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A COMPARISON OF RECORDINGS OF GROUND-WATER TABLES AND SOIL-MOISTURE MEASUREMENTS BY NEUTRON-SCATTERING DEVICE ON A CLAYEY MORAINE WITH A HIGH WATER TABLE

SAMMENLIGNING AF GRUNDVANDSPEJL-REGISTRERINGER OG JORDFUGTIGHEDSMÅLINGER MED NEUTRON-SCATTERING DEVICE PÅ LERMORÆNE MED HØJTSTÅENDE GRUNDVAND

BY

H. HOLSTENER-JØRGENSEN, L. M. EISELSTEIN
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1. Introduction

In 1965 *H. Holstener-Jørgensen* planned an investigation of the ground-water fluctuations in observation wells of various diameters. The basis for this research project should be a grant from the *Danish State Research Foundation.*

An application was filed with the Foundation. While considering the application, *C. G. Lamm*, dr. agro., pointed out that part of the problems involved in the investigation might be solved by neutron-scattering measurements. If, by means of neutron-scattering measurements, the depth at which the soil is saturated with water could be determined with a fair degree of accuracy, it should be possible by such measurements to find the correct location of the water-table and compare it with the water-tables recorded in wells of various diameters.

The scheme was discussed with a number of institutions, the discussions being best characterized by mentioning the following names of experts involved: *C. G. Lamm*, dr. agro., lecturer at the Technical University of Denmark, *V. Haahr*, lic. agro., of the Atomic Energy Commission Research Establishment at Risø, *Andersen*, lecturer, of the Geological Survey of Denmark, *Somer*, civil engineer, of the Isotope Central. After thanking all these gentlemen for inspiring discussions carried out in a very positive atmosphere, we will mention that, as a result of the discussions, it was decided that we should carry through a series of measurements and see what results they would bring. The measurements were made with an instrument kindly placed at our disposal by the Geological Survey of Denmark.

The following is a review of the results, emphasis, however, being given solely to what light the investigations may throw on the ground-water problems we are dealing with. Our chief problem, which is to elucidate to what degree the results of the measurements are dependent on the diameters of the wells, has been treated in a separate paper (*Holstener-Jørgensen* and *Eiselstein*, 1968).

2. Some remarks on the neutron-scattering measuring method

This measuring method and the problems attached to it have been treated in so many articles that there is no reason for discussing the method, its advantages and limitations, here.

The apparatus we have used is of Danish design (*Danbridge A/S*). We have not, for the purpose of the present investigation, compared its qualities with those of other makes. *Schultz* (1967), in a comparison of the apparatus with a couple of American designs, says that "A special tungsten-polyethylene shield arrangement surrounds the source and results in good resolution for detecting moisture variations with depth as well as providing considerable radiation shielding" (p. 793). "... so that greater discrimination is obtained than with either American make" (p. 793). "Perhaps the Danish probe offers the most satisfactory design from the point of view of sampling the soil uniformly and being able to detect abrupt changes in soil moisture within the profile" (p. 795).

Judging from this expert opinion, we should hardly have been able to find any apparatus on the market that was better suited to our purpose than the one we have actually used.

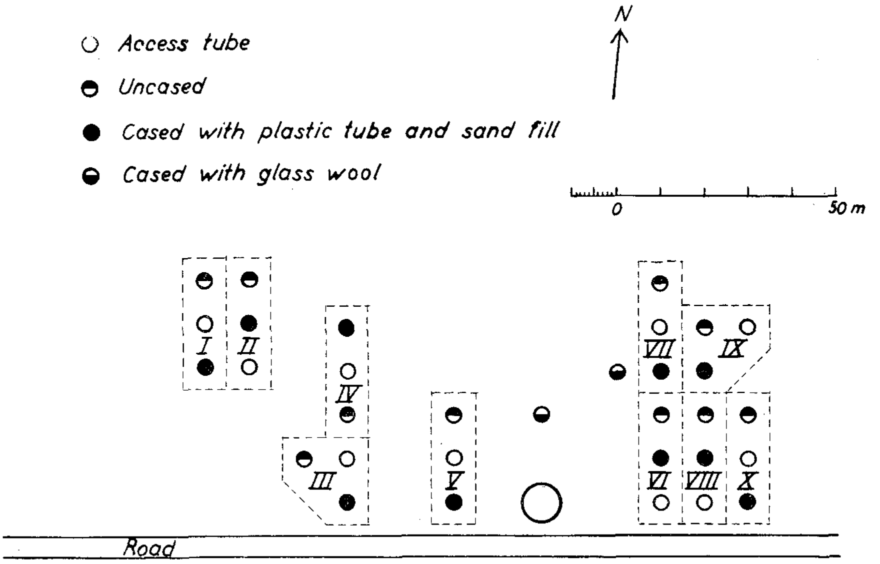
3. The establishment of the investigation

The investigation was carried out in a 90-year-old beech stand in the Billesborg Indelukke of the Vallø forest district. The soil is fat moraine clay with a high water table.

In April 1966, 23 ground-water wells of various types were bored in this stand. (For further details, see *Holstener-Jørgensen* and *Eiselstein*, 1968). Fig. 1 represents the positions of the wells.

At the same time, with assistance from Risø (*V. Haahr*, lic. agro.), 20 access tubes were placed in the area. They were of aluminium and 2.8 metres long. Ten of these access tubes are included in the randomised design, whereas the other ten are placed 1.5 metres from the cased wells which are part of the experimental plan. In the following, the latter are marked with an A, all access tubes being denoted by their block number.

