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THE GEOHYDROLOGICAL SITUATION OF THE WESTERN PART OF THE NETHERLANDS[1]

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ABSTRACT

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This paper gives a conspectus of the geohydrological situation of the area. Based on surveys carried out during the last decade.

Not only a description of the geological situation to establish which layers in the subsoil have importance for groundwater flow has been given, but also the hydrological properties of the observed layers were calculated.

It appeared that there is a basic difference between the geohydrological situations in the northern and the southern part of the area studied. The observed variations in transmissivity mostly are due to differences in thickness and less to different hydraulic conductivities. Beside this the hydrological units appeared to belong to layers of different geological origin. Also, intercalating clay layers may divide stratigraphic units in parts belonging to different aquifers.

INTRODUCTION

During the last decade hydrological investigations were made in the western part of The Netherlands by a working party of the Institute for Land and Water Management Research (ICW). First the southern part of the area was taken into research and during the last five years the northern part (Fig. 1).

Now a comparison can be made between the observations and conclusions of both studies. The main subject of the investigations was to find an explanation of the phenomenon of salinization and other pollutions of the surface and groundwaters in the area, so providing a basis for improvement of the situation. Aside from a large programme of surface water observations, the geohydrologic situation was investigated. This paper gives in short the results of the last mentioned part of the examination.

DESCRIPTION OF THE AREA

The Netherlands can be divided in two by the contour line of 1 m above datum level (mean sea level). The higher part consists of a mainly hilly landscape with a semi-natural drainage system; the lower part consists of a rather flat landscape with a rather complicated manmade drainage system.

The study region described in this paper (Fig. 1) is part of the lower part of The Netherlands and it has an area of about 3560 sq. km. It has the densest population of The Netherlands. There is a concentration of larger and smaller cities, many of which having grown together resulting into longlined urban areas surrounded by and partly encircling rural areas.

Along the westcoast a ridge of dunes is found based by marine sands of the Holocene beach barrier, which locally is interrupted. Behind this dune ridge a low lying polder area is present, which at the eastside is bordered by the rise to the Utrecht Hills in the southern part and IJsselmeer – a former seabranch, now a fresh water lake – in the northern part. In the south the area is bordered by the Nieuwe Waterweg (an artificial rivermouth of the river Rhine) and the Nieuwe Maas (a branch of the Rhine).

The landscape found is the result of a more than a thousand years of human activity. After the reclamation of lakes to polders starting in the early Middle Ages, the need of fuel for the existing cities led to a cutover of thick peat toplayers. Since the 16th century the thus grown lakes were gradually reclaimed, as they presented a growing danger by floods during storm periods mainly in wintertime. The bottoms of these reclaimed lakes, situated 4 to 5 m below the surrounding ground level, appeared to have a great value for agricultural production.

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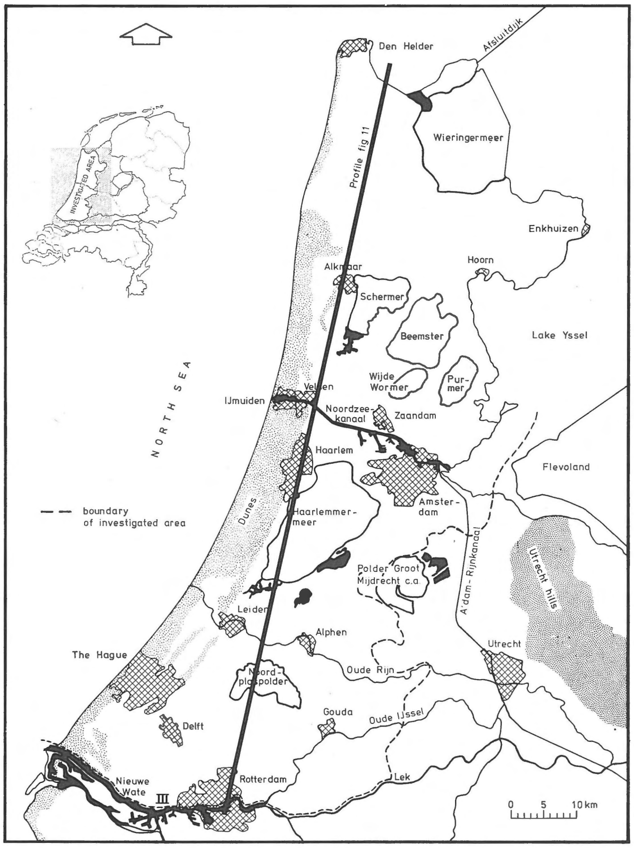


Fig. 1
General map of the area investigated.

Along the inland fringe of the dune area outcropping marine sands of the mentioned beach barriers with land surfaces above mean sea level appeared to have a special value for horticultural activities, moreover, when the sandy subsoil was mixed with the locally existing peat occurrences. This horticultural use was based on the need for horticultural products in the urban areas. This later resulted in a growth of these activities in the bordering originally, dairying and arable areas. The present dairying areas are found on original not cutover peat areas.

So the location of the different agricultural activities – dairying agriculture and horticulture – are geographically, pedologically and historically determined: horticulture along the dunes and in the neighbouring areas; agriculture on the reclaimed lake bottoms and dairying in the remaining areas.

WATER MANAGEMENT

The surface water management in the area is traditionally organized in semi-private waterboards. These waterboards, originating from the Middle Ages, have their responsibilities for one or more polders and there is a certain hierarchy succession of waterboards at different levels of organizations.

Originally the waterboards were mainly interested in flood protection and groundwater level control. During the last decades, however, more and more attention is being paid to water quality control next to their traditional duties.

