Geoinformatics Toolset for Integrated River Basin Management (IRBM) of the Saale River, Thuringia, Germany

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Abstract: In the joint research project "Development of an Integrated Methodology for the Sustainable Management of River Basins - The Saale River Basin Example", coordinated by the Centre of Environmental Research (UFZ) in Germany, concepts and tools for an integrated management of large river basins are developed and applied. The ultimate objective of the project is to contribute to the holistic assessment and hydrological benchmarking for water resource planning, as required by the European Water Framework Directive (EFD). The study presented here deals with (1) the refinement of a regionalization approach adapted for integrated basin modeling and (2) the implementation of a river basin information and modeling system . The approach combines a user-friendly basin disaggregation method that preserves the catchment's physiographic heterogeneity, with a process-oriented hydrological basin assessment for scale bridging integrated modeling. The well-tested regional distribution concept of Hydrological Response Units (HRU) will provide the spatial modeling entities for process-oriented and distributed simulation of the vertical and lateral hydrological transport processes. Based on their topological network structure improved modules have been developed to describe the lateral fluxes between them and towards their associated channel segments. This methodical enhancement will be applied to the river basin of the Saale (A = 23179 km²) and validated by a nested catchment approach, which allows multi-response-validation and estimation of uncertainties of the modeling results. The integration of simulation models describing the different stakeholder activities (reservoirs, agriculture, consumption by urban settlements and industry) in such a complex basin system is realized by coupling various modeling approaches within a well-defined model framework system. The latter is interactively linked with a comprehensive geo-relational database (DB) serving all research teams involved in the project. This interactive linkage is a core element comprising an object-oriented, internet-based modeling framework system (MFS) for building interdisciplinary modeling applications and offering different analysis and visualization tools.

Keywords: *River basin information; Hydrological Response Units; Modeling*

1. INTRODUCTION

This paper presents one of the work packages of the project "Development of an integrated methodology for the sustainable management of river basins - The Saale River Basin example". The main objective of the project is the regional hydrological modeling of the Saale Basin with the modeling system MMS/PRMS (Precipitation Runoff Modeling System, LEAVESLEY ET AL. 1996). To account for scale transfer, the concept of HRUs (Hydrological Response Units, FLÜGEL 1996), delineated by means of GIS, is used for the regionalization of processes and parameters. The aim is to find spatial units which still bear the capability to model hydrological transport in a range of scales and in a process-oriented way. Specific interest will be put on process modeling according to the minimum requirements of input data necessary for physically based approaches. Thus, the generic applicability of the model methodology for other large mesoscale to macroscale basins in similar environments will be investigated. Hence the study will contribute to the holistic assessment and benchmarking approaches in water resource planning, as required by the European Water Framework Directive.

1.1 Objectives

The research will be carried out according to the following specific objectives and work tasks:

- Development of a representative hydro-meteorological project database;
- Development of a spatially enabled information system on basis of the project database;
- Hydrological systems analysis of precipitation and runoff variability in the basin;
- GIS-based and process-oriented delineation of HRUs, and landscape oriented aggregation of model units;

- Regional hydrological modeling of runoff generation with specific respect to quick flow components using different modeling approaches available within MMS/PRMS and using a nested catchment approach based on the hydrological systems analysis to account for spatial scaling; and
- Development of a protocol, including a tutorial with sample data and modeling problems, to enable the methodical integration of systems analysis, GIS and remote sensing for process parameterization into a regional integrated modeling system.

The analysis of the distributed HRUs, their dominant processes and their topological interactions will be central in the study. Besides the methodical integration, specific macroscale problems will be tackled.

2. STUDY AREA

The methodical development and the model validation is carried out in the Saale river basin. The Saale springs in the Fichtelgebirge, runs through the Thuringian Forest and its forelands, and crosses the Thuringian Basin as well as the Magdeburger Bördelandscape to mouth into the Elbe north of Calbe. On its way it picks up several larger tributaries like the Ilm, the Unstrut, the Weiße Elster and the Bode, and altogether is

➢ ***Geology:*** The catchment is characterized by shale bedrock of the mid-mountain range, the porous Sandstone of its forelands, the karstic Limestone bordering the Thuringian Basin, the keuper-landscape and the lowland-sediments of the börde-region.
➢ ***Climate:*** The Saale basin is influenced by oceanic climatic conditions. There is a typical increase of precipitation which highly correlates with increasing altitude from the Magdeburger Börde (500 - 600 mm/year) to the Thuringian Forest (>1300 mm/year). The average Temperature shows an inverse behaviour.
➢ ***Topography:*** Parts of the catchment belong to the midmountain range as well as to the basin- and bördelandscape.
➢ ***Land use:*** Different characteristic types of landscape like the forested highlands, agricultural areas and börde-landscapes can be differentiated.

