Hydrobiologia **233**: 95–104, 1992.
L. Van Liere & R.D. Gulati (eds), Restoration and Recovery of Shallow Eutrophic Lake Ecosystems in The Netherlands.

Restoration and resilience to recovery of the Lake Loosdrecht ecosystem in relation to its phosphorus flow

Louis Van Liere [1,2,*] & Jan H. Janse[2]
[1] *Limnological Institute, Rijkstraatweg 6, NL-3631 AC Nieuwersluis, The Netherlands;* [2] *National Institute of Public Health and Environmental Protection, P.O. Box 1, NL-3720 Bilthoven, The Netherlands*
(author for correspondence)*

Key words: water management, food-web, phosphorus flow, lake restoration, recovery, resilience

Abstract

A reduction in external phosphorus loading since 1984 to Loosdrecht lakes system by the dephosphorization of the inlet water, yielded only minor effects in Lake Loosdrecht. This reduction measure turned out to have decreased the loading only by a factor of two. A conceptual model was constructed based on laboratory measurements to describe phosphorus flow in the lake ecosystem for the summer of 1987. The role of zooplankton and fish was more important in phosphorus recycling than diffusion at the sediment-water interface. The input and output of phosphorus of the lake were at equilibrium and therefore, further reduction in external loading was needed for recovery. The results of the conceptual model agreed well with the output of the mathematical model PCLOOS. Additional measures such as dredging, flushing, chemomanipulation, or biomanipulation would be ineffective at the present level of external loading. Only a significant further reduction in external input will restore Lake Loosdrecht's water quality over a long period of time.

Introduction

The Loosdrecht lakes system (Fig. 1) consists of the three shallow (average depth about 2 m) interconnected lakes, Loosdrecht, Vuntus, and Breukeleveen (for detailed description, see Gulati *et al.* 1991a; Hofstra & Van Liere, 1992). The banks and ditches of the Kievits Area also form a part of the system influencing its water and phosphorus balances. The eutrophication of these lakes started from the beginning of the 20th century from various sources (Engelen *et al.*, 1992). The trophic status of these lakes, passing through various intermediate stages, has become eutrophic, with cyanobacteria and detritus dominating the particulates in the water column (Hofstra & Van Liere, 1992). To restore the water quality, a series of measures have been taken to reduce phosphorus input. The most important step was the replacement of inflow to the lake in 1984; the inflow from River Vecht, with its phosphorus level at 1–2 mg P l^{-1}, was switched to Amsterdam-Rhine Canal by means of a pipeline (Fig. 1). The Canal water was dephosphorized before entering the lakes by coagulation with iron (III)-chloride followed by sedimentation of the resulting floc (Van der Veen *et al.*, 1987). L. Breukeleveen and L. Vuntus have shown little effect by the diversion, probably because they are situated far from the inlet. Thus, this paper will focus on L. Loosdrecht near the inlet.

To understand the persistence of trophic status

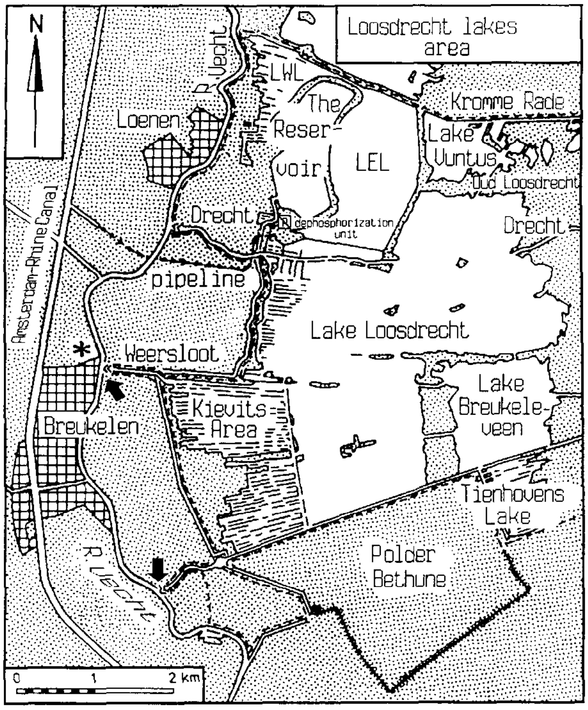

Fig. 1. The Loosdrecht lakes area. Arrows indicate the sluices used before 1984 to supply the lakes with water from the River Vecht. The Reservoir, L. Eastern Loenderveen (LEL) and L. Western Loenderveen (LWL) are hydrologically separated from the L. Loosdrecht and L. Vuntus. Asterix: Limnological Institute.

in the lake, an accurate phosphorus budget for the lake was first estimated (Engelen *et al.*, 1992). A conceptual model of phosphorus cycling through various ecosystem compartments was made as presented below. Using various parameters measured in water and various compartments of the ecosystem, a mathematical model was developed (Janse & Aldenberg, 1990). This model output was compared with empirical data, in order to test its possibilities to simulate further water management measures in L. Loosdrecht (Janse *et al.*, 1992). The needs for further (and additional) measures to restore Loosdrecht lakes are indicated.

