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How an estuary changed into a freshwater lake

The water management of Lake Volkerak/Zoom

Proceedings and information No. 46
Verslagen en Mededelingen No. 46

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Editors
J.C. Hooghart
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Technical Meeting 50
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PREFACE

On March 8, 1989, Technical Meeting 46 of the TNO Committee on Hydrological Research (CHO-TNO) was held on the theme: "Hydro-ecological relations in the Delta Waters of the South-West Netherlands". The results of this meeting are published in Proceedings and Information CHO-TNO No. 41.
On June 4, 1992, Technical Meeting 50 of CHO-TNO took place. During this meeting the results have been presented of an evaluation of the water management of Lake Volkerak/Zoom - a new freshwater system in the Delta. This publication contains the papers presented at this meeting, which was organized in co-operation with Rijkswaterstaat, Directorate Zeeland. These papers consider the key questions, whether water management has been able to deal with the changes in Lake Volkerak/Zoom and whether the management policy targets will be achieved.

Delft, December 1992

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FROM SALT TIDE ..... TO FRESHWATER LAKE
Origins, structure, scheme and management

F.L.G. de Bruijckere

1 INTRODUCTION

In the night of 17 April 1987 the upper tidal reaches of the Eastern Scheldt estuary disappeared forever, when engineers closed the last gap in the Philips Dam to create a new freshwater lake free from ebb and flow. A whole new ecosystem was about to be developed. But there was one question mark hanging over Lake Volkerak/Zoom. Would it become a flourishing freshwater lake complex? To find the answers, this latest product of the Delta project has been monitored for the last few years.

This collection of articles describes the development of Lake Volkerak/Zoom from the creation of the lake system in 1987 up to the present day. It looks at the ecological threats to the lakes and the measures taken - or planned for the future - to create healthy, sustainable ecosystems.

Figure 1 The Delta area before the Delta project (left) and after 1987 (right)

2 ORIGINS

Lake Volkerak/Zoom has its origins in the flood disaster of 1953. The destruction of life and property was so great, and feelings in the country that this should never happen again so unanimous, that a specially appointed committee was set up to solve the flooding problem once for all. This committee proposed sealing off all the tidal inlets to the delta, with the exception of two major shipping routes, the New Waterway and the Western Scheldt. Then freshwater lakes would be created behind the dams.

Figure 1 (left) (see page 3) shows the delta area before the inlets were closed. Eleven dams and dikes of different sizes and design have been built over the last 30 years. Figure 1 (right) shows the delta area in 1987, with the various sea defences then in place.

The original plan was to close off the Eastern Scheldt completely by a large dam with a solid structure. But in the mid-1960s perceptions of the environment were changing and this plan was increasingly being opposed in scientific circles, as well as by environmental groups and fisheries interests. A compromise was reached in 1974: to build a storm surge barrier, that leaves tidal movement largely unmodified, but can be closed during storm surges.

The storm surge barrier has narrowed the mouth of the Eastern Scheldt, by which less water enters and leaves the estuary with the tide. Special measures had to be taken to ensure that this reduction would not lead to a serious reduction in tidal movement between the high and low water levels. Partly for this reason two dams were built in the Eastern Scheldt inland of the storm surge barrier. This reduced the area of the estuary and ensured an adequate tidal range despite the construction of the storm surge barrier. Another reason for constructing these dams was that as early as the 1960s the Netherlands had agreed with Belgium to provide a shipping connection between Antwerp and Rotterdam which would no longer be affected by tidal movements.

The Volkerak Dam (Figure 2) was already completed in 1969 as part of the scheme to close off the Haringvliet. The Oester Dam, sealing off the upper Eastern Scheldt estuary, was finished in 1986. In the following year, 1987, after completion of the construction of the Philips Dam closing off the Krammer-Volkerak, an area of fresh water with a permanent level was created, Lake Volkerak/Zoom.

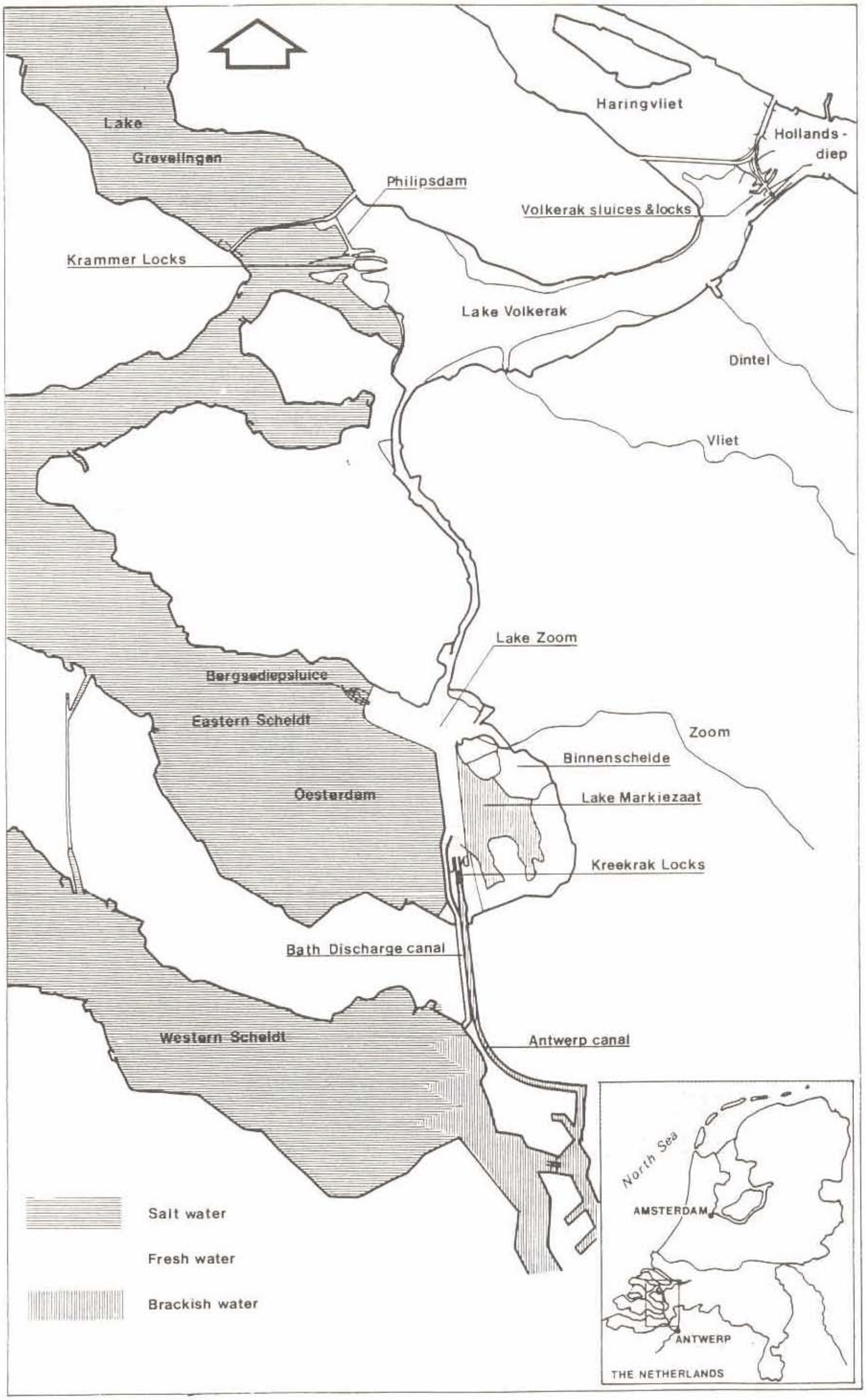

Figure 2 Map of Lake Volkerak/Zoom

3 INFRASTRUCTURE

Locks have been incorporated in the dams to maintain navigation as follows:

- the Volkerak Locks in the north giving access to the Rhine and Meuse river systems;
- the Krammer Locks in the northwest giving access to the Eastern Scheldt and thence to the Western Scheldt via the Canal through South Beveland;
- the Bergsche Diep Lock for access to Bergen op Zoom and the Eastern Scheldt;
- the Kreekrak Locks in the south for access to Antwerp Docks.

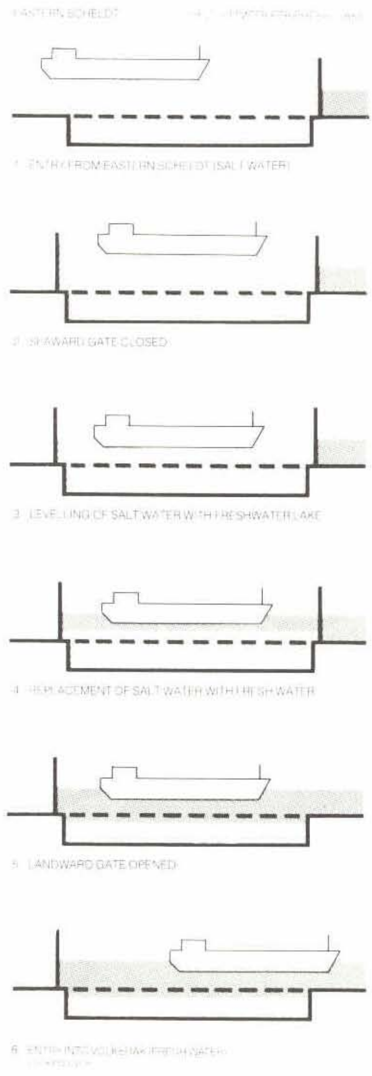

Figure 3 The salt/freshwater separation system at the Krammer Locks

Volkerak Locks

Krammer Locks

Bath Discharge canel and Scheldt-Rhine canel. In the centre the Kreekrak Locks

Bath Discharge canal and sluices

To compensate the loss of the freshwater lakes in the Delta area, it was decided to make Lake Volkerak/Zoom a freshwater lake to provide water for agriculture in the adjacent parts of West-Brabant, Zeeland and Zuid-Holland. In addition to ship locks, the Volkerak Locks complex at the north end of the lake includes a sluice to admit water from the Hollandsch Diep. This is necessary in dry periods, when flows in the West-Brabant rivers and from polder drainage are very low and there is a risk that minimum lake stage will not be maintained, or that lake salinity will exceed the permitted maximum. The main sources of salinity in the lake are losses through the locks on the Eastern Scheldt, saline intrusion through the sea dike, and delayed release from the old sea bed.

The Krammer Lock complex is fitted with a salt/freshwater separation system that prevents salt water entering the freshwater lake and fresh water entering the Eastern Scheldt. The system works on the principle that salt water is denser than fresh. When ships pass through the locks, salt water is exchanged for fresh or vice versa (Figure 3). The Kreekrak Locks are equipped with a similar system to prevent brackish water from Antwerp's industrial area from entering Lake Zoom. The Bath Discharge canal was dug across the South Beveland isthmus, on an alignment parallel to the Scheldt-Rhine canal, to discharge excess fresh water from the lake into the Western Scheldt. The design capacity of the drain (max. 130 m^3/s) is based on an extremely wet period.

4 MORPHOMETRY

Hydromorphologically, Lake Volkerak/Zoom consists in reality of two lakes: Lake Volkerak in the north, which is the largest of the two lakes, and the much smaller Lake Zoom in the south. The Eendracht, a section of the Scheldt-Rhine Navigation Link between Antwerp and Rotterdam, connects the two lakes to form a single hydraulic system. The table below gives morphometric data for the two lakes.

Table 1 Morphometry of Lake Volkerak/Zoom

	Lake Volkerak	Lake Zoom
Surface area (ha)		
water	4570	1580
"dry" margin	1775	220
total	6345	1800
Depth (m)		
max	24	20
mean	5	6

Lake Volkerak/Zoom covers an area of some 8,300 ha, one quarter of which is new dry land. These "dry" areas are former mud flats and salt marshes. Retention times of water in the lakes vary from 2 to 4 months depending on season. Depths vary from a few centimetres to 24 metres. The average depth of Lake Volkerak/Zoom is 5.2 metres.

5 BASIC POLICY

After designing the infrastructure, which has taken shape by the early 1970s, attention has been shifted to water management and the ancillary structures that would be required. A government policy document entitled Water Management in Lake Zoom after 1987 (Anonymus, 1986) reviewed the possibilities and made recommendations on lake levels and the extent that flushing with fresh water would be needed. Following public consultations held by the Public Works Council in 1987, the Minister defined basic policy principles on water management of the lakes.

In summary these are:
- selective inflow directed to minimize imports of contaminants;
- target lake stage to be NAP (Normaal Amsterdams Peil, the reference level in the Netherlands) with variations permitted between NAP +0.05 m and -0.25 m;
- an upper limit of 400 mg/l on chlorides to comply with irrigation requirements; chloride content to be measured at the mouth of the Bath Discharge canal.

In 1987 also an agreement, covering water management and civil works on Lake Volkerak/Zoom once impounding began, was signed between all the parties involved (Anonymus, 1987). The blueprint for future development of the area was now ready in the form of an integrated Krammer-Volkerak policy plan, which defined the functions of the scheme as follows:
- primary function of navigation within defined canals;
- primary function of nature area for the shallow water areas and margins exposed at low stage;
- primary function of water supply for irrigation;
- other functions such as commercial fishing, recreation and drainage.

Irrigation was accorded high priority in the drafting of the original policy on water management. Krijger (1992, this volume) looks at the importance of irrigation in his article.

6 ECOLOGICAL RISKS

It was recognized early on that damming the Krammer-Volkerak and turning the upper Eastern Scheldt estuary into a freshwater lake entailed certain ecological risks. The inflow of polluted river water combined with the loss of flushing by the tide would have far-reaching effects on rates of erosion, eutrophication, and contamination with hazardous substances.

With tidal fluctuations eliminated, there is always a strip of bank exposed to erosion by wave attack. Banks are receding by tens of meters every year, leaving a miniature cliff line at the eroding front. Of course, this hampers the establishment of a balanced community of shoreline plants. As a result the Minister has authorized bank consolidation works to be carried out within eight years of impoundment.

The lake is also particularly susceptible to eutrophication, as a result of its conversion to fresh water. River water and polder drainage are high in phosphates, and this produces excessive algal blooms. Experience of the Veluwerandmeer suggests that remedial measures will take a long time to work, with the results only beginning to show after several years. For more about the dangers of eutrophication on Lake Volkerak/Zoom, I refer you to the article by Van den Hark et al. (1992, this volume).

Another effect of impounding is increased siltation, as we know from the damming of the Haringvliet. Pollutants in rivers tend to adhere to particles of sediment carried in suspension. As a new sedimentation zone, the lake accumulates contaminants in its bottom mud. Readers interested in the details of this danger to Lake Volkerak/Zoom should consult the article by Schmidt and Termeer (1992, this volume).

7 OPERATIONAL WATER MANAGEMENT

The 1988 Water Management Plan Lake Zoom (Anonymus, 1988) defined the operational management of the lakes in more detail. The plan aims for integrated management of all functions of the lake. Within certain guidelines laid down by the Minister, the plan aims to:
- minimize water losses in order to reduce imports of hazardous material;
- create favourable conditions for nature area on and near banks;
- minimize the flood disaster risk;
- maintain low enough chloride levels at abstraction points in the growing season for irrigation water;
- maintain lake stage appropriate to proper drainage and good navigable access to ports;
- operate salt/freshwater separation systems to minimize salt intrusion without impeding shipping.

8 MEASURES

If all the ecological challenges facing Lake Volkerak/Zoom are to be met, we must ensure that water entering the lake poses no threat. Pollution has to be tackled at source.

International agreements, such as the Rhine Action Plan or the North Sea Action Plan, help to clean up the drainage basins of the Rhine and the Meuse. But "pollution at source" measures alone are not enough for Lake Volkerak/Zoom. Direct intervention is necessary as well. Measures are now being drawn up and implemented in West-Brabant catchments specifically to protect the new lake. Readers are referred to the article of Van Oers et al. (1992, this volume) for details. Rijkswaterstaat is also experimenting with a biofilter to treat water from the Hollandsch Diep as it enters the lake at the Volkerak Locks. The results are described in the article by Noordhuis et al. (1992, this volume).

Water treatment is time-consuming, however. Consequently we try to keep the lake hydraulically insulated from its surroundings, so that water loss is minimized and influx of polluted water reduced. Behrens (1992, this volume) discusses ways of sealing off the lake and the results so far.

We are now using a systematic approach to steer aquatic populations in the right direction, so that Lake Volkerak/Zoom does not end up as a murky green lake. Key concepts here are fish stocks and habitat development. For these subjects respectively I refer to the articles by Ligtvoet and Grimm (1992, this volume) and Iedema et al. (1992, this volume).

9 EVALUATING WATER MANAGEMENT

This collection of papers presents the results of an evaluation of water-management practice over the three or more years since the conversion to a freshwater lake. The key question is whether water management has been able to deal with the changes in Lake Volkerak/Zoom and achieve the goals of management policy.

This resolves into three specific questions:
- are current management practices adequate for the ecological health and proper functioning of Lake Volkerak/Zoom in the future?
- do current management practices meet the needs of all the functions for which the lake is designed?
- what else must we do to achieve sustainable development?

In the concluding article Turkstra and Saeijs (1992, this volume) will look at these questions in the light of our present experience and understanding of the lake water system.

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FROM MERELY SUPPLYING WATER TO INTEGRATED WATER MANAGEMENT

H.W.A. Behrens

1 INTRODUCTION

Lake Volkerak/Zoom, originated in 1987, really consists of two lakes, Lake Volkerak (Volkerakmeer) in the north and Lake Zoom (Zoommeer) in the south, both connected by the canal 'Eendracht'. Lake Volkerak is in the north connected to the Hollandsch Diep by the Volkerak intake sluices and shipping locks. Via these sluices fresh water from the Rhine and Meuse can flow into Lake Volkerak. In the west Lake Volkerak is connected to the salt waters Eastern Scheldt (Oosterschelde) by the Krammer locks. Lake Zoom is separated from the Eastern Scheldt by the Oysterdam (Oesterdam). The Bergse Diep lock is located in this dam. In the south the Kreekrak locks form the shipping connection with the brackish Antwerp harbour basin. Next to these locks is a discharge canal to Bath (Spuikanaal Bath), where excess water can be discharged into the Western Scheldt (Westerschelde).

The water management of Lake Volkerak/Zoom is on the one hand determined by user demands and ecological aims, which together are interpreted into management targets, and on the other hand by the possibilities of supply and discharge of water and by the storage capacity in the system. Not so long ago the quantity control determined how the water management was regulated. Hence it was stipulated that a certain amount of water was required for the water-level preservation and salt reduction. The harmful effect of the connected loads of pollutants was recognised, but that was a problem ecologists had to solve. Nowadays there is a more integrated approach. Because the load of polluting materials is the product of discharge and concentration, it is examined from a viewpoint of quantity control what possibilities exist as to limiting this load by reducing the inflow via the Volkerak intake sluices and what the effects would be on the water management.

In this article a concise evaluation is given of the applied water management. It also describes the possibilities for further optimization.

2 MANAGEMENT TARGETS

In 1987 the most important targets for water management were:

- Rapid desalination so that agriculture can have fresh water at its disposal from the beginning of the 1988 growing-season;
- For water-level control the level aimed at is NAP (Normaal Amsterdams Peil, the reference level in the Netherlands). Deviations ranging from NAP + 0.05 m to NAP - 0.25 m are permitted incidentally. The purpose of these level margins is that, when it is expected that through circumstances the water cannot be temporarily let in, the water storage from this basin can be used so that the temporary inlet flow can be stopped - the so called selection inlet. This might occur in the event of large discharges from the river Rhine with large concentrations of suspended solids or in the event of calamities. This procedure is called selective letting-in;
- The chloride concentration should not exceed 400 mg/l during the growing-season. The mouth of the discharge canal to Bath had been qualified as a measuring point for the chloride concentration. In the event of this concentration being imminently exceeded, flushing has to be carried out at the maximum rate of 22.5 m^3/s;
- At the Krammer locks the separation system for salt/fresh water had to be controlled in a way that fresh water would be recovered in periods of water shortage only, thus accepting some larger salt intrusion;
- In order to limit the load of pollutants from the rivers Rhine and Meuse as much as possible, it is also aimed at minimizing the water intake flow rate via the Volkerak intake sluices.

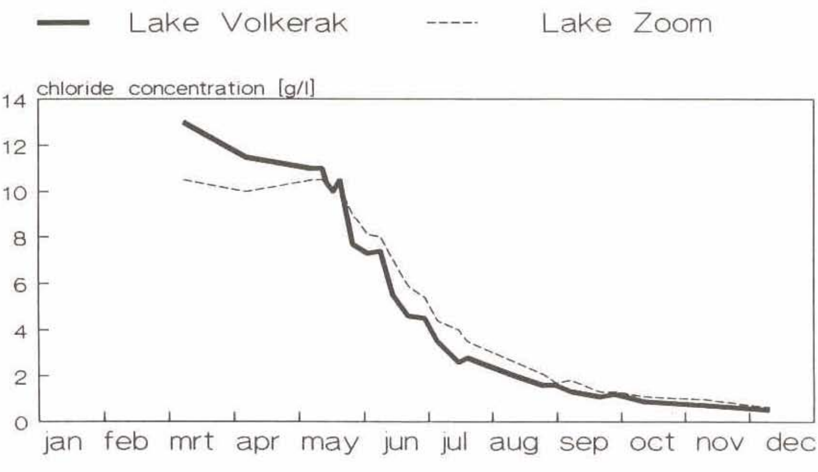


Figure 1 The desalination in 1987

One of the questions arising now, at the evaluation of the water management, is what has become of these management targets. Based on the experience gained until now, the following conclusions can be drawn:

- The rapid desalination has been realized, as Figure 1 shows. At the beginning of 1988 Lake Volkerak/Zoom was a freshwater lake. The chloride concentration in almost the entire lake was less than 400 mg/l;

Exceptions to this were some deep underwater pits which still contained salt water at greater depths. After the desalination period the boundary plane between salt- and fresh water in these pits had lowered systematically. Since the beginning of 1990, after a storm, the water in the pit near the Krammer locks has changed entirely into fresh water;

- The water level can easily be maintained close to NAP;
- The possibility of limiting the inflow of water via the Volkerak intake sluices by means of selective letting-in has hardly been used. In periods of greater discharges from the river Rhine the amount of water required by Lake Volkerak/Zoom appeared to be so modest that there was no need for a water intake.
  The supply via the Volkerak intake sluices was obstructed due to calamities for only a few days during the complete evaluation period. None of these obstructions lasted long enough to reach the lower water level limit;
- Because water from Lake Zoom had not been extracted yet for agricultural purposes, the measuring point for flushing had been temporarily moved from the mouth of the discharge canal to Bath to the southern mouth of the Eendracht. As long as no water was being extracted for agricultural purposes, it was not necessary to maintain the chloride concentration in Lake Zoom - which is correlated with the salt load via the Bergse Diep lock - below the limit value. Because of this, considerably less water was required for flushing, so that on a yearly basis 4 m^3/s less water could be let in via the Volkerak intake sluices;
- As part of optimizing the separation system for salt/fresh water at the Krammer locks, water has always been partly recovered. It is true this involved a slightly higher chloride concentration in Lake Volkerak, but on the other hand the loss of water via these locks could be limited considerably. It also turned out that the chloride load via this complex was considerably less than originally assumed.

3 WATER BALANCE

The water balance of Lake Volkerak/Zoom in the past few years is shown in Table 1. It is striking that only a few items are really important. For the supply these are the Volkerak intake sluices and the river Dintel. Naturally the Dintel runoff cannot be influenced, but the inflow via the Volkerak intake sluices on the other hand can be directly controlled according to the management targets. Load reduction by reducing the inflow can only be achieved here.

For the outflow the Krammer locks, the Kreekrak locks and the discharge sluice Bath are the most important balance items.

The fact that a smaller inflow via the Volkerak intake sluices is possible, can be illustrated by the following figures:
In 1985 it was assumed that the needed inflow via the Volkerak intake sluices and shipping locks would be 35.8 m^3/s. In 1987 this had already been reduced to 22 m^3/s. (Both inflows excluding the amounts of water required for flushing). Because of all the measures taken already, the inflow of water via the Volkerak intake sluices has been reduced to less than 10 m^3/s on a yearly basis in a dry year, with a total inflow to Lake Volkerak/Zoom of 20 to 25 m^3/s.

4 POSSIBILITIES FOR REDUCTION OF THE INFLOW

Because further limitation of the inflow of water via the Volkerak intake sluices is desired, there are basically three possibilities of realizing this:

- The outflow from Lake Volkerak/Zoom can be minimized, so that less water has to be supplemented;
- Flushing can be limited;
- The storage capacity in the system can be used.

4.1 Outflow restriction

The possibilities of minimizing the outflow exist especially at the shipping locks. (See Table 1)

Table 1 The water balances of Lake Volkerak/Zoom in m^3/s

	1988	1989	1990	1991
IN				
Precipitation - evaporation	1.0	- 0.1	0.1	0.2
Discharge Volkerak locks	2.5	2.5	2.5	2.5
Inlet Volkerak sluices	8.9	7.5	9.6	9.0
Discharge river Dintel	18.0	7.4	6.1	7.9
Discharge river Vliet	0.7	0.3	0.1	0.3
Discharge river Zoom	0.5	0.3	0.3	0.3
Discharge polders	5.2	2.4	2.8	2.7
Seapage	0.1	0.1	0.1	0.1
Total in	36.9	20.4	21.6	23.0
OUT				
Discharge via Bath	22.0	7.3	11.7	13.5
Krammer- and Kreekrak locks	15.1	16.1	11.4	10.3
Agricultural purposes	0.0	0.0	0.0	0.0
Infiltration	0.1	0.1	0.1	0.1
Total out	37.2	23.5	23.2	23.9

By limited recovery of fresh water at the Krammer locks the loss of water has almost been halved to 8 m^3/s. A further reduction will be accompanied by such an increased load of salt, that the chloride concentration at the northern mouth of the Eendracht in Lake Volkerak will increase, demanding a greater flushing flow. At the Kreekrak locks the discharge via the separation system for salt/fresh water has been reduced even more, up to 33% or some 4 m^3/s, without causing an objectionable salt load. For technical reasons a further reduction is impossible with the current facilities, whereas here also a further reduction of the discharge would result in an undesirable salt load on Lake Zoom. The flushing flow via Bath is necessary to maintain the water level and can therefore not be influenced. In this way the possibilities of reducing the outflow have been fully used.

As a result of the expected increased extractions for agricultural purposes, the inflow to Lake Volkerak/Zoom will increase in the future by a volume which almost equals the quantity extracted for agricultural purposes.

4.2 Limitation of flushing

To limit the flushing there are basically two possibilities:
- Limitation of the salt loads on Lake Volkerak/Zoom;
- Acceptation of larger chloride concentrations in Lake Volkerak/Zoom.

For the limitation of the salt loads, the chloride concentration in Lake Volkerak/Zoom will be examined first. This is shown in Figure 2. Lake Zoom has higher concentrations, while directly north of this lake there is a strong gradient. Higher concentrations are also found near the Krammer locks. This means that the largest sources of salt intrusion can be found at the Krammer locks and the Bergse Diep lock. At the Krammer locks the separating system for salt and fresh water has already been optimized, so that a further reduction of the salt load cannot be realized. A different situation exists at the Bergse Diep lock. No measures to reduce the salt load have been carried out here. With each lockage the entire lock filling of salt water flows into Lake Zoom. Meanwhile it has been decided to provide the Bergse Diep lock with a separating system for salt and fresh water. This system will be operational next year, before the growing-season.

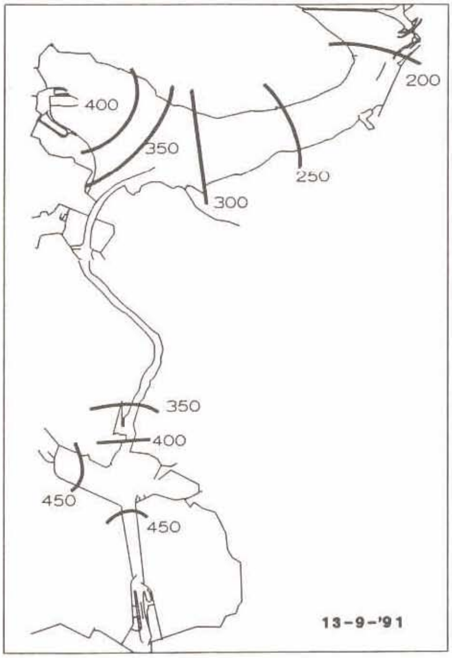


Figure 2 The chloride concentrations in Lake Volkerak/Zoom (mg/l)

Other sources of salt, for instance from polder discharges, are small and hard to influence. The only method to reduce these loads is to move these polder discharges outside Lake Volkerak/Zoom.

The second possibility of limiting the flushing is to accept higher chloride concentrations. Actually this method has been used in the past few years by moving the measuring point for flushing. Because this year water will be extracted from the discharge canal to Bath for agricultural use, the moving of the measuring point has been reversed.

For the measure of limiting the flushing, apart from the current control, two alternatives have been examined, namely:
- Flushing only in the event that the maximum chloride concentration of 450 mg/l is exceeded at the mouth of the discharge canal to Bath;
- No flushing at all.

4.3 Making use of the storage capacity

The third measure to limit the inflow is to use the storage capacity in Lake Volkerak/Zoom. By maintaining the target water level, the excess amounts of water have to be discharged as quickly as possible. If the excess amounts of water can be temporarily stored in the system, this water can be used later in a period of water shortage.

Summarizing, the possibilities shown in Table 2 have been examined for a reduction of the inflow.

Table 2 Examined alternatives for the water management

	FLUSHING		
LEVEL	400 mg/l	450 mg/l	no flushing
target level = NAP	+	+	+
NAP + 15 cm/ - 25 cm	+	+	+

5 EFFECTS

The various possibilities of limiting the inflow of course have intended as well as side effects.

All the effects shown here result from scenario calculations. Data were taken for a wet year 1988 and a dry year 1989. Based on these years the boundary conditions were drawn up and the management of the different control alternatives simulated. The advantage of this operating procedure is that the results are properly comparable with each other. One must consider that in practice somewhat different boundary conditions will occur than the values represented here.

