An interdisciplinary SDSS for planning and controlling in river management –FLUMAGIS

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SUMMARY

Spatial and planning support for the implementation of the EC water framework directive requires interdisciplinary approaches for assessment, deficit analysis, and co-operative scenario investigation. The paper presents an SDSS approach from the FLUMAGIS-project based on the integration of techniques from visualization, scale-specific modeling, knowledge processing and methods for ecological and socio-economical assessment as well as effect prediction of planning measures. Software components enable planners and planning affected citizens in a co-operative process, to investigate, debate and evaluate planning measures. Possible measures are deducted from deficit analysis, according to the goals of the EC water framework directive. The paper presents results and methods from various disciplines. However, due to high the interdisciplinary approaches only a few aspects can be described within this paper.

KEYWORDS: *SDSS, water framework directive, environmental modeling, ecological assessment, scale changing*

INTRODUCTION

Upcoming environmental planning philosophies in juridical frameworks of the EC require better integration of those, who are concerned by planning measures. As a consequence more and interdisciplinary information must be offered to citizens. In that, the role of planners will change from a technical engineering side towards a more process oriented moderator, co-ordinating planning steps and contributions of different institutions involved and conciliating between them. In consequence, this co-ordination role requires quick and comprehensive data and information availability, supported by spatial decision support systems (SDSS). Particularly the European water framework directive (WFD) requires the integration of information and knowledge from various disciplines that offer environmental and socio-economic modelling approaches.

The FLUMAGIS project aims at the interdisciplinary development of methods and DV-tools for a prototypical SDSS for the measurement planning in river basin management. The focus has been laid on the development of an interactive tool facilitating the evaluation and (3D) visualization of river basin environments. This comprises the representation of current inshore water and landscape ecological aspects as well as aspects of the water balance and substance balances. Editing virtual environments makes it possible to elaborate future planning and management scenarios on the basis of an interdisciplinary data and knowledge platform in accordance with the EC water framework directive (WFD). Possible alternatives and effects of various planning scenarios can become transparent, can be discussed and experienced in a participatory planning process. From a computational perspective ‘FLUMAGIS’ represents the implementation of a working platform for decision and planning support including various environmental (hydrological, biological) and socio-economic modelling modules.

This paper addresses the major challenges for the development of SDSS components that support planners in a co-operative planning process in their working structure. Based on practical planning examples we present our technical approaches for SDSS components that enable

- analysis of river floodplains and identification of deficits,
- editing of virtual planning measures to support scenario investigation,
- simulation of planning effects according to the WFD.

EXPECTATIONS ON SDSS FOR WFD

The use of GIS supported information systems, SDSS, or planning support systems (PSS) is becoming increasingly important for spatial planning disciplines. However, approaches that integrate numerical models, GIS, visualization components as well as scientific knowledge are hardly known. But only such an integrating approach enables the cooperative processing of complex spatial planning problems. Our understanding of SDSS resembles the definition of PSS by Geertman & Stillwell (2003), who consider PSS as an assembly of theories, methods, data, information, knowledge and tools for planning situations. The major task for planning disciplines is the development of acceptable planning solutions. Spatial planning processes include:

- problem definition,
- definition of planning objectives,
- elaboration of planning alternatives,
- selection/rejection of planning alternatives,
- realisation of measures.

The aspect of ‘planning’ is neglected in many SDSS. When the actual planning of scenarios (beside decision support) is the central part of a SDSS, we consider it as a planning support system (PSS). However, there is much equality between SDSS and PSS (Geertman & Stillwell 2003, Klostermann 2001). In order to avoid developments of software modules that do not find any usage or do not hit realistic expectations from planning practice, a requirement analysis has been executed in a close liaison with the planning administration. Essential specifications resulted from interviews, questionnaires, best planning practice rules, etc.

The European water frame directive (WFD) requires transparent and participatory planning processes. This requires increasing time effort for information retrieval in order to fulfill the growing need of transparency. But the benefit of the increasing efforts is a growing acceptance of planning scenarios. The altering planning practices with increasing participation are also changing the role of planners. The role of planners is not reduced to the preparation and presentation of planning alternative anymore, their function changes more and more towards a moderator role.

