EUTROPHISATION DES EAUX PEU PROFONDES

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RESUME

Les processus d'eutrophisation des eaux peu profondes diffèrent nettement de ceux des eaux plus profondes. Par exemple, plusieurs lacs des Pays-Bas, recevant des charges de phosphates de plusieurs grammes par an (exprimées en PO4-P) ont néanmoins des concentrations en chlorophylle relativement basses. On pense que le retard du processus d'eutrophisation est lié aux sédiments qui adsorbent de grandes quantités de phosphates, soit par l'intermédiaire d'algues soit directement par des processus physico-chimiques.

Les phosphates contenus dans les sédiments ne sont pas sans danger pour le lac ; une partie d'entre eux sont disponibles pour le développement algal. On peut craindre pour cette raison que les sédiments, après avoir mis en réserve les phosphates, en libèreront ensuite une grande quantité, retardant à nouveau les processus de dé-eutrophisation.

La chimie des composés phosphatés dans l'argile sera brièvement discutée.

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Lakes in the Netherlands are by origin shallow and not very poor in nutrients, like most lakes in delta regions. The lakes are situated in large amounts of silt deposited by the rivers Meuse and Rhine (fig. 1 and 2). Because of the adsorbing capacity of the clays in these deposits nutrients passing through in the water are retained instead of being transported into the sea. Rooted vegetation (especially during relatively warmer recent periods) has formed vast amounts of peat. Ground- or drainage water percolating through the layers of peat remobilises these nutrients and transports them into lakes and rivers. GOLTERMAN (1973a) has argued that not all these nutrients are easily available for algae as the larger part enter the lakes during the winter when light is poor, while furthermore the water contains high concentrations of humic acids rendering the light intensity (irradiance) still lower. Thus although the major part of for example the phosphates is not available, a not negligible amount will be available rendering the waters fertile already long before the present enrichment with nutrients began.

Thus it is not amazing that LAUTERBRON (1918) described blooms of blue green algae in Dutch lakes long before the second world war, the period often considered to be the beginning of the present enrichment period.

Besides this nearly natural loading the Dutch lakes receive a heavy loading with nutrients from human input, both from households and industry. KOLENBRANDER (1974) estimated that on the average the Dutch lakes receive at least 6 g m^{-2} y^{-1} of PO_4 — P. It may be roughly estimated that one third comes directly from the use of detergents, one third from human excreta and one third from the river Rhine, of which again a major part is derived from detergents.

It seems likely that, about 40 % of the total loading is derived from household detergents.

Of course large deviations from this mean loading are found ; in several cases, e.g. in the Frysian lakes the loadings are probably only a fraction of this value while for lakes in the western part of the Netherlands — the most densely populated part — loadings up to 20 g m^{-2} y^{-1} can be estimated.

If these loadings in conjunction with the mean water depth 2 1/2 - 3 1/2 m are used with VOLLENWEIDER's (1968 and 1975) graphs, one would expect very intensive algal blooms, even if with VOLLENWEIDER's newest graph, water retention time is taken into account. Indeed in a few cases chlorophyll *a* concentration may reach quite high values, e.g. 200-300 mg m^{-3}, a concentration that may be regarded as near the maximum possible.

There exist, however, several lakes with lower chlorophyll concentration. Originally the fact that low chlorophyll concentrations (e.g. 100 mg m^{-2}) were found in lakes with an average loading of 2 g m^{-2} y^{-1} was explained by assuming a rapid transport of the phosphate directly into the sediments (fig. 2, from GOLTERMAN 1973). Precipitation of iron-and calcium phosphates and adsorption onto clays are processes that may likely play a role. Later more information became available on the rapid turn-over of phytoplankton cells. This information can be obtained by comparing standing stock of phytoplankton with photosynthesis and by comparing photosynthesis with oxygen uptake over 24 hours (see e.g. GOLTERMAN 1971 and 1975).

