CONTROL OF THE WATERLEVEL IN FAINTLY SLOPING AREAS [1]

F. VAN SCHAGEN

Cultuurtechnische Dienst, Utrecht, Netherlands (Governmental Service for the Planning, Projecting and Subsidising of Rural Development Schemes)

1 Introduction

The Netherlands are well known for their flat, artificially drained, lowlying country, being naturally the delta of the rivers Rhine, Maas and Scheldt.

However, on close inspection this only comes true for the northern and western part of the country, which is as flat as a pancake, a great deal lying below normal sealevel.

The rest of the country, the central, southern and eastern part is more or less sloping (inclined) and therefore a water control in this higher part of the country has to be different from the water control in the lower part (see figure 1).

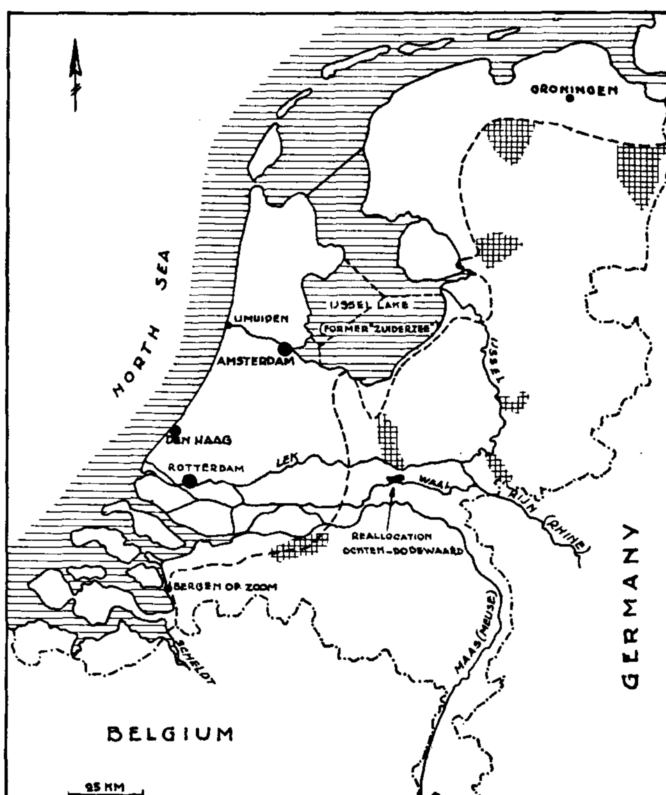


Fig. 1. General map of the Netherlands (1)
The dotted line divides the country into a high eastern part and a low western part. Crosshatching marks relatively low areas that suffer from excess water coming from the higher lying soils.

1) Received for publication April 14, 1953.

In the former case the run-off and outflow takes place by the action of the gravitation, i.e. in a natural way (which is the general occurence all over the world, although elsewhere the slopes of the areas concerned are mostly steeper than those in the Netherlands). In the latter case it follows an artificial way: the excess of water has to be pumped up (to get rid of it) which is accomplished by means of more than 2200 pumping units, windmills included, in total in that part of the country.

As the article of HELLINGA (1952) deals with the already long existing watercontrol in the above mentioned low-lying areas – the so-called "polders" – this article shall describe the recently created watercontrol in faintly sloping areas which lie above sealevel and where the water tends to flow slowly downwards to the sea, flooding their banks as soon as there is any excess of water unless they are prevented from doing so by embankments.

2 HISTORICAL DEVELOPMENT

What has been the cause of this new trend in watercontrol? To answer this question it is not necessary to go far back in history. Only a short time ago the State and the catchment boards merely argued on the question in which way they could get rid of the excess of rain- and seepagewater which chilled the soil too long in spring, or threatened to suffocate the roots of the crops in summer because after heavy rainfalls the poor drainage systems retained the water in the ditches too much.

In particular the lower brookvalleys were liable to longlasting floodings and, in consequence, rendered low yields per acre.

But owing to the increase of our population with one percent every year, at the same time there is a strong necessity for the increase of the food production.

Consequently, several measures were taken to get a higher production, e.g. all types of soils were ameliorated and improved (by means of reclaiming, levelling, use of artificial manure, composting, etc.), especially the sandy soils covered with heather.

On the other hand, several perfectly working drainage systems were set up in the lowerlying brookvalleys, creating in this way a larger acreage of better yielding fields. We are still busy creating new ones.

However, the dry years of 1947 and 1949 have clearly shown that we overstepped the mark and that we were going too far with only improving our drainage systems and not simultaneously preventing the rainwater from running to waste.

After heavy rainfalls it has been observed in improved areas with cleared ditches that the outflow accumulated into one big wave and very rapidly disappeared into the adjacent rivulets and rivers, thus being prevented from adding to the supply of the groundwater.

Therefore, in those years several areas were subjected to severe drought symptoms. Especially those crops were spoiled on soils which by nature are sensitive to a certain degree of drought, or, with other words, have a low water capacity. In these days people began to regret very much to have spoiled the retention power of more or less improductive marshes and low-lands.

In those years the idea of the necessity of a perfect watercontrol for the future, although already born, was strengthened.

As there were lots of undissolved questions to be answered, the Central National Council for Applied Scientific Research already in 1946 set up a

Committee for Hydrological Research T.N.O., in which all national agencies interested were represented. This Committee recently published the lectures which have been presented at the technical meetings from 1946–1950 (HYDROLOGISCH ONDERZOEK TNO, 1952).

Although these investigations are not yet terminated, they point to the conclusion that watertables, constantly higher or lower than the optimum watertable may cause severe reductions in the yield. More or less the same damage occurs owing to large fluctuations of the watertable (VISSER a.o., 1951/1952).

To cope with these undesirable reductions in the yield, there exists a most effective solution which is, as already has been indicated before, watercontrol, the definition of which now runs as follows: "maintaining a well balanced system of drainage and irrigation (supply of water) in order to keep the watertable or the groundwater level as constant as possible at a certain depth under the average landsurface, dependent from the season, the composition of the soil and the vegetation".

As the roots of the plants only grow in spring, summer and autumn, it is of the greatest importance to have the control of the waterlevel sufficiently settled during that period.

In the Netherlands this implies the building of weirs and inlets (outlets) and laying of tiledrains for infiltration in addition to the already mentioned improving of the drainage systems.

