Biological Conservation 72 (1995) 393–405

0006-3207/95/$09.50+.00

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0006-3207(94)00101-4

HYDROLOGICAL SYSTEMS BEYOND A NATURE RESERVE, THE MAJOR PROBLEM IN WETLAND CONSERVATION OF NAARDERMEER (THE NETHERLANDS)

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(Received 9 December 1992; revised version received 1 July 1993; accepted 29 October 1994)

Abstract

Ecological relations within a wetland depend on it is hydrology, but this is determined largely by what happens outside the wetland area. These statements are illustrated with respect to the Naardermeer nature reserve in the Netherlands. Succession and eutrophication have led to a reduction in the variety of vegetation types in the area. Eutrophication has been caused by a lowering of the water levels, deposition of guano in bird colonies, pollution of surface water and groundwater, and atmospheric deposition. The fact that most restoration activities have to be executed outside the wetland demonstrates that the management of the conservation of wetland ecosystems needs to operate on a regional scale.

The conservation of a wetland depends on water levels. However, the qualitative aspects of hydrology are also important. Since landscape ecological relations with the surrounding area provide for transport of nutrients, a wetland is not isolated. Changes in hydrology have an impact on processes that affect the ecosystems in different ways. These relations are illustrated from a reserve in the centre of the Netherlands.

Keywords: Naardermeer, Netherlands, hydrology, succession, pollution, restoration.

INTRODUCTION

The Naardermeer wetland was the first nature reserve to be established in the Netherlands. During the last 80 years this area has been managed purely for the purposes of nature conservation. During the last few decades, however, essential biotic values have been lost, in spite of management, research, expert advice and preservation strategies in rural planning. An algal bloom developed in the lakes which led to the disappearance of the extensive stands of the oligotraphent Characeae (Spruyt, 1985). The mesotraphent vegetation characteristic of mire succession disappeared. At the same time marked changes in the hydrology were reported (Witteveen + Bos, 1981). The level of the lakes became lower and the adjacent marshlands were affected. In extreme periods of drought the shores of the lakes became dry and the quality of the water in the lakes deteriorated (Zuiveringschap Amstel- en Gooiland, 1986).

Most of the problems were noted in isolation, whereas they were in fact interconnected. This paper describes the causes and effects of three main changes: (a) biotic components; (b) quantitative hydrology; and (c) qualitative hydrology. If we can obtain information about the relations between these changes, it should be possible for conservationists and planners to devise workable strategies to restore the most essential biotic values in this area.

Plant nomenclature in this paper follows Heukels and van der Meijden (1983), Margadan and During (1982) and Westhoff and den Held (1969).

DESCRIPTION OF THE NAARDERMEER WETLAND RESERVE

The Naardermeer reserve (Fig. 1) is located on the Vecht river plain, 20 km east of Amsterdam, on the western border of a sandy hill-ridge, formed during the Pleistocene and rising to *c.* 25 m above mean sea level. Naardermeer is an area of *c.* 700 ha, consisting of lakes (depth 1–2 m), ditches and canals, marshy woodlands, open reed-marshlands and, in the eastern part, a zone of meadows. The sandy Pleistocene subsoil present at the surface in the eastern part dips in a westerly direction, where it is covered by a layer of *c.* 2 m of clay and peat.

Until the end of the 14th century the Naardermeer was a lake open to the River Vecht (Van Zinderen Bakker, 1942). The lake was reclaimed in 1628 by building a dike and pumping out the water with windmills. Intensive discharge of water from the higher water levels in the surrounding polders made it difficult to maintain the polder. When there was a threat of war in 1629 the polder was flooded for military reasons. Between 1883 and 1886 the lake was again reclaimed. Many of the ditches an canals that are present today originate from this period. For economic reasons the polder was abandoned after three years: the intensive discharge of saline groundwater (influence of the nearby sea at that time, now called IJsselmeer) and sulphides in the soil (presumably acid soils which oxidised when drained) meant that the profits from the crops grown were lower than the costs of the pumping machine.

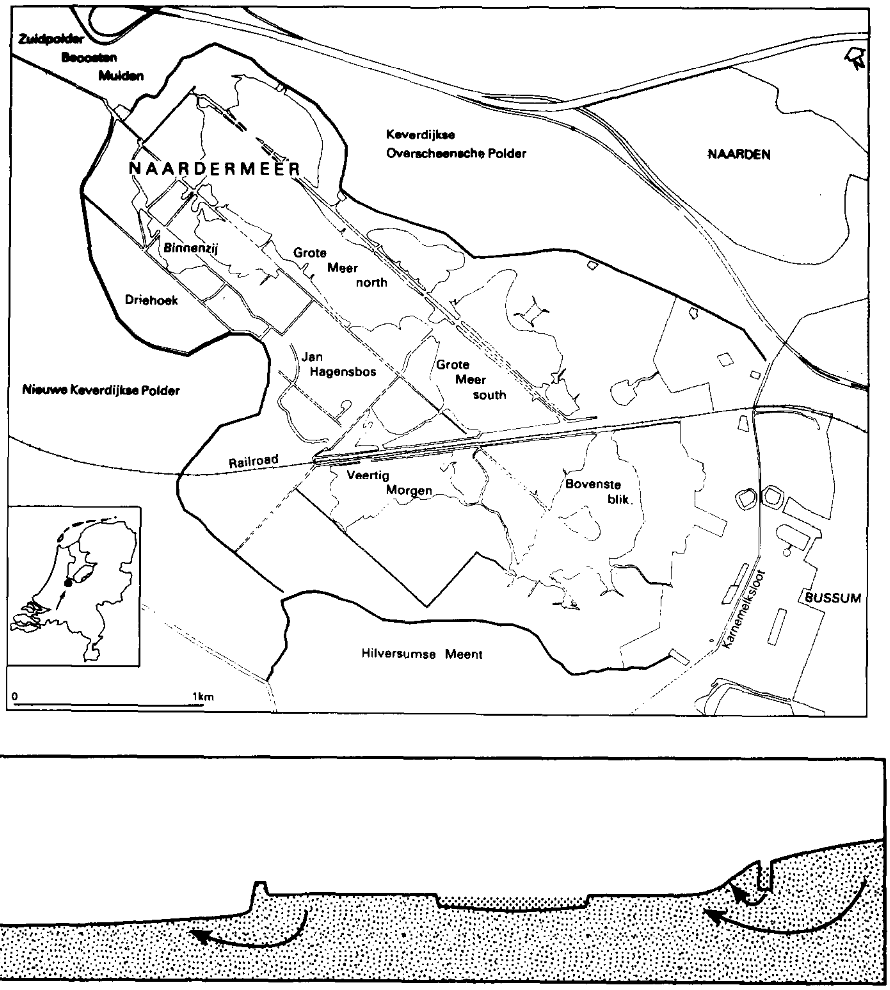

Fig. 1. Topography of the Naardermeer polder, with west-east cross-section just north of the railway. Arrows indicate flow of groundwater from the hill-ridge.

