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Comparative rainfall measurements on board Netherlands light-vessels

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Summary

In the years 1957 and 1958 rainfall measurements were made on board the Netherlands light-vessels "Texel" and "Goeree" with gauges at different levels. The resulting data are statistically used to show that the indices of comparison between two different measurements remain unaltered when the individual readings are replaced as the basic data by monthly rainfall totals, only if the origin is included in the regression between the two values to be compared.

The measurements indicate that when the gauge is hoisted slightly above the jackstay between foremast and light-tower, its catch seems to be least influenced by disturbing air currents.

An impression of the "absolute" value of maritime rainfall measurements on board the light-vessels is given by means of a number of charts showing the distribution of monthly rainfall amounts over the Netherlands and especially over the coastal regions, as compared to the light-vessel data. The differences between the light-vessels and the coastal stations appear to be of the same order of magnitude and vary greatly. Even the annual totals do not permit yet to determine with sufficient accuracy a possible systematic difference.

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Comparative rainfall measurements on board Netherlands light-vessels

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1. Introduction

Rainfall measurements on board a light-ship are influenced mainly by two effects: the rolling and pitching of the vessel and the deflection of air currents above the deck and the superstructure of the ship. A computation of the first effect (W.M.O., 1956) indicates that the catch of a rain gauge which is rigidly kept parallel to the deck will show a deficit of about 5% at the most under normal conditions of roll and pitch.

This would for instance mean a deficit of less than 0.5 mm in 10 mm rainfall, which small amount lies well within the limits of accuracy of the measurement on board a ship. That comparative measurements with rain gauges, one fitted in gimbals and the other not, did not show a significant difference between the two (Skaar, 1955) may be regarded as a confirmation of the apparent smallness of the effect.

Vertical air movements set up by the disturbing influence of the ship's superstructure may furthermore cause a deficit of the catch at one place and a surplus at another. To avoid the latter effect as much as possible the rain gauge should be installed high above the deck (W.M.O., 1960); in such a position the risk of catching spraywater will also be small.

A practical way of installing a rain gauge on board the Netherlands light-vessels seemed to be to hang the gauge at the jackstay between foremast and light tower, about 8 meters above the roof of the wheel-house (14.5 m above sea level, see figure 1). The gauge could be lowered and hauled quite easily even in bad weather, and it could be read in the wheel-house. But even in this comparatively high place at the stay it might well be that disturbed air currents still influence the catch. This had to be investigated first. The results of that investigation are presented in this report.

2. The rain gauges

A gauge which is hoisted high above the deck by means of ropes is hard to keep in a position with the orifice rigidly kept parallel to the deck, a necessary condition for controllable measurements. The management of the rather small gauge may be made easier by fixing the gauge on to a wooden cross or some other device, by which it may be handled with greater precision, but the use of ropes necessitates a constant watch because of occasional shrimping.

This difficulty can be avoided by using a fixed gauge, for instance an orifice mounted on top of a long metal tube. The rain water may then be conducted through a plastic tube inside the metal one and sampled in a bottle. Observers may prefer this method, as the amount of rainfall can be measured quite easily indoors. The method has, however, the disadvantage of a certain loss of water caused by the wetting of both the plastic tube and the sampling bottle. Therefore the tube cannot be made too long. The length of the metal tube is also conditioned by the fact that the entire structure should be made strong enough to withstand a severe storm. For these reasons a fixed gauge cannot be installed as high as a suspended gauge.

The two methods of rainfall measurement have been tested on board the two light-vessels "Texel" and "Goeree", which are sister ships, in the years 1957 and 1958.

The following rain gauges were used.

Rain gauge H - a conical gauge, constructed by the German firm Walter Eigenbrodt (Hamburg) especially for use on board ship. This type of gauge has been tested at the Royal Neth. Meteorological Institute in 1956 (Verploegh, 1957); in a suspended position 10 m above the ground this gauge caught the same measured amount of rain as the normal gauges at ground level, both in light and in heavy rainfalls.

Gauge H was hoisted up to the jackstay between foremast and lighttower, 8 m above the roof of the wheel-house and 14.5 m above sea-level. The orifice was free from obstacles and about 15 cm above the stay.

Rain gauge S-- the orifice of a dismantled conical gauge was mounted on top of a long metal tube which stood upright on the roof of the wheel-house. Rain water caught in the orifice ran through a plastic tube inside the metal one down into a bottle. The amount of rainfall was measured in a special measuring glass (figure 2).

Experiment I:

In June 1957 the two gauges were installed on the "Texel". Gauge S stood 4 m above the wheel-house and vertically clear from the gauge H, which was hoisted up to a higher position. The plastic tube had a length of 4.5 m (figure 1).

Experiment II:

In November 1957 the "Goeree" was equipped with the same experimental set-up; however, gauge S was placed at a 2 m heigher level. The plastic tube, therefore, had a length of 6.5 m and the difference in height between the two gauges amounted to 2 m (figure 1).

Experiment III:

In March 1958 the position of the gauge S on the "Texel" was made identical with the position of this gauge at the "Goeree". One important difference remained. At the "Texel" the orifice of gauge S was protected against fouling from birds by means of a circular wire which was fastened under and outward of the sharp brim of the orifice (figure 3). The idea was that birds would rather sit on this wire than on the brim of the orifice. The protection was made because the fixed gauge was hardly accessible for regular cleaning; this was rather a disadvantage on a light-vessel which lies in the migration path of many birds.

The gauge S was fitted with this protecting ring from the very beginning of experiment I. In order to obtain a measure of its possible influence on rainfall measurements the gauge was lateron (experiment III) given the same position as on the "Goeree", where the corresponding gauge S was not fitted with this protecting ring.

3. The selection of observations

A first selection was made according to the nature of the precipitation observed. Only rainfall measurements were used; the cases with snow or hail were excluded.

A second selection was based on quite a different principle. The majority of readings indicated a rainfall of less than 4 mm. In those small amounts the observed differences between the two gauges H and S often were no more than a few tenths of mm rainfall, that is on the margin of the accuracy of the reading itself. Any tendency to round off the readings to certain "favoured" decimal units (the units 0, 2, 5 and 8 seem to be preferred) naturally would effect the results of this investigation. If two instruments, which are to be compared, are read shortly after each other, the consecutive readings might influence each other; this tendency may work out both ways: either the observer might want to emphasize the observed difference by rounding off the two readings differently, or he might be too well aware of the instrumental inaccuracies and tend to neglect small differences by rounding off both readings to the same value.

In both cases, however, some decimal units will be used more often than others; if the excess is significantly larger than normally would occur with readings of a single instrument, one may conclude that the two consecutive observations have been influenced by each other.

On this basis the observations of individual observers have been investigated. The large majority did not show the anticipated effect. The other observations were excluded from further analysis.

4. The effect of data grouping

In this analysis the symbol h will be used to indicate the amount of rainfall measured with the gauge H and the symbol s for the amount of rainfall measured with the gauge S, both over a period of 12 hours. It is of some importance to note, that h and s are in fact climatological quantities which do not indicate the basic phenomenon, i.e. the amount of an individual period of rain or a rain shower.

The readings are made independently of the occurrence and the duration of individual rains. Because of this independence the comparative analysis of two simultaneous measurements might be facilitated by taking, for instance, monthly rainfall sums instead of the individual observations as a basis. Such substitution may, however, not always lead to clearly interpretable results, especially when the ratio of the corresponding sums of the respective gauges is considered. The following discussion may show this.

The following symbols are introduced:

(I) Relating to the sample of n individual readings h_i and s_i:

mean: $\bar{h} = \frac{1}{n}\sum h_i$ and $\bar{s} = \frac{1}{n}\sum s_i$

standard deviation $\sigma^2(h) = \frac{1}{n}\sum (h_i-\bar{h})^2$ and $\sigma^2(s) = \frac{1}{n}\sum (s_i-\bar{s})^2$

correlation coefficient $\rho(h,s) = \frac{\sum (h_i-\bar{h})(s_i-\bar{s})}{\left[\sum (h_i-\bar{h})^2 . \sum (s_i-\bar{s})^2\right]^{\frac{1}{2}}}$

(II) Relating to the sample of $\frac{n}{m}$ monthly rainfall totals H_j and S_j, attained by adding in each month j the m = 60 individual readings

$$H_j = \sum_{i=1}^{m} h_{ji} \quad \text{and} \quad S_j = \sum_{i=1}^{m} s_{ji}$$

mean: $\bar{H} = \frac{m}{n}\sum H_j$ and $\bar{S} = \frac{m}{n}\sum S_j$

standard deviation: $\sigma^2(H) = \frac{m}{n}\sum (H_j-\bar{H})^2$ and $\sigma^2(S) = \frac{m}{n}\sum (S_j-\bar{S})^2$

correlation coefficient $\rho(H,S) = \frac{\sum (H_j-\bar{H}).(S_j-\bar{S})}{\left[\sum (H_j-\bar{H})^2 . \sum (S_j-\bar{S})^2\right]^{\frac{1}{2}}}$

First we consider a contingency diagram composed of the individual observations. The slopes of the two regression lines are, according to general statistical principles, given by

$$p_1 = \frac{\rho(h,s) . \sigma(s)}{\sigma(h)} \quad \text{and} \quad p_2 = \frac{\rho(h,s) . \sigma(h)}{\sigma(s)} \quad .$$

Next we consider a contingency diagram composed of the monthly rainfall totals. The slopes of the two regression lines in this diagram are given by

$$P_1 = \frac{\rho(H,S) \cdot \sigma(S)}{\sigma(H)} \quad \text{and} \quad P_2 = \frac{\rho(H,S) \cdot \sigma(H)}{\sigma(S)} \quad .$$

The requirement, that the statistical relation between the rainfall data of the two gauges is not changed when (for instance) monthly rainfall totals are considered instead of the individual readings, comes down to the requirement that both

$$p_1 = P_1 \quad \text{and} \quad p_2 = P_2 \quad ,$$

which is equivalent with the assumptions

$$\rho(h,s) = \rho(H,S) \qquad (1)$$

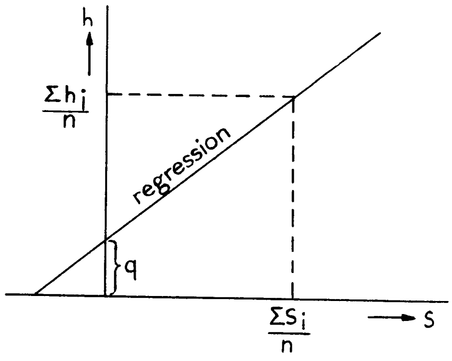
and

$$\frac{\sigma(h)}{\sigma(s)} = \frac{\sigma(H)}{\sigma(S)} \quad . \qquad (2)$$

The fact that rainfall totals are defined in a quite arbitrary way, i.e. independent of the occurrence of individual rains, may be taken as a good reason to assume that the arrangement of the original 12 - hourly sums into rainfall totals over larger periods should not influence the characteristics of the distribution of the data in a contingency diagram. The validity of the assumptions (1) and (2) seems to be in accordance with general experience (see for instance Brooks and Carruthers, 1953). Another assumption is often justified, i.e. that the linear regression includes the origin of the diagram. Then the ratio of two rainfall sums to be compared can be used as an "index of comparison". In the case that this assumption does not hold a substitution of monthly totals in lieu of individual readings should give rise to spurious "indices". The observations made on board of the two light-vessels may serve to illustrate the resulting effect when they are grouped into subtotals of various lengths.

We base our considerations on the assumed validity of the relations (1) and (2) and write one of the regression lines in the general form

$$h = ps + q \qquad (3)$$



The constants p and q for individual observations are related to the similar constants P and Q for (for instance) monthly totals as follows:

$P = p$ and $Q = mq$ (4)

The best values (by least squares) for the constants p and q can be found from

$$p = \frac{n\sum(h_i s_i) - \sum h_i \sum s_i}{n\sum s_i^2 - (\sum s_i)^2} \qquad (5)$$

$$q = \frac{\sum h_i \sum s_i^2 - \sum s_i \sum(h_i s_i)}{n\sum s_i^2 - (\sum s_i)^2} \,. \qquad (6)$$

If the circumstances of measurement are such that essentially $q = 0$, if follows from (6) and (5) that

$$p = \frac{\sum(h_i \cdot s_i)}{\sum s_i^2} = \frac{\sum h_i}{\sum s_i} \qquad (7)$$

Whatever rainfall subtotals we use, we will always find the same slope of the regression line going through the origin:

$$P = \frac{\sum(H_j S_j)}{\sum S_j^2} = \frac{\sum H_j}{\sum S_j} = \frac{\sum h_i}{\sum s_i} = p \qquad (8)$$

If the circumstances of measurement are such that essentially $q \neq 0$, then:

$$a = \frac{\sum h_i}{\sum s_i} \neq \frac{\sum(h_i \cdot s_i)}{\sum s_i^2}$$

and $$a = \frac{\sum H_j}{\sum S_j} \neq \frac{\sum(H_j \cdot S_j)}{\sum S_j^2} \,.$$

Now suppose that we compute from the observations in a <u>formal</u> way the following coefficients:

$$a = \frac{\sum h_i}{\sum s_i} = \frac{\sum H_j}{\sum S_j} , \tag{9}$$

$$a' = \frac{\sum (h_i . s_i)}{\sum s_i^2} , \tag{10}$$

$$A' = \frac{\sum (H_j S_j)}{\sum S_j^2} . \tag{11}$$

The coefficients a and a' are to be computed from the individual 12-hourly readings, the coefficient A' from (for instance) the monthly rainfall totals.

Next we investigate the relation between the regression coefficient p and the formally computed coefficients a, a' and A'. We have

$$\sum (h_i - q) = p \sum s_i \; ; \quad \text{thus} \quad p = \frac{\sum h_i}{\sum s_i} - \frac{nq}{\sum s_i} = a - \frac{q}{\bar{s}} \tag{12}$$

We rewrite the regression formula (3) as

$$h = p(s+c) \quad \text{with} \quad c = {}^{q}/p. \tag{13}$$

From (12) follows: $a = p(1 + \frac{c}{\bar{s}})$ (14)

By replacing s_i by $s_i + c$ we may now apply a formula analogous to (7), so that we have:

$$p = \frac{\sum h_i(s_i+c)}{\sum (s_i+c)^2} = \frac{\sum (h_i . s_i) + c \sum h_i}{\sum (s_i+c)^2} = \frac{a' \sum s_i^2 + cp(\sum s_i + nc)}{\sum (s_i+c)^2} ,$$

$$a' = p \, \frac{\sum s_i^2 + 2c \sum s_i + nc^2 - c \sum s_i - nc^2}{\sum s_i^2} = p\left(1 + c\frac{\sum s_i}{\sum s_i^2}\right). \tag{15}$$

From (14) and (15) it follows, that

$$a' = a \frac{1+c \sum s_i / \sum s_i^2}{1 + nc/\sum s_i} \tag{16}$$

Considering that in general $n\sum s_i^2 > (\sum s_i)^2$ (17)

We note that in (16): $\frac{\sum s_i}{\sum s_i^2} < \frac{n}{\sum s_i}$

we may therefore conclude:

$$\begin{aligned} &\text{if } c = 0, &&\text{then } p = a' = a;\\ &\text{"} \quad c > 0, &&\text{"} \quad p < a' < a;\\ &\text{"} \quad c < 0, &&\text{"} \quad p > a' > a. \end{aligned} \tag{18}$$

For monthly rainfall totals a relation analogous to relation (15) can be written down;

$$A' = P \left[1 + \frac{Q \sum S_j}{P \sum S_j^2}\right] = p \left[1 + mc \frac{\sum S_j}{\sum S_j^2}\right] \tag{19}$$

The righthand equation is based on the relations (4).

$$\text{Thus: } A' = a' . \frac{1+mc \sum S_j / \sum S_j^2}{1 + c \sum s_i / \sum s_i^2} \tag{20}$$

Considering that according to (17)

$$\sum S_j^2 = \sum_j \sum_{i=1}^{m} (s_{ji})^2 < \sum_j \sum_{i=1}^{m} ms_{ji}^{\ 2} = m \sum_{i=1}^{n} s_i^2$$

we note that in (20): $\frac{m}{\sum S_j^2} > \frac{1}{\sum s_i^2}$

$$\begin{aligned} &\text{Thus if } c = 0, &&\text{then } p = a' = A';\\ &\text{"} \quad c > 0, &&\text{"} \quad p < a' < A';\\ &\text{"} \quad c < 0, &&\text{"} \quad p > a' > A'. \end{aligned} \tag{21}$$

Lastly the combination of (20) and (16) results into:

$$A' = a \frac{1 + mc \sum S_j / \sum S_j^2}{1 + nc / \sum s_i} \tag{22}$$

Since $\sum S_j = \sum s_i$ and: $\frac{m}{\sum S_j^2} < \frac{n}{(\sum S_j)^2}$ (see (17)),

we can write as a final result:

$$\begin{array}{llll} \text{if } c = 0, & \text{then} & p = a' = A' = a; & \\ \text{"} \quad c > 0, & \text{"} & p < a' < A' < a; & \\ \text{"} \quad c < 0, & \text{"} & p > a' > A' > a. & \end{array} \tag{23}$$

Should we, therefore, neglect the possibility that the regression line could pass through the origin, and formally apply the formulas (9), (10) and (11) in order to arrive at some coefficient which is meant to express the comparative value of the two different rainfall measurements, we should find a set of coefficients which show a monotonous increase or decrease when computed on the basis of rainfall totals over increasing time intervals. Only in the case that the origin lies on the regression line all coefficients will turn out to have the same value.