3. METHODOLOGY

Based on the objectives, the methodological work is structured in several working packages, presented below.

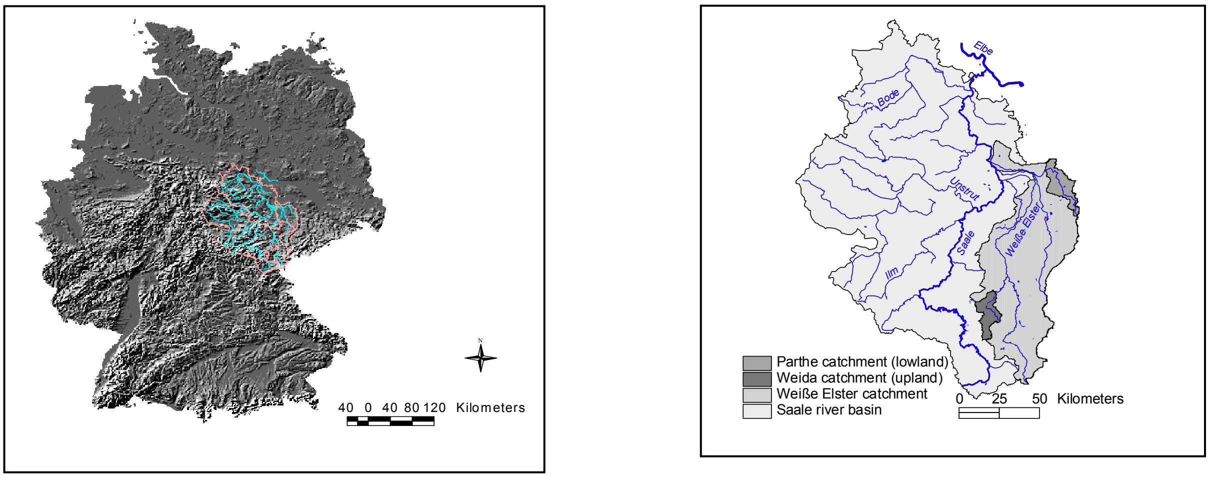

Figure 1. The Saale catchment in Germany and some of its main tributaries.

draining a catchment area of 23719 km^2 measured from the gauging station Calbe-Grizehne. With regard to the administrative borders, the bigger part of the catchment belongs to Thuringia with smaller parts in Sachsen-Anhalt, Saxony, Bavaria and Lower Saxony. The physiographic catchment structure is pretty heterogeneous:

3.1. Hydrometeorologic Project Database

A major objective of this working package is to develop a central database for the project work and especially for the hydrologic catchment modeling. For that, the data have been statistically analyzed and checked for consistency and homogeneity using statistics software that was developed at the Department of Geoinformatics. This software puts the heterogeneous datasets in a uniform file format. To estimate the data consistency and plausibility different statistical test were applied.

In consultation with other partners in the project, the period of investigation and the temporal resolution for modeling were fixed for the period from 1960 to 2000 with daily time steps. Only such hydro-meteorological time series were selected which had almost complete time series for that period. Besides that, the spatial distribution of the stations across the catchment should be as consistent as possible and represent the different landscape units. Meteorological time series were supplied by the German Weather Service (DWD). The acquisition of runoff and groundwater data proved to be very time consuming because four federal agencies with several sub-agencies were involved. The basis for time series data selection was, again, the consistency of the data sets. The number of stations and their types are summarized in table 1:

Table 1: Stations types

Station type	No.	Variables
Climatic	37	Precipitation, Temperature, Wind, rel.Humidity, Sunshine duration, Snow, Water equiv., Sort of Snow cover, Global radiation
Precipitation	441	Precipitation, Snow height, Sort of Snow cover
Streamflow	161	Runoff, Water level
Groundwater	567	Groundwater table

3.2. Hydrologic System Analysis

The aim of this work package is it to achieve the necessary hydrologic system understanding for the process modeling by analysis of the land use-specific runoff generation. For system analyses, the above mentioned data sets are used.

