WORKFLOW ORIENTED PARTICIPATORY DECISION SUPPORT FOR INTEGRATED RIVER BASIN PLANNING

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Abstract: The European Water Framework Directive implements integrated river basin management in the European Union. Decisions about the programme of measures should be done with involvement of stakeholders. This paper presents a spatial decision support system, which is aimed at supporting such decision making procedures. The design of the system is based on a comprehensive workflow analysis. An interactive, learning based multi-criteria method supports decision makers and stakeholders to explore and negotiate possible options. Thus the proposal for the programme of measures can be chosen with respect to ecological, economic and social criteria and preferences.

Keywords: decision support, river basin management, multi-criteria analysis, participation, socio-economy

1. INTRODUCTION

Under the aspects of Integrated Water Resources Management (IWRM) water is seen as an integral part of ecosystems, a natural resource and a social and economic good. The European Water Framework Directive (WFD) specifies guidelines for integrated river basin management which are implementing this holistic view by means of a coherent water policy within all member states of the European Union. The WFD sets the goal of a "good ecological status" as the objective of water management in surface waters. This ecological objective should be reached within the year 2015. The WFD also specifies the aim to improve public participation in river basin management planning.

The planning cycle of implementation is based on the general scheme of Driving forces, Pressure, State, Impact and Responses (DPSIR) adopted by EEA (1999). It emphasizes the interaction between society (human activities in the river basin) and environment in integrated river basin management.

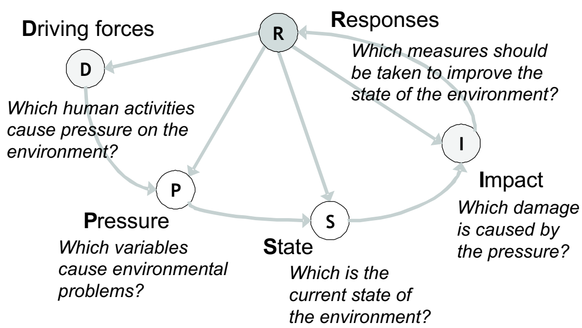

Fig. 1. The causal framework for describing the interactions between society and environment (EEA, 1999).

A relatively large number of criteria has to be considered for assessing the complex interactions between water and society. Decision support systems (DSS) are appropriate tools for this purpose. Considering the variety of stakeholders (with regard to water everybody is a stakeholder) a balancing of interests of various groups could be very difficult. That's why DSS which are designed to support the implementation of the WFD should be open and interactive useable systems, capable to provide a platform for the public discussions of measures among stakeholders. One approach based on this philosophy is presented in this contribution.

2. MANAGEMENT OPTIONS IMPLEMENTING THE EUROPEAN WATER FRAMEWORK DIRECTIVE

The WFD specifies the protection of surface waters and groundwater in order to achieve a good ecological and chemical status as the main objective of water management within the EU. The good ecological status is defined in terms of the quality of the biological community, the hydrological characteristics and the chemical characteristics. As no absolute standards for biological quality can be set which apply across the community (caused by the extreme ecological variability within Europe), the targets of planning are specified indirectly. The main objective consists in a slight departure only from the biological community which would be expected in conditions of a minimal anthropogenic impact. As these biological reference conditions vary with the natural character of the surface waters, also this general objective varies spatially. To consider this variability a river basin has to be subdivided into different reaches into the so-called surface water bodies. The WFD specifies these water bodies as key units for which environmental objectives are set. In Article 2, the directive defines them in the following way:

"Body of surface water means a discrete and significant element of surface water such as a lake, a reservoir, a stream, river or canal, part of a stream, river or canal, a transitional water or a stretch of coastal water."

A river basin and also a sub-river basin usually contain a number of "water bodies". The classification of each water body is based on the three different types of quality elements, representing the hydro-morphological, physico-chemical and biological conditions. Each quality element has to be defined by different criteria. Based on these criteria the actual conditions have to be compared with reference conditions which would be necessary to ensure the good ecological status. Based on an assessment of the actual ecological status the significant human pressures and impacts have to be specified which are responsible for gaps between the existing and the demanded good ecological status. According to the DPSIR-scheme presented before measures to improve the ecological status by modifications of human pressures have to be planned with regard to the different quality elements. These river basin management schemes have to be developed within 2009 and should contain detailed descriptions how the ecological objectives will be reached by 2015.

The general objective of the WFD, a good ecological status of all waters, is a mandatory one. However a set of uses which adversely affect the status of water, but which are considered essential on their own terms, are seen as overriding policy objectives. If it can be shown that measures to improve the ecological status are technically impossible, that they would be prohibitively expensive, or that they would produce a worse overall environmental result, exceptions from the general demand are possible. These exceptions could be prolongations of deadlines and even modifications of the objectives if such changes are needed to ensure specific water uses with high socio-economic importance. Obviously the specification of such exceptional cases demands a comprehensive characterisation of all circumstances connected with the specific water utilization. Not only technical but also socio-economic analyses of the boundary conditions of such human pressures are needed.

