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The effects of flushing with NO_3 and Ca rich water on shallow eutrophic lakes

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ABSTRACT; A long term computational results and sensitivity analysis of the eutrophication model, incorporating phytoplankton, submerged macrophytes and nutrient dynamics in sediments were performed for understanding the effects of macrophytes on algal blooming in shallow lakes. The model was successfully reproducing long term change experienced in Lake Veluwe (The Netherlands). The model also described the reduction of phosphate return flux from the sediment and phytoplankton biomass and the resulting development of macrophytes under improved light condition after restoration measurement of the lake by artificial flushing of nitrate rich water into the lake and reduction of external phosphorus loading. Numerical experiments reproduced the following phenomena successfully: the blooming after the initiation of macrophyte growth has a remarkable effect on the following macrophyte development, thus with higher nutrient load, the macrophytes are significantly depressed. Sensitivity analysis of important coefficients show that the maximum photosynthesis rate, the conversion rate from oxygen to ash free dry weight are most sensitive parameters for macrophyte and algal development.

KEYWORDS: Eutrophication; Macrophytes; Phytoplankton; Nutrient Cycle; Lake Restoration; Sediments.

1. INTRODUCTION

The restoration of turbid, eutrophic waters is highly demanded in recent years. The quantitative understanding of the interactions between macrophytes and phytoplankton is essential, normally it takes long time to experience various cases (Asaeda *et al.*, 1996; Bon and Asaeda, 1996). Thus, the application of a numerical model to investigate the interactions of submerged macrophytes and the development of phytoplankton and the exchanges of nutrients between the sediment and overlying water is paramount important for the evaluation of functions of macrophytes for lake restoration. A combination of three submodels (macrophyte, phytoplankton and sediment submodels)

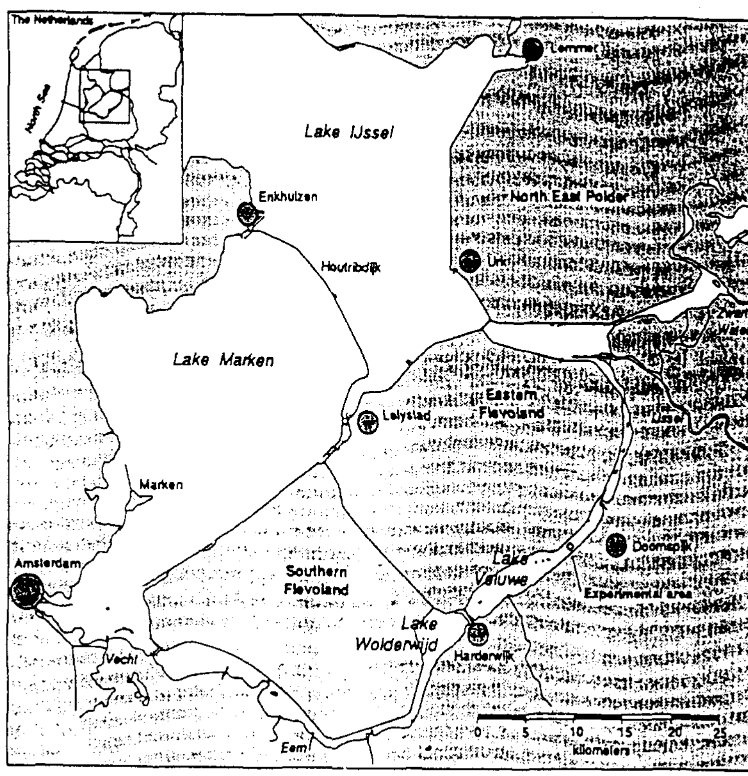

Figure 1. The Lake Veluwe (The Netherland).

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was described and the verification of the model was conducted using the observed data in Lake Veluwe in 1986 (Asaeda *et al.*, 1996). The purpose of this model is to provide a quantitative description of the interactions of submerged macrophyte growth, phytoplankton development and nutrient dynamics in eutrophic shallow lakes. In this study we present the results of the model application for long term period and sensitivity analysis of parameters of the model which is described in Asaeda *et al.* (1996). The input data used for the model were collected at Lake Veluwe, The Netherlands (Figure 1). All the input data are available in the literature. The results of model application and model sensitivity analysis will be presented in the following subsections.