As a basis for the consequent hydrologic modeling, the sub-catchments were delineated from the digital elevation model (DEM). For all catchments, statistical information about their physiographic properties (land use, hydrogeology, soils, etc.) as well as photographs describing the landscape were extracted and will be available from a River Basin Information System. These investigations in combination with the analyses of the precipitation data shall improve the system understanding in terms of seasonal runoff variability and, therefore, the modeler should be enabled to delineate catchments with similar process dynamics.

3.2.1 Scaling Problems and Modeling Concept

It is a well known problem that individual processes of the water and solute transport cycle, within a catchment, have different dominance with changing spatial and temporal scales (KLEEBERG ET AL. 1999). The scale dependence of quantitative hydrologic processes and of the important precipitation input, is presented in Figure 2 (after BLÖSCHL 1996). Shown is the changing dominance of the individual runoff generation processes and their spatial and temporal interrelation. The temporal and spatial scales of the study basins "Weida-Zeulenroda", "Weiße Elster" and the total area of the Saale are denoted by vertical lines.

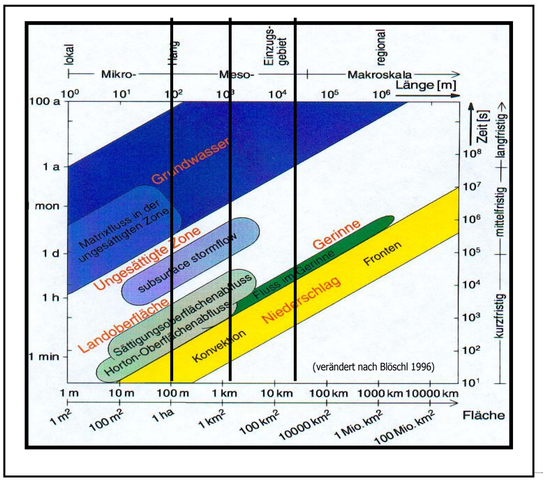

Figure 2. Scale dependency of several hydrological processes

The processes that are dominant or influence the discharge at the catchments outlet are shown by the cut lines of the catchment areas. For the river Saale it should be noted that the discharge dynamic at the confluence with the Elbe is dominated only by three processes: basis runoff, hydraulic flow and precipitation distribution (Fig.2). However, this does not mean that the other processes like interflow or direct runoff do not have influence on the hydrograph curve and are, therefore, negligible. Nevertheless, at the outlet they cannot be separated and differentiated clearly any more and thus cannot be validated against observed data. In smaller catchments, like the test area Weida-Zeulenroda (see Fig. 1), the fast runoff components and their generation also contribute to the discharge dynamics at the outlet and therefore also can be separated and validated there. Apart from spatial scale-dependent process dominance one must also consider the temporal resolution of the modeling. For example, the processes which lead to the generation of the fast runoff components (in particular infiltration surplus and thus Horton direct discharge) are temporally highly dynamical and also often of short duration. They can be modeled in detail, if high resolution, temporal data are available.

A further criterion that is indirectly coupled to the scale problem, is the increasing heterogeneity of the area characteristics and the spatial distribution of the input data with increasing catchment size. This has influence on the process reproduction on the one hand and, on the other hand, makes high demands concerning a funded regionalization of the input data. The points to the scale problem, stated above, which refer only to the quantitative hydrology are stressed additionally by integrating the solute transport into the model concept.

Small-scale and temporally short time processes in large catchments can often be simulated by strong conceptualisations of the model.

Since these processes are very important for solute transport, they have to be simulated with a substantially higher temporal and spatial accuracy. In particular, the processes of the runoff concentration (lateral flow processes), which are often very strongly simplified on the mesoscale have to be improved. From these considerations the selected distribution concept was further developed and extended with a hydrodynamic topological routing which is described in the next sections.

3.3. Model Concept

This work package elaborates and presents an approach to model the „Water Cycle" in a scale independent way. The main focus lies on the development of a spatial discretisation approach which is able to (1) represent the quantitative processes as adequate and scale independent as possible, and (2) serve all other modeling components of the integrated project, with spatial entities which allow the process-oriented representation of landscape and can be integrated over the whole investigation area.

