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TILE DRAINAGE IN THE NETHERLANDS

A SUMMARY OF THE ADDRESSES DELIVERED ON THE TILE DRAINAGE DAY

Compiled by W. C. VISSER [1]

The meeting on 16th May, 1952, of the two associated organizations, the Land improvement and drainage Section of the Building Construction and Hydraulic Engineering Department of the Royal Netherlands Institution of Engineers, and the Study Circle for Land improvement and drainage of the Netherlands Society for Agricultural Science, was devoted to tile drainage. Literature on the theoretical basis of the subject has been available for some considerable time past in a form admirably suited for practical application. It was the general desire to demonstrate at the meeting the extent to which the executive services had been able to utilize this body of theory, and the form of applied research which had arisen as bridge between theory and practice.

Under the direction of Dr. S. SMEDING the executive government services – viz., the Government Service of Reallocation, Land improvement and drainage and the Directorate of the Wieringermeer Polder – together with the Netherlands Moorland Reclamation Society, gave an exposition of their views and methods. These expositions constituted a survey of the present position of knowledge regarding tile drainage in the Netherlands. At the same time, some points were mentioned in respect of which further research was desirable. and, in particular, a plea was made for stronger organization of the existing co-operation between the official bodies present. Such organization measures have since come about, in the form of the Advisory Committee for Tile Drainage and Infiltration, the chairman of which is Dr. F. P. MESU. The object of the meeting and of the Advisory Committee alike was to bring about a considerable increase in tile drainage work in the Netherlands. The following summary of the points made by the speakers – Messrs. J. H. BOUMANS, J. DUYN, A. FRANKE, W. H. VAN DER MOLEN, P. M. VAN DER SLUIS and W. C. VISSER – indicates the basis of the Advisory Committee's activities.

The present summary, together with considerations of some aspects not discussed at the meeting, has been compiled by the last of the speakers listed above. For fundamental theory, reference should be made to the well-known writings of Dr. S. B. HOOGHOUDT. Complete reports of the addresses were given in the Landbouwkundig Tijdschrift (No. 65 (1953), pp. 65–164).

1. THE PRESENT SITUATION

The present economic conditions in the Netherlands are the reason why capital investment in soil improvement can only be a paying proposition in the case of very carefully considered plans – provided that no possibilities on a larger scale are created by government subsidy. Owing to this, projects for soil improvement are kept down to a modest scale. The figures for tile drainage confirm this.

In the Netherlands, 300.000 hectares of land have been drained mostly on good arable clay soil. Loamy and silty soils, grazing land and river clay soils still await better unwatering. Tile drainage operations now cover 12.000 hectares per year, 6.000 of which are the result of government action in the Zuider Zee polders and some farm consolidation schemes, and 6.000 are due to the initiative of the farming population. Silting-up renders a tile drainage system ineffective after an average period of forty years, consequently, on 7.500 hectares of drained soil the tiles would have to be renovated every year

[1]) Received for publication May 6, 1953.

in order to keep the existing total area in efficient working order. Present routine tile drainage activities are therefore insufficient even to maintain the status quo.

But if agricultural production is to be increased, better control of the water levels in the soil must be achieved. Accordingly, many diverse individuals and organizations are working together to find methods which will ensure that the tile drainage schemes carried out will produce maximum results. At a meeting of the associations for land improvement and drainage, a summary was given of the present state of knowledge of the subject. The lectures delivered on this occasion covered a field which can be divided into: investigation; planning; execution; and maintenance.

As regards investigation of fundamental ground water hydraulics, it should be pointed out that the studies of HOOGHOUDT, which are about fifteen years old, yielded entirely satisfactory results when put into practice, and now meet with next to no criticism. Accordingly, these basic principles were not debated; and consequently, as far as the investigation sphere was concerned, actual application of theory formed the point of discussion.

2. INVESTIGATION

In order to decide the distance between underground drains, and the depth at which they are to be laid, one of two methods is applied, according to the nature of the soil profile. In cases where better unwatering will have little effect on the permeability of the soil, permeability can be determined in situ, and calculations based on the result. For such cases HOOGHOUDT has devised a method of determining permeability, as well as a way of calculating the connection between drain spacing, hydraulic head, and discharge.

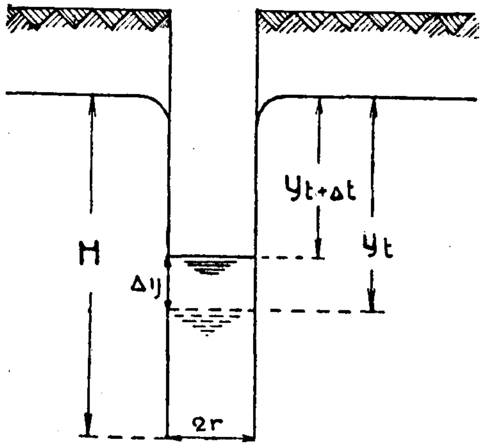
As regards profiles which undergo a change in permeability as a result of unwatering — the "ripening" of soils containing clay — a method of pedologically assessing permeability was devised for the Zuider Zee polders which makes use of comparison with results from a number of drainage trial fields in these polders, and enables a decision to be taken regarding the desired distance between tile drains. The names of DONKERSLOOT and SIEBEN are associated with this method. Tile drainage investigation technique is gradually tending to employ a combination of physical and pedological assessments of the soil profile.

2.1. PHYSICAL DETERMINATION OF THE PERMEABILITY CONSTANT

a The method of observation

Physical investigation of permeability utilizes the flow of water towards cylindrical auger holes, which penetrate the ground water zone to a depth of half a metre or more. After the water level in a hole has been lowered, by pumping, to at least 40 cm below the water table, the hole will fill again, more quickly in the case of a permeable soil than in that of an impermeable soil. The speed of rise of the water is a measure of permeability. The auger holes can be drilled to different depths for the purpose of ascertaining differences in permeability between individual layers. The average permeability of each hole is calculated (Fig. 1), and the values for the various layers are found by comparing the results obtained from holes of various depths. If the wall of the hole shows a tendency to collapse, measurements can still be carried out by working quickly or, in more difficult cases, by using perforated metal tubes to support the wall.

The rise of the water is measured at suitably chosen intervals of time by means of a light float and measuring stand (Fig. 2).



$$K = \frac{4000r^2}{(H+20r)\ (2\text{-}y/H)y}\ \frac{\Delta y}{\Delta t}$$

FIG. 1. THE RATE OF RISE $\frac{\Delta y}{\Delta t}$ OF THE WATER TABLE IN THE AUGER HOLE IS A MEASURE FOR THE PERMEABILITY CONSTANT K, DEPENDENT ON THE OTHER VALUES IN THE FORMULA.

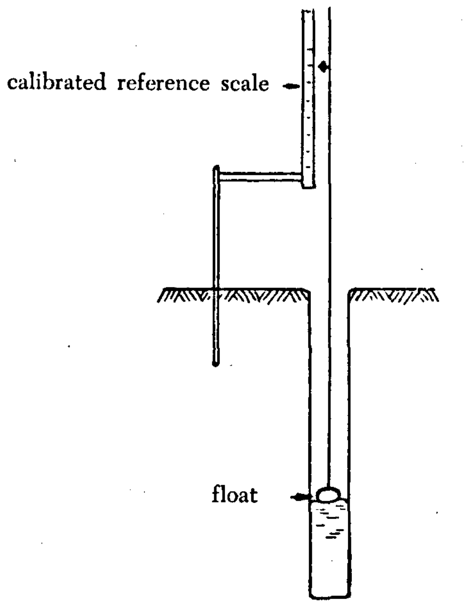


FIG. 2. THE RATE OF RISE OF THE WATER TABLE IS MEASURED BY MEANS OF THE ABOVE APPARATUS, HERE SHOWN DIAGRAMMATICALLY, DEVISED BY PROFESSOR M. F. VISSER.

b Calculations

Calculation of the permeability constant according to the formula given in Fig. 1 is carried out with the help of systematized observation forms and a nomogram. This simplification, by standardization of field work and calculation with nomograms, is regarded, both in this connection and that of other drainage operations, as an essential characteristic of a method suitable for routine work.