5. The analysis of the observations:

In the following example a coefficient

$$a' = \frac{\sum h_k \cdot s_k}{\sum s_k^2}$$

is computed on the basis of corresponding rainfall totals h_k and s_k over periods of increasing length. The observations were made on board the "Texel" from April to December 1958.

Period of rainfall totals	12 hours	5 days	10 days	month	3 months	whole period
coefficient a'	1.177	1.186	1.189	1.203	1.208	1.215

Although the differences are small, a monotonous increase of the coefficients is apparent. The example points to the occurrence of one or more influences on the catch which work out differently on gauge H and gauge S. One of these might be a certain loss of water in the plastic tube of gauge S. Especially after a prolonged period of dry weather the water of a beginning rain could stay behind in the tube and wet the inner surface. In rainy weather with showers which follow each other up at short intervals the amount of rain water thus lost will presumably be small or even negligible, as the tube does not get sufficient time to dry up. The conical gauge H, on the other hand, has not been found to show a measurable loss of water at various weather conditions.

An indirect estimate of the anticipated loss of rain water in gauge S can be obtained, on the basis of the above reasoning, from a selection of observations of a measurable amount of rainfall, which were made after a sufficiently long period of dry weather. The length of this period has been chosen to be at least 12 hours. For these observations the relation between h_i and s_i was assumed to have the form:

$$h = p(s + c), \qquad (13)$$

c indicating a mean loss of rain water in gauge S, expressed in millimeters.

The following values were obtained.

Experiment I (Texel): c = 0.0 mm
Experiment II (Goeree): c = 0.3 mm
Experiment III (Texel): c = 0.1 mm

The anticipated loss of rain water in the plastic tube has experimentally been verified on the lightvessel "Goeree" at the end of the experiment and during a period of dry weather. An amount of water equivalent to 3 mm rainfall was poured into the orifice of gauge S and after about 10 minutes the catch was measured.

A loss of 0.1 mm was experienced. Six hours later the experiment was repeated; then the loss was measured to be 0.05 mm. These experiments indicate that after a sufficient long period of dry weather - 12 hours or more - there is a loss of water in the plastic tube and the amount of it can be estimated at about 0.1 mm for a tube of 6 m length.

If this loss were the only effect which caused the monotonous increase of the coefficient a', a selection of observations, each taken after a sufficiently long period of rainy weather (of at least 12 hours), should not show a similar increase or, at least, the increase should largely be suppressed.

Based on rainfall totals over periods of increasing length the coefficients are for this selection of observations:

selective rainfall totals over:		10 days	month	3 months	whole period
Experiment I	:a'=	1.45	1.46	1.46	1.47
Experiment II	:a'=	1.02	1.02		1.02
Experiment III	:a'=	1.17	1.18	1.18	1.19

In fact the monotonous increase is reduced by this selection; we may not expect an entire elimination of any such trend, as the selection of observations was up to a certain extent an arbitrary one and since other effects may of course work similarly, for instance the influence of the wind.

We are now able to investigate the effect of the wind. Once the relevant catches of gauge S are corrected for the loss of rain water due to wetting, the observations may be expected to fit with fair degree of accuracy the mean relation $h = p.s$, especially when the observations are divided into groups according to the wind speed. In any such group the criterion for $q = 0$ should be fulfilled, as it is not to be expected that the catch s_i, which was read at the time when the wind had a certain speed, would be correlated to the catches h_k and s_k both referring to another time when the wind happened to have the same speed.

According to the measurements made on board the "Goeree" (experiment II) the difference in height of 2 meters between the two gauges H and S does not seem to cause an important difference in catch, only 2 per cent. At the "Texel" the difference is larger, 18 per cent, but in this ship the orifice of gauge S was fitted with a ring to protect the gauge for fouling due to birds.

The following table shows the variation of the coefficient $p_v = \sum h / \sum s$ with increasing wind speed, according to the observations made at the light-vessel "Texel" (experiment III) during the months when the vessel was equipped with an anemometer fixed on top of the lighttower.

wind speed	0-4	5-9	10-14	15-19	$\geqslant 20$	knots
$p_v = \sum h_i / \sum s_i$	1.05	1.14	1.18	1.21	1.27	
number of obs.	38	120	136	122	125	

A regular increase of p_v can be noted; with respect to the catch of gauge H the deficit of the catch of S is greater the stronger the wind. At calms the difference of 5 per cent corresponds fairly closely to the observed difference at the "Goeree" of 2 per cent. The effect of the wind can therefore mainly be attributed to the influence of the protecting ring around the orifice of gauge S on the "Texel". An estimate of this influence can be made by assuming that the coefficient p_v is made up by two factors r_v and p_h, such that

$$p_v = r_v . p_h, \qquad (24)$$

where r_v bears on the effect of the protecting ring and p_h on the effect of the difference in height between the two gauges H and S.

The measurements on the "Goeree" indicate $p_h = 1.02$, whereas for average wind speeds $p_v = 1.18$ for the same exposures at the "Texel". Thus on an average r_v would be 1.15.

We are now able to combine the results of the three experiments into one coherent picture. Assuming a catch of the suspended conical marine gauge H at 100 mm, the catch of the fixed gauge S would on an average be 98 mm if put up at a position 2 m below H, and 79 mm if put up at a position 4 m below H. These results indicate that the catch is less influenced by air currents which are deflected upward and/or accelerated over the ship's superstructure, if the gauge is put up at greater heights above the deck. They suggest that the catch of gauge H would not change materially if this gauge were to be hoisted at still greater heights.

These experiments led to the decision to use on board the Netherlands light-vessels the conical marine gauge and place it at the same position as during the experiments. The way of suspending the gauge at the jackstay was changed, though, at the suggestion of one of the light-vessel captains. The photographs on page 19 show the present installation.

6. A comparison of rainfall measurements between light-vessels and coastal stations

The comparative measurements on board the light-vessels can not give, on themselves, sufficient information on their representativity of the rainfall which occurred at the measuring site. Although the difference of catch is small between the gauges H and S at the higher position of S, the effect of the wind, working on both gauges at the same time, may still be greater than the few per cent difference between H and S. The rolling and pitching of the vessel also has a similar effect on both gauges.

If we knew the catch R, which would have been measured with an ideal gauge and under ideal measuring circumstances, comparison between H and this reference value R would reveal the magnitude of the combined effects of wind and ship motion still present.

The catch at land stations is not influenced by these effects and we might try to find R by means of an extrapolation of rainfall data from coastal stations. The accuracy of such extrapolation should, however, not be estimated too high.

The catch of a rain gauge at a land station is highly influenced by local conditions, such as for instance the relief of the terrain and its coverage; orographic effects on the rain producing air currents may over a large distance downwind also lead to consistent local differences of catch, exceeding 10 per cent (Bergeron, 1949; Levert, 1958). This percentage gives the error which should be reckoned with in determinating the reference value R.

The observations which are available from the light-vessel stations are still too small in number to permit an exhaustive study of local influences on the rainfall in these coastal areas. As an introduction to such a study a number of charts is represented here of the monthly rainfall pattern over the Netherlands. The corresponding monthly amounts of rainfall at the three light-vessels "Terschellingerbank" (53.29 N, 5.07 E, one rain gauge H), "Texel" (53.07 N, 4.30 E, rain gauge H), and "Goeree" (51.55 N, 3.40 E, rain gauge H) are also plotted on these charts.

The following analysis is meant to give an indication of whether the rainfall amounts at the light-vessels are consistently larger or smaller than the amounts measured at nearby coastal stations.

	1958			1959		
	T.bank	Texel	Goeree	T.bank	Texel	Goeree
March	$=$	$=$	$<$	$\approx$	$=$	$<$
April	$>$	$>$	$=$	$>$	$=$	$\approx$
May	$>$	$=$	$=$	$\approx$	$\approx$	$<$
June	$>$	$=$	$>$	$=$	$>$	$\approx$
July	$=$	$\approx$	$<$	$>$	$<$	$=$
August	$\approx$	$\approx$	$=$	$=$	$<$	$<$
September	$\approx$	$<$	$>$	$=$	$=$	$=$
October	$>$	$\approx$	$>$	$>$	$<$	$\approx$
November	$<$	$<$	$<$	$=$	$=$	$=$
December	$=$	$<$	$<$	$\approx$	$=$	$<$

The $=$ sign indicates that the mean difference with the coastal stations lying within a radius of 30 km is less than 5 per cent of the total rainfall amount. The $>$ sign and the $<$ sign are used when the difference is greater or smaller respectively, while the $\approx$ sign indicates that the rainfall amount measured at sea might "synoptically" be connected with an area of equal rainfall amounts at a greater distance along the coast.

The following table summarizes the number of cases for each light-vessel.

	$<$	$=$	$\approx$	$>$
T.bank	1	7	5	7
Texel	6	8	4	2
Goeree	8	6	3	3
	15	21	12	12

"Texel" and "Goeree" indicate either an equal or a smaller amount of rainfall in the majority of cases, while at the "Terschellingerbank" the tendency appears to be an equal or a larger amount. The difference in monthly rainfall between the light-vessels and the individual coastal stations in the vicinity often appears to be rather large, more than 10 per cent or even 20 per cent, and of the same order of magnitude as the differences between the stations along the coast and more inland. It does not, therefore, seem possible yet to determine the measuring error of the catches at the light-vessels in an absolute way; all we can deduce from this comparative analysis is that the average measuring error will probably not be greater than the apparent spreading of the catches on land, and presumably much smaller, for instance 5-10 per cent.

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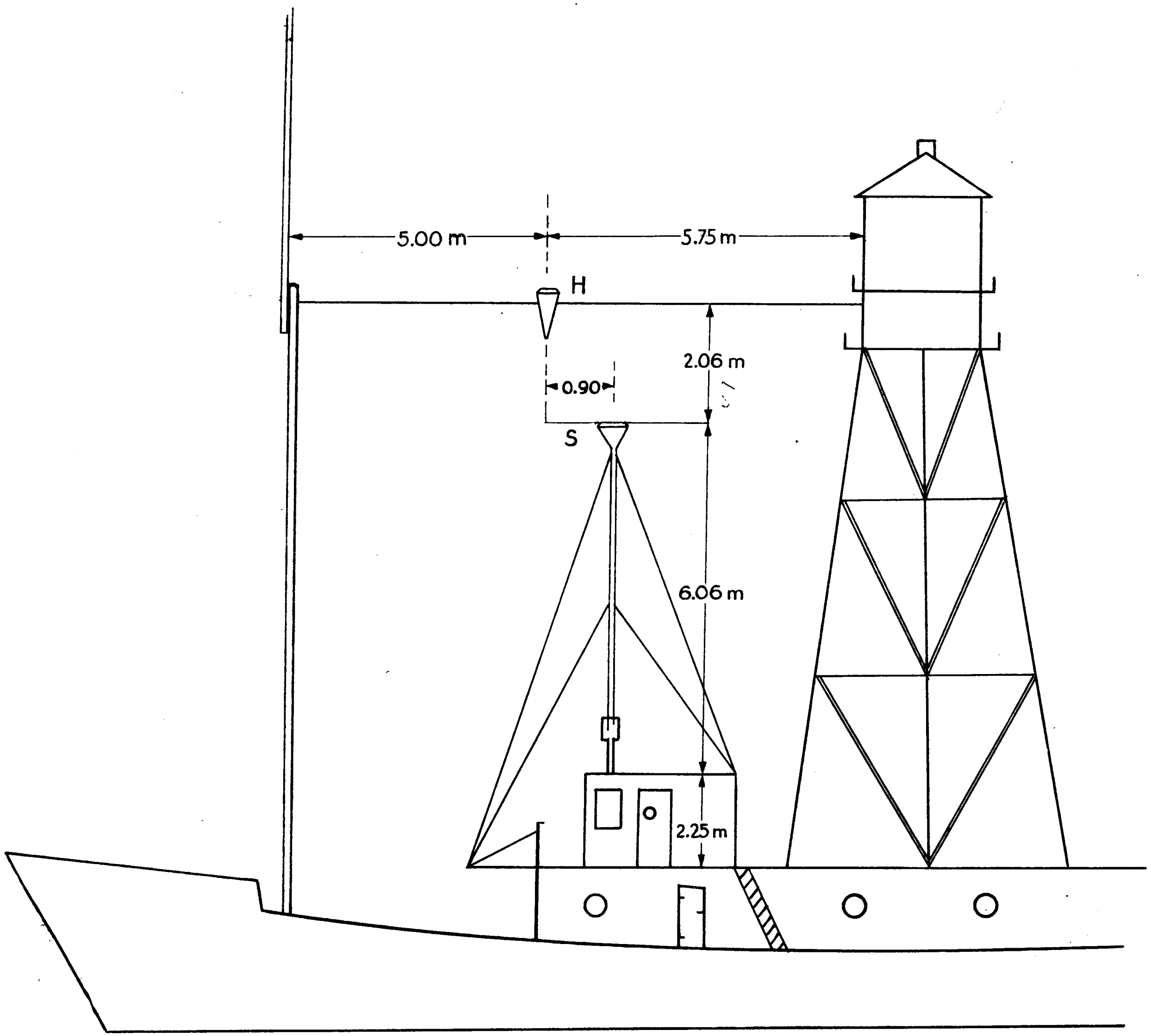


Figure 1. Position of rain gauges H and S on the light-vessels "Texel" and "Goeree" during experiment II and III

