EFFECT OF HOLE SIZE ON PERCOLATION RATE IN A FIELD PERCOLATION TEST

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Applied Sciences Section
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Publication No.S60

August, 1976.

Ministry of the Environment
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Toronto, Ontario.

ABSTRACT

The influence of the hole size in a field percolation test has been investigated at the Whitby Experimental Station of Ontario Ministry of the Environment. It was found that the inverse percolation rate (I.P.R.), which is defined as the time taken by the water level in the hole to drop one unit distance (1 cm or 1 in), increases with the diameter of the test hole provided that the sum effect of other factors on the I.P.R. is approximately equal. However, under the field testing conditions, a number of factors can simultaneously affect the I.P.R. in the test and the effect of the hole size can be overshadowed. Consequently, there is no apparent trend between the hole size and the I.P.R. Generally the variability in the I.P.R. obtained in different sized holes is less than the variability of data due to soil and climatic conditions, hence it can be concluded that in practice the effect of the hole size on the I.P.R. is not significant.

Other aspects of the field percolation testing have also been studied. Conclusions have been obtained regarding the degree of saturation of the soil adjacent to the test hole and the significant influence of the depth of the water column in the hole.

PROJECT STAFF

The following staff of the Applied Sciences Section were instrumental in the production of this report.

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1. INTRODUCTION

The field percolation test which was originally devised by Henry Ryon in the late 1920's (Federick, 1948) has been used for many years in estimating the infiltrative capacity of a soil for clear water. The clear water percolation rate can then be related to the sewage loading rate by using the empirical correlation proposed by Ryon. According to Federick (1948), Ryon's test was made by excavating a hole 30-cm (12 in) square and 45-cm (18 in) deep, or to the depth of the proposed trenches (if deeper) and saturating the soil around the hole with water. The hole was then filled with water to a depth of about 15 cm (6 in) and the time required for the surface of the water to fall 2.5 cm (1 in) was measured. This time measurement is an indication of the rate of water seepage in the soil.

In order to simplify the percolation test, the Ontario Ministry of the Environment (1974), the U.S. Public Health Services (1967) and many other government agencies have modified Ryon's testing procedure. Instead of excavating a 30-cm (12 in) square hole as originally done, an excavation of a circular hole, 10-cm (4 in) to 30-cm (12 in) in diameter is performed.

Because Ryon's empirical correlation was based on percolation tests performed in holes 30-cm (1 ft) square, in principle it would be necessary to obtain the percolation rate of a soil in a square hole in order to use his empirical data. However, if the percolation test result obtained in a circular hole between 10 to 30-cm (4 to 12 inches) in diameter is approximately the same as that obtained in a square hole, it would be justified, for practical purposes, to use a circular hole in lieu of a square hole.

The main objective of the study was to investigate the effect of the size of the hole on the measured percolation rate of the soil. In addition, opportunities were taken to study some other aspects of the field percolation testing.

2. FIELD EXPERIMENTAL PROGRAM

In the investigation of the effect of the size of the hole on the percolation rate, two approaches may be used:

(i) To perform a large number of percolation tests in holes of different sizes and to find on a statistical basis the effect of hole size on the percolation rate.

(ii) To perform a small number of percolation tests in holes of different sizes and to study in detail the factors which influence the percolation rate. From the detailed study, the hole size effect on the percolation rate is then determined.

The first approach is time consuming and the second approach involves less time, because a smaller number of percolation tests need to be performed. In this project the second approach was favoured and adopted.

2.1 Location and Subsoil Conditions at Testing Site

The land adjacent to the experimental station of the Ontario Ministry of the Environment at Whitby was chosen for the testing program. The site was chosen because of convenience and because of the apparent uniformity of the soil conditions.

The soil profile was determined by augering and by studying an exposed soil surface in a trench about 1.5 m (5 ft) deep, which was excavated by a backhoe. There was about 0.2 m (0.5 ft) of top soil containing grass roots and some organic matter. Beneath the top soil material the clayey silt* containing tiny pores (probably worm holes) and hairline cracks. Figure 1** gives some idea of the soil structure. This layer extended to about 1 m (3 ft). Below this zone, the brown clayey silt extended to a depth not less than 3.7 m (12 ft),

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* According to the Unified Soil Classification System.

** Figures are located on pages 38 to 46.

where the soil exploration was terminated.

A number of soil samples were obtained adjacent to the percolation holes for laboratory tests. It was found that the clayey silt contained 6% to 25% of sand (2 to 0.074 mm), 44% to 45% of silt (0.074 to 0.002 mm) and 30% to 50% clay (<0.002 mm). The soil was of medium plasticity with values of liquid limit equal to 33.4%, plastic limit equal to 17.1% and plasticity index equal to 16.3%.

The topography of the site was generally flat, with a gentle slope of about 5% to the north. The water table fluctuated during the testing period (Spring and Summer seasons of 1974) with an average depth of about 1.2 m (4 ft) below the ground surface.

2.2 Testing Procedure

Three sizes of percolation test holes were used in this project and they were 10 cm (4 in), 20 cm (8 in) and 30 cm (12 in) in diameter. The 10 cm, 20 cm holes were made by a commercially manufactured auger and the 30 cm diameter hole was excavated by the auger specially made for this project. In each test, the hole was augered carefully to the depth of 60 cm (2 ft), the sidewall of the hole was scarified to reduce smearing of the soil by the auger and the loose material at the bottom of the hole was removed. A 5-cm layer (2 in) of medium-sized gravel was placed at the bottom of the hole prior to the soaking period of the percolation test to protect the bottom from scouring.

A 24-hour soaking period was used to wet the soil around the hole, which was filled with clear water to the depth of about 30 cm (12 in) above the bottom of the hole. During the soaking period, the time taken by the water level to drop 2.5 cm (1 in) was measured. After soaking, the gravel at the bottom of the hole, which usually was clogged up by fine soil particles, was carefully replaced by a clean 5 cm (2 in) layer of gravel. The water level in the hole was then adjusted to 15 cm (6 in) above the bottom of the hole and the time required for the water level in the hole to lower 2.5 cm (1 in) was determined. The hole was again refilled to the 15 cm (6 in) depth level controlled by a float valve which was connected to a water supply. The measurements of the 2.5 cm (1 in) drop of the water level in the hole were repeated until consistent readings were obtained.

Three groups of percolation tests were performed at three locations approximately 45 m (150 ft) apart. At each location, percolation tests were done simultaneously in three 10-cm diameter (4 in) holes which were positioned in the form of a triangle, about 2 m (6 ft) apart. Adjacent to the perimeter of one of the holes (identified as Hole A), several tensiometers were installed in the soil at different depths and at different distances from the edge of the hole to measure the changes of the soil moisture tension (suction) before and during the soaking period and also during the percolation test measurements.

Figure 2 is an example showing the installation of tensiometers around the hole. After the percolation tests, the soil around the holes was allowed to partially dry out for 2 or 3 days. Then the tensiometers were removed from the soil and the small holes were carefully plugged up with the same subsoil. The three 10 cm diameter holes were then enlarged to 20 cm (8 in) in diameter. Again tensiometers were installed around a 20-cm diameter hole which was enlarged from the 10-cm diameter Hole A. The same testing procedure was followed in conducting the percolation tests in the 20-cm diameter and 30-cm diameter holes.

In the field study program, only one hole was instrumented with tensiometers and subjected to an extensive investigation. At each location, the three holes were placed close together and the influence of the natural variability of the soil was minimized.

2.3 Description of Field Testing Equipment

Some of the equipment used for the field testing program are described as follows:

(i) Float valve - an automatic valve which was connected to a float on the water level in the hole. The flow of water to the hole was controlled by the water level in the hole through the float. With the use of the valve, the water level in the hole during the soaking period and during the percolation measurements could be accurately adjusted and controlled.

(ii) Tensiometer - a device which was used for measuring soil moisture tension (suction). As shown in Figure 3, a tensiometer consists of a porous ceramic cup, sealed onto a tube which is connected to a mercury manometer. The system is completely filled with de-aired water. When the porous cup is embedded in the soil, a water diffusion will occur through the wall of the cup because of the difference in water pressure between the cup and the soil. This process continues until an equilibrium condition is achieved. The magnitude of moisture tension(suction) in the soil is given by the reading on the mercury manometer.

(iii) Electric point gauge - An electric device was designed and manufactured to measure accurately the position of the water level in the test hole. the essential features of the gauge is shown in a schematic drawing in Figure 4. It consists of two electrodes (2 bare wires exposed at the tip) attached to the lower end of a measuring stick which can be raised and lowered along a vertical scale fastened to a horizontal reference board placed on top of the hole during water level measurements. The position of the measuring stick relative to the reference board is secured by two rubber rings. An electric meter is used to detect the electric current flow in the system. The operating principle is based on the fact that when the wires are in contact with the surface of the water in the hole, the electric circuit is closed and the electric current is indicated by the meter.

3. PRESENTATION AND ANALYSIS OF TEST RESULTS

3.1 Field Testing Results

Table 1* and Figure 5 summarize the three groups of percolation test results which are expressed as the "Inverse Percolation Rate" (I.P.R.) in minutes/cm and minutes/inch. For these tests, the initial water level was 15 cm (6 in) above the bottom of the test hole. The I.P.R. is defined as the time taken by the water level in the hole to drop one unit distance (1 cm or 1 in).** If the value of I.P.R. is large, the percolation rate, which is a measure of how quickly the water permeates through the soil, is small.

During the soaking period (when water was used to wet the soil around the test hole), the water level in the hole was kept at a depth of 30 cm (12 in) above the bottom of the percolation hole and the time required for the water level to drop 2.5 cm (1 in) in the hole was also measured. The test results for all holes are summarized in Table 2 and Figure 6.

The tensiometer readings recorded during the soaking period of the percolation tests are plotted against the time elapsed in Figures 7 to 9. Only the data for the three 10-cm diameter (4 in) hole A are presented for illustration purposes. In the Group 1 and Group 2 holes, six tensiometers were installed and in Group 3 holes, nine tensiometers were used. These curves depict the changes in the soil moisture tension (suction) at different depths in the soil and at different distances from the perimeter of the hole.

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* Tables are located on pages 23 to 37.

** The commonly used term "percolation time" is a specific case of I.P.R. in which the initial water level in the hole is 15 cm (6 in) and the time measurement is for the water level to lower 2.54 cm (1 in).

3.2 Effect of Hole Size on Inverse Percolation Rate (I.P.R.)

Table 1 and Figure 5 summarize the inverse percolation rate (I.P.R.) of three groups of percolation tests. In the Group 1 tests, results obtained in holes A, B and C of different diameters do not seem to show any specific trend. However, the average of the three individual results of the same size of hole indicates that the I.P.R. decreases with an increase in the diameter of the hole. For the 10 cm diameter hole the average value is 9.2 min/cm and for the 20 and 30 cm holes, the average values are 6.6 and 3.7 respectively. In the Group 2 tests, the smallest I.P.R. is for the 20 cm diameter hole. On the contrary, the largest I.P.R. is for the 20 cm diameter hole in the Group 3 tests.

On the basis of 27 percolation tests performed in three different sizes of holes, it appears that under the field testing conditions, there is no apparent correlation between the I.P.R. and the size of the test hole.

The time required for the water level in the test hole to drop 1 cm (or 1 in) during the soaking period is summarized in Table 2 and Figure 6. No trend between the time measurements and the hole size appears to exist.

Before a definite conclusion is drawn regarding the effect of the size of the percolation hole on the I.P.R. measurements, it is necessary at this point to consider the factors which can influence the flow rate of water from the test hole to the surrounding soil. For a steady-state flow condition, the factors affecting the water flow rate are listed as follows:

(i) The average permeability of the soil around the test hole.

(ii) The boundary conditions existing during the flow period, i.e. the depth of the water column in the hole and the average hydraulic gradients existing in the soil at the time of testing.

(iii) The cross-sectional area through which the water seepage occurs (this area is related to the diameter of the hole).

It becomes obvious that under field testing conditions at the Whitby site, (because several factors could simultaneously affect the percolation rate of the soil and in some cases some factors could be more significant than others), it would be impossible to isolate the influence of the hole size on the percolation rate unless the influence of other factors can be isolated and evaluated.

In order to separate and evaluate the influence of the hole size on the percolation rate measurements, an attempt is made here to calculate for each test, on the basis of the field test data, the average hydraulic gradients and the average permeability of the soil adjacent to the hole.

As described previously, in this project the soil water tension (suction) was measured with tensiometers at a number of points adjacent to the test hole and the depth of the water column in the hole was 15 cm (6 in) during the percolation test. Therefore, during the test the boundary conditions were known. The inverse percolation rate of the water from the hole to the surrounding soil can be calculated because the time required for the water level in the hole of a certain diameter to drop 2.5 cm (1 in) was measured. If the assumption of a steady-state flow condition is made, then the average permeability of the soil can be computed by Darcy's Law, $Q = k \cdot i \cdot A$,

where Q = the flow rate,
k = the constant of proportionality commonly termed the permeability,
i = the hydraulic gradient, and
A = the seepage area.

The procedure used to do the calculations is given in the Appendix. Three zones adjacent to the test hole were chosen for the calculations of the average horizontal hydraulic gradient i_H, the average vertical hydraulic gradient i_V and the average permeability k, of the soil within the zone. Because it was difficult to install tensiometers below the bottom of the test hole, no tensiometers were used to measure the magnitude of the soil water tension in that region. To compensate for this deficiency, two assumptions were made in the calculations with regard to the values of the soil water tension and the hydraulic gradients in the region below the bottom of the hole. In assumption 1, hydrostatic pressure distribution was assigned in the region below the hole along its axis; and in assumption 2 about two thirds of the hydrostatic pressure was used. It has been found that with both assumptions similar values of soil permeability were obtained.