3. DEMAND FOR WORKFLOW SUPPORT AND COLLABORATIVE DECISION SUPPORT

The demand for decision support implementing the WFD is manifold. First of all a spatial distributed system has to be considered which is subdivided into a number of spatial elements (water bodies). A DSS should also be able to handle different temporal scales (e.g. based on different scenarios of future developments). As the object of planning is a natural system which depends on a complex of influencing factors, a large variety of data and information has to be considered. These data are provided by different disciplines. Integrated river basin management demands a cooperation of ecologists, hydrologists, water managers, computer scientists and socio-economists (Fig. 2). Local measures and regional management strategies have to be planned and synchronized in cooperation with local and regional authorities and stakeholders. Under consideration of their different spatial scales the possible ecological consequences of measures have to be assessed based on simulation models or expert knowledge. In some cases monitoring programmes have to be initiated

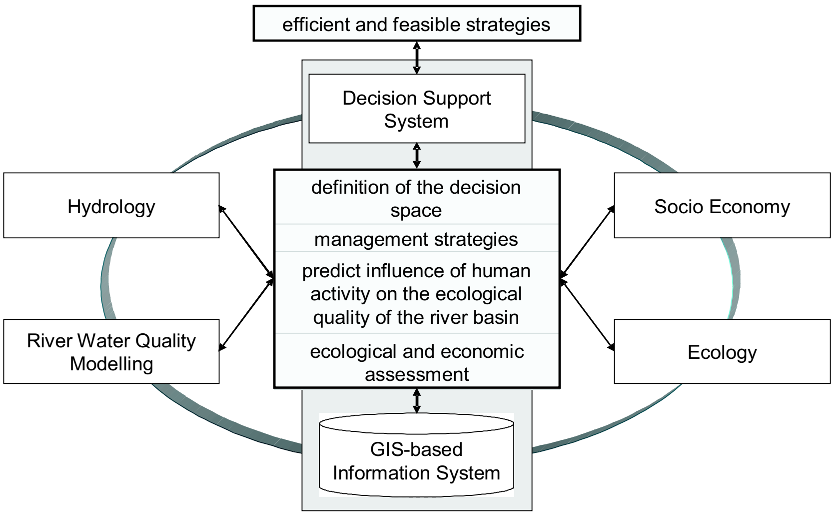

Fig. 2. Relationship between the different disciplines in integrated river basin management for the Werra pilot basin. The IT-disciplines (column in the centre) provide services for planners and decision makers.

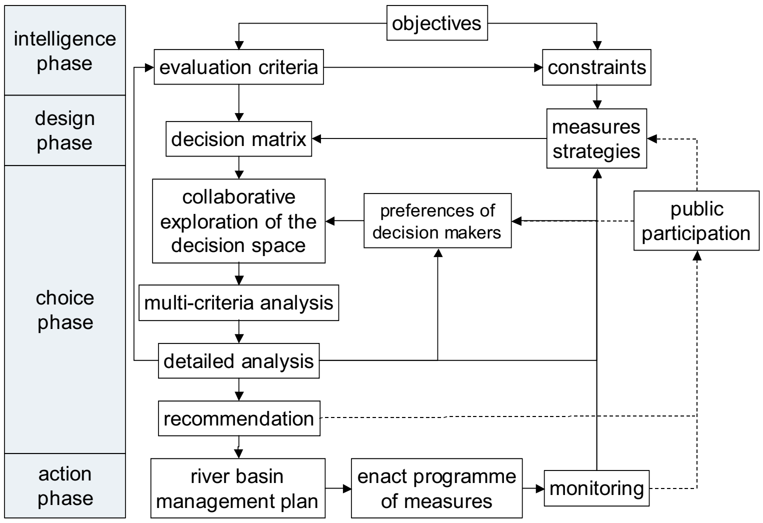

Fig. 3. Phases of a participatory decision making process in integrated river basin management (changed from Malczewski 2001).

to provide better data and information about the different quality elements. Costs, benefits and possible conflicts have to be estimated with socio-economic methods under different management schemes and under consideration of different baseline scenarios. Resulting from these activities a multi-criteria analysis has to be applied in order to find the most cost-efficient, feasible combinations of measures according to the preferences of decision makers. The most cost-efficient, ecologically effective management strategy has to be selected combining different measures. But not only efficiency and costs of technical measures have to be considered but also the social impacts of these measures which depend on the transfer of benefits and burdens related with them.

