Zeitschrift: IABSE reports = Rapports AIPC = IVBH Berichte

Band: 63 (1991)

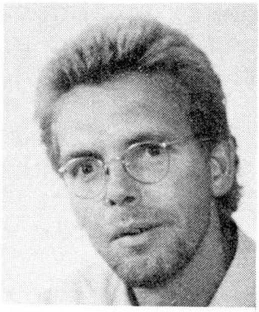
Artikel: Damming of sea arms: the salt water lake option

Autor: Iedema, Wouter

DOI: https://doi.org/10.5169/seals-48486

Damming of Sea Arms: The Salt Water Lake Option
Construction de barrages sur des bras de mer: option du lac salé
Abdämmung der Meeresarme: die Salzwasserseeoption

Wouter IEDEMA
Ecologist
Minist. of Transp. and
Public Works
Middelburg, The Netherlands



Wouter Iedeman, born 1955, obtained his biological degree at the Univ. of Groningen. For 3 years he was involved in the management of the international wetland "de Oostvaardersplassen". Presently he is jointly responsible for the integral water management of the Deltawaters of south-west Netherlands.

SUMMARY

Lake Veere and Lake Grevelingen are both former sea arms, dammed as a part of the Deltaplan. Though originally planned as freshwater lakes, they were maintained salt as a consequence of the decision to keep the Eastern Scheldt open. The infrastructure and the management was not originally aimed to meet the conditions necessary for the development of sound, well-functioning saltwater lakes. This article describes the conditions which have to be met and how the sustainable management of saltwater can be achieved.

Construction de barrages sur des bras de mer: option du lac salé

Résumé

Les lacs Veere et Grevelingen sont d'anciens bras de mer fermés à la suite de la réalisation du projet Deltaplan. Ils étaient prévus, à l'origine, comme lacs d'eau douce mais ont été maintenus en eau salée, suite à la décision de maintenir ouvert l'estuaire de l'Escaut. L'infrastructure et l'exploitation n'étaient pas, à l'origine, conçues pour un lac d'eau salée. L'article décrit les conditions à remplir et l'exploitation appropriée de l'eau salée.

Abdämmung der Meeresarme: die Salzwasserseeoption

Zusammenfassung

Die Seen "Veere" und "Grevelingen" sind beides frühere Meeresarme, eingedämmt als Teil des Deltaplans. Obwohl ursprünglich als Frischwasserseen geplant, enthalten sie weiterhin Salz infolge der Entscheidung, die Osterschelde offen zu halten. Die Infrastruktur und der Betrieb waren ursprünglich nicht für die Entwicklung gut funktionierender Salzwasserseen geeignet. Dieser Artikel beschreibt einzuhaltende Bedingungen und Massnahmen zur Wahrung des Salzgehaltes.

1. Introduction

The original Deltaplan for the south-west of the Netherlands intended to close all sea arms but one and to turn them into fresh water lakes. During the execution of the Deltaplan one became aware of the environmental and economic values of the estuaries. This has changed the Deltaplan considerably (fig 1). Well known is the construction of the storm surge barrier to combine safety against flooding and conservation of the estuarine character of the Eastern Scheldt. Less known are the consequences for the already closed sea arms Lake Grevelingen and Lake Veere which still contained seawater awaiting desalinisation. It was decided to keep these lakes salt. Now the management was challenged to utilise the full potential of these lakes and to make sustainable development possible.