As a reference for showing the effects, the situation which can be expected from next year on has been assumed on the basis of the present management. This situation is:
- A maximum chloride concentration of 400 mg/l at the mouth of the discharge canal to Bath during the growing-season;
- Target level at NAP;
- Measures to limit the outflow from Lake Volkerak/Zoom which have already been realized at present;
- The system limitating the salt load at the Bergse Diep sluice is in operation. In the calculations for this system a limitation of the salt load of 50% has been assumed; in practice a reduction of 70% is expected;
- Extractions for agricultural purposes, distributed over Lake Volkerak/Zoom, with a total volume of 5 m^3/s during the growing-season.

5.1 Water levels

Figure 3 shows how the water level develops in a wet and in a dry year when the control is effected at level margins of NAP + 15 cm and NAP - 25 cm, which is a difference of 40 cm. In a wet or a dry year the level only differs at times at which the level rises or falls. In both summers the water level would have been low and in both winters high. The resulting water level corresponds with the natural course and is favourable for the development of the banks.

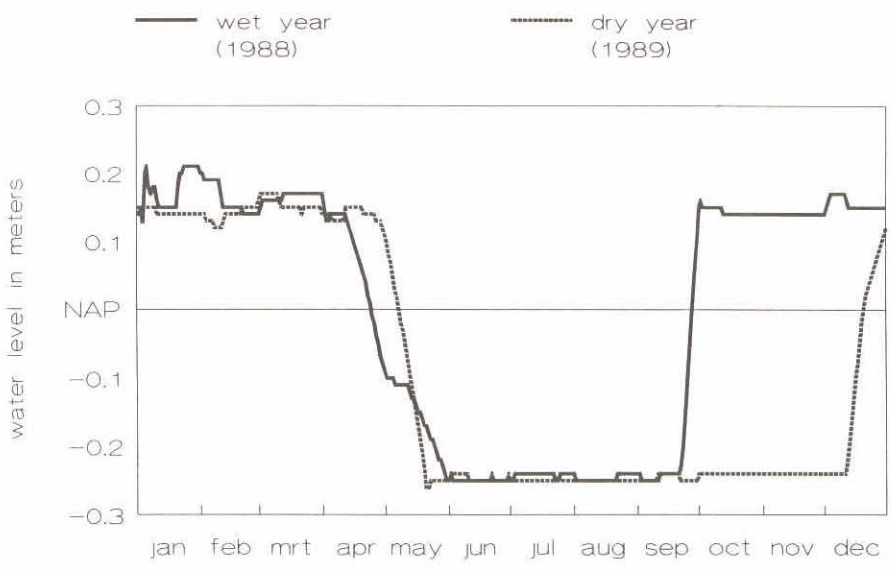


Figure 3 The water level if the control is effected at level margins of NAP + 15 cm and NAP - 25 cm

5.2 Chloride concentrations

In the reference situation the chloride concentrations will develop according to the bottom line in Figure 4. Obviously the concentrations vary in the course of the year. In this article the highest calculated concentrations are given for a dry year, during the growing-season which runs from the beginning of April till the end of September. Both other lines in Figure 4 show the comparable chloride development, if flushing would be carried out according to the criterium of 450 mg/l at the mouth of the discharge canal to Bath and in the event that there would be no flushing at all.

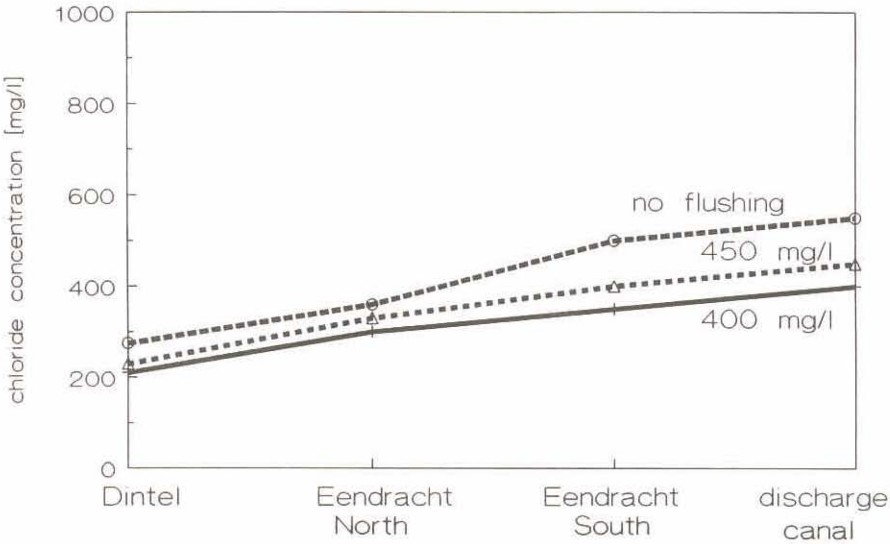


Figure 4 The chloride concentration at the different alternatives for flushing

These flushing variations show the highest increases of the chloride concentrations in Lake Zoom; the effect on Lake Volkerak is obviously less. Level variation appears to have only a marginal effect on the chloride concentrations; therefore these are not shown. Of course it is important which effect a combination of these two measures has on the chloride concentrations in Lake Volkerak/Zoom. This combined effect is shown in Figure 5. The lower line matches the reference situation, the middle line shows the concentrations for a flushing control aimed at a chloride concentration of 450 mg/l near the mouth of the discharge canal to Bath and with 40 cm difference in level. The upper line matches the 40 cm difference in level and no flushing at all.

A combination of not flushing and a difference in level of 40 cm shows here definitely higher concentrations than not flushing at a fixed level does (the upper line in Figure 4).

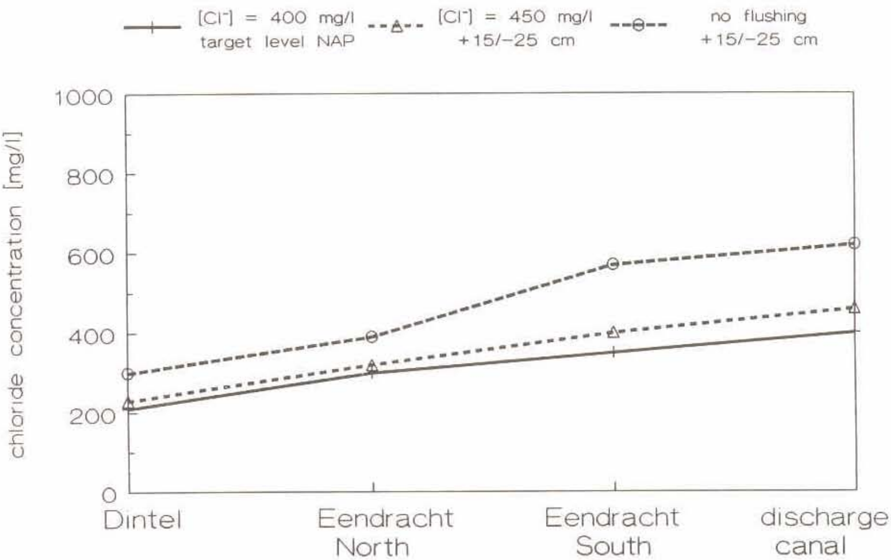


Figure 5 The chloride concentration at the different alternatives for the water management

5.3 Inflows

The inflows via the Volkerak intake sluices, expected from the control variations examined, are mentioned in Table 3. The reference situation shows an inflow via the Volkerak intake sluices of 7.9 and 13.1 m^3/s in a wet year and a dry one respectively. This discharge is higher than in the present situation. The reason is that reversing the measuring point for flushing to the mouth of the discharge canal to Bath, combined with the extractions for agricultural purposes, requires a somewhat larger amount of water than saved by reducing the salt load in the Bergse Diep lock.

Table 3 Inflow in m^3/s via the Volkerak intake sluices with the different alternatives for the water management

	Maximum chloride concentration				no flushing	
	400		450			
	dry	wet	dry	wet	dry	wet
Target level = NAP	13.1	7.9	9.7	6.8	5.7	4.6
Level margin 40 cm	12.4	6.6	9.0	4.2	4.0	0.9

The limitation of the flushing shows a smaller inflow, as may be expected. The more the flushing is limited, the larger is the reduction of the inflow.

Using the storage capacity by using the level margins of NAP + 15 cm and NAP - 25 cm has only a limited effect when the maximum chloride concentration is 400 mg/l. This is caused by the fact that even though less water is required for the level control the effect is that also less water is discharged via Bath which also results in less chloride being discharged.

Nevertheless, in order to meet the chloride standard, more water has to be flushed. However, the extra flushing flow required is indeed smaller than the amount of water saved by the level control.

If the chloride standard for flushing is increased to 450 mg/l the saving becomes somewhat greater.

Using the storage capacity has the greatest effect with no flushing at all.

6 CONCLUSIONS

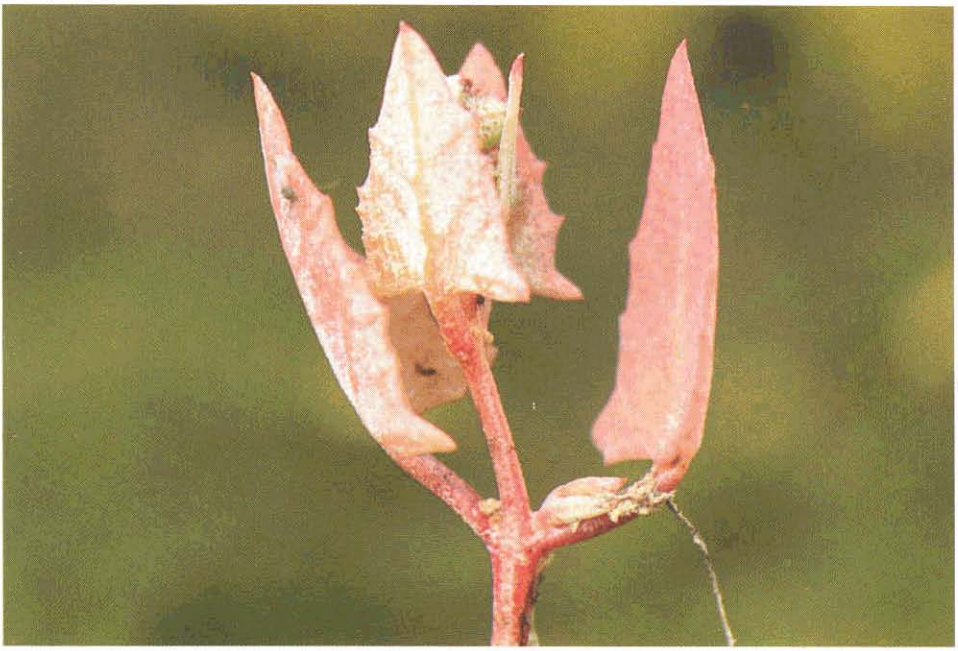
The water management aimed at the smallest possible inflow of water via the Volkerak intake sluices has been successful. When the Bergse Diep lock will be provided with a system for limiting the salt load, then within the current management targets all possibilities to reduce the inflow have been used.

Only when the management targets are adjusted a further reduction of the inflow is possible. The largest reduction of the inflow is realized, although limited at a level variation combined with the acceptation of higher chloride concentrations.

REFERENCE

BEHRENS, H.W.A., B.S. JANSEN; 1992. Rapportage scenario-berekeningen waterkwantiteit Volkerak/Zoommeer, RIZA, nota 92.001.

When tide disappears, erosion begins



Pioneer (*Atriplex prostrata*) on brackish soils

Salt marsh plants disappear slowly from the formal tidal flats

Mouth of the river Steenbergse Vliet

How an estuary changed into a freshwater lake. (Proceedings of the technical meeting held in Roosendaal, The Netherlands, 4 June 1992). Proceedings and Information, CHO-TNO, no. 46, 1992.

CHEMICALS HANG OVER LAKE VOLKERAK/ZOOM
Pollution by, processes and effects of micro-pollutants in Lake Volkerak/Zoom

C.A. Schmidt and K. Termeer

1 INTRODUCTION

Lake Volkerak/Zoom was formed by the closing of the Philipsdam in 1987. An arm of the sea was transformed into a freshwater lake. Figure 1 shows the location of the dams and sluices of the lake. From that moment the condition of the lake was thoroughly monitored. This article describes the history, the situation in 1987, the development in the first four years of its existance and the expectations of development in the field of pollution with xenobiotics.

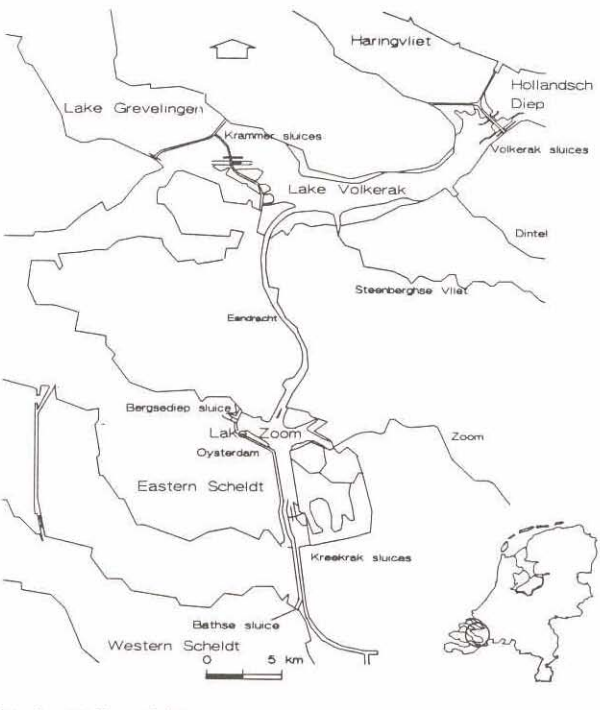


Figure 1 Map of Lake Volkerak/Zoom

1.1 Construction of Lake Volkerak/Zoom

Before the construction of the Philipsdam and Volkerakdam the area, which is now called Lake Volkerak/Zoom, was part of the delta of the rivers Rhine and Meuse. A strong tidal current was present.

By the closure of the Volkerakdam in 1969 the flow was strongly reduced, but vertical tidal movement increased because of damming up. The closure of the Philipsdam seventeen years later finally completed the compartmentalization of the Delta. 100 square kilometers of sea were converted into a stagnant freshwater lake with an average depth of 5.2 meter and with shallow and deeper areas reflecting the former tidal gully system. The northern part was called Lake Volkerak and the southern smaller part Lake Zoom. Both were connected by a canal called the 'Eendracht'.

The main functions of the lake are to supply fresh water for agricultural purposes and as an important connection between the rivers Rhine and Scheldt for commercial shipping.

strong current
tidal movement

1969 closure Volkerakdam
low current
strong vertical tidal movement

1987 closure Philipsdam
semi-stagnant fresh-water lake

1.2 Main sources of water and suspended solids

The lowland river Dintel discharges in Lake Volkerak. The flow of this river is strongly depending on rainfall.

By sluicing, water from the Hollandsch Diep, which receives water from the Rhine and Meuse, enters Lake Volkerak. To compensate for salt intrusion from the south (Western Scheldt), extra water from the Hollandsch Diep is taken in via the Volkerak sluices. The flow through these sluices in the period 1971-1991 is given in Figure 2.

With the incoming water dissolved micro-pollutants and fluvial sediments, which carry micro-pollutants, are imported.

The pollution of the Rhine and Meuse reached its maximum in the early seventies and thereafter decreased gradually. Figure 3 shows the cadmium concentration in the Hollandsch Diep, the Rhine and the Meuse[1]. Sampling point of the Rhine and Meuse are located at the borders with respectively Germany and Belgium. The total concentration of

1) The choice of micro-pollutants presented in the figures is based on representativeness. A detailed discussion and a presentation of changes in levels of all the micro-pollutants are beyond the scope of this paper.

micro-pollutants in the Hollandsch Diep is always lower than in the Rhine and Meuse due to sedimentation of polluted suspended solids in the upstream areas. Nevertheless concentrations in the Hollandsch Diep water still do not meet the required general environmental quality standard in the Netherlands: AMK (Algemene Milieu Kwaliteit).

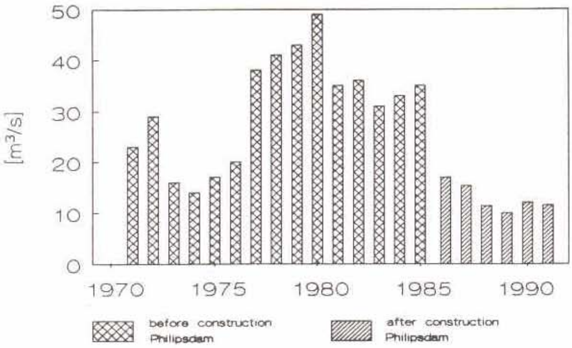


Figure 2 Flow through Volkerak sluices 1971-1991

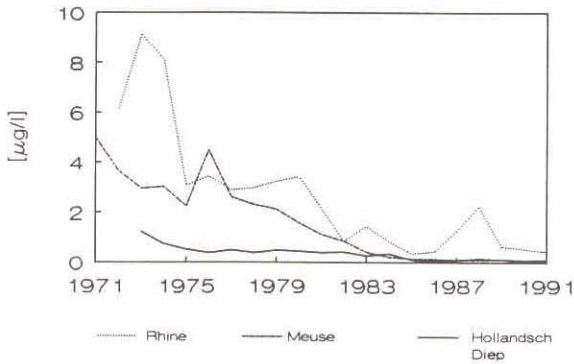


Figure 3 Concentration of cadmium in Rhine, Meuse and Hollandsch Diep

1.3 Sedimentation of solids polluted with xenobiotics

Assuming that the water quality development of the Dintel has been the same as of the larger rivers, large quantities of micro-pollutants were discharged into the Volkerak. Before 1987 the inflowing water mixed with sea water and drained off to the North Sea. As a result of the lower velocities and the tidal movement in the Volkerak a part of the suspended solids settled down mainly at the mudflats. Because of the reduction of water velocity after 1969 settlement also took place in deeper gullies. Suspended solids consisted of a mixture of strongly polluted fluvial suspended solids and relatively unpolluted marine suspended solids. When finally in 1987 the Philipsdam was closed, the tidal system had changed into a semi-stagnant freshwater lake already affected by the pollution of the rivers Rhine, Meuse and Dintel.

1.4 Pollution of former sedimentation areas

In 1987 most of the mudflats converted into lake shore lands. These former sedimentation areas appeared to be polluted with heavy metals and PAH's. The degree of pollution of the former sedimentation areas is given in Figure 4. In the Northeast the 'Hellegatsplaten' and the 'Ooltgensplaat' are polluted. Even the 'Dintelse Gorzen' and the 'Slikken van de Heen' are affected by the Dintel, Rhine and Meuse pollution. The 'Krammerse slikken' and the 'Prinsesseplaat' in Lake Zoom are free of pollutants.

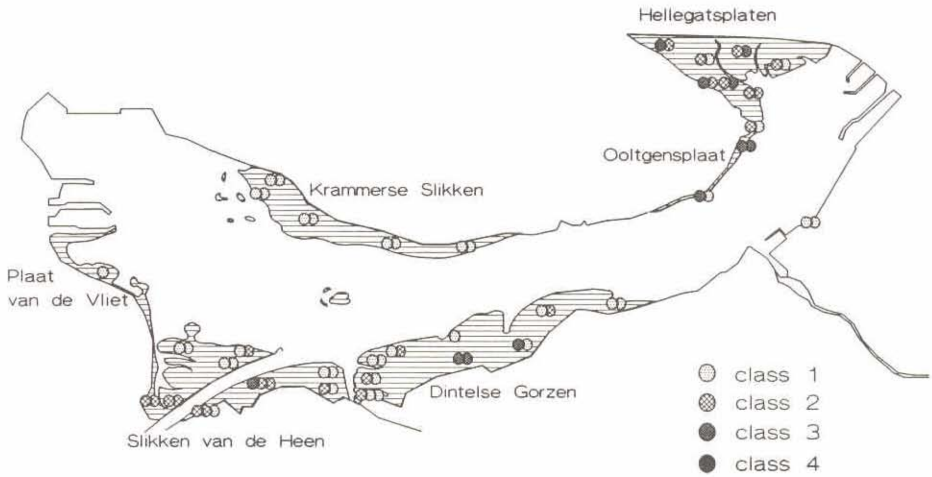


Figure 4 Pollution of the lake shore lands (Vink, 1992)

Not only the shore lands were polluted but also the lake-bed sediments. The main pollutants are PCB's and PAH's, but in the Northeast also pollution by lindane and mercury occured.

For most micro-pollutants a gradient in the concentrations is present. Figure 5 e.g. shows the concentration of mercury in the bottom sediments[1)].

In the Netherlands the grade of pollution is classified into several categories. In Figure 6 the classification is shown.

1) Because the biological availability of micro-pollutants depends on the sorption capacity and therefore on the granular consistency and content of organic material, national quality standards for micro-pollutants are defined as concentrations in sediment with a standard granular consistency (25% < 16μm) and a standard content of organic material (10%OM). To compare field concentrations with quality standards the absolute measured concentrations have to be converted to equivalent concentrations in this standard sediment.

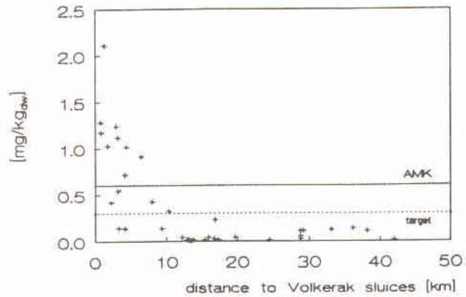


Figure 5 Gradient of mercury in bottom sediments

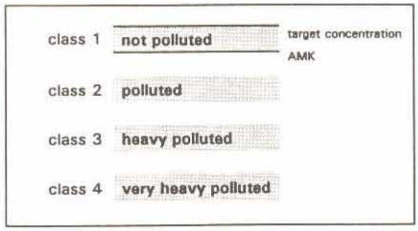


Figure 6 Classification of the grade of pollution

2 CHANGES SINCE 1987

Since 1987 the water quality of Lake Volkerak/Zoom is determined by the discharge of micro-pollutants of the Dintel and the Hollandsch Diep, atmospheric deposition and shipping. The load of micro-pollutants from the Dintel and Hollandsch Diep is determined by the concentration of micro-pollutants and the water quantity.

2.1 Water management

In 1987 and the first part of 1988 the intake of water from the Hollandsch Diep was high in order to achieve quick desalination. The water quality was still bad. When desalination was achieved, the policy in water management was to take in as little water as possible needed to achieve a maximum salt concentration in Lake Zoom of 400 mg Cl^-/l. Hereby the forecasted discharge of the Dintel is taken into account.

Rainfall was both in 1988 and 1989 below average. Therefore the intake of water from the Hollandsch Diep has been relatively high compared to years with average rainfall.

2.2 Relative contribution to the total load of micro-pollutants of Dintel and Hollandsch Diep

The load of cadmium and PAH's from Dintel and Hollandsch Diep are presented in Figure 7. The strong decline in contribution and load of the Dintel is both a result of low discharges and of decreasing concentrations. The decreased load from the Hollandsch Diep is a result of a restricted inflow and of an improved water quality.

2.3 Concentration of micro-pollutants

A quality improvement of both Dintel and Hollandsch Diep is observed for arsenicum, cadmium, chromium, copper, lead, PCB-153 as well as most PAH's. Figure 8 shows the

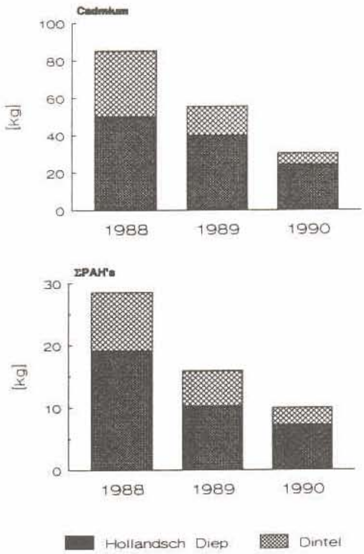


Figure 7 Load of micro-pollutants by Dintel and Hollandsch Diep

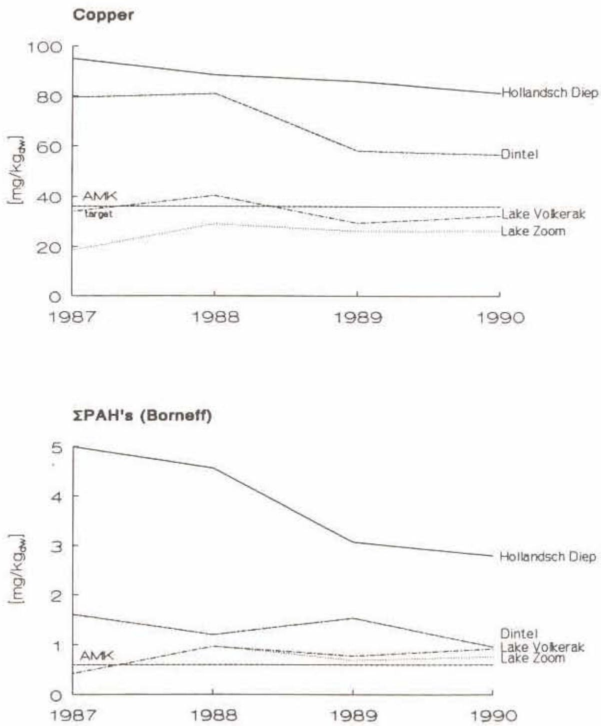


Figure 8 Copper and ΣPAH's in suspended solids in Dintel, Hollandsch Diep, Lake Volkerak and Lake Zoom

yearly average concentration of copper and ΣPAH's[1] in suspended solids in the Dintel and the Hollandsch Diep. Except for arsenicum and nickel, all micro-pollutants are found in lower concentrations in the Dintel compared to the Hollandsch Diep.

The limits of the National Water Quality standard (AMK) are regularly exceeded on a large scale. In 1990 the concentrations of copper, PAH's, BHC and most of the pesticides in the Hollandsch Diep were extremely high. In the Dintel this occurred for nickel, benzo(b)fluoranthene, PCB-28 and ΣDDT[2].

Because Lake Volkerak/Zoom is fed with water from the Dintel and Hollandsch Diep the concentrations in these waters affect the concentrations in Lake Volkerak/Zoom. Also concentrations of copper and ΣPAH's in the lake are shown in Figure 8. The difference between the low quality of suspended solids in the Dintel and Hollandsch Diep and the relatively high quality of suspended solids in Lake Volkerak/Zoom is a result of sedimentation and mixing with less polluted sediments eroded from the lake banks. This process will be discussed later in this article.

2.4 Pesticides

No declining concentrations of micro-pollutants are detected for pesticides like lindane and DDT. Concentrations in the Dintel and the Hollandsch Diep are continuously exceeding the AMK limits. Figure 9 shows the concentration of DDT in suspended solids in Lake Volkerak/Zoom. Alarming is the increased concentration in 1990 compared to 1988 and 1989. At the end of 1988 an extremely high concentration of DDT was found in Lake Volkerak and Lake Zoom. Apparently an illegal spillage had taken place or polluted sediment in an upstream area was scoured during a period of high water velocity and was carried along into the lake. In the Hollandsch Diep the peak was also observed, but no peak occurred in the Dintel.

Also a group of pesticides called cholinesterase-inhibitors (e.g. parathion) in the Dintel and the Hollandsch Diep are detected in concentrations exceeding the AMK limit. These concentrations can have toxic effects on insects, in particular on water fleas. In Lake Volkerak/Zoom the AMK limit is exceeded infrequently. The protection of water fleas in Lake Volkerak/Zoom is crucial, because they are the main grazers on algae and therefore keep the water clear.

2.5 Atmospheric deposition

In a highly industrialized area as the Netherlands atmospheric deposition is an important source of micro-pollutants. The contribution of atmospheric deposition to the total load of micro-pollutants in Lake Volkerak/Zoom is relatively high because of the extended surface compared to the total volume and the small flow through the system. Figure 10 shows the contribution of atmospheric deposition to the total load of micro-pollutants. In particular the load of lead, mercury, PAH's, PCB's, DDT and lindane by atmospheric deposition is considerable.

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1) ΣPAH's: sum of benoz(g,h,i)perylene, benzo(a)pyrene, indeno(1,2,3,c,d)pyrene, benzo(b)fluoranthene, benzo(k)fluoranthene, and fluoranthen.

2) ΣDDT: sum of 2,4-DDT, 4,4-DDT, 4,4-DDE and 4,4-DDD

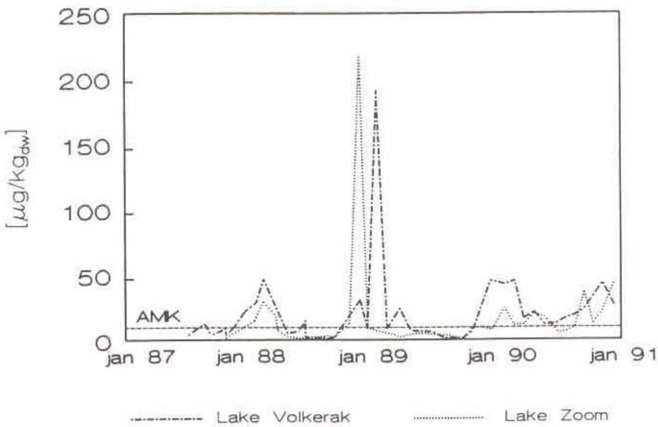

Figure 9 DDT in suspended solids in Lake Volkerak and Lake Zoom

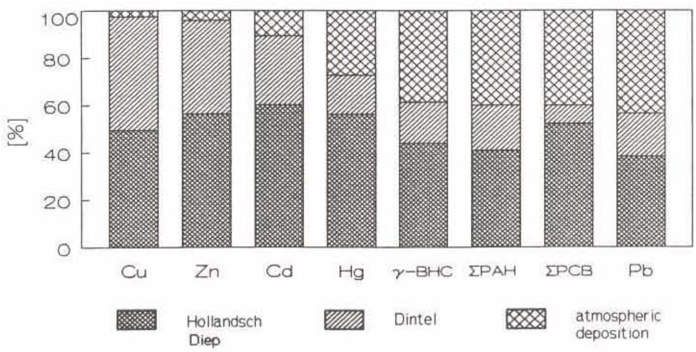

Figure 10 Relative contribution to the total load of micro-pollutants

2.6 Quality of the sediment

The history of the lake before 1987 and the import of micro-pollutants from the three main sources since 1987 has resulted in polluted bottom sediments. Figure 11 shows the present situation. The pollution is relatively strong in the eastern part of Lake Volkerak. In the western part and in Lake Zoom the pollution is not yet alarming.

