Considering aquatic habitat properties in integrated river basin management – an ecohydrological modelling approach

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THE WICKED WATER PROBLEM

Integrated water resources management is a step by-step process of managing water resources in a harmonious and environmentally sustainable way by gradually uniting stakeholders and involving them in planning and decision-making processes, while accounting for evolving social demands due to such changes as population growth, rising demand for environmental conservation, changes in perspectives of the cultural and economic value of water, and climate change (UNESCO, 2009). Yet in practical application the aspect of ecological habitat quality is often neglected and attempts to implement this aspect into integrated river basin modelling are very scarce as human needs are considered with a much higher priority. Neither the implications of river hydrology and hydraulics for aquatic habitats are fully understood nor the impact of ecology on hydrology and water quality nor are there any suitable modelling tools available to simulate the close interaction and feedbacks between ecology and hydrology.

Ecology and hydrology are disciplines that only merge so far in the field of ecohydrology where it is recognized that a sustainable development of river basins demands both a good ecological status and a good status of the water resources (Zalewski *et al.*, 1997). Both aims can be reached by the dual regulation of catchments and ecosystems.

In Germany the assessment of the actual status of surface water bodies according to the EU-WFD led to sobering results. The majority of German rivers have a severely altered hydromorphology and have deficits in water quality mostly due to non-point source pollution with agrochemicals (UBA, 2005). Thus the goals of the EU-WFD of a good ecological status will not be reached until 2015.

The tool to tackle the wicked water problem

As the basis for our integrated ecohydrological modelling system we used three freely available models. First the river basin model SWAT2005 (Arnold *et al.*, 1998) is needed to evaluate water balances and erosion as a function of catchment characteristics. In order to include the flow velocity regime, the water depth profile and river bed and bank erosion as well as deposition processes, a two-step hydraulic model cascade is applied: HEC-RAS (USACE, 2006) is used to depict the whole river reach one-dimensionally, and the two-dimensional hydraulic ADH model (Berger & Tate, 2007) with a refined resolution is applied on selected areas only. As a final step we use a habitat evaluation tool to bring abiotic and biotic properties together.

The most important steps for setting up the SWAT model were the consideration of drainages and landscape surface water retention potential in the 50-km^2 lowland catchment. The necessary boundary conditions and data for the HEC-RAS model were derived from the SWAT model, area-wide available morphological data and cross-sectional measurements. The first important step was the definition of inflows and sediment input from fields and tile drains supplied by the SWAT output at all tributaries and the distribution of surface and groundwater flow to the channel itself. An ArcGIS Interface for the ADH model has been developed so that the whole modelling system can be run from the GIS environment. For the model runs more detailed information on topography and morphology was necessary. Morphological mapping campaigns were conducted to gain detailed maps with information on the substrate, its extent and distribution along a 200-m section. The available bed and bank bathymetry from the HEC-RAS model was refined by transferring morphological information to topographic data. Therefore, a developed GIS tool was applied on the substrate information maps. Flow boundary conditions were supplied from HEC-RAS. Additional work is necessary for completing habitat assessments: quasi unsteady model runs are to be carried out to depict the hydrological flow regime and substrate stability. In order to assess the model results, parameter functions have to be derived for each parameter and each modelled aquatic species.