The A access tubes, those placed near the cased wells, have been included, because we wanted a set of measurements from places where we had some previous knowledge of the depth to the water table. As it appears from Fig. 1, there is in the design a distance of 10 metres between each well and the access tube.



F i g. 1: A sketch of the investigation area with the various installations.
F i g. 1: Skitse af undersøgelsesarealet med de forskellige installationer.

This means that, within the individual block, we must anticipate a considerable variation in the ground-water level from well to well and from well to access tube. The A access tubes are so near the wells that this variation must have been considerably reduced.

4. The measurements

The Basc-scaler instrument (made by Danbridge) can be used in two ways. It is provided with a precision stop watch, which can either be connected with the pre-set impulse counter, so that the stop watch is stopping automatically after, say, 20,000 impulses, or the stop watch can be connected with the impulse counter, and the apparatus is stopped manually after, for instance, one minute, and the counts are read.

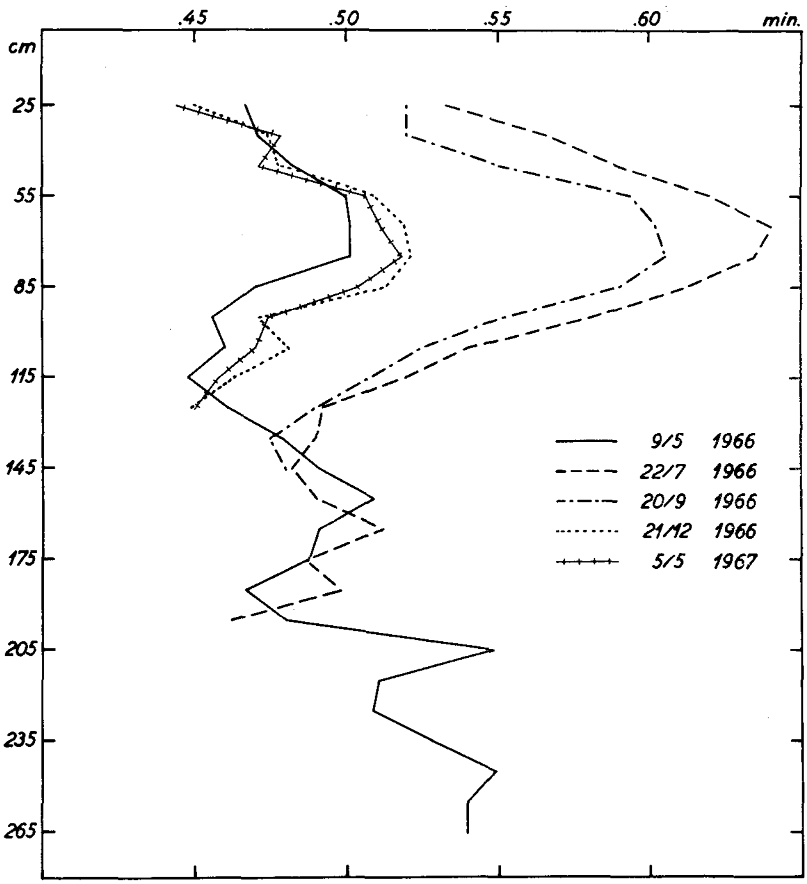
Some field experiments showed that the former method (the fully automatic one) was preferable, as it proved difficult to work the stop watch manually with sufficient precision.

All through the investigation, the apparatus was set to stop after 20,000 counts. Count times were obtained, varying between 0.410 minutes (Tube 8, 11th May, 1966, 105 cm depth) and 0.704

minutes (Tube 7, 22nd July, 1966, 45 cm depth). These figures correspond to 48,780 cpm and 28,409 cpm respectively. While working up the material we have, on the whole, preferred to use the recorded count times direct instead of converting them to cpm, which is the normal practice.

The first measurements were taken on 9th to 11th May, 1966. In the following these measurements will be marked with the date 9th May. The measurements were taken at intervals of 10 cm from 25 cm to about 265 cm below the surface of the ground.

During these first measurements the soil was saturated with water (field capacity), and the measurements are considered

