GLOWA-DANUBE: INTEGRATIVE MODELLING OF GLOBAL CHANGE EFFECTS ON THE WATER CYCLE - THE GROUNDWATER PERSPECTIVE

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Abstract. GLOWA (Global Change of the Water Cycle, www.glowa.org), funded by the German Ministry of Research and Education, addresses the manifold consequences of Global Change on regional water resources in a variety of medium sized watersheds. The Upper Danube Basin (A ~ 77.000 km²) represents a mountain-foreland situation in the temperate mid-latitudes. The major goal of "GLOWA-Danube" is the development of new water resource management modelling technologies integrating natural and socio-economic sciences. A university-based distributed network of experts are developing and utilizing the Decision Support System DANUBIA, a coupled system that is based on re-useable, refineable, well-documented sub-models. DANUBIA and its sub-components are object-oriented, spatially distributed, raster-based and developed using the Unified Modelling Language UML and Java. This paper describes the framework of GLOWA-Danube and the integrated model DANUBIA with a focus on the two models developed by the University of Stuttgart.

Keywords: Global Change, Integrative Modelling, Groundwater Model, Water Resources Management, Danube

THE GLOWA-DANUBE PROJECT

The increasing intensity of water use, as well as conflicting water-related interactions between numerous stakeholders has put increasing pressures on the natural environment and ecology. The European Water Resources Directive stresses the importance of decision support systems (DSS) as tools for sustainable development based on participatory decision making. Recently, integrated approaches to describe, model, and forecast physical, social, economic, and political processes related to the hydrological cycle, in particular with regard to Global Change, have gained worldwide attention both with administrative authorities, as well as in the research community. Within the GLOWA-initiative (Global Change of the Water Cycle, www.glowa.org, funded by the German Ministry of Research and Education (BMBF)), the Upper Danube watershed was selected as a representative mesoscale (A ~ 80.000 km² at Gauge Passau) test site in the temperate mid-latitudes. The interdisciplinary research co-operation "GLOWA-Danube" is developing the "Global Change DSS DANUBIA" to investigate the sustainability of future water resources management alternatives. The system equally considers the influence of natural changes in the ecosystem, such as climate change, and changes in human behaviour, e.g. changes in land use or water consumption (Ludwig et al., 2003). GLOWA-Danube comprises a university-based network of experts combining water-related competence in the fields of engineering, natural and social sciences. The project consists of the following disciplinary research groups which cover the essential modules in GLOWA-Danube: Coordination and GIS, Remote Sensing - Hydrology, Meteorology, Water Resources Management - Groundwater, Water Resources Management - Surface Waters, Plant Ecology, Environmental Psychology, Environmental Economics, Agricultural Economics, Computer Sciences, Glaciology, Remote Sensing - Meteorology and Tourism Research. In the first phase of the project (2001-2004), a prototype of the DSS "DANUBIA", comprised of 15 fully coupled disciplinary models, was developed and is now in a stage of validation and refinement. The second project phase (2004-2007) started in March 2004. While the focus of the first phase was on the development of technical solutions, process descriptions, definition of exchange parameters and interfaces, and disciplinary model development, in the second phase scenario evaluation, stakeholder involvement, decision making, and water management support are in centre of the research activities. However, it has become apparent that there is still a need for detailed basic research in several parts of the system to gain a better understanding of the process, namely concerning the aspects of coupling groundwater, surface water, and land surface models.

The Upper Danube Basin

The Upper Danube basin is located in Southern Germany (75%) and Austria (25%) and has an area of 77,000 km^2 at the Passau gauging station. The model area is quite heterogeneous geographically and geologically. From the high, mountainous alpine region down to the Danube lowlands there is an elevation difference of more than 3,500 m (Figure 1). Climatic conditions, geo-morphology, geology, and land use cover a wide range of different characteristics: precipitation: 650 to >2000 mm/a, evaporation: 450-550 mm/a, discharge: 150-1600 mm/a, average annual temperature: -4.8 to +9 °C, sources of income changing from industry and services to agriculture and tourism. The size and heterogeneity of the area on the one hand, and the partly limited data availability and accessibility on the other lead to a challenge in representing the water related processes in numerical models.

