the long-term discharge variability. Nutrient loads (phosphorus, nitrogen) are calculated by the model MONERIS (Behrendt et al., 1999). It is also parameterized for the 132 sub-catchments and allows the average long-term simulation of P- and N-loads from point and non-point-sources. For the river network GREAT-ER is integrated into Elbe-DSS (Matthies et al., 2001, Matthies et al., 2003). The whole digital river network is divided into reaches of about 2 km length giving a number of approximately 33500 reaches in the German part of the Elbe River (without tide influenced coastal sub-catchments). GREAT-ER delivers concentrations of hazardous substances released by point sources, e.g. sewage treatment plants. The water quality simulation model developed by ATV-DVWK (2003) will be included and coupled to the river network.

### 3.5. Data support

Spatial as well as non-spatial data are collected from various data sources (given in parentheses): Land use (CORINE, Federal Statistical Office), digital terrain model: GLOBE G.O.O.D (GLOBE Project), soil properties, hydrological and meteorological data (Federal Agencies), census data (Federal Statistical Office), waste water treatment data and discharge consents (Federal and State Environmental Agencies), monitoring data (various sources) and many more.

All spatial data sets were processed with a GIS (ArcGis, ArcInfo, ArcView) to produce a consistent geo-referenced data basis, which is coupled to the simulation models.

## 4. WATER QUALITY ISSUES

Phosphate is the major cause of the eutrophication of fresh waters. Large parts of the Elbe River and its tributaries are still in a eutrophic or oligotrophic state although much effort has been made in the last decade to improve the Elbe River water quality. With the example of runoff of phosphate attached to eroding particles the applicability of the Elbe-DSS for sustainable water management is demonstrated. The sub-catchment of the Saxonian Mulde with a size of 6,221 km² was selected. The Mulde is a tributary of the Elbe, which has its source in the highlands and flows through agricultural and highly industrialized areas. The upper part of the catchment is hilly area, which has a high potential of soil erosion. Two variants of agricultural practices were compared: a conventional and one with minimized tillage operations. Minimized tillage operations means that crop residues are left on the field to increase the soil cover. With conventional agricultural practices high soil loss could be observed in the highland regions. An annual averaged amount of eroded soil of 3.7

t/(ha*a) was calculated. A total amount of 249,022 t/a is transported to the adjacent rivers, which is equivalent to 385 t/a of phosphorus compounds. Most of the arable land is cultivated with grain and corn. An additional cover of bare soils in the growth period of grain (April to July) by litter residues would reduce the erosion of soil to 1.4 t/(ha*a). Particularly areas with high soil loss are affected (Fig. 6). This measure would minimize the sediment impact on the rivers to 76,407 t/a, which is 191 t/a of phosphorus compounds.

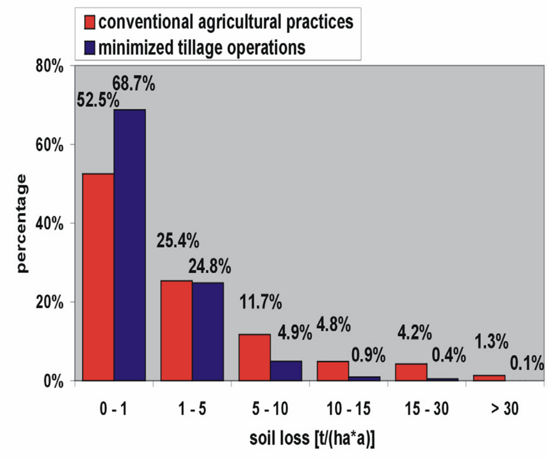


**Figure 6.** Soil losses with conventional and minimal agricultural practice.

## 5. OUTLOOK

After finishing the comprehensive systems analysis Elbe-DSS is now in the phase of implementation and calibration. A first prototype includes land-use scenarios and measures on long-term water quantity and quality issues. Next phase will integrate dynamic models into the modelling framework.


## 6. ACKNOWLEDGEMENTS

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