2. MODEL APPLICATION FOR LONG TERM PERIOD

As pointed out in Asaeda *et al.* (1996), the model is capable of reproducing seasonal patterns observed in Lake Veluwe, on phytoplankton and macrophyte development, and nutrient dynamics in the sediments and in overlying water. Utilizing the same values of model parameters (Asaeda *et al.*, 1996), a long-term simulation was conducted for the same Lake Veluwe from 1978 to 1987.

Lake Veluwe allocates in the central part of The Netherlands. The Lake has the surface area of about 32.8 km^2 with average depth of 2m. The eastern and southern zone of the lake is relatively shallow, less than 1m deep. This shallow zone was covered with *Potamogeton pectinatus L* until the end of 1960s. The decline of *P. pectinatus L.* in the Lake were considerable from 1969 onwards (Figure 2) due to the eutrophication of the lake (Scheffer *et al.*, 1994). From 1979 the restoration measures were taken by reducing external phosphorus loading from 3.0 to 1.0 g P m^{-2} y^{-1}. Furthermore, flushing of the lake with water poor in algae and phosphorus but rich in calcium and nitrate, decreased retention time of dissolved compounds from 0.5 to 0.25 years (Scheffer *et al.*, 1994).

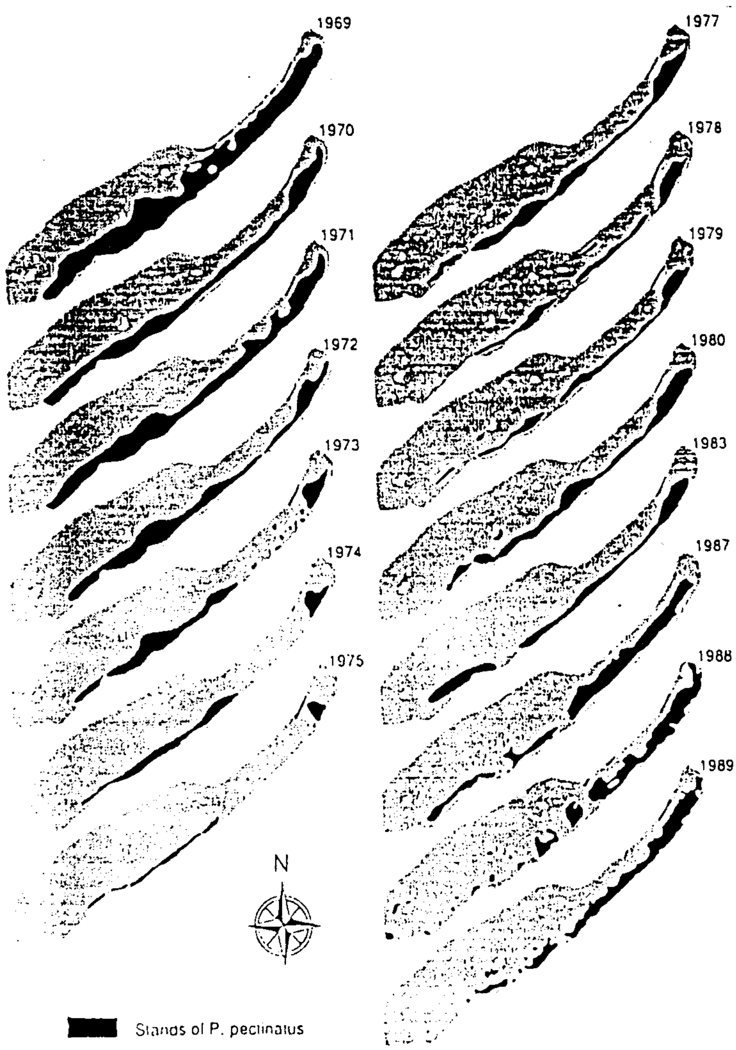

Figure 2. The area occupied by *Potamogeton pectinatus* L.in Lake Veluwe from 1969 to 1989

