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PHOSPHATE REDUCTION IN LAKES BY PRECIPITATION WITH ALUMINIUM SULPHATE

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B 84
Stockholm
November
1970

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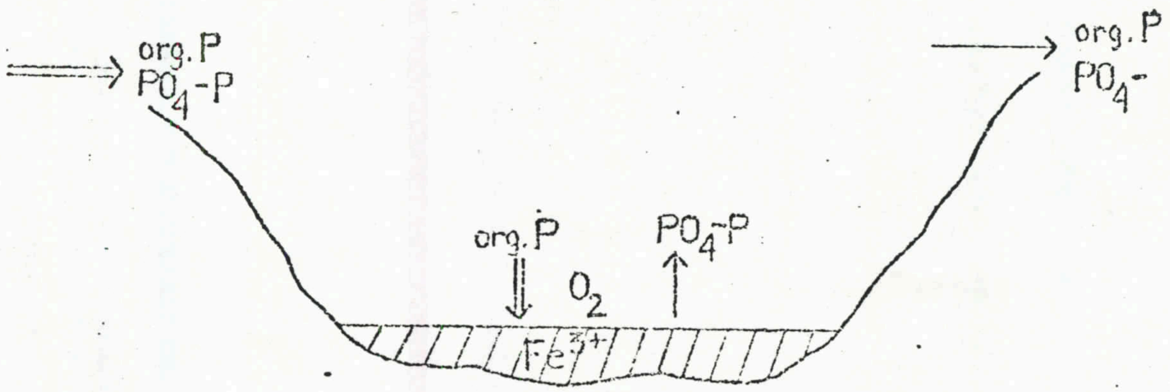
Eutrophication is a well known problem all over the world and during the last years many methods of controlling this process in lakes have been discussed and some of them have been experimentally tested. The control methods are generally based on the theory of the predominant effect of phosphate and oxygen and their interdependence.

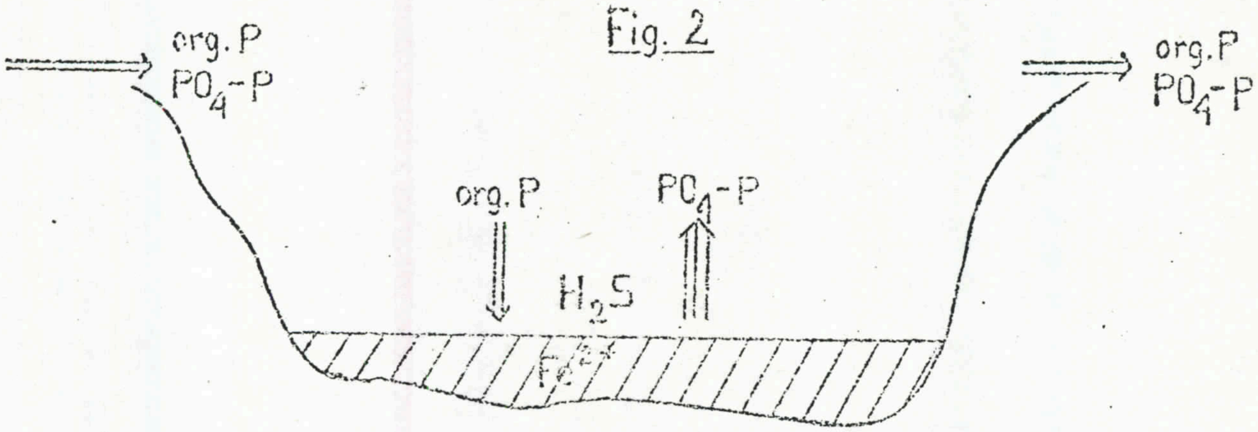
The model for ageing of lakes - naturally or under the influence of human waste-water discharge - is founded on the well-known works of Mortimer.

Fig. 1



According to this model a "young" lake (figure 1) acts as a trap for nutrients, of which phosphate is considered the most important. The amount of oxygen in the bottom water is large enough for the mineralization of the organic substances during the stagnant periods. Iron thus exists in the ferric state complexed with humus and phosphate. Phosphate released in the degradation of organic substances is to a considerable degree bound to these complexes and accumulates in the sediment.

Fig. 2



In an "old" lake (figure 2) the oxygen content of the bottom water is insufficient for the mineralization of the organic substances during the stagnant periods. Thus, at least at the end of the stagnant periods, there is a lack of oxygen; and the iron is reduced to the ferro state and released together with phosphate. Consequently there is a flow of the previously accumulated phosphate from the sediments to the water.

