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Comparison of several approaches representing terrestrial and in-stream nutrient retention and decomposition in watershed modelling

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ABSTRACT

Retention and transformation of nutrients within a river catchment are important mechanisms influencing water quality measured at the watershed outlet. Nutrient storage and reduction can occur in soils as well as in the river and should be considered in water quality modelling. Consideration is possible using various methods at several points during modelling cascade. The study compares the effects of five different equation sets implemented into the Soil and Water Integrated Model (SWIM), one describing terrestrial and four in-stream retention with a rising complexity (including algal growth and death at the highest complexity level). The influences of the different methods alone and in combinations on water quality model outputs (NO_3-N, NH_4-N, PO_4-P) were analyzed for the outlet of the large-scale Saale basin in Germany. Experiments revealed that nutrient forms coming primarily from diffuse sources are mostly influenced by retention processes in the soils of the catchment, and river processes are less important. Nutrients introduced to the river mainly by point sources are more subject to retention by in-stream processes, but both nutrient retention and transformation processes in soils and rivers have to be included. Although the best overall results could be achieved at the highest complexity level, the calibration efforts for this case are extremely high, and only minor improvements of overall model performance with the highest complexity were detected. Therefore, it could be reasoned that for some research questions also less complex model approaches would be sufficient, which could help to reduce unnecessary complexity and diminish high uncertainty in water quality modelling at the catchment scale.

1. Introduction

Within a watershed, retention of nutrients by physical, chemical and/or biological processes can take place during transport from agricultural areas to rivers in soils or riparian wetlands, as well as during routing and turnover in the surface water bodies themselves (such as streams, rivers, or lakes). These processes cause either a removal or a short- or long-term storage of nutrients, inducing a temporary or permanent reduction in the amount of nutrient concentration in river water or a delay in nutrient transport through the basin. Many authors (e.g. Kronvang et al., 1999; Hejzlar et al., 2009) refer to denitrification, sediment adsorption, and plant and microbial uptake as the main retention processes affecting nitrogen in watersheds. Phosphorus adsorbs to sediments, organic matter and clay particles or can be taken up by microbial biomass, followed by physical settling of these compounds. Therefore, deposition in water bodies and on flooded areas is usually mentioned as main reasons for phosphorus losses from river waters. Water residence time (lag time) in the river basin significantly affects retention of both nitrogen and phosphorus.

When modelling water quality of a river basin nutrient retention processes in the catchment cannot be neglected. Comparing the sum inputs (including diffuse and point source contributions) within a watershed to measured loads at the river outlet, many river basins demonstrate discrepancies in the amount and composition of nutrients (for an example see Table 1). Ignoring chemical fate and transport processes in rivers often leads to large errors in model output compared to observed values, which can partially be diminished by accounting for any kind of a retention process during the modelling procedure (Behrendt and Opitz, 2000).

Model research approaches using the eco-hydrological model SWIM (Soil and Water Integrated Model; Krysanova et al., 2000) for several sub-catchments of different sizes within the Elbe basin in Germany revealed as well that assuming only diffuse and point source emissions of nutrients to the river network and their simple routing cannot deliver efficient modelling results. Capturing retention, transformation and decomposition processes in the river was necessary to achieve sufficient and realistic outcomes. To

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Table 1
Comparison of total nitrogen (N) and total phosphorus (P) inputs to and outputs from the river network in the Saale basin for the time period 1998–2000, as well as the nutrient's natural background level.

	N [$t\,a^{-1}$]	P [$t\,a^{-1}$]
Background level (Behrend et al., 2003)	4380	106
Estimated input (Behrend et al., 2003)	35,150	2308
Point sources		
Municipal	4720	364
Industrial	1390	21
Diffuse sources		
Erosion	1940	1194
Drainage	7180	31
Atmospheric deposition	520	10
Surface washoff	190	59
Ground water	14,770	105
Urban areas	4430	518
Measured output, Groß Rosenburg (LHW[a])	25,034	874

[a] State Office of Flood Protection and Water Management Saxony-Anhalt (LHW).

accomplish this task, a simple decomposition equation for nutrients introduced to the river network by point source emissions was used during modelling (Hesse et al., 2008), or complex algae and nutrient cycles in the river channels were implemented (Hesse et al., 2012). The last approach required a lot of new, and often unknown, parameters and extensive additional calibration. Due to the limited new data, the uncertainty in the model results increased. A decision had to be made regarding which processes were pertinent to simulate and to achieve realistic results, because higher model complexity with a large number of calibration parameters considerably increases uncertainty of the model outcome (Snowling and Kramer, 2001; Adams, 2007). Using a simpler approach for simulating retention and transformation processes in the river might reduce uncertainty and support a more user-friendly handling.