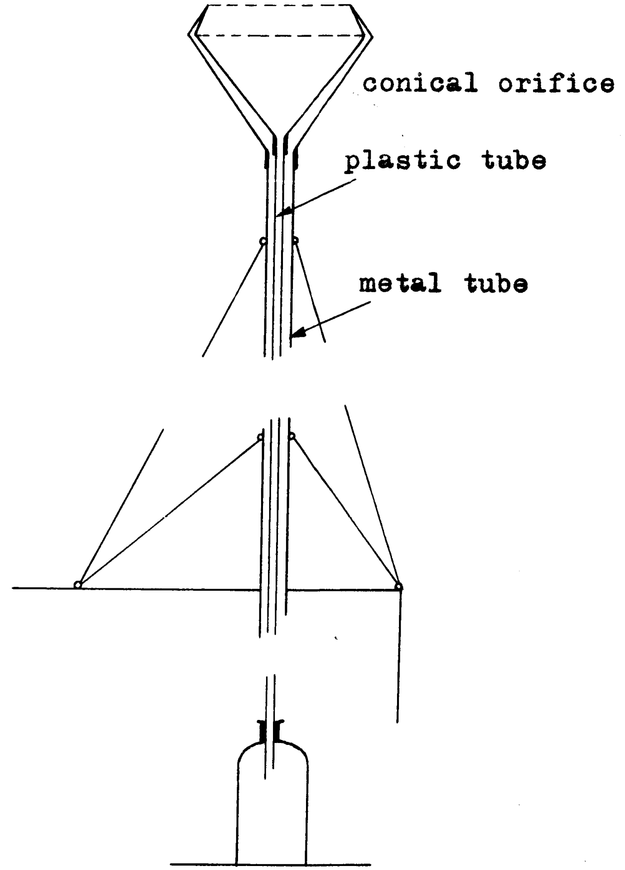


Figure 2. Construction of fixed gauge

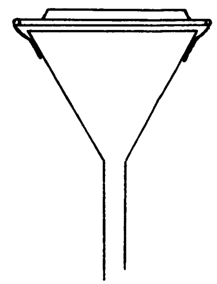
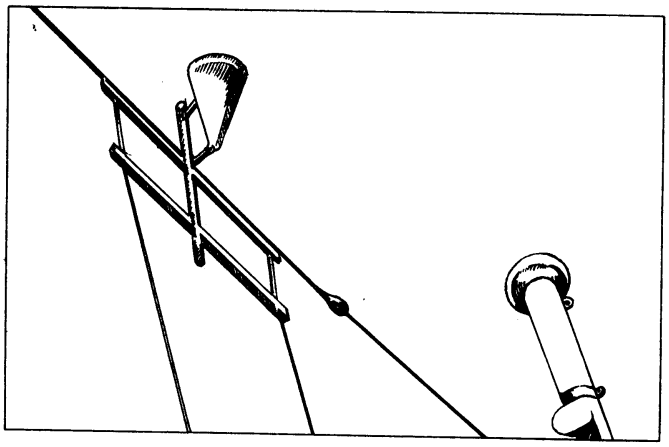
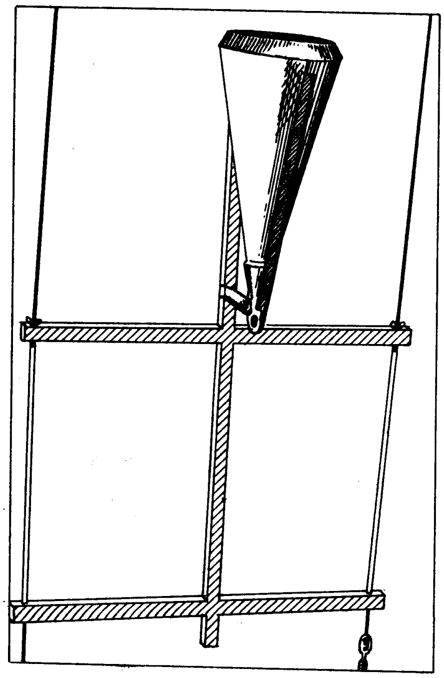


Figure 3. Construction of "bird ring" underneath brim of orifice





The installation of the conical marine rain gauge on board the Netherlands light-vessels

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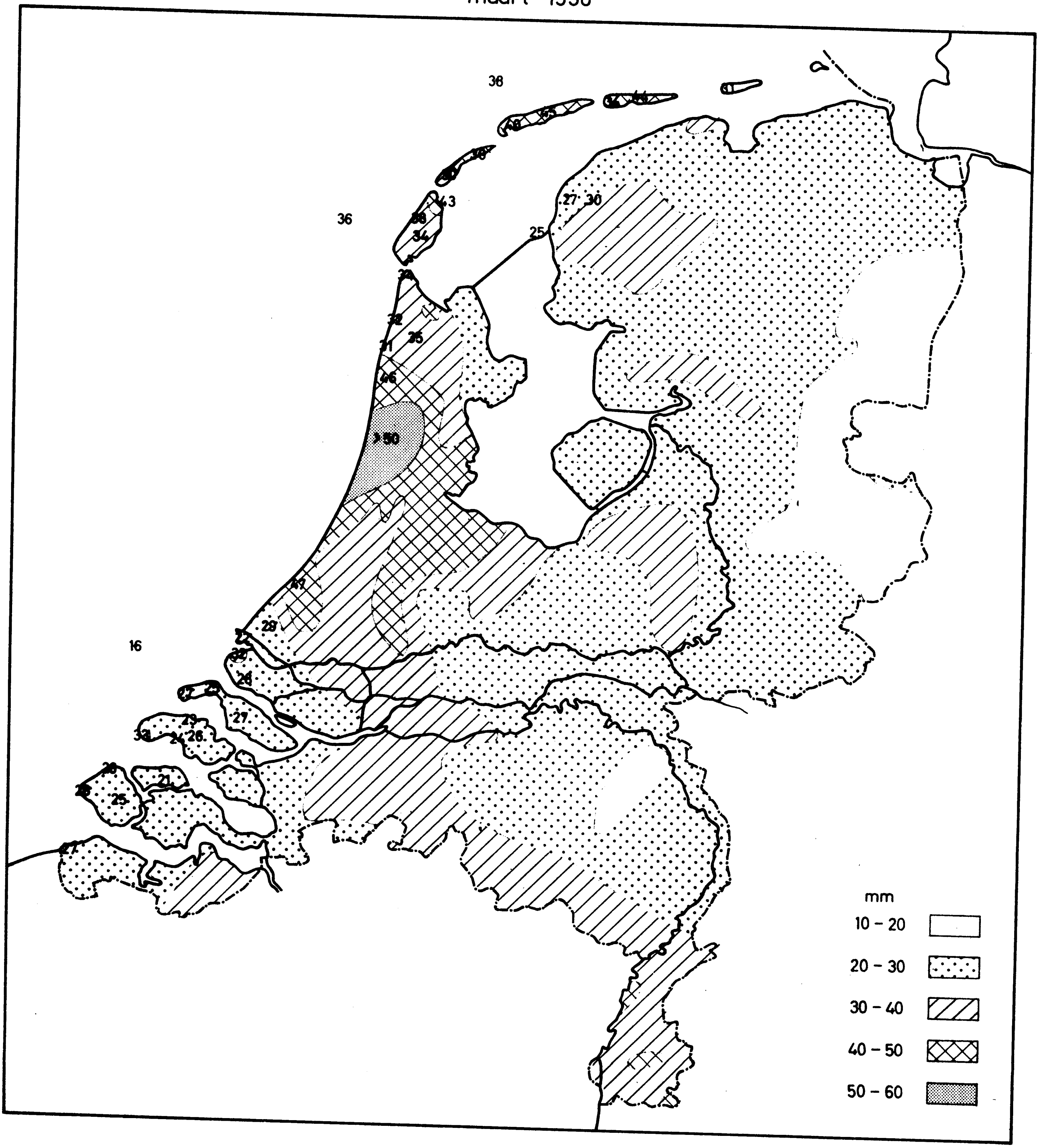
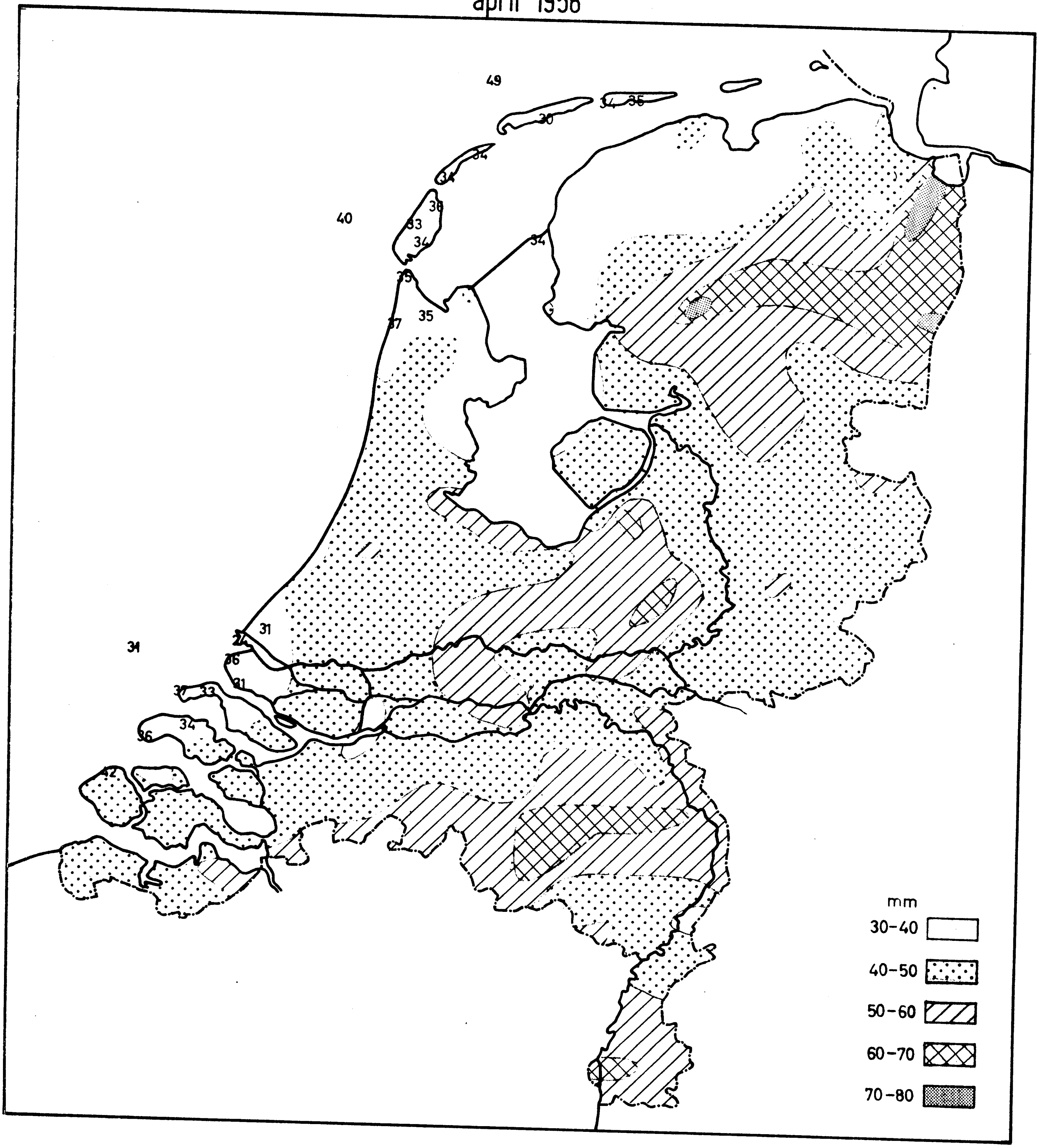


april 1958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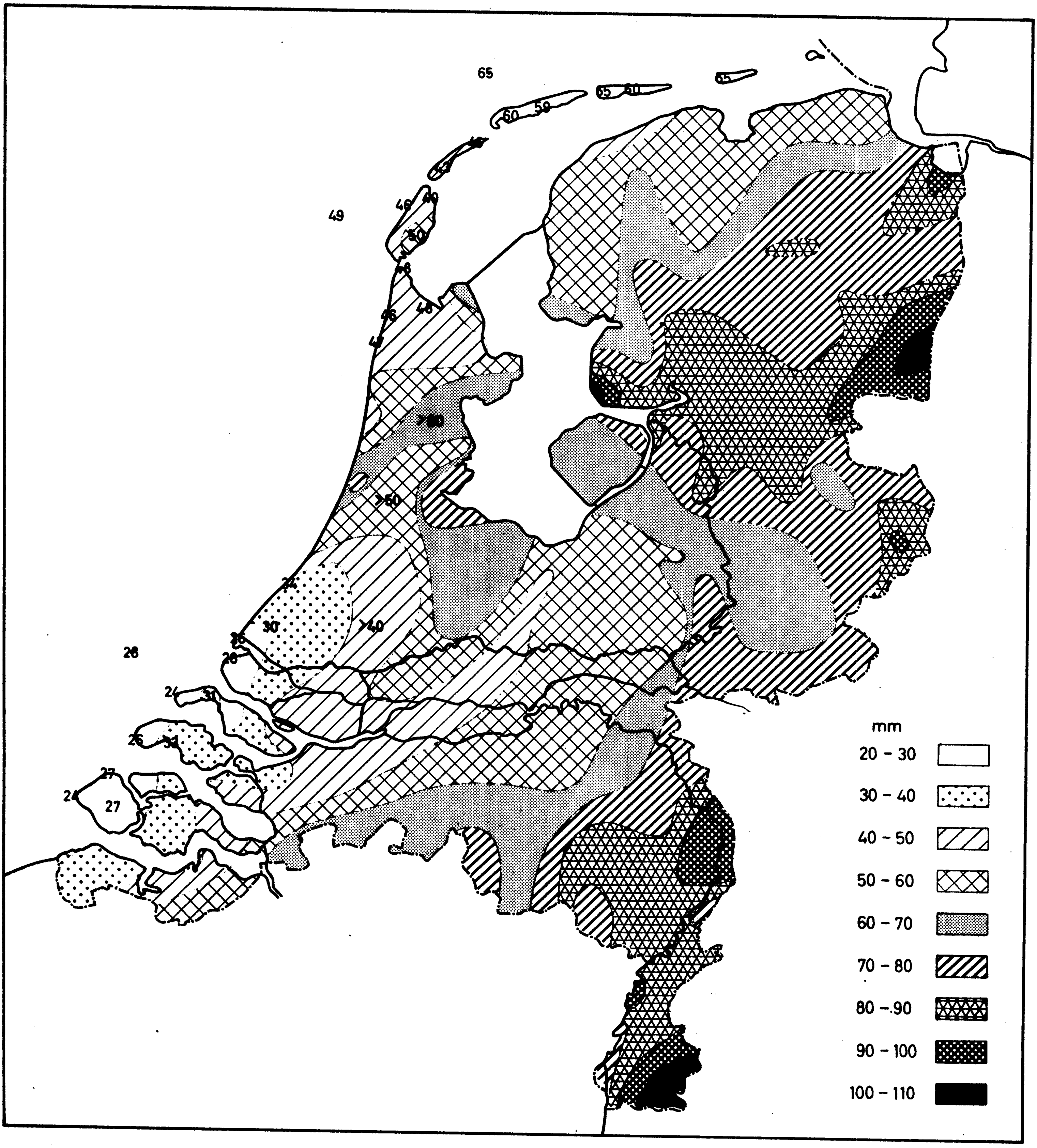