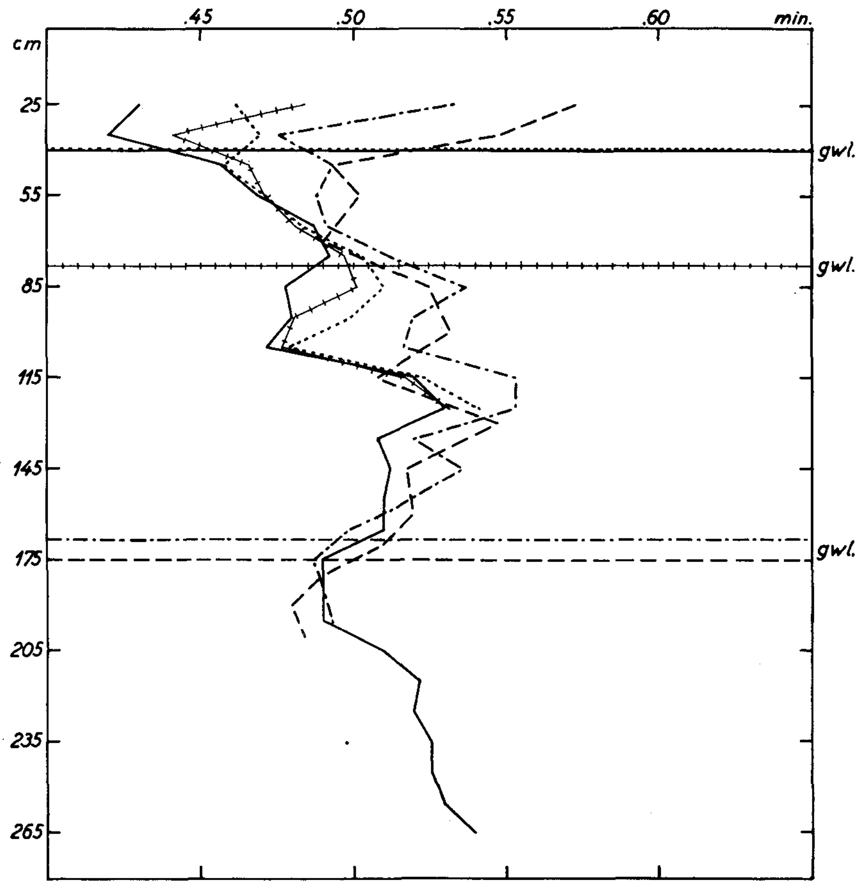


F i g. 2 a: Examples of results of the neutron-scattering measurements.
F i g. 2 a: Eksempler på resultaterne af neutron-scattering målingerne.

"basic measurements", used in judging the results of all the other measurements.

In addition to the "basic measurements", 9 sets of measurements were carried out on the following dates: 21st May, 16th June, 22nd July, 11th August, 20th September, 26th October, 23rd November and 21st December, 1966, and 5th May, 1967. At these measurings the maximum depth varied somewhat, since, apart from random sampling, we only measured at such depths as to be sure that we had gone below the water table.

Fig. 2 a and b show examples chosen among the results of our measuring. Access tube 4 (Fig. 2 a) is part of the proper ex-



F i g. 2 b: Examples of results of the neutron-scattering measurements.
F i g. 2 b: Eksempler på resultaterne af neutron-scattering målingerne.

perimental plan (Block IV), that is, it is placed at a distance of 10 metres from the nearest ground-water well. Access tube 9 A (Fig. 2 b) is 1.5 metres from the cased ground-water well in Block IX. In this figure, the ground-water tables in the neighbouring cased well have been shown with the same symbols as those used for the neutron-scattering measurements.

The measurements nicely reflect the drying out of the soil during the summer and the replenishing of the water content during the autumn. The figure also shows that there is a concordance between the neutron-scattering measurements and the water tables, although there is a considerable dispersion.

Considering the two figures, we furthermore get a clear feeling that the apparatus gives a well differentiated picture of the conditions at the various depths of measurement. Because of the heterogeneous character of the moraine material, the measurements vary considerably from depth to depth. These variations cannot be explained without an exhaustive physical analysis of the profiles surrounding the individual access tubes, and such analyses are outside the scope of the present investigation. However, a single characteristic feature should be mentioned. The two examples selected represent two main types of sets of curves into which we find that we can divide the material. In Access tube 4 the basic curve shows high count times at the depth of 75 cm. Above and below this depth the count times are lower, thus providing the curve with a characteristic peak at the depth of 75 cm. We furthermore notice that for the depth of 120 cm, at which the basic curve shows its lowest dip, and downwards into the profile the count times increase, although there are considerable variations. The mentioned peak at the depth of approximately 75 cm is repeated in about half of the measured localities, and it must be presumed that it reflects the bulk-density relationship. The greater the density of the soil is, the lower will its water content be, and the longer count times will be recorded. This point is treated in greater detail on p. 65.

Fig. 2 b shows a different type of curve. There is no distinct maximum count at the depth of 75 cm. Certainly, other peaks and dips can be seen, but in the authors' view they are due only to the texture. On the other hand, there is an average rise in the count times with depth.

5. AN ESTIMATE OF THE ACCURACY OF THE NEUTRON-SCATTERING MEASURING METHOD

We have made no repeat measurements to judge the accuracy of the method. The investigation as a whole, however, involves such repetitions during the period covered by it, namely in the form of results from measurements taken below the ground-water table.

The results of the measurements in 10 access tubes from the depths 155, 165, 175, and 185 cm and from the measuring dates 9th May, 11th August, 26th October, and 23rd November, 1966, have been subjected to an analysis of variance.

The result of this analysis was that we must reckon with the individual measurement being subject to a standard deviation of the order ± 0.00859 minutes for 20,000 counts.

The analysis of variance showed, moreover, that there was a significant difference between the access tubes, which was to be expected. Furthermore there was a difference between the depths, as, on an average, the count time is increasing with the depth (cp. the comments above on Fig. 2).

The standard deviation mentioned corresponds to ± 1.7 %, the mean count time in the part of the material included in the analysis of variance being 0.499 minutes for 20,000 counts. For the purpose of judging this standard deviation, we can mention that *Merriam* (1960) has examined the magnitude of the errors for a Nuclear-Chicago P 19 moisture probe in connexion with a Nuclear-Chicago Model 2800 scaler. He operates with random error in volume % water at various count times and various soil moisture contents (his Fig. 2, p. 644). It appears that the error is reduced with increasing count time. Absolutely it is increased with increasing soil moisture content, but relatively it falls. For water contents between 25 and 30 % of volume he finds at a count time of one minute a standard error of the order ± 0.82 % of volume, relatively corresponding to ± 3.0 %, which may be compared with our error of 1.7 % at a count time of 0.5 minute mentioned above. Consequently, the Danish instrument works with a fine degree of precision.