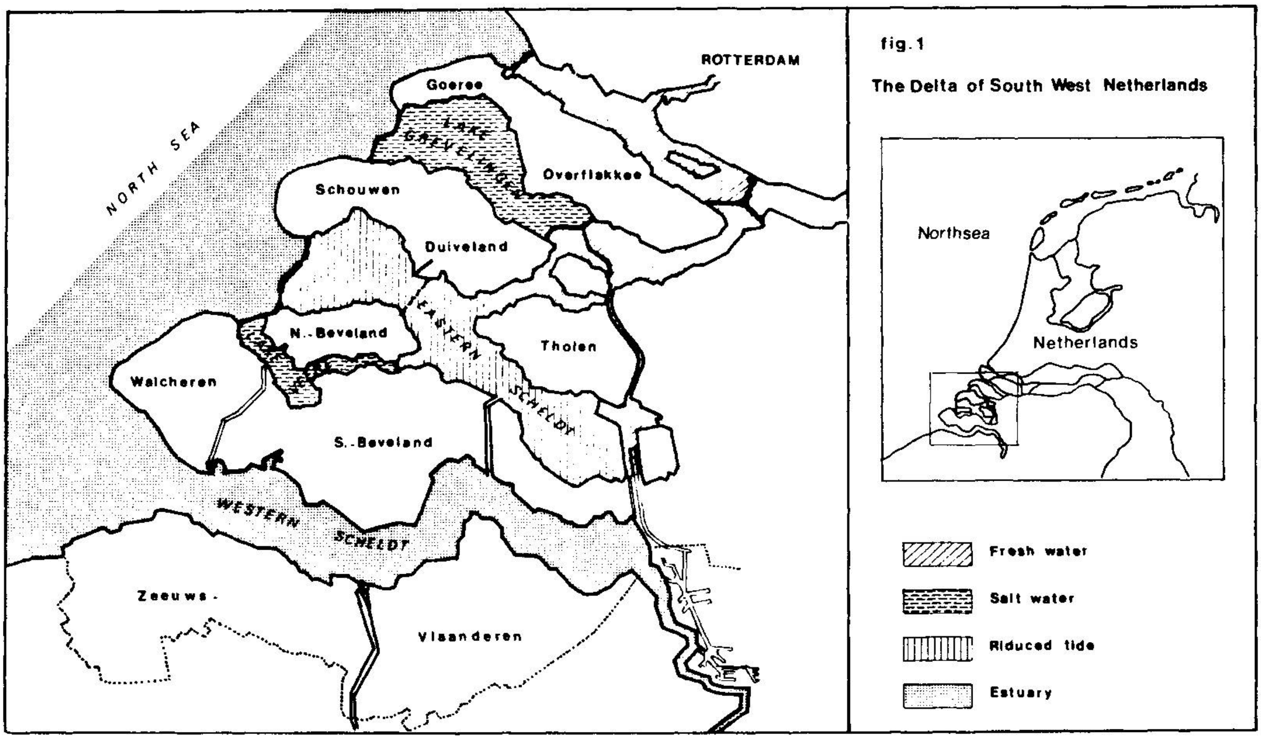


fig.1
The Delta of South West Netherlands

2. Lake Grevelingen and Lake Veere

2.1 history and characteristics

Lake Grevelingen and Lake Veere are both former seaarms. Lake Veere was dammed in 1961 and Lake Grevelingen in 1971. Since 1979 exchange with seawater is made possible in Lake Grevelingen by means of a sluice in the western dam with a capacity of 125 $m^3.s^{-1}$ averaged over a day. Lake Veere only has a lock in the eastern dam. In Lake Grevelingen the water level is maintained at MSL-0.20m. Lake Veere has a water level of MSL in summer and a lowered waterlevel of MSL-0.70m in winter for the benefit of the drainage of the surrounding polders. In table 1 the main characteristics are summarised.

table 1. morphometrics of Lake Grevelingen and Lake Veere

	lake Grevelingen	lake Veere
water surface (ha)	11000	2030 (MSL) 1742 (MSL-0.70m)
drainage area (ha)	13045	19335
mean depth (m)	5.3	5.0
max depth (m)	48	25
length (km)	23	24
width (km)	4-10	0.2-1.6

2.2 ecology

Lake Grevelingen is a good example of how valuable a saltwater lake can be. The water is extremely clear with a secchi depth of more than 5 m and the lake is characterised by the presence of typical aquatic and terrestrial animal and plant communities (2,9). Lake Veere on the other hand is bothered by problems of stratification and eutrophication. This becomes evident in high algae blooms in spring, excessive growth of sea lettuce and anoxia in deeper parts of the lake (1,4). Another problem is formed by the unstable conditions around the shoreline for benthic and plant communities, caused by the lowered water level in winter (5,10).