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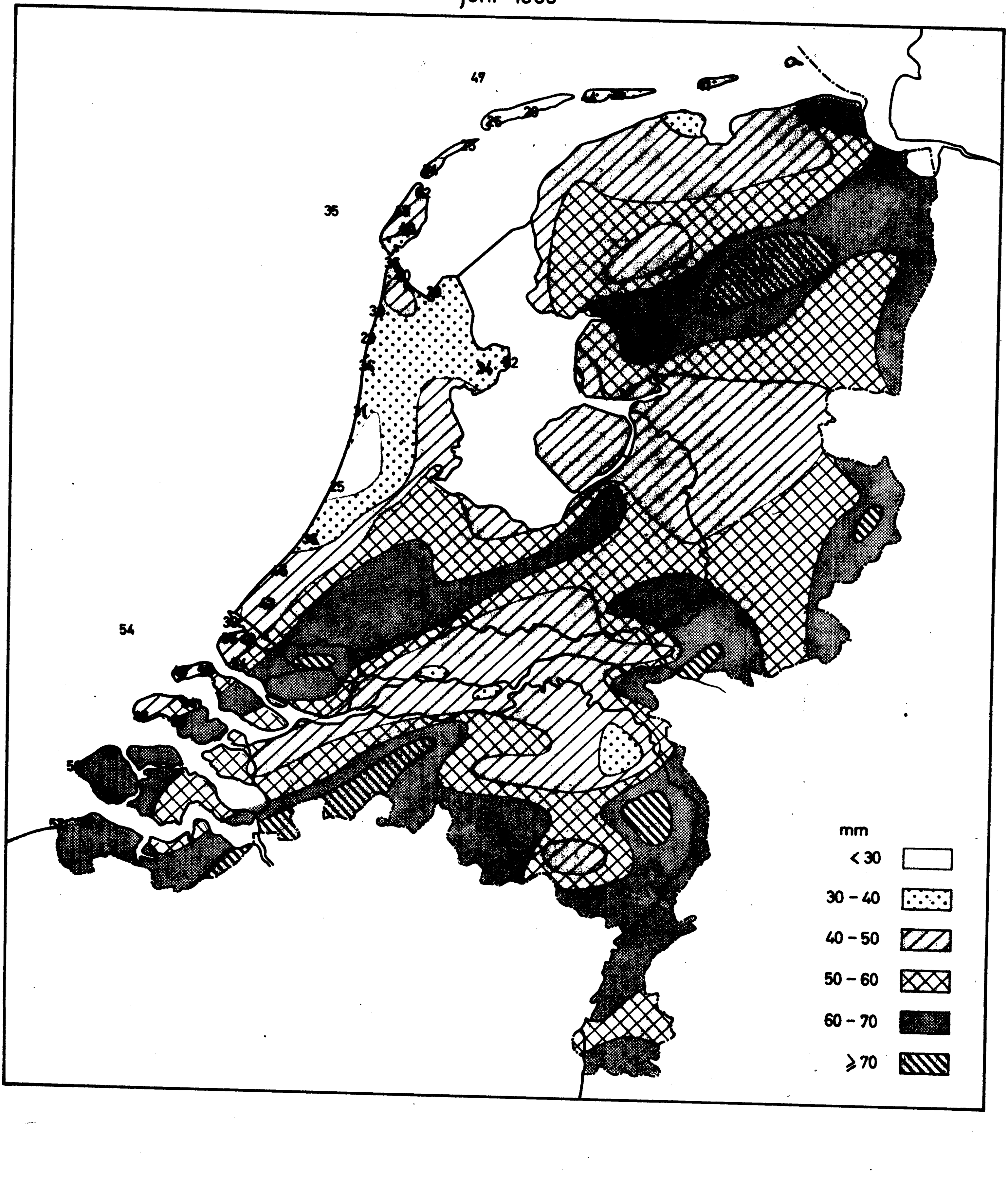

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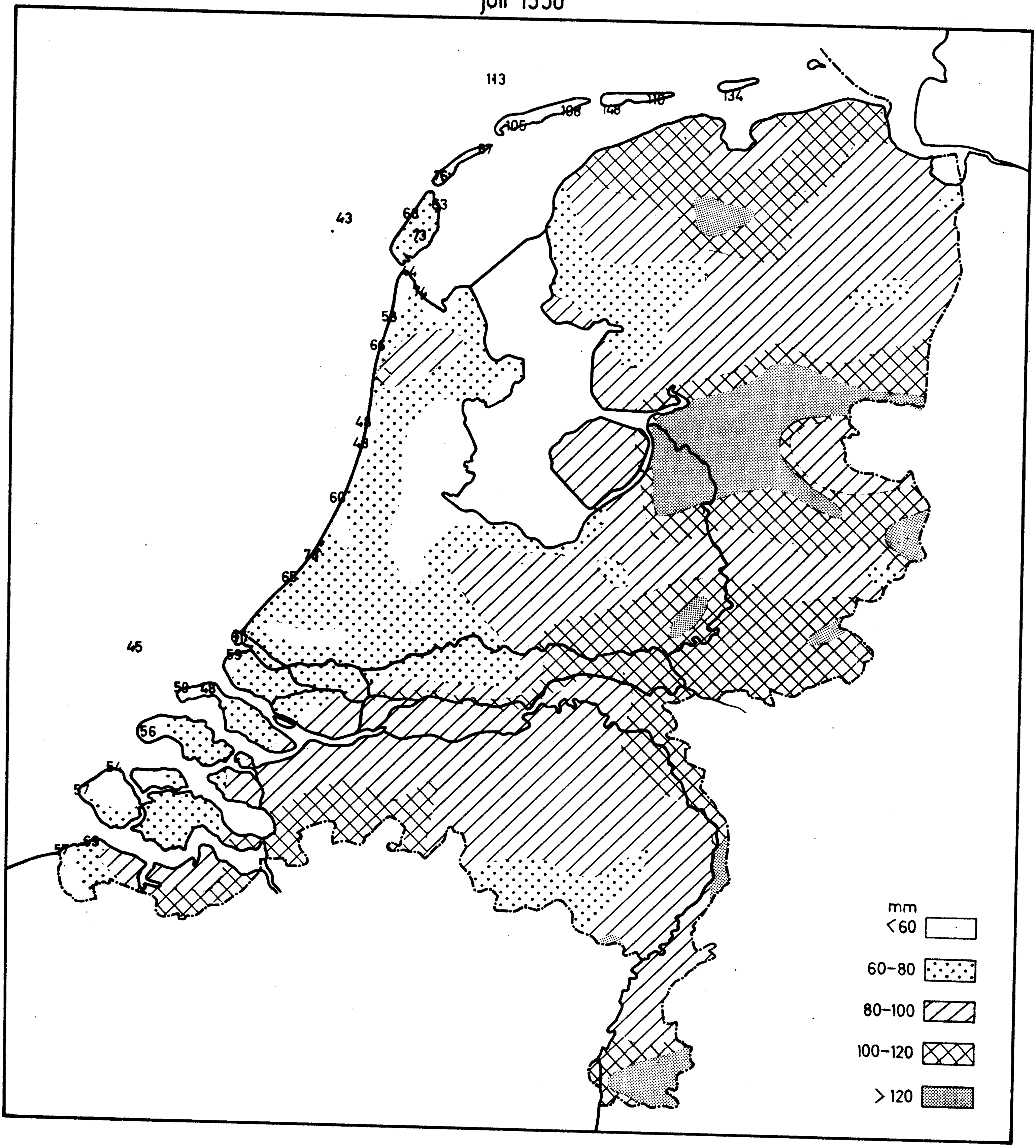
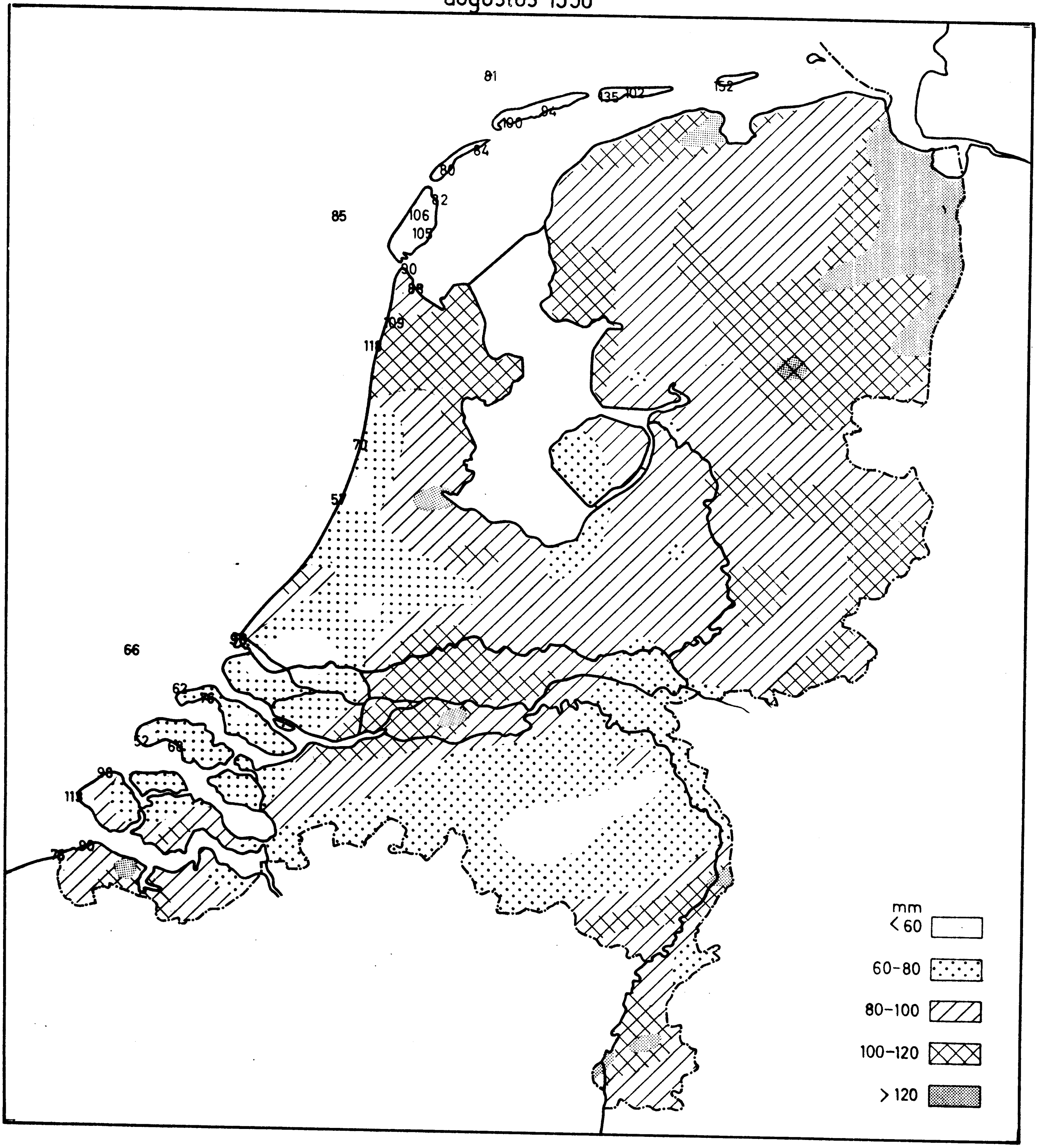


augustus 1958



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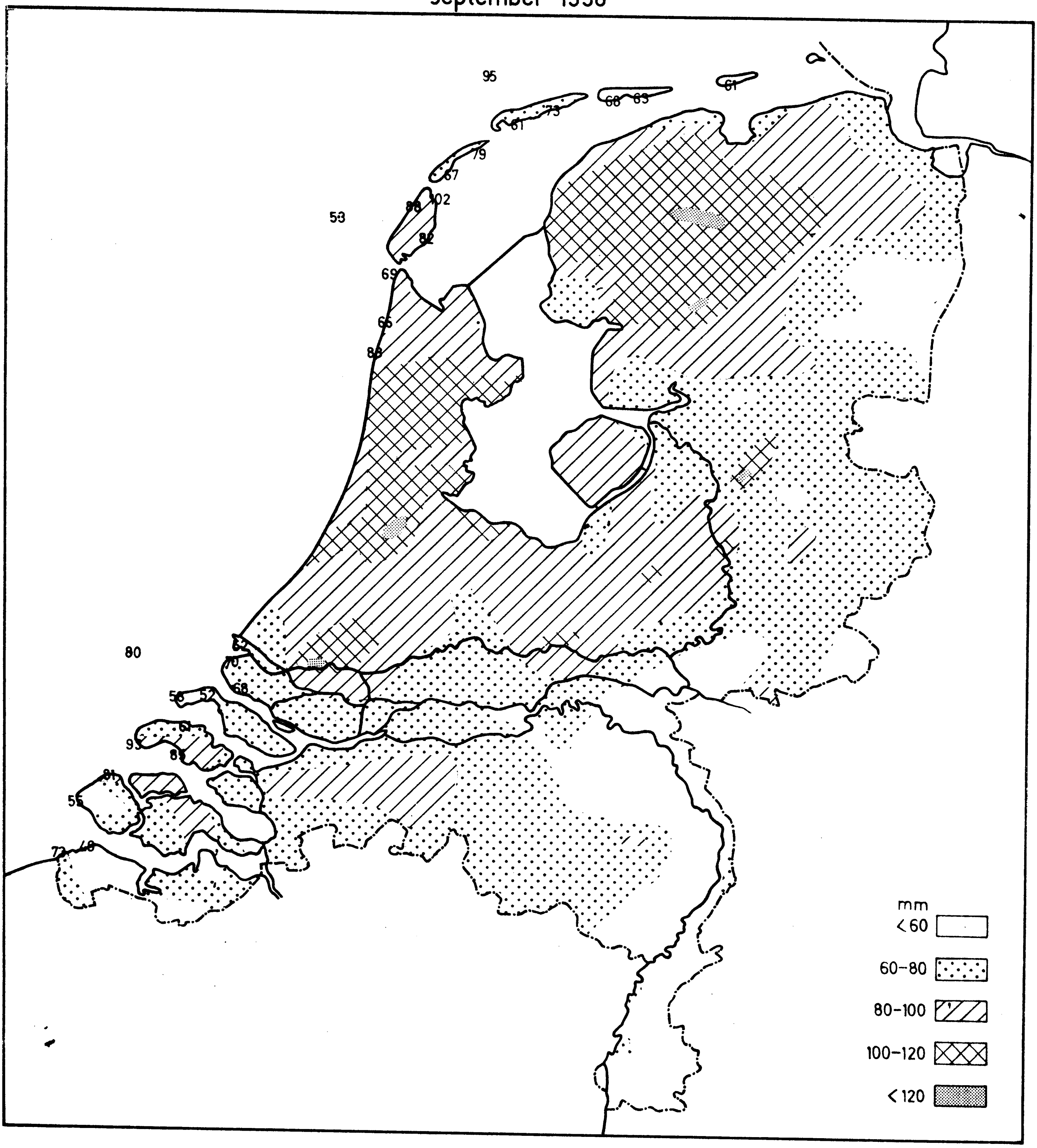