6. A COMPARISON OF THE GROUND-WATER MEASUREMENTS AND THE RESULTS OF THE NEUTRON-SCATTERING MEASURINGS

The main purpose of the present investigation is to compare the neutron-scattering measurements with the depth to the ground-water table. The access tubes placed 1.5 metres from the cased wells have been placed there to provide a set of measurements which can be compared directly with the ground-water depths recorded by soil-moisture measurements obtained by the neutron-scattering method.

Fig. 2 a and b gives the impression that the drainage at the depths around the water-table is relatively small. The distance between the curve for the given date and the basic curve (9th May, 1966) is comparatively small and near the above mentioned standard deviation for the individual measurement. Another uncertainty is caused by the fact that, from location to location in the stand, there is some difference in the distance of the ground-water from the surface of the ground, and that this variation can only be considered reduced, not eliminated.

Considering these two "uncertainties" together, it is evident that the best comparison of the two measuring methods is obtained when it is based on the total material.

This has been done in the following way:

The neutron-scattering measurements were taken at the same depths every time in all profiles and at intervals of 10 cm, starting 25 cm below the surface of the ground. For a number of dates we have chosen the depth which came closest to the ground-water table recorded in the neighbouring well, plus the two depths above it. For these three depths we have calculated the differences between the measurements on 9th May, 1966 (y_1) and the actual measurements (y_2). We used the formula: (y_2—y_1).

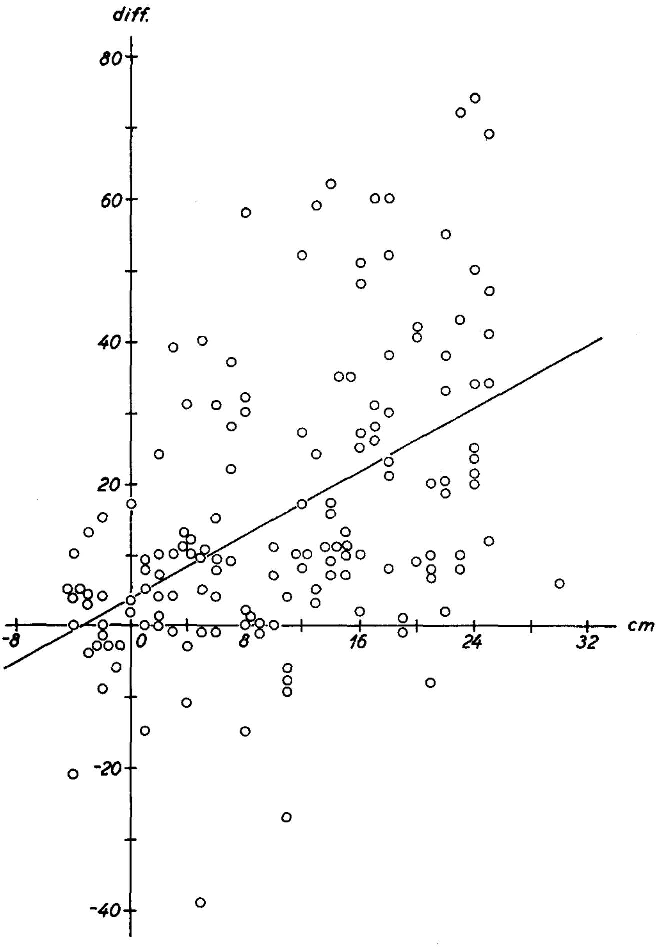
These differences we have put in relation to the distances of the depths from the water-table in the neighbouring well, thus obtaining series of, for instance, the following form:

$x_1 = -2$ cm (which means that the measured depth that comes closest to the water table is 2 cm lower than the latter)

$x_2 = 8$ cm

$x_3 = 18$ cm

For this part of the investigation we have, in addition to the basic measurements (9th May, 1966), used the measurements from 16th June, 22nd July, 11th August, 20th September, and 26th October, 1966.



F i g. 3: The connexion between the differences (diff.) between two measurements (taken at various times) and the distance of the measured localities (cm) from the ground-water table in a ground-water well 1.5 metres from access tubes. Further explanation in the text.

F i g. 3: Sammenhængen mellem differencerne (diff.) mellem to målinger (tidsforskellige) og målepunkternes afstand (cm) fra grundvandspejlet i en grundvandsbrønd 1.5 m fra access tubes. Yderligere forklaring i teksten.

In Fig. 3 the differences (difference in thousandths of minutes) are plotted against distance to water tables (cm).

Theoretically we must presume that the cluster of dots in the left-hand side of the figure — in and below the water table — is distributed evenly around the abscissa axis, that is, the dots in or to the left of the water table may presumably be represented as an adjusted line coinciding with the abscissa axis.

In the right-hand side of the figure, that is, above the water-table, it must be expected that the deviations — within a certain limit — will be constantly increasing. Theoretically we must therefore take for granted that the best adjusted curve for the cluster of dots will be a curve one end of which coincides with the abscissa axis.

As the material presents itself, we find, however, that there is nothing to prevent a linear adjustment to be made, and we have chosen this possibility, because we can offer no justification for the form of the curve.

When the distance to the water table in the cased wells are used as independent variable (x) and the differences (y) as dependent variable, the regression equation will be as follows:

$$y = 3.67 + 1.12\,x.$$

The correlation coefficient is 0.49 and significant with a statistical probability of 99.9 %.