Figure 2 gives a schematic presentation of the water management system. Although regularly technical improvements have been applied, the principle is equal to that at the beginning in Medieval times. Its basis is the natural flushing of water from storage canals ('boezems') into the open sea during low tide periods. The storage canals are filled with excess water pumped up from the polder canals and ditches. Originally this took place by windmills in several steps; nowadays diesel and electric pumps do the same in one step. Whereas in the windmill period it was not possible to maintain the same polder water levels in winter and summer, at present most polders have one water level the year over, fitted to the needs of the polder inhabitants.

Due to the enlargement of the horticulture area and an intensification of horticultural production, the need for open water of good quality for sprinkling purposes was much enlarged just in a period with a diminishing quality of the surface waters. The latter is due to water pollution and an increase of the salt content of seepage water in the lower parts of the area. In a preceding paper (POMPER, 1983) more attention is given to this problem.

The complicated history of this landscape has resulted in a mosaic of sometimes small areas with different ground and water levels. Mostly these differences are smaller than 1 m, but at many places differences of several metres occur over a short distance.

Roughly the area can be divided into:
- areas with ground levels above mean sea level;
- areas with ground levels just below mean sea level ('bovenlandpolders');
- areas with ground levels of several metres below mean sea level (deep polders).

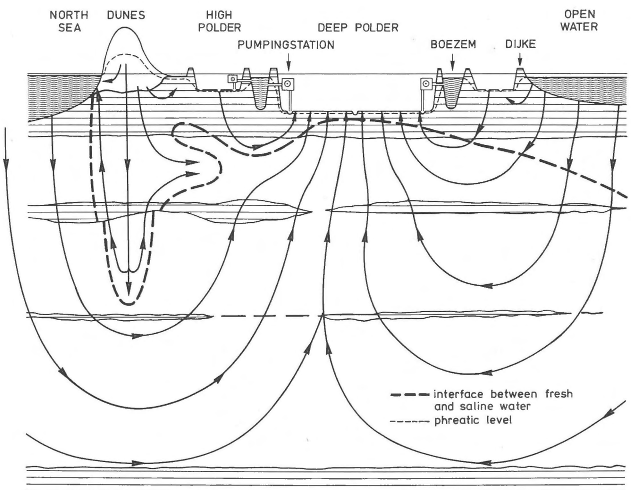


Fig. 2
Systematic presentation of the water management system (POMPER, 1983).

GEOLOGICAL SITUATION

General

Hydrological studies should be based on a good knowledge of the geological situation in the investigated region. Although the stratigraphy itself has no significance for the solution of hydrological problems, it is necessary to carry out stratigraphical examinations to find the interconnections occurring between different strate with equal hydrologic significance.

The description of the geological situation is partly based on publications of the Geological Survey of The Netherlands. It is well-known that the region discussed is part of the subsiding North Sea basin. The subsoil of The Netherlands consists of unconsolidated Cenozoic sediments with a thickness of hundreds of metres on the Mesozoic bedrock. In the northern part of the area the top of the Mesozoic bedrock is found at a depth of about 1000 m and in the southern part at about 500 m.

Stratigraphy

Figure 3 gives the stratigraphical situation of the upper part of the Cenozoic sediments (RGD, 1982). The formations with importance for this paper are specially indicated. Figure 4 gives a schematic presentation of the layers found in the area that are important for its hydrology.

During the Tertiary and the first part of the Pleistocene, marine sediments were deposited (KEIZER & LETSCH, 1963). Then a period of predominantly fluviatile sedimentation started, locally with intercalations of marine interglacial sedimentation. Although many interglacials occurred (ZAGWIJN, 1975; ZAGWIJN & DOPPERT, 1978), marine sediments of only the last three interglacials, i.e. Holsteinian, Eemian and Holocene, have been found. It is possible that older marine interglacial sediments never did exist or that they have been removed by erosion. In parts of the area discussed the sediments of the several marine sedimentation periods are found. At two levels in stratigraphy hiatuses are found (ZAGWIJN & DOPPERT, 1978).

The base of the hydrological system consists of marine clay of Upper Pliocene and Lower Pleistocene origin (Oosterhout Formation).

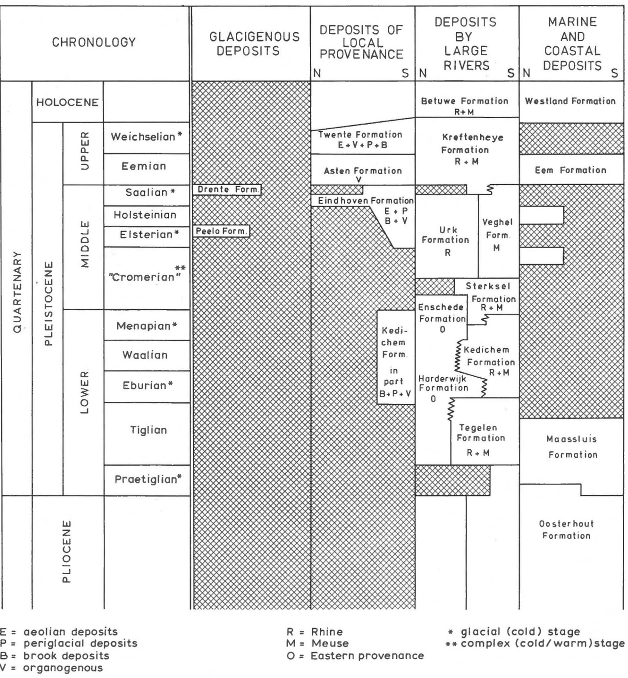


Fig. 3
Stratigraphic table (after RGD, 1982).

The Maassluis Formation

The lowest Pleistocene formation is the Maassluis Formation. These fine grained marine layers have a thickness of about 150 to 200 m over the entire region. The top of these sediments in the southern part of the area is found at about 80 m and in the northern part between 240 and 280 m below ground level. The layer consists of fine clayey homogeneous sands with clay lenses and shell waste. A few borings show a clay layer of many tens of metres.