Reduction of external phosphorus

Earlier calculations (Province of Utrecht, 1973, 1980) predicted that the replacement of inflow from R. Vecht with dephosphorized water from the Amsterdam-Rhine Canal would reduce the phosphorus load of the lake system (L. Loosdrecht, L. Vuntus and L. Breukeleveen) from 1.35 to 0.10 g P m^{-2} y^{-1}. Thus, the lake system was expected to react shortly to the replacement. However, no significant changes have been observed (Table 1).

In L. Vuntus and L. Breukeleveen, the external phosphorus load did not change. (Engelen *et al.*, 1992). For the whole lake area, the external phosphorus load after 1984 was 0.36–0.46 g P

Table 1. External phosphorus load (g P m^{-2} y^{-1}) of the whole Loosdrecht lakes' system and its separate compartments, excluding Kievits Area, before and after the restoration measures. Data according to Van Liere *et al.*, 1991.

Lake system	Before the measures (average for 1982 and 1983)	After measures (average for 1984 and 1985)	Increased load: leakage of sluices (average for 1986 and 1987)	Present estimated load (if no extra measures were to be taken)
Loosdrecht (excluding Kievits area)	0.69	0.31	0.44	0.35
Breukeleveen	0.57	0.59	0.59	0.60
Vuntus	0.24	0.26	0.25	0.25
Whole lake system (including Kievits area)	1.05	0.36	0.46	0.37

$m^{-2} y^{-1}$ (Table 1), which is much higher than the predicted 0.1 g P $m^{-2} y^{-1}$ by the earlier reports (Province of Utrecht, 1973, 1980), probably because they did not account for the load from the agricultural hinterland. The load to L. Loosdrecht was even higher in 1986 and 1987 because of a severe leakage of the Southernmost sluice. This leakage, however, did not have any effect on L. Vuntus and L. Breukeleveen.

Besides, the earlier calculation of external loading appeared to be an overestimate. Before 1984, water from R. Vecht was supplied mainly through two sluices (Fig. 1), passing through the Kievits Area with its banks and ditches where wind influence, and concomitant mixing, were negligible. The water lost a part of its phosphorus passing this area, resulting in a lower load for L. Loosdrecht. Phosphorus concentration in Kievits Area sediments was high when compared to other lakes (Boers *et al.*, 1984).

The phosphorus balance (Engelen *et al.*, 1992) revealed that the external load to the whole lake system had been reduced from 1.05 to 0.37 g P $m^{-2} y^{-1}$. The reduction of external load to L. Loosdrecht resulted in decrease only by a factor of about two (0.69–0.35 g P $m^{-2} y^{-1}$, Table 1).

However, certain parts of the system showed clear responses. Phosphorus release rate has decreased from 1 g P $m^{-2} d^{-1}$ in 1983 to 0.3 g P $m^{-2} d^{-1}$ in 1990 (Keizer & Sinke, 1992). The concentration of total phosphorus in L. Loosdrecht corrected for autocorrelation decreased from 1984 to 1988 by 12 ± 2 $\mu g\, l^{-1}$ P y^{-1}, but the concentration of chlorophyll *a* did not react (Van Liere *et al.*, 1990a; Van Tongeren *et al.*, 1992). Light energy was important as a growth-limiting factor before 1985, but later phosphorus has become more important (Rijkeboer *et al.*, 1991; Gons *et al.*, 1992). This shift in growth-limiting factor was also reflected in the C/P ratio of the seston (< 150 μm) which increased from 90 to 145 between 1985 and 1989 (Gulati *et al.*, 1991b). Other parts of the food chain showed little reaction (Gulati *et al.*, 1992; Lammens *et al.*, 1992).

The flow of phosphorus in Lake Loosdrecht

To gain more insight in the factors contributing to the persistence of the ecosystem's trophic status, a conceptual model for phosphorus flow was constructed. The model was based largely on the data from the scientific projects by the work group Water Quality Research Loosdrecht Lakes (Loogman & Van Liere, 1986; Van Liere & Gulati, 1992). The input and output of the system were derived from hydrological data (Buyse, 1988). Data on phosphorus-dynamics at the sediment-water interface were taken from Keizer & Sinke (1992) and Gons & Van Keulen (1989). Primary production was measured and calculated according to Van Liere *et al.* (1986a). A striking similarity was noted between the model that described primary productivity and the results derived from the mass balances obtained in Laboratory System Enclosures (Rijkeboer *et al.*, 1991).

Zooplankton grazing, consumption, assimilation, and egestion were determined according to Gulati (1984) and Gulati *et al.* (1992). Phosphorus flows within seston and zooplankton were calculated on the basis of the C/P ratios, of zooplankton and their seston-food, which were measured by the ^{14}C-tracer method in the laboratory. Zooplankton (> 150 μm) excretion was computed from zooplankton biomass and water temperature using the relationship between temperature and specific excretion rate (Den Oude & Gulati, 1989). Mineralization, which was measured only three times in 1986, was not included in the diagramme. The phosphorus mineralization rate of sestonic matter was in the same order of magnitude as phosphorus consumption rate (Van Liere *et al.*, 1986b). This suggests that the mineralization of seston occurs mainly in the water column and the top layer of sediments (epipelon) in contact with oxygenated water (see also Otten *et al.*, 1992).