3 WATER QUANTITIES NEEDED

Before starting such expensive measures however, a very important question had to be answered: will there be enough water from the rivers and brooklets, that if distributed on the fields, it keeps up with the evaporation in summer, even if there is no rain?

MESU (1951) and THIJSSE (1951) in their lectures at Wageningen on the 13th of July 1951, gave an idea of the water quantity needed for agricultural purposes. This quantity varies strongly per season: the evaporation exceeds the rainfall by 100 to 200 mm and this difference is withdrawn from the soil by the crops and has to be supplied: consequently 100 to 150 mm on the average are needed for raining upon the surface, and about 200 to 250 mm are needed for infiltration or sub-irrigation.

On the average, 200 mm per season is needed. In future about 12 000 km^2 of our cultivable land will need this watersupply from May till September, which means that some 2.5 milliard m^3 water are needed or some 300 m^3/sec or some 0.25 l/sec/ha on the average and 0.47 l/sec/ha in the driest period, this being 4 mm a day [2]).

It is estimated that there is about 3 times as much fresh water needed for fighting back the salt frontier in the western provinces. All this water must come principally from our main river Rhine and as in dry periods this river cannot furnish such a quantity of water, this means that in future there will be a shortage as soon as our system of water supply will function correctly.

If the proposals made by Prof. THIJSSE and by Dr MESU, viz. to close the south-western sea-arms and estuaries (the flood of Febr. 1st 1953!), to heighten the waterlevel of the IJssellake with one meter, to endike the Waddensea and

[2]) 1 m = 3.28′; 1 mm = 0.001 m = 0.394″; 1 km^2 = 100 ha = 247 acres; 1 m^3/sec = 1.308 cub yard/sec; 1 l/sec/ha = 0.0143 cub foot/sec/acre.