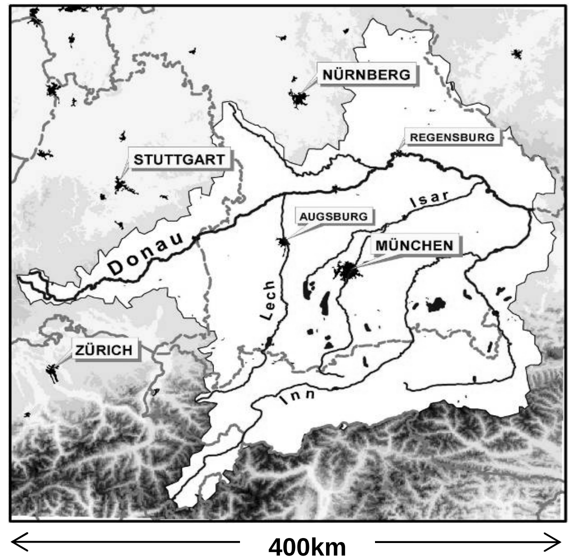

***Figure 1**: The Upper Danube Catchment*

THE DECISION SUPPORT SYSTEM DANUBIA

DANUBIA was developed on the basis of re-useable, refineable, and well-documented sub-models. It is object-oriented, spatially distributed and raster-based. In DANUBIA, models are connected with each other via customized interfaces that facilitate network-based parallel calculations. The strictly object-oriented DANUBIA architecture was developed using the graphical notation tool UML (Unified Modelling Language, Booch et al. 1999) and has been implemented in JAVA code. A prerequisite for this was the use of standardized communication procedures by all groups, such as the Java-based Remote Method Invocation (RMI). On this basis, DANUBIA was developed as a synchronized system that consists of distributed networked objects, which can communicate through RMI on the net.

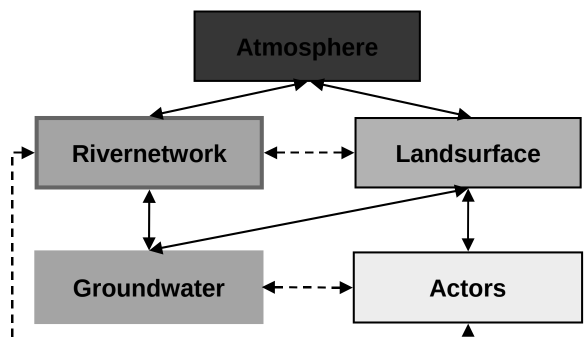

***Figure 2**: Connections and dependencies between the main model components.*

Each discipline contributes its part of the complex model compound as an object. In this respect, an object is an encapsulated unit, which completes a distinct function in the DSS and carries out the data exchange and the synchronization through defined interfaces. Hereby, the object can be implemented in any desired language. To minimize data traffic and to optimize the representation of complex interrelated processes, the 15 individual objects (= models in a broader sense) have been grouped to form five main model components as shown in Figure 2. For example, six socio-economic models form the “Actors” component. Common ground in this component are the relatively long time steps required to model e.g. population growth, and the need to model human decisions. Furthermore, compared to the intensive data exchange within this component, data exchange to the outside can be reduced to a surprisingly small number of parameters.

The Institute of Hydraulic Engineering of the Universitaet Stuttgart contributes two models to DANUBIA: (1) A groundwater flow and transport model, and (2) a water supply model. Both models are dealt with in more detail in other contributions to this conference: (1) Barthel, Rojanschi, Wolf & Braun and (2) Barthel, Nickel, Meleg & Braun.

Spatial and Temporal Modelling Concepts in DANUBIA

A common problem that affects all research disciplines involved in the fully coupled system DANUBIA arises from the fact that different, yet interdependent water cycle processes have their main focus on different scales both in space and time. Without attempting to discuss the extensive details of such problems, it can be summarized that the different process scales can lead to undesirable feedback, incorrectness of the mass balance of the system, and, finally, to instability and low model performance. In order to avoid and overcome such drawbacks, GLOWA-Danube has agreed on a uniform spatial modelling environment and uses the concept of 1*1 km Process Pixels (=Proxels). Proxels are the basic building blocks of DANUBIA and consist of a pixel (picture element) in the form of a cube, in which processes occur (Tenhunen *et al.*, 1999). The Proxel concept is schematically represented in Figure 3.

A proxel is basically a cube, which can have different dimensions depending on the respective viewing scale and connects to its environment (other proxels) through fluxes. In DANUBIA, a proxel-area of 1 km² is used for the mesoscale modelling of land surface processes as well as for the key socio-economic processes in the entire catchment area. A basic proxel in the DANUBIA architecture supplies to all disciplinary users all basic functionality for geographic referencing and spatial managing of the necessary parameters within the object as well as data imports and exports via defined and standardized interfaces. An object in DANUBIA is an extension of a basic proxel, which inherits all the properties of the basic proxel. It can thus be for example a surface proxel that describes the water flow on the surface, through vegetation and in the ground water.