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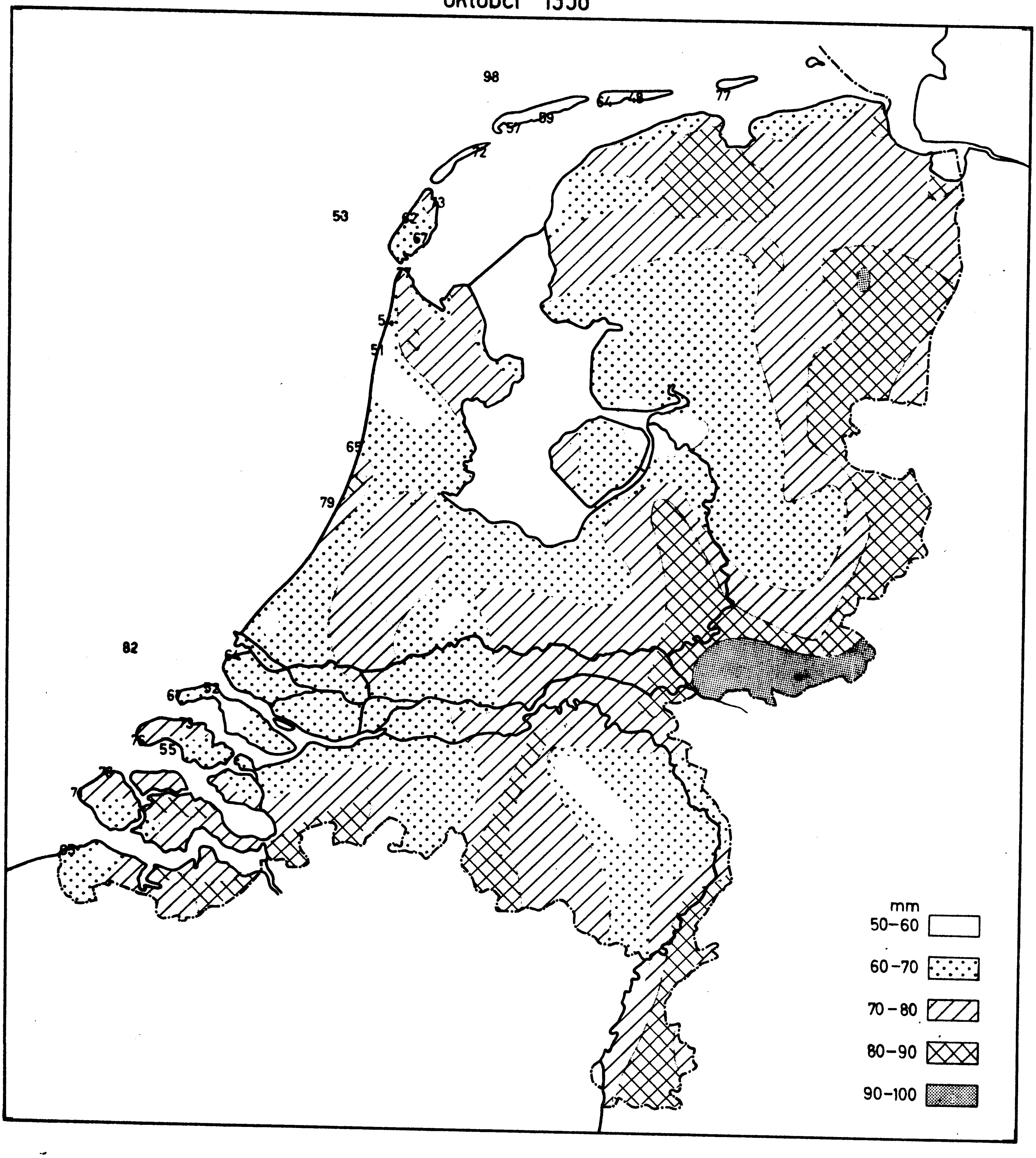
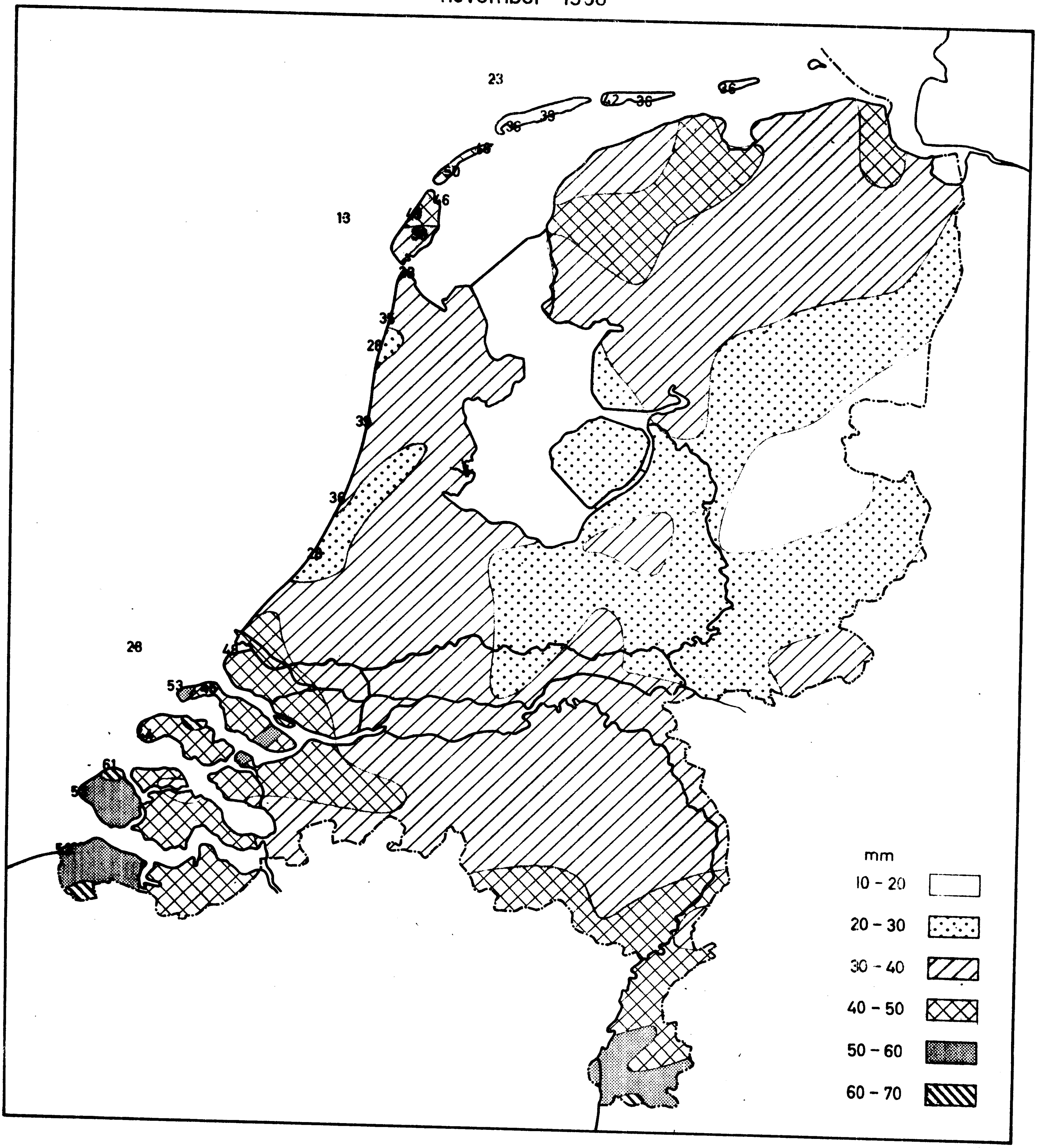


november 1958



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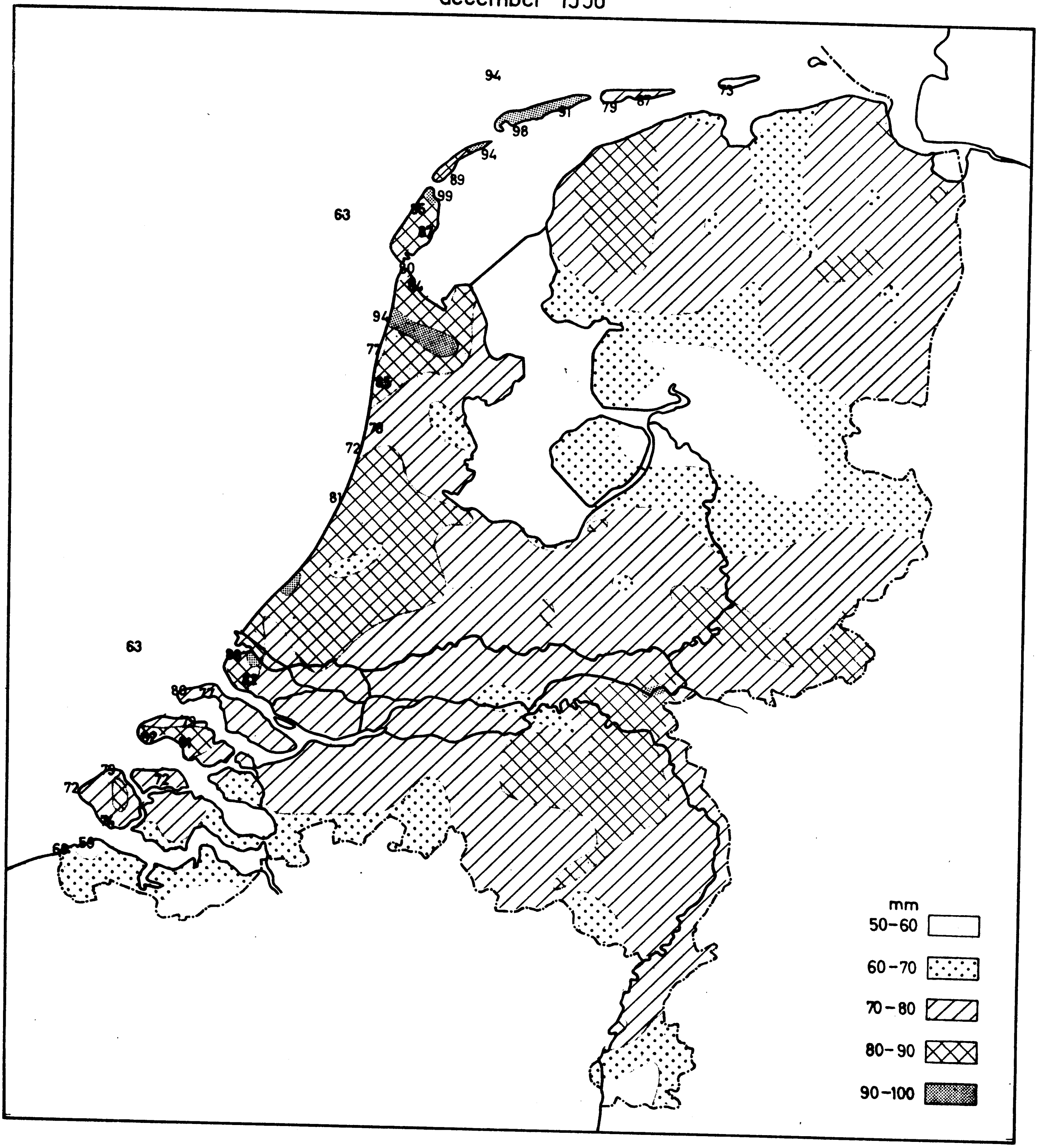

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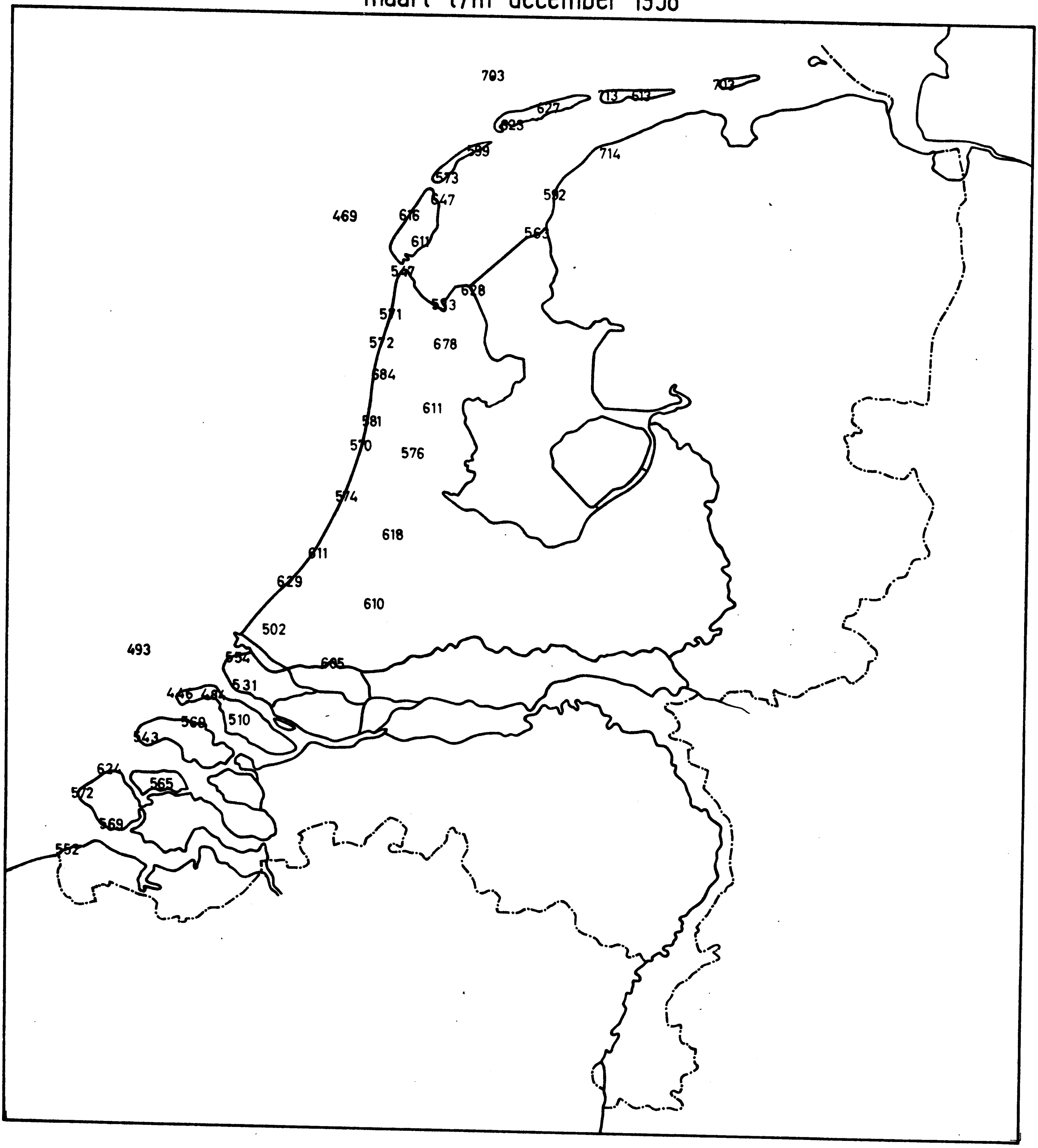
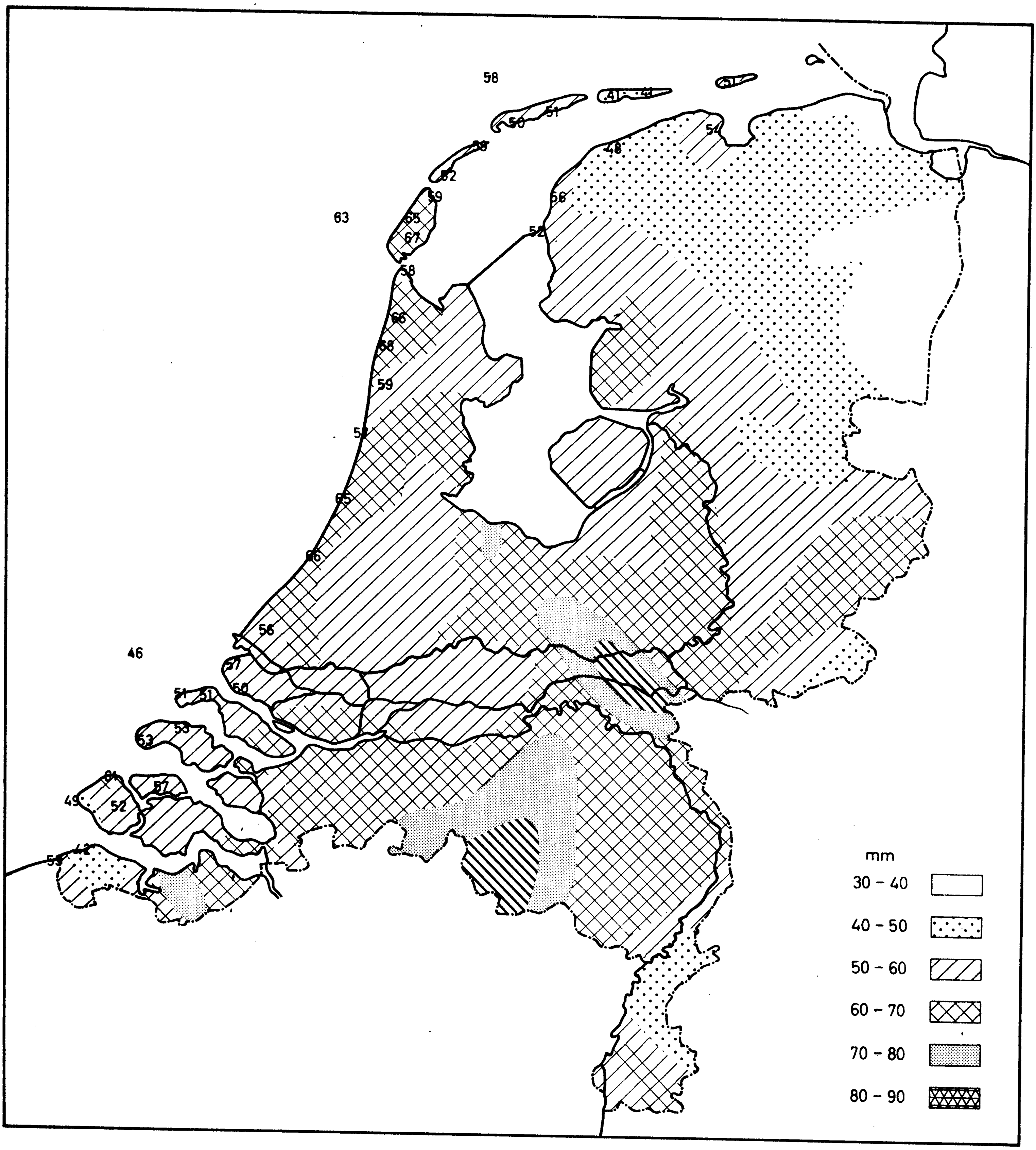


