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HYDRO-GEOLOGICAL INVESTIGATIONS IN THE NETHERLANDS

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SUMMARY

The principal aim of this paper is to demonstrate the increasing importance of the use of sedimentary characteristics in hydro-geological research projects in the Netherlands. Emphasis is laid on the methods of study used. A brief review is given of the techniques for obtaining these quantitative data and for recording them in the form of maps and sections.

RÉSUMÉ

Cet article traite quelques aspects des recherches hydro-géologiques telles qu'elles sont exécutées aux Pays-Bas par l'Instituut voor Cultuurtechniek en Waterhuishouding. Cette étude se rapporte en premier lieu à la nature géologique des couches profondes du sol, par exemple l'étendue et l'épaisseur des couches aquifères, leur âge géologique, leurs variations granulométriques en sens horizontal et vertical et leurs déformations structurales. La seconde partie de l'étude comporte la détermination des propriétés physiques des sédiments : perméabilité, résistances au courant souterrain, niveau piezométrique, etc. Une troisième partie de l'étude consiste à rassembler des données sur la composition chimique des eaux souterraines dans différentes formations géologiques. Cet article expose les essais en plein champ, les méthodes d'étude des sédiments et de représentation des données sur ces sédiments dans les cartes et les profils.

Les travaux en plein champ consistent dans des sondages profonds (50 m de profondeur au maximum) suivant la méthode de la sonde à clapet, où un échantillon de sol pour l'étude géologique et sédimentométrique est prélevé tous les 2 mètres. Presque tous les trous de sondage sont aménagés en puits d'observations en plaçant des filtres dans les couches aquifères. Les filtres servent aussi au prélèvement d'échantillons d'eau, dont on détermine la teneur en chlore ou même l'analyse ionique complète. La figure 1 donne l'exemple d'un puits équipé de 3 filtres à des profondeurs respectives de 20, 30 et 40 m dans la région du Delta, où se trouve démontrée une pression artésienne. Lorsque le but principal est de placer des filtres, on applique le forage par pression d'eau, qui permet d'atteindre rapidement la profondeur voulue (fig. 2). Depuis peu, on prélève également des carottes, dont la perméabilité verticale et horizontale est examinée en laboratoire. Après ces mesures, la structure des sédiments est étudiée dans les coupes longitudinales des carottes.

Parmi les différentes qualités granulaires, on étudie en particulier la composition granulomètrique (fig. 3) et la composition en minéraux lourds (fig. 4). Parmi les propriétés de la masse, on détermine la perméabilité par des mesures dans des échantillons de sol non déformés, par des essais de pompage en plein champ et par calcul à l'aide des résultats des analyses granulométriques.

Les données relatives aux propriétés géologiques et hydrologiques du profil sont incorporées dans des cartes et des coupes de profil. Si l'on dispose d'un nombre suffisant de données, il est très bien possible de dresser des cartes à courbes, comme la fig. 5, qui représente une carte de la table d'eau dans le Nord de la province de Limburg. Les données sur l'épaisseur des couches aquifères, l'assortiment granulométrique, la moyenne composition granulométrique, la perméabilité, la salinité de l'eau de fond etc. peuvent également être représentées dans des cartes de courbes permettant la lecture des variations de ces propriétés et du sens dans lequel ces propriétés changent.

Enfin, il est possible de représenter certaines propriétés géologiques, lithologiques et hydrologiques en une coupe de profil. La figure 6 en constitue un exemple.

1. INTRODUCTION

During the dry summers of 1947, 1949 and 1959 the high importance of water conservation on the high sandy soils of the Netherlands became evident. In particular in the eastern and southeastern part of the country large areas of arable land were desiccating and were sometimes attacked by wind erosion. In order to counter the desiccation and to increase the agricultural production in these areas, large water conservation and water management projects were initiated.

On the other hand the flood disaster of 1953 focussed attention on the dangerous position of the deep-lying polder districts in the southwestern part of the country. For this reason the Deltaplan was set up, which includes the damming of the estuaries. Behind the dams fresh water basins will be formed. This can be used to counter the seepage of salt water in these regions. Studies on subsurface hydrology, seepage, etc. are now in progress.