The level of the line, characterized by the parameter 3.67, is not significantly different from 0 for $x = 0$ (t value 1.63 with 148 degrees of freedom). Consequently, we cannot with certainty say that the line does not intersect the 0 point, which means that, within the given limits of error, the position of the water-table as measured in the cased wells and the position of the water-table as decided by neutron-scattering measurements give the same value.

It is generally thought that immediately above the water-table (Suction 0) there is a zone, the so-called "capillary fringe", in which the pores are completely filled with water, although the water is under suction. The thickness of this zone varies with the texture of the soil. It is thicker in fine-textured soil, but also other factors are influencing its thickness.

At the measurements we have made, it might be expected that the neutron-scattering measurements would record full water-saturation in the capillary fringe area. The regression described above shows nothing of the kind. The reason may be that our probe's sphere of influence is of such dimensions as to render the measurements' power of solution in the area around the water-table too small to allow details of this nature to assert themselves.

It is conspicuous, however, that the tendency in the material goes in the direction of the neutron-scattering measurements recording full water-saturation at a somewhat lower depth than the wells show water-tables, cp. the intersection of the regression line and the abscissa axis in Fig. 3. If anything, this seems to indicate that, in practice, the mentioned sphere of influence has a greater radius than the capillary fringe is able to fill.

Besides, one may form a further estimate of the certainty with which the position of the water-table may be decided by comparing Fig. 3 with the standard deviation for the counts, which has been dealt with in the previous chapter. According to the regression, 10 cm on the abscissa axis corresponds to a count time of 0.011 minutes. The standard deviation for the counts is ± 0.0086 minutes.

It is quite obvious that, at investigations under circumstances like those at Vallø, we must allow for very considerable variations from place to place (soil variation, age of stand, tree species, etc.).

7. An examination of some one-sided deviations in the material. (Hysteresis phenomena)

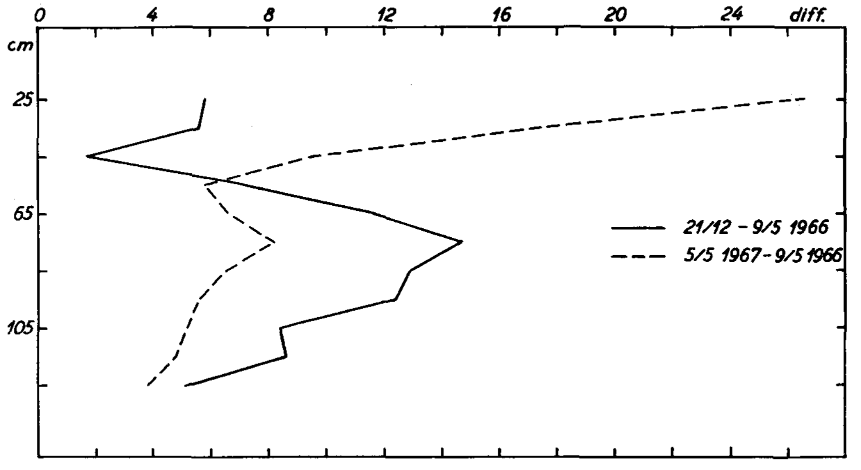
According to the plan, the final measurements were to be made in the late autumn or the early winter, when the soil was again completely saturated with water. The decision whether this was the case had to be based on two observations, one concerned with the water table, and another based on the neutron-scattering measurements themselves.

On 21st December, 1966, the full water-saturation should have been reached according to the ground-water measurements, but at certain depths the neutron-scattering measurements showed one-sided deviations, which could only mean that the conditions at these depths differed from those prevailing in the spring of 1966. The one-sidedness tended towards a smaller water content.

In Fig. 2 a and b the mentioned one-sided deviations are visible. In Fig. 2 a, dealing with Access tube no. 4, the one-sided deviations are quite clear from the depth of 55 cm down to and including the depth of 115 cm. In Fig. 2 b they are found in the depths from 75 cm to 105 cm. These two part figures illustrate the considerable variation found in the material. In a few profiles no one-sideness can be seen with any certainty, in others (cp. Fig.

2 a) it is considerable and quite clear. Fig. 4 shows the mean values for all 20 access tubes for the depths from 25 cm to 125 cm. On an average, the maximum deviation is found at the depth of 75 cm.

To follow up the matter, it was decided to take one further set of measurements on 5th May, 1967. They could be made only in 19 tubes, as one had been destroyed. It appears from these measurements that the differences had been reduced. Fig. 4 gives



F i g. 4: The average differences in time for 20,000 counts at various depths for measurements on 21st December and 9th May, 1966, and for measurements on 5th May, 1967 and 9th May, 1966.

F i g. 4: De gennemsnitlige differencer i tiden for 20.000 counts i forskellige dybder for målingerne 21/12 og 9/5 1966 og for målingerne 5/5 1967 og 9/5 1966.

an impression of the changes. Leaving out of account the desiccation of the top soil layers, the average reduction of the differences is quite conspicuous.

For the depths 65 cm, 75 cm, 85 cm, 95 cm, and 105 cm, the two sets of differences have been represented in Fig. 5. If, on an average, the differences had been equal, they would have been distributed around the angle bisector, also entered in the figure. The figure shows that this is not the case.

