RIONET: a water quality management tool for river basins

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Abstract The water quality management tool RIONET for river basins has been developed with regard to the EU Water Framework Directive. The management tool can simulate the water quality in catchment basins not only in the dimension of a single river but in whole river networks. A submodel of the IWA River Water Quality Model No. 1 is used in RIONET. The river model is based on the assumption that self purification processes in the river takes place both in the benthic biofilm and the bulk water phase. Laboratory experiments with sediment cores underline the major role of the benthic biofilm. The input parameters of the management tool such as volumetric flow rates from waste water treatment plants and flow velocities and discharge in the main river and its tributaries can be loaded directly from geographic information systems (GIS). The subcatchment basin of the river Bode in Saxon Anhalt was used for test runs of RIONET.

Keywords EU Water Framework Directive; river basin management; water quality modelling

Introduction

In 2000 the EU Water Framework Directive came into force. By it the member states of the European Union have a detailed time schedule until 2015 to ensure that a "good" status will be achieved or kept in all waters. With respect to catchment basins, river basin management plans have to be published by 2009.

Additional to the management of the hydraulic and morphological aspects of river basins the water quality is a main issue of the EU Water Framework Directive. The management of catchment basins or subcatchment basins requires management tools which can handle a complex network of rivers, tributaries and industrial and municipal waste water treatment plants.

In 2001 the River Water Quality Model No. 1 was published by the IWA (Reichert *et al.*, 2001). The IWA RWQM No. 1 set a standard for all river quality models and is a good basis for the development of river water quality management tools.

It has to be taken into account that the water quality in rivers depends not only on the biochemical processes but also on the morphology and the hydraulic situation. In the last decade it has become very clear that the benthic biofilm plays a major role in the self purification processes of rivers (Horn, 1999). Pauer and Auer (2000) showed that even in larger rivers (River Seneca: 18 m^3/s) the main nitrification processes take place in the benthic biofilm.

Until now the knowledge about the transition from benthic biofilm to bulk flow controlled self purification has been very limited. A study on degradation processes in large rivers like the Rhine showed that the hydraulic situation plays an important role. The degradation of ammonium and other substances can be described by very simple first order kinetics but the simulation of the substance concentration in the river requires a complex hydraulic 2D-model (Teichmann *et al.*, 2001a).

The purpose of this paper is to show requirements for the development of a management tool for river networks. On the one hand, experimental work in the laboratory and in the

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field (i.e. the river) is necessary to evaluate process data. On the other hand the available data from river quality monitoring must be integrated in the modeling.

Model development

Biochemical processes

A submodel of the IWA RWQM No.1 was chosen to describe substance degradation and formation in the river model (Vanrolleghem *et al.*, 2001). The following biochemical and physical processes are considered in the model:

- Aerobic growth of heterotrophic bacteria
- Growth of 1st stage nitrifiers
- Growth of 2nd stage nitrifiers
- Growth of algae
- Decay of all microorganisms dependent on biomass concentration
- Chemical equilibria between carbon dioxide, hydrogen carbonate and carbonate, between ammonium and ammonia, and between calcium, carbonate and calcium carbonate
- Aeration of the bulk phase
- Adsorption of phosphate

In the developed tool the biomass (heterotrophic, 1st stage nitrifiers, 2nd stage nitrifiers and algae) can be divided into sessile biomass which is not moved with the bulk flow and suspended biomass which is transported down the river.

Additional processes can be formulated by the user if required. Especially the degradation of toxic substances may be necessary in some scenarios. For that purpose a list of reaction coefficients for organic chemicals is in preparation. Most of these degradation processes will be first order (Teichmann *et al.*, 2001b).

River structure and substratum

The available substratum at the bottom of the river is mainly dependent on the structure of the river. Intact river morphologies without anthropogenic influence offer larger surface areas for biofilm growth compared to rivers with straightening. The concept of RIONET is to integrate as much river data from monitoring programs as possible. Therefore, the river network must be divided in segments with identical properties with respect to hydraulics, morphology and structure. The data can be loaded directly out of geographical information systems (GIS) or fed manually by the user.

A standard simulation requires:

- Width of the river
- Depth of the river
- Wetted perimeter

The following data from the ecomorphological quality mapping can be used additionally to specify the self purification processes:

- River bed structure
- Line management
- Bank vegetation (shady/sunny)

Hydraulic and discharge data of the river network

Additional to the biochemical, physical and chemical processes the hydraulic parameters must be integrated into the management tool. The mean flow velocity is required to calculate the retention time. Furthermore, the flow velocity is the main parameter which influences the aeration constant of the bulk phase. Both the flow velocity of the river and the volumetric flow rate can be loaded together directly from monitoring data. The user of

RIONET has to choose the hydraulic situation to be simulated.