The higher phosphate content of the water will then cause a still higher production of organic substance, which will consume still more oxygen, and so on in a negative feedback system.

The critical point in the "ageing" of lakes according to this model is when the amount of oxygen in the bottom water during the stagnant periods no longer suffices for the degradation of organic substances supplied to or produced in the lake. This critical point can be described by the formula: $S - t\ (N^{1} + N^{11} + M + B) \approx 0$ where S is the amount of oxygen present in the bottom water at the beginning of the stagnant period;

t is the length of the stagnant period;

N^{1} is the consumption of oxygen per unit of time from organic substance produced from nutrients circulating in the lake;

N^{11} is the consumption of oxygen per unit of time from organic substance produced from nutrients supplied to the lake;

M is the consumption of oxygen per unit of time from supplied organic substances;

B is the consumption of oxygen per unit of time from existing sediments.

Among the factors in this formula N^{11} and M can be affected through improving the effluent quality or by discontinuing the discharge. As a rule this may be said to be necessary in any attempt to restore the lake, but is not enough in the situation discussed.

The factor S is very difficult to affect. t can be affected, e.g. by bubbling of air or pumping up the bottom water.

N^1 can be affected in many ways:

1) By precipitation of nutrient, limiting the production of, e.g., phosphate.

2) The circulating amount of nutrients could be reduced by taking the water to the out-flow of the lake from the hypolimnion through a pipe line.

3) By adding herbicides which reduce the growth of algae and/or higher plants.

4) By removing organic substance before degradation. This can be done by removing Phragmites and/or Nymphaea or by extremely hard fishing.

5) By implantation of organisms feeding on the surplus of algae and/or macrophytes. For this purpose grass- and silvercarps, for example, have been used.

B can be radically affected by pumping up the existing sediments.

Precipitation of phosphate with aluminium, iron(3) or calcium is well known in plants for waste-water treatment. In our experiments the first question was whether any of these methods for phosphate reduction could be used in a lake. In this case the use of iron(3) was hardly to consider because of the possibility of reduction to iron(2) under anaerobic conditions and, as a consequence, release of iron and phosphate from the bottom. A series of laboratory experiments in aquatic ecosystems showed a permanent decrease of the amount of total phosphorus in the water and production of blue-green and green algae after precipitation with both aluminium and calcium ions. Experiments to study the release of phosphate from anaerobic bottom sediments with and without addition of aluminium and calcium were performed. There was some decrease in the released amount of phosphate in both cases. Aluminium was chosen rather than calcium in this case because it gave better flocculation in the type of water in question.

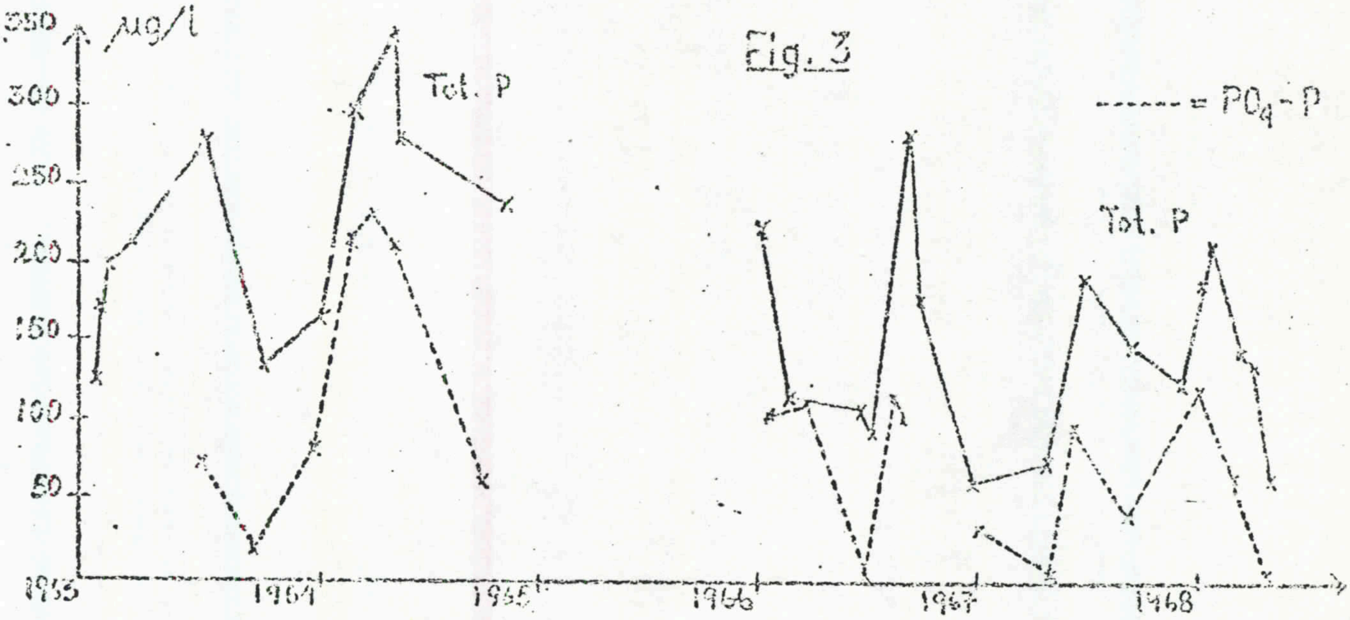
Toxicological studies were made of the effect of aluminium hydroxide formed at precipitation of lake water with aluminium sulphate on a number of lake invertebrates. Serious effects were observed only on Mysis relicta (which ordinarily do not occur in lakes where there is a need for phosphate removal).