Apart from atmospheric deposition and pollution by the Dintel and Hollandsch Diep, commercial shipping is an important source of PAH's, which can be the main cause of the pollution with PAH's of the bottom sediments in Lake Zoom.

Almost all locations in Lake Volkerak/Zoom are polluted with PAH's and PCB's. High concentrations of PCB's and DDT were found in the area near the Volkerak sluices.

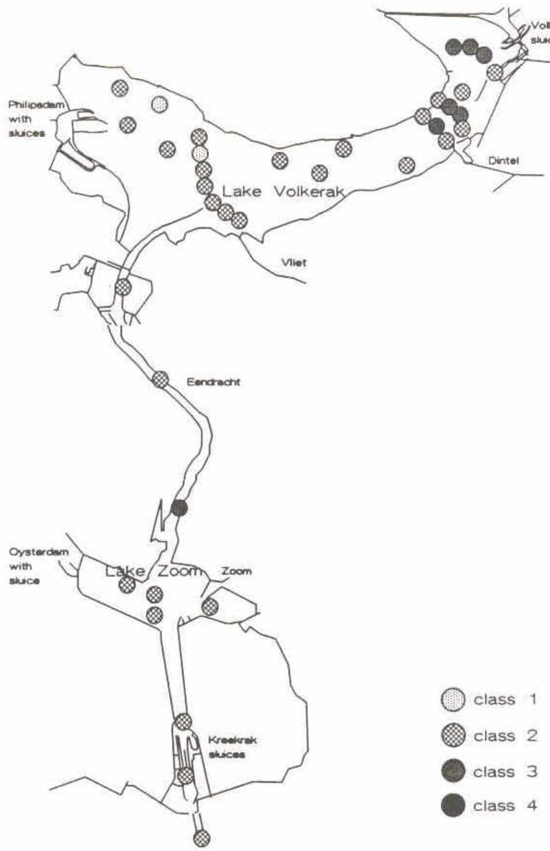

Figure 11 Quality of the bottom sediments in Lake Volkerak/Zoom

2.7 Erosion of the lake banks

As already mentioned the bottom sediment quality of the lake has not changed significantly, because of the mixing with sediments eroded from the lake banks. In 1987 the constant water level in the lake constricted the wave attack to a narrow zone. The sediment layers in this zone could not resist this, especially not during severe storms. As a result erosion of the banks has taken place on a large scale. In the last four years about 100 ha of shore land degenerated into a shallow part of the lake. The largest granular fraction of the eroded material settled in the nearby shallow water zone. The smallest granular parts were transported to the deeper zones of the lake.

Compared to the amount of material due to this shore erosion, the input of suspended solids from the Dintel and Hollandsch Diep is still small. Figure 12 compares the quantity of eroded material and the input of suspended solids by the rivers Dintel and Hollandsch Diep.

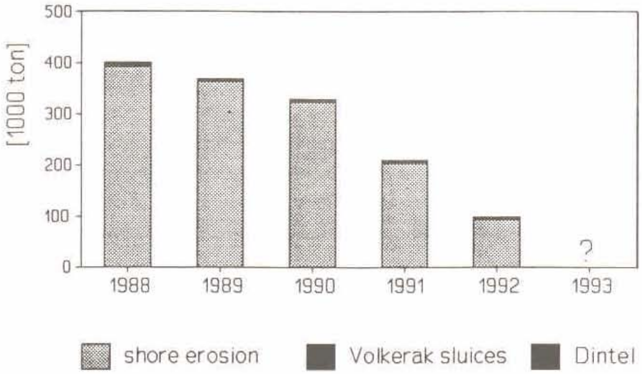

Figure 12 Internal and external load of sediments in Lake Volkerak/Zoom

After the completion of the shoreline protection dams in the near future, the banks will be well protected against erosion. In 1995 the quality of the bottom sediments will be largely depending on the quality of the suspended solids imported from the Hollandsch Diep, the Dintel, and on atmospheric deposition and shipping emmission.

2.8 Ecotoxicological research

Since 1987 research has been carried out to obtain an impression of potential effects of micro-pollutants on organisms in Lake Volkerak/Zoom. This research included the following:
- field surveys of macro-invertebrates;
- field experiments on the accumulation of micro-pollutions by Zebramussels (*Dreissena polymorpha*);
- chemical analyses of different fish species;
- chemical anlayses of eggs of different species of summer birds, which forage on different food sources in or around the lake.

The analyzed species of fish are eel (*Anguila anguila*), smelt (*Osmerus eperlanus*), ruff (*Gymnocephalus cernua*), flounder (*Platichthys flesus*), perch (*Perca fluviatilis*) and pike-perch (*Stizostedion lucioperca*). The investigated summer birds are tufted duck (*Aythya fuligula*), sheldrake (*Tadorna tadorna*), avocet (*Recurvirostra avosetta*), common tern (*Sterna hirundo*) and black-headed gull (*Larus ridibundus*).

2.9 Bio-accumulation

Figure 13 shows as an example the concentration of ΣPCB's (based on fat) in red eel since 1986. In 1987 the concentrations were relatively high as a result of the forced desalination using Rhine and Meuse water. The present concentrations are low and much lower than those found in red eel in the heavy polluted Hollandsch Diep.

The concentration of most micro-pollutants, with the exception of the pesticides DDT and dieldrin, are lower than in Lake IJsselmeer, which is regarded as a lake in the Netherlands with a relatively low level of pollution. The present concentrations are at most 10% of the product standard for fish consumption.

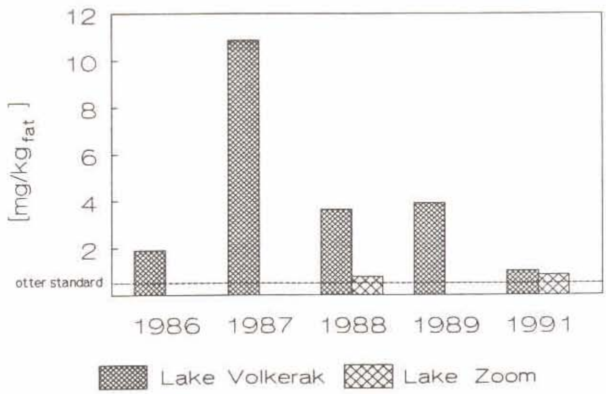

Figure 13 Concentrations of PCB's in red eel

2.10 Ecotoxicological effects

A risk assessment, based on literature study of secondary poisoning of PCB's, showed that tufted ducks can forage on zebramussels without any risk and that common terns and cormorants (*Phalacrocorax carbo*) can forage on red eel without any risk.

Figure 13 shows also the tolerable maximum concentration in red eel by which an otter (*Lutra lutra*) suffers no negative effects on the reproduction. Unfortunately at this moment the concentrations of PCB's in fish are too high for survival of otters.

3 PREDICTIONS OF THE POLLUTION DEVELOPMENT

One of the principal questions in the evaluation of the present water management of Lake Volkerak/Zoom is, what the quality of the lake will be under the present water management and what it will be under different water management alternatives. Predictions of the pollution level for several alternatives and micro-pollutants are made using a water quality model.

The results are that under the present quality of the Dintel and Hollandsch Diep and the present amount of atmospheric deposition the steady-state concentrations of micro-pollutants in the bottom sediments will be approximately identical at all locations in Lake Volkerak. Concentrations of persistent micro-pollutants (e.g. heavy metals) will be almost equal to the concentration of the incoming rivers. Because most organic pollutants evaporate slowly and/or can be bio- or photo-degraded, the steady-state concentration will be lower than in the incoming rivers.

The time needed for the bottom sediments to reach steady-state is related to the relative discharge of the Dintel and the flow through the Volkerak sluices. For the purpose of

water quality modelling the lake is divided into three compartments (Figure 14):
- shallow areas ($d<5$ m) in the north, near to the water inlet points (8 km^2);
- deeper areas in the north ($d>5$ m); now the most polluted (12 km^2);
- Krammer area; the best sediment quality in Lake Volkerak (25.7 km^2).

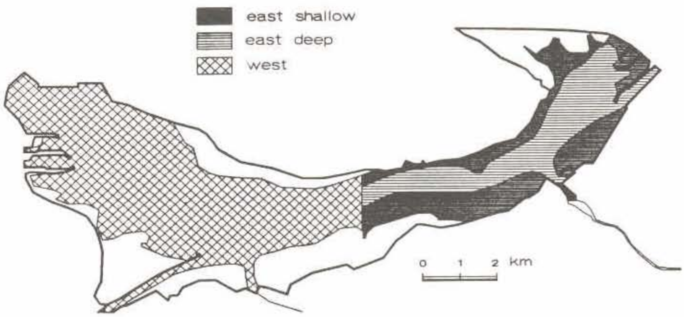

Figure 14 Three zones in Lake Volkerak distinguished for water quality modelling

Figure 15 shows also the time needed for copper to reach steady-state concentration under the present conditions. The present bottom sediment quality in the figure is the average in the compartment in question (field survey 1991). The concentration of copper will increase in each compartment.

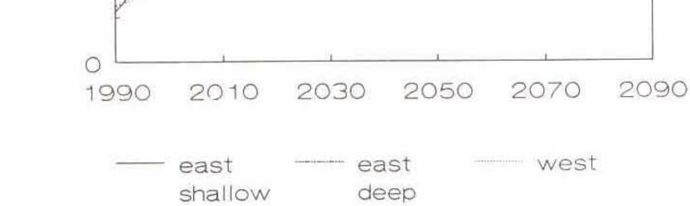

Figure 15 Development of the level of pollution by copper in bottom sediments in Lake Volkerak

For most micro-pollutants the present concentration in the deeper areas in the north of Lake Volkerak is higher than the predicted steady-state concentration, because the quality of recent settled suspended solids is better than in the past. But in the west and in the shallow parts in the northeast of Lake Volkerak the concentrations in the bottom sediments will increase for almost all micro-pollutants.

The predicted steady-state concentrations for several micro-pollutants are given in Table 1, as well as the AMK and the target concentration. The first is defined as the concentration which results in a minimal protection of the ecosystem. The latter takes care of a complete protection of the ecosystem. From the results presented in Table 1 the conclusion can be drawn that the present situation does not guarantee a sustainable growth of the ecosystem.

Table 1 Predicted steady-state concentrations in bottom sediments in Lake Volkerak (standardized)

		predicted	AMK	target concentration
Cadmium	[mg/kg$_{dw}$]	1,7	2	0,8
Copper	[mg/kg$_{dw}$]	57	35	36
Lead	[mg/kg$_{dw}$]	150	530	85
Zinc	[mg/kg$_{dw}$]	600	480	140
PCB-180	[μg/kg$_{dw}$]	9,6	4	4
Benzo(a)pyrene	[μg/kg$_{dw}$]	180	50	25
γ-BHC (lindane)	[μg/kg$_{dw}$]	1	1	0,05

To achieve more protection of the ecosystem, further reduction of the total load is needed. In Table 2 is given the needed reduction percentage for several micro-pollutants.

Table 2 Needed reduction percentage of the load of micro-pollutants to achieve AMK and target concentration in bottom sediments compared to the present load (%)

	AMK	target concentration
Cadmium	0	57
Copper	38	38
Lead	0	87
Zinc	19	75
PCB-180	70	70
Benzo(a)pyrene	75	89
γ-BHC (lindane)	0	83

Considering the measures, which are internationally agreed on in the Rhine Action Plan and North Sea Action Plan, it is to be expected that in 1995 the needed reduction will be partially achieved. For most micro-pollutants a complete protection of the ecosystem will still be out of reach. Additional measures are therefore needed.

4 MEASURES FOR SUSTAINABLE DEVELOPMENT OF LAKE VOLKERAK/ZOOM

Improvement of the water quality of the Dintel and the Hollandsch Diep, a reduction of atmospheric deposition and a reduction of the shipping emission will result in the largest positive effect. Measures to reduce the load of pesticides, PAH's, PCB's, copper, mercury, zinc and cadmium have priority herein.

As long as the quality does not match acceptable concentrations, a reduced intake of water from the Hollandsch Diep is a good interim measure. Another protection measure is a selective use of the sluices, e.g. only intake at times when the suspended solid concentration in the water of the Hollandsch Diep is low.

In the evaluation of the present water management of Lake Volkerak/Zoom several water management alternatives are evaluated. Every alternative is a combination of two types of measures: variation in water level and variation of the maximum tolerated salt-concentration in Lake Zoom. The variations in water level are: NAP (Normaal Amsterdams Peil, the reference level in the Netherlands) and tolerated fluctuations between NAP - 25 cm and NAP +15 cm. The variations of the maximum tolerated salt-concentrations in Lake Zoom are between 400 and 800 mgCl^-/l (Table 3).

Table 3 Three water management alternatives

	water level	C1 concentration
fixed 400	NAP	<400 mg/l
vari 450	NAP +15 cm to - 25 cm	<400 mg/l
vari 800	NAP +15 cm to - 25 cm	<400 mg/l

NAP = Normaal Amsterdams Peil (the reference level in the Netherlands)

Reductions on the total load of three water management alternatives, chosen out of all combinations, are presented in Table 4. The load of micro-pollutants will increase when water management alternative "constant water level and 400 mg Cl^-/l" is implemented, since this alternative will result in an increased inflow of Hollandsch Diep water.

Generally reducing the inlet of Hollandsch Diep water will result in a decreased loading rapidity. The effect of reduced inflow of Hollandsch Diep water will be most positive for micro-pollutants which mainly originate from the Hollandsch Diep. This implies that the reduction will be most substantial for cadmium, chromium, PCB-28, and several PAH's.

Table 4 Incoming load of micro-pollutants compared to the present load for three water management alternatives (%)

	fixed 400	vari 450	vari 800
Cadmium	122	101	78
Copper	132	110	86
Lead	112	100	87
Zinc	132	110	87
PCB-180	117	104	89
Benzo(a)pyrene	120	98	76
Hexachloorbenzene	111	79	46
γ-BHC (lindane)	114	95	74
2,4-DDT	121	94	65

5 CONCLUSIONS

At this moment Lake Volkerak/Zoom is threatened by the water quality of its main water sources and atmospheric deposition. Nevertheless concentrations in the lake are much lower than found in most other waters in the Netherlands. In the last few years it is shown that with restricted water intake the load of micropollutants can be drastically reduced. To prevent Lake Volkerak/Zoom from severe pollution, a significant water quality improvement of the Dintel and Hollandsch Diep and a reduced atmospheric deposition is needed. While this is not achieved the chemical pollution will slowly increase to an unacceptable level, which does not allow sustainable development. This will result in losing a most valuable ecosystem.

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LAKE VOLKERAK/ZOOM, EUTROPHIC AND CLEAR?

M.H.C. van den Hark, J.E.W. de Hoog and C.W. Iedema

1 INTRODUCTION

When Lake Volkerak/Zoom was formed in 1987, expectations were that the new lake would become just as turbid as other freshwater lakes in the Netherlands. After all, the lake is fed with nutritive water from the Rhine and Meuse rivers and with water from the agricultural land of Brabant. Eutrophic substances, phosphate (P) and nitrogen (N), in surface water usually cause excessive growth of algae in Dutch lakes. This can be identified by the brown or green colour of the water; large scale floating layers of algae can also be found.

At the beginning of the eighties, calculations were made to forecast the eutrophic condition of Lake Volkerak/Zoom (Van Eck, 1984). The forecasts for the phosphate concentration in the lake, the transparency and the algal biomass (expressed in mg chlorophyll-α per litre) are given in Table 1.

Table 1 Forecasts before 1986

P level	0.2 - 0.35 mg/l
transparency	1 m
Chlorophyll-α	60 - 100 mg/m^3

Following the desalination in 1987/1988, it soon became obvious that in the first years of its existence Lake Volkerak/Zoom had not become the turbid, eutrophic lake as had been expected. In the summer, transparency can increase up to 5 m, which is unique for freshwater lakes of this size in the Netherlands. This article describes the development of Lake Volkerak/Zoom in the field of eutrophication. Besides a description of what happened in the lake in the period 1988-1990, it deals with minimization of the phosphate load and the expectations for the future with regard to the clarity of the lake.

Topographic and morphometric data on the lake can be found in the article of De Bruijckere (1992, this volume).

2 PHOSPHATE LOAD

Right from the creation of the lake, great attention has been paid to the possibilities of minimizing the phosphate load. In freshwater lakes in this part of the world, phosphate is the natural limiting factor for the growth of algae. The prognosis came out at an annual phosphate load of 16 to 30 g P/m^2/year. To avoid excessive growth of algae, this phosphate load should be reduced to 2 to 4 g P/m^2/year. Nitrogen is not covered in this article, as the chance that nitrogen could be limiting to the algae growth in this lake is negligible and because nitrogen reduction is more difficult to achieve than phosphate reduction.

Measures, with which reduction of the phosphate load can be achieved, are on the one hand a reduction of the phosphate levels in the water of the supply sources, and on the other a reduction in the amount of water to be let in.

The actual phosphate load in the 1988-1990 period is shown in Table 2. Figure 1 shows that the Brabant rivers (68-39%) and the Hollandsch Diep (52-21%) were responsible for the largest percentage of the total load.

Table 2 Phosphate load in 1988-1990

Year Type	1988 wet *)	1989 dry	1990 dry	
Lake Volkerak	478	226	161	ton P/y
	10.4	4.9	3.5	g P/m^2/y
Lake Zoom	212	67	62	ton P/y
	13.4	4.3	3.9	g P/m^2/y

*) in 1988, three months' flushing took place for desalination purposes

Effluent of the Nieuwveer waste water purification plant (200,000 i.e.) was diverted in May 1988 from the Dintel to the Hollandsch Diep. This meant a reduction in the P load of around 230 tons P/year (Anonymus, 1989) as against the original forecasts.

In the 1988-1990 period, the mean phosphate level in the Hollandsch Diep in the summer half of the year (1 April-30 September), the period in which water is let in, had dropped from 0.27 to 0.24 mg P/l (Table 3). After 1989 there was a strong decrease in the phosphate concentration in the Dintel from 0.5 to 0.31 mg P/l. In the Dintel in particular, the decrease in phosphate concentration was the result of a number of consecutive dry years, by which there is less surface runoff and drainage of the agricultural land. This is a temporary situation. Another factor was the effect of emission reduction measures undertaken within the scope of the Rhine Action Plan and the North Sea Action Plan in the drainage area.

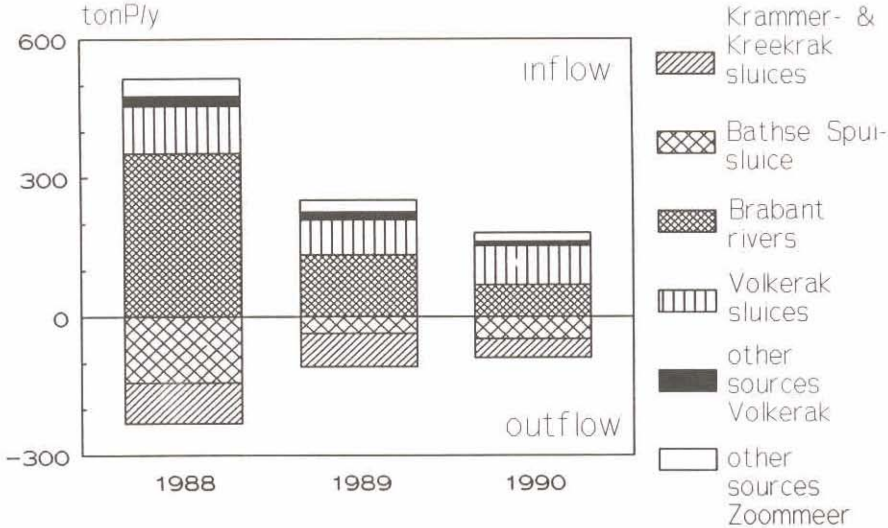

Figure 1 The contribution made by the various items in the supply and discharge of phosphate to and from Lake Volkerak/Zoom in the period between 1988-1990

Table 3 Phosphate concentration in the supplied water in mg P/l

	1988	1989	1990
Hollandsch Diep	0.27	0.25	0.24
Dintel	0.47	0.5	0.31

Further the phosphate load has been strongly reduced by decreasing the inlet via the Volkerak sluices from 22 m^3/s to approximately 10 m^3/s and because the discharge from the Dintel was low in 1989 and 1990 due to the relatively limited rainfall.

2.1 Retention of phosphate

Discharge of phosphate from the lake takes place via the Krammer sluices, the Kreekrak sluices and the Bath drainage canal. More than half of the phosphate load (51-57%) was retained in the lake. This is a high level of retention when compared with other Dutch lakes.

The largest part of the phosphate load arrived during the autumn and winter and settled in the eastern part of the Volkerak, near the water-inlet points. Here the phosphate was stored in the bottom sediments. In the future, this phosphate stored in the sediment might be released and impede the effect of measures taken to reduce phospate load to the lake.

Table 4 Average summer values of a number of eutrophication parameters

Year		P total mg/l	P ortho mg/l	transp. m	chlorophyll mg/m^3
1988	Lake Volkerak	0.18	0.11	2.1	21
	Lake Zoom	0.16	0.08	1.7	29
1989	Lake Volkerak	0.13	0.07	2.8	10
	Lake Zoom	0.12	0.06	2.4	11
1990	Lake Volkerak	0.09	0.04	3.3	7
	Lake Zoom	0.08	0.04	2.8	6
	AMK *)	0.15		0.4	100

*) AMK (Algemene Milieu Kwaliteit, the general environmental quality standard in the Netherlands)

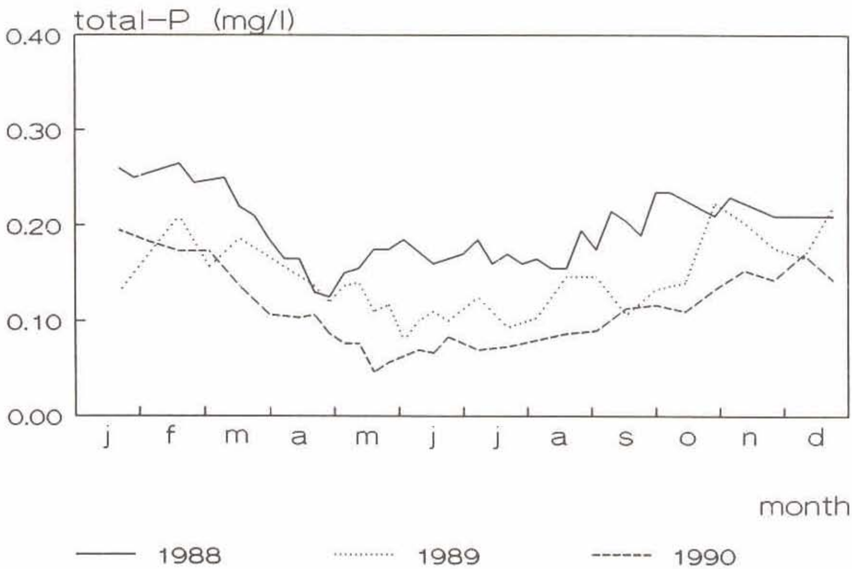

Figure 2 Phosphate concentration in Lake Volkerak/Zoom in 1988-1990

3 DEVELOPMENTS IN THE LAKE

3.1 Phosphate levels

The average summer phosphate level dropped from 0.18 mg P/l in 1988 to 0.09 mg P/l in 1990 (Table 4). The level of ortho-phosphate dropped from 0.10 to 0.04 mg P/l.

The phosphate level showed evident seasonal fluctuations (Figure 2), with maximums in autumn and winter and minimums in summer. For short periods during summer the ortho-phosphate concentration was lower than 0.01 mg P/l; a concentration which can lead to growth restriction for algae. Strong algal growth is possible at the average measured summer concentration of phosphate, so that an algal biomass of between 60 and 100 $\mu g/l$ could be expected.

3.2 Algae in the water and on the lake bottom

The average summer chlorophyll-α level dropped from 25 mg/m^3 in 1988 to less than 10 mg/m^3 in 1990 (Table 4). The highest values were found in the early spring (Figure 3). In 1988 this maximum was 110 mg/m^3, in 1990 this was down to 38 mg/m^3.

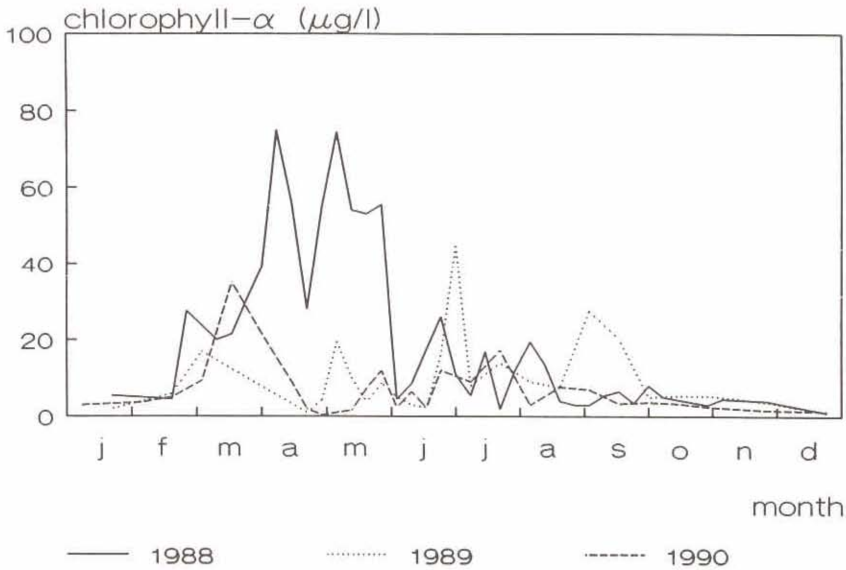

Figure 3 Chlorophyll-α level in Lake Volkerak/Zoom in 1988-1990

The composition of the algae in 1989 and 1990 was mainly determined by flagellates (*Cryptomonas sp. and Rhodomonas sp.*) and by siliceous algae. Blue algae were present from August to November, at which time the types *Microcystis aeruginosa* and

Aphanizomenon flosaquae regularly form floating layers. In 1990 there was a noticeable abundance of filamentous algae (e.g. *Enteromorpha sp.*).

The low quantity of algae were not due to a limited production. Primary production measurements showed conditions which are meso- to eutrophic. On a yearly basis the average primary production was 0.9 to 2.0 g C/m^2/day. This was just as high as in other eutrophic lakes in the Netherlands, such as the Loosdrechtse Plassen and the Wolderwijd. In 1990 the average daily production of the algae exceeded their own weight.

A characteristic feature of Lake Volkerak is the large scale presence of bottom algae. In the summer of 1990 bottom algae were found to a depth of 6 m, with a total biomass of over 3,000 kg chlorophyll-α, while in the same period in the water phase algae biomass amounted to only 1,900 kg chlorophyll-α. The biomass of bottom algae is highest in sheltered spots and lowest in places exposed to the wind. The production of the bottom algae in the summer of 1990 has been estimated at 1.7 g C/m^2/day; this is roughly comparable to the extent of the production of algae in the water phase.

The bottom algae are an important link in keeping the system clear. They can reduce the discharge of phosphate and silicate by the lake bottom and thus limit the growth of other algae.

3.3 Zooplankton

The low algal biomass was related to the presence of large types of zooplankton. Cladocera, particularly water fleas (*Daphnia sp.*) were important in this process. In the spring of 1990 the Copepod (*Eurytemora affinis*) played an important role. It is a kind which can be found in freshwater, salt water and brackish water alike. The zooplankton achieved the highest biomass in May, when the large water fleas reached their greatest density (Figure 4). Measurements in 1989 and 1990 showed the grazing pressure on the algae was highest in that period (Gulati et al, 1991); some days more algae were eaten in a day than were produced. In the summer months grazing pressure was usually lower and it peaked again in the autumn. In 1989/1990 the zooplankton filtered the entire contents of the lake in 1 to 4 days.

3.4 Transparency

The average summer transparency has increased from 1.9 m in 1988 to 3.1 m in 1990 (Table 4). From January to March the transparency was approximately 1 m (Figure 5). The highest transparencies of 3.5 to 5 m were measured in the period from mid April till June. This was a result of the strong grazing pressure by water fleas and the resultant low algal biomass (Figure 6).

The clear water offers favourable conditions for the development of a system rich in water plants and bottom algae.

