Verh. Internat. Verein. Limnol.	28	1–4	Stuttgart, October 2002

Modelling the vertical variation of temperature and dissolved oxygen in a shallow, eutrophic pond as a tool for analysis of the internal phosphorus fluxes

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Introduction

Insights into summer phosphorus supplies within the pelagic zone are important for the management of lakes. In shallow lakes and ponds with a low surface to volume ratio, however, internal nutrient sources are difficult to quantify. Knowledge of the temporal and vertical variations of temperature and dissolved oxygen is necessary to predict phosphorus release by lake sediments. Even short-term stratification with the development of anoxic conditions can affect a wide area of the sediment surface (KALLIO 1994).

Omnivorous fish, such as roach, can also be an important internal phosphorus source due to their consumption of benthic resources when zooplankton prey is scarce, which leads to a translocation of sediment phosphorus to the water column (PERSSON et al. 1999).

The object of the present study was to analyse the amount of internal P-loading by sediment release and fish activity. For that purpose, a one-dimensional dynamic model was constructed to simulate the vertical mixing process for a polymictic pond in western Germany with a maximal depth of 4 m, considering morphometry and weather conditions (STRAUSS unpublished). The results were verified by a whole-lake P balance.

Study area and methods

Lake Alsdorf is a shallow eutrophic pond near Aachen (Germany) with a surface area of 3.1 ha, a mean depth of 2.6 m, and a maximum depth of 4.1 m (Fig. 1). In 1997 the hydraulic residence time was 235 days, the mean Tot-P was 0.124 mg L^{-1}, and the maximum Tot-P was 0.217 mg L^{-1}. Roach (*Rutilus rutilus*) dominated the fish community, accounting for 80% of fish by numbers. The total fish biomass was estimated, by electrofishing and echosounding in 1997, as ca. 350 kg ha^{-1}. Due to heavy predation from roach and perch, the zooplankton was dominated by small bosminids, cyclopoid copepods and rotifers.

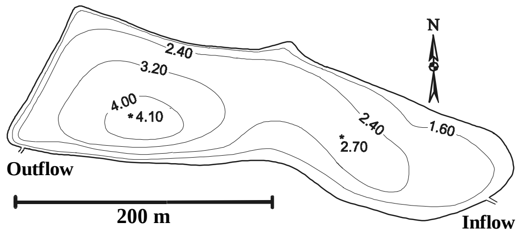

Fig. 1. Morphometric contours (m) of Lake Alsdorf (* indicates sample sites).

To simulate the vertical distribution of temperature and dissolved oxygen, a one-dimensional hydrodynamic model was coupled with a simple biological module. The meteorological input data required to run the hydrodynamic model were solar radiation, air temperature, wind speed, atmospheric pressure and humidity. These data were obtained at 10-min intervals from the meteorological station at Aachen, 13 km north of the pond. The model also required input data on chlorophyll *a* and Secchi disk depth, measured approximately every 10 days. The dissolved oxygen concentration depends on algal photosynthesis and respiration (related to chlorophyll *a*), biochemical and sedimentary oxygen demand, and aeration. The oxygen-related parameters of the biological module (Table 1) were calibrated against the observation data on dissolved oxygen concentration from 1995. The thickness of the hydraulic layers was set to 25 cm and the time interval to 1 min.

When modelling the dissolved phosphorus concentration, the P increase depends on the sediment release, while the P decrease is correlated with the oxygen production by algae (value used: 0.005 mg P mg O_2^{-1}).

Gut content analysis of roach (n = 85, 8–14 cm in

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Table 1. Parameter values (at 20 °C) used for the oxygen model (*model calibration, **measurements in 1995).

Parameter	Value
Maximum algal O_2 production mg O_2 µg chl a^{-1} day^{-1}**	0.14
Algal respiration mg O_2 µg chl a^{-1} day^{-1}**	0.016
BOD<10 °C mg O_2 L^{-1} day^{-1}*	0.3
BOD>10 °C mg O_2 L^{-1} day^{-1}**	1.4
SOD g O_2 m^{-2} day^{-1}*	1.5
Temperature coefficient	1.13*

length) was carried out according to the methods of PERSSON (1982). The evacuation rate (R) of roach per hour was obtained according to PERSSON (1982):

$$R = 0.032 \times e^{0.115 \times T}$$

The total daily intake by roach (C_{tot}) was calculated as:

$$C_{tot} = S \times R \times W \times 24$$

where S is the average amount of food in the intestine (this study: 1.51 mg dw g^{-1} fish), and W is the wet weight per fish.