Table 3 summarizes the results of calculations for the Group 1 tests. In this group, the largest value of the I.P.R. was obtained in the 20 cm diameter hole and the smallest value was obtained in the 30 cm diameter hole. In order to isolate the influence of the size of the hole on the I.P.R., it is necessary to compare the i_H, i_V and the k values of the three tests.

Consider the calculated results for the 10 and 20 cm diameter hole. The average values of i_H, i_V and k, based on assumption 1, are quite similar. Therefore the difference in their I.P.R. can be attributed to the influence of the size of the hole. In this particular case, the I.P.R. was larger for the 20 cm diameter hole than for the 10 cm diameter hole. Because the percolation rate increases with the hydraulic gradient and the soil permeability and because the average values of i_H, i_V and k are slightly larger for the 20 cm diameter hole than for the 10 cm diameter hole, the value of I.P.R. for the 20 cm diameter hole would be increased (i.e. percolation rate decreased) if the values of $i_{H,}$ i_V and k of the larger hole could be made equal to those of the smaller hole.

The I.P.R. for the 30 cm diameter hole was much smaller than those of the smaller holes. A comparison of the values of i_H, i_V and k in the three tests would indicate that the value of k was many times larger for the 30 cm diameter holes than for the 10 cm and 20 cm diameter holes. Because of the dominating influence of the k factor, the effect of the hole size on the I.P.R. was masked. If the value of k of the soil adjacent to the 30 cm diameter hole were similar to those of the 10 cm and 20 cm diameter hole, then the I.P.R. for the 30 cm hole would be greater than those for smaller holes.

The main reason for the relatively much greater value of k in the soil adjacent to the 30 cm diameter hole was probably that there existed more tiny holes in the soil around this test hole than around the smaller test holes. Also, there could be less clogging due to the deposit of fine soil particles at the bottom of that particular 30 cm diameter hole.

The calculated results of i_H, i_V and k on the basis of assumption 2 show similar conclusions with regard to the comparison of I.P.R. In the group 2 tests (see Table 4), the values of the I.P.R. were approximately the same for the 10 cm and 20 cm diameter holes. In comparison with the 10 cm diameter hole, the value of k was about three and a half times larger for the 20 cm diameter hole and the values of i_H and i_V were smaller for the larger hole (Refer to results based on assumption 1). If the value of k for the soil adjacent to the larger hole were decreased to that of the smaller hole, the percolation rate would be expected to be several times smaller (I.P.R. several times larger) for the 20 cm diameter hole. The net result would be that the larger hole (20 cm diameter) would have a smaller percolation rate (larger I.P.R.) if the values of i_H, i_V and k for the larger hole could be made similar to those of the smaller hole (10 cm diameter).

The I.P.R. for the 30 cm diameter hole was 6.6 min/cm (16.7 min/in), several times larger than that for the 10 cm diameter hole. In comparison with the 10 cm diameter hole, the values of i_H and k were larger, and the value of i_V was smaller than that of i_H in the soil adjacent to the test hole, the flow of water induced by i_V was therefore not too significant when the total flow was considered. Therefore, even though the value of i_V for the 30 cm diameter hole was not the same as that of the 10 cm diameter hole, it would not make too much difference in the percolation rate (or I.P.R.). It can be concluded that if the values of i_H, i_V and k for the 30 cm hole could be made similar to those of the 10 cm hole, the percolation rate for the larger hole would be smaller, i.e. I.P.R. would be larger.

In considering the test data of Group 3 (see Table 5) a comparison can also be made of the I.P.R. taking into consideration the differences in the values of i_H, i_V and k of different holes. Because the values of i_H and k were larger for the 20 cm diameter hole compared with the 10 cm diameter hole, the percolation rate for the 20 cm hole would be decreased further (i.e. I.P.R. increased) if the values of the hydraulic gradients and permeability could be decreased to those of the 10 cm diameter hole.

Table 6 is a summary of the I.P.R. in the test hole during the soaking period prior to the percolation testing. It can be seen that the I.P.R. was larger for the 20 cm diameter hole than for the 10 cm diameter hole. The values of i_H, i_V and k were comparable in both cases. Therefore it can be concluded that the percolation rate was smaller (I.P.R. larger) for the larger diameter hole.

3.3 Theoretical Consideration of the Effect of Hole Size on I.P.R.

To consider theoretically the effect of the size of the test hole on the inverse percolation rate (or the percolation rate), it is necessary to consider: i) the volume of water (the cross-sectional area of the hole multiplied by one unit distance), which will infiltrate into the soil, ii) the total area available for the adsorption of the water, iii) the hydraulic gradient, and iv) the permeability coefficient of the soil system.

To illustrate the theoretical effect of the size of the hole on the inverse percolation rate, an idealized mathematical relationship is proposed.

In the percolation test, there is 15 cm (6 in) of water above the bottom of the test hole of diameter d. Therefore, the total wetted surface area, A, (cm^2) is equal to:

$$A = \tfrac{1}{4} \cdot \pi \cdot d^2 + 15 \cdot \pi \cdot d \qquad (1)$$

The volume of water, V, (cm^3) to seep into the soil when the water level in the test hole drops one unit distance (cm) from an initial depth of 15 cm is given by

$$V = \tfrac{1}{4} \cdot \pi \cdot d^2 \qquad (2)$$

Assuming a steady-state flow condition, the inverse percolation rate (I.P.R.), which is calculated from the time it takes the water level to lower one unit distance in the hole can be expressed by the following equation:

$$\text{I.P.R.} = V / k \bullet i \bullet A \qquad (3)$$

where V is given by Eq. (2),
A is given by Eq. (1)
k is the permeability of the soil, and
i is the hydraulic gradient in the soil adjacent to the wetted area of the test hole.

Simplifying Eq.(3) by substitution of Eqs. (1) and (2), the I.P.R. can be related to the diameter of the hole.

$$\text{I.P.R.} = \frac{1}{(k \bullet i)} \; \frac{1}{1 + (60 / d)} \qquad (4)$$

If the term 1/k•i is assumed to be a constant, C, then according to Eq. (4), a larger hole diameter would correspond to a larger I.P.R. (smaller percolation rate).

For the test hole with a diameter of 10 cm, the I.P.R. is C/7 and for 20 cm and 30 cm diameter holes, their values are C/4 and C/3 respectively. Assuming the I.P.R. for the 10 cm hole as unity, the I.P.R. for the 20 cm hole is 1.75 and for the 30 cm hole is 2.33.

3.4 Variability in I.P.R.

The percolation test results were subjected to statistical treatment to evaluate their variability. In each group of tests, the mean I.P.R., the standard deviation and the coefficient of variation were obtained for tests in Holes A, B and C and for tests done in 10, 20 and 30 cm diameter holes. The standard deviation is a measure of the actual amount of variation present in a set of data and it is dependent on the scale of measurement. In order to compare the variation in several combinations of data, it is necessary to use measures of relative variation, expressed as the coefficient of variation (C.V.), which gives the standard deviation as a percentage of the mean.

Table 7 is a summary of the calculations for different combinations of tests. The initial depth of the water column in the hole was 15 cm. The results of I.P.R. during the soaking period, when the depth of the water column in the hole was 30 cm are summarized in Table 8.

3.5 Influence of the Height of Water Column on I.P.R.

The mean values of I.P.R. for different combinations of tests and for two water columns equal to an initial depth of 15 cm and 30 cm are tabulated in Table 9. The average ratio of the I.P.R. for these two depths of water column is approximately equal to 2.

4. DISCUSSIONS

4.1 The Relationship Between Hole Size and I.P.R.

From the analyses presented in the previous sections, it can be seen that theoretically the I.P.R. increases with the size of the hole. This relationship is also shown to be true for field tests if the influence of other factors on the I.P.R. in different-sized holes is approximately the same. However, under the field testing conditions, other factors, e.g. permeability, may frequently exert a more significant influence on the I.P.R. and overshadow the hole size effect. Consequently, the relationship between the size of the hole and the I.P.R. in the field tests could assume a form which may be different from the mathematical prediction.

There are several factors in the percolation test which can affect the I.P.R. and overshadow the influence of the size of the test hole. They are briefly discussed here:

(i) The smearing of the side walls of the test hole can reduce significantly the permeability of the soil. In preparing a hole for the test, the extent of smearing of the side walls depends on the soil type, the degree of saturation of the soil, the angering equipment and the care exercised in making the hole. It can be concluded that the disturbance to the soil on the side walls can vary in different holes and is unavoidable. Because of the significant effect of permeability on the percolation rate, the factor of smearing of side walls could easily mask the effect of the diameter of the hole.

(ii) The sedimentation of fine particles at the bottom of the test hole can reduce the permeability of the soil there. During the soaking and the percolation test periods some fine particles are washed down from the side walls and are collected at the bottom of the hole. For a smaller hole, (e.g. 10 cm diameter hole) it is more likely that the entire bottom surface of the hole is covered with fine soil particles, which form a relatively impervious layer. For a larger hole (e.g. 30 cm diameter hole), it is likely that only the bottom area near the side walls is covered with fine soil particles and the central area may be little affected. Therefore, it is quite conceivable that the average permeability of the soil at the bottom of a larger hole is reduced to a lesser extent than a smaller hole. Because the permeability factor in different sized holes has the opposite effect to the hole size factor on the I.P.R. and because the permeability influence is quite significant, the net result is that under the field testing conditions the I.P.R. could be smaller (i.e. percolation rate larger) for a larger hole. Referring to Table 1, the I.P.R. for the 30 cm diameter hole is smaller than that of the two smaller holes in Group 1 and Group 3 tests.

(iii) The natural soil conditions adjacent to a large hole may be different from those around a small hole. The soil in which a percolation test is performed is usually near the ground surface and has generally been modified by physical, chemical and biological processes in its geological history. Consequently, there often exist some hairline cracks and very small holes which very likely are not

> uniformly distributed in the soil mass. These small cracks and tiny holes obviously have very significant influence on the movement of water through the soil.
>
> At the Whitby site, it was found by careful examination of the soil profile that there existed in the soil some tiny holes and hairline cracks. In a percolation test performed at that site, the I.P.R. would have been decidedly affected by the presence or absence of the tiny openings in the soil. It is believed that the probability of having the features more conducive to the flow of water is greater for a hole with a larger diameter. The smaller I.P.R. in the 30 cm diameter holes in the Group 1 and Group 3 tests could have been attributed more to the soil condition.

The findings of this experimental study have been compared with results in literature. Only limited data related to the I.P.R. in different sized holes are available.

In the late 1940's the U.S. Public Health Service (Bendixen *et al*, 1950) undertook a comprehensive study on household sewage disposal systems. As part of their program, field studies of possible modifications of the percolation method were made. In several soil types, percolation tests were done in holes of different sizes and the results are summarized in Table 10.

According to the limited U.S.P.H.S. data it appears that a 30 cm (12 in) square hole is likely to produce a larger value of I.P.R. than a smaller hole. In 1966, a comprehensive study on percolation testing was conducted by the Connecticut Agricultural Experimental Station (Hill, 1966). The values of I.P.R. were obtained in three holes of different sizes. It was found that a 25 cm (10 in) circular hole gave an I.P.R. of 25 min/cm (66 min/in) while a 20 cm (8 in) and a 15 cm (6 in) circular hole gave values equal to 22 min/cm and 35 min/cm (56 and 90 min/in) respectively. The mean value of the three results was 27.8 min/cm (70.7 min/in) with a standard deviation of 6.9 min/cm (17.5 min/in) and a coefficient of variation of 24.7%. Although it is difficult to draw any conclusion from one set of test data, it appears that the Connecticut results showed a trend opposite to that of the U.S.P.H.S.

The effect of hole size on percolation rate was investigated in the laboratory by Healy and Laak (1973). According to their laboratory test results on a sandy soil, the percolation rate decreases with an increase in the diameter/depth ratio of the hole. That is, for an identical depth, a larger circular hole should have a larger I.P.R. (i.e. small percolation rate).

From the very limited data in literature on the subject of I.P.R. and the influence of the test hole size, it can be seen that results obtained by other investigators would confirm the conclusion that in the field, the hole size may increase or decrease the I.P.R. in a percolation test.

It has been found experimentally that under field testing conditions the I.P.R. in a 10 cm (4 in) diameter hole may be smaller or larger than that in a 30 cm (12 in) diameter hole. For the calculation of the size of a tile field using percolation test results, it is of practical importance to know how significant the difference in the percolation test data obtained in different holes would be. To answer this question, it is necessary to consider the variations of the test results obtained in holes of different sizes and also the variations of results which normally would be encountered on a site.

Referring to Table 7, in the Group 1 tests the average coefficient of variation (C.V.) for tests in holes of the same size is 52% and the average C.V. for tests in holes of <u>different</u> sizes is 59%. In the Group 2 tests, the average values of C.V. are 38% and 65% and in Group 3, 27% and 61%, respectively. If the whole test site is considered, the average C.V. for tests in the 10 cm, 20 cm and 30 cm diameter holes are 70%, 70% and 67% respectively. It can be seen that the variation of I.P.R. in different sized holes is generally greater than that in the same sized holes at the Whitby site.

In order to investigate the variation of percolation test results in other soil types, a literature study has been made to collect data obtained by other investigators.

The percolation test results obtained by Schroth (1966) are tabulated in Table 11. It was found that the coefficients of variation for the variable-head and constant-head tests were in excess of 100% (i.e. the standard deviation was larger than the mean).

Test results obtained by Hill (1966) are presented in Table 12, which shows the extent of variation in the percolation rates within sites and in Table 13 which indicates the seasonal variations of the percolation rates.

