

## RELATIONSHIP BETWEEN QUATERNARY HISTORY AND GROUNDWATER IN THE IJSELMEER AREA<sup>1</sup>

JAN A. VAN DEN BERG<sup>2</sup>

### ABSTRACT

Van den Berg, J. A. 1983 Relationship between Quaternary history and groundwater in the IJsselmeer area. In: J. H. J. Terwindt & H. Van Steijn (eds): Developments in physical geography – a tribute to J. I. S. Zonneveld – Geol. Mijnbouw 62: 577-583.

Concentrations of salt ions in groundwater bearing Quaternary sediments in the IJsselmeer area have been changed by different processes such as transport, diffusion and dispersion, and the exchange of dissolved and adsorbed ions. Two case studies at Oostelijk Flevoland, the IJsselmeerpolder which was drained in 1957, illustrate how the predominating process alternated, in relation with the geological and hydrological configuration and with human interference.

At Lelystad, in the central part of the IJsselmeer, the variation of chloride content with depth could originally be explained by diffusion. However, recently ion exchange and mixing of different types of groundwater are the main processes which determine groundwater quality, as the drainage of the polder Oostelijk Flevoland has initiated significant groundwater flow. Using the Piper diagram an interpretation is given for the origin of the various groundwater types, found near Lelystad.

A second case study (Bremerberg) revealed the importance of a semi-impermeable layer of Eem clay in the underground. The groundwater under this layer initially had low concentrations of ions as it originated from the Veluwe area. As a consequence of the polder construction and the subsequent lowering of the piezometric head, the seepage direction was inversed. Surface water from the border lake with higher ion contents started to affect the original groundwater. Contrary to this negative development, the initiated downward seepage resulted in a decrease of the relatively high ion content of the groundwater outside the area with Eem clay. The importance of the water quality in the border lake is stressed, in relation to use of the groundwater for the public water supply.

### INTRODUCTION

The geological history of the lower parts of The Netherlands during the Quaternary era is reflected in the quality of the groundwater, which is mainly characterized by type and concentration of salts and their ions. Transgressions with deposition of marine sediments that contain saline water and regressions with the accumulation of terrestrial deposits having fresh water follow each other. Subsequently, the original types of water may have been changed by diffusion, transport, or exchange of dissolved ions with adsorbed ions, depending on lithology and flow rate. Besides, human intervention in the water regime has also caused changes in groundwater quality, especially in the upper layers.

These processes are of special interest for the land reclamation project in the IJsselmeer area (Fig. 1). Originally this area formed a fresh water basin. However, from the second part of the Middle Ages the area gradually acquired a marine character and during this brackish phase it was known as the

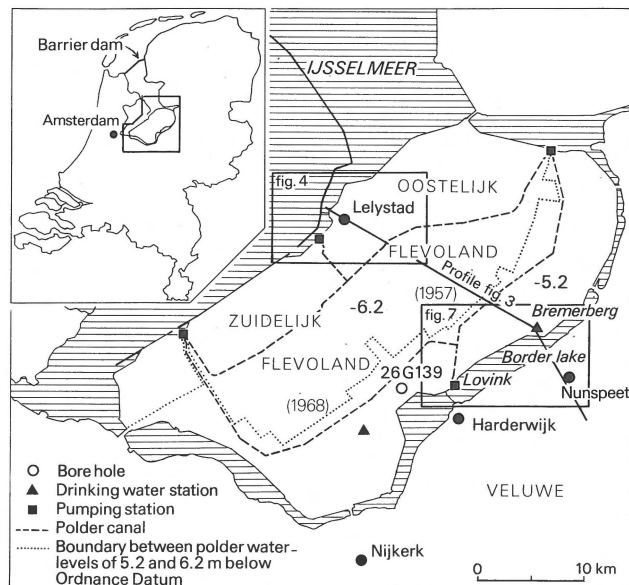


Fig. 1

Location map: the polders Oostelijk and Zuidelijk Flevoland in the IJsselmeer area (formerly called Zuiderzee).

<sup>1</sup> Manuscript submitted: 1983-03-01.

<sup>2</sup> Geographical Institute, State University of Utrecht, P.O. Box 80.115, 3508 TC Utrecht, The Netherlands.