Decisions about the River Basin Management Plan will be based on an assessment of the cost efficiency of various possible management strategies at river basin scale mainly. The possible exceptions from the environmental objectives at water body scale demand a comprehensive consideration of the socio-economic circumstances as well as the interdependencies within the river network. Setting exceptions at one water body can influence the achievement of the good ecological status of other water bodies (e.g. regarding ecological continuity for long-distance travelling fishes). Here decision makers need aggregated information about possible strategies and their effects. But also the boundary conditions which form the constraints have to be analysed to determine the chances to realize these strategies. The economic importance of existing water and land uses and existing legal restrictions should be known. To implement the WFD, many different criteria have to be considered to ensure the one, but very complex objective of a good ecological status. This results in a problem of multi-criteria decision making (MCDM).

The different steps of the decision process developed in the Werra IRBM project are shown schematically in Fig. 3. Measures are prepared in the design (or planning) phase, where they are also aggregated into alternatives (= alternative proposals for the programme of measures on basin scale). Decision making is seen as a collaborative process. Thus the exploration of the decision space and the application of a multi-criteria analysis take part in the choice phase.

The WFD asks the EU member states to encourage active involvement of all interested parties. Public participation can be supported at different levels: information, consultation or active involvement. The participation demands new tools which ensure transparency within the decision processes. These tools should be able to visualize the different criteria mentioned above in a way that supports the negotiations among stakeholders.

4. TOOLS FOR DECISION SUPPORT IN THE WFD IMPLEMENTATION

The design of the spatial decision support system for integrated management of the Werra river basin is based on a central logical model of workflow, objects and methods on the one hand. On the other hand software services are provided to planners, decision makers, administration, NGO's and stakeholders for support of decentralized collaborative negotiation and decision procedures:

- display and analysis of the state of the water bodies, deficits, spatial representations of measures and their consequences using an internet enabled Geographic Information System;
- support for access, organization and documentation of the different steps of decision making via an assistant like, internet based user interface;
- multi-criteria exploration of the decision set, setting of a reasonable goal and search for efficient measures close to the goal.

The WFD redefines existing water management procedures. So the development of the SDSS was started with a revision of existing spatial object models according to the requirements of the WFD. The object model proposed by the European Commission working group (CIS 2002) was extended to integrate and link socio-economic and management aspects (e.g. census data, agro-economic statistics, database of measures and strategies).

The required system interaction demanded a completely new development of functionality and

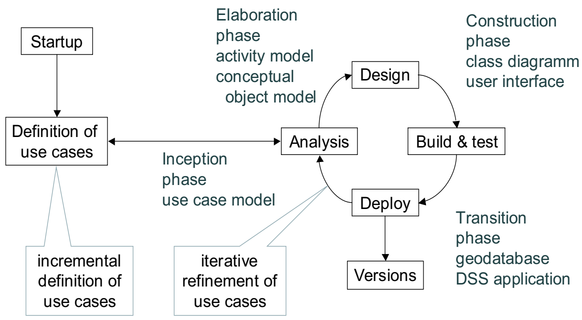

Fig. 4. Incremental and iterative software development process phases. The main products related to workflow and data modelling are written cursive.

user interfaces. The software development followed an incremental, iterative use case driven approach (Fig. 4). New use cases according to the required work package were defined incrementally. New functionality was added by iterative refinement of use cases. This software development approach helps synchronizing parallel system analysis tasks between interdisciplinary working groups. Changes in EU and national guidance papers for the WFD implementation can also be accounted.

Incremental and iterative software development process phases. The main products related to workflow and data modelling are written cursive.

Use cases are specified in detail in activity diagrams for modelling the business processes and workflow of people involved in river basin management using the formal standard of the unified modelling language (UML, Booch et al. 1997).

The example in Fig. 5 shows a simplified activity "Setting exceptions for economic reasons". From the activity start, a sequence of actions is connected with action flows. Decision points with guard conditions direct the flow through the activity (imagine tokens following the flow). Expansion regions allow the iterative treatment of a collection of inputs, e.g. for the redefinition of objectives for multiple water bodies.

Activity models for ecological assessment, planning of measures and for the decision phase have been developed in corporation of the Werra IRBM project partners. The models allowed all partners to evolve and communicate a clear logical view on the workflow of river basin managers and decision makers – not only from the software point of view, but also as a general business process model of parts of the WFD implementation.

