THE ROTTERDAM WATERWAY CONSIDERED AS A RIVERMOUTH.

By Dr Ir J. van VEEN

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(see De Ingenieur No.28,1952)

When Caland put forward his scheme for digging a Waterway through to the Hook of Holland, the Northerly branch of the mouths of the Rhine was only a remnant of a former more extensive mouth. In order to determine the boundaries of that old sea mouth boring operations were carried out, and it was found that the extent of a peat bog of depth varying from 1-3 m. gave a good indication (see fig.1). Voorne-Putten showed an almost continuous layer of peat, in the Westland there had been a large tidal creek reaching as far as the centre of the South Holland peat area in a curve. Delft and Naaldwijk were built upon this creek after it had silted up.

The route of the Old Maas was along the line Oud-Beyerland, Westmaas, Maasdam and 's-Gravendeel, coming from eastwards through the island of Dordrecht, During the Roman era, or slightly later, the Old Helinium, between Brielle and Maassluis, had been about 4 km wide. i.e. a mouth as wide as the Haringvliet is now. The Helinium was the meeting point of the Maas, Waal, "Merwede", Hollandse IJssel, Strieme and Bernisse. The creek to Delft had already silted up before the Roman era, as had those near Maassluis.

Incidentally, mention may be made here that horticulture in the Westland is only possible on the siltation in these old creeks. "De Stichting voor Bodemkartering" has recently produced accurate maps of this area.

Evidence that the Haringvliet is comparatively new is that Goeree was originally known as Westvoorne. Also the North-South direction of the Bernisse separating Voorne and Putten shows this. The Haringvliet, formed by the breaking of the old dunes of Voorne joined with the Rhine and the Maas later.

The old mouth of the Maas then silted up, and a new river, the Spui, was formed which ran almost due East-West across the Bernisse towards the Haringvliet. This disturbed the tides in the Bernisse, which now almost completely silted up. Later a similar situation arose when the Kil, running North-South, was formed cutting across the Old Maas. The Haringvliet-Hollandsch Diep gradually took over the function of the Old Helinium, which filled with sand. This became more pronounced after 1421, following the formation of the "Killen" between Dordrecht and Werkendam by the St.Elizabeth's flood.

In the course of time, nature would have formed a ridge of dunes across the sea-mouth near Brielle, because the Haringvliet has the advantage of a more Southerly location, and the tidal wave comes from the South. This is easily seen by reference to fig.2. The difference in tides between A (Haringvliet) and B (Brielle is 1 hour, the amplitudes practically being the same. At C (e.g. Dordrecht) the tide is 3 hours later than at A. Considering water levels on the ebb tide, it follows that ac > bc, i.e. when AC ≏ BC, the difference in level on the Southern route (AC) is much greater than on the Northern route (BC). Therefore there is a stronger ebb stream on the Southern route. The same applies to the flood i.e. a'c' > b' c'. Thus greater flood velocities are experienced on the Southern route. Although this principle is very simple, it accurately represents the situation, and calculations may readily be made accordingly. Tidal rivers tend to run and form their mouths in the direction from which the tidal waves starts.

If the siltation of the Old Helinium had been as complete as that of the mouth of the Old Rhine near Katwijk, (which appears from the results of borings to have been about 3 km wide,(see fig.3) then the basin near Rotterdam-Krimpen (i.e. the Nieuwe Maas, Lek, Hollandse IJssel) would have been filled and drained by the Noord-Kil and the Spui. This could not have taken place immediately, however, as in 1870, 450 years after the St. Elizabeth's flood, a gap was still in existence near Oostvoorne. To close it would then have still taken several centuries.

The mouth of the Maas would have gone the same way as that of the Rhine near Katwijk, and if this occurred the same kind of difficulties would have arisen as those confronting the people of the early middle ages at the mouth of the Rhine. These difficulties were responsible for the formation of the "Waterschap Rijnland" in 1286. The gap at Brielle would have closed around 2100, making the coast as smooth and flat as it is now at Katwijk. The Voorne canal would then become one of the most important drains of South Holland.

Caland, although primarily considering the interest of shipping, avoided this drastic modification to the drainage of South-Holland. He revived the mouth of the Old Maas, which improved the drainage. On the other hand, the increased penetration of salt water inland had a detrimental effect on horticulture and agriculture. But horticulture in the Westland was also benefited, because shipping of their products to England became easily possible. Otherwise, shipping of Westland products would have to be carried out via Scheveningen or Hellevoetsluis, or from a special and therefore expensive harbour. As a result of Caland's scheme, the daily low-water level on the rivers above Maassluis dropped, and therefore water level control in the ditches of Rijnland, IJsselmonde and Schiedam could be improved both economically and in efficiency.

Summing up, therefore, the agricultural and horticultural produce, apart from increased salinity, was benefited considerably.

Not only the Northern branch, but the whole system of the tidal rivers was influenced by Caland's work. The amount of Rhine water passing through at the Hook was greatly increased and is now rated at about 42 %, this being nearly as much as the Rhine water flowing in the Haringvliet (48 %)

The remaining 10 % passes through the IJssel into the

IJsselmeer. The function of the Northern route as a passage for Rhine water has thus been partially restored.

The width of the Waterway cannot be compared with that of the Haringvliet, but nevertheless about seven times the quantity of water passes per unit width. This does not imply that the depth of the Waterway is so much greater than that of the Haringvliet, but that the Waterway provides an easy passage for the water of the Rhine.

Fig.4 gives a graphic illustration of the distribution of the water flow in normal existing circumstances.

Fig.5 shows that the Waterway plays a big part in the escape of the Rhine water by shouwing the distance travelled per day by the water. With normal flow, water moves from Krimpen a/d Lek to the Hook in 4 days, i.e. a velocity of 13 km/day. On the Haringvliet west of Tien Gemeten the rate is ± 6 km/day. With large discharge quantity at Lobit, (10.000 m3/sec) and large quantities from the Maas, the velocity of flow on the Waterway is about 2.3 km/hr and on the Haringvliet about 1 km/hr. For a minimum quantity at Lobit of 592 m3/sec, the flow velocity on the Waterway still reaches 7 km/day, but on the Haringvliet only 0.5 km/day. From these figures it would seem to be possible to estimate a salting-coefficient for each river, reasoning that, for instance, owing to the small average daily velocity of the fresh water in the Haringvliet, considerable mixing of salt - and fresh water takes place. Not much of the water can still be termed " fresh " after needing 97 days to travel from Moerdijk to Zwarte Hoek of Voorne.

The flood in the Haringvliet is about 18,000 m/tide and the ebb about 18,500 m for minimum quantities (592 m3/sec). Thus the difference between ebb and flow is so comparatively small that considerable mixing must have taken place in the Haringvliet. The ebb as wel as flood are in some part of the cross-section predominant, and this, together with the flow turbulence, gives rise to the mixing.

On the Waterway the ratio between ebb and flood is more favourable, being about 27 km: 20 km for minimum quantities. Although theoretically the ebb is much greater than the flood, the Waterway still experiences considerable mixing, the reason for this being that the flood is predominant near the bottom of the cross-section.

For minimum river flow and other unfavourable circumstances the salinity limit (300 mg/L) on the North branch (Waterway-Lek) reaches as far as 40 km inland. i.e. past Krimpen a/d-Lek. On the Southern route, in the same unfavourable circumstances, the salinity limit of 300 mg/L reaches 65 km inland from the mouth, i.e. to Keizersveer. This is fully 25 km more than on the Northern route, but the bad proportion between ebb and flood on the Haringvliet-Hollandsch Diep leads us to expect a greater difference. Another factor important to the Southern branch of the Rhine should not be forgotten: in dry periods the Volkerak is a salt-carrying river which stabs the Haringvliet in the back, as it were. No fresh water from the Rhine flows along the Volkerak to the sea. On the contrary, sea water flows from the Volkerak into the Haringvliet, especially during dry periods. Therefore the South bank of the Hollandsch Diep has a higher salinity than the North bank, and the Vuile Gat (North of Tien Gemeten) carries more fresh water than the Haringvliet (South of Tien-Gemeten).

The same ascendancy from the South can be noticed in periods of low flow on the Kil and Spui, as these attack the Old Maas in the back by changing their direction of flow in dry periods. A "pressure" from the South can always be noticed, acting against the upper-water from the North-east. This Southerly pressure may be termed "tide pressure". It is approximately equivalent to the landward current due to waves which break on the shore. When the upper-water is low, the tide pressure can exert a bad influence. The Zijpe also carries salt water to the North, presumably even when quantities in the Maas and Rhine are large. The Volkerak always carries salt water except for the time when maximum water levels occur on the Rhine, which is of relatively short duration. The Kil and Spui only carry salt Northwards when the water level on the Rhine reaches a minimum.

