Development of a decision support system for integrated water resources management in intensively used small watersheds

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ABSTRACT
The main objective of the WSM300 project is the development of a methodology which guides and supports an improved water resources management on the level of small watersheds (up to 300 km²). The developed methodology is to be implemented into a software based tool within the framework of a generic Decision Support System (DSS). (Leichtfuss 2003, Schröter 2004). Core of the DSS is a “decision matrix”, which has been implemented as a web based application (www.wsm300.de). The management objectives are represented by the indicators labeling the rows. They will be the result of a discussion of the objectives and problems in the specific sub-basin, which is supported by the catalogue of indicators. The matrix, once the labels are defined, serves as a plot for the planning process, defining clearly which objectives have to be considered and which indicator-values have to be calculated. The DSS further includes a concept and tools for the combination of existing software components and supports the processing of model-outputs to indicator-values. Filled with the indicator-values, the matrix allows a comparison of the scenarios and provides a good basis for a decision. If desired, multi-criteria decision aid methods can further help find the optimal scenario and mediate between stakeholders. As a co-product of the web-based DSS, the “River-Information-System” was established informing the public about the newest developments in their catchment.

KEYWORDS
Decision support; Web-based water management; Scenarios; Geographical Information System; Integrated modeling; Indicators; Assessment

INTRODUCTION
Water resources management and planning is becoming increasingly complex. A multitude of conflictive demands including social, economical and ecological aspects have to be considered concurrently. Pressures and impacts on water resource quantity and quality resulting from anthropogenic activities call for appropriate concepts of management and

planning of mitigation measures. The European Water Framework Directive (WFD) asks for integrated river quality management of river basins. In addition, further objectives (e.g. flood protection, drainage of urban areas and recreational aspects) have to be considered in an integrated planning process.

In this context, the approach of integrated river basin management (IRBM), which is based on the idea of taking the watershed as a management unit, has become commonly accepted. Basically, IRBM is a multi-criteria optimisation task. It is the search for a management strategy that provides the best overall performance with respect to the considered objectives. Therefore, scenarios of different measures have to be analysed, evaluated and compared. To achieve a holistic analysis and assessment of effects of measures, an integrated modeling approach is required. In this context, computer based simulation models are accepted planning tools. The multitude of used models and the complexity of involved processes require a capable data management in order to manage the huge amount of data. These data have to be summarized in a coherent and clear form providing the essential information. In this regard, the application of DSSs is expedient. A DSS is defined as an integrated, interactive computer system, consisting of analytical tools and information management capabilities, designed to aid decision makers in solving relatively large, unstructured problems (Watkins 1995). Based on this definition in the field of IRBM, a DSS is not a single application, but a collection of suitable components including a Geographic Information System (GIS), a set of simulation models, as well as functionalities for data and time series analysis and multi-objective evaluation of results.

WSM300 APPROACH

It should be emphasized that WSM300-DSS is not a monolithic software application but rather a methodology for IRBM in small watersheds supported by suitable software tools.
Two different working levels have to be distinguished. The consultative level comprises general planning activities in which stakeholders and the public participate. The engineering level scopes technical implementations and analysis of planning specifications.

The planning process is divided into different steps:

- Deficit analysis based on the actual and required state (law, directives, requests)
- Definition of management objectives
- Proposal of scenarios of measures
- Integrated impact analysis on system dynamics
- Determination of facts for each indicator and scenario
- Specifications of weighting factors and benefit functions
- Multi criteria assessment
- Multidisciplinary discussion and agreement on a preferential scenario
- Restart from the appropriate step if necessary.

WSM300 gives assistance to all of these steps on both working levels.

DSS STRUCTURE

A decision matrix is situated in the centre of the DSS. This matrix represents a structured illustration of the decision space. Initially it does not have a fixed content or size. The management objectives labeling the columns are defined during the planning process. They are the result of an interdisciplinary discussion of occurring problems within the river basin.