maart 1959



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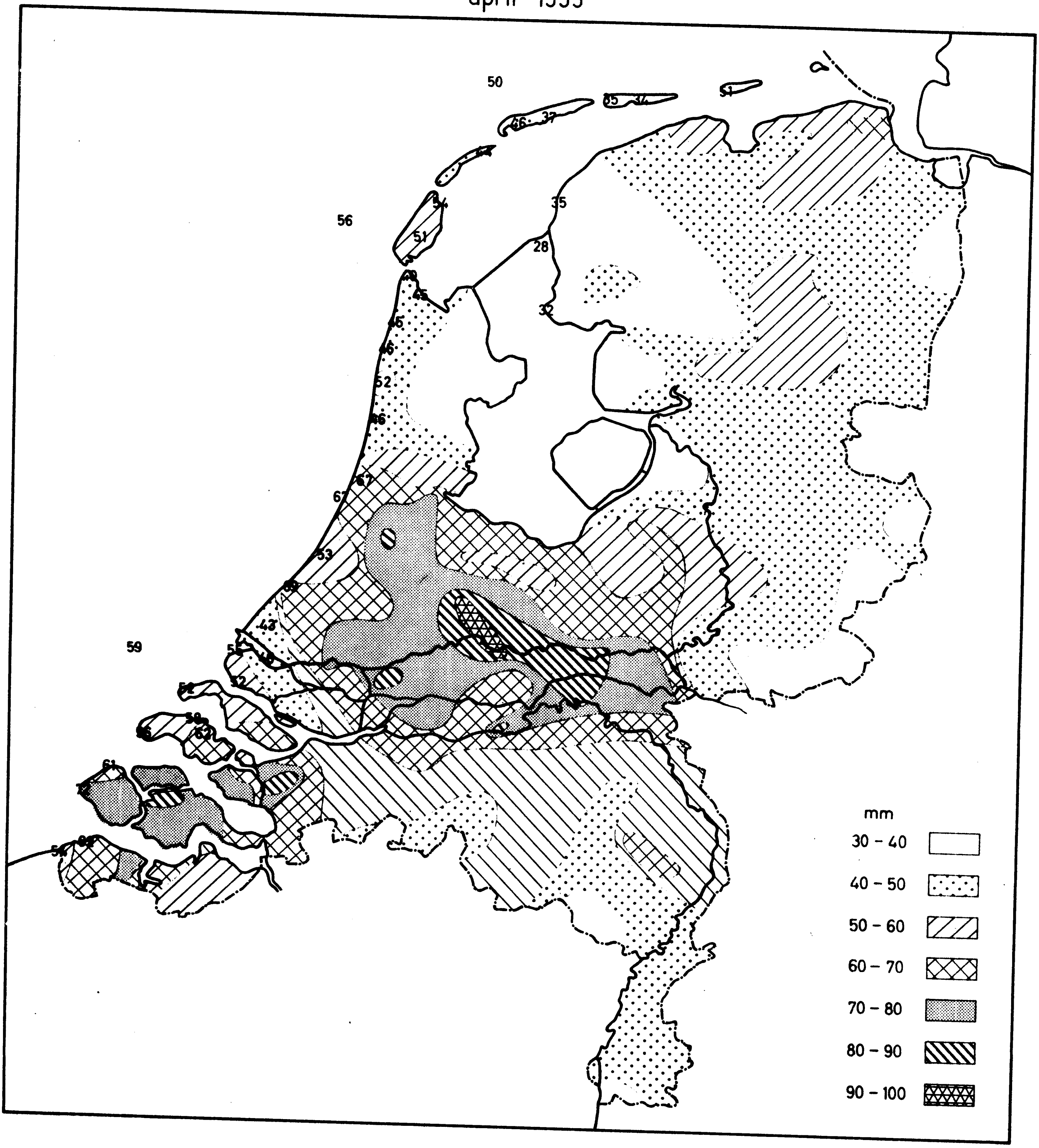
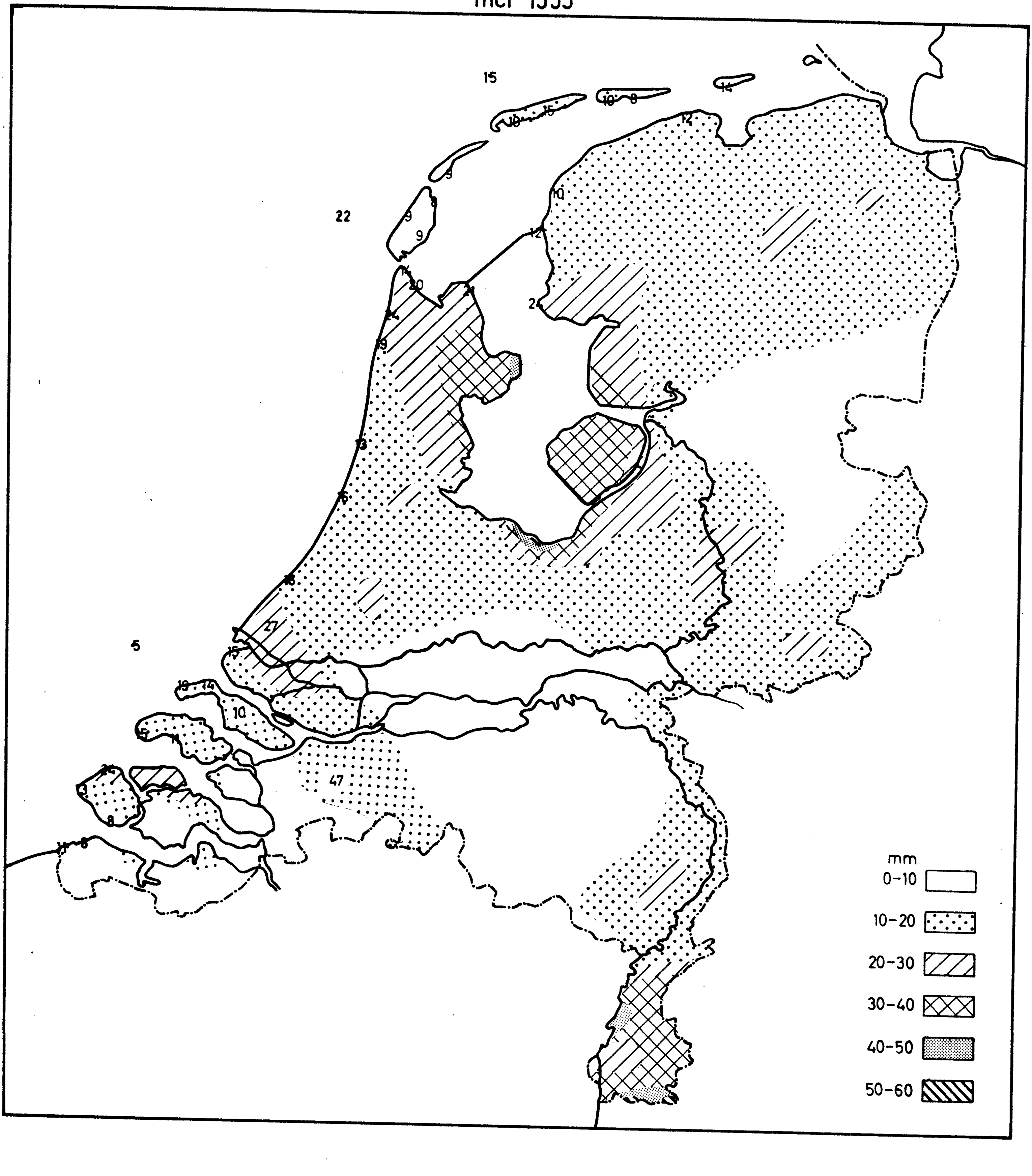
april 1959