The Lower fluviatile Pleistocene

Many borings show a clay layer at the base of the overlying fluvial sediments. This clay layer seems to have about the same age (Tiglian) in the entire area although the origin from a mineralogical point of view may show some differences between the northern and the southern part of the area (DOPPERT ET AL. 1975).

The sedimentation of this clay layer was followed by that of fluviatile sands. In the southern half of the area these sands originate from Rhine and Meuse sedimentation (Formations of Tegelen and Kedichem) and vary between moderately fine and moderately coarse, rich in clay lenses. In many borings in the southern part of the area, a clay layer occurs at the top of the Kedichem Formation. At two places it was dated as of Waalian origin (DE JONG, 1972a, 1972b). So it can be concluded that the covering younger part of the Kedichem Formation is absent. In the northern half the sands originate from North German Rivers (Harderwijk Formation) and often are very coarse grained with much gravel.

Although in the south of The Netherlands the Tegelen and Kedichem formations clearly can be distinguished, in the western part of the country the differences in mineralogical composition are too weak to make a clear distinction. So the pertaining formations in the last mentioned area have been combined to the Tegelen/Kedichem Formation (ZONNEVELD, 1958; POMPER, 1972).

In a strip of more than 10 km south of the North Sea Canal this Tegelen/Kedichem Formation has an interdigitated transition zone with the Harderwijk Formation. So the Kedichem

Clay extends to the surroundings of Beverwijk whereas the coarse grained sands underneath predominantly are from Harderwijk Formation origin, which interfingers with Kedichem sediments some 10 km more to the south.

As mentioned the Kedichem Clay was sedimented in a lower Pleistocene interglacial period (Waalian). The top of this clay layer is presumed to have been affected by erosion (POMPER, 1972) and correlates with the Middle Pleistocene sedimentation hiatus as observed by ZAGWIJN & DOPPERT (1978). The hydrological significance of mapping this level is that in this way absences of Kedichem Clay can be traced and connections between neighbouring aquifers can be located (POMPER, 1972).

At the top of the Harderwijk Formation in North Holland the presence of a clay layer also has been observed. However, it is found in only a few borings and, moreover, it seems to have an insignificant thickness.

The Middle Pleistocene fluviatile sediments

The Middle Pleistocene layers only occur in closed strata in the northern part of the area. There the sediments of the Enschede Formation – originating from the Northern European rivers – and the Sterksel Formation – originating from the Rhine river basin – are found. The presence of the Enschede Formation is limited to the northern half of the area; the Sterksel Formation locally also occurs in the southern half, but in many places it is lacking, this possibly due to erosion or non-deposition.

Both Middle Pleistocene formations exist of rather coarse gravelly sands with intercalating clay lenses. They are mostly topped by a clay layer (POMPER, 1973). In a large part of the area sediments are found of the Middle Pleistocene Urk Formation. These fluvial sediments have been deposited during a long period including two interglacials and one glacial. They have a Rhine origin and are characterized by a high content of volcanic minerals originating from Pleistocene volcanic activity in the Eifel area. In the south of the area under consideration sediments of this formation only fill up occurring depressions in the Kedichem Formation top level; in the northern part they consist of closed layers over large areas.

Glacial sediments

Glacial sediments, deposited partly synchronously to that of the Urk Formation and originating from the Elsterian glaciation are found in the northernmost part of the area. Aside from sandy sediments in the Wieringermeerpolder, more to the west 'warvenclay' (a lacustro glacial clay with season stratification) is found. Figure 5 gives the location of where it was found.

During the Saalian Ice Age a large part of the area discussed was covered with ice. The extreme border of this ice cap was found along a line just south of Amsterdam. Figure 6 gives a

