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MEASURE SEEPAGE FROM IRRIGATION CHANNELS
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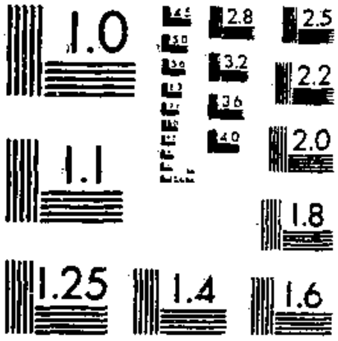

MICROCOPY RESOLUTION TEST CHART
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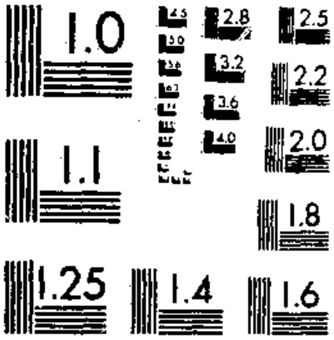

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MEASURING SEEPAGE from IRRIGATION CHANNELS

by A. R. Robinson and
Carl Rohwer

Technical Bulletin No. 1203

Agricultural Research Service
UNITED STATES DEPARTMENT OF AGRICULTURE
in cooperation with the
COLORADO AGRICULTURAL EXPERIMENT STATION
and the Bureau of Reclamation
UNITED STATES DEPARTMENT OF THE INTERIOR

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Washington, D.C. Issued September 1959

For sale by the Superintendent of Documents, U.S. Government Printing Office
Washington 25, D.C.

MEASURING SEEPAGE
from
IRRIGATION CHANNELS[1]

By A. R. Robinson, *agricultural engineer*, and Carl Rohwer, formerly *project supervisor, Soil and Water Conservation Research Division, Agricultural Research Service*[2]

INTRODUCTION

Although irrigation has been practiced for many centuries, most of the very early irrigation projects no longer exist. Some of them came to an end because water supplies failed or because irrigation works were destroyed by invading armies. Many, however, had to be abandoned because the land became waterlogged or too heavily charged with alkali to grow crops successfully. Poor drainage, over-irrigation, and seepage from canals and laterals all contributed to the failure of these projects. Today, the same factors are causing much irrigated land to become waterlogged or too alkaline for successful farming. The part that seepage from canals and laterals plays in producing these effects makes it a serious agricultural problem even aside from the fact that it involves loss of much irrigation water sorely needed by crops.

Seepage has been defined by Tolman (*15*)[3] as the movement of water into or out of the ground. This definition differs from that of Meinzer (*8*) in that the word "movement" replaces "percolation," which refers specifically to the slow movement of water through small passages among the particles that make up soil or rock. In this report, "seepage" means movement of water into or out of irrigation channels through interstices in the bed material. Seepage may be measured in cubic feet per square foot of water surface or of wetted surface per 24 hours; in cubic feet per second per mile; or in percentage

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[1] The study reported here was begun in 1949 as a project of the Division of Irrigation and Water Conservation, Soil Conservation Service, U.S. Department of Agriculture. On January 1, 1954, this division became a part of the Soil and Water Conservation Research Branch of the Department's Agricultural Research Service. Cooperation in the study was received from the Bureau of Reclamation, U.S. Department of the Interior, and from the Colorado Agricultural Experiment Station. Details of the arrangements are covered by memorandum of understanding ASc-875, signed June 20, 1949.

[2] The authors wish to express their appreciation of all aid received in the study. Dean F. Peterson, formerly head of the Civil Engineering Department, Colorado Agricultural and Mechanical College (now Colorado State University), gave his support to the project and assisted in interpreting the data. Floyd Roush, Dale Lancaster, Chester W. Jones, and John Maletic, of the U.S. Bureau of Reclamation, helped to plan and conduct the investigations. Ralph Rollins, formerly assistant professor of civil engineering, Colorado Agricultural and Mechanical College (now Colorado State University), was active on the project during its early phases. Robert C. Accola and M. A. Roebecker, of the U.S. Soil Conservation Service, and J. W. Tobiska, of the Colorado Agricultural Experiment Station, made the soil and water analyses. R. N. Rolfe, of the U.S. Geological Survey, made valuable suggestions regarding technical problems. W. G. Wilkinson, water commissioner of District 3, Division 1, Colorado, arranged for delivery of water from the Poudre River for ponding tests. Sites for tests were provided by the Bureau of Reclamation, the Jackson Ditch Co., and the North Poudre Irrigation Co. Students temporarily employed on the project gave much helpful assistance.

[3] Italic numbers in parentheses refer to Literature Cited, p. 81.

of total flow per mile. Of these units of measure, cubic feet per square foot of wetted surface per 24 hours is believed to be the most generally useful and is the one used in this report.

Seepage from canals can be reduced to reasonable limits by lining the canals with concrete or other impervious material, by giving special treatment to the canal bed, or by combining these methods. The cost of lining all the canals of a project is in most cases prohibitive. However, seepage varies widely among different sections of a canal, according to the nature of the material in which the canal was excavated and the conditions under which it is being operated; and seepage from canals could be reduced to reasonable limits at reasonable cost by lining or otherwise treating sections of canal beds, if the areas of greatest seepage loss could be definitely located. In new projects, reliable forecasts of the seepage from the various reaches of the proposed canals would make it possible to determine in advance which should have a lining and which do not need one.

The objectives of the study reported here were to devise better methods of measuring the seepage from existing canals and of forecasting the seepage from proposed canals and to obtain information on the influence of individual factors that affect seepage.

FACTORS AFFECTING SEEPAGE

Many factors are known to have a definite effect on seepage rate, the principal ones being characteristics of the soil of the canal bed, length of time the canal has been in operation, depth to ground water, amount of sediment contained in the water, depth of water in the canal, temperature of the water and of the soil, percentage of entrained air in the soil, capillary tension in the soil, and barometric pressure. Biological factors influence the seepage rate in greater or lesser degree. Salts contained in the soil or water affect the rate in some instances. Since all the factors act simultaneously, and some of them tend to counteract each other, it is difficult to segregate the effect of any one of them. Because of the many variables involved and the complexity of their relations, no satisfactory formula for computing seepage has ever been developed.

Seepage takes place under the combined influence of the forces of gravity and soil moisture-tension gradient. When water is first turned into a dry canal the force of the moisture-tension gradient may exceed that of gravity, but as the soil approaches saturation the force arising from the moisture-tension gradient becomes small. Consequently, although the canal may at first lose a large amount of water not only by the percolation of water through pores in the soil under the action of gravity but also by moisture-tension gradients, the loss due to the latter soon decreases and is overshadowed by that caused by percolation. The force associated with the tension gradient may act in any direction and may cause the soil water to rise many feet above the water surface in the canal. Frequently it carries water upward to the root zone of plants or to the soil surface. Then, water is lost through the transpiration of plants or through evaporation from the soil. Such losses are generally small in comparison with the overall seepage losses from canals.

The factor most important in determining rate of seepage is the permeability of the material forming the bed of the canal. Permeability is a porous medium's capacity for transmitting water. It is influenced both by pore size and by percentage of pore space, or porosity, but as pore size decreases permeability decreases in approximately the same ratio as the square of pore diameter (*15, p. 45*). This is the reason for the relative imperviousness of clays, which have high porosity but very small pore diameter. Soils consisting of a mixture of gravel and clay are almost completely impervious. The permeability of gravel depends on the size and the size gradation of the gravel particles. Gravel with a good range of particle sizes and good size distribution is less permeable than gravel of uniform particle size. Laboratory tests by the Geological Survey have shown that coarse gravel may transmit water 450 million times as fast as clayey silt (*20, p. 11*). The wide range of possible seepage losses is apparent from this fact.

Seepage rate is determined in part by the head available to drive the water through the soil. This factor depends not only on the depth of water in the canal but also on the depth to ground water and the nature of the material composing the canal bed. If the ground-water level is above the water surface in the canal, water will seep into the canal from the surrounding area. If it is below the bottom of the canal, the effective head depends on the depth of water in the canal and the length of the soil column required to use up the available head. For intermediate ground-water levels, the effective head is equal to the difference in level between the water table and the water surface in the canal. In a study of water spreading for underground storage, Mitchelson and Muckel (*9, p. 80*) observed that the seepage rate decreased materially when the ground-water level reached the elevation of the surface of the spreading area. An increase in rate occurred while the ground-water level was dropping below the elevation of the spreading-area surface, but this trend disappeared when the ground-water level had dropped a few feet farther.

If the soil underlying an irrigation canal bed is less permeable than the bed, water lost by seepage spreads laterally as it percolates downward. In more permeable soil, water lost by seepage moves downward as a film of moisture on soil particles in the zone directly beneath the canal. In this case a tension gradient occurs in the unsaturated soil and supplements the force of gravity in causing the downward movement. The nature of the flow under these conditions has been confirmed through tests conducted by Lauritzen and Israelsen (*7, p. 48*) on a model canal section.

Because of the many factors involved and the interrelations of these factors, it is difficult to determine what part of the seepage from a canal is due to the depth of water in the canal. Tests previously made by the Division of Irrigation and Water Conservation on canals (*13, pp. 34–39*) showed that although seepage decreases as depth of water decreases, the two changes are not directly proportional. Lack of correlation between depth of water and seepage rate has been reported also by Lane as cited by Tolman (*15*). Recent laboratory tests by Warnick (*18, pp. 40–41*) in a tank 5 feet in diameter showed that seepage generally decreased as depth decreased, but there were anomalies in the data.

Time is a factor in rate of seepage from canals, because of changes that occur in bed material with the lapse of time. Water moving into the soil carries small particles in suspension and deposits them in pore spaces, and this gradually reduces the soil's porosity. If the water contains considerable amounts of clay or silt, the process may markedly reduce the seepage rate in a relatively short time. Expansion of the soil particles in certain types of bed material as they become saturated with water also reduces seepage. This is particularly true of soils containing clays of the montmorillonite type. However, these soils also have a high capacity for shrinking while drying. Canals in soils of this type usually have a high rate of seepage when water is first turned into them. Some organisms growing in the soil may decrease the rate of seepage (*1*), but others may increase it. Tests by Muckel (*10*) showed that addition of cotton-gin waste to the soil of water-spreading grounds definitely increased seepage rates. The gradual solution of the entrained air in the soil increases soil porosity and temporarily increases the seepage rate.

Temperature, also, affects seepage rates. As temperature rises, the viscosity of water decreases about 1 percent per degree Fahrenheit. This change tends to cause rate of seepage to increase as temperature rises. However, temperature also affects the vapor pressure of the entrained air bubbles, and as the vapor pressure rises the volume of entrained air increases and soil porosity diminishes. Thus a rise in temperature, although it tends to increase seepage because it lowers the viscosity of water, also tends to decrease seepage because it reduces porosity by raising vapor pressure.

Salts contained in the soil and water may have a marked effect on seepage rate. Water containing sodium tends to puddle clay soils and thus reduce seepage rate. Water containing calcium or sulfur makes soils high in sodium more porous. Some recently developed chemicals are available that reduce the permeability of the soil.

Rise in barometric pressure theoretically increases seepage rate temporarily, because the force driving the water through the soil is greater while the barometric pressure of the air in the soil and that of the atmosphere are being equalized. No data are available as to the influence of barometric pressure on seepage.

The influence of biological factors on seepage rate is beyond the scope of this report.

Although no satisfactory formula has ever been devised for computing seepage, certain fundamental relations of the factors influencing seepage rate have been definitely established. According to Darcy's law (*2*), the velocity of flow through water-bearing materials is directly proportional to the head consumed and also to the permeability of the material. This law is generally assumed to apply to flow through all saturated water-bearing materials in which the pores are of capillary size and the flow is laminar. It applies also to seepage. Its validity has been confirmed by numerous experiments.

In terms of factors involved in the study of seepage, Darcy's law is expressed by the formula

$$Q=KIA, \tag{1}$$

in which Q is the quantity of water lost in unit time, K is the coefficient of permeability,[4] I is the hydraulic gradient, and A is the wetted area of the canal bed and banks. This formula may also be expressed in terms of the head available, as

$$Q=\frac{KhA}{l}, \tag{2}$$

in which Q, K, and A have the same significance as before, h is the total head producing seepage, and l is the length of the column of material through which seepage is taking place under the head, h.

In these formulas K, the permeability coefficient, is the measure of all the properties of the soil composing the bed of the canal that affect the seepage rate. Formulas are available for computing K from the temperature or viscosity of the water, the porosity, and the mechanical analysis of the material, but these formulas have not proved satisfactory. More accurate permeability values can be obtained by directly measuring the flow through the material by means of permeameters, by injecting dyes or chemicals into the water, or by analyzing discharge and drawdown data from pumped wells (*19*). These methods all provide useful information, but they do not measure permeability in critical areas of a canal bed, which determines the seepage rate. Furthermore, the material in the bed of a canal is not uniform, and results of a test of permeability in one part of the bed may differ materially from those of a similar test in another. Changes in the material resulting from the test procedure, also, may have a marked effect on its permeability. Although tests on undisturbed samples should give more accurate results than those on disturbed samples, a single root channel or crack in such a sample may cause erroneous results. The accuracy of the results can be increased by testing a larger number of samples, but this frequently is not feasible because of the difficulty of taking undisturbed samples and the cost of making the tests.

The area within a section of a canal from which seepage is occurring can easily be determined from the wetted perimeter and the length of the section. However, the factors h and l in the second equation expressing Darcy's law are interrelated; l affects h. The effective head can be determined by measuring the hydrostatic head in the soil at distance l beneath the bed of the canal and subtracting it from the head due to the depth of water in the canal. This procedure, however, presents many difficulties, and usually it is not attempted.

Although Darcy's law is unsatisfactory for computing seepage, because of the difficulty of determining hydraulic gradient and permeability for the section of canal under test, it is useful in showing how the various factors that affect the seepage rate are related. Seepage

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[4] The coefficient of permeability, K, of a material, according to Meinzer's definition as given by Stearns (*14, p. 148*), is the "rate of flow, in gallons a day, through a square foot of its cross section, under a hydraulic gradient of 100 per cent, at a temperature of 60° F." Other investigators have defined the coefficient in terms of cubic feet of flow per day. When the permeability is extremely low, the coefficient may be expressed in gallons or cubic feet per year. Israelsen (*5*) has proposed the use of a different coefficient, which he calls specific water conductivity and defines as "the volume of water that will flow in unit-time through a soil-column of unit cross-section area due to the driving force per unit-mass corresponding to unit potential-gradient."

is directly proportional to each of the factors permeability, hydraulic gradient, and area. An error in any one of these factors affects a seepage measurement in like proportion.

METHODS OF MEASURING SEEPAGE LOSSES[5]

Various methods have been devised for measuring seepage in the field or in the laboratory. Some of these methods yield results in terms of average seepage for a section of a canal; others give the seepage rate for a small unit of area or merely furnish information as to the permeability of a sample of the canal bed material either in its undisturbed state or in the state that results from crushing, screening, and recompacting. When methods are used that yield information on permeability only, additional observations must be made to determine the hydraulic gradient. The five commonly used methods of determining seepage are these: Inflow-outflow, ponding, seepage-meter, well-permeameter, and laboratory permeability. Special methods used include measuring the electrical resistance in areas where seepage is taking place and tracing radioactive material in the seepage water.

Inflow-Outflow Method

The inflow-outflow method of determining seepage consists in measuring the inflow to and the outflow from the reach of canal under test and determining the difference. This method is best adapted to measuring seepage from long sections of canal in which there are few diversions and in which an appreciable amount of seepage is taking place. It can be used in short sections of canal in which seepage is taking place at a high rate. When seepage is measured by the inflow-outflow method, the stage of the canal should be kept constant during the test period, in order to eliminate the effect of bank and channel storage. Failure to take account of this factor may introduce large errors into the results. All diversions and leaks must be accurately measured, likewise any inflow of waste water from irrigation of higher lands. A record of rainfall and evaporation should be kept, particularly if the seepage loss is small, even though these factors generally have no significant effect on seepage loss.

Current meters are generally used to measure the flow in large canals. Weirs, Parshall flumes, and orifices are most satisfactory, in general, for measuring diversions and leaks. Small leaks in headgates or bulkheads, which have to be taken into account in testing lined canals, can best be measured volumetrically with a calibrated can. Weirs or Parshall flumes should be used to measure the flow in farm laterals and small ditches; current meters are not adapted for measuring the small flows in such channels.

Inflow-outflow measurements of seepage can be made rather easily and do not involve interfering with the operation of the canal. It is difficult, however, to make such measurements so accurately that they will show the true loss. For this reason, the results are usually disappointing.

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[5] For a more detailed discussion of methods of measuring seepage, see Rohwer and Stout (*13*).

Ponding Method

The ponding method consists in measuring the rate of drop in a pool formed in the section of canal being tested and computing the seepage rate from this and the ratio of the water-surface area of the pool to the wetted area of the section. Since the necessary observations can be made accurately, the results should be an accurate indication of the average loss from the section. An objection is that the still water in the pool may seep out at a different rate than the flowing water in the canal. However, the difference is probably inconsequential in view of the errors associated with other methods of making seepage measurements.

To eliminate the effect of wind, the rate of drop should be measured at each end of the pool. Staff or hook gages attached to already existing structures or to stakes driven into the canal bed should be used. All leaks must be carefully measured, and evaporation and rainfall should be recorded so that the drop in water surface can be corrected for these items.

The ponding method produces the best results, and measurements obtained with it are generally used as the standard of comparison for seepage measurements obtained otherwise. This method is particularly useful in measuring small seepage losses. However, it has serious disadvantages. Ponding tests can be made only when the canal is not in use. Constructing dams to form the pools is expensive. Providing water to fill the pools sometimes involves difficulties, particularly because the pools must be filled several times before the seepage rate becomes stabilized. Filling the pools, also, is a problem. If gates are installed in the dam, they have to be large and must be watertight. If pools are to be filled by pumping, expensive pumps must be installed. For these reasons, the ponding method is not used unless the importance of the tests warrants fairly large expenditures. Furthermore, although the ponding method gives the average seepage from a pool, it does not show what the variation in the rates from different parts of the pool may be.

Seepage-Meter Method

Seepage meters measure seepage rate under normal conditions of canal operation for a small area at a time. Readings are taken at several points along the section of canal being tested and are averaged. The seepage meter consists of a cylindrical bell, a plastic bag, and a plastic hose. The bell is pressed into the canal bed. The bag is filled with water, attached to the top of the bell by means of the hose, and submerged in the canal. As water seeps into the soil under the bell, water is drawn from the plastic bag in such amount that the pressure inside the bell is constantly the same as that produced on the bed of the canal by the water in the channel. The amount of water seeping from the area under the bell is determined by weighing the bag at the beginning and at the end of the test. The seepage rate per unit area of the canal section is computed from the area of the bell, the seepage from the bell, and the elapsed time.

The plastic bag can be replaced with a small can attached to a stake driven into the bank of the canal. The can is filled with water to a level slightly above that in the canal. As water seeps into the soil under the bell, water is drawn from the can. At the time when the water level in the can becomes the same as that in the canal, the rate of seepage from the seepage meter should be the same as that from the canal. A hook gage and stopwatch are used to determine the rate of drop in the can. Since the can has a much smaller cross-sectional area than the bell, the rate of drop is greatly magnified. The seepage rate is computed from the ratio of the areas and the rate of drop in the can.

The seepage meter should be installed in the canal bed with the least possible disturbance of the bed material. Because of disturbance of the bed material, the seepage meter usually overregisters if measurements are made immediately after the meter is installed. The meter cannot be used in very gravelly soil, because of the difficulty of forcing the bell into the bed of the canal, and in sandy soil it is likely to be washed away by the current. (Details of design and operation of seepage meters are given in the section beginning on p. 22.)

Well-Permeameter Method

Because seepage is directly proportional to soil permeability, the well permeameter was devised to measure the permeability of the soil along the axis of a proposed canal and thus obtain a basis for predicting the seepage from the canal.

The well permeameter consists of a calibrated supply tank equipped with an indicator glass and an outlet pipe equipped with a float mechanism that controls the water level in the well. The wells in which it is used are holes 4 to 6 inches in diameter and of a depth that varies with the horizon to be tested but must be 10 or more times the radius. The hole is partly filled with highly permeable sand or gravel to reduce erosion and prevent caving, and the upper part, in which the float is to be installed, is cased with screen. A constant water level, usually corresponding in elevation to the high-water line of the proposed canal, is maintained in the hole by the float and valve mechanism. The discharge required to maintain this constant water level is determined from the drop in the calibrated tank. Since the loss from the well decreases with time, readings must be taken over a period of days to get the best results. It is important that the well be kept filled continuously during the test, because breaks in the continuity of the data make it difficult to interpret them.

The loss from the well in unit time can be computed from the time interval between observations and the calibrated-tank readings. These data, plotted against elapsed time, show how the rate of loss changes with time. From this information, the diameter of the well, and the depth of water in the well the permeability of the soil is computed, and from this the prospective seepage from a canal in the same soil can be computed. Because the formulas required for these conversions are based on theoretical analysis and electrical-analogy studies, and because various assumptions have to be made that may not be justified by conditions in nature, seepage computations from well-permeameter data cannot be expected to agree closely with seepage rates based on ponding tests. The method is probably accurate enough for estimating the seepage from proposed canals under favorable conditions.

This method has serious limitations in addition to those already mentioned. It requires a considerable supply of water. As the tests must frequently be made in desert areas, far from a source of water, this may be a serious handicap. The tanks must be closely watched to avoid having them go dry, which would spoil the tests. Because each test has to continue for several days, the tanks should be watched 24 hours a day, and enough men to handle day and night shifts should be assigned to the job.

(The well-permeameter method is further discussed, and results obtained with it are presented, in the section beginning on p. 37.)

Variable-Head-Permeameter Method

The variable-head permeameter can be operated not only in dry canals but also in canals carrying water. It consists of a cylindrical bell, similar to that of the seepage meter, with a calibrated glass tube attached to its top. A small-diameter or a large-diameter tube is used, according to whether the seepage rate is low or high. As water seeps into the soil in the area enclosed by the bell, the water level in the calibrated tube drops. From the rate of drop in the glass tube and the theoretical length of the soil column in which the head is dissipated, the permeability can be computed by means of a formula that takes into account the variation in head (*6*).

The difficulty with this device is that the length of the soil column cannot be accurately determined. It is usually assumed to be equal to the depth of penetration of the seepage bell. This assumption is probably satisfactory when the bed of the canal consists of a layer of a fairly tight soil overlying more porous material, but it may lead to serious errors if the soil profile is uniform. Also, when the variable-head permeameter is used in dry canals the water pressure on the inside of the bell tends to push the bell out of the ground. Sufficient weight should be put on the bell to balance the uplift. The device is useful for measuring the permeability of treated-earth canal linings that are nearly impervious.

Laboratory Permeability Method

Laboratory tests of the permeability of soil along the line of a proposed canal may be made on samples of either disturbed or undisturbed material. A large soil auger is generally used to collect disturbed samples, which are later dried and pulverized. Undisturbed samples are taken by cutting out cylindrical blocks of the soil. Samples are taken at various depths, so as to include material from the different soil horizons into which the canal would be excavated. The material is placed in a glass or plastic cylinder, according to a definite procedure. Water is allowed to flow through the samples under a definite head, usually for a week or more, and at intervals during this period the rate of flow through the soil is determined. A plot of the rate of flow against elapsed time shows how the rate changes. At first the rate decreases rapidly. After a time, for most soils, it becomes practically constant; for a few soils it may increase. The rate at which the curve starts to flatten out is used for computing permeability. The seepage from the proposed canal is then computed in the same manner as in well-permeameter tests.

Seepage rates based on permeabilities of undisturbed samples should be reasonably accurate if a large number of samples have been tested, although a satisfactory formula for converting permeability into seepage is lacking. The difficulty of obtaining representative samples and of sealing them in the permeameters makes the method time consuming and expensive.

Seepage rates computed on the basis of permeability data for disturbed samples of soil are not accurate. Even though the soil in the sample is otherwise representative of that in the canal bed, the stratification and compaction of the sample after it has been dried, pulverized, and placed in the permeameter for testing may differ widely from those of the soil in its natural state. Permeability computed by use of a disturbed sample is likely to indicate fairly well the fundamental property of the soil, but it may have no relation to the property of the soil under natural conditions. Seepage rates based on permeabilities of undisturbed samples should be reasonably accurate. However, lack of a satisfactory formula for converting permeability data makes it questionable whether the additional effort needed to get undisturbed samples is warranted.

Special Methods

Seepage can be traced by adding radioactive isotopes to the water. However, addition of radioactive material to ground water is dangerous. Because the electrical resistance of soil varies with the water content and with the salt content, measurements of this resistance can be used as the basis for estimating seepage. This method is effective in locating areas of concentrated seepage. Piezometric surveys are used to determine flow lines and pressure distribution in the soil under a canal. From this information plus permeability determinations the seepage can be computed. This method is suitable for laboratory experiments, but it is unsuitable for field use because of the large amount of labor involved.

Some idea of the amount of seepage from a canal can be gained from the rise of the ground-water level in the surrounding area. The rise is affected by evaporation, transpiration, and outflow. In the spring and fall, when evaporation and transpiration are less than in the summer, a fair estimate of seepage can be made in this manner in areas where outflow can be measured in drains.

PLAN OF STUDY

Since the major objective of the seepage study was to devise better methods of measuring the seepage from existing canals and of forecasting the seepage from proposed canals, some means of measuring seepage accurately had to be devised to check the methods being tested. Accurate means of measuring seepage had to be available also for study of the effects of temperature, ground-water level, and depth of water on the seepage rate. Analysis of the study problems disclosed that the means adopted would have to provide accurate measurements of seepage into fairly large areas of soils of different textures for hourly and longer periods. (This would involve eliminating border effects.) Drawbacks of the ordinary ponding method for this purpose have already been mentioned.

The basic plan of study adopted was to install seepage rings, consisting of metal cylinders set into the soil, in various representative soils differing widely in permeability, in order to determine whether seepage could be accurately measured by the seepage-ring method and if so to determine seepage rates for these soils. Complete analyses would be made of the soil of each seepage-ring installation and of the water supplied to the rings. All the seepage from the soil within a ring would occur through the bottom of the ring; the effect of a variable head on the sides would be eliminated. Inside the large seepage ring a smaller one would be set, the seepage from which would be unaffected by border influence. The water level in the rings would be controlled by float valves. Seepage would be determined by measuring the inflow to the rings with domestic water meters while maintaining a constant water level in the rings. For determining the seepage during a short period, the inflow would be shut off and the drop in the water surface during the period would be measured. Hook gages would be provided for accurately measuring the water level in drop tests and for determining changes in depth of water during periods of continuous operation. The drop tests would serve as a means of checking the accuracy of the water-meter measurements. Evaporation and precipitation would be measured.

With the installations described, the precision of seepage measurements would depend primarily on the accuracy with which the domestic water meters measured the inflow. Under most conditions evaporation, precipitation, and change in water level in seepage rings are rather small in comparison with the seepage, and consequently can easily be measured with the required accuracy. Since domestic water meters, under normal conditions and within the range of flows for which they are designed, measure water with an error of less than 2 percent, it was believed that the seepage-ring method, except in special cases, would measure the seepage in a definite area more accurately than any of the methods ordinarily used for this purpose could do it, and that seepage measurements made in the manner described could therefore be used as the standard of comparison for testing seepage-measuring devices and for studying the effects of various factors on seepage.

Because of limitations of the inflow-outflow, ponding, and other customary methods of measuring seepage, revealed by previous investigations, it was decided that in the present project the greatest consideration should be given to seepage meters. In previous tests with seepage meters (*13*) it had been recognized that accurate means of checking their performance would have to be developed before they could be recommended for use.

Seepage meters would be installed in the soil within the seepage rings, and the seepage rates indicated by these devices would be compared with the rates obtained through operation of the rings. Likewise the effects of various factors on seepage would be investigated by observing the changes in seepage associated with changes in each of these factors.

Field use of seepage meters in existing canals in conjunction with ponding tests was planned, also field testing of well permeameters. These tests were planned as a means of further improving and calibrating the seepage-measuring devices.

For study of the effect of depth to ground water on seepage, it was planned to prepare special installations in which this depth could be adjusted.

SEEPAGE-RING TESTS

Seepage rings were installed and operated in the vicinity of Fort Collins, Colo., in the period 1949–52, on five areas representative of sand, sandy loam, silt loam, and clay loam soils (tables 1 and 2). Two sandy loam soils were included—one with a low percentage of sodium carbonate and one with a high percentage; these soils are designated as sandy loam A and sandy loam B.

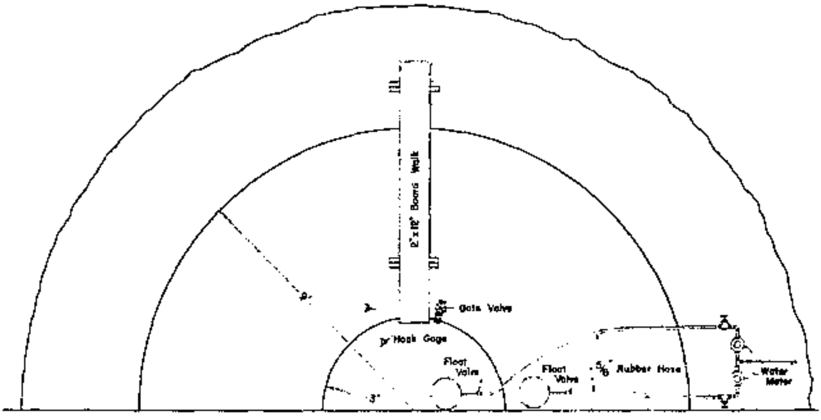
TABLE 1.—*Soil texture and other features of seepage-ring operation*

Plot and year or years	Soil texture [1]	Soil condition	Source of water	Period of operation
				Years
Horticulture, 1949–50.	Clay loam	Natural	Fort Collins city	2
Bellvue:				
1950–51	Sandy loam A	Disturbed	Poudre River	2
1952	Sand	do	do	1
Poudre Supply:				
1951	Silt loam	Natural	Fort Collins city	1
1952	Sandy loam B	Disturbed	do	1

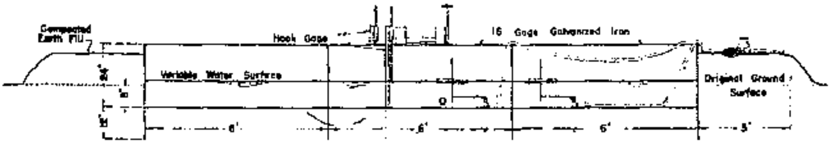
[1] Of the two sandy loam soils, in different locations, B has a larger percentage of calcium carbonate than A (table 2).

Equipment and General Procedure

For the seepage-ring installations (fig. 1), 18 feet was chosen as the diameter of the outer ring; the similar ring centered within the outer ring was 6 feet in diameter. The rings were made of 16-gage galvanized iron sheets 36 inches wide. They were set into the ground to a depth of 12 inches, and as a result formed tanks 24 inches deep. In some instances a narrow circular trench 12 inches deep was made for each ring, and when the ring had been placed in it the trench was backfilled; in others, the soil over the entire installation was excavated and was replaced after the rings were set.



PLAN



ELEVATION AND SECTION

FIGURE 1.—Plan, elevation, and section of seepage rings used in five representative soils.

Each ring was equipped with a calibrated domestic water meter to measure the water flowing into the ring, and with a hook gage, attached to a steel standard set in concrete, to measure the depth of water. Float valves were installed for use in maintaining a constant water level. A magnetic valve with float control was provided for use when very low flows were required.

A standard Weather Bureau rain gage and a Weather Bureau type A evaporation pan were used. Piezometers were installed in several locations outside the outer ring and inside the inner ring. During the last season of the study period, soil thermometers were placed in the inner rings at depths of 1 inch and 1 foot.

Water was drawn for some of the seepage rings from the Fort Collins water mains and for others from the Cache La Poudre River. The water was practically free of salt and contained little or no sediment. Total solids were less than 100 p.p.m.

In general, the rings were operated continuously for periods of from 4 to 5 months in the summer and fall.

Normally, readings of inflow as shown by the water meters and water level as shown by the hook gages were recorded for each seepage ring twice daily. At the same times, records were made of air temperatures and of water temperatures at both the water surface and the point of contact with the soil. At frequent intervals the water was shut off from the rings for a period of 1 hour or less and the drop in water surface as indicated by the hook gages was recorded. The water depths in the rings were kept constant at about 2.0 feet, except during

TABLE 2.—*Analyses of soils on sites studied*

MECHANICAL ANALYSIS

Plot and year	Colloids (<0.001 mm.)	Clay (0.001–0.005 mm.)	Silt (0.005–0.05 mm.)	Fine sand (0.05–0.25 mm.)	Coarse sand (0.25–2.0 mm.)	Gravel (>2.0 mm.)	Soil texture
	Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	
Horticulture, 1949.	18.0	11.0	33.0	30.0	8.0	0	Clay loam.
Bellvue:							
1950	1.5	4.0	19.0	55.0	19.5	1.0	Sandy loam.
1952	0	.5	.5	14.0	74.0	11.0	Sand.
Poudre Supply:							
1951	2.8	8.0	55.7	21.5	12.0	0	Silt loam.
1952	1.0	5.7	22.8	32.8	37.7	0	Sandy loam.

CHEMICAL ANALYSIS AND PERMEABILITY

Plot and year	Soil texture	pH	Total soluble salts	Total gravimetric salts	Organic material	$CaCO_3$ (calcium carbonate)	Permeability in disturbed state
			Percent	*Percent*	*Percent*	*Percent*	*Feet/day*
Horticulture, 1949.	Clay loam	7.6	0.12	<0.5	------	7.4	0.1–0.4
Bellvue:							
1950	Sandy loam A	7.9	<.02	<.5	------	1.7	3.9–6.0
1952	Sand	7.9	<.02	<.5	0.1	.1	.8–3.8
Poudre Supply:							
1951	Silt loam	7.1	.11	<.5	1.2	.2	.05–.20
1952	Sandy loam B	8.5	.08	<.5	.5	14.2	1.10–1.60

drop tests and during periods when tests were being made to determine the effect of depth on the seepage rate. The elevation of the ground water was determined at the piezometers periodically.