In 1904 the municipality of Amsterdam planned to dump domestic refuse in the lake. Refuse was to be transported via a railway that was constructed through Naardermeer in 1874. The plan was rejected as a result of demonstrations against the impending damage to an area of great natural interest. In 1906 the area, which contained, for example, breeding sites for spoonbills *Platalea leucorodia* was bought by the Society for the Preservation of Nature in the Netherlands. It was the first nature reserve to be established in the Netherlands. Since then the management has been restricted to water management and to the mowing of 25 ha of reedlands in the winter, to maintain this vegetation. The nature reserve itself still exists, but recently many of its ecological links with the surrounding area have been affected because of urban development. Power lines have been erected around the area, a main road has been built just north of Naardermeer and a new railway line runs to the west of the area. The city suburbs have gradually extended to the eastern edge of the reserve and this has impeded the movement of birds and other animals. The hydrology has also changed; for example, in the polders around Naardermeer dairy farming has intensified resulting in the lowering of surface water levels.

The nature reserve during the last few decades

The first signs of eutrophication and the absence of hydrophytes were reported in the southeastern part in Lake Bovenste Blik (Leentvaar & Higler, 1963). Previously there had been no eutrophication in this area: the water was very clear, without nutrients or algal bloom, and oligotraphent hydrophytes like Characeae and *Najas marina* were present (Van Zinderen Bakker, 1942; Van Heusden, 1944; Meijer, 1948; Westhoff, 1949).

Effects of eutrophication became apparent in the other lakes in 1976 and by 1982 were recorded almost everywhere (Barendregt *et al.*, 1989). The turbidity of the water increased until visibility was restricted to a depth of 30–40 cm due to the abundance of algae. The rare vegetation of Characeae disappeared during the same period (Van Sambeek, 1985; Spruyt, 1985). Until 1975 Characeae in dense stands of 11 species covered about 100 ha; in 1986 it covered no more than 7 ha and contained only five species (Spruyt, 1986). Gradually the species belonging to oligotrophic or mesotrophic lakes with clear water were replaced by those associated with eutrophic polluted water: *Zannichellia palustris, Potamogeton pectinatus* and the alga *Cladophora rivularis*.

There was a gradual succession of the semi-terrestrial vegetation around the lakes towards woodland. An investigation of permanent plots during the period 1931–1981 in Naardermeer demonstrated that succession from open water to woodlands took about 50 years (Wiegers, 1985). This vegetation change can be illustrated for the whole of the Naardermeer by comparing the vegetation data of the area collected by De Vries (1864) with our own data collected 120 years later: water, 366 ha, 187 ha; reedlands, 185 ha, 182 ha; woodland, 103 ha, 247 ha; meadows, 33 ha, 66 ha; other, 9 ha, 14 ha.

Half of the open water has vanished and the area of woodland has doubled within the past 120 years. This succession can be illustrated in detail with data for the Jan Hagensbos area. In 1933 open water with a vegetation of Hydrocharito-Stratiotetum and Cicuto-Caricetum pseudocyperi was still found in large areas (Van Zinderen Bakker, 1942). Fourteen years later a succession towards reed was observed (Meijer & de Wit, 1947). By 1985 there was solid soil with a vegetation of *Phragmites australis*, several *Carex* species and *Alnus glutinosa*.

The succession towards woodland has been accompanied by the disappearance of important plants from the remaining marshlands. The marshy reed areas in Naardermeer can be divided into two types: one dominated by *Phragmites australis* and *Sphagnum* species and the other by *Carex* species and herbs (Wassen *et al.*, 1989). Rainwater dominates the hydrology of the former vegetation; acidification of the topsoil has taken place. The topsoils of the second type (divided into two subgroups) have neutral pH-values as a result of the hydrology. In one the vegetation is supplied with neutral surface water from the lakes, while in the other there is discharge of neutral groundwater. The vegetation of the latter subgroup (Scorpidio-Caricetum diandrae) has become very rare in the Netherlands and is therefore important for nature conservation. This vegetation is characteristic of quagmires in peaty areas subject to discharge from Pleistocene sand ridges. In the Naardermeer this vegetation is present in the zone at the eastern edge of Lake Bovenste Blik, where discharge from the hill-ridge is most prominent (Schot *et al.*, 1988).

To determine possible changes in species composition at this location, 19 relevés were compared for different dates between 1937 and 1987 (Table 1). The species were arranged in four groups: (1) species characteristic of Scorpidio-Caricetum diandrae (Caricion davallianae), still present after 50 years (e.g. *Epipactis palustris, Valeriana dioica, Carex diandra*); (2) species that have disappeared, some characteristic of calcareous marshes (Caricion davallianae), e.g. *Dactylorhiza incarnata, Fissidens adianthoides, Liparis loeselii, Campylium stellatum* and others, characteristic of Phragmition and Filipendulion (e.g. *Scirpus lacustris, Typha angustifolia, Filipendula ulmara*), that have decreased; (3) new species characteristic of acid reed marshes (*Caricion curto-nigrae*), e.g. *Sphagnum* species, *Polytrichum commune, Aulacomnium palustre* and *Carex curta*; (4) other species which have been continuously present. Table 1 shows that although a number of endangered species are still present after 50 years, the vegetation has changed significantly since 1945. Many of the species known from locations fed by a natural discharge of groundwater or by surface water have been replaced by species characteristic of acid localities fed by rainwater. This points to a hydrological change, whereby groundwater has been partly replaced by rainwater.

A general trend in the whole nature reserve is that the variety of vegetation types has been greatly reduced. Many reed areas have changed from being species-rich to being dominated by *Sphagnum* species only. Diversity has also decreased because intermediate succesion phases are absent and the climax phases dominate. The biotic changes not only induce a further accumulation of peat but also influence the availability of nutrients. The presence of woodlands with *Alnus glutinosa* means that 60–130 kg/ha/year of nitrogen is fixed by the *Alnus* nodules (data from comparable wetlands in the Netherlands: Akkermans, 1971). Lower pH-values of these soils also mean a higher availability of phosphate (Scheffer *et al.*, 1982) and less denitrification (Focht, 1974). Consequently more nitrogen and phosphate have become available with the changes in vegetation.

Changes in hydrology

For the last 350 years Naardermeer has been a polder. Water is supplemented by rainfall and by the natural discharge of groundwater from the adjacent hill-ridge. In periods of water surplus, surface water was pumped out towards the River Vecht; in periods of deficit, water was fed in from the Vecht. In this way a constant level could be maintained. The pumping of extra water from the Vecht, which was necessary in dry summers, was stopped in 1960. At that time the river contained such a concentration of nutrients (due to sewage water and water from the Rhine) that it seemed irresponsible to direct this polluted water into the nature reserve. It was decided that a shortage of water would be less harmful than a supply of polluted water. During the climatologically wet years 1960–1969 the water levels were stationary; during the dry period 1970–1977 and in the following years the surface water level in summer dropped by 30 cm; the mean winter level dropped by 10 cm (Fig. 2).

The level of the surface water in the Naardermeer is influenced by the level of the groundwater. The isohypses of the piezometric levels of the groundwater (Schot, 1988; Schot *et al.*, 1988) illustrate the main hydrological factors. The higher levels of groundwater in the hill-ridge result in a flow of groundwater towards Naardermeer so that the eastern part of Naardermeer is a seepage zone. In the four polders around Naardermeer the surface water levels (and thus also the groundwater levels) are 10–80 cm lower than in Naardermeer. These levels induce a flow of groundwater

Table 1. Relevés from marshland at the eastern edge of Lake Bovenste Bilk (Naardermeer)

Relevés covered *c.* 10 m^2. Species arranged in four groups: Group 1, still present; Group 2, disappeared; Group 3, new; Group 4; other. Data were taken from the following: 1937, Van Zinderen Bakker (1942); 1944, Meijer & de Wit (1944); 1945, Van Dijk *et al.* (1946); 1972, Van Wijngaarden (1981); 1986 + 1987, authors.