As a result, diatoms and green algae became dominant from 1985 instead of previously dominating blue green algae, and macrophytes, *P. pectinatus L.* gradually recovered (Figure 2)

Since external nitrate and ammonium loadings data were limited for computation except for 1985 to 1987, it was assumed that average nitrate and ammonium concentrations of the inflow were nearly same as those of inside the lake for the last three years (1985-1987) as shown in Figure 3(a). During winters from 1979 onwards the retention time of the dissolved compounds in the lake was reduced from 0.35 to 0.15 years, and from 1985 to 1987 the retention time during summer of the dissolved compounds decreased from 0.5 to 0.25 years by flushing the lake with water from Flevoland. Thus, the inflow volume was assumed as shown in Figure 3(b). The reported data were utilized for the meteorological data such as daylength, temperature and daily insolation (van Vierssen *et al.*, 1994).

The simulated phosphate return fluxes and nutrient concentrations in the overlying water are shown in Figures 4 and 5. The comparison between the observation and the simulation for the chlorophyll-a concentration is given in Figure 6. A little higher values of computed total chrorophyll-a than that observed values are due to the higher computed total phosphorus (fig. 5) causing from the lack of observed inflow data and also due to the assumption of averaged light atenuation coefficient of macrophytes over entirely the

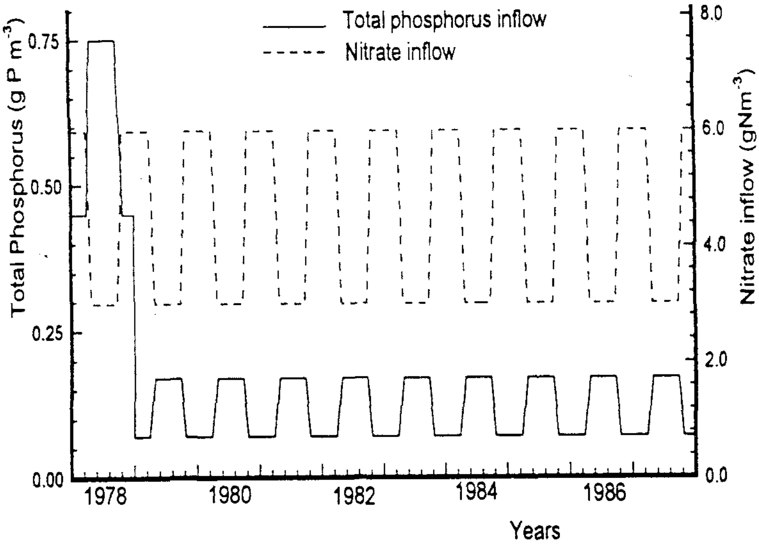

Figure 3(a). Total phosphorus and nitrate concentration of inflow data in Lake Veluwe from 1978 to 1987.

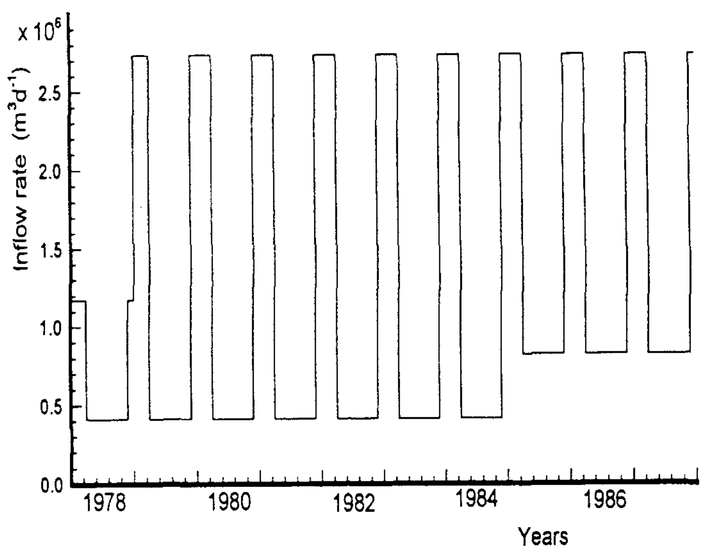

Figure 3(b). Inflow rate of Lake Veluwe from 1978 to 1987 water column. Although there is a large amount of fluctuation, sufficient agreement is achieved for all components to make a further discussion. The total biomass and the maximum height of macrophytes are given in Figure 7.