The tool can be used to simulate the influence of different discharges into the river network. Furthermore, the influence of the river structure and the ecomorphological quality on the water quality can be simulated. This feature is of great interest with respect to restoration of heavily anthropogenic influenced rivers. The water quality can be simulated for high or low runoff during summer or winter.

To carry out a simulation the concentrations of the nitrogen species, the organic and inorganic carbon species, phosphorus, oxygen and calcium at all discharge points must be available. Furthermore, pH-value and temperature are required. The data can be loaded from monitoring data or typed in manually by the user.

Diffuse pollution

Diffuse pollution such as nitrogen and phosphorus from agriculture is intended to be integrated into RIONET on the basis of land use in the river basin. The integration of the mass flux of nitrogen and phosphorus into the river model is not difficult. One possibility is the introduction of a term that feeds mass nitrogen per kilometre river length and by it increases the nitrogen concentration in the river. The problem is still the data base. Both the geological and morphological properties and the extent of agriculture in the river basin must be well defined. This work is still ongoing.

The river basin of the Bode

To verify the developed model, data from the river basin of the Bode with a catchment area of 3,200 km^2 and 515,000 inhabitants were used (Figure 1). The river basin of the Bode was declared a sub-basin which belongs to the river basin of the river Elbe. The Bode rises in the low mountain range Harz in Saxon Anhalt. It develops from a mountain brook with a high water quality to a medium polluted and straightened flatland river. The Bode flows into the Saale after 144 km. Four main tributaries were considered in the first stage of the project: Selke, Goldbach, Holtemme, Grosser Graben and Sarre.

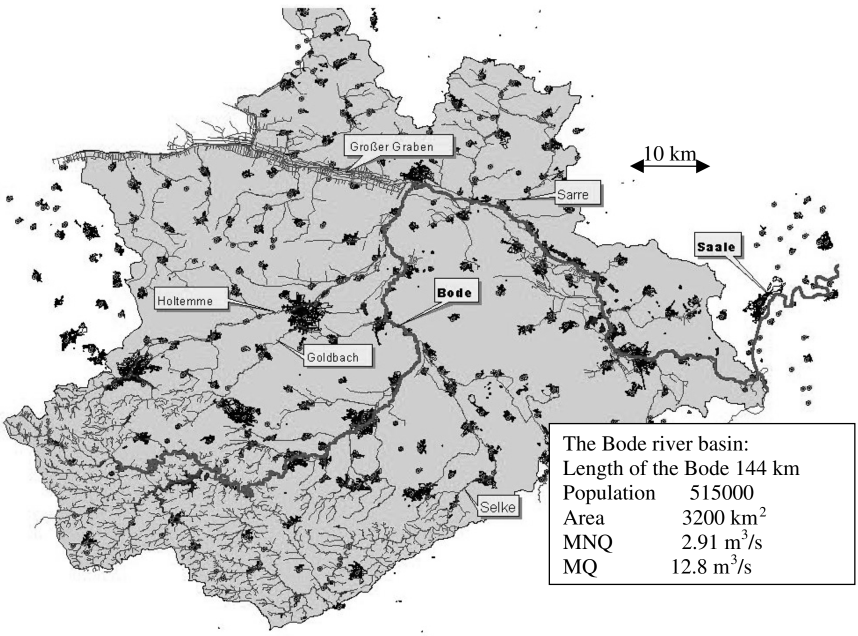

Figure 1 The Bode river basin

Several anthropogenic pollution sources are located in the river basin. In the upper part of the river Bode in the Harz region most inhabitants are connected to waste water treatment plants and the river is in a good status. In the flatland part of the Bode a number of diffuse sources and industrial discharges lead to a minor water quality. Both the discharge of polluted water into the lower part of the Bode and the river structure give the impression of a strongly anthropogenic influenced river.

The geographic data of the river basin of the Bode were available as electronic data by means of the GIS software package ArcView. The river kilometres and the discharge points of the waste water treatment plants were loaded directly from the GIS. The monitoring data were partly available in Excel files.

Results and discussion

Nitrification in the benthic biofilm

To throw more light on the question whether the conversion processes take place in the benthic biofilm or in the bulk flow, batch experiments with sediment cores from the Bode were carried out. Sediment cores were taken at different locations upstream and downstream in the Bode with cylinders of 6 cm diameter and a biofilm surface of 28 cm^2. For stony sediments the sampling method was modified. Several stones were collected and placed in a beaker. The biofilm surface was calculated from the surface of the stones. If necessary the ammonium concentration in the bulk water phase was increased to 2 mg/L before starting the experiment. The experiments lasted up to 24 h and the bulk phase was stirred slightly. Both the decreasing ammonium concentration and the reaction products nitrate and nitrite were measured. At the same time river water of the sample site was investigated in the same way.