Year	'37	'44				'45				'72	'86 + '87								
No. of relevé	1	2	3	4	5	6	7	8	9	10	1	2	3	4	5	6	7	8	9
Group 1																			
Peucedanum palustre	+	1	1	+	+	1	+	+	+	+	1	+	+	1	1	1	1	+	+
Potentilla palustre	1	+	1	1	+	—	+	+	+	2	1	1	2	2	2	2	2	1	2
Juncus subnodulosus	+	+	2	3	2	+	1	+	2	+	1	1	2	2	2	2	1	—	1
Valeriana officinalis	—	—	2	1	+	—	+	+	1	2	—	+	—	—	+	—	+	—	—
Caltha palustris	+	—	—	+	—	—	+	+	—	—	+	+	+	+	+	+	—	—	—
Dactylorhiza majalis prae.	—	—	1	—	—	—	—	—	—	—	+	+	1	—	—	—	—	—	—
Plagiomnium affine	—	+	+	+	—	+	1	+	+	—	+	+	—	+	—	—	—	—	—
Epipactis palustris	—	—	1	—	2	—	—	—	—	1	—	—	+	—	—	—	—	—	—
Carex diandra	3	+	2	+	—	—	—	—	—	—	1	+	—	—	—	—	—	—	—
Valeriana dioica	—	—	1	1	3	—	—	—	—	—	+	+	—	—	+	—	—	—	—
Sphagnum squarrosum	—	—	—	+	—	—	+	—	—	5	+	+	—	—	—	—	—	—	—
Calypogeia fissa/trichoides	—	—	—	+	3	—	1	—	—	1	—	+	—	—	—	—	—	—	—
Group 2																			
Typha angustifolia	1	1	+	—	—	1	+	+	—	+	—	—	—	—	—	—	—	—	—
Brachythecium rutabulum	—	—	1	—	3	+	—	1	+	—	—	—	—	—	—	—	—	—	—
Carex pseudocyperus	1	1	+	—	—	+	—	—	—	—	—	—	—	—	—	—	—	—	—
Berula erecta	+	+	—	—	—	+	—	—	—	—	—	—	—	—	—	—	—	—	—
Campylium cf. *stellatum*	—	4	4	—	—	+	+	—	—	—	—	—	—	—	—	—	—	—	—
Rhinanthus angustifolius	—	—	1	—	—	—	+	+	—	—	—	—	—	—	—	—	—	—	—
Stellaria palustris	+	—	+	—	—	—	+	—	—	—	—	—	—	—	—	—	—	—	—
Hydrocotyle vulgaris	—	—	—	1	1	—	+	+	+	—	—	—	—	—	—	—	—	—	—
Sium latifolium	+	—	—	—	—	—	—	+	—	—	—	—	—	—	—	—	—	—	—
Utricularia minor	3	2	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Dactylorhiza incarnata	1	—	+	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Eupatorium cannabinum	—	+	1	+	+	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Liparis loeselii	—	+	+	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Fissidens adianthoides	—	—	—	+	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Filipendula ulmaria	—	—	—	—	—	—	+	+	—	—	—	—	—	—	—	—	—	—	—
Group 3																			
Drosera rotundifolia	—	—	—	—	—	—	—	—	—	1	—	+	—	—	—	—	—	—	—
Carex curta	—	—	—	—	—	—	—	—	—	—	+	+	+	+	—	—	—	+	—
Polytrichum commune	—	—	—	—	—	—	—	—	—	—	—	—	1	—	+	—	+	+	+
Sphagnum palustre	—	—	—	—	—	—	—	—	—	—	—	+	+	—	3	3	1	2	2
Sphagnum flexuosum	—	—	—	—	—	—	—	—	—	—	+	2	2	—	—	—	2	—	—
Sphagnum fimbriatum	—	—	—	—	—	—	—	—	—	—	—	2	—	—	—	—	—	—	4
Calliergon cordifolium	—	—	—	—	—	—	—	—	—	—	+	+	—	+	—	+	—	1	—
Aulacomnium palustre	—	—	—	—	—	—	—	—	—	—	+	1	—	—	—	+	+	+	+
Pedicularis palustris	—	—	—	—	—	—	—	—	—	—	+	—	2	—	—	—	—	—	—
Luzula multiflora	—	—	—	—	—	—	—	—	—	—	+	+	—	—	—	—	—	—	—
Group 4																			
Phragmites australis	2	3	3	+	+	2	+	1	+	2	+	1	2	2	2	2	2	2	2
Calamagrostis canescens	—	2	—	1	1	1	4	2	3	2	1	1	1	1	—	—	1	2	1
Cirsium palustre	+	—	+	+	+	—	1	+	+	—	+	+	1	1	2	2	1	+	+
Thelypteris palustris	—	—	+	3	4	—	—	3	2	1	+	1	2	+	2	2	1	2	2
Galium palustre	3	1	+	+	—	2	+	+	+	+	+	+	1	1	—	—	1	1	—
Calliergonella cuspidata	—	—	3	4	2	+	—	+	—	+	4	3	3	—	—	—	+	3	2
Lycopus europaeus	+	1	+	+	—	+	+	+	—	+	—	+	+	+	—	—	—	—	—
Salix repens	—	—	2	+	1	—	1	1	3	—	+	1	1	—	+	1	—	—	—
Salix cinerea & *S. aurita*	+	+	+	—	+	—	+	+	1	2	+	+	1	—	—	—	1	—	—
Calystegia sepium	—	—	—	1	+	+	+	+	+	—	—	—	—	—	—	—	—	+	+
Juncus conglomeratus	—	—	—	—	—	—	+	—	+	—	—	—	—	+	—	—	+	1	
Carex paniculata	+	—	+	—	—	+	1	—	—	—	+	+	—	2	1	2	2	—	—
Lysimachia vulgaris	—	—	—	—	1	—	+	+	—	—	—	+	—	—	—	—	—	—	—
Alnus glutinosa	—	—	—	+	—	—	+	—	+	—	—	—	—	—	—	+	—	—	—
Lythrum salicaria	+	—	+	1	+	+	—	—	—	+	—	—	—	—	—	—	—	+	+
Betula pubescens	—	—	+	+	+	—	+	+	1	+	—	+	+	—	—	—	—	—	—
Carex riparia	—	—	—	+	—	—	—	—	+	—	1	+	+	—	+	—	—	1	—
Lysimachia thyrsiflora	+	—	+	+	—	—	—	—	—	—	1	+	1	1	1	2	1	1	1
Holcus lanatus	—	—	+	+	+	—	—	—	—	—	+	1	+	+	1	+	1	+	2
Agrostis canina	+	3	+	—	—	—	—	—	—	—	+	—	+	+	+	+	1	—	+

continued

Table 1. — continued

Group 4																			
Mentha aquatica	+	+	2	+	—	—	—	—	—	+	+	+	+	+	—	—	+	+	—
Lotus uliginosus	—	—	+	—	+	—	—	—	—	—	+	+	1	—	1	1	+	—	—
Cardamine pratense	1	+	+	—	—	—	—	—	—	—	+	+	—	+	—	—	—	—	—
Mnium hornum	—	—	—	1	2	—	—	—	—	—	+	+	—	—	—	—	—	—	—
Chiloscyphus polyanthos	—	—	+	2	+	—	—	—	—	—	—	—	—	+	—	—	—	—	—
Rumex hydrolapathum	+	+	—	—	—	+	—	—	—	—	—	—	—	—	+	—	—	+	—
Lychnis flos-cuculi	—	—	+	+	—	—	—	—	—	—	—	—	—	—	+	—	—	—	—
Stachys palustris	—	—	+	1	—	—	—	—	—	—	—	—	+	—	—	—	—	—	—
Angelica sylvestris	—	—	—	—	+	—	—	—	—	—	—	+	—	—	—	—	—	—	—