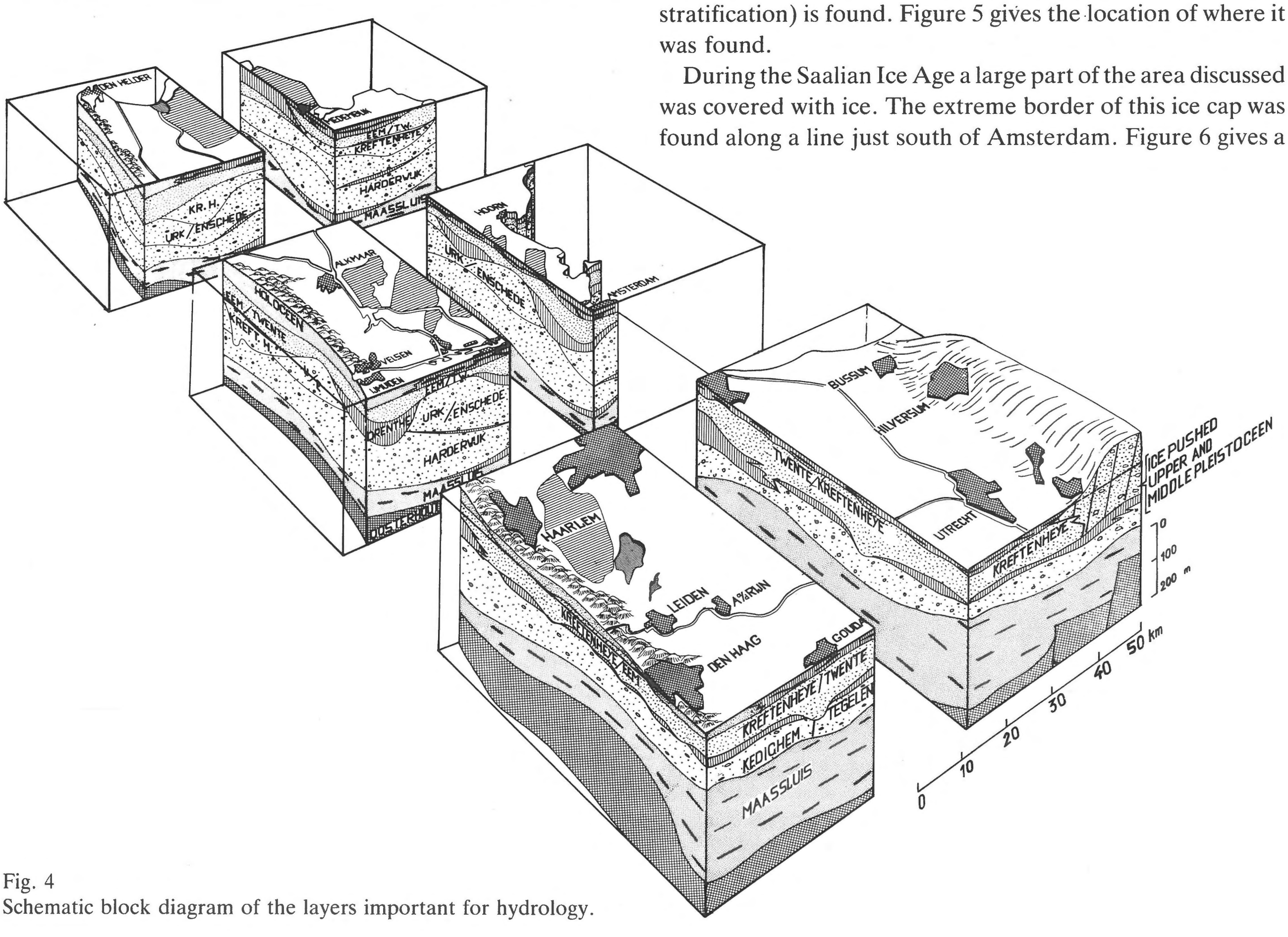


Fig. 4
Schematic block diagram of the layers important for hydrology.

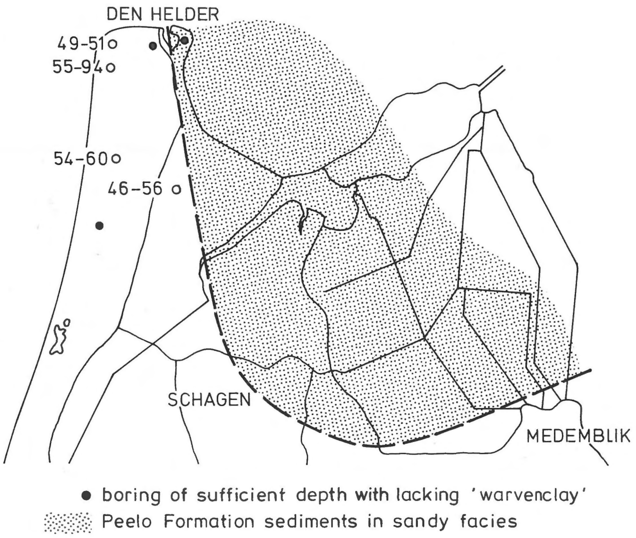


Fig. 5
Location 'warvenclay' sites (POMPER, 1979).

detail of the map of glacial phenomena from the Saalian glaciation in The Netherlands as given by JELGERSMA & BREEUWER (1975). It not only gives the location of glacial sediments in the area, but also the contour lines of the base level of the proglacial basin clays. Due to the stepwise retirement of ice caps at the end of glaciations several border lines can be found. Such border lines among other things are marked by the presence of deep glacial basins filled up with 'warvenclay'. In between glacial sediments are preserved, e.g. glacial till and coarse grained sandy deposits.

South of the edge of the glacial ice cap fluvial and eolian proglacial sediments are found.

The Upper Pleistocene

During the retiring of the ice cap in the northern part of the area discussed a deep glacial valley of several tens of metres in the then ground level was eroded between Enkhuizen and Bergen (Fig. 7). In the time following, this valley has been gradually filled up, first by coarse grained fluvial ice-marginal valley sediments and later on of Eemian interglacial and Weichselian sediments (Kreftenheye and Eem formations).

During the Eemian interglacial period a large part of the area discussed was flooded by the sea. Before the arrival of the sea and after its retreat, continental sediments were deposited (Kreftenheye Formation). In the mentioned glacial basins the sedimented glacial warvenclay gradually blends into continental Eemian humous clay. The last mentioned clays were found near Vijfhuizen in boring 25A/857 at a depth of 31 m below mean sea level. According to DE JONG (1972b) it concerns clay deposited under nearby coastal conditions. The covering marine sands are indeed of marine Eemian origin.

Figure 8 shows a cross-section through the Eemian sediments, just north of The Hague (POMPER, 1978). Many borings show a succession of layers with shell waste in the toplayers, layers with complete shells and large pieces underneath and then again layers with shell waste. This succession of layers, having been observed at many places is presumed to be due to the existence of littoral phases at the beginning and end of the inundation period and a neritic phase in the middle of it.

Figure 9 gives the base level of the Eemian marine and littoral sediments. There are several gully systems, three of which are westward directed and one eastward. In the northern part, the original postglacial landscape is found. The northernmost gully system is a relict from the glacial drainage system from the Saalian glaciation as part of the ice-marginal valley of the Vecht (JELGERSMA, 1983). The gullies between Amsterdam and Beverwijk originally are drainage gullies of the glacial basins.

The gully system in the southern part of the area can be regarded to be a relict of the local postglacial premarine drainage system.

The construction of the toplayer of the marine Eemian sediments is impossible with the data available, because the original Eemian sands were the source of the windblown sedimentation during the following Weichselian glaciation. So the littoral Eemian sediments locally pass onto eolian Weichselian sedimentation.