The above mentioned research projects require a clear insight in the hydro-geological conditions of the investigated regions. In the first place, it is necessary to obtain information on the subsurface geology, such as the areal extent and thickness of the aquifers, their geologic age, their textural variations in a lateral and vertical sense and their structural deformations. The areal extent, depth and textural variations of the aquicludes should also be known.

The second part of the research consists of the determination of the physical properties of the sediments, such as permeability, transmissibility, resistances to groundwaterflow, piezometric head of the pore-water.

In the third place, the collection of data on the chemical composition of the groundwater from various formations forms an important part of the research.

This paper deals mainly with the field procedures and the methods of study of sedimentary data and with the methods for recording these data in maps and sections.

2. GEOLOGICAL REVIEW

The greater part of the Netherlands belongs to the, continuous subsiding, North Sea basin. During the Tertiary this basin has been filled mainly with marine sediments, consisting of glauconite-bearing fine sands or heavy clays, reaching considerable depths (locally 1 000 to 1 500 m.). As a consequence of the subsidence, which was greatest in the northwestern part of the basin, most of the Tertiary abrasion surfaces pitch to the northwest. The anomolous pitch of the Miocene abrasion surface in southeastern direction, as known in the SE part of the country, is due to transcurrent faulting (Lensen and De Ridder, 1960). The Tertiary deposits are generally considered as the impervious basement of the overlying Quaternary sediments, which are mainly laid down by the Rhine and the Meuse. These sediments consist of coarse, gravel-bearing sands, fine sands and clay beds of varying thickness (from a few meters to a few hundreds of meters). In general the thickness increases in northwesterly direction.

3. FIELD PROCEDURE

In studying groundwater problems, such as seepage, drainage, subirrigation and the like, the required data on the subsurface geology and hydrology are generally obtained by borings. The number, spacing and depth of these borings depend on the problem which is studied. For exploration purposes the cable-tool method is used. These borings are cased, to stabilize the bore hole, with steel pipes of 2 m. length and an inner diameter of 5″. The maximum depth that can be reached is 50 m. Samples are taken of material dumped from the bailer. The sampling interval depends on the textural variation, but in general every 2 m a sample is taken, which is described directly in the field and afterwards with a binocular microscope in the laboratory.

The borings are equipped as observation wells by installing two or three piezometers at different depths. These piezometers consist of a filter of 1 m. length, the rest of the pipe consists of 1″ pipes of polyvenylchloride (P. V. C.). To prevent damage, the upper 2 or 3 m. of the pipes are made of iron (gas pipes).

The influence of the leakage is generally small when the work is done carefully. As soon as the filters are installed, the casing is withdrawn and the filters are pumped. Pumping is continued until clean water reaches the surface. A water sample is then taken for laboratory analyses, in order to gain information on the salinity distribution of the deep groundwater. The piezometers are then ready for periodical readings of the hydraulic head. Fig. 1 gives an example of an observation well with three piezometers at different depths in the Delta region (Isle of Schouwen) showing artesian pressure.