Only present once (no. of relevé, abundance): *Scirpus lacustris* (1,1), *Eriophorum angustifolium* (1,+), *Cicuta virosa* (2,+), *Lemna trisulca* (2,+), *Riccardia pinguis* (2,1), *Pellia epiphylla* (2,+), *Riccardia chamedryfolia* (3,+), *Sagina nodosa* (3,1), *Taraxacum officinale* (3,+), *Ranunculus repens* (3,+), *Lophocolea bidentata* (4,+), *Typha latifolia* (4,+), *Pyrola rotundifolia* (4,+), *Rhizomnium* cf. *pseudopunctatum* (5,1), *Lophocolea heterophylla* (5,+), *Cephalozia bicuspidata* (5,1), *Plagiothecium denticulatum* (5,+), *Scutellaria galericulata* (6,+), *Festuca rubra* (6,2), *Sphagnum nemoreum subnitens* (8,+), *Viburnum opulus* (9,+), *Eurhynchium praelongum* (9,+), *Iris pseudacoris* (11,+) *Bryum pseudotriquetrum* (11,+), *Anthoxanthum odoratum* (12,+), *Aronia prunifolia* (16,1), *Viola palustris* (17,+).

from Naardermeer towards these polders and cause infiltration in the larger part of Naardermeer (Schot & Molenaar, 1992).

The most obvious change over the last few decades has been the lowering of the surface water level in the lakes. To understand the cause of the sudden drop in Naardermeer after 1970, one has to know how the components of the hydrosystem interact. Chronological data relating to the hydrological components were therefore collected. The piezometric level in the hill-ridge is influenced by rainfall and the abstraction of drinking water, so such data were included. Three-year running means were calculated (Fig. 3).

Since the data collection began, all the water levels have become gradually lower. In the period 1910–1980 the piezometric levels in the centre of the hill-ridge dropped by *c.* 1·5 m (Provinciale Waterstaat van Noord-Holland, 1986). In three polders around Naardermeer there was a 25 cm drop between 1925 and 1984; for the Naardermeer polder the drop was 15 cm. In the hill-ridge the difference was 10–15 cm between 1955 and 1984. During the years 1970–1978 the levels of Naardermeer and the piezometric level in the hill-ridge were at their lowest ever. There is a direct relation between net precipitation (gross precipitation minus the Penman evaporation) and the piezometric level in the hill-ridge. The abstraction of groundwater for drinking water increases in dry years, so the influence on the piezometric level is a combined result of abstraction and precipitation. The piezometric level in its turn influences the amount of water discharged in the Naardermeer polder.

To find out which factor has most influence on the level in Naardermeer, we calculated the differences between all the water levels and divided the data into

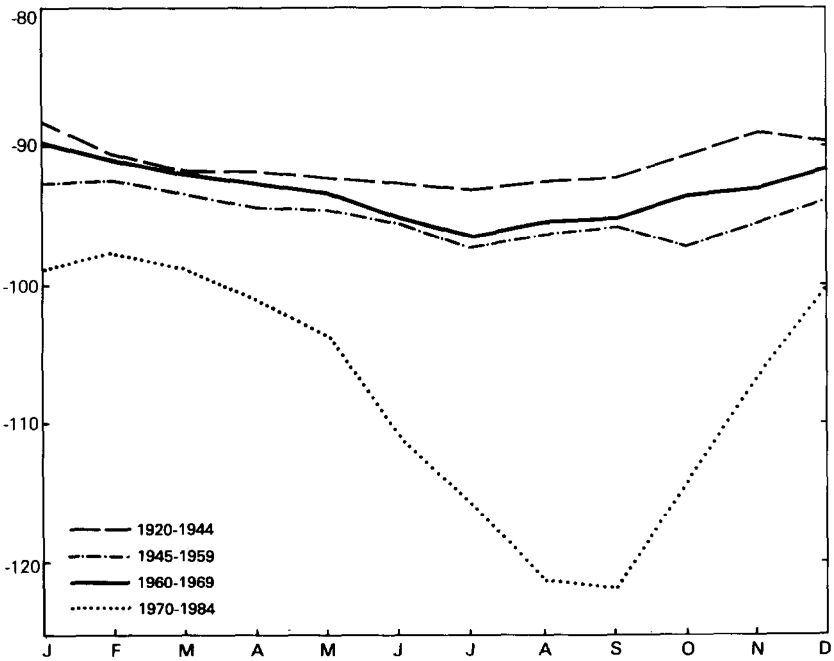

Fig. 2. Annual trend in mean surface water level (cm below mean sea level) in Naardermeer in the periods: 1920–1944 (n = 11), 1945–1959 (n = 14), 1960–1969 (n = 10) and 1970–1984 (n = 15).

