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The complexity of integrated flood management: Decision Support Systems

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Abstract Regarding the increase of extreme flood events and flood damage during the last decades, it has become obvious that an integrated approach is crucial in flood protection. In the complex field of integrated flood management many issues, e.g. technical measures, spatial management, retrofitting, raising risk awareness as well as environmental and land use management, have to be incorporated. Water related biotopes and especially flood plains are extremely important and rich ecosystems with a huge variety of species and functionalities. So technologies for integrated flood management should have the possibilities to integrate water and environmental aspects. Availability of digital data is crucial to manage these systems with complex cause-and-effect relationships. Moreover, the interfacing of different models plays a central role. But simulation of natural systems alone is not sufficient, public participation is also essential. For transparent and knowledge-based decisions the possibilities of participation technologies such as Decision Support Systems (DSS) are important and can be very helpful. But for large-scale and complex catchment based systems, there is a series of requirements, such as for example a good database, administrative boundaries, data availability/access, standards of methodologies, communication (e.g. between water and environmental managers) exist. Development of a DSS is usually time and money-consuming. So it is crucial to identify strategies and synergies to minimize costs and optimize the benefit. This paper illustrates some aspects of an incorporated approach in water and environmental technologies and discusses possible improvements and synergies in the field such as data collection and access, cooperation between water and environmental management, and integrated planning on a catchment scale.

Key words catchment scale; Decision Support Systems; environmental management; extreme floods; integrated approach

Complexité de la gestion intégrée des crues: les systèmes d'aide à la décision

Résumé Au vu de l'accroissement des évènements extrêmes de crues et de leurs dommages au cours des dernières décennies il est devenu évident qu'il était crucial d'adopter une approche intégrée de la protection contre les crues. Dans le domaine complexe de la gestion intégrée des crues de nombreux aspects tels par exemple que les mesures techniques, la gestion de l'espace, le rattrapage, la sensibilisation au risque ou que la gestion de l'environnement et de l'utilisation des sols se devaient d'être inclus. Les biotopes liés à l'eau et tout particulièrement les plaines d'inondation sont des écosystèmes extrêmement riches et importants accueillant de très nombreuses espèces et assurant de nombreuses fonctions. Les technologies pour la gestion intégrée des crues doivent donc avoir la possibilité de prendre en compte la dimension de l'eau et celle de l'environnement. Pour gérer de tels systèmes où les relations de cause à effet sont complexes, il est fondamental de disposer de données numériques.

De plus l'interfaçage des différents modèles joue un rôle central. Mais ce n'est pas seulement la simulation des systèmes naturels qui est importante. Pour des décisions transparentes et fondées offrant des possibilités de participation des technologies telles que les systèmes d'aide à la décision sont importants et peuvent être très utiles. Mais pour les systèmes complexes à grande échelle il existe un certain nombre de limites telles que la disponibilité d'une bonne base de données, les limites administratives, la disponibilité et l'accessibilité des données, les normes méthodologiques, les comunications (par exemple entre les gestionnaires de l'eau et ceux de l'environnement). Le développement de systèmes d'aide à la décision est coûteux et demande du temps. Il est donc particulièrement important de déterminer des stratégies et des synergies pour minimiser les coûts et optimiser les bénéfices. La présente communication montre quelques aspects d'une approche intégrée dans les technologies de l'eau et de l'environement et discute de possibilités d'amélioration et de synergies dans des domaines tels que la collecte et l'accès aux données, la coopération entre la gestion de l'eau et celle de l'environnement et la planification intégrée à l'échelle du bassin.

Mots clefs évènements extrêmes de crues; approche intégrée; la gestion des crues; les systèmes complexes à grande échelle; les systèmes d'aide à la décision

INTRODUCTION

The extreme increase of flood events and flood damages during the last decades makes it obvious that an integrated approach is crucial to flood protection. Many issues such as technical measures, aerial and spatial management, retrofitting, raising risk awareness as well as environmental and land-use management have to be incorporated into the complex field of Integrated Flood Management (IFM).