Artificial flushing of nitrate and calcium rich water increased the nitrate concentration in the overlying water specially from 1985. It oxidized the sediment, then the phosphate release to the overlying water was reduced. A clear inverse correlation is shown in the nitrate concentration in the overlying water and phosphate release from the sediment. Together with the increase in phosphate consumption by the enriched macrophyte biomass, the phosphate concentration in the water halved within 5 years.

Although phosphate in the overlying water was consumed competitively by phytoplankton and macrophytes, macrophytes are able to uptake nutrients also directly from the sediments. Thus, reduction of phosphate in the overlying water was more influential to phytoplankton. Therefore, the macrophyte biomass gradually increased, and reduced the amount of insolation in the water available for phytoplankton. As a result, phytoplankton biomass was gradually decreased with increasing macrophyte biomass (see Figures 6 and 7).

3. SENSITIVITY OF COEFFICIENT-SELECTION ON THE RESULTS

A sensitivity analysis was carried out in order to investigate the influence of

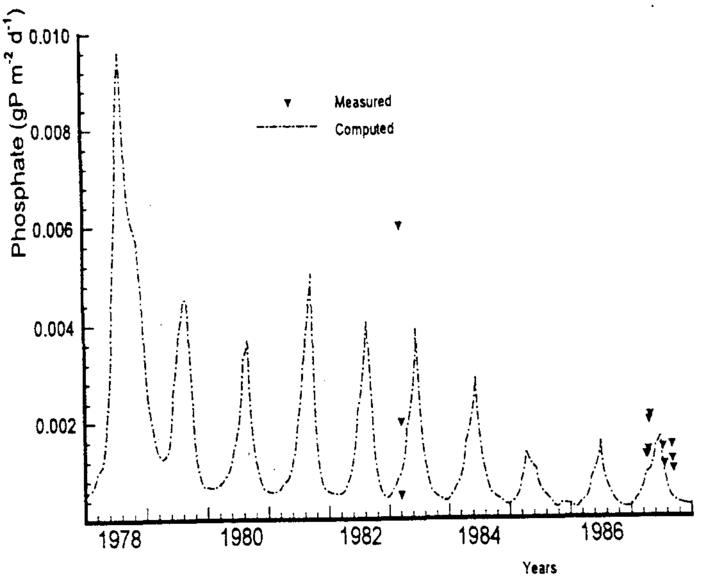

Figure 4.. Computed phosphate release rate within 10 years in comparison with the observed data in Lake Veluwe.

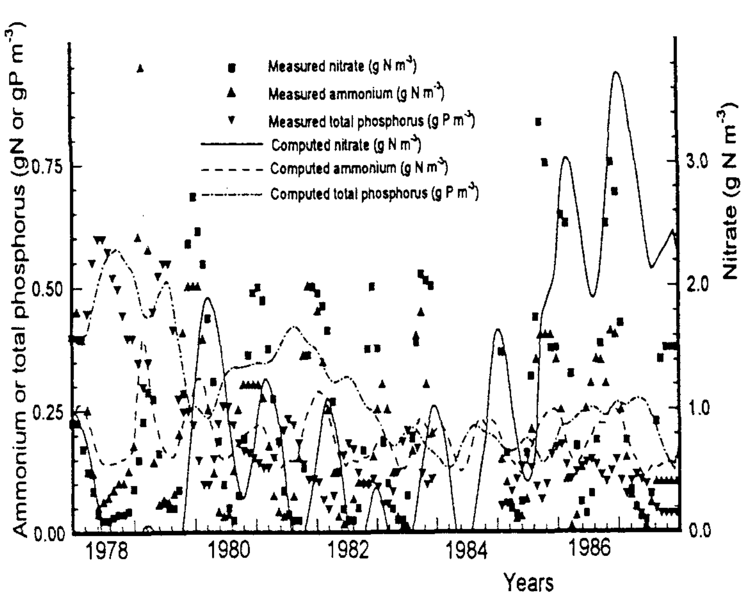

Figure 5. Computational results for 10 years transition of nutrient concentrations in the overlying water for 10 years in comparison with observed data.

important parameters on the results. Each parameter was changed by 10%, and 50 %, then resulting biomasses of aboveground and belowground macrophytes and the total phytoplankton are presented in Figures 8 and 9 by the percentage of change with respective to the absolute quantities of the original condition.