Tables 14 and 15 summarize the variations of percolation data in different soil series (Mokma, 1966). Figure 10 illustrates the variability in percolation rates during the year for several soil series.

The variation of percolation rate within a site was investigated by the U.S. Public Health Service (Weibel *et al*, 1954) and it was found on a lot of 92 m x 9.2 m (300 ft x 30 ft) in area that the percolation rates varied from 10 cm to 0.25 cm (4 in to 0.1 in) per hour. The very low rates occurred at two corners of the lot and if they could be ignored, the range of the percolation rates would be from 2.5 cm to 10 cm (1 to 4 in) per hour.

Similar study performed by the U.S. Public Health Service (Bendixon *et al*, 1950) showed that for a relatively uniform loam, the percolation rate variation among several holes of the same size, determined on the same site and on the same day, was greater than the variation between holes of different sizes.

In summary, there have been a great deal of experimental data which indicate that the variation of the percolation rate within a test site is as large or sometimes larger than the variation of the percolation rate between holes of different sizes. Because the percolation rate is affected by many factors which work together in different ways to produce a resultant influence, it would not be expected that the variation of the percolation rate would follow a specific pattern. On a statistical base, therefore, it would be concluded at least for practical purposes, that the effect of the hole size is not significant.

4.2 Comments on the Soaking of the Soil Before Percolation Rate Measurements

In a field percolation test, before the percolation rate measurements, the soil around the test hole is soaked for a specific period of time. The procedure for soaking the soil varies among different agencies. The U.S.P.H.S. (1967) states:

> “.... carefully fill the hole with clear water to a minimum depth of 12 inches over gravel. In most soils, it is necessary to refill the hole by supplying a surplus reservoir of water, possibly by means of an automatic syphon, to keep in the hole for at least 4 hours and preferably overnight. Determine the percolation rate 24 hours after water is first added to the hole. This procedure is to insure that the soil is given ample opportunity to swell and to approach the condition it will be in during the wettest season of the year. Thus, the test will give comparable results in the same soil, whether made in a dry or a wet season. ..."

The soaking procedure suggested by the Ontario Ministry of the Environment (1974) is slightly different.

> “.... Clear water poured into the excavation to a depth of at least 12 inches. Additional clear water shall be added as necessary to maintain a depth of water of at least 12 inches until the soil has swollen and become saturated so that the water being added seeps away at a constant rate..."

The Wisconsin State Board of Health specifies:

> "....a minimum water depth of 12 inches shall be maintained above the gravel for a 4-hour period by refilling whenever necessary or by the use of an automatic siphon. Water remaining in the hole after 4 hours shall not be removed. The soil shall be allowed to swell not less than 16 hours or more than 30 hours...."

As stated in different procedures, the purpose of soaking the soil before the percolation-rate measurements is to saturate the soil, to allow some minerals in the soil to swell and to increase the chance of obtaining consistent data. These objectives are examined in the light of the data in literature and the results obtained from the Whitby site.

The moisture content in the soil (Merrimac fine sandy loam) adjacent to a percolation hole was examined in detail by Hill (1966) and it was found that the soil was not saturated (i.e. all voids in the soil are not filled with water) 400 minutes after the soaking period. However, an equilibrium percolation rate was attained 200 minutes after the soaking period. The rate did not change between 200 and 400 minutes after soaking was begun and presumably the "saturation" condition referred to in the U.S.P.H.S.'s Manual of Septic Tank Practice had been observed. Similar results were obtained in the same soil in a different hole.

In the Whitby tests, tensiometers were installed in the soil adjacent to the test hole and the degree of saturation in the soil during the soaking period could be monitored by the tensiometer readings. A positive reading would indicate a saturated condition and a negative reading would indicate an unsaturated condition in the soil. Referring to Fig 7 (Group 1, Hole A, 10 cm diameter), three tensiometers registered positive readings, which showed that at some locations the soil adjacent to the perimeter of the hole was saturated.

However, two tensiometers located farther away from the perimeter of the hole and one located at a shallower depth still registered negative readings. In the Group 2 and Group 3 tests (see Figs. 8 and 9), with the exception of two tensiometers at a distance of 7.5 cm (3 inches) away from the test hole, all the tensiometers showed negative water pressures. In Group 1 tests, the soil was quite moist prior to the soaking period because the groundwater table was about 30 cm below the bottom of the hole and the tests were performed in the Spring season. Consequently, the soil immediately adjacent to the hole became saturated during the soaking period. In other tests, (Group 2 and Group 3) the soil was initially quite dry, a condition indicated by very high initial negative water pressure readings in the soil and the 24-hour soaking period failed to saturate the soil.

It can be concluded that for most soils with some silt and clay particles it would be very difficult to saturate the soil in 24 hours unless the initial degree of saturation of the soil is very high.

In the Whitby tests, it has been found that after the overnight soaking period (i.e. soaking time approximately equal to 24 hours) the I.P.R. measurements in most tests with a water head equal to 30 cm (12 in) in the hole became fairly constant. It can be considered that after the soaking period the boundary conditions in the soil adjacent to the test hole became quite steady. Referring to Fig. 7, the tensiometer readings are levelling off after 4 hours soaking time and in Figs. 8 and 9, the tensiometer readings become fairly steady after approximately 22 hours soaking time. The longer time period in the Group 2 and Group 3 tests was because the soil was initially very dry prior to soaking.

On the basis of the Whitby data and the data obtained elsewhere, it is believed that a soaking period of 24 hours is sufficiently long for many soils to produce steady boundary conditions in the soil and reasonably constant percolation-rate measurements. For sandy soils, a shorter period of soaking time seems acceptable because their permeability is quite high. The arbitrary 4-hour soaking time for sandy soils would appear reasonable and practical.

4.3 Influence of the Water Head in the Test Hole on I.P.R.

In Table 9, it is shown that the mean I.P.R. for a water head equal to 15 cm is about 2 to 3 times the value for a water head equal to 30 cm in the hole. Test results obtained by Schroth (1966) and Winneberger (1967) also showed that the I.P.R. in a percolation hole would be smaller when the water head in the hole was larger. It was found that when the depth of the water column was doubled, the I.P.R. was decreased by more than 2 to 3 times. These test data illustrate the importance of having the correct depth of water column in the hole when the percolation rates are measured. According to Ryon (Federick, 1948), the depth of the water column should be 15 cm (6 in) in the hole.

5. CONCLUSIONS

A number of conclusions can be drawn from this experimental investigation which was conducted at the Whitby Experimental Station in Ontario.

(1) Mathematically the I.P.R. (Inverse Percolation Rate) in a percolation hole is larger if the diameter of the hole is larger. The same conclusion holds true in the Whitby field tests in which the influence of other factors were comparable. However, in a field percolation test, several factors can often affect the test results and the effect of the hole size can frequently be overshadowed. Consequently, under field testing conditions, the relationship between the I.P.R. and the diameter of the hole may not show a specific trend.

(2) Based on the data obtained from the Whitby site and by other researchers, it is found that the variability of I.P.R. in different-sized holes is smaller than that due to differences in soil and climatic conditions. On a statistical basis, the influence of the hole size on the I.P.R. would not be considered significant. From a practical view point, a 10 cm (4 in) diameter hole would be preferable for the field percolation test.

(3) The soil adjacent to a percolation hole usually would not be saturated after the normal period of soaking time (i.e. 24 hours). However, for the Whitby clayey silt, a 24 hour soaking period could produce reasonably steady boundary conditions in the soil and also reasonably constant I.P.R. From a practical view point, for fine-grained soils, the arbitrary soaking period of 24 hours appears to be a reasonable length of time. For sandy soils, a shorter soaking time, (e.g. 4 hours) would be acceptable.

(4) The depth of water column in the test hole has a significant influence on the I.P.R. The I.P.R. for a water column equal to 15 cm is 2 to 3 times the value for a water column equal to 30 cm in the hole. According to Ryon (Federick,

1948), the hole should be filled with water to a depth of 15 cm (6 in) for the field percolation test.

(5) Care should be exercised in the preparation of the test hole. The smearing of the soil on the surface of the hole should be minimized and any deposit of fine soil particles at the bottom of the hole should be carefully removed after the soaking period and before the percolation-rate measurements.

TABLE 1. Summary of Three Groups of I.P.R. Measurements. Initial Water Level Was 15 cm (6 Inches) Above The Bottom of The Test Hole.

Hole Dia.	10 cm (4 in)		20 cm (8 in)		30 cm (12 in)	
I.P.R.* Hole (Group 1)	min/cm	min/in	min/cm	min/in	min/cm	min/in
A	5.3	13.5	9.2	23.3	2.3	5.9
B	14.2	36.1	2.8	7.0	2.8	7.2
C	8.1	20.5	7.8	19.9	6.0	15.3
Average (Group 1)	9.2	23.4	6.6	16.7	3.7	9.5

Hole Dia.	10 cm		20 cm		30 cm	
I.P.R. Hole (Group 2)	min/cm	min/in	min/cm	min/in	min/cm	min/in
A	2.1	5.4	2.0	5.1	6.6	16.7
B	5.1	13.0	0.7	1.8	3.9	9.8
C	4.7	12.0	1.5	3.7	5.0	12.7
Average (Group 2)	4.0	10.1	1.4	3.5	5.2	13.1

Hole Dia.	10 cm		20 cm		30 cm	
I.P.R. Hole (Group 3)	min/cm	min/in	min/cm	min/in	min/cm	min/in
A	2.1	5.3	3.5	8.8	1.0	2.6
B	3.3	8.3	5.3	13.5	1.3	3.3
C	3.9	10.0	4.1	10.5	0.7	1.7
Average (Group 3)	3.1	7.9	4.3	10.9	1.0	2.5

* I.P.R. (Inverse Percolation Rate) is defined as the time taken by the water level in the hole to drop one unit distance (1 cm or 1 in) and is expressed as minutes/cm or minutes/in. in the above table.

TABLE 2. Summary of Three Groups of I.P.R. Measurements During The Soaking Period. Initial Water Level Was 30 cm (12 Inches) Above The Bottom of The Test Hole.

Hole Dia.	10 cm		20 cm		30 cm	
Hole (Group 1) I.P.R.	min/cm	min/in	min/cm	min/in	min/cm	min/in
A	1.3	3.4	3.3	8.3	1.6	4.1
B	5.8	14.8	1.9	4.7	1.8	4.5
C	1.8	4.5	2.9	7.3	2.5	6.3
Average (Group 1)	3.0	7.5	2.7	6.9	2.0	5.0

Hole Dia.	10 cm		20 cm		30 cm	
Hole (Group 2) I.P.R.	min/cm	min/in	min/cm	min/in	min/cm	min/in
A	1.4	3.5	1.3	3.2	5.8	14.7
B	1.4	3.6	0.6	1.4	3.5	9.0
C	1.5	3.8	1.0	2.5	4.1	10.3
Average (Group 2)	1.4	3.6	1.0	2.5	4.7	11.3

Hole Dia.	10 cm		20 cm		30 cm	
Hole (Group 3) I.P.R.	min/cm	min/in	min/cm	min/in	min/cm	min/in
A	0.8	2.1	1.5	3.9	0.7	1.7
B	1.3	3.3	2.1	5.3	0.9	2.3
C	1.6	4.0	1.5	3.8	0.4	1.1
Average (Group 3)	1.2	3.1	1.7	4.3	0.6	1.7

TABLE 3. Summary of Values of Hydraulic Gradients And Soil Permeability (Group 1 Tests).

	Hole Diameter (cm)	10				20				30			
	Inverse Percolation Rate (min/cm)	5.3				9.2				2.3			
	(min/in)	13.5				23.3				5.9			
	Zone	1	2	3	Avg.	1	2	3	Avg.	1	2	3	Avg.
Assumption 1	i_H	1.95	1.28	0.71	1.31	1.51	1.72	1.04	1.42	1.14	1.98	1.57	1.56
	i_v	0.26	0.32	0.41	0.33	0.33	0.39	0.47	0.40	0.12	0.31	0.23	0.22
	k (10^{-4} cm/sec)	1.49	1.18	1.10	1.26	2.55	1.39	1.43	1.79	21.98	8.38	6.94	12.4
Assumption 2	i_H	1.96	1.05	0.72	1.24	1.64	1.26	1.00	1.30	1.18	1.62	1.52	1.44
	i_v	0.86	0.67	0.63	0.72	0.90	0.78	0.78	0.82	0.74	0.63	0.66	0.68
	k (10^{-4} cm/sec)	1.39	1.35	1.01	1.25	0.86	1.69	1.22	1.26	17.04	9.22	6.31	10.86

TABLE 4. Summary of Values Of Hydraulic Gradients And Soil Permeability (Group 2 Tests).

Hole Diameter (cm)		10				20				30			
Inverse Percolation Rate													
(min/cm)		2.1				2.0				6.6			
(min/in)		5.4				5.1				16.7			
Zone		1	2	3	Avg.	1	2	3	Avg.	1	2	3	Avg.
Assumption 1	i_H	2.39	1.87	0.88	1.71	1.36	1.82	0.85	1.34	1.98	2.44	1.69	2.04
	i_v	0.79	0.37	0.46	0.54	0.22	0.19	0.29	0.23	0.11	0.12	0.19	0.14
	k (10^{-4} cm/sec)	3.33	2.07	2.46	2.62	12.70	6.31	7.70	8.90	4.58	2.50	2.33	3.14
Assumption 2	i_H	2.18	1.19	0.74	1.37	1.83	1.04	0.81	1.23				
	i_v	0.30	0.55	0.56	0.47	0.78	0.59	0.60	0.66				
	k (10^{-4} cm/sec)	2.92	3.09	2.50	2.84	8.47	9.48	7.07	8.34				

TABLE 5. Summary of Values of Hydraulic Gradients And Soil Permeability (Group 3 Tests).