The amount of benthic P consumed per day (C_{benth}) can be written as:

$$C_{benth} = C_{tot} \times B \times P_{detr}$$

where B is the relative amount of benthic food items, and P_{detr} is the P content of detritus.

A reduction in the energy content of the diet leads to an increase of gastric evacuation, so that the intake of energy remains relatively constant (JOBLING 1980, HOFER et al. 1982). Assuming that the ash-free dry weight (AFDW) of food items represents their energy content, the P content of the AFDW of detritus was used for further calculations. This value was obtained by measuring the P content of trapped matter, sampled by sedimentation traps, representing the quality of the uppermost layer of the sediment (mean from 1997: 10.9 mg P g^{-1} AFDW detritus).

The temperature required to calculate the evacuation rate was computed, using the simulation model, as the average temperature of all layers with a dissolved oxygen concentration above 2.5 mg L^{-1} (criterion for fish habitat according to STEFAN et al. (1996)).

Gross sedimentation was measured using sedimentation traps with a height of 60 cm and a diameter of 6 cm. To calculate the net sedimentation, the trapped matter was corrected for resuspension (GASITH 1975), using the TP/dry-weight ratio for separation. The traps were emptied at 3- to 10-day intervals.

The release rate of phosphorus across the sediment surface was measured monthly (April–July) with intact sediment cores from several parts of the pond. The experiments were carried out in the laboratory at 10, 15 and 20 °C under aerobic and anaerobic conditions, according to the methods of KAMP-NIELSEN (1974).

The concentrations of total and dissolved phosphorus were measured approximately every 10 days at the inflow and outflow, and within the water column (at every 50-cm depth during stratification).

Results and discussion

There was close agreement between simulated and measured profiles of temperature (Fig. 2) and dissolved oxygen (Fig. 3), indicating that

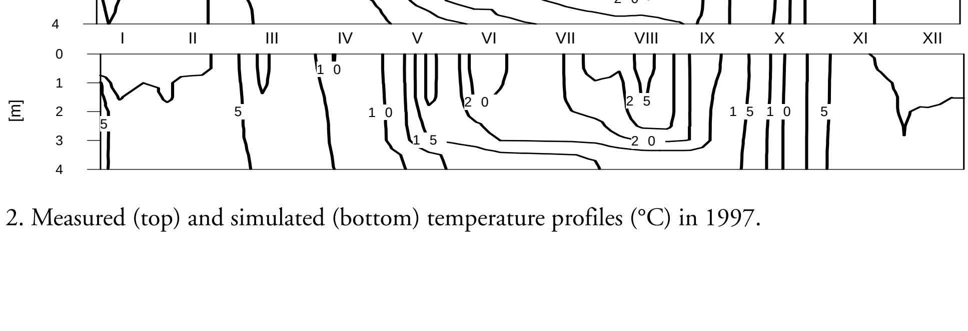

Fig. 2. Measured (top) and simulated (bottom) temperature profiles (°C) in 1997.

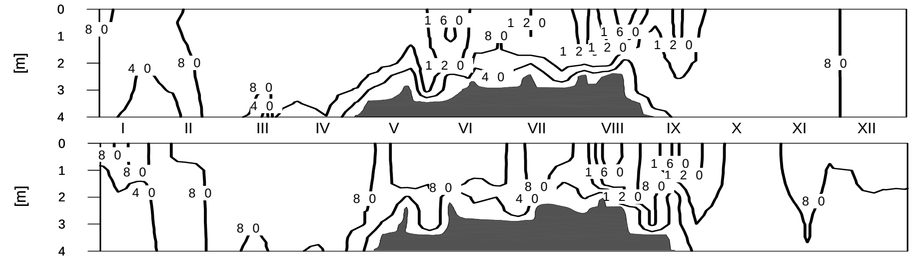

Fig. 3. Measured (top) and simulated (bottom) dissolved oxygen profiles (% saturation) in 1997. Shaded areas indicate oxygen saturation <1.