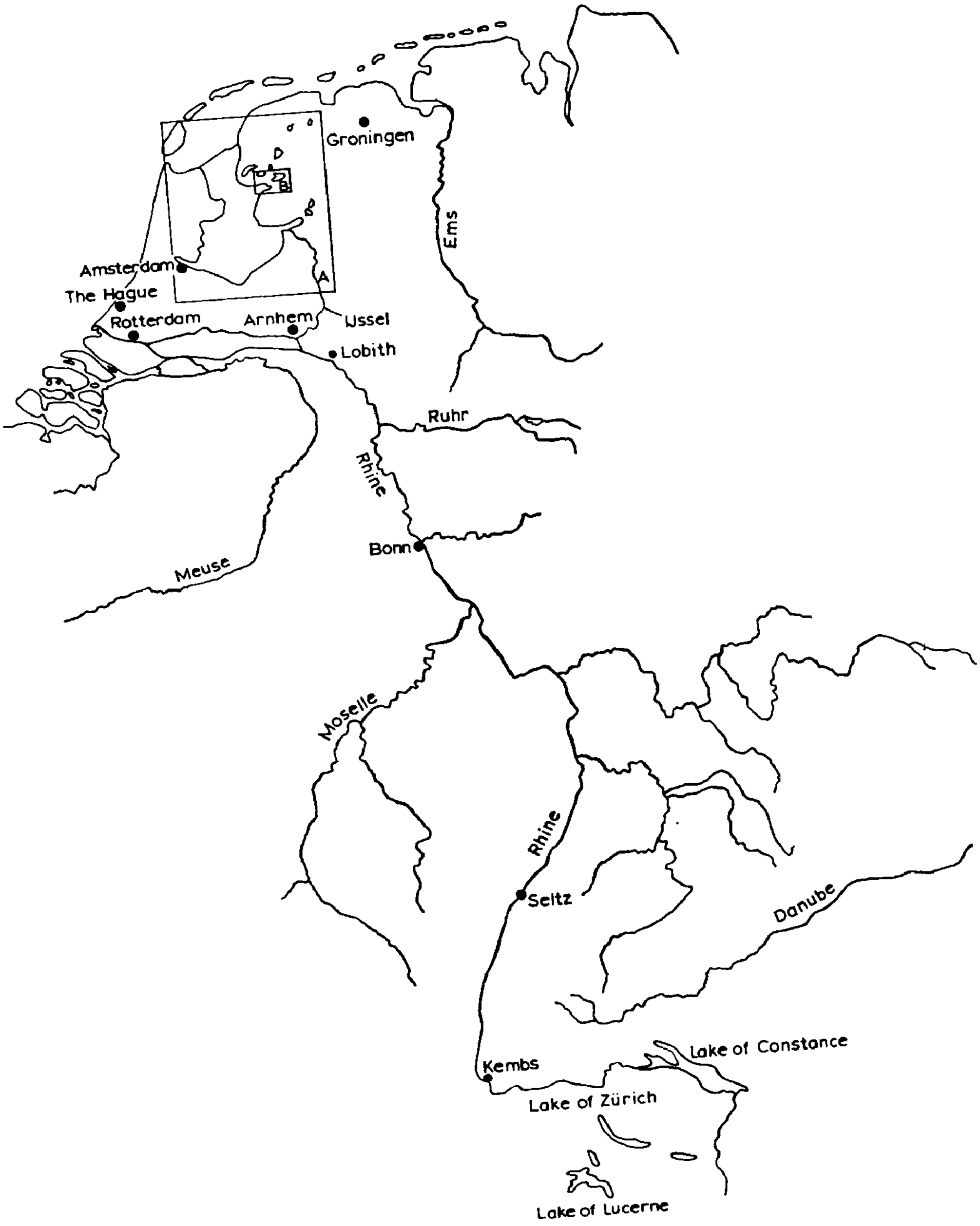

Figure 1 : Map of the Netherlands showing position of border Lakes.

