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The Role of Groundwater Recharge in Regional Scale Integrated Groundwater Flow Modelling

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ABSTRACT

This contribution deals with the discussion of groundwater recharge as a process and its meaning for groundwater flow modelling on the regional scale with a special focus on integrated management models. Integrated water resources management (IWRM) is often concerned with problems on the river catchment scale (> 10,000km^2) where the impacts of climate change or human intervention usually affect all components of the hydrological cycle. Various interactions and interdependencies between different components exist and have to be considered in the attempt to meaningfully describe processes and to evaluate the consequences of human intervention. Groundwater plays a very important role as a resource in many parts of the world and therefore deserves special attention in integrated management. Thus far groundwater flow models are the only means to meaningfully describe the effects of hydrological changes on the groundwater system. In contrary to (conceptual) hydrological models or water balance based modelling approaches, numerical 3D groundwater flow models can consider multiple aquifers, can describe horizontal as well as vertical flow, calculate flow direction and velocity, can quantitatively simulate groundwater discharge to surface waters at a specific location and above all provide hydraulic heads in different aquifers as a result. For all kinds of groundwater related management questions, but in particular with respect to ecological issues the mentioned capabilities of groundwater flow models are essential.

However, the application of groundwater flow models on the regional scale in heterogeneous areas poses severe problems due to insufficient data availability, discretisation problems and numerical instability etc. Therefore regional scale groundwater flow models are still rare. A particularly significant issue we identified in two regional scale integrated modelling projects (RIVERTWIN, Neckar catchment, Germany, 14,000 km^2, financed by the European Commission, www.rivertwin.org and GLOWA-Danube, Upper Danube catchment 77,000 km^2, financed by the German Ministry of Research and Education, www.glowa-danube.de) is the question of how to determine and apply groundwater recharge as a boundary condition for a groundwater model. In both catchments, recharge is the most important boundary condition. In the integrated systems, it is calculated by coupled soil water balance or hydrological models. It proves that the recharge calculated by a distributed conceptual model (HBV) or a physically based SVAT scheme respectively can not be applied to the groundwater flow model unmodified without changing the hydraulic properties of model cells to values outside the reasonable ranges. The reason is that the underlying hydrological concepts of recharge determination and the conceptual set up of the groundwater flow model do not match. Whereas the groundwater flow model considers mainly regional scale aquifers, the hydrological models are partly based on *soil* parameters which are determined on a 'local' scale (1*1 km grids). The soil parameters determine percolation through the soil or root zone (often 0 to 5 m) whereas regional aquifers can be located at a depth of even more than 100 m.

A more detailed analysis of the encountered problems reveals that groundwater recharge, as a process and as a quantity, is something that always needs to be defined in a scale and context specific way. Groundwater recharge is an apparently well defined process and commonly defined as 'water entering the saturated zone'. However, groundwater recharge remains a quantity that cannot directly be measured and, in particular, not on a large scale. The large number of methods to estimate or calculate groundwater recharge indicates that its quantification is not an easy task. At the same time it is widely believed amongst groundwater modellers that groundwater recharge is one of the least uncertain 'physical' input values for groundwater flow models. It is therefore very often used as a 'fixed' input (meaning no calibration takes place) whereas other values (hydraulic conductivity, leakage coefficients etc.) are changed and used for model calibration over wide ranges. This assumption forms a good

basis for many groundwater flow models and is usually valid in all cases where recharge is aggregated over longer periods and larger areas.

However, in regional groundwater flow modelling and in integrated (coupled) systems the situation is different. Here recharge needs to be defined specifically for the regional aquifers that are considered in the numerical groundwater model. As on larger scales, small (shallow) aquifers of small vertical and horizontal extent can usually not be included in the models; it must be discussed how the actual natural recharge to those smaller scale aquifers can be treated in the numerical model. Depending on the relief and the geological setting of a region it is very often the case that groundwater recharge entering such small aquifers does not reach the deeper regional aquifers because it leaves the saturated system as springs or groundwater discharge to smaller surface water bodies. For the regional groundwater flow model, such local recharge must, therefore, be subtracted from the actual recharge applied. It is obvious, that it is a question of how groundwater recharge is defined or, in other words, on which conceptual approach the recharge determination is based. Here a distinction between physical approaches based on soil water budgets and unsaturated flow processes (e.g. Richards Equation), and more conceptual water balance and storage cascade based approaches, can be made. The physically based approaches tend to provide a groundwater recharge that can be called ‘root zone percolation’. The recharge values in that case are often far larger than the actual recharge to regional aquifers and can therefore not be directly used, in particular if thick unsaturated zones exist. The conceptual approaches, which often rely on a calibration to river discharge, provide better results with respect to the total volume because they integrate over larger areas - catchments or sub-catchments – and can distinguish to a certain extent between slow, regional groundwater discharge (baseflow) and faster, local groundwater discharge (interflow). On the other hand, conceptual methods provide results that are spatially less accurate due to their integrative approaches.

With respect to integration, problems occur because in coupled modelling systems of the hydrological cycle the input to groundwater flow models is usually determined by other models (hydrological models, soil water balance models) and the output of groundwater flow models is used as input to other models (hydraulic surface water models). That means the groundwater modeller has to accept an input (groundwater recharge) that was not necessarily calculated to suit the groundwater model’s specific set up and at the same time to provide an output that is usually not important in groundwater flow modelling.

In this contribution we will demonstrate the problems mentioned so far using the practical examples from the Neckar and Upper Danube Catchment groundwater flow models. The models and their conceptual and numerical set-up are briefly presented as well as the different coupling strategies to hydrological and hydraulic models. Modelling results of the stand alone groundwater models for steady state and transient conditions are presented and discussed. It is shown that an individual calibration of the models yields relatively good results with respect to measured discharge in the case of the hydrological/hydraulic models and to measured groundwater levels for the groundwater flow models (MODFLOW) respectively. However, if coupled together the results get worse. The joint, coupled calibration of all parameters involved, that is required here, is an extremely tedious and conceptually difficult task on the regional scale. However, we think that even if coupled model results might, from a strictly disciplinary view point of view, be worse than results of stand alone models, model coupling is beneficial. Here we will show that an integrated approach provides more information than the single models alone; not only does it provide more than one measurable quantity for model calibration, it also gives us the chance for an indirect check on usually internal state variables, the model structure and the conceptual base of the model. This can help to better understand process representation in individual models and might thereby be a means to reduce uncertainty. Coupled modelling is a valuable exercise because it forces us to describe the water cycle in a holistic, scale and context specific, consistent way that acknowledges both the groundwater and the surface water system. Integration provides a means to better understand and quantify linking processes such as groundwater recharge.

Keywords: Groundwater Recharge, Groundwater Model, Hydrological Model, Coupling, Neckar