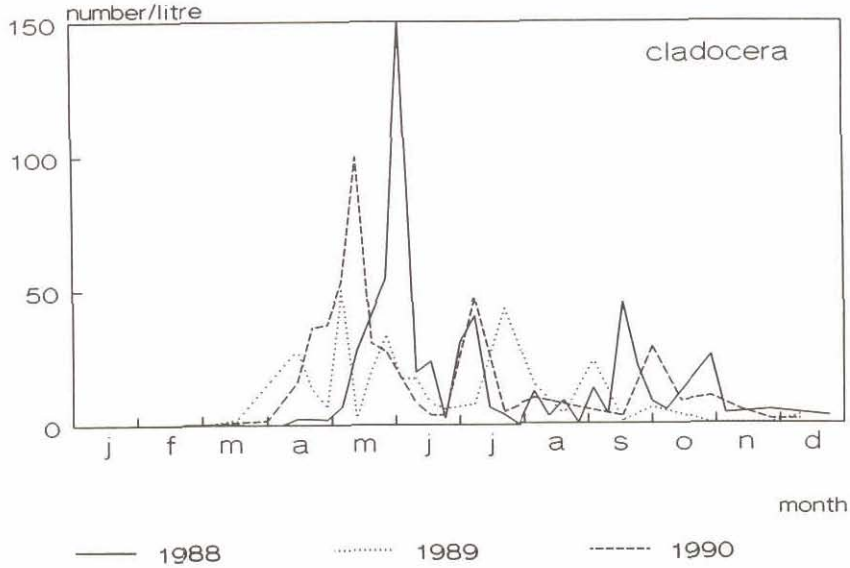

Figure 4 Number of Cladocera in Lake Volkerak/Zoom in 1988-1990

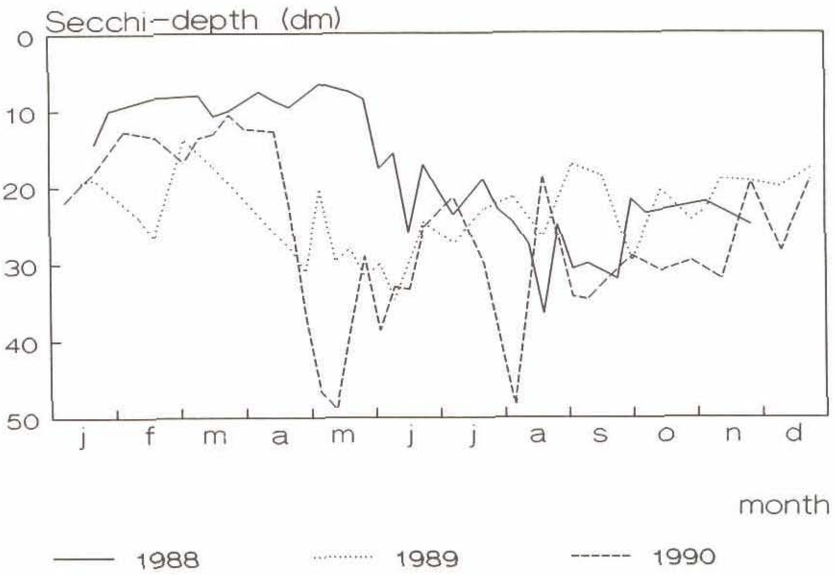

Figure 5 Transparency in Lake Volkerak/Zoom in 1988-1990

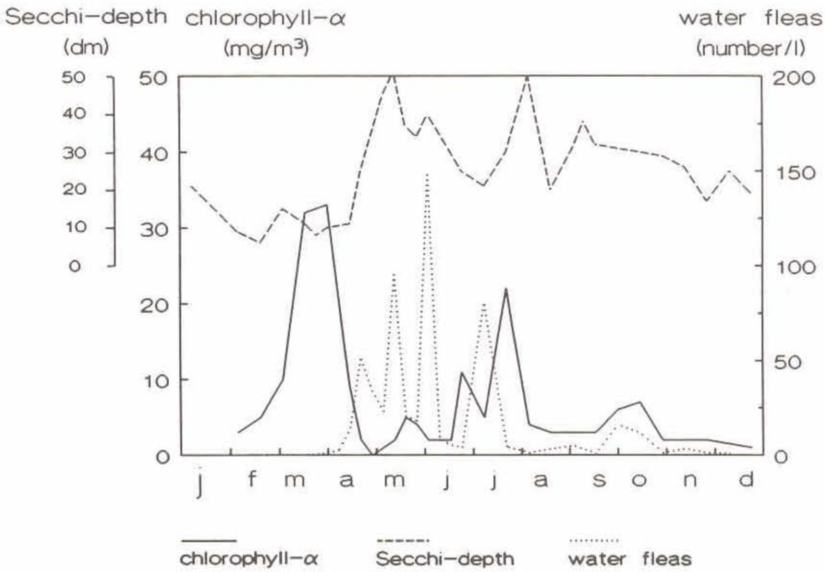

Figure 6 Chlorophyll-α level, the number of water fleas and the transparency in 1990 in the eastern part of Lake Volkerak

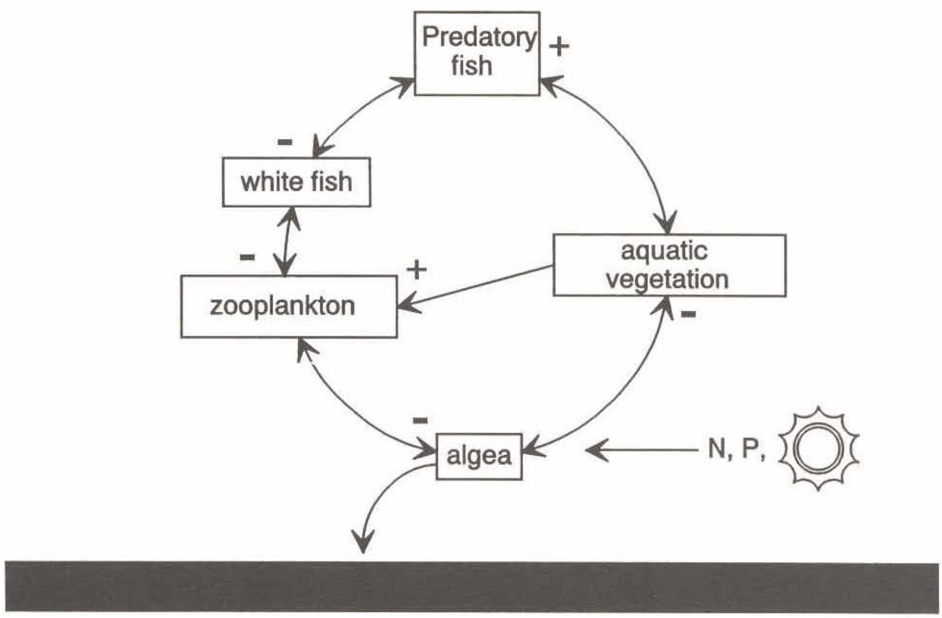

Figure 7 Schematic representation of part of the food chain in Lake Volkerak/Zoom

4 ANALYSIS OF THE AQUATIC ECOSYSTEM

The great transparency of the lake is a direct consequence of the presence of large zooplankton and the resultant grazing pressure on the algae. Figure 7 shows how the various components in a lake influence one another. There were few whitefish in Lake Volkerak/Zoom in the period 1988-1990 (Ligtvoet 1992, this volume), so that the large water fleas were not grazed on. In turbid lakes on the contrary, the numbers of whitefish, particularly bream, are so great that all the zooplankton is eaten away. The grazing pressure on the algae diminishes and excessive algal growth is the result.

Expectations are that with the present phosphate concentrations and without further measures being taken, in Lake Volkerak/Zoom the fish population will develop to a bream dominated stock. This will mean a great reduction in the numbers of zooplankton leading to a lower grazing pressure, an increase in algal biomass and a decreased transparency of the water.

In order to keep Lake Volkerak/Zoom permanently clear with a transparency of approximately 2 m, the amount of algae must be restricted to a chlorophyll-α level of approximately 10 to 20 μg/l. According to the CUWVO ratio (CUWVO, 1988), achieving such a low level through lack of phosphate is possible at an average summer phosphate concentration of 0.016 to 0.032 mg P/l. However, experience in other lakes has shown that, even at higher concentrations of phosphate, up to approximately 0.10 mg P/l (Hosper et al, 1992), systems can be kept clear thanks to the great grazing pressure of water fleas. But this is only possible if the fish population is of a balanced composition.

5 PROGNOSIS

The above paragraphs have made it clear that, despite the favourable developments until now, the present phosphate loads can be expected to result in undesirable symptoms of eutrophication. The manner in which the phosphate load will develop depends greatly on the implementation of cleaning measures, bottom protection measures and with the realization of water removal for agricultural use from Lake Volkerak/Zoom. The developments in the lake itself are also dependent on changes in the phosphate retention of the lake bottom and changes in the aquatic ecosystem.

5.1 Rhine Action Plan and North Sea Action Plan

It is difficult to predict the phosphate levels in the Hollandsch Diep in 1995 in connection with the progress of the Rhine and the North Sea Action Plan. In 1991 the phosphate level in the Hollandsch Diep already dropped below the levels predicted for the year 2000, based on model calculations. This could be the result of a rapid progress of sanitation measures, but could also be the result of the sequence of three dry years. The prognosis are calculated for two situations for the phosphate level of the inlet water from the Hollandsch Diep:

- 0.15 mg/l: the average summer level in 1991;
- 0.19 mg/l: the predicted level for the year 2000.

5.2 Brabant rivers

In 1991 Rijkswaterstaat entered into a managerial agreement with the Waterauthority Hoogheemraadschap West Brabant and the Flemish Environmental Company (Vlaamse Milieu Maatschappij) to reduce phosphate emission from the purification plants in the Mark and Dintel basin before 1 January 1993 (see the contribution by Van Oers et al., 1992, this volume).

Within the framework of this management agreement, agreements will also be made on reductions in the surface runoff of manure from the agricultural land in the drainage area of the Mark and Dintel. Expectations are that, in an average year, the phosphate load from the Mark and Dintel will be reduced by approximately 54 tons as from 1993. Following optimization of the sedimentation capacity for silt in the Dintel, estimates show that more phosphate can be left in the Dintel (55% instead of 45%), which will further reduce the P load on the lake.

A factor which will complicate matters is that the phosphate loads of the Mark and Dintel fluctuate strongly as a result of differences in the hydrological conditions. The measures will have more effect in wet years than in dry years. For wet and dry years we must take account of a range between 68 and 231 ton P/year.

5.3 Other sources

Elimination of phosphate in waste water purification plants along Lake Volkerak and the Eendracht will lead to a reduction from 8.8 tons phosphate in 1990 to 5.8 tons in 1995. Polder discharges depend strongly on meteorological conditions. No further reduction in the load is expected. Diversion of the polder discharges on Tholen from the Eendracht to the Oosterschelde can lead to a reduction of 9 to 16 tons phosphate in Lake Zoom.

From 1992 the flushing of Lake Volkerak/Zoom will rise as a result of the removal of water for agricultural use from the Bath drainage canal. This will mean a 35 ton P increase in the phosphate load, based on the phosphate loads of the last year. This can be reduced by 50% by preventing salt water to enter the lake at the Bergsediep sluice, which will be achieved in 1992.

Table 5 shows a summary of the prognosis for the phosphate load of Lake Volkerak and Lake Zoom for a wet and a dry year, respectively. The expected phosphate load after 1995 is lower than the present load (Table 2).

The most important question is whether the expected load will be sufficiently low to prevent the lake from becoming turbid. In order to answer this question, an estimate has been made as to what the maximum phosphate load in Lake Volkerak can be in order to arrive at an annual average of total phosphorus of 0.10 mg P/l (Table 6). The extent of the admissible load depends on the retention of phosphate in the lake. Such an estimate cannot be made for Lake Zoom, as there is insufficient information on the retention ratio.

Table 5 Prognosis of the phosphate load after 1995 (ton P/year). (The range in values is arrived at after calculating with a phosphate level of 0.15 and 0.19 mg P/l in the Hollandsch Diep).

	wet year	dry year
LAKE VOLKERAK	293 - 306	149 - 169
g $P/m^2/y$	6.4 - 6.7	3.3 - 3.7
Hollandsch Diep	49 - 62	73 - 93
Dintel & Vliet	231	68
other	13.5	7.5
LAKE ZOOM	126 - 131	58 - 63
Eendracht	94 - 99	41 - 46
other	31.6	17.1

Table 6 Estimate of the maximum admissible phosphate load (in g/m^2/year) on Lake Volkerak, in order to achieve an annual average phosphate level of 0.10 mg/l.

	wet	dry
Admissible		
optimistic	5.6	4.3
pessimistic	4.6	3.2
Prognosis	6.4 - 6.7	3.3 - 3.7
Present situation	10.4 (1988)	4.9 (1989)

The calculation of the admissible load is based on the CUWVO ratio between phosphate loads, retention and residence time (Figure 8) (CUWVO, 1988). When calculations are based on the information from Lake Volkerak itself, where the retention of phosphate is still high now, we arrive at an optimistic estimate. However, when the CUWVO ratio is applied, a ratio which is based on the information from other Dutch lakes with a lower retention, a more pessimistic image is presented.

Table 6 shows that in the optimistic assumption on retention, the P load will be lower than the maximum admissible P load in dry years. However, in wet years the P load will be too high. If the retention decreases (pessimistic situation), the maximum admissible load drops, and in that case the predicted P load is still too high to uphold an annual average phosphate level of 0.10 mg/l.

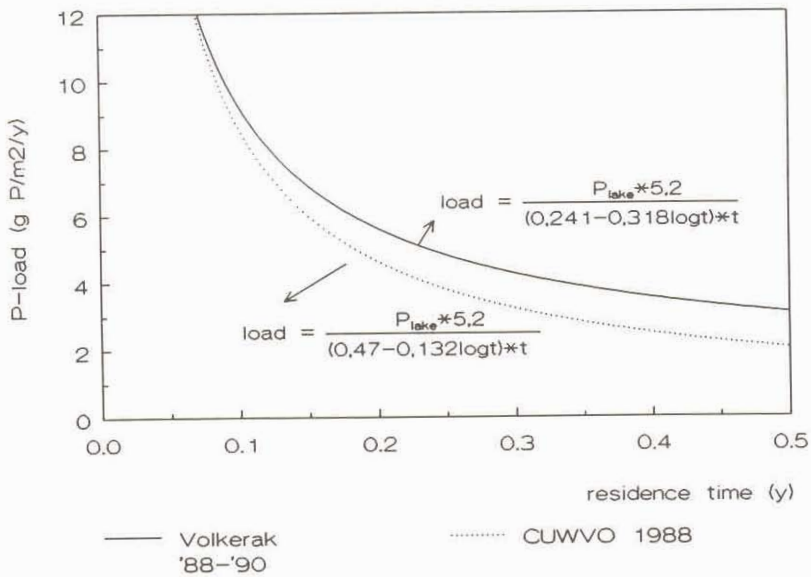

Figure 8 The maximum admissible phosphate load in Lake Volkerak in order to achieve an average phosphate level of 0.10 mg P/l in relation to the residence time. Shown are the ratio according to CUWVO (1988) and the ratio based on the information on Lake Volkerak over the period 1988-1990. The lake is 5.2 metres deep.

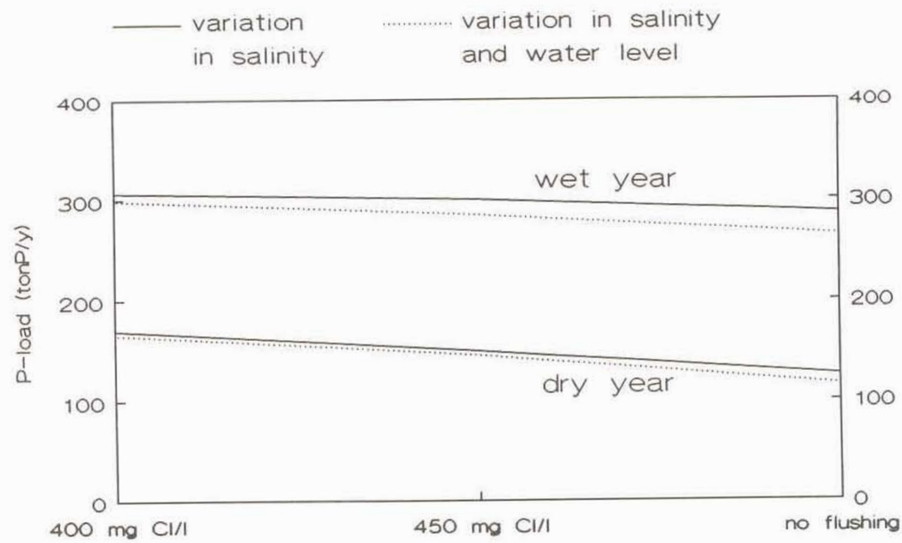

Figure 9 The phosphate load in Lake Volkerak in the case of various alternatives for salt levels and water level variations

5.4 Effect of management alternatives

In order to reduce the load of pollutants to the lake, several alternatives were designed for reducing water supply at the Volkerak sluices. Behrens (1992, this volume) gives a description of the alternatives and their consequences for the water supply. The results for the phosphate load are presented in Figure 9. It shows the effect of the alternatives "steering towards 450 mg Cl/l" and "no flushing" on the phosphate load of Lake Volkerak in relation to the reference situation "steering towards 400 mg Cl/l". In a dry year "no flushing" can lead to a reduction of approximately 25% in the phosphate load. In a wet year supply is mainly via the Dintel and the reduction will be 5% at the most.

When a water level fluctuation of between NAP (Normal Amsterdam Peil, the reference level in the Netherlands) - 0.15 m and NAP + 0.25 m is allowed (Figure 9), a maximum extra profit of 5% can be attained, compared to a fixed water level.

Due to the lower load of phosphate, the lake bottom will not pile up as quickly with phosphate. However, the phosphate concentrations in the lake will remain approximately as high as ever. This is because the residence time will be prolonged and the admissible load will drop (see Figure 8), though to the same extent as the actual drop in P load.

6 CONCLUSIONS

Until now Lake Volkerak/Zoom was eutrophic but also clear. The average summer levels of phosphate were higher than 0.08 mg P/l and there was a strong algal growth. However, the algae were grazed away by large numbers of water fleas, so that the system remained clear.

Upon realization of the proposed water quality improvement measures, the phosphate load of 1995 could balance out around the admissible load. But there is a risk that the phosphate retention of the lake bottom will decrease in the long term. In that case, the phosphate load will have to decrease as well. Extra efforts to improve water quality seem to be inevitable in order to guarantee a clear Lake Volkerak/Zoom in the future.

Construction of suitable habitats and fish stock management are essential in order to avoid the aquatic ecosystem from prematurely developing into the undesirable turbid situation.

The management alternatives do not have a direct effect on the phosphate concentration in the lake. However, by limiting the flushing process, the phosphate load will be reduced in a dry year, along with the speed with which the bottom sediments pile up with phosphate. This is favourable in order to keep down the internal phosphate load through consequent release from the lake bottom.

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SANITATION OPERATIONS IN THE BASIN OF THE RIVER MARK

R.E.M. van Oers, J.B.M. Somers and J.V. Witter

1 INTRODUCTION

In 1987 a freshwater lake, Lake Volkerak/Zoom, was created, which is fed to a substantial degree by the river Mark. The lake is stagnant and hence susceptible to eutrophication, so that additional sanitation measures proved necessary in the catchment area in order to avoid the impending rapid growth of algae and the bottom becoming saturated with micropollutants. As the catchment area covers part of the Belgian province of Flanders, the problems also have international aspects.

This article looks at the basic philosophy of the regional water control boards in the Netherlands and Flanders and the (differing) water-quality objectives for the Mark in force in the various regions through which the Mark flows.

The source of the pollutants is given in broad outline and the relative importance of the various sources illustrated on the basis of mass balances for phosphate, nitrogen and heavy metals. The results of the sanitation measures taken in West Brabant and Flanders are also given.

Finally, the conclusions look at the forecasts of future water quality and the need to reduce even further non-point pollution from agriculture in particular.

2 DESCRIPTION OF THE CATCHMENT AREA (Figure 1)

The total surface area that drains into Lake Volkerak/Zoom from West Brabant and the northern Kempen region of Flanders is about 1,500 km^2, 70% of which is situated in the Netherlands and 30% in Flanders.

The largest part (75%) consists of sandy soil which is primarily used for (intensive) cattle farming and market gardening. The other 25% is marine clay which is principally in use as arable land. More than half a million people live and work in this area in a number of medium-sized towns and villages. Industrial sites are located around the towns and along the large Dutch state-administered waters that bound the area in the west and north. The main branches of industry in the region are the canned foods, sugar and chemical industries. The height of the region varies from 35 m above NAP (Normaal Amsterdams Peil, the reference level in the Netherlands) in Flanders to 0.5 m below NAP in the polders of West Brabant.

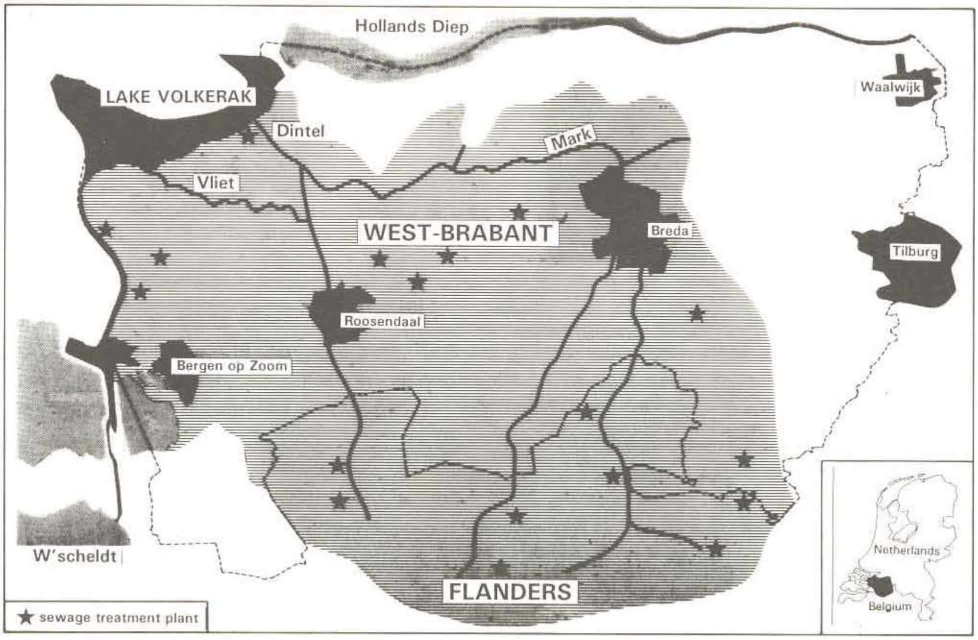

Figure 1 The basin of the Mark

The principal waters are:

* The Mark and Dintel.
  This 76-km-long river drains about 80% of the area in question and where it flows into Lake Volkerak/Zoom it has an average flow rate of 12 m^3/s;
* The Roosendaalse and Steenbergse Vliet, which accounts for about 15% of the drainage (average flow rate about 2 m^3/s);
* The other waters. These consist mainly of polder-water courses and together they discharge on average less than 1 m^3/s into Lake Volkerak/Zoom.

More than 85% of the domestic waste water and industrial effluent from the West Brabant section of the catchment area is drained off (after biological purification) into the Westerschelde and the Hollandsch Diep. The remaining Dutch and Flemish waste water is treated biologically in situ in seventeen, for the most part small, purification plants. In addition, a limited amount of purified industrial effluent is also discharged directly.

3 BASIC PHILOSOPHY OF THE REGIONAL WATER CONTROL BOARDS IN THE NETHERLANDS AND FLANDERS

There is no fundamental difference in the bases of policy relating to water control in the Netherlands and Flanders. This is illustrated by the following examples.

In both countries:
- immission objectives for waters with a special purpose are based on current EC (European Community) guidelines, supplemented by basic quality standards for the remaining waters;
- emission objectives are based on the EC black-listed substances policy and on agreements made during the three North Sea Ministers' Conferences (50% reduction in environmentally hazardous substances in 1995);
- regional water management plans have been drawn up on the basis of policy plans.
  The following plans are of direct interest for the area under consideration in this article:
  * Water Management Plan Lake Zoom 1988-1992.
    = Elaboration of the Management Plan for State-administered Waters and of the Third Policy Document on Water Management.
  * Integrated Water Management Plan West Brabant 1993-1996.
    = Elaboration of Provincial Water Policy Plan.
  * Environmental Policy Plan for Flanders, 1990-1995, section on surface waters.
    = Elaboration of MINA-plan 2000.

However, there is a substantial difference in the way these policy plans are elaborated and the stage of implementation of the policy. For example, in Zeeland and West Brabant strong emphasis is placed on integrated water management, whereas in Flanders emphasis is for the moment placed on protection against pollution. This is evidenced by, amongst others, differences in water quality objectives. To illustrate this we shall follow the Mark from its source in Flanders to its mouth in Lake Volkerak/Zoom. Along its way the river passes through three control areas. Table 1 compares the objectives and standards that apply for the liquid phase. In the case of the standards, options are presented for those parameters which are most important for the oxygen balance, the nutrients and the inorganic micropollutants.

On closer examination the following points stand out:
- In the downstream direction increasingly stricter objectives and concomitant standards apply: from the basic quality in the upper reaches via cyprinid water to natural water in Lake Volkerak/Zoom;
- It should be noted that increasingly stricter objectives in the direction of the mouth of the river conflict with the natural tendency of a river to become richer in nutrients downstream;
- Furthermore, basic quality standards differ between Flanders and the Netherlands;
- In the Netherlands the general environmental quality standard (Algemene Milieu Kwaliteit - AMK) applies, in Flanders the basic quality standard for Belgium. The AMK standard is stricter with regard to nutrients, heavy metals and pesticides. In addition, a water's function as fishing water results in a higher oxygen standard;
- The natural objective for Lake Volkerak/Zoom is aimed primarily at obtaining clear water (very low nutrient content) and a clean sedimentary layer (very low micropollutant content). This goes even further than the AMK.

Table 1 Comparison of objectives and standards

Control area	Flanders	West Brabant	Zeeland
water	Mark	Mark and Dintel	Lake Volkerak/Zoom
objective	basic quality	fishing waters basic quality	natural waters fishing waters swimming waters basic quality
stand. O_2 (mg/l) $N(NH_4)$ N-tot P-tot	A > 0.5 G < 1 G < 0.3	A > 6 G < 0.8 (Z) G < 0.15	A > 6 G < 0.8 (Z) G < 2.2 (Z) G < 0.08 (Z)
(μg/l) Cd Hg Cu Pb Zn Cr Ni	A < 2.5 A < 0.5 A < 30 A < 50 A < 200 A < 50 A < 50	A < 0.2 A < 0.03 A < 3 A < 25 A < 30 A < 25 A < 10	as low as possible
(μg/l) Cl-pesticides P-pesticides	M < 0.02 M < 0.5	A < 0,01 (I) A < 0,5	as low as possible

Notes A = absolute value M = median value I = applies to a few
G = average Z = summer average individual substances

4 EXAMINATION OF WATER-QUALITY OBJECTIVES

The various water-quality objectives in force for the Mark were examined at the crossing points of the three control areas in question. Table 2 gives the water-quality data gathered by Waterauthority Hoogheemraadschap West Brabant in the period 1989-1991 at these locations, together with the results of the examination.

Before interpreting the data, the following notes need to be made:
* Only the environmental compartment "water" was examined using the same parameters as in Table 1;
* The period in question, 1989-1991, comes *after* the effluent from the big sewage treatment plant at Nieuwveer was diverted to the Hollandsch Diep;
* The average values presented in the table have been incorporated as an indication only and have not been used for examining the (often) absolute standards.

Table 2 Examination of water-quality objectives

Location		border Flanders/West Brabant			border West Brabant/Zeeland		
Parameter		measure-ment (average	examination result		measure-ment (average)	examination result	
			basic qual. (B)	AMK/fish-ing water (N)		AMK/fish-ing water	Natural water
(mg/l)	O_2	8.0	-	-	9.4	+	+
	$N(NH_4)$	2.1	-	-	0.7	+	+
	N-tot	10.3	-	-	8.4	-	-
	P-tot	0.56	-	-	0.33	-	-
(μg/l)	Cd	0.2	+	-	0.2	-	-
	Hg	0.07	+	-	0.1	-	-
	Cu	5	+	-	4	-	-
	Pb	3	+	+	2	+	+
	Zn	30	+	-	15	-	-
	Cr	1	+	+	1	+	+
	Ni	11	+	-	9	-	-
(μg/l)	Cl-pesticides	0.08	-	-	0.17	-	-
	P-pesticides	1.9	-	-	0.9	-	-

In respect of the results of the examination the following comments can be made:

1. With regard to the Mark where it crosses the border between Flanders and West Brabant:
   - the oxygen content is not as it should be regarding the fishing-water objective;
   - the concentrations of nutrients are too high, but there are no problems with eutrophication here;
   - the heavy-metal contents satisfy Belgium's basic quality, but are a long way from meeting Dutch AMK standards;
   - the organochlorine and organophosphorous pesticides exceed both the Belgian and the Dutch basic quality.

2. With regard to the Dintel where it crosses the border between West Brabant and Zeeland:
   - there is nothing wrong with the oxygen content;
   - in the light of the impending problem of eutrophication, the concentrations of phosphate and nitrogen are 2 - 4 times too high;
   - the heavy metals and pesticides do not meet AMK standards and constitute a potential source of pollution for the sediment layer of the river.

The problems have been clearly outlined above. Further remedial action to sanitize sources of pollution is required in order to reach our water-quality objectives in the long term. Further quantification of the various sources is important in order to enable specific sanitation measures to be taken. The following section looks at this in greater depth.

5 SOURCES OF POLLUTION

The water pollution in Flanders and West Brabant is caused by the same types of point sources and non-point sources.

The point sources can be subdivided into:
- discharges of effluent from sewage treatment plants;
- industrial discharges;
- overflows from sewers;
- discharges from dwellings not connected to the central sewer system.

In the case of the non-point sources, a distinction can be drawn between:
- agricultural fertilizers and pesticides being washed off or away;
- wet and dry deposition;
- natural washing away ("background").

Table 3 gives mass balances of phosphate, nitrogen and heavy metals. The mass balances reflect the present situation and roughly quantify the sources of pollution.

Table 3 Rough mass balance of substances in catchment area

	phosphate tonnes/year	nitrogen tonnes/year	heavy metals tonnes/year
Flanders - sewage treatment - agriculture - other	 55} 50} 170 65}	 } } 1800 }	 } } 12 }
West Brabant - sewage treatment - agriculture - other	 30} 50} 145 65}	 200} 1500} 2400 700}	 1} -} 4 3}
Total Retention	315 140	4200 -	16 11
In Lake Volkerak/ Zoom	175	4200	5

The following comments should be observed when looking at the table:
* Only the largest (groups of) sources have been shown;
* The mass balances have not been compiled for pesticides as a result of insufficient data;
* The loads for the point sources have been calculated for 1990;

* The "other" item is to a substantial degree the result of natural background processes;
* The cross-border loads and the non-point discharges have been calculated for an average hydrological year. Very big differences can occur in these items as a result of wet or dry years.

The following concluding and explanatory remarks can be made with respect to Table 3:
* Phosphate and nitrogen pollution from Flanders is of the same order as the discharges on Dutch territory. This does not hold true for the heavy metals, the majority of which come from Flanders;
* The point sources in West Brabant have been sanitized to a large extent.
  In the 1970s and 1980s, domestic waste water and industrial effluent were largely diverted away from the river basin. Purification takes place at the large plants at Bath and Nieuwveer, which discharge their effluent into the Westerschelde and the Hollandsch Diep respectively;
  There are another ten small sewage treatment plants in West Brabant which discharge directly or indirectly into Lake Volkerak/Zoom;
* Until recently only limited dephosphatization was possible at the small West Brabant sewage treatment plants. The current statutory requirements in the Netherlands, regarding dephosphatization (75% removal per control area in 1995) in the first place, stimulate the taking of steps at the large plants;
* The sugar industry, which has historically been strongly represented in West Brabant, purifies its own effluent to a very high degree;
* The point sources on Flemish territory have likewise been sanitized. Seven small to medium-sized biological purification plants purify the domestic and industrial waste water brought in. Large-scale removal of phosphate was not originally intended;
* As only a low percentage of the so-called scattered dwellings in Flanders are connected to the sewer system, the discharges from these dwellings continue to constitute a major source of pollution;
* The agricultural industry in West Brabant as well as in Flanders is a major supplier of nitrogen and phosphate. In particular intensive cattle-breeding on the sandy soils is to blame for this. Its contribution of phosphate is estimated at 30%, and of nitrogen 50% of the total burden in the catchment area;
* The high retention capacity of the waters in the area is favourable. Of the phosphates and heavy metals carried in, 45% and 70% respectively are retained in the sediment.