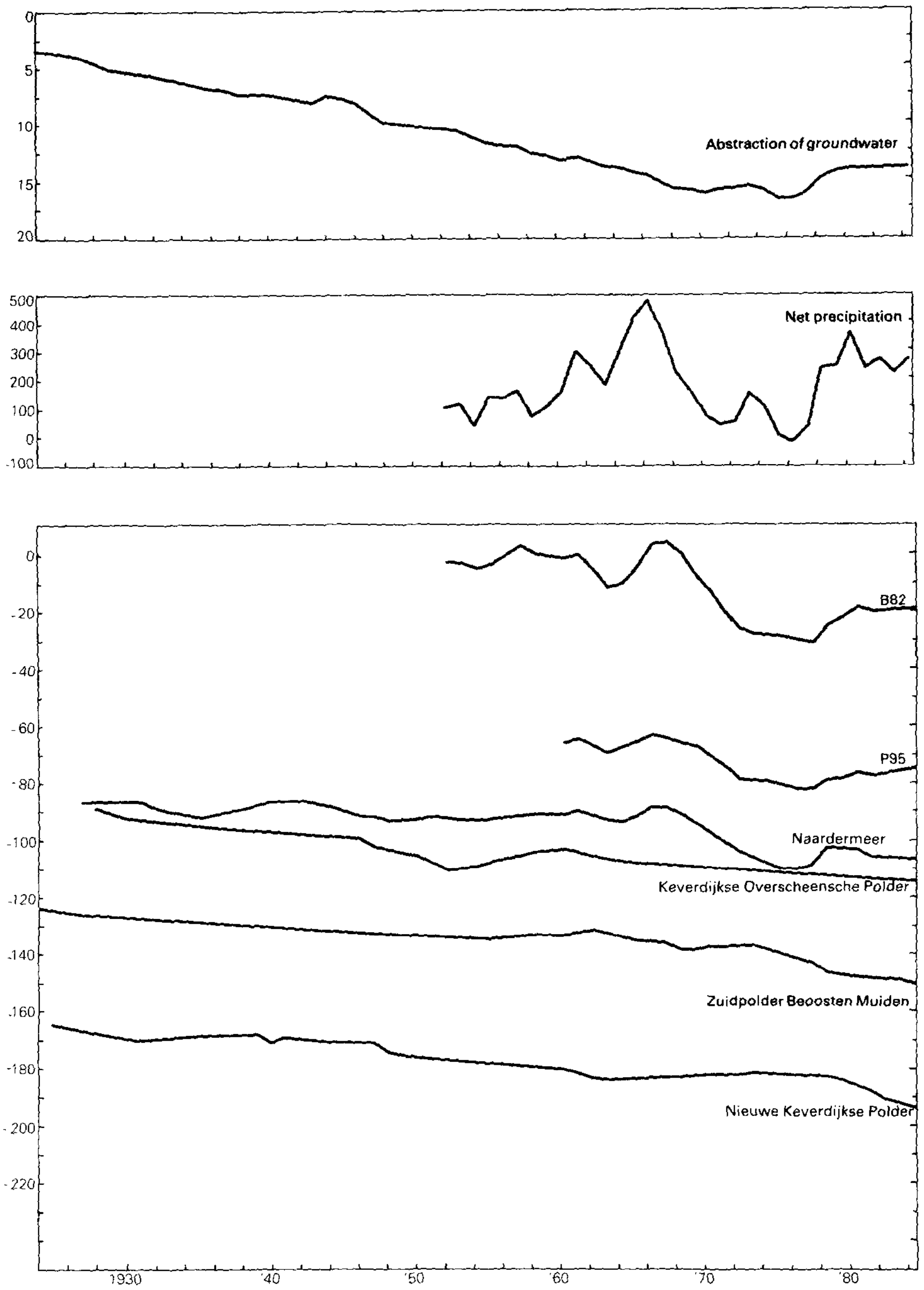

Fig. 3. Three-year running means of parameters affecting the hydrology of Naardermeer in the period 1924–1984. From top to bottom: groundwater abstraction (inverse; in million m^3/year), net precipitation (mm/year), piezometric level of groundwater in hill-ridge (B82 & P95), surface water levels (in cm below mean sea level) of Naardermeer Polder, Keverdijkse Overscheense Polder, Zuidpoler Beoosten Muiden and Nieuwe Keverdijkse Polder. The records of piezometric levels of the groundwater in the hill-ridge originate from the files of TNO-Dienst Grondwaterverkenning (Delft): locality B82 (filter 27–47 m blow mean sea level) *c.* 1 km east of Naardermeer and locality P95 (filter 33 m below mean sea level) just at the eastern border. Data of surface water levels in four polders and of abstraction of groundwater in the hill-ridge originate from the files of PWS-Noord-Holland (Haarlem). Climatological data are from KNMI (De Bilt).

winter and summer half-years (Fig. 4). We conclude that there is a direct (almost linear) relation between the piezometric level in the hill-ridge and the surface water level in Naardermeer. This is why the amount of water discharged from the hill-ridge is fairly constant. In the summers when the water levels in Naardermeer were extremely low (1972–1977) the difference between the level of the Naardermeer and that of the surrounding polders decreased (Fig. 4). This implies that the losses by infiltration also decreased and that the polders were not the cause of the extreme levels. Therefore the only two parameters that can explain the low levels in Naardermeer are the low precipitation (and high evapo-transpiration of the vegetation) and the abstraction of increased quantities of groundwater, resulting in lower piezometric levels in the hill-ridge.

In the period 1978–1984 piezometric levels were expected to be higher if the trends for the previous

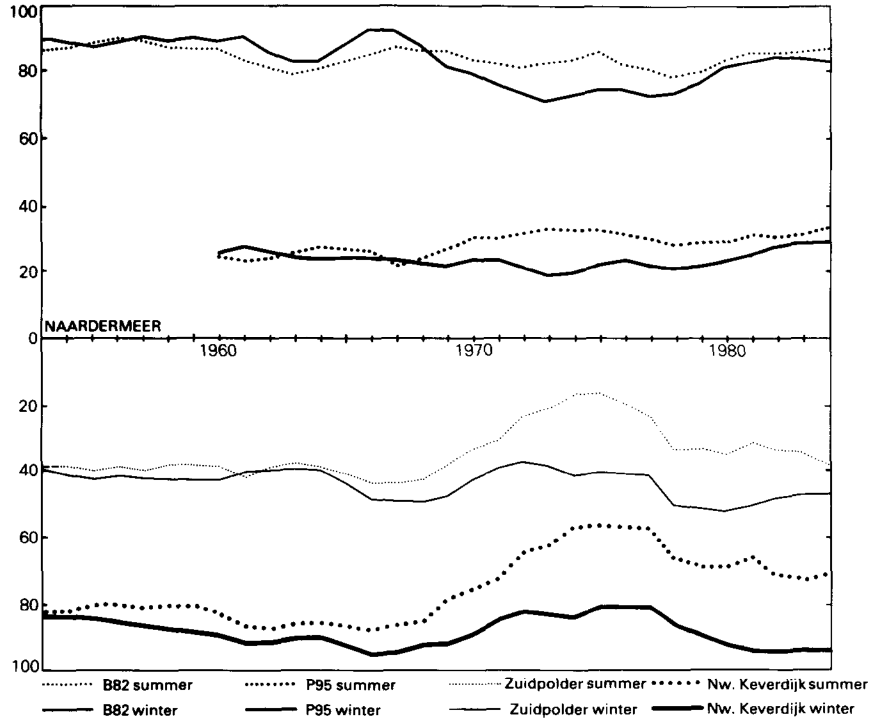

Fig. 4. Three-year running means for summer and winter values for the difference in the hydrological heads in the hill-ridge (B82 & P95), surface water level in Zuidpolder Beoosten Muiden and Nieuwe Keverdijkse Polder and surface water level of Naardermeer (zero-line). Dotted line = May–October; solid line = other months.

years were extrapolated: both net precipitation and abstraction of groundwater were the same as in the period 1960–1968. However, in the period 1978–1984 the piezometric level was 10–15 cm lower (Fig. 3). Since neither precipitation nor abstraction can explain the unexpected drop in the piezometric level and the water level in Naardermeer, another factor must be involved.

In the period 1960–1985 three external hydrological changes took place. In 1969 a very large polder (Zuidelijk Flevoland) was reclaimed 3 km north of Naardermeer. This polder, 4 m below mean sea level, influences Naardermeer (Witmer, 1989) either directly by increased infiltration in the reserve, or by lowering the piezometric levels in the hill-ridge and in this way the levels in Naardermeer. This relation was demonstrated east of the hill-ridge (Van Westrienen *et al.*, 1991). The second change took place 1 km south-east of Naardermeer. At the beginning of the 1970s a new suburb was built in the Hilversumse Meent Polder. To drain the land at this location the piezometric level was lowered by *c.* 25 cm. This influences the groundwater flow from the hill-ridge. The third change was the gradual lowering of water levels in the surrounding polders (especially after 1978, Fig. 3). This not only influences the groundwater flow from Naardermeer (extra infiltration) but also the hydrology in the hill-ridge (Witmer, 1989). It is likely that all three changes have influenced the piezometric levels in the hill-ridge and Naardermeer.