The observation form (Fig. 3) is divided into a lefthand and a righthand half. In the lefthand half details are given of the clay content, coarseness of grain of sand, colour, and presumably impermeable layers, of the soil profile, and the rise in the water table is recorded beside these data. A column for 2H-y values provides material for the first part of the calculation. In the righthand half log y and log (2H-y) are plotted against the measurement periods in order to establish the speed of rise of the water table in the auger hole. The values of log y and log (2H-y) lie on straight lines in the graph. Shifting of the 2H-y line parellel with itself to the y line, as shown in the figure, yields the auxiliary quantity P, which is a measure of the integral of the expression

$$\frac{1}{\left(2-\frac{y}{H}\right)y} \cdot \frac{dy}{dt}$$

Calculation of the permeability constant K for the values of H and r prevailing in the auger hole is carried out with the nomogram in Fig. 4, which is self-explanatory. The fact of its being drawn on transparent paper, to the same scale as the graph on the observation form, renders it capable of simple, speedy application, in the field, if necessary, as well as in the office.

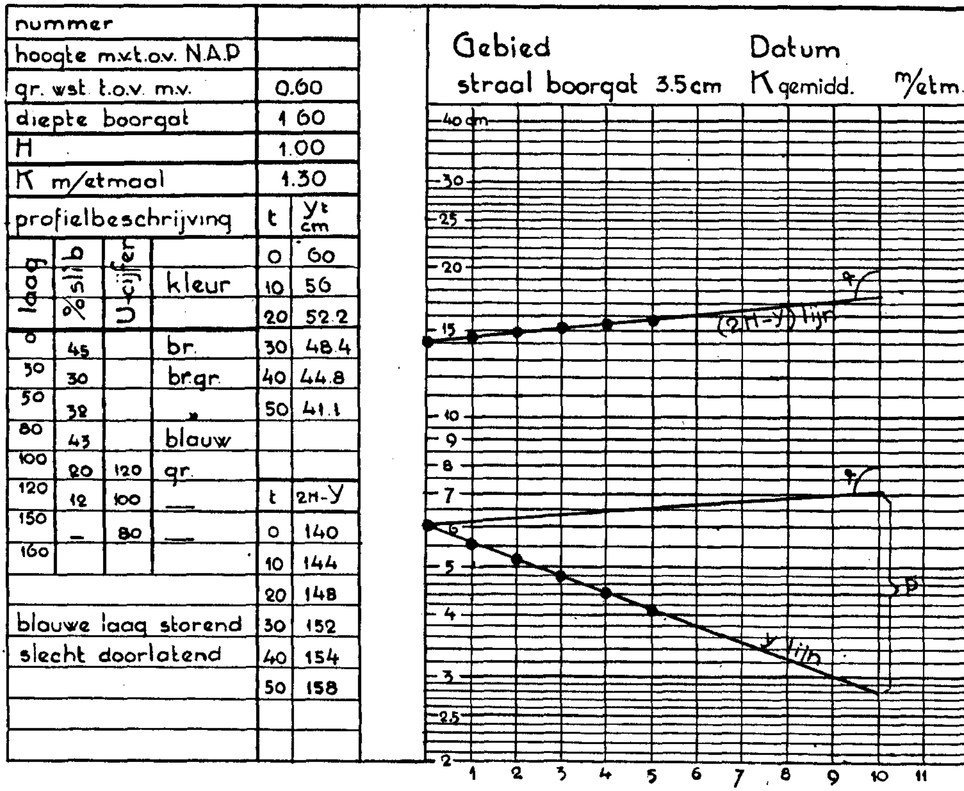


Fig. 3. Form for recording data regarding the soil profile and rate of rise of water, used in determining permeability.

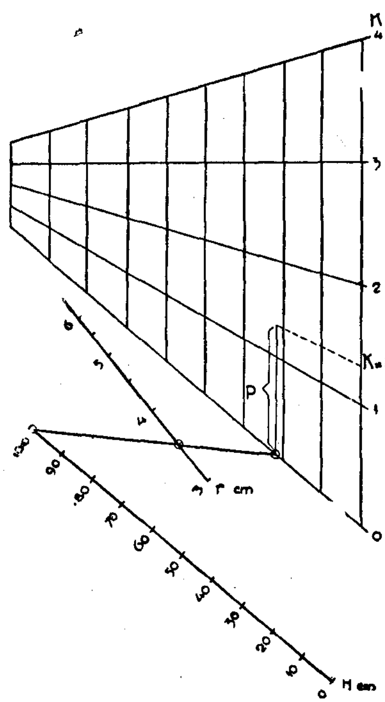


Fig. 4. In the nomogram for calculating the permeability constant, the value of K is determined from the value P in fig. 3, and from H and r.

X

2.2. Pedological assessment of permeability

In young, heavy polder soils, which have only just been reclaimed, permeabilities are found of an order of magnitude of 0.1 mm. per day. At such a time, drainage is out of the question. In the face of such a degree of impermeability, tile drainage is useless. But drying causes cracks to appear, which increase permeability considerably. Then, permeabilities of an order of ten metres per day are often encountered. The soil's capacity for storing water also increases greatly, and this results in reducing the demands which have to be made on the drainage system. Finally, water discharge improves still further owing to the fact that drying-out causes the impermeable zone to recede to ever deeper layers.

a Pedological assessment of permeability in heavy young profiles

Comparison of many fields with empirically spaced ditches and drains has shown that the natural moisture conditions in a profile are entirely dominated by the clay content and the formation of cracks. These properties have to be investigated in test pits. The observations, based on estimates, are reproduced on a scale which, although otherwise empirical, is always uniformly applied, and thus provide a standard of measurement for further operations.

The profile is conceived as being divided into layers 20 cm. in thickness, and the degree of crack formation, and the clay content $< 2\mu$, are determined visually for each layer.

Dependent on these two characteristics, a table of evaluation figures, as shown here, arises.

Table 1. Evaluation figures for the structure of medium clay soils in the Zuider Zee polders.

Lutum %	Crumb or nut structure	Vertical cracks			No cracks
		Interval 5–10 cm	Interval 10–25 cm	Interval > 25 cm	
< 5%	2	–	–	–	0
5– 8%	2	1	1	0	0
8–12%	4	3	1	0	0
12–18%	6	4	2	1	0
18–25%	8	6	4	2	0
25–35%	10	8	6	3	0

The depth of the layers is, however, of importance as a third criterion. Good permeability is much more valuable in a deeplying layer than in a layer not far below the surface.

The following values were established as multiplication factors:

Table 2.