6 SANITATION MEASURES

As stated above, the sanitation of point discharges of oxygen absorbents in West Brabant was virtually completed in the 1970s and 1980s. The final step was the diversion of the effluent from the big sewage treatment plant at Nieuwveer to the Hollandsch Diep in May 1988. A new policy of removing nitrogen and phosphate at the large sewage treatment plants has been implemented. Stricter standards are also being introduced for industrial discharges and emissions from sewer systems.

The water-quality control board cannot directly enforce the sanitation of non-point discharges. In this respect it is dependent on other rules and legislation. The applicable legislation regarding the reduction of nutrients from the Dutch agricultural sector are the Manure Act and the Soil Protection Act. The long-term plan for crop protection is of importance with regard to reducing pesticides.

Unfortunately, positive effects for the aquatic environment can only be expected in the long term due to, in particular, the phosphate-saturation of terrestrial soils. Favourable effects have already been achieved by, or can be expected from the introduction of unleaded petrol, phosphate-free detergents and the ban on the use of PCBs and other black-listed substances in production processes.

Point discharges have also been sanitized in Flanders and in principle the same supplementary measures will be taken. Due to the less strict standards regarding water quality, these measures are expected to be carried out at a slower pace and for the time being to be less far-reaching regarding reduction objectives.

The high number of scattered buildings constitutes an additional problem, because a large number of dwellings and industrial premises are not connected to a sewer system. The large concentration of intensive cattle-breeding in northern Kempen also poses a threat to the quality of surface waters. The Flemish authorities are attempting to limit the effects of this development with the Fertilizer Decree, which came into effect in January 1991.

As it soon became obvious that the above measures would not be adequate to save Lake Volkerak/Zoom from an overabundant growth of algae, Rijkswaterstaat, Directorate Zeeland; Flemish Environmental Company and Waterauthority Hoogheemraadschap West Brabant concluded an administrative agreement in September 1990. The agreement contains two important supplementary measures:

- the swift introduction of dephosphatization at the 10 West Brabant and 3 Flemish sewage treatment plants in the catchment area (by 1 January 1993);
- investigation of the sedimentation behaviour and sediment quality of the Mark.
  This will look at both source- and effect-oriented solutions for the problems of dredging.
  Phosphate dredging and (in the future) the separate in-situ entrapment of clean sand and polluted silt are being considered in order to maintain or improve the river's retention capacity with respect to phosphates.

7 EXPECTED RESULTS OF SANITATION MEASURES

One of the principal objectives of the sanitation measures described above is to reduce the phosphate content in the water to such an extent that the growth of algae in the Dintel and Lake Volkerak/Zoom is greatly inhibited. The target value for the Dintel is 0.15 mg P_{tot}/l. Translated into the amount of phosphate, that would be permitted to leave the catchment area in average years, this equals 60-80 tonnes P_{tot}/year.

Table 4 shows the expected phosphate loads after completion of the sanitation measures around 1995. Rough forecasts are given for the other substances.

As can be expected, the reduction in phosphate will mainly be achieved through dephosphatization at the sewage treatment plants and maintaining/improving the river's capacity to retain phosphate. Due to the large buffer stocks of phosphates in the soil of sandy regions, no effect is expected for the time being from the reduction in fertilizer doses. However, nitrogen emissions are expected to drop by an estimated 10 - 20% as a result. It is difficult to estimate the effect of the planned reduction in the use of pesticides in the (Dutch) agricultural sector for the period up to 1995.

As a result of so-called autonomous policy (reduction of grey and black-listed substances), the heavy metals load could drop by 10 - 30%. Obviously, the biggest "win" should be made in Flanders.

Translated into objectives, all this means that the standards will be more closely approximated, but not yet achieved. The biggest difference can be found in the nutrients. Without additional effort, in particular in the field of agriculture both in West Brabant and in Flanders, an excessive growth of algae seems inevitable in the long term. Much still needs to be done in the sphere of reducing pesticides.

Table 4 Expected results of sanitation measures

phosphate loads (tonnes P/year)			
	1990	1995	target value
Flanders - sewage treatment - agricultural - other	 55} 50} 170 65}	 25} 50} 140 65}	
West Brabant - sewage treatment - agricultural - other	 30} 50} 145 65}	 10} 50} 120 60}	
Total Retention	315 140	260 140-160	
In Lake Volkerak/ Zoom	175	100-120	60-80

Forecast for other substances:
Nitrogen : 10 - 20% reduction
Heavy metals: 10 - 30% reduction
Pesticides : no forecast

8 CONCLUSIONS

1. In recent decades great efforts have been made in Flanders and West Brabant to remedy pollution and improve the oxygen balance in the basin of the river Mark, and hence also to reduce the burden on Lake Volkerak, which at the time was salty;

2. Going from the source to the mouth of the Mark, especially in the Netherlands the allocated functions and the water-quality objectives have been continually raised, which is contrary to the natural tendency of the river to absorb more substances downstream and become richer in nutrients;
3. The control measures, implemented within the context of the international action plans governing the Rhine and the North Sea and the administrative agreement concluded between Rijkswaterstaat, Directorate Zeeland; Flemish Environmental Company and Waterauthority Hoogheemraadschap West Brabant, to achieve the above quality objectives and to protect the stagnant, freshwater lake Volkerak/Zoom against an impending rapid growth of algae and pollution of the sedimentary layer of the lake, are resulting in improvement but are not adequate in the long term to secure this ultimate objective;
4. A sweeping reduction in nutrients and pesticides is therefore necessary. In view of the predominantly non-point and partly foreign origin of these substances, Waterauthority Hoogheemraadschap West Brabant does not have at its disposal the statutory instruments to enforce such sanitation measures;
5. Further consultation followed by agreements at a higher and broader administrative level could lead to openings which would provide a way out of these difficulties.

9 SUMMARY

In recent decades great efforts have been made in Flanders as well as in West Brabant to improve the oxygen content of the surface waters in the basin of the river Mark. Through the creation in 1987 of the freshwater lake Volkerak-Zoom, which is stagnant and hence susceptible to eutrophication, the need for a sweeping sanitation of nutrients and micropollutants in the catchment area became urgent. Although a huge step was made in the right direction in 1988 with the diversion of effluent from the large sewage treatment plant at Nieuwveer to the Hollandsch Diep, and the proposed measures for reduction in the context of the policy objectives of the international action plans governing the Rhine and North Sea hold a further improvement of the water quality in the basin of the Mark in prospect, mass balance studies showed that the load on Lake Volkerak/Zoom would nevertheless remain too high. This was directly related to the high water-quality objectives in force for this surface water.

The largest point sources still present in the area are the effluent discharges from the seventeen, mostly small, Flemish and West Brabant sewage treatment plants. For this reason the three water control organizations concerned, namely Rijkswaterstaat, Directorate Zeeland; Flemish Environmental Company and Waterauthority Hoogheemraadschap West Brabant, signed an administrative agreement on steps to accelerate dephosphatization at thirteen of the said sewage treatment plants (by 1993). On top of this, the sedimentation behaviour and sediment quality of the Mark will be investigated. Depending on the results of the investigation, this may result in the near future in dredging of phosphate-rich sediments in order to maintain or slightly improve the river's important capacity to retain phosphates. Although the aim of these supplementary control measures is to bring the water-quality objectives for the Mark and Lake Volkerak/Zoom closer, in the long term they are not adequate permanently to prevent an impending rapid growth of algae and saturation of the sedimentary layers of these waters with pollutants. A more sweeping reduction in nutrients and micropollutants is therefore necessary.

The only remaining source of significance which has not been sanitized is constituted by the non-point discharges from the agricultural sector in Flanders and West Brabant. The water control organizations do not have at their disposal the statutory instruments to enforce specific sanitation measures to eliminate this source. Further agreements at a higher and broader administrative level could possibly lead to openings which would provide a way out of these difficulties.

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FISH IN CLEAR WATER
Fish-stock development and management in Lake Volkerak/Zoom

W. Ligtvoet and M.P. Grimm

ABSTRACT

The objective for Lake Volkerak/Zoom is to maintain the current clear-water situation and prevent a shift to turbid water with a heavy algae concentration dominated by cyprinids. To accomplish this, the two most important methods are supressing the nutrient load and controlling the development of the aquatic ecosystem. As fish-stock development plays a central role in the development of the aquatic ecosystem, it has been monitored and a fish-stock management plan has been formulated with the aim of maintaining water quality.

The development of stocks of predatorous fish (pike, perch and pike perch) as well as of cyprinids (including bream and roach) is an essential part of fish-stock management. The fish-stock development from the time the lakes were closed off from salt water, and the most important processes, including the stock processes in 1991, are discussed.

The prognosis for the lakes, based on an empirical model of which the most important control variables are the nutrient concentration (P concentration) in the water column and the environmental structure of emergent bank vegetation and submerged water vegetation, creates a prospect to maintain clear water on a permanent basis. One of the preconditions for this is the establishment of a pike/tench fish community, with pike as the dominant predator. However, neither the fish stock nor the bank and water vegetation are currently adequate for this.

The outlines of the strategy for developing and managing the fish stock are as follows:
1. Nature development: the development of the required habitat for pike, together with the promotion of the pike stock;
2. Fish stock management: until the pike stock is sufficiently developed the present predator fish stock should be promoted and the development of the cyprinids retarded by means of specific control fishing.

Management objectives for the composition of the predator fish stock, structure of the lakes as pike waters, and the maximum allowable whitefish stock have been quantified.

1 INTRODUCTION

With the closure of the Oesterdam in the spring of 1986 and the Philipsdam in April 1987, Lake Volkerak and Lake Zoom were closed off from salt water and a new freshwater system with a stagnant level was created. Next to shipping, "nature" is considered to be the area's main function. The lakes underwent favourable development immediately after enclosure. Despite the high phosphate load (Van Veen, 1990) the water was very clear, with a Secchi depth of 2-3 m, a situation which has been maintained to the present day (Van den Hark et al., 1992, this volume). However, developments in other desalinated, formerly marine areas (IJsselmeer, Lauwersmeer) indicate that the initially clear water becomes turbid 5-10 years after enclosure.

Within the framework of the desired nature development in Lake Volkerak/Zoom, a major objective for the lakes is the prevention of the reversion to turbid water and the maintenance of the clear-water situation. The two most important methods to accomplish this are the reduction of the nutrient load (Van den Hark et al., 1992, this volume) and a controlled development of the aquatic ecosystem.

The control of the development of aquatic ecosystems, in which fish-stock management is a central factor (Benndorf, 1989), has become nationally familiar under the name Active Biological Management. Below will be described how this has been applied to Lake Volkerak/Zoom. Consideration is given to the three most important variables controlling the size and composition of the fish stock, namely (1) nutrients, (2) predation, and (3) bank and water vegetation. The relationship between nutrients, environmental structure in the form of bank and water vegetation, and the fish community are briefly outlined. Based on these relationships, and following a description of the developments of the fish stock so far, a prognosis is made of developments without supervisory management. Then the fish stock targets are specified and quantified and the desired management strategy formulated.

2 NUTRIENTS, VEGETATION AND FISH STOCK

There is a positive correlation between the fish biomass and the total phosphate concentration in the water column (Hanson and Leggett, 1982; Grimm and Backx, 1990). Grimm et al. (1992) present an empirical model in which the nutrient concentration of the water expressed as the average of the total summer phosphate concentration (hereafter called the P concentration) and the environmental vegetation structure are linked to the size and composition of the fish stock. Three water types can be distinguished, characterized as "perch water" (I), "pike/tench water" (II), and "pike perch/bream water" (III) (Figure 1). The first two types represent clear waters with relatively low nutrient concentrations. Under natural conditions in the Netherlands perch is the dominant predator in sparsely grown type I waters and pike in type II waters with an extensive and differentiated emergent and submergent vegetation (Grimm, 1989). Pike perch is more generally associated with eutrophic, turbid waters with little vegetation and is frequently the main predator in waters with high stock densities of bream (e.g. Lammens, 1986).

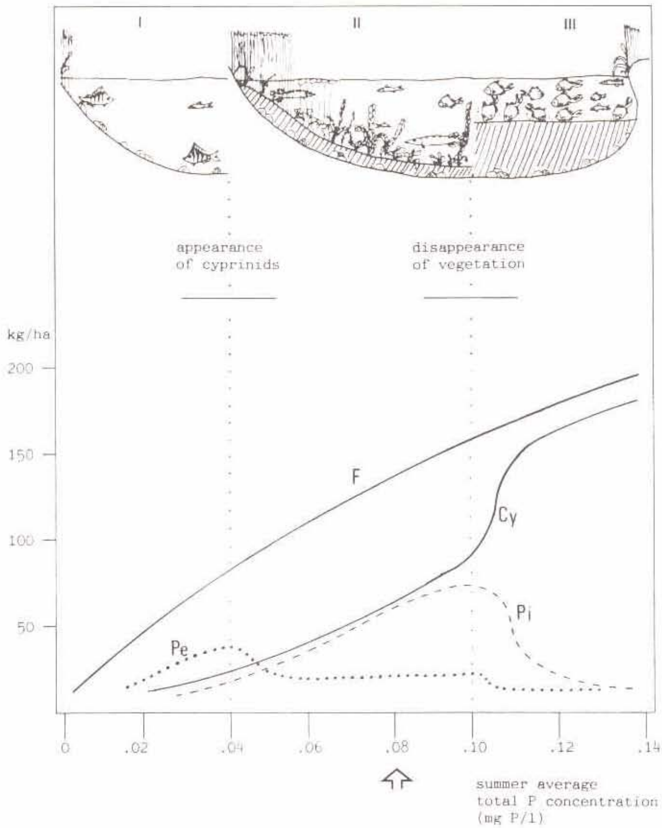

Figure 1 The occurrence of three fish communities (I- perch type; II- pike/tench type; III- pike perch/bream type) and the size (kg/ha) of the total fish stock (F), perch stock (Pe), pike stock (Pi) and cyprinid stock (Cy) in relation to the summer average total P concentration (mg P/l) in the water. By Grimm et al. (1992). The arrow indicates the P concentration in Lake Volkerak/Zoom in 1991.

It appears that waters remain clear up to a nutrient concentration of 0.1 mg P/l (Figure 1; Jeppesen et al., 1990). A further increase in eutrophication causes a shift to turbid water. The underlying explanation for this is that the predator fish density in a water has a definite upper limit, while the prey fish stock can continue to increase with an increasing nutrient concentration. In the process of eutrophication the switch from clear to turbid water occurs when the predator stock has reached its maximum density and can no longer regulate the ever-increasing prey stock (mainly cyprinids as bream and roach). The cascading effects are overgrazing of the zooplankton by the expanding planktivorous cyprinid stock resulting in a excessive growth of algae.

The actual P concentration in Lake Volkerak/Zoom is about 0.08 mg P/l [*)]. This means

[*)] The summer average P concentration of 0.08 mg P/1 is equivalent to the annual average P concentration of 0,1 mg P/1 as used by Van den Hark that should the lakes contain a pike/tench fish community, there would be a prospect of a permanently clear ecosystem with an abundant vegetation (cf. Figure 1).

3 FISH STOCK DEVELOPMENTS UNTIL 1992

The water system became desalinated almost immediately after enclosure in 1987 (Behrens, 1992, this volume), and was quickly colonized by freshwater fish. Nine species could be recorded in 1987 and this has increased to 17 species in 1991 and 1992 (Table 1, Figure 2). Over the same period the number of salt-water and brackish-water species has fallen from 26 to 15 (Bureau Waardenburg, 1991). Of the species found in the original salt-water system only flounder and eel are now found in significant numbers in the lakes (Bureau Waardenburg, 1991; Ligtvoet et al., 1991 a, b).

Because of the lack of a breeding population the development of the freshwater fish stock originally depended on an influx of fish from adjacent waters: the Hollandsch Diep (via the Volkeraksluis) and the Mark-Dintel and Steenbergse Vliet. A study of the fish immigration from these waters in 1989 and 1990 revealed that the most important inflow of fish consisted of larvae up to 3 cm long of mainly perch and pike perch and only of small amounts of cyprinids (bream, roach, etc.) (Ligtvoet et al., 1991 c). The fish stock in Lake Zoom, at a considerable distance from the above mentioned intake points in Lake Volkerak, has developed more slowly than in Lake Volkerak (Figure 2, Table 2), thus illustrating the effect of immigration.

Trawl samples taken in 1989-1991 show that the fish community is dominated by the perchids (perch, pike perch and ruffe). These, together with the cyprinids bream and roach, represent more than 90% of the freshwater fish stock (Ligtvoet et al., 1991 a, b, in preparation). Table 2 shows the estimated stock size (kg/ha) and relative percentages of these five types of fish separately for Lake Volkerak and Lake Zoom. Ruffe, which is neither an important fish predator nor a plankton eater, does not play a significant role in fish stock management aiming at water quality control; developments in this stock are therefore not considered further.

Restricting ourselves to the developments in the Volkerak, we note that the perch and pike perch stock in 1989 consisted predominantly of 1989 year class from the Hollandsch Diep and the rivers of Brabant. In 1990 and 1991 this 1989 group continued to represent a predominant part of the predator stock (Figure 3). Although from 1990 onwards there was in principle a sufficiently large breeding population (mainly one and two-year-old perch) to produce significant numbers of larvae, 1990 and 1991 year class perch and pike perch populations in 1990 and 1991, unlike those of 1989, did not contribute greatly to the fish stock (Figure 3). There are two possible reasons for this:
- A low reproductive succes in the years 1990, 1991. The extremely low densities of juvenile fish may indicate that these two years were indeed poor breeding years.
- The dominant 1989 cohort may have reduced the numbers of the 1990 and 1991 cohorts by cannibalism or competition. Studies in other lakes have shown that cannibalism can have a serious impact, especially in situations where the abundance of prey fish is limited (as is the case in Lake Volkerak/Zoom) (Buijse et al., 1992; Staub et al., 19[illegible]

Table 1 Presence of freshwater fish in Lake Volkerak/Zoom between 1987-1991, as recorded by monitoring the catch of professional fishermen between 1987 and 1991 (Bureau Waardenburg, 1991; Meijer, in press) and by summer and autumn trawl fishing between 1989-1991 (Kalkman et al., 1991 a, b; Ligtvoet et al., 1991 a, b, in preparation). Denoted are occurrence (+) or the abundance as average percentage of the annual registered fyke catches, and occurrence (t) in trawl catches.

species		Year			
	1987	1988	1989	1990	1991
Perch *Perca fluviatilis*	27	56	85/t	99/t	100/t
Pike perch *Stizostedion lucioperca*	60	75	89/t	95/t	95/t
Ruffe *Gymnocephalus cernua*	22	27	48/t	55/t	49/t
Bream *Abramis brama*	21	14	21/t	50/t	42/t
Roach *Rutilus rutilus*	21	23	48/t	44/t	51/t
White bream *Blicca bjoerkna*	17	16	15/t	12/t	11/t
Rudd *Scardinius erythrophthalmus*	4	13	17	39	44/t
Carp *Cyprinus carpio*	19	25	30/t	57/t	65/t
Powan *Coregonus lavaretus*	+	+	+	7	7/t
Pike *Esox lucius*		15	16	11	7/t
Tench *Tinca tinca*		7	17	13	13
Burbot *Lota lota*		1	+	+	+
Brown trout *Salmo trutta fario*		+	+		
Bullhead *Cottus gobio*			3	7/t	4/t
Spined loach *Cobitus taenia*				5	9
Ide *Leuciscus idus*			+/t	+/t	t
Bleak *Alburnus alburnus*				+/t	t
Ten-spined stickleback *Pungitius pungitius*			t	t	
Number of species	9	13	15	17	17

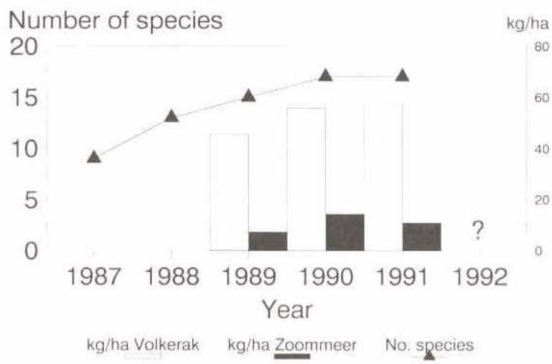

Figure 2 Number of recorded freshwater fish species and the size of the fish stock in Lake Volkerak and Lake Zoom between 1987-1991 (Bureau Waardenburg, 1991; Meijer, in press; Ligtvoet et al., in preparation).

Table 2 Size and composition of the fish stock in Lake Volkerak and Lake Zoom, shown for the five most important freshwater fish, in the period 1989-1991.

	Kg/ha			Percentage		
	1989	1990	1991	1989	1990	1991
Lake Volkerak						
Perch	21.0	28.5	17.9	46.2	51.0	31.2
Pike perch	7.7	10.6	10.7	16.9	19.0	18.6
Ruffe	6.6	10.2	12.6	14.5	18.2	22.0
Roach	5.7	2.3	6.0	12.5	4.1	10.5
Bream	4.5	4.3	10.2	9.9	7.7	17.8
Total	45.5	55.9	57.4	100.0	100.0	100.0
Lake Zoom						
Perch	1.4	3.9	4.7	19.2	27.1	43.1
Pike perch	3.4	2.4	3.2	46.6	16.7	29.4
Ruffe	0.2	0.6	1.3	2.7	4.2	11.9
Roach	0.5	7.5	1.6	6.8	52.1	14.7
Bream	1.8	-	0.1	24.7	0.0	0.9
Total	7.3	14.4	10.9	100.0	100.0	100.0

Although the fish stock is still dominated by percids to a large extent, a marked increase in cyprinids was observed in 1991 (Table 2). Fish-scale readings show this to consist mainly of larger bream and roach, 4 to 8 summers old, which means that these fish must have come into Lake Volkerak/Zoom from outside. Since bream are sexually mature in their fifth year (Van Densen et al., 1990), and roach in their third to fourth year, it must be concluded that in 1992 the lakes contained a breeding population of both species. Thus, the growth potential of the whitefish stock, in principle, has increased. However, whether this potential will be realized, mainly depends (apart from climatological conditions) on the numbers eaten by predators.

Since 1988 pike has been present in the lakes, although in limited numbers (Table 1). The occurrence of this predator is associated with the presence of well-developed, varied water and bank vegetation (Grimm, 1989). The most extensive pike populations (up to 75 kg/ha) are found in waters with an emergent bank vegetation of about 10-15%, and submerged water vegetation of about 40-60% of the total surface area. The present conditions in Lake Volkerak/Zoom, with a submerged water vegetation covering about 15% and emergent bank vegetation less than 1% (Iedema et al., 1992, this volume), are thus not sufficient to maintain a considerable, self-supporting pike population.

Natural habitat for pike

Water plants demand clear water

Blue algae, the threat of eutrophication

Fish management as a tool for water management

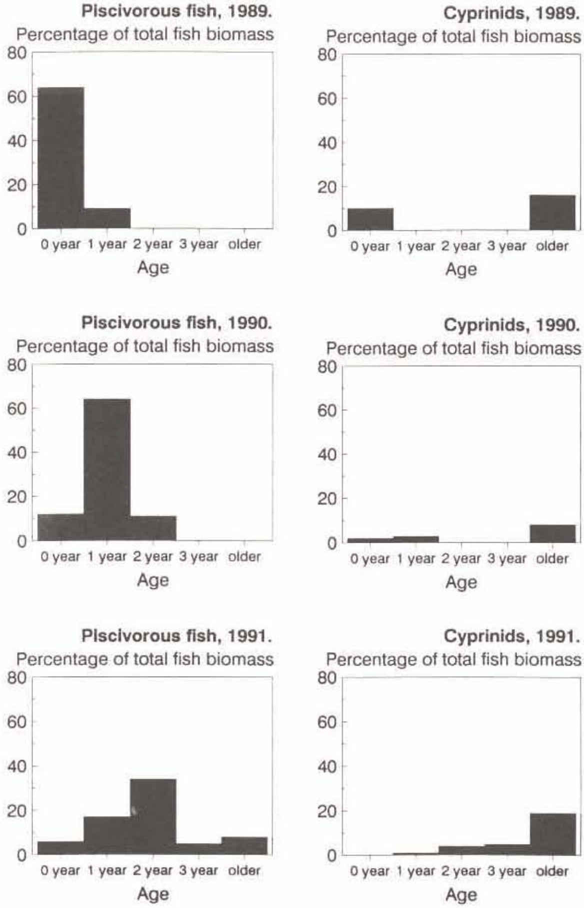

Figure 3 Age structure of the predator and whitefish stock for the years 1989-1991. The predator stock consists of perch and pike perch, and the whitefish stock of roach and bream.

4 PROGNOSIS FOR THE LAKES WITHOUT MANAGEMENT

As described above, presently the clear Lake Volkerak/Zoom with a fish stock dominated by percids, especially perch, largely resembles the characteristic of type I perch waters (cf. Figure 1). Because vegetation development is insufficient, pike only constitutes an insignificant part in the fish community. Figure 1 shows that a water system in which perch is the main predator will only remain permanently clear if the P concentration is less than 0.04 mg P/l. This implicates that, even after the removal of excess phosphates (Van den Hark et al., 1992, this volume) when the P concentration is expected to be 0.08 mg P/l, the aquatic system will not remain permanently clear, but will turn into a turbid water.

5 ECOLOGICAL OBJECTIVES

To establish a permanently clear water system at a P concentration around 0.08 mg P/l, it is necessary to develop a water of a pike/tench type (compare Figure 1). To this end it is essential to create a favourable habitat for pike and to promote the growth of the pike stock.

At the present level of water clarity with Secchi disk readings beyond a depth of 2 m (Van den Hark et al., 1992, this volume) the lake bottom is expected to become covered with vegetation to a depth of at least 3 m, representing a water area of 30 % of the total surface area (Iedema et al., 1992, this volume). Thus an estimated 70 % of Lake Volkerak/Zoom will consist of open water with sparse vegetation. Taking this into account, the ecological potential with a controlled fish-stock development can be assessed as follows (Ligtvoet and Grimm, 1992):

- the shallower areas (above NAP -3 m [NAP = Normaal Amsterdams Peil, the reference level in the Netherlands]), overgrown with submerged and bank plants, have potential for the development of the pike/tench community, with pike as the dominant predator;
- the deeper areas (below NAP -3 m) comprising 70% of the waters have potential for the development of a predator stock dominated by perch and pike perch, with larger pike (>60-70 cm) as an associated predator.

As originally perch and pike are the dominant predators in clear waters in the Netherlands and the potentials of pike perch (generally associated with turbid waters) in controlling prey-fish stocks are still uncertain, quantifying management objectives for fish stock development are concentrated in the first instance on perch and pike, as described below.

6 QUANTIFICATION OF MANAGEMENT OBJECTIVES

The ecological objective formulated above is a qualitative one, providing little basis for specific targets for an effective and decissive management. The following important questions should be answered:

1) what densities of the pike and perch stock are required for lasting control of the cyprinid stock?
2) what are the required dimensions and structure of the pike habitat?
3) what is the allowable density of the cyprinid stock whilst the pike stock is not fully developed and perch is the most important predator?

6.1 Desirable predator stock

Grimm et al. (1992) present a model for estimating the potential consumption of plankton-eating prey fish by perch and pike. If the prey-fish stock is to be controlled by these two predators, consumption by the predator should equal the overproduction of prey fish. Grimm and Backx (1991) find indications that, parallel to the total fish biomass (Figure 1), also the gross production of planktivorous prey fish is correlated with the P concentration. By inferring the prey-fish production from the P concentration, and allowing an overproduction of the prey-fish stock to replenish the losses of the adult stock, it is possible to calculate the size of the perch and pike stock needed to consume the remaining production of planktivorous prey fish.

The calculation of the potential consumption is based on that part of the predator population that depends mainly on fish as a source of food. Pike are obligately piscivorous from about 10-15 cm. Perch, on the other hand, eat mainly large zooplankton, insect larvae and small freshwater shrimps until they reach a length of about 15 cm. Perch between 15-25 cm eat 50% fish, and only when they grow larger than 25-30 cm they become obligatory fish-eaters.

Applying the production/consumption model to the target situation with a favourable shallow-water habitat for pike and deep-water habitat for perch, and estimating a basic production level of perch based on literature data, it is estimated that in combination with the perch stock, a pike stock of about 30-40 kg/ha is required to control overproduction of planktivorous fish (Table 3).

Table 3 Estimation of the required pike stock using the production/consumption model of Grimm et al. (1992), based on a P concentration of 0.08 mg P/l. Given are the average stock size (= total fish biomass, Figure 1) at this P concentration and a 15% margin. Based on literature data a maximum basic production of 5-6 kg/ha for fish-eating perch is estimated. By Ligtvoet and Grimm (1992).

		Average	15% margin
(1)	Total fish stock	130	110 - 150
(2)	80% planktivorous fish production: 0.8 x (1)	100	88 - 120
(3)	20% necessary overproduction; rest of planktivorous fish production: 0.8 x (2)	80	70 - 96
(4)	Basic production fish-eating perch	5 - 6	
(5)	Food conversion efficiency = 0.16-0.18		
(6)	Basic perch consumption: (5)x(4)	28 - 38	
(7)	Necessary pike consumption: (3)-(6)	42 - 52	32 - 68
(8)	Food conversion efficiency = 0.16-0.2		
(9)	Necessary pike production: (8)x(7)	7 - 10	5 - 14
(10)	Production/biomass ratio = 0.25		
(11)	Necessary pike stock (9)/(10)	28 - 40	20 - 56

However, the production - and thus the consumption - of a predator population is linked to the population structure. Where larger and older predators are dominant, the juvenile predator stock can be seriously depleted by cannibalism, particularly in situations where prey fish are scarce (see also Section 3). This population dynamical process has been demonstrated in a pike population in the Jan Verhoefgracht (Maarseveen), where after a strong reduction of the numbers of larger pike due to a extremely high winter mortality, the production of year class and one year old pike was found to be 3-5 times larger (Grimm, unpublished data). Therefore, to stimulate the production of the predator stock and to reduce the number of juvenile predators killed by cannibalism, a fishing management in Lake Volkerak/Zoom is advocated aiming at the reduction of the larger, older and potentially cannibalistic specimens from the predator population.