2.2.1 salinity and stratification

Though Lake Veere and Lake Grevelingen are cut off from the river influence, there is still a fresh water load from the surrounding polders. In Lake Veere the freshwater load equals the seawater load. This is the cause of the strongly fluctuating chlorosity (8-12 $g.Cl^{-}.l^{-1}$) (7). In Lake Grevelingen the seawater load exceeds the freshwater load by about twentyfold. The chlorosity is constant and reflects the chlorosity of the coastal waters (15-17 $g.Cl^{-}.l^{-1}$)(2,12).

table 2. hydrology of Lake Veere and Lake Grevelingen

	lake Grevelingen	lake Veere
fresh waterload ($m^3.y^{-1}$)	$40-55.10^6$	$110-125.10^6$
salt waterload ($m^3.y^{-1}$)	10^9	100.10^6
volume (m^3)	575.10^6	102.10^6 (MSL) 89.10^6 (MSL-0.70m)
residence time (days)	200	180

A low, strongly fluctuating salinity is typical for the transition zone in estuaries. It is characterised by a low species diversity. This is true for Lake Veere, where the species diversity is rather low in comparison with Lake Grevelingen. For instance, the number of bottom fauna species in Lake Veere numbers around 40, in Lake Grevelingen on the other hand about 60 (5,8,10).

Another effect of the fresh water load on salt water lakes is the appearance of stratification. This is the phenomenon in which there is a sharp transition in the water column between layers of water with a different salinity or temperature (fig 2). In stagnant waters only wind can alleviate stratification.

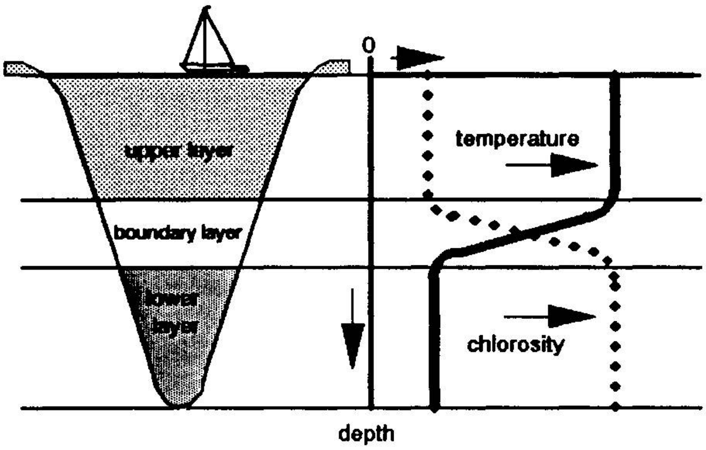


fig.2 Scheme of salt and temperature stratification

The boundary layer, which separates the upper and lower layer, forms a barrier for the exchange of oxygen and can lead to anoxia in the lower layer. The anaerobic surface depends strongly on the position of the boundary layer; the higher the position of the boundary layer, the greater the potential anaerobic surface. This is most striking in Lake Veere. In summer the boundary layer can rise to 4-6 m below water level and up to 25% of the lake can suffer from oxygen depletion (7). In Lake Grevelingen however stratification stays confined. Even in unfavourable years oxygen depletion rarely exceeds 5% of the lake surface (2,12) (fig 3 and 4).