Changes in water quality

During the last century the quality of the surface water in Naardermeer has changed in two respects: from brackish to fresh and from unpolluted to rich in nutrients.

It has been suggested that the algal blooms in recent years resulted from the decreasing salinity. When the Naardermeer was reclaimed in 1884, the salinity of the surface water was high due to the great quantity of saline groundwater (64,000 m^3/day) discharged from the nearby sea. Salinity was much lower (almost fresh water) in the area south of the railway (Rutgers van Rozenburg, 1888), indicating that fresh groundwater originating from the hill-ridge formed a substantial portion of the discharged water in this area. After flooding in 1886 the salinity gradually decreased. Data supplied by Schoorl (1909), Van Zinderen Bakker (1942), Leentvaar and Higler (1963), Provinciale Waterstaat Noord-Holland (1973) and Zuiveringschap Amstel- en Gooiland (1986) were used to compile the following sequence in lake Grote Meer: Cl^- in mg/l — 1908, 480; 1928, 240; 1937, 176; 1942, 108; 1963, 105; 1972, 109; 1984, 102. It is concluded that the chlorine concentration has been relatively stable for about 50 years. The succession and eutrophication of the ecosystem cannot therefore be explained by changes in the salinity.

During the last 25 years the concentrations of nitrogen (nitrate, ammonia and organic nitrogen) and of ortho-phosphate in the surface water have increased (Table 2). Comparable data on, for example, heavy metals or pesticides are not available. We will focus on two main nutrients, nitrogen and phosphorus, and briefly discuss the eight most important sources of these nutrients in the surface water.

Table 2. Nutrient concentrations in Lakes Grote Meer and Bovenste Blik, in surface water near the cormorant colony and in dephosphorised supplied water

Data 1963: Leentvaar (1976); 1972: Provinciale Waterstaat van Noord-Holland (1973); 1978–1984: Zuiveringsschap Amstel- en Gooiland (1986); 1985: own data.

Nutrients in mg/l		PO_4	NO_3	NH_4	org.-N
Grote Meer	1963	<0·03	<0·1	0·1	0·5
Bovenste Blik	1963	<0·03	<0·1	0·37	1·0
Grote Meer	1972	<0·03	0·3	0·3	
Bovenste Blik	1972	<0·03	0·5	0·1	
Grote Meer	1978–1984	0·02	<0·1	0·12	1·54
Bovenste Blik	1978–1984	0·02	<0·1	0·12	1·86
Grote Meer	1985	0·05	0·38	0·18	
Bovenste Blik	1985	0·09	0·63	0·13	
Cormorant colony	1985	10·41	19·33	47·58	
Supplied water	1985	<0·03	0·68	0·05	

(1) The influence of guanotrophy on the lakes was analysed a long time before the eutrophication developed (Leentvaar, 1958). The presence of many Flagellatae near the breeding colonies was an indication of eutrophication. These algae were absent in Lake Bovenste Blik, which was isolated from the colony and received nutrient-poor groundwater.

The reserve has always been famous for its breeding colonies of spoonbill *Platalea leucorodia*, purple heron *Ardea purpurea* and cormorant *Phalacrocorax carbo sinensis*. Colonies of black-headed gull *Larus ridibundus* were also present at the beginning of this century (Thysse, 1912). A common feature in these birds is that they find most of their food outside the Naardermeer, so there is a flow of nutrients into the reserve. Until 1965 this did not cause any problems.

Before 1965 the number of nesting cormorants was restricted by law in order to protect commercial fishery interests. However, in 1965 the cormorant became a protected bird in the Netherlands and because this bird was rare in the whole of western Europe the restrictions on the colony in Jan Hagensbos (in the middle of the reserve) were removed. As a result the colony expanded: whereas there were 500 pairs of cormorants in 1955, by 1986 there were 5 000 pairs. Over the last 25 years *c.* 55,350 pairs have nested over an area of 30 ha. An estimate can be made of the amount of nutrients added by the flow of food into the ecosystem. If we assume that the adults stay for about 165 days in the colony and the juveniles (2·2 per nest) for 75 days, and that the guano-production is 50 g dry-weight/bird/day (Denneman & de Vries, 1985), then it can be concluded that 1,350,000 kg of guano have been produced in the last 25 years. If 1 g of guano contains 20 mg phosphorus and 150 mg nitrogen (Denneman & de Vries, 1985), then 25,000 kg phosphorus and 200,000 kg nitrogen were produced by the birds. The greater part of these nutrients was deposited in the colony. Although this calculation is only a rough estimate, it indicates the large quantity of nutrients the birds add to the Naardermeer ecosystem. Part of these nutrients will be carried away by groundwater flow (the colony is in the infiltration area) to areas outside Naardermeer. Since there have been open connections between the ditches in the colony and the lakes, an unknown amount must have been transported by surface water. This means that the lakes are likely to have been seriously polluted by nutrients for many years.

(2) Another cause of eutrophication is the mineralisation of the peat soil. The low water levels in the period 1970–1980 resulted in the solidification and oxidation of the soil in the marshlands around the lakes. In the literature one finds contradictory data about the release of nutrients. Due to the high C/N-ratio in these marshlands (30–40), theoretically no nutrients should be freely available (Alexander, 1977). In another area in the river plain, Verhoeven and Arts (1987) estimated that the amount of inorganic nitrogen and phosphorus released is 18–175 kg N/ha/year and –0·6–28·5 kg P/ha/year. In nutrient balance studies of peaty nature reserves in the province of Friesland, Corpel (1987) calculated a natural leaching of 5 kg N/ha/year and 1·7 kg P/ha/year. If these latter data are used to give an estimate of the possible quantity of nutrients produced during mineralisation, the 185 ha of marshlands must have produced at least 9 250 kg nitrogen and 3 145 kg phosphorus over a 10-year period.

(3) Local pollution of Lake Bovenste Blik (Provinciale Waterstaat van Noord-Holland, 1973; Leentvaar, 1976) was caused by the discharge of water from the Karnemelksloot canal at the eastern border into the lake. Especially during the period 1963–1975 large quantities of effluent from a sewage plant and the chemical industry were present in this canal. A distinct gradient in the concentration of phosphate and nitrogen was detected in the surface water of Naardermeer during that period — extremely high values near Karnemelksloot, decreasing towards Lakes Bovenste Blik and Grote Meer (Leentvaar, 1976). The metals (Pb, Zn, Cu, Cr) and polycyclic aromatic hydrocarbonates (e.g. fluoranthene) detected in the lake could be used as traces of intruding polluted water (Braam, 1974; Van der Meer, 1982). In 1985 local concentrations of nickel and zinc (up to five times the maximum standard in surface water) were detected in the surface water of Bovenste Blik (own data).