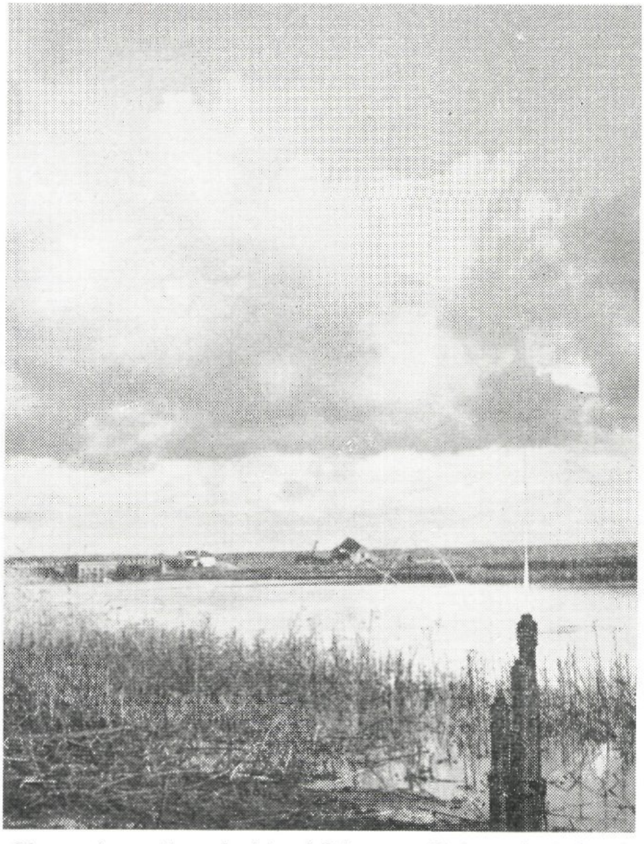

Fig. 1 — Observation well on the isle of Schouwen (Delta region) showing artesian pressure. The filters in this well are installed at 20, 30 and 40 m. below ground surface. The ground surface lies at approximately 2 m. below mean sea level

Although the cable-tool method gives rather accurate information on the sequence, thickness and identity of the subsurface strata, it is time-consuming and therefore expensive. When additional hydrological observation wells are needed, it is better to make wash borings, which are less expensive. These borings are advanced by jetting water into the casing. The water is pumped from a ditch or canal through a drill rod or even a rubber tube. Material is removed from the hole by circulating water (fig. 2). In the Delta region wash borings are carried out with great success because of the presence of fine sands and the absence of gravel. In this region holes to 40 m. are made within a few hours.

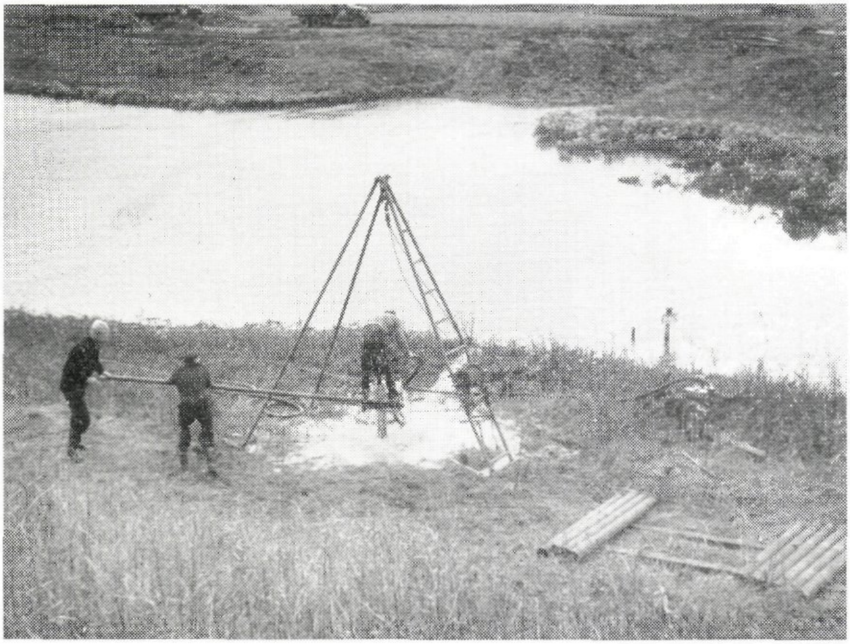

Fig. 2 —Wash boring to a depth of 40 m. carried out just behind the sea dike.The observations from this well are used to study the transmission of the tidal wave in the artesian basin

Hydro-geological studies as described here also include the determination of the in-situ permeability (transmissibility) of the aquifers at a number of places by means of special field pumping tests.

In recent time a field sampling procedure was developed, that permits undisturbed sampling of fine and coarse sands and of clay below the water table (Wit, 1960). Although this is a project still in progress, reasonably accurate results on the vertical and horizontal permeability measurements have been obtained. As a further project of study, the minor structures of the sediments from the cores can be mentioned. These structures are of importance for the explanation of the observed differences in the vertical and horizontal permeability which are often found to be significant in various sediments. It is already evident that practically all structural properties in sediment cores can be made visible by making lacquer peels from dried core sections (Van Straaten, 1959). Van Straaten stressed that these minor structures may provide indispensable criteria for understanding the manner of formation of the sediments. Studies like these are now in progress and they form part of the hydro-geological investigations carried out in relation with the Delta plan.