The cluster of dots can be adjusted with a line with the following equation —

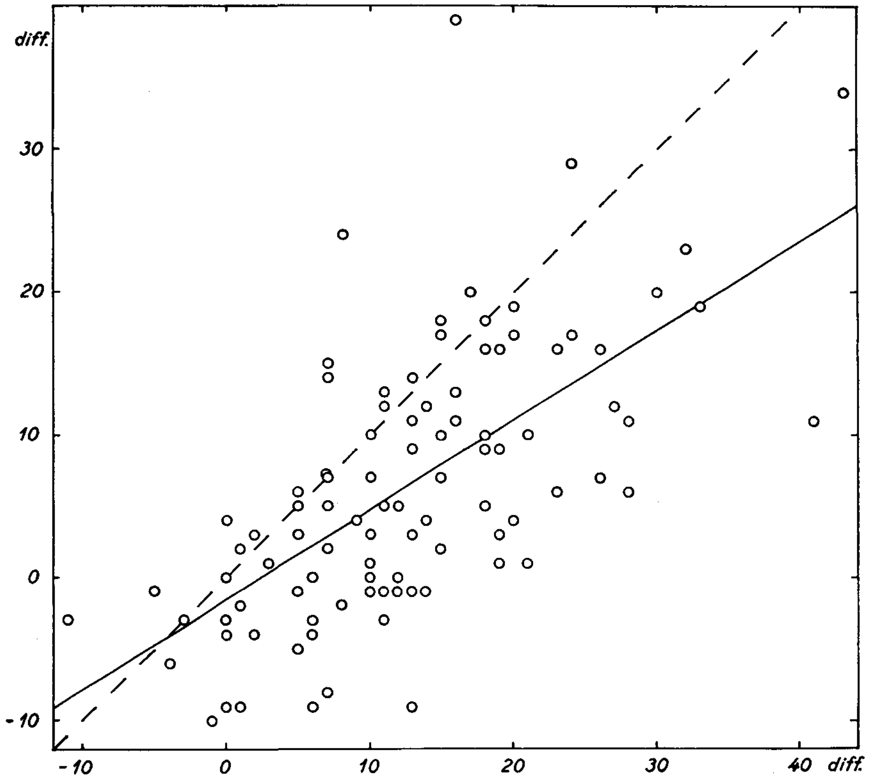


Fig. 5: A comparison of connected differences in count time for 20,000 counts at the depths 65 cm, 75 cm, 85 cm, 95 cm, and 105 cm for the measuring dates 21st December and 9th May, 1966 (abscissa) and for the measuring dates 5th May, 1967 and 9th May, 1966 (ordinate).

Fig. 5: Sammenligning af sammenhørende differencer i måletiden for 20.000 counts i dybderne 65 cm, 75 cm, 85 cm, 95 cm og 105 cm for måledatoerne 21/12 oa 9/5 1966 (abscisse) og for måledatoerne 5/5 1967 og 9/5 1966 (ordinat).

$$y = -1.51 + 0.63\ x$$

where: y = the difference between the measurements on 5th May, 1967 and the measurements on 9th May, 1966

x = the difference between the measurements on 21st December, 1966 and the measurements on 9th May, 1966.

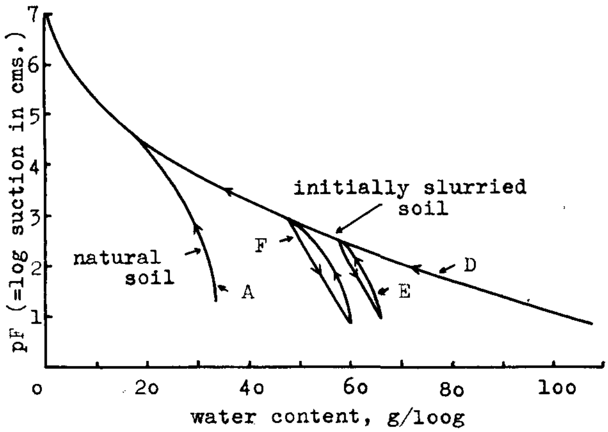
The regression coefficient (b = 0.63) is significantly different from 1.00 (the angle bisector). The statistical probability for this is 99.9 % (t = 4.76 with 93 degrees of freedom).

As to the reason for the mentioned differences we can at present only guess. The differences show that on 21st December, 1966 and 5th May, 1967 there is less water (fewer H-atoms) than on 9th May, 1966 at the depths in question. This "state of affairs" is to some degree, but not completely, adjusted in the period from 21st December, 1966 to 5th May, 1967. One reason might be a compression of the earth, caused by the traffic around the access tubes in connexion with the measurements. By the compression the pore volume is reduced, involving — especially below the ground-water table — a lower water content at full water-saturation. This explanation, however, is not very credible, because (1) the greater part of the traffic took place in the growing season, during which the soil is relatively dry and therefore has a higher carrying capacity, and (2) the differences which we are dealing with here are found at such a depth as to make it hard to imagine that traffic should be able to cause any compression.

It is more probable that it is a question of hysteresis phenomena. Hysteresis phenomena are known to occur in clay during moistening and desiccation processes. In this connexion we will refer only to *Marshall's* (1959) account (l.c., p. 17—19, Fig. 6), which is sufficient for the purpose of the present investigation, and of which we shall give a brief résumé. His figure has been reproduced here as our Fig. 6.

When a sample of so-called slurried clay is desiccated, there will be a connexion between water content (abscissa) and the suction applied, corresponding to the one which appears from Curve D. If the desiccation is discontinued and the clay is re-moistened, the result will be a curve like E or F in the figure. The moistening phase (arrow turned downwards) gives a smaller water content per suction unit than the suction phase (arrow turned upwards). Curve A in the figure represents the desiccation of natural earth. The slurried earth catches up with the natural earth only when it has been desiccated to pF 4.8. From this it should be possible to deduct that the natural earth has been exposed to desiccation (on one or more occasions?) to pF 4.8.