In the river Bode the transition from benthic biofilm to bulk phase dominated nitrification depended on the water level above the sediment. For water levels higher than 1 m the nitrification rate in the bulk phase was approximately equal to that of the benthic biofilm. Furthermore, it could be shown that the nitrification rate was directly dependent on the ammonium concentration in the river. Usually the nitrification rates of the benthic biofilm after waste water treatment plants were up to 5 times higher than those upstream. The results for the sediment core experiments are summarized in Figure 2. In the first stage of the project a mean maximum nitrification rate (j_{max}) of 100 mg/m^2d ammonium was used to simulate the water quality in the river net with respect to ammonium (see simulation in the next passage).

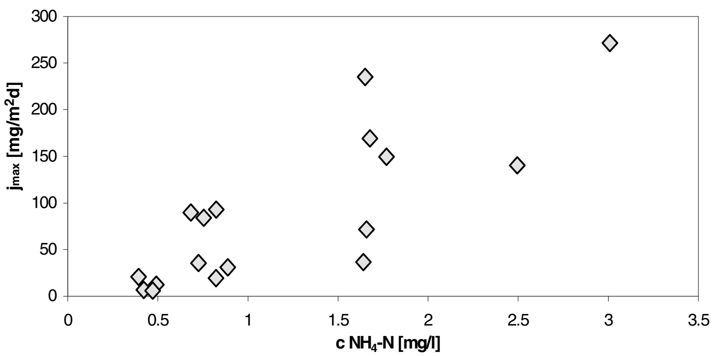

Figure 2 Dependence of the benthic nitrification rate (j_{max}) on the ammonium concentration in the bulk phase of the river

Nitrogen from diffuse sources

As already mentioned the input of nitrogen and phosphorus from diffuse sources is a main problem when modelling water quality in rivers. In Figure 3 data of the total mass flow of nitrogen in 2000 are shown in relation to the volumetric flow rate in the Bode. Considering a reduction of 50% nitrogen by denitrification in the waste water treatment plants, approximately 2,100 kg/d nitrogen should result from the 515,000 inhabitants. According to this assumption up to 8,000 kg/d nitrogen resulted from diffuse sources.

Simulation of water quality in the main river network of the Bode basin

In a first test the water quality in the main tributaries and the river Bode was simulated. The simulation focussed on waste water discharge from municipal treatment plants and on ammonium, organic carbon (COD) and oxygen. The main input parameters are shown in Table 1. The simulated hydraulic situation with a low runoff can be expected in the river Bode between July and December. River width and depth, volumetric flow rate and discharge concentrations from the treatment plants were loaded from Excel files.

In the presented simulation only sessile biomass was considered. The biomass concentrations of nitrifiers in the benthic biofilm were adapted to the experimental results of the batch experiments. The simulation results for ammonium along the river axis of all rivers are shown in Figure 4.

The simulation shows very well that the main pollution in the river network comes from the waste water treatment plants which discharge into the Holtemme. On the other side the highest impact can be seen in the smallest tributary, the Sarre. Due to the small volumetric flow rate of the river the discharge of the treatment plant at Wanzleben increased the ammonium concentration up to approximately 1 mg/L.

The mean values of the available monitoring data are shown for the Bode, the Holtemme, the Selke and the Grosser Graben. The measured and simulated ammonium concentrations fit very well. Although diffuse pollution was not considered in this simulation the user greatly profits by comparing different scenarios of waste water discharge and other anthropogenic pollution. Only the simulation of the entire river network including all pollution sources can be regarded as river basin management.

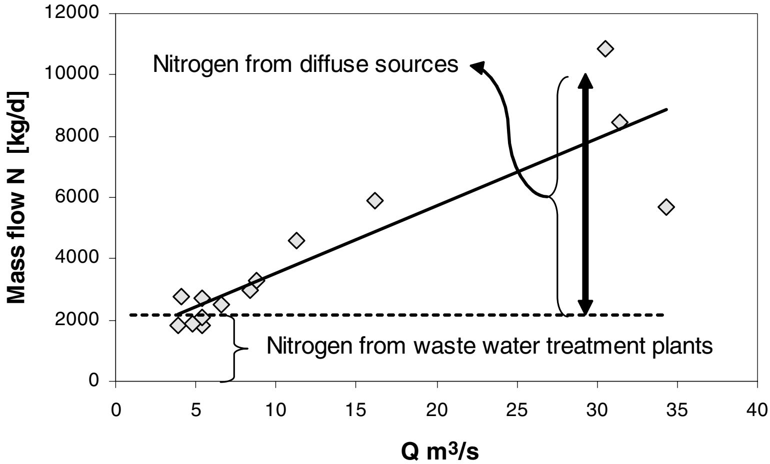

Figure 3 Total nitrogen mass flow of the Bode before discharge into the Saale dependent on the volumetric flow rate

