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MODELLING CONCEPTS AND DECISION SUPPORT IN ENVIRONMENTTAL SYSTEMS

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The purpose of the present publication is to popularize information tools and applications of informatics in environmental engineering and environment protection that have been investigated and developed in Poland and Germany for the last few years. The papers published in this book were presented during the workshop organized by the Leibniz-Institute of Freshwater Ecology and Inland Fisheries in Berlin in February 2006. The problems described in the papers concern the mathematical modeling, development and application of computer aided decision making systems in such environmental areas as groundwater and soils, rivers and lakes, water management and regional pollution. The editors of the book hope that it will support the closer research cooperation between Poland and Germany and when this intend succeeds then also next publications of the similar kind will be published.

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CHAPTER 2

Rivers / Lakes

LAKE MÜGGELSEE: WHAT WAS HAPPENED IN THE PAST AND WHAT WILL BE IN THE FUTURE – A CHALLENGE IN MODELLING AN ECOSYSTEM

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Abstract: *During the last 20 years the nutrient input into the lakes and rivers of the Spree catchment declined. In the future we expect a warmer climate together with a lower discharge and a further reduction of nutrients into the lake especially in this region. In order to predict the impacts of these changes on the ecosystem of the lake Müggelsee we redeveloped the ecosystem model EMMO which was adapted to that shallow lake. The model was modularised and extended with the temperature evolution model TEMIX. Besides the development of the model EMMO the ECOBAS system which supports modelling and simulation was improved. With EMMO we now have a complex ecosystem model for detailed simulations and with the ECOBAS-system a tool to develop, extend and analyze ecosystem models. But what are the limits of the model and how can we overcome that?*

Keywords: water quality, ecosystem model, global change, shallow lake, ECOBAS, future scenarios.

1. Introduction

During the last 20 years the catchment of the river Spree experienced drastic changes of mainly three areas.

- Firstly, the nutrient input into the river declined due to the breakdown of the industry and of the agriculture of the former GDR.
- Secondly, the discharge of the river is reduced due to the flooding of the open cast mining pits in the upper Lausitz-region.
- Thirdly, the temperature increased due to the climate change.

Any of these factors alone may affect the lakes inside the catchment in a biological, chemical and physically manner respectively.

A lower nutrient input into the lake may lead to a reduced primary production with a trend to a more oligotrophic lake. Due to better light conditions at the bottom of that shallow lake growth of macrophytes becomes possible, which themself may change the ecological state of a lake, following the paradigm of bistability of shallow lakes due to dominance of algae with a high turbidity or due to a dominance of macrophytes with a low turbidity.

In connection with the lower nutrient input a reduced discharge of the river is to be expected. Hence a more stratified behaviour due to one missing driving force of mixis may be the consequence. Another driving force of mixis is the light and the temperature. How will they influence the stratification of a shallow lake?

To answer such questions it is important to know how the combination of these three influences affects to the shallow lake Müggelsee. We were applying the ecosystem model EMMO to predict the situation in the past (20 year period) and to the future using appropriate nutrient and climate scenarios. We will show that the model describes the main processes in the lake and is able to predict a possible trend into the future. The model EMMO is based on an approach by Schellenberger et al. (1983) and the reorganization of that old model in order to obtain an executable simulation tool was difficult. Therefore it was of great importance to use the ECOBAS system, developed in University of Kassel by Benz et al. (2001). The other way round the development of ECOBAS was highly motivated by the needs of the extensions of EMMO. Hence this paper aims at two different directions: On the one side we show that an efficient water management needs an understanding of the ecological processes and on the other side we inform about ECOBAS.

2. Materials and Methods

2.1. The ecosystem model EMMO

The ecosystem model EMMO was developed by Schellenberger et al. (1983) in order to study the interactions between the water body and the sediment in a shallow lake and to predict the impacts due to changes in nutrient concentrations in the inflowing river Spree. Conceptually, the model EMMO is divided into a water and sediment compartment. The water compartment contains 9 components: 3 groups of algae (diatoms (DIA), cyanobacteria (springform (BCF) and summerform (BCS)), bacteria (BAKT), zooplankton (ZOOPL), fish (FI), detritus (DET), the concentration of dissolved inorganic nitrogen (N) and phosphorus (P). The sediment compartment includes the zoobenthos (ZOOB), the nutrients in the active layer as well as in the burial. The nutrient cycle contains the organic matter (M), the dissolved inorganic form of nitrogen (NS) and phosphorus (PS) and a burial form of all (UM, UNS, UPS). Moreover the phosphorus cycle includes an adsorbed sediment form (PAS) and its burial form (UPAS) (see Figure 1). All further information like the composition of the organic and inorganic components, the equations, the units with a detailed explanation are given by Schellenberger et al. (1983), Strube (2005) and Strube et al. (2006).