As seen in these figures, maximum photosynthetic rates and conversion rate of carbon dioxide to the ash free dry weight are sensitive to the resulting quantities of macrophyte biomass and phytoplankton concentration. Only 50% change in these coefficients create about 160% of deviation in aboveground biomass and 15% in total phytoplankton biomass (see Figure 8 and 9). Thus, care must be taken while selecting these values for modeling. These deviations are, however, simply proportional to the change in the coefficient values, thus the difference in concluding trends are systematic.

The sensitivity analysis also indicates that initial tuber biomass and the starting day of growth produce only minor effects on the results in comparison with maximum photosynthesis rate and the coefficient for the conversion from carbon dioxide to ash free dry mass.

4. CONCLUSIONS

The simulated results show that the model is capable of reproducing long term transitions observed in Lake Veluwe, on phytoplankton and macrophyte development, and nutrient dynamics in the

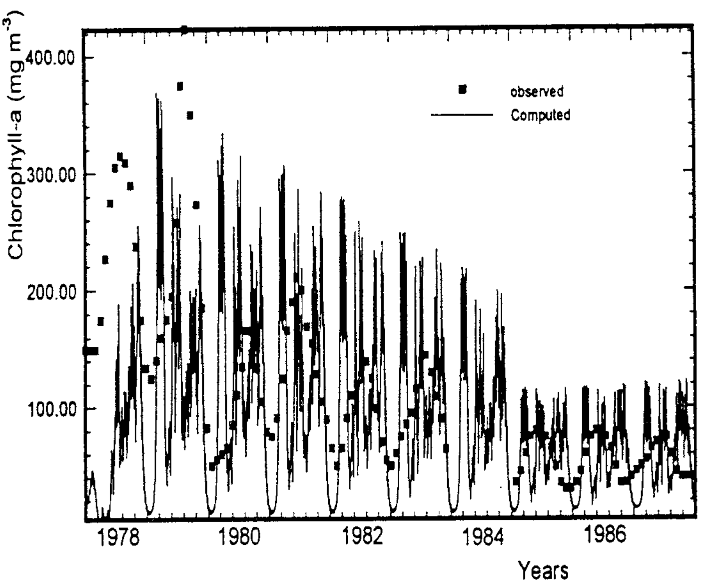

Figure 6.. Simulated 10 years transition of chlorophyll-a concentration in the overlying water in comparison with observation in Lake Veluwe.

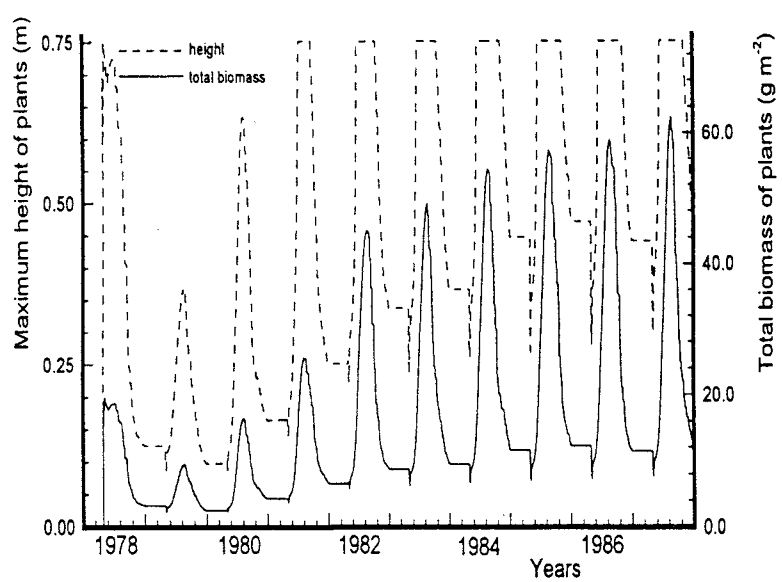

Figure 7. Simulated development of *Potamogeton pectinatus L.* and maximum height of macrophytes in Lake Veluwe from 1978 to 1987.

sediments and in overlying water.