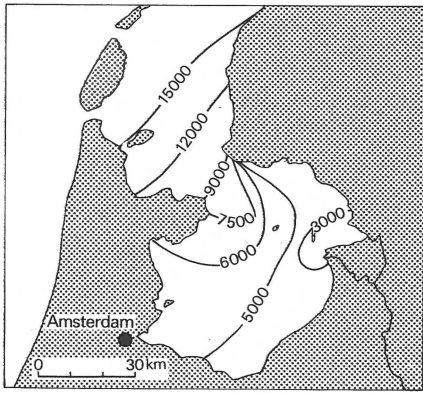


Fig. 2  
Isohalines of the Zuiderzee between 1894 and 1930.

Zuiderzee. The mean distribution of the chloride content during the last 35 years of that phase is shown by the isohalines in Fig. 2. The inundation in 1916 of 150 km<sup>2</sup> of land, surrounding the former inland sea was the immediate cause to carry out the Zuiderzee project: the construction of a barrier dam in the north and of five polders (Fig. 1). The barrier dam was completed in 1932. Then the inland sea was renamed IJsselmeer (Lake IJssel), as its water was soon refreshed by the inflow from the IJssel river. The major activity until now is the development of the two Flevopolders (970 km<sup>2</sup>, Fig. 1). Two case studies will illustrate how groundwater quality changes and how this is important for the development scheme of the new polders.

The first case concerns the changes in groundwater quality at the new town of Lelystad, its effects on the surface water quality and the corrosiveness to building materials. Here the

reclaimed Flevopolder has an open water level of O.D. - 6.2 m (Ordnance Datum N.A.P., i.e. about mean sea level), which causes seepage of groundwater from the underlying aquifer. The original quality of groundwater was mainly determined by diffusion when groundwater flow was very small. During the recently established seepage through the Holocene clay and peat layers, dissolved ions are exchanged to some extent with adsorbed ions.

The second case illustrates the effective use that can be made of the presence of fresh groundwater along the border lake in the southeast of Oostelijk Flevoland (groundwater pumping station Bremerberg, Fig. 1). Here the open water level at O.D. - 5.2 m has reinforced the flow of fresh groundwater towards the polder, which may make it possible to enlarge the amount of groundwater of good quality for the public water supply. A discussion of these two cases will be preceded by a short introduction into the geohydrology of the IJsselmeer area.

### QUATERNARY GEOLOGY AND GEOHYDROLOGICAL INTERPRETATION

The impermeable basis of the local geohydrological scheme (Fig. 3) is formed by the early Quaternary marine clays of the Formation of Maassluis (formerly called Icenien). According to data from boring 26G 139 opposite Harderwijk (Fig. 1) this formation reaches from a depth of 300 m to 245 m in the south of the Flevopolders, which confirms here the map of ZONNEVELD (1958). Like most Quaternary strata in the IJsselmeer area the surface of this formation dips towards the north-west.

