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HYDROGEOLOGIC INVESTIGATIONS IN THE NOORDPLASPOLDER, THE NETHERLANDS

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CONTENTS

INTRODUCTION

The Noord Plaspolder is situated in the central part of the western Netherland and covers approximately about 4326 hectares (Hs 1.2). It is a reclaimed lake which originates from an exploitation of peat in the 16th and 17th century. The groundwater-flow in the polder area is characterised by diffuse upward seepage. In the Netherlands, all of the polders are more or less characterised by this phenomenan and the water table is artificially maintained by a dense drainage system of ditches and drains.

Fresh water is mainly found in pleistocene deposits and in the lower part of the Netherlands, these deposits have become salty, except below the dunes. Although the surface water quality in the Noord Plaspolder is mostly rather good, the discharge of saline water through upward seepage have an adverse effect on quality of it. Especially in the dry periods during the crop growseason the surface water is rather salty and unusable for sprinkling purposes. The soils are sticky when wet and hard when dry. If the water can be kept fresh, it can be used for so many purposes, and will permit a more intensive land-use (e.q. horticulture). In the Netherlands, the use of the ground water for domestic, municipal, industrial and agricultural purposes is rapidly increasing and with the increasing requirements, it has become necessary to have a better insight in the subsurface geology and hydrology of the region. Keeping this view in mind, the present study was proposed. In the present paper seepage flow intensity has been calculated by using hydrogeological and hydrological methods.

AVAILABLE METHODS

As basis for these investigations the following data were available:

- the well logs of 20 borings
- data about the deeper and shallow water groundwater-level (1971)
- chemical analysis results of the groundwater
- pumping test data of one test well
- data about precipitation, evaporation and subsurface outflow

GEOLOGICAL SITUATION

In the area under investigation only a few borings were carried out, most of them by the water companies. On the basis of these informations and those of the surroundings the subsurface geology of the area can be set as below.

m-mean sealevel

m			
5	HOLOCENE	peat, clay, silt and sand intercalations	marine, fluviatile and terrestic
15	Upper Pleistocene	coarse sand coarse to medium sand with gravel	marine fluviatile
40	INTERCALATING CLAY LAYER		
	Middle/Lower pleistocene	fine sand with clay and silt coarse sand at bottom	fluviatile
120	Lower marine Pleistocene (marine Icenien)	fine sands with many clay layers	marine

Fig. 1 Map of The Netherlands

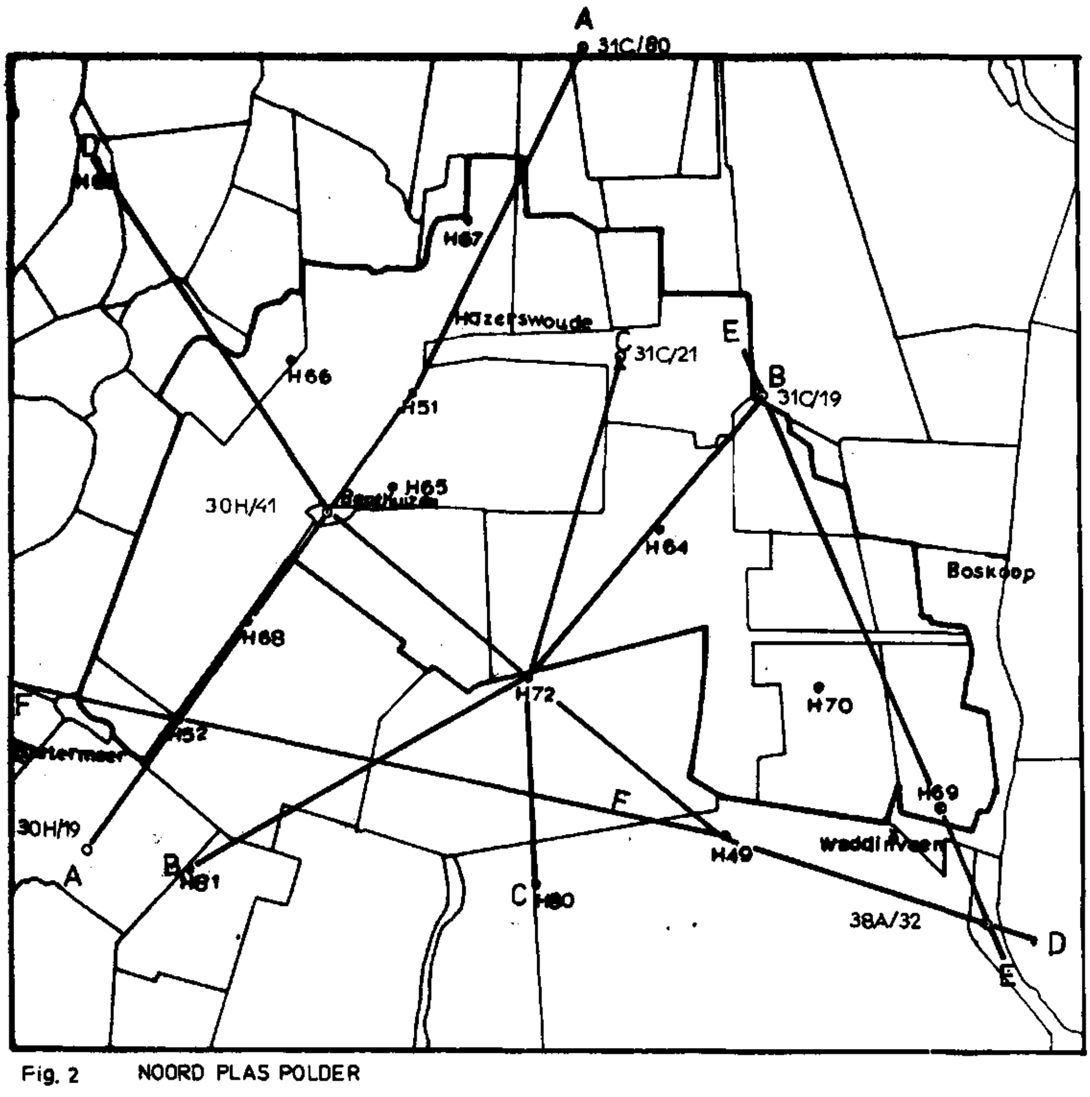
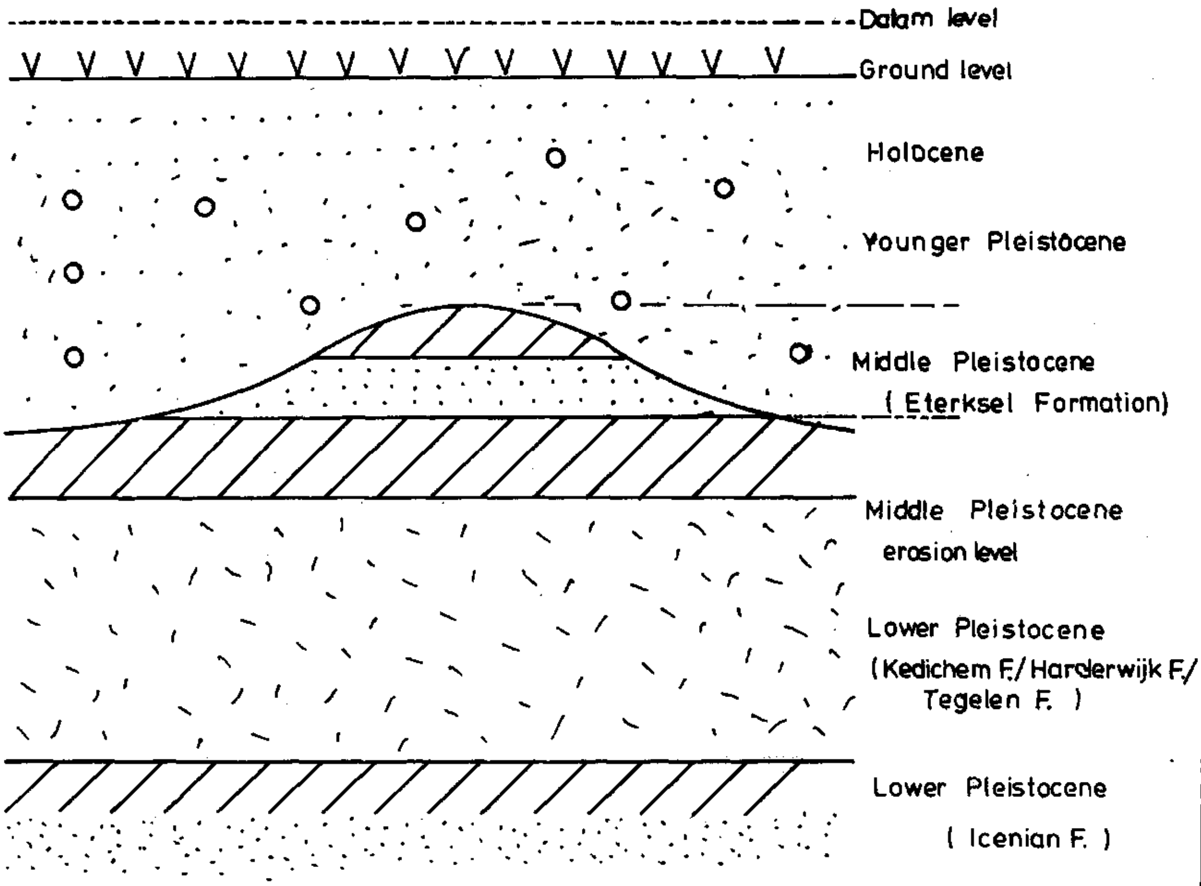


Fig. 2 NOORD PLAS POLDER

Fig. 3



Datam level
Ground level
Holocene
Younger Pleistocene
Middle Pleistocene
(Eterksel Formation)
Middle Pleistocene
erosion level
Lower Pleistocene
(Kedichem F./ Harderwijk F./
Tegelen F.)
Lower Pleistocene
(Icenian F.)

M a r i n e   I c e n i e n

Not any bore hole has been encountered through this formation in the Noord Plaspolder. It is only known from a few very deep borings in the large surroundings, but it has been presumed through geological sections that it can be expected below 120 meters NAP (WITT and VAN REES VELLINGA, 1971).

M i d d l e / L o w e r   P l e i s t o c e n e

Middle Pleistocene

The sediments of this period originate from the following formations:

. Sterksel formation

. Kedichem/Harderwijk formation

. Tegelen formation

The upper interface of these sediments is the Middle Pleistocene erosion level, which was formed at the beginning of the Elsterian glacial epoch (POMPER, 1972). Many sediments which were present were eroded away in deep gullies. In the present region a capture basin of this gully-system was formed. In the gullies the Sterksel formation and a part of the Kedichem formation (in fact the top-Kedichem clay layer) were eroded away. In the intervening parts of the polder only a part of the Sterksel formation was removed (fig. 3).

The interfaces between the three lower Pleistocene formations can hardly be detected by petrologic and paleo-botanic methods. Therefore the three formations are combined.

Upper Pleistocene formations

Overlying the Kedichem formation are Upper pleistocene formations. The lower part of these formations, mainly consists of coarse to medium fine grained sand with gravel. These are fluviatile deposits. In the western part of the polder the upper layer is rather coarse grained and marine. Organic matter and concretions are found in these formations.