One option to support the mediation process is an interactive collaborative exploration of the variety of possible decisions by administration and stakeholders ("explore, what is possible"), e.g. during a focus group meeting or in the process of indepen-

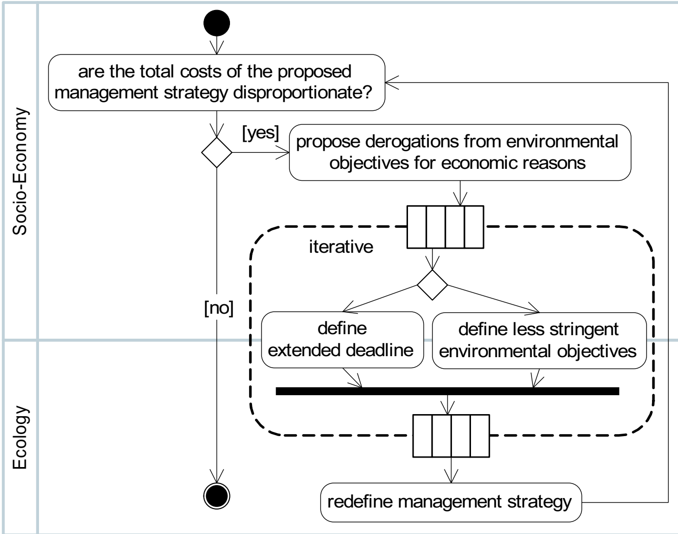

Fig. 5. UML activity diagram showing an exemplary workflow for the socio-economic assessment of the total costs of the program of measures.

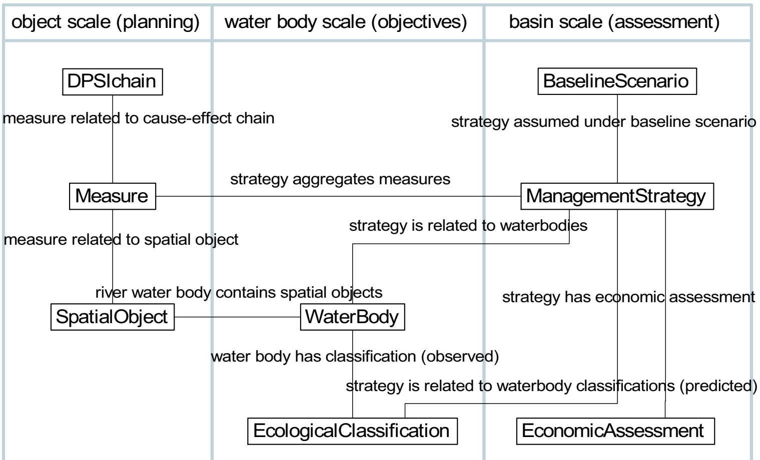

Fig. 6. Conceptual object model of the spatial information system. The decision matrix will be dynamically computed from the measure and strategy classes according to the users' preliminary filtering of the database.

dent exploration. Here the preferences of decision makers may not be defined a priori. Also the use of complex physical models and interdisciplinary assessment tools is not practicable in such a situation. Instead of modelling in the decision phase, a database of measures and strategies was prepared during the previous planning phase, spanning a discrete set of feasible decision vectors.

The database of measures can be interactively filtered in several steps:

- set restrictions (e.g. budget maximum),
- explore only strategies responding to specific driving forces,
- analyze the consequences of setting exceptions and
- finally set exceptions like heavily modified water bodies, less stringent objectives, extension of deadlines.

When a filter is applied, the set of selected strategies is dynamically reduced. At this stage of the decision support process the relationships between the different objects and scales are evaluated.

5. INTERACTIVE MULTI-CRITERIA DECISION ANALYSIS

To select the most cost-efficient, ecologically effective management strategy, a multi-criteria visualisation-based decision and negotiation support technique, named the Reasonable Goal Method / Interactive Decision Map (RGM/IDM) technique, is applied. In the framework of the technique, it is assumed that the decision alternatives (strategies) are given in the form of rows of a rectangular table (matrix), whose columns contain selection criteria. The rows of the matrix (that is, strategies) are associated with points in

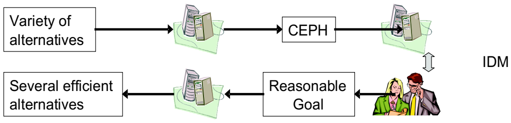

Fig. 7. General workflow of the RGM/IDM method (changed from Lotov et al. 1997).

criterion space. The technique is based on approximation of the convex hull of the criterion points and subsequent interactive exploration of its Pareto frontier by user. To be precise, the maximal set is approximated that has the same Pareto frontier as the convex hull of criterion points (Convex Edgeworth-Pareto Hull, CEPH). Approximation of the CEPH is carried out to simplify the exploration of the Pareto frontier. Exploration of the Pareto frontier helps user to understand the criterion tradeoffs and to identify a preferred criterion point directly at the Pareto frontier (the goal point). Since user explores the Pareto frontier of the convex hull, the goal is usually not feasible. However, it is close to the set of criterion points; therefore it is denoted as the reasonable goal. Several criterion points that are close to the identified goal and related decision alternatives are selected by computer and used for further detailed discussion (see Fig. 7).