4. SEDIMENTARY ANALYSES

From a sedimentary point of view, six particle properties are of basic importance: 1. size; 2. shape; 3. roundness; 4. surface texture; 5. mineral composition; 6. orientation (Krumbein, 1945). Among these properties only size and (heavy) mineral composition are studied for the investigations discussed in this paper. Although of great importance, shape and roundness are only studied incidentally. Apart from these particle properties, also mass properties of the sediments can be distinguished, These properties depend upon the aggregation of the particles and include porosity permeability, compactibility, thickness, structure, etc.

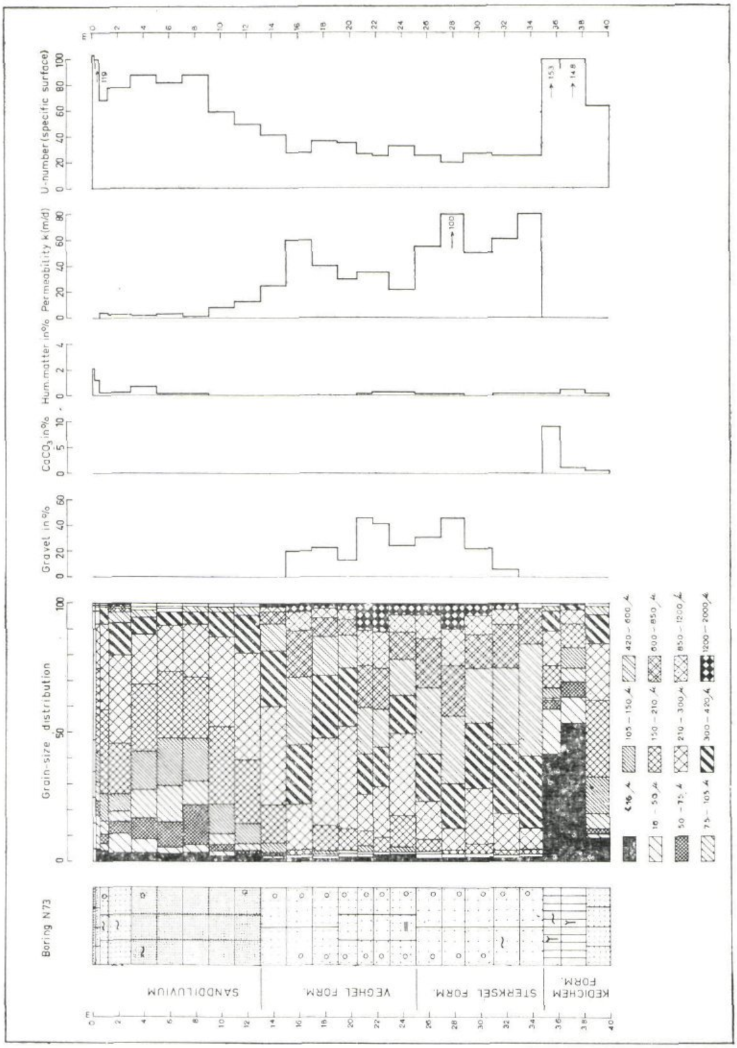

Fig. 3 — Lithology of a bore hole in the province of Noord-Brabant, showing grain size distribution, gravel-, $CaCO_3$- and humic matter content, specific surface of the sand fraction and permeability in m/day

4.1. *Particle properties*

4.1.1. *Grain size*

Mechanical analyses are made of most of the samples obtained from the borings. The results are used to describe the characteristic size-frequency distributions of the sediments of each formation, to examine the horizontal and vertical variations in grain size of the formations, to examine the sorting features, to determine the environment of deposition and to gain an impression of the over-all permeability of the sandy sediments.