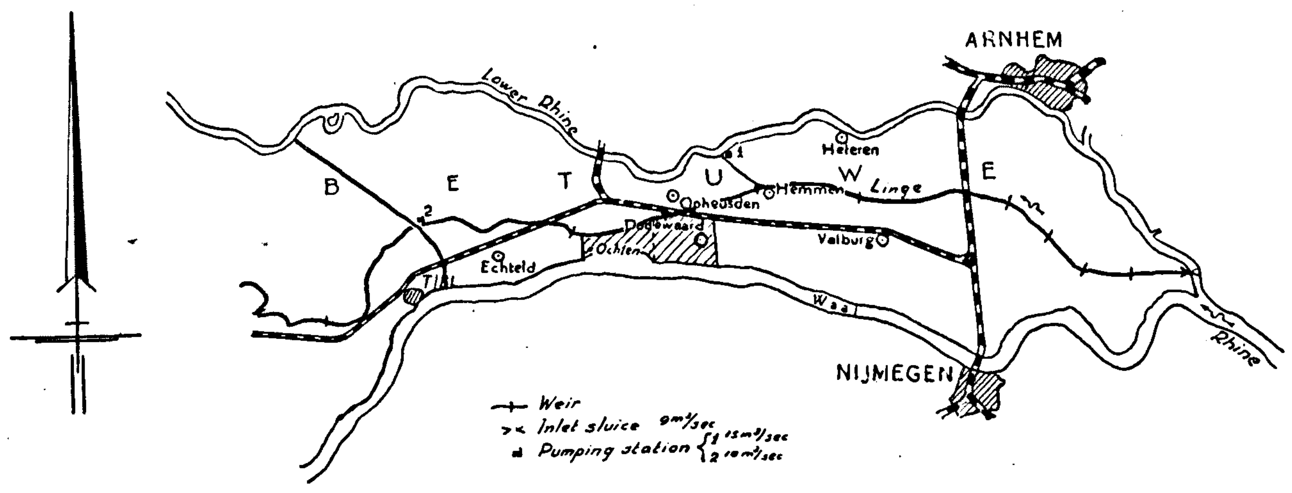


fig. 3

REALLOCATION OCHTEN-DODEWAARD

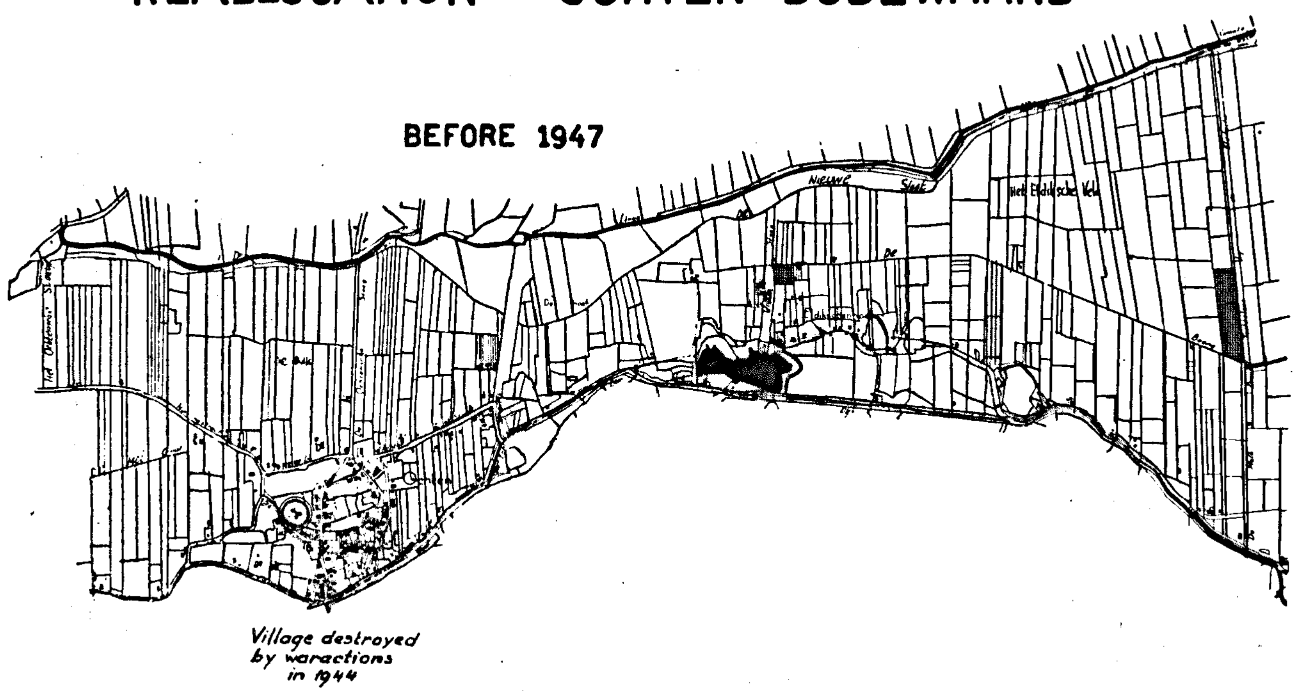


fig. 4a

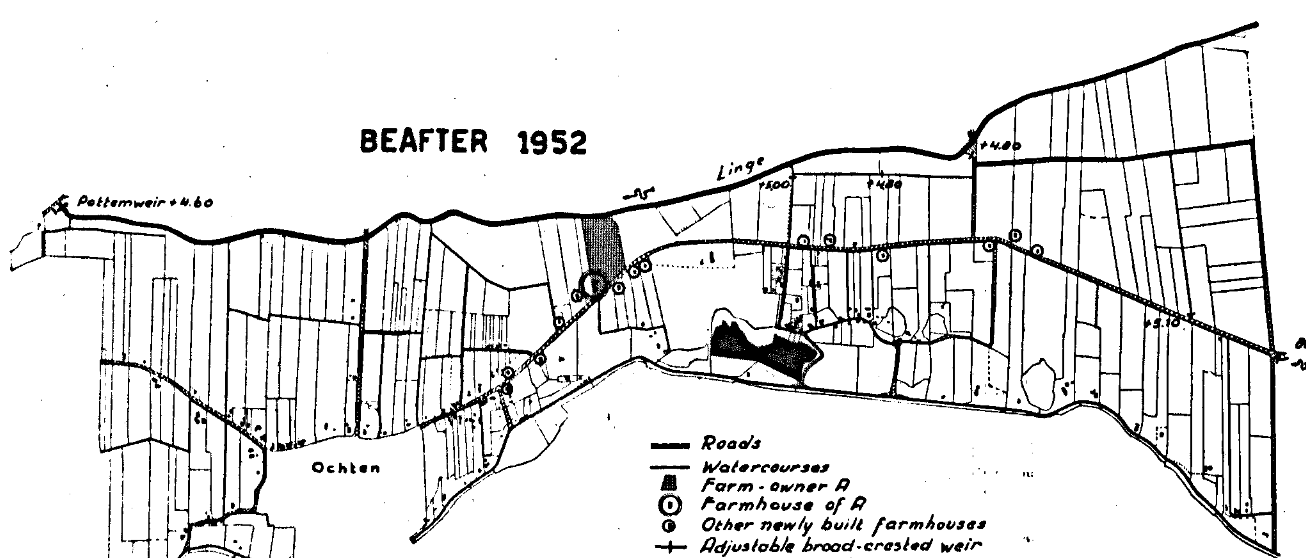


fig. 4b

Adjustable broad-crested gauging weir

Regelbare Meetoverlaat v.g. type Romijn-Vlugter

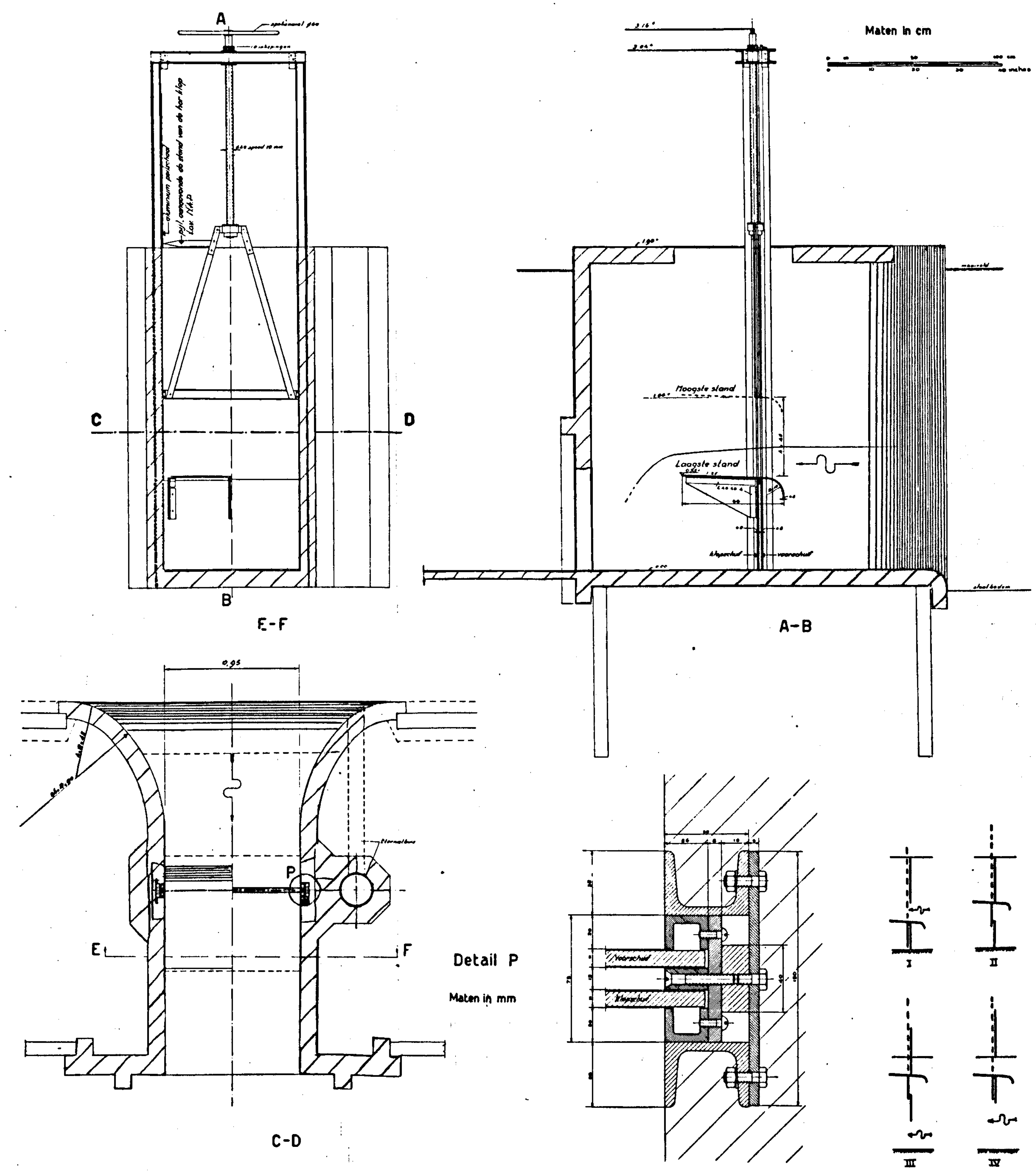
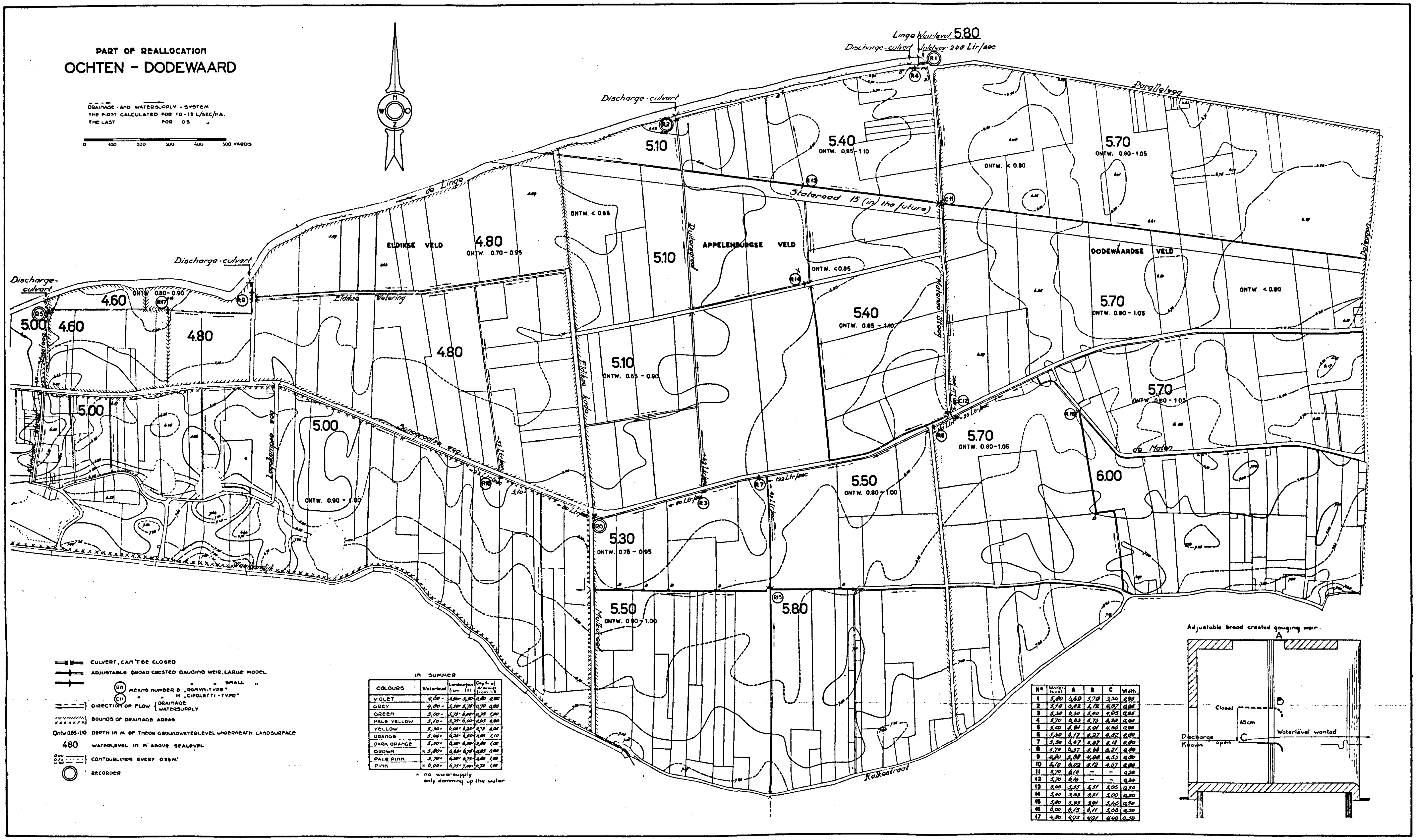


Fig. 5



IN SUMMER

COLOURS	Waterlevel	Landsurface from till	Depth of drainage from till
VIOLET	4,60 ·	5,40 - 5,50 ·	0,80 0,90
GREY	4,80 ·	5,50 - 5,75 ·	0,70 0,95
GREEN	5,00 ·	5,75 - 6,00 ·	0,75 1,00
PALE YELLOW	5,10 ·	5,75 - 6,00 ·	0,65 0,90
YELLOW	5,30 ·	6,05 - 6,25 ·	0,75 0,95
ORANGE	5,40 ·	6,25 - 6,50 ·	0,85 1,10
DARK ORANGE	5,50 ·	6,30 - 6,50 ·	0,80 1,00
BROWN	× 5,80 ·	6,65 - 6,75 ·	0,85 0,95
PALE PINK	5,70 ·	6,50 - 6,75 ·	0,80 1,05
PINK	× 6,00 ·	6,75 - 7,00 ·	0,75 1,00

× no watersupply only damming up the water

N°	Water-level	A	B	C	Width
1	5,80	6,69	5,70	5,34	0,95
2	5,10	6,02	5,12	4,07	0,95
3	5,30	6,30	5,40	4,95	0,95
4	5,70	6,63	5,73	5,28	0,95
5	5,00	5,91	5,01	4,56	0,95
6	5,30	6,17	5,27	4,82	0,00
7	5,30	6,47	5,57	5,12	0,00
8	5,70	6,57	5,66	5,21	0,00
9	4,80	5,88	4,98	4,53	0,00
10	5,10	6,02	5,12	4,67	0,00
11	5,70	6,10	–	–	0,24
12	5,70	6,10	–	–	0,24
13	5,40	5,55	5,51	5,06	0,50
14	5,40	5,55	5,51	5,06	0,50
15	5,80	5,95	5,91	5,46	0,50
16	6,00	6,15	6,11	5,66	0,50
17	4,80	4,95	4,91	4,46	0,50

FIG. 7

to canalize the Lower Rhine and the Waal, come true within a period of a hundred years (see figure 2), perhaps less fresh water will be needed, but still there will be the necessity of distributing the water among the farmers.