A crucial point of course is to optimize the retention potential of the river basin. It depends mainly on:

– the expansion and the size of the effective flood plain;
– the land use of the effective flood plain;
– the land use across the whole catchment area.

Flood plains are diverse landscapes where various requirements, which increasingly compete with one another, can be observed. The four main areas of interest and responsibility are mentioned here:

1. Water management: Water managers do not only have the task to protect residents from floods, they also have to meet demands such as navigability of rivers, water supply, and water quality.
2. Nature conservation: With regard to nature conservation, flood plains are especially important and are, because of their diversity, valuable habitats worth protecting. The most important characteristics are the natural flood dynamics and gradual processes that are not influenced by human beings. The preservation of riparian landscapes, of course, but also of extensively used pastures and meadows in flood plains (the cultural landscape) can also be of great interest. Flood protection and nature conservation should go hand in hand.
3. Agriculture: Farmers have an interest in regular and secure yields from agricultural areas within flood plains and protected areas. Furthermore, in the case of polluted

flood plains it is important for them to stick to legal limits for pollutants (e.g. regulations for food crops) in order to produce food of high quality. When it comes to the planning of flood protection, the appropriate use of land and adequately designed flood plains are of relevance. The forms of land use, such as tillage operations (e.g. conservation tillage) or quality of woodland play a major role.

4. Spatial planning: Areas along rivers have historic interest as well as present-day importance as spaces for urban development. People want to live by rivers and to account for changing demographics, space is required to build houses. A crucial aspect in spatial planning is to derive a balance between the restrictions of flood risk areas and flood-adapted constructions. A whole variety of possible measures that reduce flood risks have to be taken into account across the whole river basin.

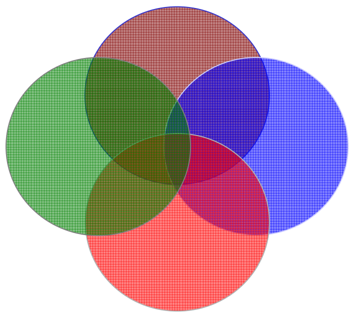

Fig. 1 The important players in Integrated Flood Management.

All four of these aspects, as shown in Fig. 1, have to be incorporated at the river basin scale. Thus, water management, nature conservation, agriculture and spatial planning form the complex body of Integrated Flood Management. These components make it on the one hand a complicated matter; on the other hand, synergies and common approaches emerge. Two of them shall be described here.

FLOOD AND ENVIRONMENT

Water related biotopes and especially flood plains are not only extremely important but also rich ecosystems with a huge variety of species and functionalities. "*Freshwater ecosystems, when scored on the area they cover and the number of species they harbour, are in fact the most species-diverse habitats on Earth*" (IUCN, 2005). Freshwater habitats connected with river systems include both static water bodies (such as flood plain pools and meander cut-offs) and flowing water environments. Flood plain environments range from dry-land environments (often quite distant from the river itself) to low-lying wetland areas. Both aquatic and flood plain ecosystems are subject to the dynamic flow patterns of the river, in terms of annual discharge regime as well as the size and duration of shorter-term flood events. A similar dependence is shown by the groundwater regime and especially the distribution of groundwater in space and time (Tsujimoto, 1999). A holistic view of the typical landscape dynamics in flood plains is required if an ecological means of flood protection is to be found (Henrichfreise, 2003).

Most relevant for these ecosystems are flood parameters such as the frequency of floods and inundation depth (Evers *et al*., 2001; Redecker, 2004).

The development potential of certain biotopes like flood plain meadows or riparian woodland can be derived by the following methodology. The determinant factors are hydrology, especially the median flood inundation period per year, and soil conditions. In order to create a model for flood plains we need:

– water level simulation with a one-dimensional (1-D) hydraulic model;
– statistical interpretation of flood periods with the focus on ecologically important time periods (e.g. 76–122 day year^{-1} for riparian soft woods; 12–76 day year^{-1} for riparian hard woods; 27–122 day year^{-1} for flood plain meadows);
– a digital elevation model (DEM).