	Hole Diameter (cm)	10				20			
	Inverse Percolation Rate								
	(min/cm)	2.1				3.5			
	(min/in)	5.3				8.8			
	Zone	1	2	3	Avg.	1	2	3	Avg.
Assumption 1	i_H	3.00	1.48	0.89	1.79	3.27	1.72	0.99	1.99
	i_v	0.25	0.45	0.52	0.41	0.20	0.36	0.45	0.34
	k (10^{-4} cm/sec)	2.50	2.61	2.23	2.45	3.29	3.75	3.68	3.57
Assumption 2	i_H	2.85	1.48	0.89	1.74	3.13	1.59	0.99	1.90
	i_v	0.99	0.67	0.64	0.77	1.09	0.76	0.56	0.80
	k (10^{-4} cm/sec)	2.48	2.52	2.15	2.38	3.12	3.70	3.54	3.45

TABLE 6. Summary of Values of Hydraulic Gradients And Soil Permeability. Initial Water Level in Hole Was 30 cm. Group 1 Tests.

Hole Diameter (cm)	10				20			
Inverse Percolation Rate								
(min/cm)	1.3				3.3			
(min/in)	3.4				8.3			
Zone	1	2	3	Avg.	1	2	3	Avg.
i_H	3.27	2.06	0.92	2.08	3.10	3.16	1.75	2.67
i_v	0.29	0.48	0.64	0.47	0.63	0.44	0.64	0.57
k (10^{-4} cm/sec)	1.93	1.79	2.22	1.98	1.95	1.33	1.52	1.60

TABLE 7. Mean Values and Percent Variations of The Three Groups of I.P.R. Initial Depth of Water Column in The Hole Was 15 cm.

Combination of Tests	Mean I.P.R. (min/cm)	Standard Deviation	Coeff. of Variation (%)
GROUP I			
Hole A, Dia. 10, 20, 30 cm	5.60	3.46	61.79
Hole B, Dia. 10, 20, 30 cm	6.60	6.58	99.70
Hole C, Dia. 10, 20, 30 cm	7.30	1.14	15.62
Tests in 10-cm dia. holes	9.20	4.55	49.46
Tests in 20-cm dia. doles	6.60	3.36	50.91
Tests in 30-cm dia. holes	3.70	2.01	54.32
GROUP II			
Hole A, Dia. 10, 20, 30 cm	3.57	2.63	73.67
Hole B, Dia. 10, 20,30 cm	3.23	2.27	70.28
Hole C, Dia. 10, 20, 30 cm	3.73	1.94	52.01
Tests in 10-cm dia. holes	3.97	1.63	41.06
Tests in 20-cm dia. holes	1.40	0.66	47.14
Tests in 30-cm dia. holes	5.17	1.36	26.31
GROUP III			
Hole A, Dia. 10, 20, 30 cm	2.20	1.25	56.82
Hole B, Dia. 10, 20, 30 cm	3.30	2.00	60.61
Hole C, Dia. 10, 20, 30 cm	2.90	1.91	65.86
Tests in 10-cm dia. holes	3.10	0.92	29.68
Tests in 20-cm dia. holes	4.30	0.92	21.40
Tests in 30-cm dia. holes	1.00	0.30	30.00
THREE GROUPS			
Tests in 10-cm holes	5.42	3.77	69.56
Tests in 20-cm holes	4.10	2.87	70.00
Tests in 30-cm holes	3.29	2.20	66.90

TABLE 8. Mean Values And Percent Variations of The Three Groups of I.P.R. Initial Depth of Water Column in The Hole Was 30 cm.

Combination of Tests	Mean I.P.R. (min/cm)	Standard Deviation	Coeff. of Variation (%)
Group I			
Hole A, Dia. 10,20,30 cm	2.07	1.08	52.17
Hole B, Dia. 10,20,30 cm	3.17	2.28	71.92
Hole C, Dia. 10,20,30 cm	2.40	0.56	23.33
Tests in 10-cm dia. holes	2.97	2.47	83.16
Tests in 20-cm dia. holes	2.70	0.72	26.67
Tests in 30-cm dia. holes	1.97	0.47	23.86
All tests in Group I	2.54	1.38	54.33
Group II			
Hole A, Dia. 10,20,30 cm	2.83	2.57	90.81
Hole B, Dia. 10,20,30 cm	1.83	1.50	81.97
Hole C, Dia. 10,20,30 cm	2.20	1.66	75.45
Tests in 10-cm dia. holes	1.43	0.06	4.20
Tests in 20-cm dia. holes	0.97	0.35	36.08
Tests in 30-cm dia. holes	4.47	1.19	26.62
All tests in Group II	2.29	1.76	76.86
Group III			
Hole A, Dia. 10,20,30 cm	1.00	0.44	44.00
Hole B, Dia. 10,20,39 cm	1.43	0.61	42.66
Hole C, Dia. 10,20,30 cm	1.17	0.67	57.26
Tests in 10-cm dia. holes	1.23	0.40	32.52
Tests in 20-cm dia. holes	1.70	0.35	20.59
Tests in 30-cm dia. holes	0.67	0.25	37.31
All tests in Group III	1.20	0.54	45.00
Three Groups of Tests	2.01	1.41	70.15

TABLE 9. Mean Values of I.P.R. And The Ratio of I.P.R. For Two Columns of Water Equal to 15 And 30 cm In Depth.

Combination of Tests	Mean I.P.R. (min/cm) Initial Water Column 15 cm (1)	Mean I.P.R. (min/cm) Initial Water Column 30 cm (2)	Ratio (1) /(2)
GROUP I			
Hole A, Dia. 10,20,30 cm	5.60	2.07	2.7
Hole B, Dia. 10,20,30 cm	6.60	3.17	2.1
Hole C, Dia. 10,20,30 cm	7.30	2.40	3.0
Tests in 10-cm dia. holes	9.20	2.97	3.1
Tests in 20-cm dia. holes	6.60	2.70	2.4
Tests in 30-cm dia. holes	3.70	1.97	1.9
All tests in Group I	6.50	2.54	2.6
GROUP II			
Hole A, Dia. 10,20,30 cm	3.57	2.83	1.3
Hole B, Dia. 10,20,30 cm	3.23	1.83	1.8
Hole C, Dia. 10,20,30 cm	3.73	2.20	1.7
Tests in 10-cm dia. holes	3.97	1.43	2.8
Tests in 20-cm dia. holes	1.40	0.97	1.4
Tests in 30-cm dia. holes	5.17	4.47	1.2
All tests in Group II	3.51	2.29	1.5
GROUP III			
Hole A, Dia. 10,20,30 cm	2.20	1.00	2.2
Hole B, Dia. 10,20,30 cm	3.30	1.43	2.3
Hole C, Dia. 10,20,30 cm	2.90	1.17	2.5
Tests in 10-cm dia. holes	3.10	1.23	2.5
Tests in 20-cm dia. holes	4.30	1.70	2.5
Tests in 30-cm dia. holes	1.00	0.67	1.5
All tests in Group III	2.80	1.20	2.3
Three groups of tests	4.27	2.01	2.1

TABLE 10. I.P.R. In Holes of Different Size And Shape. U.S.P.H.S. Data.

Soil	I.P.R. in Minutes/Inch			Mean	Standard Deviation	Coefficient of Variation (%)
	30-cm Square Hole (12 in)	20-cm Circular Hole (8 in)	10-cm Circular Hole (4 in)			
1	203	177	147	175.7	28.0	16.0
2	67	41	43	50.3	14.5	28.8
3	145	84	81	103.3	36.1	35.0
4	706	723	387	605.3	189.3	31.3

TABLE 11. Means And Standard Deviations Of The Percolation Rates. Penn State University Data (Schroth, 1966).

Type of Test	Mean (inches/hr)	Standard Deviation	Coeff. of Variation (%)
4V	1.46	2.08	142
6V	2.17	2.81	129
8V	4.34	6.07	140
10V	5.30	8.38	158
4C	4.05	7.86	194
6C	4.90	7.76	158
8C	10.59	17.31	163
10C	10.59	17.85	169

REMARKS: (1) The test plot was approximately 200' x 120'.

(2) The diameter of the hole was 4 inches and tests were done at 20 locations.

(3) "4V" (type of test) means that water column in the test hole was 4 inches above the bottom of the hole and the variable head procedure was used in the test; "4C" means the water head was 4 inches and the constant head procedure was used. The same rule of identification is used for 6V, 6C etc.

TABLE 12. Variations of Percolation Rates Within Sites. Hill (1966).

Site	Depth (inch)	Percolation Rates (inches per hour)	Mean	Standard Deviation	Coefficient of Variation (%)
Cheshire 1	18	28, 9, 10	15.67	10.69	68.24
	36	33, 16, 18	22.33	9.29	41.61
Cheshire 2	18	10, 7, 11	9.33	2.08	22.31
	36	5, 6, 6	5.67	0.58	10.18
Merrimac	18	33, 18, 10	20.33	11.68	57.42
	36	33, 60, 143	78.67	57.33	72.87
Wethersfield 1	18	0.44, 0.19, 0.81	0.48	0.31	64.99
	36	0.06, 0.09, 0.06	0.07	0.02	24.74
Wethersfield 2	18	7.1, 2.9, 20.0	10.00	8.91	89.11
	36	0.9, 0.8, 1.9	1.20	0.61	50.69

TABLE 13. Variation in Percolation Rates In Wet, Moist And Dry Soils. Hill (1966).

Soil	Depth (Inches)	Percolation Rate (inches/hr) Initial Moisture Wet	Moist	Dry	Mean	Standard Deviation	Coefficient of Variation (%)
Merrimac	18	13.3	20.4	20.6	18.10	4.16	22.97
Cheshire 1	18	12.5	15.7	10.7	12.97	2.53	19.53
Cheshire 2	36	7.3	22.2	11.6	13.70	7.67	55.98
Wethersfield	18	0.26	0.31	0.17	0.25	0.07	28.76

TABLE 14. Variation of Percolation Rates Within a Soil Series (Data Obtained Before June 1). Mokma (1966).

Soil	Mean (in/hr)	Standard Deviation	Coefficient of Variation (%)
Miami	1.94	1.44	74.23
Celina	2.14	1.22	57.01
Sisson	2.81	1.86	66.19
Tuscola	3.45	2.76	80.00
Owosso	2.04	1.17	57.35
Kendallville	1.90	1.14	60.00
Metea	8.74	4.41	50.46
Spinks	6.94	6.15	88.62
Boyer	9.61	5.32	55.36
Oshtemo	11.71	4.08	34.84
Conover	2.24	2.26	100.89
Metamore	6.80	2.64	38.82
Metea (imp. dra.)*	8.96	5.92	66.07
Spinks (imp. dra.)	7.75	5.26	66.87
Wasepi	12.58	15.02	119.40
Hoytville	0.85	0.74	87.06
Brookston	2.31	1.76	76.19
Gilford	2.61	1.49	57.09

* imp. dra. = imperfectly drained.

TABLE 15. Variation of Percolation Rates Within a Soil Series (Data Obtained After May 31). Mokma (1966).

Soil	Mean (in/hr)	Standard Deviation	Coefficient of Variation (%)
Miami	4.05	6.21	153.33
Celina	2.42	2.12	87.60
Sisson	4.94	2.88	58.30
Tuscola	4.55	6.04	132.75
Ockley	1.92	1.09	56.77
Owosso	5.26	4.72	89.73
Kendalville	2.10	1.61	76.67
Fox	2.00	0.84	42.00
Spinks	7.73	4.51	58.34
Boyer	6.54	4.44	67.89
Perrien	4.11	0.72	17.52
Oshtemo	16.51	8.80	53.30
Oakville	7.61	2.78	36.53
Napanee	1.44	0.95	65.97
Aboite	3.62	3.26	90.06
Conover	2.54	1.70	66.93
Kibbie	4.95	4.26	86.06
Metamora	3.93	2.61	66.41
Locke	5.61	4.26	75.94
Metea (imp. dra.)*	2.43	2.42	99.59
Wasepa	17.96	14.05	78.23
Tedrow	10.80	5.85	54.17
Au Gres	15.61	8.15	52.21
Hoytville	2.21	3.84	173.76
Wauseon	4.70	5.49	116.81
Bookston	4.17	4.06	97.36
Colwood	3.94	2.70	68.53
Westland	5.78	2.93	50.69
Berville	1.24	1.52	122.58
Sebewa	2.64	1.77	67.05
Gilford	6.19	12.25	197.90
Granby	5.65	9.86	174.51

* imp. dra. = imperfectly drained.