(4) Since the input of water into Naardermeer depends on the quantity of water discharged from the hill-ridge, the quality of this groundwater is very important. We took monthly samples in 1986 (1–6 m below surface). Average data calculated for 10 piezometers distributed all over the discharge zone were: 0·75 mg/l nitrate, 0·35 mg/l ammonia and 0·20 mg/l phosphate. This results in a yearly input of *c.* 640 kg nitrogen and 94 kg phosphorus. However, since the system is not oligotrophic at present the recharging groundwater transports nutrients out of the system. Average data for 12 piezometers in the infiltration area were: 0·42 mg/l nitrate, 1·31 mg/l ammonia and 0·19 mg/l phosphate. The yearly export will be *c.* 2400 kg nitrogen and 92 kg phosphorus.

(5) The atmospheric deposition of nutrients has increased during the last few decades. Data from the localities of Nieuwkoop and De Bilt (KNMI/RIVM, 1987) indicate an average concentration of 7 mmol ammonia/m^2/month, 3 mmol nitrate and 0·03 mmol phosphate. This means that 11,760 kg nitrogen and 78 kg phosphorus are deposited each year in the Naardermeer area (700 ha).

(6) The toilets in the trains on the 3 km of railway line through the Naardermeer are also a source of nutrients. If it is accepted that all the resulting nutrients are deposited in the system, three different methods of calculation with the total number of passengers (about 30,000/day) and the human excretion (10 g N and 1·5 g P/day) suggest that there is a yearly addition of approximately 128 kg nitrogen and 18 kg phosphorus. These methods include (i) the average number of passengers/km of railway line and 1% of the passengers using the toilet (Dutch Railway Company, pers. comm.); (ii) the number of toilets/train/day; and (iii) travelling the 3 km takes 2 min (or 0·001389 day) times the number of passengers.

(7) Another source of nitrogen in the reserve is the nitrogen fixation by *Alnus glutinosa*. There are *c.* 200 ha of alder woodland. The fixation by the nodules of approximately 70 kg nitrogen/year (Akkermans, 1971; Akkermans & van Dijk, 1976) means a loading of 14,000 kg/year for the whole reserve. Part of this nitrogen will be denitriphicated or stored; however, some will run off into the surface water.

(8) Finally it should be noted that nutrients are also present in the lake-bed sediments. This sediment can contain a high concentration of nutrients: 63% of the nitrogen of an ecosystem is present in the sediment and only 8% is freely available in inorganic form in the water (Van Vierssen, 1982). More than 0·3 million m^3 of sapropelium and silt are present in the Naardermeer polder (Zuiveringschap Amstel- en Gooiland, 1989). Consequently a large part of the nutrients from the first seven sources is probably stored in the lake sediments (Barendregt *et al.*, 1989). The sediment of lake Bovenste Blik is especially rich in phosphorus (Zuiveringshap Amstel- en Gooiland, 1989), which points to the addition of nutrients from Karnemelksloot canal. It is therefore surprising that in some places the growth of Algae is inhibited, mainly because of a shortage of nitrogen (De Vries, 1986).

Restoration of the quantity of water

The ecology of the lakes and marshlands of Naardermeer was affected because the water levels were too low. There were three possible ways of re-establishing the equilibrium in the hydrology: (1) increase the input by discharge of groundwater from the Pleistocene ridge; (2) find an alternative source of supplementary water; and (3) decrease the output by infiltration of water in the reserve.

(1) The input by discharge of groundwater can be enlarged by increasing the difference between the piezometric level in the hill-ridge and that in the Naardermeer polder. Lowering the level in Naardermeer is not a solution to the problem (mineralisation of peat soil will occur), so a rise in the water levels in the hill-ridge should be the starting point. Not only Naardermeer but also most natural areas in the Vecht river valley suffer from the effects of a decreasing inflow of groundwater (Provinciale Waterstaat van Noord-Holland, 1986). In 1986 the regional government therefore planned to restore the groundwater flow from the hill-ridge to the valley. Within 10 years the abstraction (15 million m^3/year) of drinking water should be reduced by a total of 8 million m^3/year.

(2) The second option was to find a new source of unpolluted water to supplement the water balance in the wetland. Since the problems were becoming serious, a rapid technical solution had to be found. With the help of the government a plant was installed in 1983 to dephosphorize water from Lake IJsselmeer (Witteveen + Bos, 1981). In periods of water shortage it is now possible to supply 14,000 m^3/day of water low in phosphate. In the dry summer of 1986 this installation produced 1·6 million m^3 water, which is equivalent to the volume of surface water in the whole of Naardermeer. Since the electrical conductivity of the water that enters at the extreme western edge of the polder was higher than that of the original water, the flow in surface water could be traced (Schot *et al.*, 1988). It appeared that most water infiltrated at the western edge, close to the locality of suppletion.

(3) The decrease in output can only be realised by raising the water levels in the surrounding polders at the western edges of Naardermeer. This option is now being studied, although the solution is not easy for economic reasons: high water levels will restrict agricultural management in these pastures. Politics will decide whether the regional government will opt to stimulate nature or reap economic benefits.

Restoration of water quality

The deterioration in the surface water quality of Naardermeer has been due to eight sources of nutrients; three are clearly defined, the others are diffuse; five are inside the reserve while the others are beyond its boundaries.

Two clearly defined local sources could be eliminated in the short term by internal management. The flow of nutrients from the cormorant colony into the lakes was changed. The ditches carrying the surface water to other parts of the nature reserve played an important role in the distribution of the nutrients. The breeding area was therefore isolated hydrologically from the lakes at the beginning of 1986. The local problems in the discharge zone caused by the polluted Karnemelksloot canal were more difficult to eliminate, because the causes were outside the nature reserve. First the problem was solved locally by pumping the polluted discharged water from the ditches in the meadows back into the canal. At the same time measures were taken to prevent pollution in the canal (Prins & Verstraelen, 1986) and in 1986 this aim was achieved (Zuiveringschap Amstel- en Gooiland, 1986). The third local source is the human excretion from the trains, but the only way to remove this source would be to change the toilets in the trains.

Two diffuse sources of nutrients inside the nature reserve could to be eliminated. First the storage of nutrients in the water sediment, the sink for many years, is a continual source of eutrophication. The majority of the nutrients can be removed from the system if the layer of sapropelium and mud is removed (Moss *et al.*, 1986). Since the quantity of sediment involved is likely to be more than a quarter of a million cubic metres (Zuiveringschap, 1989), a large site has to be found to store the sediment. This has been a major problem, and at the moment the sediments are dredged. The second diffuse source of nutrients is connected with the mineralisation of the peat soil. This source has been eliminated by the supply of dephosphorised water so that water tables have been stable since 1985. The small concentration of phosphate in the water supplied also helps to reduce eutrophication in Naardermeer. However, there are also complications. The 'new' water differs from the original water in the lakes. This can be seen by comparing the concentration of ions just before the extra water supply was introduced in June 1985 and the concentration in September 1986 after the extra water had been supplied for a long period (Table 3). Obviously the supplementary supply leads to salination. This change in water quality could have contradictory effects on biotic values and might lead to the former saline environment being restored. On the other hand, the effect could be negative and plant species that flourish in mesotrophic fresh lakes and marshes might disappear (Wassen *et al.*, 1986).