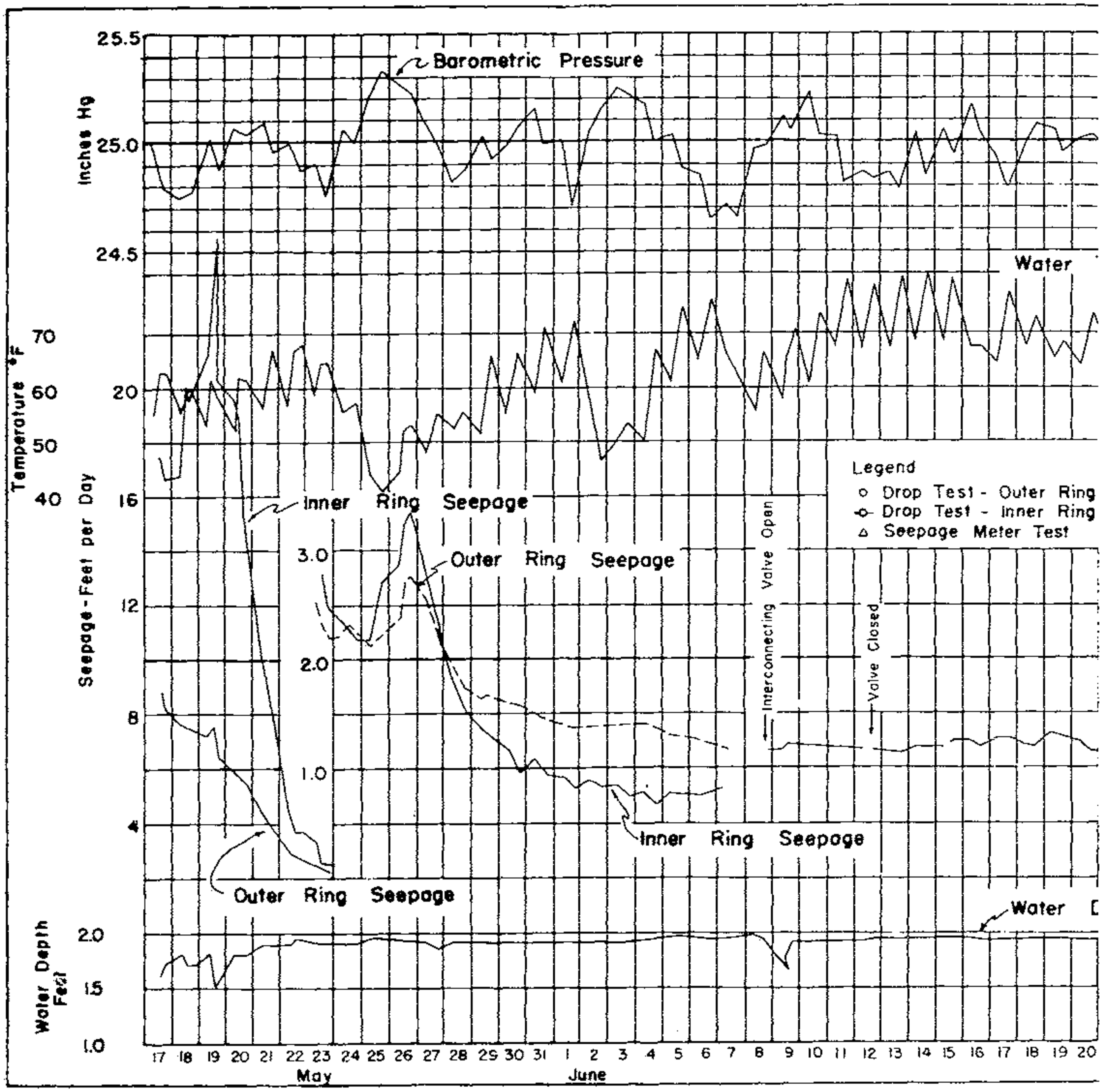
Procedure and Results on Individual Soils

Clay Loam (Horticulture Plot)

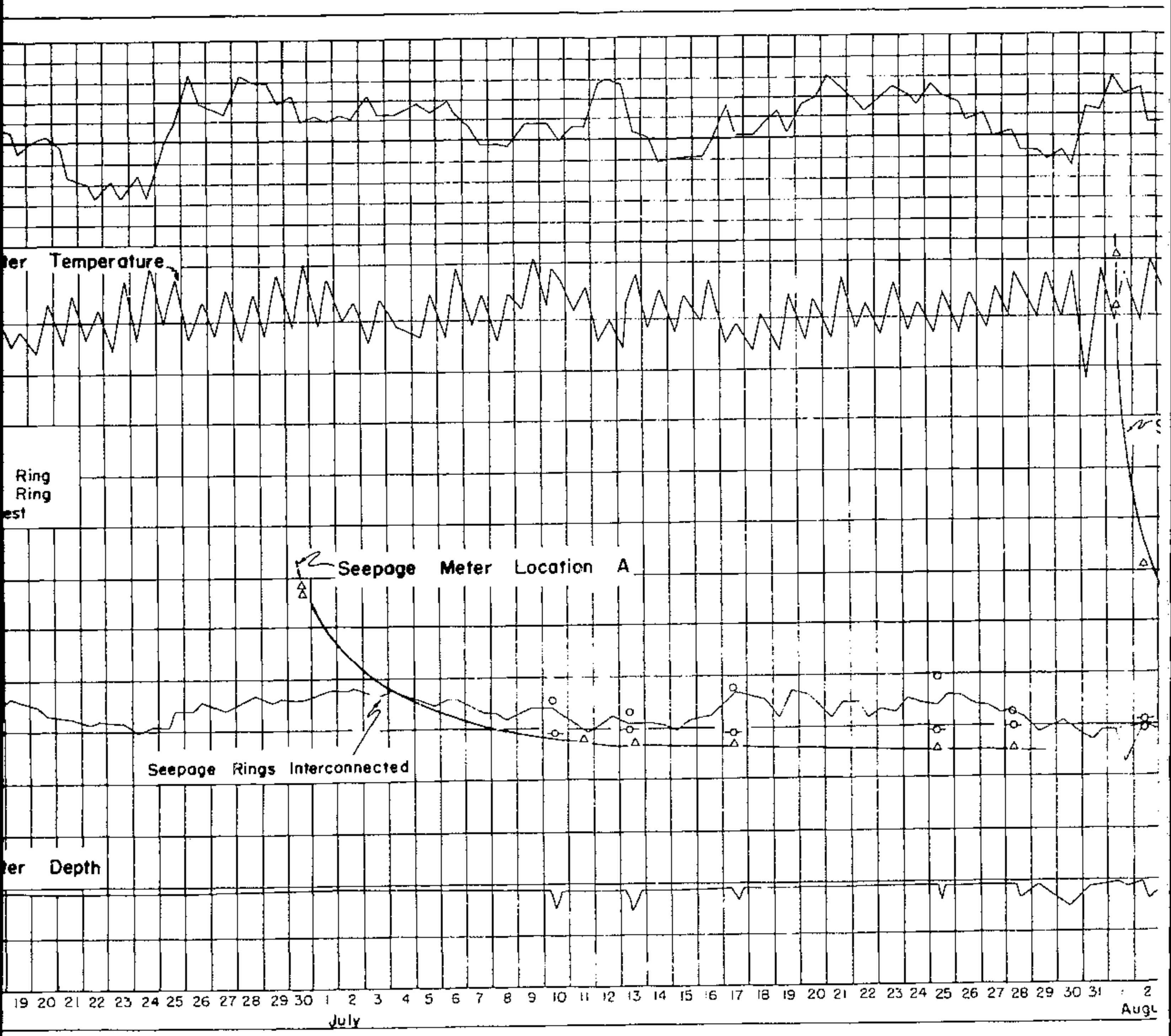
The seepage rings in clay loam (fig. 2) were operated in 1949 and 1950. This soil was very sticky when wet and contained a large number of small root channels. The 1950 seepage rates and associated data are presented in figure 3 (in pocket inside back cover). The correction in the seepage readings for evaporation was insignificant; its maximum was of the order of 0.03 foot per day.

Maximum seepage per square foot per day in 1950 was 25.5 cubic feet for the inner ring and 9.0 cubic feet for the outer ring. These maximum rates are much higher than those for the previous season of

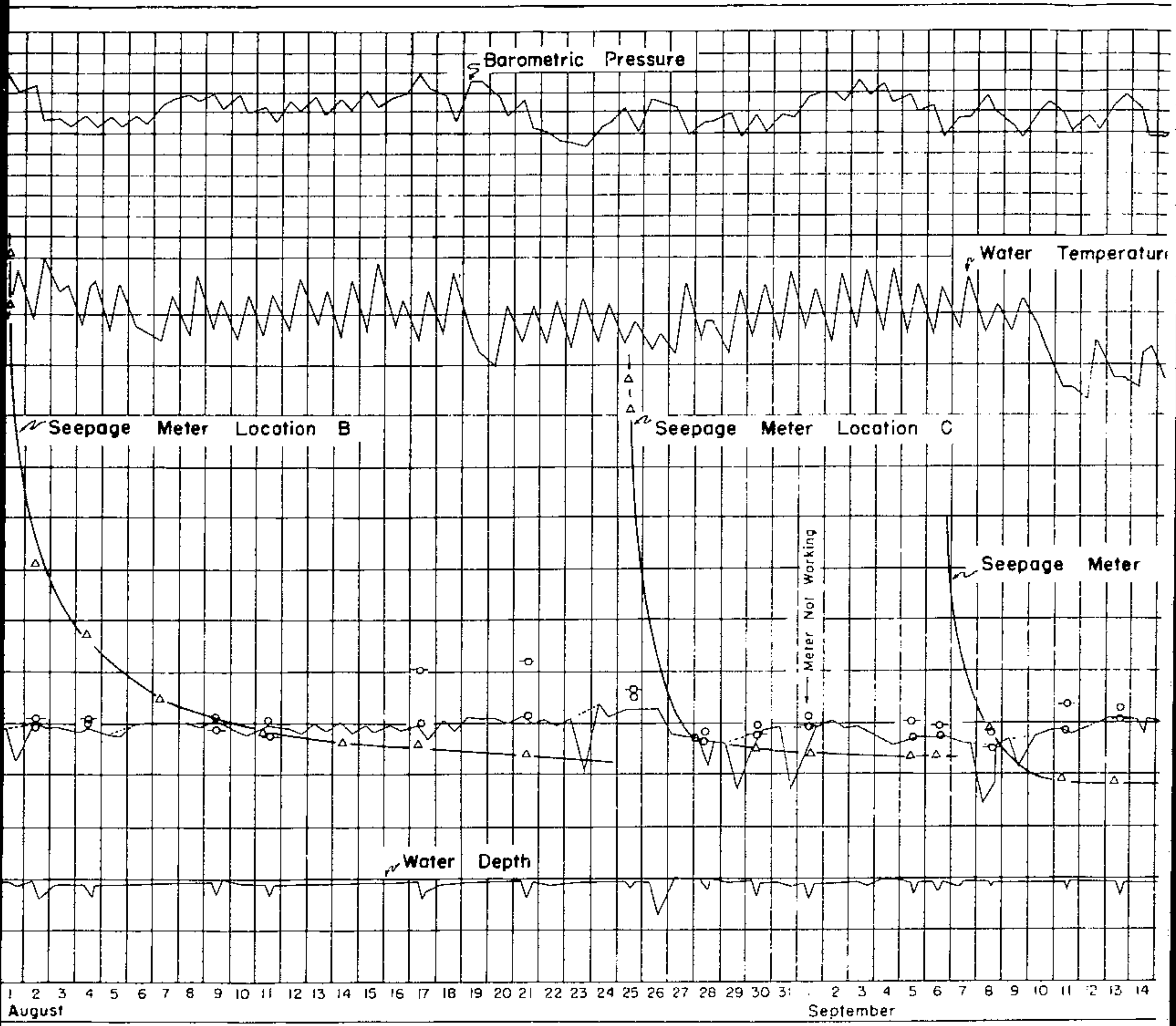
Figure 3



497397 O - 59 (In pocket)



ter Temperature
Ring
Ring
est
Seepage Meter Location A
Seepage Rings Interconnected
ter Depth
19 20 21 22 23 24 25 26 27 28 29 30 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 1 2
July
Augu


Barometric Pressure
Water Temperature
Seepage Meter Location B
Seepage Meter Location C
Seepage Meter
Meter Not Working
Water Depth
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31
August
1 2 3 4 5 6 7 8 9 10 11 12 13 14
September

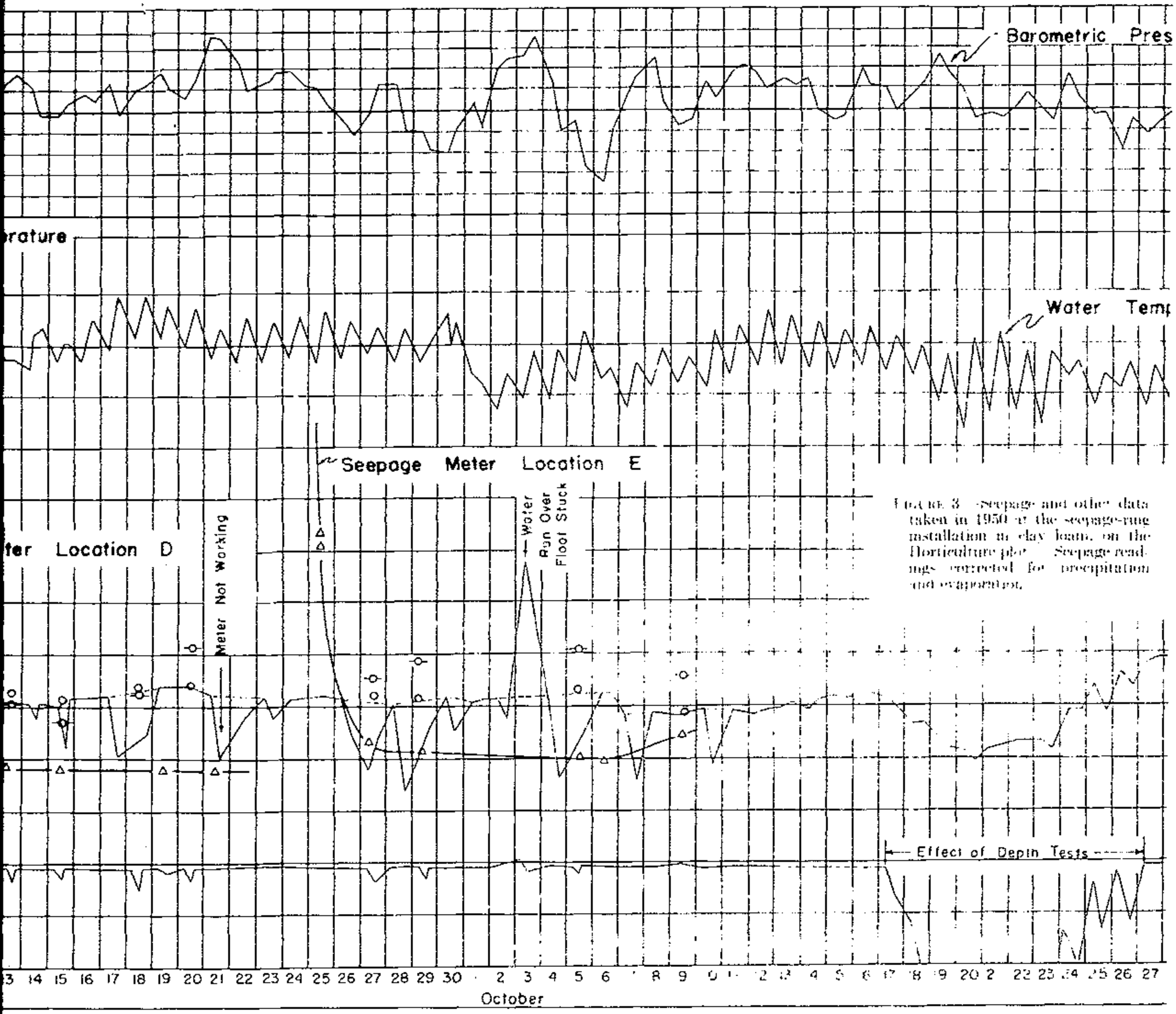
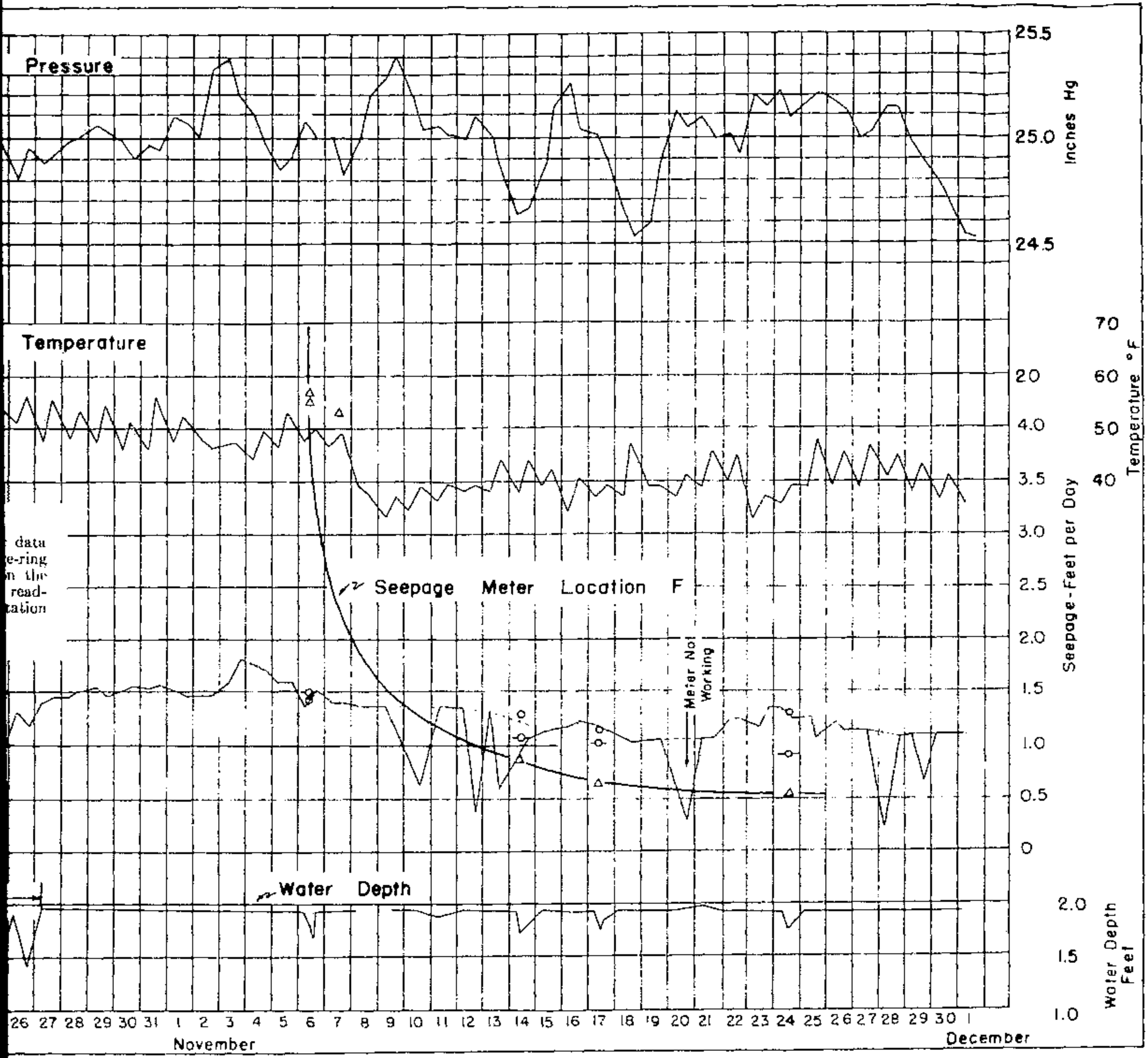


FIGURE 3.—Seepage and other data taken in 1950 at the seepage-ring installation in clay loam, on the Horticulture plot. Seepage readings corrected for precipitation and evaporation.

Figure 3



data
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read-
tation

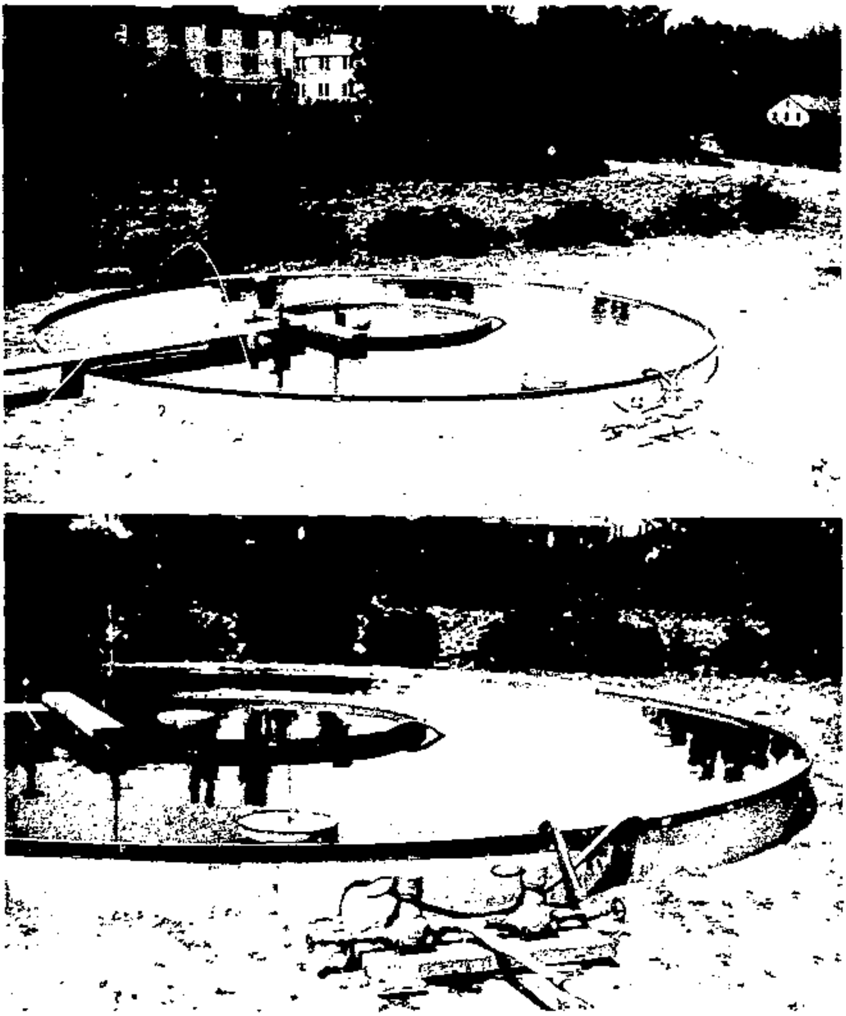


FIGURE 2.—Seepage-ring installation in clay loam, on the Horticulture plot, with water meters and float control in place.

operation. After approximately a month of operation in 1950, the seepage rate had decreased to such an extent that it was impossible to keep the inner-ring meter operating. The connecting valve between the inner and the outer ring was then opened and the two pools were operated as a unit through the remainder of the season, except during the drop tests. After the high initial seepage rates, a fairly constant rate of about 1.0 foot per day is indicated.

The seepage rates indicated by drop tests agreed closely with those based on the readings of the water meters. The seepage rate for the inner ring sometimes exceeded that for the outer ring.

After a period in which the water level had been allowed to drop and had then been brought up again, the seepage rate increased materially.

At no time was any free water found either in the inner-ring piezometers, which had been installed at depths of 1, 2, 4, and 6 feet, or in the piezometers outside the rings.

Sandy Loam A (*Bellvue Plot*)

In the seepage rings in sandy loam A (fig. 4), because of the nonuniformity of the soil and the presence of lenses of coarse sand, the soil

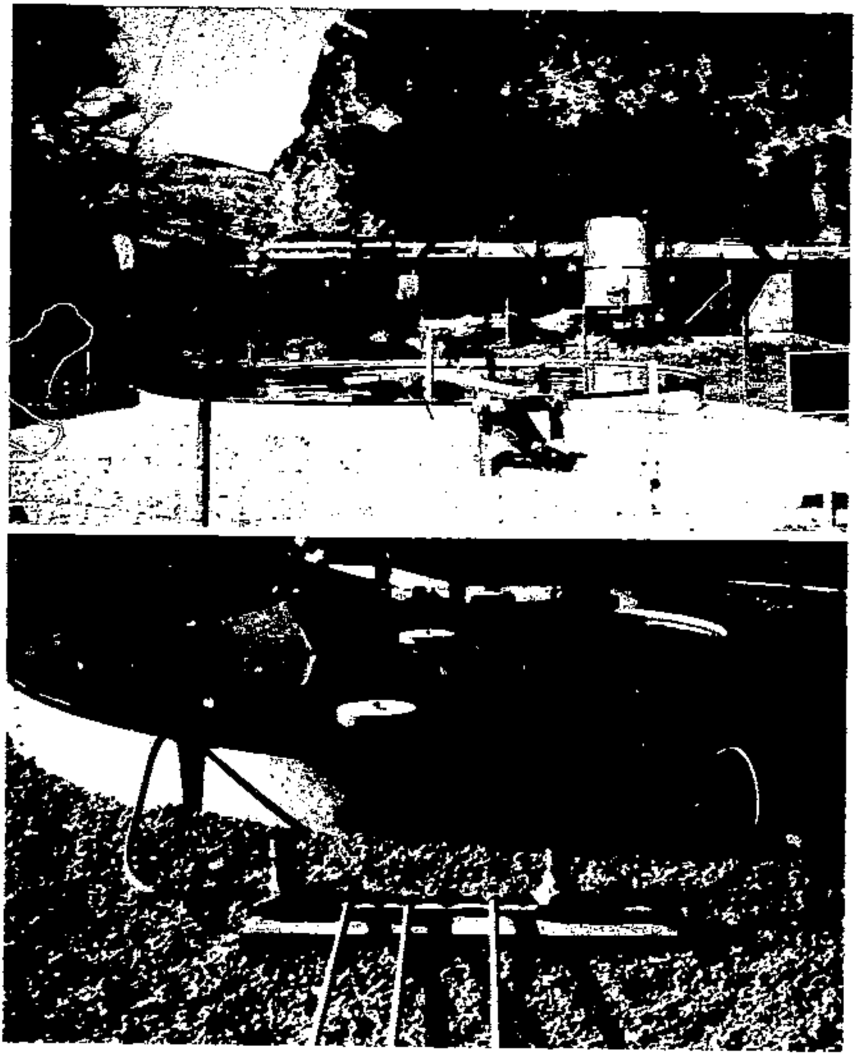
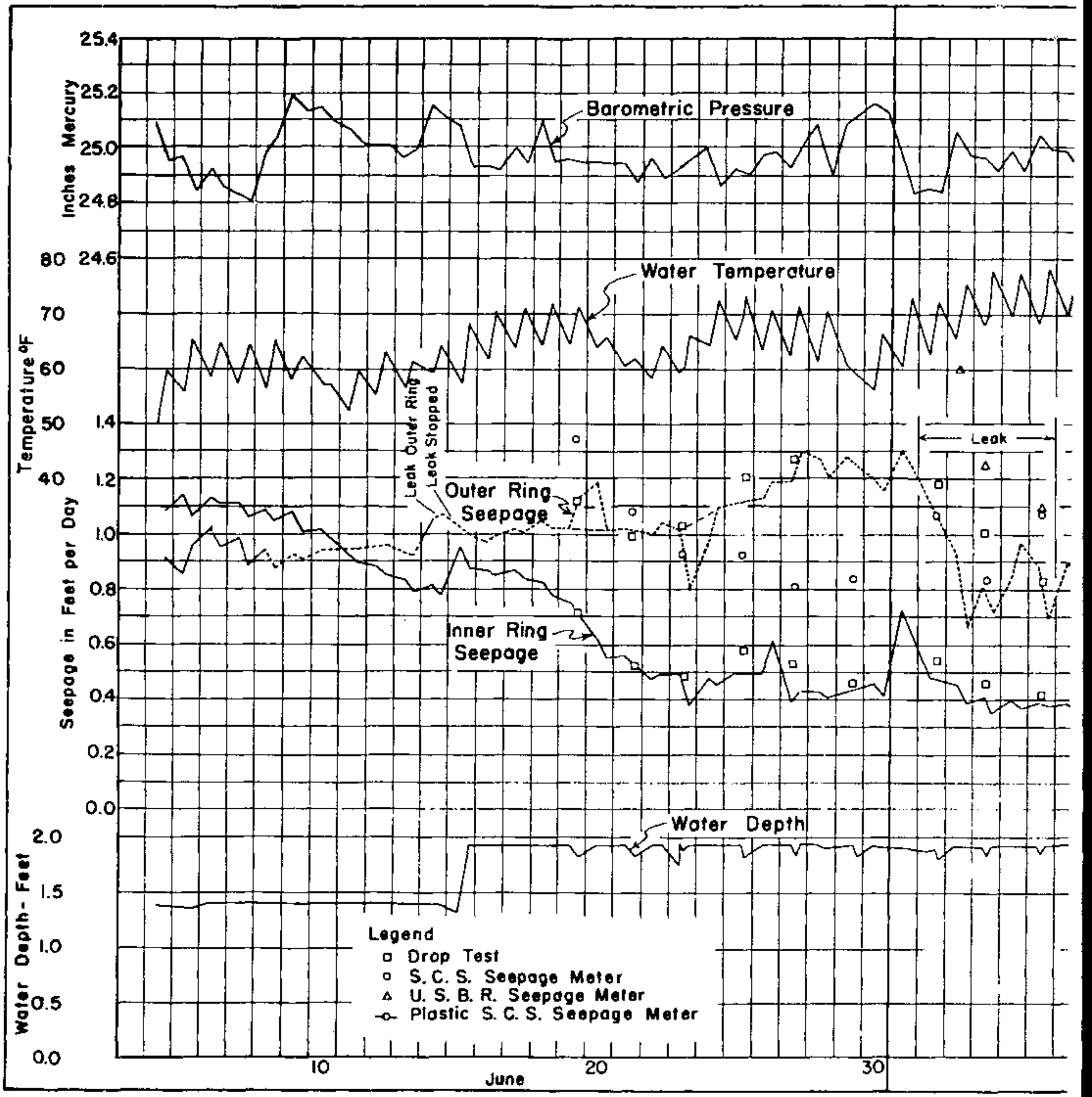
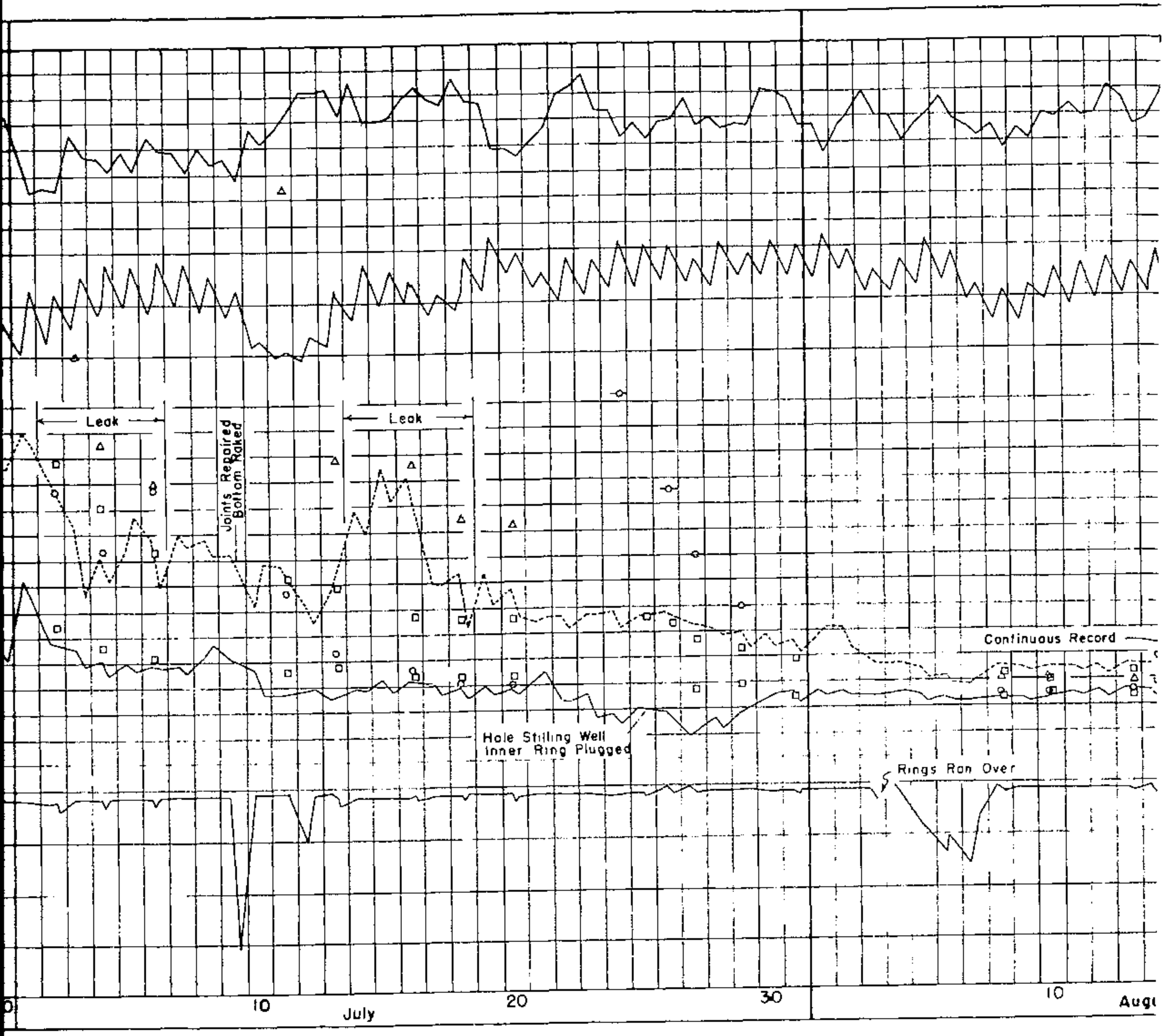


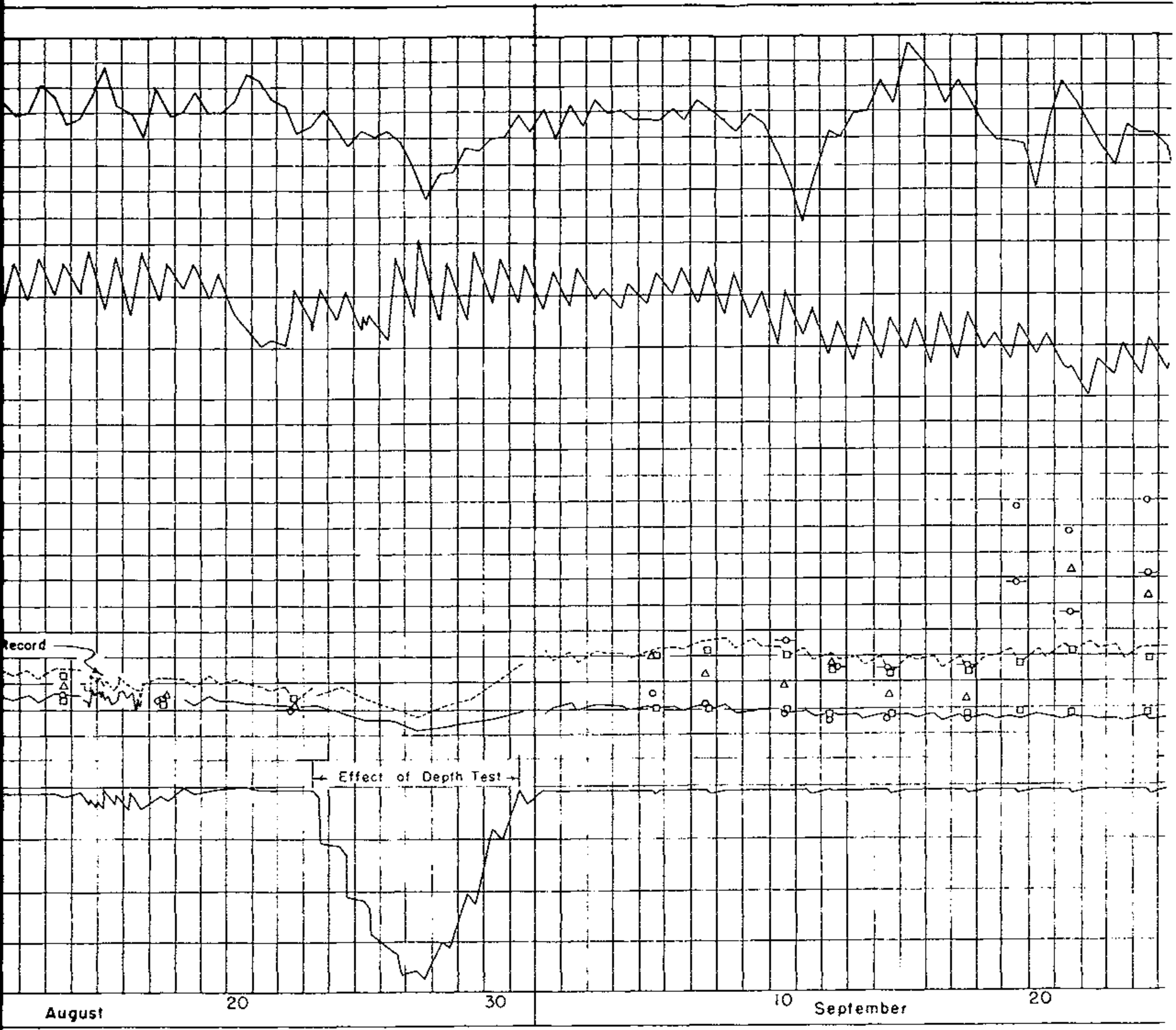
FIGURE 4.—Seepage rings in sandy loam A, on the Bellvue plot. Settling tank appears in background of *A*. Water meters and float controls appear in *B*.