A vision of the FLUMAGIS project is the enhancement of transparence and participation within planning processes. In order to support planning, assessment, evaluation, simulation and prognosis, we couple various techniques and methodologies from visualisation, knowledge engineering and processing, modelling and simulation. The following summary of ‘overall goals’ set up the basis for the FLUMAGIS-SDSS to support the implementation of the WFD:

- tools for analysis and assessment (referring to defined ecological goals of WFD),
- tools for deficit detection in the river-ecosystem,
- participation support and tools that support measure planning,
- and prognosis and analysis of effects of planning measures.

LANDSCAPE EDITING

Visualization within the context of spatial planning represents the basis for information transfer and data processing. Since multidisciplinary projects like FLUMAGIS require the integration of different technical aspects for co-operation of persons from different domains, the way of information transfer plays a crucial role. For the quality of planning the early information and participation of direct or indirectly concerned persons is essential. In addition this information must be coded by the sender in a suitable way, so that it can be decoded and understood by the recipient as well as possible. For this reason it is necessary to combine abstract and close-to-reality types of visualization - depending upon focussed question - in an appropriate way. This means among other things that a 2D visualization - the per se more abstract form of representation - and a 3D-visualization - as the representation more based on human natural surroundings (virtual reality) - stand in a balanced relationship to each other. So it can be made possible, that the information input is not only based on an attributive textual form, but also on the positioning and change of certain geo-objects as landscape editing by use of adapted interaction tools.

Therefore some special requirements for the 3D environment have been combined in FLUMAGIS: the use of suitable VR environments, the organization as real time capable component, the creation of suitable interaction tools and the direct reference to geo-objects. The interaction shall enable the editing process, which means to alter conditions of geo-objects. In that manner user can ‘plan’ and debate measures and investigate their ecological and socio-economic impacts through support of knowledge-based techniques. As environment a desktop PC (see. Fig. 1) and a semi-immersive workbench (see. Fig. 2) environment are used. For both environments different interaction tools that are adapted to the technical basic conditions and the respective application purpose, are necessary. The results from the expert knowledge modelled in the knowledge base are to become directly visible in the 3D visualization and to give the possibility for creative system handling. Therefore the 3D environment is made real time capable and visualized as scene graph in an appropriate environment. The link from visualization objects to geo-objects is from great importance for direct data manipulation and thus to enable the further system components to access these.

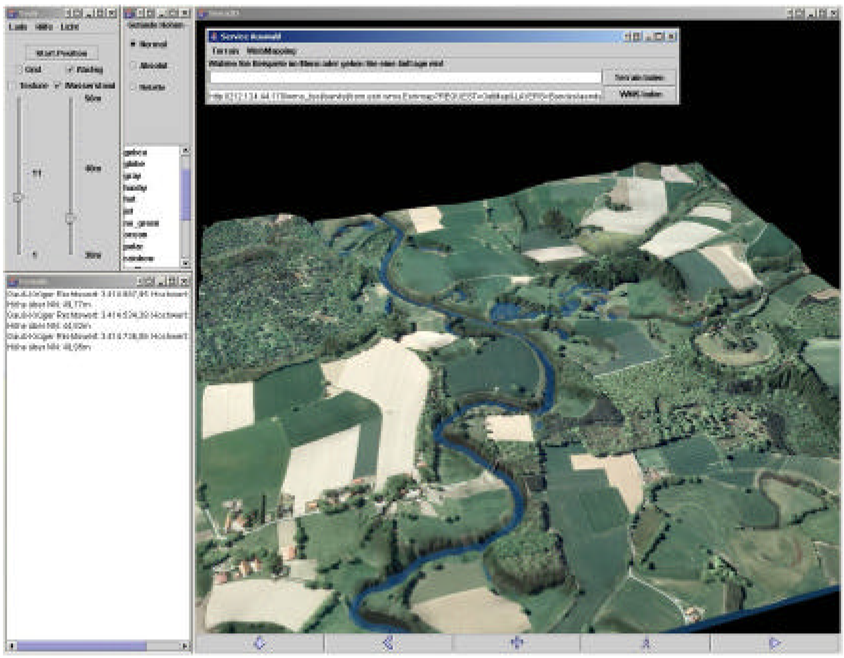

Figure 1. Desktop PC environment

Figure 2: Semi-immersive Workbench that enable interaction within the virtual environment in order to 'plan' measures and investigate their impacts