By using a Geographical Information System (GIS) it is possible to create a difference grid that is blended with the elevation model. Thus we obtain spatial information about inundation periods for all areas in the flood plain. This map provides important evidence for developing flood-related biotopes.

In many cases the use of GIS is an adequate tool for analysing environmental systems. In some cases, GIS technologies even provide a useful approximation for flood risk assessment (Huang, 2005). The advantage over a complex time consuming 2-D simulation is the fact that information is received much faster. Even though it cannot show dynamic processes, it can give us important information on for example inundation depth and possible assessment. Of course the quality of the hydrological data and the digital elevation model are essential for the quality of the results. It is often difficult and costly to get good quality data on topography and elevation (for example via laser scans). We need high-quality elevation data to be able to obtain good simulation results because the microrelief of the flood plain (caused by dynamic flood characteristics such as erosion and sedimentation) is a very important parameter.

Another environmental aspect that depends on flood dynamics and flood plain elevation is the deposition of nutrients and pollutants in the flood plain. Understanding of the pollutants is especially important for managing the land use of flood plains. In many rivers and flood plains, pollutants like heavy metals or chlorinated organic compounds (e.g. dioxin) cause serious problems when concentrations exceed the allowed level. For example, for the River Elbe in Germany, newly contaminated sewage is not the problem, but instead the already deposited particles in the sediment. With every flood these contaminated sediments are redistributed in the flood plain. The patterns of sediment deposition are again related to flood frequency and topography, as well as to distance from the river and soil structure. And soil development is also dependent on flood dynamics. Schwartz (2003) considered that general predictions on the occurrence of different soil types in the flood plain were possible by correlating the absolute altitude of the study locations and the mean water level of the Elbe.

The measurement of sedimentation is not trivial. One needs a set of measurement data that ranges over several years and has been collected at many representative places. Also, the assessment has to be organized instantly due to flood events. As a consequence, modelling the quality and quantity of sedimentation can be helpful to estimate possible pollutant rates and risk areas.

These examples not only illustrate the complexity of flood plain systems, shown schematically in Fig. 2, but also the common interest in a reliable basis for obtaining good data for computer-based water and environmental technologies. Table 1 indicates important flood-related data and relevant fields of use.

Table 1 Flood related data and relevant fields of use (for water and environmental technologies).

No	Data	Relevant research field
1	Flood frequency	Flood protection
2	Elevation of the flood plain	Flood protection
3.1	Flood frequency in the flood plan	Flood protection Soil development => nutrients & pollutants Sedimentation rate => nutrients & pollutants
3.2	Inundation depth	Flood protection Soil development => nutrients & pollutants
4	Land use	Retention potential Value of biotopes Economic consequences of changes
5	Groundwater quantity	Retention potential Development potential of wetland biotopes
6	Land user and owner, stakeholders	Development and management of the catchment area—especially the flood plain

IFM has to incorporate environmental aspects such as the protection and the development of riparian woodlands to increase flood protection. It also has to incorporate land use options that depend on nutrients, pollutants and nature conservation issues, amongst others. These are two sides of the same coin. We achieve better solutions for sustainable flood management if we go for Integrated Flood Management which includes the environmental aspects at the same time.

An important component is an integrated database with easy availability and access.

THE ROLE OF LAND USE AND DECISION SUPPORT SYSTEMS (DSS)

We have seen that Integrated Flood Management has to include multidisciplinary components, so the technologies must have the possibilities to integrate the water and environmental aspects. In order to manage these systems that have complex cause-and-effect relationships, the interfacing of different models plays a central role.