mei 1959



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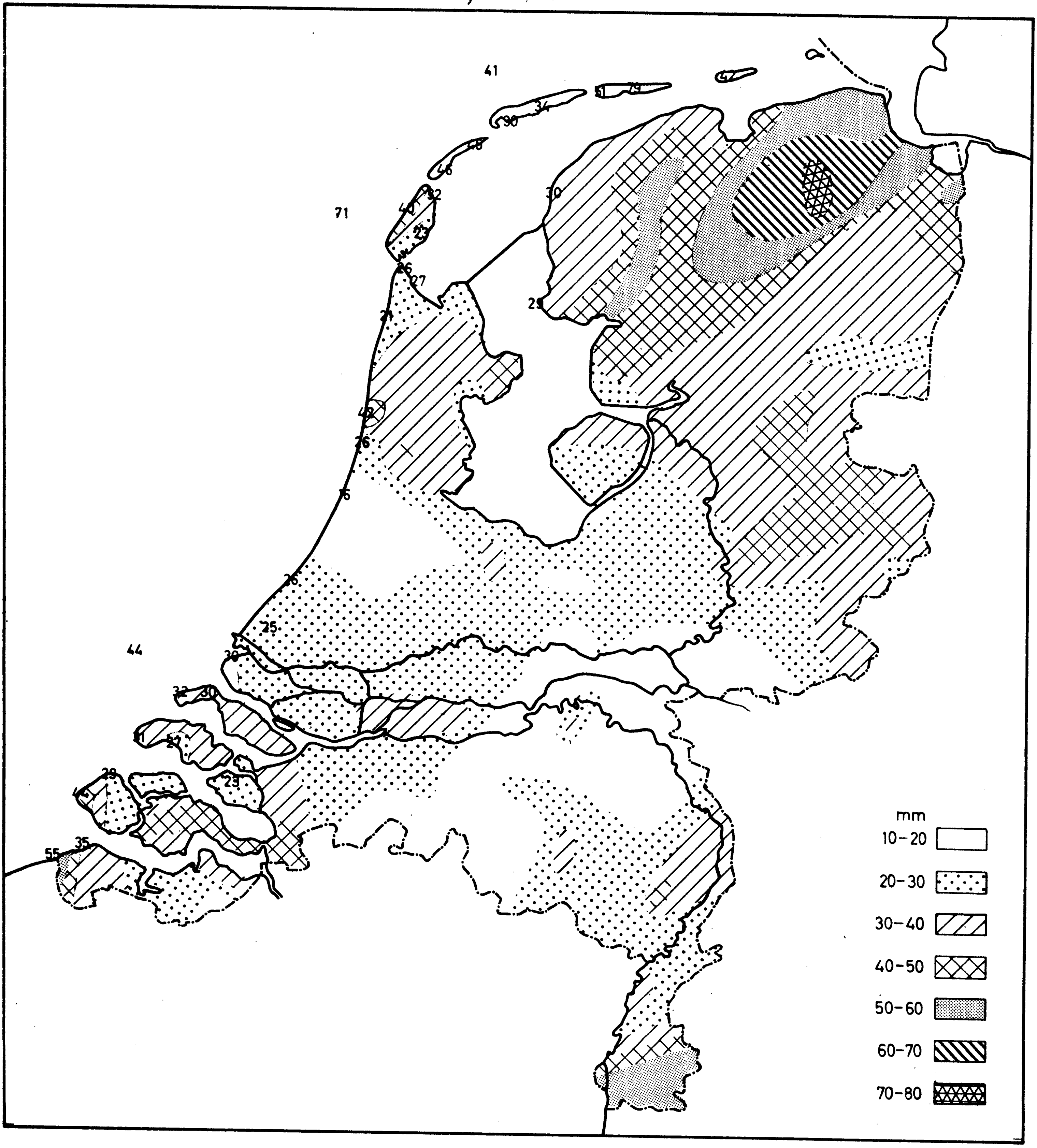
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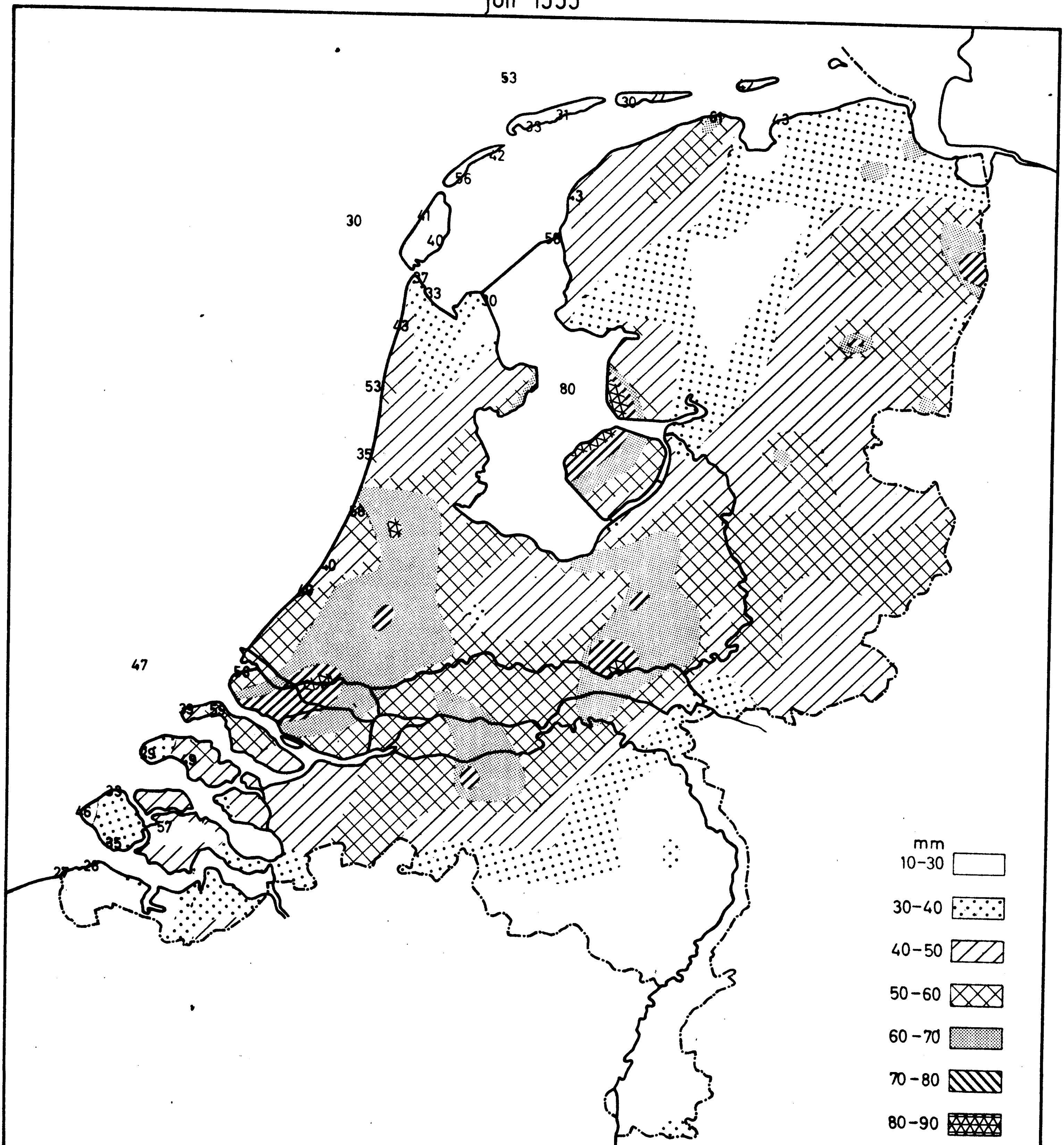
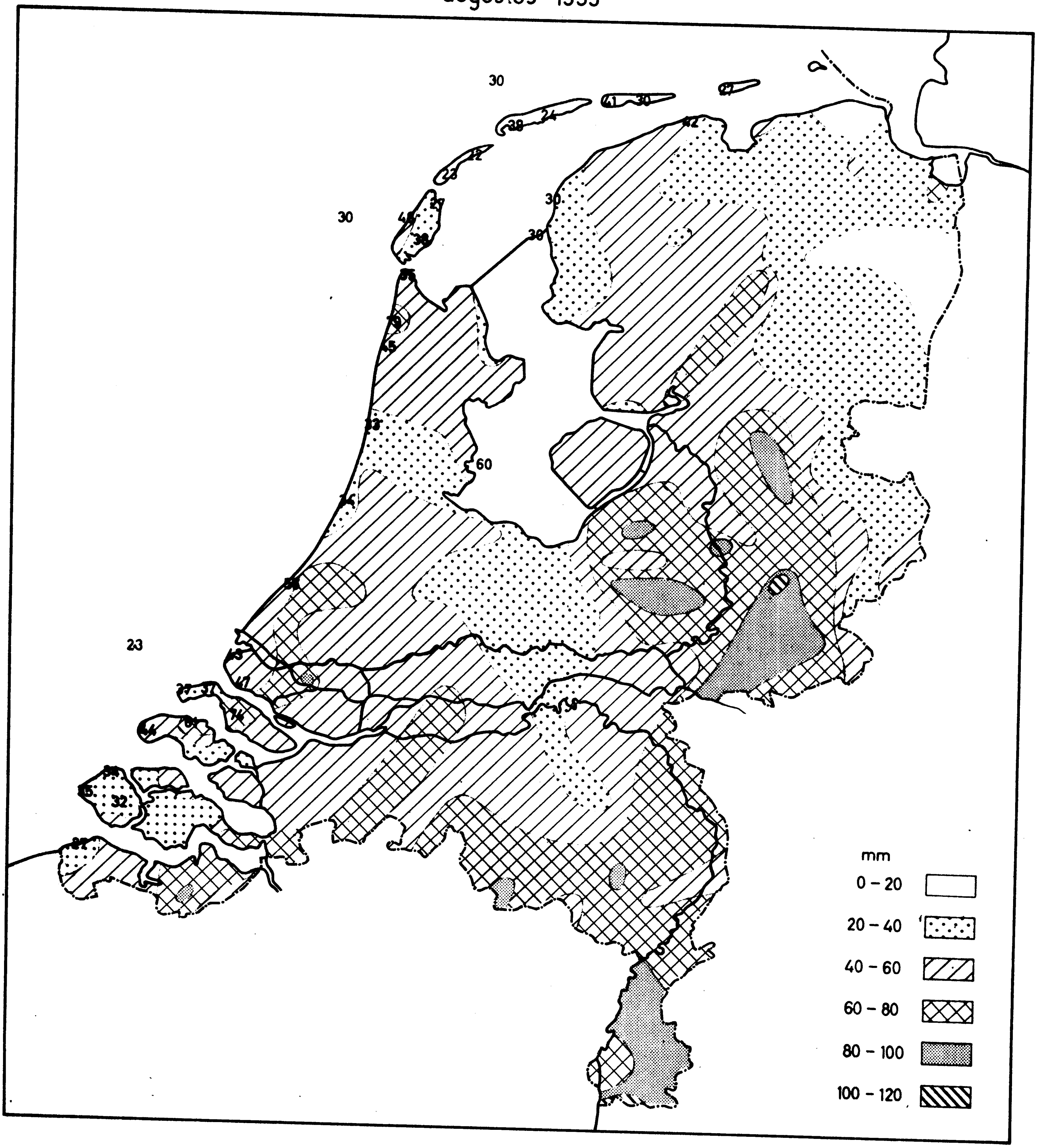
juli 1959



augustus 1959



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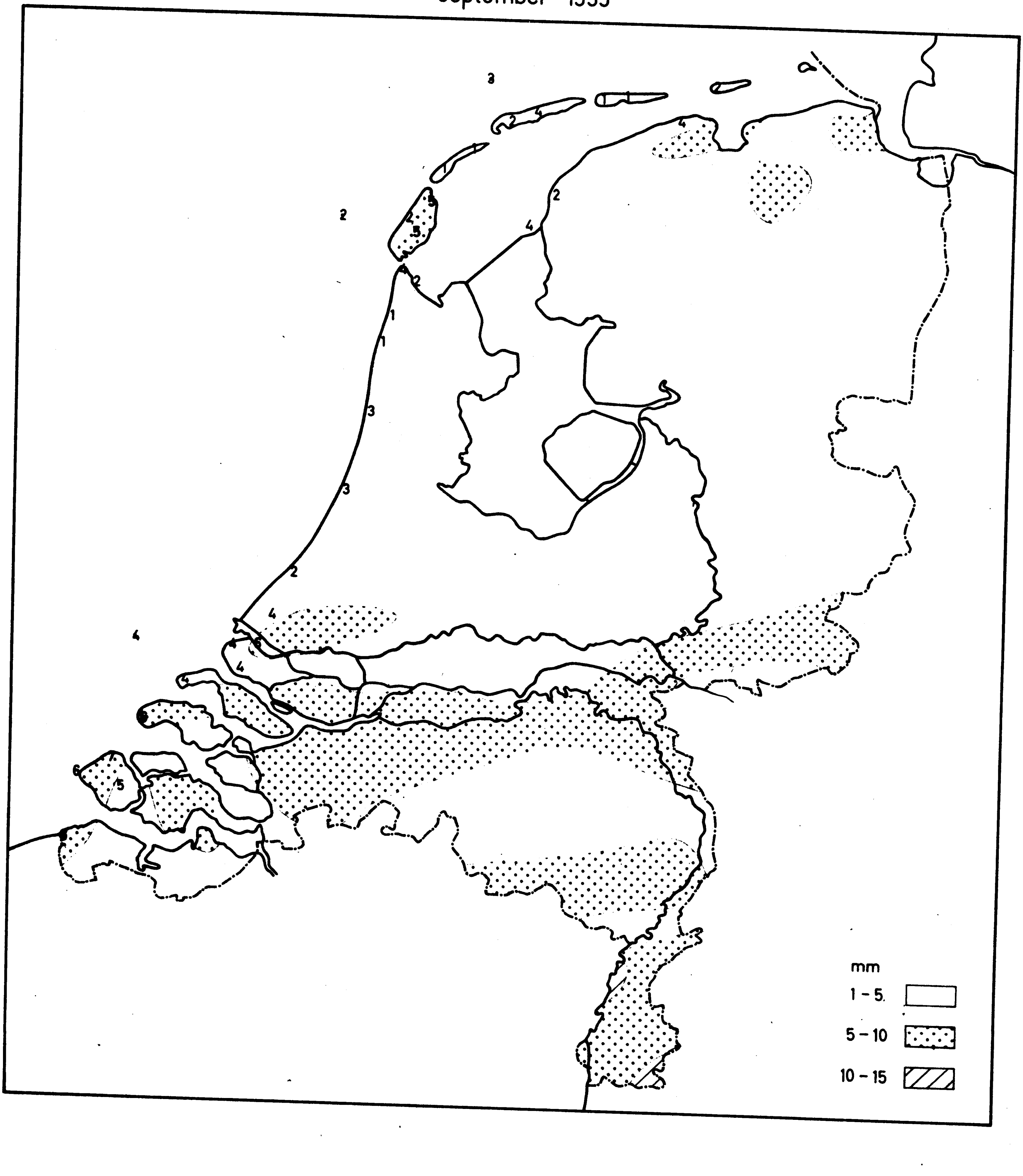

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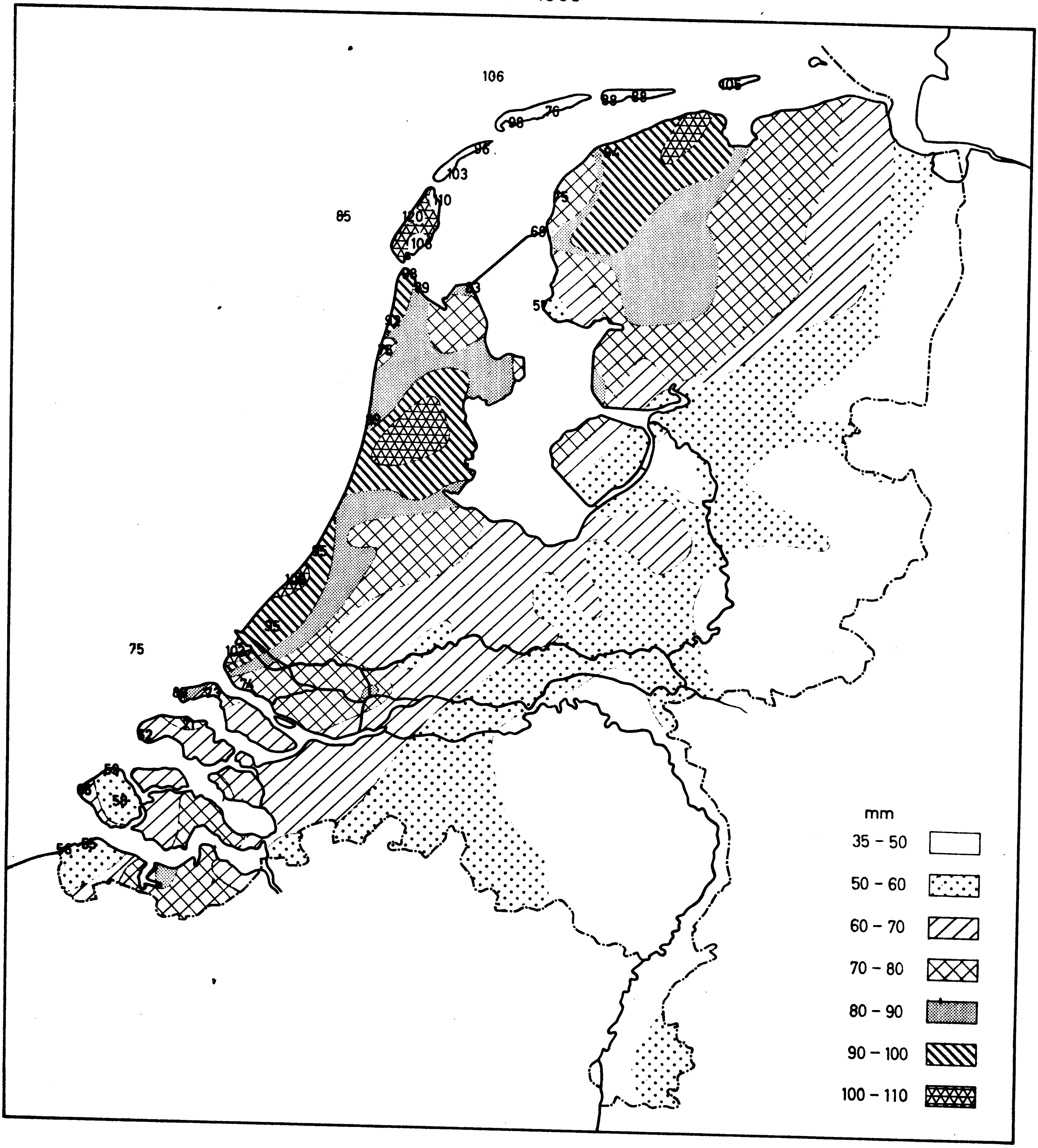