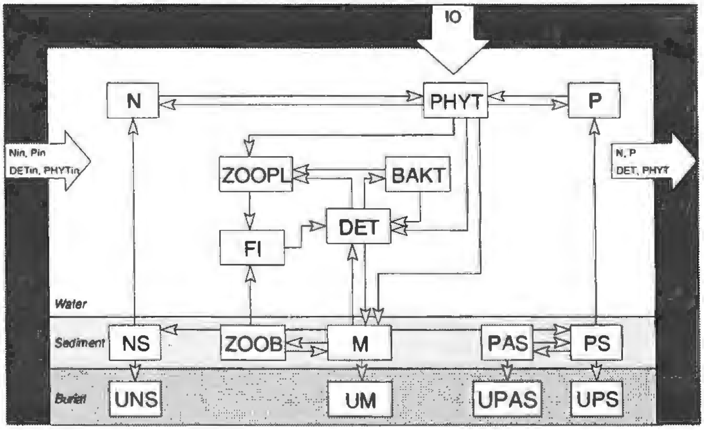

Figure 1. The structure of the ecosystem model EMMO using the global radiation (IO), the incoming nutrients (Nin, Pin), phytoplankton (PHYTin) and detritus (DETin) as external data (for further explanation see the text).

Most of the state variables of EMMO are described by ordinary differential equations. The processes considered in EMMO (sedimentation, primary production etc.) appear as single terms in any of these differential equations. The model was comprehensive tested (calibrated and validated) by Strube et al. (2006).

2.2. The ECOBAS system

In order to extend the model EMMO by including additional processes it was modularised and redeveloped with the ECOBAS-system. ECOBAS is a simulation- and model development platform which supports the modelling process in modularization, in system analysis and in developing of consistent models (Benz et al. 2001, Strube 2005, Strube et al. 2005). Last not least a standardized complete information about the model can be obtained.

ECOBAS stores all available and relevant information about an ecological model: (i) the structural information, (ii) the mathematical approaches (including the units), (iii) the ecological context and (iv) the input time series. ECOBAS itself is modular designed. Hence the information about an ecological model will hold in different modules. In recent years the ECOBAS-system was significantly extended by the inclusion of new functionalities for modelling (see below). The structure of the ECOBAS-system is shown in Figure 2.

The Graphical Model Editor (GME) provides the aggregation of two or more modules building a higher-level-module until the entire model is contained in one "super-module". During that aggregation process a comprehensive check routine is operating in order to merge the right In-/Output-variables.

The ECOBAS simulation system (ESS) is that part of ECOBAS which is responsible for all aspects of numerical simulation. That concerns the simulation itself, the parameter analysis, the parameter fitting and the sensitivity analysis.

The ECOBAS data management stores the input time series, the observed data and the simulation results as well in a SQL-database. Furthermore, that database will hold the units and the measuring methods of the observed data.

The ECOBAS system relieves the model developer from all aspects of numerical implementation. It helps to check the units of state variables and parameters, it supports by a graph-theoretical tool the optimal modularization and last not least it provides an automatic documentation of the model, which goes far beyond the description of models in journal papers.

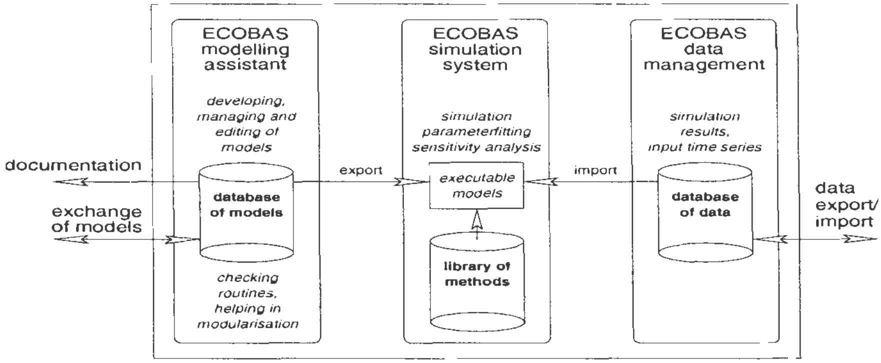

Figure 2. The structure of the ECOBAS-system with the ECOBAS modelling assistant (EMA) (including the Graphical Model Editor GME), the ECOBAS simulation system (ESS) and the ECOBAS data management (EDM).