The two environments are developed on the basis of specified use cases. As far as possible the 2D-visualization-component corresponds to a specialized 2D-GIS. This component provides 2D-images, which will be reused for the virtual reality as textures for the terrain-model. In addition to this simple way of information-transfer between 2D and 3D there are special 3D-objects, like the water body and the trees. Special focus in the virtual reality is on the modelling of the terrain and the water body. Here special geometrical operations have been used that enable adjusting of base data with one another like the digital land model in form of a raster and the process of waters and other vector data. Yet an open question is whether the integration a very complex terrain model must be modelled, or whether the connection to the GIS can be held by additional objects, which represent at the same time specialized widgets. Because of its optimised data-volume and as the need arises precision capabilities a triangulated irregular network has been chosen. A topological model has been integrated, which is expandable with additional fixed regions and thematic information.

Since now a virtual GIS was created that enable the binding between 2D and 3D-geodata. The utilized renderer was as far as possible encapsulated and thus hold exchangeable. The 2D-visualization-component and both 3D-variants are executable and in the next step continued to be integrated with other FLUMAGIS components. Since the semi-immersive Workbench in progress cannot be photographically illustrated, an approximate impression is to be obtained in Fig. 2.

TOOLS AND METHODS FOR ANALYSIS AND PROGNOSIS

According to the EC-WFD the assessment of the actual state of water quality in river systems is mainly based on biological indicators. The living conditions for organisms in river system depend on the abiotic environment that is heavily influenced by land use activities in the catchment area. Based on this fact the development of management plans requires an integration of different hydrological, biological, chemical and socio-economical aspects. FLUMAGIS components embrace an integration of different simulation models to deduce measures for river basin management and to give prognosis of the effects of those measures to the water quality and habitat conditions in rivers. Fig. 3 gives an overview of specified function groups and their underlying software components.

