Simulation of the Eutrophication Process in Shallow Rivers and Lakes

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Abstract

Natural and man induced nutrient loads affect the functioning of freshwater ecosystems and restrict various water uses. Especially, internal pollution by phosphorus remobilisation from sediment plays an important role in shallow water bodies. To forecast the eutrophication process of a shallow river lake-system a modelling and simulation framework was developed. Data are taken from the Lower Havel River. For water quality management options two control strategies are discussed.

Keywords: eutrophication, water quality modelling, simulation, optimisation

1 Introduction

The eutrophication process of freshwater ecosystems is supported by intensive man-made activities in river basins. Polluted water affects not only the functioning of freshwater ecosystems but risks human health. Sustainable management decisions to control the quality of freshwater ecosystems can only be achieved by using powerful simulation tools. For a shallow river-lake ecosystem a modelling and simulation framework was developed. Changing water quality levels are simulated by an eutrophication simulator which was carried out within a MATLAB environment. To get best management options the eutrophication simulator was coupled with the optimisation tool *ISSOP* [5}, [6], [1]. In this paper, optimised simulation results are presented and discussed for important water quality indicators.

2 The eutrophication simulator

To simulate the eutrophication process in shallow water bodies a stationary 1D-model was developed. The model concept is given in fig. 1. The mathematical model consists of nine differential equations, some site constants and model specific parameters. Detailed descriptions of model equations, parameters, site constants and system specific parameters are given by [1], [2]. A phosphorus remobilisation submodel was included in the phosphorus balance equation. Model state variables are given by the indicators phytoplankton, zooplankton, orthophosphate phosphorus, ammonia nitrogen, nitrite nitrogen, nitrate nitrogen and phosphorus remobilisation from sediment as well as by dissolved oxygen (DO) and biochemical oxygen demand (BOD).

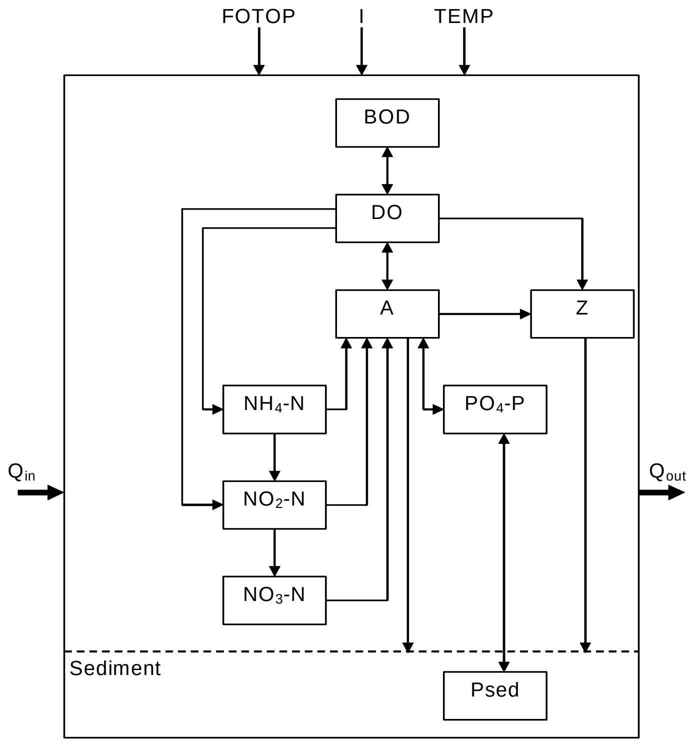

Figure 1: Conceptual model of the eutrophication simulator

Q_{in} and Q_{out} describe the discharges into and out of the river segment or lake under consideration. External driving forces are photoperiod (FOTOP), solar radiation (I) and water temperature (TEMP).

3 The optimisation tool *ISSOP*

To combine simulation and optimisation procedures the software tool *ISSOP* was used. It contains an open interface of MATLAB models [8] which was used for coupling. Fig. 2 shows the general structure of coupling. Goal functions are represented by $f_1,...,f_n$ with $f_i(M(\alpha_1 x_1,..., \alpha_k x_k)) = f_i(y_1,...,y_m)$ for i = 1, ... n where arbitrary continuous functions f_i can be used. If $n > 1$, then the goal functions $f_1,...,f_n$ are aggregated to a weighted sum $S = \Sigma\, w_i\, f_i$. For weighting factors w_i the condition $\Sigma|w_i| = 1$ is valid. The data transfer between optimisation and simulation system is organised by *ISSOP*. The model variables and target values are as input data while optimised state variables are given back to the simulation system.