Data of phosphorus flow to and from water plants were from calculations by Malthus *et al.* (1990).

Phosphorus recycling in the fish compartments was derived from Lammens *et al.* (1992), rates of consumption of zooplankton and benthic fauna were derived from observations in the fish intestine and fish growth rate (Lammens, personal communication).

The phosphorus flow diagramme shown in Fig. 2 represents the time period between April and September, 1987. It was shown earlier that phosphorus dynamics did not change appreciably (Van Liere *et al.*, 1990b); this was not surprising, considering the relatively small changes in external phosphorus loading (Table 1). However, there are some striking features in the flow diagramme which might be of importance for future developments of the Lake Loosdrecht ecosystem.

- The concentration of soluble phosphorus was very low at 12 mg P m^{-2} (6 $\mu g\,l^{-1}$). Of this, about 30–40% was soluble reactive phosphorus (SRP). This means that whatever its source, available phosphorus would be taken up very fast by either phytoplankton, detritus, or both.
- Sediments contained a vast amount of phosphorus compared to other compartments. Apparently, only a small part of this was released to overlying water by diffusion (Keizer & Sinke, 1992). Diffusing phosphorus was reported to be largely from the mineralization of organic particles in the sediments (Sinke & Cappenberg, 1988). Adsorption was considered to be small because the aerobic layer in which it takes place was only a few-millimeters deep.
- Desorption of phosphorus after resuspension might be an important source of phosphorus for the phytoplankton. However, it was difficult to separately quantify adsorption/desorption processes between living and dead material within the complex resuspension-sedimentation compartment. Rijkeboer *et al.* (1991) showed that the exchange of phosphorus between detritus and phytoplankton components in the seston might be of paramount importance in phosphorus exchange.
- Phosphorus concentrations in the seston and fish were equal. One half of phosphorus in the water column was in fish and most fish phosphorus (70–80%) was associated with bream

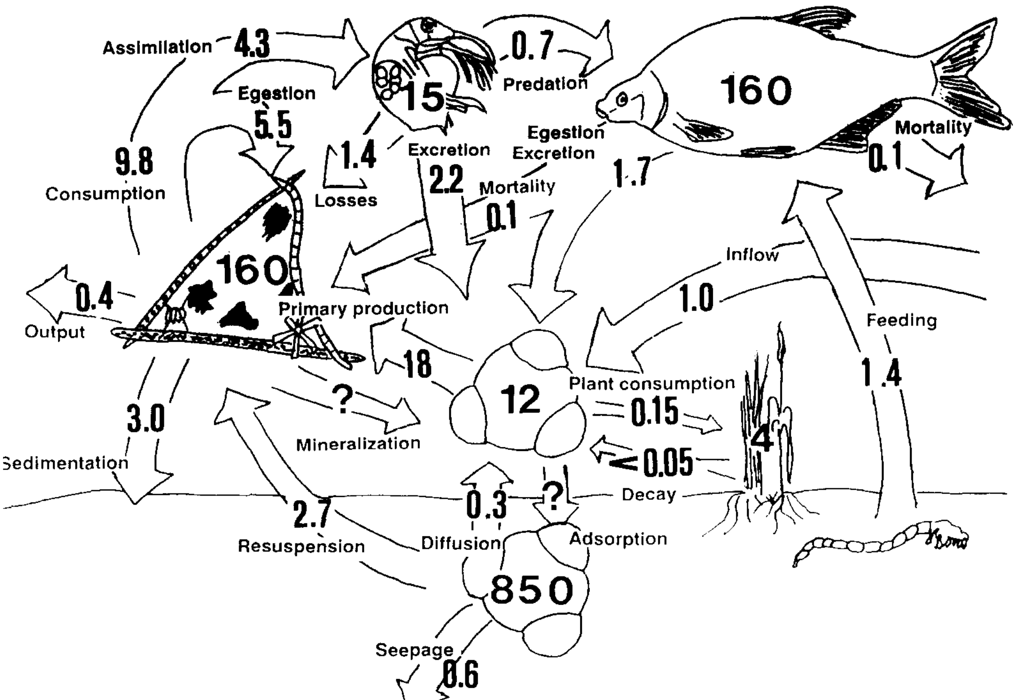

Fig. 2. Flowdiagramme of phosphorus (mg P m^{-2}) and its flux between compartments of Lake Loosdrecht (mg P $m^{-2}\,d^{-1}$) for the period April–September 1987.

(*Abramis brama*). If bream was of any commercial value the problem of eutrophication might have been partly solved because then it would be harvested.