3. Results

3.1. The past period (1980-2000)

During the last 20 years the nutrient input into the lake has been changed drastically. The challenge of the simulation run was, whether the model can reproduce that trend with the seasonal pattern or not. However, in this paper we will only show some results concerning the dissolved nutrients phosphorus (DIP), nitrogen (DIN), the biomass of diatoms and of both cyanobacteria forms (spring and summer).

The results of the past period simulation run are in a close agreement with the measurements (Figure 3). The nitrogen concentration declined continuously during the past period with the exception of two years probably because of a measurement error. In some years the nitrogen concentration was remarkably higher than in other years (1987 and 1994) due to the relatively low biomass of cyanobacteria. Obviously the model can handle these annual changes in nitrogen concentration very well.

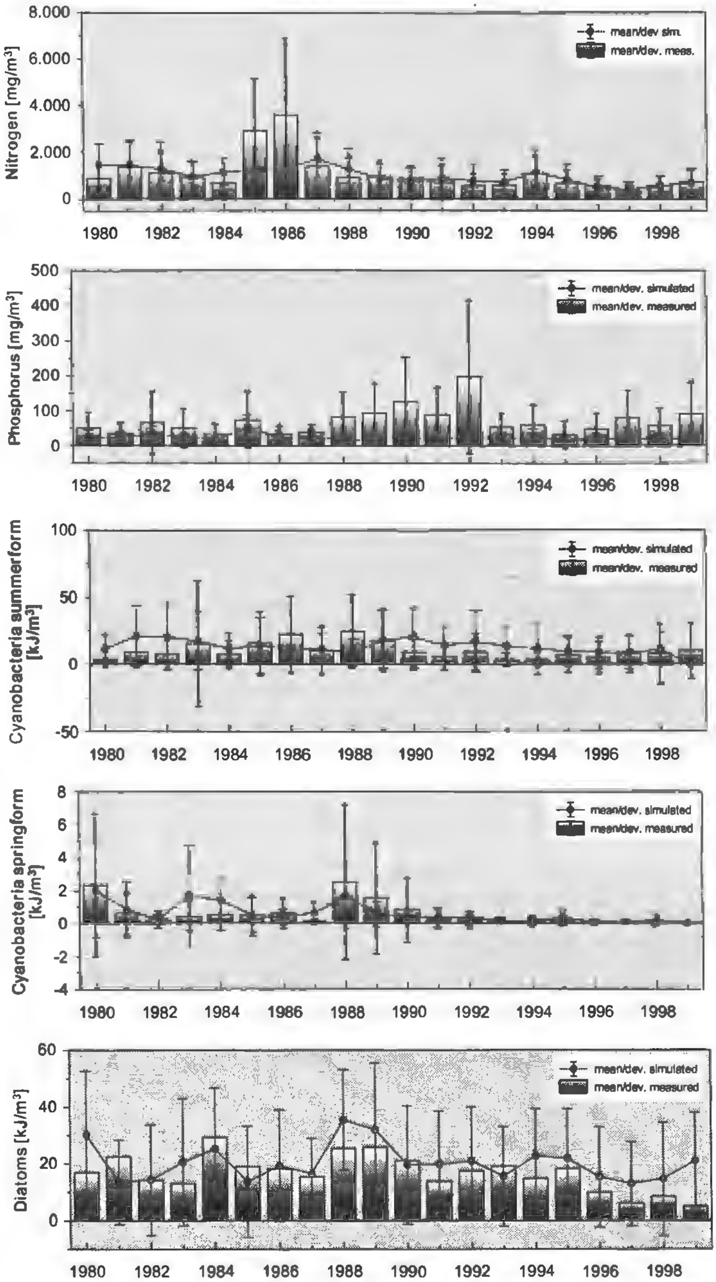

Figure 3. The results of the past period simulation run: The mean values (bars) with the standard deviation (error bars) of the nitrogen concentration, the phosphorus concentration, the biomass of cyanobacteria (summer- and springform) and diatoms.

