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Institut für Wasserbau (IWS)

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Comparison of tools for integrated assessment and management of groundwater resources in different river basins with special regard to sustainability

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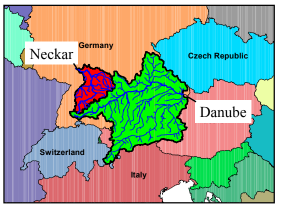
Introduction: Integrated Management of Groundwater Resources – Groundwater Management Models as parts of Global Change Decision Support Systems

Sustainable management of water and land resources is widely understood as an integrative, cross-border task. Research activities such as the **BMBF-GLOWA-Initiative** and the **European Community** financed **RIVERTWIN Project** take up this idea and link it to the investigation of the effects of Global Change on the hydrological cycle. Models are important tools that help to understand systems, to predict changes and to support decisions with far-ranging implications. Since groundwater is a major drinking water resource in many parts of the world, the groundwater system and its accurate representation play a major role in integrated modeling systems.

Within **GLOWA-Danube** a large scale three-dimensional numerical groundwater flow model has been developed for the Upper Danube Catchment (~80.000 km²). The model runs within the **DANUBIA** framework coupled to 15 other models. A second large scale groundwater flow model is now being developed for the Neckar Catchment, Germany (~15.000 km²). It will be part of the river basin management tool developed by the **RIVERTWIN** research cooperation.
The purpose of both groundwater models within the integrated frameworks is to predict the quantitative and qualitative state of groundwater resources under conditions of Global Change. The models quantify the effects of changes in precipitation and temperature mainly on groundwater levels. Along with the parameters calculated by the hydrological model components (recharge, discharge etc.) they provide the information necessary to detect deficits in the water balance and to set the limits of sustainability. In this attempt it is crucial to be able to "translate" calculated model results to meaningfull index parameters that can be used in decision making processes. Here the concept of "flags" is introduced.

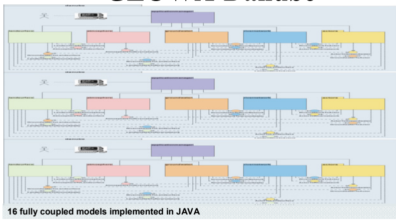


The Upper Danube and the Neckar Catchment.

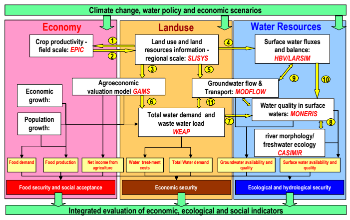
Integration Concepts and Model Coupling

GLOWA-Danube develops the integrated model DANUBIA. DANUBIA comprises 16 object-oriented, spatially distributed and raster-based fully coupled models. In DANUBIA, models are connected to 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 and has been implemented in JAVA code.
RIVERTWIN uses a loose coupling scheme. The individual models are coupled via data sets that are calculated after a prior model adjustment and calibration. The integrated framework is a GIS-interface that draws upon result data from a huge results data base. In order to run scenario simulations, data sets for reference years are combined in the desired number and sequence.

GLOWA-Danube

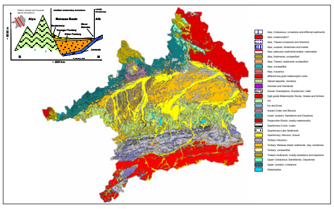


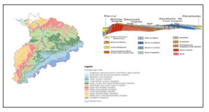
RIVERTWIN



Hydrogeology – Conceptual Models

Both basins are very complex with respect to geology and hydrogeology. In the upper Danube Basin, the Alps, crystalline and carstic areas area extremely heterogeneous and the hydrogeological situation is dominated by small scale local features. On the other hand, in the Danube Catchment we find a wide "basin type" area (Molasse Basin), which is dominated by unconsolidated, porous quite homogeneous rocks. In this basin part it is possible to model groundwater flow very successfully.
In the Neckar Basin, the geological situation is dominated by quasi-horizontal mesozoic formations. Limestones, sandstones and siltstones form fractured or carstic areas. The hydrogeological sequence is highly differentiated vertically resulting in a high number of individual aquifers separated by rocks of low permeability.

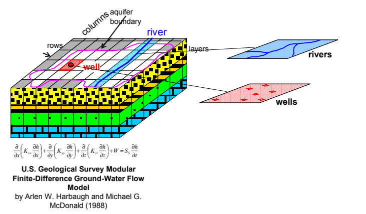




Cross Section through the Danube Basin

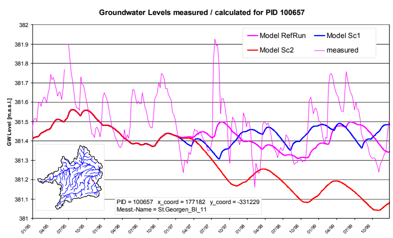
Cross Section through the Neckar Basin

Numerical Groundwater Flow Model



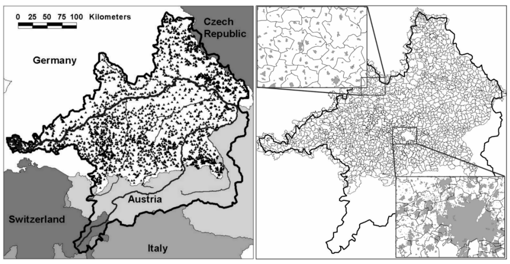
In both cases MODFLOW is used to model grounwater flow using a horizontal discretisation of 1 * 1 km

Scenario based Results



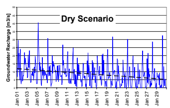
Comparison of measured and calculated groundwater levels for an observation well located near the river Salzach. RefRun: Model validation period 1995-1999, Sc1: "wet" scenario, 1995-1996, 2002, 2002, 2002; Sc2: "dry" scenario, 1995, 1996, 2003, 2003, 2003.