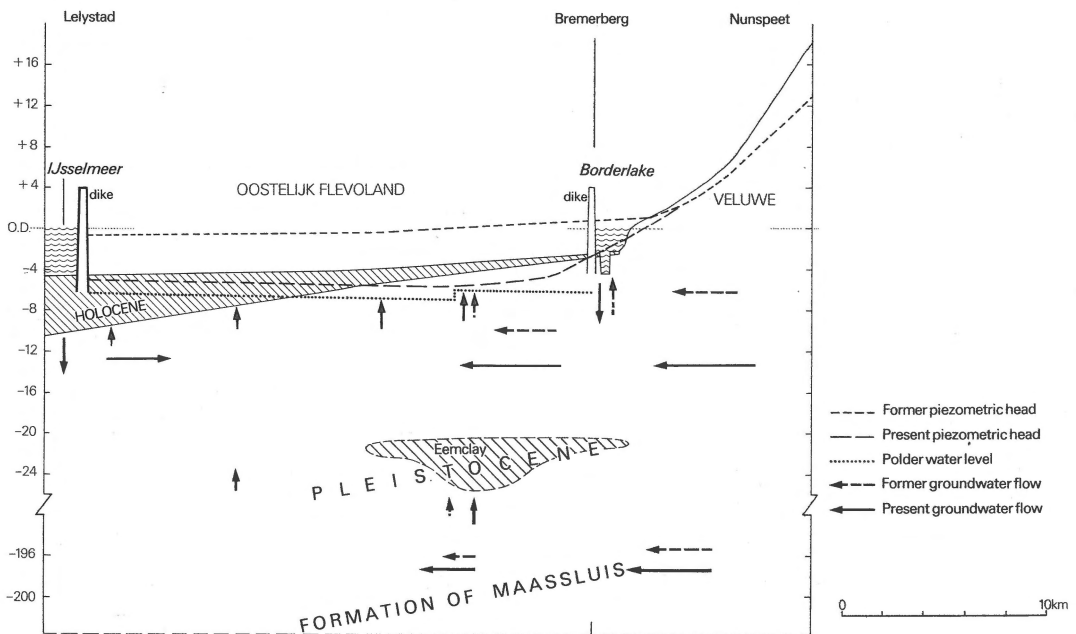


Fig. 3  
Schematic representation of the geohydrological configuration along a NW-SE cross profile (see Fig. 1) in the polder Oostelijk Flevoland.

The Formation of Maassluis is overlain by the Tegelen Formation which consists of alternating layers of sand and clay. As the Tegelen clay does not form a coherent, continuous layer, it does not contribute to the underlying aquitard.

The main aquifer is made up of medium to coarse terrestrial sands from the Harderwijk up to the Twente Formation (Figs 5 and 8). The aquifer is locally interrupted by intercalations of marine clays (Eem Formation) or clayey glacial deposits (Drente Formation), subdividing the aquifer into a lower and an upper one. The upper part of the Pleistocene aquifer is composed of late Pleistocene fine aeolian sand of the Twente Formation.

The aquifer is capped by Holocene Lower Peat (Wold Formation) and marine clay and silty sediments, deposited under fresh (Almere, IJsselmeer) or brackish (Zuiderzee) conditions (Groningen Formation) (VAN LOON, 1981). The Holocene strata have a thickness that varies between 1 m along the border lake in the southeast to about 7 m in the northwest of the Flevopolders (COMMISSIE SPAARBEEKEN IJSELMEER, 1979).

This geological description and the geohydrological interpretation is a simplification of the real situation, which shows a spatial variability of both thickness and granular composition of the layers. Similarly the groundwater quality varies as shown by the isohaline maps of the upper and lower Pleistocene aquifer. (COMMISSIE SPAARBEEKEN IJSELMEER, 1979). A detailed analysis is hampered by the lack of observation wells. However, it is possible to provide a useful prognosis of groundwater quality, based on three models describing variation in type and concentration of ions.

## MECHANISMS OF CHANGE IN WATERQUALITY

Diffusion will smooth differences in concentration  $c$  ( $m \cdot l^{-3}$ ). With  $z$  for depth (l),  $t$  for time (s) and  $k$  the diffusion coefficient ( $l^2 \cdot s^{-1}$ ), the diffusion equation can be written as

$$\frac{\delta c}{\delta t} = k \frac{\delta^2 c}{\delta z^2} \quad (1)$$

Research by the Delft Hydraulic Laboratory (1945) reveal that the diffusion coefficient is nearly the same for the different soils of the IJsselmeer area.

The effect of diffusion can only be found if other processes like transport by groundwater flow are sufficiently small. VOLKER (1961) assumed these conditions to be valid at least for the central part of the IJsselmeer area since the last 200 000 years, i.e. since the pre-Saale interglacial. Apart from diffusion, variation in groundwater quality may be caused by transport or exchange of dissolved ions with ions adsorbed on clay minerals. Depending on the geological configuration and boundary conditions such as the gradient of hydraulic head, one of these mechanisms will be predominant.

For the sake of completeness, change of ion concentration by dispersion also has to be mentioned. Here it may be applied to where groundwater flows slowly but perpendicularly to the gradient of ion concentration. A theoretical solution of this case has been given by VERRUJT (1971). In fact dispersion is a combination of molecular motion and flow on macro scale. MEINHARDI (1973) has tried to explain spatial variation of chloride concentration in the Pleistocene aquifers qualitatively by dispersion instead of diffusion, disputing VOLKER's (1961) premise of nearly stagnant groundwater during 200 000 years.