With the analysis in hand, the significance of retention and transformation processes in the landscape and river network was tested by modelling the large-scale Saale basin in Germany using SWIM. One would expect that including complex in-stream processes in the model seems to be closer to nature than using a simple equation to represent river retention. However, the question arises, whether only such detailed description of in-stream processes allows to reproduce the measured concentrations and loads, or whether sufficiently good results can also be achieved using a simpler approach with less parameters. To answer this question, several methods representing nutrient retention processes in rivers were inter-compared, also in combination with the approach to simulate nutrient diminishment in the soils of the catchment.

Publications can be found regarding a comparison of methods and results achieved by different individual models dealing with water quality and nutrient retention in river basins (e.g. Horn et al., 2004; Migliaccio et al., 2007; Hejzlar et al., 2009). However, a comparison of modelling results, achieved by using several model approaches of different complexity implemented into one model, could not be found, but will be presented in this research study.

The objective of the study was to identify the level of model complexity necessary to realistically represent nitrogen and phosphorus in-stream behaviour during water quality modelling aiming in a decrease of complexity and high uncertainty within water quality modelling at the catchment scale.

2. Materials and methods

2.1. The model SWIM and implemented retention approaches

2.1.1. General model description

The eco-hydrological model SWIM (Krysanova et al., 1998, 2000) was developed on base of the two models SWAT (Arnold et al., 1993) and MATSALU (Krysanova et al., 1989) to simulate hydrology, nutrients (nitrogen and phosphorus), vegetation and water quality at the regional scale using climate, soil and land use conditions as driving forces and considering feedbacks (Fig. 1). Hence, the model is a suitable tool for analysis of climate and land use change impacts on hydrological processes, agricultural production and water quality. According to Pechlivanidis et al. (2011) the SWAT model (and

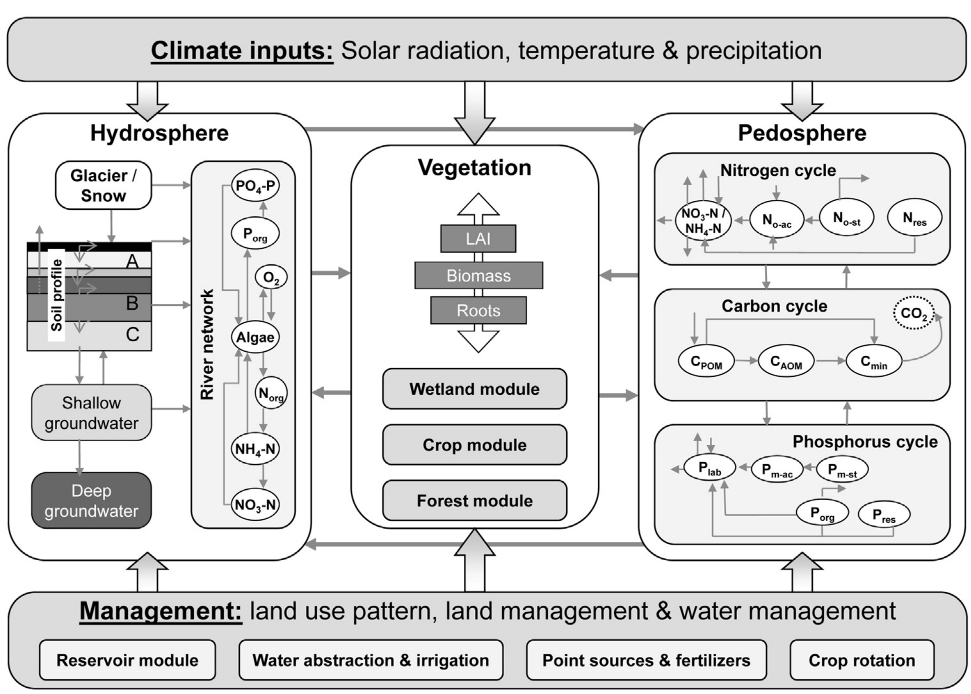

Fig. 1. Conceptual diagram of the SWIM model showing compartments, processes and feedbacks included as well as driving forces and border conditions needed for model calculations.