Layer	Factor
0– 20 cm	1
20– 40 cm	2
40– 60 cm	4
60– 80 cm	6
80–100 cm	7

The product of the structure figure and the multiplication factor relevant to each layer, which is further divided by two in order to obtain a centesimal scale, yields the evaluation index figure for the profile. This latter number gives an idea of the permeability.

b Pedological assessment of older soils

Where soils have already reached their final condition, or, as is the case with light soils, undergo no alterations in permeability when drainage is improved, profile properties can be invoked in order to obtain more detail by interpolation between the places where permeability has been determined by physical methods. The particular property which may be decisive in determining permeability can be ascertained in each individual case.

In Figs. 5 and 6 some of these correlation diagrams with local significance are shown for clay content and sand grain coarseness ("U figure").

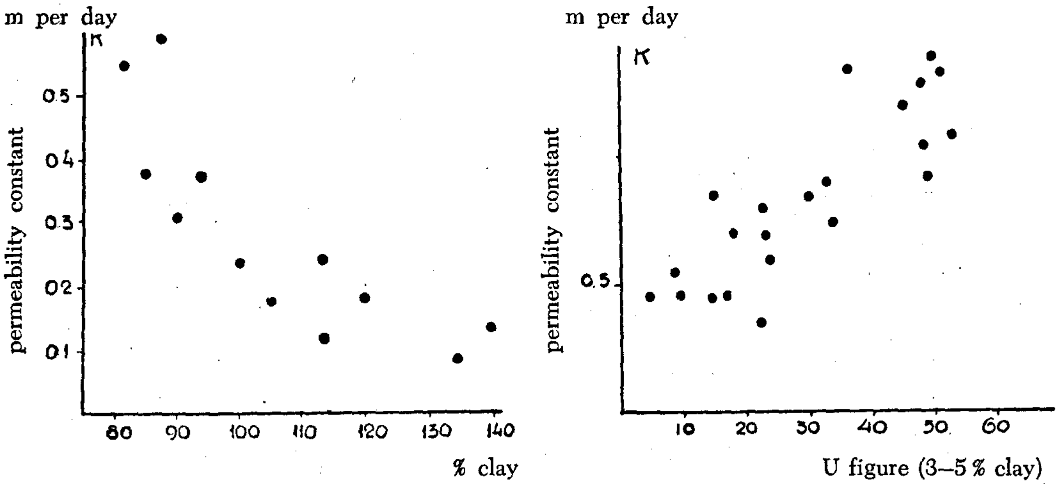


FIG. 5 AND 6. IN THE COURSE OF INVESTIGATIONS, USE CAN OFTEN BE MADE OF A FIXED MATHEMATICAL RELATIONSHIP, CAPABLE OF REGIONAL APPLICATION, BETWEEN THE SOIL AND THE PERMEABILITY CONSTANT.

In this way it is possible to convert a soil map into a tile drain spacing chart, in which adequate detail can be obtained with little trouble.

2.3. PHYSICAL DETERMINATION OF CORRECT DISTANCE BETWEEN TILE DRAINS

HOOGHOUDT's formula establishes the connection between hydraulic head m, discharge s, distance between tile drains l, permeability constant K, and an index figure d, which is derived from tables and takes into account drain spacing, the depth of the impermeable layer H, and the tile diameter r. A distinction may be made between, on the one hand, the two extreme cases in which the impermeable layer is either at infinite depth or on the level of the drainage tiles, both of which cases are capable of easy solution, and, on the other hand, cases in which the impermeable layer lies at intermediate depths, which are more complicated.

a Drains on the impermeable layer

This case (Fig. 7) answers to a simple formula, and drain spacing here can

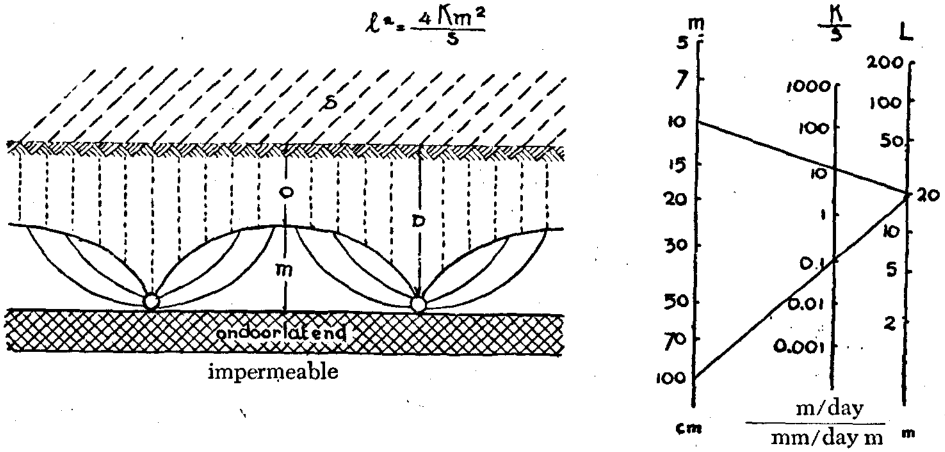


FIG. 7 AND 8. WHEN DRAINS LIE IMMEDIATELY UPON AN IMPERMEABLE LAYER, THE RIGHT DISTANCE BETWEEN THEM CAN BE ASCERTAINED BY APPLYING A SIMPLE FORMULA, THE CALCULATIONS BEING CARRIED OUT BY MEANS OF THE NOMOGRAM GIVEN ABOVE.

be calculated by means of a simple nomogram (Fig. 8) – if desired, in situ. The shallow location of the impermeable layer is the reason why the instance of flow is unfavourable.

b Cases in which the impermeable layer is absent

The permeability of each of the layers of soil through which the water flows is assumed to be the same, for the purpose of applying the formula and nomogram. This enables a great part of the water movement to be considered

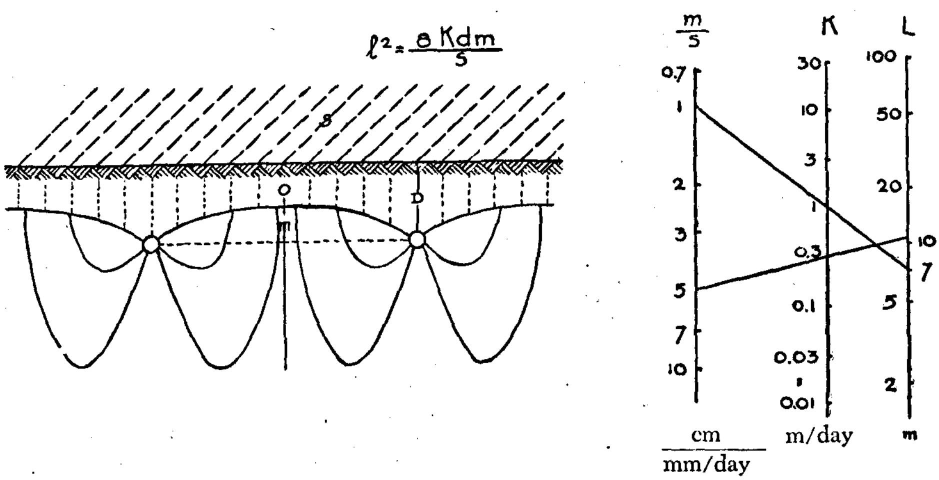


FIG. 9 AND 10. WHEN NO IMPERMEABLE LAYER IS PRESENT, A SIMPLE FORMULA CAN ALSO BE APPLIED, IN DOING WHICH CALCULATIONS MAY BE EASILY PERFORMED WITH THE HELP OF THE ABOVE NOMOGRAM.

as taking place througd deep layers. (Fig. 9). Just as in the case of the previous nomogram, a conclusion must first be reached regarding discharge in connection with permissible height of rise before calculations are possible.

c Cases in which the impermeable layer is present at any given depth

Up till now, when draining soil with an impermeable layer at such a depth that it cannot be ignored, the complete formula with the index figure d has been used as a measure of the influence of the impermeable layer. The d value has been derived from HOOGHOUDT's tables. Use of these tables, and reiterative calculation of the distance between tile drains, have been found to be great drawbacks. In a treatise by L. F. ERNST (not yet published), the relation between the depth of the impermeable layer and the other factors has been investigated with the help of a series of *Southwell* analyses. The results (likewise still unpublished) of an investigation carried out by J. H. BOUMANS showed that the *Southwell* results, in graph form, could be summarized in two simple nomograms (Figs. 11 and 12). With this solution to the problem of calculating the correct distance between tile drains, the two investigators — who willingly placed their work at the disposal of this publication — have rendered an important service to the cause of rapid, accurate advisory work for practical operations.