There are logical reasons for the easy salting-up of the Haringvliet and Hollandsch Diep which has irregular shores and widths; also the influence of the salt-carrying Volkerak is an evident factor. The Waterway, however, is of fairly regular cross-section, there being no entry of salt-water en route, and the average ebb is predominant over the average flow. On the Waterway salting up is caused by underflow, open harbours and shipping.

The movement of the lighter fresh water over the wedge of salt water lying on the bottom of the Waterway gives rise to a considerable amount of brackish water. Near the bottom in the seaward part of the Waterway the flood is the ruling factor rather than the ebb. In the open harbours at Rotterdam brackish water replaces the fresh water during the periods of high water (H.W.) and also long afterwards. At low water the brackish water runs out of the harbours again, until the next flood begins to carry it far upstream. Open tidal harbours of brackish water cause the formation of much brackish water in the river. The velocities in these harbour mouths often reach 0.3 - 0.5 m/sec on account of the differences in specific gravity. In this sense the Old Maas can be considered as one big open harbour.

The salinity of the brackish water on the Waterway at Vlaardingen, is shown in fig.6. Throughout the tidal period the salinity curve is smooth, there being no sudden change from fresh to salt water. On the other hand, examination of the salinity variation on the Old Maas near Spijkenisse reveals sharp transitions between fresh and salt water. During flow the curve is nearly vertical, and during ebb it is still steep. Thus there is a fairly clear cut boundary between salt and fresh water, while on the Waterway this is not so, due to the large quantities of brackish water. The closing of the Botlek in 1950 resulted in some change in the peak salinity values measured at Spijkenisse, but the sharp transitions remained.

This mixing of fresh and salt water is the greatest cause of our difficulties. If there was no mixing on the Waterway, the surface would be fresh as far as the Hook at the end of the ebb tide, and salty only about as far as Maassluis at high water. It is difficult to improve the existing salinity position. Narrowing of the Waterway would be one solution, but this is out of the question. The effect of closing the harbours (by means of locks) and decreasing the amount of shipping would also prove beneficial, but these solutions, too, are not feasible. The same applies to a general smoothing of the banks of the Waterway.

An increase in the transport of upper-water may, however, be considered as follows. Both before and after Caland, stream scouring by the tide was a desirable aim, as it would decrease the need for dredging. Unfortunately, by deepening the channel to attract more tidal flow, the salt crept still further inland on the river bottom. In the early days the primary consideration was shipping, and increase of salinity remained unnoticed.

Since 1885 the average flood quantities have increased just South of the Westgeul,(see fig.7) the flood maxima increasing less than both the ebb maxima and the quantity of upper water. In spite of this, the salinity limit crept much further inland. Is it possible to find a logical explanation ? Considering fig. 8, we see that the total content of the Waterway east of the Noordgeul since 1885 has increased in the ratio of 100-182 and 100-190 for the part West of the Noordgeul, in each case below zero datum (N.A.P.).

The harbour areas at Rotterdam have changed from 100 to 276,(from 262 ha to 722 ha in area). However, although the curves in fig.8 all show an increase, there are no sharp transitions evident. This is also true for quantity curves measured in the river joining just east of Rozenburg. An exception is 1950, when the Botlek was closed.

Has the salting up been as regular ? Fig.10 shows yearly average chlorine observations taken at low water at Maassluis as a function of the average yearly quantity of fresh water on the Rhine. A remarkable difference is noticed in the periods before 1930 and after 1934. During the years 1925-1929 (before 1925 the chlorine data cannot be considered reliable) the chlorine standard near Maassluis at low water and for small Rhine water quantities of about 1500 m3/sec was about 400 mg/L, whereas after 1934 this was increased to about 1600 mg/L.

The chlorine standards at high water in the summer months at Vijfsluizen are given by fig.11, and these show a similar tendency. A comparatively sudden change of standard occured therefore on the Waterway althrough there were no sudden changes in the flow or the quantities below N.A.P., or in the harbour areas. It is remarkable that there have been no further changes in the chlorine standards since 1934. The closing of the Botlek in 1950 is as yet too recent for its influence on the standards to be determined accurately.

On the question of the change experienced by the tidal rivers in the period 1930-1934, consider that caused by the modifications to the Old Maas. The average flood quantity in its mouth increased from 12.000.000 m3 to 14.000.000 m3 and the ebb from 21.000.000 m3 to 24.000.000 m3. In comparison with the Waterway (in 1934 : 44.000.000 m3 flood, 83.000.000 m3 ebb) this increase is not great (see fig.9) but it may have had a bad effect on the chlorine standards. It could have been the drop that made the bucket flow over, or in other words, the relatively small cause of the salinity limit reaching beyond the Westgeul and thus to the large mixing area of the harbour basins. This is not certain however, and investigations must be made in other directions. Both the salinity and mud problems have by no means been solved in all their aspects.

With regard to the mud, the authorities at Rotterdam state that more dredging has been necessary since 1945 than formerly. The question is, what took place in 1945 to explain this ? We can only say that since then there has been less dredging on the Waterway, but any relation between this and the increase of mud in the harbours seems unlikely, as the effects should have been felt since 1934. A relation between the mud and the salt seems more probable.

As yet, much is still unknown about the Waterway, and more information is desirable before further extensive schemes can safely be carried out in this area. That is why small changes in chlorination (e.g. closing of the Botlek) are being investigated with the greatest possible accuracy. Also mathematicians are working on the problems of the salt. One ominous fact is that the Rhine is salting up very rapidly due to effluents from Germany and France ; since 1898 the chlorine transport on the Rhine has increased from 40 kg/sec to 173 kg/sec in 1951.

The salinity, although increasing more rapidly since 1945, has not exceeded the limit of 300 mg/L, but in the advent of another dry summer such as 1947 or 1949, this figure will presumably be reached.

The increase of pollution in the Rhine is also dangerous, being responsible for a decline in the numbers of salmon and twaite. The Waterway itself is very badly polluted. By use of the new American electric membrane to separate out the salt the quantity of the Rhine water might be safeguarded in the future.

A change as large as the forming of the Waterway in 1880 was certain to cause drastic adjustments. Before 1880 the Haringvliet dominated the scene to an ever increasing extent, but now the new Maas mouth is constantly trying to upset this domination. The future is difficult to predict, as non-hydraulic interests must be taken into account. Caland thought primarily of shipping and hydraulics, but social and economic interests cannot be omitted any more. Two important points must be the basis of future development :

1. The quantity of fresh water available in the Netherlands is insufficient in dry periods. i.e. too much flows unused into the sea.
2. That until recently there were 14 inlets (4 brackish Rhine mouths and 10 completely salt inlets) and this was far too great a number.

Two of the Rhine mouths have been closed, the Gelderse IJssel (Zuiderzee) in 1932 and the Brielse Maas in 1950. It may be that in the future the Rotterdam Waterway will be the only open Rhine mouth. Thus Caland's idea may develop and at present no serious obstacles can be seen to this.

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Titles of accompanying diagrams.

Fig. 1. The Old Maas mouth and channels as obtained from the extent of the peat bog (1 - 3 m. depth) The tidal creeks to Delft and near Maassluis had already sanded up in pre-Roman times.

Fig. 2. Diagram explaining the "leftwards" inclination of the Dutch river mouths and inlets.

Fig. 3. The old Rhine mouth near Katwijk. (Determined from boring operations as shown).

Fig. 4. Upper water distribution (1952) at average river discharge.

Fig. 5. (a,b,c,d) Distances moved/day by water for large, average, O.L.R., and minimum quantity on the Rhine and the Maas.

Fig. 6. Examples of chlorine curves in the Old Maas (Spijkenisse) and the New Maas (Vlaardingen). Note the sharp transitions between fresh and brackish water on the Old Maas. The peaks of the curves become smoother following the closing of the Botlek. There are no sharp salt boundaries on the New Maas (Waterway).

Fig. 7. Flood quantities on the Waterway have increased quite regularly since 1885, without much alteration in ebb and flood duration. Velocities increased only slightly, as the depth increased too.

Fig. 8. Graphs of the contents of the Waterway since 1885, of ebb and flood maxima since 1885, and of the increase in harbour area along the Waterway since 1920.

Fig. 9. Graphs of the change of flow-quantity (ebb and flood) on the rivers near the east point of Rozenburg since 1878.

Fig.10. Yearly average chlorine data during low water near Maassluis compared with yearly average discharge of the Rhine. We can conclude that there was a change in the salinity standard about 1930-1934. In 1950 when the Botlek was closed there was no change, as far as is known.

Fig.11. The summer averages of chl.stds. (since 1922) at low water at Vijfsluizen gives the same picture as fig.10.

Fig.12. The increase of chlorine on the Rhine due to industrial effluents is very dangerous.