This model produced following structures occurred in Lake Veluwe: such as the nutrient concentation in the overlying water, phosphate release from the sediment, the macrophyte development. Phosphate release is stabilized by the function of macrophyes

The model described the following restoration process in Lake Veluwe.

Artificial flushing of nitrate rich water into the lake reduced the phosphate return flux from the sediment, together with the reduction of external loadings, phosphate concentration decreased by halves and becomes the limiting factor for phytoplankton developments, especially from 1985 onwards. It was more influential to the phytoplankton than macrophytes, thus phytoplankton biomass decreased dramaticaly. Then macrophytes gradually recovered under the improved light condition, which then inhibited the dominance of phytoplankton in the lake.

5. ACKNOWLEDGEMENT

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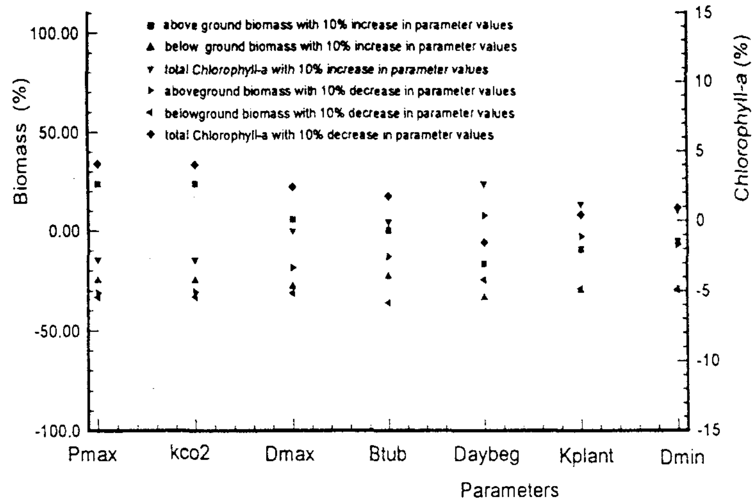

Pmax: maximum photosynthetic rate
kco2 : conversion rate of CO_2 to afdw
Dmax: maximum daylength
Btub : initial tuber biomass
Daybeg: Julian starting day for growth
Kplant : shelf shading extinction coefficient
Dmin : minimum daylength

Figure 8.. Sensitivity of parameters (10% changed) utilized in the model..

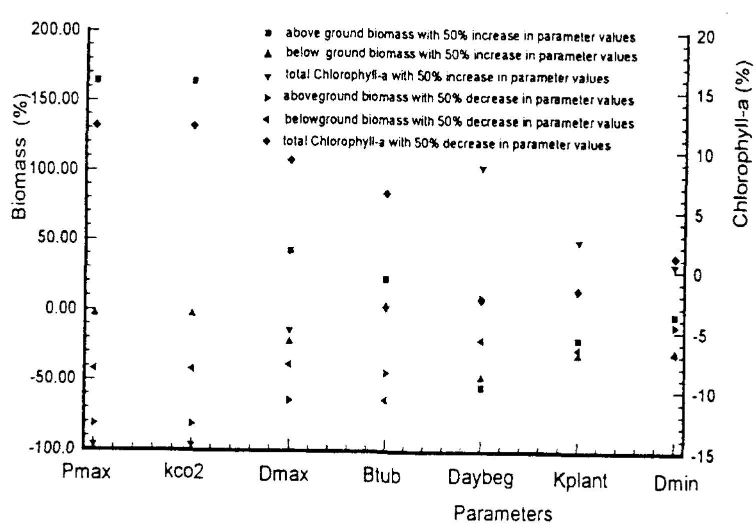

Figure 9. Sensitivity of parameters (50% changed) utilized in the model...

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