2.4. PEDOLOGICAL DETERMINATION OF CORRECT DISTANCE BETWEEN TILE DRAINS

Pedological evaluation of young polder soils leads to figures characterizing the permeability of the profile, which, theoretically, may be between 1 and 100, but in reality are not above 50. On the basis of the results from many drainage trial fields it was possible to translate these figures into terms of distance between drains.

The scale for this is as follows:

Table 3.

Evaluation figure	Distance between tile drains
< 5	8 m [1]
5–10	8–10 „
10–15	10–12 „
15–20	12–16 „
20–30	16–24 „
30–40	24–36 „
40–50	36–48 „

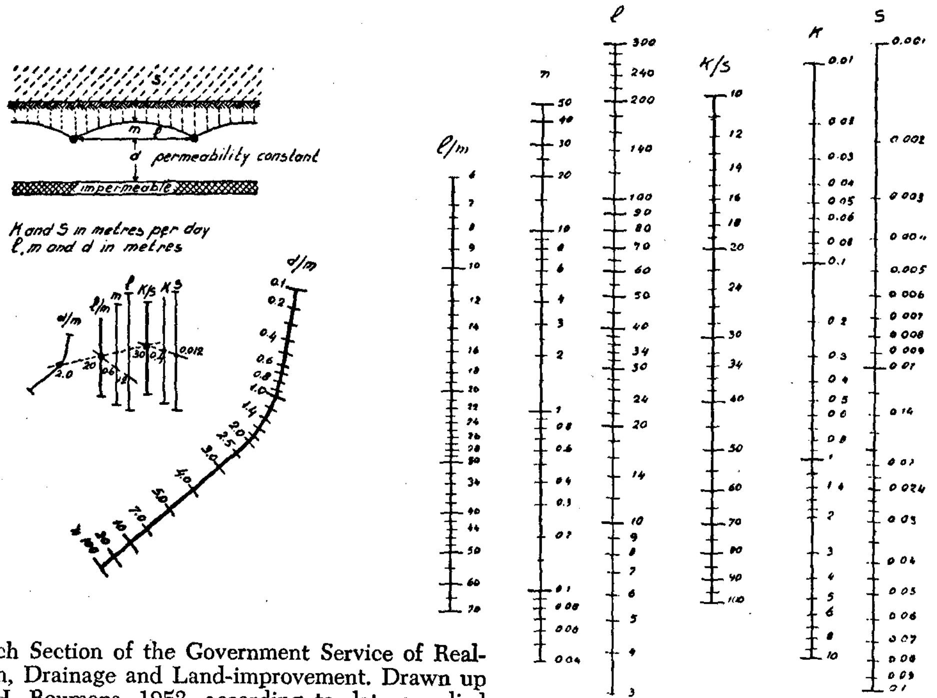
[1]) If possible, combined with loosening the subsoil.

Extensive experience in the Zuider Zee polders has shown that, in this way, a serviceable figure for the distance between drains can be arrived at under conditions in which all other methods would be sure to end in failure, owing to the changes in the profile brought about by drainage. But the presence of a number of good drainage trial fields is essential for application of the method.

2.5. SOME QUESTIONS OF ACCURACY

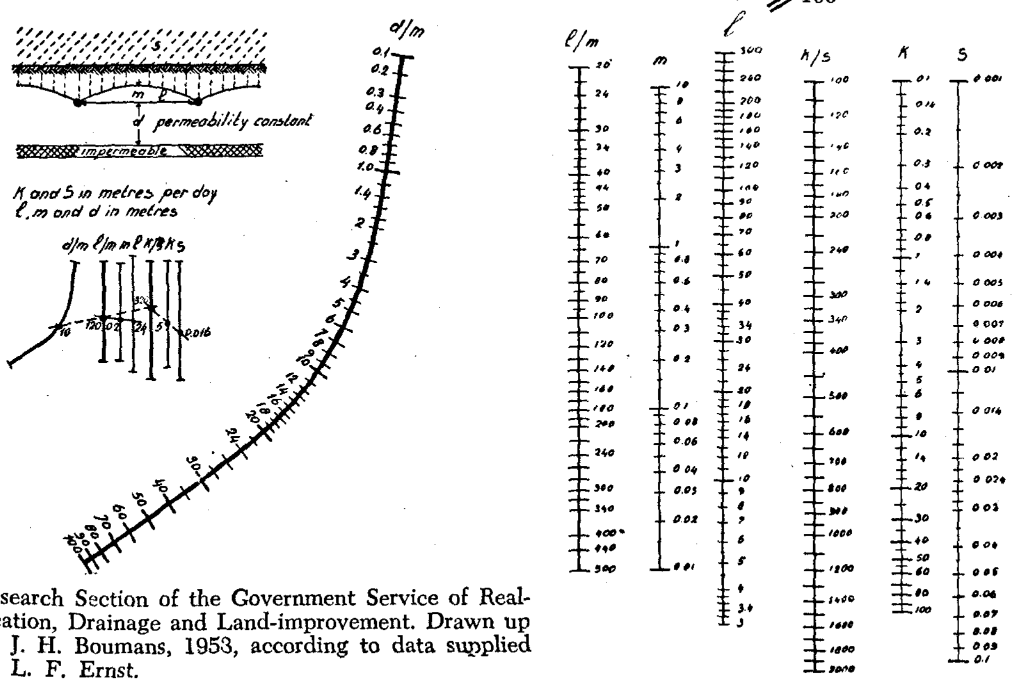
Physical determination of permeability according to the auger hole method must have a good reproducibility compared with duplicate determinations as well as with regard to the results when used in a drainage formula. The values obtained must be reproducible; and the theoretically estimated flow must tally with the actual situation.

Nomogram for calculating distances between tile drains when $K/S \leqslant 100$



Research Section of the Government Service of Reallocation, Drainage and Land-improvement. Drawn up by J. H. Boumans, 1953, according to data supplied by L. F. Ernst.

Nomogram for calculating distances between tile drains when $K/S \geqslant 100$



Research Section of the Government Service of Reallocation, Drainage and Land-improvement. Drawn up by J. H. Boumans, 1953, according to data supplied by L. F. Ernst.

FIG. 11 AND 12. NO SIMPLE FORMULA CAN BE EVOLVED TO COVER THE CASE OF AN IMPERMEABLE LAYER AT ANY ARBITRARY DEPTH. It was, however, possible to ascertain, by means of *Southwell* analyses, mathematical relations which could be empirically summarized in the form of the above nomograms. Use of these simplifies calculations for general cases considerably.