The laboratory experiments also showed that the best time for adding aluminium sulphate was when as much as possible of the "mobile" phosphorus in the aquatic system was in the form of phosphate in the water. Having regard to some practical problems this means, in Sweden, that shallow lakes should be precipitated in the early spring as soon as the ice is gone. In deeper lakes the treatment can be done in the spring (as above) or in the autumn immediately before the circulation.

For the experiment with restoration of a lake by precipitation with aluminium sulphate, Lake Långsjön in Stockholm was chosen. It is a shallow lake with a maximum depth of 3 m, an area of 350,000 m^2 and a volume of 650,000 m^3. During a long period the lake has received municipal sewage. Even before this it was a typical eutrophic lake with tendencies to oxygen deficiency in the winter and blooming of blue-green algae in the summer. The waste water caused these situations to occur regularly. Also Phragmites and Nymphaea spread out over an increasing area of the lake. The main discharges of sewage were gradually stopped during the late fifties and early sixties. Some attempts to help up the oxygen situation at the end of the winter season through bubbling of air were made in the winters 1963, 1965 and 1966. During the summers 1960-66 copper sulphate was used to prevent blooming of blue-green algae.

Macrophytes, mainly Phragmites and Nymphaea, were removed in July 1966 and (after the precipitation) in August 1968. Observations, extensive chemical analysis and sampling of plankton had been done in the lake by the City of Stockholm (Miss Märta Cronholm) for more than twenty years.

In late April 1968 the lake was precipitated with 33,5 tons of granulated aluminium sulphate. The break-up of the ice in that year came two weeks earlier than usual, but troubles with the delivery of the granules delayed the precipitation. This meant that the phosphate concentration had dropped from a maximum of 130 µg/l to 60-70 µg/l (Fig. 3 and 4). Because of the delay the effect achieved was thus only 40 per cent of the possible.



As an immediate result of the precipitation the sight depth went up from 0.5 - 0.6 m to >2.5 m (the bottom). The concentration of phosphate in the water dropped from ≈60 to >5 µg P/l (Fig. 3) and of total phosphorus from ≈140 to ≈60 ug P/l. The flocculated aluminium hydroxide covered the bottom with a light-grey layer 1-3 cm thick.

A sudden mass movement of neuropteran larva towards suitable places for chrysalisation started a few hours after the precipitation.

During the first weeks in May the flocculated aluminium hydroxide gradually changed its colour to that of the bottom sediment and at the same time there was a decrease in volume. To some extent this coincided in time with an increase of the concentrations of phosphate and total phosphorus in the water (Fig. 4).