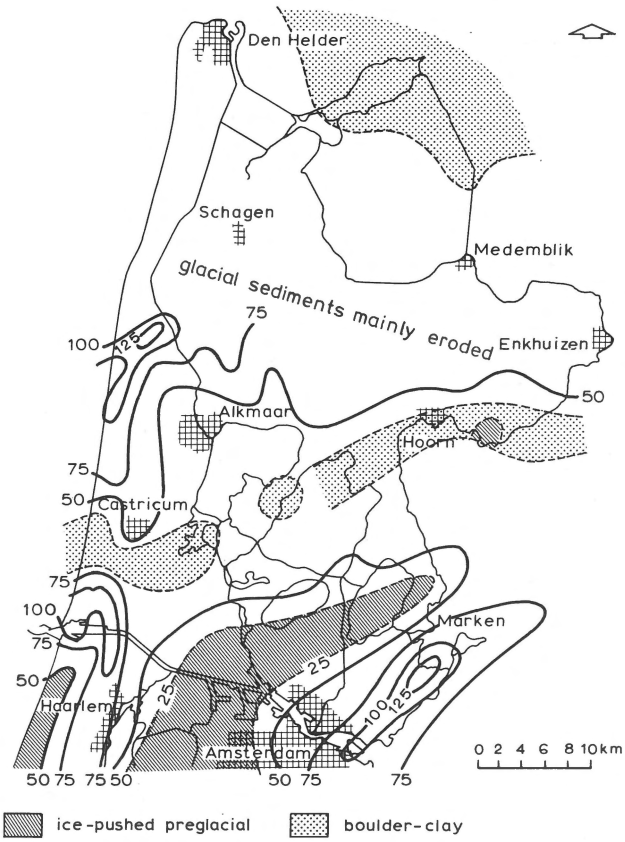
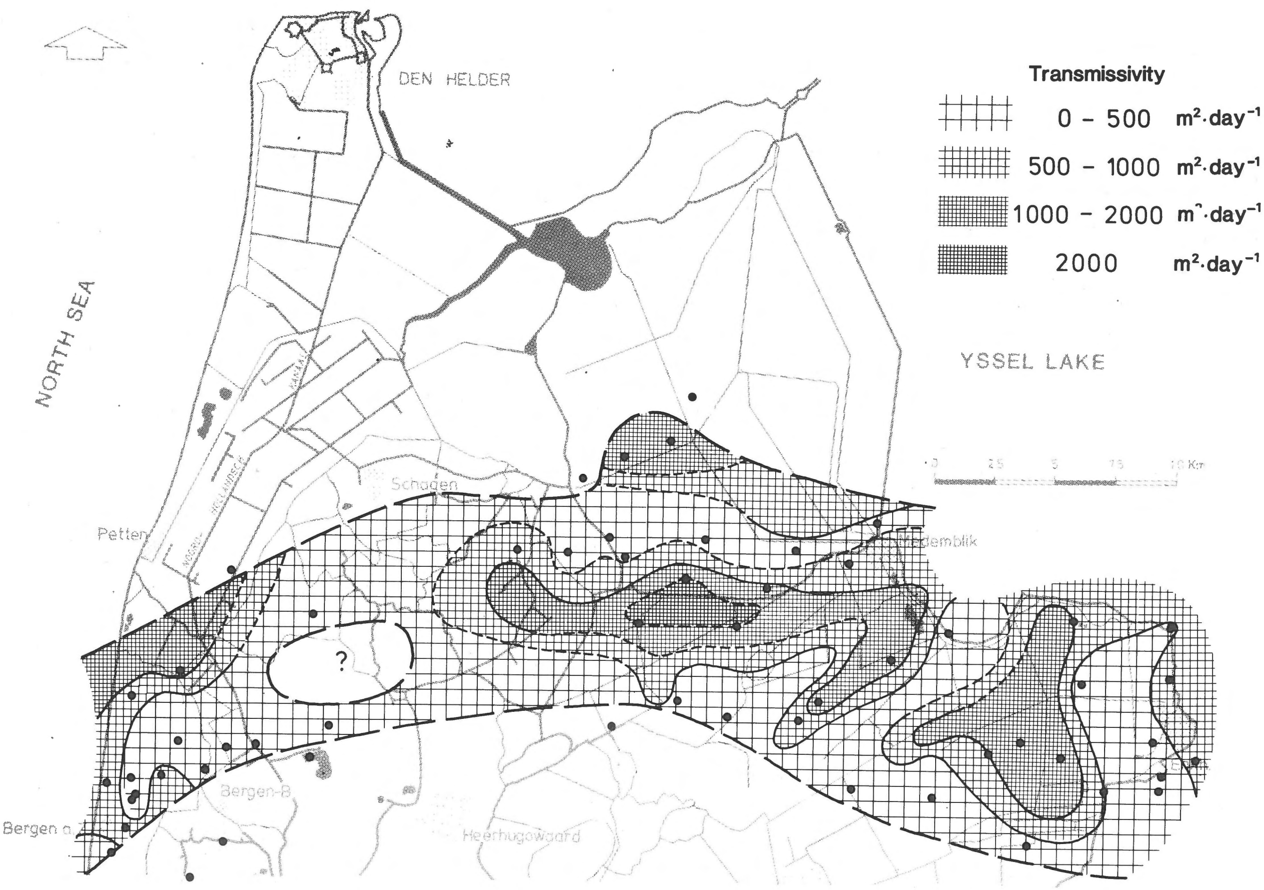


Fig. 6
Map of glacial phenomena of the Saalian glaciation (after BREEUWER & JELGERSMA, 1979).