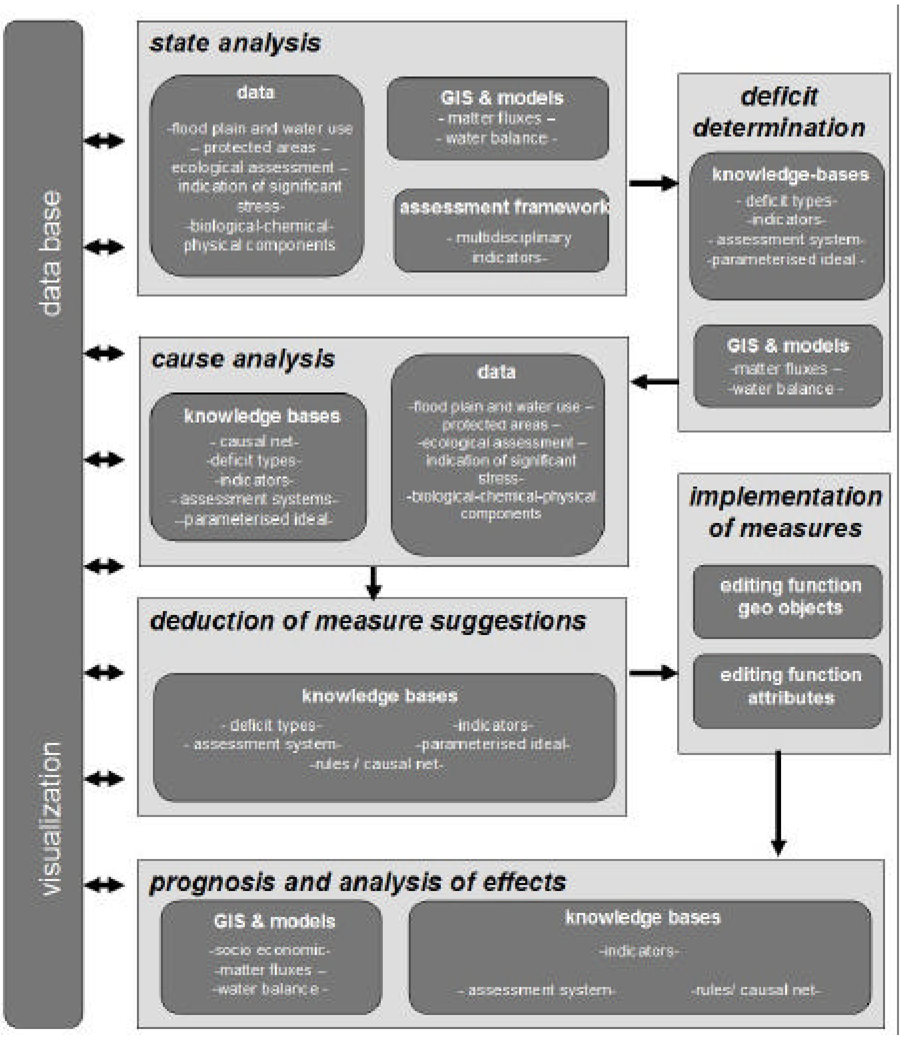

Figure 3: FLUMAGIS-functionality (in italics) in relation to system components

Scales in modelling

Since the water body is the medium of nutrient and pollutant transport, its runoff dynamic has determining influence on the condition of all aquatic habitats. That is why the modelling of water balance and matter fluxes as well as modelling of socio economic and biological aspects is an inevitable basis for condition analysis and assessment interrelated with ontology based knowledge processing. The WFD provides only one scale level for state reporting: the macro scale. On the other hand water quality assessment or measure planning, the development and implementation of management measures as well as the efficiency control require scale levels with higher spatial resolution. According to the specific measure types for river management and the interdisciplinary relevance, particular scale levels have been defined comprising the micro-, meso- and macro scale. Thus, for the description of the water balance and matter fluxes within the landscape the models NASIM (micro to meso scale), ArcEGMO (micro to macro scale), SWAT (meso to macro scale) and ABIMO (macro scale) are applied (Schmidt et. Al. 2003). At the first step these models are used to describe water balance and hydrological processes in different scales. In the next phase of our work we use SWAT for the simulation of the nutrient balance in the catchment-macroscale.

The usage of modelling systems on varying scales required an examination of transferability and applicability of information on these scales (next higher or lower scale level), as well as an implementation approach, that is open for other model systems. The scale transition in FLUMAGIS occurs scale-specific under the application of a compilation of existing indicators. Therefore the transmission of these indicators had to be verified. By the use of synthetic catchment areas scale specific indicators - specifying the hydrological state - have been identified. An essential influence on the indicators could be observed for the use of time series data of different time resolution depending on the scale level. The result is a matrix (see table 1) with hydrological indicators applicable on the specific scale levels.

Table 1: Matrices for indicator use in different water balance models depending time-step of rainfall input data

Indicator	Nasim (6 min)	SWAT & ArcEGMO (daily data)	ABIMO (monthly data)
MQ (mean discharge)	x	x	x
MoMQ (monthly mean discharge)	x	x	-
$MQ_{summer/winter}$ (mean discharge for summer and winter period)	x	x	-
HQx (x=1; 2; 10; 50; 100)	x	-	-
HQ (high water discharge)	x	-	-
MHQ (mean high water discharge)	x	-	-
MNQ (mean low water discharge)	x	-	-

The aim is to keep FLUMAGIS open for integration and use of other (hydrological) models and not to create an inflexible software monolith. Beside current implementation techniques an indicator-based approach is necessary for an open integration. Model data can be manipulated from the FLUMAGIS user interface be setting up planning scenarios.