In Fig. 6 there is no moistening curve for natural earth, but it must be of the same nature as the moistening curves F and E,



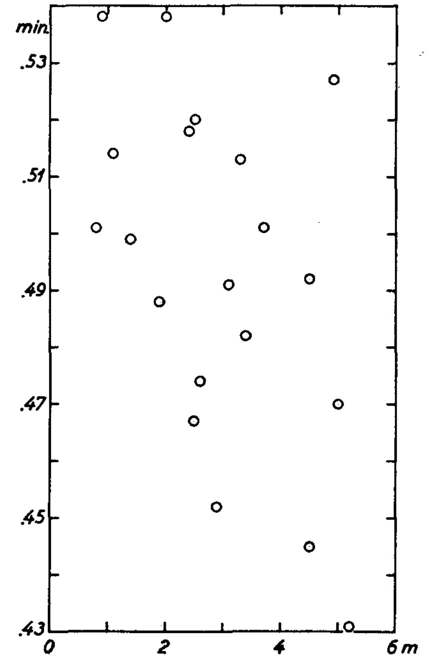
F i g. 6: *Marshall's* (1959) Fig. 6. For further details, see text.
F i g. 6: Marshall's (1959) figur 6. Se i øvrigt teksten.

that is, it must show a lower water content per suction unit during moistening than during desiccation.

Other investigations show, moreover, that the pressure of, for instance, higher layers in the soil have the same effect as suctions: "The structure of soil of high clay content is affected by the maximum load or the maximum degree of desiccation to which it has been subjected in its history" (*Marshall*, 1959, p. 18).

A comparison of Marshall's compilatory account with the results we have had shows a very considerable parallelism.

In about half of the access tubes we have found a characteristic maximum count time at the depth of 75 cm (see Fig. 2 a). Moreover, this maximum coincides with the "maximum difference" shown in Fig. 4. Both maxima coincide with the soil zone in which, in old beech stands, a very heavy desiccation takes place in the latter half of the growing season. This desiccation is generally coupled with the earth being hard as a clay pan. On the basis of the present investigation we cannot conclude without further proof that there is a connection: (1) desiccation — (2) hysteresis — (3) shrinkage or other physical change of the clay colloids and consequently the zone involved — (4) clay hardpan; *but the parellelism is so striking that a specially arranged investigation with the purpose of elucidating this problem is worthwhile.*



F i g. 7: The connexion between the distances from access tubes to nearest tree (m) and the time for 20,000 counts at the depth of 75 cm on 9th May, 1966 (min.).

F i g. 7: Sammenhængen mellem access tubes afstand til nærmeste træ (m) og tiden for 20.000 counts i 75 cm's dybde d. 9/5 1966 (min.).

It belongs to the picture that certain correlations are discernible in the material collected, which support hypothesizing along the lines indicated. Fig. 7 shows the connexion between the distance to the nearest tree (m) and the time, on 9th May, 1966, for 20,000 counts at the depth of 75 cm (min.). There is a clear tendency for the time to be longest near the trees (the rank correlation coefficient = 0.467, which is only just significant on the 5 % level). So the figure suggests that the greatest physical change has taken place near the trees.

Fig. 8 shows the relationship at the depth of 75 cm between the time for 20,000 counts on 9th May (min.) and the differences in time between 21st December and 9th May, 1966 (diff.). Here there seems to be a tendency for the greatest differences to occur at the lowest count times, i.e., when the original water content

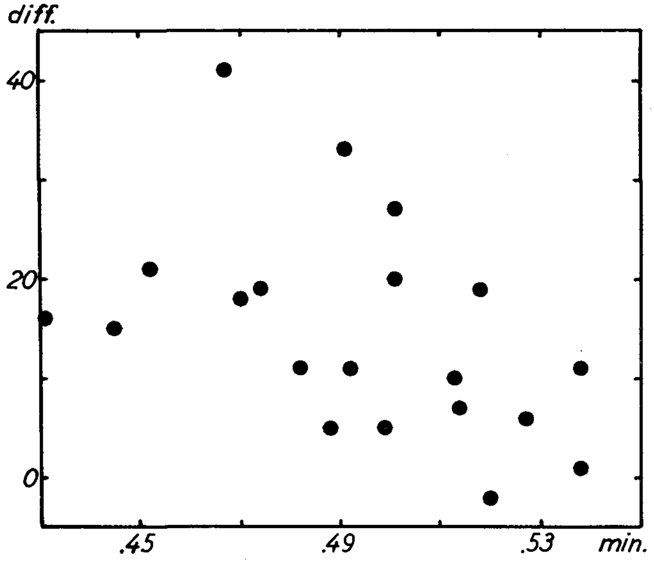


Fig. 8: The connexion between the time for 20,000 counts at the depth of 75 cm on 9th May, 1966 (min.) and the difference between the times for 20,000 counts at the same depth on 21st December and 9th May, 1966, respectively (diff.).

Fig. 8: Sammenhængen mellem tiden for 20.000 counts i 75 cm's dybde d. 9/5 1966 (min.) og differencen mellem tiderne for 20.000 counts i samme dybde henholdsvis d. 21/12 og 9/5 1966 (diff.).

was highest (rank corellation coefficient = —0.495 is significant on the 5 % level). This tendency points towards the hysteresis phenomena being most heavily pronounced at the greatest distances from the trees.

However, the correlation between distances to trees and differences in count times is far from being significant.