Figure 5



497397 O - 59 (In pocket)


Leak
Leak
Joints Repaired
Bottom Raked
Hole Stilling Well
Inner Ring Plugged
Rings Ran Over
Continuous Record
10
20
30
July
10
Aug


Record
Effect of Depth Test
20
30
10
20
August
September

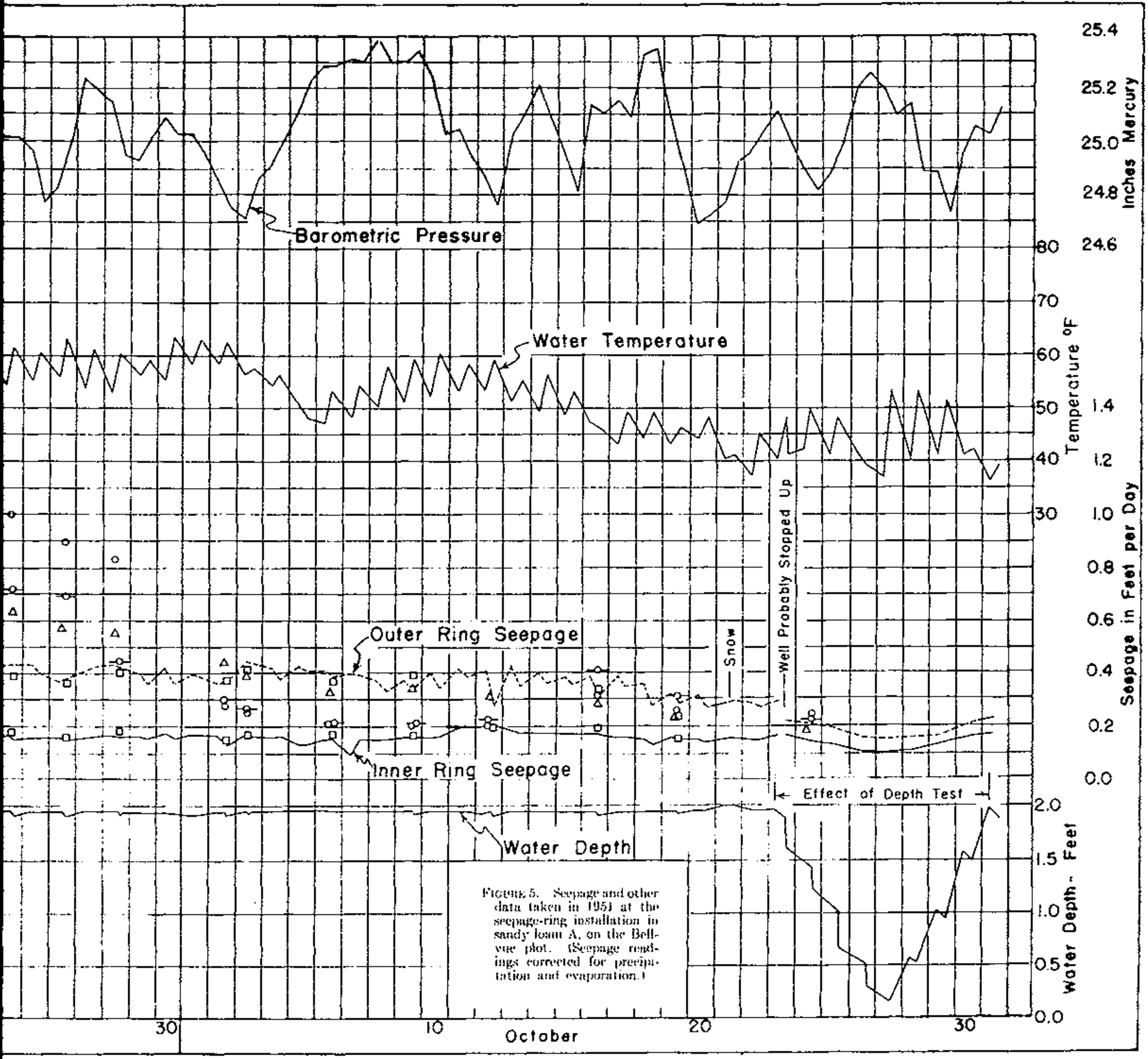
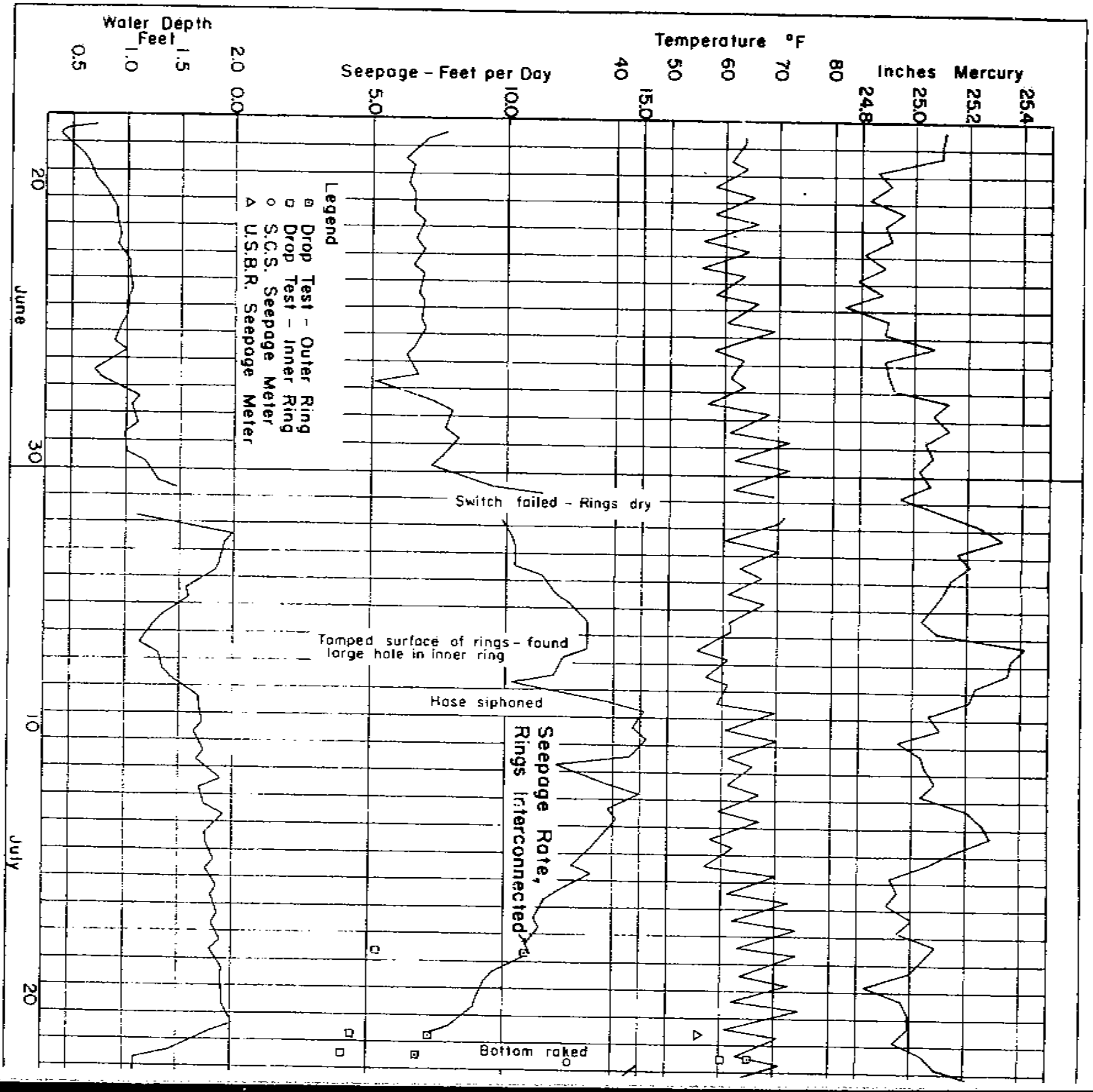
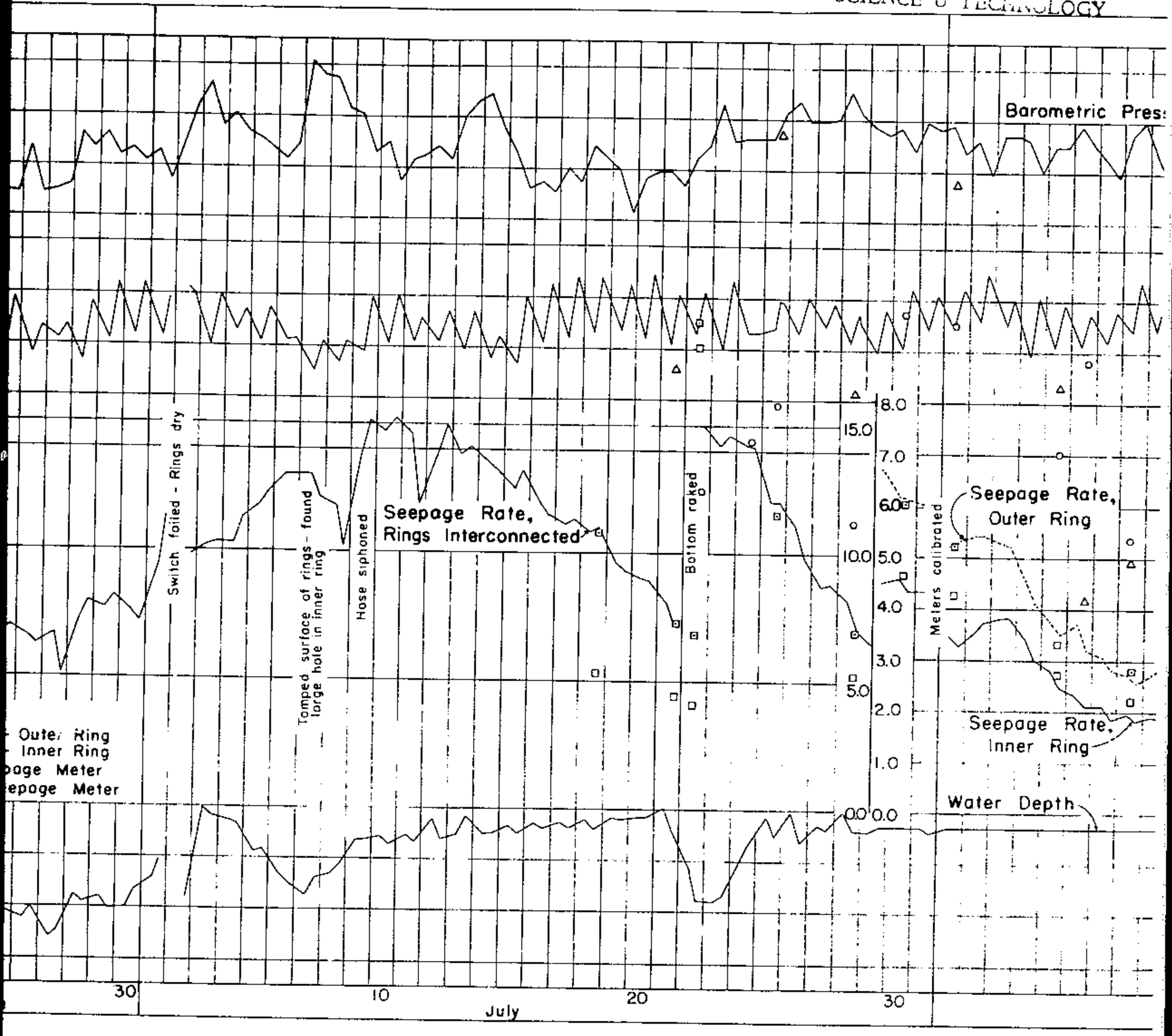


FIGURE 5. Seepage and other data taken in 1951 at the seepage-ring installation in sandy loam A, on the Bellevue plot. (Seepage readings corrected for precipitation and evaporation.)

497397 O - 59 (In pocket)

Figure 6




Barometric Pres
Switch failed - Rings dry
Tamped surface of rings - found large hole in inner ring
Hose siphoned
Seepage Rate, Rings Interconnected
Bottom raked
Meters calibrated
Seepage Rate, Outer Ring
Seepage Rate, Inner Ring
Water Depth
15.0
10.0
5.0
0.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.0
Outer Ring
Inner Ring
page Meter
eepage Meter
30
10
20
30
July

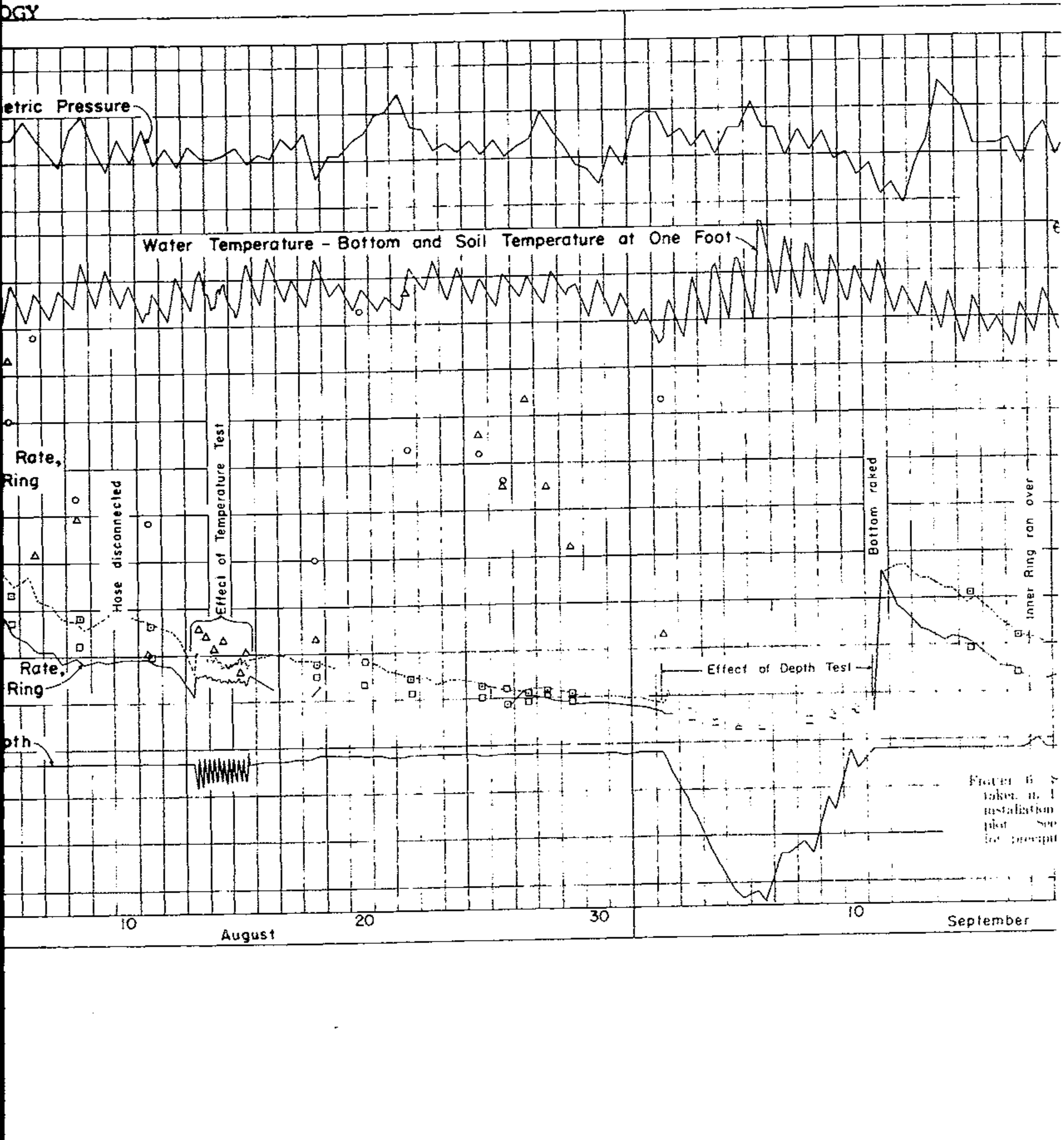


Figure 6. S
taken at I
installation
plot. See
for precipit

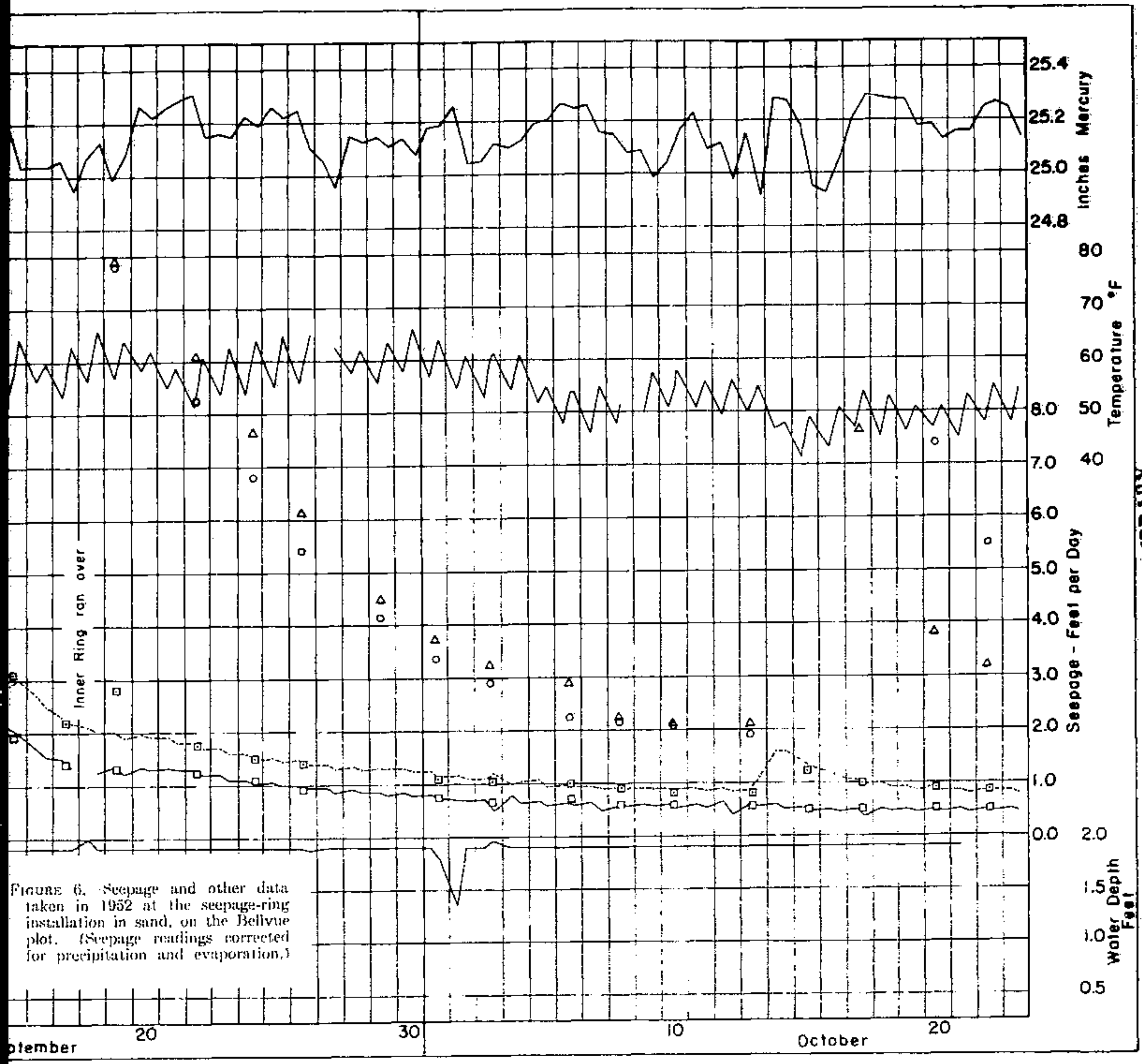
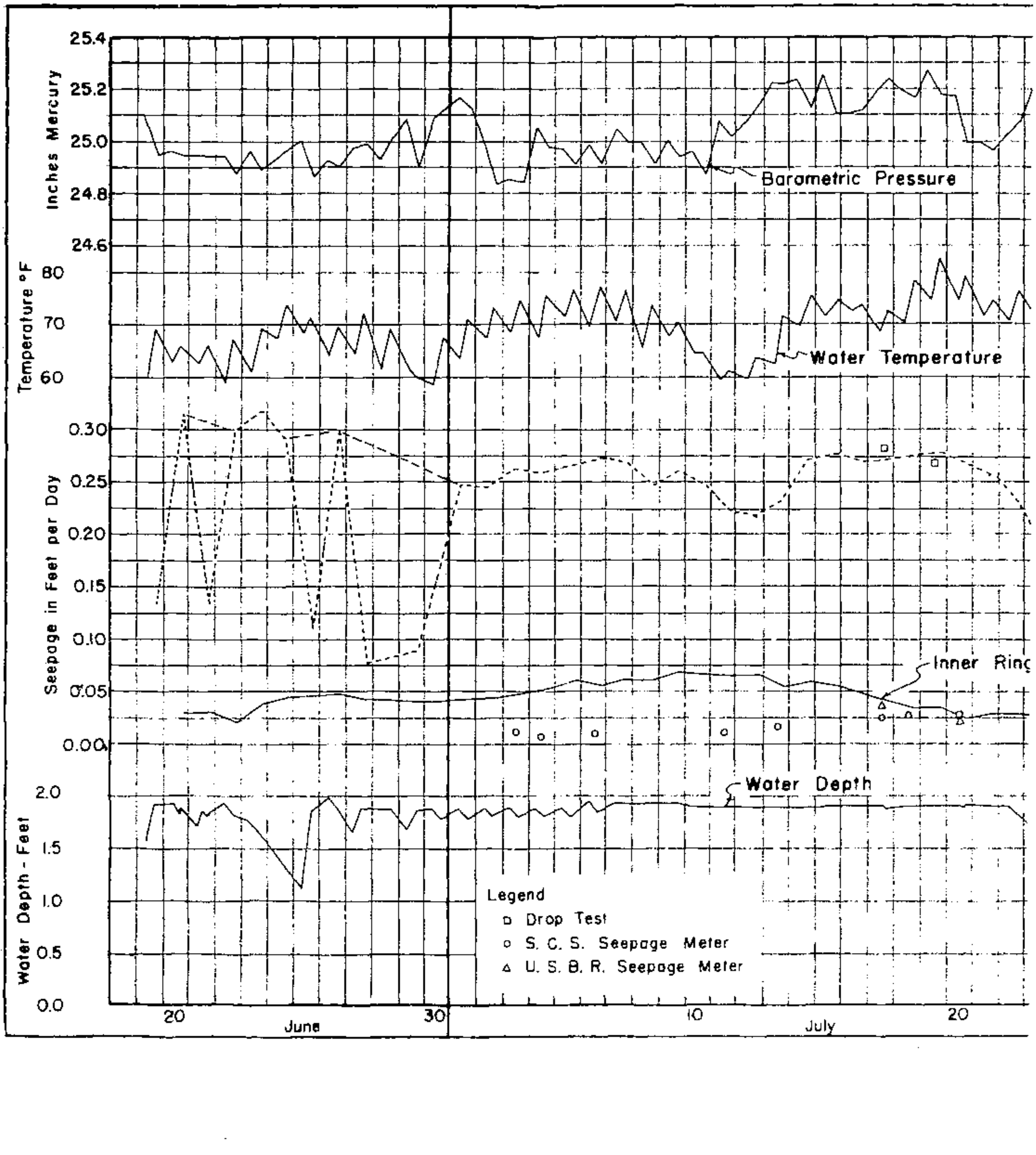
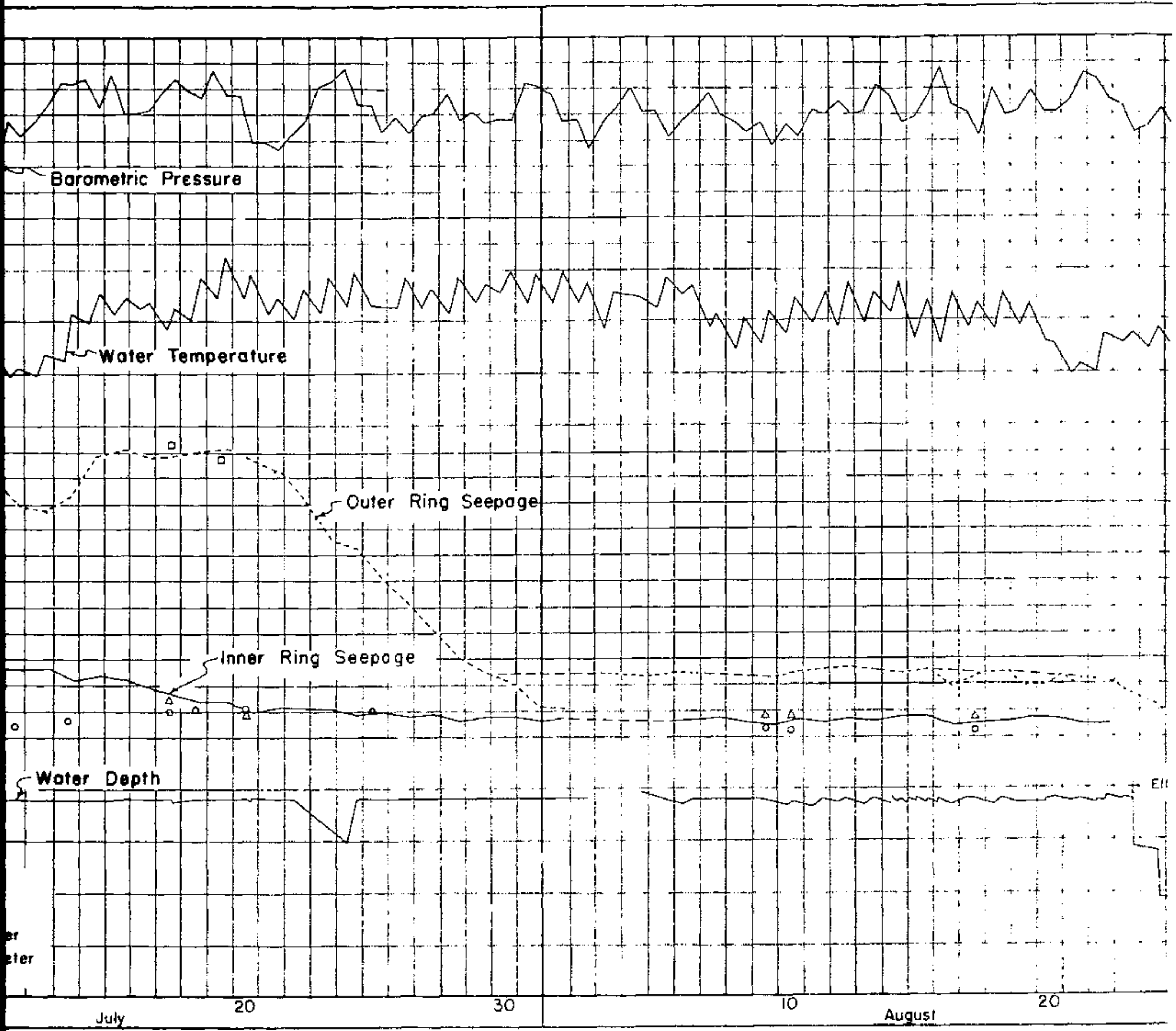


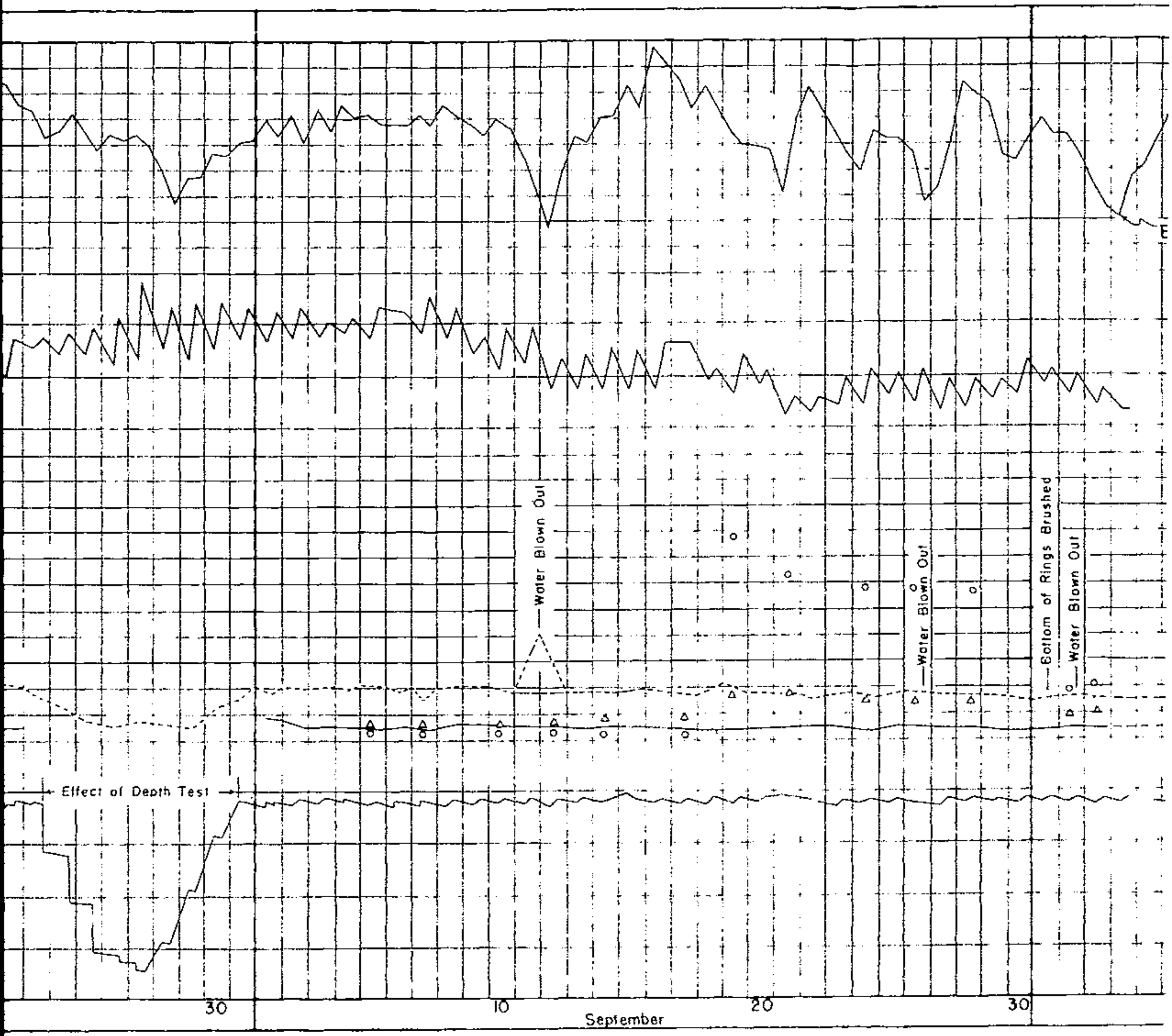
FIGURE 6. Seepage and other data taken in 1952 at the seepage-ring installation in sand, on the Bellvue plot. (Seepage readings corrected for precipitation and evaporation.)

Figure 7



497397 O - 59 (In pocket)


Barometric Pressure
Water Temperature
Outer Ring Seepage
Inner Ring Seepage
Water Depth
Ell
er
eter
20
30
10
20
July
August


Effect of Depth Test
Water Blown Out
Water Blown Out
Bottom of Rings Brushed
Water Blown Out
E
30
10
20
30
September

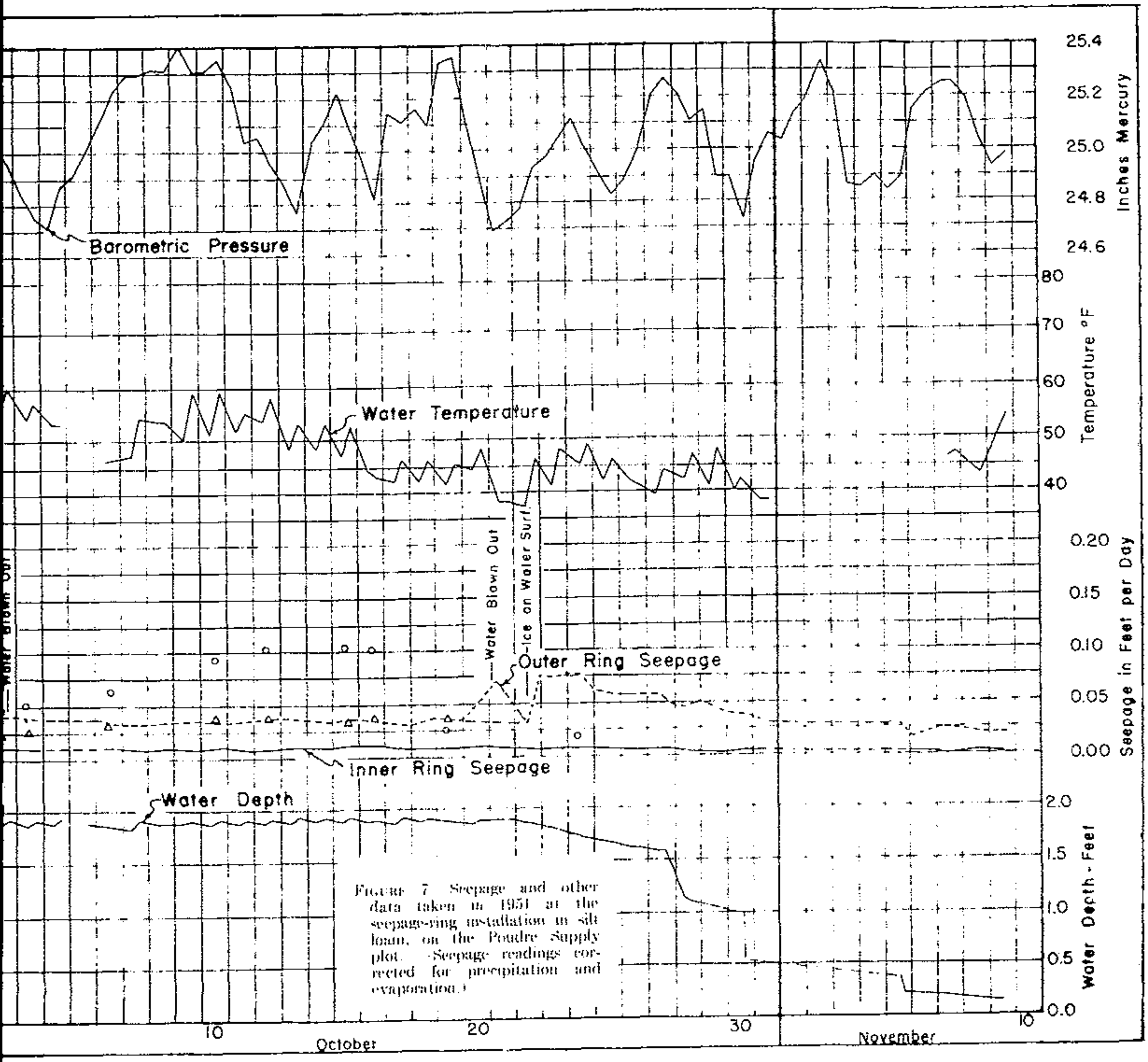
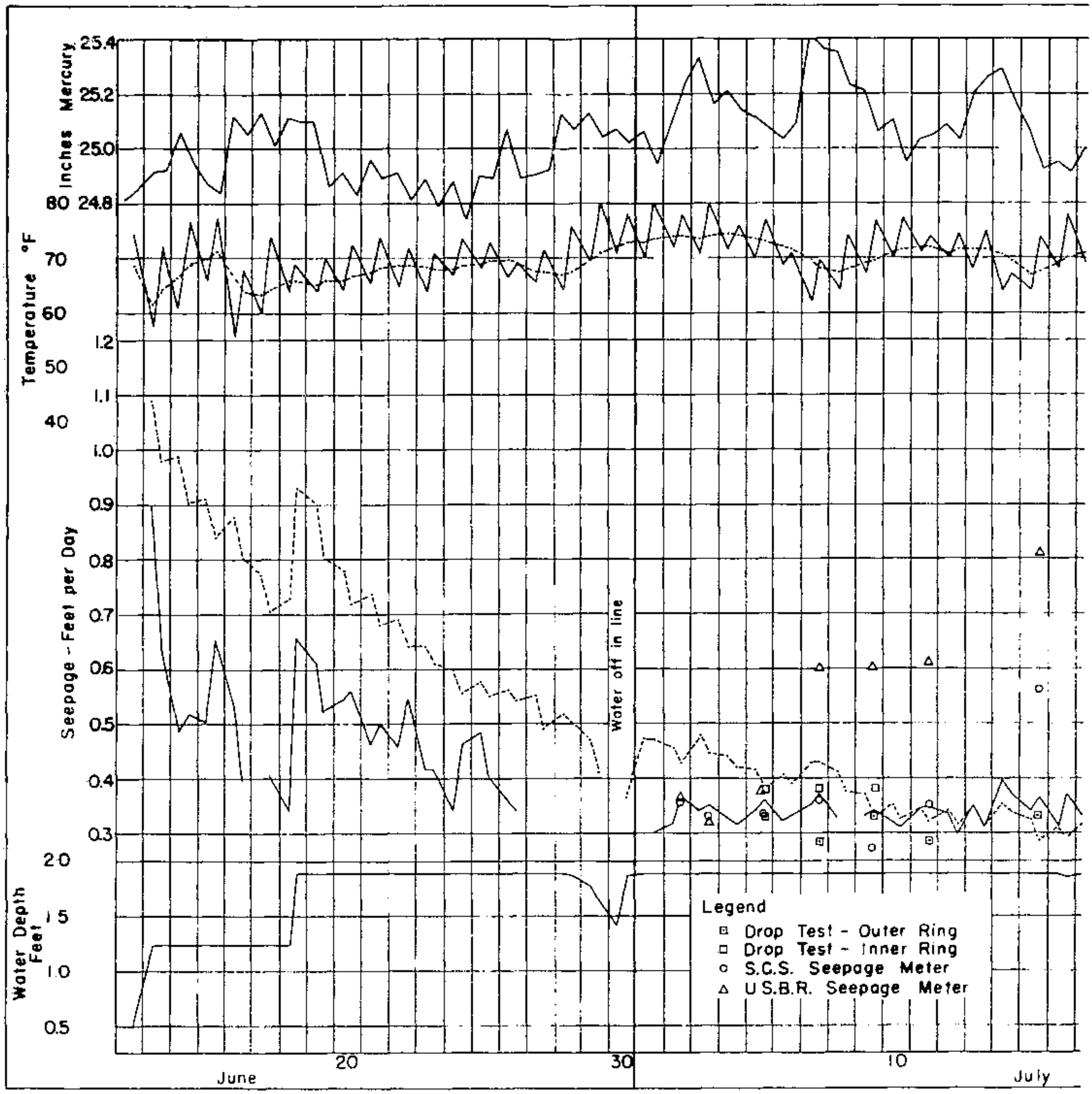
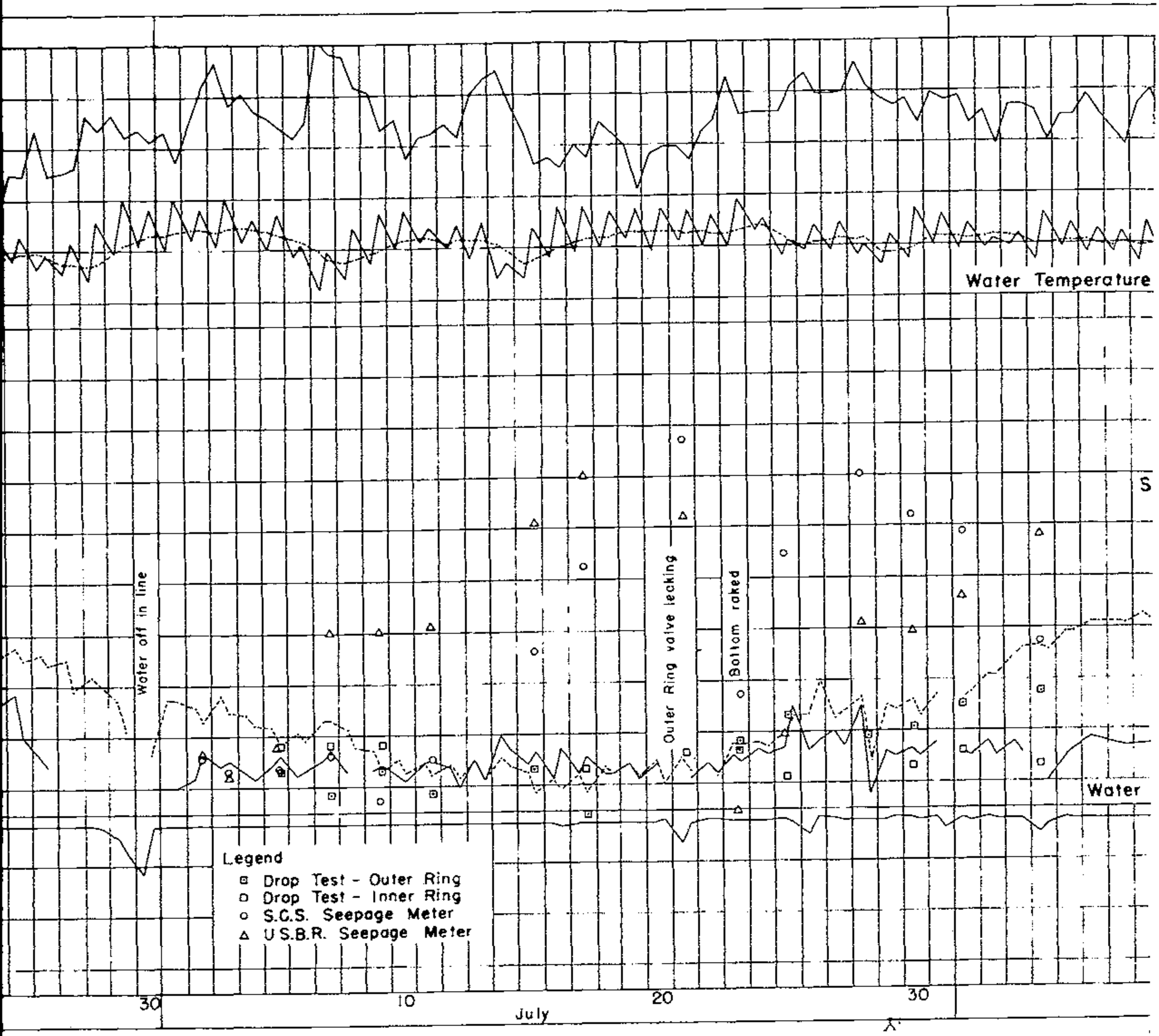