Even if these four sources of nutrients inside and outside the wetland are eliminated, some diffuse sources will remain: the concentration of nutrients in the groundwater and the supplementary water, nitrogen fixation in alder woodlands, and atmospheric deposition (plus the local nutrients from the railway). To indicate the relative importance of these sources, Table 4 shows the water balance (Ecotest, 1990) for the Naardermeer polder in an average year. This water balance and the average nutrient concentrations (mentioned above) result in a nutrient balance. The harvest of fish and reeds is so small that it can be ignored. Since in future the surface water will have a lower concentration of nutrients, the quantity of nutrients that will infiltrate will decrease. The denitrification rate depends on local

Table 3. Mean concentration of major ions in surface water before (1985) and after (1986) addition of dephosphorised water

Grote Meer: 300 m from point of inlet; Bovenste Blik: not reached by supplementary water.

Ions in mg/l		Cl	SO_4	Na	Mg	K	Ca	HCO_3
Grote Meer	1985	104	46	73	7·7	5·0	67	163
Grote Meer	1986	189	105	132	15·6	8·4	70	126
Bovenste Blik	1985	115	41	78	7·4	4·4	60	154
Bovenste Blik	1986	129	36	87	9·2	4·8	52	118

Table 4. Water and nutrient balance in Naardermeer in an average year

	Water in million m^3/year	Nitrogen in kg/year	Phosphorus in kg/year
Input of the Naardermeer system			
Discharged water	1·45	640	94
Supplementary water	1·15	700	22
Precipitation	5·40		
Railway		128	18
Atmospheric deposition on aquatic system		3 500	22
Atmospheric deposition on terrestrial system		9 000	56
N-fixation nodules of *Alnus glutinosa*		14 000	
Output of the Naardermeer system			
Recharged water	2·28	2 400	92
Artificial drainage	1·92	2 000	96
Evaporation	3·80		
Denitrification in reedlands		250	
Denitrification in alder woods		5 000	
Denitrificiation in aquatic system		?	

and internal processes (Damman, 1988; Koerselman, 1989; Kemmers, 1990). Denitrification in reedlands in the river plain might be 1·4 kg N/ha/year (Koerselman, 1989). Data on denitrification in alder woods in various countries range from 4·9 kg N/ha/year (Struwe & Kjöller, 1989, 1990) to 24 kg N/ha/year (Bowden, 1986) or to 60 kg N/ha/year (Denmead *et al.*, 1979). A value of 20 kg N/ha/year was assumed in our calculation. Denitrification in the aquatic system occurs (Patrick & Tusneem, 1972), but quantified data are not available.

Although the data on nutrient balance are imprecise, it can be concluded that the total reserve mainly depends on both nitrogen fixation by alder woods and on atmospheric deposition; nitrogen especially will accumulate. Since the atmospheric deposition is a result of agriculture, traffic and industry, this complex problem will have to be solved in a national or even international, context. Although the amount of denitrification in the system is unknown, an equilibrium in the nutrient balance of the aquatic system could be obtained if the input from alder woods and atmospheric deposition could be eliminated. Without these two sources the total input of nitrogen and phosphorus (1 468 and 134 kg/year) does not really exceed the output (4 400 and 188 kg/year). This is important, since conservation of a mesotrophic wetland would then be possible.

However, to restore the water quality it is not sufficient simply to increase the quantity of discharging water of the hill-ridge. This measure needs to be linked with other measures to protect the quality of this water (Verhoeven *et al.*, 1988). The seepage water originates from precipitation in an infiltration area of *c.* 8 km^2 (Schot, 1989), which includes several towns. This water is affected by atmospheric deposition as well as by pollution from households, leaking sewage, industry, etc. (Janssen & Verkroost, 1989). Because groundwater flows very slowly it will take many decades for the pollution to disappear. Thus the preservation of the groundwater quality in Naardermeer will also require special measures and the removal of existing pollution in the groundwater of the hill-ridge.

DISCUSSION

After 80 years of high-quality management of the Naardermeer wetland the ecologists and hydrologists are wondering whether it is really possible to conserve the biotic values of this wetland in the long term. All those concerned sought to preserve the area using the information available to them at a given time. They did their best, but their efforts have not been entirely successful, although the protection of birds and of climax phases has been achieved. At the same time, however, the diversity in succession phases has decreased and the aquatic systems have become dominated by algal bloom. This does not imply that there is no future for this nature reserve. In recent years the Characeae vegetation (and *Najas marina*) has become re-established in the western parts due to the dephosphorised water supply. The vegetation should expand when the proposed measures are achieved (Barendregt *et al.*, 1991). Moreover, the regional government intends to solve the external problems with an integrated approach in which all the authorities (such as water boards, drinking water companies, regional and local government) will join forces under a covenant (De Groot *et al.*, 1991). This is an important step because nature conservation needs to be in the interest of all the participants involved.

Because Naardermeer is located in one of the most densely populated areas in the Netherlands it has been subject to many harmful influences. It is impossible to detect one major cause of its deterioration; rather there is a series of problems connected with three main topics: succession, hydrology and increase in nutrients.

(1) Succession has resulted in the disappearance of initial succession phases (Table 1) and the growing dominance of alder woodlands. Among the consequences of succession are changes in the diversity of vegetation types and solidification of peat soils, which will continue to occur unless management undertakes a number of radical measures such as the clearance of woodlands and the removal of lake sediments.

(2) Hydrology is totally controlled by forces outside the reserve. The piezometric level of the hill-ridge affects the input of groundwater. The amount of infiltration into the reserve is increased by lowering the water levels in the surrounding polders (Fig. 3). The alternative solution to the shortage of water, the introduction of a supplementary water supply from the River Vecht, was at that time not practicable because the river water was polluted. Protecting the hydrology of a wetland means conserving all the hydrological relations with the surrounding area.

(3) The increasing concentration of nutrients leads to the disappearance of mesotrophic conditions and a reduction in species diversity. These extra nutrients are provided partly by changes in (i) vegetation (ageing of the system with accumulation of nutrients, N-fixation of *Alnus*); and (ii) hydrology (mineralisation of peat soils, increased supply of nutrient-rich water). Eutrophication is also partly a result of special internal circumstances, such as guano deposits and pollution near the Karnemelksloot. It is possible that the algal bloom is caused not only by increased nitrogen and phosphorus but also by other factors. However, there is no doubt that the external sources are important: pollution is transported into the reserve by air, trains and groundwater (Table 4).

Consequently, the general conservation of wetlands requires management at various levels. Local (internal) management deals mainly with the conservation of succession phases and the internal hydrology. However, conditions for the preservation of wetlands are controlled at a regional level. Hydrology, the dominant ecological factor, has to be preserved for it is impossible to separate the hydrological relations between the wetland and the hydrological system of which it forms a part. Human influences around the wetland have an effect on the surface water and the groundwater (flow and quality), so management should concentrate on those external areas.

These problems are not unique to Naardermeer. For instance, the Norfolk Broads in England have suffered extreme eutrophication from polluted rivers (Moss *et al.*, 1986). The problems connected with a regional approach to wetlands also apply to arid areas: the natural environments of Cota Doñana in Spain are also endangered by groundwater abstraction (Llamas, 1988). These external hydrological problems should be recognised at an early phase because it is generally impossible to restore a balance in ecological relations quickly. Moreover, solving external problems takes time because politics are involved.

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