Let us provide a more detailed informal introduction of the RGM/IDM technique. Mathematical description of the technique along with its applications is considered in the book by Lotov and et al. (2004). We illustrate the technique by a water management example, in the framework of which decision alternatives (strategies) are given by such attributes as cost, conflicts, residual pollution, etc. We begin with the case when only two attributes are used as choice criteria, namely cost of the strategy and resulting conflicts. Though the use of the RGM/IDM technique is not particularly advantageous in the case of two criteria, we use it anyway to explain the fundamentals of the technique. In Fig. 8, about two dozens of strategies are depicted by points and crosses in the criterion plane (cost and conflicts plane, in this example). Non-dominated (Pareto) points, from which the decision must be selected, are given by crosses.

Since the number of decision criteria (in the above example) is two, Fig. 8 provides full information about the variety of alternatives. However, one is unable to construct a similar graph for the case of three, four, five and more criteria, and so a different graphic technique must be used. In the IDM technique, the frontier of the "convex cloud" (convex hull of the variety of points, see Fig. 9) is displayed instead of points. Convex hull also includes artificial criterion points, which help to explore the properties of the variety of feasible alternatives.

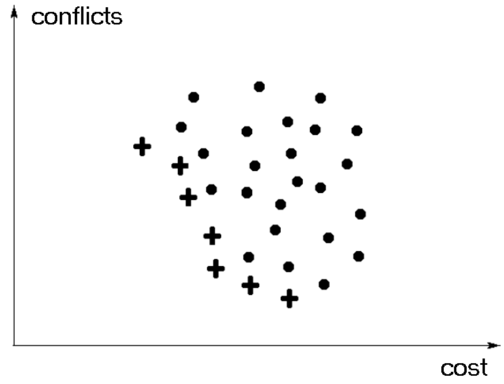

Fig. 8. Criterion points related to decision alternatives.

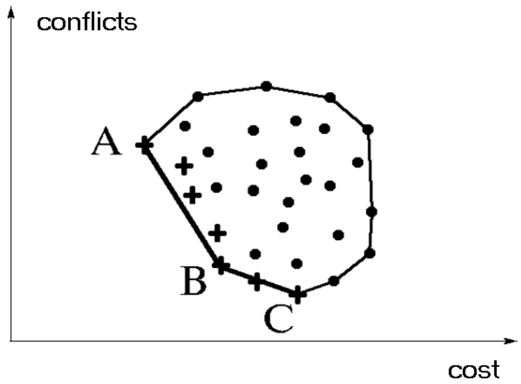

Fig. 9. Convex hull of points.

Since the user is interested in minimizing both cost and conflicts, the "south-western" frontier of the convex hull should be of interest (curve ABC in Fig. 9). This part of the frontier is denoted as the Pareto (efficiency, non-dominated) frontier of the convex hull. The Pareto frontier shows the efficient (criterion) tradeoffs between two criteria: how much the increment of cost is related to the decrement of conflicts if points from the convex hull are used. At the same time, the Pareto frontier of the convex hull roughly describes location of the non-dominated criterion points for the variety of original feasible alternatives, and so it can be considered as the proxy efficient (criterion) tradeoff curve for feasible alternatives. Note that the notion of the efficient (criterion) tradeoff differs from the notion of the value tradeoff, which is related to preferences and means the subjective compensation of losses in one criterion by gains in another.

In addition to the Pareto frontier of the convex hull (curve ABC), Fig. 9 displays other frontiers (so-called dominated frontiers). These frontiers are not needed since they only confuse the interpretation of the graph. They would be especially harmful in the case of three and more criteria when the user has to compare multiple frontiers

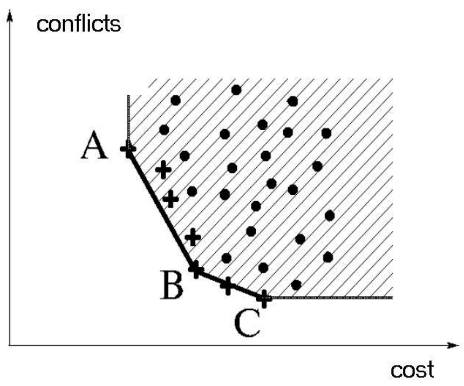

Fig. 10. Convex Edgeworth-Pareto Hull.

related to several values of the third criterion (such graphs are discussed a bit later). In order to avoid the dominated frontiers, the convex hull may be broadened, i.e. additional artificial dominated alternatives may be included in the hull in such a way that the resulting broadened variety of points has the same Pareto frontier as the convex hull.

For example, the broadened variety in Fig. 10 has the same Pareto frontier (curve ABC) as in Fig. 9. This broadened variety is named, in honor of the founders of multiple criteria decision theory — Edgeworth and Pareto, as the Edgeworth-Pareto Hull of the convex hull of the criterion points or the Convex Edgeworth-Pareto Hull (CEPH) of the original criterion points. Since the Pareto frontier has not been changed, substituting the CEPH for the original convex hull can not influence the selection result, but the application of CEPH makes the display simpler in the case of more than two criteria.