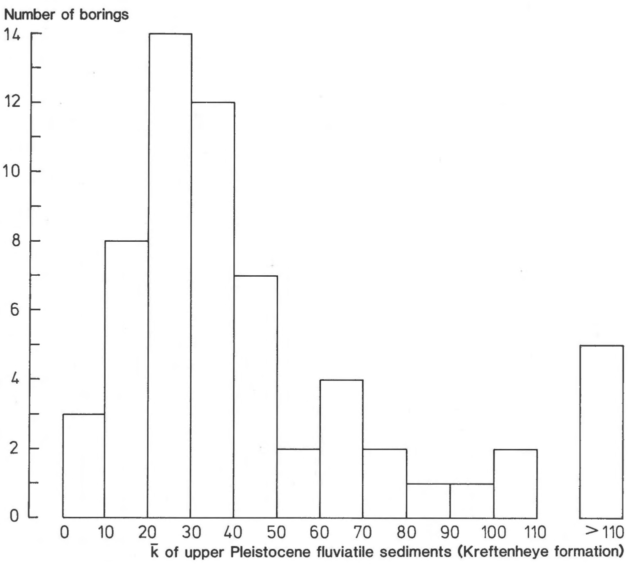


Fig. 7 (above)
Location of the buried Saalian glacial valley, filled up with Upper Pleistocene sediments (Kreftenheye Formation) (POMPER, 1979).

During part of the Weichselian glaciation a glacial desert occurred in this part of Europe (ZAGWIJN, 1975; ZAGWIJN & DOPPERT, 1978). This resulted in extensive eolian sedimentation in this area, while also periods with fluvial sedimentation occurred (Kreftenheye Formation). So layers with homogeneous windblown sediments are found beside coarse grained inhomogeneous fluviatile sands with gravel.

There is no Weichselian glacial sedimentation in the area because then the ice cap did not reach this part of Europe.

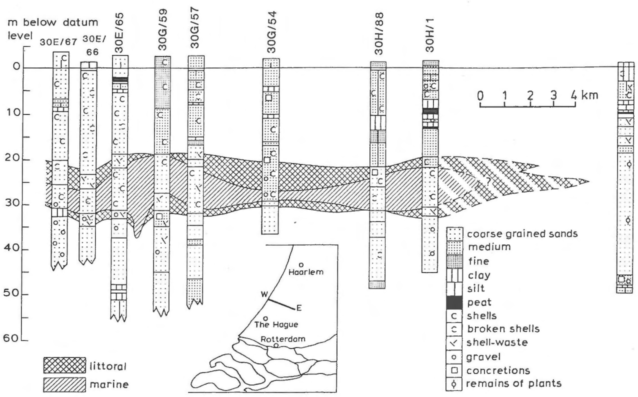


Fig. 8
Cross-section through the Eemian sediments north of The Hague (POMPER, 1978).

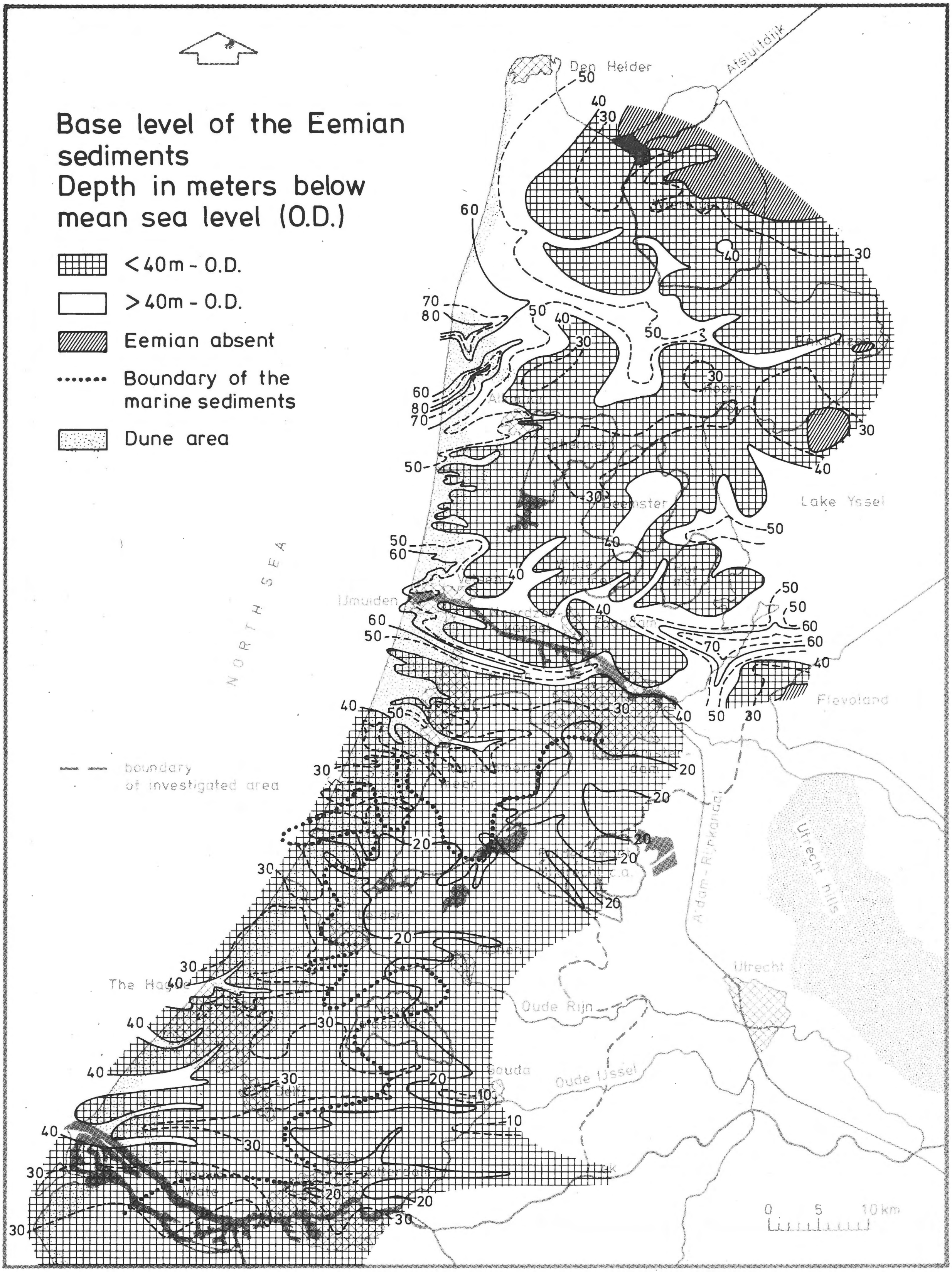


Fig. 9
Topography of the base level of Eemian sediments.