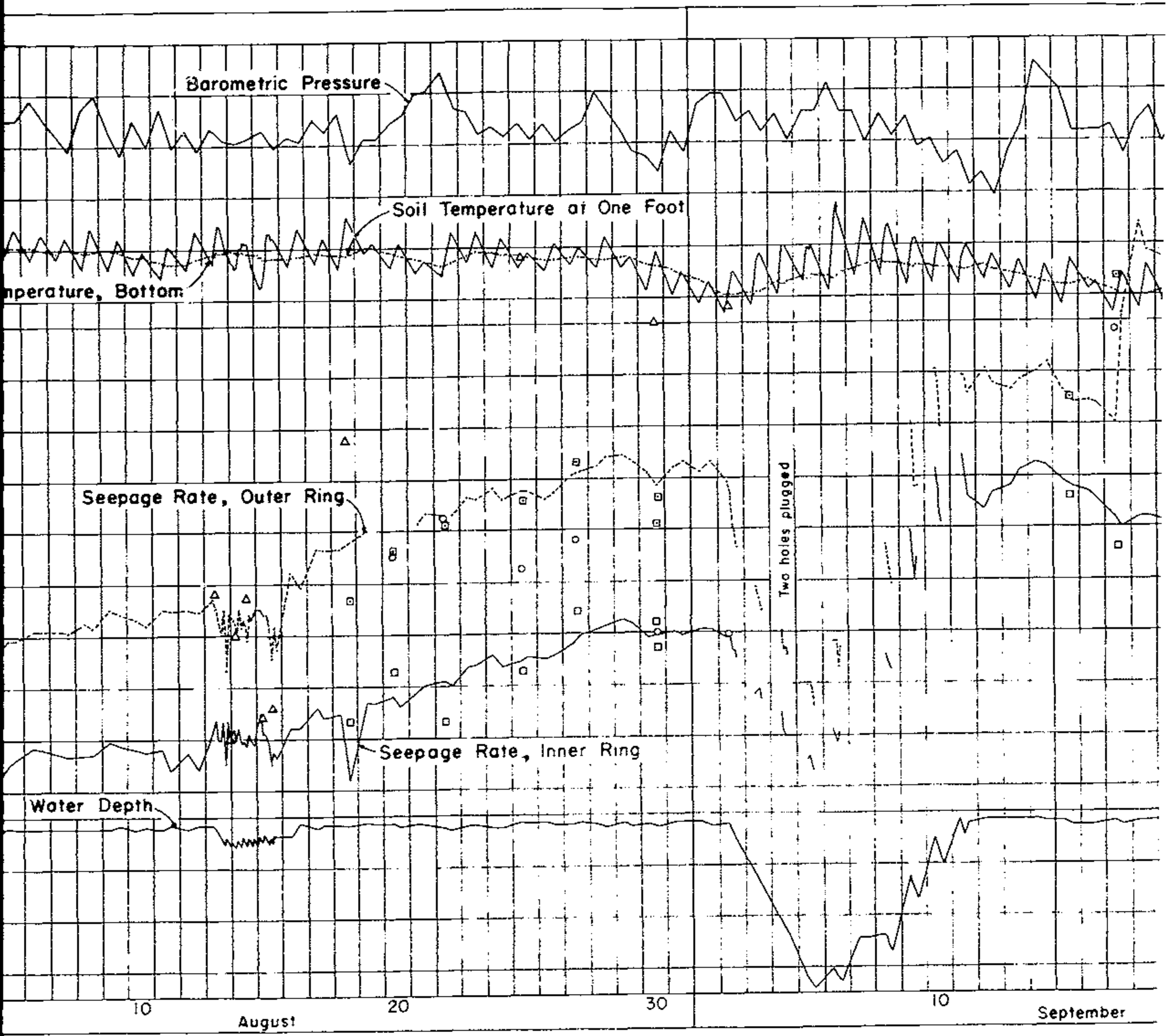
FIGURE 7. Seepage and other data taken in 1951 at the seepage-ring installation in silt loam, on the Poudre Supply plot. (Seepage readings corrected for precipitation and evaporation.)

Figure 8



497397 O - 59 (In pocket)


Water Temperature
S
Water off in line
Outer Ring valve leaking
Bottom raked
Water
Legend
⊡ Drop Test - Outer Ring
□ Drop Test - Inner Ring
○ S.C.S. Seepage Meter
△ U.S.B.R. Seepage Meter
30
10
20
30
July


Barometric Pressure
Soil Temperature at One Foot
nperature, Bottom
Seepage Rate, Outer Ring
Two holes plugged
Seepage Rate, Inner Ring
Water Depth
10
August
20
30
10
September

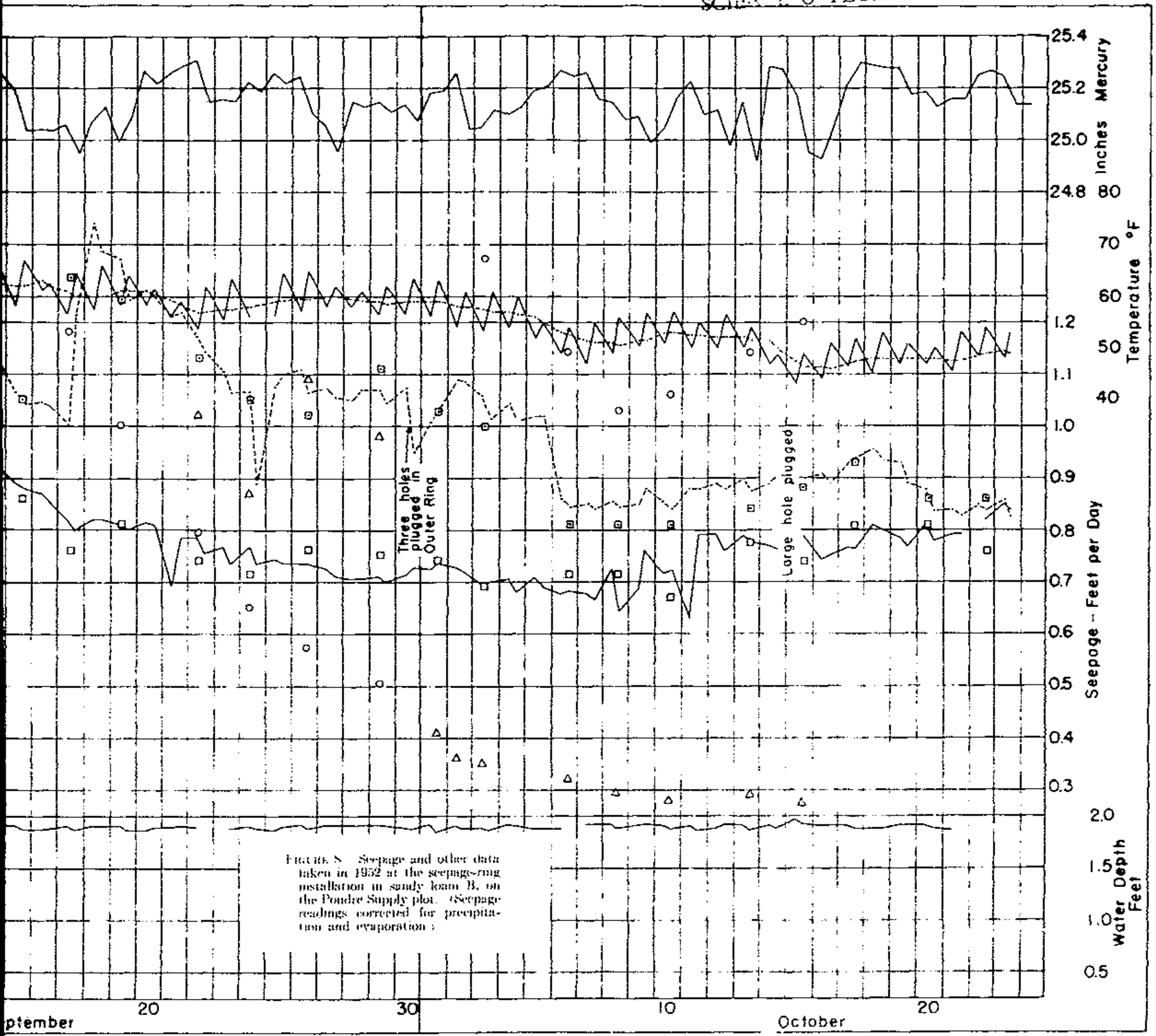


Figure 8. Seepage and other data taken in 1952 at the seepage-ring installation in sandy loam B, on the Poudre Supply plot. (Seepage readings corrected for precipitation and evaporation.)

was excavated down to the underlying cobbles, carefully mixed, and shoveled back into the rings in layers, each of which was compacted by turning water into the rings. This soil contained only 1.7 percent of calcium carbonate. The rings were operated in 1950 and 1951. Because the rate of seepage from the inner ring was relatively low, water meters could not be used to measure the inflow there and it was necessary to fill the ring at each reading and then allow the water level to drop until the next reading to determine the seepage loss. However, water was allowed to flow into the outer ring continuously throughout the season, the inflow being measured with the water meter. As a check on the water-meter readings, frequently the water was cut off and the rate of drop noted for a short period. Drop tests of brief duration were made on the inner ring, also.

The 1951 seepage rates and associated data are presented in figure 5 (in pocket inside back cover).

At the start of the 1951 season the outer ring had a seepage rate of about 0.90 foot per day. Seepage increased gradually for about 3 weeks, until it amounted to 1.30 feet per day. The rate then declined gradually until at the end of the test period it was just over 0.20 foot per day. Seepage from the inner ring started at a rate of 1.10 feet per day but gradually decreased throughout the season, ending at about 0.15 foot per day. The rates for both inner and outer ring consistently ran below the rates determined the previous season.

The drop tests usually checked closely with the water-meter measurements.

The initial seepage rates for the second season (1951) were practically the same as the final rates for the first. The rates declined during the 1951 season, and at its end they were only one-quarter as great as the final rates of 1950.

Feeding water into the soil at a high rate had no effect on the position of the water table in the vicinity of the rings. The only observed fluctuation of the water table was due to changes of stage of the Poudre River nearby.

Sand (Bellvue Plot)

To obtain seepage data for a material more permeable than the fine-grained soils on which tests had previously been made, in 1952 a seepage-ring installation was made in relatively coarse sand on the Bellvue plot. The sand used, characteristics of which are given in table 2, was a river-bed material that had been screened and washed. Before the rings were set in place, the soil was excavated to a depth of 3 feet over an area 20 feet in diameter. The sand was shoveled into the rings in layers, each of which was compacted with water. These rings were operated continuously for a period of about 4 months.

The 1952 seepage rates and associated data are presented in figure 6 (in pocket inside back cover).

The initial rate of seepage through the sand was about 7.0 feet per day. The daily rate increased for about 20 days until it reached a maximum of 15.0 feet, then decreased to the original 7.0 feet. Because of these high rates, some difficulty was encountered in supplying enough water and it was necessary to operate with the rings interconnected for the first month. On several occasions, silt was brought in with the water because of a rise in the river. To break up the resulting silt layer, the bottom of each ring was raked at two different times. Near the middle of the testing period, seepage from the inner ring became so low that it was necessary to install a magnetic valve to control the flow. By use of this valve, all the flow was made to take place during short periods at high rates, which facilitated accurate measurements.

When the valve connecting the rings had been closed and the two rings were operated separately, seepage from the outer ring was always greater than that from the inner ring. On September 1 the rates for both rings dropped below 1.0 foot per day. When the bottoms of the rings had been raked the rates increased to 3.5 feet per day, but they then declined gradually. At the end of the period, the inner ring had a daily rate of 0.4 foot compared with one of 0.8 foot for the outer ring. During the whole test period the soil temperature at 1.0 foot was practically the same as the water temperature at the bottom of the pool.

Results of drop tests are in close agreement with losses shown by the water-meter measurements.

As in the case of the water-level determinations outside the rings during the tests on sandy loam A at the Bellvue plot, the fluctuations were governed by changes in water level of the Poudre River.

Silt Loam (Poudre Supply Plot)

The first seepage-ring installation at the Poudre Supply plot was made in a soil (table 2) classified by the U.S. Soil Survey as a silt loam. This site was chosen because of the heavy soil, seepage through which was expected to be small. Digging for placement of the rings was done in such a way that virtually undisturbed soil would be tested. Water for the rings was obtained from the Fort Collins water-supply pipeline, which passed nearby. The rings were operated in 1951.

Very soon, seepage from the inner ring was found to be too low to keep the water meter in operation. Accordingly, the ring was filled once each day and the seepage rate was determined by noting the drop in the water surface. A similar difficulty was encountered in the outer ring after about 2 months of operation. From this time, the water was allowed to run into the outer ring during the day but was cut off overnight, and the seepage during the night was determined from the drop in water surface. The soil surface in the rings was brushed on October 1. This treatment did not increase the seepage materially. The seepage rates were corrected for evaporation by subtracting 0.70 of the pan evaporation, 0.70 being the factor required for converting Weather Bureau pan evaporation to reservoir evaporation.

The 1951 seepage rates and associated data are presented in figure 7 (in pocket inside back cover).

At the start the inner-ring rate was only about 0.025 foot per day. This rate gradually increased for about 3 weeks until a maximum of 0.060 foot per day was reached. Afterward occurred a gradual decrease almost to zero. At times, it was almost impossible to separate the seepage and the evaporation. In the outer ring an initial daily rate of approximately 0.30 foot was maintained practically constant for 1 month. After that time a rather rapid decrease was shown for about 2 weeks, when the rate became fairly constant at about 0.05 foot. There was a gradual decrease to a rate of about 0.03 foot per day. This rate was maintained from about October 6 to October 22, when a sudden increase in seepage occurred in a very cold period during which the water temperature decreased sharply. The results of the drop tests agree closely with the water-meter measurements made in the outer ring.

No free water was found in the piezometers outside the seepage rings at any time during the tests.

Sandy Loam B (*Poudre Supply Plot*)

After one season's operation of seepage rings in fairly heavy soil on the Poudre Supply plot, it was decided to move them to more permeable soil farther up the slope in the same vicinity. Characteristics of this soil are given in table 2. It should be noted that this soil contains 14.2 percent of calcium carbonate.

In making the excavation required for installing the rings, channels of material of an entirely different type were found, indicating the existence of an old prairie dog colony. For this reason it was necessary to excavate a hole about 20 feet in diameter and 3 feet deep, thoroughly mix the soil, and then replace it in the hole. The mixed soil was put back into the hole in layers, each of which was settled with water. After the hole had been filled to a depth of 2 feet, the seepage rings were installed and another foot of soil was put into the rings and compacted by flooding.

These seepage rings in sandy loam B were operated for about 4 months of 1952. Three times a week the water was cut off and seepage determinations were made by observing the drop in water-surface elevation. A magnetic valve to control the flow into the inner ring was installed after the seepage rate there dropped so low that the conventional meter would not operate. The seepage rates and associated data are presented in figure 8 (in pocket inside back cover).

The initial daily rate for the outer ring was about 1.1 feet and that for the inner ring was 0.9 foot. There was a general decrease in rates for about a month. Rates then increased until, after about 3 months of operation, a maximum of nearly 1.4 feet was reached in the outer ring and one of 0.95 foot in the inner ring. The greater part of the increase occurred after the water level was lowered and then raised. The results of the drop tests check closely with the continuous data.

The soil temperatures at 1-foot depth at this location agreed closely with the mean of the water temperatures for the 24-hour period.

At no time during the season did water appear in piezometers that had been installed inside the inner ring and near the outer ring.

Discussion

The close agreement between the seepage rates based on water-meter measurements and those based on drop tests demonstrated that seepage loss from the rings in each of the different soils could be accurately determined with the water meters except when it was of the same order of magnitude as the evaporation. Precise agreement of the results obtained with the two methods should not be expected, because whereas the water meters measured the seepage for periods of 8 hours or more the drop tests measured it for periods of not more than 1 hour. Tests discussed later (on pp. 57–69) showed that there was considerable variation in seepage rate during a 24-hour period, which would account for the differences between the results obtained with the two methods. Seepage from the rings as determined by use of the water meters could therefore be used as an indicator of the seepage rates for the soils represented in the tests and as the standard of comparison in testing seepage meters and in studying the effects of various factors on seepage rates.

In clay loam, where the rate of seepage from the rings in 1950, very high at the beginning, decreased rapidly for a short time and then remained practically constant for the remainder of the season, any variations from these trends seemed to be due to changes in temperature[6] and barometric pressure. Because of the low salt content of the soil and the purity of the water used, application of the water would be expected to have very little effect on the soil's permeability (*3*). The fact that the rate of seepage from the inner ring was higher than that from the outer ring for part of the season, both in 1949 and in 1950, indicates that border effect was not always the controlling factor in determining the difference between the inner- and outer-ring rates. That the lapse of time is an important factor is shown by the fact that the seepage rate was lower at the close of the 1950 season than at the close of the 1949 season.

The fact that no free water was found in the inner-ring piezometers indicated that moisture tension existed in the soil under the ring.

In sandy loam A, as in clay loam, decrease in seepage rate apparently resulted from changes accompanying the lapse of time. Because of the chemical composition of the soil, the water used would not be expected to affect soil permeability. The rise in the seepage rates that occurred when the water levels were allowed to drop and then brought up again was not so great as the one that took place under similar conditions during the tests on clay loam.

In sand, in which seepage began at a very high rate, increased for about 20 days, and then decreased gradually to about one-tenth of the original rate, the decrease could be attributed chiefly, but not entirely, to silt brought in with the water on several occasions. As in previous tests, time was a factor in the decrease. Because of the chemical composition of the soil, addition of the water used would not be expected to affect soil permeability.

In silt loam, the results demonstrated the fact that a large range in permeabilities can be encountered within a small area. The increase in the outer-ring seepage rate after a few days of extremely cold weather was probably due to absorption of entrained air in the soil. As water never appeared in the piezometers, it was evident that a saturated zone under pressure never existed beneath the rings.

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[6] For an account of special tests to determine the effect of temperature on seepage, see pp. 57–69.

The fact that seepage in sandy loam B followed trends entirely unlike those of seepage in any of the other soils, decreasing for about a month and then increasing and staying at high levels for the remainder of the period, probably reflects the influence of two factors: The original disturbance of the soil, and the leaching of soluble material from the soil, which has a high calcium carbonate content. No satisfactory explanation was arrived at for the major increase in seepage after a series of drop tests.

Although silting was believed to be the chief reason for a rapid early decrease in rates of seepage through sand, reduction in rates that occurred in clay loam, sandy loam, and silt loam could not possibly have resulted from silting. In these soils, reductions were probably caused in the main by microbiological action and the breaking down of soil aggregates. Maximum and minimum rates for each of the soils are presented in table 3.

The results show that soil texture may not be the controlling factor in seepage rate, although generally lower seepage was associated with higher percentage of clay. The fact that the clay loam had a very high initial rate of seepage, one much higher than would be expected in this kind of soil, may have resulted from the presence in the soil of a considerable number of small holes caused by decay of roots.

TABLE 3.—*Maximum and minimum rates of seepage for soils of different textures in seepage-ring tests*

Soil texture [1] and year or years	Outer ring		Inner ring	
	Maximum	Minimum	Maximum	Minimum
	Feet/day	*Feet/day*	*Feet/day*	*Feet/day*
Clay loam, 1949–50	9.0	1.0	25.5	1.0
Sandy loam A, 1950–51	1.3	.2	1.1	.1
Sand, 1952	15.0	.8	15.0	.5
Silt loam, 1951	.3	.02	.07	.01
Sandy loam B, 1952	1.4	.3	.9	.3

[1] Of the 2 sandy loam soils, in different locations, B has a larger percentage of calcium carbonate than A (table 2).

The increase in seepage rates that usually followed when the water level, after being allowed to drop, was brought back to its original height made it seem that the increase in head had opened up new interstices for the passage of water.

The fact that no free water was found in the piezometers around the outer rings showed that no ground-water mound was built up under the rings in any of the soils. This, and the fact that the only fluctuation in ground-water level observed was due to an outside factor, the stage of the river, indicated that there was no impermeable layer in the soil near the ground surface. Apparently the rate of seepage was governed by a thin layer of relatively impermeable material at the surface and this layer was underlain by a stratum through which water could move freely.

SEEPAGE-METER TESTS

Two types of seepage meter were used in this study, those developed by the Soil Conservation Service and the Bureau of Reclamation, respectively. In this report they are called the SCS meter and the USBR meter. The meters were tested in seepage rings to find how closely the rates they showed agreed with the rates shown by the

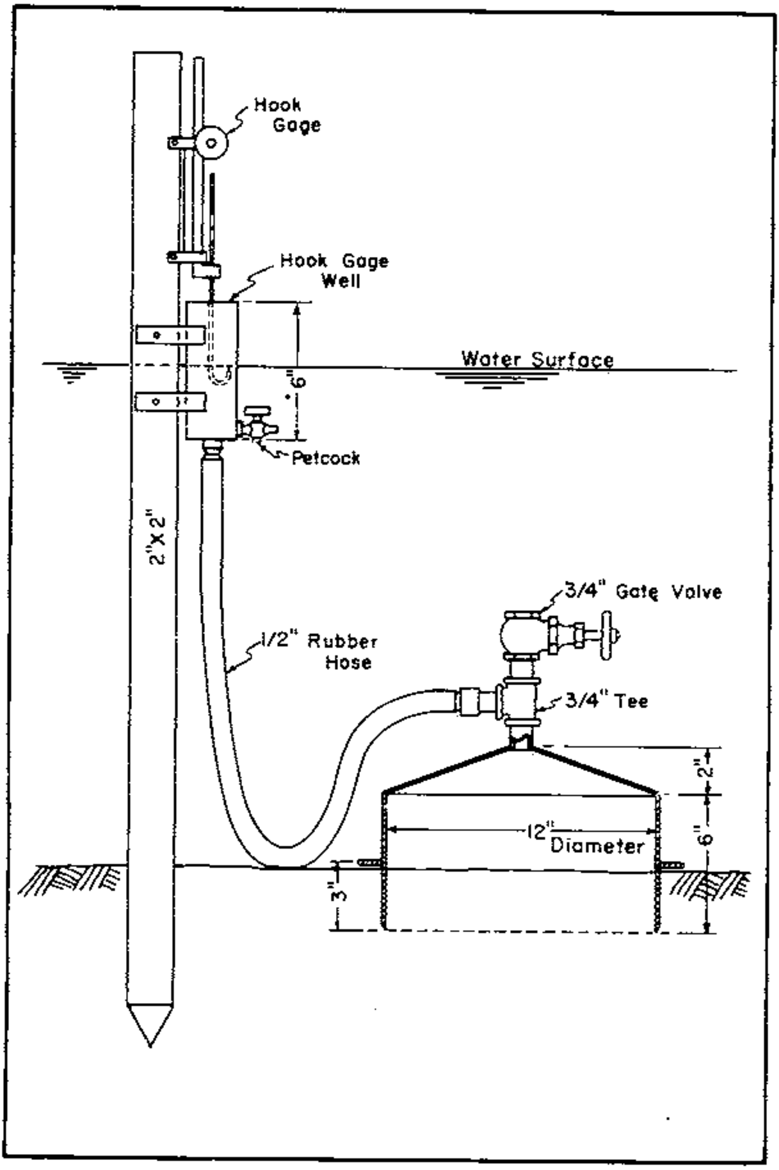

FIGURE 9.—Diagram of the Soil Conservation Service seepage meter.

seepage rings and also to find out how the meters should be installed and operated to get the best results. Some measurements were made with the meters in operating canals and compared with ponding measurements.

Equipment

The SCS seepage meter (figs. 9 and 10) has a bell 12 inches in diameter and 6 inches deep, with a sharpened edge around the open end to facilitate installation. A valve at the top of the bell is used for releasing trapped air. A cup about 2 inches in diameter having a petcock attached near the base is connected with the bell by means of a ½-inch rubber hose. The cup, together with an attached hook gage, is fastened to a stake. This stake is driven into the ground or, when the meter is used in seepage rings, clamped to the upper edge of the outer ring. The hook gage was used to measure the drop in the cup when the valves were closed and the elevation of the water surface in the rings when the valves were open.

FIGURE 10.—Soil Conservation Service seepage meter, with metal bell.

The design of the USBR meter (fig. 11) is essentially the same as that of the SCS meter except that a different measuring device is used. This meter has a bell 2 square feet in cross-sectional area and 8 or 12 inches deep, at the top of which are a valve that can be opened to expel trapped air or water when the meter is being installed and a small connection for attaching a flexible tube that leads from a plastic bag for holding water.

Procedure

In preliminary tests of seepage meters, the meters were forced into the soil by hammering them with a bar. Because this seemed to have

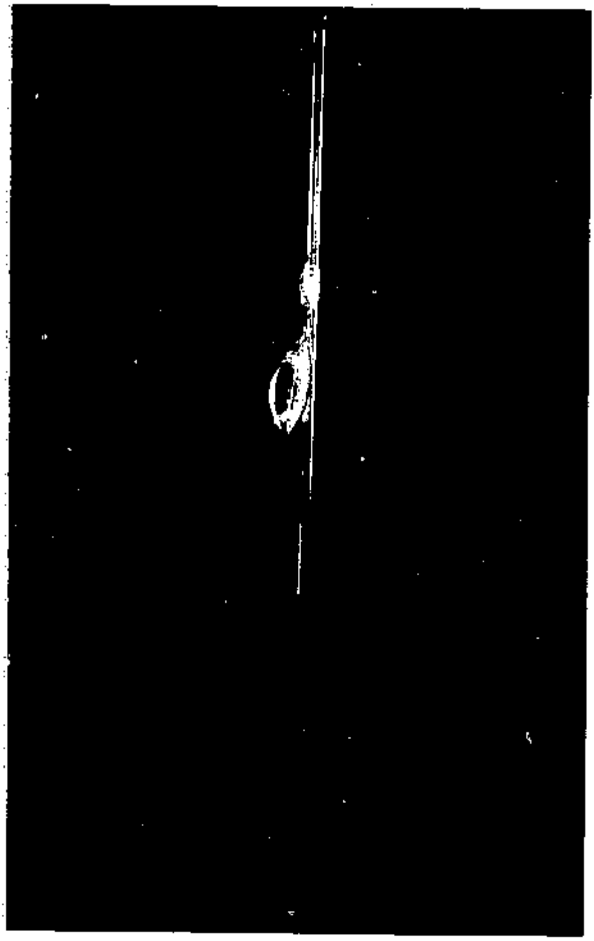

FIGURE 11.—Bureau of Reclamation seepage meter, with metal bell and plastic bag.

the effect of puddling the soil and thus lowering the indicated seepage rate, all subsequent installations were made either by standing on the bell to force it into the soil or by using a jack. In most cases two men were able to force the meter into position by standing on it and rocking back and forth.

After the SCS meter had been installed in the soil, the petcock on the cup was closed and water was poured into the cup. This forced out the air trapped in the rubber hose and in the top of the bell. The hook gage and cup were then clamped to the outer ring and a reading of the water elevation was taken with all the valves open. Next, all valves were closed and water was poured into the cup to a level an inch or so higher than that of the water outside. The drop in the cup as the water seeped into the soil under the bell was timed with a stopwatch until the water level in the cup sank below that in the rings. The rate of drop in the cup at the time when the two water levels were the same was converted to a rate of drop over the area of the bell. The result was the seepage rate.

In preparation for making a seepage determination with the USBR meter, care was taken to expel trapped air by forcing water through the flexible tube with the valve at the top of the bell open. The plastic bag was then filled with water, weighed, attached to the tube, and submerged. The valve at the top of the bell was closed, and the clamp on the tube was opened. As the water in the bell seeped into the soil it was replaced by water from the plastic bag. After a prescribed length of time the bag was removed and again weighed. This gave a seepage rate for the area of the bell.

For tests that were made for the purpose of calibrating a seepage meter, the meter was always installed in the outer seepage ring. The inner ring, because seepage from it was to be used as a standard, was not disturbed. The rates determined could be compared with the rate of seepage from either the inner ring or the outer ring.

The SCS seepage meter was tested in each of the seasons 1949–52, the USBR meter in 1951 and 1952. In the two seasons when both types of meter were used, they were usually installed side by side in the outer seepage ring, and a determination with one of them was followed immediately by a determination with the other. The tests with the SCS meter were always duplicated and the results averaged.

The first test in a seepage ring was made within the day after the meters were installed, and others followed at 2-day intervals. After 14 to 20 days the meters were pulled out and reinstalled at a short distance, so that by the end of the season meter tests had been made at a sufficient number of points within the outer ring to sample the area adequately.

In two tests the measuring devices of the two meters were interchanged to see whether this might affect the results. To determine whether absence of sunlight inside the standard SCS meter might affect results, a meter of clear plastic was constructed on the same design and tested.

During 4 seasons of testing, almost 300 seepage-meter determinations were made in the seepage rings.

On four occasions, the seepage meters were tested in canals in which ponding tests were in progress. They were always installed in the bottoms of the canals, never in the sides.

Experimental Results

Seepage Meters in Seepage Rings

Seepage rates determined with seepage meters installed in seepage rings are presented in tables 4–10 in comparison with the rates determined with the seepage rings.

Determinations made in clay loam in 1949 with an SCS meter installed by hammering were all much less than those obtained by use of the seepage rings, but those made in this soil with an SCS meter installed by pressing corresponded closely with the seepage-ring rates (table 4). Considerable variation appeared among rates determined with this meter at three of the four individual settings.

TABLE 4.—*Seepage rates in clay loam in 1949 as determined with the SCS seepage meter, installed by hammering and by pressing, in comparison with those determined with seepage rings*

Method of installing meter, location,[1] and time	Water depth	Rate obtained with—		
		SCS meter	Inner seepage ring	Outer seepage ring
Hammering:				
Location A:	*Feet*	*Feet/day*	*Feet/day*	*Feet/day*
11/12 3:07 p.m	1.37	1.07	3.45	4.73
3:35 p.m	1.37	1.13	3.45	4.73
11/14 2:35 p.m	1.46	1.61	3.05	3.37
2:54 p.m	1.46	1.75	3.05	3.37
3:37 p.m	1.46	1.77	3.05	3.37
11/18, 3:05 p.m	.87	.53	1.80	2.30
11/19, 10:13 a.m	.76	.39	1.31	1.70
Location B:				
11/19, 3:12 p.m	.82	.26	1.27	1.40
11/21 3:03 p.m	.83	.49	1.57	2.20
3:46 p.m	.83	.49	1.57	2.20
Pressing:				
Location C, 12/4 1:55 p.m	.86	1.83	1.60	1.60
2:13 p.m	.86	1.78	1.60	1.60
Location D:				
12/7 3:12 p.m	1.43	1.47	1.79	2.05
3:40 p.m	1.43	1.44	1.79	2.05
12/9 2:56 p.m	1.93	2.56	3.06	2.55
3:10 p.m	1.93	2.88	3.06	2.55
3:32 p.m	1.93	2.87	3.06	2.55
3:46 p.m	1.93	3.05	3.06	2.55
12/10 2:15 p.m	1.94	1.87	2.54	2.00
2:27 p.m	1.94	1.87	2.54	2.00

[1] Location of the seepage meter within the outer seepage ring.

The results of tests made in clay loam in 1950 with an SCS meter installed by pressing followed a definite pattern for each location (table 5 and fig. 3). Rates determined with the meter within a day after it was installed were usually much higher than the true rates. Invariably, after a period of from 2 to 8 days the meter gave readings comparable to the true rates. At the end of a 12- to 30-day period the meter readings, on an average, were about one-half as large as the inner-ring rates.

In sandy loam A in 1950, the first rate determined with the SCS meter at each of four different locations was lower than the inner-ring rate (table 6). Generally, the meter gave rates that were fairly constant for a given location and close to the inner-ring rates. The meter rates, unlike those in clay loam, did not decrease with time.

When tests were made in sandy loam A in 1951 with the standard SCS meter, a meter made on the SCS design but of clear plastic, and the USBR meter, generally installed side by side and read almost simultaneously, variations appeared in the results obtained with each of the three meters (table 7, fig. 5). The rates determined with

TABLE 5.—*Seepage rates in clay loam in 1950 as determined with the SCS seepage meter, in comparison with those determined with seepage rings*

Location and time	Water depth	Rate obtained with—		
		SCS meter	Inner seepage ring	Outer seepage ring
Location A:	*Feet*	*Feet/day*	*Feet/day*	*Feet/day*
6/29	1.94	3.25	-------	1.29
7/11	1.92	.73	0.86	1.52
7/13	1.92	.70	.98	1.50
7/17	1.92	.65	.83	1.38
7/25	1.92	.52	.92	1.38
7/28	1.92	.54	.96	1.09
Location B:				
8/1	1.90	5.38	1.05	.98
8/2	1.90	2.51	1.05	.98
8/4	1.90	1.84	.93	.93
8/7	1.90	1.17	.93	1.00
8/9	1.90	1.04	.89	.97
8/11	1.90	.90	.84	.95
8/14	1.90	.79	1.50	.94
8/17	1.90	.71	1.50	.96
8/21	1.90	.64	1.50	1.00
Location C:				
8/25	1.90	4.17	1.30	1.20
8/28	1.90	.81	.81	.86
8/30	1.90	.73	.93	.88
9/1	1.90	.78	.88	1.07
9/5	1.90	.66	.97	.84
9/6	1.90	.68	.94	.87
Location D:				
9/8	1.90	.86	.73	.88
9/11	1.90	.47	1.08	.90
9/13	1.90	.45	1.00	1.07
9/15	1.90	.40	.83	1.05
9/18	1.90	.38	1.10	1.20
9/20	1.90	.37	1.55	1.18
Location E:				
9/25	1.90	2.58	1.39	1.12
9/27	1.90	.70	1.23	1.08
9/29	1.90	.60	1.43	1.02
10/5	1.90	.46	1.51	1.17
10/6	1.90	.45	-------	-------
10/9	1.90	.66	1.32	.90
Location F:				
11/6	1.90	4.36	1.39	1.46
11/7	1.90	4.15	-------	1.41
11/14	1.90	.83	1.08	1.24
11/17	1.90	.63	1.00	1.15
11/24	1.90	.55	.92	1.30

TABLE 6.—*Seepage rates in sandy loam A in 1950 as determined with the SCS seepage meter, in comparison with those determined with seepage rings*

Location and time	Water depth	Rate obtained with—		
		SCS meter	Inner seepage ring	Outer seepage ring
Location A:	*Feet*	*Feet/day*	*Feet/day*	*Feet/day*
8/18	1.42	1.86	2.08	4.57
8/21	1.40	2.64	2.00	5.00
8/24	1.40	1.82	1.82	3.75
8/29	1.50	1.71	1.45	2.60
8/31	1.50	1.61	1.42	2.65
9/5	1.50	1.85	1.28	2.43
9/7	1.50	1.45	1.30	2.35
Location B:				
9/8	1.50	.81	1.26	2.35
9/12	1.52	.76	.88	1.83
9/14	1.52	.64	.80	1.63
9/20	1.55	.55	.83	1.58
9/21	1.55	.83	.72	1.73
Location C:				
9/26	1.92	.71	.78	1.55
9/29	1.92	.62	.78	1.40
10/3	1.92	.50	.70	1.40
10/6	1.88	.59	.75	1.37
10/9	1.90	.59	.72	1.25
Location D, 11/7	1.90	.49	1.20	1.20

the meters were usually greater than those for the inner ring. The rates at individual installations tended to decrease with time.

