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Water and nutrient mass balance of the partly meromictic temperate Lake Verevi

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Abstract

Mass balances of total nitrogen and total phosphorus were calculated for Lake Verevi (area 0.126 km^2, maximum depth 11 m, mean depth 3.6 m), a sharply stratified small lake located in South Estonia within the borders of the town Elva. The lake has up to 10 small inflows but only three of them are nearly permanent. Accidental overflows from near-by oxidation ponds during high floods have been the major source of the nutrient load of the lake in the past. L. Verevi receives a significant part of its inflow from groundwater, which is difficult to measure. In dry years the outflow is temporary. During summer the lake is sharply thermally and chemically stratified. The spring turnover is often incomplete even in homothermal conditions, thus giving the lake some meromictic features. The influx of nitrogen exceeded the outflux at any supposed proportion (20%, 50%, 80%) of surface runoff. The lake retained 45–90% of the nitrogen influx by sedimentation and/or by denitrification. The largest nitrogen losses with loss rates more than 10 kg N d^{-1} occurred in May and June. The calculated phosphorus retention rate became strongly negative during mixing periods. From June to November, phosphorus release from the sediment exceeded sedimentation by 205 kg in 1991 and by 79 kg in 1993. Earlier stagnation and absence of a full spring turnover in the 2000 has slowed down the recovery of the lake because less phosphorus is flushed out. However, the stronger stratification and significantly smaller phosphorus content in the epilimnion limits biological activity and as a result improves the water quality of the surface layer.

Introduction

Construction of a sound mass balance entails two main subjects: (a) evaluation of the water balance, and (b) evaluation of the balance of any substance in question. As far as possible, these evaluations should be based on measurements in the catchment area and in the lake. If direct measurements of some component, e.g., the groundwater inflow to lakes, are not available, indirect estimates can be made. However, as warned by Jørgensen & Vollenweider (1988), indirect estimates must be used and interpreted with caution. Nutrient balances have provided data on a large variety of lakes, from those acting as efficient sinks of phosphorus up to the lakes in which almost continuous phosphorus release occurs from anaerobic (Laugaste, 1994) or aerobic sediments (Löfgren, 1987). If combined with sediment investigations, nutrient balances become a useful tool even for measuring intimate processes like denitrification (Jensen et al., 1990, 1992; Dudel & Kohl, 1991; Ahlgren et al., 1994). The greatest value of mass balances is that they give at least a clue of the

magnitude of the processes that is needed to understand the functioning of the ecosystem. A mass balance calculation for shallow L. Võrtsjärv, for example, showed that the internal phosphate load from the sediment during a one-day storm exceed the total annual load from the watershed (Nõges & Kisand, 1999).

Water balance and mass balances of total nitrogen and total phosphorus in a sharply stratified small lake are discussed in the present paper on a daily and vegetation period scale. Development of thermal stratification is analysed with respect to its effect on the external and internal nutrient balance.

Description of the study area

L. Verevi (area 0.126 km^2, maximum depth 11 m, mean depth 3.6 m) is located within the borders of the small town Elva in South Estonia. The lake has an elongated shape in the north-to-south direction with the deepest and widest part near the southern end of the lake (Fig. 1). By origin L. Verevi is a kettle lake formed by melting of a buried ice block of a decaying glacier (Mäemets, 1991). The 1.1 km^2 large drainage basin (including the lake area) represents a hydrologically complex landscape: in south and southeast the lake is surrounded by sandy hills and dunes covered with pinewoods. The densely populated east shore slopes strongly towards the lake. The area to the west is low and swampy. During high floods, overflow from oxidation ponds of the wastewater treatment plant was discharged to the lake via this swampy area and can be considered the major source of nutrients in the lake. In the year 2001, a soil barrier was built to exclude the ponds from the drainage area. The lake has up to 10 small inflows but only three of them (Fig. 1: 1, 4 and 5) are nearly permanent. Inflows 4 and 5 begin from two spring-fed lakelets, Linajärv and Jaani järv, which are located in the northern part of the watershed. L. Verevi gets a significant part of its water as hardly measurable subsurface runoff (Mäemets et al., 1991). The outflow of the lake is located on the west shore of the lake and flows into River Kavilda. In dry years the outflow becomes discontinuous.

The funnel-like bathymetry (Fig. 1) causes a sharp thermal and chemical stratification of the lake during summer (Nõges & Kangro; Ott et al., 2005a). The spring turnover is often incomplete even in homothermal conditions, thus giving the lake some meromictic features. The metalimnion is progressively eroded during summer and autumn and complete mixing takes usually place in November.

Material and methods

Water balance calculations for the years 1991 and 1993 were based on the general equation:

$$I + P - E - O \pm \Delta V = 0 \qquad (1)$$

in which
I – inflow (surface runoff + groundwater);
P – precipitation onto the lake surface;
E – evaporation from the water surface;
O – outflow;
ΔV – change in storage during the period in question.

All components of the water balance were expressed in $m^3\ d^{-1}$. The inflow to the lake was calculated using the method of analogy. Calculations were based on daily runoff data of the nearby River Elva (gauging station Elva, watershed 239 km^2) measured by the Estonian Institute of Meteorology and Hydrology. Daily precipitation data were provided by the Tõravere meteorological station located at a distance of 5 km from the lake. To take into account the losses through evaporation, we used the long-term average evaporation measured at Tiirikoja (N-E Estonia), 460 mm y^{-1}, multiplied by 1.33, the coefficient for transition from land to open water areas (Pärn & Eipre, 1983). The seasonal distribution of evaporation is given in Table 1.

Outflow from the lake was modelled using the overflow weir equation (Eloranta, 1992) that relates the flow rate (Q, L s^{-1}) to the head on the weir (H, m) and width of the weir (B, m):

$$Q = 1.8 \cdot B \cdot H^{3/2} \qquad (2)$$

As an initial condition the maximum depth of the lake was set to be 10 m and supposed to characterise the winter low flow period. The width of the weir and the initial head were used as variables for model calibration. Calculations were made with a daily