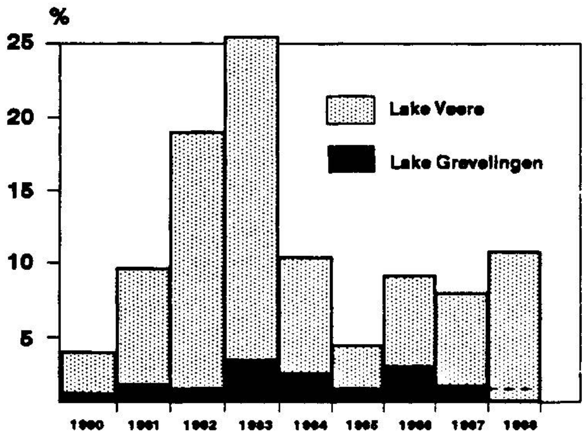


fig.3 Anaerobic surface in Lake Veere and Lake Grevelingen

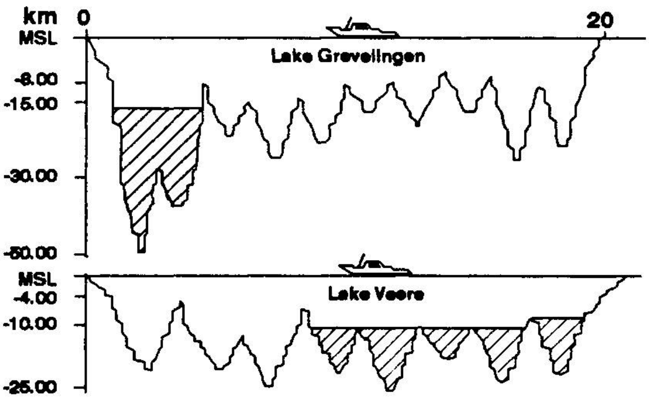


fig.4 Extension of anaerobic surface in Lake Veere and Lake Grevelingen

Anoxia is detrimental for life in the deeper parts. In Lake Veere little bottomfauna is found below 12m in the mid- and eastern section of the lake (5,10), whereas in Lake Grevelingen about 10% of the biomass lives below 14m (2,8). Also the surface of the feeding grounds for fish is reduced by anoxia.

2.2.2 eutrophication

Before damming nutrient cycles were dominated by external influences. The nutrient load originated mainly from rivers and sea. The residencetime of about a month reduced the importance of internal processes in the systems. By damming the influence of rivers and sea has been reduced a great deal. The nutrient load is now chiefly regional in origin. The surrounding polders form the main source for this nutrient load. Also hydrologic conditions have changed, through which the effect of internal processes in the lakes has increased. The overall effect is the increased susceptibility of the newly created salt water lakes to eutrophication.

This is most obvious in Lake Veere. In spring an excessive abundacy of algae and sealettuce (Ulva spec.) occurs and anoxia appears in deeper parts. Lake Grevelingen is not plagued by these problems. The cause of the problems of eutrophication in Lake Veere lies in the relation between nutrient load and carrying capacity of the system. The main nutrient is nitrogen, which is limiting for algae growth in the salt water lakes as well as in other shallow coastal waters. The nitrogen load on Lake Veere is 40 $gN/m^2.j^{-1}$. This is ten times as high as the load on Lake Grevelingen (table 3). Less than 50% of the nitrogen load disappears from Lake Veere by denitrification (14). In Lake Grevelingen the polder load is almost completely compensated by denitrification. This is caused by the high turnover rate of nitrogen in Lake Grevelingen. Each year the total amount of nitrogen goes through the cycle of uptake, transformation and regeneration at least five times (13). In Lake Veere this is about 2-3 times.

table 3. nitrogen fluxes in Lake Veere and Lake Grevelingen ($gN.m^{-2}.y^{-1}$) (13,14)

	Lake Veere	Lake Grevelingen
net load	35	3.5
exchange North Sea	-18	0.3
denitrification	15	3.0
bottom detritus	2	0.8

A very important link in this cycle is formed by the grazing bottom fauna like mussels (Mytilus edule) and cockels (Cerastoderma baltica). By grazing and excretion they accelerate the turnover rate (13,14). In parts of Lake Veere the bottom fauna is very poorly developed because of anoxia. As a result the grazing rate is rather low and algae concentrations are increased. This explains for the greater part the differences in chlorophyl concentrations between the western and eastern part of Lake Veere (25 $ug.l^{-1}$ against 150 $ug.l^{-1}$) (7). Due to the high turnover rate the primary production of 200 $gC.m^{-2}.y^{-1}$ in Lake Grevelingen is fairly high in comparison with the nutrientload (9). The primary production in Lake Veere amounts 380 $gC.m^{-2}.y^{-1}$ (11,14). This increased production leads to an increased sedimentation of organic material on the bottom and thus to an increased oxygen demand. In combination with stratification anoxia is likely to occur.

3. Ecological standards

Standards for sustainable, ecologically sound functioning saltwater systems do not exist. For natural waters like the North Sea a reference can be found in history or elsewhere. For artificially created lakes like Lake Veere and Lake Grevelingen this is not possible. A system orientated approach based on a fundamental understanding of the systems themselves and of other saltwatersystems therefore is necessary. The directorate of Zeeland and the Tidal Waters Division have in this manner tried to formulate conditions under which saltwater lakes can develop themselves into stable, sound systems (1,6). These conditions can be divided in those concerning chlorosity and stratification, eutrophication and water level management.