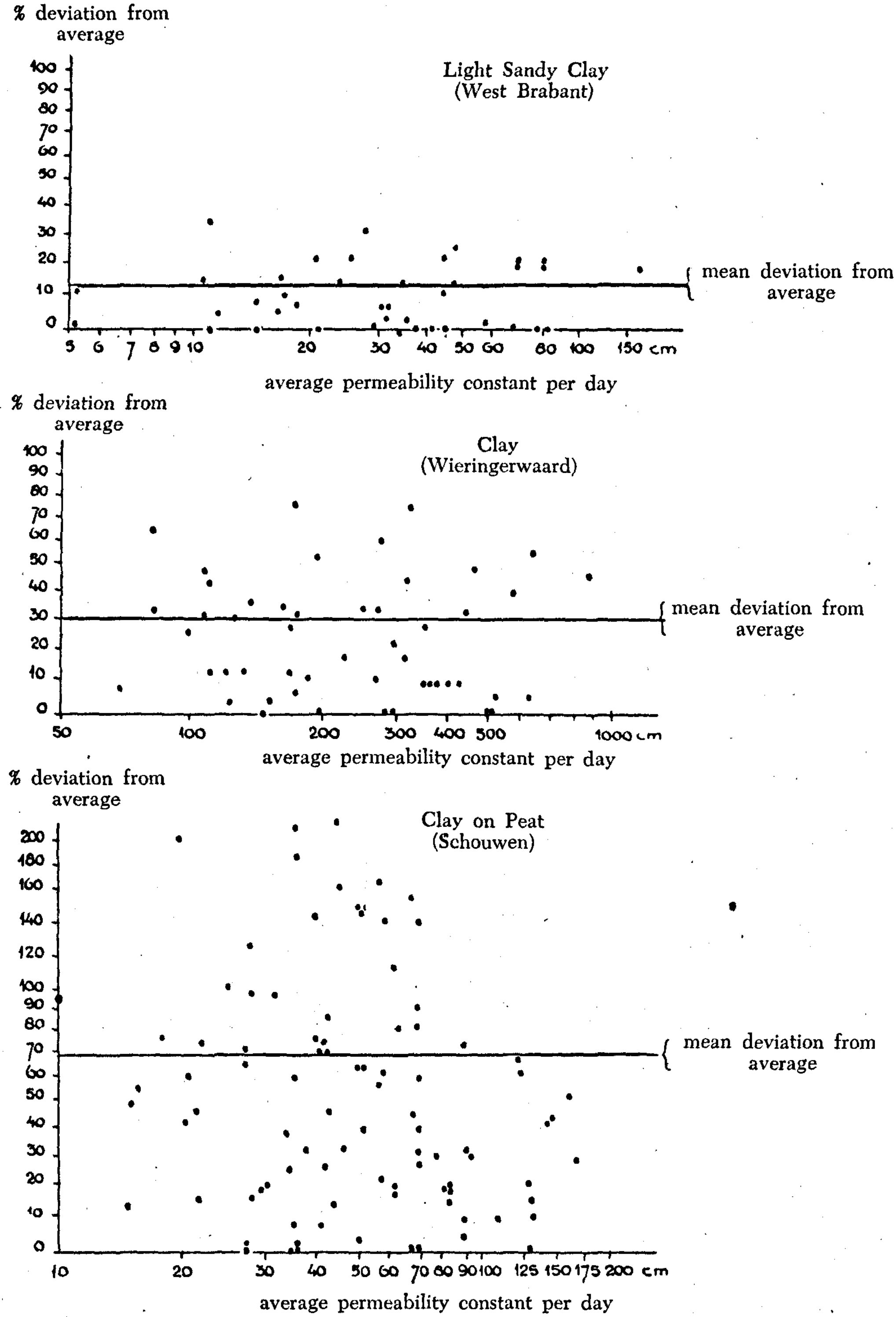


FIG. 13. VARIATION IN PERMEABILITY CONSTANT IN OBSERVATIONS CARRIED OUT AT DISTANCES OF ABOUT 1 M APART. The variation has been calculated as the percentage by which, in two observations, the higher value exceeds the average, or the average value exceeds the lower.

The auger hole method derives its numerical values from flow into a small cylindrical hole in the soil, and is consequently highly sensitive to irregularities slight distances away, such as cracks, passages made by worms and roots, etc. Three diagrams (Fig. 13) demonstrate the widely different way in which this heterogeneousness can influence the reproducibility of the results.

Previous knowledge of the order of magnitude of this heterogeneousness is of great importance for field work. If, in the first type of soil shown in Fig. 13, single determinations were to be carried out, four would be required in the case of the second type of soil, and fifteen repetitions would be necessary in the case of the third type of soil, in order to obtain a uniform error. The third example may well be regarded as an extreme case of a soil which is irregular and difficult to investigate. But the large error must really be looked upon as the consequence of a method of measuring in which only a limited volume of soil is concerned in the measurement.

The results of the measurement and calculations have been repeatedly compared with actually determined rates of discharge. In these cases, the errors proved to be insignificant.

Table 4.

Observation point	Permeability constant, determined by		Discharge during measurement
	auger hole	measurement of discharge	
1	0.30	0.35	4
2	0.18	0.18	2
3	0.22	0.18 0.19	9 3
4	0.19	0.24 0.15 0.12	10 4 2
5	0.19	0.22 0.13 0.16	11 5 4.5
6	0.18	0.24 0.18 0.16	8.5 5 3

The permeability was calculated back from the actual discharge. Certain abnormalities present themselves, especially as regards high waters tables, which suggest better permeability in higher layers of the profile. It should be borne in mind that, besides the measurement error, a part is also played by the degree of exactness with which it has been possible to force the multiform, highly individual concrete case into the strait jacket of the standardized scheme of calculation. It has been found that this can be done in a reliable manner.

2.6. The practical necessity of scientific investigation

If the distances between tile drains adopted in practice are compared with those arrived at by theoretical calculation, it will be found hat uniform distances of between 10 and 15 metres are usually strictly adhered to. The deviations necessary are often considerably smaller than calculations indicate. Fig. 14 shows a comparison between the variation in the distances advised as a result of theoretical calculation, and those resulting from empirical judgment.

3. Planning a tile drainage system

After scientific examination has established the desired distance between the

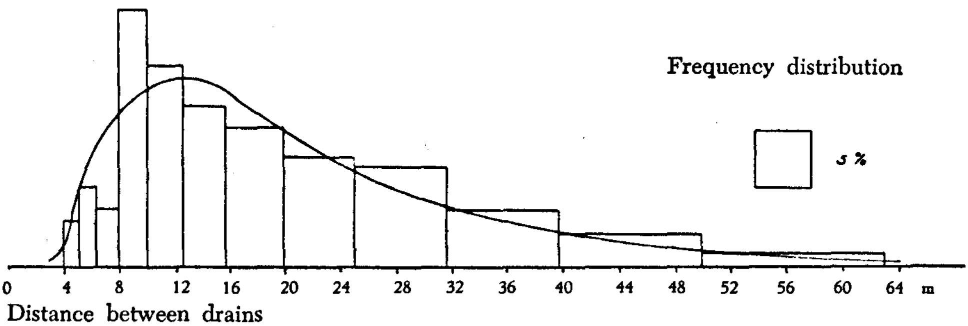


FIG. 14. IN AN AREA IN WHICH IT IS CUSTOMARY TO LAY TILE DRAINS AT DISTANCES OF 15 TO 20 M APART, INVESTIGATION PRODUCED THE ABOVE FREQUENCY DISTRIBUTION OF SPACES BETWEEN DRAINS.

tile series on the basis of possible depth, a number of other points still have to be decided before a tile drainage system can be designed.