In connection with 1951 tests of the SCS and USBR meters in silt loam, it was found that great differences in the character of the soil existed within the outer seepage ring. Frequently, readings on the meters in silt loam differed greatly from the rates shown by the seepage rings (table 8, fig. 7). The rates indicated by the meters tended to be less than the rates for the outer ring and greater than those for the inner ring. At two locations the rates indicated by the seepage meters increased with time.

In highly permeable sand, in 1952, seepage rates were materially reduced by silt that was brought in with the water early in the season and formed a film of low permeability on the soil surface. Rates indicated by both the SCS and the USBR meter were prevailingly much greater than the rates for the inner or outer ring (table 9, fig. 6). Very high initial rates were indicated by the meters, but these gradually decreased. At the end of a series of observations, which lasted from 5 to 29 days, the rates were nearly always substantially higher than those shown by the seepage rings.

In sandy loam B, which had been excavated to a depth of 3 feet, thoroughly mixed, and then replaced after installation of seepage rings and settled with water, seepage rates indicated by the SCS and USBR meters in 1952 tests tended to be closer to the outer-ring than

TABLE 7.—*Seepage rates in sandy loam A in 1951 as determined with standard and plastic SCS seepage meters and with the USBR seepage meter, in comparison with those determined with seepage rings*

Location and time	Water depth	Rates obtained with meters			Rates obtained with seepage rings	
		Standard SCS meter	Plastic SCS meter	USBR meter	Inner ring	Outer ring
Location A:	*Feet*	*Feet/day*	*Feet/day*	*Feet/day*	*Feet/day*	*Feet/day*
6/19	1.92	1.34	--------	--------	0.72	1.11
6/21	1.92	1.08	--------	--------	.51	.99
6/23	1.93	.92	--------	--------	.48	1.03
6/25	1.91	.93	--------	--------	.57	1.20
6/27	1.92	.80	--------	--------	.52	1.27
6/29	1.92	.84	--------	--------	.47	1.26
7/2	1.88	1.06	--------	1.59	.54	1.18
7/4	1.91	.84	--------	1.25	.45	1.00
7/6	1.91	1.07	--------	1.09	.42	.82
Location B:						
7/11	1.94	.66	--------	2.23	.36	.72
7/13	1.90	.42	--------	1.18	.37	.68
7/16	1.93	.35	--------	1.16	.33	.56
7/18	1.91	.30	--------	.95	.32	.55
7/20	1.92	.30	--------	.92	.32	.55
Location C:						
7/24	1.91	--------	1.43	--------	.31	.57
7/26	1.98	--------	1.05	--------	.30	.52
7/27	1.97	--------	.79	--------	.27	.46
7/29	1.94	--------	.58	--------	.29	.43
Location D:						
8/8	1.95	.24	--------	.31	.23	.32
8/10	1.93	.24	--------	.30	.25	.29
8/13	1.93	.25	--------	.29	.24	.33
8/17	1.90	.23	--------	.24	.22	.23
8/22	1.95	.19	1.09	.22	.21	.24
8/23	1.95	--------	.84	--------	.21	.24
8/24	1.37	--------	.85	--------	.18	.24
Location E:						
9/5	1.95	.25	--------	.40	.19	.40
9/7	1.95	.21	.82	.33	.19	.42
9/10	1.95	.18	.46	.28	.19	.39
9/12	1.95	.15	.35	.36	.17	.33
9/14	1.95	.16	.34	.25	.17	.33
9/17	1.95	.15	.34	.24	.17	.33
Location F:						
9/19	1.95	.96	.68	.95	.17	.37
9/21	1.95	.88	.56	.72	.18	.41
9/24	1.95	.99	.71	.62	.17	.38
9/26	1.95	.89	.68	.57	.16	.36
9/28	1.95	.83	.44	.55	.18	.40
Location G:						
10/2	1.95	.27	.29	.44	.14	.37
10/3	1.95	.25	.26	.39	.17	.41
10/6	1.95	.21	.21	.33	.17	.36
10/9	1.95	.20	.21	.32	.17	.39
10/12	1.95	.20	.22	.31	.20	.37
Location H:						
10/16	1.95	.31	.41	.28	.19	.33
10/19	1.95	.25	.31	.23	.15	.24
10/24	1.45	.24	.23	.18	.14	.22

TABLE 8.—*Seepage rates in silt loam in 1951 as determined with standard and plastic SCS seepage meters and with the USBR seepage meter, in comparison with those determined with seepage rings*

Location and time	Water depth	Rates obtained with meters		Rates obtained with seepage rings	
		Standard SCS meter	USBR meter	Inner ring	Outer ring
Location A:	*Feet*	*Feet/day*	*Feet/day*	*Feet/day*	*Feet/day*
7/3	1.83	0.006	--------	0.042	0.256
7/4	1.83	.003	--------	.046	.252
7/6	1.87	.004	--------	.052	.256
7/11	1.88	.005	--------	.060	.220
7/13	1.88	.010	--------	.052	.225
7/17	1.88	.019	0.030	.037	.265
7/18	1.88	.022	.021	.030	.270
7/20	1.88	.023	.021	.023	.265
7/25	1.89	.022	.019	.018	.155
Location B:					
8/9	1.88	.002	.015	.007	.053
8/10	1.85	.001	.014	.009	.055
8/17	1.88	.001	.013	.008	.056
Location C:					
9/5	1.87	.001	.011	.008	.047
9/7	1.89	.001	.011	.006	.041
9/10	1.88	.001	.010	.010	.045
9/12	1.90	.002	.013	.008	.041
9/14	1.90	.001	.015	.008	.042
9/17	1.90	.001	.017	.007	.040
Location D:					
9/19	1.88	.192	.038	.006	.045
9/21	1.94	.154	.040	.009	.040
9/24	1.88	.142	.034	.006	.038
9/26	1.87	.141	.032	.009	.041
9/28	1.90	.138	.032	.007	.039
Location E:					
10/2	1.90	.044	.019	.007	.037
10/3	1.89	.048	.022	.008	.037
10/6	1.85	.062	.028	.009	.033
10/10	1.90	.092	.037	.008	.032
10/12	1.90	.101	.035	.007	.035
10/15	1.90	.103	.031	.010	.034
10/16	1.89	.100	.035	.010	.033
Location F:					
10/19	1.89	.024	.034	.007	.033
10/24	1.75	.018	.035	.006	.075

TABLE 9.—*Seepage rates in sand in 1952 as determined with the SCS and USBR seepage meters, in comparison with those determined with seepage rings*

Location and time	Water depth	Rates obtained with meters		Rates obtained with seepage rings	
		Standard SCS meter	USBR meter	Inner ring	Outer ring
Location A:	*Feet*	*Feet/day*	*Feet/day*	*Feet/day*	*Feet/day*
7/18	1.88	55.5	36.9	5.34	10.80
7/21	2.01	30.2	17.2	4.41	7.10
7/22	1.95	12.4	--------	[1] 18.00	[1] 19.00
Location B:					
7/24	1.50	14.4	[2] 30.0	14.10	14.10
7/25	1.92	15.8	26.4	11.53	11.58
7/28	1.97	11.2	16.3	5.24	6.91
7/30	1.87	9.72	14.1	4.61	6.03
8/1	1.66	9.48	12.2	4.24	5.19
8/5	1.88	7.00	8.30	2.67	3.29
Location C:					
8/6	1.86	8.78	4.14	2.10	3.23
8/8	1.79	5.36	4.90	2.19	2.81
8/11	1.85	4.79	2.03	1.95	2.62
8/13	1.81	--------	2.56	1.57	2.00
	1.68	--------	2.42	1.59	1.96
8/14	1.85	--------	2.07	1.52	1.96
	1.84	--------	2.31	1.45	1.81
8/15	1.70	--------	1.63	1.41	1.83
	1.62	--------	2.04	1.36	1.68
8/18	1.83	3.97	2.33	1.48	1.79
Location D:					
8/20	1.87	9.25	17.20	1.29	1.81
8/22	1.88	6.30	9.65	1.10	1.45
8/25	1.88	6.24	6.62	1.02	1.26
8/26	1.88	5.58	5.53	1.17	.86
8/27	1.88	--------	7.35	.90	1.10
8/28	1.89	[3] 25.4	5.50	1.05	1.14
8/29	1.89	13.4	4.21	.93	1.10
9/2	1.89	7.32	2.28	.63	.93
Location E:					
9/15	1.88	37.8	24.6	[1] 1.90	[1] 3.10
9/17	1.88	23.4	20.4	1.36	2.19
9/19	1.88	10.8	10.9	1.33	2.78
9/22	1.88	8.26	9.13	1.26	1.74
9/24	1.88	6.80	7.66	1.10	1.53
9/26	1.88	5.37	6.16	.93	1.38
9/29	1.89	4.14	4.53	.81	1.27
10/1	1.89	3.34	3.74	.76	1.12
10/3	1.89	2.92	3.24	.67	1.05
10/6	1.90	2.26	2.93	.72	1.00
10/8	1.90	2.14	2.25	.57	.90
10/10	1.90	2.13	2.08	.57	.95
10/13	1.90	1.88	2.10	.55	.81
Location F:					
10/15	1.89	39.0	19.5	.50	1.24
10/17	------	15.2	7.66	.50	.98
10/20	1.90	7.40	3.82	.52	.90
10/22	1.90	5.53	3.18	.57	.81

[1] Bottom of each seepage ring was raked.

[2] USBR meter was moved and reset within designated location.

[3] SCS meter was pushed farther into the soil.

TABLE 10.—*Seepage rates in sandy loam B in 1952 as determined with the SCS and USBR seepage meters, in comparison with those determined with seepage rings*

Location and time	Water depth	Rates obtained with meters		Rates obtained with seepage rings	
		Standard SCS meter	USBR meter	Inner ring	Outer ring
Location A:	*Feet*	*Feet/day*	*Feet/day*	*Feet/day*	*Feet/day*
7/2	1.85	0.359	0.365	0.366	0.431
7/3	1.85	.333	.322	.351	.444
7/5	1.85	.336	.382	.381	.381
7/7	1.86	.360	.598	.381	.286
7/9	1.86	.268	.603	.333	.333
7/11	1.86	.349	.608	.286	.286
7/15	1.86	.560	.812	.333	.262
7/17	1.86	.726	.901	.333	.238
7/21	1.87	.926	.823	.357	.211
Location B:					
7/23	1.88	.472	.246	.331	.381
7/25	1.88	.744	.392	.310	.429
7/28	1.85	.900	.612	.387	.387
7/30	1.88	.820	.594	.333	.405
8/1	1.86	.787	.662	.357	.452
8/4	1.88	.570	.780	.333	.476
Location C:					
8/13	1.83	---------	.678	.434	.651
	1.62	---------	.403	.398	.578
8/14	1.69	---------	.602	.398	.602
	1.68	---------	.671	.386	.590
8/15	1.73	---------	.445	.410	.639
	1.70	---------	.458	.373	.614
8/18	1.89	1.58	.976	.429	.667
Location D:					
8/20	1.90	.750	1.42	.524	.762
8/22	1.90	.826	1.55	.429	.810
8/25	1.89	.726	1.33	.524	.857
8/27	1.90	.777	1.52	.643	.929
8/30	1.89	.602	1.25	.619	.810
9/2	1.89	.594	1.23	.590	.867
Location E:					
9/15	1.87	1.52	2.97	.857	1.048
9/17	1.88	1.18	2.08	.762	1.286
9/19	1.88	1.00	1.40	.810	1.238
9/22	1.88	.794	1.02	.742	1.129
9/24	1.88	.648	.872	.714	1.048
9/26	1.88	.575	1.09	.762	1.024
9/29	1.89	.506	.980	.750	1.107
Location F:					
10/1	1.88	---------	.415	.742	1.032
10/2	1.89	1.56	.356	.727	1.087
10/3	1.89	1.32	.348	.690	1.000
10/6	1.88	1.14	.318	.714	.810
10/8	1.88	1.03	.296	.714	.810
10/10	1.88	1.06	.280	.667	.810
10/13	1.88	1.14	.288	.774	.839
10/15	1.94	1.20	.276	.738	.881
Location G:					
10/17	1.88	3.89	4.02	.810	.929
10/20	1.88	3.06	3.01	.810	.857
10/22	1.88	2.65	2.77	.857	.762

to the inner-ring rates (table 10, fig. 8). At several locations the rates indicated by the meters increased with time, but at one location they decreased with time. Interchanging the meters' measuring devices during these tests did not cause any difference in the rates indicated.

USBR seepage-meter readings made in sand and sandy loam B at intervals during a period of continuous tests in August 1952 showed considerable daily variation (table 11). The meter readings in sand ranged from 1.63 to 2.56 feet per day; those in sandy loam B ranged from 0.403 to 0.976 foot per day. Smaller variations occurred in the seepage rates obtained with the seepage rings. Interchanging the measuring devices on the meters, on two occasions, caused no appreciable differences in the measured rates.

TABLE 11.—*Seepage rates indicated by the USBR seepage meter in sand and in sandy loam B during continuous tests in August 1952*

Date	Hour	Seepage rate obtained with— USBR meter	Seepage rate obtained with— Inner ring	Seepage rate obtained with— Outer ring	Temperature
		SAND [1]			
		Feet/day	*Feet/day*	*Feet/day*	*° F.*
8/11	11:00 a.m.	2.03	--------	--------	62.0
8/13	1:46 p.m.	2.56	1.56	2.00	70.7
	8:42 p.m.	2.42	1.52	1.88	69.5
8/14	3:52 a.m.	2.07	1.52	1.96	64.2
	1:55 p.m.	2.31	1.40	1.71	67.2
8/15	7:18 a.m.	1.63	1.41	1.83	62.0
	1:16 p.m.	2.04	1.36	1.68	69.2
8/18	1:40 p.m.	2.33	--------	--------	70.5
		SANDY LOAM B [2]			
8/13	10:52 a.m.	0.678	0.434	0.651	70.5
	11:35 p.m.	.403	.398	.579	69.0
8/14	5:09 a.m.	.602	.422	.651	66.2
	3:58 p.m.	.671	.410	.639	71.2
8/15	6:05 a.m.	.445	.410	.639	63.0
	3:33 p.m.	.458	.373	.615	72.8
8/18	1:45 p.m.	.976	--------	--------	74.0

[1] Meter placed 8/5.
[2] Meter placed 8/12.

Seepage Meters in Canals

Seepage-meter tests made in the bottoms of four canals in which ponding tests were in progress produced results differing widely in their relation to the results of the ponding tests (table 12). In only one of four instances did the seepage-meter results agree with the

TABLE 12.—*Seepage determinations made in 4 canals with seepage meters and by ponding*

Canal	Seepage rate as determined with—	
	Seepage meter [1]	Ponding test
	Feet/day	*Feet/day*
Arthur ditch [2]	0. 203	0. 076
Canal-cross-section pit	1. 13	1. 18
Poudre Supply Canal	. 024	. 20
North Poudre Supply Canal	. 15	. 71

[1] Each value in this column is a weighted average of determinations made in the test reach with both the USBR and the SCS seepage meter.

[2] Water depth was greater during the seepage-meter test than during the ponding test.

results of ponding. In one instance the seepage-meter reading was much higher than the rate determined by ponding, and in two instances the meters indicated much lower rates than the ponding tests.

Analysis of Data and Discussion

In many cases the seepage rates as measured by the seepage meters decreased markedly with time. Results indicated that more accurate data may be obtained with the meters when they have been in place for at least a week. In a few cases the rates shown by the meters were low at first and gradually increased. Meters installed side by side often gave conflicting results. In highly permeable sand the meter values were nearly always much higher than the values shown by the seepage rings, which indicated that a film of lower permeability had been broken when the meters were installed.

Results from using a plastic SCS meter did not reveal that presence or absence of light inside the meter had any effect. The results of the two tests in which the measuring devices on the SCS and USBR meters were interchanged showed that differences between these two devices did not cause differences between the measurements made with the two meters, respectively.

The calibration chart presented as figure 12 was based on all the seepage readings taken on meters in seepage rings 2 days or longer after the meters were installed. The meter determinations within each of the ranges indicated in table 13 were grouped and averaged, and the averages were plotted in relation to the corresponding averages of inner- and outer-ring rates (likewise given in table 13).

Seepage-meter rates up to 1 foot per day agreed fairly well with the seepage-ring rates. Beyond that range, the rates determined with the seepage meters were too high. However, there is considerable scatter in the data for rates greater than 1 foot per day, so it is doubtful that the trend they show is significant. Highly permeable material usually had a film of less permeable material

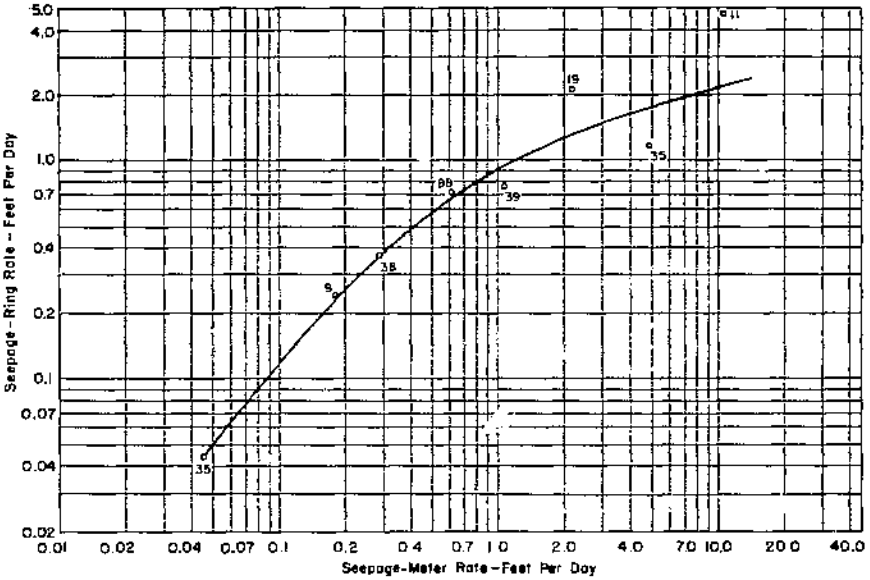

FIGURE 12.—Relationship of readings taken on seepage meters in seepage rings (at least 2 days after meter installation) to averages of seepage rates determined at the same times with inner and outer seepage rings. The number on each point indicates how many meter readings were averaged to determine the point.

TABLE 13.—*Averages of readings taken on seepage meters installed in seepage rings (at least 2 days after meter installation) in comparison with seepage rates determined at the same times with inner and outer seepage rings*

Range of seepage rates (feet per day) determined with meter	Meter readings	Average seepage rate obtained with—			
		Seepage meter [1]	Inner ring	Outer ring	Inner and outer rings [2]
	Number	*Feet/day*	*Feet/day*	*Feet/day*	*Feet/day*
0.00–0.10	35	0. 046	--------	0. 043	0. 043
0.11–0.20	9	. 18	0. 17	. 32	. 24
0.21–0.40	38	. 29	. 30	. 44	. 37
0.41–0.80	88	. 61	. 61	. 81	. 71
0.81–1.60	39	1. 07	. 64	. 88	. 76
1.61–3.20	19	2. 23	1. 73	2. 52	2. 12
3.21–6.40	35	4. 90	. 93	1. 34	1. 14
6.41–12.80	11	10. 60	4. 20	5. 10	4. 65

[1] Rates determined with the USBR and the SCS seepage meter were averaged together.

[2] Rates determined with the inner and the outer ring were averaged together.

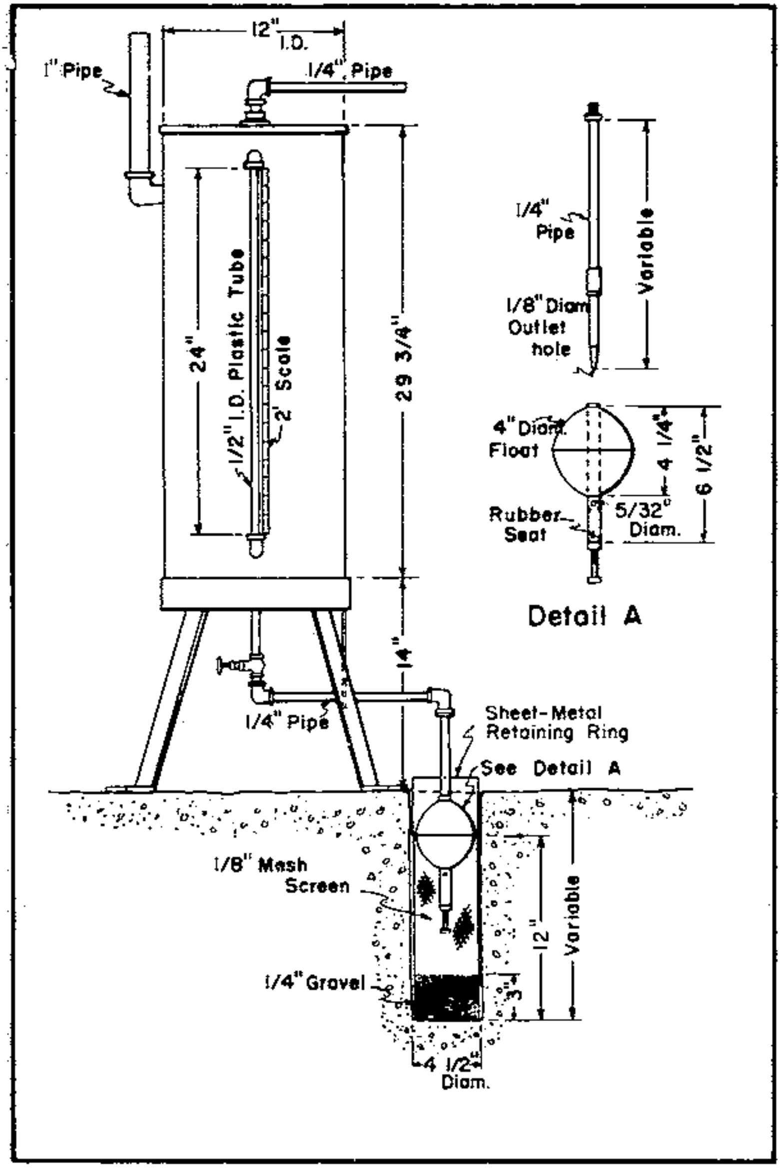

FIGURE 13.—Diagram of well permeameter having simplified float control.

over its surface. When such a film had been broken in installing a meter, the meter indicated seepage rates higher than the actual rates.

According to the results of this study individual measurements with seepage meters, although they do not give exact seepage rates, do indicate the order of magnitude of losses. In nearly every case, the seepage meters indicated correctly whether the loss was high, intermediate, low, or very low.

The wide divergence of the seepage-meter and ponding test results shown in table 12 is probably due largely to the fact that in these tests the seepage meters were always installed in the bottom of the canal—never in its sides, where seepage is usually much greater than in the bottom.

To obtain satisfactory results with seepage meters in canals, the meters should be installed in the sides as well as in the bottom. The measurements should be made as close together as the time and money available will allow, because more dependable averages will be obtained and also because areas of high seepage will not be so likely to be missed. Care in setting the meters is important; the soil inside the meter must be disturbed as little as possible.

Measurements made with the SCS meter and the USBR meter, respectively, tend to agree fairly well with each other, but the USBR meter is to be preferred because it is easier to operate.

FIELD PERMEABILITY TESTS

Equipment

In field tests of the well permeameter (the purpose and nature of this instrument and the method by which it is used are discussed on pp. 8–9), two types of permeameters were used (figs. 13 and 14). The essential difference between these two is in the mechanism for automatic control of the water level in the well. The type shown in figure 13 has a valve inside its float that operates without levers. This valve responds immediately to small changes in the water level and effec-

FIGURE 14.—Well permeameter equipped with float and lever mechanism.

tively holds the water level constant. The one shown in figure 14, which was developed by the U.S. Bureau of Reclamation (*17*), has a float and lever mechanism that operates the valve. The two types were used in this study indiscriminately. Since the function of the permeameter is only to deliver water at a required rate, the type of equipment does not affect the results of the tests if the equipment is operating properly.

Procedure and Results

Water free of sediment was used for these tests, as any suspended matter deposited on the periphery of the well would reduce the flow. Normally, readings to determine the volume of water seeping from the well were taken at hourly intervals during the day. In all cases they were taken several times during the day, and in some they were continued through the night. Each test continued for about a week. In addition to the calibrated-tank readings, the temperature and depth of water in the hole were recorded.

The tests were run long enough to develop a saturated envelope in the soil but not long enough to build up the water table or produce an excessively large saturated envelope. The minimum and maximum times for the duration of the tests are given by equations and nomographs in the Bureau of Reclamation's Earth Manual (*17*).

The permeability coefficient, K, is determined from the results of well-permeameter tests by use of a formula developed by electrical-analogy methods by the Bureau of Reclamation. When the distance from the water surface in the hole to the water table is greater than three times the depth of water in the hole, the formula is

$$K=1{,}440\left[\sinh^{-1}\left(\frac{h}{r}\right)-1\right]\frac{Q}{2\pi h^2}, \qquad (3)$$

in which K is the permeability coefficient in feet per day, h is the depth of water in the hole in feet, r is the radius of the hole in feet, and Q is flow in cubic feet per minute required to maintain a constant water level. A nomograph for quick solution of this equation is given in the Earth Manual (*17*). (As is shown later, on p. 69, better results will be obtained with this nomograph if the viscosity correction is not applied.)

In well-permeameter tests made in the vicinity of the seepage rings, practically no correlation was found between the permeability indicated by the well permeameters and that indicated by the rings. Later it was recognized that no correlation should be expected, since the seepage rings essentially measure vertical permeability whereas the well-permeameter measurement is more nearly one of horizontal permeability. For this reason, the tests in the vicinity of the seepage rings were discontinued. However, well-permeameter tests were made along three canal sites. Later, ponding tests afforded a means of checking the estimates of seepage made by the well-permeameter method.

North Poudre Supply Canal

One series of well-permeameter tests was made along the centerline of the reach between stations 245+45 and 257+90 of the proposed North Poudre Supply Canal, Colorado-Big Thompson project. Soil samples were taken at various points along the test reach and were analyzed with results given in table 14. The soil varied from silt and silty clay to poorly graded sand (near the lower end of the reach). Ground water was not found in any of the test holes.

TABLE 14.—*Classification of soils of the reach of the North Poudre Supply Canal in which well-permeameter tests were made*

Station	Depth of sample	Classification [1]
	Feet	
246+35	0-1.0	Silt with trace of clay.
	2.0-3.0	Clay, lean.
	3.0-12.0	Silt with trace of clay.
248+48	0-13.0	Silt with trace of clay.
248+55	0-3.0	Clay, lean.
	3.0-5.7	Silt.
250+80	1.0-15.0	Silt.
	15.0-16.0	Sand with silt.
	16.5-17.0	Silt with trace of clay.
254+73	1.0-7.0	Silt with trace of sand.
265+65	2.0-4.0	Silt with trace of clay.
	4.0-7.0	Sand with excess of silt.
	7.0-9.0	Sand, poorly graded.
256+86	0-2.0	Silt with trace of clay.

[1] Made by the U.S. Bureau of Reclamation according to a system adapted from the Airfield Classification system developed by Casagrande.

Well-permeameter tests were made at five locations. The holes used were about 6 inches in diameter and varied in depth according to the amount of excavation that would be required for the canal at the point. Observations were carried on for a week during May 1951. The results of one test are plotted in figure 15, and the results of all are shown in table 15.

The values of K determined varied rather widely over the test period. The permeability value at the time when minimum-volume requirements were fulfilled was taken as the standard of comparison. In the example illustrated in figure 15, this value is 1.14 feet per day. The weighted average of the permeabilities for the entire series of wells is 0.98 foot per day. (A different method of determining at what point the K value should be measured is used by the Bureau of Reclamation. In some instances the permeabilities determined by the two methods may differ considerably.)

To check the well-permeameter data for the test reach of the North Poudre Supply Canal, ponding tests were made in 1953. This unlined part of the canal has a bottom width of 12 feet, side slopes of 1½:1, a normal water depth of 5.61 feet, and a capacity of 250 cubic feet per second. The pond (fig. 16) was formed by constructing watertight

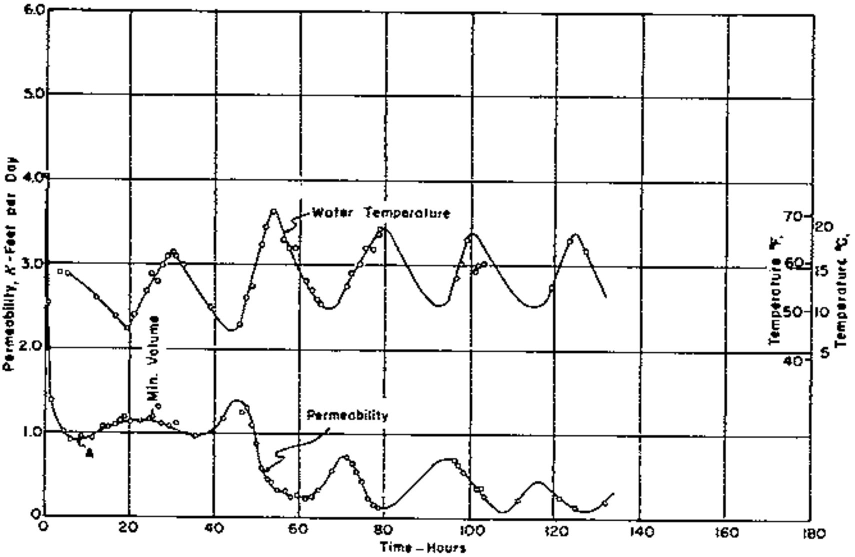

FIGURE 15.—Results of well-permeameter test on the site of the proposed North Poudre Supply Canal. (*K* values corrected to 60° F. "A" marks initial low point in curve.)

TABLE 15.—*Summary of results of well-permeameter tests* [1]

Canal, station, and well location	Length of section	*K* at minimum volume
North Poudre Supply Canal, 245+45—257+90:	*Feet*	*Feet/day*
246+48	314.0	1.14
250+70	310.5	[2].48
252+69	206.0	[2].95
254+76	192.5	1.20
256+60	222.0	[2] 1.27
Weighted average		.98
Canal-cross-section pit, 18 feet long:		
0+04.5	9	.43
0+13.5	9	.40
Weighted average		.42
Poudre Supply Canal, 167+50—186+00:		
170+44	495	.29
174+46	443	.37
179+30	457	.76
183+60	455	.61
Weighted average		.50

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[1] All tests corrected to 60° F.

[2] Test not carried to required minimum time.

FIGURE 16.—*A*, Lower part of pool used for a ponding test made on the North Poudre Supply Canal in 1953 to check data from well-permeameter tests; *B*, bulkhead across lower end of pool.

bulkheads at the transition sections at each end of the reach. Because of the length of the reach, it was necessary to mount a gage at either end to eliminate wind effect. The pool was filled from the canal through a gate in the upper bulkhead, which was then closed. Leakage through the bulkheads was checked on several occasions and found to be negligible. Hook-gage readings of the drop were taken several times a day, and the temperature of the water at those times was recorded. Cross-section measurements were made at two different stages.

The reach was filled five times, and seepage measurements were made after each filling. After the fourth filling the pool was divided with another bulkhead, to isolate a short part at the lower end that was believed to have a high seepage rate. After the fifth filling, the losses from the two separate pools were measured. The results of the ponding tests are shown in figure 17. A separate curve is shown for the losses from each of the two pools after the fifth filling, also one for the weighted averages of the losses from the two pools.

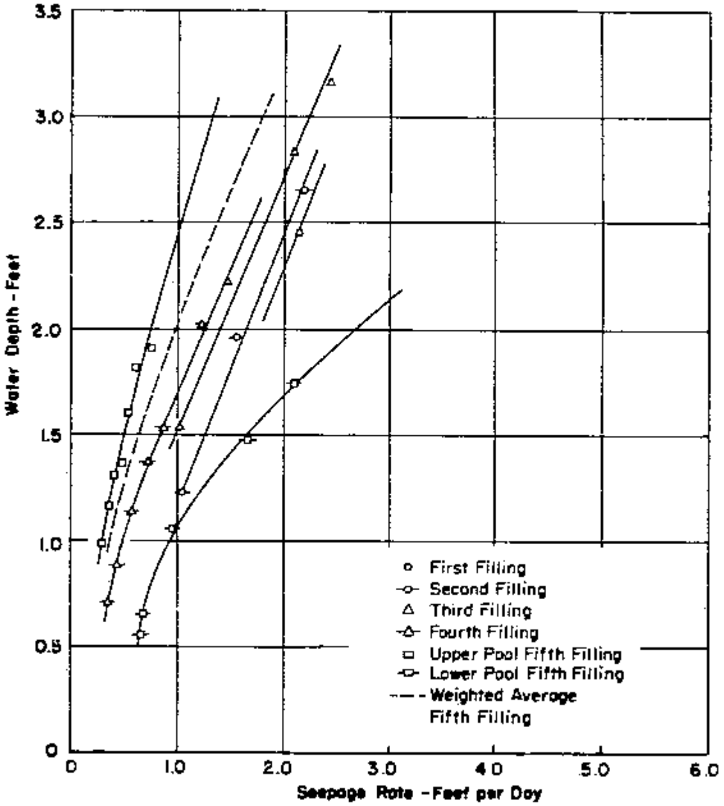


FIGURE 17.—Results of ponding tests made in the North Poudre Supply Canal. (Values not corrected for temperature.)

While the ponding tests were in progress, seepage measurements were made with seepage meters installed along the bottom of the upper pool. The results of these measurements are set forth in table 12.

Canal-Cross-Section Pit

A sandy loam site, on the Poudre Supply plot, on which a pit shaped to represent an 18-foot cross section of a canal was later to be excavated was subjected to two well-permeameter tests in 1952. Permeameter wells about 4.5 inches in diameter and about 2 feet deep were excavated at equally spaced points along the centerline of the projected canal-cross-section pit. The weighted average of the permeability

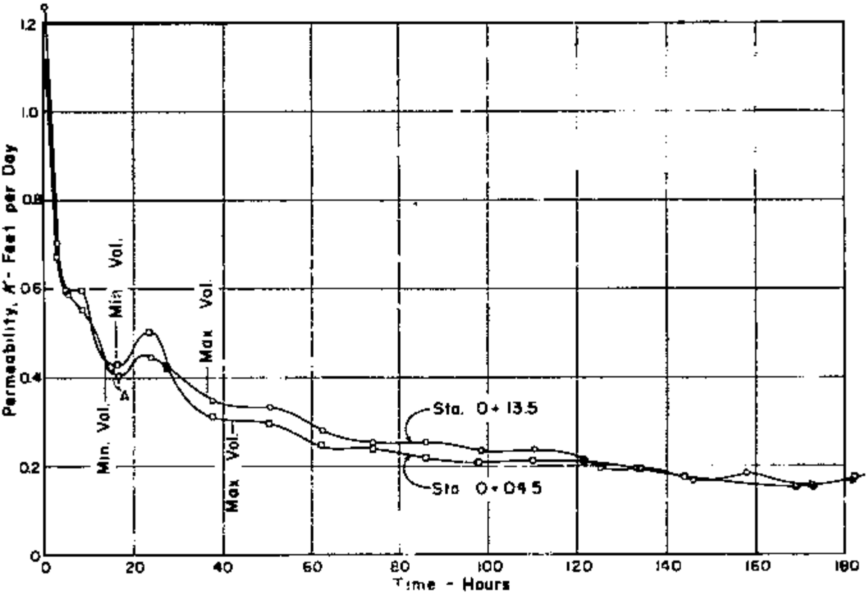


FIGURE 18.—Results of well-permeameter tests on site of projected canal-cross-section pit, 1952. (Values corrected to 60° F. "A" marks initial low point in curve.)

values for the wells (table 15) was 0.42 foot per day. The results of the tests are plotted in figure 18. The following year, after the pit was excavated, the results were checked with those of well-permeameter tests nearby and were found to be practically identical with them. Ground water was not found in test holes extending 8 feet or more below the surface.

The pit (fig. 19), which had a width of 3 feet, side slopes of 1½:1, and a depth of 3 feet, was subjected in 1952 to ponding tests. In the

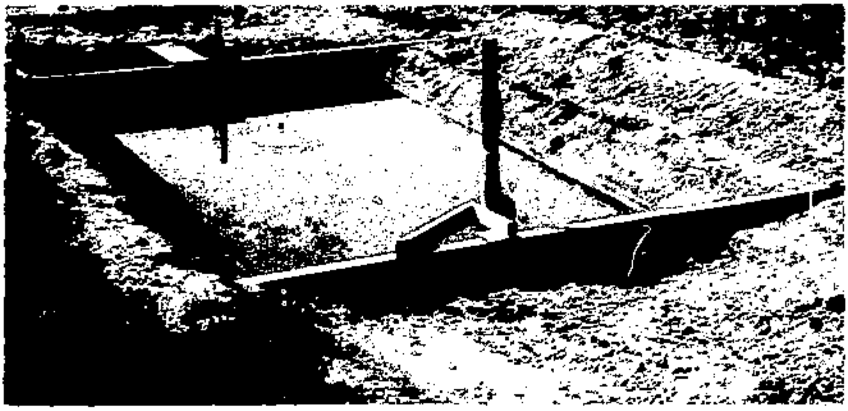


FIGURE 19.—View of canal-cross-section pit at the Poudre Supply plot, showing bulkheads, hook gage, and installed seepage meters.

first of these, the inflow of water was cut off daily for several short periods and the drop in water surface during each of these periods was measured with a single hook gage. This continued for about a month. The water was then turned off for almost 3 weeks. After it was turned on for the second time, a lining of waste cement dust was placed in the pit by sifting the dust into the water and letting it settle to the bottom and sides. The pit was then kept filled for a week. During this time a water meter was used in the line, and seepage was determined continuously. The results of the ponding tests are shown in figure 20.