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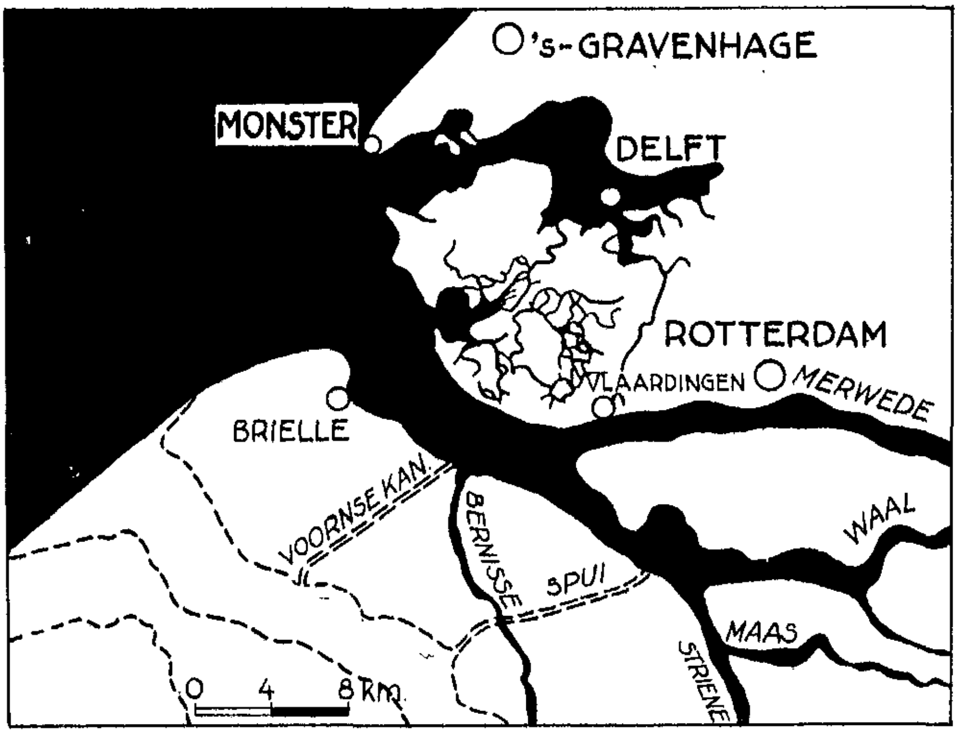
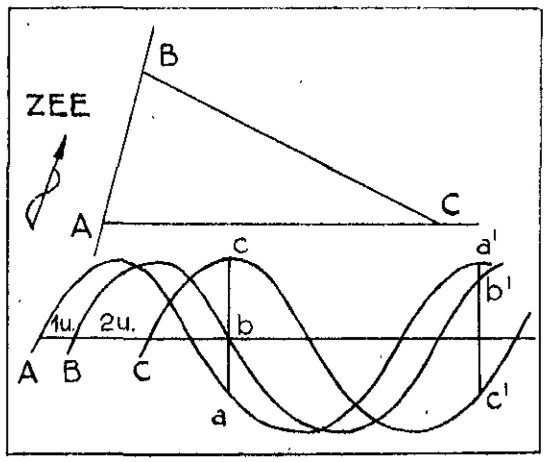
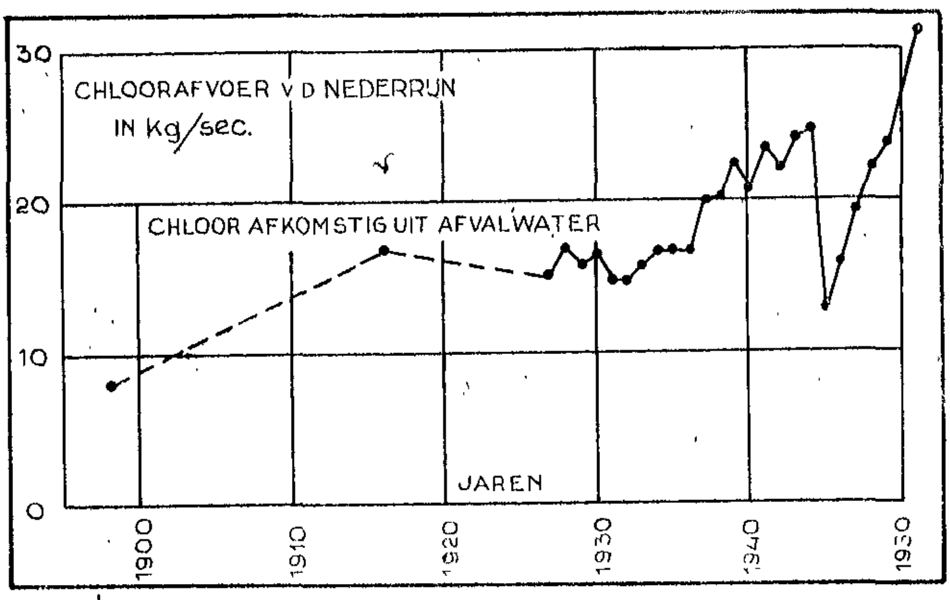


R 523[b] FIG. 1



R 523[b] FIG. 2



R 523[b] FIG. 12

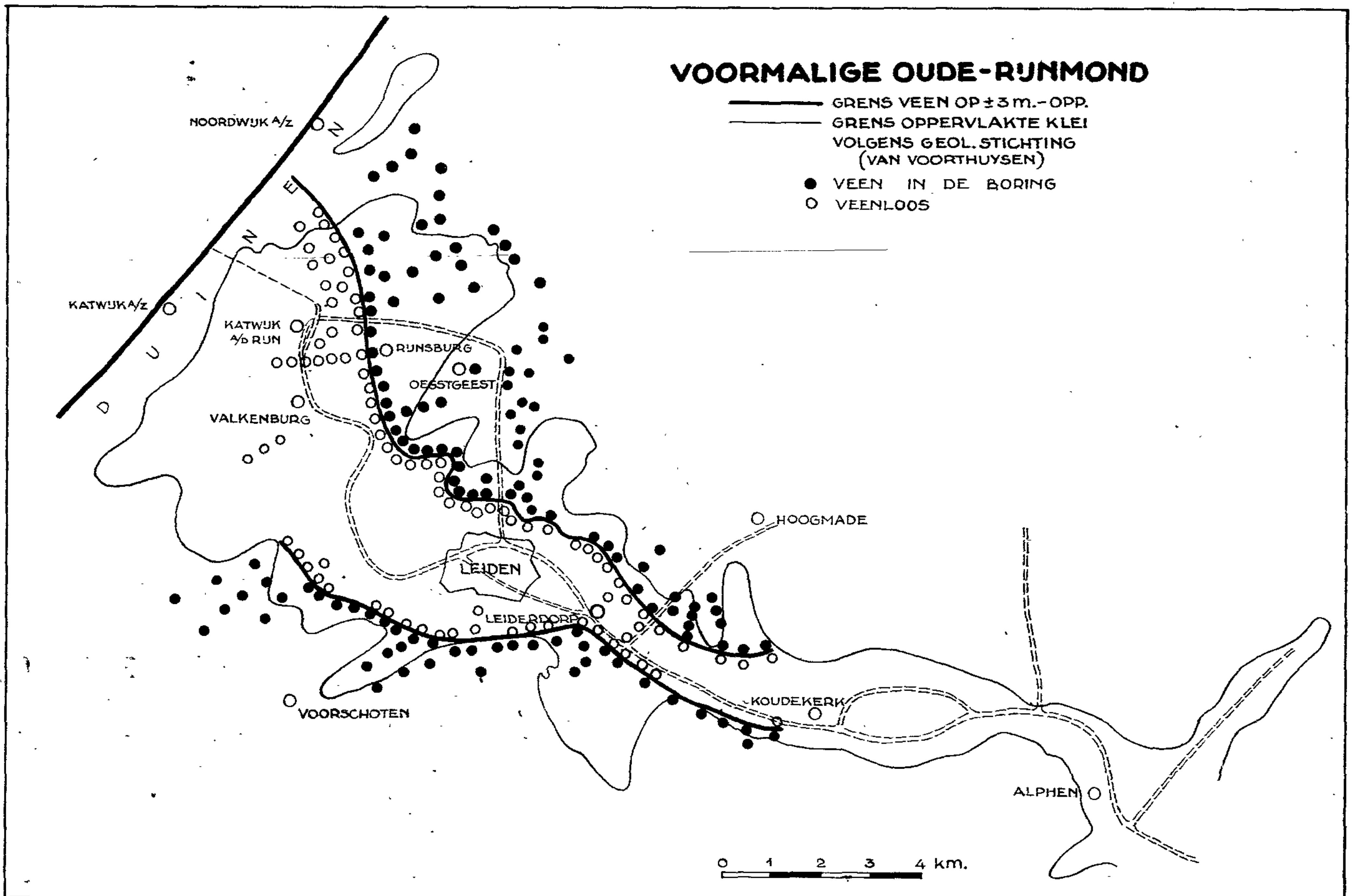

VOORMALIGE OUDE-RIJNMOND
GRENS VEEN OP ± 3 m.- OPP.
GRENS OPPERVLAKTE KLEI
VOLGENS GEOL. STICHTING
(VAN VOORTHUYSEN)
VEEN IN DE BORING
VEENLOOS
NOORDWIJK A/z
KATWIJK A/z
DUINEN
KATWIJK A/D RIJN
RIJNSBURG
OEGSTGEEST
VALKENBURG
LEIDEN
LEIDERDORP
HOOGMADE
VOORSCHOTEN
KOUDEKERK
ALPHEN
0 1 2 3 4 km.

