A LARGE-SCALE WATER SUPPLY MODEL FOR THE UPPER DANUBE CATCHMENT (GERMANY)

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Abstract: Within the framework of the research project "GLOWA-Danube", a model of the water supply sector has been developed. GLOWA-Danube (for details see Barthel, Braun & Mauser, this volume) investigates long-term changes in the water cycle of the Upper Danube river basin in light of global environmental change. The Water Supply model forms the link between various physical models determining water quality and availability and several socio-economic models determining water consumption and demand. Its aim is not only to be able to simulate the present day system of water extraction, treatment and distribution but also its development and change with time. Changes to the water supply system are brought about by decisions influenced by political and economic boundary conditions, changes in water demand or water quality, and advances in technology. Rather than aiming to predict the appearance of the future water supply system in the Danube Basin, the model will be used to evaluate and compare scenario driven simulations based on rule sets defining the behaviour of the different decision makers and stakeholders, which are represented by agents. The model is conceptualised using the object oriented concepts of the Unified Modelling Language UML and implemented in JAVA.

Keywords: Water supply model, agents, decision making

THE ROLE OF THE WATER SUPPLY MODEL WITHIN THE FRAMEWORK OF GLOWA-DANUBE

The GLOWA-Danube project, which began in 2001, aims to develop integrative techniques and strategies to cope with regional effects of Global Environmental Change coupled with human activities (water and land use) on the water cycle in the Upper Danube catchment. The Upper Danube catchment till Passau covers an area of approx. 77.000 km² and encompasses parts of the German Federal States Baden-Wuerttemberg and Bavaria as well as northern Austria (Figure 1). Small corners of Switzerland, Italy and the Czech Republic make up less than 3% of the area. To meet the central GLOWA-Danube aim, an interdisciplinary approach is required: Physical processes control to a great extent the natural water cycle and water availability. In GLOWA-Danube, several independent physical models are being developed in the fields of meteorology, hydrology, remote sensing, groundwater and hydrogeology, plant ecology, and glaciology. In turn, however, water demand and quality are widely determined by human behaviour. So-called "Actors" models – for the most part agent-based models – cover the disciplines economy, agricultural economy, tourism, environmental psychology, computer science, and not least water supply. The Water Supply model, which is contributed by the Universität Stuttgart, assumes thereby the central mediation role between the physical and the socio-economic side by administering the available resources, the various users and their needs. The development and integration of the models from the relevant disciplines in the web-based fully coupled Global Change decision support system DANUBIA constituted the main challenge of the first project phase of GLOWA-Danube (2001-2003) (Ludwig *et al.*, 2003). The exchange of information between the models – each of which has a stringently defined area of expertise – is supported by the use of the Unified Modelling Language (UML). For the direct coupling of these independent models with each other for the purpose of parameter exchange, a uniform rectangular 1km*1km grid was chosen for all models.

Motivation and Aim of the Water Supply Model

The specific aim of the Water Supply model is the creation of a model which is not only able to simulate the present day system of water extraction, treatment and distribution but also its development and change with time. A number of factors can trigger change in a water supply system in the form of modernisation or decay, expansion, centralisation or decentralisation. Some of these factors are of a natural source. For example, climate and weather pattern change can increase or diminish local water supplies and/or the quality of the water. Yet most changes are brought about by decisions made by relevant actors in the field of water management or their behaviour. Systems of water rights and other political instruments governing the distribution and quality of water resources place direct demands on the state of water supply systems and determine trends such as centralisation/ decentralisation and liberalisation. Competing uses of water resources such as navigation, fishery, or tourism have a long-term effect upon water quality, as do the behavioural norms of certain productive branches of the economy: the use of fertilizers and pesticides in agriculture is here an evident example. Water demand changes as population increases or decreases, or as consumers make increasing use of new and water-efficient technologies. All of these factors in turn require decisions to be made on the part of the water supply administration: is it necessary to tap on to new resources, are new methods of water treatment required, does the water pricing systems cover all costs, need scarce water be allocated, and if yes, how should the needs of different users be weighted?