- Although zooplankton may seem unimportant quantitatively, they are highly important for the fast recycling of phosphorus to the pool of available phosphorus for phytoplankton through excretion, perhaps even more if rotifer phosphorus excretion is also included (Gulati *et al.*, 1990).
- In recycling phosphorus to the available phosphorus pool, fish is important next to zooplankton. However, a half of phosphorus in dead fish is in the form of calcium phosphate, an insoluble form. Therefore, the death of fish is a phosphorus loss factor for the ecosystem.
- Egestion products by fish and the death of phytoplankton, zooplankton, and fish is a source of detritus. Detritus is partly refractive (Otten *et al.*, 1992) and therefore, eutrophication builds recalcitrant debris in sediments. However, their density allows an easy resuspension in the water column by wind action (Gons *et al.*, 1986), and they may play the role of sorbate in sorbing and desorbing the available phosphorus for phytoplankton (Rijkeboer *et al.*, 1991).
- The largest flow was from the soluble phosphorus pool to the seston compartment at 18 mg P m^{-2} d^{-1}. This daily flow is the most important process in the internal phosphorus cycle of the lake ecosystem.
- Submerged plants were unimportant in phosphorus recycling. They virtually disappeared from the system (Hofstra & Van Liere, 1992). Only emergent plants or those with floating leaves played a minor role (Malthus *et al.*, 1992). The balance between phosphorus utilized by the plants and phosphorus release upon their death is probably negative, meaning a small net loss to the system. This loss was probably less than shown in the diagram, because a part of phosphorus in plants entering the seston compartment would become available by mineralization. Thus, the loss factor by plants was considered negligible.
- Very little quantitative research has been performed on benthos, although the presented estimation of the flow of phosphorus from benthos to fish, which was derived from fish intestine investigations, revealed it to be important.
- Output from the ecosystem was indicated by the arrow 'output' (0.4 mg P m^{-2} d^{-1}) in the seston compartment. This may not be always true, since the discharge or outflow to the hinterland also contains zooplankton which would carry P. Another main loss was downward seepage to the Polder Bethune. This loss was calculated to be 0.6 mg P m^{-2} d^{-1} (Keizer & Sinke, 1992).

The most important point in the conceptual model is that input and output are nearly in equilibrium. This implies that if there is no further reduction of external P, the system will remain in its present state. However, the flow diagramme was based on the summer of 1987, the time period during which the leakage of the Southern sluice occurred (Table 1). During other years, the summer input was in the order of 0.75 mg P m^{-2} d^{-1}. Then, the phosphorus loss factor due to downward seepage the summer value of 1987 was somewhat larger.

The mathematical model PCLOOS was developed to evaluate the input, output, and recycling over various periods with a better precision (Janse & Aldenberg, 1990; Janse *et al.*, 1992). The model was calibrated with hydrological and material-balance data (Engelen *et al.*, 1992; Buyse, 1988) as well as with the measurements made by the WQL work group. Following the calibration, it was used to simulate the results of a further reduction in external input and additional measures (dredging, flushing, biomanipulation; Janse *et al.*, 1992). The flow rates shown in the flow diagramme were also calculated for the same time period (Fig. 3). The model output of these parameters was strikingly similar to those in the diagram, including those of the sediment compartment and its exchange with the water compartment.

In open water the results were variable, but the difference was no more than by a factor of two. The reason for this difference was that the math-