When species diversity is considered as an important natural value, a higher and more stable salinity is necessary. An analysis of the species diversity in estuaries has revealed that a salinity of >13 $g.Cl^{-}.l^{-1}$ can be considered as a minimum condition for the establishment of stable aquatic communities of a marine character. At the same time this forms a potential for shellfish-fisheries.

When the total anaerobic surface is restricted to <5% of the bottom surface, no significant problems seem to appear. To achieve this it is necessary to reduce the boundary layer in Lake Veere to a depth of >12-13m.

To prevent eutrophication the nutrient load should be in balance with the carrying capacity of the system. In this case accumulation of nutrients rarely appears and the primary production is mainly driven by internal nutrient regenaration. To judge this the total nutrient cycle should be considered. Nutrientconcentrations in winter are not only of importance, but also the effects on the system. A good indication is formed by the oxygen concentration in the deeper parts. This is influenced by the oxygen demand from the sedimentated algae and by the oxygen supply from the upper layer. The anaerobic bottom surface should therefore be restricted to maximal 5%. It is not possible to formulate a coherent set of standards for the other eutrophication parameters. They should be considered in relation to the standard for oxygen. Yet general directions can be provided: Lowered concentrations of chlorophyl in spring, lowered concentrations of nitrogen in winter and an adequate primary production (>200 $ug.l^{-1}$) with respect to carrying capacity for consumers. For a reduction of the amount of sea lettuce for recreational purposes nitrogen concentrations have to be reduced to less then 1.0 $mgN.l^{-1}$.

For the development of stable plant and animal communities along the shorelines a stagnant water level is necessary. Best conditions are found around the mid position of the former tides (MSL), because of the balance between shallows, transition and terrestrial zones. To protect the former intertidal areas against erosion outer bank defences should be built, as has been the case in Lake Veere and Lake Grevelingen.

table 4. standards for a ecologicaly sound functioning saltwater lake compared with the current values of Lake Veere and Lake Grevelingen

	standard	Veere	Grevelingen
chlorosity ($gCl^{-}.l^{-1}$)	>13	8-12	15-17
boundary layer (m)	>12	8-10	15-17
anaerobic surface (%)	<5	<25	<5
max.NO_3+NH_4 ($mgN.l^{-1}$)	1.0	3.0	0.5
max chlorofyl-a ($ug.l^{-1}$)	<<	150	25
primairy prod.($gC.m^{-2}.j^{-1}$)	>200	380	200
waterlevel	MSL	MSL/ MSL-0.70m	MSL-0.20m

4. Solutions

To create the required conditions for the development of a sustainable functioning salt water lake, two types of solutions can be chosen. The load can be adjusted to the carrying capacity of the system, or the carrying capacity of the system can be enlarged to handle the incoming load in a proper way. Also a combination of both solutions is possible (1,6).

Lake Grevelingen has, unintentionally, benefitted from both solutions. The polder load after damming was already low and the capacity of the sluice is large enough to take care of this load. All standards are met easily with the current management of waterexchange. Without exchange however chlorosity would drop to 11-12 $gCl^{-}.l^{-1}$ within 3 years (3). Lake Veere has been harmed in two ways. The polderload has been concentrated on the lake and the capacity of the system to handle this load is restricted by the absence of exchange with coastal waters. The effect of different solutions is investigated with the help of computermodels for chlorosity and stratification (STRESS, Tidal Water Division) and for eutrophication (VEERWAQ, Delft Hydraulics) (7,14).
When the management of the existing lock is optimalised with respect to exchange, an exchange rate of 5-10 $m^3.s^{-1}$ is realizable. In addition to this a 75% reduction of the total polder load is necessary to meet the standards (table 5). Reduction of the polderload requires severe and expensive measures in the drainage area. Measures to enlarge the carrying capacity of the system are of preference. This can be done by increasing the exchange rate to 20 $m^3.s^{-1}$ or more. Doubling the exchange rate to 40 $m^3.s^{-1}$ provides an even more solid base to the system, so the standards can also be met under unfavourable conditions (1,6,7).