3.1. TILE DIAMETER

The quantity of water which has to be removed by drainage lines of customary length and distance apart necessitates use of small tiles only, even when the hydraulic gradient is slight. In the Netherlands, as elsewhere, the size of tile chosen is larger than is strictly necessary, although, in this respect, we do not go as far as other countries do. The reason for using tile diameters which are too large is obscure. The most cogent argument put forward in their defence is that they enable the tile to accommodate that certain quantity of soil which will inevitably be washed into it without the tile's discharge capacity being too greatly reduced.

It would appear best to determine this safety factor of excess size according to each individual case, as an addition, over and above what is hydrologically necessary, to the flow cross section.

Tile diameter d is found according to the formula :

$$2408\ h^{0.55}\ d^{2.67} = mb\ l^{1.55}$$ (see subsection 3.4)

A rule-of-thumb method for ascertaining the area which can be drained by a tile system of a certain diameter can be found as follows, taking as a basis for calculations the area which can be drained with a hydraulic gradient of 10 cm. per 100 m. :

diameter in cm.	=	5	6	8	10	12	15	20
area in hectares	=	0.65	1	2	4	7	12	25

Conversion to other values of the hydraulic gradient can be effected proportionally, using the root of the gradient figure. It should be remembered that, as the tile diameter increases, the gradient can be substantially reduced.

3.2. TYPE OF TILE

One question on which opinions differ is whether collar tiles or plain tiles should be used. In view of the fact that two views *can* exist on the subject — views which necessarily find concrete expression in choice of one or the other form of tile — the difference between the types cannot be great; the price of collar tiles, however, is considerably higher than that of plain tiles.

One disadvantage of collar tiles is that it is impossible to check up on whether they have been correctly laid, and the connection between the tiles is often not very satisfactory. Il must therefore be assumed that the argument put forward in their favour, i.e., that soil penetrates them less easily, is not true.

The assertion that roots are unable to force their way into them also seems ill-founded. Admittedly, in weaker soil, such as that of filled-in ditches, the collar tile will offer a better guarantee of being less quickly dislocated in the event of subsidence. In other cases, the plain tile, provided it is well finished technically, and carefully laid, will provide a drainage system to satisfy the most exacting demands.

3.3. Hydraulic gradient

In flat country, provision of unnecessary gradient cannot be permitted. Accordingly, the question as to whether the usual slope of 20 cm. per 100 m. is necessary or can be reduced is of great importance. The argument that a gradient must be provided in order to generate a water velocity of more than 20 cm. per sec., which can wash the tiles clean, is not valid in most cases. If too large tile diameters are chosen, this velocity can be expected, with the quantity of water to be discharged, only when the area to be drained is abnormally large.

Calculations have shown that a hydraulic gradient of a few cm. per 100 m. is sufficient for the drain spacing and the length of terrain most generally encountered, and so it is perfectly possible to drain without a gradient. It is still uncertain whether the head of water above the tile can be considered effective in assisting the required gradient to bring about good drainage. As regards small drainage schemes, the general view seems to be gradually changing in the direction of laying tiles without gradient. But in removing water from large areas, very careful attention should be paid to the gradient, if it is desired to avoid unnecessarily high expense in flat country by using too large types of tile.

3.4. Composite drainage

Whereas abroad emphasis is generally placed on composite drainage, in the Netherlands the simple drainage system, according to which the tile drain debouches immediately into a ditch, is almost the only way of unwatering the country.

If the cause of this comparative neglect of composite drainage is investigated, the disadvantages are seen to be greater laying expenses, and greater difficulty in ascertaining whether each tile removes the water properly. In regions where surface drainage is necessary, ditches at slight distances from each other are indispensable. Moreover, a certain area of ditch surface is of value in polders for water accommodation purposes.

The higher cost of the composite system forms, however, the principal argument against it. The expense is certainly 10 % more than that of a simple drainage system.

Its advantages, however, are substantial. Ditches become superfluous and no longer need to be maintained; and the worthless water area can be replaced by productive land. The vital main ditches remain to receive the output of the main drains in a few places only. Maintenance is not rendered difficult by the existence of many tile drain outlets, and the larger parcels of land may be

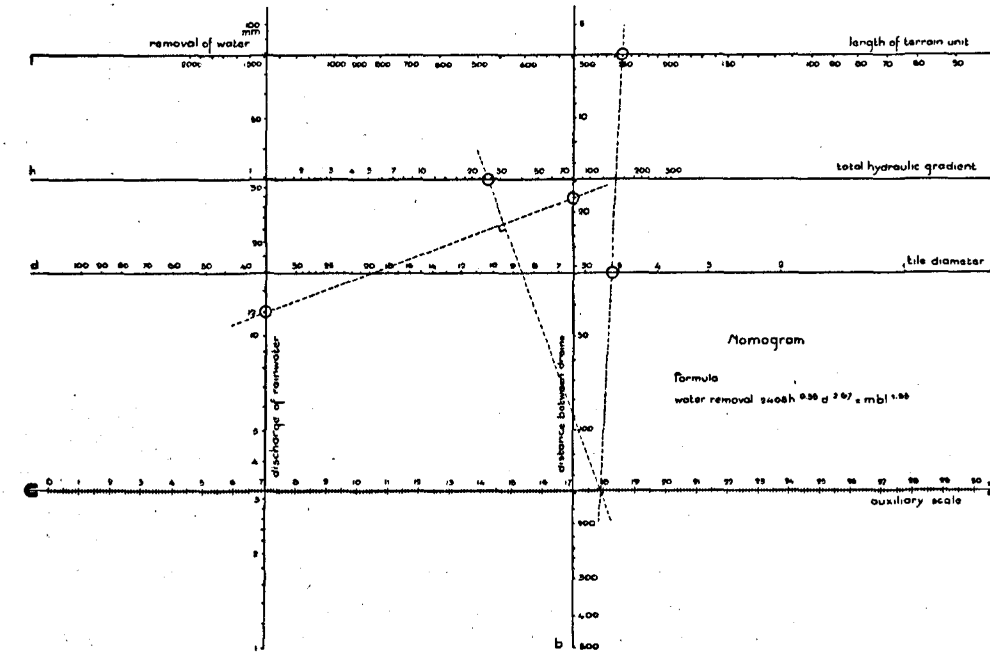


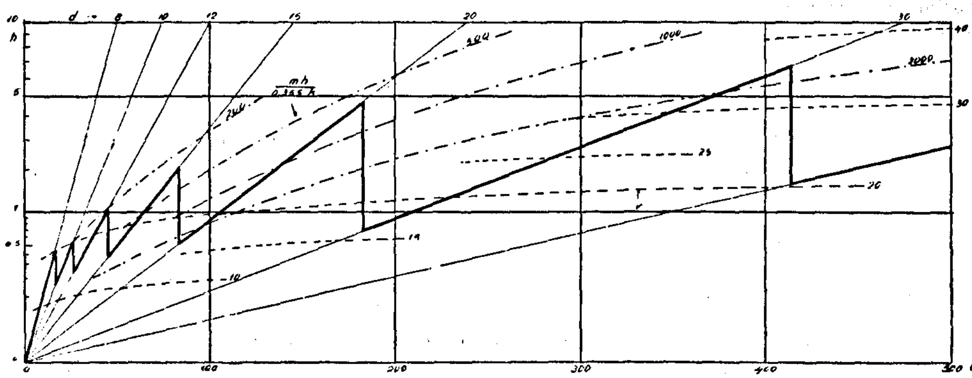
FIG. 15. NOMOGRAM FOR THE CALCULATION OF COMPOSITE DRAINAGE SYSTEMS, ON THE BASIS OF LENGTH OF COLLECTING DRAIN l, hydraulic gradient h throughout this length, tile diameter d, breadth b of the field unwatered by the laterals, and the maximum quantity of water to be discharged m. Values b and l are expressed in metres; h and d in centimetres; and m in millimetres of height of water.

developed more freely. Finally, with composite drainage more precise adaptation to differences in height of the ground surface and to differences in permeability in the pedological profile can be obtained without its being necessary to divide the land up into plots of unsuitable shape.