Assessment approaches

The WFD obliges the EC member states to monitor the ecological status of surface waters using biological communities. The Directive focuses on the ability of biological communities to deal as an integrative assessment basis to evaluate human disturbance effects over time and in correspondence of disturbance types. Ecological river quality is measured against an almost natural condition. For the FLUMAGIS river assessment modules we employ approaches based on macro-zoobenthic community, macrophytes, and a typological classification of watercourses. A total of 165 indices, ranging from the British BMWP (Armitage et al., 1983) to Camargo's ecotoxicological index (Camargo, 1990) and including every measurable autecological attribute, such as functional feeding types, current and habitat preferences and even locomotion types has been tested (Böhmer et al., in press). Autecological information necessary for the attribution of a feeding type or a habitat or current preference to any given macrobenthic organism was taken from ecological data tables for central European taxa published in Austria (Moog, 1995) and Germany (Aqem, 2000). Based on a selection of 12 individual indices we combine them in a multimetric index for stream assessment.

In addition to the macrozoobenthic community macrophytes are another important element to assess the ecological quality of surface waters. For NRW exists an assessment procedure which was developed by van de Weyer (LUA 2001). It works on the concept of the potential distribution of plant communities ("potentielle natürliche Vegetation") for macrophytes in streams (Herr et al. 1989, van de Weyer et al. 1990). This concept describes classes of macrophyte vegetation under near-natural, moderate and heavy disturbed conditions. As a result of this classification it is possible to deduce the vegetation according to the "potential natural state model" for every type of stream. Depending on its value the ecological quality is measured by using indicators for several disturbances (e.g. trophic level, waste water load, structural alterations).

Prediction

As a result of the assessment of the status-quo and the identification of deficits it is necessary to propose measures to eliminate deficits. These measures cause among hydrological, morphological and biological changes also changes in nutrient flow. In line with the prognosis these changes will be modelled resp. predicted for having the possibility to evaluate the impact of the measures. Therefore different specialised models and methods have been applied.

The alternative measures proposed by the knowledge-base are evaluated in the course of a socio-economic impact analysis. For the proposed measures designed to ameliorate river structure, costs are calculated on the basis of similar projects already accomplished: They lie between 50,000 and 250,000 € for removing weirs and minor dams or building fishpasses. Widening the river-bed costs between 50 and 300 €/m, removing embankment structures and flattening the slope of river-banks between 90 and 250 €/m. Establishing a 10m wide strip of initial riverside vegetation costs 45 to 60 €/m. The costs for reducing immissions from point sources (mainly sewerage and sewage treatment plants) vary widely according to capacity and are calculated per project individually.

Emissions from diffuse sources (mainly nutrients from agriculture) are tackled with a variety of measures: Convert arable into grassland or even forest, reduce the spreading of manure and mineral fertilizer (below a nutrient surplus of 50 kg N/ha), ban cultures with high nutrient intensity and run-off potential (like maize) from sensitive areas or introduce zero tillage systems. Farmers have many different possibilities to adapt to these measures – with very different economic consequences. To reflect these management options a linear optimization model is applied. The BEMO model was originally developed by Kleinhanss (FAL Braunschweig, see e.g. Kleinhanss 1996) to predict consequences of changes in national and EU agricultural policies. In the course of FLUMAGIS and a dissertation project (see Hirschfeld 2003) it was modified and extended to test environmental policy measures. The model is calibrated with current regional management data (yields, shares of different cultures, animal numbers, prices, capacities) to represent the current situation, respectively the baseline scenario. Alternative measures to reduce diffuse nutrient emissions are introduced as additional restrictions. Optimization under different management restrictions leads to altered production programs and mostly to reductions in gross margins. These losses represent the economic costs of the environmental measures and can be taken as an orientation to design compensation programs. The losses in gross margins lie for example between 400 and 600 €/ha per year for conversion of arable into grassland and 100-150 €/ha per year for restrictions concerning crop rotation options. The effects of management changes on cultivation pratices and nutrient application are passed to the models of the other project partners and integrated into the SDSS.