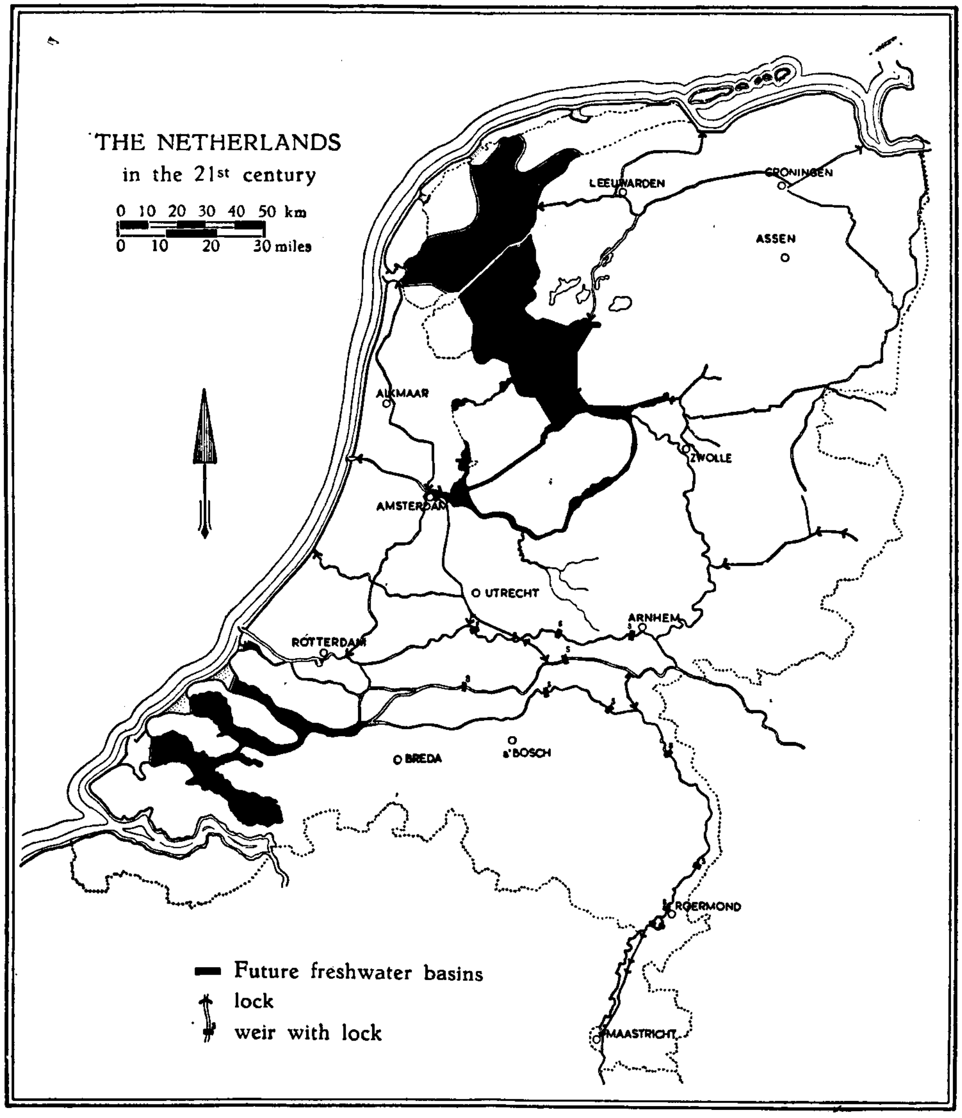


FIG. 2. THE MAP OF THE NETHERLANDS IN THE 21ST CENTURY, IF IN FUTURE ALL THE WORKS ON BEHALF OF THE DRAINAGE AND WATER SUPPLY, THE MAINTAINING OF THE WATER-LEVEL AND THE FIGHTING BACK OF THE SALT FRONTIER SHOULD BE PERFORMED. Copied from : J. H. THIJSSE (1951).

4 DISTRIBUTING AND GAUGING THE WATER NEEDED

The problem of shortage of water has risen already in the Betuwe, the region which lies between the rivers Lower–Rhine and Waal (see fig. 3).

In close cooperation of the State ("Rijkswaterstaat"), the province of Gelderland ("Provinciale Waterstaat") and the catchment boards – after long negotiations about sharing the financial burden – it was decided to regulate the small river Linge which receives its water from precipitation and in winter mainly from the seepage underneath the dikes of the big surrounding rivers.

Some 8 weirs, 4 of them planned as gauging weirs with a width of 6 m, are under construction now; at the start of the river in the east an inlet-sluice has been built with a maximum capacity of 9 m^3/sec. Two pumping stations at about ⅓ and ⅔ of the length of the river with capacities of 15 and 10 m^3/sec are under construction. This entirely improved drainage system will start functioning in 1954.

When calculated for ½ l/sec/ha in dry periods it is possible to distribute 9 m^3/sec over 18 000 ha. As the area concerned is as large as 32 300 ha, a righteous distribution will be necessary in the long run. To meet this requirement the quantity of water, distributed among the farmers, should be gauged with a certain degree of accuracy.

For that purpose the "Cultuurtechnische Dienst" created an adjustable broadcrested gauging weir [3]) adapted to our circumstances – the type of which originally was investigated and designed at the hydraulic laboratory at Bandung in Java by Prof. Ir H. VLUGTER (1940).

The first model can be seen in figure 5. This model, with a width of 95 cm, gauges up to 500 l/sec, with an accuracy within 3–5 %, whilst the crest, the "peak"-slide, can be moved up and down over a distance of at least 45 cm, damming up the water at the level wanted.

Such a weir can be used for an area up to 1000 ha. With a difference of 20 cm between two adjacent waterlevels, the cost will run into 2 to 20 guilders/ha, approximately, dependent on the slope of the land.

In the right-hand corner of figure 5 the four main positions of the upper "peak"-slide and the lower front-slide are diagrammatized.

The position I (the lowest position of the "peak"-slide) is the position at which the maximum discharge can be gauged. If a smaller quantity should be wanted the "peak"-slide can be lifted as much as necessary (see table) by means of a screw-spindle with (detachable) wheel. This position, the normal position, will be used exclusively during the period of crop growing. (May till September, or extended: March till November).