If the advantages of composite drainage are set against the disadvantages, the former would appear greatly to outweigh the latter, in cases in which ditches have not yet been dug and composite drainage has to beconsidered. But in the Netherlands, since ditches are already present in abundance and to fill them in would be an extremely costly business, transition to this drainage system is often difficult to defend. Where, however, it is desired to combine the drainage of large areas in one single system, it will be necessary, in flat regions with artificial unwatering, to make a careful compromise between tile diameter and hydraulic gradient, so that wide tiles do not increase expenses too much, nor does too steep a gradient necessitate deeper drainage, with consequent increase in costs.

In planning a composite drainage system, use can be made of the nomogram in Fig. 15, in which the length of the laterals b in metres, the length of the main drain l in metres, the tile diameter d in centimetres, the hydraulic gradient h in centimetres and the maximum quantity of water to be discharged m in millimetres per day, are co-ordinated with each other by calibrated lines intersecting at right angles, plus one straight reference line.

A working chart, on which it is possible to record the straight lines representing the gradient required for tiles of different diameter, as well as the lines for the same rate of flow of water, can simplify the making of a decision as to what



v = velocity

Fig. 16. A WORKING CHART WITH SCALES FOR h AND l CAN BE USED IN PLANNING AN COMPOSITE DRAINAGE SYSTEM. The straight lines for hydraulic gradient in the case of various tile diameters d are formulated with the help of the nomogram. Lengths of drain with the same tile diameter are determined, taking into consideration the lines for equal speed and the ratio of cost to necessary gradient. The thick line shows what drain lengths were chosen for tiles of different diameter, and where thicker tiles were adopted.

lengths of tile of the same diameter are to be used. Choice of the point of change-over to a larger tile diameter has consequences — which, in this case, can easily be read from the chart — affecting the total gradient necessary. The working chart in Fig. 16 enables a concise, summarized view of the entire plan to be obtained.

3.5. The criterion of discharge

The discharge coefficient is determined by the highest water table considered permissible, and the quantity of rainwater which then has to be removed per day. It is assumed that the water must not rise to a point higher than 50 cm. below the surface of the ground. Results from drainage trial fields in the Zuider Zee polders show, however, that higher levels are usually quite harmless. The outcome of investigation into the influence of the winter and summer water tables respectively (Fig. 17), points in the same direction. Nevertheless, it would appear to be advisable not to let the water table rise too high.

In the case of the water level mentioned above, — i.e., not higher than 50 cm. below the ground surface — the discharge rate is fixed at 5 to 7 mm. This figure must be deducible from the rainfall frequency and the soil's capacity for storage of gravitational water. Up till now, it has not been possible to find a satisfactory solution to a number of problems connected with this subject. Research into it is being continued.

4. Execution

Questions of actual execution of drainage projects lie, to a large extent, in the sphere of economics. In this connection the problems involved are partly dependent on the conditions controlling the governmental grants, such as provision of work for the unemployed or current policy regarding production. These matters govern the degree of mechanization and the profitability limit.

One technical point requiring much consideration however, is that of the

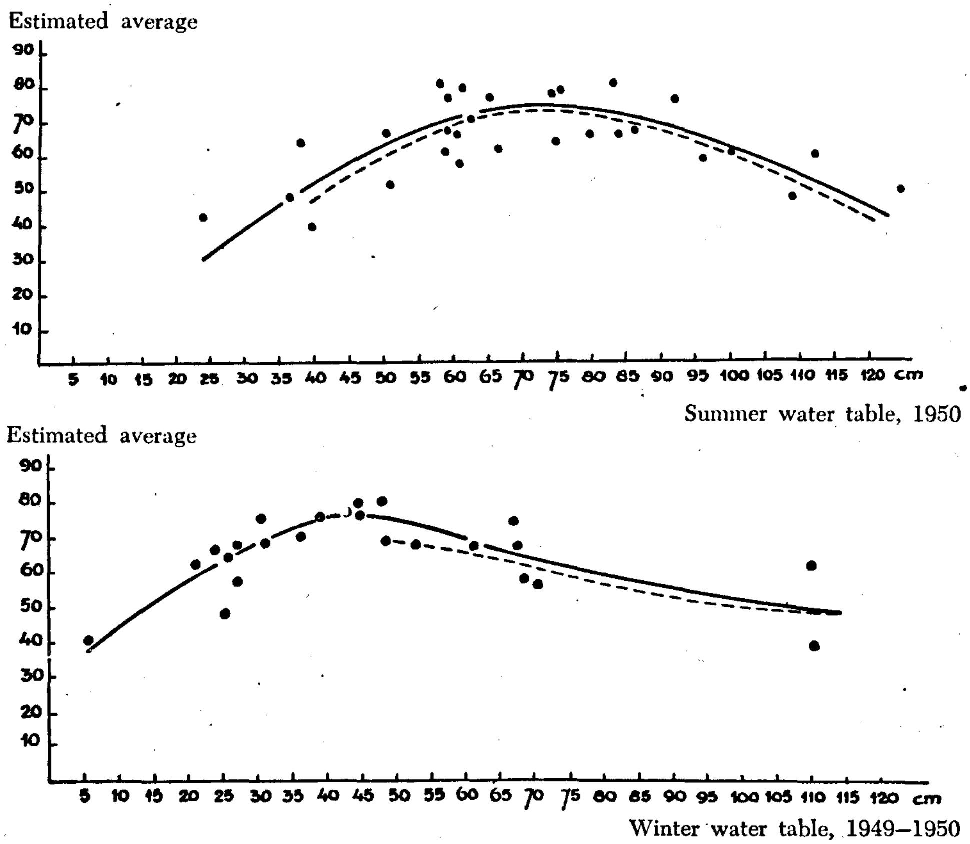


FIG. 17. THE YIELD FROM GRASSLAND ON SANDY CLAY SOIL HAS PROVED TO BE DEPENDENT ON THE WINTER AND SUMMER TABLES, ACCORDING TO YIELD CURVES WHICH SHOW THAT IT IS DESIRABLE TO HAVE A HIGHER WATER TABLE IN WINTER THAN IN SUMMER. The dotted line represents the yield for 1949, the unbroken line that for 1950.

means to be applied when carrying out a tile drainage scheme in order to prevent soil material from penetrating into the drains, and, at the same time, to promote the influx of water. The oldest method of effecting the former consists in wrapping peat litter round the tiles, or only round the joints. Later, heather, reeds, straw, etc., came to be used, and these porous filtering substances enable both objectives to be achieved.