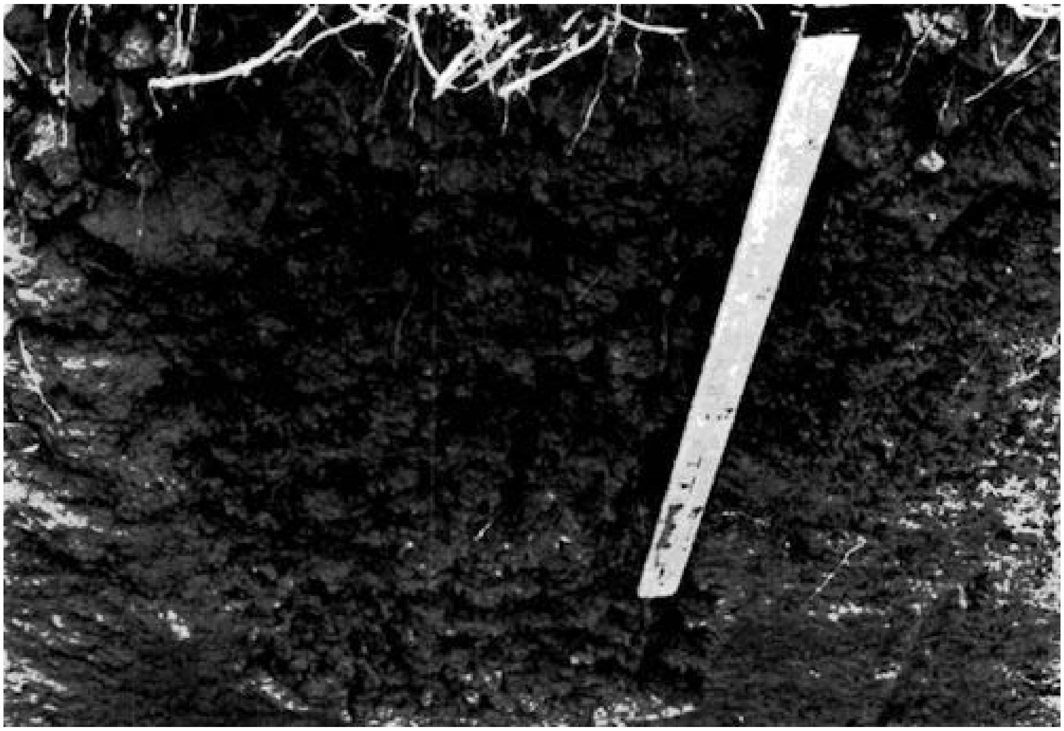

FIGURE I. Picture Illustrating Soil Structure .

FIGURE 2. Picture Showing The Installation Of Tensiometers Around A Test Hole **.**

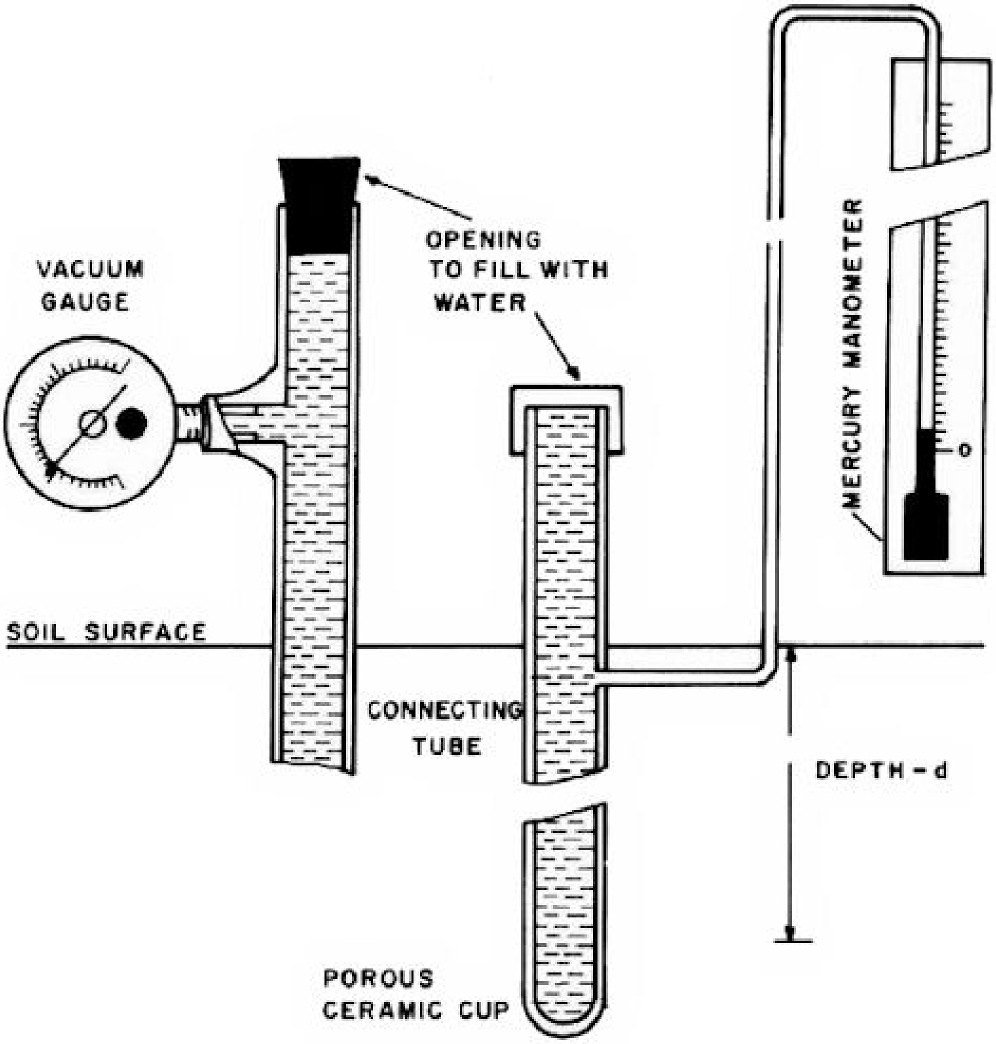

FIGURE 3. Schematic Diagram Of The Essential Parts Of A Tensiometer.

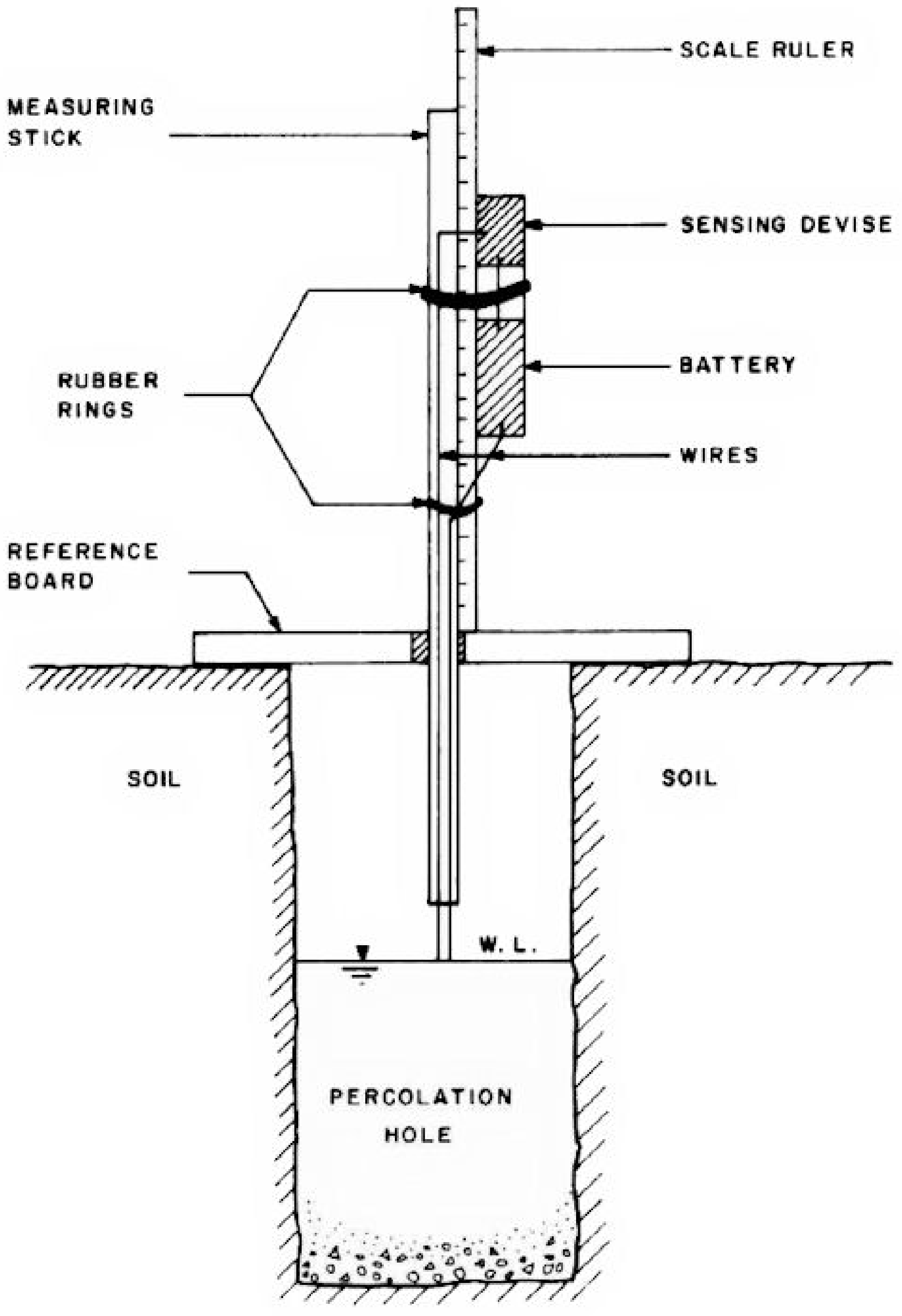

FIGURE 4. Schematic Diagram of a Point Gauge For Measuring Water Level.

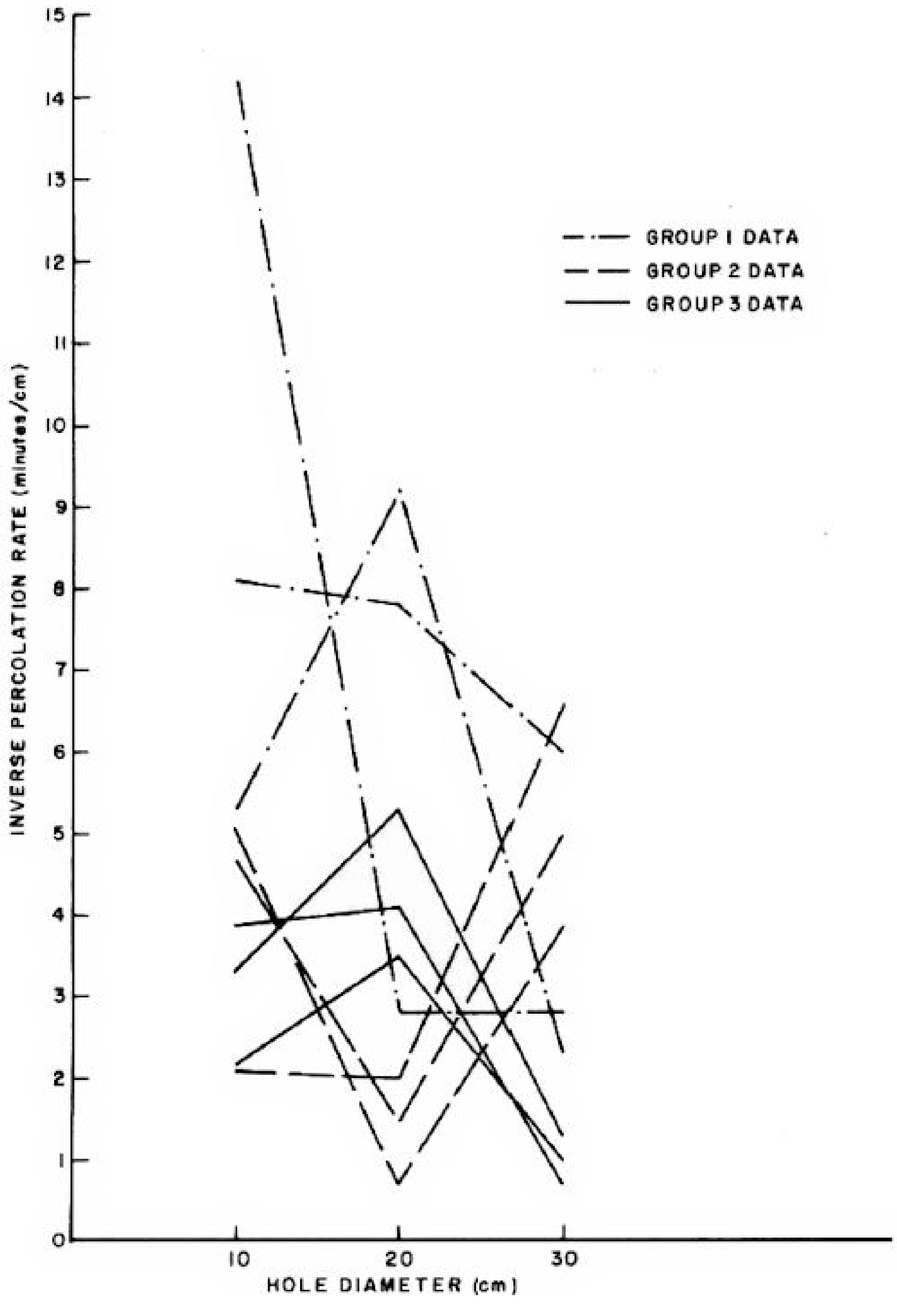

FIGURE 5. Inverse Percolation Rate Measurements vs Hole Diameter. Initial Water Level 15cm (61in) Above The Bottom of Test Hole.