## HUMAN INTERFERENCE

Until now four polders are reclaimed. As the surface of these polders lies several metres below sea level, a rather deep level of the polder water is maintained: In Oostelijk and Zuidelijk Flevoland the open water level has been established at O.D. - 5.2 m in the southern part, and at O.D. - 6.2 m in the northern part (Figs 1 and 3). Within the polders this resulted in seepage of groundwater through the Holocene semi-permeable strata and consequently in a lowering of the hydraulic head and a steepening of its gradient in the Pleistocene aquifers. A reconstruction of the hydraulic head by modelling (RIJKSINSTITUUT VOOR DRINKWATERVOORZIENING, 1959) shows that before the presence of the polders Oostelijk and Zuidelijk Flevoland this head amounted to about O.D. - 1 m at the place of the future Lelystad. Twenty years after Oostelijk Flevoland was drained in 1957 the head has been lowered down to O.D. - 5 m (Figure 3).

Outside the polders this initiated a downward seepage of water from the IJsselmeer and the borderlakes into the Pleistocene aquifer. Moreover, the hydraulic gradient became steeper within the Pleistocene aquifers, which has especially significance along the southern border of the polders. Formerly, the hydraulic head in the Pleistocene aquifers there reached above the water level in the basin, producing a seepage into the surface water. Where the Eem clay is present

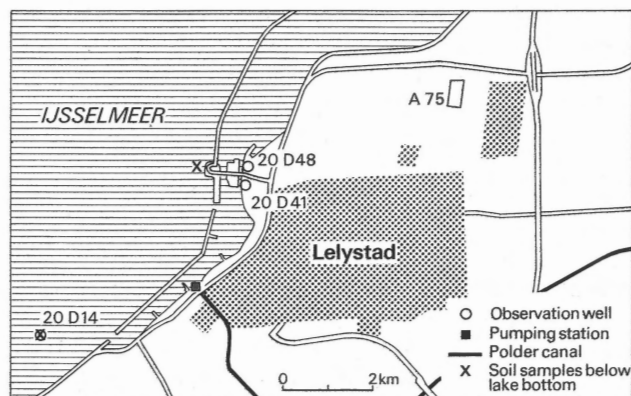


Fig. 4  
Observation sites near Lelystad.

in the underground, the overpressure of the hydraulic head could not easily be released by seepage. Hence, groundwater flow was maintained and proceeded farther north than in the areas where the Eem clay is absent, i.e. generally where the border lake is wide (Fig. 7).

After realization of the Flevopolders the hydraulic head has been lowered so that nowadays it falls below the open water level at the southern side of the border lake, and this has resulted in a reversed seepage from the border lake (Fig. 3). This downward seepage is still increased where a fairway has been dug through the Holocene strata.

METHOD AND DATA

Data about the distribution of ions in time and space have been obtained from the chemical analysis of water samples, most of which came from temporary or permanent observation wells. Some values of chloride content were derived from soil water samples viz. from observation plot A 75 for soil ripening and shrinkage, and from the bottom of the actual lake, both near Lelystad (Fig. 4). At plot A 75 samples have been taken half a year after the closure of the polder dikes i.e. a long time before the polder got a detailed drainage system. Therefore, these chloride contents are supposed to be representative for the variation of chloride content with depth at the time before the polder was drained.

As the chloride ion is almost inert with respect to ion exchange in the soil matrix, its concentration is a useful characteristic for diffusion. All concentrations are expressed in parts per million (ppm) which equals nearly milligrammes per litre. Results of more elaborate analyses have been arranged in a Piper diagram in which the content of each ion is expressed as the percentage of the sum of anions or cations taken into account. In the Piper diagram different fields can be distinguished, each of those representing a special type of groundwater; the boundaries of the fields have been chosen similar to those of CLAESSEN (1972) for the area southwest of Harderwijk (Fig. 6).

Field 9 represents the mixing of two types of groundwater belonging to different fields, for instance as a result of downward seepage. In the Piper diagram parent groundwaters and the mixed one are on a straight line while the intercepts may be used to estimate the mixing ratio (PIPER 1944).

CASE STUDY LELYSTAD (FIG. 4)

Before the reclamation of the polders in the IJsselmeer there was hardly a hydraulic gradient in the central part of the basin. Hence, VOLKER (1961) has explained in a general way the change of chloride content with depth by diffusion.