In position II, by turning the wheel, the "peak"-slide has been lifted on its highest position, at the same time closing the gap in the frontslide, so that no water can pass. This is the position in winter for an irrigation-weir, if no watersupply is needed, (or for a drainage-weir in summer, when inundation must be prevented from sudden back-water).

Position III follows from position II by continuous lifting the "peak"-slide. This position is called the "emergency-position" as it can be used in case of sudden inundations, in order to allow passage to high-water peaks, or for flushing the ditches and drains.

Position IV follows from position I by coupling both slides by means of a pin and lifting them together. This is the position preferably used in winter for weirs in drainaged areas. In this case the maximum amount of discharge can be allowed to pass easily.

The drawing in the upper left-hand corner shows the gauge [4]), (attached to

---

[3]) Dutch: regelbare meetoverlaat.

[4]) Dutch: peilschaal.

the stanchion of the metal frame) which indicates the position of the "peak"-slide.

The drawing in the lower left-hand corner shows the typically rounded form of the inflow and the shaft for the float of a recorder.

One of the chief advantages of this broad-crested weir is that it can be submerged quite considerably without suffering any change in its characteristics; that is to say, it will still behave as a free discharging weir and the formula:

$$Q = m.b.\ 2/3\ h_1 \sqrt{2/3\ h_1 \cdot g.} = 1.7\ m.b.\ h_1$$

Q = discharge in m^3/sec

b = transverse crest length in m

h_1 = head above the crest in m

m = coeff. of discharge

will still be applicable.

The diagram in figure 6 shows the results of a test made by our hydraulic laboratory at Delft. From this graph one can see that the coefficient of discharge "m" only varies to a small amount, not exceeding 3%, which means that it has a practically constant value, when the head h_1 varies from 3 to 45 cm (0.1′–1.5′).

Also may be seen that considerable submergences up to 3/4 of the head h_1 are possible and this is of very great importance for measuring the water in the rivulets and watercourses of our flat country, whereas sharp edged weirs with their great loss of head could not be used.

Table I shows the translation of the graph of figure 6 for practical purposes.

Now with this type of weir it will be possible to make the difference of two adjacent waterlevels not more than 10–15 cm, rather a small difference for an accurate gauging weir.

Also in future it will be possible to set up a fair retribution scheme, for it must be taken as normal that the farmers should be charged for their water supply. In any case they are not getting it free, as they have to pay for their fertilizers and fuel too.

5 Prefabrication of weirs

In 1950 the difficulty with this brand-new designed water control system arose from the fact that at that moment the agricultural research workers did not yet know the exact waterlevel desirable to be maintained under the average landsurface. As a result the designer could not fix the depth of the foundations of the weirs. He had to rely upon the farmers' opinions which might be wrong.

The problem was solved by prefabricating the weirs and putting them by means of a heavy crane on the bottom of the drain (watercourse) on a light foundation (see Photo I).

If in the following years it may become necessary to lower both the waterlevel and the weirs considerably, the weirs have only to be lifted again by means of a crane, the foundations lowered and the weirs replaced on the former but now lower lying foundations.