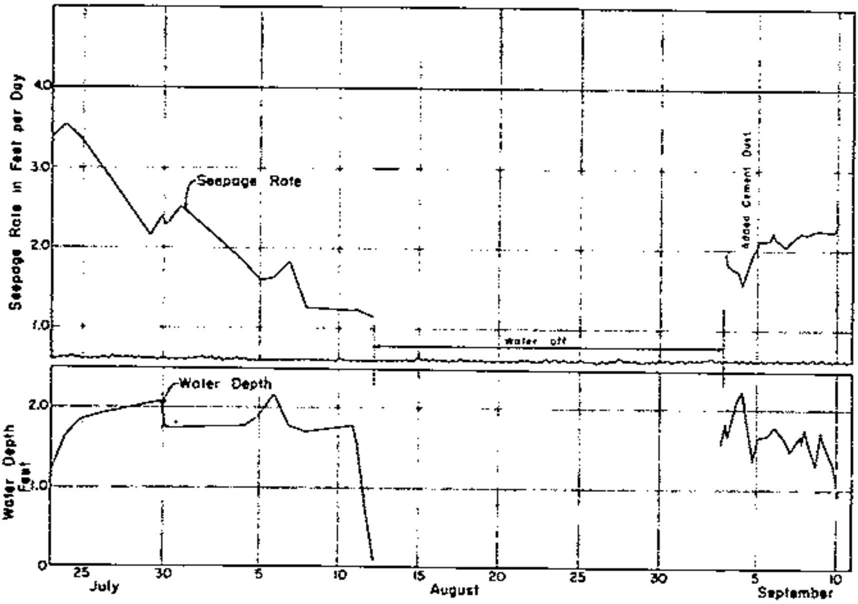


FIGURE 20.—Results of ponding tests in canal-cross-section pit, 1952.

Seepage-meter tests were made along the bottom of the pit during the last part of the first ponding test. They indicated a seepage rate of 1.13 feet per day (table 12).

Poudre Supply Canal

The Poudre Supply Canal had already been excavated when the well-permeameter tests were proposed. This canal has a bottom width of 32 feet, side slopes of 1½:1, a normal operating depth of 10.76 feet, and a capacity of 1,500 cubic feet per second. Because it was desired to conduct the tests in undisturbed material and in the same horizon with the bed of the canal, they were made along a line approximately 60 feet to the right of the canal centerline, outside the embankment, between stations 167+50 and 186+00. Four well-permeameter tests were made at points equally spaced along this line. Results of physical and chemical analyses of the soil encountered at each location are given in table 16. Generally, the soil was classified as a sandy loam.

Ground water was not found, and it was assumed to be at a great depth below the canal.

The well-permeameter tests were made according to the procedure previously described, except that the depths of the holes were such that the bottoms were not at a level corresponding to that of the invert of the canal. The results of two of these tests are plotted in figure 21.

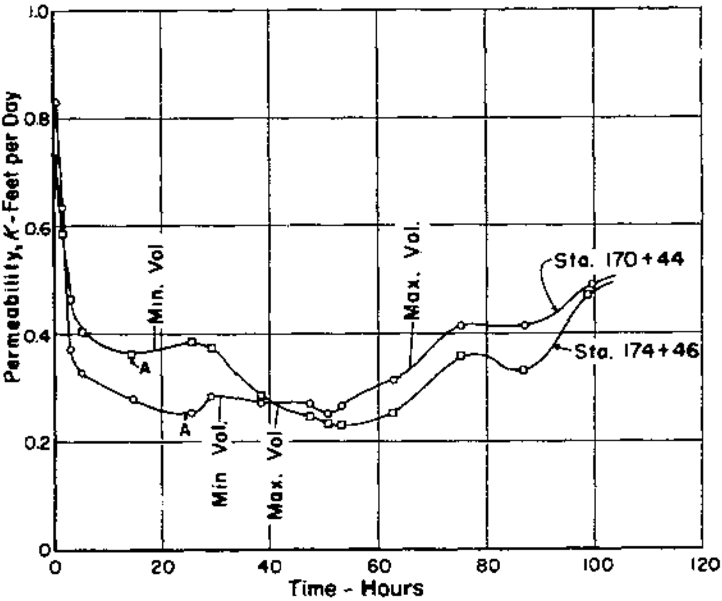


FIGURE 21.—Results of well-permeameter tests in the Poudre Supply Canal, 1952. (Values corrected to 60° F. "A" marks initial low point in curve.)

The determinations of permeability at minimum volume (table 15) averaged 0.50 foot per day.

Ponding tests were made on the section of the Poudre Supply Canal in 1951 and 1952. Because of changes in grade where the water emerged from a lined into an unlined section and from the unlined into a lined section, a pool was formed between stations 167+50 and 186+00 when the water was cut off. This pool averaged about 1.5 feet deep when the water stopped running from the section.

Since the section of the Poudre Supply Canal used for the measurements was 1,850 feet long, it was necessary to install a staff gage at each end of the pool to compensate the effect of the wind's piling the water up at either end. In addition to staff-gage readings taken twice a day, the temperature of the water was recorded. During 1951 the pool was filled twice, first with clear water (as the initial trial run for the canal) and second by floodwater, which was very muddy. Seepage rates (fig. 22) averaged about 0.2 foot per day in the first 1951 test. In the later test, with muddy floodwater, the seepage rates averaged only about 0.07 foot per day. In 1952, after one season's operation of the canal, the average rate was about 0.15 foot per day. Seepage-meter tests made along the bottom of the

TABLE 16.—*Analyses of soils, at the 1.5- to 2.5-foot depth, in which the Poudre Supply Canal was excavated*

MECHANICAL ANALYSIS

Station	Colloids (<0.001 mm.)	Clay (0.001–0.005 mm.)	Silt (0.005–0.05 mm.)	Fine sand (0.05–0.25 mm.)	Coarse sand (0.25–2.0 mm.)	Gravel (>2.0 mm.)	Soil Survey classification
	Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	
170+44	2.5	3.0	37.5	46.0	11.0	0	Sandy loam.
174+46	1.0	4.5	24.5	61.0	9.0	0	Do.
179+30	1.0	8.0	46.5	38.5	6.0	0	Loam.
183+60	0	3.0	18.5	69.0	9.5	0	Sandy loam.

CHEMICAL ANALYSIS

Station	pH	Total soluble salts	Total gravimetric salts	Organic material	C_aCO_3 (calcium carbonate)
		Percent	*Percent*	*Percent*	*Percent*
170+44	7.8	0.10	0.5	1.3	0.6
174+46	7.7	.02	.5	.7	.2
179+30	8.1	.08	.5	1.1	5.6
183+60	8.3	.02	.5	.9	1.0

canal during the first ponding test of 1951 indicated a seepage rate of 0.024 foot per day (table 12).

Analysis of Data and Discussion

Previous to this study, well-permeameter tests were made on the Riverton Project in Wyoming by the U.S. Bureau of Reclamation (*16*). The results were found to be correlated with results from ponding tests on the Riverton Project when the permeability values were converted to seepage rates by use of an equation proposed by Muskat (*11*). This equation, derived for areas where the water table is at a considerable depth below the bottoms of the canals, is

$$q=\frac{K(B+2H)}{WP}, \qquad (4)$$

in which q is the seepage rate in cubic feet per square foot per day, K is soil permeability as determined in well-permeameter tests in feet per day, B and H are the width of the water surface and the depth of the water in feet, and WP is the wetted perimeter of the canal in feet.

The ratios of the Riverton ("Wyoming canal") seepage rates based on well-permeameter data to those based on ponding data are plotted in figure 23, together with the ratios of such rates obtained for three

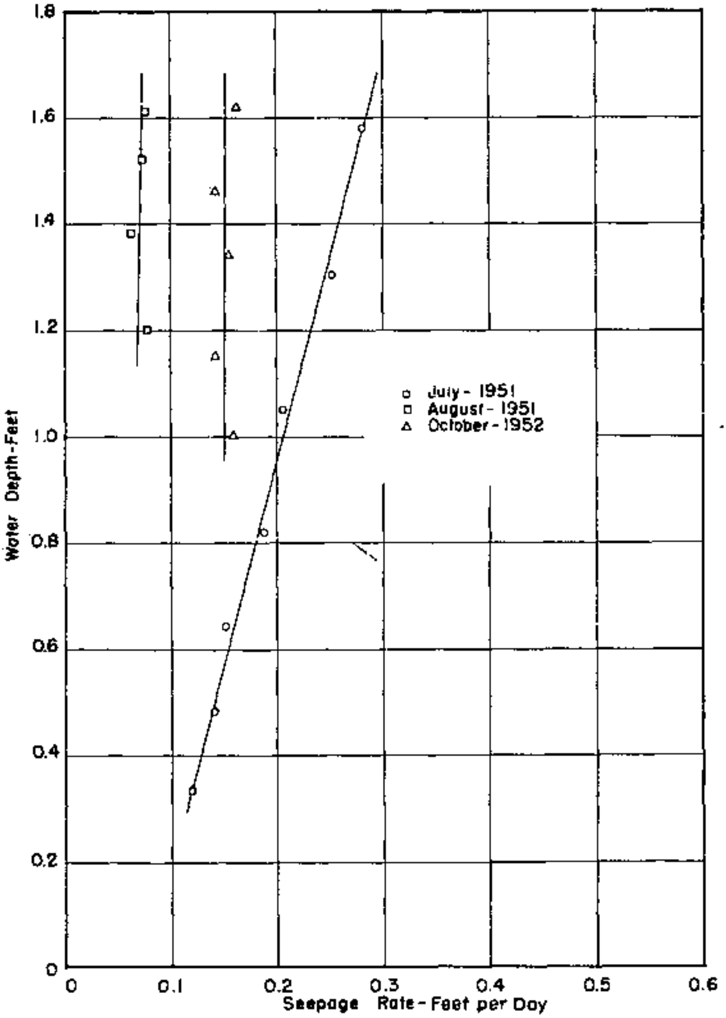


FIGURE 22.—Results of ponding tests between stations 167+50 and 186+00, Poudre Supply Canal. (Values not corrected for temperature.)

canals in the present study and a comparable value obtained by the Bureau of Reclamation on Middle Loup Canal No. 2, in Nebraska. (Seepage rates for the three canals used in this study are presented also in table 17.) No correlation appears between the results obtained in the Riverton Project and those obtained in the other tests. One explanation of the difference in results is the fact that the same procedure was not followed in making the well-permeameter tests in the different projects.

In using equation 4 it was noted that almost constant values of *q* were obtained for a particular canal regardless of depth of water; in other words, that in a given canal the seepage per unit area was practically the same for all depths. Ponding tests on canals usually

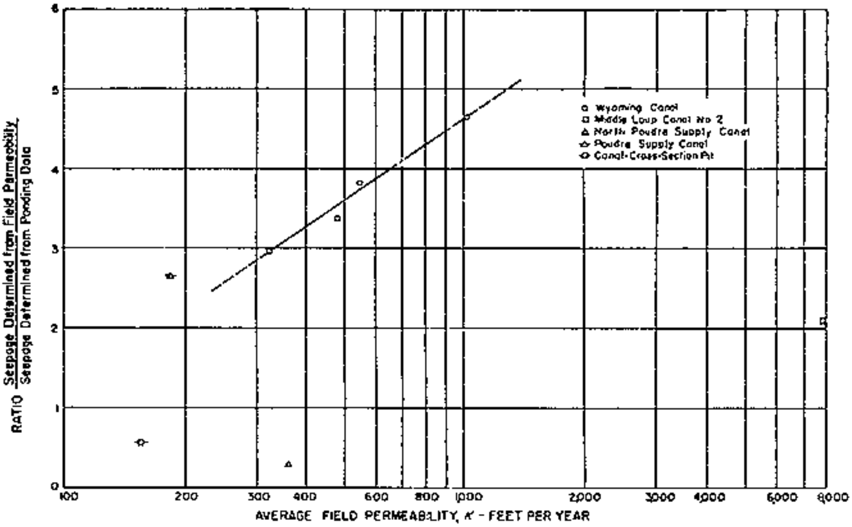


FIGURE 23.—Relationship of seepage rates derived from field permeameter data and those derived from ponding data by use of the equation $R=3.3 \log_{10} K-5.3$, for three series of tests made in the present study and two made by the Bureau of Reclamation.

TABLE 17.—*Comparison of seepage values based on well-permeameter and seepage-meter tests with those based on ponding tests*

Canal and section	Seepage rate as determined by—			Ratio of seepage rate based on well-permeameter data to that based on ponding data	Permeability, K, as determined with well permeameter	
	Well-permeameter tests [1] [2]	Ponding tests [2]	Seepage-meter tests			
North Poudre Supply Canal:	*Feet/day*	*Feet/day*	*Feet/day*		*Feet/day*	*Feet/year*
1,245-foot section	1.25	[3] 4.40	0.13	0.28	0.98	358
1,100-foot section	1.20	[3] 4.00	.13	.30	.94	343
Canal-cross-section pit	.53	1.20	1.13	.44	.42	153
Poudre Supply Canal, 1,800-foot section	.53	.22	.024	2.41	.50	183

---

[1] Permeability data were converted to seepage rates by applying an equation proposed by Muskat (*11*).

[2] Seepage rates corrected to 60° F.

[3] Determined for 5.61-foot depth by extrapolation.

show, however, that the seepage per unit area increases with depth of water, especially if the rate is high. Equation 4 was derived for homogeneous, isotropic soils—a condition that is seldom found in nature.

Increase of seepage with depth of water can partially be attributed to the fact that the horizontal permeability of soil is usually several times the vertical permeability and as depth of water in a canal increases more and more of the area of the sides is under water. In several cases in which seepage as determined with seepage meters in the bottom of a canal was very low, ponding tests in the same section gave high rates. In these cases it could be deduced that most of the seepage was through the canal sides.

For the purpose of developing a better method of correlating the test results, a different approach was tried: the outflow from the well in the well-permeameter test was converted to a rate of seepage over the well's entire boundary area, and this was compared directly with the rate determined by ponding. The rate of outflow in the well-permeameter tests was taken at the initial low point in the curve, which is shown in figures 15, 18, and 21 as point A. The results are presented in table 18.

Because tests had indicated that most of the seepage from the North Poudre Supply Canal and the Poudre Supply Canal (both of which had been in operation for only one season) was through the sides, the unit seepage for each of these two canals was converted on the assumption that all the seepage had taken place through the sides (table 19 and fig. 24). Although the seepage meters showed a high seepage rate on the bottom for the canal-cross-section pit, the data for this pit, also, were thus converted. By using this method a high degree of correlation was found between the seepage determined with well permeameters and that determined by ponding.

When this method was applied to the data from the Riverton tests, a similar relationship was not found. One reason for this could be the fact that the well-permeameter tests in the Riverton canal were made in the bottom and sides after the canal was completed, not along the centerline of the unexcavated canal. Also, they were generally not continued long enough to fulfill the minimum-volume requirements.

Although the ponding tests in the North Poudre Supply Canal were made within 2 weeks after operation of the canal ceased for the season, the rates determined there by individual tests decreased progressively. When the lowest 145-foot section was isolated with another bulkhead, the seepage rate for this section was found to be about 3 times that for the remaining 1,100 feet.

Rates of seepage from the canal-cross-section pit, tested with clear water from the city water mains, decreased markedly with time. The seepage appeared to speed up materially after the section was lined with waste cement dust. Evidently there was some base exchange that increased the permeability of the material.

The ponding tests in the Poudre Supply Canal strikingly showed the effect of sediment in water in reducing seepage. In the second 1951 test, made when the pool was filled by floodwater heavily laden with sediment, the seepage rate was less than one-third that of the earlier test, in which clear water was used. The rates during the 1952 test

Table 18.—*Comparison of seepage rates based on well-permeameter data with those based on ponding data when seepage from each permeameter well was converted to a rate for the well's entire boundary area* [1]

Canal section and well location	Length of section	Radius of hole	Depth of water	Wetted area	Discharge from well	Seepage rate based on—	
						Well-permeameter data	Ponding data
North Poudre Supply Canal, 1,100-foot section:	*Feet*	*Feet*	*Feet*	*Square feet*	*Cubic feet/minute*	*Feet/day*	*Feet/day*
246+48	314	0. 275	5. 25	9. 30	0. 041	6. 35	
250+70	311	. 272	6. 23	10. 81	. 052	6. 90	
252+69	202	. 240	3. 99	6. 21	. 024	5. 57	
254+76	273	. 272	5. 98	10. 45	. 061	8. 40	
Weighted average						6. 85	4. 00
Canal-cross-section pit, 18 feet long:							
0+04. 5	9	. 188	2. 22	2. 73	. 0041	2. 16	
0+13. 5	9	. 188	1. 92	2. 37	. 0031	1. 88	
Weighted average						2. 02	1. 20
Poudre Supply Canal, 1,800-foot section:							
170+44	495	. 188	1. 94	2. 40	. 0020	1. 22	
174+46	443	. 188	1. 48	1. 86	. 0019	1. 48	
179+30	457	. 188	1. 48	1. 86	. 0027	2. 07	
183+60	455	. 188	1. 36	1. 71	. 0030	2. 49	
Weighted average						1. 87	. 22

---

[1] Seepage rates corrected to 60° F.

TABLE 19.—*Seepage rates derived from well-permeameter data and ponding data on the basis of the assumption that all seepage occurred through canal sides*

Location	Length of section	Depth of water	Width of bottom	Wetted perimeter	Wetted sides	Seepage[1] from wells	Seepage[1] from ponds	
							Through bottom and sides	Through sides only
	Feet	*Feet*	*Feet*	*Feet*	*Feet*	*Feet/day*	*Feet/day*	*Feet/day*
North Poudre Supply Canal	1, 100	5. 61	12. 0	31. 5	19. 5	6. 85	4. 00	6. 46
Canal-cross-section pit	18	2. 12	3. 0	10. 6	7. 6	2. 02	1. 20	1. 67
Poudre Supply Canal	1, 800	1. 57	32. 0	38. 2	6. 2	1. 87	. 22	1. 35

[1] Corrected to 60° F.

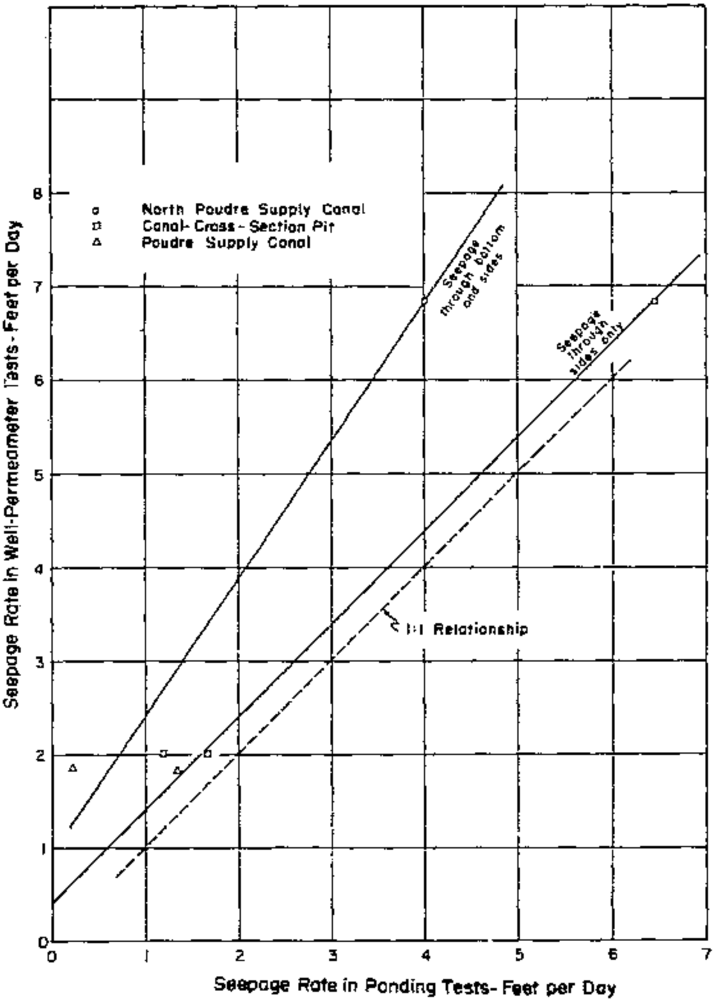


FIGURE 24.—Relationship of seepage rates derived from well-permeameter data and those derived from ponding data on the basis of the assumption that all seepage occurred through canal sides. (Rates corrected to 60° F.)

were much less than those of the first test in 1951 but were twice those of the second 1951 test.

The conclusion is drawn that the Muskat formula is unreliable as a means of computing seepage from the results of permeability tests, because it applies only to homogeneous, isotropic soils, which rarely exist in canals.

Computing seepage rather than permeability from well-permeameter test data seems to have merit. If the total seepage determined by ponding is assumed to go through the sides of the canal, the results are closely correlated with a seepage estimate based on well-permeameter data.

SPECIAL STUDIES

Effect of Depth of Water on Seepage

Seepage measurements made by the ponding method in a previous investigation (*13*) showed that seepage rate tends to increase as depth of water in the canal increases. Different parts of a canal bed are under different depths of water ranging from zero to the maximum depth of water in the canal. A second factor affecting the comparative seepage through the sides and the bottom is the greater permeability of the sides. Separating the effect of side seepage from that of bottom seepage has not proved feasible (*13*). For this reason the effect of water depth on seepage was studied by means of seepage rings in which all the seepage occurred through the soil at the bottoms of the rings, where the head was constant over the entire area.

Equipment and Procedure

The seepage rings that were used for study of seepage in different soils were used also for testing the effect of depth of water on seepage rate. These rings, described on pages 12–13 and illustrated in figures 1, 2, and 4, were operated in clay loam, silt loam, sand, and sandy loam for periods ranging approximately from 4 to 6 months in a season. The tests for determining the effect of depth of water were made about the middle of the seasonal period of operation.

During the day, the inflow was cut off from the seepage rings and depth readings were taken every 2 hours as the water level fell because of seepage. At the end of the day the float controlling the water level was lowered 6 inches and the water turned on, so that a constant level would be maintained during the night. This procedure was repeated until near zero depth was reached. Thereafter, the water levels were raised by a 6-inch increment daily and the seepage determinations were repeated. This procedure was followed until the maximum depth, 2 feet, was again reached. Observations of evaporation, precipitation, and temperature were also made.

Approximately 9 days were needed to make a complete cycle of determinations. Generally, one test was made at each location each season; two tests, one in August and one in October of 1951, were made in the sandy loam A and the silt loam. Since the rings in clay loam and in sandy loam A were operated for 2 years without being moved, it was possible to obtain depth-effect data for these soils for 2 successive years.

Experimental Results

Representative data on the relation between depth of water and seepage, those for the tests in 2 successive years in sandy loam A, are shown graphically in figure 25. For the inner ring, the rates when the levels were successively lowered coincided with those when the levels were raised. For the outer ring, these two series of rates diverged somewhat as depth of water varied. The rates were higher in 1950 than in 1951, and the outer-ring rates were always higher than those for the inner ring.

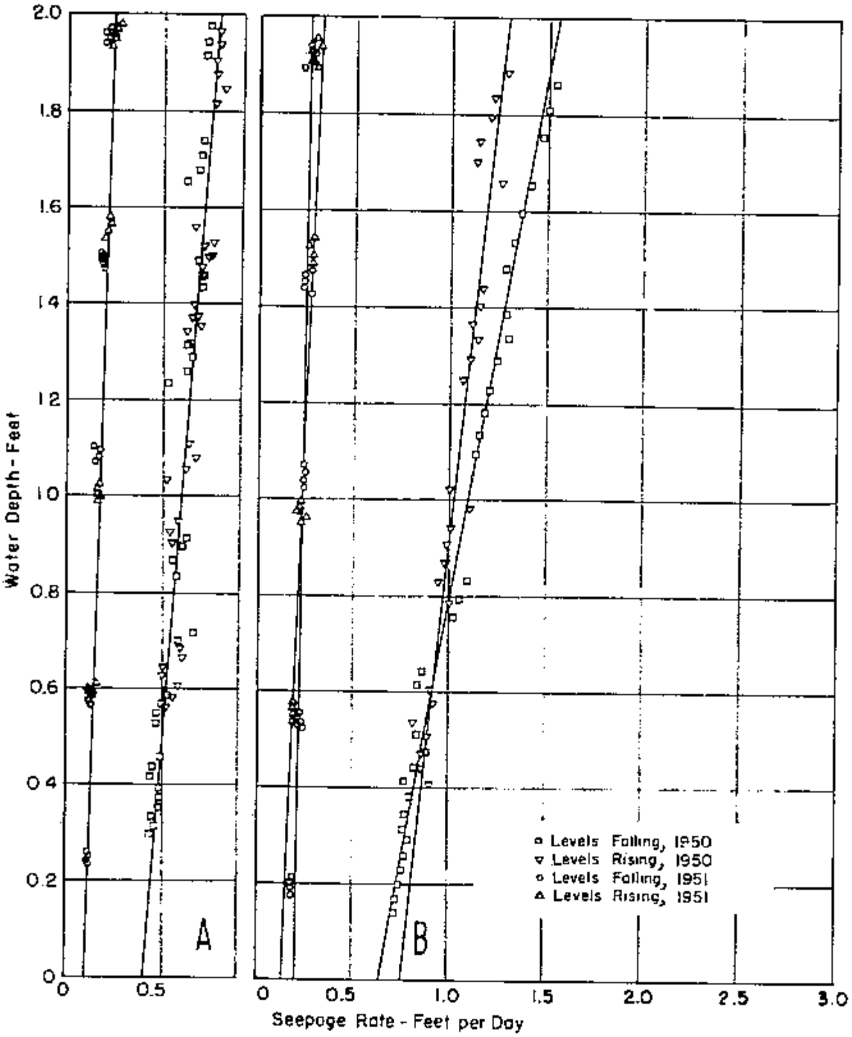


FIGURE 25.—Effect of depth of water on seepage rate in sandy loam A in seepage rings: *A*, inner ring; *B*, outer ring. (Rates corrected for evaporation and precipitation and adjusted for viscosity to 60° F.)

Table 20 summarizes the results of the effect-of-depth tests made over a 4-year period, showing rates at depths of 0.0 foot and 2.0 feet. These rates were obtained by slightly extending the curves for the plotted data. This procedure was justified because the data plot on a straight line. Also shown in table 20 is the rate of change of the seepage rate with depth, which is the slope of the seepage-rate-versus-depth relationship.

In about two cases out of three, the seepage rate for the inner ring was less for a given depth than that for the outer ring.

In about one case out of three, seepage was the same or practically the same regardless of whether water level was falling or rising. In

TABLE 20.—*Summary of results of tests on the effect of depth of water on seepage in seepage rings*

Soil texture and time	Trend of change in water level	Seepage rate[1] in inner ring			Seepage rate[1] in outer ring		
		When depth of water was 0.0 foot	When depth of water was 2.00 feet	Rate of change per foot	When depth of water was 0.0 foot	When depth of water was 2.00 feet	Rate of change per foot
		Feet/day	*Feet/day*	*Feet/day*	*Feet/day*	*Feet/day*	*Feet/day*
Clay loam:							
1949	Falling	1.62	5.20	1.79	0.23	4.06	1.92
	Rising	.62	2.80	1.09	.34	2.40	1.03
	Average	1.12	4.00	1.44	.28	3.23	1.48
1950	Falling	.55	1.32	.38	.42	1.15	.36
	Rising	.55	1.84	.64	.43	1.75	.66
	Average	.55	1.58	.52	.42	1.45	.52
Sandy loam A:							
1950	Falling	.40	.78	.19	.64	1.55	.46
	Rising	.40	.78	.19	.75	1.28	.26
	Average	.40	.78	.19	.70	1.42	.36
August 1951	Falling	.085	.193	.054	.133	.307	.087
	Rising	.088	.168	.040	.133	.307	.087
	Average	.086	.180	.047	.133	.307	.087
October 1951	Falling	.102	.203	.050	.203	.263	.030
	Rising	.075	.248	.086	.129	.326	.098
	Average	.088	.226	.069	.166	.294	.064
Sand, 1952	Falling	.080	.677	.298	.04	1.13	.54
	Rising	.115	.580	.232	.18	.75	.28
	Average	.098	.628	.265	.11	.94	.42
Silt loam:							
August 1951	Falling				.0042	.0315	.0136
	Rising				.0042	.0315	.0136
	Average				.0042	.0315	.0136
October 1951	Falling				.0196	.1000	.0402
	Rising				.0196	.1000	.0402
	Average				.0196	.1000	.0402
Sandy loam B, 1952	Falling	.25	.57	.16	.33	.84	.26
	Rising	.20	.93	.36	.35	1.12	.38
	Average	.22	.75	.26	.34	.98	.32

---

[1] All rates corrected for viscosity to 60° F.

the cases in which a marked difference in seepage rate was associated with difference in the trend of change in water level, the greater seepage more often occurred when the water level was falling.

Analysis of Data and Discussion

The slight tendency toward greater seepage when water level was falling can be attributed to the drainage and storage effect in the underlying soil, which would affect the soil moisture tension. An average of the two rates determined at each level was used as the correct rate. The average seepage rate always decreased as depth of water decreased, but seepage was indicated even when the depth approached zero. This shows that seepage rate is directly proportional not to depth of water above the ground surface but to this depth plus some distance below the surface. According to Lauritzen and Israelsen (*7*), the head resulting from the depth of water is used up within the upper few inches of the soil. If this is so, only a small error would be incurred in assuming that seepage rate varied directly with water depth, provided the depth was fairly great. In all cases, it should be noted, the average seepage rate did vary in a straight line with depth, increasing with depth.

A method of solving for permeability, K, for the seepage rings was developed on the basis of the inner-ring results of the effect-of-depth study. By projecting the lines representing the depth-seepage relationship, a value was determined for the seepage rate for zero depth. According to Darcy's equation

$$q=K\frac{h}{l}, \tag{5}$$

where q is the rate of flow per unit area, K is the permeability, h is the hydraulic head, and l is the length of the soil column. At 0 depth of water h and l are equal, so that $\frac{h}{l}$ equals unity and q equals K. It should be pointed out that this is true only if a negative head caused by soil moisture tension does not exist or is negligible. The seepage rates shown in table 20 for 0.0-foot depth, then, are also values for permeability, K, provided there is no soil moisture tension.

This method is believed to be a fairly accurate one for determining the permeability of undisturbed soil where soil moisture tension is negligible and the ground-water level is not close enough to the surface to affect the seepage rate. It should prove useful under conditions that sometimes make it necessary to compute permeability so that comparisons can be made with other methods of making field estimates of seepage.

For all soils tested and for the whole of the large range in seepage rates, a correlation was noted between the slope of the depth-seepage rate curve and the seepage rate at constant depth. This relationship appears in figure 26. It is not so well defined for the 0-foot depth as for the 2-foot and 5-foot depths. With the seepage rate known for a particular depth, the rate for any other depth can be determined by use of figure 26. From this figure it can be noted that the depth of

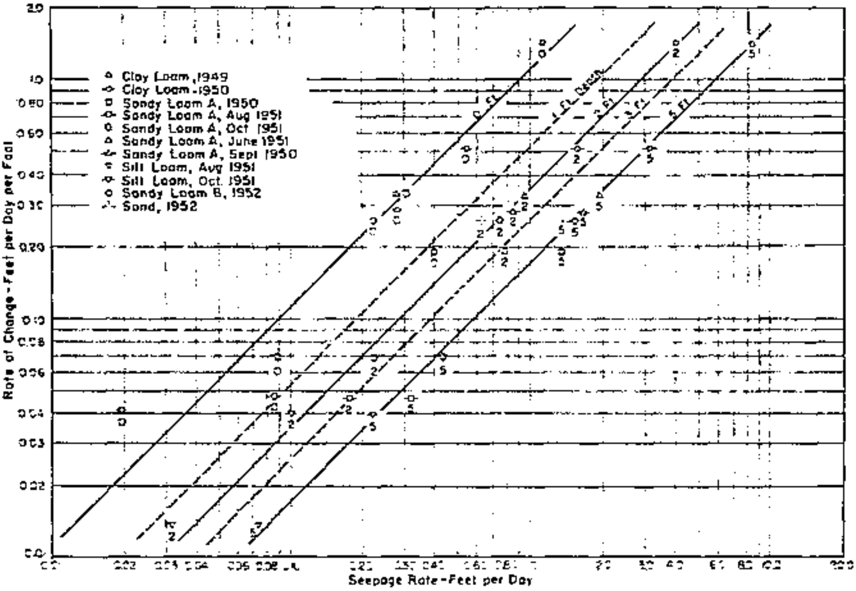


FIGURE 26.—Summary of results of effect-of-depth tests. The number on each point indicates the depth, in feet, for which the point was determined. (All rates corrected to 60° F.)

water has more influence on the seepage rate when the rate is high than when the rate is low.

Although the effect-of-depth tests in the seepage rings showed that the increase of seepage rate with depth of water in the rings always followed a straight-line trend, the results of several ponding tests on canals (see pp. 39–52) revealed that the depth-seepage relationship was not linear; that the slope usually decreased with depth. It should be remembered that the effect-of-depth tests in seepage rings are comparable only with tests made on the bottoms of canals. Any deviation from the relationship shown in figure 26 is believed to be due to seepage from the canal sides. The ponding tests conducted on canals showed that in two cases seepage from the sides was much greater than that from the bottom; in fact, seepage-meter measurements indicated that in one canal there was practically no loss from the bottom. However, the test canals were all newly constructed, and results for old canals would probably be different.

Effect of Temperature

In the operation of the seepage rings, it was noted that seepage rates as determined by twice-daily readings were fairly constant after the rings had been in operation 2 or 3 months, but that the rates determined in 1-hour tests fluctuated widely. This fluctuation seemed to have some relation to the temperature of the water. In order to check on its cause, special tests were conducted with several different types of seepage equipment in three different soils.

Equipment and Procedure

Special tests on the effect of temperature on seepage were made in connection with operation of the rings used in studying seepage from different soils and the rings (described on pp. 70–72) used in studying the effect of depth to ground water on seepage rate. These effect-of-temperature tests were made in sand, sandy loam A, and sandy loam B. The 1952 tests in sand and sandy loam B were made in inner seepage rings. The 1953 tests in sand and sandy loam B and the 1952 and 1953 tests in sandy loam A were made in the installations prepared for the depth-to-ground-water study. Effect-of-temperature tests were made also in connection with the well-permeameter tests along the centerline of the then proposed North Poudre Supply Canal (described on pp. 39–42). In addition, such tests were made under laboratory conditions.

The procedure followed for determining the effect of temperature in seepage rings and in depth-to-ground-water rings was essentially the same. After the rings had been in operation about 3 months, the seepage was determined every 2 hours for a period of 3 days, and at the same times water temperature at soil level, soil temperature at 1 inch and at 1 foot, and evaporation were noted. Outflow for short intervals from the permeameter wells along the centerline of the proposed North Poudre Supply Canal and the temperature of the water in the wells at these times were noted over a period of about 4 days. Both

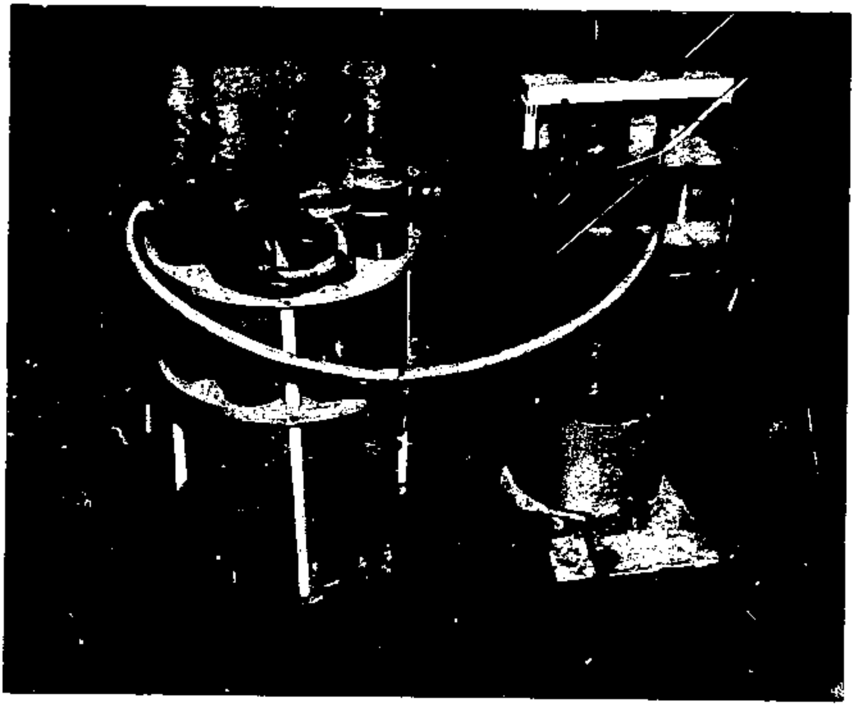


FIGURE 27.—Laboratory equipment used for studying the effect of temperature on permeability.

in seepage rings and in wells, the changes in temperature were those resulting from natural causes. All the effect-of-temperature tests with the seepage rings were made during the same period of August in 1952 and 1953. In all the tests, seepage rates were corrected for viscosity to 60° F.