The rows of the matrix are specified by scenarios of conceivable measures. Catalogues of indicators and measures include background information and application experiences. Further components of the DSS are a GIS for data-storage, presentation and handling as well as techniques for a multi-criteria assessment. Simulation models take on an important part for impact analysis on system dynamics. The described DSS structure is made for experts.
The WFD demands not only an integrated river quality management, but also a participation of the public. In this regard, the WSM300 DSS is used as well as a "river information system". In charge of the web page should be the authorities responsible for the implementation of the European Water Framework Directive.

Decision Matrix
The core of the DSS is a "decision matrix" (figure 1), which has been implemented as a web based application. The management objectives are represented by the indicators labeling the rows. They will be the result of a discussion of the objectives and problems in the specific sub-basin, which is supported by the catalogue of indicators.

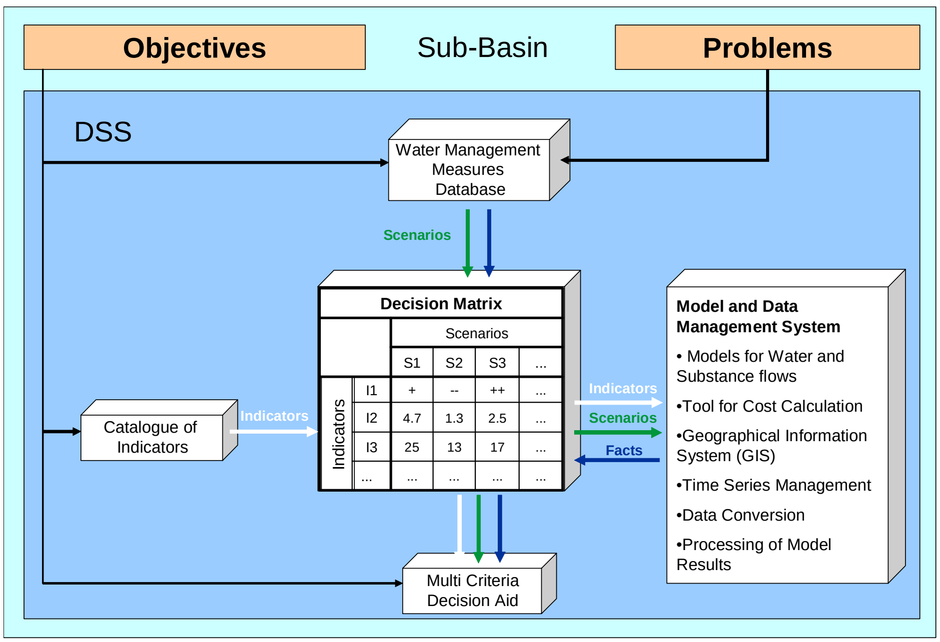

Figure 1: Structure of WSM300 DSS

The columns of the matrix are specified by the scenarios whose development is supported by the database of measures and a Geographical Information System (GIS) containing all important information about the catchment.

The matrix, once the labels are defined, serves as a plot for the planning process, defining clearly which objectives have to be considered and which indicator-values have to be calculated.

Filled with the indicator-values, the matrix allows a comparison of the scenarios and provides a good basis for a decision. Multi-criteria decision aid methods can (if desired) further help find the optimal scenario and to mediate between stakeholders. Finding the optimal scenario will likely be an iterative process. This means that in a first step, some basic scenarios are developed and analyzed that will be further refined during the planning process and evaluated again until the optimum scenario is found.

The DSS supports both working levels: The consultative level (decision matrix, catalogue of indicators, Database of measures, multi criteria decision aid methods) and the engineering level (Database of measures, model combination, and cost calculation). The DSS is to be operated by experts, who moderate the process, build up the decision matrix and run the models. The decision matrix application will be capable of administering different projects. A demonstration version is available at www.wsm300.de.