In the framework of the RGM/IDM technique, user has to study the criteria tradeoffs by exploration various graphs that display the Pareto frontier of the CEPH. After the exploration of the Pareto frontier is completed, user has to identify a preferable combination of criterion values, which belongs to the Pareto frontier of the CEPH (the reasonable goal). In the case of two criteria, it can be done at the graph of the CEPH. In Fig. 11 the identified reasonable goal is displayed by a small circle. It is important to note that user does not need to be involved in complicated interactive procedures aimed at eliciting his/her preferences. Instead, user can identify the most preferable criterion point (the goal) after visual inspecting the Pareto frontier. Multicriteria decision aid methods that are aimed at graphically displaying the Pareto frontier, but that do not require the elicitation of user preferences are named Pareto frontier generating methods. The RGM/IDM technique belongs to this group of multicriteria methods. In the framework of the generating methods, users

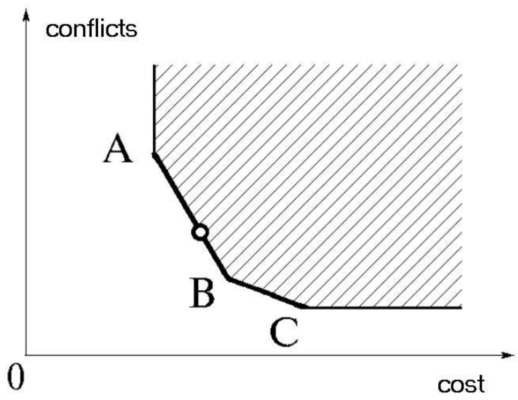

Fig. 11. The reasonable goal.

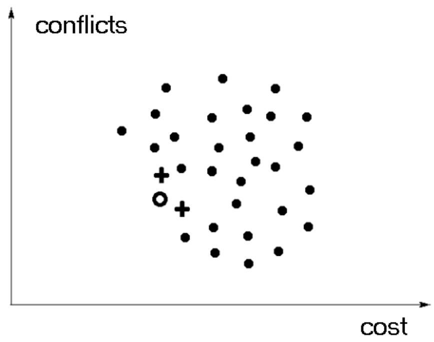

Fig. 12. Selected criterion points.

are given the full freedom of choice with respect to the Pareto frontier. It is assumed that user will identify the goal consciously, in accordance with his/her preferences. In contrast to other goal-based methods, the RGM/IDM technique restricts the identification of the goal to the Pareto frontier of the convex hull. Due to this, the identified goal is close to feasible points. Since the goal is identified on the graph, which displays the Pareto frontier of the CEPH, the goal is likely to coincide with feasible points only occasionally. For this reason, a computer algorithm is used to select several feasible points, which are close to the identified goal (Fig. 12). The selected points (and the corresponding alternatives) are of interest to user since they reflect both his/her subjective preferences expressed in the form of the goal and the objective situation represented by the criterion points. The short list of selected alternatives may be studied by other tools. Say, spatial alternatives can be visualized on thematic maps. They can be displayed to user by photos and films, too. Actually, all multimedia tools can be used to support selecting from the short list.

If more than two attributes are used as the screening criteria, the IDM technique is used to generate and display tradeoffs among the criteria. Let us first include the third attribute, say, residual

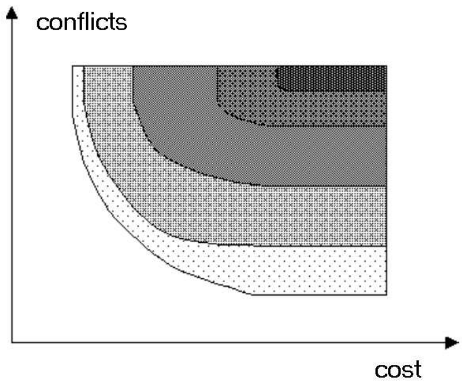

Fig. 13. Decision map.

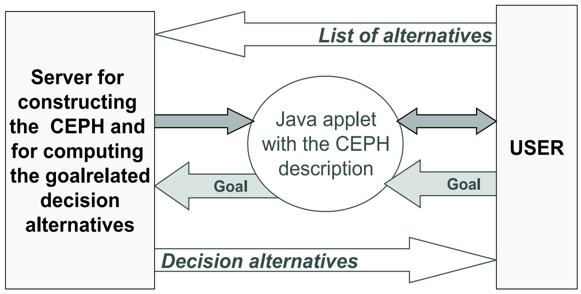

Fig. 14. Implementation of the RGM/IDM technique in Web.

pollution into the list of decision criteria. It is expected that user prefers to decrease pollution. To include pollution into the analysis, let us approximate the CEPH of the criterion points in the three-dimensional criterion space. Then two-criterion slices of the CEPH can be displayed to user. Each of them looks as the CEPH given in Fig. 11 and is related to a certain value of pollution in the following sense: its frontier displays a tradeoff among cost and conflicts if pollution is not greater than its given value. Such differently colored two-criterion slices of the CEPH are superimposed one over another.