From each sample the organic matter-, lime- and gravel content is determined, as well as the specific surface of the sand fraction. It is usual practice in present-day sedimentary studies to express properties of the size-frequency distribution, such as sorting, average, skewness, by means of a single number. The advantages of this single-number representation are many, some of which will be discussed below.

Besides this single-number representation it is possible to plot graphically the results of all the mechanical analyses of a boring. An example of such a graph is shown in fig. 3. A representation in this manner gives a full picture of the grain size distribution of each layer, as well as of the variations in grain size in a vertical direction through the different formations. The depth, thickness and character of the water-bearing formations and of the aquicludes (clay beds) can be read at once. On the right side other characteristics, such as organic matter —, lime — and gravel content, specific surface (U-number) and permeability coefficient (k in m/day) are plotted.

From a sedimentary, as well as a hydrological, point of view it is important to know in what manner the mean grain size and the sorting of the sediments change in the investigated region. These properties may amongst others shed light on the environment of deposition and the direction and intensity of streamflow during the deposition. On the other hand it is known from earlier experimental work that the coefficient of permeability is affected by the grain size and sorting of the (unconsolidated) rock. In studying the areal variations in mean grain size and sorting, variations in mass properties, such as horizontal permeability, are better understood. Mean grain size and sorting are determined in the way as given in most sedimentary textbooks (Pettijohn, 1958).

4.1.2. *Heavy minerals*

Heavy mineral composition can give information on the source area of the sediment and on post-depositional changes. The use of heavy mineral analyses for stratigraphic purposes has appeared to be very useful, as is shown by Zonneveld (1947, 1958). This method of study requires some caution, however, since especially in fluvial deposits, leaching, granular variation and mixing with other or older sediments may cause important variations in the heavy mineral associations. Studies on heavy minerals should therefore be carried out together with those on grain size, pollen, fossils, etc.

It has become common practice in most hydro-geological research projects to make a number of heavy mineral analyses to recognize the sedimentary history of the region. An example of such analyses is given in fig. 4, showing a graphical representation of the procentual variation in heavy mineral composition of each formation. Each formation is characterized by special associations of minerals. The Sterksel Formation, which is composed of Rhine sediments (saussurite is a guide mineral of the Rhine) can easily be distinguished from the Lower Pleistocene Kedichem Formation and the Upper Pleistocene Veghel Formation, which were both deposited by the Meuse. The results of these analyses are used, together with other geological data, for subsurface correlation.

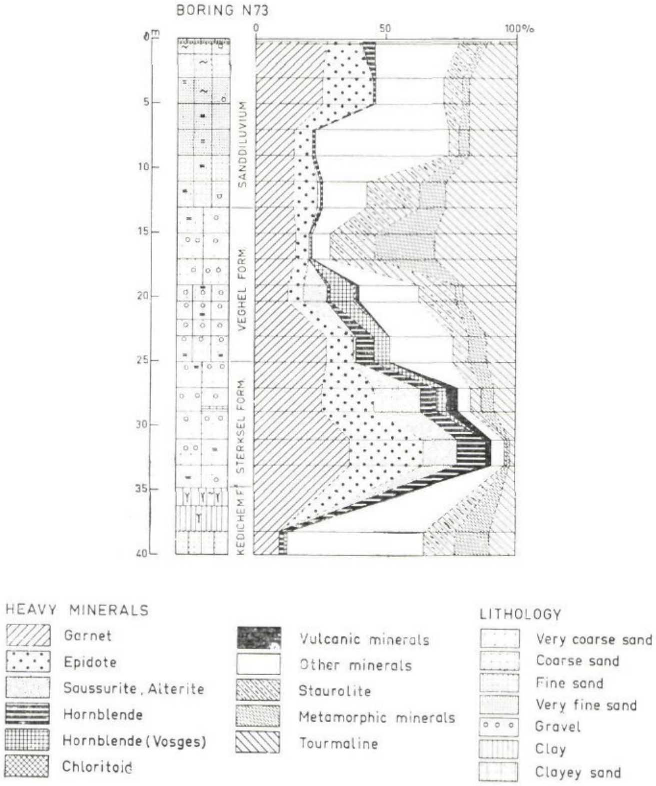

Fig. 4 — Heavy mineral composition and lithology in a bore hole from the province of Noord-Brabant