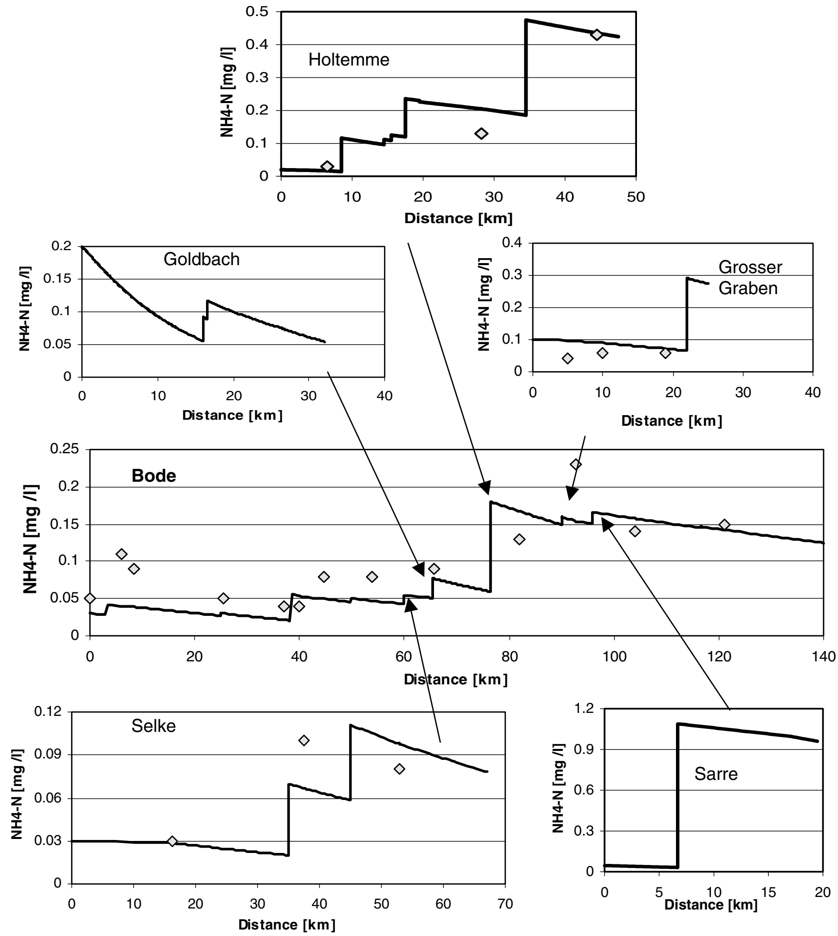

Figure 4 Simulation results and measured values for ammonium in the river Bode and the main tributaries

Table 1 Data of the river Bode and the main tributaries including wastewater treatment plants which were used in the simulation

River	Discharge [m^3/s]	Wastewater treatment plants	Population
Bode	2.084	Rübeland	42,887
		Treseburg	120
		Thale	14,185
		Quedlinburg	31,327
		Wegeleben	19,929
Tributaries:			
Selke	0.376	Ballenstedt	3,556
		Hoym	5,519
Goldbach	0.020	Langenstein	1,127
Holtemme	0.637	Silstedt-Wernigerode	70,400
		Halberstadt	57,654
Großer Graben	0.171	Oschersleben	38,991
Sarre	0.041	Wanzleben	14,858

With respect to the EU Water Framework Directive both the management of the hydraulic situation and the water quality in the river basins are the two main tasks for the states of the EU. For that purpose the simulation of water quality for different scenarios is one tool to establish river basin management plans for the declared river basins.

Conclusion

RIONET has been developed as a simulation tool for water quality management. Beside the classical biochemical water quality model, structural components of the simulated rivers can be integrated in the tool. Experimental results show that the nitrification in the river Bode takes place mainly in the benthic biofilm and is dependent on the bottom structure. Furthermore, it was shown that the nitrification rate of the benthic biofilm is dependent on the ammonium concentration in the bulk phase. Higher ammonium concentrations in the river lead to higher nitrification rates in the benthic biofilm.

The required data for the simulation of the water quality can be loaded from geographical information systems. The main advantage of RIONET is the network structure. Different scenarios can be simulated to establish river basin management plans.

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