table 5. the effects of different management scenario's for Lake Veere

	A	B	C	D
chlorosity ($gCl^-.l^{-1}$)	8-12	13-14	13-14	14-16
boundary layer (m)	8-10	20	13	13
anaerobic surface (%)	<25	<5	5	5
max.NO_3 + NH_4 ($mgN.l^{-1}$)	3.0	2.3	2.2	1.5
max. chlorofyl-a ($ug.l^{-1}$)	150	55	65	35
primairy prod.($gC.m^{-2}.j^{-1}$)	380	250	285	210

A: current management
B: exchange rate of 5-10 $m^3.s^{-1}$ + reduction load of 75%
C: exchange rate of 20 $m^3.s^{-1}$
D: exchange rate of 40 $m^3.s^{-1}$

5. Conclusions

When the damming of sea arms is considered to be the only real solution to guarantee safety against flooding, the creation of a saltwater lake can be an attractive option with a high potential for nature, recreation and fisheries. In order to create the conditions necessary for the development of an ecological well functioning saltwater lake it is essential to make sufficient exchange with seawater possible and to adjust the freshwater and nutrient load to the carrying capacity of the system.

References

1. ANONYMOUS, 1989. Waterbeheer Veerse Meer, beleidsanalyse tevens milieueffectrapport voor het waterbeheer van het Veerse Meer. Rijkswaterstaat directie Zeeland, Nota AXW 90.050.
2. ANONYMOUS, 1991. Evaluatierapport Grevelingenmeer 1980-1989. DGW- GWWS (In press).
3. BOLLEBAKKER, P, 1990. Resultaten STRESS runs Grevelingenmeer. DGW-GWWS 90.13186.
4. BIJLSMA,L. & C.W.IEDEMA, 1991. Het Veerse Meer uit de wachtkamer. De Levende Natuur, 92ste jaargang, nr 2.(In Dutch, with English summary).
5. COOSEN, J., P.MEIRE, J.J.STUART & J.SEYS,1990. Trophic relationships in brackish Lake Veere: The role of macrophytes. Trophic relationships in the marine environment, 1990, pp404-423.Proc.24th Europ.Mar.Biol.Symp. Margaret Barnes and R.N.Gibson, Editors.Aberdeen University Press.
6. IEDEMA, C.W., 1991. Een meer duurzaam meer. De Levende Natuur, 92ste jaargang, nr2.(In Dutch, with English summary).
7. KAMER, J.P.G. VAN DE, J.STRONKHORST & G.P.BOLLEBAKKER, 1990. A sustainable water management for Lake Veere. The significant choice between a brackish or a salt lake. H2O, 23, no 8, pp 211-215 (In Dutch, with English summary).
8. LAMBECK, R.H.D., E.G.J.WESSEL & A.HANNEWIJK, 1989. Macrozoobenthos in het Grevelingenmeer, een bestandsopname in het voorjaar 1988. DIHO, Rapp. en verslagen nr.1989-5.
9. NIENHUIS,P.H., 1985. Het Grevelingenmeer, van estuarium naar zoutwatermeer. Natuur en Techniek. Maastricht-Brussel.
10. SEYS, J. & P.MEIRE, 1988. Macrozoobenthos in het Veerse Meer. Rapport W.W.E.4, Rijksuniversiteit Gent.
11. STRONKHORST, J., R.N.M.DUIN & H.A.HAAS, 1985.Primaire productieonderzoek in het Veerse Meer (1982-1985). Rijkswaterstaat Nota DDMI 85.10.
12. STRONKHORST,J, 1989. Stratificatie en nutrientengehalten in het Grevelingenmeer over de periode 1980-1988. DGW-GWWS 89.403.
13. VRIES, I. DE, F.HOPSTAKEN, H.GOOSSENS & M.DE VRIES, 1988a. GREWAQ: an ecological model for Lake Grevelingen. Documentation report T0215-03. Delft Hydraulics , Delft.
14. VRIES, I. DE, M.DE VRIES & H.GOOSSENS, 1990. Ontwikkeling en toepassing van VEERWAQ t.b.v. beleidsanalyse Veerse Meer. Simulatie van beheersvarianten. Eindrapportage, T430. Delft