4.2. *Mass properties*

4.2.1. *Permeability*

Among the mass properties already mentioned, permeability is studied most intensively as well in the field as in the laboratory. In most groundwater studies the determination of the transmissibility of a given sand stratum or aquifer is of basic importance. This can be done most accurately by pumping tests. Such tests consist of pumping a well at a particular rate of flow. The drawdown in the well and in adjacent piezometers is measured. These data, together with data on the thickness of the aquifer, the radius of the well and the distances to known points of drawdown make it possible to compute the transmissibility of the aquifer being tested.

It is questionable if the results of a single pumping test are representative for the whole area under study. In regions accumulated by rivers, as in the Netherlands, this will certainly not be the case. Generally, the high costs prevent the determination of the transmissibility by means of special pumping tests at more than a few places. The present author therefore estimates the transmissibility from: 1) the results of mechanical analyses of samples obtained from bailer borings, 2) the results of laboratory permeability tests on undisturbed samples.

From laboratory tests on remolded samples a relation was found by Ernst (unpublished report) between particle size and permeability. When the size-frequency distribution of a sample is known, the permeability coefficient can be computed. Corrections are made for the clay- and gravel content and the sorting of the sample. The thickness of the layer from which the sample is taken, is known from field observations and thus from each layer the transmissibility can be computed by multiplying the thickness and the permeability. When the values of all sequential layers are added together, the transmissibility of the entire aquifer can be found.

The accuracy of this method may be questionable and it is noted that in comparing the results obtained according to this method with those from pumping tests, variations of 200 per cent are sometimes found. The same was found by Mansur (1958), who pointed to the fact that the field permeabilities of given sand stratum sometimes exceeded the permeabilities in the laboratory two to four times.

More accurate results can be obtained, however, with laboratory permeability tests on undisturbed samples. With the sampler now in use by the present author, samples can be taken of 30 cm length and a diameter of 6 cm. The vertical and horizontal permeabilities of the samples are tested while they remain in the sampler tube.

5. Representation of data in map and section form

In modern hydrological and geological work most data are quantified. These data should be translated, however, into forms which can be used directly by workers interested in special problems. This can be done best in the form of maps and sections.

When sufficient quantitative data on groundwater and sedimentary properties are available, they can be used to construct contour-type maps. These maps consist of lines connecting points of equal magnitude of a given variable, which may be thickness of layers, permeability, mean grain size, sorting, salinity of the groundwater, piezometric head, etc. Such contour-type maps show the areal variations of a given property and the directions in which the property changes.

In most groundwater studies, for instance, it is necessary to know the direction and intensity of the groundwater flow. These can be derived from a hydrologic contour map. Such a map can be prepared from data on the depth of the groundwater table obtained from records of measurements in auger holes, and heights of the water table of open channels. Lines of equal piezometric head can then be drawn and from these the direction of groundwater flow, which is normal to these lines, can be derived. The gradient of the groundwater table is also shown by the map and when the transmissibility is known, the intensity of the groundwater flow can be derived in accordance with Darcy's law.

Figure 5 gives an example of a hydrologic contour map, showing a region along the river Meuse in northern Limburg. The normal gradient in this region varies between 1:500 and 1:1 000. Locally much steeper gradients occur, however, and at some places an abrupt fall in the groundwater table is even encountered. This last phenomenon is caused in this case by a sealed fault, which was active during the Tertiary and the Early Pleistocene, as could be demonstrated by Ernst and De Ridder (1960).