A semi-logarithmic plot of chloride content with depth was compiled from data from several sites in the vicinity of Lelystad (Fig. 5). As reference level for the distribution of ion

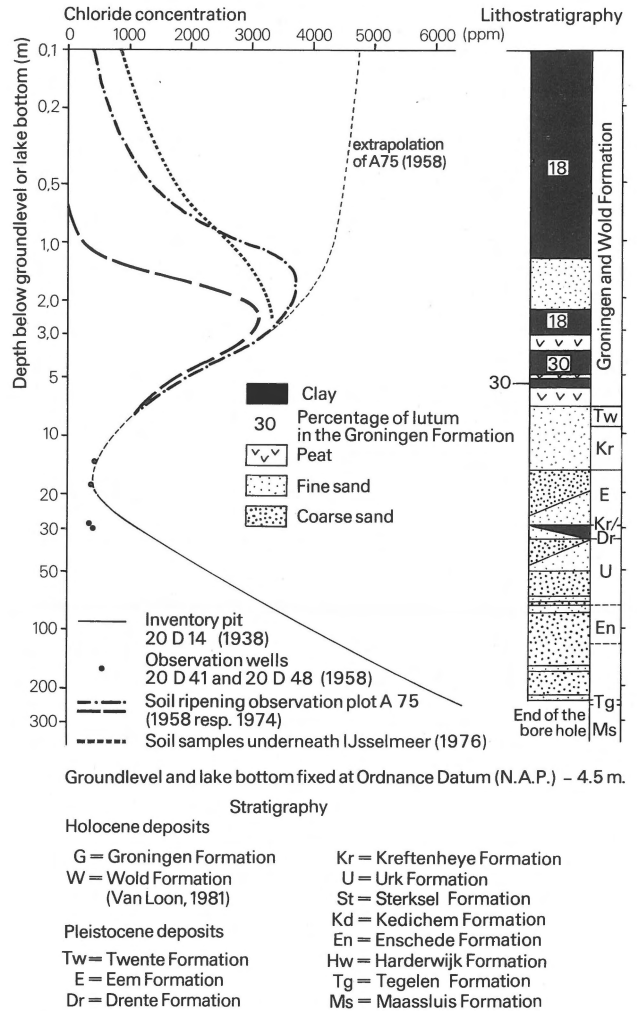


Fig. 5 Variation with depth of chloride concentration in groundwater near Lelystad, before and after Oostelijk Flevoland was drained.

content with depth, the groundlevel or bottom of the lake has been chosen. From 300 m up to 30 m there is a gradual decrease in chloride content. VOLKER (1961) argued that this is the result of a continuous upward diffusion of chloride originating from the Maassluis Formation (Fig. 5, site 20 D 14).

The graph shows an increase in chloride content between 15 and 2 m, attributed by VOLKER (o.c.) to a downward diffusion of chloride from the former Zuiderzee. The mechanism of diffusion can be made more plausible if extrapolation of the data of site A 75 (1958) unto the former bottom of the sea would approximate the chloride content of the seawater. According to the diffusion equation (1) the quasi-stationary relation between concentration *c* and depth *z* becomes

$$c = a \cdot z + c_0 \tag{2}$$

with *c*<sub>0</sub> being the concentration at *z* = 0. Linear extrapolation of the data (A 75, 1958) yields *c* = 4700 ppm at *z* = 0.1 m (Fig.

5). This value is close to the measured chloride content of the seawater of the former Zuiderzee at that location (Fig. 2).

At shallow depth the chloride content decreases again in the direction of the bottom of the former IJsselmeer (Fig. 5, site A 75, 1958). This is the result of desalination during the fresh water phase of the basin after the barrier dam was closed in 1932.

Another possibility to determine groundwater quality may be found in the analysis of the Piper diagram data. The groundwater below 50 m is all of the sodium-chloride type, corresponding with field 6 in the Piper diagram, which represents groundwater with a full marine character (Fig. 6, point B). This agrees with the diffusion of salt from the Formation of Maassluis. The water samples taken in 1958 at a depth between 13 and 30 m are plotted in the diagram along the boundary of field 9 (Fig. 6, point A), i.e. nearly unaffected fresh water.

After Oostelijk Flevoland was drained in 1957 groundwater started to flow as indicated in Fig. 3. That means that outside the polder surface water seeps downwards from the IJsselmeer – with a local mean chloride content of 200 ppm – into the Pleistocene aquifer, where it is mixed with the present groundwater. Due to the increased hydraulic gradient this

groundwater of changed quality flows through the aquifer towards the polder, where it seeps upwards. In observation well 20 D 48 at the border of the polder (Fig. 4) the chloride content at a depth of 14 m decreased from 490 ppm in 1958 to 250 ppm in 1978, whereas it remained still unaffected at a depth of 29 m (360 ppm).