Database of Measures

For water management, a great variety of time-tested, as well as innovative measures exist. To make them available for the planning process, a database of measures has been developed. It contains information about preconditions, effects, technical design, contact persons, literature, legal aspects and costs. The database covers the following fields: sustainable and conventional drainage, source separation, flood control, agricultural measures. So far more than 100 different measures are included.

Information System

For scenario development, quick accessibility of information is essential, especially when it comes to a discussion about the scenarios in a group of stakeholders. Most of the information in a catchment has a spatial reference. Therefore, a GIS is used to store this information. Figure 2 illustrates how the Information System (IS) can be used in a discussion about river restoration, providing maps, photographs and river-habitat-survey data. Other examples for information that can be stored in the GIS are: river profiles, several types of texts (historical information, local problems and measure descriptions) or modeling results.

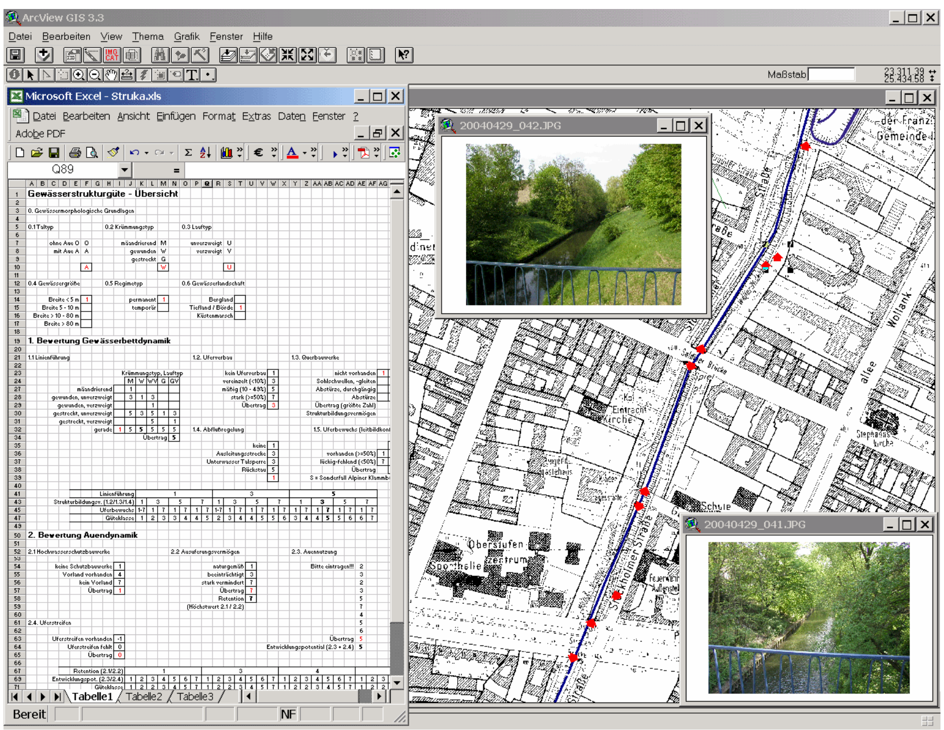

Figure 2: Information system for the Panke river catchment

Catalogue of Indicators

Indicators play a central role in the comparison of different scenarios. Simulation models generate huge amounts of data that cannot be compared directly. For this reason it is necessary to process the data into a manageable number of significant indicators.

Definition: An **indicator** is a variable, the value of which quantifies the effects of water-management scenarios. **Target values** for the indicators are set by local decision-makers or directives and laws.

The indicators pass information in both directions. On one hand, they provide the decision-makers with concise descriptions of each scenario's effects. On the other hand, decision-makers can put restraints on the indicator values used in the development of scenarios. The calculated indicator values are displayed in the decision-matrix, which allows for comparison of the scenarios.

Figure 3 explains the development of the catalogue of indicators. The indicators were derived from more general objectives (e.g. good surface water status, good ground water status, flood protection, drainage of urban areas, drinking water abstraction, bathing water quality, fishing, soil protection, etc) which partly depend on the specific pressures in the case studies. Many of these general objectives are made more specific by EU-directives (first of all the EU Water Framework Directive), river classification systems like the German LAWA-System, laws and technical rules.