Among maps which are of use in hydro-geological studies, those on thickness and permeability of the aquifers must be mentioned. As shown above the product of these two data gives the horizontal transmissibility of the aquifer. The variation in thickness can be made visual by an isopach map. Such a map is very illustrative in block-faulted regions, as for instance in the southeastern part of the Netherlands. The thickness of the aquifer in the sunken blocks exceeds many times the one on the raised blocks, as was proved by De Ridder (1959). It was found that, for instance, in a given Graben the thickness of the aquifer increased in SE direction, while on the

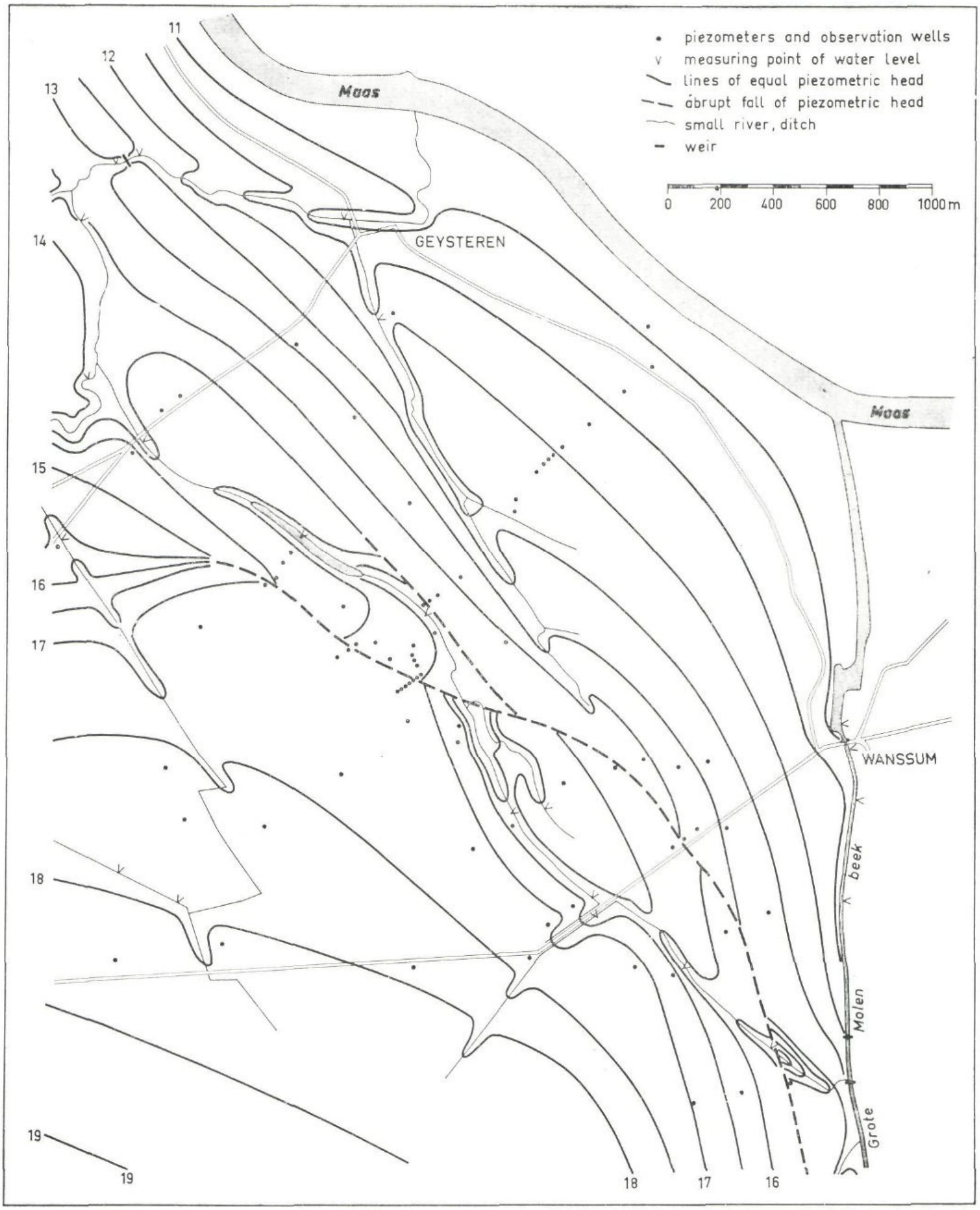

Fig. 5 — Contour map of the groundwater surface in the northeastern part of the province of Limburg, showing abrupt falls in the piezometric head