The Holocene

The sediments of this period have not been researched during the ICW-examination. The data needed were obtained from literature and from intensive contacts with the Geological Survey of The Netherlands (RGD).

At the end of the Weichselian glaciation a landscape with a bad natural drainage system was left (ZAGWIJN & DOPPERT, 1978). The numerous small and larger depressions in the landscape were filled up with water and were the basis for the start of peat growth. In the area discussed this Holocene peat growth several times was interrupted by marine inundations followed by sedimentation of marine clay and clayey sands (Fig. 10).

During the Middle Ages the reclamation of the area was started and the marine and fluviatile sedimentation in the reclaimed areas stopped.

During the Holocene the formation of a system of coastal barriers started, behind which the mentioned littoral and lacustrine sedimentation happened. On these coastal barriers a ridge of dunes came into being.

GEOLOGIC AND GEOHYDROLOGIC SCHEMATIZATION

The transmissivity of a layer not only depends on its thickness, but also on its hydraulic conductivity. The hydraulic conductivity can be determined with different techniques, e.g. pumping tests, water balance studies, estimations, etc. The large thickness of the hydrological system resulted in a limitation of the applicable techniques for estimations and water balance studies.

Water balance studies mostly concern large areas which can be a disadvantage. The technique of estimations is based on the relation between grain size distribution (better would be pore size distribution) on the one hand and hydraulic conductivity on the other. Its reliability depends to a great extent on experience. Its advantage is that it is cheap and gives data at many sites, if in the mean time an acceptable accuracy has been gained. If furthermore gives the possibility to separate the hydraulic conductivity values of the different layers observed in one boring. In this manner it was possible to get information about the mean values of specific geologic formations.

The above given concise description of the subsoil should be schematized for hydrological purposes. Geological boundary levels may have no significance for groundwater processes, whereas hydrological boundaries can cross geological formations. Layers must be distinguished with rather the same hydrological properties.

Figure 11 gives a simplified cross-section from north to south through the area discussed. The depth of the hydrological base will be formed by the Upper Tertiary Oosterhout Formation clay. In the northern part of the area it is found at a depth of 380 m below datum level (BREEUWER & JELGERSMA, 1979), in the southern part about 300 m below O.D. (JELGERSMA & BREEUWER, 1975). In a boring northwest of Leiden the toplayer of the Oosterhout Formation seems to have been reached at a depth of almost 200 m (BREEUWER, pers. comm.).

The toplayer of the Maassluis Formation appears to have a depth of almost 300 m below O.D. in the northern part of the area and only 80 m in the south. This means that the overlaying layers show great differences in thickness between the north and the south (respectively more than 200 m and 80 m).

The hydrological significance of this layer is discutable. Although mostly the top of the Maassluis Formation has been taken as the base of the hydrological system, in most borings this layer cannot be found to be impervious. POMPER (1977) calculated for the hydraulic conductivity in nine borings in the area (mostly in the southern part) an average value of 11 m.day^{-1}. Then six deep borings were carried out in the northern part of the area and it seemed that in one boring thick clay layers occurred. Another five gave a similar image as the nine borings mentioned above. LAGEMAN & HOMAN (1979) describe these layers as 'moderately permeable'. Anyhow, it is not justified to take these layers as hydrologic base.

The Lower Pleistocene coarse grained fluviatile layers are

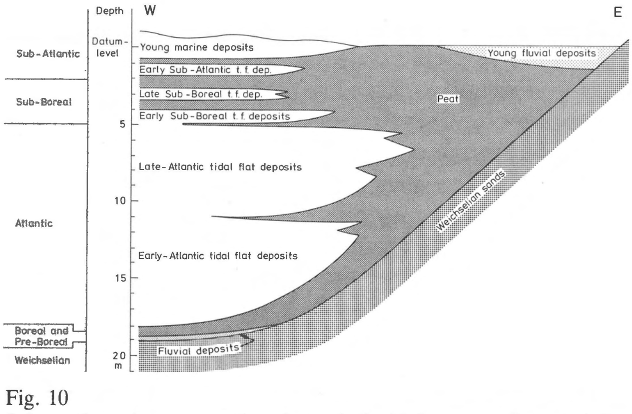


Fig. 10
Schematic W-E cross-section through the Holocene sediments (after JELGERSMA in PONS ET AL. (1963)).

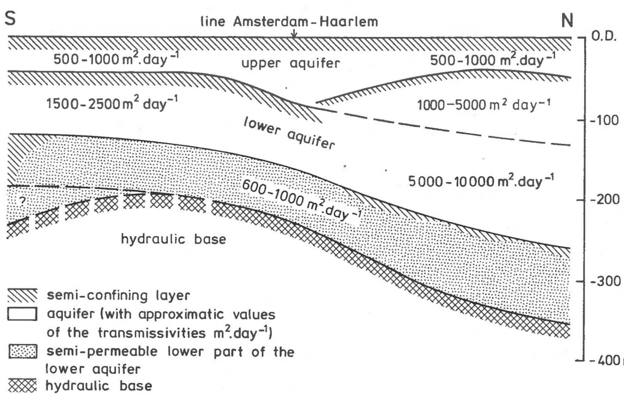


Fig. 11
Simplified hydrological N-S cross-section through the area.

found under the entire area. As mentioned they are different from a stratigraphical point of view, but hydrologically they are one layer. In the southern part of the area their thickness amounts to about 40 m. According to water balance studies of WIT (1974) the transmissivity amounts to 2500 to 3500 m^2.day^{-1}. In the scarce borings available with a sufficient depth, lower values appear. The mentioned values calculated by WIT may include the values of the underlying marine Lower Pleistocene beds (Maassluis Formation) which amount to approximately 1000 m.day^{-1}. The remaining 1500 to 2500 m.day^{-1} for the fluviatile layer with 40 m thickness results in an average transmissivity of 35 to 60 m.day^{-1}. This is in agreement with the scarce data in the central part of the southern half of the area. Along the southern fringe of the area two borings of sufficient depth give estimated k-values of 10 to 20 m.day^{-1}.