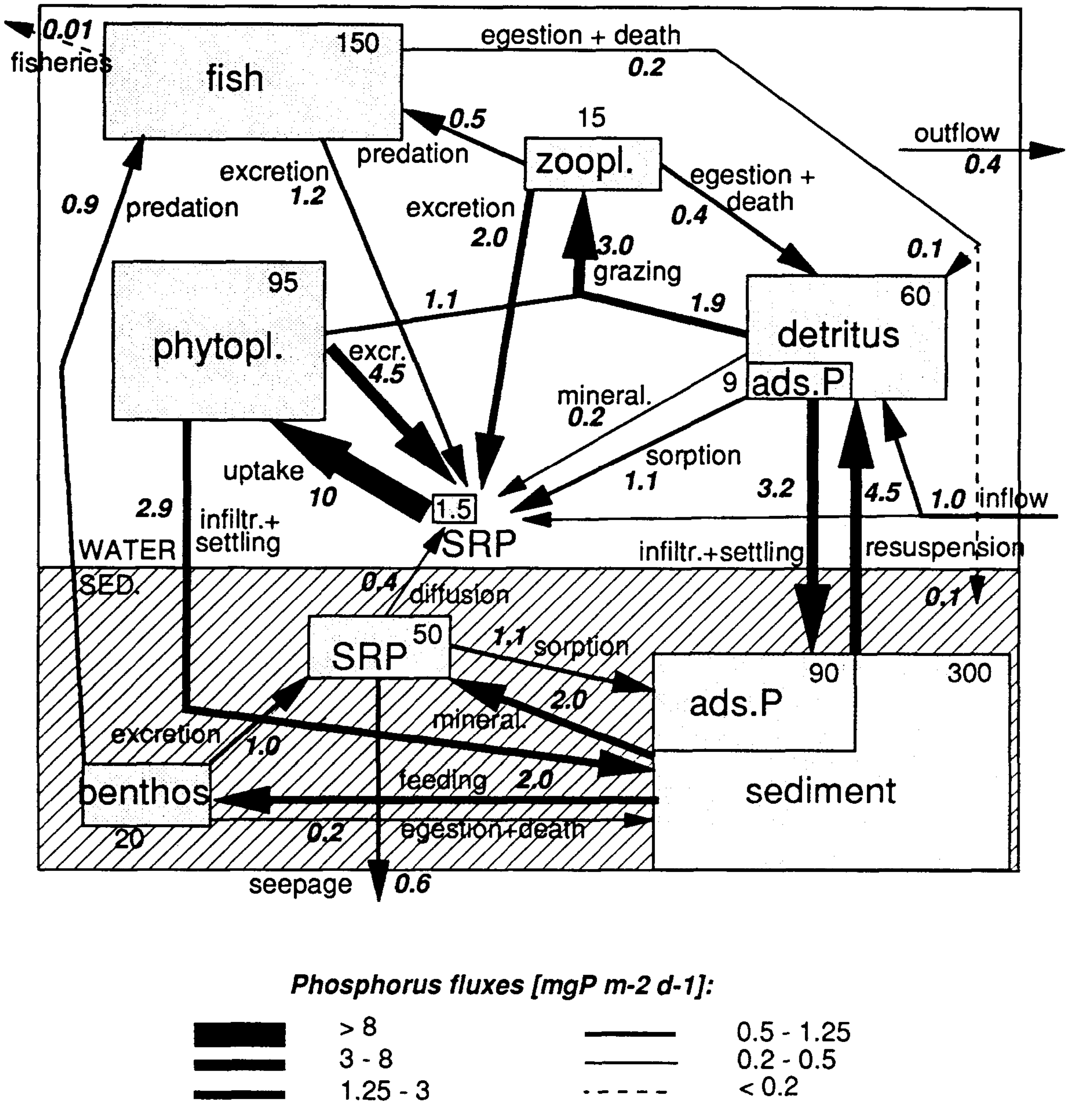

Fig. 3. Phosphorus content (mg P m^{-2}) and fluxes (mg P m^{-2} day^{-1}) and phosphorus amounts in various compartments of Lake Loosdrecht for the time period April–September 1987 as calculated by the mathematical model PCLOOS.

ematical model separated seston into two fractions, phytoplankton and detritus, whereas the flow diagramme used them as a single compartment. Calculated growth rates were different from the estimated values based on primary production measurements (Van Liere *et al.*, 1986). The calculated phosphorus flow from zooplankton deviated only a little from the measurements.

Overall, the model gave a good description of phosphorus flow through various compartments of the ecosystem. It predicted with a reasonable accuracy the outcome of further reduction of external phosphorus load over a short term, pointing out at the same time additional measurements to be taken to reduce primary production (Janse *et al.*, 1992).

Additional measures

If an ecosystem does not react instantaneously on the external phosphorus load additional measures are often called for. Such measures are reviewed here, especially in regard to their applicability or otherwise in the Loosdrecht lakes.

Further reduction of the external phosphorus load

For the Loosdrecht lakes, any further reduction of external phosphorus load is technically difficult, but possible. As mentioned earlier, a reduction of the external load by a factor of two was not sufficient to induce significant responses from the ecosystem. Engelen *et al.* (1992) have pointed out several possible hydrological measures which could decrease the load an additional 50%, including the diversion (or dephosphorization, De Ruiter, 1992) of the Eastern hinterland water with its high phosphorus concentrations.

Flushing

Hosper & Meijer (1986) and Jagtman *et al.* (1992) have shown positive results with flushing in the recovery of L. Veluwe and L. Wolderwijd. However, the chemical composition of the flushing water with high concentration of calcium and nitrate facilitated chemomanipulation (Jagtman *et al.*, 1992). In L. Loosdrecht the situation is more problematic. The inlet point of the dephosphorized Amsterdam-Rhine Canal water is close to the discharging pumping station. A mixing time of at least a week is needed and thus flushing has to be repeated several times. It also does not deal with the problem of organic deposits on the lake bottom. Therefore, it is not recommended.

Dredging

Keizer & Sinke (1992) have shown that a major phosphorus exchange at the sediment-water interface involves the diffusion of mineralized phosphorus to the overlaying water. Therefore, it is unlikely that phosphorus release will be reduced by removing the top layer of sediments. In fact Van Liere *et al.*, (1986) reported only 30% reduction in phosphorus release rate from Lake Loosdrecht sediments following the removal of its top layer. With the present high external load of phosphorus, organic matter in the top layer will be replenished rapidly. However, removing more than just the top layer will reduce resuspension (Gons & Van Keulen, 1989), which is an important factor in phosphorus exchange between seston and sediments (Rijkeboer *et al.*, 1990). Dredging may also increase downward seepage (Engelen *et al.*, 1992), which can readily be compensated for by an increased supply of dephosphorized water. Although dredging would increase external phosphorus load slightly per unit area, its load per unit volume would decrease relatively. The cost of dredging L. Loosdrecht is estimated to be 35 ± 10 10^6 ECU. Technical problems of dredging a large amount of organic deposits with its specific density close to that of water have not yet been solved (Van der Does *et al.*, 1992), not to speak of the disposal of the dredged material. Considering the present high external load and the equilibrium situation between its input and output, it is questionable whether dredging will significantly help the recovery of L. Loosdrecht.