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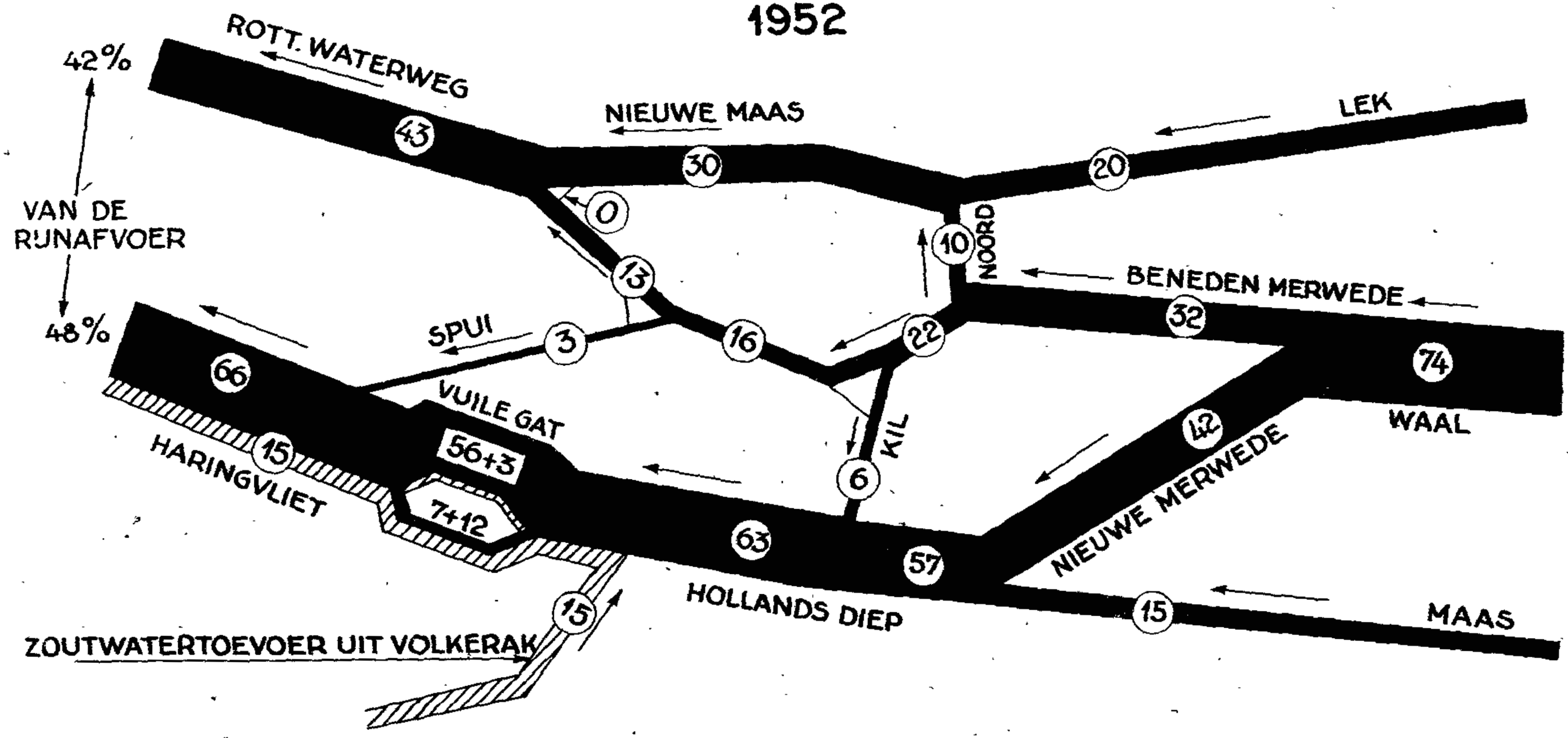
FIG. 3