Our present material is unsuited for more detailed analyses, and we must maintain that only specially arranged investigations can elucidate the problem in a satisfactory way.

Finally it should be mentioned that the general increase of the count times (fewer H-atoms) in the deeper layers is in keeping with the fact that the deeper we go into the soil, the more will the weight of the higher layers increase, the greater will the bulk density be, and the more limited the H-atom content (sp. the citation from *Marshall*).

8. Conclusion

The investigation shows that there is a connexion between the results obtained from measuring the humidity of the soil by the neutron-scattering method and those obtained by measuring the depth to the ground-water-table in simple, cheap observation wells. As far as we can judge from comparing the results of our measurements, humidity measurements made by the method mentioned are not adequate where information about ground-water tables and water table fluctuations are wanted. Compared with simple observation wells and cheap, reliable measurements in these, the soil-humidity measurements call for expensive investments in apparatus and installations, and the measurements and their working-up are time-consuming.

This does not involve a judgment of the value of the apparatus and the installations for more detailed studies of changes in the humidity of the soil. The neutron-scattering method must be considered most suitable for such studies.

As a "by-product" of the investigation, the method has disclosed some discrepancies in the results of the measurements, which, with some probability, may be presumed to show hysteresis phenomena in the water balance in clayey soil under natural conditions. These hysteresis phenomena may be put in connexion with the well-known occurrences of clay hardpan in Danish beech stands on clayey soil.

The investigation of the true nature of the hysteresis phenomena calls for further field experiments, for the purpose of which the neutron-scattering method would seem to be well suited.

The Danish State Research Foundation enabled us, through its grant, to carry through this investigation, for which we should like to express our thanks.

DANSK SAMMENFATNING

Undersøgelsen har haft til formål at sammenligne resultaterne af jordfugtighedsmålinger med resultaterne af målinger af grundvandsspejlets beliggenhed under jordoverfladen.

Jordfugtighedsmålingerne er foretaget ved hjælp af den såkaldte neutron-scattering metode. I korthed går denne ud på, at man fra en neutron-kilde, anbragt i den såkaldte „probe" sender hurtige neutroner ud i jorden. De hurtige neutroner bremses og reflekteres af brintatomer i jorden. Mængden af langsomme (nedbremsede) neutroner er et mål for jordens indhold af brintatomer, og mængden kan registreres ved et automatisk tælleranlæg, hvis detektor ligeledes er anbragt i den såkaldte „probe". Brintatomerne i jorden findes overvejende i jordvandet, og mængden er altså et mål for vandindholdet.

„Proben" er relativt kompakt og kan sænkes ned i et rør, som forud er anbragt i jorden. I det foreliggende tilfælde er der anvendt tyndvæggede aluminiumsrør med en indvendig diameter på 4.5 cm og en længde på 2.8 m. Rørene var lukkede i den nedre ende, og mellem målingerne blev de tilproppet i den øvre ende. De blev anbragt i borede huller med en diameter, som sikrede, at der praktisk taget var fuld kontakt mellem jord og rør (access tube). Ved at sænke „proben" ned i røret, kan man når som helst foretage målinger i en hvilken som helst dybde. Ved hjælp af kalibreringskurver kan man omsætte måleresultaterne (tiden i minutter for 20.000 tællinger eller tællinger pr. minut = cpm) til volumenprocent vand. Dette er ikke gjort ved denne undersøgelse.

Jordfugtighedsmålingerne er beheftede med temmelig små fejl i sig selv, men der er en betydelig arealvariation. Denne skyldes dels, at jorden (Vallø moræneler) formentlig varierer i sin teksturelle sammensætning, dels at træerne — som ventet — øver en stærk indflydelse på jordfugtigheden. Udtørringen er størst nær træerne. Det viste sig, at grundvandstanden i december (21/12-1966) nåede forårsstanden, men neutron-scatter-målingerne nåede — i dybden 50—115 cm — ikke helt tilbage til forårsstandpunktet (figur 2a og b, figur 4). I foråret 1967 var forskellen udlignet noget (figur 5). Forskellen kan skyldes hysteresisfænomener (se hertil figur 6). Ved stærk udtørring eller vægtmæssig belastning ændres en lerjord, så en genopfugtning eller aflastning giver mindre vandindhold pr. vandbindingsenhed. Processen er ikke helt irreversibel; men ofte meget langsomt reversibel. På undersøgelsesarealet (90-årig bøg, Vallø) viste det sig, at karakteristisk, lave forårsvandindhold i dybden omkring 75 cm, fortrinsvis forekommer nærmest træerne (figur 7). Der er grundlag for at opstille en nogenlunde velfunderet hypotese om, at der virkelig er tale om hysteresisfænomener, og at de på langt sigt påvirker jord-vandsystemet, specielt nær træerne, så man får strukturændringer, som måske alene kan forklare de velkendte leralforekomster i danske skove.

Jordfugtighedsmålene viser parallelitet med grundvandsbevægelserne. Omkring det niveau i jorden, hvor grundvandspejlet befinder sig, er udtørringen imidlertid lille, så det, under hensyntagen til målefejlene, er vanskeligt med sikkerhed at bestemme, hvor neutron-scattermålingerne viser fuld vandmætning. Imidlertid viser en regressionsanalyse (figur 3), at fugtighedsmålingerne i gennemsnit viser fuld vandmætning i den dybde, hvor forede brønde viser vandspejlets beliggenhed. Sammenligningen er baseret på brønde og access-tubes med en indbyrdes afstand på 150 cm.

LITTERATUR

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