6.2 Desirable pike habitat

The abundance and structure of the pike stock in a water is mainly determined by the emergent vegetation and especially those plant species which remain available throughout the year (e.g. reed, ingrowing willows). The emergent vegetation provides both an important breeding area for adult pike and a sheltering area for their young. The areas covered with submerged vegetation are colonized by young pike from the emergent bank vegetation.

Data from a number of pike waters have been used to quantify the relationship between the emergent vegetation and the pike biomass. It appears that on average an area of emergent vegetation covering 1% of the total surface area represents a pike stock of about 4.5 kg/ha. The recruitment of young pike is, amongst other factors, determined by the emergent vegetation: from each hectare of emergent vegetation some 4000-5000 young pike of 10-15 cm long may recruit, corresponding to 200-400 kg/ha. This means that, with a maximum young pike biomass of 75 kg/ha in the submerged areas, from 1 hectare of emergent vegetation about 3-5 ha of submerged vegetation can be occupied.

On the basis of these guidelines concerning the relationship between vegetation cover <-> pike biomass and emergent <-> submerged vegetation, the desired area of the emergent and submerged areas of vegetation in Lake Volkerak/Zoom have been estimated at respectively 6-9% (325-490 ha) and 24-36% (1300-1950 ha) of the total lake area (Table 4). Given that, with the present water clarity of the lakes, 30% of the total surface area has potential for plant growth (depth < NAP -3 m), adequate pike stock development in principle is possible, subject to the development of emergent water plants. A total vegetation coverage of 30% (6% emergent + 24% submers) represents the lowest limit of the conditions under which the predator stock is expected to regulate the prey stock. The margins for a durable stable system are thus very small. In order to establish a more robust ecosystem in Lake Volkerak/Zoom an aim of a total vegetation cover near 40% would be desirable.

Until the vegetation has developed to the required level, the structure of the pike population can be manipulated by removing the larger fish so as to create the conditions for a relatively high stock production. The lowest limit as to the vegetation development, at which a pike stock in combination with the perch stock is expected to regulate the numbers of plankton-eating fish, is a total coverage of 20-25% of the total lake area, including 4-5% emergent vegetation (Table 4). As indicated above, however, this cannot be regarded a stable and robust end-situation.

6.3 Allowable cyprinid stock

Perch is not capable of suppressing the growth of the whitefish stock at a summer average phosphate concentration of around 0.08 mg P/l (compare Figure 1).

Table 4 Objectives for establishing Lake Volkerak/Zoom as a pike habitat, showing the desired areas of emergent bank vegetation and submerged vegetation, at a P concentration of 0.08 mg P/l. The situation for a high-productive stock of fished pike is given for comparison.

Pike stock production level		Normal	High
Necessary pike stock kg/ha		28-40) [1]	18-20 [2]
Emergent veg. zone	% lake area	6-9	4-5
	surface (ha)	325-490	210-270
Submerged veg. zone	% lake area	24-36	16-20
	surface (ha)	1300-1950	840-1080
Total veg. zone	% lake area	30-45	20-25
	surface (ha)	1625-2440	1050-1350

[1] See Table 3
[2] Ligtvoet and Grimm (1992)

Table 5 Estimation of the potential predator fish stock (kg/ha), consisting of perch, pike perch subject to fishing, and the maximum allowable cyprinid stock (kg/ha). The targeted maximum predator/prey (P/P) ratio for perch and pike perch is 1:1. Taken from Ligtvoet and Grimm (1992).

	Anticipated predator stock	P/P ratio	Permissible cyprinid stock
Perch	15-25	1:1	15-25
Pike perch	3-5	1:1	3-5
Total	18-30	1:1	18-30

Table 5 gives an indication of the allowable stock size of cyprinids in relation to the expected size of the predator stocks. In view of the uncertainties in estimating to what extent perch and pike perch are capable of regulating the numbers of cyprinids in Lake Volkerak/Zoom, we advocate that it is desirable to exercise the maximum caution in determining the permissible cyprinid stock. Taking this into consideration, the predator/prey ratio for these predators has been conservatively estimated at 1:1. This conforms with the relationship which Jeppesen et al. (1990) found between planktivorous fish and predators in permanently clear, perch-dominated waters. Thus, in the actual situation in Lake Volkerak/Zoom, where pike does not yet play a significant role, the cyprinid stock should not amount to more than 20-30 kg/ha (Table 5).

The regulating capability of pike is assessed to be higher (maximum predator/prey ratio 1:2; Grimm et al., 1992). When the pike stock in the lakes has reached the desired level of about 28-40 kg/ha, the allowable cyprinid stock may roughly fluctuate between 70-110 kg/ha, assuming the values given for perch and pike perch in Table 5 are as well representative for that situation.

7 STRATEGY

The targets formulated for the structure of the fish stock and vegetation, and the status in 1991, lead to the following strategy:
1. Nature development: the development of the required habitat for pike, together with promotion of the pike stock;
2. Fish stock management: until the pike stock is sufficiently developed the present predator fish stock should be sustained at a high production level and the development of the cyprinid stock retarded.

1) Iedema et al. (1992, this volume) investigates the possibilities of creating a sufficiently large pike habitat in the short term. The most important conclusion is that the instigation of a 40 cm fluctuation in water level (high in winter, low in summer) will bring about an important increase in emergent vegetation, mainly as a result of the improved helophyte colonisation of the shallow water area. This regime is expected to create a pike breeding area of about 230 ha. Given the estimated area of emergent vegetation around 300-400 ha (Table 4) required for breeding biotopes, it must be concluded that setting up a sufficiently large variation in water level in Lake Volkerak/Zoom could be an important contribution to the creation of an adequate pike breeding area in the short term.

2) In order to realize the maximum production of the perch and pike perch stock through the greatest possible recruitment of young fish, it is desirable to minimize the chance of the new cohorts being decimated by cannibalism. It is suggested that this is to be effected by control fisheries, removing the larger and older predators from the fish population.

Two types of control fishery are suggested to retard the expansion of the cyprinid stock:
- removal of sexually mature cyprinids during the breeding season;
- removal of concentrations of cyprinids which occur in winter.

In Ligtvoet and Grimm (1992) the specific details (period, gears, areas to be fished) regarding the suggested control fisheries are given.

8 IMPLEMENTATION

Within the framework of the management agreement of the Bestuurlijk Overleg Krammer-Volkerak (Krammer-Volkerak Managerial Consultation Agreement), the Ministry of Agriculture, Nature Management and Fisheries has set up a management advice commission for the fish stock and fishery in Lake Volkerak/Zoom. This commission comprises: the director of Agriculture, Nature Management and Recreation of the Province of Zuid-Holland and representatives of the professional fishermen (permit-holders for the eel fishery), the Organization of Recreational Fishermen (authorized issuer of licences for fishing scale fishes) and Rijkswaterstaat, Directorate Zeeland (responsible for water quality management). In April 1992 the commission gave its agreement to the fish-stock management plan as formulated by Ligtvoet and Grimm (1992) and broadly outlined in the foregoing Sections. Recognizing that Lake Volkerak/Zoom as ecosystem is still in the development stage, the management advice commission considers it advisable to assess the management on a yearly basis, so as to anticipate the (possibly unexpected) developments in the system in a proper and timely manner. The management measures necessary for carrying out the fish-stock management plan will be assessed and specified in detail each year, on the basis of an evaluation of the most recent available data. The control fisheries will be carried out by the professional fishermen operating in Lake Volkerak/Zoom.

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TOUGH MEASURES FOR A WEAK SYSTEM

C.W. Iedema, J. Schutten and J.A. van der Velden

1 INTRODUCTION

In the night of 17 April 1987 the tidal heartbeat disappeared from the eastern part of the Eastern Scheldt forever, when the closure of the final gap in the Philips Dam cut off the area behind the dam from the tidal influence of the North Sea. Where once the sea had reigned supreme, the rivers and the water from the polders now had the upper hand. It was the dawn of a new ecosystem: Lake Volkerak/Zoom. It was by no means purely a matter of course that this new lake would develop into a valuable freshwater system. In addition to the excessive volume of pollutants that the lake would have to contend with from the Hollandsch Diep and the rivers flowing down from Brabant, changes in the lake itself might impede its development into a sustainable and healthy system. To forestall such problems and to enable Lake Volkerak/Zoom to develop to its full potential, it was necessary not only to stimulate major clean-up operations upstream and to restrict the influx of polluted water into the lake, but also to guide the changes taking place in the system from the very beginning.

2 CLEAR WATER AND BIODIVERSITY

The aim for Lake Volkerak/Zoom is to create a clear-water environment that supports a wide variety of species and attracts a large number of waterfowl. The clarity of the water plays a crucial role in this plan, as does the development of the shore areas. The former is threatened by the excessive level of phosphates in the lake (Van den Hark et al., 1992, this volume). The shore areas are under threat from erosion. In addition, the growth of vegetation along the shores of the lake is limited by the aim of keeping the water at NAP (Normaal Amsterdams Peil, the reference level in the Netherlands). Once all the proposed clean-up operations in the drainage area have been completed, the phosphate level will fall. Although it will not fall so drastically as to restrict the development of algae (Van den Hark et al., 1992, this volume), it is expected that, with careful management, it can be reduced to the point that the water might remain clear. With a phosphate level of 0.10 mgP/l, algae can be restricted in waters where at least 30% of the surface is covered with aquatic plants and in which predatory fish are dominant (Ligtvoet and Grimm, 1992; Van den Hark, 1992). In this situation the grazing pressure of zooplankton would be high. An essential condition for a healthy population of predatory fish, such as pike, is the availability of sufficient breeding areas in the form of half-open vegetation (helophytes) growing in the water or grasslands that flood during the spring. Although it is difficult to specify exact quantities, it is assumed at present that this would need to be at least 5% of the total surface area of the lake, corresponding to approximately 300 hectares (Ligtvoet and Grimm, 1992). In summary, if Lake Volkerak/Zoom has at least a 30% covering of aquatic plants, a half-open vegetation in the outerbank areas amounting to more than 5% of the total surface area of the lake and a ratio of predatory to planctivorous fish greater than 1:2, the water will remain clear at the level of phosphates expected from 1995 on (Table 1).

Table 1 Criteria for a healthy Lake Volkerak/Zoom with clear water, at a phosphate level of 0.10 mgP/l

Criteria	
clarity (m)	2-3
aquatic plants (covering in %)	>30%
helophytes (ditto)	>5%
predatory fish/planctivorous fish	>0.5

3 AQUATIC PLANTS

Many typical marine plant species (such as eelgrass (*Zostera spec.*)) disappeared during the desalination process. Wigeon grass (*Ruppia maritima*), an aquatic plant that lives in light brackish water, managed to survive and even thrived for a time. The first freshwater plants appeared in 1988, after which colonisation of the lake by freshwater and other aquatic plants from drainage and adjoining water systems began to gather pace (Figure 1) (Schutten et al., 1991). Pondweed (*Potamogeton pussilus*) in particular spread very rapidly. In 1990 and 1991 stonewort (*Chara*) and starwort (*Callitrichaceae*), species that are characteristic of clear-water environments, began to appear.

Where the lake is up to 0.5 m deep, there are practically no higher aquatic plants, due to the effects of waves and waterfowl. At depths greater than 5 m, there is also little plant life due to lack of light. The majority of the biomass in the lake is therefore found at a depth of between 0.5 m and 2.5 m (Figure 2). The zone between 0.5 and 5 m deep, which could support aquatic plant life at the current level of water clarity, accounts for about 50% of the total surface of the lake bottom. In 1991 approximately 22.5% of this zone was covered with higher aquatic plants, the equivalent of about 11% of the total surface of the lake.

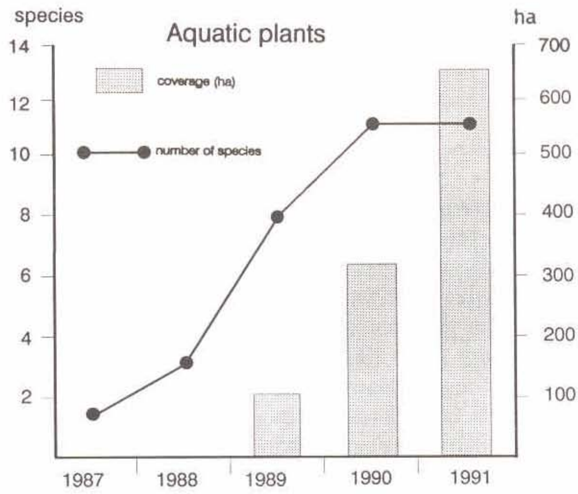


Figure 1 The diversity of species of aquatic plants has decreased considerably since the closure of the lake

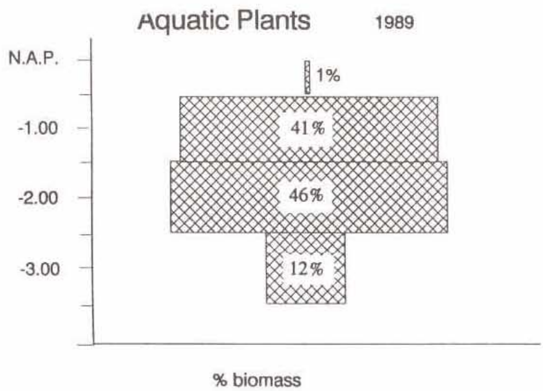


Figure 2 Most aquatic plants are found where the water is between 0.5 and 2.5 m deep

If the water remains clear, with a visibility to a depth of 2 to 3 m, 30% plant cover is feasible. It is expected that this can be achieved by 1995. The composition of the plant life will also change, with a greater proportion of clear-water species. However, if the current high visibility falls to between 0.5 and 1 m, plant cover of between 1 and 8% is expected, with reduced diversity of species and structure. Only plants which grow horizontally on the surface, such as sago pondweed (*Potamegoton pectinatus*) and perfoliate pondweed (*Potamegoton perfoliatus*), will be able to survive. The growth season will be shorter, and with it the primary production of aquatic plants will decrease. If there is a dense population of planctivorous fish, new plant shoots will be eaten, restricting plant growth even further.

A shortage of protective plant cover for zooplankton will increase the predatory pressure of fish on these organisms and decrease the grazing pressure on algae.

4 HELOPHYTES

Sea club-rush (*Scirpus maritimus*) and glaucous club-rush (*Scirpus lacustris ssp. tabernaemontani*) already grew on the former salt marshes. Other vegetation began to appear on most of the desalinated parts of the shore zone after the closure of the dam. In 1990, 30 species of helophytes were recorded, 6 more than in 1989. So far, only species resilient to brackish water in the germinating environment have managed to thrive in the most desalinated areas of the shore (Schutten et al, 1991). Reed (*Phragmites australis*), reedmace (*Typha spec.*) and marsh fleawort (*Senecio congestus*) seeds are carried massively by the wind. Further growth is hindered by the lack of suitable germinating zones, which are restricted mostly to a small waterlogged strip along the water's edge. In 1991 reed was found growing into the water along the shore to a depth of NAP -0.20 m, sea club-rush to -0.35 m, bulrush (*Scirpus lacustris ssp. lacustris*) to -0.15 m and large reedmace (*Typha latifolia*) to -0.10 m (Figure 3). Helophytes spread into deeper water very slowly, which may be partly due to grazing by birds. In 1991 less than 1% of the zone between NAP and NAP -0.50 m was covered with vegetation.

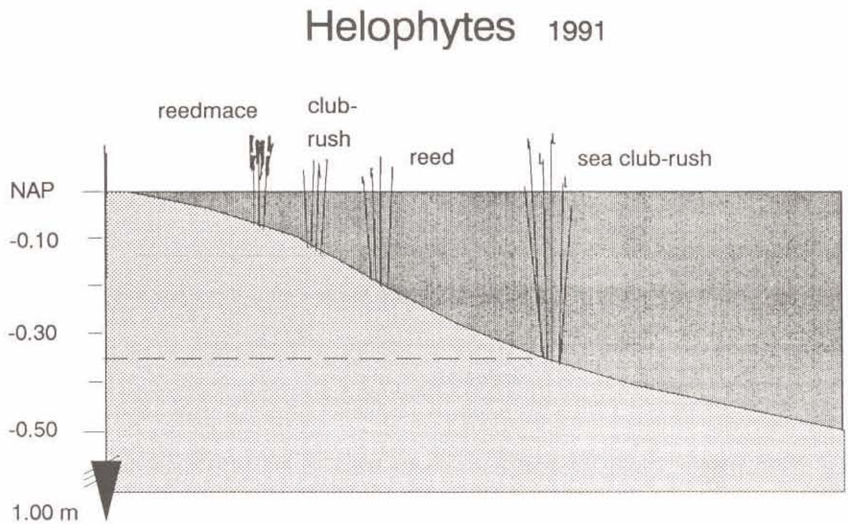


Figure 3 Helophytes do not grow far into the water

With a fixed water level the spread of helophytes is restricted by the almost total absence of suitable conditions for seeds to germinate, grazing by birds and the effect of waves on the young seedlings (Van der Velden et al, 1992). The presence of large numbers of waterfowl along the shores of the open water will restrict the spread of helophytes into the water. It is expected that this vegetation will grow to a depth of about 0.5 m, with only bulrush possibly growing to a depth of 1 m. In more sheltered areas, such as inlets, helophytes may thrive more successfully. It is estimated that roughly 10 to 35 hectares of the lake surface will ultimately be covered with half-open vegetation growing in the water, which will then be suitable as breeding grounds for pike (Van der Velden et al, 1992).

5 FISH (see also Ligtvoet, this volume)

Until 1990 the build-up of the freshwater fish population was largely determined by the introduction of fish larvae via the waters flowing into the lake. Ruffe (*Gymnocephalus cernua*) was the only species to reproduce with any success. Great quantities of perch (*Perca fluviatilis*) and pike perch (*Stizostedion luciopercia*) larvae were introduced via the influx waters. In 1991 the import of larvae was practically nil due to the cold spring, although this was the first year in which adult fish - particularly bream (*Abramis brama*), roach (*Rutilus rutilus*) and pike perch - entered the lake. The development of the fish population in the lake until now reflects the pioneering state of Lake Volkerak/Zoom. Perch and pike perch continue to be the most dominant species (Figure 4). In 1991 the ratio of predatory fish to planctivorous fish was very high, approximately 3:1 in Lake Volkerak and even higher at approximately 5:1 in Lake Zoom.

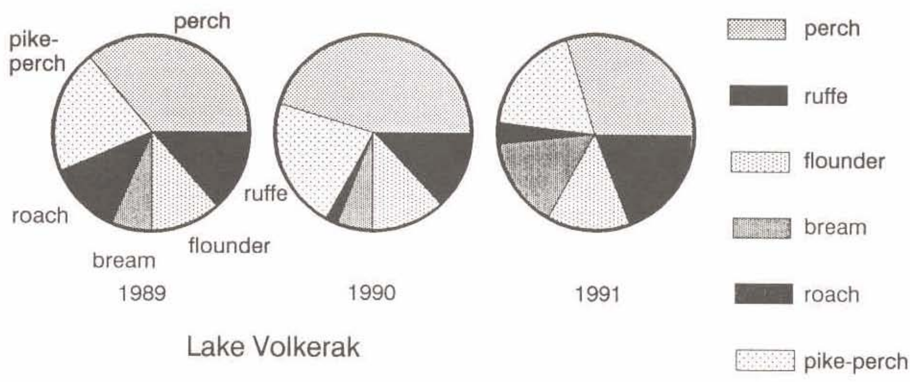


Figure 4 The fish population is still dominated by perch and similar species

The biomass of freshwater fish increased sharply until 1990, to reach 76 kg/ha in Lake Volkerak and 25 kg/ha in Lake Zoom. In 1991 it decreased noticeably to 60 kg/ha in Lake Volkerak and 17 kg/ha in Lake Zoom. This unexpected fall was primarily due to insufficient numbers of freshwater fish entering the lake in 1991 and an inexplicably high death rate among the perch and pike perch. There was a particularly high increase in planctivorous fish from less than 5 kg/ha in 1990 to about 16 kg/ha in 1991. This was partly the result of the influx of adult bream in 1991.

Further development of the fish population depends largely on the phosphate level in the waters. At current levels the lake could support approximately 130 kg/ha. Without interference this would consist of approximately 100 kg/ha of planctivorous fish and 30 kg/ha of predatory fish. On the basis of developments so far, this trend should become visible from 1993/1994. From then on the chances of the lake developing into a turbid, algae-rich system would be considerably increased.

6 CONTROLLED DEVELOPMENT OF THE ECOSYSTEM

Developments so far and prognoses suggest that the preservation of a clear-water system is threatened by the expected changes in the fish population and the inadequate development of helophytes (Figure 5). Now the expectation is that the phosphate load can be reduced to the maximum permissible level from 1995, efforts should be made to prevent the water from turning green and turbid before that time. This means that the system must be rendered sufficiently robust to retain its clarity at the expected phosphate levels. Active fish management has been introduced in 1992 in an attempt to prevent the lake from being over-populated by bream (Ligtvoet, 1992, this volume). It is also crucial that sufficient suitable habitat is available in the near future to provide a structural basis for the preservation of a productive pike population.

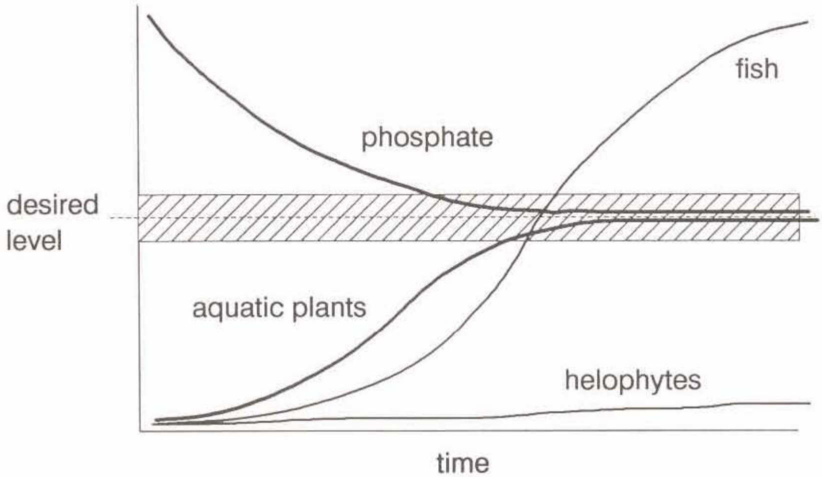


Figure 5 The development of the fish population and the helophytes pose a threat to the clarity of the waters of Lake Volkerak/Zoom at present phosphate levels

6.1 Shore protection

One of the first steps required to guarantee the preservation of the shoreline and areas, where there is a gradual transition from land to water, was to prevent erosion. To this end, since 1987 protective shore defences have been introduced around the whole Lake Volkerak/Zoom, where possible along the foreshore. In addition to preserving the existing areas of land and shallow water, the purpose of these indirect forms of protection is to create a sheltered zone behind the defences in which natural processes have optimal opportunity to develop. Sufficient openings have been provided to allow the deep and shallow water to function as a single ecosystem. Work on the outer bank defences has already been started in the areas most susceptible to erosion. By the end of 1990 some 18,500 m of foreshore, including the Noordplaat, the Krammer mud flats, the Dintelse Gorzen and the Hellegatsplaten (Figure 6), had been treated, providing protection for large areas of shallow water and exposed land. Where outer bank defences are in place, no deterioration of the shoreline has yet been observed. A certain amount of erosion has occurred as a result of the protective work being carried out in phases, due to considerations of cost. A total of approximately 100 ha of the exposed land in the Krammer-Volkerak and 4 ha in Lake Zoom have been turned into shallow water areas since the closure of the lake as a result of erosion. This is 5.5% of the total of some 1,800 ha of exposed land. The plan is for all endangered shores in Lake Volkerak/Zoom to be protected by 1995.

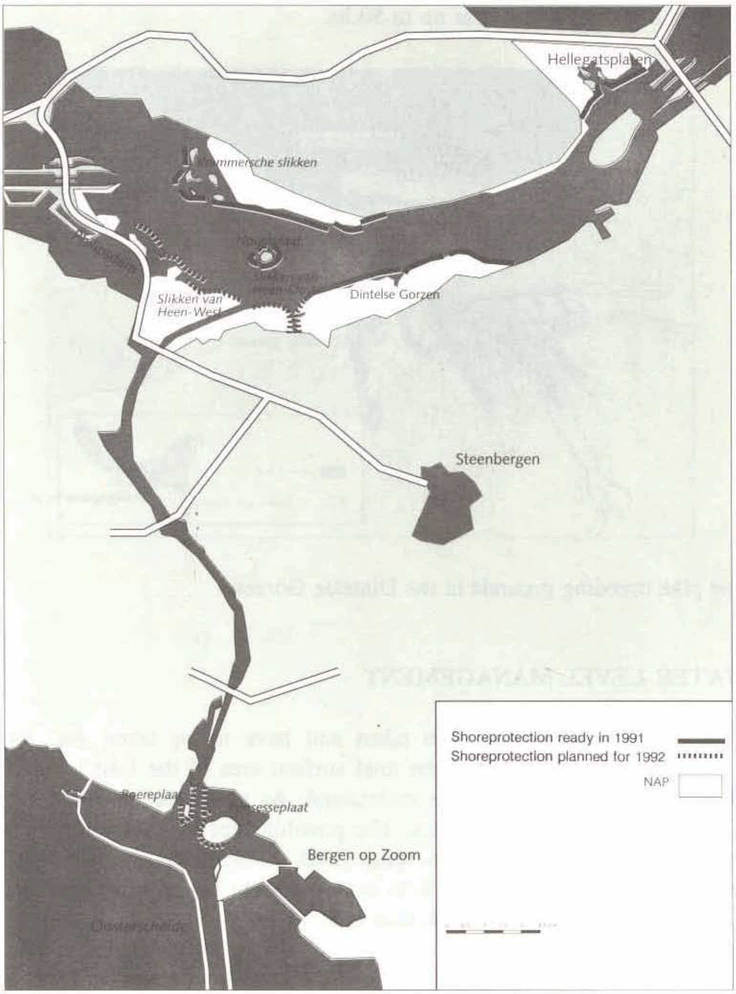


Figure 6 Shore defences already in place or planned before 1992

6.2 Habitat development

In addition to the preservation of the existing shore areas, new shore and shallow-water zones are being created to extend the total length of the shoreline. This serves to increase the total area in which helophytes can grow, thereby also creating more potential breeding grounds for fish, particularly pike. Small islands have been created, such as the Noordplaat and others near the Hellegatsplaten and Oude Tonge. Inlets that had filled up with sand have been restored and shallow-water areas have been deepened in places. A special breeding area for pike has been constructed on the site of a former inlet in the Dintelse Gorzen (Figure 7). These activities follow the existing morphology of the system as far as possible. The creation of the islands has extended the length of the soft shoreline by almost 25% (excluding the edges of the channels in the exposed areas). The additional pike breeding area has increased the length of the shoreline by a further 4,800 metres. It is expected that by 1995 the total length of the shoreline will have been extended by at least 50%, resulting in breeding grounds of up to 50 ha.

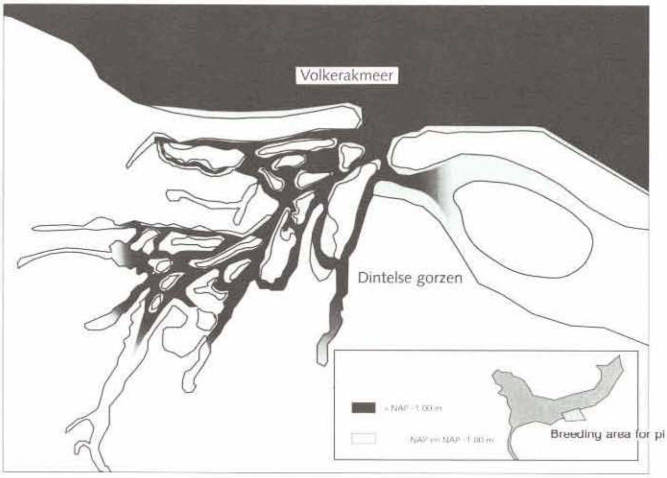


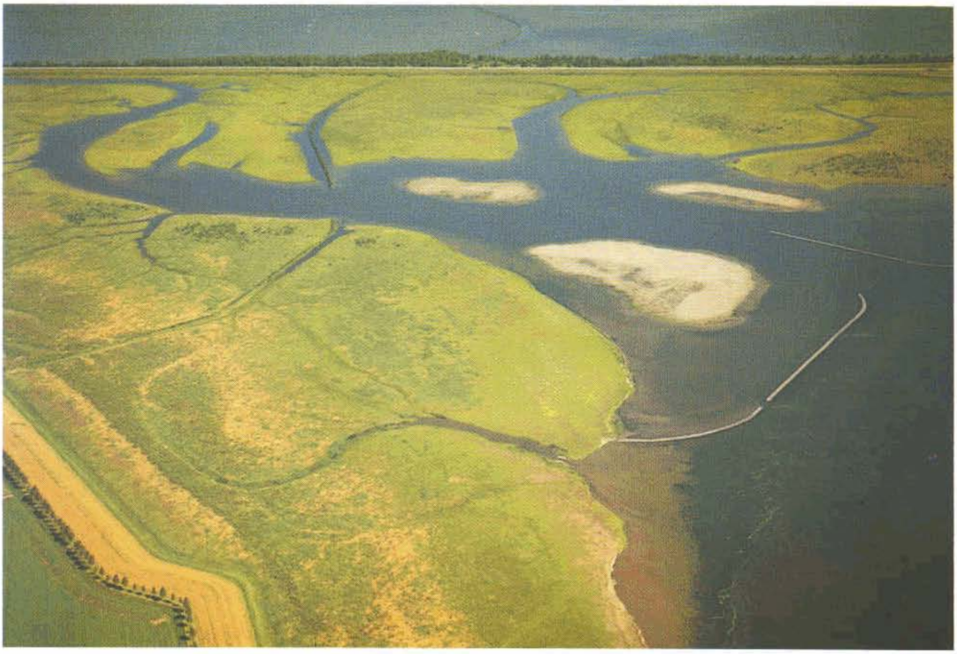
Figure 7 The pike breeding grounds in the Dintelse Gorzen

7 WATER LEVEL MANAGEMENT

In spite of the steps which have been taken and have to be taken yet, the target of helophytes covering more than 5% of the total surface area of the lake is not expected to be achieved if the present water level is maintained. As mentioned above, the fixed water level restricts the expansion of helophytes. The possibilitities have therefore been explored of allowing a more natural variation in water level, between NAP +0.15 m (the upper limit for the shore defences) and NAP -0.25 m (the present lower limit), giving differences in level of 20, 30 and 40 cm (Van der Velden et al., 1992).