In the northern half of the area higher values occur. POMPER (1979) calculates average values of 50 to 75 m.day^{-1} for the hydraulic conductivity. Together with thicknesses of more than 100 m transmissivities of more than 10 000 m^2.day^{-1} locally occur. Together with the sediments of the Middle Pleistocene formations (Sterksel and Enschede formations) this results in a transmissivity of the lower aquifer of 6000 to15000 m^2.day^{-1}. Figure 12 gives a graphical presentation of estimations according to VAN REES VELLINGA (pers. comm.) of the hydraulic conductivities of boring 19E/85 near Hoorn. Some samples in the Harderwijk Formation show values of up to 400 m.day^{-1}. It may be that due to the drilling system (air lift counter flush) the values from estimations are somewhat too high.

It is remarkable that the lower part of the Harderwijk Formation contains sands with hydraulic conductivities lower than found for the upper part. This bipartition has been found in every boring to a satisfactory depth.

The Middle Pleistocene sediments (Sterksel and Enschede formations) in the south only occur in a rather thin interrupted layer and they together with the Upper Pleistocene layers can be regarded to belong to the upper aquifer. In the north, however, they have a thickness of up to 80 m and are separated from the Upper Pleistocene layers by clay layers of different origin (Saalian glacial sediments, Eem Formation, marine clay). Locally a thin clay layer is found at the base of these layers in the north and the mentioned Kedichem Clay in the south. In the north this separating layer is only found at a few sites. So in that part of the area under consideration the Middle Pleistocene and the Lower Pleistocene layers can be taken to belong to one aquifer.

The upper aquifer consists in the southern part of the area discussed of sediments from Middle and Upper Pleistocene origin; in the northern part only of Upper Pleistocene origin. The reason is that in the southern part in most cases the first semi-permeable layer below the Holocene toplayer, aside from local clay layers, is formed by the Kedichem Clay. In the northern part of the area this first clay layer consists of sediments of Eemian and Saalian origin.

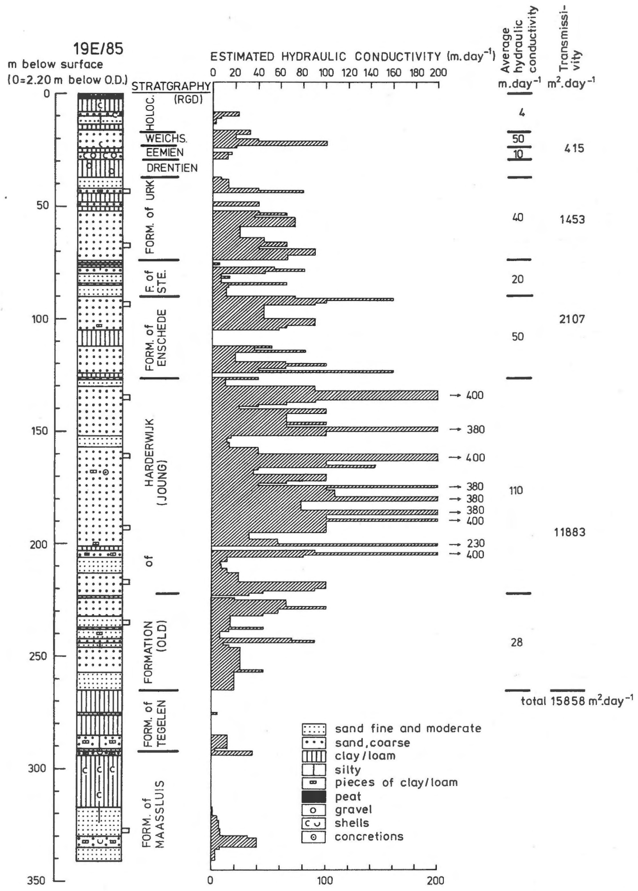


Fig. 12
Graphical presentation of the hydraulic conductivities of samples of the boring 19E/85 near Hoorn after VAN REES VELLINGA (pers. comm.).

Although differences in origin of the sediments of the upper aquifer exist, there are no large differences in hydraulic properties. Its transmissivity amounts in the entire area to 500 to 1000 m^2 day^{-1}, except in the northeastern part of the area (Wieringermeerpolder) where the Upper Pleistocene layers thin out against the upcoming Saalian sediments (boulder clay). In this area the upper aquifer is absent.

CONCLUSIONS

- The base of the hydrological system of the western Netherlands is situated at the top of the Oosterhout Formation marine clay at the boundary between the Tertiary and the Quaternary.
- Although the existence of the covering Pleistocene layers is the result of a complicated succession of geologic processes, a rather simple geohydraulic system is found in the area.
- There is a great difference in the geohydraulic situation between the southern and the northern half of the area.
- This difference is mainly due to the thickness of the Lower Pleistocene sediments.

- The hydraulic system is divided into two parts by a separating layer of different geologic origin between 20 and 40 m below mean sea level.
- The hydraulic properties of the upper aquifer do not show great differences over the entire area, although large differences in geologic origin of the sediments exist. An exception to this statement is the absence of the upper aquifer in the northeastern part of the area.
- The hydraulic conductivities of the lower aquifer in the northern part of the area have values the fourfold of those in the southern half of the area.
- There is a rather sharp boundary between the two parts of the area along an E-W line over Amsterdam.
- In spite of the rather low hydraulic conductivities of the lower marine Pleistocene sediments (Maassluis Formation), their transmissivities have a significant value due to the large thickness of these layers.

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