As interests are often conflicting, alternative strategies for river and flood plain management have to be developed and planners as well as policy makers have to be provided with realistic options to choose from. The assessment of impacts requires, in terms of both quality and quantity, a rigorous analysis of the different processes in the river and flood plain. For an integrated and multidisciplinary approach to the design and evaluation of river and flood plain management, generic Decision Support Systems (DSS) are useful. With regard to the requirements of users and to planning processes, and with the aim to come to transparent and knowledge-based decisions, DSS are especially suitable for the analysis and the visualization of complex spatial contexts.

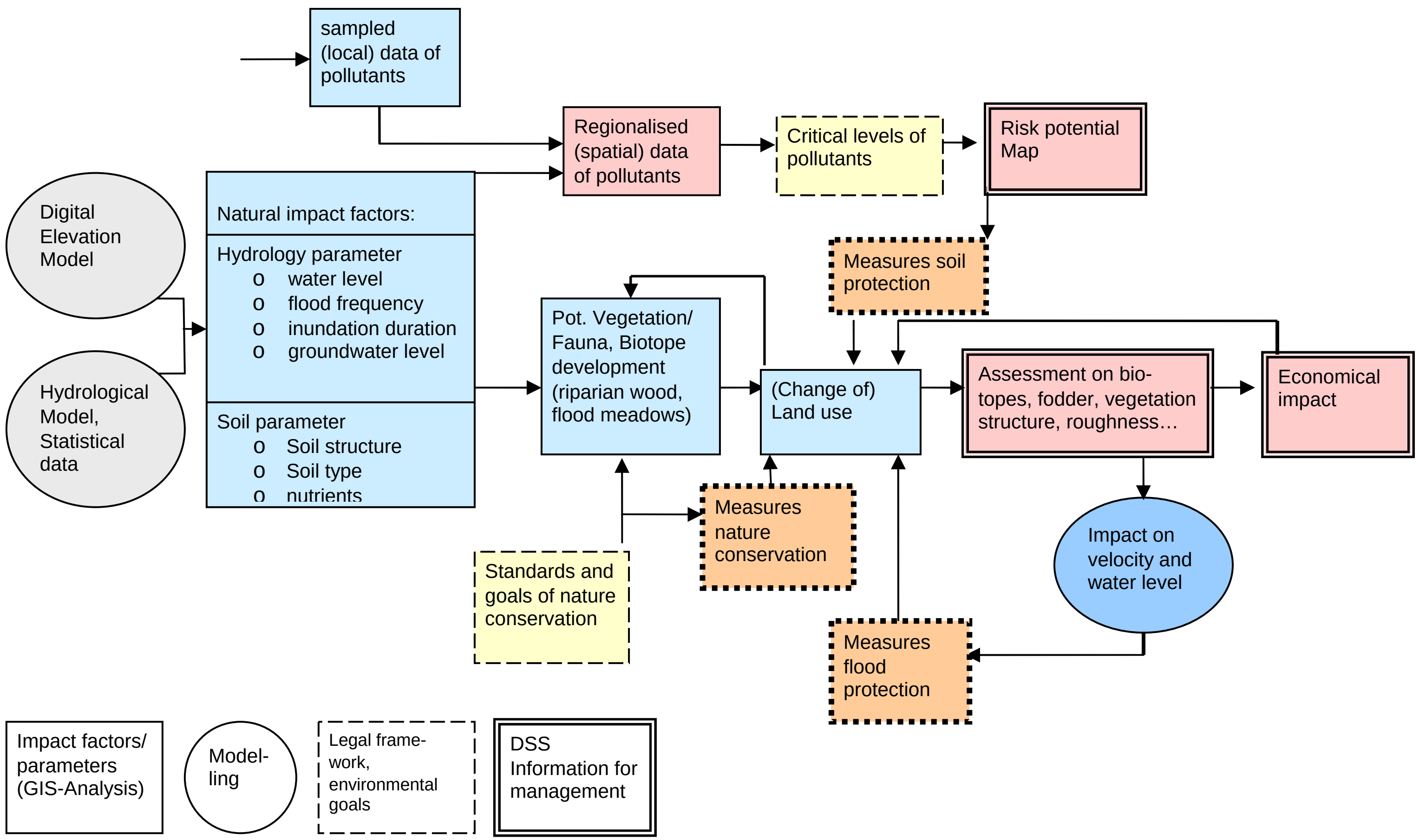

Fig. 2 System diagram of cause-and-effect relations in Integrated Flood and Land-Use Management (simplified) in a DSS.