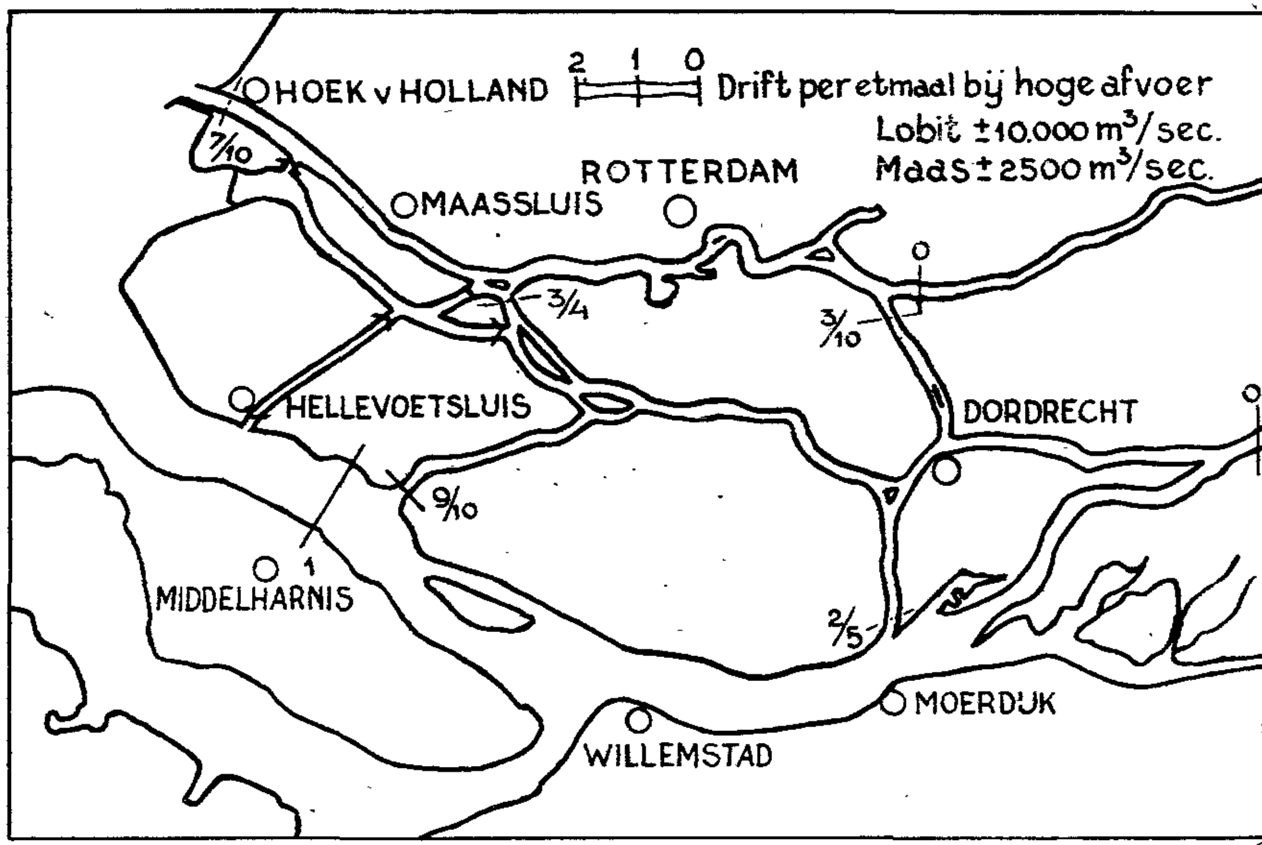
VERDELING VAN HET OPPERWATER BIJ GEMIDDELDE RIVIERAFVOEREN 1952

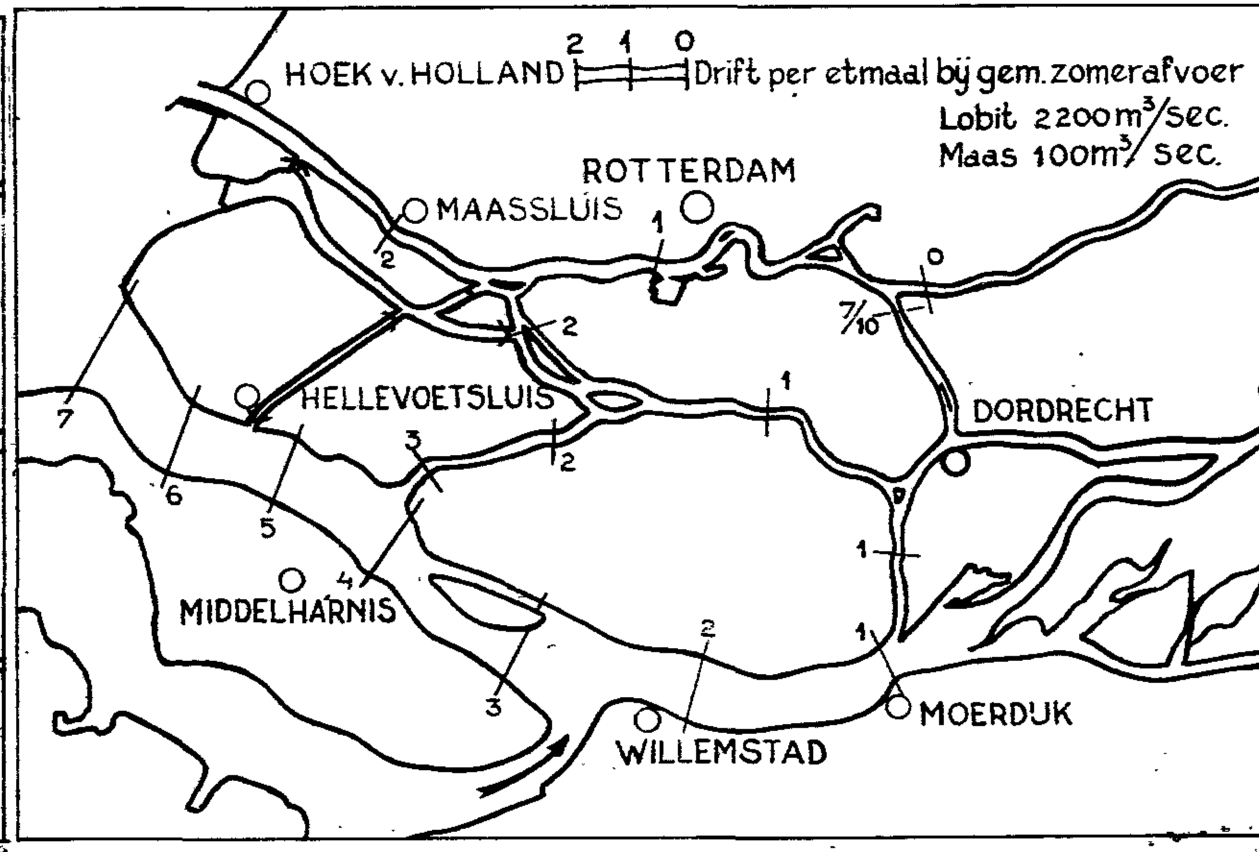


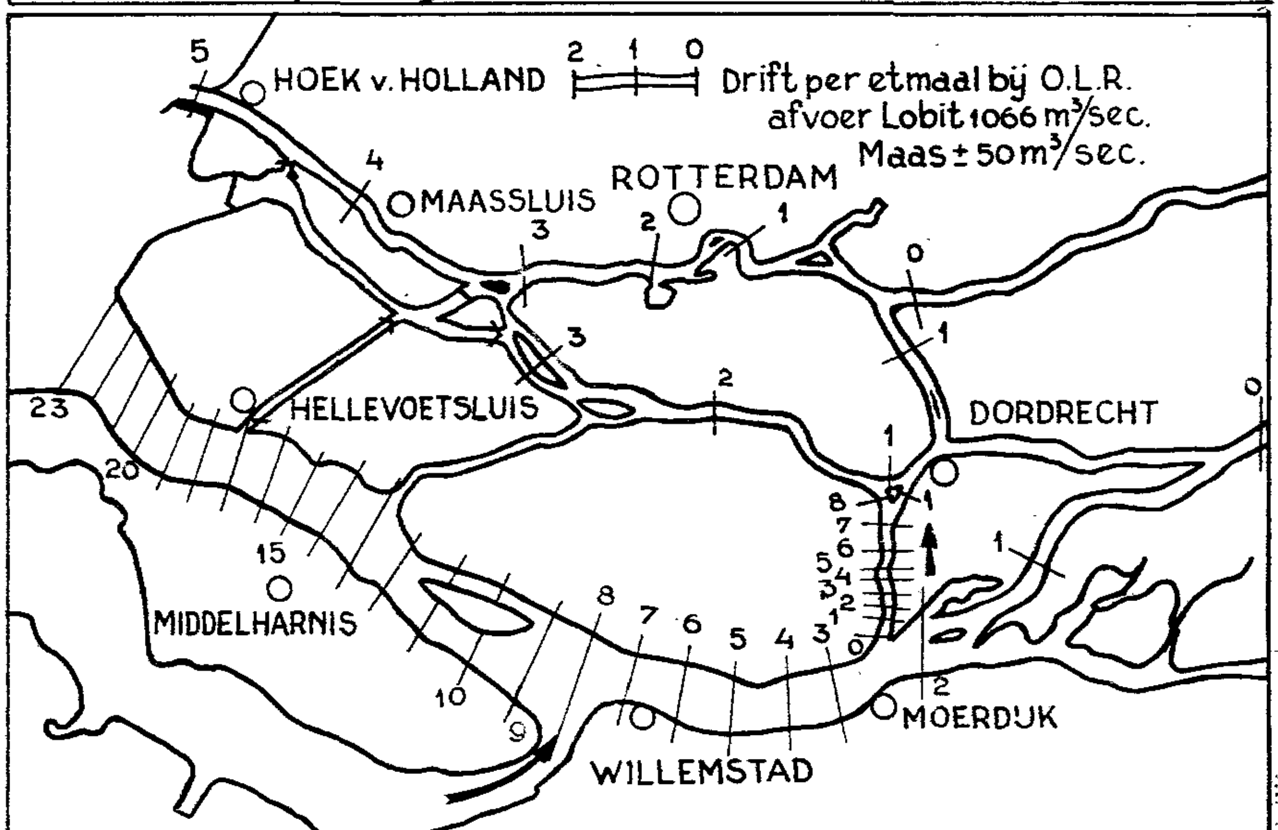
DE GETALLEN GEVEN DE AFVOER IN MILLIOENEN m^3/GETIJ