If water was allowed to flow into the lake only if the level fell below the lower limit and to flow out if the upper limit was exceeded, a natural situation would develop with high water levels in the winter and low levels in the summer (Figure 8). This would provide optimal

Shore protection with newly developed islands



Krammerse Slikken

Hellegatsplaten

Formal tidal flat with shore protection

Mat rush (*Scirpus lacustris*) florish in shallow areas conditions for the growth of vegetation in the exposed shore zones and the plants would be less susceptible to grazing once the vegetation zone had expanded in breadth. A further advantage of this approach is that less polluted water needs to be let into the lake (Behrens, 1992, this volume).

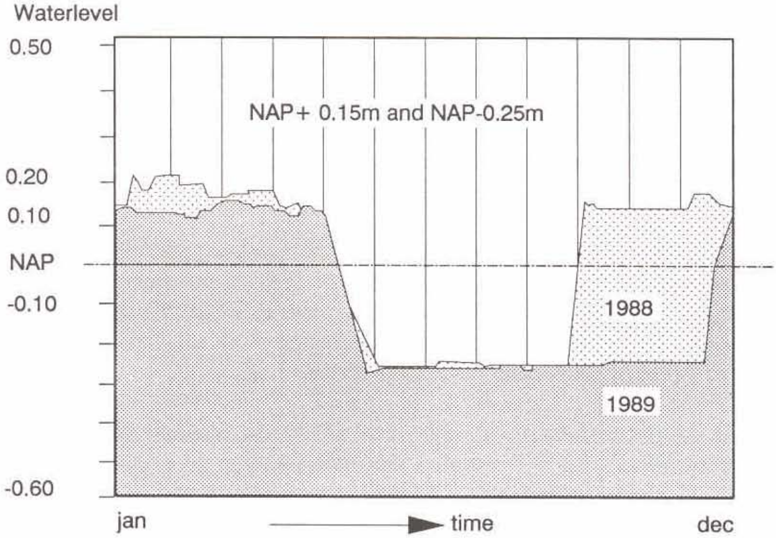


Figure 8 A more natural variation in water level

7.1 Development of the shoreline

Alternative water levels have been assessed in terms of their effects on the helophytes that provide breeding grounds for pike and a natural habitat for waterfowl. Since pikes require a water depth of at least 25 cm for breeding, it was decided that the water should be between 0.25 and 0.60 m deep in the pike-breeding grounds, with half-open vegetation partly consisting of perennial species (verbal information from M. Grimm). Apart from being a requirement for a clear aquatic system, extensive and healthy helophytes also provide a favourable habitat for waterfowl and are crucial for the area's value as wetland.

It is also assumed that, if the water level rises or falls by 1 cm, 10 ha of the shore zone will be affected. This is based on the morphology of the system at the time of closure. When the total length of the shoreline has been increased, as described above, a larger area - ultimately amounting to 15 ha - will be affected.

Under the present policy of maintaining the water level, there will not only be insufficient breeding grounds for pike, but the lake's potential as a habitat for waterfowl will not be exploited to the full. The breeding areas for shore birds, such as plover (*Charadriidae*), tern (*Sternidae*) and avocet (*Recurvirostra avosetta*), will be threatened by the advance of terrestrial vegetation, and freshwater wading birds, such as black-tailed godwit (*Limosa limosa*), ruff (*Philomachus pugnax*) and sandpipers, will depend on a steadily decreasing strip of shoreline for their food supply.

If the water level is allowed to rise and fall more naturally, with a difference of 20 cm between the summer and winter levels, the shore zone will be able to develop more successfully. In this situation the time at which the level falls is crucial. If it falls before 15 May it will largely be the helophytes (such as reed and club-rush) that germinate and if it falls after 15 May it will mainly be annuals, such as marsh fleawort. Helophytes that are already present have a better chance of spreading into the shallow water. The vegetation zone will, however, be quite narrow in most places with 20 cm variation in water level, whereby the grazing density of geese, which largely feed along the edges, will be relatively high. All in all, the vegetation cover in shallow water (<0.50 m) will not be more than 2-7%. Since pikes require a water depth of at least 0.25 m to breed, they will not be able to make use of the submerged zone in the spring, restricting the total amount of vegetation suitable as pike breeding-grounds to between 15 and 50 ha.

Ducks, such as pin-tail (*Anas acuta*), wigeon (*Anas penelope*) and teal (*Anas crecca*), will benefit in the autumn from the large quantities of seeds from grasses and annuals which germinate in the exposed areas in the spring. In years in which the water level falls early, there will be limited breeding space for ground-nesting birds and freshwater waders will be able to forage in the exposed zone for a short period.

With a more natural difference in water level of 30 cm between winter and summer, a narrow strip of helophytes will develop that will function as a permanent zone for the colonisation and recolonisation of the deeper areas. Grasses and annuals will be able to grow on the exposed land. Cover in this permanent strip could be between 10 and 50% and would be more resilient to grazing by herbivorous waterfowl. The chances of helophytes spreading into the shallow water are greater than those with a 20 cm variation in water level. This would result in a considerable increase in breeding grounds for pike to between 30 and 110 ha, however, still insufficient to reach the ultimate desired acreage of 300 ha. Waterfowl would also benefit from the more favourable conditions compared to a 20 cm variation in water level.

With a more natural variation in water level of 40 cm, a fairly wide strip of helophytes will develop that will be less susceptible to grazing by birds. Reed will be able to grow under water to a depth of about 0.5 m, bulrush to about 1 m and, where there is greater shelter, reedmace and reed sweet grass (*Glyceria maxima*) to about 0.8 m and 0.5 m respectively. In addition to reed, sea club-rush will also be able to grow in the flood zone, with assorted varieties of sedge (*Carex* spec.) in more sheltered spots. Vegetation in the exposed area would tend to be made up of reedmace and reed sweet grass, with reeds and rushes in quiet spots. The breeding grounds for pike will increase considerably and could be expected to reach between 95 and 230 ha, almost the aimed target. During the spring the shore areas would gradually be exposed, providing foraging grounds for migrant waders for about four weeks. Other parts of the shore without vegetation would provide a larger area for ground nesting birds. In the autumn there would be an ample supply of seeds for seed-eating and dabbling ducks in the half-submerged marshy zone and the shallow water. This wide strip of vegetation would also provide suitable breeding grounds for herons (*Ardeidae*), rails (*Rallidae*) and marsh harriers (*Circus aeruginosus*).

In summary, it can be concluded that the best guarantee of successful development of the shore zone is to allow a more natural variation in the water level, preferably of 40 cm, but certainly no less than 30 cm. In the latter case, large-scale measures will be necessary to develop the shore and the outer bank. If these measures are taken, the helophytes can be expected to increase in area by approximately 50%. The greater the variation in water level, the greater its effect will be on the total area covered by vegetation (Figure 9).

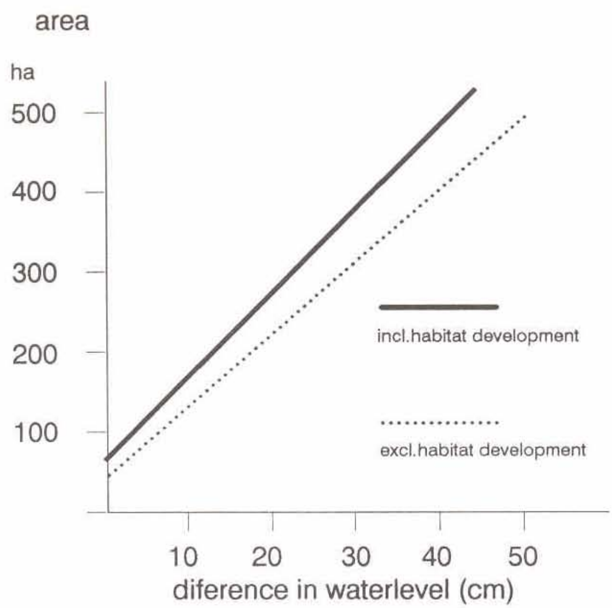


Figure 9 The more the shoreline can be extended, the greater the area affected by the water level

7.2 Optimal variation in water level

The above is based on a natural variation in water level, with intervention only occurring to keep the level within certain limits. In this way the differences in the water level will also vary naturally between wet and dry years. The situation described above will therefore only be achieved in the longer term. This may mean that in the first few years the water level might not be optimal for the development of the shore zone. The time at which the dry areas emerge is, for example, crucial for the germination of the vegetation and the time at which the level rises again has a considerable effect on the extent to which the young plants are washed away or grazed by birds.

The development of helophytes has a high priority at present in Lake Volkerak/Zoom. A variation in water level aimed at producing optimal conditions for the germination and survival of shore vegetation would make an invaluable contribution to this in the next few years. This would involve, for example, a gradual fall in the water level between mid-April and June from the winter to the summer level and subsequently maintaining the lower level throughout the first and possibly also the second winter (Iedema and Kik, 1985). This would provide a solid basis for further development and the water level would only need to be kept within the set limits.

8 EPILOGUE

Lake Volkerak/Zoom no longer has a tidal heartbeat. Intensive care was and continues to be necessary to help the system survive this shock. Before the lake can leave intensive care, it will have to be given a new pulse - a pulse that is strong enough to survive and yet will beat to the gradual change of the seasons.

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POSSIBILITIES OF A BIOLOGICAL FILTER WITH ZEBRA MUSSELS *DREISSENA POLYMORPHA* IN THE MANAGEMENT OF MICROPOLLUTANTS

R. Noordhuis, H.H. Reeders and E.C.L. Marteijn

ABSTRACT

Dreissena polymorpha is a freshwater filter-feeder that often occurs in large densities, attached to solid substrate like stones or shells of other bivalves. Through filtration and pseudofaeces production it can play an important role in water processing in lakes and rivers. This can be put to use by applying filtrating *Dreissena* in biological water management projects. To reduce deterioration of Lake Volkerak/Zoom through influx of micropollutants out of the rivers Rhine and Meuse, a large biological filter was proposed, consisting of vertical nets colonized by *Dreissena*. This paper describes the results of several experiments carried out to test possibilities, necessary dimensions and its impact. Theoretically about 70% of suspended matter can be removed from the water flowing into Lake Volkerak/Zoom and some important micropollutants may be reduced by 50% or more. Experiments with different types of filter-netting showed that colonization with spat is intense, but on most nets the mussels disappear before a full grown population has developed. The inability of the nets to support sufficient densities of mature mussels is a bottle-neck for conducting large scale experiments.

1 INTRODUCTION

The freshwater bivalve *Dreissena polymorpha*, or Zebra Mussel, invaded Western Europe in the course of the 19th century (review in Leentvaar, 1975). Nowadays it is common in many of our lakes and rivers and often occurs in large densities (up to tens of thousands per m^2; Bij de Vaate and Greijdanus-Klaas, in press). Just a few years ago the species appeared in North America where it has colonized the Great Lakes (Roberts, 1990). This colonizing potential is largely due to the production of huge numbers of free swimming larvae (to almost 1 million eggs per female). Like most bivalves, *Dreissena* is a filter feeder, living mainly on micro-organisms like bacteria and planctonic algae. Selection of food particles takes place on the ciliated surface of the gills and by the labial palps (Morton, 1969). Digestible particles are transported to the mouth, and after digestion faeces are produced that are excreted through the exhalant opening. Non-digestible particles are embedded in mucus and excreted through the inhalant opening as "pseudofaeces". These sink to the bottom together with the faeces. This means that due to filtration and pseudofaeces-production, the sedimentation rate of suspended matter is increased. Where densities of *Dreissena* are high, this may result in higher transparancy of the water. Several authors have stressed the importance of water processing by *Dreissena* to the ecosystem (e.g. Kryger and Riisgard, 1988; Reeders and Bij de Vaate, 1990; Reeders et al., 1989; Stanczykowska et al., 1975). Due to its large impact, *Dreissena* can be very useful in biological management of water quality. Apart from increasing transparancy (Hinz and Scheil, 1972; Noordhuis et al., in press; Reeders et al., in press; Smit et al., in press), *Dreissena* can be used to process micropollutants from the water column (Reeders and Bij de Vaate, in press). Micropollutants, of which a large part is attached to suspended matter, can largely be filtered out of the water column and concentrated on the bottom, which facilitates control.

2 BIOLOGICAL FILTER WITH *DREISSENA*

The bottom in Lake Volkerak/Zoom is less contaminated than many other lake bottoms in the Netherlands. However, this lake receives polluted water from the rivers Rhine and Meuse through the Volkerak sluices. The amount of water passing the sluices (on average

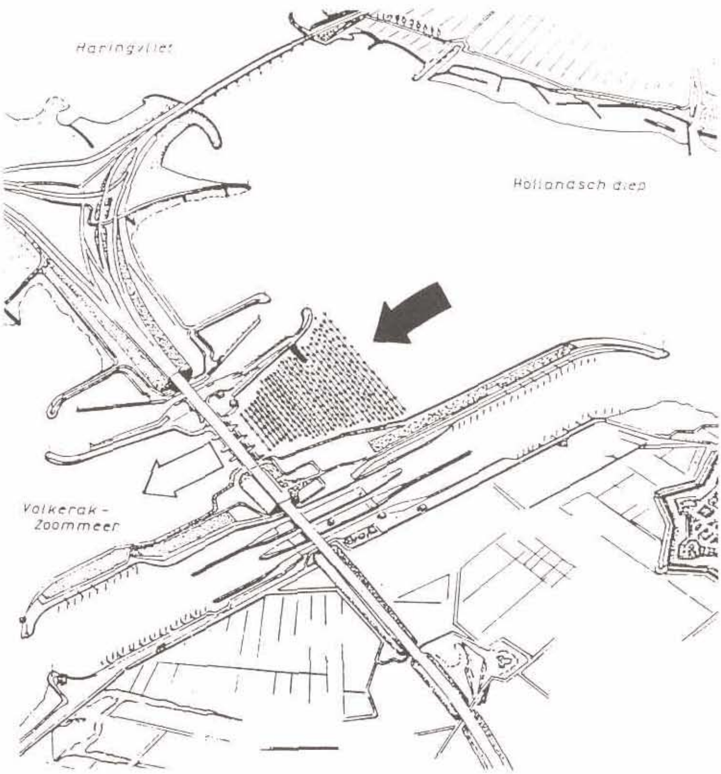

Figure 1 Location of the biological filter. Black arrow = river water flowing towards the filter. White arrow = water that has passed the filter and entered Lake Volkerak/Zoom

ca.14 m^3/s) has been minimalized, but inlet of river water is necessary with respect to agricultural needs and countering salt-stress (Behrens, 1992, this volume). Hence the influx of micropollutants remains a substantial threat (Schmidt, 1992, this volume). As a measure against this influx the construction of a large biological filter with *Dreissena* was proposed. Such a filter should be built in the supply canal of the sluices (Figure 1) and should consist of large vertical nets, colonized with mussels. In experiments carried out in Poland, nets like these were colonized by very large numbers of mussel larvae (Piesik, 1983). The nets should extend from bank to bank (300 m) and from surface to bottom (8 m), and be placed at right angles to the direction of water flow. To increase the efficiency of the filter many of these units should be placed in series. In order to be able to estimate the efficiency of a filter, experiments were carried out to determine filtration rate and pseudofaeces production of *Dreissena* (Reeders and Bij de Vaate, 1990, in press; Reeders et al., 1989). Concentrations of micropollutants in suspended matter, pseudofaeces and mussel tissue were compared in experiments carried out in 1988. In 1989 and 1990 colonization of filter nets with spat and subsequent changes of population structure were studied using different substrate materials.

3 FILTRATION RATE AND PSEUDOFAECES PRODUCTION

In 1987 we managed to measure the filtration rate of *Dreissena polymorpha* in undisturbed field conditions ("clearance rate", based on differences in extinction before and after filtration; methods are described in Reeders and Bij de Vaate, 1990). Adaptation to experimental conditions in lab experiments can take as much as 24 hours, which has often lead to comparatively low filtration rates (Reeders et al., 1989). Pseudofaeces production (faeces included) was measured in an experiment that was carried out in 1988 in a field lab using River Meuse water (methods in Reeders and Bij de Vaate, in press). The activity of the mussels was related to three variables in particular: 1. size of the mussel, 2. temperature and 3. suspended matter content.

1. Size:
   Both filtration rate and pseudofaeces production showed a sigmoid relationship with shell-length. A decrease in activity in the largest and oldest mussels was regarded as a sign of degeneration. The relations of filtration rate and pseudofaeces production with shell-length are best described by the equations:
   $FR = 15.43/(0.29+52.38\exp(-0.367L))$ ($R^2=0.59$; $p<0.001$)
   $PSP = 1.45/(1+34.87 \times 0.83^{L})$ ($R^2=0.56$; $p<0.001$)
   (FR = filtration rate in ml/mussel/hour, PSP = pseudofaeces production in mg dry-weight/mussel/hour, L = shell-length in mm).

2. Temperature:
   Activity (filtration rate and pseudofaeces production) showed a lower "winter level" and a higher "summer level", with a strong increase between 5 and 10°C. Over 10°C activity (especially in the River Meuse experiments) was hardly related to temperature. A similar pattern was also found in other bivalve species (Bayne et al., 1976; Walne 1972).

3. Dry matter content:
   Filtration rate decreases with increasing suspended matter content (Figure 2), as described by the equation:
   FR = 187.1 exp(-0.037DMC) (R^2=0.70; $p<0.001$)
   (shell-length of mussels 22 mm, DMC = dry weight of suspended matter in mg/l)

   Similar relationships were found by Morton (1971), Sprung and Rose (1988) and Walz (1978). According to these studies, when dry matter content is very low, filtration rate remained constant or decreased. According to our pseudofaeces experiments this seems to occur approximately at dry matter contents below 2 mg/l.

   In our experiments, pseudofaeces production seemed to increase linearly with increasing suspended matter content, but this is in contradiction to the results of the filtration experiments and is probably a bias caused by certain characteristics of the set-up. In the experiments by Walz (1978) pseudofaeces production initially increased with increasing dry matter content, but very soon it reached a plateau and remained constant. (Morton, 1971; Walz, 1978). Maximum pseudofaeces production (with faeces included) can be estimated by multiplying filtration rate by suspended matter content.

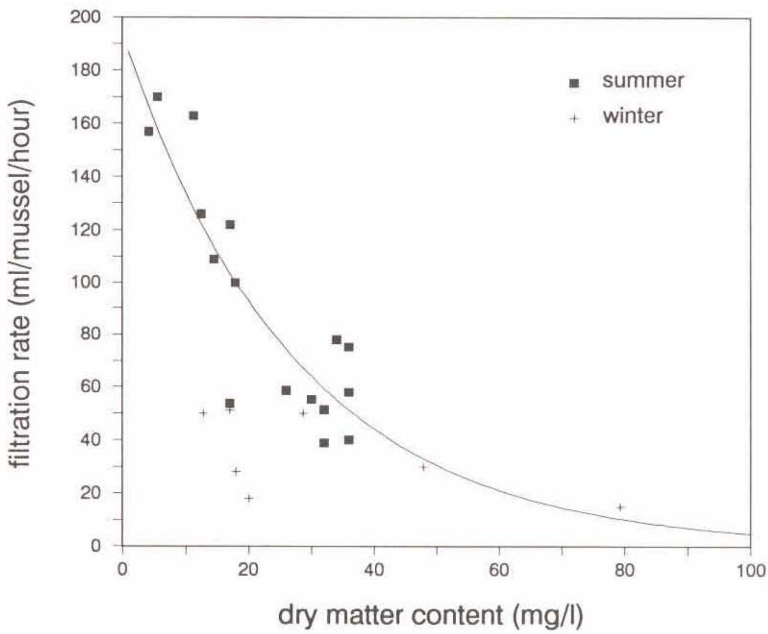

Figure 2 The effect of suspended matter content on filtration rate of *Dreissena polymorpha*. Lake IJsselmeer area, 1985 and 1988. Square symbols: values measured at water temperatures over 10°C; plus-signs: values measured at temperatures under 10°C.

Several other factors may influence the activities of the mussels. Morton (1971) showed relationships with pH (rapid increase when pH exceeded 7.8) and composition of suspended matter (different species of algae). Others found certain diurnal patterns (Benedens and Hinz, 1980; Morton, 1969). In a 24 hour experiment (measurements every 1.5 hours) we found fluctuations in filtration rate that could significantly be fitted by a sigmoid oscillation with a period of 5.3 hours (amplitude about 15% of maxima). Overall filtration rate was not lowered during night. In other bivalve species filtration rate appeared to be positively correlated with current speed (Walne, 1972). Filtration rate of *Dreissena* has only been measured in standing water. In the (marine) species used in Walne's experiments the effect of current speed seemed to be fairly strong and it might be important to determine the impact of this factor on *Dreissena* filtration rate.

4 THEORETICAL EFFICIENCY AND DIMENSIONS OF A BIOLOGICAL FILTER

At temperatures over 10°C (April-October), activity of a population with a known length frequency distribution mainly depends on suspended matter content. For a "standard mussel" the relationship between filtration rate and suspended matter content is described by the equation:

$FR_{st} = 97.8 \exp(-0.037 DMC)$

(FR_{st} = filtration rate of 1,000 individuals with representative length frequency distribution, divided by 1,000).

Using this equation the efficiency of biological filters of different dimensions can be estimated. When all suspended matter in the filtrated water is removed, the efficiency of a filter unit equals $E = (FR_{st} \times N)/f$ (N = number of mussels per filter unit; f = water flow in ml/h). At the Volkerak sluices mean water flow is 14 m^3/s (5.04×10^{10} ml/h) and expected mussel density on the nets is 5,000/m^2 (units are 8x300 m, total number of mussels per unit 12 million). Repeating the calculation for each unit, using the adjusted suspended matter content, yields the efficiency of the entire filter. Figure 4 shows the efficiency of filters of different numbers of units. Like filtration rate, efficiency decreases with increasing suspended matter content. At values under about 2 mg/l the cost of filtration exceeds the gain and the filtration rate decreases. At the most common suspended matter contents (at the Volkerak sluices mostly between 5 and 25 mg/l) efficiencies of about 80% are reached by filters consisting of 100 units. As filtration rate measurements were carried out in standing water the actual efficiency of such a filter might be higher.

The extent to which micropollutants can be reduced by the filter is related to their specific distribution coëfficient. At an efficiency of 80%, cadmium of which about 64% is attached to suspended matter (at mean dry matter content of 12 mg/l) may be reduced by 51%. Benzo-a-Pyrene is reduced by 49%, PCB-153 even by 75%. With given filter dimensions and population structure the efficiency will change with changing suspended matter content (due to changes in affinity of pollutants to suspended matter) and current speed (although the mussels partly compensate for current speed by changing their filtration rate (Walne, 1972).

On account of the results described above a filter consisting of 100 modules was thought to be capable of making a considerable contribution to the struggle against future deterioration of Lake Volkerak/Zoom. The next step towards its realization was testing different substrates in their potential of being colonized by *Dreissena* spat and of supporting a mussel population with sufficient filtrating capacities. Colonization should take place spontaneously when nets are put in the water just before the larvae begin to settle. Development of the population can then be followed by taking samples with regular time intervals and determining the density and size frequency distribution of the mussels.

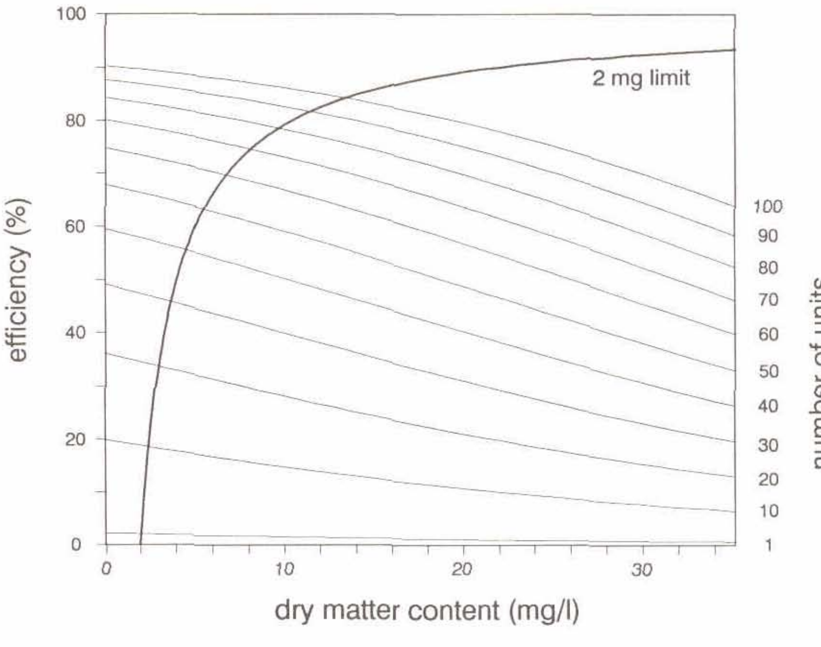

Figure 3 Efficiency of a biological filter out of different numbers of units (right axis), as a function of dry matter content. Water flow is 14 m^3/s, mussel density on the nets is $5{,}000/m^2$. In practice, when dry matter content falls below 2 mg/l, filtration decreases (see text).

5 MICROPOLLUTANTS IN PSEUDOFAECES AND MUSSEL-TISSUE

In 1988 faeces and pseudofaeces of *Dreissena* from the filter location were analysed and concentrations of micropollutants were compared to those in suspended matter (Table 1). Concentrations of inorganic pollutants appeared to be slightly elevated in pseudofaeces, probably related to the somewhat smaller size of the particles as compared to suspended matter (apparantly the largest particles are rejected by the cirri of the inhalant opening).

Concentrations of organic micropollutants showed no differences, unless only the organic part of suspended matter to which they are largely attached is concerned. Concentrations are higher in pseudofaeces, suggesting active selection of less contaminated particles by the mussels or concentration of micropollutants in the faeces (unseparable from pseudofaeces in our experiments).

Table 1 Concentrations of some micropollutants in pseudofaeces of *Dreissena*, compared to those in suspended matter (mean and standard deviation (s.d.)) out of 7 samples in metals, 6 in organic compounds, taken between July and December 1988). Concentrations of organic compounds are also expressed per kg organic dry matter.

Pollutant	Pseudofaeces mean	s.d.	Suspended matter mean	s.d.	
Cu	106.7	15.4	110.6	9.8	mg/kg dry
Cd	9.6	1.6	9.2	0.9	mg/kg dry
Pb	206.9	22.6	183.3	15.8	mg/kg dry
fluorantheen	1.3	0.4	1.4	0.3	mg/kg dry
benzo[a]pyreen	1.6	0.6	1.6	0.5	mg/kg dry
PCB-153	50.5	7.0	49.3	6.3	ug/kg dry
dieldrin	14.0	1.7	14.2	3.5	ug/kg dry
fluorantheen	26.5	10.0	23.2	11.7	mg/kg C
benzo[a]pyreen	30.6	15.6	27.5	17.0	mg/kg C
PCB-153	952.0	109.7	777.8	162.1	ug/kg C
dieldrin	266.6	52.2	219.8	51.7	ug/kg C

Table 2 Concentrations of micropollutants in tissue of *Dreissena* from Lake IJsselmeer and concentrations in tissues of mussels out of the same sample after 271 days of incubation at "Hollandsch Diep", in front of the Volkerak sluices (site of biological filter).

Pollutant	IJsselmeer	Hollandsch Diep	
Cu	16.85	23.61	mg/kg dry
Cd	1.79	2.08	mg/kg dry
Pb	1.63	4.17	mg/kg dry
fluorantheen	146.7	319.4	ug/kg dry
benzo[a]pyreen	38.0	312.5	ug/kg dry
PCB-153	70.7	118.1	ug/kg dry
dieldrin	0.3	3.0	ug/kg dry

While a large part of filtered micropollutants is excreted with faeces and pseudofaeces, another part accumulates in mussel tissue. Tissue of mussels originating from the less contaminated Lake IJsselmeer, was analysed before and after 271 days of incubation in water at the filter site. These mussels had accumulated most pollutants to some extent, especially PAHs and PCBs (Table 2). The concentrations here encountered are commonly found in mussel tissue from (normally reproductive) populations in Western European rivers. In the 1970s distribution and growth of *Dreissena* in the River Rhine were influenced by extremely high contents of micropollutants, particularly cadmium. Van Urk (unp.) showed that this was the case at contents of more than 40 mg Cd/kg dry tissue. Pollutants in concentrations as found in our experiments are not expected to affect reproduction or mortality rate.

6 COLONIZATION AND DENSITY CHANGES ON DIFFERENT TYPES OF NETTING

In May 1989 nets of three different materials were tested in the water near the sluices, hanging down from interconnected buoys. Initial densities after colonization amounted to 60,000 animals per m^2 (mussels <2 mm excluded) on one of the net types. This net type, which will hereafter be referred to as "brush nets", consists of polyester cords to which polyamid "flocks" are glued with PVC-glue. Meshes are 15x15 cm.

However, when the nets were sampled again in January 1990, virtually all mussels had disappeared. Three factors were selected as possible causes: (1) predation by water fowl, (2) wind- and wave-action and (3) active migration of the mussels or "second settlement". This phenomenon is known to occur in the first period after first settlement in *Dreissena* (Lewandowski, 1982) as well as in other species of bivalves (Bayne, 1964).

During a second experiment in 1990/1991 the role of these three factors was investigated. Apart from nets simply hanging down from the water surface, now serving as reference, some nets were surrounded by wire netting to prevent predation by water fowl and larger fish. Other nets were placed in calmer water or were standing on the bottom, held upright by buoys floating underneath the surface, to reduce the impact of waves. A last group of nets was placed horizontally on the bottom after being colonized by spat in hanging position. The chance of second settlement taking place on another part of the same net was supposed to be enhanced by this change of position. Sample nets were sized 50x50 cm and during October 1990 - March 1991 eight samples were taken, of which five were analysed (density and size frequency distribution determined in the lab).