Decision Support Systems (DSS) are explicitly designed to handle semi- or ill-structured problems (El-Najdawi & Stylianou 1993; Geertmann & Stillwell, 2003). A DSS can be defined as a computer-based instrument that can be used to support the planning and/or policy-making process. In a DSS, a structured approach towards river basin management is combined with eminent Information Technology, leading to an instrument that facilitates the processing, the analysis and the presentation of information (BfG, 2000). A DSS helps the end-user to assess what is the relevant information in the planning process. This information enables the end-user to enhance the quality of the various actions that are to be taken. On the one hand, these are actions with respect to the content of the policy like problem analysis, forecasting of future contexts, design and screening of alternatives, impact assessment and comparing and ranking alternatives. On the other hand, these involve more actions including communication, interactive policy making, etc.

There is a wide range of possible DSS definitions and core functionalities. Hahn, & Engelen (2000) distinguish two types of computer-based DSS:

1. *Data-oriented DSS* are primarily concerned with retrieval, analysis and presentation of data.
2. *Model-oriented DSS* include activities such as simulation, goal seeking and optimization.

They list the possible functions of computer-based DSS as:

– analysis (holistic representation of the system—linkages between natural systems and socio-economy);
– communication between policy makers and stakeholders in participating planning efforts (dynamic);
– library (serve as a knowledge management infrastructure);
– management (evaluation of general decisions and revealing of measures);
– learning (linkage of processes, natural and user functions).

Experiences with model-based DSS, for example in The Netherlands with a generic DSS for flood management and landscape planning (Delft Hydraulics, 2005; http://www.wldelft.nl/rnd/intro/topic/generic-dss/index.html), including intensive and interactive public participation, show successful examples of their use and their implementation in planning processes.

But developing large-scale and complex catchment-based systems with integrated participatory tools is very time and money consuming. One of the reasons is a series of frontiers, for example:

– unsatisfactory database (hydrological, digital elevation model);
– administrative boundaries;
– data availability, technical access, high costs;
– different methodologies are used;
– complex and costly models (understandable only for experts);
– problems with language and communication (e.g. between water and environmental managers) exist so the exchange of information is suboptimal.

Furthermore a DSS has to be purpose-driven and tailored otherwise the implementation is not sophisticated enough. So a careful process and user analysis along with extensive exchange between developers and users are essential for creating an accepted DSS for practical use, which makes DSS development again quite complex.

Therefore, it is crucial to identify strategies and synergies to minimize costs and optimize the use of flood-related technologies.

In the flood plain of the River Elbe in Germany, one of the projects in the European cooperation project FLOWS (http://www.FLOWS.nu) is developing a data-based DSS for land use management. It was important not only at the beginning of this project to make a thorough data search and to perform a process analysis to obtain information about the real planning processes, the data used and needed, and about the technical equipment of the institutions and boards which are involved in flood protection and planning. During interviews with planners, their technical infrastructure and personal commitment to the use of information systems were assessed. As a result it became obvious that the system has to be designed to be as simple and user friendly as possible. This is the reason why the concept of the DSS omitted the use of integrated simulation models. Therefore, a data-oriented DSS was developed which supplies planners with structured interdisciplinary information and flood related data. These data allow planners to view, organize and even analyse relevant planning information to support knowledge-based decisions (Evers *et al*., 2005).