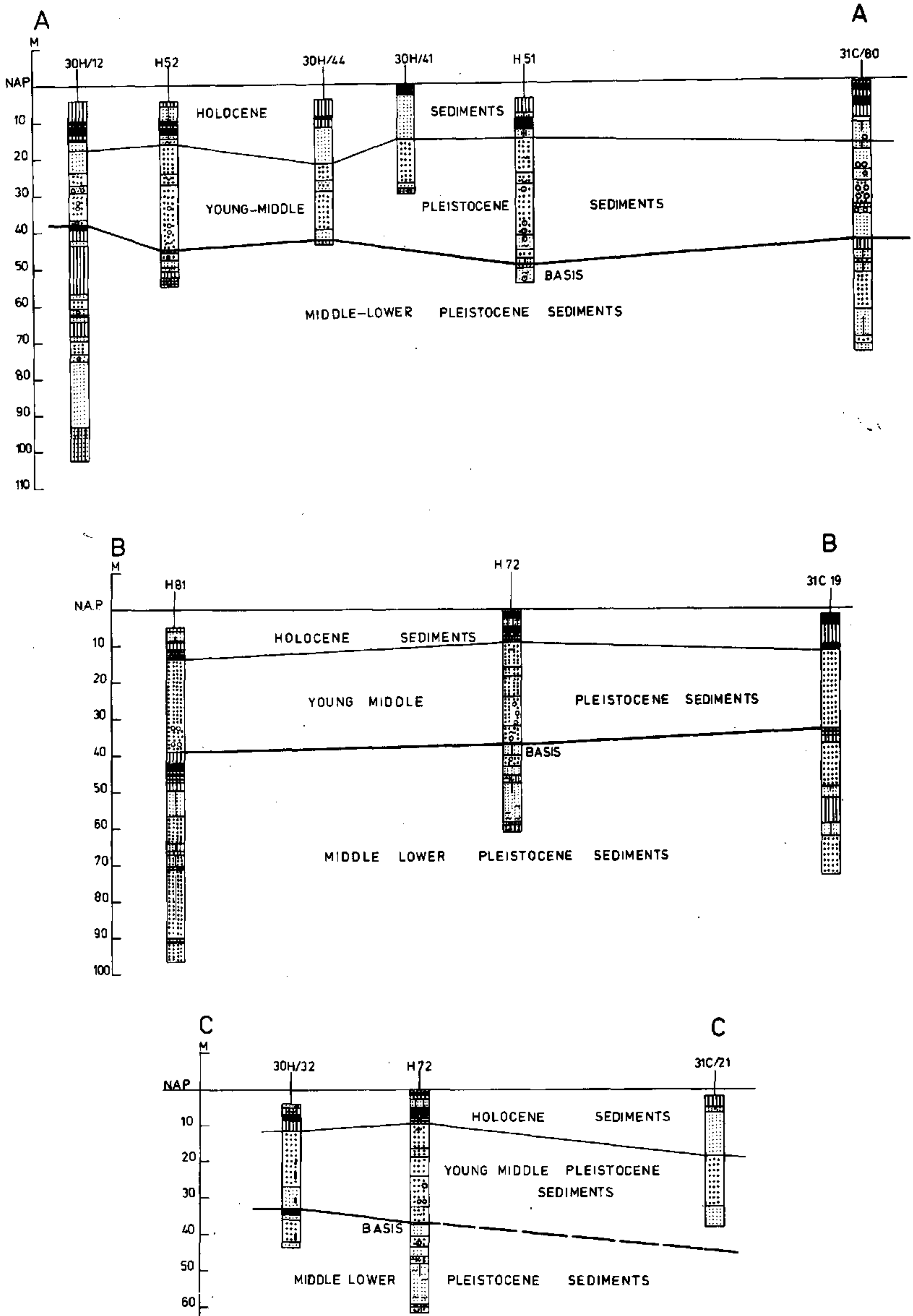
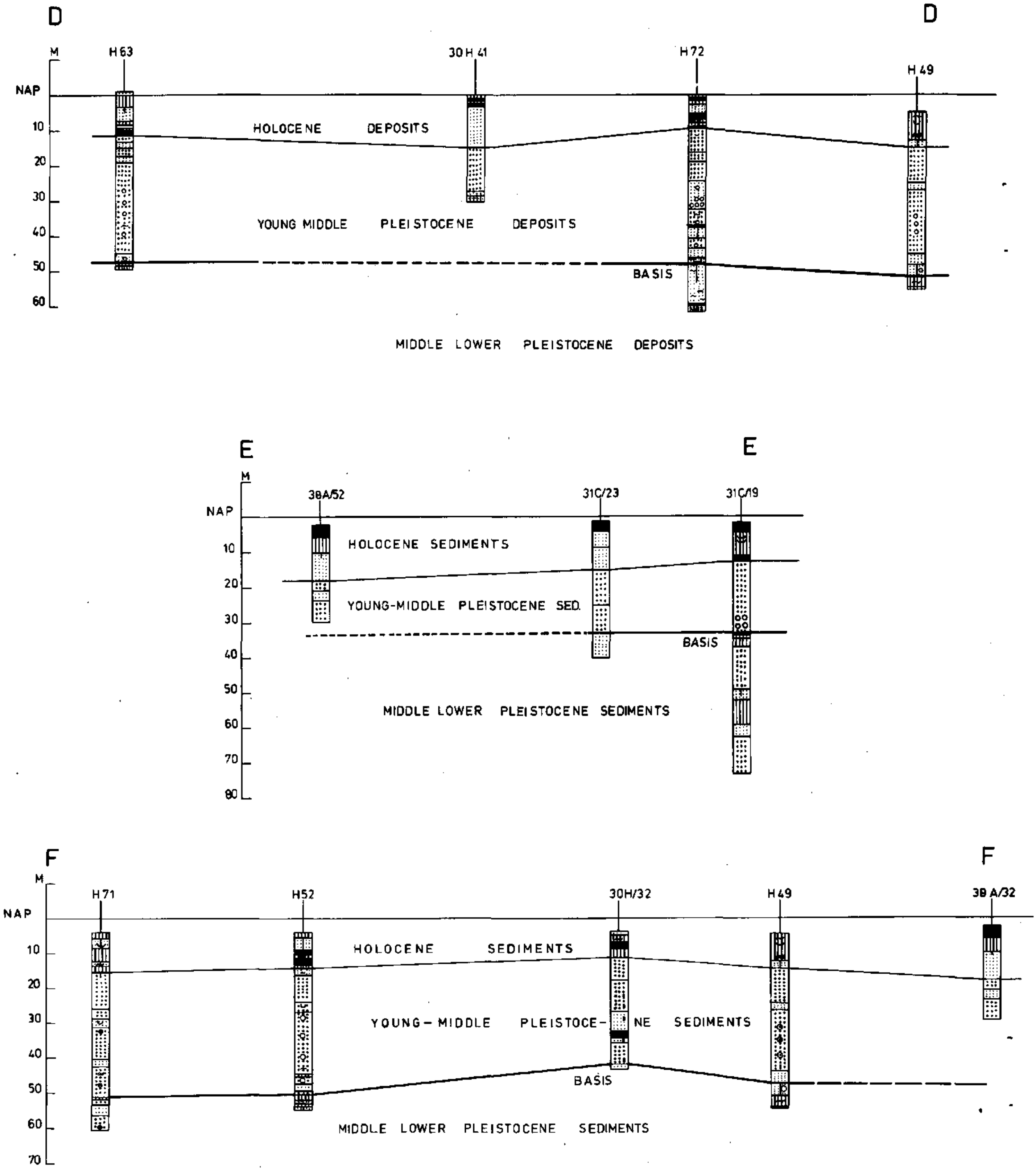

A
A
M
NAP
10
20
30
40
50
60
70
80
90
100
110
30H/12
H52
30H/44
30H/41
H51
31C/80
HOLOCENE
SEDIMENTS
YOUNG-MIDDLE
PLEISTOCENE
SEDIMENTS
BASIS
MIDDLE-LOWER PLEISTOCENE SEDIMENTS
B
B
M
NA.P
10
20
30
40
50
60
70
80
90
100
H81
H72
31C 19
HOLOCENE SEDIMENTS
YOUNG MIDDLE
PLEISTOCENE SEDIMENTS
BASIS
MIDDLE LOWER PLEISTOCENE SEDIMENTS
C
C
M
NAP
10
20
30
40
50
60
70
30H/32
H72
31C/21
HOLOCENE SEDIMENTS
YOUNG MIDDLE PLEISTOCENE
SEDIMENTS
BASIS
MIDDLE LOWER
PLEISTOCENE SEDIMENTS

fig. 4 a,b,c



D
D
M
H 63
30 H 41
H 72
H 49
NAP
10
20
30
40
50
60
HOLOCENE DEPOSITS
YOUNG MIDDLE PLEISTOCENE DEPOSITS
BASIS
MIDDLE LOWER PLEISTOCENE DEPOSITS
E
E
M
38A/52
31C/23
31C/19
NAP
10
20
30
40
50
60
70
80
HOLOCENE SEDIMENTS
YOUNG-MIDDLE PLEISTOCENE SED.
BASIS
MIDDLE LOWER PLEISTOCENE SEDIMENTS
F
F
M
H 71
H52
30H/32
H 49
38 A/32
NAP
10
20
30
40
50
60
70
HOLOCENE SEDIMENTS
YOUNG-MIDDLE PLEISTOCE- NE SEDIMENTS
BASIS
MIDDLE LOWER PLEISTOCENE SEDIMENTS

fig. 4. d,e,f

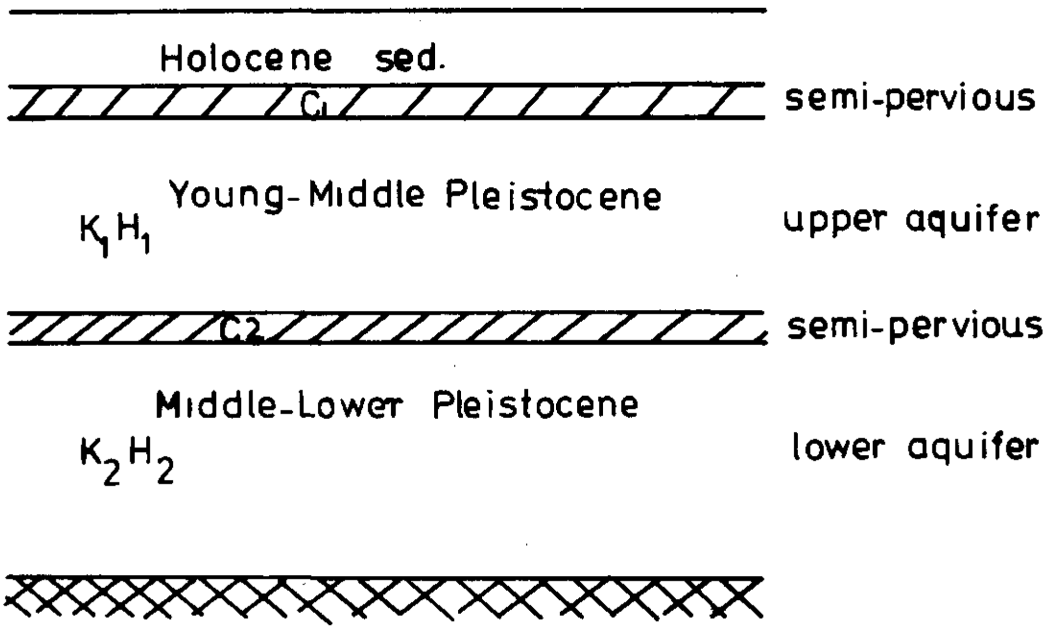


fig. 5

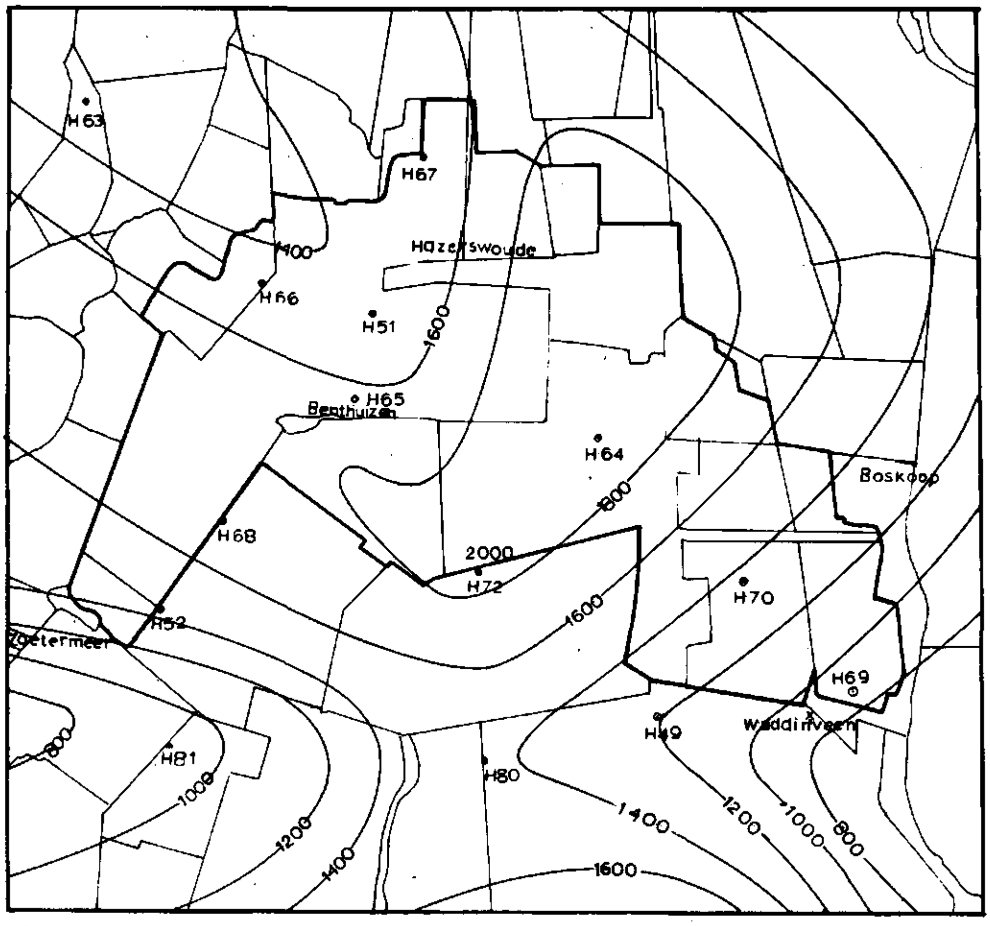


Fig. 6 Contour map of transmissivity of the upper aquifer ——1000—— Contour line of 1000 KD (m^2/days)

Holocene formation

Overlying the Pleistocene deposits are the group of deposits belonging to the Holocene period. These consist mainly of peat, loam and fine sand intercalations with organic material.

Six lithological cross sections are shown in fig. 4a,b,c,d,e and f.

WATER BEARING LAYERS

On the basis of lithology the good water bearing deposits date from the Pleistocene age. They consist of two semi-confined aquifers which are separated by semi-pervious layers. The upper aquifer consists of coarse sediments of upper Pleistocene age and the lower aquifer contains coarse grained fluviatile sediments of middle and lower pleistocene (fig. 5).

TRANSMISSIVITY OF AQUIFERS

The transmissivity of aquifers is of special importance because it defines the hydraulic characteristics of water bearing formations particularly flow of groundwater and indicates how much water with move through the aquifer. It is expressed by a symbol T or KD. In the Noord Plaspolder, the hydraulic conductivity or transmissivity and hydraulic resistance of the semipervious covering layer have been calculated by the following methods.

a) from grainsize-distributions of well-log-samples

b) from pumping tests

TRANSMISSIVITY CALCULATED FROM GRAIN SIZE

SEELHEM (1880), KOZENY (1927), HOOGHOUDT (1934), CARMAN (1939), CHILINGAR, MAIN and SINNOKROT (1963) and others found a relationship between hydraulic conductivity and the grain size distribution of sands. It is expressed by a parameter U which values the surface/volume ratio of the grains, multiplied by 1/6. In case of spheres with diameter of one cm

$$U = 1/6\ (4\pi\gamma^2 / \tfrac{4}{3}\pi\gamma^3) = \frac{1}{2r} = 1\ cm^{-1} \qquad (1)$$

ERNST (Unpublished research, 1955) found from laboratory experiments with artificially mixed samples of natural sediments with a pore volume of 35 percent, a proportionality factor between k and $^1/U^2$ or the product $kU^2 = 27 \times 10^3$. Actually the general formula is $kU^2 = C$, where C is a constant, the valve of which depends on the grain size distribution. The valve of C is obtained from data obtained from pumping tests. In the present area, from a series of pumping tests carried out over an area covering about 100 000 hectares around the area, the valve of C has been calculated 54 000.

ERNST further corrected the hydraulic conductivity to (a) sorting of sand, (b) the clay plus silt content and (c) gravel content because it is difficult to determine the natural pore volume and pore size distribution. The sorting of sand is expressed as the percentage of the material in the three adjoining main subfractions.