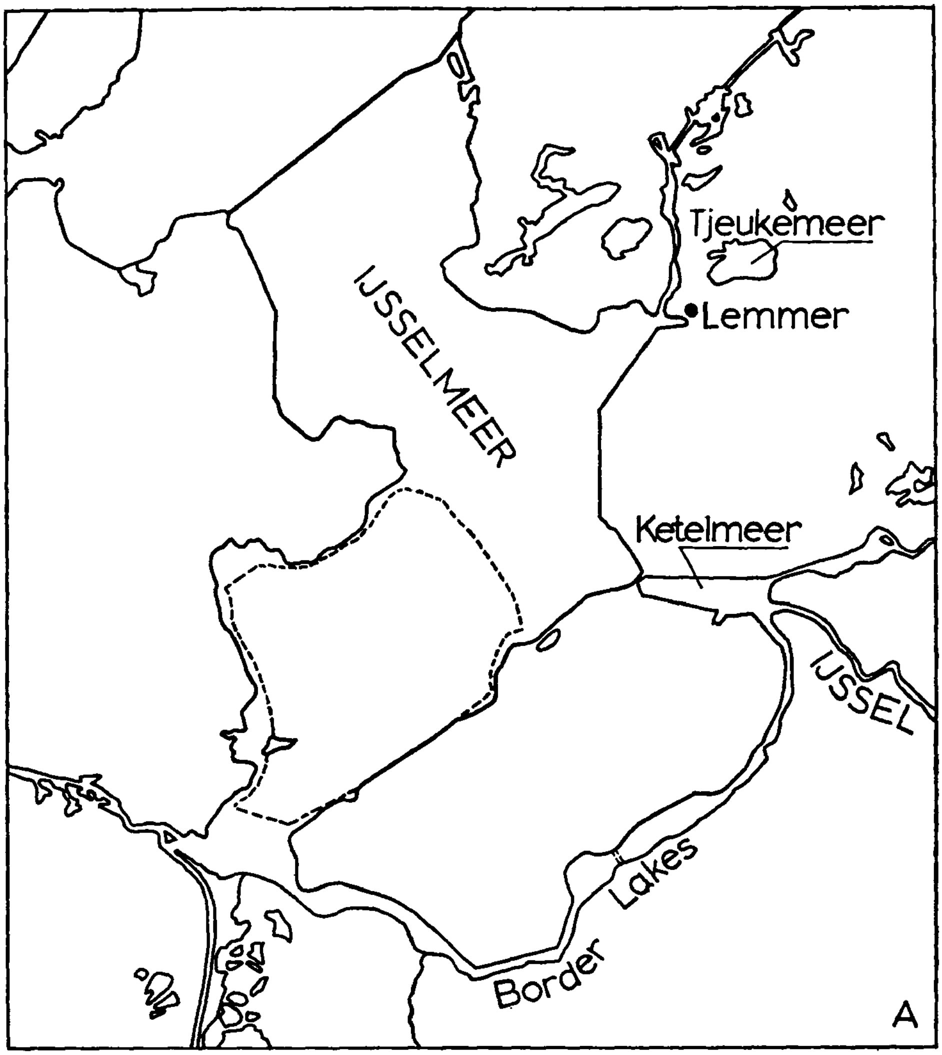

Figure 2 : Map of the part A of the figure 1.

The picture arising from these considerations involves a rapid turnover of nutrients from decaying cells into simple inorganic compounds, which in their turn are taken up almost at once during growth. The apparent life expectancy of the phytoplankton population appears to be in the order of about 5 to 10 days. After algal death nutrients are mineralised very rapidly and to a large extent. A small part of the nutrients may remain in refractory compounds and will fall into the sediments. Although per algal cycle this may be a small part, the fact that several cycles occur per year will render this small quantity per cycle a rather important quantity per year (fig. 4).

The net results of the two schemes from figures 3 and 4 is the same : the major part of the allochthonous phosphate eventually reaches the sediments.