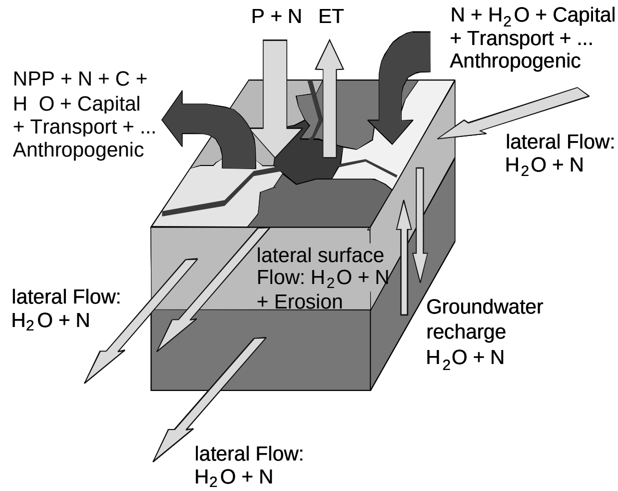

***Figure 3**: Schematic raster based modelling in DANUBIA on the proxel basis.*

The Proxel concept, which is, after all, a highly specialized raster concept, may not be the optimal spatial representation for all disciplines and processes. However, it simplifies the interdisciplinary description of the interactions between the considered processes and, making use of its capability to represent more than one dimension as well as sub-scale information, minimizes the disadvantages of a traditional simple raster approach.

Discretisation of time is an equally complex issue in the fully coupled integrated model DANUBIA. Whereas a common spatial discretisation could be agreed on, model time steps can differ from model to model. One main reason for this is computation time is that simulating very slow processes such as economic development with short times steps would result in a undesirable redundancy. On the other hand, processes that depend strictly on seasonally and diurnally varying parameters can not be reasonably treated using large time steps. Therefore, the time related aspects are dealt with firstly by using a powerful time management tool developed by the computer science group, and secondly by a thorough joint analysis of the dynamics of coupled processes. Ludwig *et al.* (2003) exemplify this and other time related aspects in more detail.

MODELS DEVELOPED BY THE GROUNDWATER AND WATER RESOURCES SUB-PROJECT AT STUTTGART

The Danubia Groundwater Component

In the Upper Danube Basin, groundwater is the dominant source of drinking and process water (95% in the domestic, 80% in the industrial sector). Therefore, groundwater related processes ranging from recharge, surface water in- and exfiltration, nitrogen leaching and transport, and extraction from wells for domestic, agricultural, and industrial purposes, play an important role in both the physical and the socioeconomic parts of the hydrogeological cycle. It is evident that none of the corresponding processes should be treated independently, nor should they be represented in an over-simplified manner. Integrative modelling, however, is a challenging and demanding task. In addition to well known (technical) problems of coupled modelling, certain previously partially neglected aspects of groundwater management pose interesting challenges that are crucial in successful integrative water resources modelling. Such challenges are, for example, the difficulties in calibrating three strictly interdependent models (simulating saturated zone, unsaturated zone, surface water processes), and feedback problems between water demand, water resources, and water supply. The main aim of the DANUBIA groundwater component is to assess and forecast quantity and quality of the groundwater resources under conditions of global change together with the other natural science models. In accordance with the size of the model area and the Proxel -based DANUBIA approach, a finite-difference model approach (MODFLOW; McDonald & Harbaugh, 1988) was chosen. The construction of a conceptual hydrogeological model for such an enormous area is a task which requires not only the collection of extremely large quantities of data but also the use of advanced data managing and evaluation tools. For more details see Barthel, Rojanschi, Wolf and Braun, this conference.

The Danubia Watersupply Model Within the Actors Component

Within DANUBIA, the water supply model strives to meet the water needs (quality and quantity) of consumers represented by other objects within the actors component (household, agriculture, industry, tourism) at a reasonable and realistic price, and in doing so acts as the interface between supply and demand, that is between the natural science and the social science models. It is, therefore not a conventional water supply model which focuses on the specific technical functioning and optimisation of water supply structures. Rather, it is a more abstract model which attempts to display typical decisions made by stakeholders in water supply in response to changing demand and water availability and/or quality and which should show the evolvement of water supply systems or cost structures as a result of such (mainly economically driven) stakeholder decisions. Data on the potential water resources (quantity and quality) for each proxel is obtained from the Groundwater and Rivernetwork objects at each time step (supply side). This is then compared to the water demand of the Actors (demand side). If the supply meets the demand, the model determines the best possible s water source economically and ecologically, and conveys the necessary extraction rates to the resources models. The model is not currently able to deal with the problem that arises if the supply side is not be able to meet the demand in a reasonable way. The focus of research of the second project phase is to achieve a realistic solution in this process of decision making and to develop the required optimization procedures. For more details see Barthel, Nickel, Meleg & Braun, this conference.

Conclusion and Outlook

Using a network-based approach and the discipline-independent diagrammatic modelling language UML, the natural-science basis of the decision support system DANUBIA was designed and implemented during the first phase of GLOWA-Danube (2001-2004). It considers all hydrologic and many socio-economic processes related to the water cycle. The results of the simulations will be presented to the interested stakeholders. Among them are members of the water management authorities of the different political-administrative entities, the agricultural management authorities, the power industry, and the tourist boards. Appropriate scenarios for further simulation runs will be developed in cooperation with them. Developing the basin scale groundwater model proved to be a challenge, but, after careful consideration of the model geometry and parameterisation, a solvable problem. The results, however, should always be regarded as results of a regional model, lacking the spatial and temporal details of local simulations.

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