In this experiment the brush nets were used as well as nets made up of strips of polypropylene. Like in 1990 colonization with spat was intense and on the brush nets up to 180,000 mussels/m^2 (mussels <2 mm included) were counted. Extremely high densities (up to 580,000/m^2) were reached on the polypropylene nets. However, in this net type meshes were only 4x4 cm and five layers of "netting" were glued together, resulting in a very dense and heavy structure. Per unit material mussel densities were therefore much lower than on the brush nets.

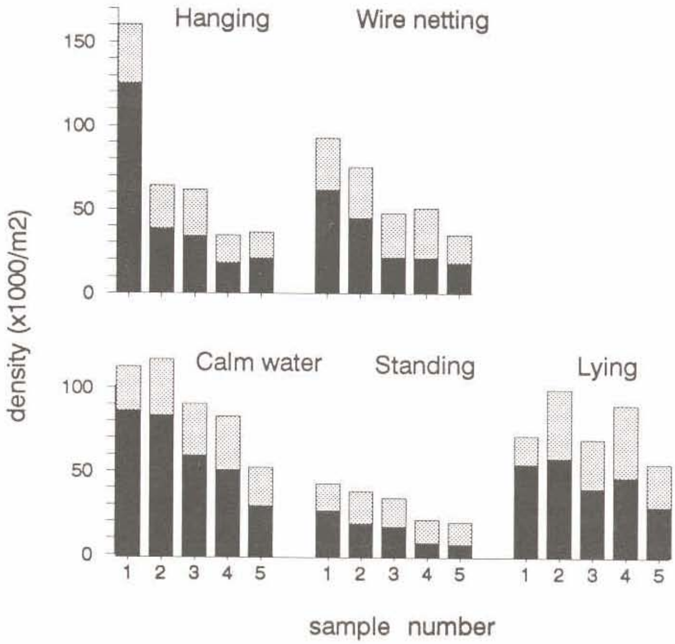

Figure 4 Densities of mussels on brush nets in different set-ups. Black = mussels ≤ 2 mm, grey = mussels ≥ 3 mm. Sampling dates: 1 = Oct. 2, 1990; 2 = Oct. 30, 1990; 3 = Nov. 27, 1990; 4 = Jan. 8, 1991; 5 = March 27, 1991.

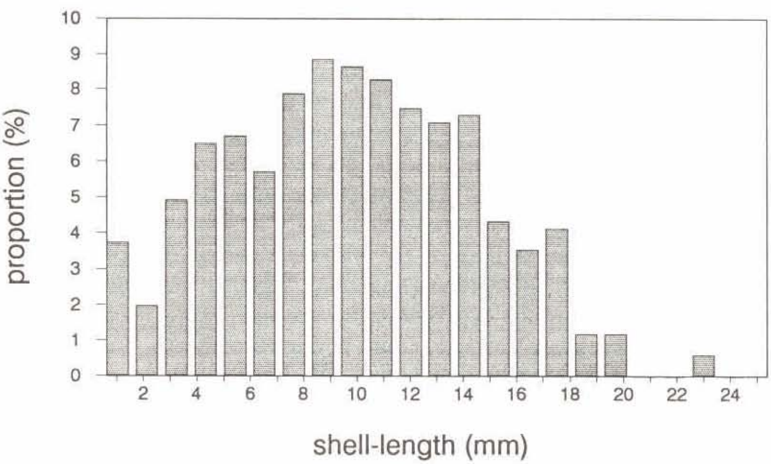

Figure 5 Length frequency distribution of mussels on a polypropylene net, sampled on October 15, 1991.

In all set-ups densities decreased considerably during winter, but not as drastically as in the previous year. During October, shortly after colonization, densities on the reference brush nets decreased rapidly, but only a moderate decrease was found in the other set-ups (Figure 4). During the rest of the winter no clear differences in rates of decrease were found between set-ups, with the exception of the lying nets that showed slower decrease than those in the other set-ups. On the polypropylene nets the rate of decrease was higher than on the brush nets. Densities on the reference nets decreased stronger than densities in the other set-ups and the decrease on the lying nets did not differ from decrease on standing and calm water nets. The difference between these set-ups was probably minimalized by the dense and voluminous structure. The results suggest an important role for second settlement as a cause for decreasing densities on the nets, probably stimulated by movement caused by wind and waves.

At the end of March 1991 about 20-50,000 mussels/m^2 were left on the brush nets, on average about 33% of the initial density. On the polypropylene nets about 22% was left in March. However, when additional samples were taken in October 1991, the mussels of this generation had almost completely disappeared from the brush nets. On the polypropylene nets on the other hand the mussels had developed into a mature population. A density of 120,000/m^2 was found on this net type, of which over 90% belonged to the 1990 year class (Figure 5).

7 APPLICATION

Apparently, of the materials used in the experiment only the polypropylene strip nets yield a population that holds on long enough to contribute substantially to filtration in a biological filter. In spite of the very high densities, however, efficiency of the filter will be low if this material is used in the original design of the filter. Because of the small mesh size, little water will pass through the nets once the mussels have grown to adulthood. Use of this material therefore demands a different filter design, one in which water passes between horizontal or vertical rows of smaller units. The less efficient distribution of mussels over the water column could be compensated for by the enormous densities on these nets. Due to these densities even separate units of the material (manufactured in units of 1 m^2), colonized with mussels, could prove useful in water quality management, especially in smaller waters. After colonization the units can easily be moved to waters in which no *Dreissena* occur and they can just as easily be removed or replaced after service. But in case of the biological filter at the Volkerak sluices, switching to another design would mean several years of additional research. Together with some financial problems, this has obliged us to stop the experiments for the time being. Contaminated river water continues to flow into Lake Volkerak/Zoom through the sluices. The amount of water let into the lake cannot be lowered any further and other means of tackeling the influx of pollutants at this site have not been suggested yet.

8 ACKNOWLEDGEMENTS

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FRESH WATER IS A MUST
The importance of fresh water for agriculture in the Province of Zeeland

A.K. Krijger

ABSTRACT

It is of great importance for agriculture in the Province of Zeeland, The Netherlands, that it has fresh water of good quality at its disposal. This importance will be shown with the help of a short description of Zeeland's agriculture and a couple of current developments. Also the water demand and especially the salt content will be dealt with.

1 INTRODUCTION

The Deltaplan has raised several expectations. Many of these have been fulfilled. Thus the majority of the population of Zeeland feels safe behind dams and dikes and several new possibilities for recreation and nature have been created. For traffic a number of new routes have been realized. However, not all expectations raised by the original Deltaplan have been fulfilled. Some concern the agriculture. The enterpreneurs in agriculture are of course pleased with the security, they profit from the new routes on the dams and enjoy the nature as well as the occasional recreation. Nevertheless, some points are still missing.

The original Deltaplan anticipated the changing of salt- to freshwater systems, amongst others in the Oosterschelde and the Veerse Meer, and possibly even in the Grevelingenmeer. This would have created immense possibilities for water supply for agriculture in the south-west of the Netherlands. After the final plan has been executed, however, only Lake Volkerak/Zoom has been left as a possible freshwater source, at the very edge of Zeeland.

2 A SHORT DESCRIPTION OF AGRICULTURE IN ZEELAND

Zeeland is traditionally an agricultural province. Most of its total acreage is used for agricultural purposes.

Table 1 Acreage of cultivated land in Zeeland for the different types of agriculture in 1990 (rounded off).

	x 1000 ha	% of the total
Total cultivated	124	
- arable	103	83
- grassland	13	10
- horticulture	7	6
* fruit	(4)	(3)
* outdoor vegetables	(2)	(2)

Table 1 shows how the cultivated area is divided among the different types of agriculture. Arable farming, taking up well over 80% of the cultivated area, is by far the largest field of agriculture. Animal husbandry (grassland) involves only a small part in this province. The percentage of cultivated land for horticulture is rather small, but on national scale, however, plays an important role. Zeeland is one of the major fruit producing areas in the Netherlands. Growing outdoor vegetables is still rather modest but steadily increasing. In 10 years time the acreage has grown by 80%. Most of these outdoor vegetables are grown on arable farms. All in all it is obvious that arable farming predominates.

In 1990 there were about 4,200 arable farms in Zeeland, spread over 103,000 ha with an average acreage of under 25 ha. 40% of the farms with mainly arable farming was smaller than 10 ha and only 20% was larger than 50 ha. Zeeland's arable farming is clearly characterized by being small-scale.

3 DEVELOPMENTS

For agriculture two important developments are being implemented. These are:

a. The changing European market- and price policy;

b. The stricter environment legislation.

ad a) Within the EC (European Community) guaranteed prices have been fixed for a number of important arable products or the marketing has been protected by limiting cheap imports from third countries. As a result of this policy considerable surpluses, especially cereals, have arisen. These surpluses involve high expenses for the EC. In order to cut back on them, the EC aims to reduce and even cut these guarantee prices. As a consequence, production has to be more market-directed. This implies further price-cuts for a number of arable crops, in particular cereals, which take up an important part of the arable acreage.

ad b) In order to protect the environment, stricter demands are required in agriculture and horticulture as well. Examples are the Soil Protection Act and the Surface Water Pollution

Act, involving specific effects for agriculture and horticulture in the More-Year Plan Crop Protection and the Manure and Ammonia Policy. Even more than in the past the natural resources will have to be used economically, and the emission of these substances to soil, water and air will have to be limited.

These two developments have a negative effect on the incomes. Especially in the weaker branches, such as arable farming, rentability is put under great pressure, which would cause a large number of liquidation of farms. This threat can only be prevented if the income capacity can be raised. In the present situation in Zeeland, with its high land prices, enlarging the acreage of small-scale arable farms is impossible. More realistic chances for enlarging the possibilities for a livelihood must be found in an increase of the turnover and therefore an increase of the output per surface unit. For arable farms this means the introduction of more labour-, skill- and capital-intensive crops, characterized by higher costs per hectare and higher cropping risks.

For the horticultural sectors, in Zeeland particularly fruit and outdoor vegetable growing, the higher environmental demands will equally lead to higher costs per hectare. On top of that ousting will take place when arable farming starts to invade horticultural markets. The horticultural sectors will have to direct their attention to better and new products. This can be achieved by intensification and the timely renewal of variaties and assortments within the companies. This too will lead to higher costs per hectare and higher cropping risks.

4 WHAT IS THE ROLE OF FRESH WATER IN THESE DEVELOPMENTS

The lowering of the product prices and the subsequent need for a more market-directed production is an international development. Equally the care for the environment, linked to stricter environmental regulations, is important in a growing number of countries. Obviously, not only in the Netherlands people are looking for alternatives and solutions. Zeeland cannot claim the sole right to the agricultural possibilities shown before. There is a good market only for quality and only economically sound production methods can offer sufficient competitive power now and in the future. The condition to live up to these demands and to minimize the cropping risks is that the circumstances for production are optimal. In Zeeland the circumstances for production are naturally profitable. The soil is healthy, the type of soil suits the growing of many different crops, the geographic situation favours a soft climate offering possibilities for early crops, and the susceptibility for nightfrost is low. However, a major negative factor is the limited availability of fresh irrigation water. In summer polder water is salt or brackish owing to salty percolating water. Fresh polder water is found only here and there, and only in limited amounts. The groundwater is practically everywhere brackish or salty. In a few places, in creek-ridges, freshwater storages exist which form a limited supply of water for agriculture as long as the average bulk of the storage is not affected. In general it can be stated that Zeeland cannot have the required amounts of fresh water at its disposal.

This bottle-neck in the developing possibilities of both arable and fruit growing farms was already noted many years ago, but the actual realization of the infrastructural provisions to do something about it has only very recently come into the picture for a few regions of Zeeland. This is partly due to the fact that this bottle-neck has a greater impact than ever and partly to the fact that the Ministry of Agriculture, Nature Management and Fisheries, within its policy of the regional reorganization of arable farming, is now willing to subsidize projects to supply fresh water. Other public authorities have shown the same willingness.

Up to now the Ministry of Agriculture, Nature Management and Fisheries has granted about NLG 25 million for several projects around Lake Zoom. For the joint public authorities it is about NLG 55 million. Also the Ministry of Traffic and Public Works is investing large amounts in Lake Zoom on behalf of water quality and with that on behalf of agriculture. The best-known project is the freshwater pipeline on Zuid-Beveland by means of which fresh water from Lake Zoom can be used for agricultural purposes. Apart from this, freshwater projects on Tholen, St. Philipsland and the Reigerbergsche Polder (east Zuid-Beveland), and outside Zeeland on Flakkee and the Westhoek in Noord-Brabant, can be mentioned.

It has been shown that many of the farmers involved are willing to give a substantial financial contribution for the realization of the freshwater supply. From this we can deduce that there is a wide support for it. This is very understandable, realizing that the availability of fresh water on their plots will open many doors that have hitherto been locked.

Fresh water has a number of different positive effects on agriculture:
- By stopping moisture deficiencies crop yields will be higher and the product quality will improve so that crop returns will increase;
- Various crops with higher returns can be grown, for instance outdoor vegetables that require a certain soil moisture content to strike. Flower bulbs are another possibility. Irrigation reduces the cropping risk;
- In fruit growing there is the anticipation effect. By means of drip irrigation and fertigation fruit trees can come into production one year earlier, which means earlier results and lower costs. Anticipation also allows fruit growers to adapt to assortment changes a lot faster;
- Irrigation also has a positive environmental effect. The growth-process of crops can be controlled better. Regular growth promotes a healthy crop in which pests and diseases have less chance. The dependence on and use of pesticides will therefore decrease.

On top of that fertigation allows fertilization to the exact need of the crop. Fertilizers are put exactly where they are needed, so that few losses occur. Clearly for agriculture there is a number of positive effects. Studies on the basis of these effects show that for farms the economical results due to the availability of fresh water for irrigation or fertigation can be substantially higher. Depending on the distance to Lake Zoom and the method of water supply, net results have been calculated of several hundreds to several thousands of Dutch guilders per irrigated hectare.

5 QUALIFICATIONS OF FRESH WATER

The quality of water for agriculture is determined by several factors. Apart from the chemical composition (how much of which elements), the quality is also determined by the (micro-)biological activity and physical parameters such as turbidness and temperature.

Much research is done on behalf of glasshouse-horticulture. The effect of the possible compositions of water for open air cropping has hardly been looked at. The standards that are presently used are mainly based on 'accidents' in the past.

One of the most important aspects of water quality about which some knowledge exists is the salt content (referred to in mg chloride per liter). Salt can negatively influence crop growth and thus influence yields in various ways. Distinction can be made between scorching leaves and roots, a toxical effect and an earlier drought depression. For many crops it is known at what maximum total salt content of the soil moisture damage occurs. The knowledge to translate the chloride content in the irrigation water to the total salt content of the soil moisture is lacking. It is not even simple to approximate, on the one hand because the relation between chloride content and total salt content is not constant, on the other hand because the soil moisture is a mix of groundwater, rainwater, irrigation water and percolating water. The composition of this mix is itself dependent on soil type, groundwater levels, groundwater characteristics and climatological circumstances. All this makes it impossible to indicate precisely the maximum limits of an acceptable chloride content of the irrigation water.

Agriculture in Zeeland has accepted that only some of the crops that could possibly be grown can actually be grown with Lake Zoom water. Unfortunately, because of the relatively high chloride content the water is not suitable for glasshouse-horticulture and part of the flower- and vegetable crops.

Since it cannot be clearly indicated what the exact salt-tolerance of the various crops is, crops are divided into crop categories according to their salt susceptibility. A common division is one with limits of 300 or 600 mg chloride per liter of water. If the chloride content should be above these levels, the damage to susceptible crops would be so high that supplementing is no longer possible. Hence 400 and 450 mg chloride means that a number of crops cannot really be grown.

Furthermore there is the problem that in the inlet areas in the open-water systems salination takes place because of seepage. Thus, setting the standards of for instance the water supply plan Tholen, it is accepted that water that is let in with a 250 mg chloride content can, at the end of the system, under certain conditions, reach a peak value of 750 mg chloride. Evidently, the further into the system, the smaller the number of crops that can possibly grow.

6 CONCLUSIONS

For the sake of agriculture it is important to aim for a chloride content of Lake Zoom that is as low as possible, while keeping an open eye for other environmental parameters. A low chloride content, on the one hand to minimize the risk of damaging crops, on the other hand to be able to grow as many crops as possible with the help of fresh water. The result of this will be that agriculture in Zeeland can cope with the negative results of EC price policy and can adapt to stricter environmental legislation.

At the end of my contribution I come to the following conclusion:
In order to give agriculture in Zeeland the chance to extend its farms and to move to farms that can maintain a lasting competitive position, THERE IS A NEED FOR FRESH WATER.

How an estuary changed into a freshwater lake. (Proceedings of the technical meeting held in Roosendaal, The Netherlands, 4 June 1992). Proceedings and Information, CHO-TNO, no. 46, 1992.

SUSTAINABLE FLEXIBILITY
An evaluation and forecast

E. Turkstra and H.L.F. Saeijs

1 INTRODUCTION

Everything changed in the upper Eastern Scheldt estuary when the Philips Dam finally started impounding in 1987. The estuary changed into a freshwater lake. In this volume the preceding authors discuss in great detail the effects on the natural environment of this human intervention. In this article we discuss some of the questions which have been raised in relation to water management so far, and especially how to go on.

2 INTEGRATED WATER MANAGEMENT

Lake Volkerak/Zoom cannot be looked at in isolation. Its water quality is affected by Rhine and Meuse water at the Volkerak Locks, and the lake itself in turn influences water quality in the Western Scheldt and, to a lesser extent, in the Eastern Scheldt. Three other rivers - the Mark, the Dintel and the Vliet - drain the lake's eastern catchment.

The lake is performing a double function here, receiving runoff from these catchments - which includes polder drainage - and providing farmers with a water supply in dry periods. This applies equally to the lake's western shore.

The list of parties with an interest in Lake Volkerak/Zoom is long, and it includes three ministries, three provinces, ten municipalities, four waterboards, three bodies responsible for the old tidal flats, and also various lobbies, such as for agriculture, fishing, recreation and shipping. This requires a lot of discussion, teamwork, and above all flexibility on the part of managers and politicians. This is nothing new - it is the very foundation of integrated water management.

In their recent study, Grijns and Wisserhof (1992) claimed that integrated water management was becoming broader in its aims, objectives and methods. This phenomenon is being manifested in a variety of ways with, however, one thing in common - the notion that integrated management should apply as much externally as internally. In effect, this means paying as much attention to interactions between the people involved as we have traditionally paid to the hydraulic relations within and between different water bodies.

Lake Volkerak/Zoom is an ideal candidate for integrated water management and is seen as something of a test case. The hope is that an integrated approach can be maintained, given that it is in the interests of all parties concerned to have a lake which is both ecologically sound and functional. The water in the lake has been clear so far, and must stay that way.

3 PROBLEMS AND SOLUTIONS

So, what are the problems and how can we solve them? How can we, the parties involved, join forces to create a healthy, functional lake?

The authority that manages the lake is expected to produce an ecologically sound and functional water system. The degree to which this is achieved, determines the capacity of the water system. With that the functions have to be geared for this capacity.

But the capacity is adversely affected by pollution. The evaluation period has shown that the pollution load entering Lake Volkerak/Zoom is still a real threat. When management policy was originally drafted in 1987 (Rijkswaterstaat, Directie Zeeland, 1988), the Public Works Council advised that reducing pollution should be the central issue.

Most of the pollution originates outside the lake. Combating pollution is therefore largely outside the jurisdiction of the local water resources manager. Of course, there are other clean-up programmes (the Rhine and North Sea Action Plans, for example) and these will reduce the pollution load in the long-term.

Nevertheless, in the period 1987-1992 a variety of measures have been proved and implemented. These measures are especially aimed at reducing pollution loads and improving the ability of the lake system to withstand pollution. A variety of examples will be found in the articles published in this volume.

The point is to create the right conditions and let nature do the rest - a process of managed ecosystem development. The delta project has given us a great deal of experience with what is, after all, a comparatively new approach. It has also proved that the approach works.

Collaboration between the various parties involved is just as important as creating the right ecological conditions. It is essential, for instance, when it comes to resolving conflicting interests, as some examples will illustrate:
- thanks to the efforts of Waterauthority Hoogheemraadschap West Brabant and the cooperation of Rijkswaterstaat, Directorate Zuid-Holland, effluent from the Nieuwveer van de Dintel sewage treatment plant has been re-routed to the Hollandsch Diep, which is less susceptible to eutrophication;
- Waterauthority Hoogheemraadschap West Brabant has signed a management agreement with the Flemish Environmental Company (Vlaamse Milieu Maatschappij) which includes speeding up the programme to reduce by 75% phosphate discharges from sewage works in the catchment. The programme will be completed by 1993;
- water losses through the Krammer and Kreekrak locks have been minimised by more

efficient operation of the saltwater-freshwater separation system. This entailed the cooperation of the lock users.

By the end of 1992, Rijkswaterstaat will have invested some 22 million Dutch guilders in Lake Volkerak/Zoom. Most of this has been spent on water control works and other measures designed to create the right conditions for a healthy lake.

4 MANAGEMENT OPTIONS

One of the conclusions of the evaluation is that within the constraints of agreed policy all the possible measures have been taken. The managing authority has done everything in its power, and now has little room for manoeuvre.

Problems remain, however, with pollution loads still too high and the lake unable to sustain them. The question "are current management practices adequate for the ecological health and proper functioning of Lake Volkerak/Zoom in the future?" must regrettably be answered in the negative.

The managing authority has suggested some interim solutions to prevent the situation deteriorating any further. These require a certain input from the parties involved. In the evaluation report, these interim solutions are presented as management options for limiting the risk (Table 1).

Table 1 Management options

Summary	
flushing options	400 mg/l Cl^- standard (current practice) 450 mg/l Cl^- no flushing
water level options (range: NAP + 0.15 m/ - 0.25 m)	current water level management practice natural water level cycle, range 30 cm natural water level cycle, range 40 cm

NAP (Normaal Amsterdams Peil, the reference level in the Netherlands)

In the short term, the only way of reducing the input of pollutants to Lake Volkerak/Zoom is to minimise water intake by limiting flushing. This would increase the concentration of chlorides in the lake, which in principle would be against farmers' wishes.

Alongside the active biological management which is already taking place, a more natural cycle of fluctuations in the water level would help reduce algal blooms and improve the ecological balance. The waterboards are opposed to this, because it would cause drainage difficulties, restrict navigation on rivers serving the Brabant ports, and introduce extra pumping requirements for irrigation abstractions.

The farming community has been asked to accept a temporary increase in chlorides in irrigation water, until the AMK (Algemene Milieu Kwaliteit, the general environmental quality standard in the Netherlands) is met. The waterboards have been asked to help setting the parameters for a properly functioning ecosystem. Is this too much to ask? Before we can answer this question, we must look first at the management options and their effects.

5 FLUSHING OPTIONS

The "no flushing" option is not considered here, since the lake would not be able to perform its irrigation function.

The effective difference between 400 and 450 mg/l Cl^- is marginal for agriculture. In practice for large parts of the lake, setting the standard at the higher chloride value means a difference of less than 30 mg/l. The full 50 mg/l differential will only be observed in dry years at the most southern abstraction point, the Bathse Spui drain. Table 2 shows the effects of the various flushing options.

Table 2 Effects of flushing options

During growing season	Increase in chloride content (mg/l Cl^-)		
Site	Chloride content (mg/l Cl^-) with 400 mg/l Cl^- standard	with 450 mg/l Cl^- standard	with no flushing
Lake Zoom and southern Eendracht	290 - 400 (530)	0 - 50	- 0 - 160
northern Eendracht	210 - 290 (370)	+20 - 30	- 0 - 90
west Lake Volkerak	200 - 340 (400)	+20 - 30	- 10 - 80
east Lake Volkerak	00 - 2101 (280)	+20	- 10 - 80

(...) = maximum concentrations outside the growing season

Increasing the chloride level in Lake Volkerak/Zoom implies higher chlorides in the water courses in areas where lake water is used for irrigation. Farms on the Zeeland side are more critical in this respect, because of the possibility of saline intrusion here. However, a slight rise in chloride content in water leaving Lake Volkerak/Zoom will be negligible by comparison. Tail-end irrigation canals may even show an improvement.

Theoretically, a higher chloride concentration in irrigation water reduces crop yields. It has been calculated that the proposed maximum increase in lake chloride content of 30 mg/l in the north and 50 mg/l at the Bathse Spui drain will result in crop yield reductions of only tenths of a percent, taken as a long term average over wet, dry and normal years.

Irrigation projects are in operation for a number of polders, and more are planned. Once these are in place, farmers will be able to switch to more profitable, irrigated crops. These schemes are expected to be completed over the next five to ten years.

In the light of this, it is not unreasonable to ask the farming community to accept the 450 mg/l Cl^- option in the short term. As water quality improves, the 400 mg/l standard can be adopted. This is the kind of flexibility that will lead to a long-term resolution of the conflicting interests of farmers and ecologists.

6 WATER LEVEL OPTIONS

Figure 1 shows typical fluctuations in the water level in a wet and a dry year under a more natural cycle. The "natural cycle" option creates drainage difficulties along the Dintel, whose banks would also need protecting against a high winter lake level. A low summer level would restrict shipping and require pumping for irrigation.

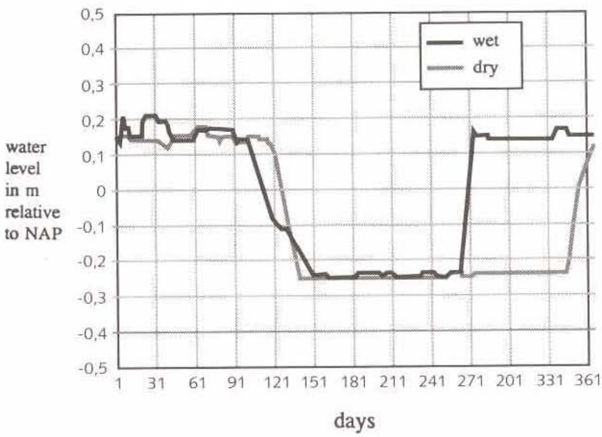

Figure 1 Fluctuations in water level in a wet (1988) and a dry (1989) year, with maximum and minimum at NAP + 0.15 m and NAP - 0,25 m

Some waterboards have calculated that extra pumping capacity would be needed to meet land drainage requirements if the high water levels were adopted. Waterauthority Hoogheemraadschap West Brabant also believes that bank defences along the Dintel would have to be modified. The same authority points to the adverse effect of a low summer water level on Dintel navigation, while several waterboards estimate to need more pumping capacity for irrigation. Possible solutions - and their cost - are still being discussed with the waterboards. On past experience, an amicable arrangement is likely to be found.

The evaluation has concluded that, notwithstanding measures already taken, the ecological and functional future of the lake is in doubt if present management practices continue. It is the managing authority's job, therefore, to come up with proposals for better management. New proposals for the next five years include:
- adopting the 450 mg/l chloride level at the mouth of the Bathse Spui drain (400 mg/l Cl^- is not feasible under current pollution loads);
- aiming for a natural fluctuation in water level, with a difference preferably of 40 cm and at least 30 cm between summer and winter levels. This management change should be adopted as soon as possible.

The decision is now a political one. The Minister of Traffic and Public Works will take the advice of the Public Works Council before she makes a final decision, probably in 1993.

7 THE FUTURE

It can be expected that the demand for clean and sufficient water will increase in the future. We also have to assume that the demand will increase partly as a result of the water becoming cleaner. Stocks of clean groundwater are already at a premium. Water is set to become a scarce commodity in the economic sense. At the UN (United Nations) water conference in Dublin it was argued that water should be treated as a commodity with an economic value, whatever its use (Alaerts et al., 1992). The trend is apparent already in Lake Volkerak/Zoom. Here water is currently scarce because poor quality is limiting its usefulness. As water becomes scarcer, we will have to be more economical in its use.

In Zeeland, demand for irrigation water is likely to increase (Provincie Zeeland, 1992), partly as a result of EC (European Community) agricultural policy and partly because of tougher environmental standards. Both these factors make it worthwhile for farmers to switch to more intensive methods of cultivation. The irrigation demand is expected almost to double.

As long as water flowing into Lake Volkerak/Zoom fails to meet the AMK, the water system will be unable to cope with any increase in demand. We also have to avoid cancelling out any improvements in lake water quality by letting in more polluted river water in response to increased demand.

Agriculture can also contribute to the improvement of the water quality by reducing diffuse sources of pollution, such as nutrients and pesticides. Van Oers (1992, this volume) has drawn attention to the phosphate loads coming out of Brabant. The Dintel is a major source of pesticide contamination in the lake, most of it coming from agriculture. This is one example of a common interest, which at one and the same time underlies a problem and indirectly suffers from its effects. Insecticides used by farmers end up killing zooplankton in the lake; but the zooplankton plays a key role in maintaining the low turbidity water farmers require for irrigation.

Combating eutrophication is expensive and the cost is currently met by the taxpayer. The Commissie Onderzoek Financieringsstelsel Waterbeheer (1992) believes that the "polluter pays" principle should now be applied, with a levy on agricultural businesses which cause pollution. This is difficult for the farming community to accept. There is still a generation of farmers who think that agriculture is impossible without crop sprays. However, agricultural production at the expense of the environment is simply not sustainable.

Waterboards themselves can help to reduce levels of poly-chlorinated aromatic hydrocarbons in water courses, by using bank reinforcement methods which are better for the environment than the traditional creosoted timber piling. Better management of water levels would also lower leaching rates, reducing at the same time levels of chlorides and nutrients in canals draining into the lake.

Another way of reducing chloride and nutrient inputs would be to divert all polder drainage from Tholen - the land area immediately west of the Eendracht - into the Eastern Scheldt estuary. This would remove one source of chlorides from the lake, and considerably reduce the phosphate loading. The tidal Eastern Scheldt is much less sensitive to pollution by substances such as these.

Atmospheric deposition is another source of anxiety. Possibilities to influence this case are limited, because this is a supra-regional problem.

There remains a need for closer cooperation with the managing authorities of the "dry" margins of the lake. Existing mechanisms probably offer sufficient scope to achieve this.

The philosophy of working with interested parties to achieve an ecologically sound water system will also be the basis of a new water agreement to be drawn up with the various waterboards involved. This can only take place when the management policy has been decided.

8 CONCLUSION

Can Lake Volkerak/Zoom become a proper functioning water system that meets the conflicting needs of its users? Experience so far suggests that this is possible, if all parties continue to cooperate and put the common good above individual interests. Sustainability is - in the long term - the only answer.

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