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Aspects of choosing appropriate concepts for modelling groundwater resources in regional integrated water resources management – Examples from the Neckar (Germany) and Ouémé catchment (Benin)

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Abstract

Two regional groundwater flow models (Neckar catchment, Germany, 14,000 km^2, and Southern Ouémé Basin, Benin, 11,000 km^2) were developed within the framework of the integrated management project 'RIVERTWIN' (www.rivertwin.org). Both models were evaluated with respect to the question if the chosen modelling approaches (multi-layered finite difference numerical flow modelling, steady state and transient) are appropriate in view of the existing management problems in the catchments, the data availability and the hydrogeological and hydrological conditions in the basins. It is shown that neither the model in the well-investigated, data-rich basin in Western Europe with its highly developed water related infrastructure, nor the model in the hydrogeologically less well-known and less developed basin in Western Africa provide results that are fully applicable to the main regional management tasks. In the case of the Ouémé, the groundwater related problems are foremost of local character and therefore cannot be addressed by regional models in a meaningful way. Data scarcity and complex, unfavourable geological conditions (crystalline rocks, discontinuous aquifers) support the conclusion that numerical 3D groundwater flow models are currently not helpful to manage groundwater related management problems in the Ouémé basin. A better understanding of regional hydrological surface and subsurface processes is required first. Methods for a reliable estimation of groundwater recharge and subsequently groundwater availability were identified as the most urgently needed tool for meaningful groundwater management in view of climatic, demographic and land use change. In the Neckar catchment the results of the analysis are less pronounced; here regional groundwater problems could clearly benefit from a physically based 3D model since the hydrogeological system is strictly stratified with several important aquifers in the vertical sequence. As a general conclusion it can be stated that regional scale groundwater flow modelling concepts seem to be difficult to integrate in management systems and difficult to transfer from one basin to another. This means the question of how to represent the groundwater resources appropriately has to be discussed very thoroughly for any new integrated water resources management problem. It is not possible to give a final recommendation on which modelling concept is the most appropriate one in regional integrated modelling and management. Hence, this article is only intended to provide an in depth discussion of the aspects that need to be considered in the process of choosing appropriate modelling concepts.

Keywords: Groundwater modelling; Integrated water resources management; Neckar; Benin; Modflow; Regional scale

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1. Introduction: regional integrated groundwater resources modelling and management

Since groundwater is a major drinking water resource and very important for irrigation purposes in many parts of the world, the groundwater system and its appropriate representation play a major role in integrated modelling systems. In order to determine what 'appropriate representation' of a basin's groundwater system in integrated groundwater resources modelling and management means, a large number of questions and issues have to be addressed. In the present paper, this is done based on theoretical considerations which are partly backed up by results from case studies. For that purpose the paper is structured as follows: In this section, *integrated management* with respect to groundwater on a regional scale is defined more clearly and previous and current related studies on the matter are briefly mentioned. The particularities of the *regional scale* with respect to groundwater systems and groundwater modelling concepts are described. Section 2 discusses the general aspects that should be considered in the process of deciding on a modelling strategy to represent groundwater resources in an integrated system on the regional scale. In Section 3, these general considerations are exemplified using two groundwater modelling case studies from the RIVERTWIN research project. Section 4 sums up the discussion and presents the conclusions drawn from the theoretical considerations and the case studies. It should be pointed out that the focus of this paper is on *quantity* aspects of groundwater management and modelling.

Today, sustainable management of water and land resources is widely understood as an integrative, cross-border task, in particular in Global Change research. The impacts of climate change cannot be evaluated meaningfully without considering, for example, land use changes (subsequent or independent) or other natural and socio-economic developments. Evaluating and predicting the availability of groundwater quantity and quality under changing boundary conditions (scenarios) is a central task in Integrated Water Resources Management (IWRM) (Kinzelbach et al., 2003; Villholth, 2006; Quinn et al., 2004; Holman, 2006; Sophocleous, 2002). Models are an essential part of such integrated projects. As fully integrated, i.e. holistic model concepts do not exist, integration is often achieved by the coupling of existing disciplinary models (Bronstert et al., 2005; Barthel, 2006).

There are two research activities that the authors are currently involved in, and that the theoretical considerations mainly stem from. The GLOWA-Initiative funded by the German Ministry of Research and Education (www.glowa.org; www.glowa-danube.de; BMBF, 2005; Barthel et al., 2007) and the European Community financed RIVERTWIN project (www.rivertwin.org; Gaiser et al., 2007) use the idea of integrated research and link it to the investigation of the effects of Global Change on the hydrological cycle and to the development of an integrated model based Decision Support Systems (DSS). There are an increasing number of similar or related projects that follow the same idea. Examples would be the WAVES project (Gaiser et al., 2003), projects carried out under the framework of the HELP initiative of the UNESCO (UNESCO, 2001) and projects within the framework of the Sixth Framework Programme – Priority 1.1.6.3 – Global Change and Ecosystems (http://ec.europa.eu/).

Integration with respect to groundwater resources management is a term that can be understood differently depending on individual disciplinary viewpoints. In the present article, we understand integrated projects are projects that:

- operate on a 'regional' scale (river basins, >10,000 km^2),
- are based on a number of different, (coupled) individual *models* used to describe different components of the hydrological cycle and different socio-economic sectors,
- have a long-term, future perspective and deal with human intervention as well as with changing natural boundary conditions (e.g. climate change and related consequences).

The traditional approach to apply groundwater models for groundwater management tasks is to develop local scale models for specific aquifers and specific management problems (Holman, 2006). Large (regional) groundwater (flow and transport) models were until now in the most cases developed for single aquifers or aquifer systems rather than for catchments (e.g. Gossel et al., 2004; Brouyère et al., 2004; Holman, 2006). The larger the model domains get, the less deterministic the approaches usually are. GIS based, or more conceptual approaches in general, are quite common on the large scale (Quinn, 2004; Cools et al., 2006; Gossel et al., 2004). New legislation, e.g. the requirement to set up River Basin Management Plans according to the EU water framework directive, demands for basin wide approaches, which necessarily have to address groundwater resources as well. On the river basin scale, however, groundwater is usually not explicitly modelled; it is represented using conceptual models, which neglect to a large degree the three-dimensional, complex nature of groundwater systems. Until now, regional, basin wide *and integrated* numerical groundwater flow models, as they were developed by the authors for the Neckar catchment (Jagelke and Barthel, 2005) and the Upper Danube Catchment in Germany (Barthel et al., 2005) are rare.

The reason why standard approaches to simulate the state and to predict the fate of groundwater resources do not exist on the *regional scale* is obviously the growing degree of complexity of groundwater systems which increases as the size of the model domain gets larger: multiple aquifers have to be considered, geology diversifies, relief and topography vary. Under these circumstances, three-dimensional simulations of flow and transport in groundwater are difficult, in particular if data is scarce and/or if the hydrogeological conditions are complex. Scale