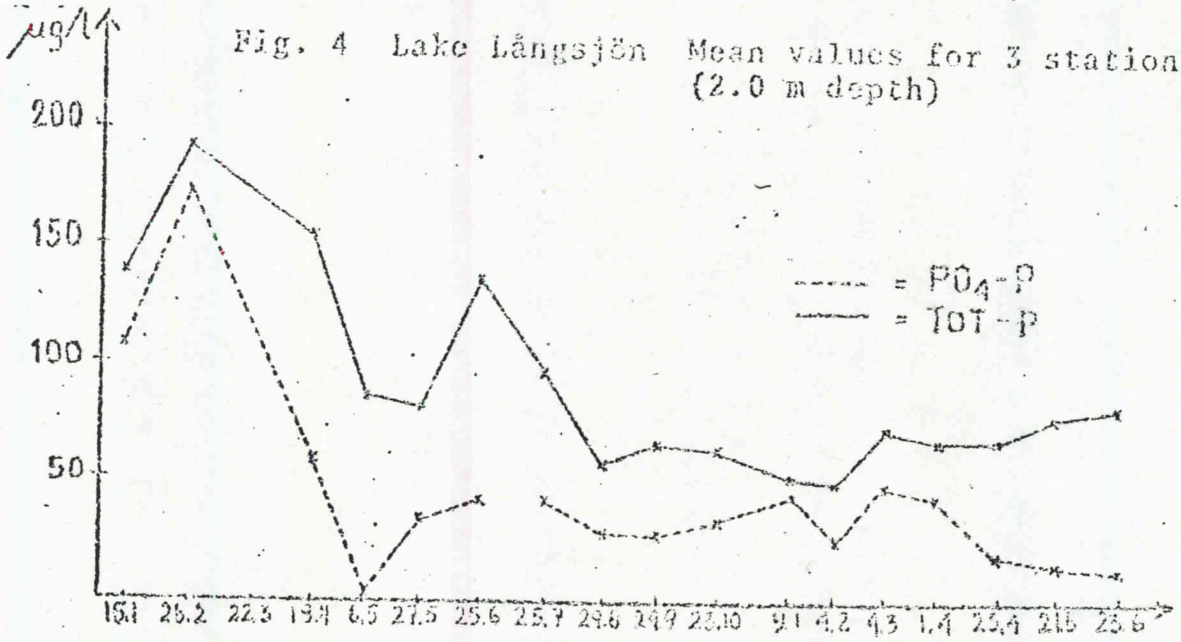


Fig. 4 Lake Långsjön Mean values for 3 stations (2.0 m depth)

In samples of bottom sediment brought to the laboratory these visible changes in the flocculated aluminium hydroxide occured during the same time, but without any increase in the concentrations of phosphorus in the water above the sediment. From the beginning of June and until August there were sudden peaks in the number of thermostable coliform bacteria in the lake water. After the increase in concentration of total phosphorus during May and June a maximum of ≈120 µg P/l was reached around midsummer 1968 (Fig. 4). After that there was a gradual decrease during late summer and a plateau at ≈65 µg P/l was reached during the autumn. During the period of ice-cover, from the middle of November 1968 until the middle of April 1969, there were only small changes in the concentrations of phosphate and total phosphorus in the water.