Thus the formula is

$$k = \frac{54\ 000}{U^2}\ a.b.c. \qquad (2)$$

where:

k = hydraulic conductivity in m^2/day
U = specific surface of the soil particles
a = correction factor of degree of soring
b = correction factor for silt content (<16 microns)
c = correction factor for gravel content (>2000 microns)

In the present study the U-factor has been estimated by binocular study of the samples and hydraulic conductivity for each sample has been calculated using formula (2). The transmissivity of the aquifer then is calculated by multiplying the k-values of the sample with the thickness of the layer from which they were taken. The transmissivity values varies between 300 m^2/day and 2000 m^2/day.

A transmissivity contour map is presented in fig. 6. Values of the transmissivity are tabulated in table 1.

Table 1. Transmissivity (kD) of the upper aquifer calculated from the estimation of k from samples

Boring no.	kD (m^2/day)	Boring no.	kD (m^2/day)
30H-11	102	38A-21	450
12	370	23	920
32	>550	19	1818
36	1550	32	>375
40	1000	47	2150
41	522	80	1680
43	1000	145	680
48	1175	163	525
49	1195	31C- 6	>950
50	2600	16	>850
51	1045	45	1200
52	1451	80	1680
53	1150		
54	700		
55	1516		
57	>1422		
60	1300		
63	1980		
72	1990		
76	1756		
77	397		
80	1473		
81	881		
83	>900		
84	1650		
90	500		
96	>375		
97	1650		

P u m p i n g   t e s t s

The main object of a pumping test is to get information about the performance and the efficiency of the well being pumped and to obtain hydrological constants from the aquifer. These results are generally most accurate and reliable. Close to the Noord Plaspolder

Location of Pumping test

fig.7

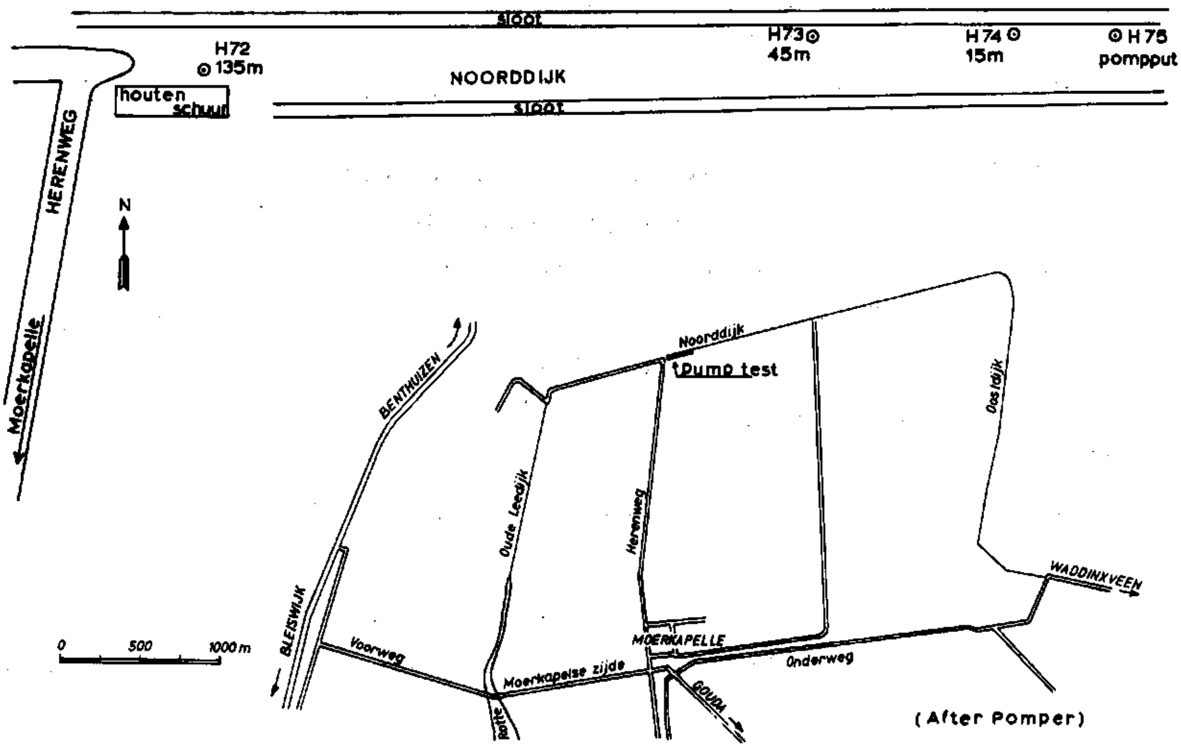


fig. 8

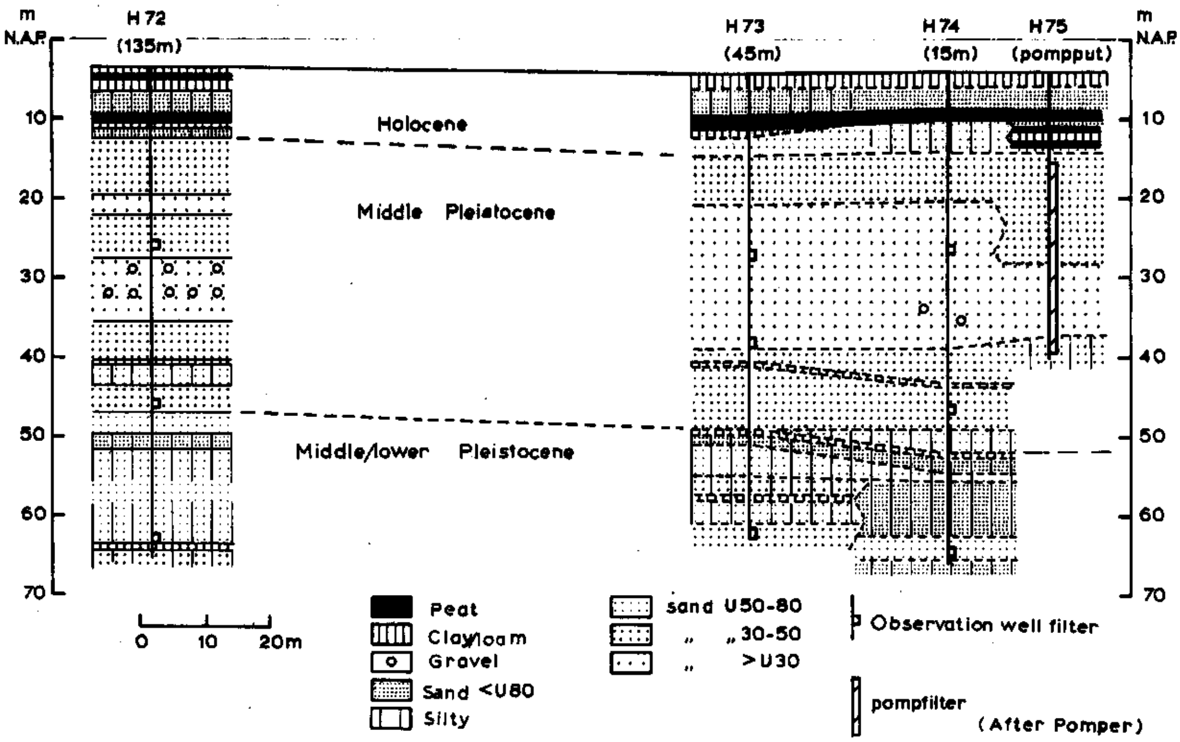


fig. 8.

a pumping test was carried out on boring H72 by POMPER (1970. The geological section is shown in fig. 8.

Description of the pumping test H 72

The location of the pumping test site is shown in the fig. 7. The site is located near the Noorddijk, the bordering dike of the late Noordplas, about 4 km north of Moerkapelle and 6 kms south east of Benthuizen. The test was conducted by Pomper on 10th august 1970 for 24 hrs. The position of the filters in the pumping well, and piezometers are shown in the fig. 7. The discharge of the pumping well was 681.9 m^3/day.

The summary of the observations is shown in the table

	Pumping well	Piezometer I at 15m			Piezometer II at 45m			Piezometer III at 135m		
		I	II	III	I	II	III	I	II	III
Filter position meter-NAP	15.5-39.5	64.5	46.5	26.5	62.0	38.0	27.0	63.0	46.0	26.0
S.W.L. mm-NAP	186.6	177.1	177.1	170.7	169.0	171.4	169.0	231.1	238.0	267.4
Pumping water level after 24 hrs. of pumping mm-NAP	296.5	184.0	200.5	197.7	174.7	190.1	186.4	235.9	250.2	279.8

POMPER (1970) calculated the following results:

	kD (m^2/day)	c (days)
1. By De Glee method	1414	163
2. By Thiem method	1890	-
3. By Theis method	1950	-
4. By De Glee correction method according to Huisman	1800	304
5. By recovery method	2070	-

HUISMAN and KEMPERMAN METHOD

HUISMAN-KEMPERMAN (1951) developed a method for the analysis of pumping test data obtained from a two-layered leaky aquifer in which the flow is in a steady state. The main advantage of this method is that the transmissivity and hydraulic resistance of semi-pervious layers of upper and lower aquifer can be calculated simultaneously when the upper part of the aquifer is pumped and this continues till a steady state is reached.

For the drawdown in the different parts of the aquifer, HUISMAN and KEMPERMAN (1951) derived the following formulas, valid for small values of 1/L.

$$S_1 = a_1 - \frac{2.3Q}{2\pi k_1 D_1} \log r \qquad (3)$$

$$S_2 = \frac{2.3Q}{2\pi k_1 D_1} a_2 \qquad (4)$$

where: $L = \sqrt{kDC}$ = Leakage factor of the water-bearing layers

S_1 = drawdown in the upper part of the aquifer (m)

S_2 = drawdown in the lower part of the aquifer (m)

$k_1 D_1$ = transmissivity (m^2/day) of upper aquifer

π = distance of piezometer from the pumped well

a_1 and a_2 are constants depending on the values of $k_1 D_1$, $k_2 D_2$, c_1 and c_2

PROCEDURE

Alle the values of steady-state drawdown of all the three piezometers are corrected at a standarized discharge rate Q^1 = 250 m^3/day by using the formula

$$S^1 = \frac{Q^1}{Q} S \qquad (5)$$

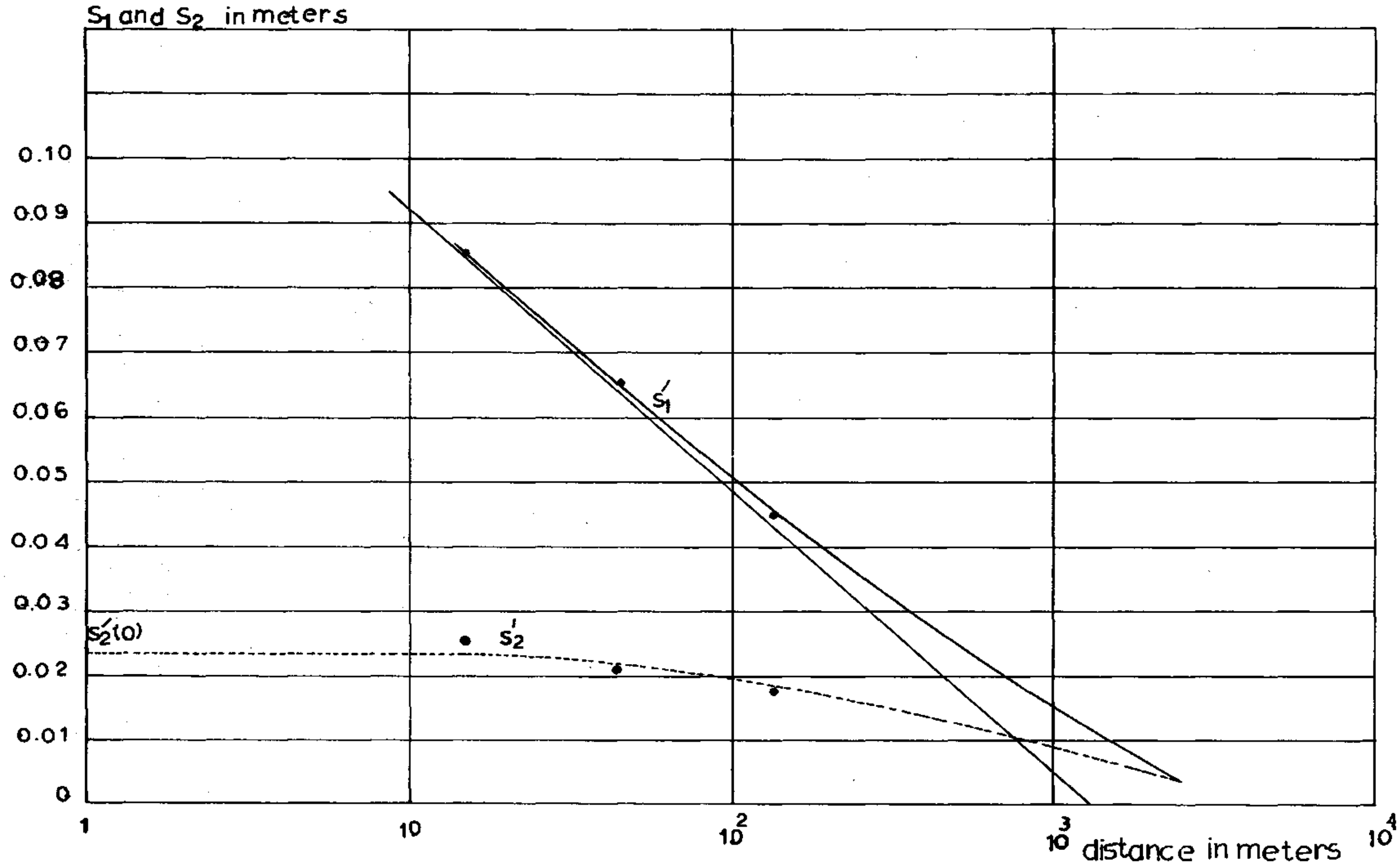


Fig.9 Schematic illustration of the superposition of the distance-drawdown curves on the Huisman-Kemperman type curves

where: S^1 = corrected drawdown for the standarized pumping rate Q^1 (= 250 m^3/day)

S = observed drawdown at the actual pumping rate Q (in the present case Q = 681.9 m^3/day)

These corrected drawdown values in both of the aquifers are plotted versus distance on a single logarithmic graph paper (r on logarithmic scale), and a tangent is constructed to the curve S^1 versus r for small values of r (fig. 9).