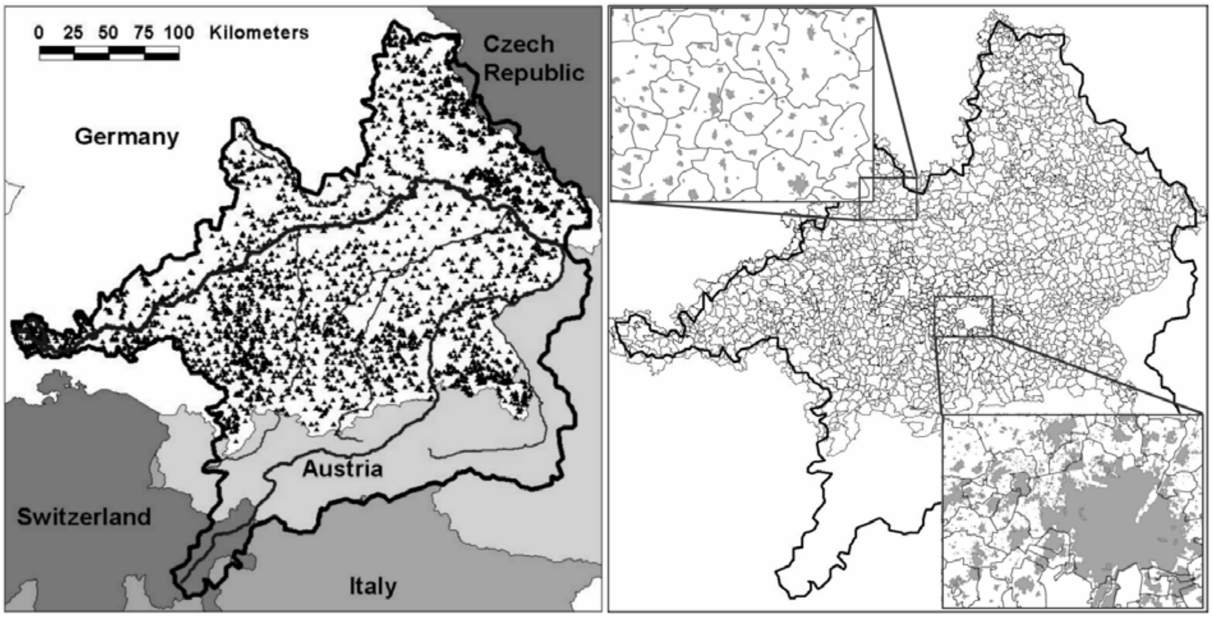

Figure 1: *Left - Wells in the German part of the Upper Danube Catchment (triangles)*
Right - Community boundaries in the German part of the Upper Danube Catchment. The close-ups show additionally the populated areas - lower right: Munich, capital of Bavaria; upper left: typical rural area

The Water Supply System in the Upper Danube Basin

The water supply system in Germany and particularly in the South is highly decentralized (see Table 1). It provides 10 million inhabitants and the industry with drinking water, derived for the most part from groundwater. In the German part of Danube Basin approximately 2000 water supply companies exist (Emmert 1999). Some are very small, comprising just one water source (well, spring, etc.), one waterworks and the distribution network. Few long distance water supplies companies supply up to several 100.000 people with drinking water. In somewhat short of 300 special purpose associations ("Zweckverbaende") two to several tens of communities share maintenance, administration, financial matters, and in many cases also technical infrastructure. In comparison to other European regions, this represents a highly atypical and decentralised structure, which can be highlighted by a simple ratio: the number of companies supplying 1 million consumers for various European countries (Table 1).

	Total number of supply companies	# of companies per 1 mil. consumers
Federal Republic of Germany	6959	88,2
The Netherlands	22	4,4
England / Wales	29	0,7
France	5	0,13

Table 1*: Number of Water Supply Companies for various European countries (BMBF 2000)*

This finely structured system in the model area is for the most part a result of the high degree of autonomy of the municipalities (communities), which are traditionally responsible for water supply. Whereas today, the great majority of the water supply companies are still owned and run by the municipalities, recent trends show that formal privatisation (a company receives a private legal form of organisation but is still owned by the municipality) and material privatisation (a company is actually sold to a private third party) are becoming increasingly common (UBA 2001).

Data Requirements, Data Availability and Data Acquisition

As customary for most computer models based on real world cases, the availability of data to parameterise the water supply model is a crucial aspect in the attempt to represent the system realistically. The water supply companies, though mostly run by public authorities on the community level, are not obliged to provide detailed data to the public. Only limited data, often spatially and temporally aggregated, is therefore available from the authorities, common interest organisations or in the public statistics. In order to gain access to more specific information regarding individual water supply companies, the Water Supply group has carried out a wide-spread questionnaire addressed to all water supply companies in the GLOWA-Danube model area. The questionnaire contains questions pertaining to the two distinct fields "economics and pricing" and "technical aspects", and aims at gathering information regarding the present day situation of the water supply system, the developments over the past 10 years as well as planned developments for the immediate future. The return rate of the questionnaire was around 10%. The results were analysed statistically and are currently being used along with other data to characterise company types. The types will be used to determine behaviour and future development options of the supply companies present in the basin.