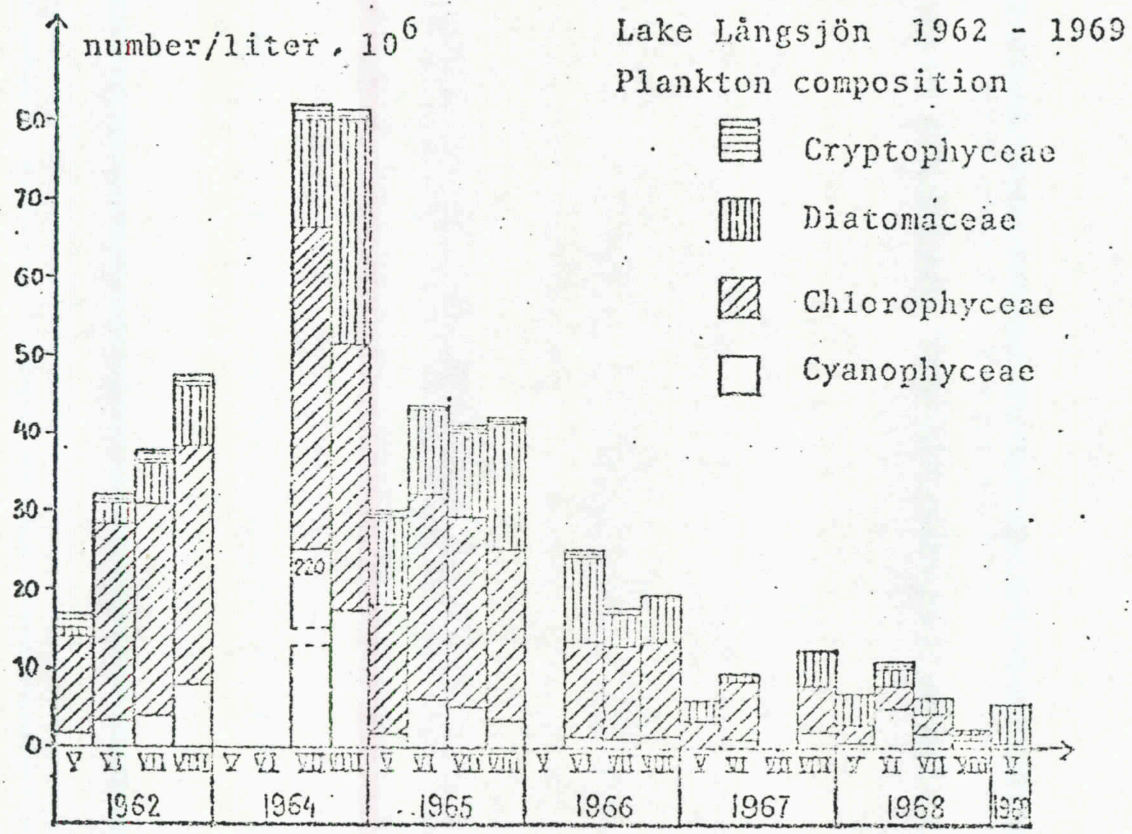
Table 5

Winter	Probable date for ice-cover	Date when oxygen content of <0.5 mg/l is observed in the bottom water	Number of days
61-62	2.12	6.3	84
62-63	18.11	2.2	76
63-64	7.12	5.3	88
64-65	15.12	5.3	80
65-66	13.11	4.1	52
66-67	14.12	-	-
67-68	9.12	26.2	79
precipitation			
68-69	14.11	4.3	110

As will be seen from Table 5, the mean time from the date of ice-cover to the date when bad oxygen conditions (<0,5 mg/l) in the bottom water were observed is 77 days for the winters 1961-62 to 1967-68 (with the exception of the winter 1966-67 when no lack of oxygen occurred). The first winter after the precipitation the same period is 110 days.

The number of planktic algae from the main morphologic groups will be seen from Fig. 6.

From the summer of 1964, when the number of algae reached $\approx 80 \cdot 10^6$/liter, there is a gradual decrease to about 10 per cent of that number in the summer of 1968.



DISCUSSION

The purpose of the precipitation was - as said above - to break the self-fertilising process in an "old" lake. The addition of aluminium ions was presumed to effect this is two ways:
1) by a primary reduction of the amount of oxygen-demanding organic substances produced and
2) by "locking up" the phosphate in the sediment even under anaerobic conditions. This would mean - in the first case - a better oxygen situation and thus a smaller mobilisation of phosphate from the bottom sediments and, in the second case, a smaller amount of phosphate coming from the bottom sediments despite a lack of oxygen. In both cases the result in the following spring would be a lower concentration of phosphorus in the water and thus a lower production during the summer, which would mean that the "vicious circle" was broken and that the aim of the precipitation was fulfilled.

The oxygen situation during the winter was less bad in the year 1968-69 than during preceding winters (with the exception of the abnormal winter 1966-67) in the sense that it took a longer period of ice-cover until the oxygen concentration in the bottom water became very low. Of course this was partly effected also by the removal of higher plants that took place in the preceding summer. After the precipitation there was an increase in the concentration of total phosphorus in the water. This could come from a resolution of the precipitated phosphate - but as the parallel increase in the amount of thermostable coliform bacteria indicates - a temporary discharge of untreated sewage could be responsible. The results from the laboratory tanks support the last hypothesis.

Although there was a lack of oxygen in the bottom water at the end of the winter due to the long period of ice-cover, there was no remarkable release of phosphate from the sediments. The number of planktic algae was lower in the summer of 1968 than for the mean of the preceding summers in the 1960´s. As this decrease in the number of algae started several years before the precipitation, nothing can be said about the effect on the standing crop of planktic algae. It should be kept in mind, however, that the climatic conditions for a high production of planktic algae was not very good (a warm winter 1966-67 and a not very sunny summer) while the summers 1968 and specially 1969 were unusually warm and sunny and the preceding winters were cold.

SUMMARY

Lake Långsjön - an eutrophic shallow lake near Stockholm, Sweden - was precipitated in April 1968 with ≈50 g granulated aluminium sulphate per m^3 of the lake volume.

The results were

1) a lower concentration of total phosphorus than before
2) a somewhat better oxygen situation during the winter 1968-69 and
3) no release of phosphate from the sediments although the conditions were anaerobic.

As the trend for the standing crop of planktic algae in the lake is negative, no sure effect on the number of algae from the precipitation can be seen.