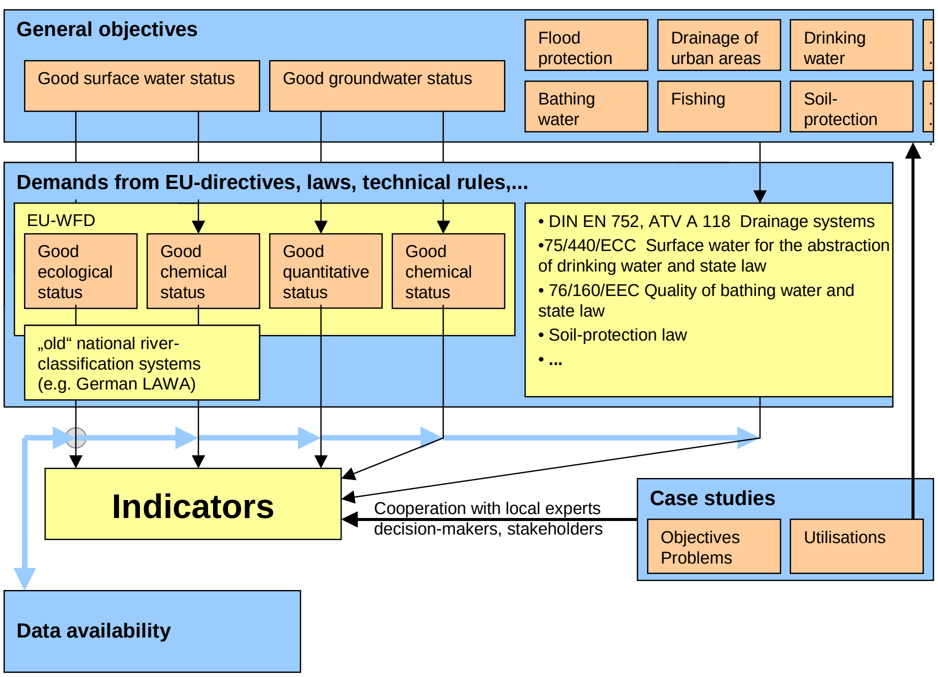

Figure 3: Development of the catalogue of indicators

In addition, data availability has to be taken into consideration. The good ecological status as defined by the WFD, for example, is measured by biological parameters (composition and abundances of aquatic flora, benthic invertebrate fauna, fish fauna), which can not be calculated by existing models. For this reason, hydrological, morphological, physical and chemical indicators, which allow experts to determine whether good ecological status will be achieved, have been developed. Subsequently, target values can be derived with the help of case study experts.

A very important criterion for suitable indicators is that they have to be able to describe the objectives and problems in the case studies. River committees and local authorities provided valuable information and feedback for this issue.

The current version of the catalogue of indicators is presented in table 1. As the conditions are different in the specific case studies, not all indicators are used in every case study. The intention in developing the catalogue of indicators was **not** to compile a database containing hundreds of possible indicators, but to carefully select and reduce the amount of indicators as much as possible without violating the previously stated criteria (i.e. without neglecting important objectives). This catalogue should be generally applicable to sub-basins with rather minor additions or modifications.

Assessment

Filled with indicator values, the decision matrix provides a concise description of the scenarios' effects and allows a comparison. This provides a good basis for a decision. It will rarely occur a scenario is optimal for all indicators, but rather each scenario has advantages and disadvantages corresponding to each indicator. This makes it difficult both to reach a decision and also to explain such a decision to parties with opposing views.