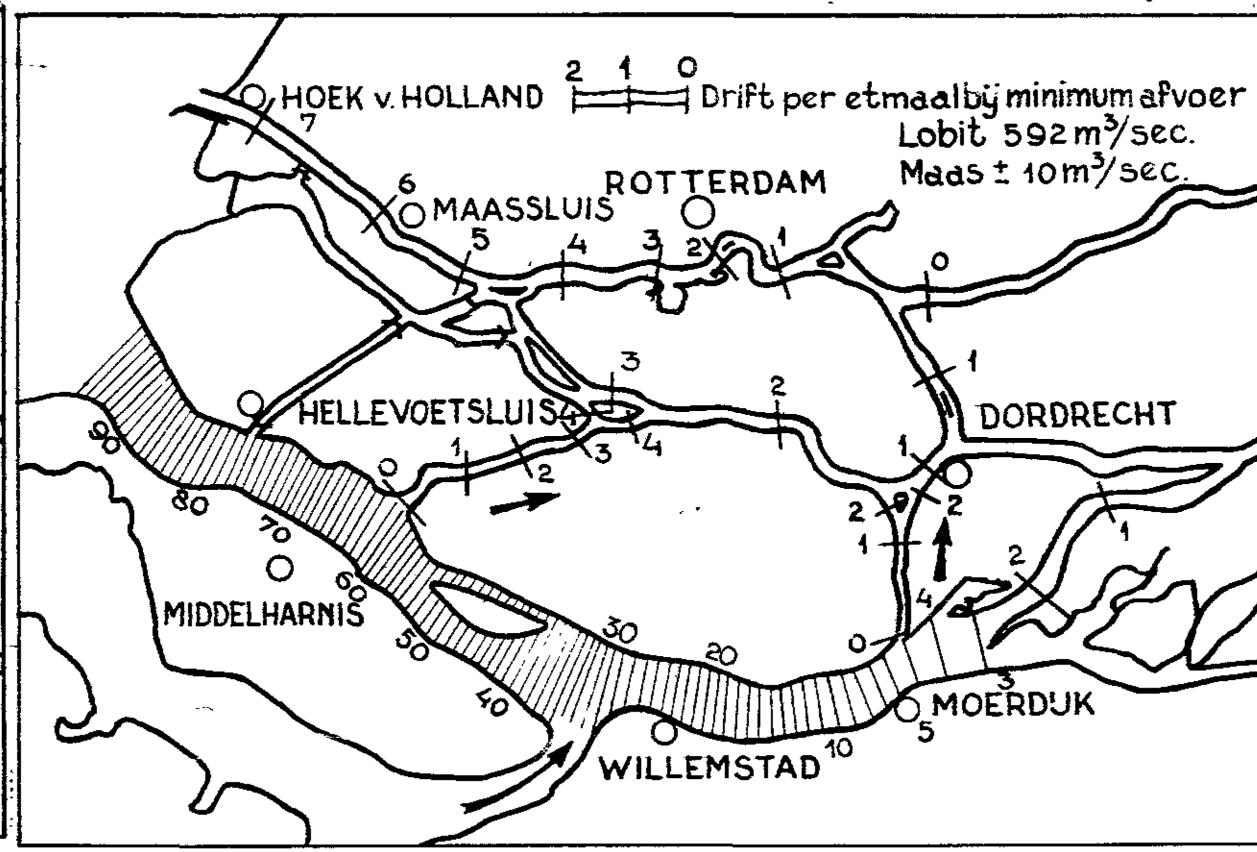
R 523b

FIG. 4


HOEK v HOLLAND
2 1 0
Drift per etmaal bij hoge afvoer
Lobit ±10.000 m³/sec.
Maas ± 2500 m³/sec.
ROTTERDAM
MAASSLUIS
HELLEVOETSLUIS
DORDRECHT
MIDDELHARNIS
MOERDIJK
WILLEMSTAD
7/10
3/4
3/10
9/10
2/5


HOEK v. HOLLAND
2 1 0
Drift per etmaal bij gem. zomerafvoer
Lobit 2200 m³/sec.
Maas 100 m³/sec.
ROTTERDAM
MAASSLUIS
HELLEVOETSLUIS
DORDRECHT
MIDDELHARNIS
MOERDIJK
WILLEMSTAD
7/10


HOEK v. HOLLAND
2 1 0
Drift per etmaal bij O.L.R.
afvoer Lobit 1066 m³/sec.
Maas ± 50 m³/sec.
ROTTERDAM
MAASSLUIS
HELLEVOETSLUIS
DORDRECHT
MIDDELHARNIS
MOERDIJK
WILLEMSTAD


HOEK v. HOLLAND
2 1 0
Drift per etmaal bij minimum afvoer
Lobit 592 m³/sec.
Maas ± 10 m³/sec.
ROTTERDAM
MAASSLUIS
HELLEVOETSLUIS
DORDRECHT
MIDDELHARNIS
MOERDIJK
WILLEMSTAD

VOORBEELD V/D REGISTRATIE V/H CHLOORGEHALTE

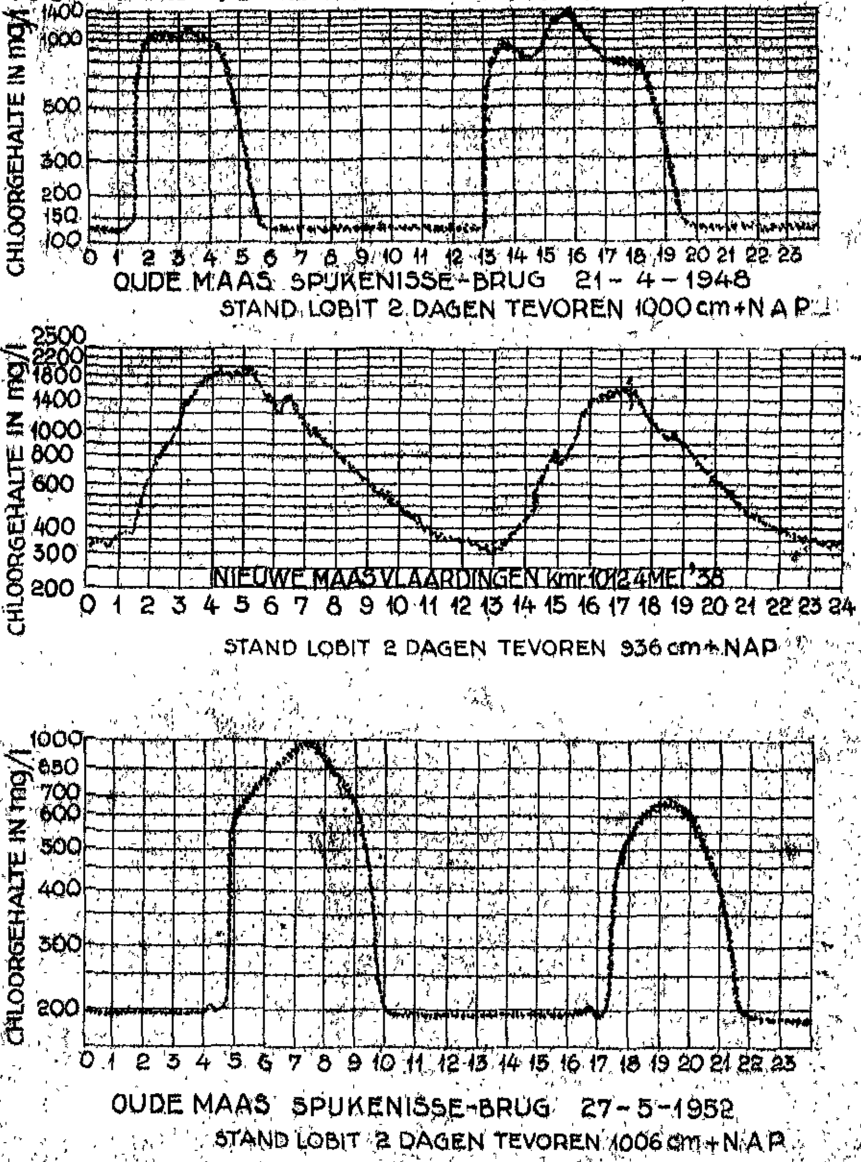


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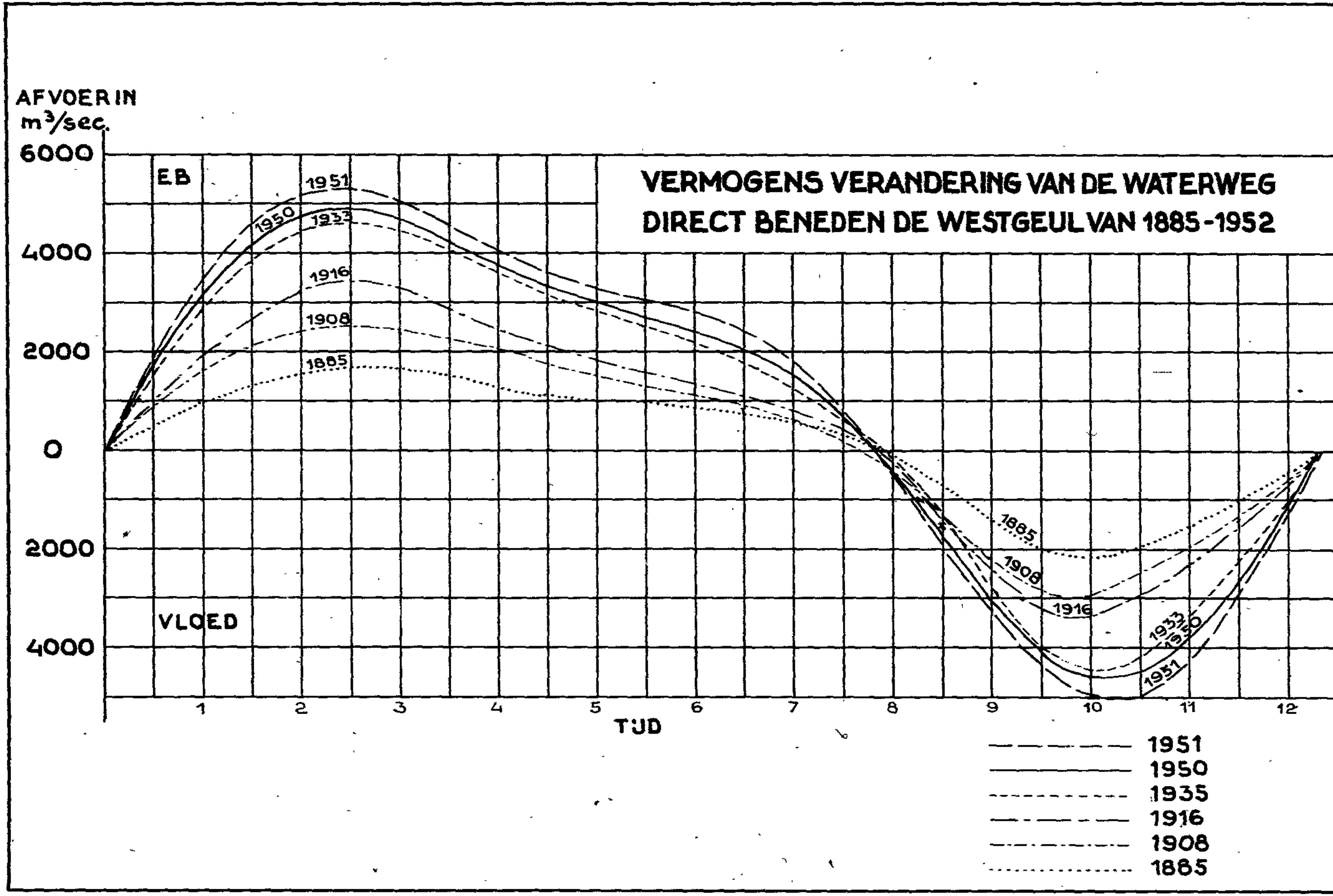
FIG. 6