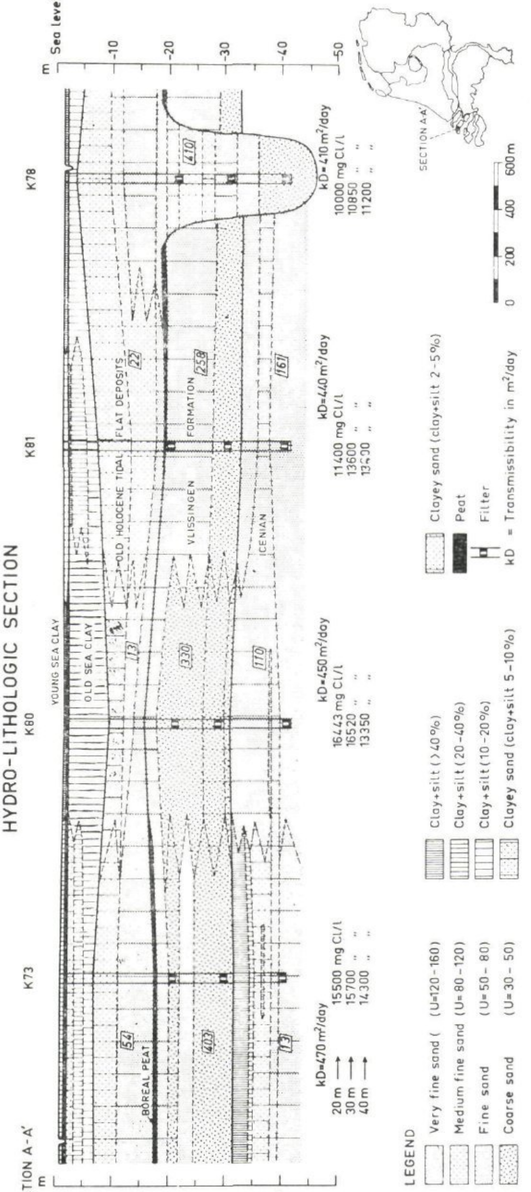

Fig. 6 — Hydro-lithologic section showing lithologic units and transmissibility of the various formations and the chloride content in mg/l of the deep groundwater at 20, 30 and 40 m below soil surface

adjacent blocks the thickness increased in NW direction as a consequence of the opposite pitching of the surface of the impervious basement. On other blocks the thickness can be almost equal. An isopach map of such regions can best be constructed in combination with a tectonic map, showing the location, strike and importance of the faults.

Of great importance in groundwater studies are the informations on magnitude, and variations in transmissibility of the aquifers. When sufficient data are available, they can be used in preparing a permeability, or better transmissibility, map. This is a map also based on a combination of properties (product of thickness and permeability). Data on the transmissibility lend themselves well for the preparation of a contour map. When such a map is coloured, other properties such as thickness of layers, as well as the fault pattern of the region can be drawn into the same map. In this way a hydro-geological map can be constructed. A map like this has been prepared by the present author for the southeastern part of the Netherlands and will soon be published.

Of course it is not possible to draw all sedimentary and hydrological properties into one map. It may be necessary in some cases to prepare a series of individual maps, for example on mean particle size, sorting, mineral composition, salinity of the groundwater and others. In comparing these maps dissimilarities in a given attribute can be better understood and attention will be focussed on particular areas. A transmissibility map for example will be more clear when individual maps on thickness of layers (isopach map), mean particle size (isomegathy map) and on sorting are available. When transmissibility maps are present, dissimilarities in salinity of the groundwater can be sometimes explained.

Besides the usual geologic sections, showing the sequence and thickness of the geological formations, it has its uses to construct, what is called by the present author, hydro-lithologic sections. A hydro-lithologic section not only shows the stratigraphic boundaries, but special attention is given to the lithology of the formations. The lithologic units of each formation are analysed and the mean grain size and silt-clay content is plotted with classic symbols on the section. Mass properties, such as permeability or transmissibility and salinity of the groundwater are also plotted in these sections. The transmissibility of each formation is given in figures next to each bore hole. The permeability of each lithologic unit can be indicated by means of different colours. Under each bore hole the chemical composition of the groundwater can be given in figures or in diagrams (fig. 6).

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