Additionally to the economic analysis the acceptance of WFD goals and measures was evaluated in the course of a dynamic actor network analysis. It identified relevant regional actor groups and their preferences. Thereby potential conflicts were identified and integrated into the knowledge base as attributes of the alternative measures.

KNOWLEDGE MODELLING

Beside the visualization the knowledge-processing module is the bracket around all methods and models contributed from other domains. Since software developers are not able to fill a knowledge-base (KB) with domain experts (from other disciplines), a KB-framework is required that can be understood and filled by domain experts. This excludes hard-coded knowledge in domain software. The KB has to be editable and must be stored in a formalized and machine-readable way. Then it will be transparent, readable and revisable for all participants of the knowledge acquisition process.

Causal analysis as well as *prognosis* and *prediction* appear as most important tasks of the our KB. Thus we have developed a *causal network* as a core of the *decision support system (DSS)*, which includes three basic components:

1. **Ontologies** represent taxonomies and categorizations of certain domains. They are organized hierarchically by the type-subtype relation and show concepts of different levels of abstraction (Sowa, 2000).

2. A **Bayesian Belief Network** is the underlying concept of the causal net. It deals with causal relationships and probabilities of discrete states. Uncertainty can also be handled, so reasoning is enabled even if the knowledge is incomplete or vague (Marcot et al., 2001).

3. Actions and processes are described by **Coloured Petri Nets**, a well known model to visualize and prove proceedings and events (Jensen, 1998).

The ontology component delivers the basic node and net concepts to the causal network. It introduces the fundamental relationships "*is cause of*" and "*is effect of*" between nodes. For special tasks several subtypes of the basic node concept are created (examples, s. fig. 4):

- A **status node** defines a state of objects (certain attribute values)
- A **deficit node** links a bad object state to an *action node* to handle the deficit.
- An **Action node** specifies measures to be taken to remove or mitigate bad states. It carries a link to a Petri Net that can execute the desired action in the database.

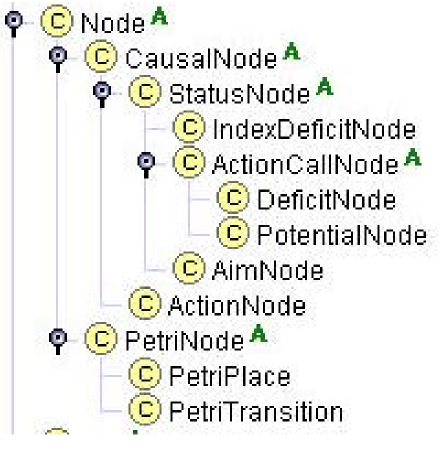

Figure 4: Node type hierarchy (ontology)

The inference machine of our KB can take any status node as **starting node** in order to analyze object attributes in the database. Deficits for example can be detected and also their potential causes. In case of incomplete or uncertain data probabilities are invoked if possible. Different kinds of analysis can be executed:

- **Causal analysis** checks object attributes to identify objects fitting the state described by a starting node, and it uses the "*is cause of*" relation of status nodes to find causing nodes. If the found nodes carry links to action nodes, measures can be proposed to remove deficits or to improve potentials.

- **Prognosis** goes the opposite direction: it estimates the effects of states and actions using the "*is effect of*" relation. It can also calculate probabilities if the database does not provide certainty (what is the normal case).

- **Simulations** are conceivable if the relevant procedures can be modeled by Petri Nets (Desel et al., 1997).

We have chosen **Protégé** as a KB-platform because it provides a wide functionality and because it is an open extendable system. Basically Protégé serves as a knowledge editor to create domain ontologies using the frame logic (Noy et al., 2000). In frame logic, rules, axioms, and constraints can be seen as predicates of the concepts they aim at, so they follow an object-oriented approach and can be accessed more efficiently compared to rule-based systems. After having developed some extensions (*plug-ins*, Borchert, 2003) we have implemented the causal net inference machine.

The KB gets currently filled with facts about assessment, interrelated effects, deficit analysis, modelling aspects, indices, index values, etc. Fig. 4 shows the concept of knowledge structuring as a causal net, here related to the river structure.