Table 1: Catalogue of indicators

1. Ecological and Chemical Status of the River and its Surroundings		**2. Quantitative, Physical and Chemical Status of Groundwater and Soil**	
1. Hydrological regime		1. Groundwater quantitative status	
1. HQ_1 (annual high flow) deviation from the respective natural flow	%	**1. Deviation from the natural water balance**	%
2. MNQ (average low flow) deviation from the respective natural flow	%	2. Groundwater quality	
2. Physico-chemical elements		**1. Nitrogen load into the groundwater**	kg/(ha*a)
1. Oxygen concentration with respect to duration and frequency of occurrence	mg/l	**2. Heavy metal loads into the groundwater**	kg/(ha*a)
2. Phosphorus load (river)	kg/a	**3. Pecticede load into the groundwater**	kg/(ha*a)
2a. Concentration of phosphorus in a lake	mg/l	3. Soil	
3. Nitrogen load	kg/a	**1. Heavy metal loads into the soil**	kg/(ha*a)
4. Ammonia concentration (NH_3-N) with respect to duration and frequency of occurrence	mg/l	**2. pH of the soil**	[-]
4a. Ammonium concentration (NH_4-N) in a drinking water reservoir	mg/l	**3. Preservation of soil fertility**	
5. Suspended Solids (SS) load	kg/a	**1. Soil erosion**	t/(ha*a)
6. Heavy metal loads	kg/a	**2. Nutrient supply degree**	
7. Trace organic substances	g/a	**3. Demands from Antropogenic Use**	
8. Pesticedes		1. Flood protection	
9. Pathogens		**1. HQ_x, e.g x=50, high flow with a defined statistic occurre (e.g. 1 / 50 a)**	m³/s
3. Morphological elements		**2. Available retention volume in (drinking water) reservoirs**	m³
1. River habitat survey (LAWA) *Includes the following quality components:* **Migration barriers, depth and width diversity, bed structure and materials, bank sturcture, flow diversity**		2. Drainage of urban areas	
		1. Frequency of sewer manhole overflows	[-]
		2. Distance from groundwater table to to surface	m
4. Other		3. Recreation	
Case specific components e.g. minimum flux into a specific lake	m³/s	**1. Score depending on size, value and accessibility of an area**	[-]
5. Emission standarts		4. Drinking water production	
		1. Minimun water quantity in drinking water reservoirs	m³
		5. Other	
		Case specific components e.g. minimum flux into a river brach for urban planning reasons	m³/s
		4. Economy	
		1. Present value of the project	
		Distinguished between cost units:	
		1. Public authorities	
		2. Citizens	
		3. Companies Water supply and disposal)	

Due to these problems, multi-criteria decision aid methods are implemented to further support the assessment of the scenarios (if desired) and to transparently document the way a decision is made. These multi-criteria decision aid methods determine a ranking based on the indicators' values and weightings. Different methods and variations have been tested. 'PROMETHEE' (Merz and Buck 1997) and a form of 'MAVT' (Merz and Buck 1997;

Eisenführ and Weber 1999) (preferred) were identified to be suitable and have been implemented into EXCEL applications (Figure 4). Sensitivity analysis functionality has been added to support the discussion about weightings and value functions.

Case Studies

For testing the DSS has been applied in three different case studies (figure 5) which cover a wide spectrum of different sub-basins.

Panke: heavily urban character

Modau: urban and agricultural character

Saidenbach: agriculture and forestry, catchment area of a drinking water dam

The varying conditions in these case studies guarantee a wide range of possible applications for the DSS.