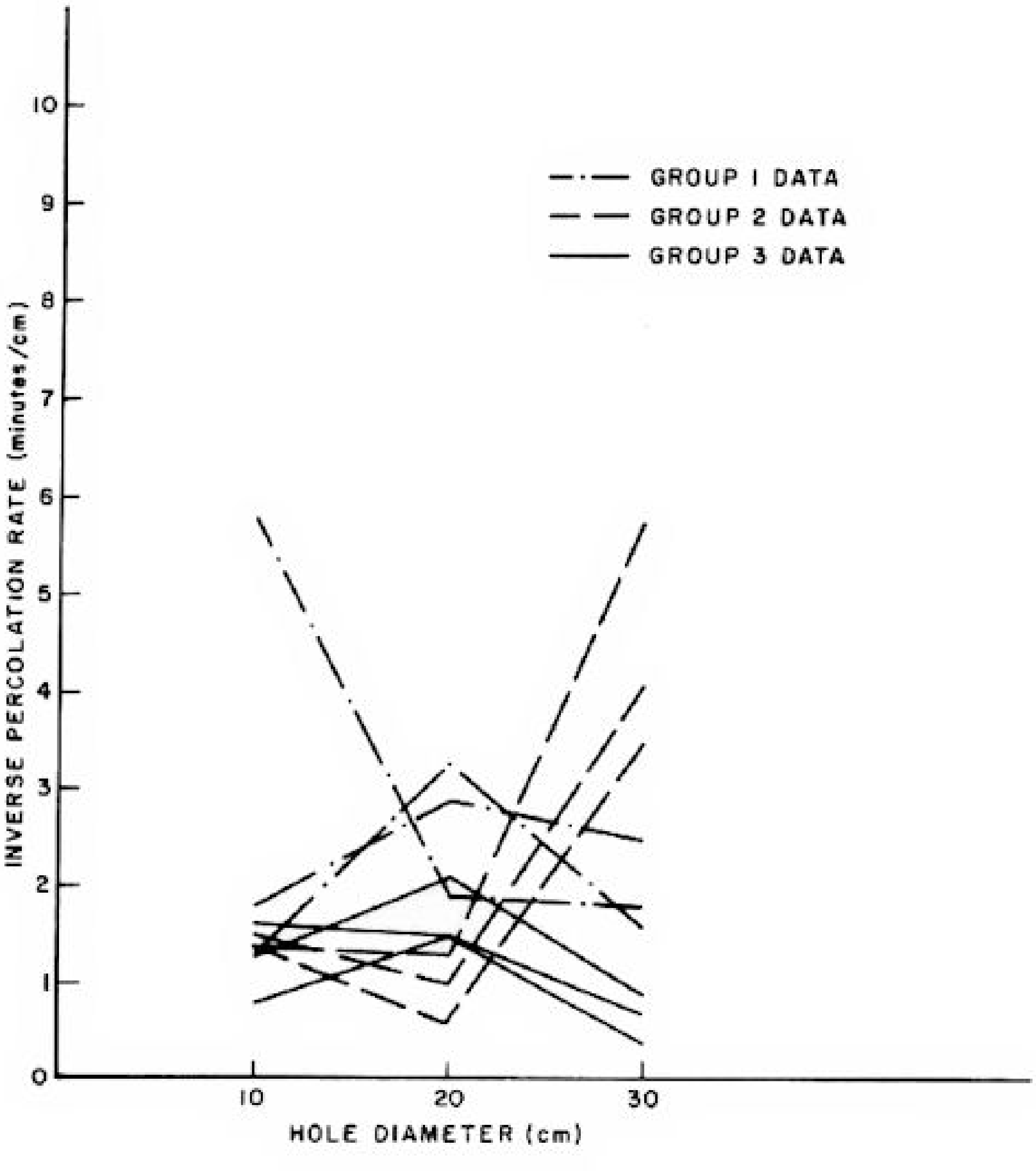

FIGURE 6. Inverse Percolation Rate Measurements vs Hole Diameter. Initial Water Level 30cm (12 in) Above The Bottom of Test Hole.

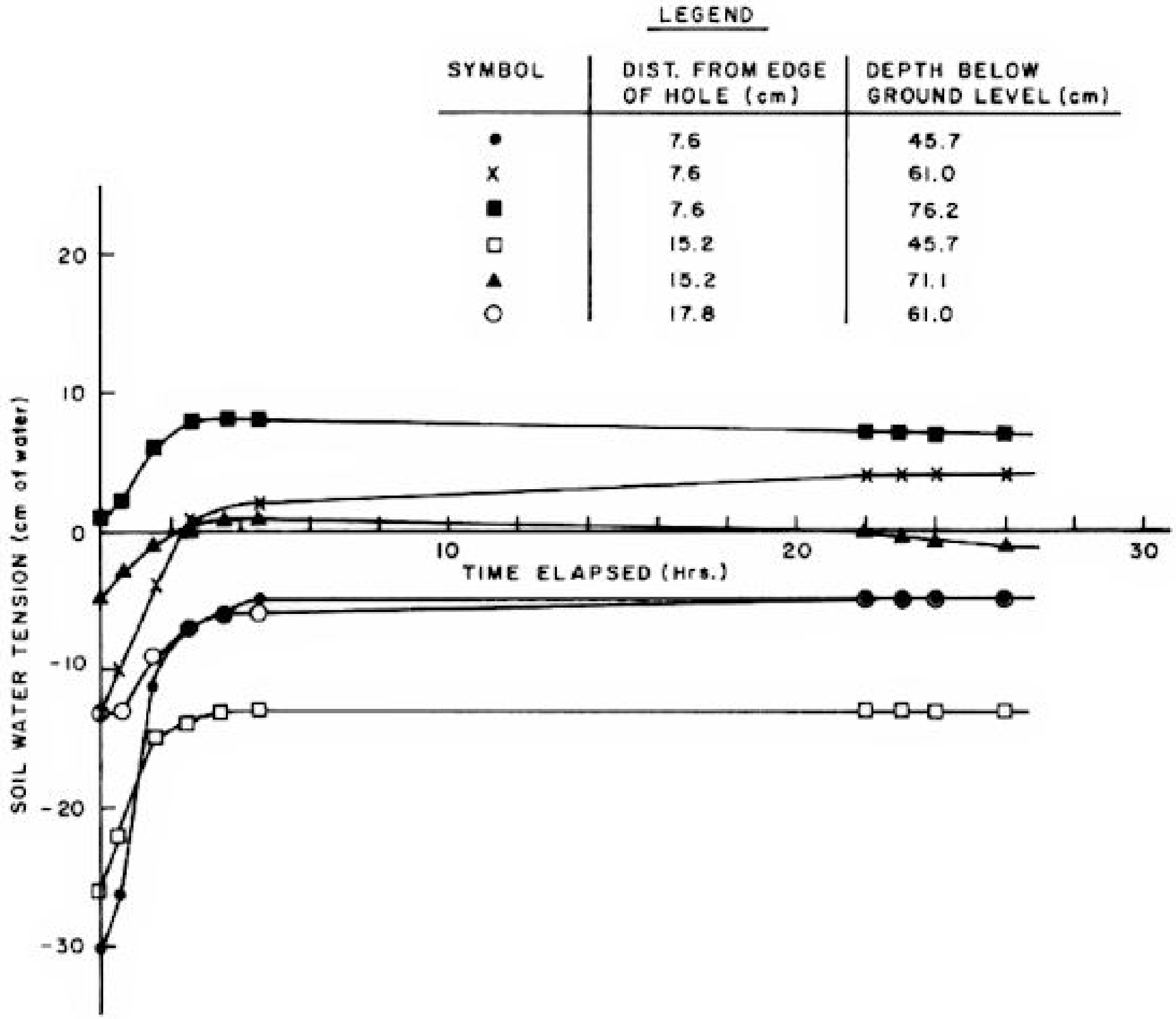

FIGURE 7. Variations in Soil Water Tension During The Soaking Period (Group I. Hole A. 10 -cm Diam. Hole).

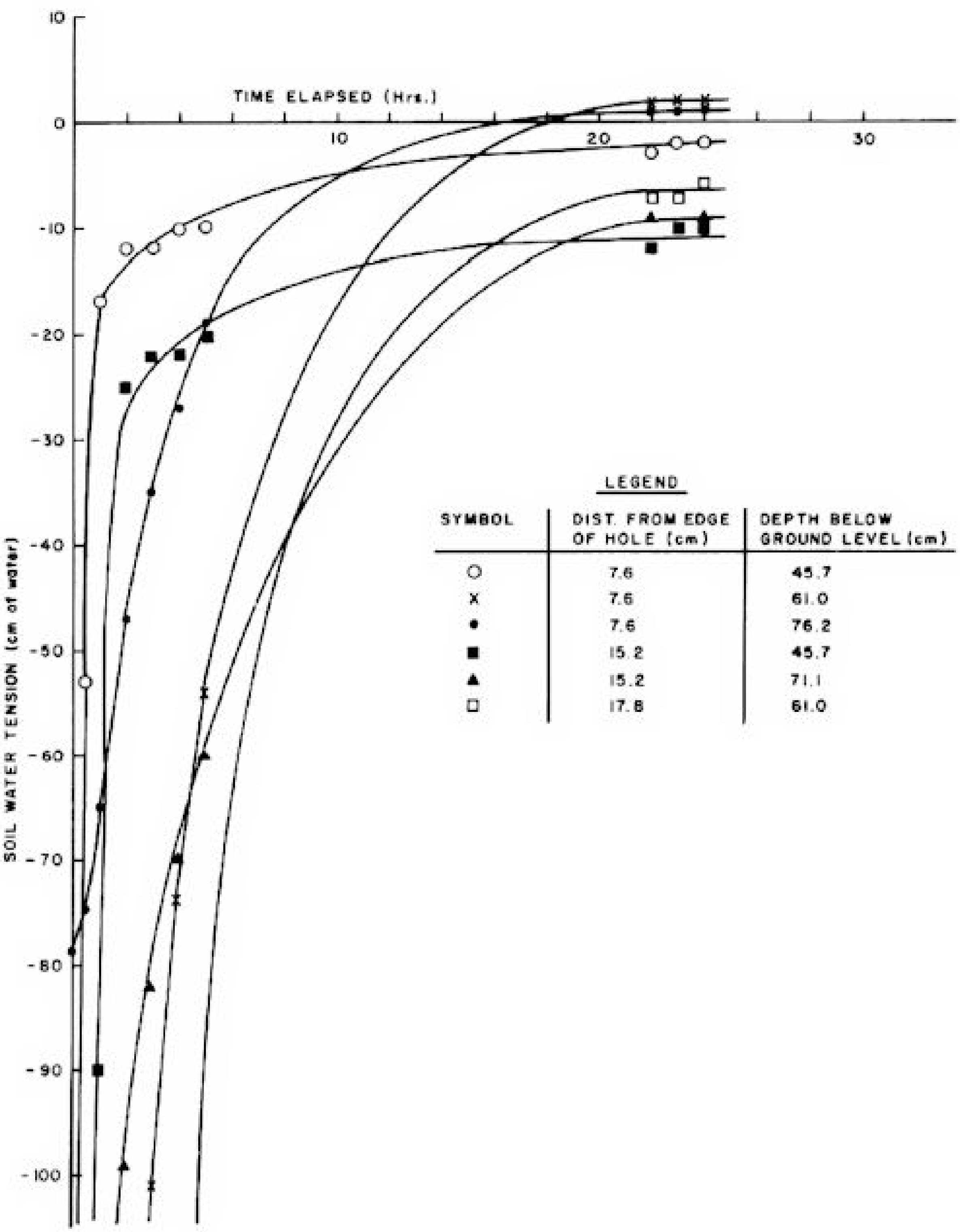

FIGURE 8. Variations in Soil Water Tension During The Soaking Period (Group 2. Hole A. 10-cm Diam. Hole).

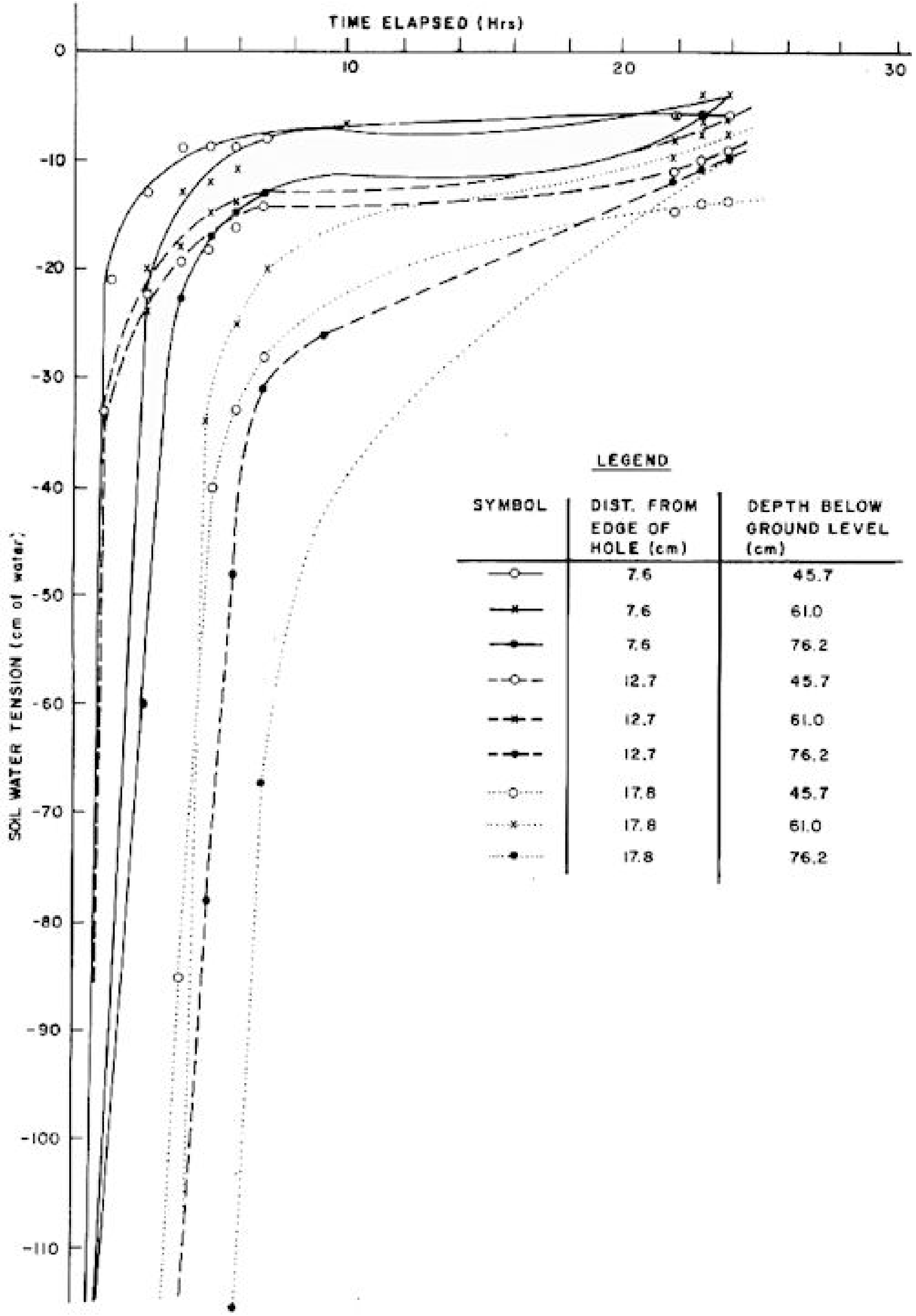

FIGURE 9. Variations in Soil Water Tension During The Soaking Period (Group 3. Hole A. 10-cm Diam. Hole).