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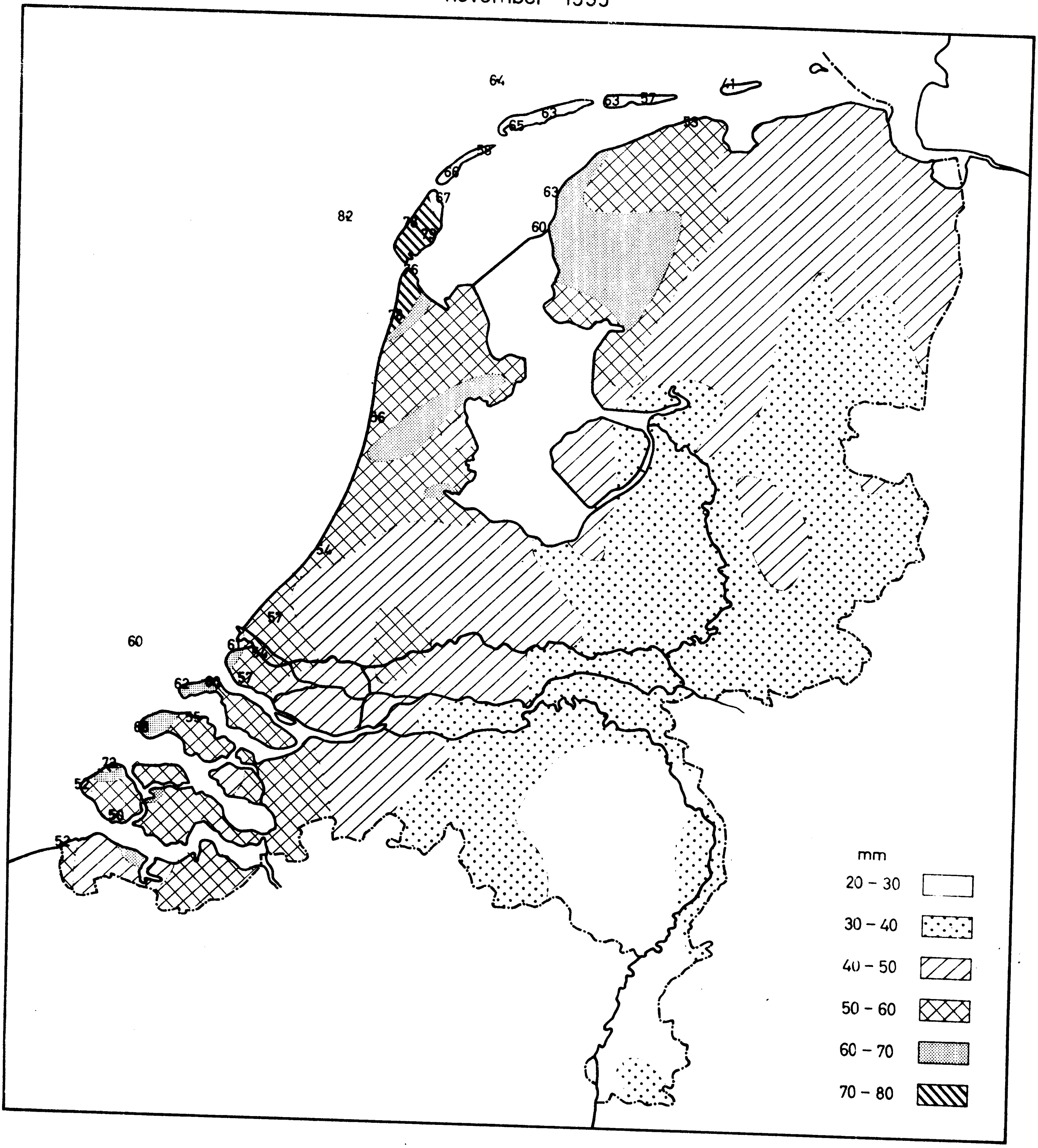
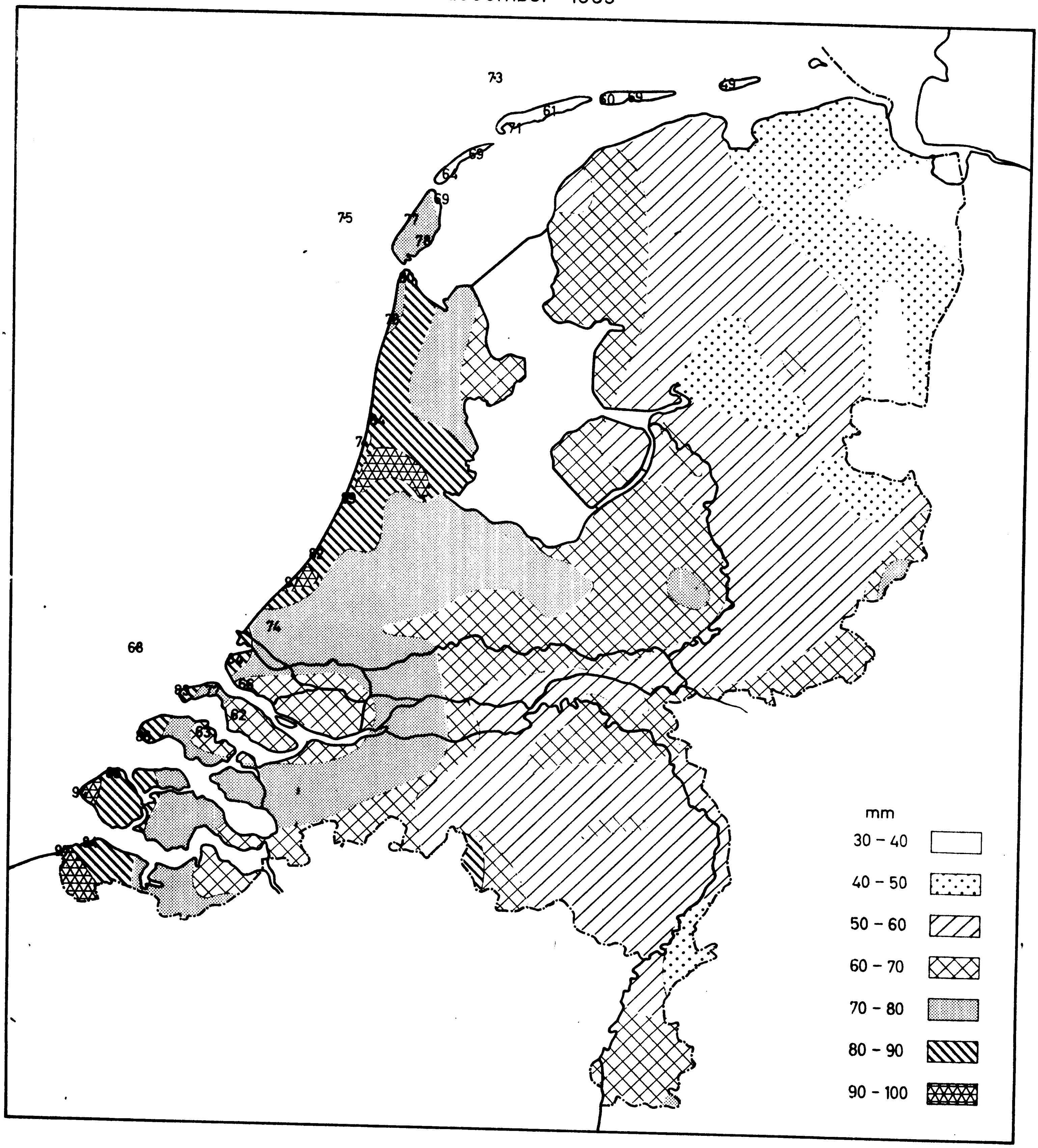


december 1959



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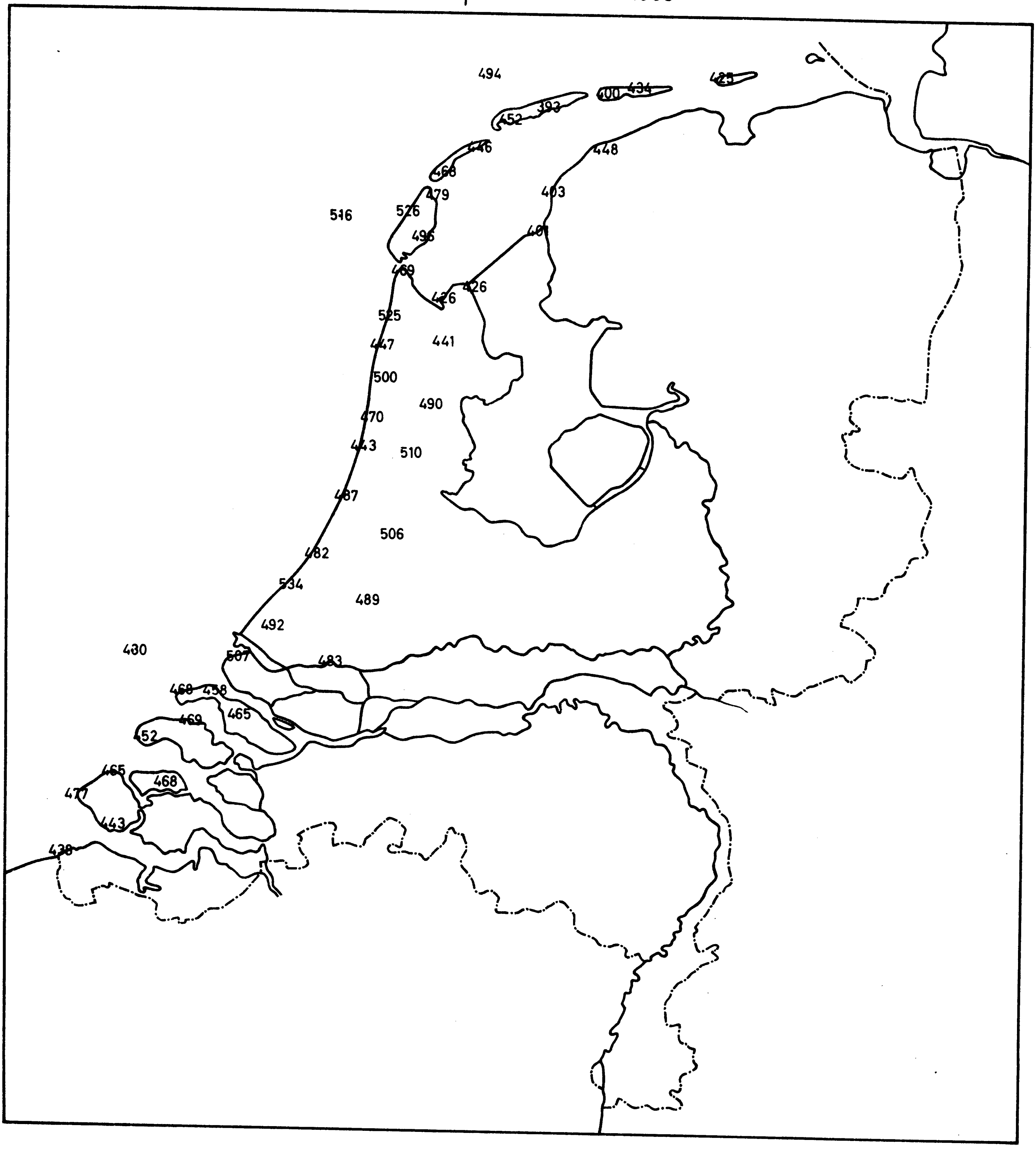

Percentage of the number of ¼ hours during which rain fell

Year 1958

Bft	March T.bank	March Texel	March Goeree	April T.bank	April Texel	April Goeree	May T.bank	May Texel	May Goeree
0	-	-	-	-	-	0.2	-	-	8.0
1	0.5	3.3	12.8	-	-	-	0.2	-	13.3
2	14.0	15.4	17.0	0.2	0.9	-	0.4	12.3	15.9
3	26.1	20.2	13.2	23.2	14.2	32.8	69.8	42.0	12.9
4	26.0	34.9	26.2	43.5	41.1	28.9	7.3	11.6	22.8
5	30.4	13.1	6.8	25.6	37.2	26.4	22.3	30.2	9.2
6	1.8	12.9	20.4	3.3	3.3	11.7	-	3.9	17.9
7	1.2	0.2	3.6	4.2	3.3	-	-	-	-
8	-	-	-	-	-	-	-	-	-

Bft	June T.bank	June Texel	June Goeree	July T.bank	July Texel	July Goeree	August T.bank	August Texel	August Goeree
0	-	0.6	-	-	-	-	1.6	-	3.8
1	0.3	-	-	1.9	10.1	5.4	18.8	2.3	2.3
2	12.7	15.3	20.7	24.1	25.2	34.1	27.0	23.5	15.7
3	46.6	42.7	12.0	18.0	14.2	18.7	19.9	30.5	18.0
4	23.5	16.8	48.1	25.2	15.3	20.5	17.9	30.9	27.3
5	16.9	24.6	15.6	7.8	16.6	17.0	11.6	12.8	15.1
6	-	-	0.9	18.6	18.4	3.7	2.9	-	17.8
7	-	-	2.7	4.4	0.2	0.6	0.3	-	-
8	-	-	-	-	-	-	-	-	-

Bft	September T.bank	September Texel	September Goeree	October T.bank	October Texel	October Goeree	November T.bank	November Texel	November Goeree
0	-	-	-	-	-	-	-	-	-
1	0.8	-	0.6	0.1	-	0.8	5.1	-	6.3
2	2.6	4.4	-	1.4	4.3	15.2	19.5	5.2	9.5
3	9.7	14.1	17.3	13.4	9.9	4.6	38.7	31.9	11.9
4	32.2	33.9	25.2	31.0	26.5	31.1	22.5	24.2	25.4
5	15.6	21.7	23.3	25.4	31.9	26.2	13.2	29.2	26.6
6	26.8	7.6	10.6	15.4	13.6	9.1	1.0	3.7	20.3
7	5.9	18.3	13.3	4.5	7.0	8.1	-	5.8	-
8	3.8	-	9.7	1.1	2.0	4.9	-	-	-
9	2.6	-	-	4.0	4.8	-	-	-	-
10	-	-	-	3.7	-	-	-	-	-

Bft	December T.bank	December Texel	December Goeree
0	-	-	0.4
1	1.3	4.2	2.3
2	10.3	1.5	3.4
3	17.7	12.5	16.6
4	11.7	28.4	26.7
5	21.0	25.0	39.9
6	30.5	22.1	7.4
7	7.5	6.3	3.3
8	-	-	-

Percentage of the number of ¼ hours during which rain fell

Year 1959

Bft	March T.bank	March Texel	March Goeree	April T.bank	April Texel	April Goeree	May T.bank	May Texel	May Goeree
0	-	10,9	-	-	-	-	-	-	-
1	17.2	0.7	7.2	2.3	0.7	-	-	-	4.8
2	7.9	1.4	1.4	8.5	8.2	2,5	0.7	1.1	1.0
3	36.0	45.5	27.8	11.4	3.5	11,6	37.7	18.6	29.5
4	27.9	13.4	54.7	14.3	24.0	16.9	35.7	29.1	24.1
5	-	24.0	6.9	39.8	22.1	27.4	25.2	41.0	1.0
6	5.2	0.1	2.0	19.0	11.3	20.5	0.7	10.2	39.6
7	5.8	2.6	-	4.7	30.2	13.5	-	-	-
8	-	1.4	-	-	-	7.6	-	-	-
9	-	-	-	-	-	-	-	-	-

Bft	June T.bank	June Texel	June Goeree	July T.bank	July Texel	July Goeree	August T.bank	August Texel	August Goeree
0	-	-	-	-	-	-	-	-	-
1	-	-	-	-	-	15,6	10,7	1.6	1.2
2	11.1	-	14.2	6.7	3.4	7.4	-	2.4	1.8
3	13.5	13.7	20.9	32.7	21.3	15.6	7.8	13.6	16.4
4	11.9	2.3	26.8	27.9	33.8	17.6	55,6	36.8	55.1
5	53.2	25.8	9.6	7.7	13.7	8.9	25.9	44.0	19.4
6	-	35.3	28.5	25.0	17.9	29.0	-	1.6	6.1
7	10.3	21.6	-	-	9.9	5.9	-	-	-
8	-	1.3	-	-	-	-	-	-	-
9	-	-	-	-	-	-	-	-	-

Bft	September T.bank	September Texel	September Goeree	October T.bank	October Texel	October Goeree	November T.bank	November Texel	November Goeree
0	-	2.2	-	-	-	-	-	-	-
1	-	-	3.6	-	-	-	1.4	-	-
2	2.2	-	-	-	-	3,7	3.8	1.6	1.1
3	41.7	40.6	-	-	1.2	8.5	9,9	13.2	4.1
4	21.3	23.1	10.7	14.3	4.9	9.9	58.7	54.9	40.3
5	34.8	6.6	25.0	29.8	10.4	5.1	11.8	8.4	13.4
6	-	27.5	60.7	26.8	22.0	25.9	1,5	10.0	15.0
7	-	-	-	23,6	38.8	10,8	1,4	5,6	17.2
8	-	-	-	-	3.8	19.5	8,6	6.3	6.8
9	-	-	-	5.5	18.9	7.6	2,9	-	2.1
10	-	-	-	-	-	7.9	-	-	-
11			-			1.1			-

Bft	December T.bank	December Texel	December Goeree
0	-	-	-
1	2.0	-	0.4
2	3.2	2.3	1.4
3	7.2	1.0	-
4	21.2	1.8	10.7
5	19.8	21.8	22.9
6	24.8	29.9	32.1
7	8.9	25.8	26.0
8	10.1	14.7	6,4
9	-	2.7	0.1
10	2.8	-	-