Generally two fundamental distribution concepts can be differentiated within quantitative and qualitative hydrologic modeling, which are the raster-based procedures and the Response Unit (RU) procedure. Using raster-based procedures the implementation of individual process methods is simpler and in particular the reproduction of lateral processes can be more easily solved whereas the Response Unit procedure is more suitable for process-oriented considerations of the catchment area. Additionally, they permit a substantially better and scientifically more founded arrangement of large heterogeneous catchment areas by the classification of scale-independent process entities. The topology of the entities required to specify the lateral linkage between RUs has been established by STAUDENRAUSCH (2001). The classification methodology of these process entities and the determination of their topological relationship is described more detailed in section 3.3.1.

3.3.1 HRU as spatial modeling entity

- For vertical processes the well-tested HRU approach (BONGARTZ 2001) will be applied. GIS overlay functions are used to delineate units with the same modeling parameters, which leads to physiographic Response Units (FLÜGEL 1996) which are scattered in the catchment but include a distinct geo-referenced location in the basin.
- The RUs from step 1 are disaggregated to discrete RU-Polygons (STAUDENRAUSCH 2001), whereby the information content of the basic HRUs is preserved. Additionally the topology of the patches can be determined, for example by their center of gravity.
- Using a digital river net the relationship of the individual process entities is determined concerning their neighborhood (polygon topology).

The lateral linkage of the HRU-Entities (Fig. 3),the association of RU entities to the appropriate channel reach, the connectivity of the river reaches among each other as well as the location of reference points within the river network build the topology within the basin (STAUDENRAUSCH 2001). This reproducable distribution concept has the advantage that a multiplicity of important physiographic parameters can be pre-determined. Thus the actual formulation of the process methods for the different components of the water and solute transport becomes simpler and more durable.

3.4. Data Modeling and Integration

Due to it interdisciplinary characteristics and the amount of data, the project must be supported by tools which allow all partners and, eventually, members of the public to have access to the data.

System integration is achieved by two tools, each of which implements different aspects of data use in a project. On the one hand there is the data visualisation. At the first project stage it is necessary to provide access to the time series, which are all related to the monitoring stations. In a second phase, all project data, including geographic data, must be made available. The Internet has been chosen due to its de facto ubiquity to serve as a graphical front end to selection of stations.

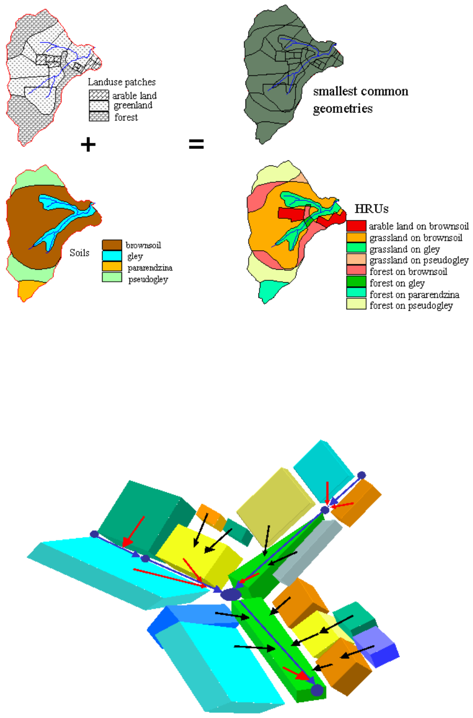

Figure 3. Scheme of delineation and topology of HRUs

There are also interoperability issues to be solved. Time series are input data for the simulation models and must be made available in textual, i.e. in ASCII, tabular or in other form, also through the Internet. Here the Extensible Markup Language (XML; W3C 1997) has been chosen to function as an interface between database and simulation models.

Thus, data are available through an Internet-based Saale River Information System (Saale RIS). The Saale RIS is built up using an object-oriented components library that provides visualisation and XML-based interoperability tools (TADDEI 2002). For object-oriented hydrological process modelling a new framework has been developed which is described in the next chapter.