AFVOER IN m³/sec.
6000
4000
2000
0
2000
4000
EB
VLOED
VERMOGENS VERANDERING VAN DE WATERWEG DIRECT BENEDEN DE WESTGEUL VAN 1885-1952
1951
1950
1933
1916
1908
1885
1 2 3 4 5 6 7 8 9 10 11 12
TIJD
1951
1950
1935
1916
1908
1885

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FIG. 7

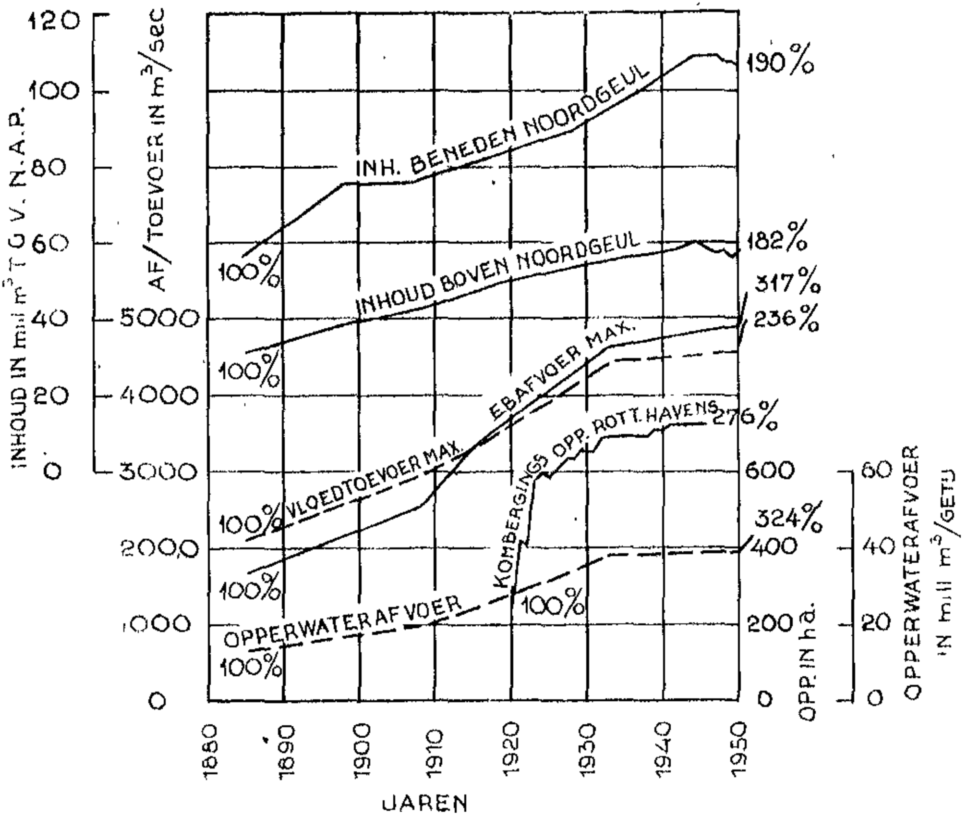
INHOUD IN mil m³ T.O.V. N.A.P.
AF/TOEVOER IN m³/sec
INH. BENEDEN NOORDGEUL
INHOUD BOVEN NOORDGEUL
EBAFVOER MAX.
VLOEDTOEVOER MAX.
KOMBERGINGS OPP. ROTT. HAVENS
OPPERWATERAFVOER
100%
190%
182%
317%
236%
276%
324%
OPP. IN ha.
OPPERWATERAFVOER IN mill m³/GETIJ
JAREN
1880 1890 1900 1910 1920 1930 1940 1950

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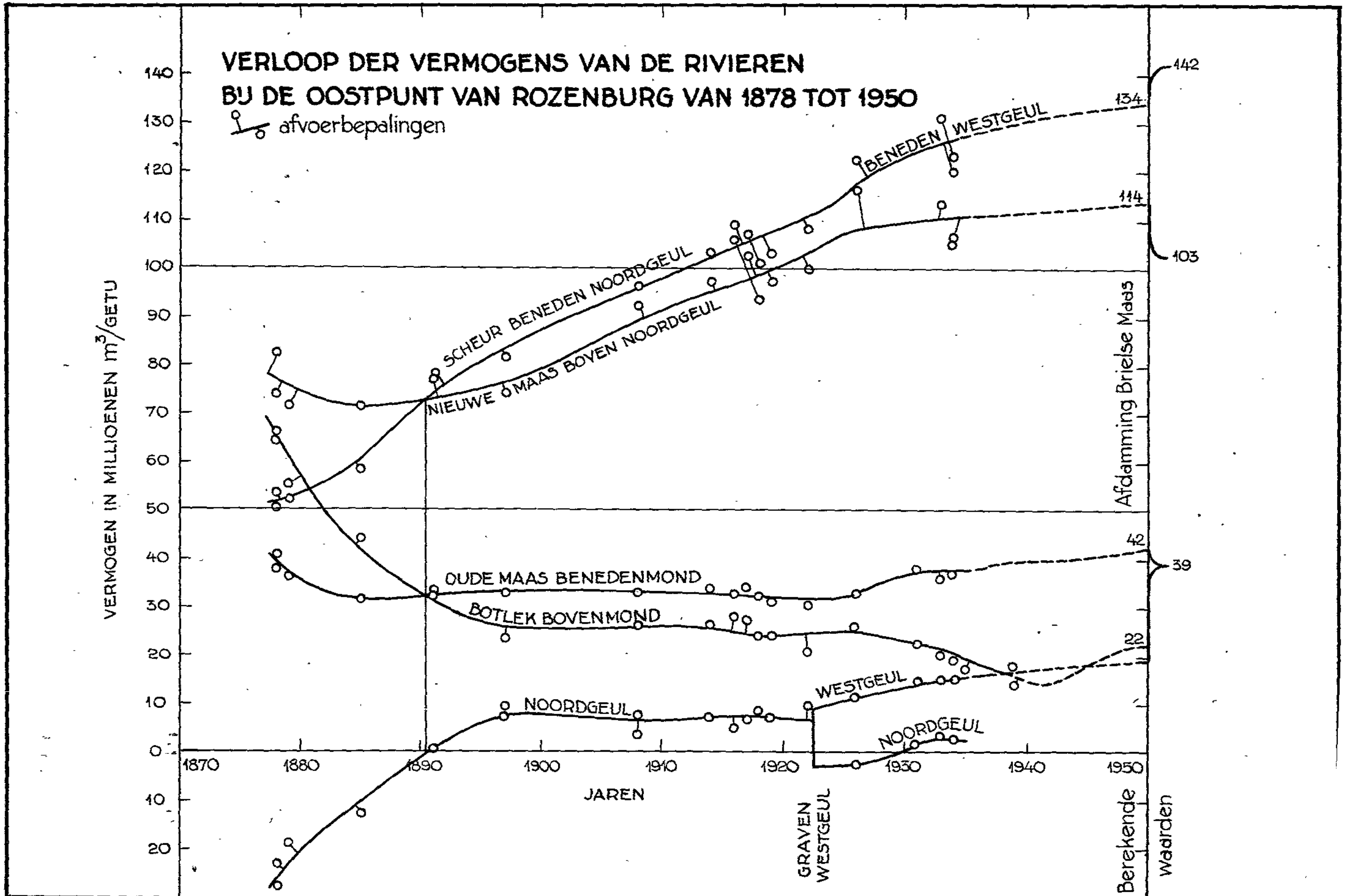
FIG. 8