The Conceptual Water Supply Model

The development of a conceptual water supply model entails defining the boundaries and area of expertise of the model as well as the parameters to be exchanged between the Water Supply model and other models. Second, the necessary model objects and agents must be chosen at a resolution appropriate to the size of the area to be modelled. For example, the water supply model receives the information "maximum groundwater withdrawal" per Proxel (grid cell) from the groundwater model and cannot withdraw more than the amount determined by this model. On the other side, the water supply model receives the information "consumer demand" from the consumer groups and must decide if this demand can be met fully with the available infrastructure and water resources. The Water Supply model further acquires new resources, provides for the operation, maintenance, modernisation and expansion of the infrastructure, regulates contracts between user groups (e.g. municipalities) and water supply companies, and – last but not least – generates the actual costs of water supply. With the latter, the Economics group calculates the water price, which is passed on to the consumers and has, naturally, an effect upon their water consumption behaviour.
The main components of the water supply system are represented by the following objects in the model: water supply companies (WSC), water works (WW), sources (S) (springs, wells, etc.), resources, pipelines, access points, communities, sub-communities. Each of these objects has a defined set of characteristics and/or functions and stands in a particular hierarchical relationship to the other objects. Only a small number of the objects will later show the necessary qualities to be considered agents, namely the water supply companies and the communities. These will communicate with consumer agents of other GLOWA-Danube models. Following the object oriented philosophy of JAVA, the water supply system was broken down to a small number of main classes that represent the hierarchy typical for the water supply - consumer relation in Germany. Sub-classes that inherit properties of their parents are used to categorize the main objects. Decisions are based on sets of rules that are defined according to the sub-class membership. A catalogue of decision-making rules will be prepared as a basis for discussion and will be debated with the relevant stakeholders. These rules will provide the basis for decision-making algorithms which will allow model agents to respond to their environment, communicate with one anther and behave in a goal-oriented manner to bring about change in the water supply system in response to changing conditions with regard to the climate, water quality, political and social boundary conditions, and changing demand.

Implementation of the Water Supply Model

The model implementation in JAVA has been carried out in several steps, some of them in parallel. First there was the need to keep up with the development of the DANUBIA system. Its prototype version 0.92 including 16 model components was already successfully tested. Model results of several reference and scenario runs combined in so-called "sets" are currently being evaluated. In order to provide a working water supply component to this prototype version, a relatively simple, yet well functioning model was developed. Being a simple input-output model, it is capable of fulfilling the requirements of DANUBIA but has no decision making capabilities. Parallel to this prototype version, the conceptual model as described above was implemented and parameterised for a much smaller sub-region of the Danube Catchment as a standalone application. The output of partner models in this case have to be represented by predefined time dependent input tables. Figures 2 and 3 provide some insights in the static and dynamic concepts of this model. This small scale, standalone model will now be extended using the full data set and its statistic derivatives for the whole catchment.

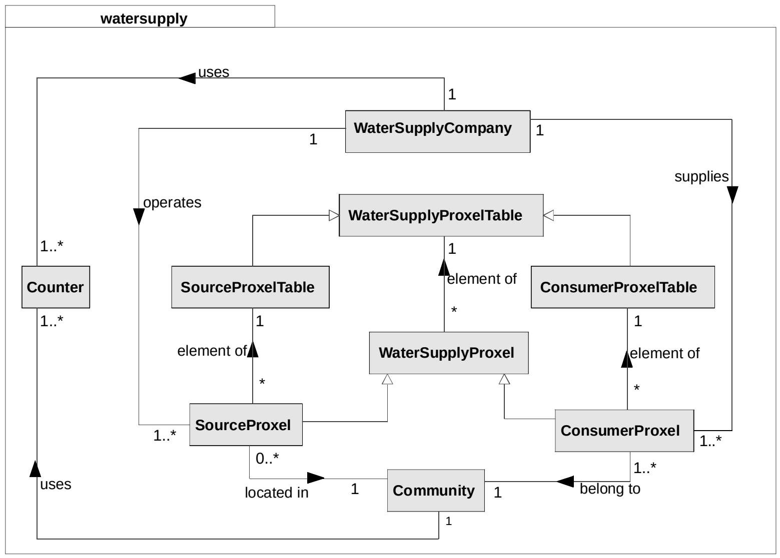

Figure 2: *UML-Class diagram for the water supply model. The WaterSupply class has been included in the model to represent its abstract relation to the other classes (Meleg, 2004).*

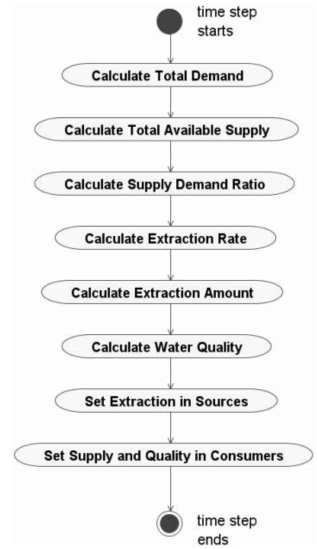

Figure 3: *Activity diagram for a WaterSupplyCompany object during one time step (Meleg, 2004).*

Outlook

In the second project phase (2004-2007), the focus will shift towards the active integration of the stakeholders from the field of water resources management. Decision-making rules will be debated with the relevant stakeholders and adapted where necessary. Based on these rules, algorithms for decision making will be developed and integrated in the Water Supply model to create an agent-based model, with agents able to respond to their environment, communicate with one another and behave in a goal-oriented manner to bring about change in the water supply system in response to changing conditions with regard to the climate, water quality, political and social boundary conditions, and changing demand. The second project phase will furthermore be dedicated to the refinement of the various GLOWA-Danube models and to the formulation, testing and comparison of complex scenarios of future development with the aim of identifying sustainable forms of water management and consumer behaviour. Ultimately, DANUBIA will be able to serve as a tool for monitoring, analysing and modelling the impacts of Global Change on nature and society in the Upper Danube basin for various future scenarios, taking into account a multitude of environmental, social and economic aspects formulated by the water-related stakeholders.

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