4. THE OBJECT MODELLING SYSTEM OMS

The Object Modelling System (OMS) (DAVID, O. 1997) developed from the idea of a modular modelling framework started off by LEAVESLEY ET AL. (1996) with the development of the Modular Modelling System (MMS). MMS is a framework for modelling as well as for the development, support and application of any dynamic model. A major limitation of MMS is that it is object based and not object oriented. That is, it does not support the object-oriented functionality of features such as abstraction, inheritance, or encapsulation. OMS tries to take the good parts and ideas of the MMS and to implement them as a fully object-oriented modelling framework using Java, which also makes the OMS operating system platform independent. The basic system architecture (Figure 4) is divided into components, i.e. process modules, data libraries, and a model builder, which is used to build a specific simulation model. An Internet interface and DB access rounds the system up.

The OMS System Components provide the common functionalities that are needed for a consistent and flexible runtime environment for model development and application. Additional components like a GIS Client or the Update Centre enhance the overall system and enable spatial data processing and shared development and application of model components or model assemblies. The OMS System Components are complemented by the OMS Model Components, which form the building blocks for all models created within the framework.

Whereas the model components themselves are implemented as Java classes, the real functionality covered by the mentioned methods can be implemented in different languages, e.g. F77 or C++. This foreign code - included into the module as Java comment - is automatically parsed and compiled into a shared library during the development stage. The resulting native code library will be accessed at execution time via the Java native interface.

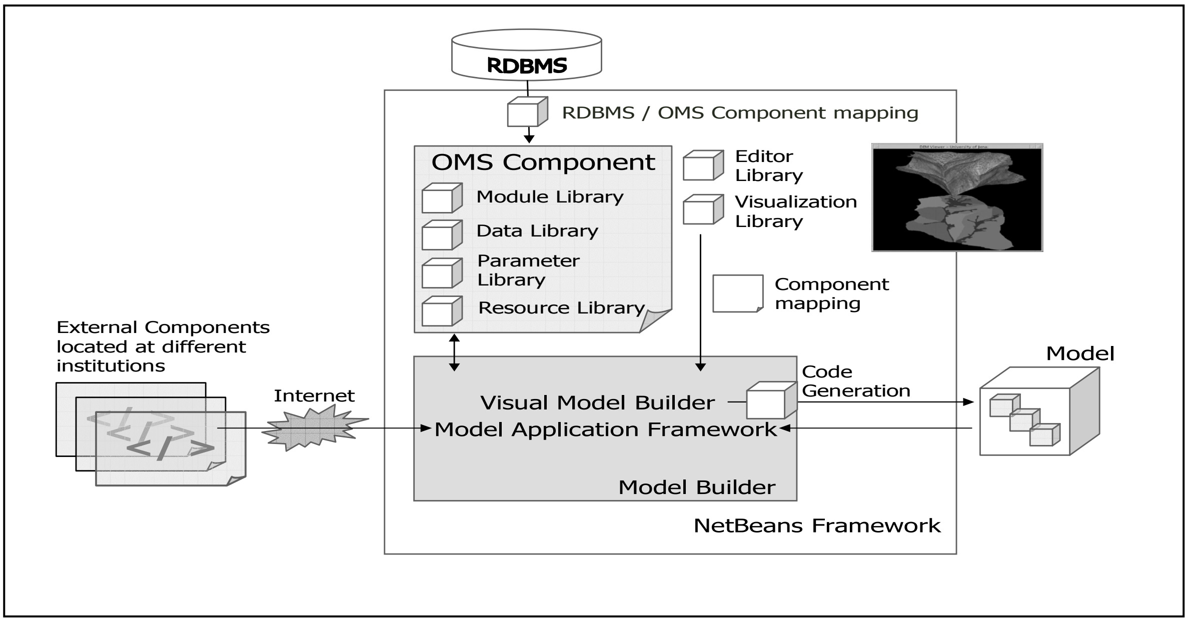

Figure 4. Schematic layout of the Object Modeling System OMS (after DAVID, 1997)

5. CONCLUSIONS

The object oriented distribution concept for the Saale river basin differentiates the basin in process oriented landscape entities. They are applied by the PRMS model embedded in the Object Modeling System OMS. The latter is at present under design as a state of the art framework for platform independent model development and application. The hydrological models PRMS and RZWQM (RZWQM Team 1995) have already been integrated into the system and are under test. These tests will be complemented by the development of a comprehensive Module-Library for quantitative and qualitative hydrology.

The object-oriented and modular approach of the OMS and its implemented models will provide the basis for efficient and innovative model development, required for large scale and global hydrological research.

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