Fig. 13 provides an example of the graph that contains five two-criterion slices related to five different pollution values. A pollution value is related to a certain color of the slice provided on display (to a certain shading in Fig. 13). Note that the frontiers of these slices do not intersect, and so the graph is fairly simple to interpret. The graphs of this type, which display the Pareto frontier for two criteria depending on the value of the third one, are called the decision maps. Changing one frontier for another, one can see how constraints imposed on the value of the "third" criterion influence the criterion tradeoff curve among the initial two criteria. Remember that this information is provided for the convex hull of criterion points. So, the decision map displays efficient criterion tradeoffs among three criteria for the convex hull. Due to it, the decision map at Fig. 13 informs roughly about the influence of the value of pollution on the tradeoffs among cost and conflicts for the set of criterion points.

In the RGM/IDM technique, the decision maps for three and more criteria are displayed on-line. The most important feature of the technique is related to the way of how decision maps are computed in the case of three, four, five and more selection criteria: the CEPH is approximated in advance for the entire set of criteria under consideration (three to eight criteria can be studied). Then, several two-dimensional slices of the CEPH related to several equidistant values of the third criterion (and fixed values of other criteria in the four and more criterion case) are computed and superimposed. They provide decision maps such as given in Fig. 13. Since the CEPH is approximated in advance, various decision maps may be displayed on request very fast. Hundreds of decision maps related to various values of the fourth and fifth criterion can be computed and displayed in a matter of few seconds. By this, animation of decision maps is possible. This option is very important in the case of four and more criteria.

The information on the Pareto frontier displayed by the IDM technique helps user to identify a preferable goal. The goal is identified on a decision map (specified by user) by a simple click of the computer mouse. After a moment, a short list of non-dominated alternatives, which are close to the identified goal, is constructed and displayed to the user. Note that in the case of three and more criteria, it is impossible to display the selected alternatives at a criterion plane (as it was done in Figure 5 for two criteria). Various procedures for selecting of the goal-proximate alternatives can be used, and so we do not describe them. One particular selection procedure is given in the book of Lotov and et al. (2004). It is clear that, in the framework of the RGM/IDM technique, the approximation of the CEPH and its exploration may be easily separated in time and space. This feature of the technique can be effectively used in its Web applications.

The RGM/IDM technique is usually implemented in Web in the form of an application server. It supports an easy selection of preferable alternatives from tables using simple graphic interface based on Java applet technique. The calculation server constructs an approximation of the CEPH. The graphic presentation window is a Java applet executed at the user computer. So, exploration of the variety of decision alternatives is carried out via Internet: user receives a Java applet, which displays the Pareto frontier in the form of decision maps and helps user to identify the goal point. Once again, it is important that a full freedom of choice with respect to the efficient combina-