Biomanipulation

As can be derived from Dawidowicz *et al.* (1988), the removal of a large amount of bream (*Abramis brama*) failed to improve L. Breukeleveen (Van Donk *et al.*, 1990), because this top-down control is effective only when the food quality for large *Daphnia* can sustain their growth. Apparently, this was not the case for L. Breukeleveen, one of the lakes in the Loosdrecht lakes' area. Furthermore, with the present high amount of organic deposits in the lake where wind action plays such a dominant role, any increase in water transparency resulting from biomanipulation may not be enough to sufficiently enhance the growth of submerged plants to remove any significant amount of phosphorus. Thus, this measure does not appear to be suitable for L. Loosdrecht (see also Van der Vlugt *et al.*, 1992).

However, since so many phosphorus is stored in the fish compartment (Fig. 2) annual reduction of fish stock may be a tool for removing phosphorus, thus also diminishing flows to and from other compartments.

Chemomanipulation

In laboratory chemomanipulation experiments, the addition of iron(III)-chloride to L. Loosdrecht sediments was unsuccessful (Keizer & Sinke, 1992), because the aerobic layer of the sediments was extremely thin. With significant downward seepage in the lake, the chemical would also move out of the system in weeks or months when the aerobic layer is mixed with the anaerobic part by wind. In a whole lake experiment in a comparable lake, the addition of iron(III)-chloride also failed to improve water quality (Boers *et al.*, 1992).

External nitrogen reduction

Based on a comparative study of nitrogen-fixing and fixed-nitrogen utilizing strains of cyanobacteria, Zevenboom & Mur (1980) concluded that in turbid lakes, the former could not compete with the latter because of unfavourable energy balance. This implies that if the input of external N is reduced, it would increase light transmission, thus favouring nitrogen-fixing species. For example, *Oscillatoria* spp. and *Prochlorothrix hollandica* will be replaced by species as *Aphanizomenon flos-aquae*. However, Burger-Wiersma (1991) reported that nitrogen fixation was already an important component in the nitrogen budget of Dutch eutrophic lakes. External N reduction thus may effect the composition of biota, but not biomass production.

Return of the upwelling water from the ice-pushed sand-ridge of Het Gooi

At the beginning of this century, the Loosdrecht lake system used to be oligotrophic because of the low phosphorus level in the upwelling water from the Eastern Sandridge (Hofstra & Van Liere, 1992). It was thus suggested that an optimum corrective measure would be the return of this water (Engelen & Schot, 1989). However, the quality of ground water in the Eastern hinterland has degraded by the inflow from the Loosdrecht lakes and agricultural activities. Furthermore, the water table in that area has been lowered, resulting in the oxydation of peat in the region. If the flow of the upwelling water is restored, its present phosphorus level would be more than 1 mg P l^{-1} (Hettling, 1985). Such water should not enter the lakes; rather it should be diverted as suggested by Engelen *et al.* (1992) in the case of waters from the hinterland.

The return of the former upwelling water can be achieved by inundating the Polder Bethune. However, this is not practical, because Polder Bethune water is the source of the processed drinking water for the city of Amsterdam with an important socio-economic function. Furthermore, the inundation would prevent downward seepage from the Loosdrecht lake system, thus removing a phosphorus sink of the system. Besides, it will also increase upwelling water in the Eastern hinterland, which will in turn force a large volume of water with a high phosphorus level to flow into the lakes (Hettling, 1985). Therefore, the inundation of the Polder Bethune will mean an increased net external phosphorus load to L. Loosdrecht than now.

Conclusions

A reduction of external phosphorus load to L. Loosdrecht did not diminish the in-lake phosphorus sufficiently enough to restore the clear water in which macrophytes dominate primary production. However, with the reduction it has become a P-limited system in a relatively short time. The input and output of phosphorus appear to be in equilibrium. Therefore, any additional measures not involving the curtailment of the present loading will fail. A further reduction in external phosphorus load will decrease phytoplankton production with concomitant reduction in organic accumulation in sediments. It will also facilitate phosphorus loss from the system by downward seepage and discharge and reduce the amount of phosphorus recycling in the food web. These results would eventually bring the ecosystem to a new equilibrium with a lower external input, which can maintain an acceptable water quality through the future.

However, the eutrophication of the system which has been going on for decades is not expected to be reversed or solved within a few more years. The timespan needed for recovery may be as long as the time needed to eutrophicate the system.

References

Boers, P. C. M., J. W. Th. Bongers, A. G. Wisselo & Th. E. Cappenberg, 1984. Loosdrecht lakes restoration project: sediment phosphorus distribution and release from the sediments. Verh. int. Ver. Limnol. 22: 842–847.

Boers, P. C. M., J. Van der Does, M. P. Quaak, J. C. Van Der Vlugt & P. Walker, 1992. Fixation of phosphorus in lake sediments using iron(III)chloride: experiences, expectations. Hydrobiologia 233: 211–212.

Burger-Wiersma, T., 1991. Inventarisatie van de stikstoffixatiecapaciteit in twee ondiepe Nederlandse meren gedurende het groeiseizoen van 1990 (Inventarization of nitrogen fixing capacity in two shallow Dutch lakes during the growth season of 1990). Technical Report University of Amsterdam 65 pp.