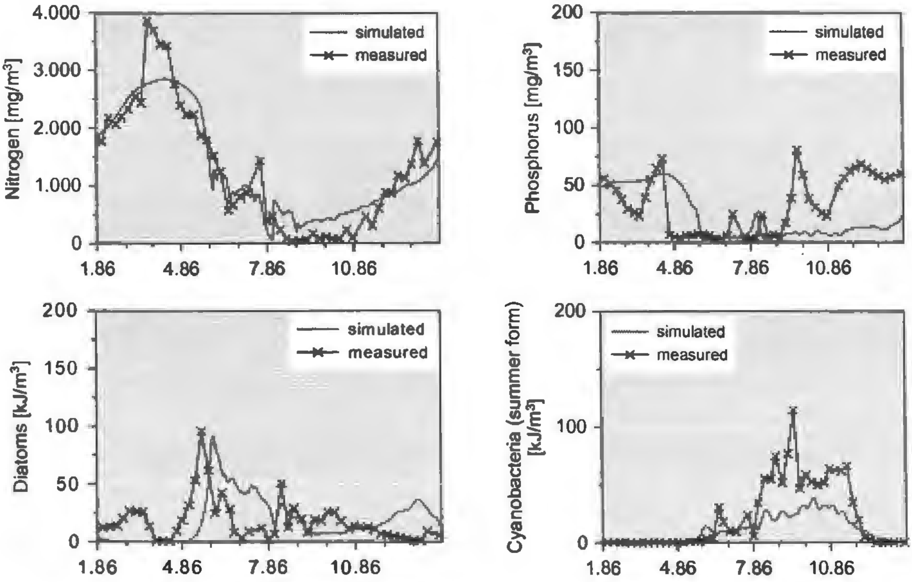

Figure 4. The measured vs. simulated annual dynamic of the components concentration of nitrogen and phosphorus, the biomass of diatoms and cyanobacteria (summer form) in 1986. That year was selected arbitrary.

The simulation results of the mean concentration of phosphorus show discrepancies to the measurements. Especially in the years from 1988 to 1992 an enormous phosphorus release occurred in the lake (Kleeberg and Kozerski 1997, Kleeberg and Dudel 1997, Kozerski et al. 1999) which cannot reproduce by the model. However, this high phosphorus concentration did not have a remarkable effect to the simulated primary production of the lake.

In general, the biomass of cyanobacteria coincides with the measurements. The slight discrepancies in the prediction of the cyanobacteria arise from the difficulties to model the competition of cyanobacteria and diatoms appropriately (shown by Strube et al. (2006)). However, the model can reproduce the strong decline of the spring forms of cyanobacteria very well over the past period.

Considering the annual dynamic of the components a similar result has been obtained (Figure 4). The abiotic nutrient fraction can be well reproduced by the model except the release of phosphorus during the late summer each year. The results concerning the biotic components are satisfactory with two exceptions: In 1986 the beginning of growth of the diatoms had a time shift and the clear water phase in May could not be presented sufficiently. That pattern is changing from year to year. Often the beginning of growth can be simulated, however the clear water phase as a function of Zooplankton biomass cannot reproduce sufficiently. One reason for the failing of the model is the static food web matrix: If preys of one type become scarce then the dynamic shift to other preys cannot described. Hence the mathematical description of adaptation in food interactions has to be improved in next steps of the model development.

In most of the years the beginning and the end of growth of the cyanobacteria coincide well with the measured data. In 1986 the measured maximum cannot be simulated probably due to the underestimation of phosphorus. Note, however that the higher phosphorus concentration did not have a detectable effect on the primary production. The discrepancy may be explained by the fact that EMMO considers the lake Müggelsee as uniform with respect to its morphometry. Hence the measurements which were taken from the deepest point of the lake may not representative for the lake.

3.2. The future scenario (2048-2052)

To look forward to the next 50 years we had to formulate some realistic scenarios regarding the climate change and the nutrient immission (biotic/abiotic environment) into the lake. All input information was given by several simulation runs of climate models within the GLOWA-Elbe project (Wechsung et al. 2006). The only exception is the abiotic/biotic nutrient immission. Here we used data from the nutrient emission model MONERIS published by Behrendt (2002). However, in the case of the incoming biotic nutrients even no simulation runs existed. Thus we had derived the input time series by means of existing data. We used the percentage of reduced phosphorus (33%) and assumed that the incoming phytoplankton and detritus concentration will be reduced in the same way. These assumptions are related to the mean seasonal dynamic between 1993-1995 (Table 1). The results of the future scenario are to be compared with a time period without such drastic changes of nutrients and discharge: 1982-1988

Table 1. Input data used for the future scenario simulation run with EMMO.

