SPATIAL APPROACH IN RIVER BASIN MANAGEMENT USING DECISION MAKING STRATEGIES

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Abstract: The information needed for River Basin Management covers a wide range of hydrological and environmental data and methods. Since all measurement data are spatial and time related, spatial services fulfill the requirements in a decision making process best. In this work an open data structure for storing spatial temporal related data is proposed. Based on the data structure the modeling process can be performed directly in a GIS environment by using visualization and spatial analysis techniques. This concept incorporates the functions available in a GIS environment with the modeling concepts used in River Basin Management. The paper concludes with experimental results and gives a short outlook to future work.

1 INTRODUCTION

The development and management of water resources requires the simultaneous consideration of numerous relationships and impacts such as water quality, land use, rainfall, water storage, reservoir management, irrigation, agricultural use, groundwater, water supply, drinking water, and pollution. There is a great interest for optimizing the management of river basins, and there is the need for coordination and integration of a large amount of spatially related information and models for decision making (Gunatilaka, 2003).

The information needed for *River Basin Management* (RBM) covers a wide range of hydrological and environmental data and methods. Several needs to meet these objectives have to be fulfilled. Among those are commitments to sustainable development, to support decisions for the basin for environmental measures and to consider diverse flood mitigation options. A *Decision Support System* (DSS) thus contains tools to support hydrologists in their decision making process. From database management or information systems via simulation models with mathematical programming or optimization, almost any computer-based system could support decisions.

In this work a concept is proposed which combines the functions available in a GIS environment with modeling concepts used in RBM. The advantage is that the construction of a model can be performed directly within a GIS environment using spatial services. Once the model is constructed a simulation for a given situation in the river basin can be performed. This approach can be used for different kinds of calculations like precipitation run off or even river quality monitoring. The fact that a river system is based on network structure with edges and nodes and connection rules each part of the network can be based on a specific model.

Once a model is calculated all results can be stored in a central database as time series data. This gives different kinds of applications the possibility to access these data through standard interfaces. The results can be visualized and analyzed in the GIS environment using standard functions.

2 ENVIRONMENTAL INFORMATION SYSTEM

To support the modeling of hydrological events an *Environmental Information System* (EIS) can serve as the central unit.

An important aspect is how the measurement data are transferred to this central unit. In a river basin all kinds of monitoring stations measuring rainfall, river quality, industrial flow or water level

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are located all over the basin. These monitoring stations can be offline or online stations. At an offline station the data are collected manually by means of lists. Compared to offline stations, online stations are directly connected to the central database via telemetry network. As soon as, for example, the water level in an online quantity station is measured, the actual value together with the timestamp is sent to the central unit.

Consisting of a set of digital maps, input, and output forms, special tools for numerical and spatial data analysis, plausibility control, visualization and presentation the EIS guarantees the appropriate handling and evaluation of all measurement data.

2.1 Spatial Temporal Data Storage

The EIS is planned to consist of a centralized state of the art database management system, providing functions necessary for storing, monitoring and analyzing of data. The basic data structure should be designed in an open standard, thus any application can access these data using standard interfaces.
For each measurement it is important to know where the measurement was made, what was measured and when the measurement took place.

These spatial temporal data have to be stored in such a way that each model can easily access the data. A data structure for flexible data storage consists of the following entities:

- Measurement Unit (MU)
- Measurement Parameter (MP)
- Time Series (TS)
- Measurement Data (MD)

Each MU has at least a unique identifier, a name, a location and a description. This MU can have one or many *Measurement Parameters* (MP) (or

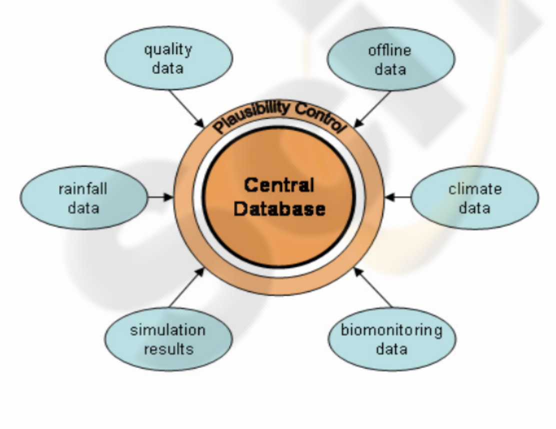

Figure 1: Different kinds of possible data sources

measurement sensors). Each MP (sensor) records *Measurement Data*, which have at least a timestamp, location and the measured value.