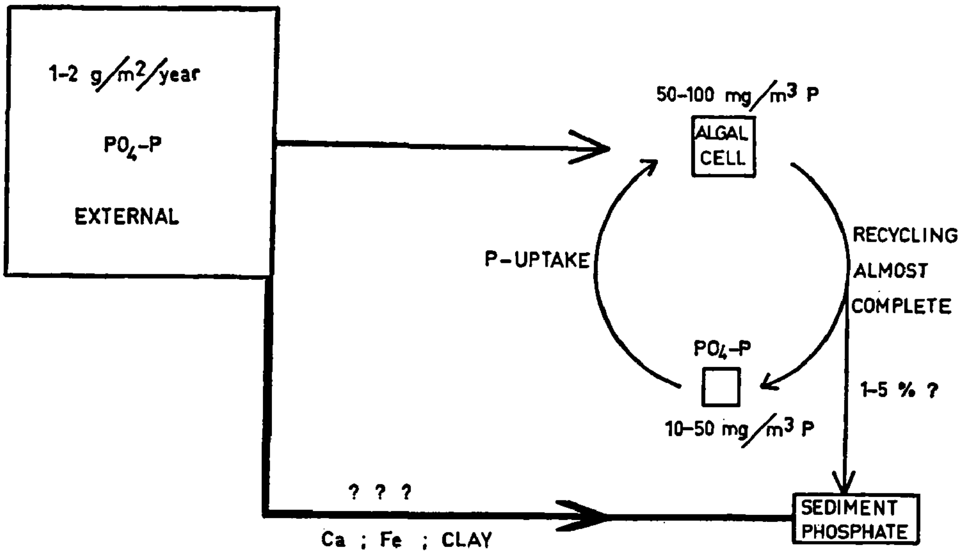

Figure 4 : As fig. 3, but considering high algal turnover rates, i.e. showing a dyna-over rate, i.e. showing natural P losses in a static system.

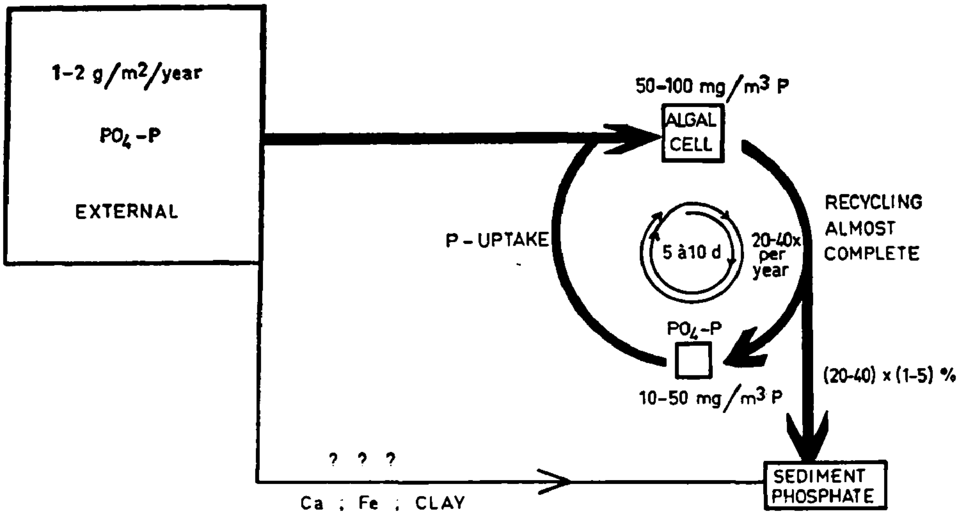

Figure 4 : As fig. 3, but considering high algal turnover rates, i.e. showing a dynamic picture where heavy artificial input rate matches the recycling rate.