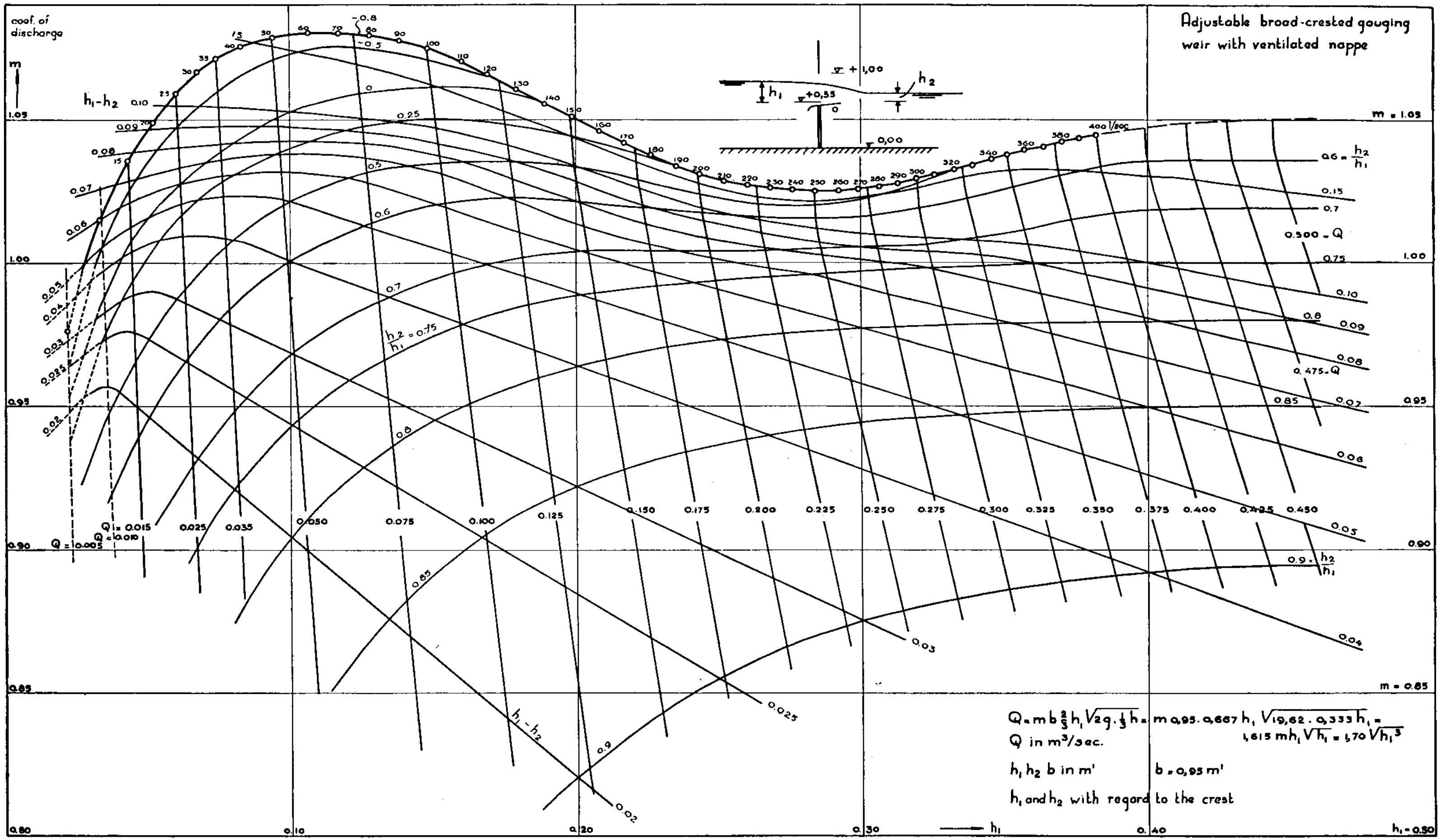

Adjustable broad-crested gouging weir with ventilated nappe
coef. of discharge
m
$h_1 - h_2$
m = 1.05
m = 0.85
$Q = m b \frac{2}{3} h_1 \sqrt{2g \cdot \frac{1}{3} h} = m\, 0{,}95 \cdot 0{,}667\, h_1 \sqrt{19{,}62 \cdot 0{,}333\, h_1} = 1{,}615\, m h_1 \sqrt{h_1} = 1{,}70 \sqrt{h_1^3}$
Q in m³/sec.
h_1, h_2, b in m'
b = 0,95 m'
h_1 and h_2 with regard to the crest
h_1 = 0.50 m'
h_1
0.6 = $\frac{h_2}{h_1}$
0.9 = $\frac{h_2}{h_1}$
$\frac{h_2}{h_1}$ = 0.75
0.500 = Q
0.475 = Q
Q = 0.005
Q = 0.010
Q = 0.015
400 l/sec

Fig. 6

Table I.

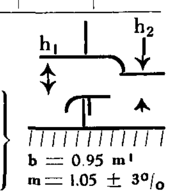
h_1 cm	Q in l/sec h_1-h_2 ≧ 15	Q in l/sec h_1-h_2 ≧ 10	Q in l/sec h_1-h_2 ≧ 7	Q in l/sec h_1-h_2 ≧ 4
2.2	**5**	5	5	5
3.0	**9.5**	8.5	8.5	8
3.3	**10**	10	10	9
4.3	**15**	15	15	14
5.2	**20**	20	20	19
6.0	**25**	25	24	24
6.7	**30**	30	29	28
7.4	**35**	34	34	33
8.2	**40**	40	40	38
9.35	**50**	49	48	47
10.6	**60**	59	58	56
11.7	**70**	69	68	65
12.8	**80**	78	77	73
13.8	**90**	88	86	81
14.8	**100**	97	96	90

h_1 cm	Q in l/sec h_1-h_2 ≧ 15	Q in l/sec h_1-h_2 ≧ 10	Q in l/sec h_1-h_2 ≧ 7	Q in l/sec h_1-h_2 ≧ 4
15.9	**110**	108	106	100
17.0	**120**	119	117	110
17.9	**130**	129	126	119
18.9	**140**	139	136	129
19.85	**150**	149	146	138
20.8	**160**	159	156	147
21.7	**170**	169	166	156
22.6	**180**	179	176	166
23.5	**190**	189	186	175
24.3	**200**	199	196	184
25.2	**210**	209	206	193
26.0	**220**	219	216	202
26.8	**230**	229	226	211
27.6	**240**	239	235	220
28.4	**250**	249	245	229

h_1 cm	Q in l/sec h_1-h_2 ≧ 15	Q in l/sec h_1-h_2 ≧ 10	Q in l/sec h_1-h_2 ≧ 7	Q in l/sec h_1-h_2 ≧ 4
29.2	**260**	259	255	238
29.9	**270**	268	263	246
30.6	**280**	277	271	254
31.3	**290**	287	280	262
31.95	**300**	296	289	269
32.6	**310**	305	297	276
33.25	**320**	314	306	284
33.9	**330**	323	314	292
34.5	**340**	331	322	300
35.1	**350**	340	330	307
35.75	**360**	349	339	315
36.4	**370**	358	347	323
37.5	**380**	367	356	330
37.65	**390**	375	364	338
38.3	**400**	385	372	346

h_1 cm	Q in l/sec h_1-h_2 ≧ 15	Q in l/sec h_1-h_2 ≧ 10	Q in l/sec h_1-h_2 ≧ 7	Q in l/sec h_1-h_2 ≧ 4
38.95	**410**	395	381	354
39.6	**420**	404	390	361
40.2	**430**	413	399	369
40.8	**440**	421	407	376
41.4	**450**	430	415	384
42.0	**460**	439	423	391
42.6	**470**	448	431	399
43.2	**480**	457	440	406
43.8	**490**	466	448	413
44.4	**500**	475	457	421
45.0	**510**	485	466	428

$$Q = 1.615\, m\sqrt{h_1^3}$$
$$h_1 = 0.726\sqrt[3]{\frac{Q^2}{m^2}}$$



adjustable gauging weir

See text on p. 169.

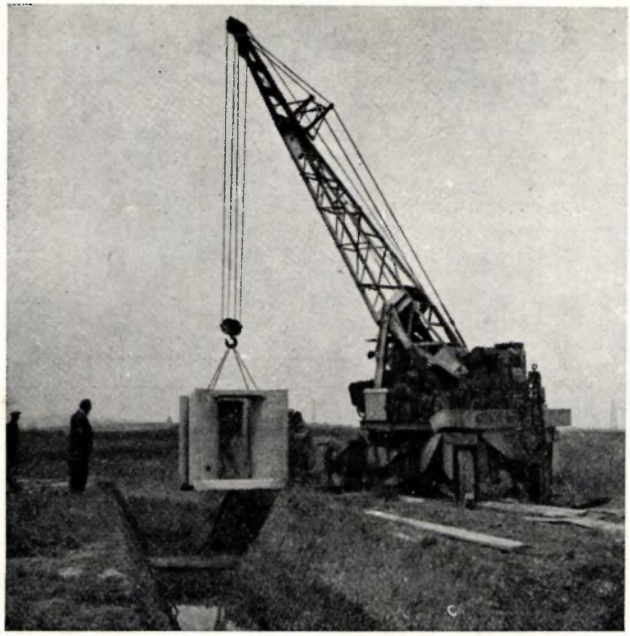


Photo I (See text on p. 169).

Photo II shows a weir with its recorder. The head h_1 of the watertable above the crest of the "peak"-slide can be read on the disk behind the round window.