The value of ΔS^1 (drawdown difference per log cycle of r) form the graph is noted, and substituted in the formula

$$k_1D_1 = \frac{2.3Q^1}{2\pi\Delta S^1} \qquad (6)$$

in the present case S^1 = 0.043 which gives

$$k_1D_1 = 2130 \ m^2/day$$

Next a value of the drawdown with the corresponding value of r is read from the drawdown-distance curbe say r = 10 m, and substituting in the formula (1)

$$S^1 = a^1 - \Delta S^1 \log r \qquad (7)$$

in the present case for r = 10m, S^1 is 0.093 m which gives

$$a^1 = 0.136$$

The curve S_2^1 versus r is now extended to zero distance and the value for S_2^1 (0) is read from it and substituted in the formula

$$G = k_1D_1 \ S_2^1(0)$$

where G is constant in the present case $S_2^1(0)$ = 0.023 m which gives the value of G = 50.

Now a value for k_2D_2 is assumed, say 2130 m^2/day and ratio of k_1D_1 and k_2D_2 is calculated in the present case k_1D_1 = 2130 m^2/day, k_2D_2 = 2130 m^2/day (assumed value) so

$$\frac{k_1D_1}{k_2D_2} = 1$$

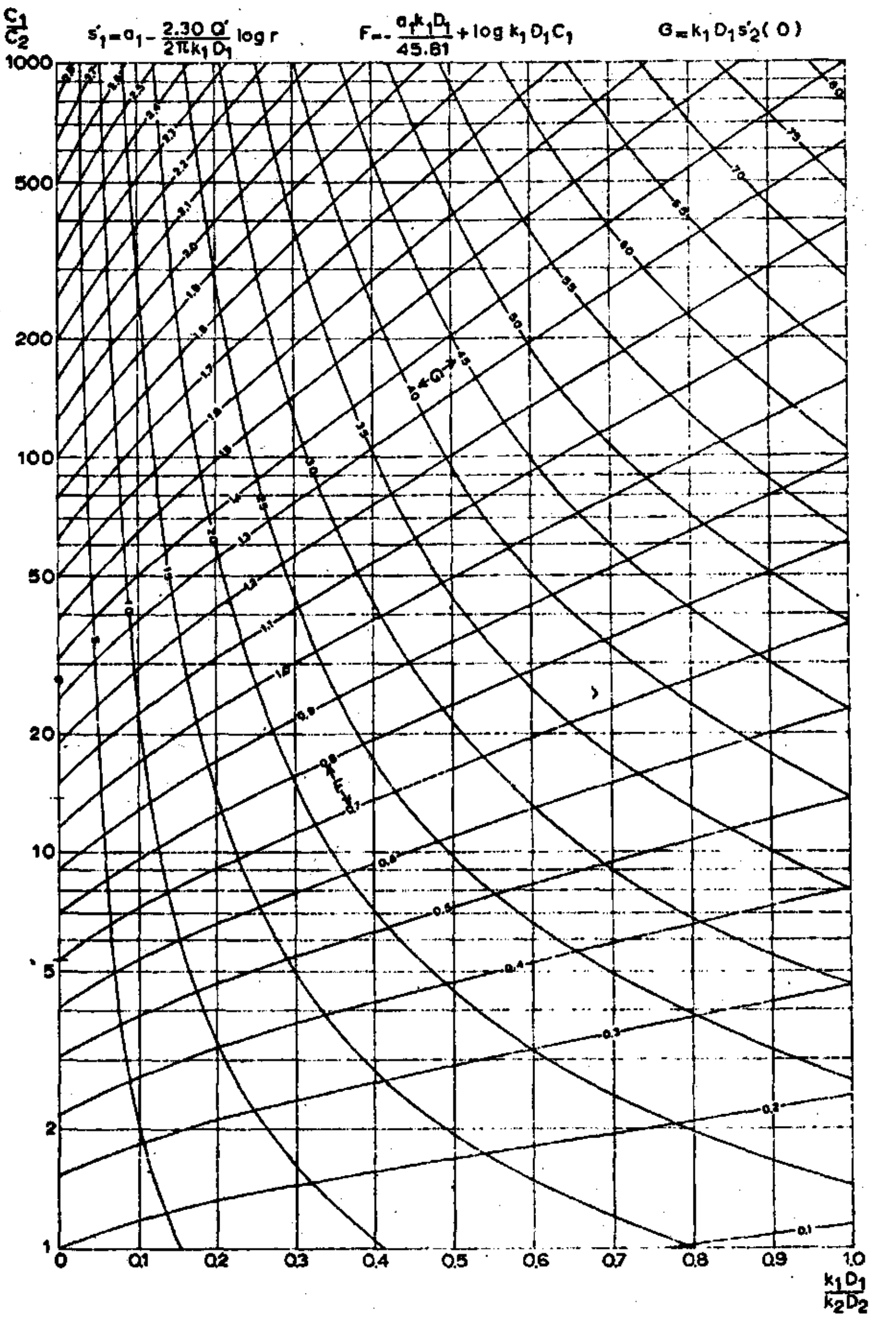


Fig. 10. Huisman-Kemperman's nomogram showing the relation between c_1/c_2 and k_1D_1/k_2D_2 for leaky aquifers separated by a semi-pervious layer with the overlying aquifer also covered by a semi-pervious layer

Next, with the help of the HUISMAN-KEMPERMAN monogram (fig. 10) and calculated ratio of k_1D_1 and k_2D_2 and calculated value of G, the corresponding values of F (a constant) and c_1/c_2 are read in the present case F = 0,7 and $\frac{c_1}{c_2}$ = 73.3 now substituting these values in the formula

$$F = -\frac{A_1k_1D_1}{45.81} + \log k_1D_1c_1 \qquad (8)$$

$$0.7 = -\frac{0.136 \times 2150}{45.81} + \log 2150 \times c_1$$

hence c_1 = 5570 days
c_2 = 147 days ($\frac{c_1}{c_2}$ = 37.3)

In the same way, different values for k_2D_2 are assumed and the corresponding values of c_1 and c_2 are calculated.

In the present the following results were obtained

	k_1D_1 (m^2/day)	k_2D_2 (m^2/day)	c_1(days)	c_2(days)
1 combination	2150	2150	5570	147
2 combination	2150	200	4860	159
3 combination	2150	1708	4080	163

Now, to see which combination is best, the municipal water works in Amsterdam (the Netherlands) has developed a computer programme by which with the known values of k_1D_1, k_2D_2 and distances, the corresponding values for drawdown are calculated.

For the present pumping test, the values observed with computer are given in table 2.

By comparing the results obtained by pumping test and those observed with a computer, the following results were found reasonably accurate:

k_1D_1 = 2150 m^2/day
k_2D_2 = 2000 m^2/day
c_1 = 4860 days
c_2 = 159 days

Table 2.

No.	k_1D_1 m^2/days	k_2D_2 m^2/days	c_1 days	c_2 days	Draw down in upper aquifer at					Draw down in lower aquifer at				
					15 m	45 m	135 m	300 m	500 m	15 m	45 m	135 m	300 m	500 m
I	2130	1708	4080	163	23.5	17.9	12.5	8.84	6.74	6.52	6.49	6.34	5.74	5.39
II	2130	2000	4850	159	23.4	17.9	12.25	8.80	6.73	6.29	6.27	6.14	5.77	5.28
III	2130	2130	5570	147	23.4	17.8	12.4	8.79	6.74	6.34	6.32	6.18	5.82	5.33
Observed draw down by pumping test					23.4	18.0	12.2			6.9	5.7	4.8		

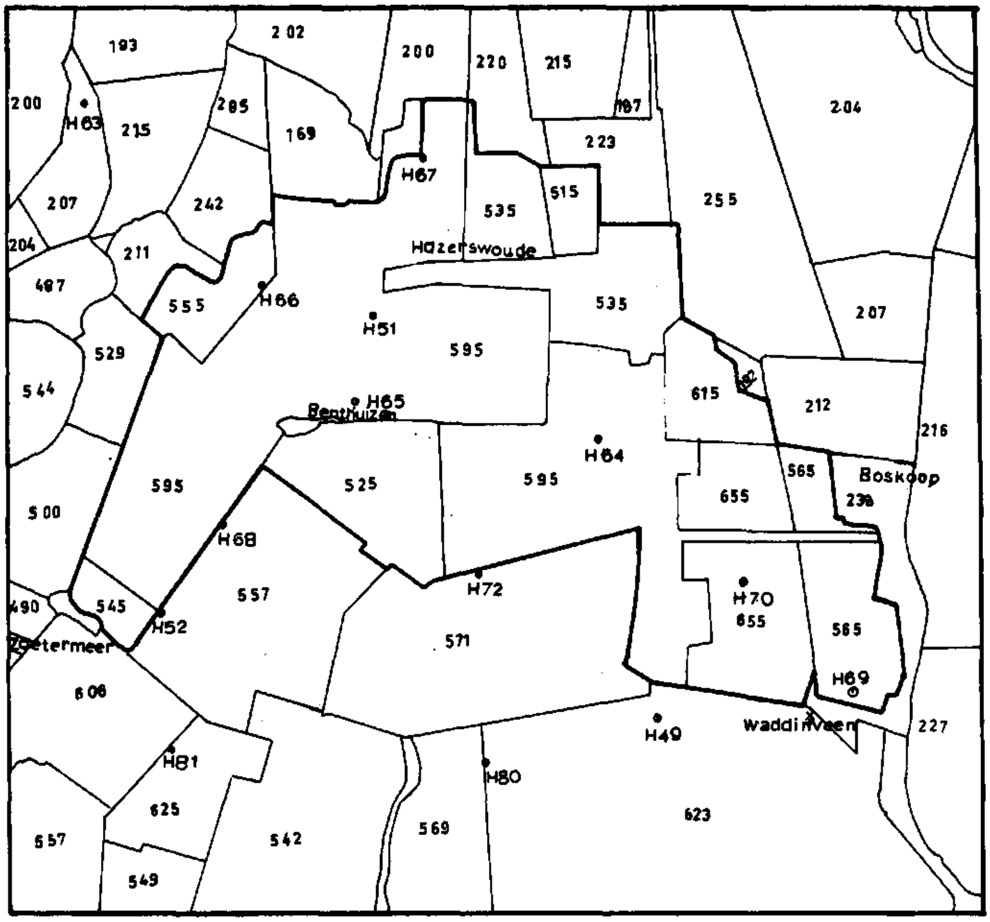


Fig 11 Contour map of the phreatic surface (average for 1971) in meter mean sea level

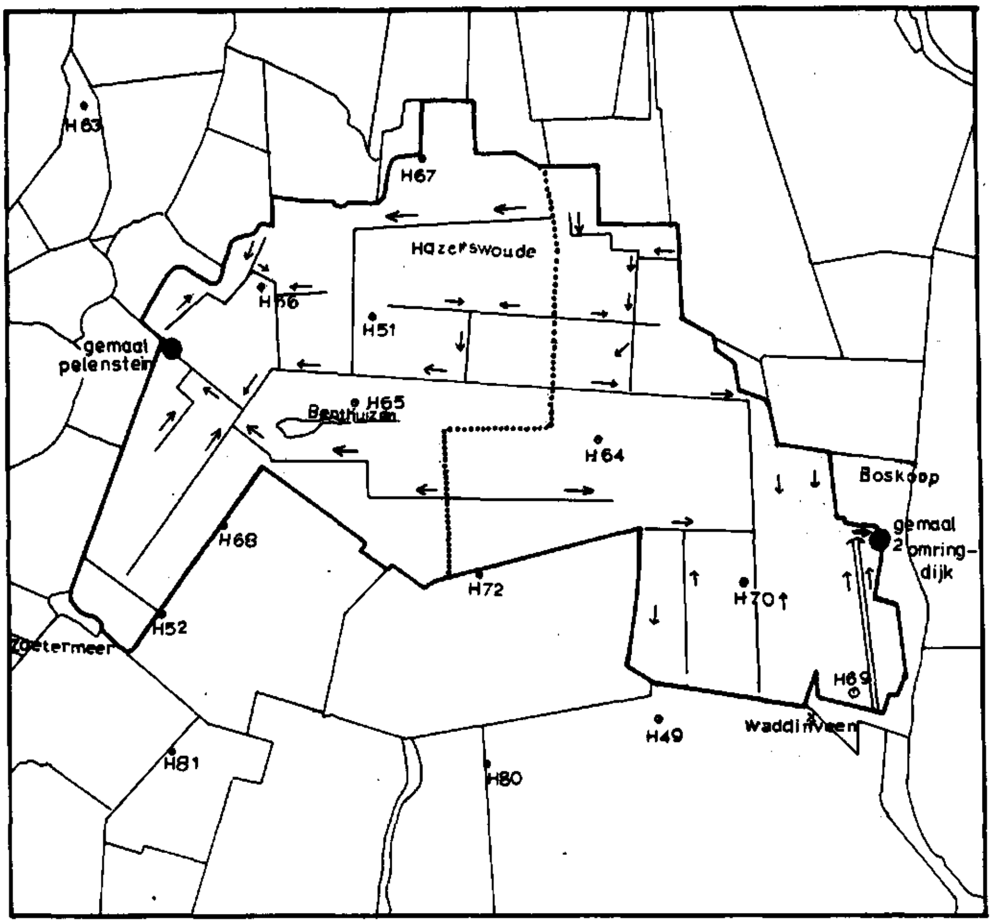


Fig 12 map showing flow of water during rain towards pumping station

If these results are compared with the results which have been calculated using other methods than HUISMAN-KEMPERMAN method the values are more or less similar.

The value of hydraulic resistance of semi pervious layer according to POMPER is 163 to 304 days

here, $\frac{1}{c} = \frac{1}{c_1} + \frac{1}{c_2}$ (9)

where c_1 = hydraulic resistance of upper semi pervious layer in days

c_2 = hydraulic resistance of lower semi pervious layer in days.