VERLOOP DER VERMOGENS VAN DE RIVIEREN
BIJ DE OOSTPUNT VAN ROZENBURG VAN 1878 TOT 1950
afvoerbepalingen
VERMOGEN IN MILLIOENEN m³/GETIJ
JAREN
SCHEUR BENEDEN NOORDGEUL
NIEUWE MAAS BOVEN NOORDGEUL
BENEDEN WESTGEUL
OUDE MAAS BENEDENMOND
BOTLEK BOVENMOND
NOORDGEUL
WESTGEUL
NOORDGEUL
GRAVEN WESTGEUL
Afdamming Brielse Maas
Berekende
Waarden
142
134
114
103
42
39
22
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
10
20
1870
1880
1890
1900
1910
1920
1930
1940
1950

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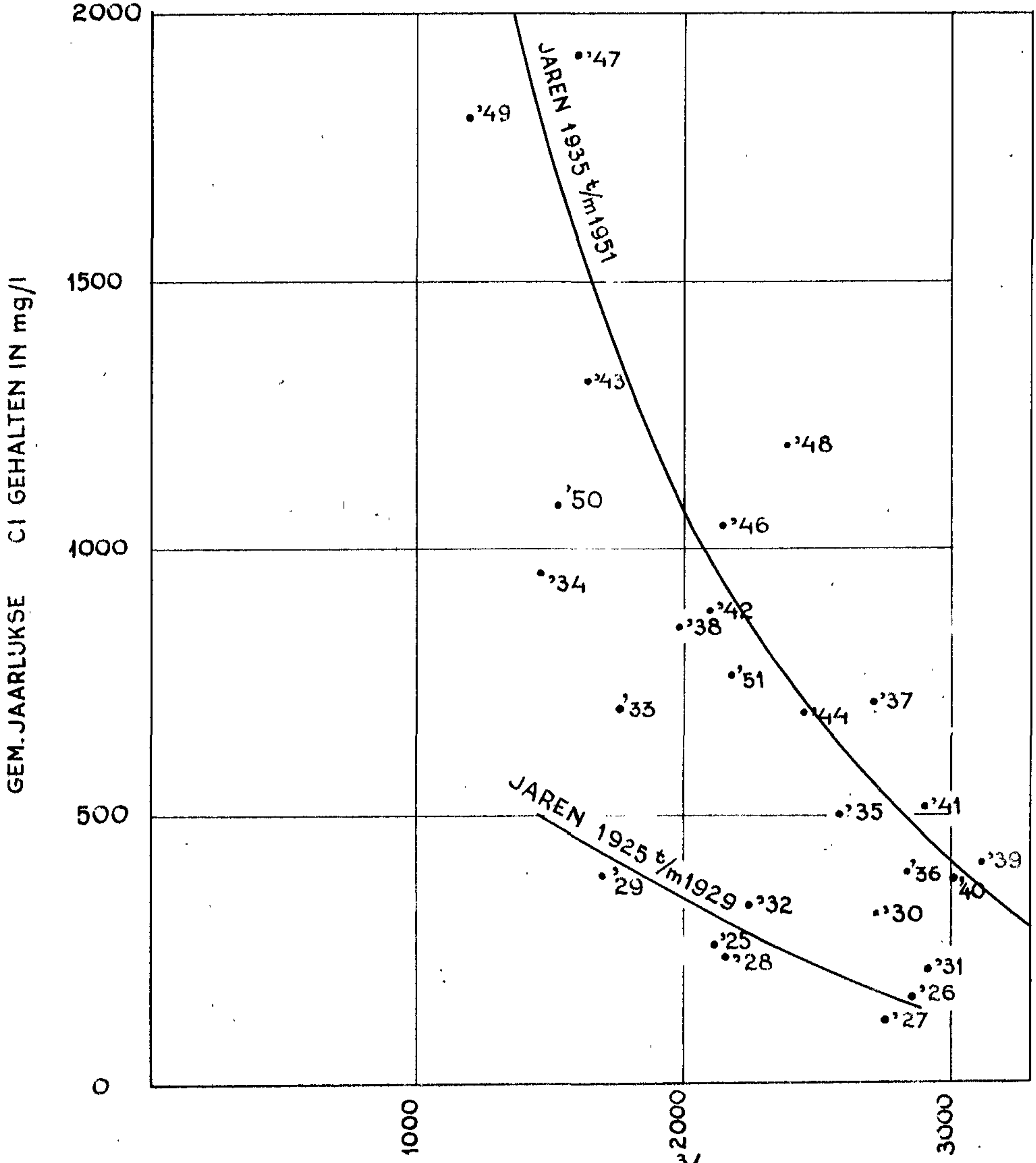
FIG. 9

GEMIDDELDE JAARLIJKSE CHLOORGEHALTEN OP DE WATERWEG

MAASSLUIS 1925 t/m 1951
L.W. PERIODE



GEMIDDELDE JAARLIJKSE CHLOORGEHALTEN OP DE WATERWEG VIJFSLUIZEN H.W.

VOLGENS GEGEVENS VAN DELFLAND

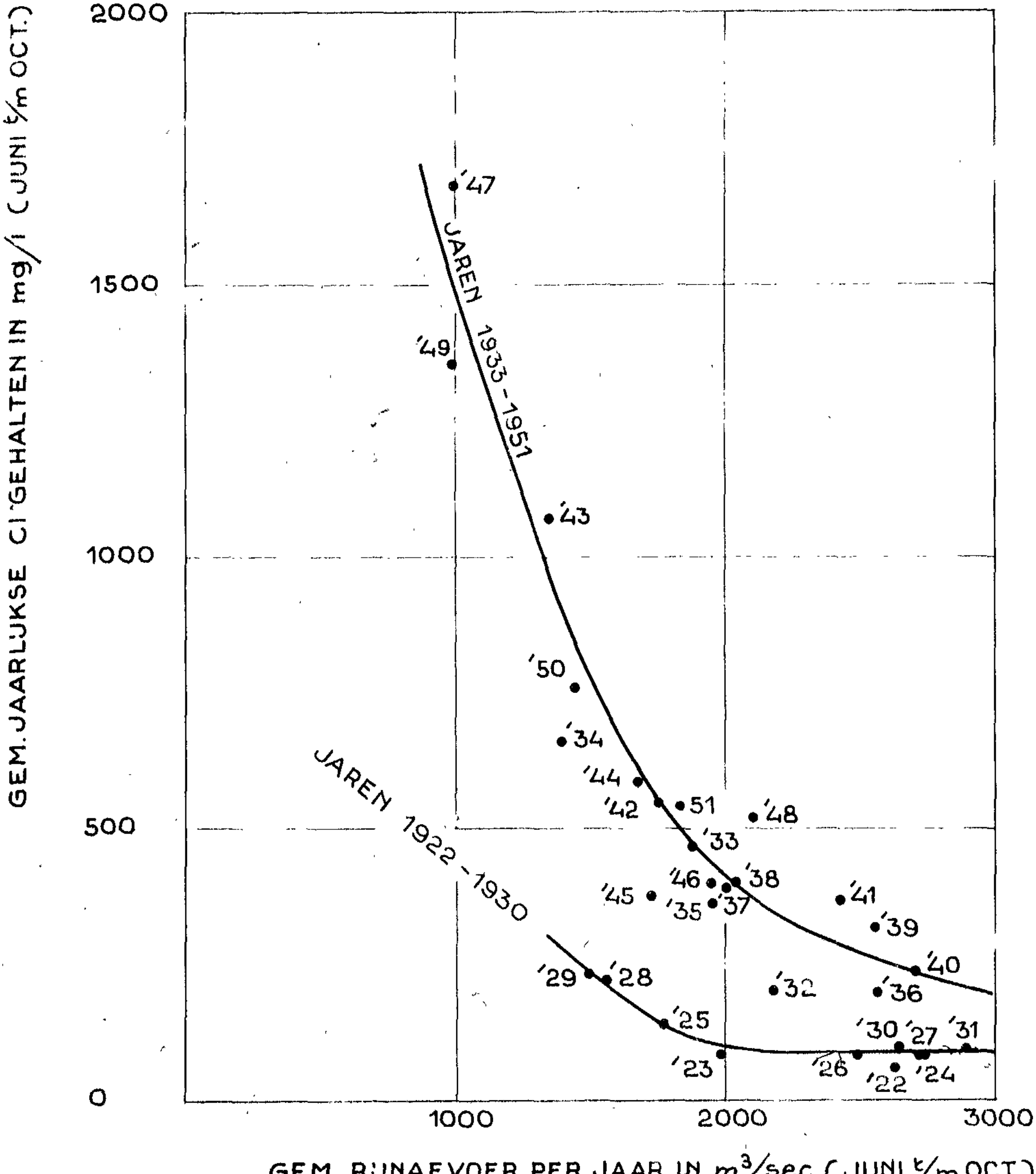


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FIG. 11