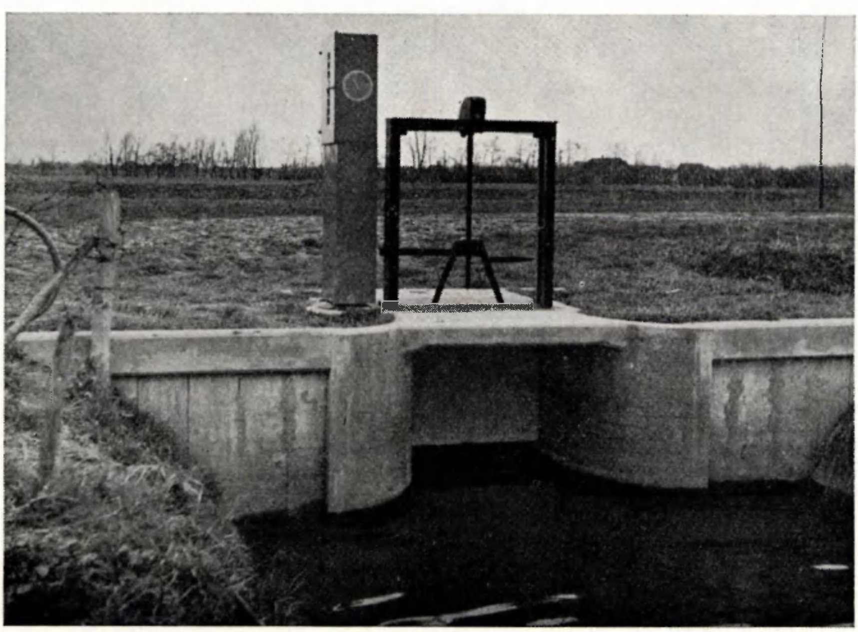


Photo II

The first locality in the Netherlands where, in 1951, these broad-crested gauging weirs have been placed, is in the reallocated area of the municipalities of Ochten and Dodewaard in the "Betuwe" (see figures 3, 4 and the enlargement in figure 7), where a perfect water control system shortly will become a reality. This will be a fact as soon as the (6m) broadcrested weir in the river Linge near Opheusden shall be ready in the next summer (in figure 7 at top righthand).

From that moment onwards the already established drainage system will be superposed by the system of watersupply and, in consequence, the water control in that area will be a fact.

The system of water control

In figure 7 the direction of the watersupply has been indicated by fulldrawn arrows, the direction of the drainage by brokenlined arrows.

The big figures denote the fixed waterlevels in the various compartments. These compartments are bordered by roads and sometimes by watercourses – which in some cases are closed by earthen dams.

In designing the water control system there should be aimed at including only 3 successive contourlines of 25 cm equidistance in every compartment.

Per compartment the average height of the land surface will be determined from these contourlines as follows: the acreage will be determined between two consecutive contourlines and this acreage will be multiplied with the average height of the mentioned contourlines. Thereupon the sum of these multiplications will be divided by the sum of the acreages. The quotient represents the average level of the landsurface in the compartment concerned.

Then the waterlevel wanted in the drains will be fixed 50–100 cm – dependent on soil and crop – below the average level of the landsurface.

In the case of Ochten–Dodewaard the soil merely consists of clay and so the average depth of the watertable was kept 70 cm below the lower-lying grassland and 100 cm below the arable land.

It is almost inevitable that in one part of a compartment the watertable may be too high and in another part it may be too low, due to the undulating topography.

With a view to the type of soil it should be investigated which one of either the extremes is able to undergo a raising or a lowering of the watertable. From these considerations the average watertable can be corrected.

Outlook

As soon as the summer watertables in the various compartments are fixed with a variation of no more than 10 cm, gradually a crop succession should be introduced which is adapted to the fixed watertable in each compartment.

For that purpose the land owners in each compartment should unite into small combinations which every year should come to an agreement on the crop succession by mutual agreement.

In consequence of these agreements the public authorities, with a view to the nature of the soil and the season, could decide upon the amount of water to be supplied in order to reach a maximum yield.

But the time for such planning has not yet come in the Netherlands and, therefore, the preceding is a utopian scheme which could be realized only if owing to a succession of dry spring- and summer seasons the authorities, the farmers and the horticulturists were urged to cooperate.

But although the realization of crop succession and combination is a matter for the future, at the moment there is one question that claims our full attention, viz. the necessity of giving priority to the system of feeders or laterals in all those reallocations [5]) (VAN SCHAGEN, 1952) where water supply lies within the possibilities. These feeders should be constructed as much as possible in a direction parallel to the contourlines.

After this the new roads and drains and the newly designed fields (the reallotment scheme, compare fig. 4a to fig. 4b) may easily be adapted to the grid of the laterals which carry the water from the bottom of the (shallow) valley to the flanks.

In that case the loss of head will be as small as possible and the acreage benefiting by the water control will be as large as possible with the aid of a number of weirs which may be kept as small as possible.

In our densily populated country this demand can only be realized with the aid of the reallocation procedure, laid down in the new reallocation law, which is under way.

Only in that case, the costs – which come before the profits! – spent on water control are wholly justified.

May the Government which subsidizes the reallocation schemes with ± 75% always keep this truth in mind!

LITERATURE

HELLINGA, F.: Water Control, Soil Science vol. 74, 1 (1952). Williams & Wilkins Cy, Baltimore 2, U.S.A.

Hydrologisch Onderzoek TNO: Verslagen Technische Bijeenkomst 1946–1950. The Hague, 1952.

VISSER, W. C., a.o.: Several publications in "Maandblad voor de Landbouwvoorlichtingsdienst", The Hague, 1951 and 1952.

MESU, F. P.: De watervoorziening ten behoeve van de Nederlandse landbouw. Landbouwk. Tijdschrift, 62 (1951).

THIJSSE, J. H.: De zoetwatervoorraden in Nederland. Landbouwk. Tijdschrift, 63 (1951).

VLUGTER, H.: De "regelbare meetoverlaat". Mededelingen en Onderzoekingen verricht in het Waterloopkundig Laboratorium van het Departement van Verkeer en Waterstaat te Bandung, 1940.

SCHAGEN, F. VAN: Regional Reorganization through reallocation, particularly the control of the waterlevel. Lecture to Danish experts, Sept. 16th, 1952.

---

[5]) Dutch : "ruilverkaveling"
French : "remembrement" or "remainiement parcellaire"
German : "Flurbereinigung" or "Güterzusammenlegung".