Algal growth on sediments

In earlier studies we have shown that algal cultures can grow excellently on a culture solution with sediments as the only source of phosphate (GOLTERMAN, BAKELS, MÖGLIN 1969). Good growth was obtained by suspending some sediments in a culture solution freshly inocculated with *Scenedesmus sp.* With all lake sediments we tried good growth was also obtained by solidifying the sediments with agar-agar and slicing into lumps at a thickness of about 1/2 cm. By counting the algal cell density we could estimate the total cell phosphate content and the amount of phosphate being used by the algae. In all but one sediment sample we found that this amount is roughly as large as the amount of phosphate that can be extracted with a 0.01 M solution of nitrilotriacetic acid (NTA ; pH adjusted to about 7). The percentage of this extractable phosphate varies with the different samples.

We noticed that the sediments are an equally good source of iron for the algae ; nitrogen and potassium must always be added, although the latter may be present adsorbed in considerable quantites. In experiments with pure clay we had to add even large quantities of potassium, the smaller quantities being rapidly withdrawn from algal growth.

Potassium is thus behaving differently in these cultures from the normal lake situation, where it never limits algal growth. Nitrogen not being adsorbed onto sediments will be washed away more rapidly and may therefore in several phosphate enriched lakes became a limiting factor.

The fact that algae can grow on sediments in culture may be important when considering the future of lakes where by technical measures the external phosphate input is decreased, if not stopped fully. The risk exists that the large amounts of phosphates may then become available for the algae, which will then try to meet their demands from these sources, after being deprived from the now existing daily input. With regard to nitrogen we must note that the input of this element will not (yet) be decreased drastically as this removal is much more expensive and may be counteracted by nitrogen fixation by blue green algae, of which the nitrogen fixing types will then be stimulated.

The problem of the restoration of shallow lakes cannot be solved using the results obtained in deep lakes. The time that will elapse before improvements will be noticed cannot be predicted at all. Therefore we have built an experimental pond in one of our richest lakes, the Veluwe Border Lake, where chlorophyll concentrations are 200-300 mg m^{-3} (fig. 2). An enclosure has been made of about 2 000 m^3 such as was originally built by LUND (1972 ; see also LACK and LUND, 1974) separating a pond with a diameter of about 50 m from the main lake. This pond can be flushed through with relatively phosphate poor water. During the summer of 1975 the pond was flushed through six times, respectively once with 1500 and the other times with 3 000 m^3. After the first time no extra nitrogen was added and no algal growth was obtained. As soon as nitrogen was added (after the first flush through after .. days, after the other times directly after the flushing) the chlorophyll concentration increased to the same level as outside in the lake, and the particulate phosphate concentration rose concomitantly. In total 1 200 mg of P per m^2 was removed from the pond, the major part of which was in particulate form, while the minor part was orthophosphate (table 1). During this period we measured the amounts of extractable phosphate and separated iron phosphate from calcium phosphate by first extracting with a 0.01 M solution of NTA containing an equal amount of calcium followed by an extraction with NTA neutralised with NaOH.

It was estimated that 1 000-1 600 mg m^{-2} of extractable PO_4-P was removed from the sediments by the algae and finally flushed away. This amount

Table 1 : Increase in the concentrations of chlorophyll, PO_4-P and Part-P in the periods after the flushings.

Period	Chlorophyll		P - Part µg/l	Water Flushed Through in m³
	µg/l	in %		
18- 7/18- 8	168-206	23	3	1 670 (16/17 July)
22- 8/ 1- 9	123-193	57	231	3 150 (18/21 August)
3- 9/16- 9	63-213	238	11	3 500 (1/2 September)
18- 9/23- 9	68-96	41	20	3 400 (16/17 September)
25- 9/ 7-10	42-139	231	95	3 500 (23/24 September)
9-10/22-10	54-180	233	145	3 500 (7/8 October)

is about 1.0 % of the total NTA extractable phosphate, so that we hope to deplete the available phosphate with perhaps ten flushings. If this proves correct we will eventually try to flush through the whole lake, which may be possible because in the neighbourhood of the lake a « machine d'épuisement » is situated with a capacity to renew the lake volume in about three weeks.

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