This system combines spatial and flood-relevant as well as economic data. By modelling various scenarios, central questions which were first discussed with the relevant interest groups and stakeholders, were then analysed and possible development variants were visualized. All the data and results will be put at the decision makers' disposal by means of an OGC-conforming (Open GIS Consortium http://www.opengeospatial.org) web-based mapping and information service. A user-friendly operating service is provided. The aim is to support knowledgeable and objective planning in order to achieve the integrated land use management of flood plains in terms of sustainable development. The DSS shall not only simplify and support planning and decision processes but also make them more transparent. An important aspect was the discussion and interactive learning process of all stakeholders and participants in this planning process.

Important assumptions are (Evers *et al*., 2005):

1. The DSS architecture should fit best into the already existing architecture of the relevant administration boards and other institutions.
2. All relevant dislocated (Geo) data should be collected, smartly organized and concentrated in one structure.
3. The possibility of continuous data integration must be provided.
4. The DSS should visualize scenarios and possible solutions for upcoming questions.
5. It is more important to create a user friendly system which meets the requirements than to build up a complex model system.

STRATEGIES FOR USING WATER AND ENVIRONMENTAL TECHNOLOGIES

One aspect which is especially important for Integrated Flood Management is the operating in the context of the catchment area. But as shown above, there are some restrictions that have to be eliminated. The following illustrate some ideas and strategies for a better use of water and environmental technologies for integrated flood management:

- Minimum standards for data collection.
- Calibrated and coordinated evaluation and data collection for the whole river basin, and a multilateral approach where international cooperation is needed on transboundary rivers.
- Data collection programmes for the whole catchment (hydrology, land use, elevation of the flood plain) with several priorities.
- Free and unrestricted provision and transfer of meteorological data and products, as defined by World Meteorological Organization (WMO) in resolutions 40 and 25 of the twelfth and thirteenth WMO Congresses, respectively, and close cooperation between hydrological and meteorological services (UN, 2000).
- Free exchange and application of flood-related information and services across networks, different platforms and products by using standards such as OGC (less time, less cost, and more flexibility for data exchange).
- Accessibility of flood related data via the Internet by using standards for internet-based retrieval of geospatial maps. One way is to distribute GIS data via an OGC conforming Web Mapping Service (WMS) where predefined data and data with a similar layout can be visualized in grid pattern format. The second is vector-oriented exchange by the Web Feature Services (WFS). These data may be integrated in existing geo infrastructures and be analysed by a wider functionality. For example, municipalities are interested in being able to access land use plans where flood areas are being identified. The mutual access to spatial data has several advantages. The costs of data handling are shared. Data can be kept where it is collected and administered by the responsible persons. For example the Federal Emergency Management Agency FEMA of the United States is providing a national Flood Map Web Mapping Service for the United States. This service is in compliance with OGC's Web Map Service (WMS) Interface.
- Because of the multi-purpose demands of integrating water and environment, establishment of a network centred, modular structured system might be a solution for more cooperation and synergies in modelling (Tumwesigye *et al*., 2005). Web enabled agents (components) which are loosely coupled could communicate via the Internet. Within this approach, the clients would be able to access the modelling software via Internet facilities and to develop models, execute them and analyse their results in a more efficient and cost-effective way.

CONCLUSIONS

Water and environmental technologies have to be seen as two sides of one coin. Within the complex field of Integrated Flood Management, a wide range of possible synergies becomes obvious.

Both sides can profit from each other. Diverse data sets are important for different research questions.

In fulfilling this research approach, e.g. optimizing the retention potential by adapting land use in the catchment, or protection and development of riparian woodland in the flood plain, go hand in hand.

For many environmental or spatial analyses, the use of GIS-based technologies is adequate.

To obtain hydrodynamic information the application of water models is necessary. When it comes to river basin management questions and decision processes, public participation must be included. Therefore water and environment technologies integrated in data-based or model-based Decision Support Systems (DSS) are extremely helpful. Since the development of a sophisticated DSS is normally very time and money consuming, effective approaches such as Internet-based modelling and modularization might be a solution. It is very important to run coordinated data collection for the entire catchment area, and equally important to establish smart structures that enable the exchange of, and access, to flood related data.

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