Equipment used for preparing and testing samples in the laboratory included 2.5-inch OD lucite percolation cylinders and a constant-head tank (fig. 27). Immersion heaters were provided for controlling the temperature of the water in the constant-head tank. A standard procedure was followed in packing the cylinders and conducting the tests. Samples of soil were dried, ground, and passed through a 2-mm. sieve. About 350 gm. of each sample was poured into a lucite percolation cylinder from a height of 21 inches above the base, by use of a funnel and a rubber hose. For compaction, the sample was dropped 10 times on a block of soft wood from a height of 2.5 cm. The cylinders were placed in a rack connected by hose with the constant-head water supply.

Water was allowed to percolate down through the soil in the percolation tubes at normal room temperatures for a period of about 2 weeks. After this time the temperature of the water was raised by use of the immersion heaters. The outflow from the tubes was measured for periods of one-half hour before and after the temperature was changed. The water was kept at the new temperature for several hours, then its temperature was raised again. Porosity was determined for each sample, also the percentage of the voids filled with air at the end of the tests.

Experimental Results

The results of the tests on the effect of temperature on seepage from seepage rings in sand, sandy loam A, and sandy loam B are presented in figures 28, 29, and 30. Shown in these figures are the seepage rates, corrected for viscosity to 60° F., and the associated bottom water temperatures and 1-foot soil temperatures, also the water depths at which the tests were made.

In sand (fig. 28), there was very little variation in rates for 1952, the first year tests were made. However, during 1953 the maximum variation in sand over a 24-hour period was 65 percent. The highest seepage rates occurred at the lowest water temperature, and the lowest seepage rates at the highest water temperature. For sandy loam A (fig. 29), the variation in rates followed a similar cycle, amounting to about 10 percent the first year and 20 percent in 1953. During 1953 temperatures had a larger range than in 1952. For sandy loam B also (fig. 30), the seepage rates were highest when the water temperatures were lowest. Here the rates varied by about 37 percent in 1952 and about 33 percent in 1953. Here, also, the variation in temperature was greater in 1953 than in 1952.

In the test made in conjunction with the well-permeameter determinations along the centerline of the proposed North Poudre Supply Canal (fig. 31), the highest permeability was noted during the period of lowest water temperatures and the variation in rates amounted to several hundred percent.

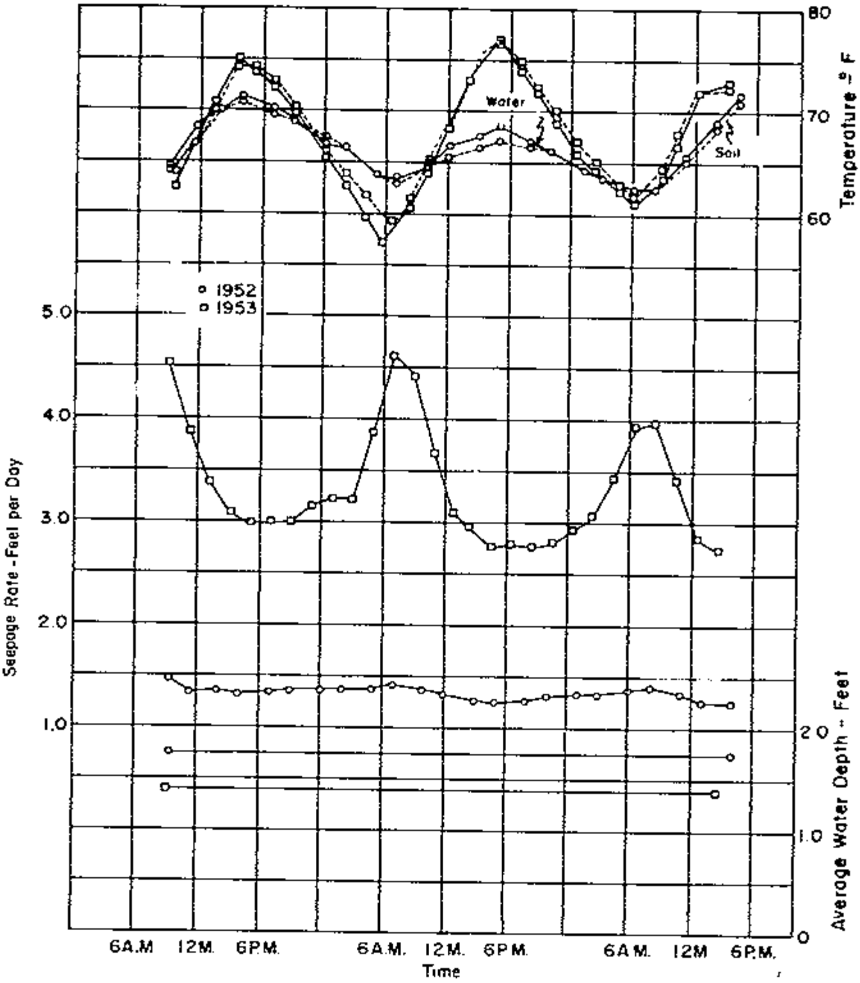


FIGURE 28.—Effect of temperature on rate of seepage in sand. (Rate corrected for viscosity to 60° F. Soil temperature determined at 1 foot.)

The results of the laboratory tests are presented in figure 32, which shows both the observed permeability and that corrected for viscosity to 60° F.

Variation in permeability was considerable even after correction for viscosity to a standard temperature. This variation, however, diminished with air content. Seepage rates uncorrected for viscosity showed a more pronounced variation with temperature than the corrected rates. In contrast with the tests made with seepage rings and well permeameters, these tests show the highest permeabilities associated with the highest water temperatures and the lowest with the lowest water temperatures.

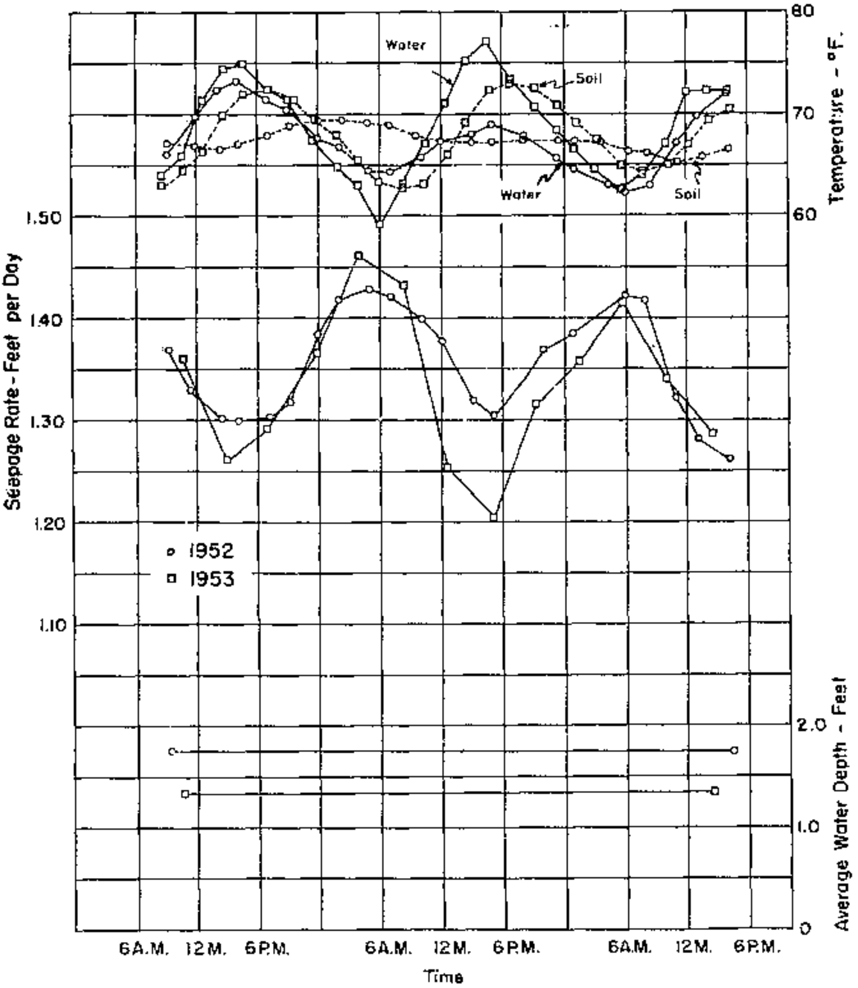


FIGURE 29.—Effect of temperature on rate of seepage in sandy loam A. (Rate corrected for viscosity to 60° F. Soil temperature determined at 1 foot.)

Analysis of Data and Discussion

Apparently some factor dependent on temperature affects the seepage rate. The air that, in the form of small bubbles, remains in the soil even after long periods of wetting may have a variable effect on seepage as temperature changes. It would be expected that air would be absorbed by the water as the water cools and released in the soil as the water warms. Analysis of the data disclosed that generally the seepage increased when the water cooled and decreased when the water warmed.

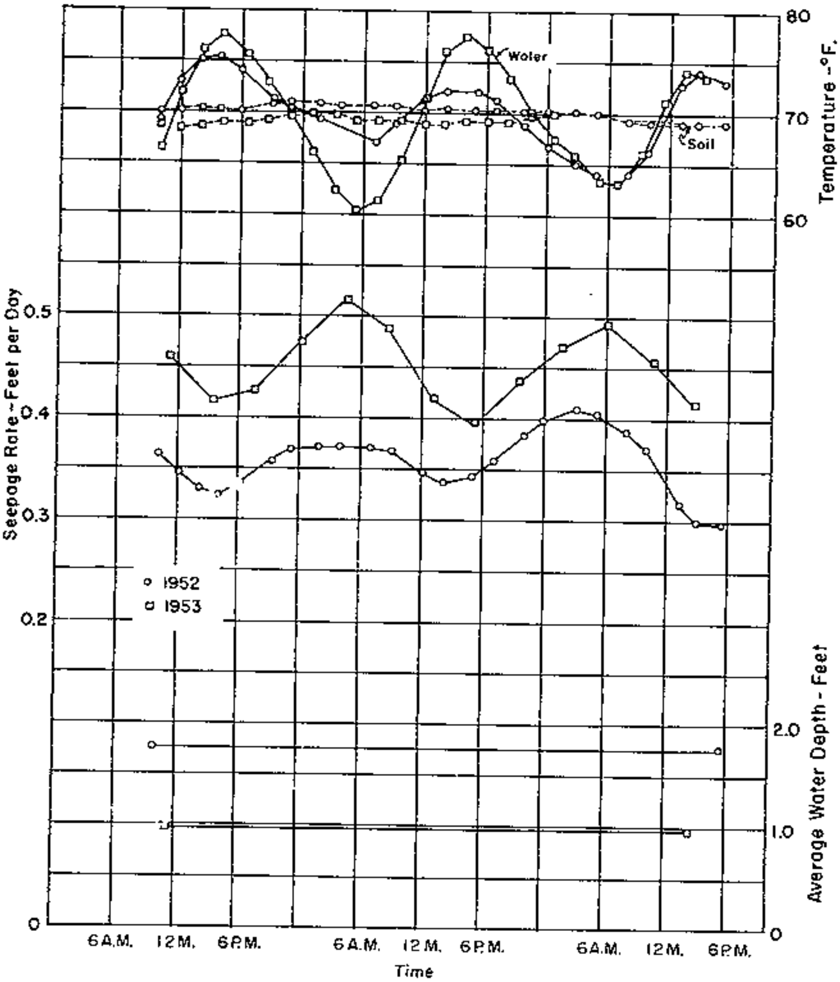


Figure 30.—Effect of temperature on rate of seepage in sandy loam B. (Rate corrected for viscosity to 60° F. Soil temperature determined at 1 foot.)

Because the range of temperatures encountered was so small, expansion of air resulting from temperature change could not account for the seepage differences noted.

It has been suggested that changes in vapor pressure with temperature may affect rate of seepage; that because vapor pressure changes rapidly with temperature, air bubbles would be expected to expand and contract appreciably within soil material, thereby changing its effective porosity. Fair and Hatch, as cited by Franzini (4), have demonstrated for granular material that

$$K \propto \frac{n^3}{(1-n)^2}, \tag{6}$$

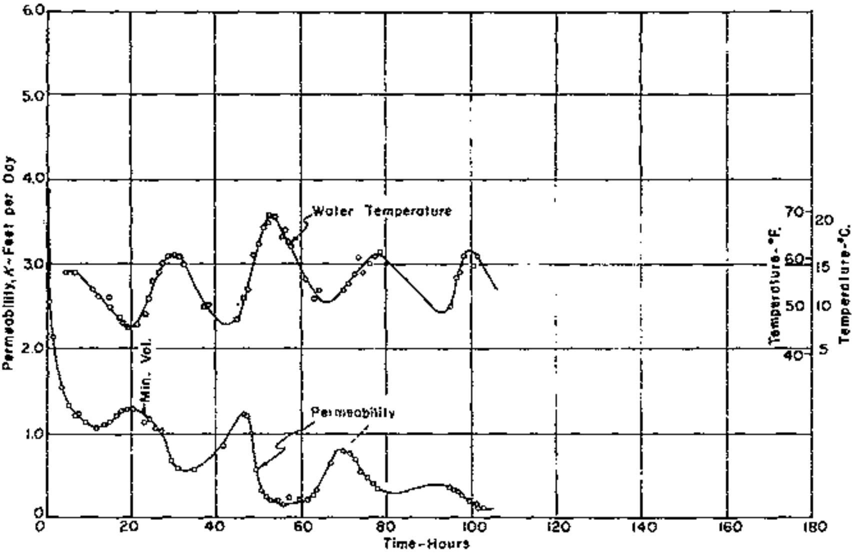


FIGURE 31.—Effect of temperature on soil permeability in well-permeameter tests, proposed North Poudre Supply Canal. (Permeability corrected for viscosity to 60° F.)

where K is the permeability of the material and n is the porosity. These investigators found that small changes in porosity produce large changes in permeability and consequently in seepage rate. Since the change in volume of air bubbles is directly proportional to the change in pressure, the change in porosity can be computed if the percentage of air and the temperature are known. Unfortunately, the percentage of air in soil cannot readily be determined in the field. However, the porosity of soil under field conditions can be determined, and it is possible to calculate the relative effect of change in vapor pressure on soil porosity on the basis of an assumption regarding the percentage of air in the soil.

Computations of changes in seepage in sand resulting from changes in vapor pressure were made on the assumption that at 60° F., 15 percent of the voids in the sand were filled with air. The field porosity of the sand as determined by tests was 0.35 percent. Corresponding computations were made on the assumption of 10-percent air content. The data are presented in table 21, and curves obtained by applying the corrections for temperature and air content appear in figure 33.

The curve obtained by correcting for a 10-percent air content and for viscosity is very close to the uncorrected seepage curve. If the correction were for a lower percentage of air, near 7 percent, the two curves would probably coincide. This indicates that the effects of changing viscosity and porosity on seepage as temperature varies are compensating factors.

Tests on the permeability of sands at widely different temperatures were made by Pillsbury (*12*). In his tests, increasing the temperature of the water from 40° F. to 120° did not materially change the uncorrected permeability of sand. However, if his data had been corrected

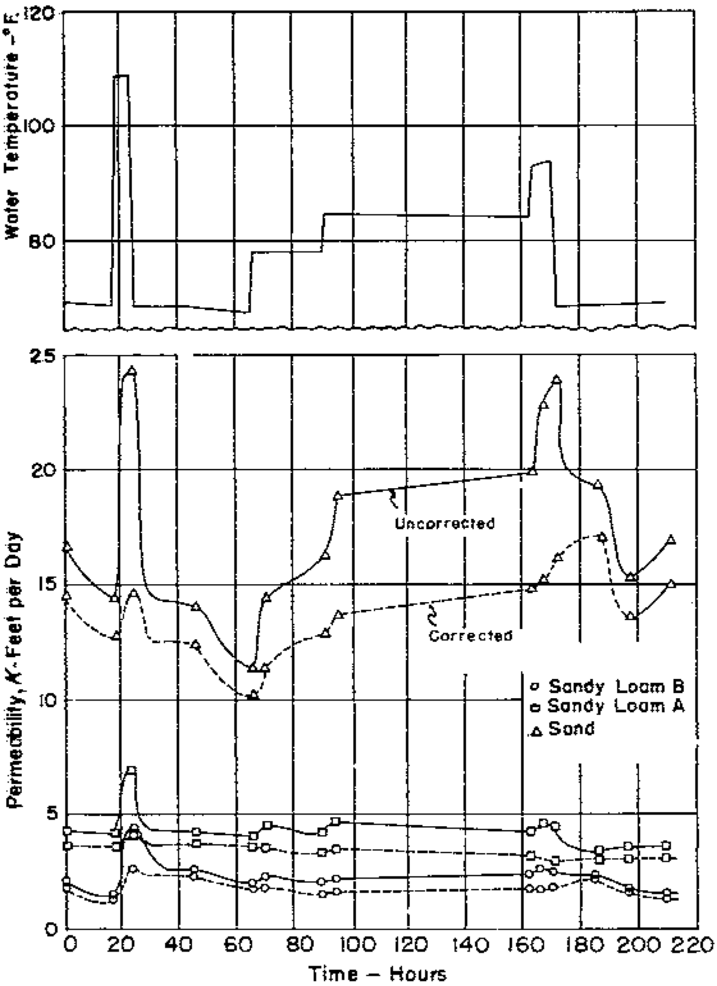


FIGURE 32.—Effect of temperature on soil permeability in laboratory permeability tests. (The water temperature shown is an average of the temperature as the water entered the sample and that of the effluent. For sandy loam A, $n=53.8$ percent, air=2.2 percent; for sandy loam B, $n=57.3$ percent, air=18.3 percent; for sand, $n=43.1$ percent, air=24.7 percent. Correction is for viscosity at 60° F.)

for changes in viscosity to a standard temperature they would have indicated a wide variation in permeability.

In the tests of disturbed samples of soil (fig. 32), the permeability of sand varied widely with the temperature of the water in the sand. This variation decreased somewhat when the data were corrected for viscosity. It is noteworthy that the variation of the corrected permeability decreased with the amount of air present; sandy loam, with 2.2-percent air, had the smallest variation.

Under normal conditions the temperature of soil several feet beneath the ground surface changes slowly through a season. Its diurnal

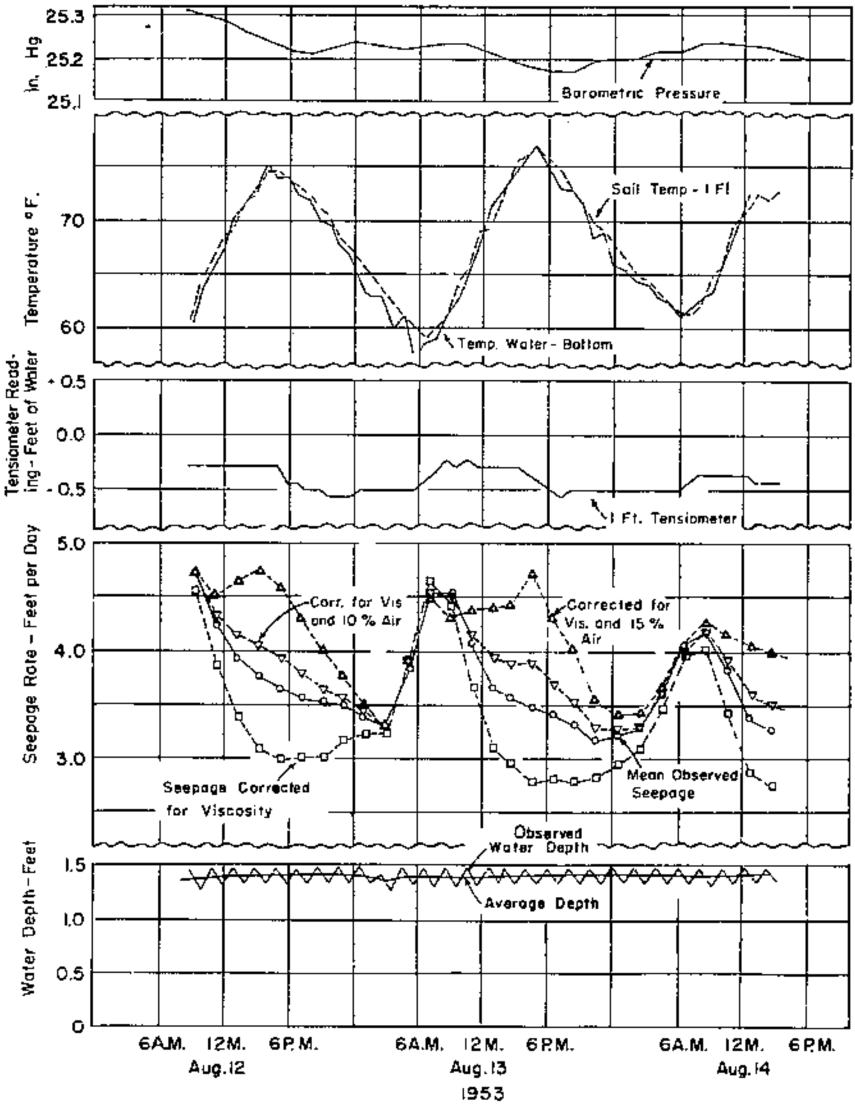


FIGURE 33.—Effect of temperature on rate of seepage in sand, 1953. (Correction for viscosity is to 60° F.)

variation, also, is small. However, conditions in the soil under a canal carrying water are different. Some heat from the water in the canal will be carried into the soil by conduction; but this is a slow process, and the effect is usually small. If water seeps from the canal, the soil will be warmed by the water seeping through it. Because of its high specific heat, water is very effective in warming the soil. If the seepage is large, the soil and water temperatures will approach each other and in some cases will become the same.

TABLE 21.—*Effect of change in porosity with temperature on seepage rate in sand, 1953*

Time (average)	Average depth	Observed seepage rate [1]	Bottom water temperature	Correction factor for viscosity at 60° F.	Seepage corrected for viscosity to 60° F.	Vapor pressure at water temperature	Vapor-pressure correction factor ($n=35$ percent, air=15 percent)	Seepage rate corrected for viscosity and vapor pressure (air=15 percent)	Vapor-pressure correction factor ($n=35$ percent, air=10 percent)	Seepage rate corrected for viscosity and vapor pressure (air=10 percent)
	Feet	*Feet/day*	*° F.*		*Feet/day*	*Feet of water*		*Feet/day*		*Feet/day*
8/12/54:										
9:10 a.m	1. 387	4. 704	61. 8	0. 973	4. 577	0. 628	1. 040	4. 76	1. 023	4. 68
11:10 a.m	1. 401	4. 224	66. 0	. 919	3. 882	. 729	1. 165	4. 52	1. 110	4. 31
1:10 p.m	1. 408	3. 936	71. 0	. 859	3. 381	. 865	1. 370	4. 64	1. 227	4. 15
3:10 p.m	1. 407	3. 744	74. 0	. 827	3. 096	. 957	1. 530	4. 73	1. 313	4. 06
5:10 p.m	1. 409	3. 624	74. 0	. 827	2. 997	. 957	1. 530	4. 59	1. 313	3. 93
7:05 p.m	1. 412	3. 552	72. 2	. 846	3. 005	. 900	1. 430	4. 30	1. 260	3. 79
9:05 p.m	1. 417	3. 504	69. 8	. 872	3. 055	. 830	1. 310	4. 00	1. 195	3. 65
8/13/54:										
11:00 p.m	1. 415	3. 480	67. 0	. 907	3. 156	. 754	1. 200	3. 78	1. 130	3. 56
1:00 a.m	1. 416	3. 384	63. 5	. 952	3. 222	. 668	1. 085	3. 50	1. 055	3. 40
3:00 a.m	1. 355	3. 288	61. 5	. 978	3. 216	. 621	1. 030	3. 31	1. 020	3. 28
5:00 a.m	1. 412	3. 816	59. 0	1. 017	3. 881	. 569	. 978	3. 79	. 988	3. 84
7:00 a.m	1. 398	4. 536	58. 8	1. 020	4. 627	. 565	. 972	4. 49	. 985	4. 55
9:00 a.m	1. 400	4, 536	61. 8	. 973	4. 414	. 628	1. 040	4. 31	1. 025	4. 53
11:00 a.m	1. 404	4. 056	66. 8	. 909	3. 687	. 749	1. 192	4. 40	1. 125	4. 15
1:00 p.m	1. 412	3. 684	71. 8	. 850	3. 131	. 890	1. 410	4. 42	1. 248	3. 95
2:30 p.m	1. 413	3. 576	74. 0	. 828	2. 691	. 957	1. 530	4. 44	1. 313	3. 89
4:30 p.m	1. 408	3. 480	76. 5	. 802	2. 791	1. 042	1. 700	4. 73	1. 396	3. 90
6:30 p.m	1. 415	3. 408	74. 0	. 827	2. 818	. 957	1. 530	4. 31	1. 313	3. 70
8:30 p.m	1. 414	3. 312	72. 5	. 843	2. 792	. 910	1. 445	4. 03	1. 268	3. 54
10:30 p.m	1. 417	3. 192	68. 8	. 883	2. 819	. 802	1. 270	3. 58	1. 173	3. 31
8/14/54:										
12:30 a.m	1. 422	3. 216	65. 8	. 922	2. 965	. 725	1. 155	3. 42	1. 103	3. 27
2:30 a.m	1. 420	3. 288	64. 2	. 942	3. 097	. 685	1. 105	3. 42	1. 068	3. 31
4:30 a.m	1. 414	3. 600	62. 8	. 960	3. 456	. 651	1. 065	3. 68	1. 042	3. 60

6:30 a.m	1. 402	4. 056	61. 5	. 978	3. 967	. 621	1. 032	4. 10	1. 020	4. 04
8:30 a.m	1. 393	4. 176	63. 0	. 958	4. 001	. 656	1. 070	4. 28	1. 045	4. 18
10:30 a.m	1. 409	3. 816	67. 5	. 900	3. 434	. 767	1. 217	4. 17	1. 142	3. 92
12:45 p.m	1. 416	3. 384	72. 0	. 848	2. 870	. 895	1. 420	4. 07	1. 254	3. 60
2:45 p.m	1. 421	3. 288	72. 5	. 843	2. 772	. 910	1. 445	4. 00	1. 268	3. 51

---

[1] Corrected for evaporation and precipitation.

If the difference in temperature between canal water and the soil when the water temperature is at its daily maximum is used as the basis of comparison, it will be seen in figures 28–30 that the seepage tends to vary inversely with the temperature difference. This difference and the seepage rates are given in table 22 for all the tests. The means of the data for each series, corrected for differences in depth of water, are plotted in figure 34. Although there are inconsistencies, the data indicate a fairly close correlation between daily maximum difference in temperature and the seepage rate. Because the temperature differences are dependent on the temperature of the water in the canal, this relationship cannot be used to measure the actual seepage, but it should prove useful in finding where the maximum seepage in a canal is occurring.

The hour-to-hour variation in seepage rates found in the present study may be due to some indirect effect of changes in temperature of the water. Evidence of such an effect was observed in tests made

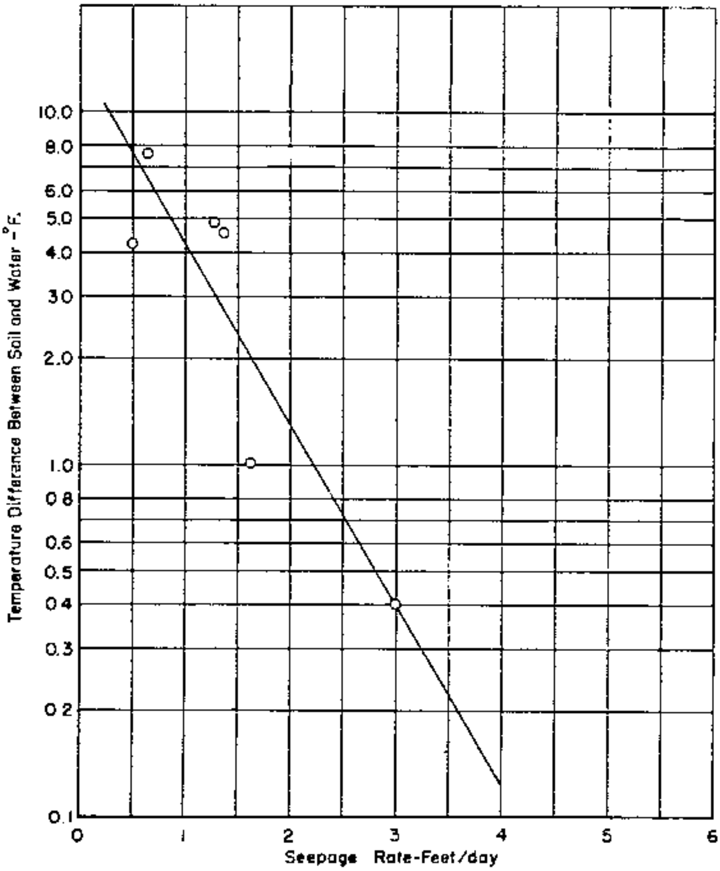


FIGURE 34.—Relationship of seepage rate and difference in temperature between soil and water when water temperature was at its maximum. (The six points graphed represent means for two series of tests made in the years 1952 and 1953, respectively, in sand, sandy loam A, and sandy loam B.)

TABLE 22.—*Effect of differences between soil temperature and water temperature on seepage rate when water temperature was at its daily maximum* [1]

Time and soil	1st maximum		2d maximum		3d maximum		Mean	
	Temperature difference	Seepage rate	Temperature difference	Seepage rate	Temperature difference	Seepage rate	Temperature difference	Seepage rate
Aug. 13 to 15, 1952:	*° F.*	*Feet/day*	*° F.*	*Feet/day*	*° F.*	*Feet/day*	*° F.*	*Feet/day*
Sand	0.5	1.68	1.5	1.57	0.9	1.57	1.0	1.61
Sandy loam A	6.5	1.30	2.0	1.30	6.0	1.26	4.8	1.29
Sandy loam B	5.5	.49	2.2	.53	5.0	.49	4.2	.50
Aug. 12 to 14, 1953:								
Sand	.6	3.00	.0	2.80	.6	2.80	.4	[2] 3.00
Sandy loam A	4.6	1.37	5.0	1.27	4.0	1.35	4.5	[2] 1.37
Sandy loam B	9.0	.42	8.5	.40	5.4	.41	7.6	[2] .65

[1] Seepage rates corrected for viscosity to 60° F.

[2] Corrected for effect of difference in depth.

in both disturbed and undisturbed material of several soil types with several different types of equipment. The variation ranged from a practically insignificant amount in one case to several hundred percent in another.

Inasmuch as seepage rates corrected for viscosity to a standard temperature in some cases varied even more widely than the observed rates, and correcting for change in porosity with change in vapor pressure seemed only to compensate the viscosity correction, it appears that seepage data should not be corrected for viscosity changes due to temperature for the purpose of comparisons with other data.

The wide fluctuation in seepage rates cannot be explained at this time. It is believed that it may depend on an air-water relationship involving the solubility of air in water and the process of solution or dissolution of soil air.

A fairly close correlation was found between the temperature gradient in the soil and the seepage rate. A large difference between daily maximum water temperature and temperature of the soil at 1-foot depth indicated a low seepage rate, whereas a small difference indicated a high rate. With the development of proper equipment, this fact could be used for locating areas of high seepage.

Effect of Depth to Ground Water

In connection with water-spreading studies, investigators have noted that seepage rate decreases when the ground-water level approaches the ground surface of the spreading area (*9*). An effort was made in the present study to find out how closely depth to ground water and rate of seepage are related and within what limits of ground-water level the relation exists.

Equipment and Procedure

In order to study the effect of depth to ground water on the seepage rate, special installations shown in figures 35 and 36 were provided. A metal ring 12 feet in diameter and 3 feet deep was sunk in an excavation and was floored with concrete. A 3-inch thickness of gravel was placed immediately above the concrete floor, and a 1-inch-diameter

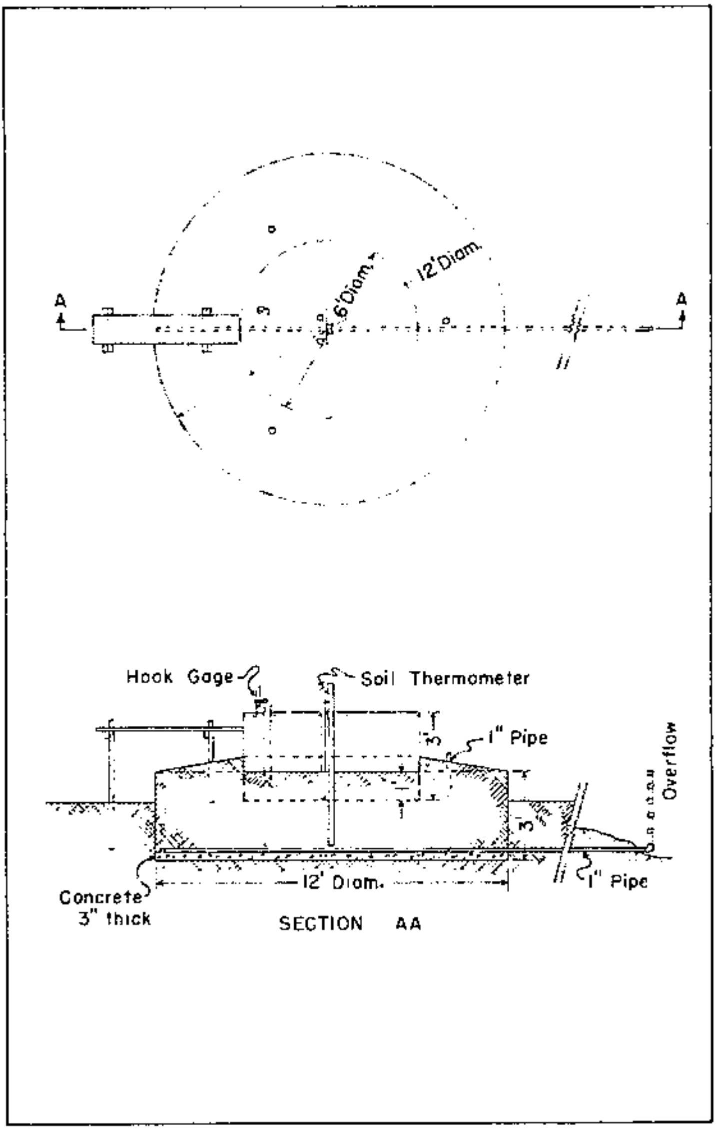


Figure 35.—Diagram of ring for studying the effect of depth to ground water on seepage.

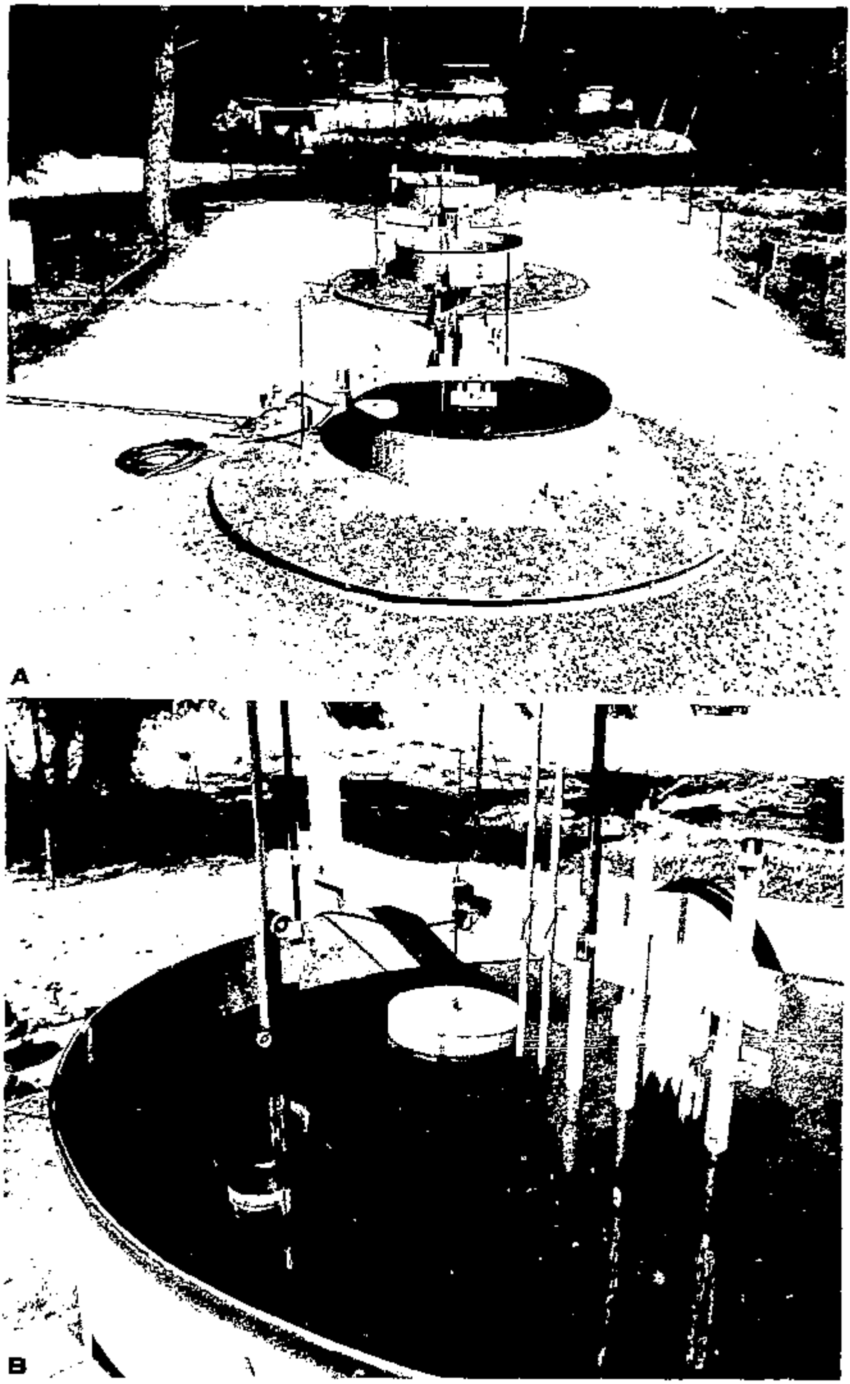


FIGURE 36.—*A*, Rings for studying the effect of depth to ground water on seepage; *B*, equipment in position within one of the rings.

perforated pipe was embedded in this gravel to serve as a drain for the ground water. Removable sections of pipe 6 inches long were attached vertically to the outlet end of this pipe, outside the ring, for adjustment of the depth to ground water. The ring was then refilled with soil. Next a ring 6 feet in diameter and 3 feet deep was set inside the 12-foot ring and 2 feet higher, to accommodate a 1-foot layer of soil and a 2-foot depth of water. Three piezometers were equally spaced around the outer ring to measure the distance to ground water. During the second year of the tests, piezometers were installed also in the inner ring and tensiometers were installed in the rings to measure the soil moisture tension. One tensiometer was set 1 foot below the ground surface in the inner ring and another at 2-foot depth in the outer ring. Soil thermometers were installed in the inner ring 1 inch and 1 foot below the soil surface.