In Fig. 5 the curve of site A 75 – 1974 shows the variation of chloride content with depth 15 years after drainage. The chloride in the layer on top of the drains has been washed out rather quickly by the surplus of rain. Comparing this variation with other curves, one has to note a lowering of the ground-level with about 0.7 m as a result of shrinkage. Comparison of the curve of plot A 75 – 1958 with that of the bottom of the IJsselmeer in 1976 shows that the desalination still continued during the passed 16 years (the lower chloride contents at A 75 at depths shallower than 0.8 m are not considered).

The analysis of the groundwater quality by the Piper diagram confirms the scheme of the groundwater flow initiated by the presence of the polder. In 1978 the groundwater at a depth of 14 m has to be plotted at about the centre of field 9, which is characteristic for mixed groundwater (Fig. 6, point M). Moreover, the quality of the downward seeping water from the IJsselmeer will be affected by ion exchange in the Holocene layers.

As will be shown in the second case study, the Piper diagram can be used to demonstrate the change in concentrations of ions by the mixing of different types of groundwater. Here it is used just the other way around: assuming the mixing principle and knowing the contents of ions from before and 20 years after the polder was drained – i.e. of the original groundwater and the mixed one – we estimated the concentrations of ions in the water from the IJsselmeer after its passage through the Holocene layers (Fig. 5, point X; VAN DEN BERG ET AL., in prep.).

The calculation has been performed under the assumption that the chloride content has not changed by ion exchange. According to this estimation the content of sulphate ions (up to 350 ppm) and sodium ions (250 ppm) should be four times and the content of calcium and magnesium ions twice that of IJsselmeer water.

This mixed groundwater flows towards the polder where it moves upwards and joins the phreatic groundwater and the surface water after a renewed passage through the Holocene strata. The deviating concentrations of some ions in this seepage water not only have consequences for the quality of the surface water (VAN DEN BERG ET AL., 1982) but they also have consequences for the use or composition of some building materials like aluminium and concrete. For instance, groundwater with a sulphate content greater than 350 ppm has to be considered as aggressive to concrete (PENNINGS & VAN DER SCHEER, 1982); such high concentration of sulphate also promote a continuing corrosion of aluminium (e.g. lamp posts), especially in a more or less anaerobic soil.

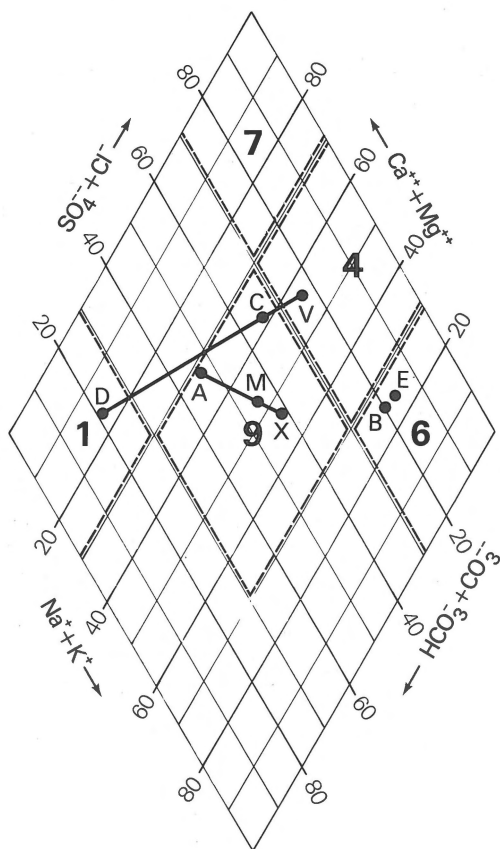


Fig. 6 Classification of groundwater (points A, B, C, D, E, M and X) according to ion concentration in a Piper diagram. The lines connecting D, C, V, resp. A, M, and X represent two examples of mixing of groundwater.