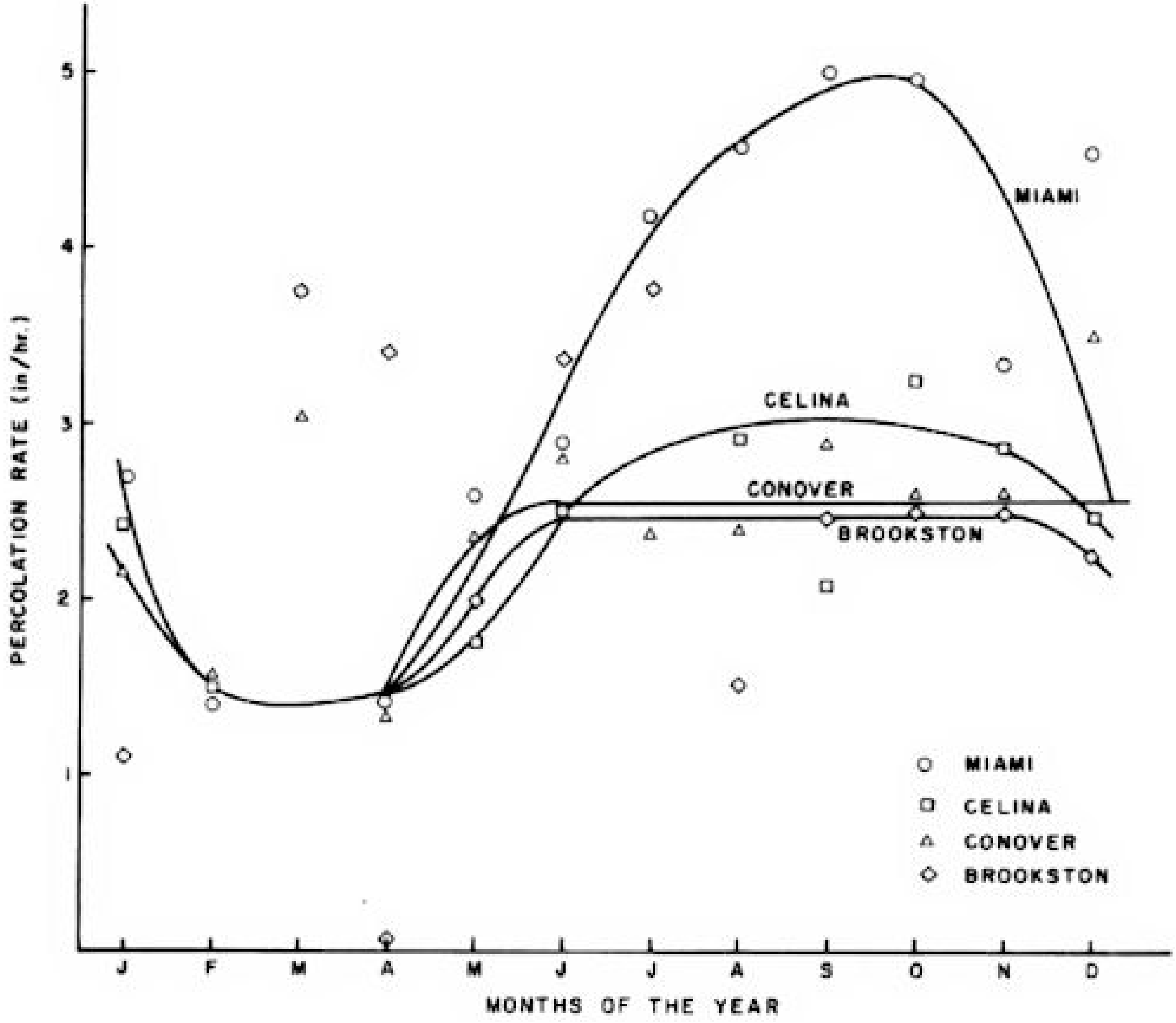

FIGURE 10. Variability in Percolation Rates During The Year For Miami, Celina, Conover, and Brookston Series. After Mokma (1966).

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APPENDIX

Method for Calculating the Average Permeability of the Soil Adjacent to a Percolation Hole.

The procedure for back-calculating the permeability of the soil adjacent to a percolation hole using the measured tensiometer readings and the I.P.R. is described in the following steps:

1. Plot the tensiometer readings (soil water pressure) as shown in Figure Al. (6 tensiometers in Group 1 and Group 2 tests and 9 tensiometers in Group 3 tests). A 10 cm diameter hole is used here for explanation purposes. An assumption is made regarding the distribution of the soil water pressure below the bottom and along the axis of the percolation hole. Two assumptions are made in the calculations:
    (i) Assumption 1 - the soil 15 cm (6 in) below the bottom of the hole is saturated and the water pressure distribution is hydrostatic, and

    (ii) Assumption 2 - the water pressure distribution is ⅔ of the hydrostatic value. The assumptions are necessary in the computations since no tensiometers were installed below the bottom of the hole because of difficulties in instrumentation.

2. From the three curves in Fig. A1, a family of curves are generated (Fig. A2) for the region adjacent to the test hole (ABCDEF in Fig. A1).

3. The selected region shown in Fig. A3 (a cross-section of the test hole) is divided into many small squares (2.54 cm x 2.54 cm) and a value of water pressure (either negative or positive) is assigned to each nodal point (corners of squares) according to the curves in Fig. A2. Three zones are arbitrarily chosen for the calculation of the permeability of the soil. Zone 1 consists of a vertical cylindrical surface created by line 1-2 revolving around the axis of the hole and a horizontal circular surface with a radius equal to the length of line 2-3. Zone 2 and zone 3 are also made up of a cylindrical and a circular surface but with a larger diameter. The procedure for calculating the soil permeability is described as below:

(a) The flow rate of water into the soil in a percolation test is calculated from the I.P.R. (the time taken by the water level in the hole to drop 2.54 cm (1 in)). It is assumed that for the steady-state flow condition, the amount of water seeping into the soil from the hole is equal to the amount of water passing through a zone (e.g. zone 1).

(b) Because the pressures at the nodal points are known the horizontal and the vertical hydraulic gradients for each square can be calculated.

(c) The total seepage area in a zone can be obtained by adding up the vertical side area (cylindrical surface) and the horizontal bottom area (circular plane).The small horizontal surface area (e.g. a circular band with radius F7) at the upper end is ignored because the flow through that area is only a few percent of the total volume of flow.

(d) The average permeability of the soil in a zone can be calculated by Darcy's Law, which states:

$$Q = k \cdot i \cdot A$$

in which:
Q is the flow rate
k is the permeability
i is the hydraulic gradient, and
A is the seepage area.

The flow rate 9, through a zone is calculated as described in (a). The average horizontal gradient on the vertical cylindrical surface can be computed by taking the average of the horizontal gradients in the appropriate squares. Similarly, the average vertical gradient on the horizontal circular plane can be calculated. Assuming a steady-state flow condition, the permeability, k, in a given zone can be readily obtained. An example of the calculations is contained in Fig. A4.

It should be pointed out that the permeability calculated by the above method is the average permeability of the soil in a particular zone and is obtained on the basis of simplifying assumptions. In reality, the permeability of the soil in each square is different because the soil water tension (suction) is different and because the permeability is a function of the soil water tension. However, for the purpose of comparing the permeability in different zones adjacent to the hole and in different percolation tests, it is practical and also adequate to use the average permeability of the soil.

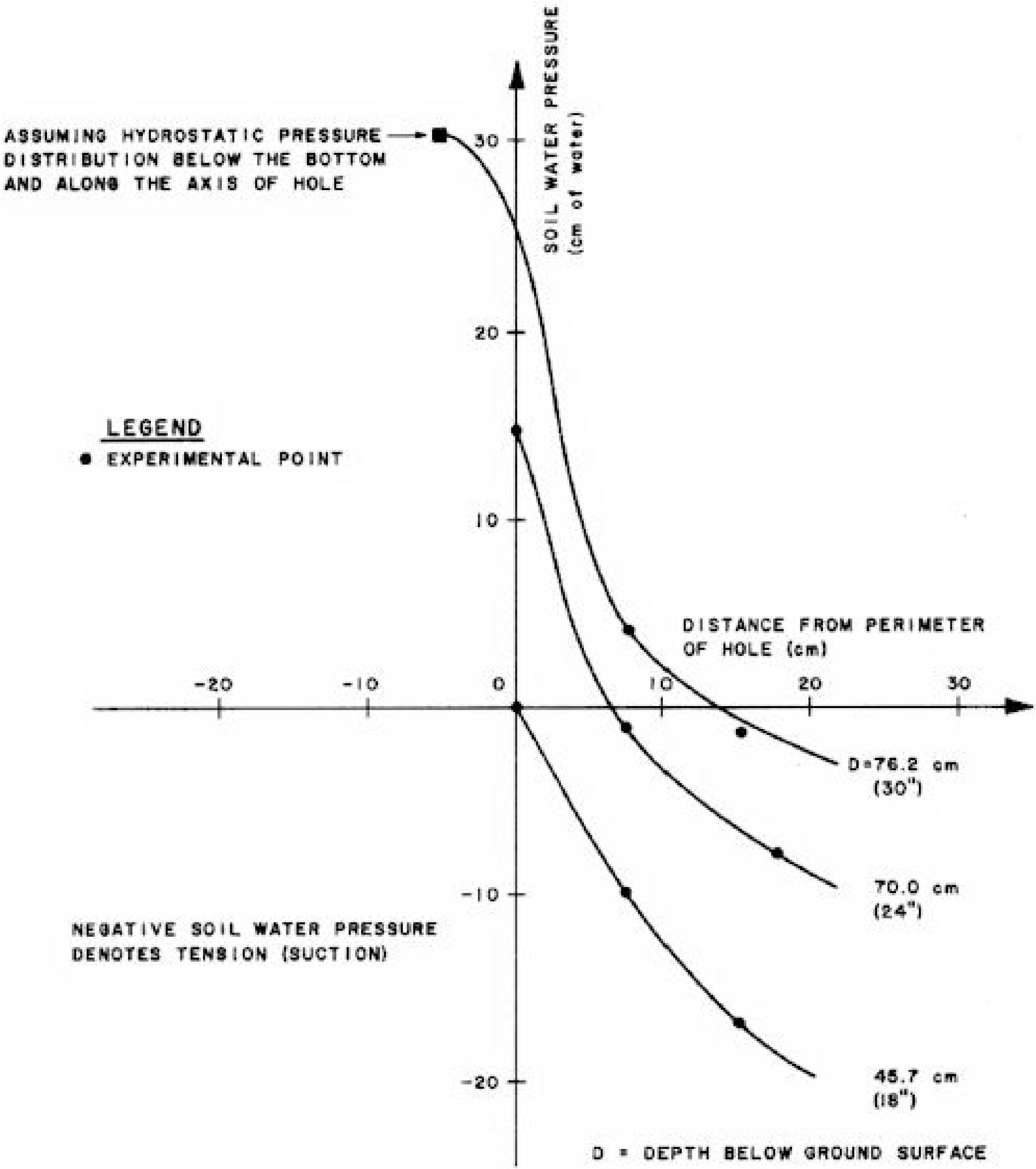


FIGURE A1. Soil Water Pressure at Different Depths in The Soil And at Different Distances From The Perimeter of Test Hole (Negative Distance in The Direction Toward The Axis of Hole). Group I. 10-cm Diameter Hole.