Buyse, J. J., 1988. Water- en stofbalansmodellen voor de Loosdrechtse Plassen (Water- and matterbalances of the Loosdrecht lake system). WQL report 1988–7. 87 pp.

Dawidowicz, P., Z. M. Gliewicz & R. D. Gulati, 1988. Can *Daphnia* prevent a blue-green algal bloom in hypertrophic lakes? A laboratory test. Limnologica 19: 21–26.

Den Oude, P. J. & R. D. Gulati, 1989. Phosphorus and nitrogen excretion rates of zooplankton from the eutrophic Loosdrecht lakes, with notes on other P-sources for phytoplankton requirements. Hydrobiologia 169: 379–390.

De Ruiter, M., 1992. Water quality research in the Loosdrecht lakes: proposals for the follow-up restoration measures. Hydrobiologia 233: 161–163.

Engelen, G. B. & P. P. Schot, 1989. Analyse van de watersystemen in het Goois/Utrechts stuwwallengebied, de Vechtstreek en het Eemdal, probleemsignalering. Analysis of watersystems in the Gooi/Utrecht Sandridge-area, the lakes bordering River Vecht, and the valley of River Eem. CHO/TNO Reports 22: 21–32.

Engelen, G. B., B. F. M. Kal, J. J. Buyse & F. Van Pruissen, 1992. The hydrology of the Loosdrecht lakes area. Hydrobiologia 233: 21–38.

Gons, H. J., R. D. Gulati & L. Van Liere, 1986. The eutrophic Loosdrecht lakes: current ecological research and restoration perspectives. Hydrobiol. Bull. 20: 61–75.

Gons, H. J. & R. Van Keulen, 1989. De relatie tussen doorzicht en slib in de Loosdrechtse Plassen (Relation between Secchi depth and suspended matter in Lake Loosdrecht). WQL-report 1989–4. 35 pp.

Gons, H. J., T. Burger-Wiersma, J. H. Otten & M. Rijkeboer, 1992. Coupling of phytoplankton and detritus in a shallow, eutropic lake (Lake Loosdrecht, The Netherlands). Hydrobiologia 233: 51–59.

Gulati, R. D., K. Siewertsen & G. Postema, 1982. The zooplankton: its community structure, food and feeding and its role in the ecosystem of Lake Vechten. Hydrobiologia 95: 127–163.

Gulati, R. D., 1984. Zooplankton and its grazing as measures of trophy in the Loosdrecht lakes. Verh. int. Ver. Limnol. 22: 848–852.

Gulati, R. D., J. Ejsmont-Karabin, J. Rooth & K. Siewertsen, 1990. A laboratory study of phosphorus and nitrogen excretion of *Euchlanis dilatata lucksiana*. Hydrobiologia 186/187: 347–354.

Gulati, R. D., L. Van Liere & K. Siewertsen, 1991a. The Loosdrecht lake system: Man's role in its creation, perturbation and rehabilitation. In: O. Ravera (ed.), Terrestrial and aquatic ecosystems. Ellis Horwood Limited, London. pp. 593–606.

Gulati, R. D., K. Siewertsen & L. Van Liere, 1991b. Carbon and phosphorus relationships of zooplankton and its seston food in Loosdrecht lakes. Mem. Ist. ital. Idrobiol. 48: (in press).

Gulati, R. D., A; L. Ooms-Wilms, O. F. R. Van Tongeren, G. Postema & K. Siewertsen, 1992. The dynamics and the role of limnetic zooplankton in the Loosdrecht lakes (The Netherlands). Hydrobiologia 233: 69–86.

Hettling, H., 1985. Een hydrogeologische inventarisatie van het Loosdrechtse Plassengebied (A hydrogeological inventarization of the Loosdrecht lakes area). WQL report 1985–2. 116 pp.

Hofstra, J. J. & L. Van Liere, 1992. The state of the environment of the Loosdrecht lakes. Hydrobiologia 233: 11–20.

Hosper, S. H. & M-L. Meijer, 1986. Control of phosphorus loading and flushing as restoration methods for Lake Veluwe, The Netherlands. Hydrobiol. Bull. 20: 183–194.

Jagtman, E., D. T. Van Der Molen & s. Vermij, 1992. The influence of flushing on nutrient dynamics, composition and densities of algae and transparency in Veluwemeer, The Netherlands. Hydrobiologia 233: 187–196.

Janse, J. H. & T. Aldenberg, 1990. A mathematical model of the P cycle in the Loosdrecht lakes. Hydrobiol. Bull. 24: 69–89.

Janse, J. H., T. Aldenberg & P. R. G. Kramer, 1992. A mathematical model of the phosphorus cycle in the Lake Loosdrecht, and simulation of additional measures. Hydrobiologia 233: 119–136.

Keizer, P. & A. J. C. Sinke, 1992. Phosphorus in the sediment of the Loosdrecht lakes and its implications for lake restoration persectives. Hydrobiologia 233: 39–50.