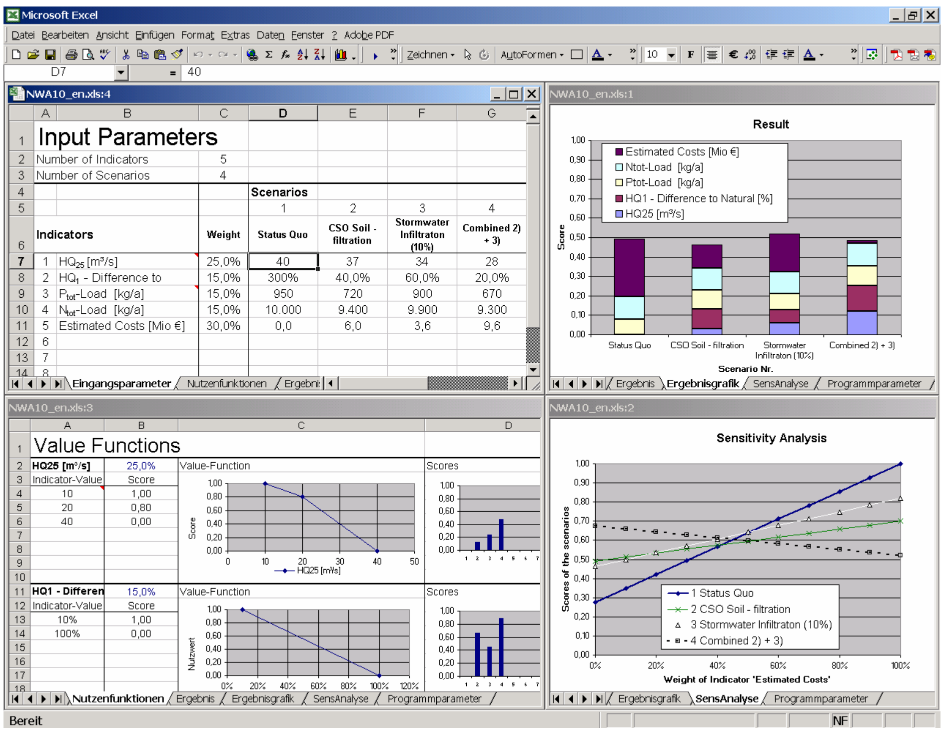

Figure 4: Decision matrix, MAVT and sensitivity analysis

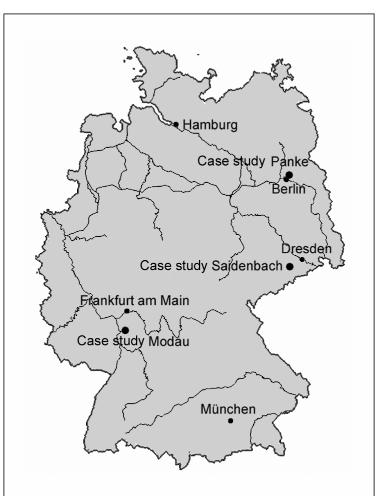

Figure 5: Location of case studies in Germany

Stakeholder Involvement

The case studies provide contact with local decision-makers, stakeholders and local experts. In all three case studies a "Day of the Panke" (... Modau … Saidenbach) was held with the participation of local stakeholders (local authorities, local experts, environmental groups, angler associations, etc) Valuable information about the objectives had been obtained. New contacts have arisen, not only between stakeholders and the project but also between stakeholders themselves. An important outcome of the project is that communication between different stakeholders or even between different departments of public institutions is one of the key problems in today's water management practice.

River committees have been founded which meet regularly and have been contributing significantly to identify the key problems, define the objectives and develop the scenarios.

RESULTS

So far the following results could be obtained:

- Model combination concept
- Multi-criteria decision making methods
- Decision matrix concept and application
- Catalogue of indicators
- Database of measures
- GIS based information systems for the three case studies
- Stakeholder involvement

Scenarios are currently being developed. The next work packages will be:

- Simulation Scenarios
- Testing of the indicator concept, data processing and assessment

CONCLUSIONS

The WSM300-DSS is a toolbox that guides water experts in the process of integrated water management. The core of the DSS – a web-based decision matrix - provides the possibility for a larger group of stakeholders to work together on the complex project of a river basin management plan. Tools like the catalogue of indicators, the database of measures or multi-criteria analysis assist the decision makers within the process of finding good solutions for water management on a catchment level.

WSM300-DSS has been successfully applied in three case studies with different water related problems. With the open structure it can be easily adapted to other catchments.

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