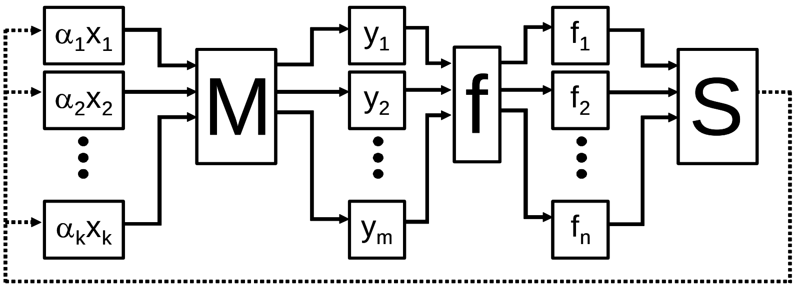

Figure 2: Coupling of *ISSOP* with the eutrophication simulator *HavelMod*

4 Experimental area and data treatment

For water quality simulations the river basin of the Lower Havel was divided into several segments of different length (fig. 3).

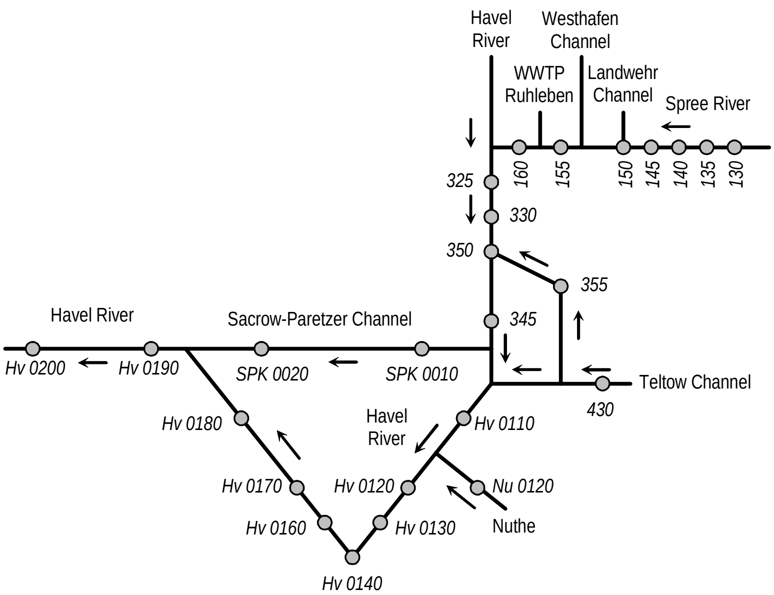

Figure 3: Scheme of the experimental area of the Lower Havel River

Irregular sampled time series from 1990 to 2002 from different measuring points along the course of rivers Spree and Havel are used for modelling and parameterisation. Before modelling data series were tested by different interpolation methods to get equidistant daily data. For the investigated river-lake ecosystem mostly linear interpolation method has been proved the smallest standard error compared with nearest neighbour method, cubic splines and cubic Hermite polynomials (tab. 1).

Table 1: Interpolation results for lowland rivers

Indicator	River Spree	Teltow Channel	River Havel
NH4-N	linear	linear, spline	linear
NO2-N	linear	linear	linear
NO3-N	linear	linear	linear
o-PO4-P	linear, spline, polynomial	linear, spline	linear
chlorophyll-a	linear	linear, spline	linear

5 Simulation results

For simulation of changing nutrient levels the P-remobilisation process [3], [4] was included into an eutrophication simulator called *HavelMod*. After model validation the simulator was used to evaluate the eutrophication process in the Lower Havel River. Because of nutrient rich water body the bio-production is high in spring and late summer. In late summer algal blooms collapse. This leads to anoxic conditions at the sediment-water interface. A decrease of phosphorus concentrations due to phytoplankton uptake by diatoms in spring, and an increase due to phosphorus remobilisation from sediment in fall can be seen from fig. 4.