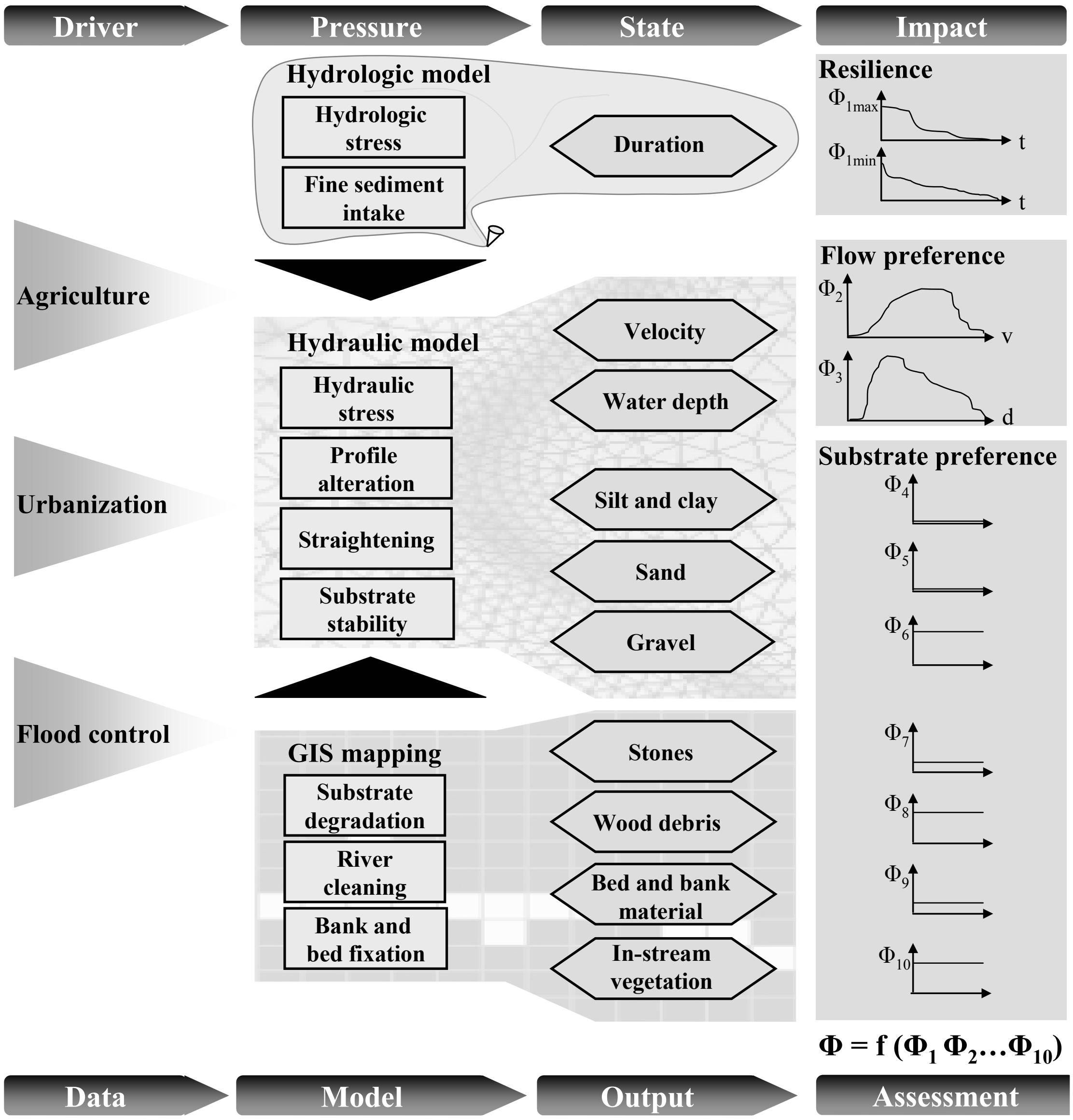

Fig. 1 Integrated modelling concept to simulate ecohydrological feedback mechanisms.

The application area and key results

The modelling system was tested in the 50-km^2 Kielstau catchment in northern Germany. A detailed description of the catchment and the ecohydrological monitoring and modelling studies can be found in Schmalz *et al*. (2010). The mean annual precipitation and temperature are 893 mm and 8.3°C, respectively (DWD, 2007). The rural catchment is scarcely settled and the river has a total length of 17 km and a mean gradient of 0.2 ‰. The topography ranges from 78 m to 27 m a.s.l., is flat but relatively uneven with rolling hills and numerous depressions. The hydrology is characterized by agricultural drainage, near surface groundwater, low hydraulic gradients and thus a high interaction between groundwater and surface water. Water quality is impaired by agrochemicals. In terms of hydromorphology many parts of the Kielstau have been changed markedly during the reallocation of land from its natural course. The river has been straightened, incised and thus disconnected from its flood plains. Here, hydromorphological variety and value is relatively low, while near-natural river sections still exist and can act as reference points. The overall morphological state of the stream is assessed as "poor" to "moderate" (Olbert *et al*., 2006) according to the standard hydromorphological river survey method in Germany (LAWA, 2000) and is typical for many streams in northern Germany. Nevertheless, the Kielstau is part of the flora–fauna habitat protection area (FFH-directive; EC, 1992) and 175 ha of land along the river and around Lake Winderatt are owned by two nature conservation foundations, which improve the potential for river rehabilitation measures within and beyond the scope of the WFD. The macro-invertebrate assemblage of the Kielstau was assessed by Brinkmann (2002) and LANU (2006); further data have been generated in the framework of the present study.

The established hydrological model performs well in depicting the catchment hydrology (r^2 = 0.82, NSE = 0.78) for the 10-year modelling period. Summer and winter discharge events have been used for steady-state model runs with the 1-D and 2-D hydraulic models. HEC-RAS shows good agreement with measured flow velocity and surface water profiles along the modelled stream channel. The integrated depiction of erosion and sediment transport processes gives plausible results when compared to the measured sediment load. The ADH results show a high dependency on the morphological and topographical channel characteristics. The 2-D results are compared and verified with stream velocity and water depth measurements. Further advantages of the modelling system and the developed coupling methodologies are the cheap and practical application.

KEY LESSONS LEARNED

In order to understand the complex interaction and feedback mechanisms between aquatic ecology and hydrology, integrated ecohydrological modelling can grant valuable insights into the dominating processes. Only if we succeed in implementing these modelling strategies within the framework of integrated river basin management will it be possible to show impacts of land use, water management and climate change on aquatic habitat in scenario runs and thus integrate ecological aspects in decision making. However, for the integration of positive effects of ecological mechanisms on water resources we still have a lack of algorithms to describe the processes properly. Also, the database for a thorough model testing is still difficult to come by, and if data sets are available they were usually collected with a monodisciplinary view and lack important information for an integrated ecohydrological approach.

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