Substituting the values of c_1 and c_2 which have been calculated by using HUISMAN-KEMPERMAN method

$$\frac{1}{c} = \frac{1}{159} + \frac{1}{4860}$$

c = 154 days.

This value is more or less similar to the value, calculated by other methods.

GROUND-WATER LEVEL

General: Water level data are very important because it provides records of fluctuations of storage within ground water reservoirs. The direction of ground water flow can be detected from ground water elevation contour maps. The time-rate of change in ground-water storage predicts about the ground-water supply outlook for the future.

Phreatic level

A phreatic level contour map in the Noordplaspolder and its surrounding area has been prepared for the year 1971 and is shown in the fig. 11. Since the depth to the water level varies from place to place within the polder, no systematic pattern could be seen. There are two pumping stations in the polder (fig. 12). One pumping station is gemaal Palenstein at the western side of the polder and the other is gemaal Omringdijk in the east. How the surface water flows towards these pumping stations is shown in fig.12.

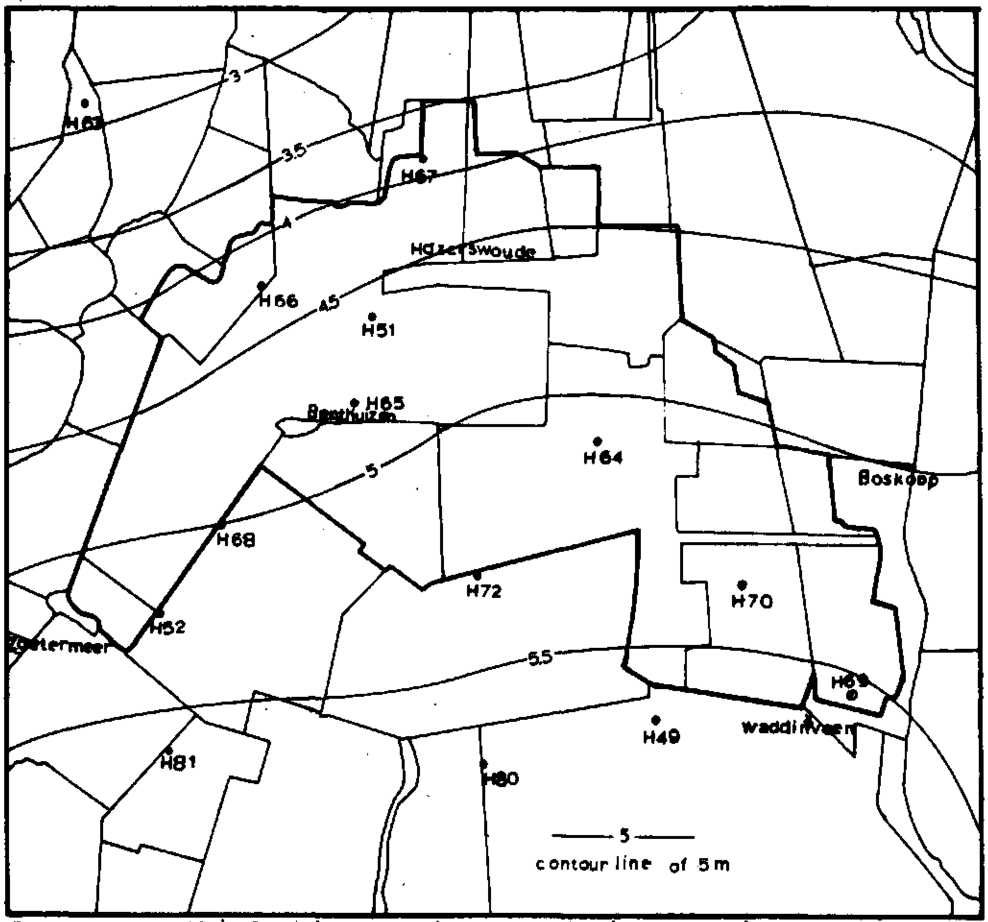


Fig 13 isoplezometric map of the upper aquifer (average 1971)

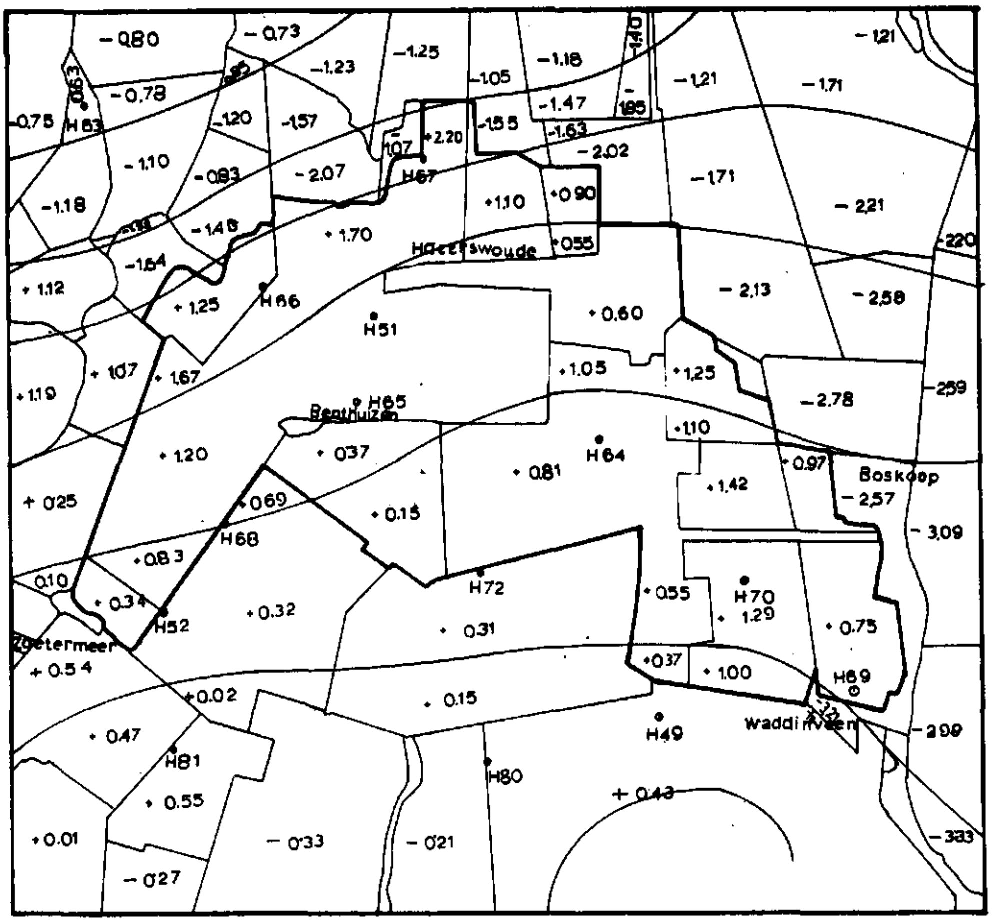


Fig 14 Contour map of the differences in potential between the mean phreatic level and the mean piezometric level of the upper aquifer (m)

Piezometric level

For preparing a contourmap of the Piezometric surface, the measured data were corrected to the large difference in salanity of the groundwater by using the below mentioned formula.

$$hr_o = Z - (Z - hr_1)r_1 \qquad (10)$$

where: hr_o = groundwater level - mean sea level
Z = median of the screen - mean sea level
hr_1 = measured ground level - mean sea level
r_1 = density of a water sample of the screen

The iso piezometric map of the upper aquifer is shown in the fig. 13 . From the map it can be observed that the flow of groundwater is mainly from the higher polder and borderland from the Oude Rijn and Gouwe to the Noordplaspolder. The hydraulic gradient varies from $\frac{1}{700}$ to $\frac{1}{5000}$ and more at some places. The horizontal flow intensity varies from 0.4 to 3.0 m^2/day in the upper aquifer.

Difference in the potentials between Phreatic and Piezometric level

A map showing difference in the potentials between shallow and deep level has been prepared and is shown in the fig. 14. It appears from the map that the difference in the potentials vary from 0.08 to 2.20 meter which indicates that the hydraulic resistance of the semipervious layer is relatively high, although variations in hydraulic resistance values are present due to variations in the lithology and permeability of the formation.

WATER BALANCE OF SURFACE WATER SYSTEM

The water balance is a quantitative statement of the balance between the total water gains and losses of a basin, for a period of time. Water entering a basin is equated to water leaving a basin, plus or minus changes in basin storage. When water level in open courses is lower than the water table elevation, ground water flows out into these basins (seepage). It may be expressed as below by an equation:

$$N = E + A - K \quad (11)$$

when N = Precipitation
E = Evapotranspiration
A = outflow
K = seepage

if precipitation, evapotranspiration and outflow are known, the seepage flow intensity be calculated.

S u r f a c e o u t f l o w d a t a (A)

There are two pumping stations in the area. The total amount of water pumped has been calculated by multiplying discharge of the pump with hours of pumping.

P r e c i p i t a t i o n (N)

The nearest rain gauge station is situated in Boskoop. So the precipitation data collected by KNMI (Royal Netherlands Meteo Institute) during the year 1971 have been used.

E v a p o t r a n s p i r a t i o n (E)

Direct measurement of evapotranspiration is difficult. Usually it is estimated from evaporation data from a free water surface. The potential evapotranspiration for the year 1971 has been estimated from data on evaporation from a free water surface collected by

KNMI at surrounding stations. These values have been multiplied by an empirical factor depending on the type of vegetation, on time and the character of the land surface.

The values for precipitation, evapotranspiration, surface-outflow are given in the table below.

Table 3.

Month	N (mm)	A (mm)	E_{vp} (mm)
Jan.	55.2	66.1	3.6
Feb.	45.4	65.0	10.8
March	40.0	42.1	31.5
April	18.5	23.8	50.4
May	42.6	21.5	92.0
June	96.2	30.7	89.6
July	45.8	19.6	103.2
Aug.	50.5	21.5	70.7
Sept.	22.5	19.5	46.9
Oct.	25.7	18.5	28.7
Nov.	86.5	36.5	12.0
Dec.	31.2	35.2	4.2
	560.1	400.1	543.6

$K = A + E - N$

$= 400.1 + 543.6 - 560.1$

$= 383.6$ mm/year

This value of seepage flow intensity is twice as much as the values calculated by WIT (1974). It may be possible that the value for the evapotranspiration is too high.

SEEPAGE FLOW ANALYSIS BY ORTHOGONAL GRID METHOD

For an orthogonal grid (fig. 15a) forming squares with side a , the seepage flow intensity v_z can be estimated by using the differential equation:

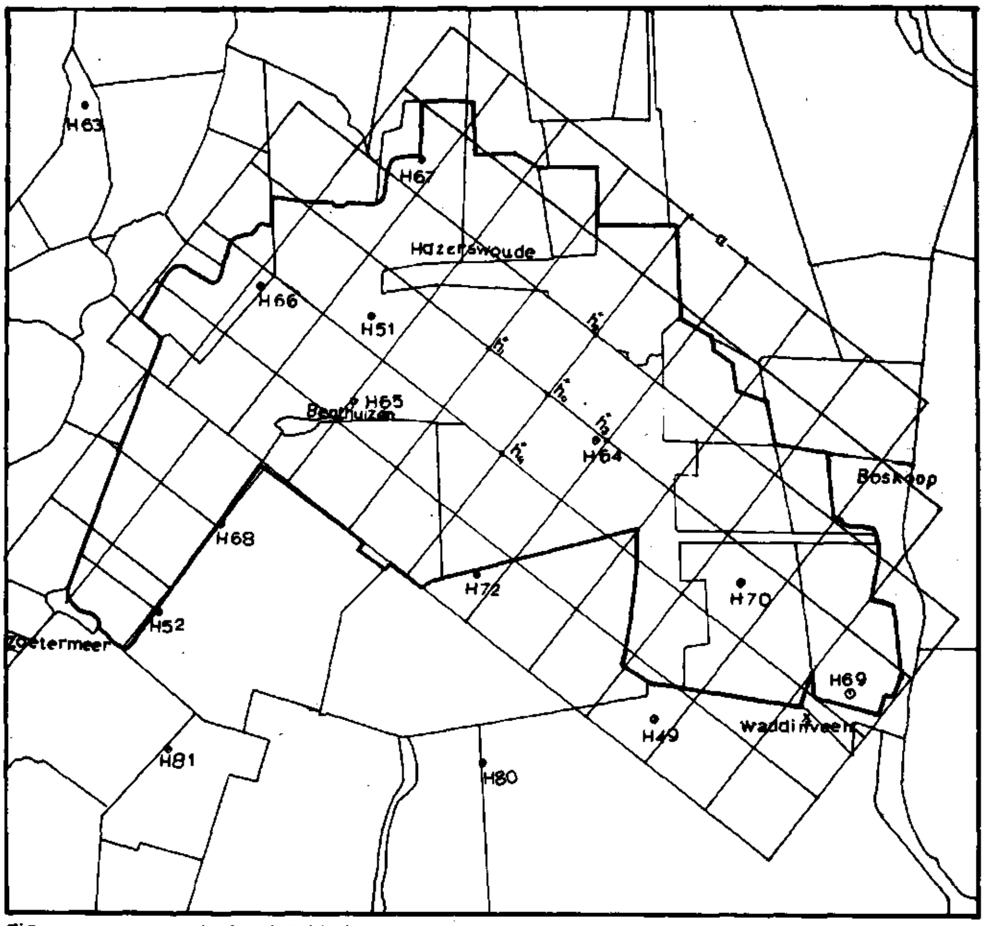


Fig 15a Orthogonal grid forming squars

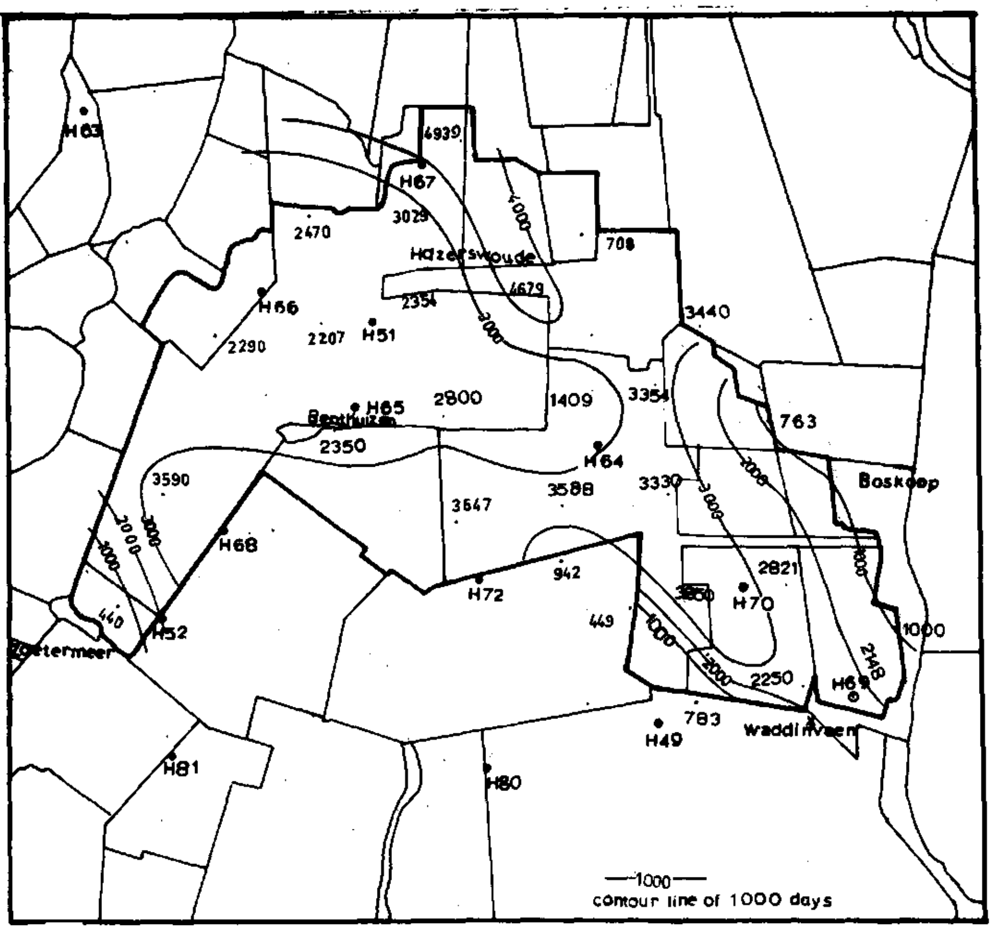


Fig 15 Contour map of the hydraulic resistance of the upper semi pervious layer

$$h_1'' + h_2'' + h_3'' + h_4'' - 4\ h_o'' = \frac{a^2}{k_1D_1c_1}\ (\alpha+1) \qquad (12)$$

$$v_z = \frac{h'_o - h_o''}{c_1} \qquad (13)$$

where: h_o'', h_1'', h_2'', h_3'' and h_4'' are piezometric levels in m for upper aquifer

$h_o' - h_o''$ = difference in the potential between phreatic and piezometric level

k_1D_1 = transmissivity of upper aquifer in m^2/day

α = $\frac{k_1D_2}{k_2D_2}$

k_2D_2 = transmissivity of lower aquifer in m^2/day

c = vertical resistance of the covering layers

Since the values of k_1D_1, k_2D_2 and phreatic and piezometric water level are known, v_z can be calculated.

A p p l i c a t i o n

The area is divided into equal squares having sides of 1000 meter . In order to have piezometric level elevation at each nodal point, the grid is superimposed on the piezometric water level contour map (1971) and values are noted at each nodal point. In the same manner the grid is superimposed on the phreatic level contour map (1971) and for each nodal point corresponding values of phreatic level are noted. After getting these values, v_z is calculated by substituting these values in the formula (11) and (12). All these values are tabulated in the table 4.

On the basis of these values contour maps for seepage and for hydraulic resistance are produced which are shown in figs. 24 and 25. The average seepage flow intensity was found about 0.512 mm/day, which is in the same order of magnitude of the value of WIT (1974).

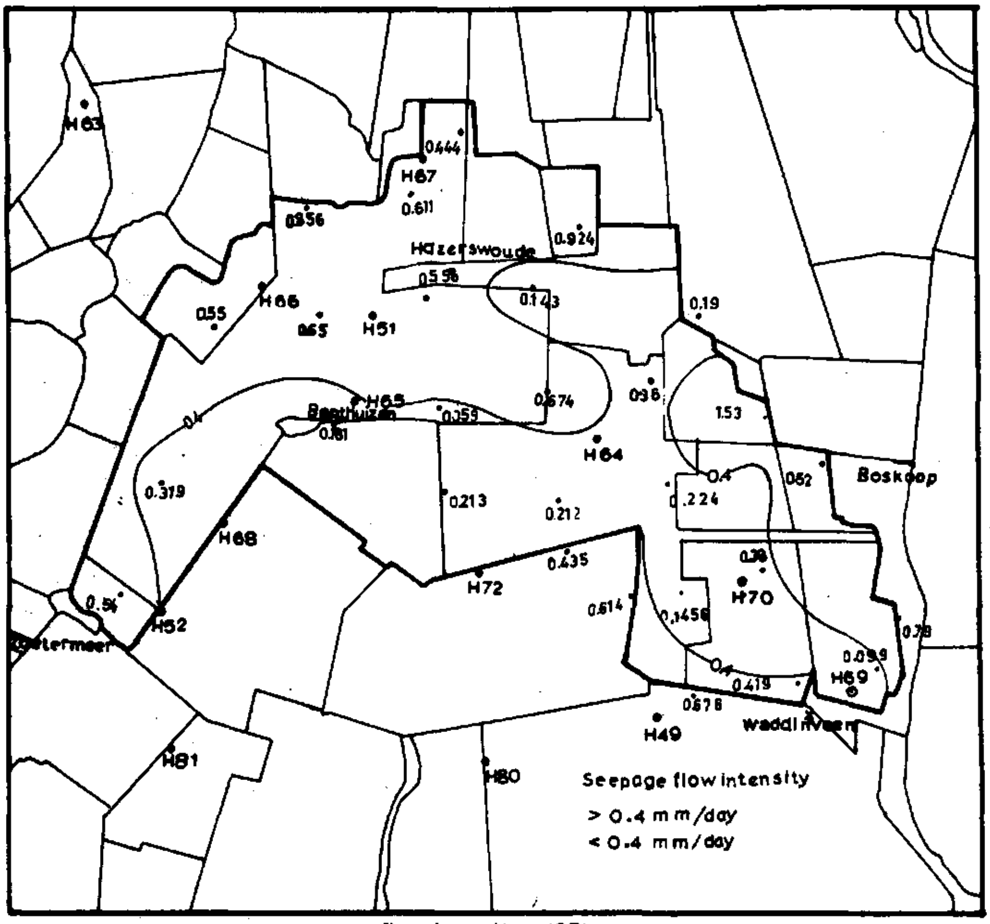


Fig 16 Contour map of seepage flow intensity, 1971

	h_1'' m	h_2'' m	h_3'' m	h_4'' m	h_o'' m	h_o' m	$h_o'-h_o'$ m	a m	K_1D_1 m^2/days	α	c_1 days	Vz mm/days
A	3.400	3.445	4.190	4.100	3.757	5.950	2.193	1000	2150	1.9302	4938	0.4441
B	4.190	4.1875	4.644	4.6704	4.500	5.400	0.9	"	"	"	703	0.924
C	4.6444	4.585	4.858	4.955	4.800	5.350	0.55	"	"	"	3440	0.170
D	3.440	3.647	4.3488	4.1521	3.9545	5.950	1.990	"	"	"	2470	0.8056
E	4.3488	4.500	4.829	4.7329	4.6363	5.95	1.314	"	"	"	2354	0.5581
F	4.829	4.8181	5.0882	5.0845	5.000	5.950	0.95	"	"	"	1409	0.674
G	5.0927	5.04166	5.3225	5.3225	5.1916	5.950	0.7604	"	"	"	3330	0.228
H	5.2541	5.1661	5.3879	5.4829	5.330	6.550	1.2175	"	"	"	2820	0.4306
I	3.9054	4.1489	4.6190	4.4706	4.3191	5.550	1.2309	"	"	"	2238	0.550
J	4.6190	4.7329	5.02678	4.950	4.8255	5.250	0.4245	"	"	"	2349	0.180
K	5.0288	5.100	5.333	5.2946	5.172	5.950	0.778	"	"	"	3647	0.2131
L	5.500	5.467	5.800	5.870	5.700	6.230	0.53	"	"	"	781.5	0.6764
M	4.5322	4.6558	5.017	5.000	4.803	5.950	1.147	"	"	"	3589	0.3195
A_1	3.647	3.757	4.5	4.3488	4.10	5.950	1.85	"	"	"	3028	0.6109
B_1	4.5	4.500	4.8181	4.829	4.6704	5.350	0.67	"	"	"	4679	0.143
C_1	4.8181	4.750	5.0328	5.0882	4.945	5.950	1.120				3355	0.3606
E_1	4.1521	4.3488	4.7329	4.6190	4.5027	5.950	1.4473				2207	0.6557
AA_1	4.7329	4.829	5.0952	5.0263	4.9443	5.95	1.00569				2799	0.3593
G_1	5.0045	5.0882	5.2985	5.2777	5.200	5.950	0.75	"	"	"	3538	0.2119
H_1	5.2985	5.25	5.4666	5.505	5.3888	5.950	0.5612				3852	0.1456
I_1	5.4824	5.3877	5.600	5.8125	5.5025	6.550	1.0435				2252	0.4656
a	4.9322	4.890	5.021	5.066	5.00	6.150	1.15	500	"	"	763	1.51
b	5.021	4.9622	5.071	5.100	5.048	5.650	0.62	"	"	"	1195	0.518
d	5.272	5.226	5.321	5.962	5.285	5.650	0.366	"	"	"	1000	0.748
e	5.435	5.362	5.443	5.50	5.436	5.65	0.214	"	"	"	2148	0.099
f	5.355	5.346	5.452	5.450	5.410	5.71	0.31	"	"	"	488	0.614
g	5.2328	5.246	5.355	5.34	5.300	5.71	0.41				942	0.435
h	5.0857	5.09	5.29	5.30	5.2	5.45	0.25	"	"	"	440	0.568

CHEMICAL CHARACTERISTICS OF GROUNDWATER

Chemical characteristics of the groundwater are of a special significance because they determines the usefulness of groundwater for municipal, industrial and agricultural watersupply. In the present study, the relationship of surface water to groundwater is important.

From the salts being solved in sea-water sodium chloride is most predominant. From all ions in seawater 30% is sodium (Na^+) and 55% is chloride (CI^-).