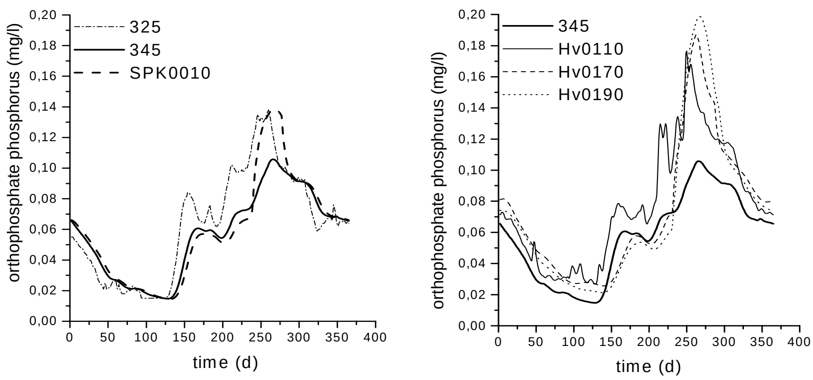

Figure 4: Simulation of phosphorus dynamics

To get water quality management options two control strategies are considered: The limiting nutrient concept and target values of German Working Group LAWA [7]. For optimisation the following goal functions are used:
phytoplankton biomass $f_1(t) = \Sigma_x \Sigma_t \, y_1(x, t) \rightarrow \min$,
orthophosphate phosphorus $f_2(t) = \Sigma_x \Sigma_t \, y_2(x, t) \rightarrow \max$,
nitrate nitrogen $f_3(t) = \Sigma_x \Sigma_t \, y_3(x, t) \rightarrow \max$.

1. Optimised simulation results are presented in fig. 5. An eutrophication control according to the limiting nutrient concept leads to a diminished phytoplankton

maximum in late summer due to optimised nitrate concentrations. No effect of optimised orthophosphate phosphorus concentration can be stated.

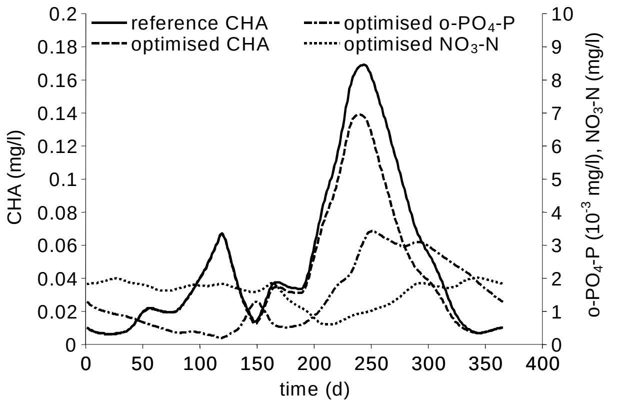

Figure 5: Eutrophication control according to limiting nutrient concept

2. Eutrophication control according to LAWA target values leads to nearly the same behaviour of phytoplankton biomass in spring but to smaller differences of phytoplankton maxima and to low nutrient concentrations in late summer (fig. 6).

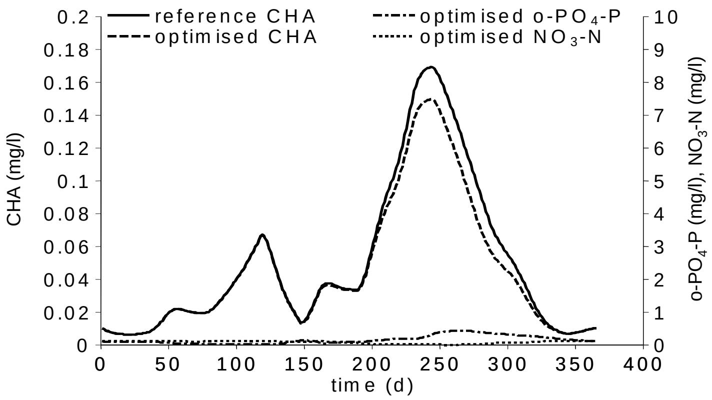

Figure 6: Eutrophication control due to LAWA regulations

6 Conclusions

Sustainable management options to control freshwater ecosystems can only be achieved by using powerful informatic tools. The use of a combined simulation-optimisation procedures to manage the water quality of freshwater ecosystems is an approach promising more theoretical understanding of complicated natural processes and software engineering methods. Direct interrelations exist between nutrient release from sediment and water quality. Phosphate remobilisation from sediment can be considered as a result of contradictory processes of matter changes. In consequence the LAWA strategy leads to significant lower nutrient concentrations but to a slight increase of phytoplankton biomass. In opposite of that eutrophication control by means of limiting nutrient concept results in lower phytoplankton concentrations but higher admissible nutrient inputs.

7 References

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