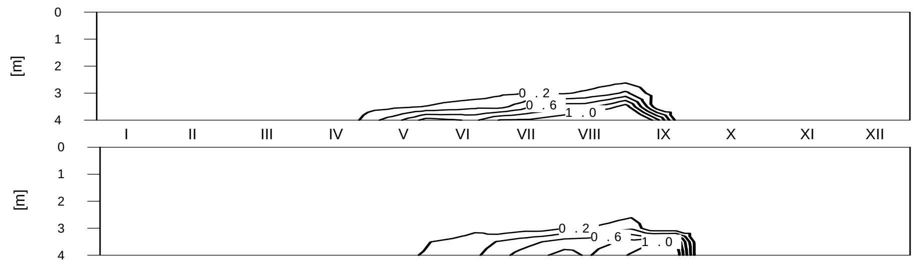

Fig. 4. Measured (top) and simulated (bottom) dissolved reactive phosphorus profiles (mg P L^{-1}) in 1997.

the model allows the reproduction of the vertical mixing process depending on variable weather conditions. The sediment-P release rates under laboratory conditions were 9.8 ± 1.3 SE mg P m^{-2} day^{-1} (anaerobic) and 0.121 × $e^{0.168 \times T}$ mg P m^{-2} day^{-1} (aerobic). The simulation generated significant results using these data to model the accumulation of dissolved reactive phosphorus during the summer months (Fig. 4). Nevertheless, the delay of simulated P accumulation in May is seen as a consequence of a less stratified water body at that time.

The total amount of sediment P being consumed by a sediment-feeding roach (with 12 g ww at 20 °C) (1.65 mg P $fish^{-1}$ day^{-1}, present study) was within the same range of P excretion rates (1.56 mg P $fish^{-1}$ day^{-1}) as those calculated by BRABAND et al. (1990).

In summer, the gut contents of both smaller and larger roach were dominated by sediment (Fig. 5). From September onwards, cyclopoid copepods and bosminids were the preferred food items of roach. This indicates that the fish phosphorus release of 'new' phosphorus added to the water column may have been of special importance during June and August.

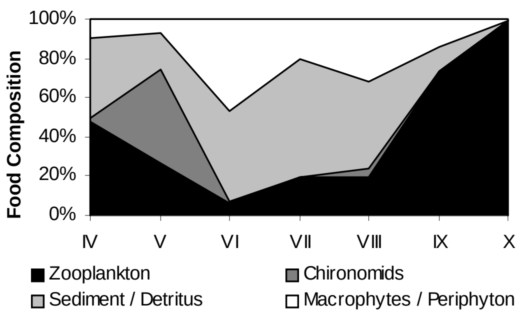

Fig. 5. Food composition (% relative proportion of biomass) of roach during summer 1997.

The comparison of the phosphorus sinks and sources, calculated for the whole pond for four

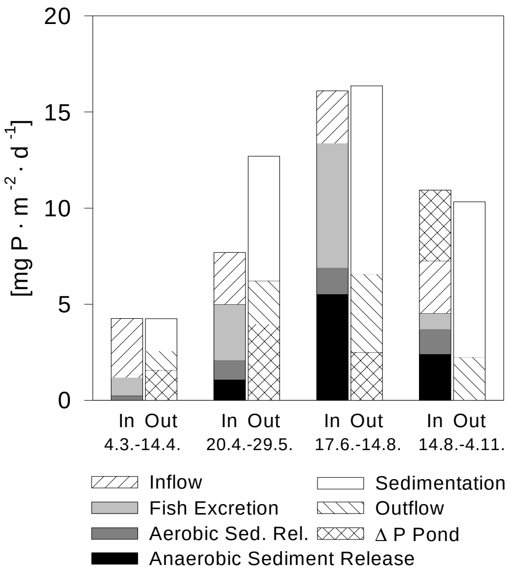

Fig. 6. Phosphorus balance for Lake Alsdorf in 1997: P input (left bar) and P output (right bar) calculated per pond area.

periods in 1997, shows a balanced budget (Fig. 6) for most of the time. In particular, the release of P from the sediment, from June to August, was nearly of the same order as the P input by benthivorous fish. Both processes were responsible for about 80% of the total P input at that time.

The model presented to date is a powerful tool for interpreting the phosphorus loading of a small stagnant lake. It will be further developed and is intended as a building stone for future models, which can be applied as predictive tools in the management of shallow waters.

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