Installations of this kind were made in three different soils—sand, sandy loam A, and sandy loam B—the properties of which are given in table 2.

Water for the rings was obtained by pumping directly from the Poudre River into a settling tank. The water was then drawn from the tank through calibrated domestic-type water meters. The water levels in the rings were controlled by floats. Solenoid valves were used to permit high rates of flow for short periods so that the water meters would operate in the range for which they were designed. Analysis of the water showed that it had a low salt content.

Readings were made on these rings as on the seepage rings, with the addition of daily determinations of ground-water elevation and of soil tension or pressure. Twice-daily measurements were made of the seepage from the rings, by noting the inflow through the water meters and measuring the fluctuation of water surfaces by means of hook gages.

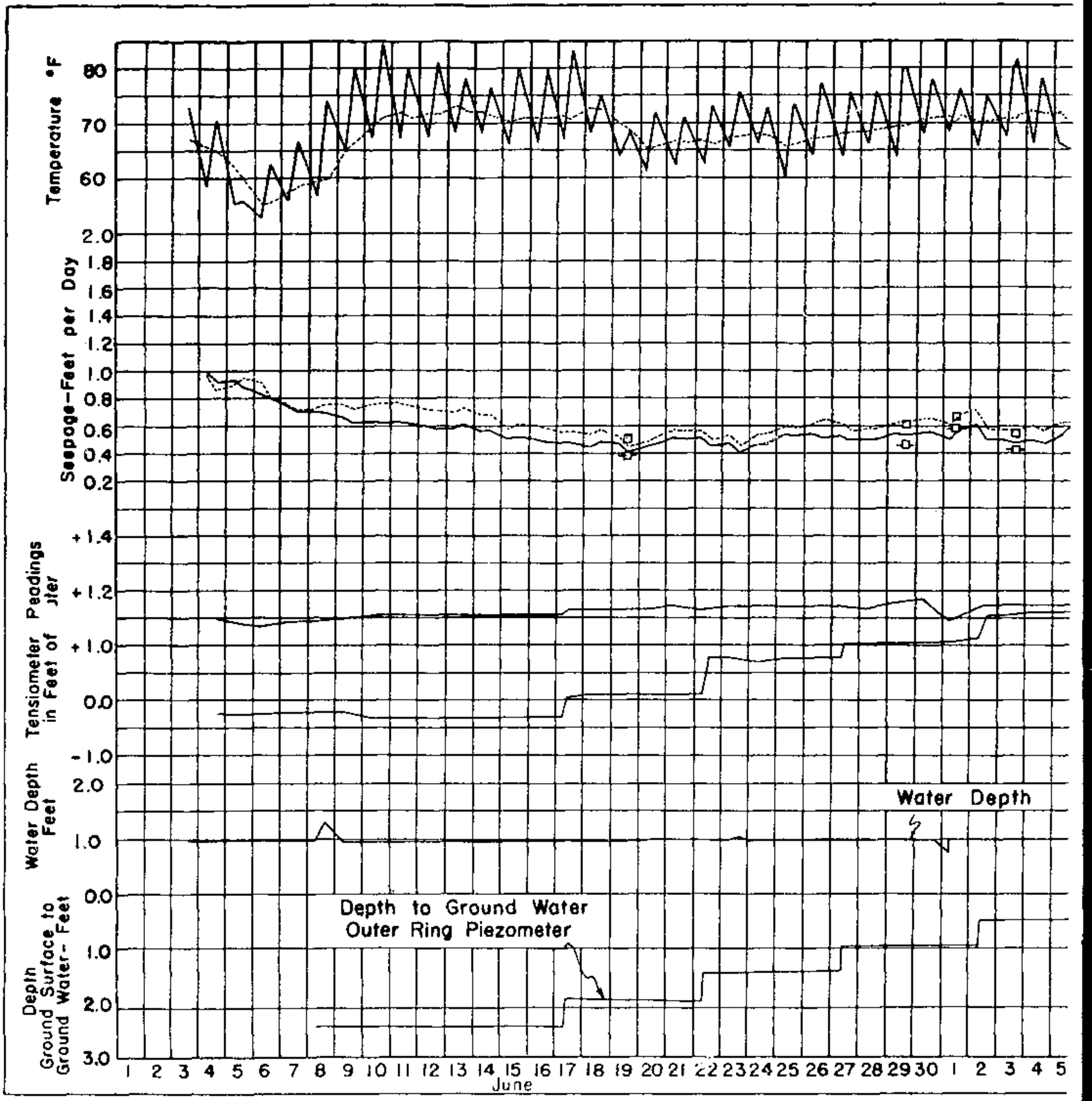
Records were made of air temperature, of water temperature at the soil surface within the inner ring, and of soil temperatures at 1 inch and 1 foot below the soil surface. Precipitation was measured with a standard Weather Bureau rain gage, and evaporation with a Weather Bureau type A evaporation pan.

Depth to ground water was held constant for a period of about 5 days. After this time it was changed, by adjusting the elevation of the outlet pipe, first to maximum and then, by decrements of approximately 6 inches each at intervals of about 5 days, to zero. It was then correspondingly increased until it again reached its maximum. Approximately three complete cycles were made during each annual test period.

Experimental Results

Figure 37 (in pocket inside back cover) presents results of the tests made in sandy loam A during the 1953 season, in which operation was continuous from June 3 until October 30 and the water depth was held at 1 foot during the first series of tests but increased to 1.5 feet for the second and third series. (This was the second year of operation in this soil. The 1952 tests were inconclusive on account of the large number of leaks that occurred.) Included in figure 37 are the depths to ground water, the operating depth of water, the

Figure 37



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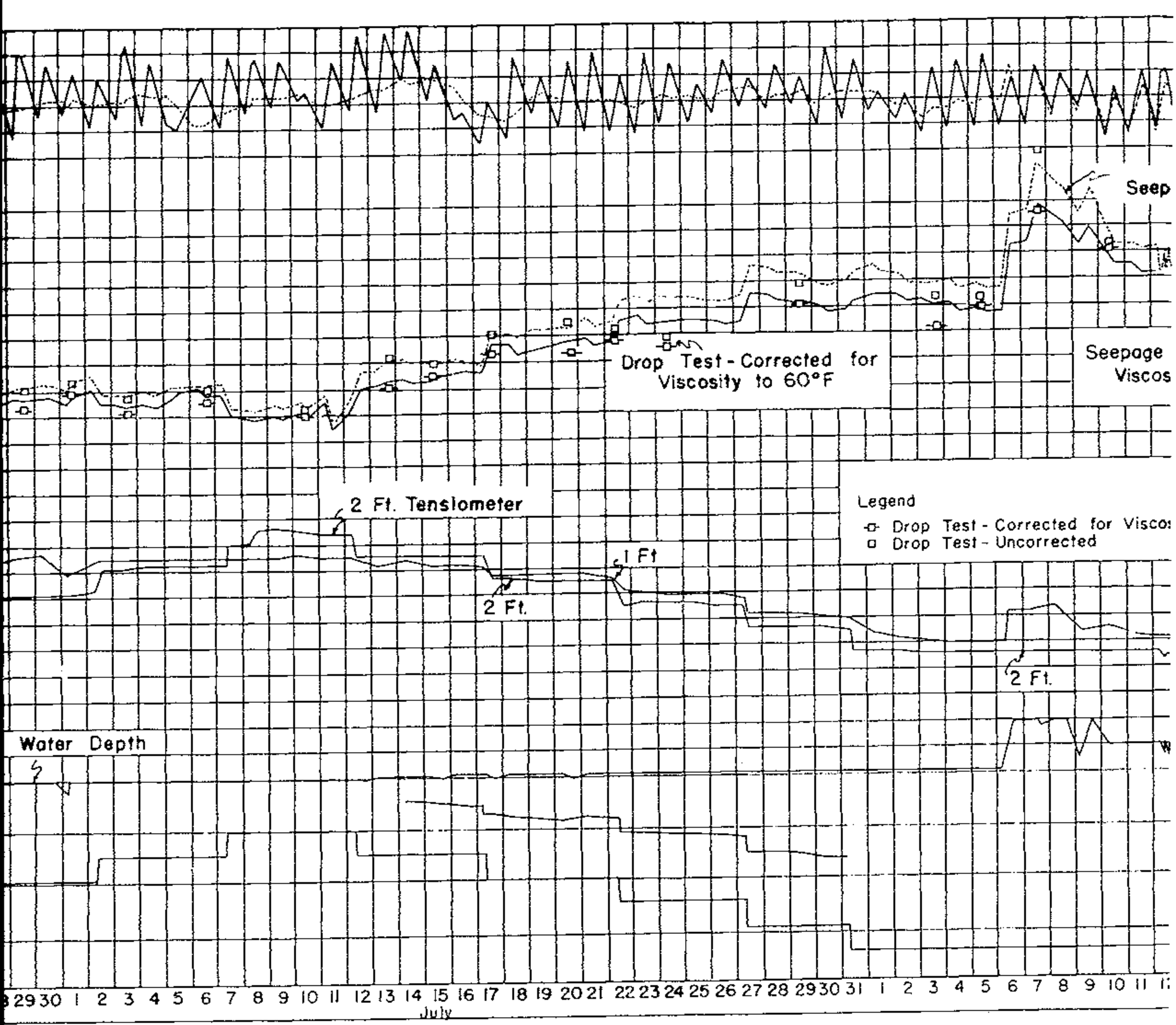
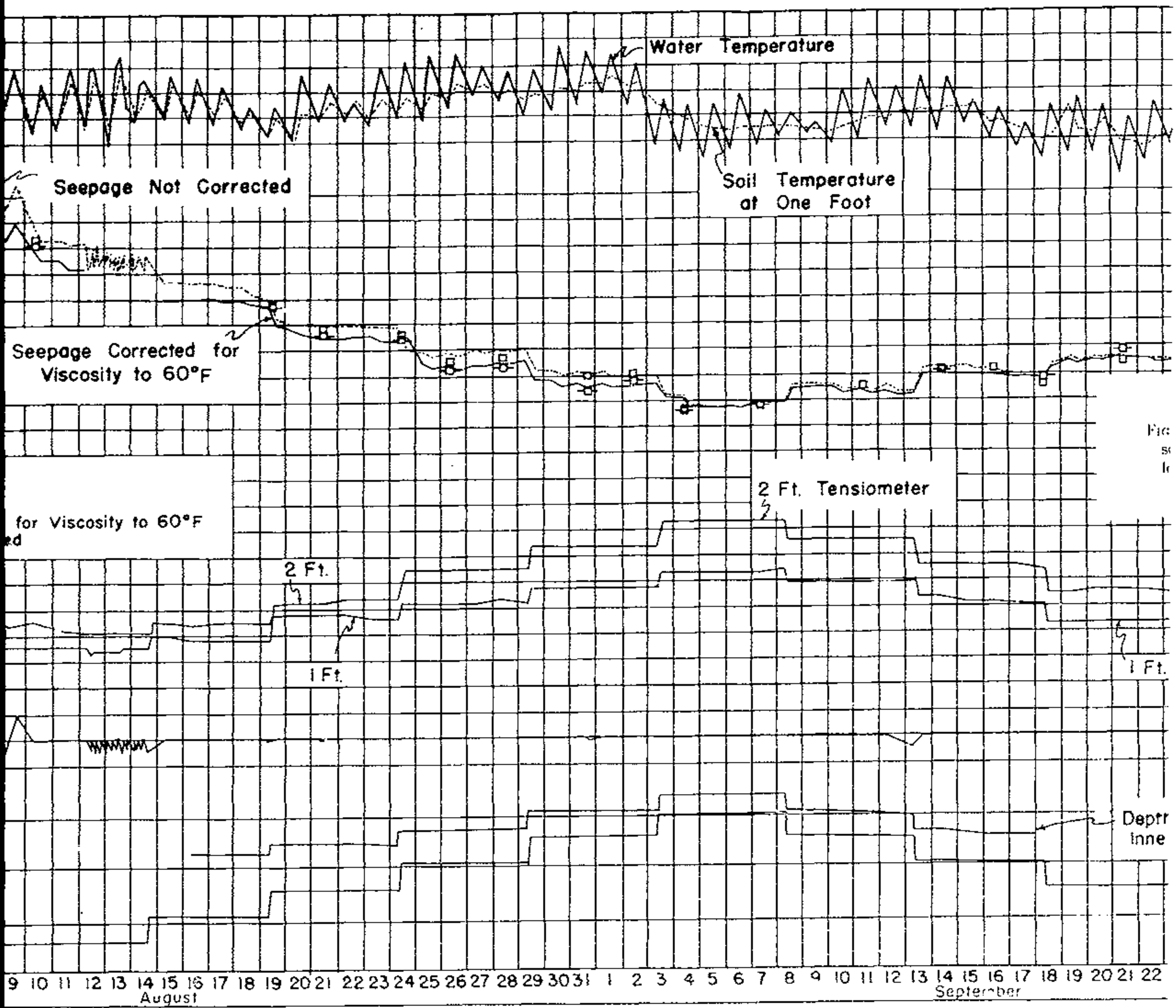

Seep
Drop Test - Corrected for Viscosity to 60°F
Seepage
Viscos
2 Ft. Tensiometer
Legend
-□- Drop Test - Corrected for Visco
□ Drop Test - Uncorrected
1 Ft
2 Ft.
2 Ft.
Water Depth
29 30 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 1 2 3 4 5 6 7 8 9 10 11
July

TB 1203 (1959)   USDA TECHNICAL BULLETINS   UPDATA
MEASURE SEEPAGE FROM IRRIGATION CHANNELS
ROBINSON, A R ; ROHWER, C   2 OF 2


Water Temperature
Seepage Not Corrected
Soil Temperature at One Foot
Seepage Corrected for Viscosity to 60°F
2 Ft. Tensiometer
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9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22
August
September

Fig

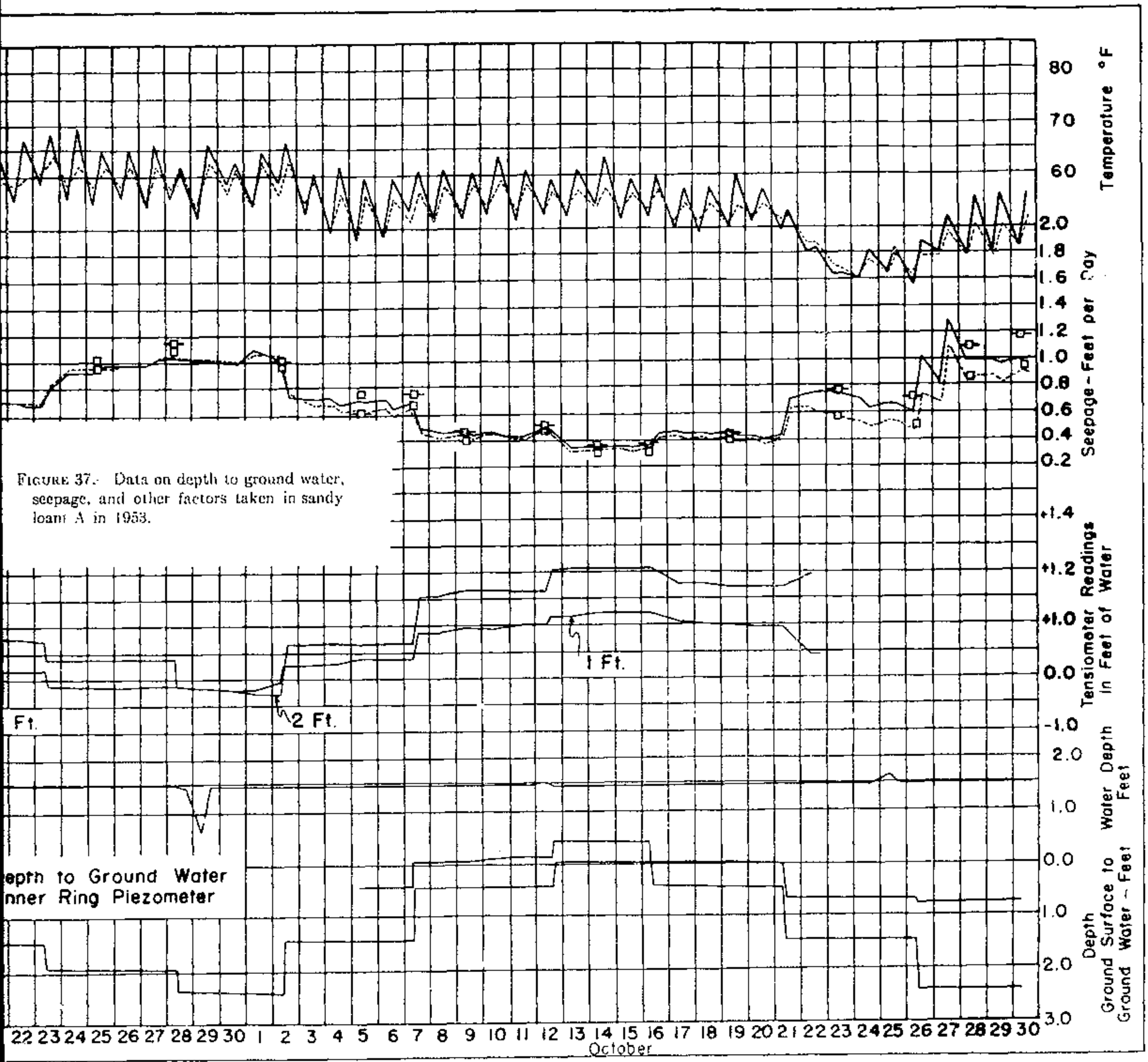

FIGURE 37.– Data on depth to ground water, seepage, and other factors taken in sandy loam A in 1953.

soil-moisture-tension determinations, the observed seepage rates. and the water and soil temperatures.

Except for the first month of operation, when the seepage rate remained fairly constant at about 0.6 foot per day, and for a short period after the water level was raised, the seepage rate fluctuated with depth to ground water. The daily rate ranged approximately from 0.34 foot to 2.0 feet, according to the depth to ground water and the depth of water.

The results of the depth-to-ground-water tests in sand, sandy loam A, and sandy loam B are given in table 23 and are plotted in figure 38. (Data for series 2 of the tests in sand are omitted, because of the erratic nature of the results obtained.) It was found that the seepage rates varied over the 5-day periods within which depth to ground water remained constant, so only the rates immediately

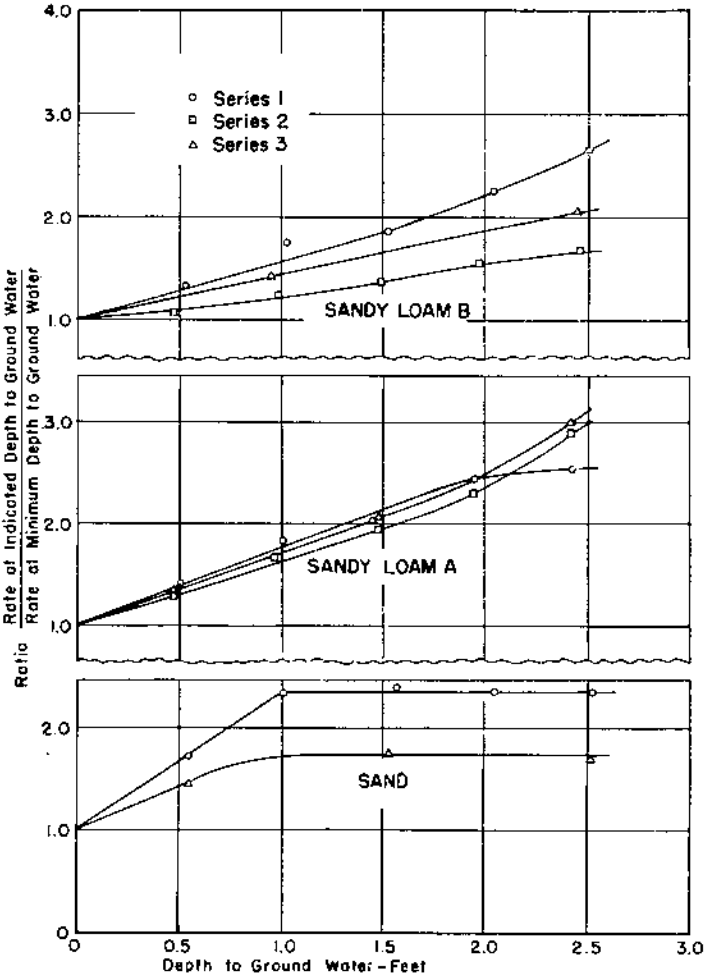

FIGURE 38.—Effect of depth to ground water on seepage rate in sand, sandy loam A, and sandy loam B.

TABLE 23.—*Effect of depth to ground water on seepage rate*

SAND[1]

Test series and date	Depth to ground water			Seepage rate					
	Before change	After change	Average for comparable stages of decrease and increase	Before change	After change	Difference after change	Difference plus rate at minimum depth	Average at comparable depths	Ratio of average to rate at minimum depth
	Feet	*Feet*	*Feet*	*Feet/day*	*Feet/day*	*Feet/day*	*Feet/day*	*Feet/day*	
Series 1:									
6/17	2.59	2.12	2.53	3.14	3.31	+0.17	1.97	3.88	2.34
6/22	2.10	1.63	2.05	3.06	3.12	+.06	2.04	3.92	2.36
6/27	1.63	1.01	1.57	3.14	3.13	−.01	2.10	3.98	2.40
7/2	1.02	.52	1.01	1.91	1.76	−.15	2.09	3.92	2.34
7/7	.52	.03	.53	1.94	1.15	−.79	1.94	2.84	1.71
7/8–7/11	----	----	.03	----	----	----	----	1.66	----
7/12	.03	.54	----	2.17	3.75	+1.58	3.75	----	----
7/17	.54	1.00	----	2.62	4.63	+2.01	5.76	----	----
7/22	1.03	1.52	----	4.26	4.35	+.09	5.85	----	----
7/27	1.52	2.01	----	3.39	3.34	−.05	5.80	----	----
7/31	2.02	2.48	----	2.62	2.61	−.01	5.79	----	----
Series 3:									
10/2	2.52	1.52	2.52	2.48	2.61	+.13	2.43	2.38	1.70
10/7	1.53	.53	1.53	2.62	2.19	−.43	2.56	2.46	1.76
10/12	.53	.03	.53	2.13	1.45	−.68	2.13	2.04	1.46
10/13–10/15	----	----	.03	----	----	----	----	1.40	----
10/16	.03	.54	----	1.35	1.94	+.59	1.94	----	----
10/21	.54	1.53	----	1.56	1.99	+.43	2.37	----	----
10/26	1.53	2.53	----	1.76	1.73	−.03	2.34	----	----

SANDY LOAM A

Series 1:									
6/17	2.43	1.92	2.42	.483	.473	−.010	.779	1.012	2.54
6/22	1.93	1.43	1.94	.514	.452	−.062	.769	.972	2.44
6/27	1.42	.99	1.44	.529	.490	−.039	.707	.828	2.08
7/2	.99	.50	1.00	.610	.491	−.119	.668	.730	1.83
7/7	.50	.03	.50	.549	.391	−.158	.549	.562	1.41
7/8–7/11	----	----	.025	----	----	----	----	.398	----
7/12	.02	.49	----	.406	.576	+.170	.576	----	----
7/17	.50	1.00	----	.712	.929	+.217	.793	----	----
7/22	1.00	1.47	----	.939	1.096	+.157	.950	----	----
7/27	1.47	1.96	----	1.079	1.304	+.225	1.175	----	----
7/31	1.96	2.41	----	1.168	1.240	+.070	1.245	----	----
Series 2:									
8/14	2.43	1.93	2.42	1.314	1.179	−.135	1.116	1.142	2.90
8/19	1.94	1.47	1.94	1.143	.992	−.151	.981	.906	2.30
8/24	1.47	.96	1.47	.858	.696	−.162	.830	.767	1.95
8/29	.96	.46	.96	.697	.561	−.136	.668	.653	1.66
9/3	.46	.03	.46	.532	.422	−.110	.532	.508	1.29
9/4–9/7	----	----	.03	----	----	----	----	.394	----
9/8	.03	.47	----	.366	.485	+.119	.485	----	----
9/13	.48	.97	----	.422	.575	+.153	.638	----	----
9/18	.98	1.47	----	.556	.623	+.067	.705	----	----
9/23	1.48	1.95	----	.672	.799	+.127	.832	----	----
9/28	1.96	2.41	----	1.030	1.367	+.337	1.169	----	----
Series 3:									
10/2	2.42	1.46	2.42	1.026	.734	−.292	.958	1.014	3.00
10/7	1.46	.46	1.46	.678	.482	−.196	.666	.698	2.06
10/12	.46	−.02	.46	.470	.331	−.139	.470	.454	1.34
10/13–10/15	----	----	−.02	----	----	----	----	.338	----
10/16	−.02	.47	----	.345	.438	+.093	.438	----	----
10/21	.47	1.47	----	.431	.724	+.293	.731	----	----
10/26	1.47	2.41	----	.613	.951	+.338	1.069	----	----

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[1] Data for series 2 of the tests in sand are omitted because the results obtained in that series were erratic.

TABLE 23.—*Effect of depth to ground water on seepage rate*—Continued

SANDY LOAM B

Test series and date	Depth to ground water			Seepage rate					
	Before change	After change	Average for comparable stages of decrease and increase	Before change	After change	Difference after change	Difference plus rate at minimum depth	Average at comparable depths	Ratio of average to rate at minimum depth
Series 1:	*Feet*	*Feet*	*Feet*	*Feet/day*	*Feet/day*	*Feet/day*	*Feet/day*	*Feet/day*	
7/7	2. 51	2. 19	2. 50	. 306	. 246	−. 060	. 365	. 441	2. 69
7/12	2. 04	1. 53	2. 03	. 290	. 249	−. 041	. 305	. 372	2. 27
7/17	1. 53	1. 03	1. 52	. 321	. 285	−. 036	. 264	. 309	1. 88
7/22	1. 03	. 51	1. 02	. 255	. 243	−. 012	. 228	. 289	1. 76
7/27	. 52	. 02	. 52	. 216	. 162	−. 054	. 216	. 218	1. 33
7/28–7/30			. 015					. 164	
7/31	. 01	. 52		. 167	. 221	+. 054	. 221		
8/5	. 52	1. 02		. 232	. 361	+. 129	. 350		
8/10	1. 02	1. 52		. 407	. 411	+. 004	. 354		
8/14	1. 52	2. 02		. 432	. 516	+. 084	. 438		
8/19	2. 00	2. 50		. 516	. 595	+. 079	. 517		
Series 2:									
8/24	2. 50	1. 99	2. 47	. 522	. 479	−. 043	. 776	. 922	1. 67
8/29	1. 98	1. 49	1. 97	. 644	. 585	−. 059	. 733	. 858	1. 56
9/3	1. 49	. 99	1. 48	. 692	. 635	−. 057	. 674	. 760	1. 38
9/8	. 99	. 49	. 98	. 600	. 531	−. 069	. 617	. 675	1. 22
9/13	. 47	−. 04	. 47	. 548	. 520	−. 028	. 548	. 588	1. 07
9/14–9/17			−. 035					. 551	
9/18	−. 03	. 47		. 582	. 628	+. 046	. 628		
9/23	. 47	. 97		. 657	. 762	+. 105	. 733		
9/27	. 98	1. 47		. 778	. 890	+. 112	. 845		
10/2	1. 47	1. 96		. 855	. 993	+. 138	. 983		
10/7	1. 94	2. 44		1. 043	1. 127	+. 084	1. 067		

Series 3:									
10/12	2.44	.93	2.44	1.159	.812	—.347	1.161	1.245	2.07
10/16	.93	—.05	.94	.814	.601	—.213	.814	.852	1.42
10/17–10/20	----------	----------	—.045	----------	----------	----------	----------	.601	----------
10/21	—.04	.94	----------	.601	.889	+.288	.889	----------	----------
10/26	.94	2.43	----------	.895	1.335	+.440	1.329	----------	----------

before a change in depth was made and those a day after the change were used for plotting in figure 38. Changes in rate were added cumulatively to the rate at minimum depth to ground water. The algebraic signs for the differences in rates were reversed for that portion of each series in which the water table was being raised. This was necessary because the rate at minimum depth was used as a base. To minimize any effect of the trend of change (increase versus decrease) in depth to the water table, the rates at approximately equal ground-water depths in the same series were averaged.

The seepage rate for sand increased, on an average, to about twice the rate at zero depth when the ground-water level was lowered to 1 foot below the ground surface (fig. 38). The difference in the effect of this change in ground-water level between series 1 and 3 cannot be explained. Lowering the water table beyond the 1-foot depth did not change the seepage rate in sand. In sandy loam A, a fairly constant effect was noted for the three series of tests, each of which extended over about 6 weeks. In this soil the seepage rate when the ground-water level was 2.0 feet below the ground surface was about 2.5 times that when the ground-water level was at zero depth. In sandy loam B, there was considerable scatter in the three series of tests, but the average rate for the three series increased by nearly 100 percent when the ground-water level was lowered from 0.0 foot to 2.0 feet below the ground surface.

Since the equipment used did not permit increasing the depth to ground water beyond 2.5 feet, it was impossible to determine at what depth ground-water elevation ceases to affect rate of seepage except in sand. Mitchelson and Muckel (*9*) found that rate of percolation was increased when the water table was lowered to a depth of more than 5 feet below the ground surface. Results of the present experiment in sand do not indicate any further increase in seepage after the ground-water depth reached 1 foot. For sandy loam A and sandy loam B, the rates of seepage were still increasing when a ground-water depth of 2.5 feet was reached. The rate of increase at that point seemed to be greater in sandy loam A than in sandy loam B.

SUMMARY

Seepage of water from irrigation canals constitutes a serious agricultural problem not only because it involves loss of much water needed by crops but also because it tends to shorten the usefulness of much agricultural land by causing the land to become waterlogged or excessively alkaline. Seepage from canals could be reduced to reasonable limits at reasonable cost by lining or otherwise treating sections of canal beds where seepage is greatest, if these sections could be definitely located. In the period 1949–53 the Department of Agriculture, the U.S. Bureau of Reclamation, and the Colorado Agricultural Experiment Station carried out a study, in the vicinity of Fort Collins, Colo., dealing with methods of measuring the seepage from existing canals and forecasting that from proposed canals and with the influence of individual factors affecting seepage. Greatest emphasis was given to calibrating seepage meters and determining the best method of installing them.

To obtain accurate measurements of rates of seepage from fairly large areas of different soils, on the basis of which various practical methods of measuring seepage could be evaluated, seepage rings, consisting of concentric pairs of metal cylinders set into the soil, were installed in five representative soils differing widely in permeability. The soils were clay loam, two sandy loams, sand, and silt loam. Analyses were made of all the soils and of the water supplies used. The water was practically free of salt and contained little or no sediment. While a constant water level was maintained in the rings by use of float valves, the inflow was measured with domestic-type water meters. To check the accuracy of the meters, from time to time the inflow was shut off and the drop in the water surface during a test period was measured with a hook gage. Evaporation, precipitation, and temperature were measured.

Close agreement between the seepage rates based on water-meter measurements and those based on drop tests demonstrated that seepage loss from the rings in each of the different soils could be accurately determined with the water meters except when it was of the same order of magnitude as the evaporation. Seepage from the rings as determined by use of the water meters could therefore be used as an indicator of the seepage rates for the soils represented in the tests and as the standard of comparison in testing seepage meters and in studying the effects of various factors on seepage rates.

The rates of seepage in cubic feet per square foot as determined with seepage rings ranged from a maximum of 26 feet per day for clay loam to a minimum of 0.01 foot per day for silt loam. The daily rate for sand reached a maximum of 15 feet, but by the end of the test period it had decreased to 0.5 foot.

Seepage rate was found to change considerably from hour to hour even though its daily average might be fairly constant.

The seepage from the inner ring was generally less than that from the outer ring. Because of the buffer effect of the outer ring, the seepage from the inner ring is believed to be similar to that from a large area uninfluenced by boundary effects.

Although the seepage rings were operated continuously for periods of approximately 5 months each season, no ground-water mound was ever built up under any of them.

When seepage measurements made with seepage meters of the Soil Conservation Service type and the Bureau of Reclamation type were compared with the rates shown by the seepage rings, the results indicated that the seepage meters do not accurately measure seepage but that they do indicate the order of magnitude of seepage rates. Readings taken about a week after installation of meters were generally more accurate than those taken earlier. The average of a series of seepage-meter measurements usually agreed fairly well with the average of a comparable series of seepage-ring measurements if the seepage rate was less than about 1 cubic foot per square foot per 24 hours. For higher rates of seepage, the seepage meters definitely overregister. In highly permeable soil having a surface film of less permeable material, installing a meter breaks the surface seal and allows excessive seepage to take place.

Seepage-meter results did not differ significantly according to whether the Soil Conservation Service or the Bureau of Reclamation type of meter was used, although the USBR meter had a larger bell than the SCS meter. Interchanging the measuring devices on the meters did not affect results. The USBR meter is easier to operate; it does not require close attention while the observations are being made.

Care is needed in setting the meters. Carefully forcing a meter into the soil by means of a jack or by standing on it and rocking gives better results than hammering it into place.

To obtain satisfactory results with seepage meters in a canal, meters should be installed in the sides of the canal as well as in the bottom.

Field measurements of soil permeability made with well permeameters can satisfactorily be used as a basis for estimating the seepage from proposed canals. This is made possible by a new procedure developed in this study, in which seepage from the permeameter well is converted to a rate of loss from the entire boundary area of the well.

Seepage rates were derived from well-permeameter data for two canals for which it had previously been determined that most of the seepage was taking place through the sides. (Both these canals had been in operation for only one season.) In comparing the results with those of ponding tests, all the seepage was assumed to be taking place through the sides of the canal bed. On this basis, satisfactory agreement was found between the two values for each canal.

The seepage rate indicated by well permeameters varies with time. Usually it decreases rapidly for 8 hours or more, then rises, then gradually declines. The point at which it begins to rise was used as the base in making the seepage computations.

A simple float valve that has been developed for use with well permeameters effectively holds the level of the water in the well constant. Since this valve operates without levers, it responds immediately to small changes in the water level.

Studies of the effect of depth of water in the seepage rings on rates of seepage in various soils proved that seepage always increases as depth of water increases. The seepage from the rings was directly proportional not to the depth of water but to this depth plus some depth of soil required to use up the available head.

Depth of water was found to have more influence on seepage rate when the rate is high than when the rate is low.

Evidence was found that the seepage rate tends to be slightly greater when the water level is falling than when it is rising.

Appreciable seepage continues so long as an appreciable depth of water remains. Seepage rate when the depth of water approaches zero is the permeability, *K*, of the soil, if the test has been run long enough so that soil moisture tension is no longer a factor and the ground-water level is not close enough to the surface to affect the seepage rate. This finding provides a simple method, believed to be fairly accurate, of determining the permeability of undisturbed soil.

Observations on seepage rate at 2-hour intervals, extending over several days, revealed that the rate was higher when water temperature was low than when water temperature was high. Correcting the seepage rate for the difference in viscosity made the variation with temperature more pronounced. This variation was shown by seepage-ring tests in various soils and also by well-permeameter tests.

The effect of expansion and contraction of air bubbles in the soil with changes in vapor pressure due to temperature was investigated. Since the porosity of the soil diminishes as the bubbles expand, this phenomenon tends to explain why seepage decreases as temperature increases. Corrections based on this phenomenon tended to compensate the correction for viscosity. The final values were about the same as the uncorrected values.

When water temperature was at its daily maximum, rate of seepage from a canal was correlated to some extent with the relation of soil temperature several feet beneath the canal to the temperature of the water. A high seepage rate was associated with a small difference between the temperature of the soil and the temperature of the water.

That depth to ground water has a significant effect on seepage rate was shown by tests in which the water table was held for definite periods at different depths. Seepage increased as depth to ground water increased within the 2.5-foot range of depths tested, with the exception that in sand this correlation ceased when the depth went beyond 1 foot. At maximum depth to ground water, the seepage rate in sandy loam soils was several times as great as when the water table was at the ground surface.

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U.S. GOVERNMENT PRINTING OFFICE : 1959 O—497397

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