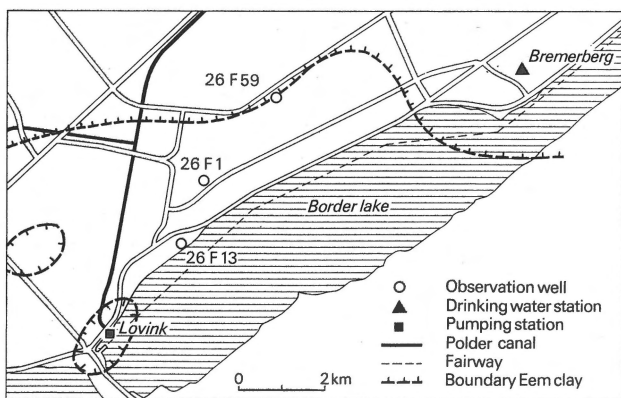


Fig. 7  
Observation wells and distribution of Eem clay along the border lake near Bremerberg.

### CASE STUDY BREMERBERG (FIG. 7)

The Pleistocene aquifers are incorporated here into the Veluwe sands in the south where the aquifers become unconfined (Fig. 3), and where the hydraulic head attains values up to O.D. + 40 m. Since upper-Pleistocene times a part of the phreatic groundwater flows from the Veluwe to the north where it supplied some springs and seeps into lower-lying areas. This groundwater was found in the lower Pleistocene aquifer in the area around Bremerberg where Eem clay is present (Fig. 7). It has a very low chloride content of about 10 ppm and it is of a characteristic calcium-bicarbonate type, i.e. the common product of infiltrated rainwater after percolation through an unsaturated soil (Fig. 6, point D).

Outside the area of Eem clay the seepage of groundwater was more extensive and consequently the groundwater flow extended less far northward. This has favoured the influence of diffusion at the southern coast of Oostelijk Flevoland, where the groundwater in the upper part of the Pleistocene aquifer had a chloride content of about 1000 ppm, and the types of ions pointed to a marine character (Fig. 6, point E).

After the drainage of the polder the border lake changed into an area of downward seepage, especially within the area with Eem clay (Fig. 3). Hence, surface water now infiltrates from the border lake into the groundwater, inclusive that in the lower aquifer. This has resulted in an increase of the chloride content to about 60 ppm in 1970 and 100 ppm in 1976. Moreover, the seepage of water from the border lake could be proved by the presence of tritium in the lower aquifer, as tritium is a radio-active isotope of hydrogen with a short half-life of 12,3 years (MEINARDI, 1974).

Taking other ions into account as well, the position of the mixed groundwater is indicated by point C in the Piper diagram. Point V represents the surface water in the border lake (Fig. 6). Together with point D (the original groundwater) the three points appear to be on a straight line and according to Piper's method these data confirm the assumption of mixing of groundwater. The ratio of surface water to

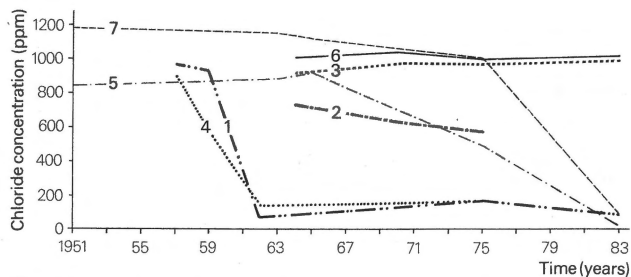


Fig. 8A  
Variation of chloride concentration as a function of time after Oostelijk Flevoland was drained. Numbers 1-7 refer to filter location, plotted in Fig. 8B.

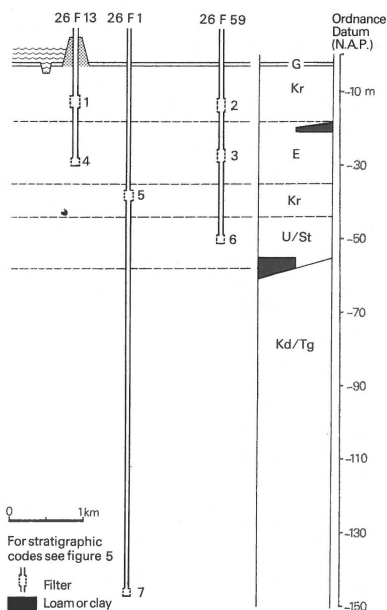


Fig. 8B  
Observation wells (see also Fig. 7) and location of the filters as related to distance from the border lake and to depth.

original groundwater is calculated to be 7:13 during 1970-72, which agrees with the measured content of tritium. Since, this ratio is still increasing (as the Holocene strata are relatively thin here, ion exchange is not accounted for).

