Modelling and Simulation of Internal Pollution of Shallow Lakes

Albrecht Gnauck, Bernhard Luther and Ralph Heinrich

Abstract

In this paper results of a water quality modelling framework for riverine shallow lakes are presented. Based on investigations of interrelations between variables of freshwater quality by advanced time series analysis methods a process model for phosphorus remobilisation from lake sediments was developed. For predicting the changing water quality of shallow riverine lakes caused by internal pollution this submodel was included into the eutrophication model HavelMod. Simulations of water quality variables for different river-lake sections as phytoplankton biomass, phosphate phosphorus, ammonia nitrogen and nitrate nitrogen, which are important for water quality management activities, are discussed.

Zusammenfassung


1. Introduction

Environmental research is connected with an increasing demand for management alternatives. The public expect prompt and secure statements on critical changes of environmental conditions and their consequences on living conditions. To control water quality management activities and to predict concentration levels of important water quality indicators of shallow lakes a modelling framework for the River Havel...
was established. Up to 1990 the water quality of the River Havel was characterised by high eutrophication rates (Klose 1995). After 1990 the nutrient concentrations of effluents of sewage water treatment plants are diminished according to German environmental laws. Furthermore, a reduced usage of fertilisers and changes in the land use of agricultural areas have diminished the amount of nutrients from diffuse sources. But the actual phosphate concentrations of the riverine lakes in the course of the River Havel are high as before due to internal nutrient pollution.

Therefore, a first step of the modelling framework was the detection of control mechanisms describing this phenomenon. It depends on a lot of different conditions (Lijklema 1980, 1983, Furrer and Wehrli 1993, Schettler 1993). Modern time series analysis methods (Powell and Steele 1995) are suitable for process identification. Wavelet analysis (Mallat 1998) was used to identify interrelations between water quality variables and sediments. As a second step, Hoffmann (1999) developed a process model describing the phosphorus remobilisation from sediment. For shallow riverine lakes of the River Havel an eutrophication model HavelMod was developed as a third step of the modelling framework. In opposite of the most eutrophication models it includes the phosphorus remobilisation from sediments explicitly. It serves as a tool for computer-aided planning and design of a river enlargement program (Gnauck 1999). In future, this model shall form the simulation kernel of a decision support system for river basin water quality management. In this paper, simulation results with the model HavelMod are presented for important water quality indicators where phytoplankton biomass, phosphate phosphorus, ammonia nitrogen and nitrate nitrogen are taken into consideration.

2. Experimental Area and Data Material

The River Havel belongs to the greatest tributaries on the right hand site of the River Elbe. The source region lies in the south of the Mecklenburg Lake Area. The length of the River Havel is 325 km. It is characterised by a very small elevation difference between source of River Havel (63 m above sea level) and the mouth into the River Elbe (22 m above sea level). Fig. 1 shows a sketch of the experimental area. Hydraulic works and banked-up water levels influence water levels and flows along the course of the river. In opposite of rivers in hilly mountain regions the slope of the River Havel is extremely low. For low-flow situations a slope of the water level of 2 cm/km is observed. The watershed is characterised by high evaporation rates. Only 25% of precipitation contribute to flow. Mostly, the active sediment layer of the River Havel is given by 2 cm to 6 cm. Land use and hydromorphological characteristics of the experimental area are described by Gnauck (2001). Different hydraulic conditions between canalised and riverine stretches influence the intensity and kinetics of the chemical and biological water quality processes.
In fig. 2 a comparison of the orthophosphate concentrations of sub-watersheds with different land use structures in the catchment at measuring points Potsdam (Hv0110) and Ketzin (Hv0190) is shown. The amplitudes at Ketzin are higher than at Potsdam. This can be explained by a higher internal pollution load caused by remobilisation of phosphate from sediments (Klose 1995, Schettler 1995, Kalbe 1997). For system identification, parameter estimation and water quality modelling work samples are taken from different measuring points along the course of the river by the Environmental Agencies of the States of Berlin and Brandenburg. Water quality data series for the years 1990 to 1997 were investigated by advanced statistical methods as correlation analysis, cluster analysis and trend analysis (Gnauck and Rothe 1998). As a result, qualitative and quantitative measures of the ecosystem state are obtained. Some trends of water quality changes were detected. Also transfer factors for pollution loadings were calculated.
3. The eutrophication model *HavelMod*

To describe the eutrophication process in shallow riverine lakes the model *HavelMod* was developed. The model concept is given in (fig. 3).

![Diagram of the eutrophication model HavelMod](image-url)

**Fig. 3**

Model concept of the eutrophication model *HavelMod*

$Q_{in}$ and $Q_{out}$ is the water inflow and outflow. Driving forces are photoperiod (FOTOP), solar radiation (I) and water temperature (TEMP). State variables are
phytoplankton, zooplankton, orthophosphate phosphorus, ammonia nitrogen and nitrate nitrogen. The model consists of six differential equations. The phosphorus remobilisation submodel is included in the phosphorus balance. The time behaviour of physical water quality variables are modelled by sinusoidal functions (Straškraba and Gnauck 1985).

4. Results and discussion

After calibration and validation procedures the model HavelMod was used to simulate phytoplankton biomass, orthophosphate, ammonia and nitrate for different sections of the River Havel between measuring point 25002 (subsystem input) and measuring point 25014 (subsystem output), and between 25014 and SPK0010.

Fig. 4 shows simulation results for phytoplankton biomass. During the first five months the growth of diatoms can be seen while summer and autumn green algae and blue-green algae (so-called cyanobacteria) dominate.

The minima of phytoplankton biomass are caused by zooplankton. In late summer the algal blooms collapse. For shallow lakes, this leads to anoxic conditions at the sediment-water interface.
Fig. 5 shows simulation results for orthophosphate phosphorus. After depletion of the phosphate pool due to growth of diatoms up to the end of spring an increase of phosphorus concentration can be seen. This is in accordance with experimental results.

Fig. 5
Simulation of orthophosphate phosphorus

Fig. 6
Simulation of ammonia nitrogen
Simulation results for ammonia nitrogen (fig. 6) show some special features. For the first half of the year higher values are obtained for subsystem outputs 25014 and SPK0010. In the second half of the year the behaviour is changed because of higher nitrification rates and a stronger utilisation of inorganic nitrogen by cyanobacteria.

The behaviour of the nitrogen subsystem follows the phytoplankton dynamics. As can be seen from fig. 7 the utilisation of nitrate nitrogen by algae, low nitrification rates and reduction of nitrate as a result of anaerobic processes on the sediment-water interface leads to low concentration levels during summer. The disturbances of the curve for measuring point 25002 is caused by the influence of the River Spree.

5. Conclusions

The full water quality modelling framework of the River Havel consists on a set of different types of models: process models describing interrelations between single processes (wavelet models, regression type models), an eutrophication model for riverine lakes, an Streeter-Phelps type eutrophication model for river stretches, multi-objective water quality management model. Up to now, the first two positions are realised. The last two model developments are in progress.

The simulation results gives a suitable basis for water quality management alternatives and have to be considered for sanitation programs and regional developments in the catchment. As a result of this part of the modelling framework it can be stated that phosphate remobilisation from sediment must be included into a eutrophication...
Comparing the simulation results of both river stretches some differences are observed. The phytoplankton concentrations of the river stretch between measuring points 25002 and 25014 are higher than for the river section between 25014 and SPK0010. The dynamics of both nutrient compartments is in accordance with changes in phytoplankton biomass.

Bibliography