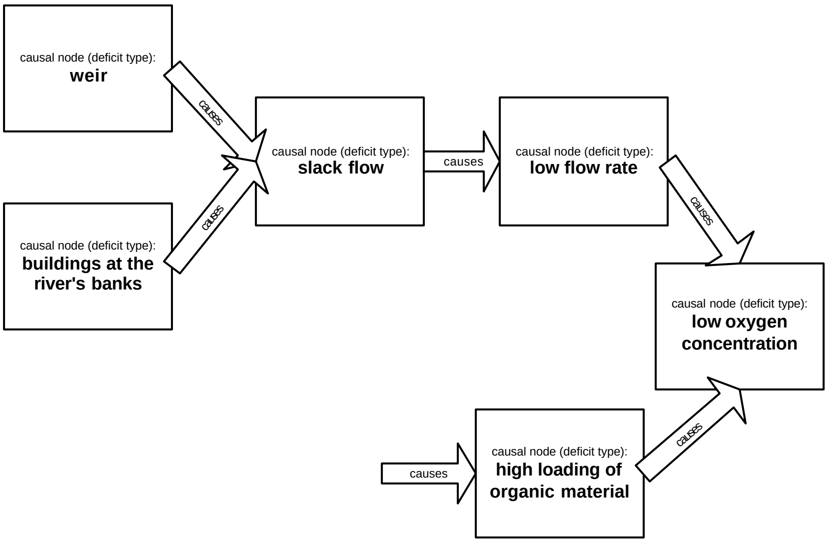

Figure 5: Causal net (simple example)

EXEMPLARY PROCESS SEQUENCE

FLUMAGIS offers three main functions: the state visualisation, measure planning and prognosis (see figure 1). The user starts the program by the 2D- or 3D-visualisation of a state and can choose between various functions of exploration. For example assessment data or background information about typical landscape vegetation can be added. Furthermore manipulation and generation of data is supported by different tools. The subsequent measure planning consists of three analysis steps: the deficit determination, causal analyse and the measure suggestion. These steps can either be automatically run by the system, be managed manually by the user or be organised by a combination of both. Completing the measure planning, the system suggests the sequence of the measures that will be delivered to the prognosis. The sequence depends on the kind of measures that are selected whether they're hydrological, structural etc.

Every measure can cause diverse effects and this can influence other measures and their effects. Therefore the measures are sequentional processed by the prognosis expect measure packets which must be processed in once. The states which are generated during the prognosis and the final forecasted state can be visualised. The measure planning is mainly based on the interactions of the knowledge base and the GIS-functions. The prognosis utilises the different simulation models additionally.Beside these three main functions there are two more ones: the effect analyse and the assessment. The effect analyse provides the relative values of the measure effects. The assessment of the final forecasted state as a trend indication can just point out how far the conditions for the aimed ecological state could be prepared.

CONCLUSION

The presented approaches for planning and decision support are ongoing work. In a final implementation user are able to analyze the status quo, to perform diverse ecological assessment, to detect concrete deficits according to the goals of the WFD, to 'edit' measures in a virtual world and finally to investigate the effects of these edited measures. This editing and assessment approaches can improve the opportunities of participatory planning enormously. Core applications are the interactive visualization, ecological and socio-economic models and the knowledge-processor. Most indicators and methods are already included in the knowledge base. Modeling measures and processes by Petri Nets and refinement of the causal network will be the next step.

ACKNOWLEDGEMENTS

The FLUMAGIS research project is funded by the Ministry of Education and Science (BMBF) in Germany in its research program 'Flusseinzugsgebietsmanagement'. The project will be conducted by the following partners in close co-operation: Institute for Geoinformatics, Institute of Landscape Ecology, Department of Limnology (all University of Münster) , Labor of water resources management (University of Applied Sciences Münster), Institute for Ecological Economy Research (Berlin) and Centre for environmental research, Leipzig. The authors wish to thank all project partners for their kind collaboration.

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