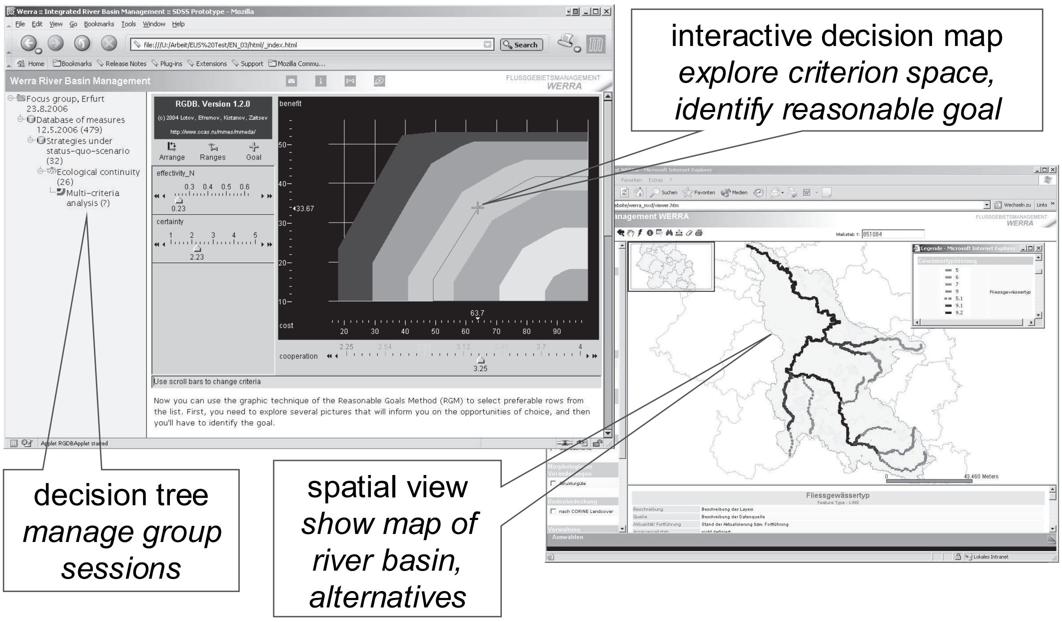

Fig. 15. User interface of the prototype of the interactive spatial decision support system for integrated management of the Werra river basin.

tions of criteria is given to user. Then, the applet transmits the goal to the server, and the server returns the selected rows to user. The scheme of such an interaction is given in Fig. 14. Detailed description of the RGM/IDM technique in Web is given in (Lotov et al., 2001).

6. RESULTS FROM THE WERRA PILOT STUDY

In the joint research project introduced in Fig. 2, a collaborative spatial decision support system was developed for the integrated management of the Werra river basin following the approach described above. Recently developed tools for river type specific ecological assessment (e.g. AQEM, Hering et al. 2004), a hydrological model (SWAT) and water quality models (ATV and RWQM1) were applied by the three environmental subprojects in order to design measures and strategies, which could prognostically achieve the environmental objectives. All information needed by and produced by all planners were organized in a modelled spatial database. Pilot focus groups initiated by local water management authorities were accompanied by the socio-economy subproject.

The following evaluation criteria were defined. They will be calculated for all strategies on river basin scale. Some of them will also be available on water body or object scale:

- **costs**: estimated from prior studies or technical guidance papers;
- **additional ecological benefit**: the strategies are designed to achieve the good ecological status or potential of the surface water bodies in the river basin where the plan is developed for. However also side-effects should be considered as the ecological effects are not limited in any cases to the planning region. Also the following main river downstream respectively the estuary will benefit e.g. from a reduction of the chemical loads of hazardous substances;
- **additional socio-economic benefit**: use and non-use values of the river ecosystem, e.g. tourism, biodiversity which are promoted implementing the WFD;
- **cooperation**: index calculated from actors analysis, cost recovery and other “soft” socio-economic criteria related to stakeholders. This criterion expresses the relative possibility of cooperation among stakeholders and with river basin managers for each strategy (as a positive formulation of “conflicts”);
- **certainty of planned results**: certainty of planning depends on the uncertainty of data, information and models. With regard to the WFD especially ecological assessment tools used to specify the ecological status and tools to predict the effects of changing quality elements on the ecological status are subject to uncertainty. An index will be calculated to express the relative certainty (as a positive formulation) of the planned results for each strategy.

Socio-economic constraints like existing water use rights, which cannot be compensated (e.g. small hydropower plants) and small farms, which cannot abandon their land, have to be considered in the planning phase.

CONCLUSION

The implementation of the Water Framework Directive in the EU is a new task of policy for many water authorities, coinciding or even conflicting with spatial planning.

Multi-criteria methods allow water resources managers to search for efficient measures, which take into account ecological and socio-economic criteria according to the preferences of decision makers including stakeholders. Learning based interactive methods provide a suitable solution for collaborative participatory decision making in a dynamic decision environment like the implementation of a new directive.

Based on the traditional planning approach decision makers implementing the WFD by measures would mainly consider the cost-efficiency of the combinations of measures. Hence it would follow that the WFD contains no multi-criteria problem. In real world the planning is much more complicated as multiple social and economic criteria has to be considered within a political planning process. Within the Werra River Basin Management Project such criteria are considered explicitly with the main aim to bring together the top-down approach of the European framework legislation and the bottom-up approach of active involvement of stakeholders in regional aspects of river basin management planning. Further more, the placement of exceptions due to budget restriction should be directed by the best ecological and economic benefit.

Complex simulation models and tools for environmental assessment can not be integrated in the SDSS due to performance issues. This might limit the application of the SDSS, because the decision space is limited by the prepared database of measures. Thus the generation of measures and strategies seems to be one of the most critical tasks of the project. On the other hand, decision makers often don't want to apply complicated simulation models in collaborative negotiation and the choice phase. Further research should be done in the development of scenario generators, which could produce a large amount of alternatives in a semi-automatic process, and meta-models, which could be integrated in an SDSS without the performance issues of numerical models.

An incremental and iterative software development process is a suitable way to cope with rapidly changing requirements of river basin managers during the implementation of the WFD. Formal models of workflow and objects allow a detailed discussion between water management experts and system analysts. They can further be used as a standard for the description of river basin managers' business processes.

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