The Consumers: The Water Supply System of the Upper Danube Catchment

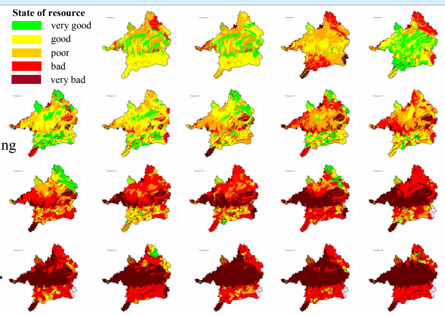


Left - Extraction sites in the German part of the Upper Danube Catchment (triangles) Right - Community boundaries in the German part of the Upper Danube Catchment. The close-ups highlight the differences in population structure found in different parts: lower right: Munich, capital of Bavaria; upper left: typical rural area

The transfer of relevant information between the groundwater model and the water supply model is based on "flag values". In the water supply model the flag values are used for decision making: business as usual, expand capacities, tap new resource or crisis management depending on how "bad" the situation is



Consequences of a **dry** scenario (30 years): decreasing recharge and the subsequent changes of the state of the groundwater resources



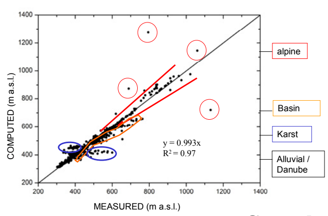
Checking the Sustainability: Communication between the Groundwater Model and the Water Supply Model

Summary, Results and Outlook

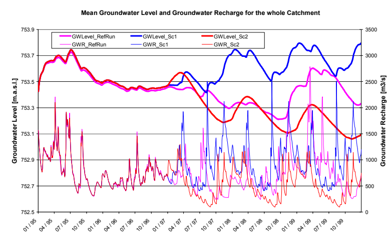
As stated in the introduction, groundwater models play an important role in integrated river basin management. Typical groundwater models are used on much smaller scales, or, only for homogeneous aquifers. In river basin management conceptual hydrological models are usually used to represent the groundwater system in a very simple way. It is therefore desirable to find out if it makes sense to develop such large scale groundwater flow models, if yes, one must determine whicl model concept should be used, how such models can successfully be coupled or integrated in decision support or management systems and what data requirements exist. A reliable groundwater model is the key to reasonable groundwater management but it provides only information, not the solutions.

Currently, great efforts are being made to merge the Groundwater and the WaterSupply models in DANUBIA to form a full integrated tool for Groundwater Resources and Supply Management. This is especially important for the 'Deep Actor Model' deepWaterSupply, which is currently being implemented. Deep Actor Models are comprised of a number of individual 'Actors', objects which perform different actions depending on their individual attributes. A common Deep Actors architecture or framework, similar to the common DANUBIA framework is used to model decisions similarly in all Deep Actor Models. In DeepWaterSupply, the Actors are represented by the water supply companies (WSC). The WSC objects decide on specific plans and actions based on analyses of parameters calculated by the Groundwater Model.

Any decision in water supply that concerns sustainability has to consider the past, present and future state of a groundwater resource. Looking at the present state of a groundwater resource is often not very helpful, since groundwater is a system with slow dynamics and a long memory. Since the future is unknown, the main information used for the analysis of a groundwater resource has therefore to be derived from past time series of different variables: Recharge, Discharge, Groundwater Levels and Baseflow. Instead of looking at the values itself, we found it to be helpful to translate states and trends in "flags" that can be understood as "warnings" by the decision makers.

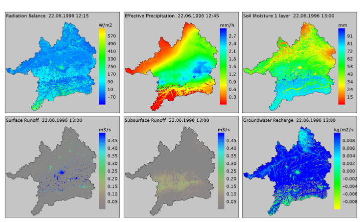


GLOWA-Danube Groundwater Flow modelling results: Comparison of measured and calculated values of groundwater heads (left hand side: all mean values for a steady state simulation, right hand side: transient simulation for one observation well)



Groundwater Model Results

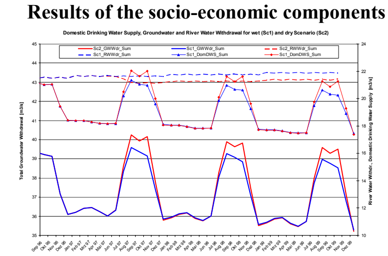
DANUBIA-Results:



Results of partner models

Examples of spatially distributed outputs during runtime of DANUBIA for June 22nd 1996, 1 pm.

Results of the socio-economic components



Comparison of domestic drinking water supply, groundwater and river water withdrawal for the whole catchment for a wet (Sc1) and a dry scenario (Sc2).