	2003 – 2007	2048 – 2052
Climate	According IPCC (2001)	+1.5K
Discharge of the Spree river	WBalMo[1] GLOWA	-18%
Nitrogen	Mean annual dynamic 1993-1995	-24%
Phosphorus		-33%
Phytoplankton		-33%

For the future period the model EMMO predicts a reduction of nutrient concentration and phytoplankton biomass as well. An important difference between the

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[1] WBalMo: **W**ater **Bal**ance **Mo**del. This model takes into account the activities of agriculture,of the mining industry, the tourism ministry and the water companies.

nutrients nitrogen and phosphorus is obtained: Whereas the nitrogen decreases (by 68%) during the non-growing as well as during the growing season, the phosphorus decline (by 35%) occurs only during the non-growing season (Figure 5).

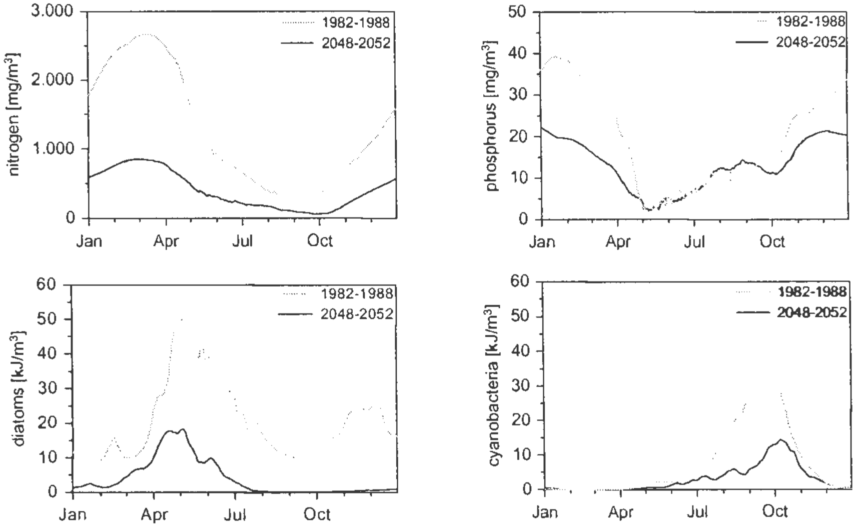

Figure 5. Results of the future scenario: The mean concentration of nitrogen and phosphorus and the mean biomass of diatoms and cyanobacteria (summer form).

This reduction of the nutrients leads to a decline in the biomass of diatoms by about 80%. Further, it affects not only a decrease of maximum biomass but also is responsible for their absent in the second half of the year (Figure 5). The effect on cyanobacteria is not as drastical as for diatoms: The cyanobacteria are able to store nitrogen into their cells hence they are relatively independent from the nitrogen concentration in the water. Nevertheless due to the low mean concentration of nitrogen is so slight the biomass of cyanobacteria is reduced by 60%.

4. Conclusion

The simulated results over a 20 year past period have generally shown the applicability of the model. Prognosis is the one side, understanding of the mechanisms which control an ecosystem is the other one. The model EMMO appears as helpful with respect to both sides. However some of the urgent problems in lake management are still open. We already mentioned that the static food web matrix must be supplied by an adaptive modelling framework in order to simulate the dynamical variations of food preferences. Another aspect is that macrophytes play an important role as they influence the nutrient and oxygen balance. A new module for macrophytes can be formulated on the basis of literature. However the integration of such module into an already complex model may be difficult. Here, however ECOBAS will be very helpful, as most of the software technical problems will be supported by means of the tools of ECOBAS.

Optimal water management can be derived from complex simulation models either by optimization procedures as shown by Studzinski, et al. (2006), this book, or by deriving different discrete scenarios which can be evaluated by by multiattributive decision support systems. An example was given by Kardaetz, et al. (2006) by applying methods which also are explained by Brüggemann et al. in this book.

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Jan Studzinski, Olgierd Hryniewicz (Editors)

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This book presents the papers that describe the most interesting results of the research that have been obtained during the last few years in the area of environmental engineering and environment protection at the Systems Research Institute of the Polish Academy of Sciences in Warsaw and the Leibniz-Institute of Freshwater Ecology and Inland Fisheries in Berlin (IGB). The papers were presented during the First Joint Workshop organized at the IGB in February 2006. They deal with mathematical modeling, development and application of computer aided decision making systems in the areas of the environmental engineering concerning groundwater and soil, rivers and lakes, water management and regional pollution.

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