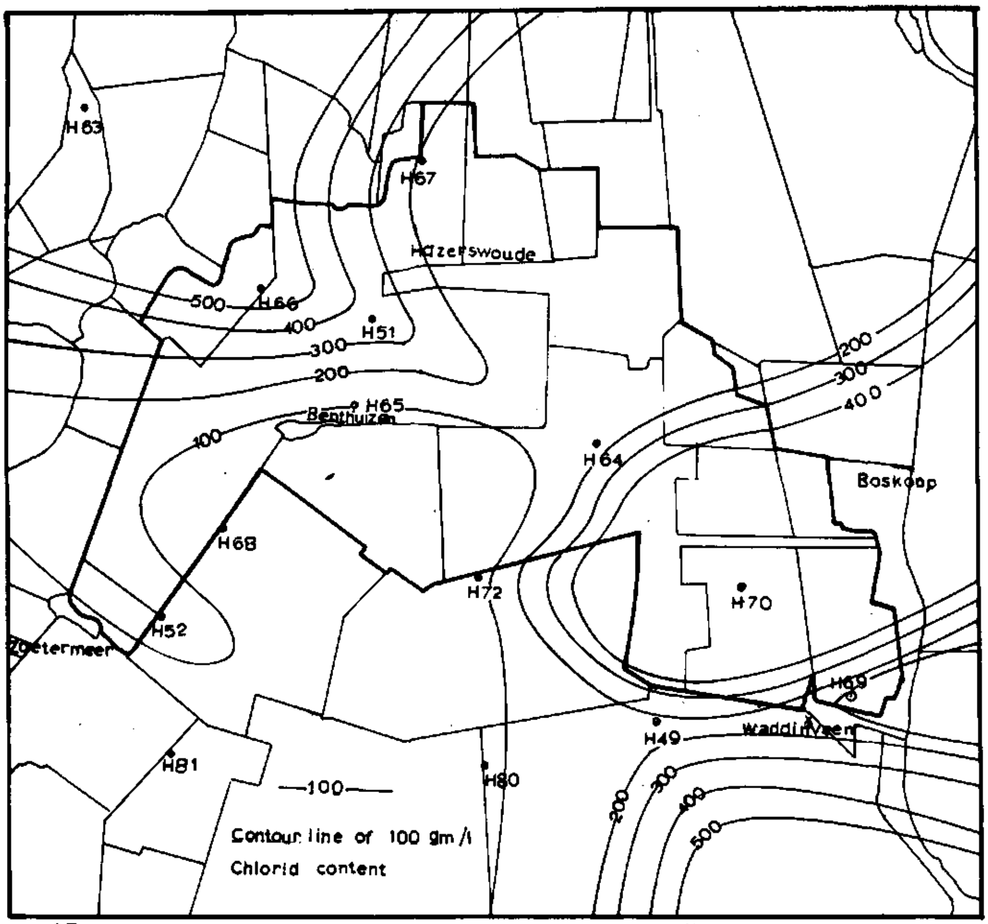


Fig. 17 Isochlor map of the ground water between 5-15 meter NAP

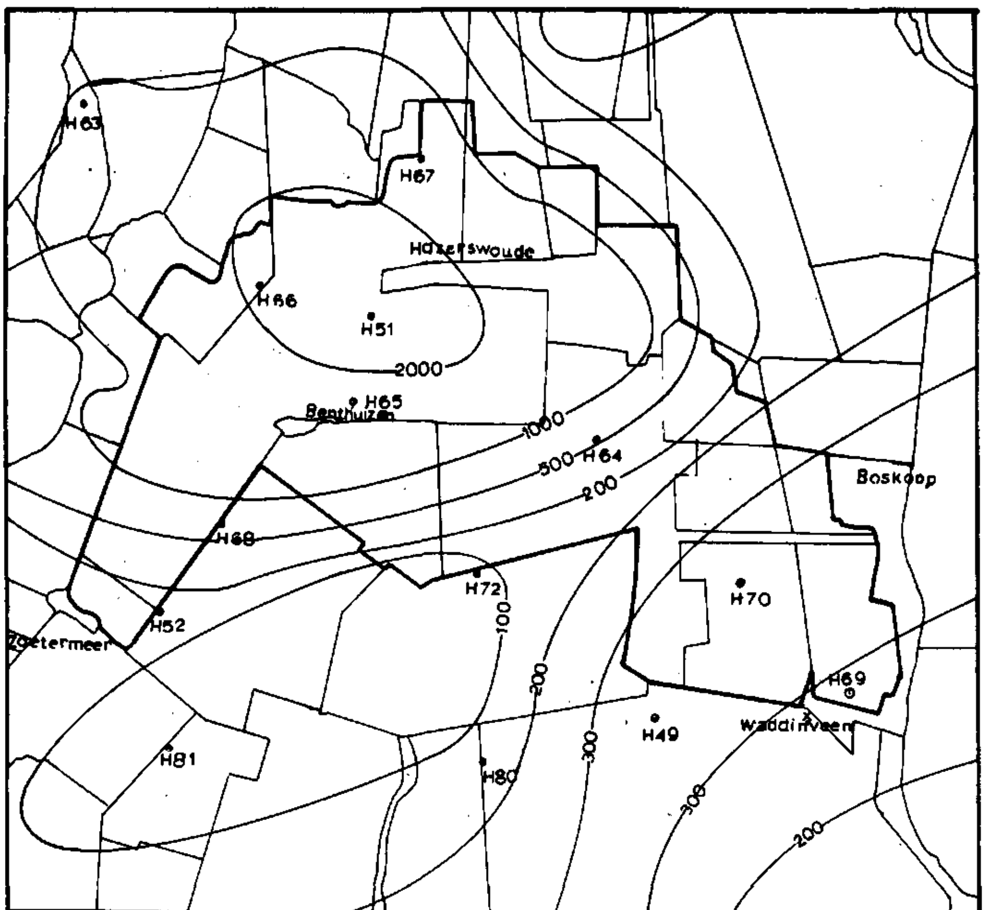


Fig 18 Isochlor map of the ground water between 15-25 meter NAP

—1000—
contour line of 1000 Cl^- (mg/l)

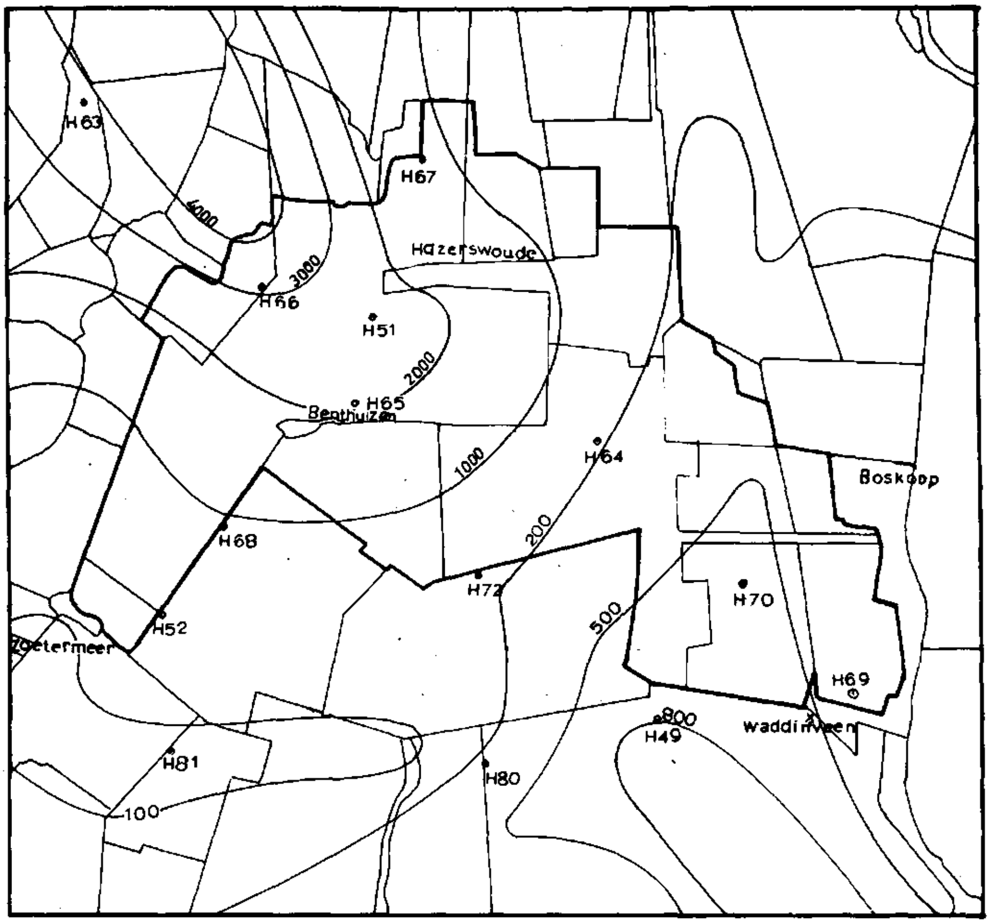


Fig 19 Isochlor map of the ground water at a depth between 25-35 m NAP

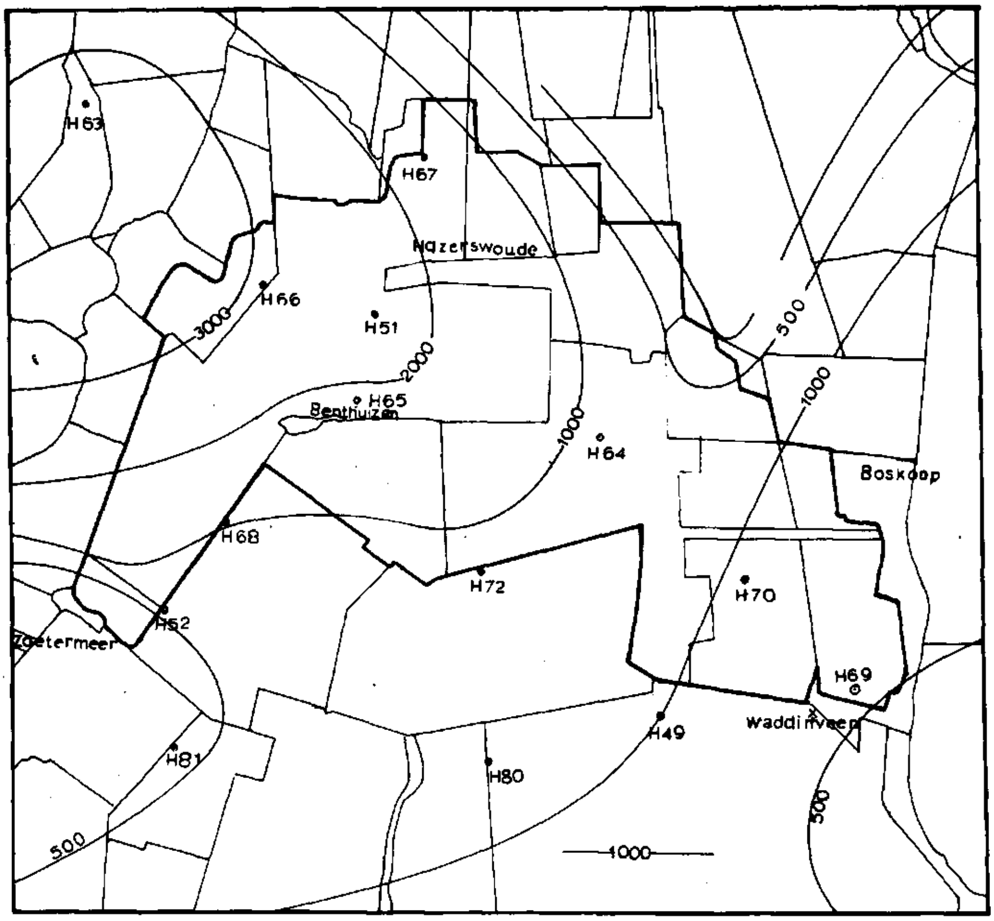


Fig 20 Isochlor map of the ground water at the depth between 35-45 m NAP

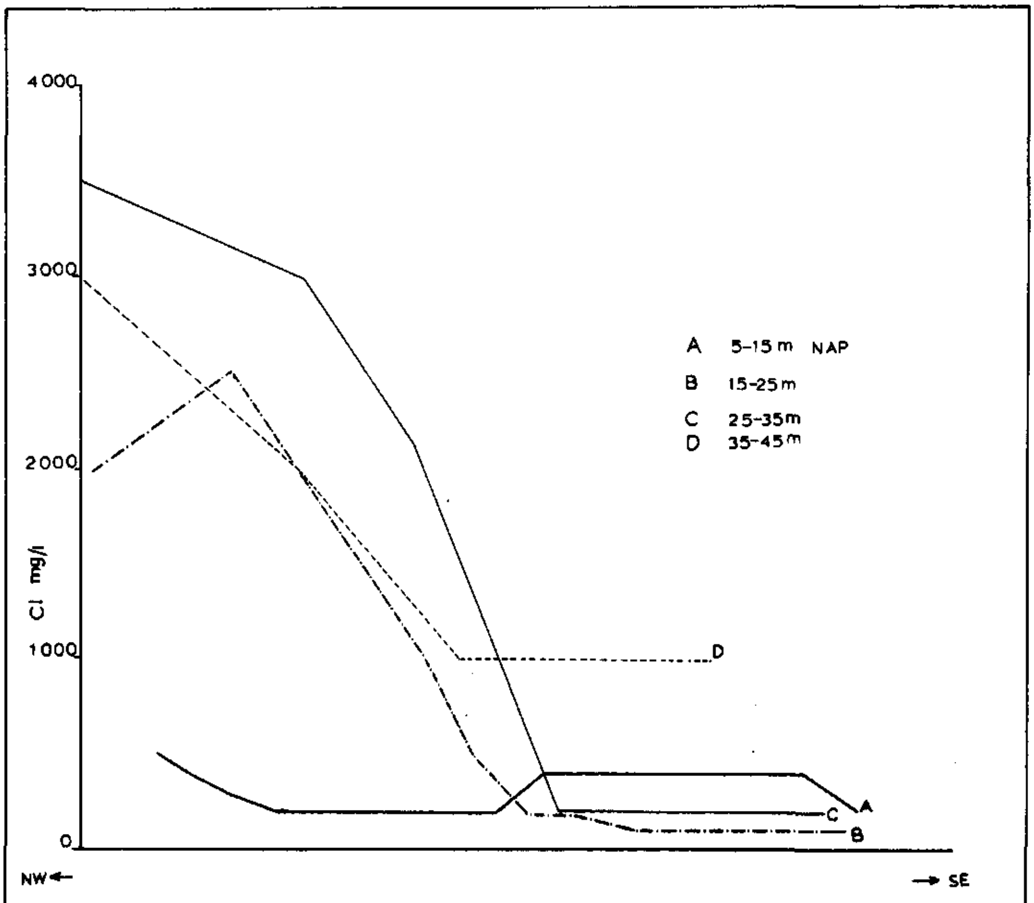


Fig. 21 Variation of Chloride of the ground water with depth

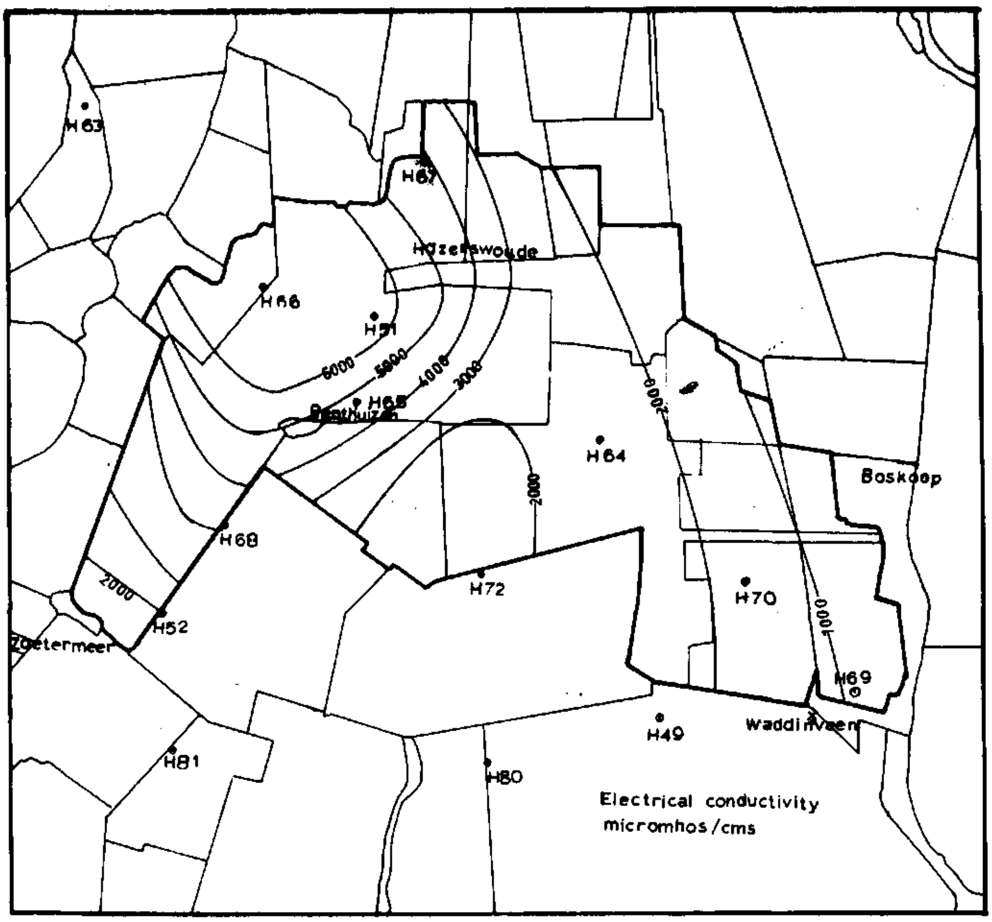


Fig 22 Electrical conductivity of the ground water

In the subsoil of coastal area salt water is often found at shallow depth. Mostly the concentration increases with the depth. The ratio of the ions in groundwater is different from that of sea-water. Mostly salt groundwater is not as salt as seawater; often not more than half of it is due to the mixing in the underground of infiltrated precipitation- and river-water with seawater.