Outside the area with Eem clay the increased hydraulic gradient generated a groundwater flow in the Pleistocene aquifer much farther northward than before the polder was drained. Here the inflow of groundwater from the Veluwe and from the border lake refreshes the groundwater as is illustrated by the change of chloride content with time at different depths and different distances to the dike (Fig. 8).

It can be concluded that along the border lake the construction of the Flevopolders produced a smoothing of differences in concentration of chloride and other ions in the Pleistocene aquifers. The presence of fresh groundwater under Oostelijk Flevoland is very essential for the water supply of the inhabitants of the polder. A groundwater pumping station has been installed already where the semi-impermeable layers occur in

the subsoil (Figs 1 and 7). It may be expected that also outside this area with Eem clay – when the refreshing has proceeded sufficiently – the seeping groundwater can be used for the public water supply (seepage intensity up to 5 mm/day). Thus, in both cases a good quality of the water in the border lake is of more than environmental importance (DRIEBERGEN 1982).

#### ACKNOWLEDGEMENTS

I thank H. Th. Riezebos and J. H. J. Terwindt of the Geographical Institute of the State University of Utrecht for their valuable comments. Moreover, I am grateful to the IJsselmeerpolders Development Authority and the Directorate of Water Management and Hydraulic Research, district Noord, for permission to publish some of their groundwater data.

#### REFERENCES

- Claessen, F. A. M. 1972 De geohydrologische gesteldheid van het gebied rondom het Veluwemeer tussen Harderwijk en Nijkerk – Dienst der Zuiderzeewerken, Afdeling Waterloopkunde, Nota B72-25: 15 pp.
- Commissie Spaarbekken IJsselmeer – technische werkgroep 1979/80 Geohydrologische aspecten van belang voor de aanleg van een spaarbekken in het IJsselmeergebied: 50 pp.
- Driebergen, J. 1982 Environmental development in two of the borderlakes of the IJsselmeerpolders in the Netherlands. In: Polders of the world, Int. Symp. (Lelystad). I.L.R.I., Wageningen: 665-674.
- Meinardi, C. R. 1973 Het zoutwatervoorkomen in de ondergrond van de lage gedeelten van Nederland – *H<sub>2</sub>O* 6 (18): 454-460.
- 1974 Tritiumbepalingen aan grondwater toegepast te Bremerberg (Oostelijk Flevoland) – *H<sub>2</sub>O* 7 (14): 274-277.
- Pennings, L. K. & A. Van der Scheer 1982 Onderzoek naar de agressiviteit van grondwater op betonconstructies in Lelystad, Almere en Zeewolde – Rijksdienst voor de IJsselmeerpolders, Lelystad, RIJP rapt 229: 42 pp.
- Piper, A. M. 1944 A graphic procedure in the geochemical interpretation of water-analysis – Trans. Am. Geophys. Union Trans., VI: 914-923.
- Rijksinstituut voor Drinkwatervoorziening 1959 Rapport inzake de resultaten van een modelonderzoek naar de invloed van de droogmaking der IJsselmeerpolders op de diepe grondwaterstand in het Pleistoceen – R.I.D. rapt 1959-3: 19 pp.
- Van den Berg, J. A., A. K. Constandse et al. 1982 Water in new towns in the IJsselmeerpolders. In: Hengeveld, H. & C. De Vocht (eds): Role of water in urban ecology – Elsevier (Amsterdam): 251-292.
- Van Loon, A. J. 1981 Problems of Holocene Lithostratigraphy – Geol. Mijnbouw 60: 353-361.
- Verruijt, A. 1971 Steady dispersion across an interface in a porous medium – J. Hydrology 14: 337-347.
- Volker, A. 1961 Source of brackish groundwater in Pleistocene formations beneath the Dutch polderland – Econ. Geol. 6: 1045-1057.
- Zonneveld, J. I. S. 1958 Lithostratigrafische eenheden in het Nederlandse Pleistoceen (Lithostratigraphical units in the Dutch Pleistocene), with summary in English – Mededelingen Geologische Stichting, Nieuwe Serie 12: 31-64.