An important aspect towards open systems is that for each measurement at a MU for a certain MP an entry in the *MeasurementData* table is created. Using this kind of storage enables data access from different kinds of external models or applications without using middleware. Furthermore, this data structure enables the extensibility of MU's and MP's.

2.2 Plausibility Control

In an EIS the data themselves are of utmost importance. For decision supporting purposes the data have to be complete, correct and feasible. By transferring data from online stations or manually to the central database, these data can be corrupted due to sensor errors or input failures. By using wrong data the modeling process will be strongly affected, thus leading to wrong simulation results. In Figure 1 the data import through the plausibility layer from different kinds of possible data sources is depicted.

In order to avoid passing wrong data to the central database, a plausibility control is proposed. Each entry of a measurement should pass this check. A simple approach is to store a certain set of limits that is used to inspect the measurement values for each parameter. For each MP the following attributes are possible:

- minimum threshold value,
- maximum threshold value,
- allowed deviation from the mean value

For special purposes a constant limit is not sufficient, because the measurements for some MP's are time dependent. The limit values during the night may differ from the daily limits.

In order to have temporal dependency these limits can be modeled as a time series pair for upper and lower boundary for each MP. These limits are used to check the incoming data. Depending on whether the measurements are within the allowed range, the data are set to valid or invalid. Only valid data are accepted for analysis and reporting.

2.3 Spatial Data Retrieval

A *Geographic Information System* (GIS) incorporates all necessary tools for visualizing and analyzing geographically related data. Results of queries can be visualized directly on a map and data from different geographic related assignments like catchments areas can be handled.

An EIS should combine all necessary tools for managing and analyzing data in the central database. All clients have the possibility to retrieve all kinds of data from different sources (quality data, simulation results, climate data, etc.) from this database. An important aspect towards interoperability is that spatial related data are stored in a database which supports Open GIS technology defined by the Open Geospatial Consortium (OGC) (OGC, 2005).

All data in an EIS are related to spatial temporal information, thus all monitoring stations, catchment areas, river reaches etc. can be visualized and analyzed in a GIS.

Since a MU has a spatial reference which can be static (online measurement unit) or even dynamic (mobile measurement unit) it can be visualized on a map using spatial services. A river network consists of nodes and edges and relations to catchments or reservoirs. A node, for, instance, can be a junction or diversion, whereas an edge can be a river reach, a channel, etc. In Table 1 different possible spatial representations of a MU are shown. In a river network it is evident that each network node, edge or region has the possibility to store time series data.

Table 1: Different kinds of spatial representations

Representation	Objects in a river network
point	source, junction, diversion, etc.
polyline	river segment, channel, etc.
polygon	catchment, reservoir, etc.

3 SPATIAL DECISION SUPPORT SYSTEM

Basically, a *Spatial Decision Support System* (SDSS) attempts to provide the water-resources managers with analytical assistance based on spatial information in making rational choices based on objective assessment, thereby reducing the element of subjective opinion (Gunatilaka, 2001), Malczewski, 1999). This requires a broader approach, which is otherwise limited within the narrow realms of hydrology and water resources. For the decision making process there is the need to include spatial and quantitative information wherever possible on economical and environmental considerations (Clemen, 1996). Therefore, an SDSS can be regarded as form of artificial intelligence in which computers are used not only to predict, what is likely to happen given various assumptions, but mainly to supplement management experience in decision-making.

3.1 Spatial Modeling

The first step towards a SDSS is to describe processes and data by means of hydrological, hydraulic, sediment transport, meteorological and ecological models. These models have to be integrated into general decision making approaches.