Lammens, E. H. R. R., N. Boesewinkel-De Bruyn, H. Hoogveld & E. Van Donk, 1992. Phosphorus load, phytoplankton, zooplankton and fish stock in Loosdrecht Lake and Tjeukemeer: confounding effects of predation and food availability. Hydrobiologia 233: 87–94.

Loogman, J. G. & L. Van Liere, 1986a. Restoration of shallow lake ecosystems with emphasis on Loosdrecht lakes. Proceedings of the Water Quality research Loosdrecht lakes Symposium. Hydrobiol. Bull. 20: 5–259.

Malthus, T. J., E. P. H. Best & A. G. Dekker, 1990. An assessment of the importance of emergent and floating-leaved macrophytes to trophic status in the Loosdrecht lakes (The Netherlands). Hydrobiologia 191: 257–263.

Otten, J. H., H. J. Gons & M. Rijkeboer, 1992. Dynamics of of phytoplankton detritus in a shallow, eutropic lake (Lake Loosdrecht, The Netherlands). Hydrobiologia 233: 61–68.

Province of Utrecht, 1973. Over de veiligstelling van de waterkwaliteit van de Loosdrechtse Plassen (Securing the Loosdrecht lakes water quality). Report of the Province of Utrecht, Utrecht. 63 pp.

Province of Utrecht, 1980. Over de keuze van een suppletiemodel ter beveiliging van de waterkwaliteit van de Loosdrechtse Plassen (The choice of a supply model to secure Loosdrecht lakes water quality. Report of the Province of Utrecht, Utrecht. 90 pp.

Rijkeboer, M., F. De Bles & H. J. Gons, 1991. The role of sestonic detritus as a P-buffer. Mem. Ist. ital. Idrobiol. 48: (in press).

Sinke, A. J. C. & Th. E. Cappenberg, 1988. Influence of bacterial processes on the phosphorus release from sediments in the eutrophic Loosdrecht lakes, The Netherlands. Arch. Hydrobiol. Beih. Ergebn. Limnol. 30: 5–13.

Van der Does, J., P. Verstraelen, P. Boers, J. Van Roestel, R. Roijackers & G. Moser, 1992. Lake restoration with and without dredging of phosphorus-enriched upper sediment layers. Hydrobiologia 233: 197–210.

Van Der Veen, C., A. Graveland & W. Kats, 1987. Coagulation of two different kinds of surface water before inlet into lakes to improve the self-purification process. Wat. Sci. Technol. 19: 803–812.

Van Der Vlugt, J. C., P. A. Walker, J. Van Der Does & A. J. P. Raat, 1992. Fisheries management as an additional lake restoration measure: biomanipulation scaling-up problems. Hydrobiologia 233: 213–224.

Van Donk, E., M. P. Grimm, R. D. Gulati, P. G. M. Heuts, W. A. De Kloet & L. Van Liere, 1990. First attempt to apply whole-lake food-web manipulation on a large scale in The Netherlands. Hydrobiologia 200/201: 291–301.

Van Liere, L., L. Van Ballegooijen, W. A. De Kloet, K. Siewertsen, P. Kouwenhoven & T. Aldenberg, 1986a. Primary production in the various parts of Loosdrecht lakes. Hydrobiol. Bull. 20: 77–85.

Van Liere, L., P. C. M. Boers, P. J. Den Oude, H. J. Gons, R. D. Gulati, M. Rijkeboer, A. J. C. Sinke, J. P. R. A. Sweerts, J. Bril & L. Postman, 1986b. Water Quality Research Loosdrecht lakes, studying and modelling the impact of water management measures on the internal nutrient cycle. Final report to the European Community ENV 839-NL(N). 155 pp.

Van Liere, L., O. F. R. Van Tongeren, L. Breebaart & W. Kats, 1990a. Trends in chlorophyll and total phosphorus in Loosdrecht lakes, The Netherlands. Verh. int. Ver. Limnol. 24: 707–712.

Van Liere, L., R. D. Gulati, F. G. Wortelboer & E. H. R. R. Lammens, 1990b. Phosphorus dynamics following restoration measures in the Loosdrecht lakes (The Netherlands). Hydrobiologia 191: 87–95.

Van Liere, L., J. Ebert, W. Kats & J. J. Buyse, 1991. The waterquality of Loosdrecht Lakes reviewed. Mem. Ist. ital. Idrobiol. 48: (in press).

Van Liere, L. & R. D. Gulati, 1992. Restoration and recovery of shallow eutrophic lake ecosystems in The Netherlands: epilogue, Hydrobiologia 233: 283–287.

Van Tongeren, O. F. R., L. Van Liere, R. D. Gulati, G. Postema & P. J. Boesewinkel-De Bruijn, 1992. Multivariate analysis of the plankton communities in the Loosdrecht lakes: relationship with the chemical and physical environment. Hydrobiologia 233: 105–117.

Zevenboom, W. & L. R. Mur, 1980. N_2-fixing cyanobacteria: why they do not become dominant in Dutch hypertrophic lakes. In: J. Barica & L. R. Mur (eds), Hypertrophic ecosystems pp. 123–130. Junk Publishers, The Hague.