Prevention of silting-up is the more important of the two where sandy soils of reasonable permeability are concerned. Here, it will be necessary to pay more attention to the penetration of sand into the tile via the joints than to its being entrained by the flow of water entering the tile. In this case it will be sufficient to cover the top and sides of the tile or joint.

In the case of impermeable clay soils, the other problem will be more important, i.e., conduction of water into the tile. The poor permeability, and convergence of the flow of water on to the small surface of the joint, will result in great resistance and, consequently, less influx.

It is important to fit round the tile permeable material which greatly increases the surface over which the water leaves the soil, as compared with the area of the joint. Since most water enters the drain at the bottom, envelopment of the tile with porous material is an advantage.

Peat litter consisting chiefly of Eriophorum is especially valued as a permanently porous material with a long active life. Sphagnum peat is less suitable; moreover, the right kind is very scarce. Chopped straw and chaff also have a very good filtering effect, but their effective life is too short. Further search should be made for really suitable material combining long life with adequate availability.

5. Maintenance

When a tile drain ceases to function, the reason is generally to be found in its having become blocked up, and not in damage to the tiles. Deposits of iron or lumps of earth, plant roots and sometimes the bodies of animals, prevent the water from being discharged properly. Regular inspections have shown that very little trouble is needed to clean out the tiles by removing foreign material, while it is evident that such action greatly lengthens the life of a drainage system. In the Zuider Zee polders the capitalized cost of such maintenance

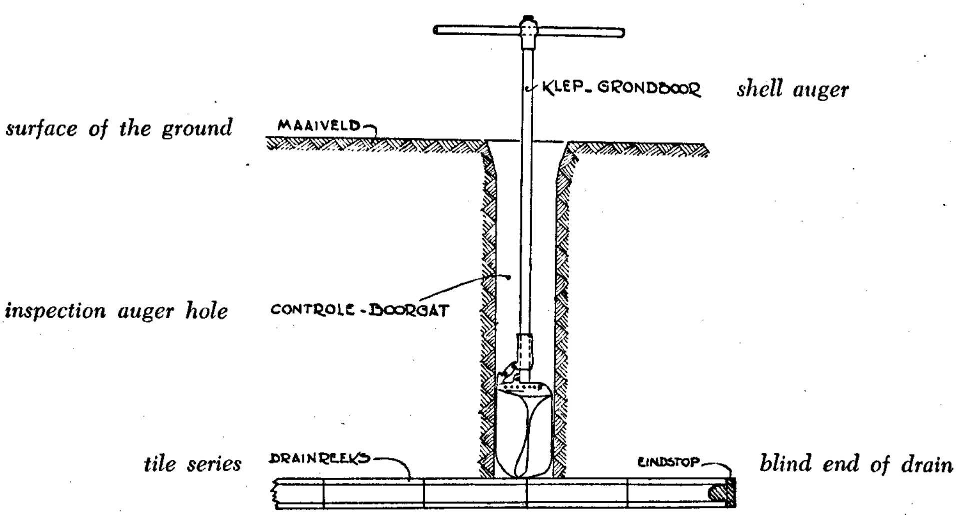


Fig. 18. Sectional view of an inspection auger hole.

operations proved to be 10 to 15% of the cost of laying the drains. Given good organization, such cleaning action can also be made very profitable elsewhere.

Obstruction of a tile series can be ascertained by drilling a hole, in the wet season, down to the tile at the top end of the series. This is done by means of a suitable auger and a gauging iron (Figs. 18 and 19). If water remains standing above the tile, even after some dry days, the drain is choked. Such an inspection, like cleaning, is best carried out in November or December.

Many methods of cleaning tiles have been tried. Flushing them out with water, thrusting iron rods along the pipes, or drawing scrapers or wads through them, etc., have usually either not worked sufficiently well, or caused tiles to break.

One practical method of cleaning a tile drain, when incipient stoppage has been detected in time by the annual check with auger holes, is by means of rattan rods (Figs. 20 and 21). During a period in which the drain should normally

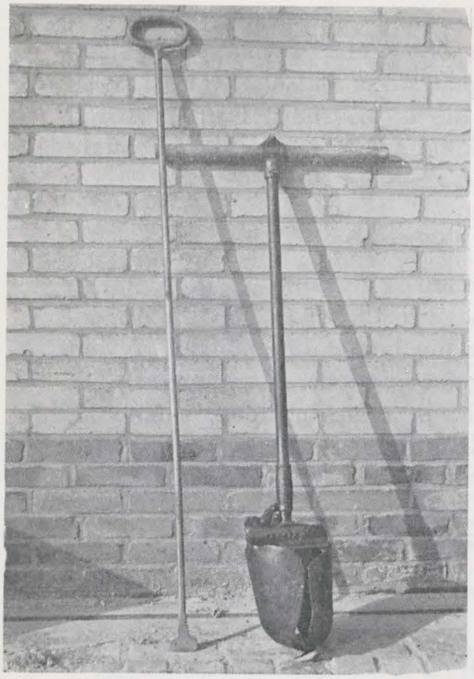


FIG. 19. GAUGING IRON AND SHELL AUGER.

FIG. 16. BUNDLE OF RATTAN RODS, AS USED FOR PASSING THROUGH SILTED-UP DRAINAGE TILES IN ORDER TO CLEAR THEM.

be flowing, a series of connected rattan rods, each 5 metres long, is pushed through it and moved to and fro, thereby stirring and mixing the silted-up material so that it forms a thin suspension. The water running away entrains this suspension.

It is only rarely found to be impossible to thrust the rattan rods through the obstruction. When this happens, the tile there has to be dug up, though sometimes it is sufficient to fasten scrapers to the rods and pull them through the drain. Lengths of drain of up to 200 metres can be cleared with the help of

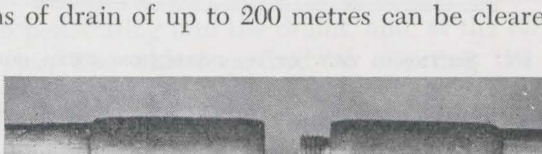


FIG. 21. CONNECTING ENDS FITTED TO RATTAN RODS.

only a few workmen. When the rods are withdrawn, thy can be pushed, floating on the water of the ditch, to the following drain to be cleaned. One end of the connected series of rods can be inserted in the next drain while the other end is still being drawn out of the last drain. The flexibility of rattan makes it very suitable material for this work. An area of up to 250 ha can be treated with a single set of rods in the course of one winter.

A well-laid drain obviously requires less maintenance than a system composed of inferior tiles, or one that has been carelessly laid. Use of good end tiles at least one metre in length can have a particularly favourable effect on the cost of maintenance.

Above all, attention must constantly be paid to regular inspection. If one waits too long, it will cost three times as much to clean out the drain. Inspection, the cost of which per hectare is 40 % that of the actual cleaning operations, has the advantage of being possible to carry out at a time when permanent staff have no other urgent tasks to perform.

6. Future development

In the Netherlands a good tile drainage system is capable of substantially increasing the productivity of the soil. Scientifically speaking, the underground drainage problem has been solved, in so far that the body of theory available is already sufficient to enable valuable practical advice to be provided to suit concrete cases. The executive services and organizations have given an account of the way in which they base their activities on the knowledge and experience at their disposal. This applied scientific research has developed widely in recent years. The new coöperation between government departments and executive societies and companies has rendered it possible to make effective plans and carry them out in profitable fashion. The stage of development has now been reached when tile drainage can be brought, by energetic publicity, to those areas to which this method of unwatering would be well suited but where it is, as yet, not sufficiently known. Steps in this direction are planned for the near future.