Most ions take part of chemical processes in the subsoil. The result is great variances in concentrations of most of the ions. The only ion that has almost no chemical activity is chloride. Variances in the concentrations of this ion are due to ge-hydrological processes. The result is that it is excellently fit to be used as a 'guide-ion'.

CHLORIDE

High concentrations of chloride in groundwater may cause heavy agricultural damages particularly so in horticulture.

To have a clear idea about the variations of the chloride-concentrations in the polder at several depths, 4 isochlormaps have been compiled from data in the ICW-archive 5 - 15 m-datum level (fig. 17), 15 - 25 m-datum level (fig. 18), 25 - 35 m-datum level (fig. 19) and 35 - 45 m-datum level (fig. 20). It can be observed that the highest concentrations of chloride are found in the north western part of the polder (fig. 21). The explanation for this may be that in this part of the polder the heaviest seepage is found. Unless the high concentrations of chloride at shallow depths in this region there are not much agricultural damages. The reason is that in the root-zone of the cropfields there is a thin layer of fresh water, build up in wintertime by the infiltrating precipitation-water. In the crop growing season this layer may be completely evaporated and consumed by plants but it is mostly sufficient.

Horticulture is very difficult to carry out in this polder because in Holland it is the use to have much sprinkling of the

	h_1'' m	h_2'' m	h_3'' m	h_4'' m	h_o'' m	h_o' m	$h_o'-h_o'$ m	a m	K_1D_1 m^2/days	α	c_1 days	Vz mm/days
A	3.400	3.445	4.190	4.100	3.757	5.950	2.193	1000	2150	1.9302	4938	0.4441
B	4.190	4.1875	4.644	4.6704	4.500	5.400	0.9	"	"	"	703	0.924
C	4.6444	4.585	4.858	4.955	4.800	5.350	0.55	"	"	"	3440	0.170
D	3.440	3.647	4.3488	4.1521	3.9545	5.950	1.990	"	"	"	2470	0.8056
E	4.3488	4.500	4.829	4.7329	4.6363	5.95	1.314	"	"	"	2354	0.5581
F	4.829	4.8181	5.0882	5.0845	5.000	5.950	0.95	"	"	"	1409	0.674
G	5.0927	5.04166	5.3225	5.3225	5.1916	5.950	0.7604	"	"	"	3330	0.228
H	5.2541	5.1661	5.3879	5.4829	5.330	6.550	1.2375	"	"	"	2820	0.4386
I	3.9054	4.1489	4.6190	4.4706	4.3191	5.550	1.2309	"	"	"	2238	0.550
J	4.6190	4.7329	5.02678	4.950	4.8255	5.250	0.4245	"	"	"	2349	0.180
K	5.0288	5.100	5.333	5.2946	5.172	5.950	0.778	"	"	"	3647	0.2131
L	5.500	5.467	5.800	5.870	5.700	6.230	0.53	"	"	"	783.5	0.6764
M	4.5322	4.6558	5.017	5.000	4.803	5.950	1.147	"	"	"	3589	0.3195
A_1	3.647	3.757	4.5	4.3488	4.10	5.950	1.85	"	"	"	3028	0.6109
B_1	4.5	4.500	4.8181	4.829	4.6704	5.350	0.67	"	"	"	4679	0.143
C_1	4.8181	4.750	5.0328	5.0882	4.945	5.950	1.120				3355	0.3606
E_1	4.1521	4.3488	4.7329	4.6190	4.5027	5.950	1.4473				2207	0.6557
AA	4.7329	4.829	5.0952	5.0263	4.9443	5.95	1.00569				2799	0.3593
G_1	5.0845	5.0882	5.2985	5.2777	5.200	5.950	0.75	"	"	"	3538	0.2119
H_1	5.2985	5.25	5.4666	5.505	5.3888	5.950	0.5612				3852	0.1456
I_1	5.4824	5.3877	5.600	5.8125	5.5025	6.550	1.0435				2252	0.4656
a	4.9322	4.890	5.021	5.066	5.00	6.150	1.15	500	"	"	763	1.53
b	5.021	4.9622	5.071	5.100	5.048	5.650	0.62	"	"	"	1195	0.518
d	5.272	5.226	5.321	5.362	5.285	5.650	0.366	"	"	"	1000	0.748
e	5.435	5.362	5.443	5.50	5.436	5.65	0.214	"	"	"	2148	0.099
f	5.355	5.346	5.452	5.450	5.410	5.71	0.31	"	"	"	488	0.614
g	5.2328	5.246	5.355	5.34	5.300	5.71	0.41				942	0.435
h	5.0857	5.09	5.29	5.30	5.2	5.45	0.25	"	"	"	440	0.568

cropfields and hot-houses in horticulture. The water for this sprinkling is mostly obtained from the ditches or sometimes from wells. The high concentrations of chloride in the open water and the groundwater makes it impossible.

These high concentrations also result in high values for the electrical conductivity of groundwater. Fig. 20 gives the values in contours, constructed from the data in the ICW-archive at depths of about 30 m-datum level.

OTHER IONS

As mentioned in the former chapter the percentage of other ions but chloride is low. The most important of these ions are sulphate, hydrocarbonates, calcium and iron.

Sulphate: The sulphate-concentration decreases with the depth, which is demonstrated with the following values:

Depth range (m)	SO_4 (mg/l)	Boring hole no.
31.5 - 32.5	28	
52 - 53	7.8	H81
30 - 31	36	
56 - 51	13.6	H80
27 - 28	18	
55 - 56	10	H71

The decrease of the sulphate-concentration can be explained by the fact that sulphate in groundwater comes into being by leaching of the Holocene toplayers.

Further, reduction of sulphate to sulphide takes place when the redox potential of the groundwater is sufficiently low. Such low redox potentials can be expected in those areas where the water bearing layers are rich in organic material and the water is poor in oxygen.

The presence of organic material in the water bearing formation of the Noordplaspolder gives support to this phenomenon.

Iron: the iron content of the groundwater varies from 3,4 to 32,4 mg/l (fig. 24). The maximum concentration was found near Benthuizen, the lowest near Hazerswoude. It is noticed that high iron-contents are related to low sulphate contents and vice versa.

Hardness: the concentration of calcium and hydrocarbonates is generally expressed in the hardness with German degrees (^{o}D). Soft water has a hardness of less than 8^{o}D, medium 8 - 16^{o}D and hard water more than 16^{o}D.

Almost everywhere in the western Netherlands very hard water is found. Fig. 25 gives the values for the Drooggemaakte Noordplas. The values vary between 20^{o}D near Boskoop and 80^{o}D West of Hazerswoude. Hard water is especially unusable for horticulture.

C o n c l u s i o n: The quality of groundwater in the polder is very bad and it is unusable for many agricultural and non-agricultural purposes. Because of the rather high seepage the influence of the groundwaterquality on the surface water - especially in dry periods - is high. The influence of this has not only importance for the activities in the polder itself but moreover in the canals where the surplus of water is drained into.

SUMMARY AND CONCLUSIONS

The hydrogeological investigations in the Noordplaspolder reveals that there are two semi-confined aquifers which are seperated by semi-pervious layers and covered by a semi-pervious covering layer. The base is formed by the lower pleistocene (marine Icenian), and the top by the Holocene clay, and peat deposits. The upper aquifer contains coarse to medium fine sand with gravel of marine and fluviatile origine and the lower aquifer contains fine sands with clay- and silt-layers and coarse sand at the bottom. The ground water quality at a depth between 5 - 15 meter NAP is rather bad and with the increasing depth the concentration of chloride and

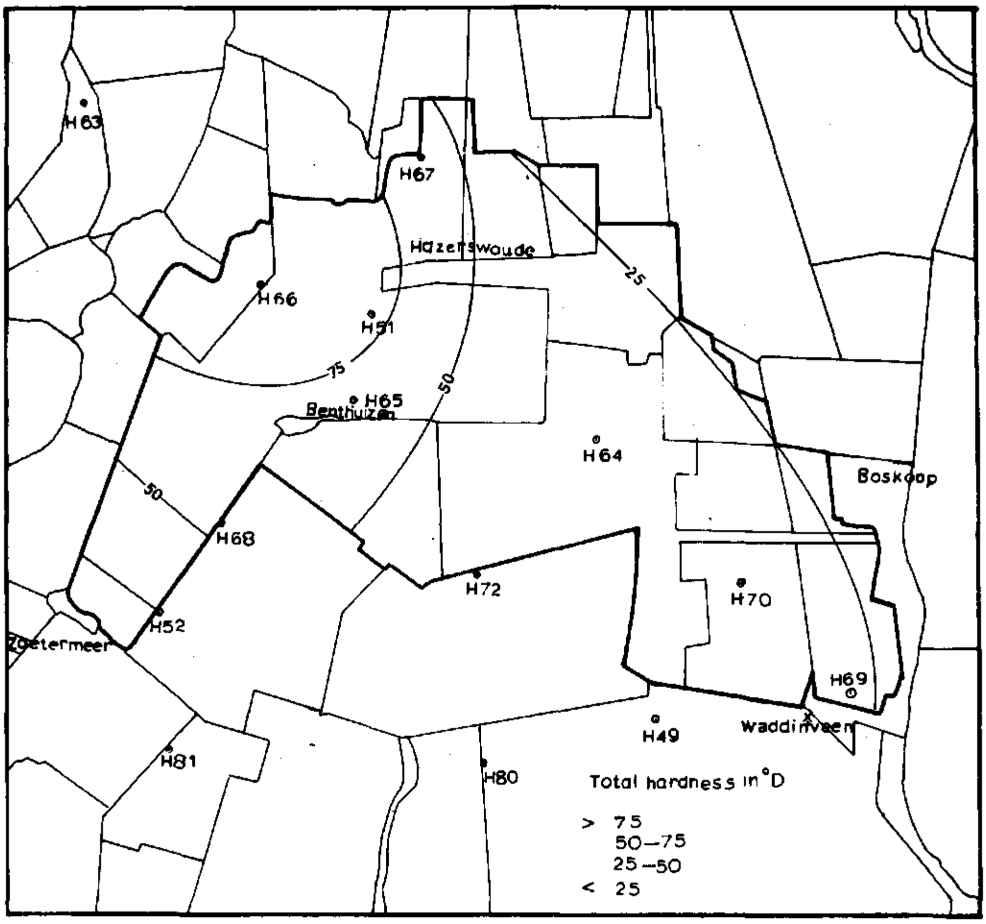


Fig 23 Hardness (in German degrees)

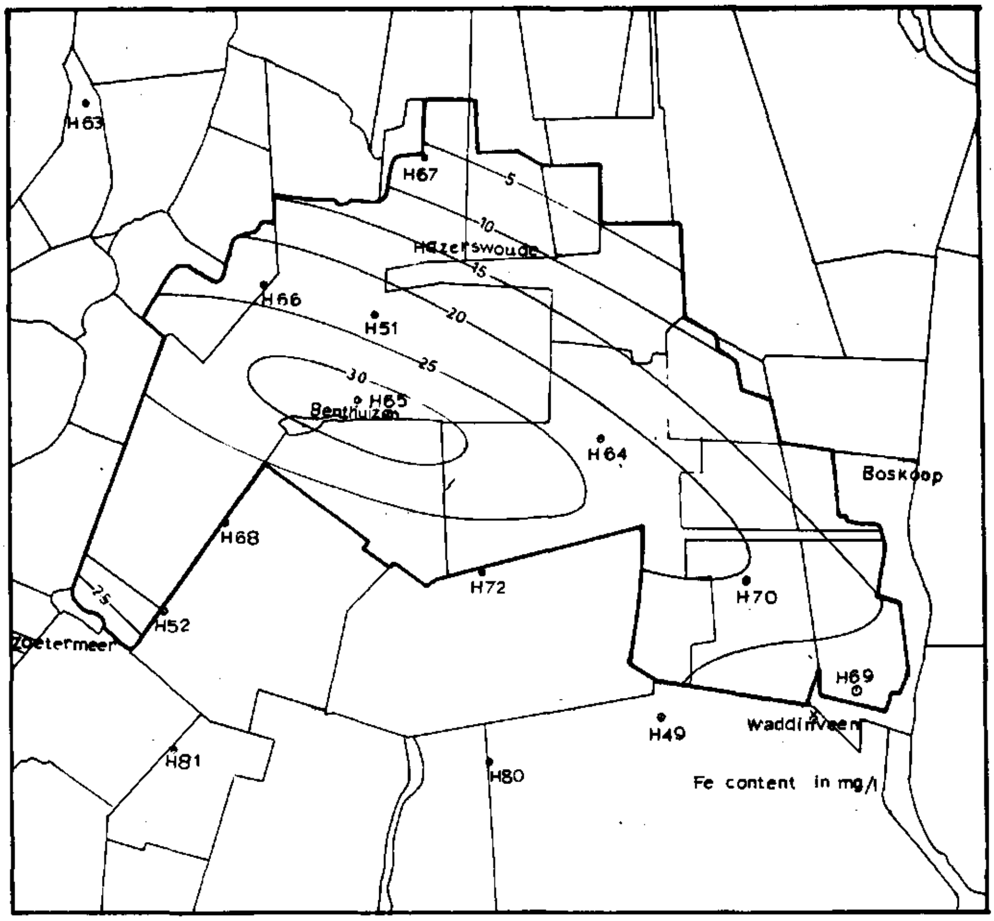


Fig 24 Contour map of iron content of ground water

other some minerals increases, particularly in western part of the polder. The ground water flow is horizontal and is low about 0.4 to 3.00 m^2/day in the upper aquifer. The HUISMAN-KEMPERMAN method which has been applied for analysing the pumping test data, gives solutions of sufficient accuracy.

In the western part of the polder, seepage flow intensity is more than in eastern part and it varies from 0.10 to 1.50 mm/day. It seems that leaving few parts of the polder the average seepage is not much(average seepage flow intensity about 0.50 mm/day).

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