Integrated mathematical computer models comprising hydrological models, hydraulic models, flood forecasting models, water balance models, water resources management and reservoir optimization models as well as water quality models are in themselves tools that support decision making. In order to transform the outputs from these models into practical decisions, they need to be combined with other type of information, such as details of infrastructure, possibilities for control, spatial information etc. In an SDSS these tools combined with spatial data can be integrated in a GIS environment. A model can be an internal model, which runs on the same machine in the decision support environment, or an external model, which is an external application like HEC-1 or HEC-HMS (Cunge, 1992). Important for an external model is that a preprocessor prepares the data necessary for

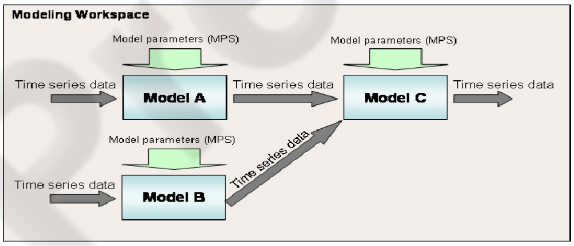

Figure 2: Modeling Workspace.

the external model and a post processing task which retrieves the result data back to the central database (Fürst, 2005).

A model can be controlled by means of model parameters. A *Model Parameter Set* (MPS) contains all attributes necessary to initialize and control a model calculation. As input data for a model calculation all time series data in the EIS are valid. After successful calculation of a model the results are stored again as time series data. One model can be defined as network and can have one or more predecessor and one or more successor models. Using this principle, different models are using time series data from the EIS. All connected models together with the MPS's build up a *Modeling Workspace* (MW), which is depicted schematically in Figure 2.

3.2 Simulation Results

When starting a MW, a *Simulation Run* (SR) is created. Each model in the MW is started in respect to its correct order. A model can only be started if the necessary input data are already calculated by the previous model. In this example a precipitation run off simulation is used. The area of the MW

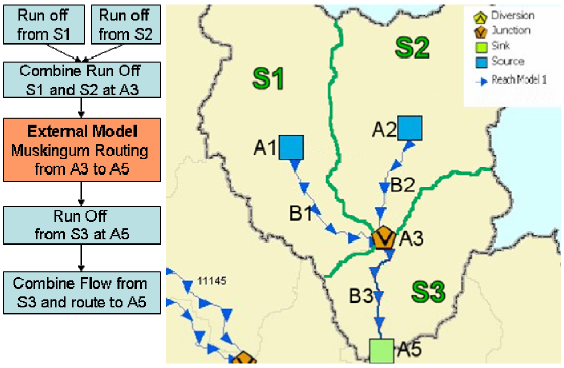

Figure 3: Modelling Workspace for a precipitation run off model

consists of three sub basins *S1-S3* two sources *A1, A2* one junction *A3*, a sink *A5* and three reaches *B1-B3* (see Figure 3). As river reach several models can be used like Simple Lag, Modified Puls, Muskingum, etc. In this example the Muskingum routing model was used for the reach *B3*.

First the run off from the two sub basins *S1* and *S2* are calculated and combined at the junction *A3*. Next an external calculation of Muskingum routing from *A3* to the sink *A5* is performed using HEC routines. Finally the run off from *S3* is calculated and combined with the routed flow to the sink *A5*.

One MW can be started for different MPS's, thus resulting in several simulation results. The MW can be represented directly in a GIS environment (see Figure 3).

In Figure 4 the results of a simulation run is presented where the simulated flow at sink *A5* can be visualized as time series. In addition to the simulated flow the observed flow can be displayed.

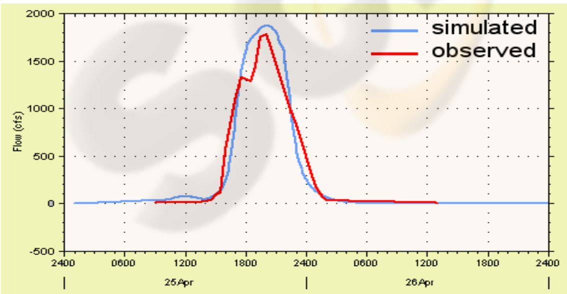

Figure 4: Observed and simulated flow at sink *A5*.

4 CONCLUSION AND OUTLOOK

An *Environmental Information System* contains tools to manage data from online or offline monitoring stations in a river basin. All data in a river basin are spatial temporal related. GIS functions and external tools can be combined for hydrologic modeling and will support hydrologic experts in decision finding processes.

Future work will concentrate on concepts for integrating digital elevation models (DEM) for watershed management, thus allowing stream and sub basin delineation.

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