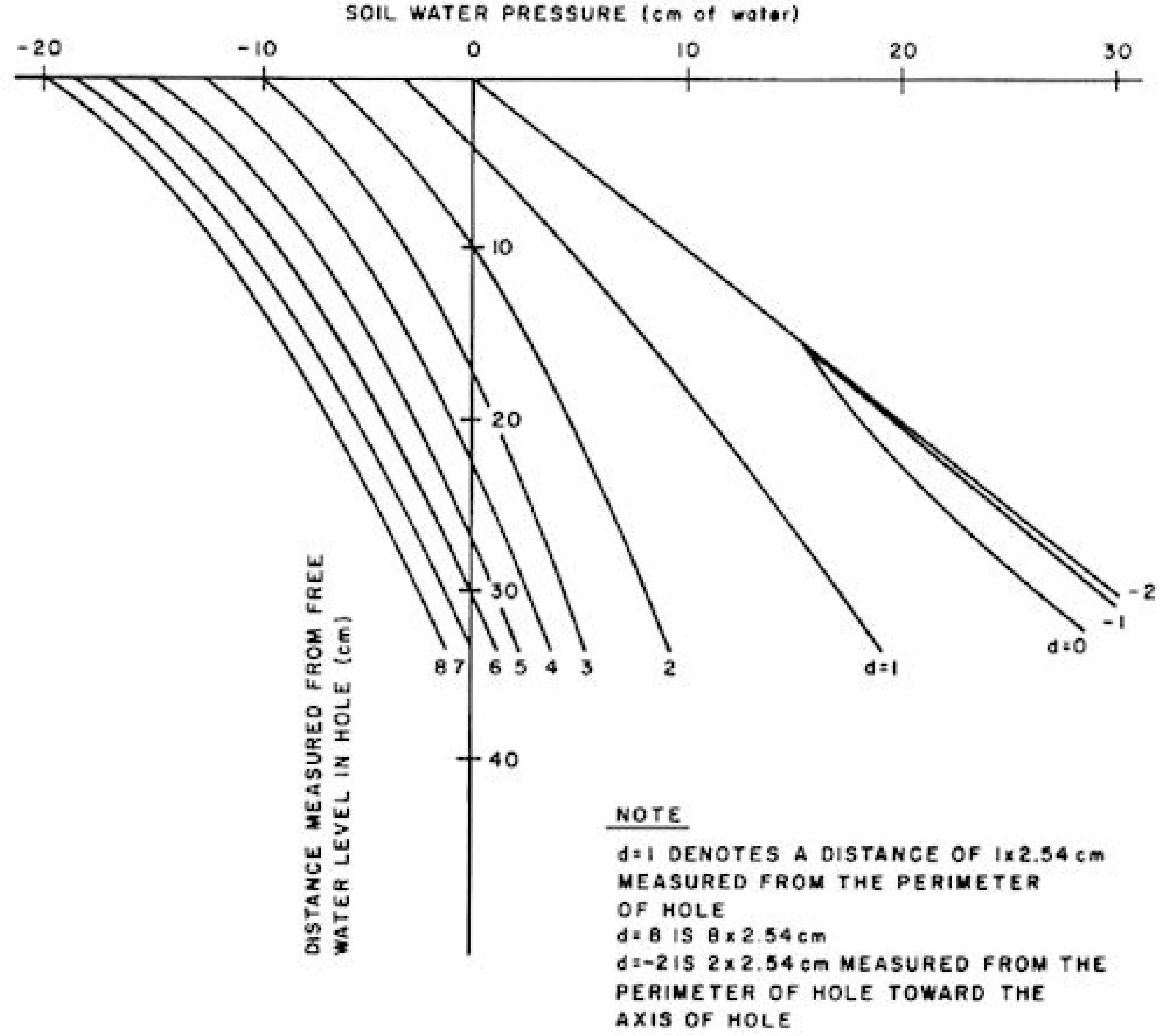


FIGURE A2. Soil Water Pressure Values Generated From Figure A1.

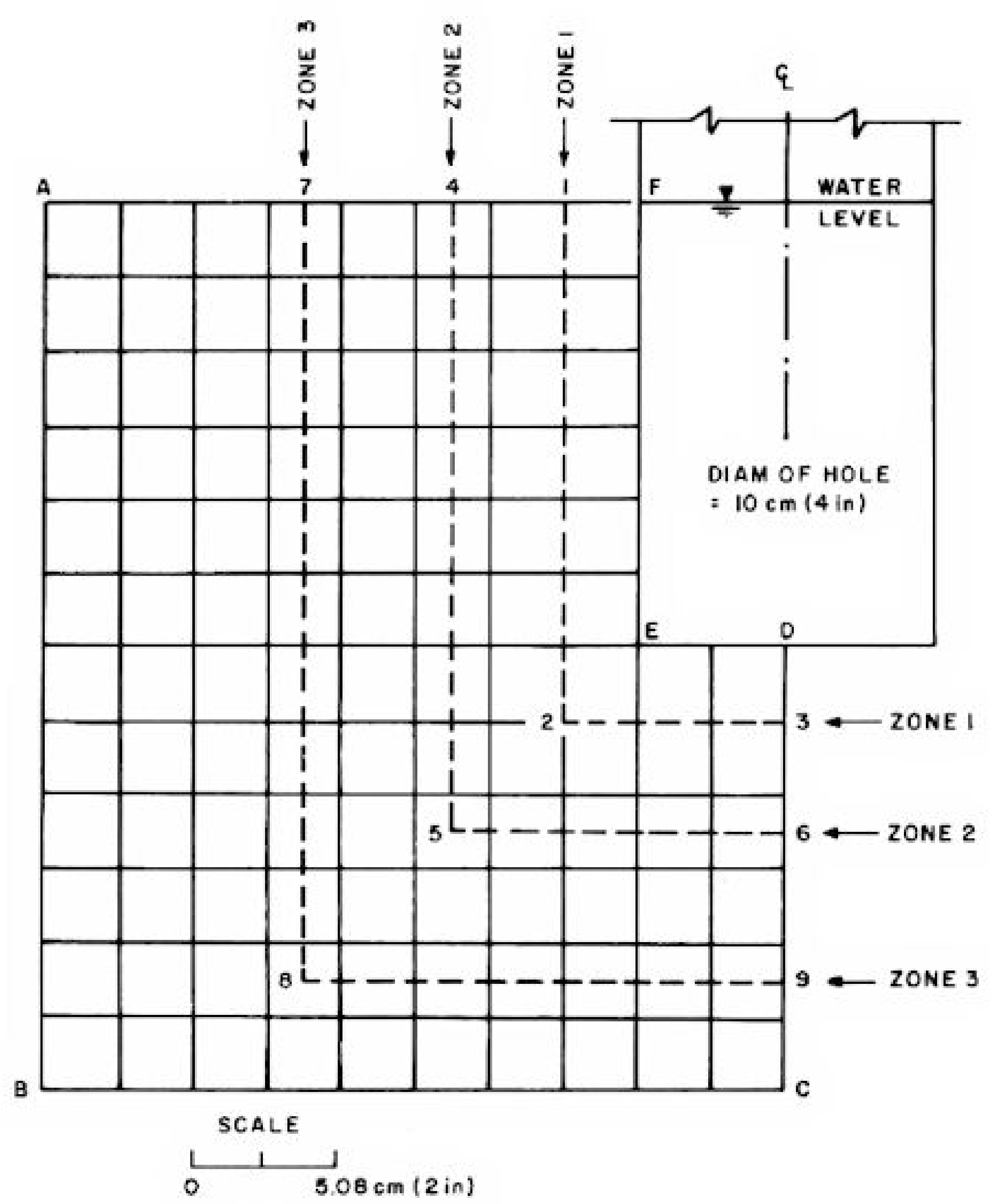


FIGURE A3. Diagram Showing The Location of Three Zones of Which The K Values Are Computed For The Soil.

THE SOIL WATER PRESSURE DISTRIBUTION AROUND THE TEST HOLE

Group 1 test. Hole Diam.10 cm (4 in), I.P.R. = 5.3 min/cm 113.5 min/in)

Flow rate = 0.254 cm^3/sec,

Consider Zone 1.

Average hydraulic gradient in horizontal direction

i_H = (10+7) + (2.54+4.8) + (5.08+3.2) + (7.62+1.4) + (10.16-0) + (12.7-1.3)
+ (15.24-2.2) +(16.5-3.3) x [1/(5.08 x 8)] = 1.95

Average hydraulic gradient in vertical direction

i_v = [(5.08+8.0-11.0) + (5.08+15.24-18.0) + (5.08+15.24-19.5) + (5.08+15.24-20.32) x [1/ (5.08 x 4)] = 0.26

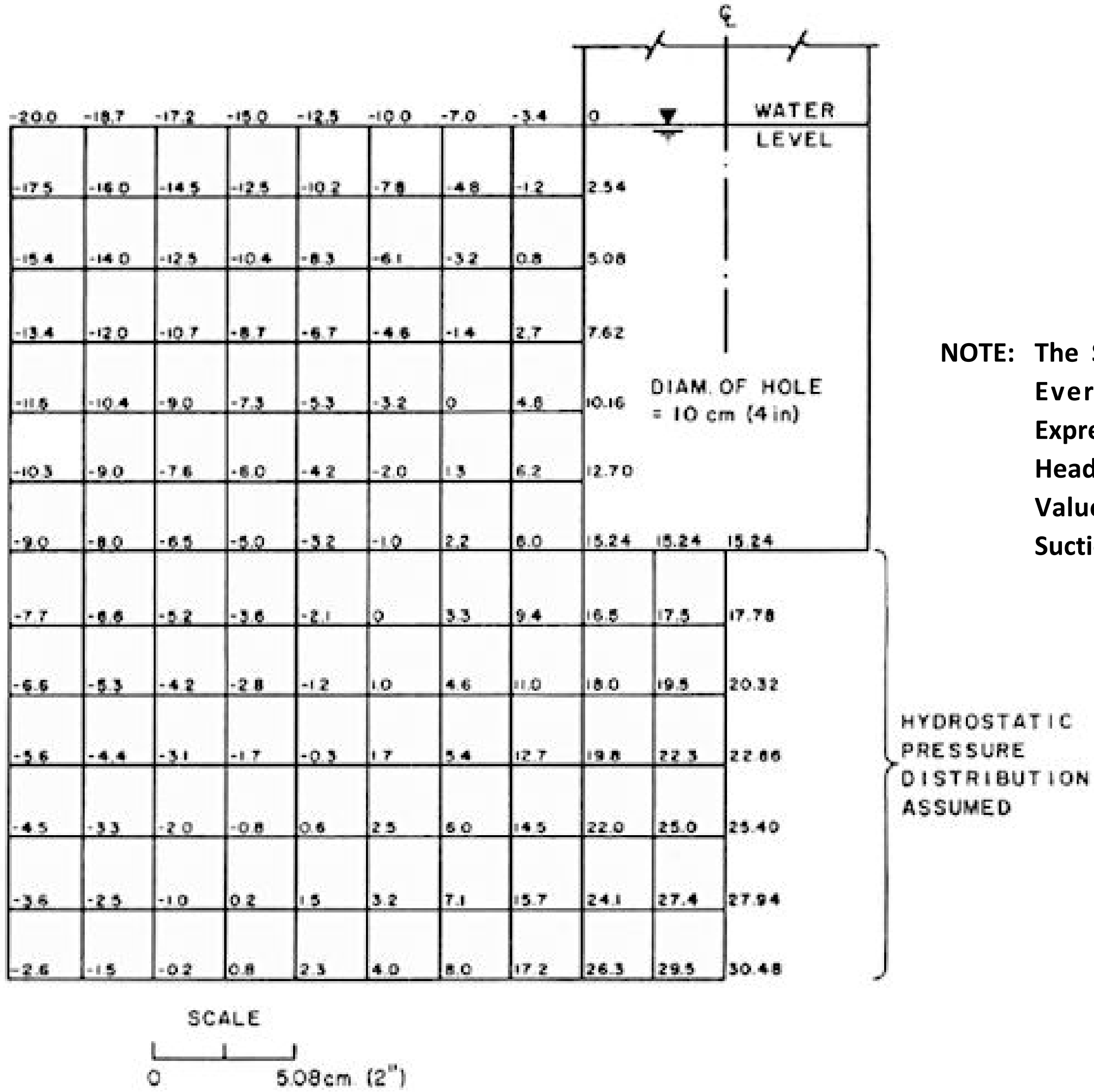
Vertical area

A_V = 2• π •r • h = 2• π • (3 x 2.54) x (7 x 2.54) = 850.84 cm^2

Horizontal area

A_H = π r^2 = π $(3x2.54)^2$ = 182.32 cm^2

$$\text{The average k} = \frac{0.254\ cm^3/sec}{(1.95 \times 850.84)+(0.26 \times 182.32)} = 1.49x10^{-4}\ cm/sec$$



-20.0	-18.7	-17.2	-15.0	-12.5	-10.0	-7.0	-3.4	0		
-17.5	-16.0	-14.5	-12.5	-10.2	-7.8	-4.8	-1.2	2.54		
-15.4	-14.0	-12.5	-10.4	-8.3	-6.1	-3.2	0.8	5.08		
-13.4	-12.0	-10.7	-8.7	-6.7	-4.6	-1.4	2.7	7.62		
-11.6	-10.4	-9.0	-7.3	-5.3	-3.2	0	4.8	10.16		
-10.3	-9.0	-7.6	-6.0	-4.2	-2.0	1.3	6.2	12.70		
-9.0	-8.0	-6.5	-5.0	-3.2	-1.0	2.2	8.0	15.24	15.24	15.24
-7.7	-6.6	-5.2	-3.6	-2.1	0	3.3	9.4	16.5	17.5	17.78
-6.6	-5.3	-4.2	-2.8	-1.2	1.0	4.6	11.0	18.0	19.5	20.32
-5.6	-4.4	-3.1	-1.7	-0.3	1.7	5.4	12.7	19.8	22.3	22.86
-4.5	-3.3	-2.0	-0.8	0.6	2.5	6.0	14.5	22.0	25.0	25.40
-3.6	-2.5	-1.0	0.2	1.5	3.2	7.1	15.7	24.1	27.4	27.94
-2.6	-1.5	-0.2	0.8	2.3	4.0	8.0	17.2	26.3	29.5	30.48

NOTE: The Soil Water Pressure In Every Nodal Point Is Expressed In Cm Of Water Head And The Negative Value Denotes The Soil Suction.

FIGURE A4. Example Showing Details Of Calculation For k.