5-1953

# Drainage of Land Overlying an Artesian Aquifer: Logan-Cache Airport

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## Recommended Citation

Riley, John Paul, "Drainage of Land Overlying an Artesian Aquifer: Logan-Cache Airport" (1953). *All Graduate Theses and Dissertations*. 1835.
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# DRAINAGE OF LAND OVERLYING AN ARTESIAN AQUIFER

## LOGAN-CACHE AIRPORT

by

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A thesis submitted in partial fulfillment
of the requirements for the degree

of

IRRIGATION ENGINEER

UTAH STATE AGRICULTURAL COLLEGE
Logan, Utah

1953

# ACKNOWLEDGEMENT

This thesis project was supported by the Utah Agricultural Experiment Station. Appreciation is extended to Dean R. H . Walker for the financial assistance rendered by this organization.

Gratitude is expressed to members of the graduate committee for their valuable suggestions. Dr. Vaughn E. Hansen was especially generous in his assistance during the analysis of the data. Most sincere appreciation is due to Dr. O. W. Israelsen whose guidance and encouragement led to the development and satisfactory conclusion of this research.

Thanks are extended to Professor Eldon Stock and to Mr. E. U. Moser, Cache County Surveyor, for their helpful suggestions throughout the period of investigation. Appreciation is also extended to Mr. Walter Raudsepp, Hydraulic Engineer for the Government of British Columbia, who offered valuable suggestions and criticisms during the final preparation of the manuscript.

My sincere thanks are due to Mr. Floyd Hansen, Manager of the Logan-Cache Airport, for his cooperation in permitting the work to be conducted on airport property, and to Dr. C. W. Lauritzen for the use of the River Laboratory and equipment.

J. P. Riley

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## INTRODUCTION

### Drainage problem

Logan-Cache Airport is situated approximately 4 miles northwest of Logan, Utah, in sections 8, 9, 16, and 17, Township 12 north, Range 1 east, of Salt Lake Base and Meridian. The area of approximately 200 acres is a part of what is known as Cache County Drainage District No. 2. This district in itself contains more than 8,400 acres of waterlogged lands. Drainage of these lands has, for many years, been a baffling and unsolved problem, complicated by 3 factors: (a) The whole of the valley in this area is underlain by an artesian ground-water reservoir. (b) The artesian aquifer is overlain by a layer of heavy clay of very low permeability, ranging in depth from 40 to 70 feet. (c) Human relations with farmers within the area who consider that drainage will deprive them of their plentiful ground-water supply. The general characteristics of the artesian aquifer are shown in figure 1.

### Design and construction of the airport drainage system

The tile drainage system, installed at the site of Logan-Cache Airport in 1942, represents the first major attempt to drain lands overlying the artesian basin in lower Cache Valley. Both the attitude of the farmers in the area and state legislation made it impossible to install a system of large pumped wells at the airport to reduce upward flow from the artesian aquifer. At the same time it was realized that, because of the highly-impermeable clay, tile drains would not effectively remove water from the soil. Therefore, the only solution to the drainage problem which seemed apparent was to intercept excess water from rain and snow and surface runoff from higher lands before the water entered the surface soil. The only source of ground water remaining would then be the upward flow from the artesian aquifer.

In 1941 E. U. Moser, then Logan City Engineer, who proposed the initial plan for the airport tile drainage system, made the following statements:

> . . . it would not (within reason) be economically feasible to keep the drainage and irrigation water from crossing the airport area.
>
> Soil borings made on and in the vicinity of the airport show from 40 to 70 feet of compact clay and then a porous water-bearing formation in which the water is under pressure. The pressure gradient at all points in the soil profile is upward, showing that no water moves downward through the soil to the water-bearing formation. The surface soil is so compact that it permits very little lateral movement of moisture. Therefore, under-drainage is of no use in draining this area. The drains should be designed to remove quickly the surface water and if this is done the soil surface in the area retains its stability. The proposed design contemplates crossing the runways at various points, but these crossings will be constructed so as to furnish sufficient load-carrying capacity and to provide quick removal of all surface water, thus eliminating any possibility of softening of the sub-base and the surface of the runways along the drain lines.

The original plans were revised in 1941 to enlarge the system. Work was started in the same year and carried on as a W. P. A. project. In 1942 additional drains were added by the U. S. Army Engineers who expanded the airport to its present size. As is shown in figure 2, the airport is now made up of 3 landing strips and 3 taxiways. In general, each landing strip is drained by 4 equally-spaced, covered concrete tile drains, ranging from 12 to 36 inches in diameter. Two of these drains run longitudinally down each side of the landing strip. The remaining 2, also parallel to the landing strip, are spaced 244 feet on either side of the center line of the strip. Thus, each of these drains is spaced 176 feet from the drain adjacent to the landing strip. The average length of these main tile lines is 5,500 feet and the depth range is from 4.5 to 10 feet. Randomly-spaced laterals run into these main drains at various points. A shallow gutter borders the northerly and easterly edges of the airport tract. All tile drains discharge into existing canals. One interesting feature about the installation of the tile lines is that they were all gravel backfilled to a level with the soil surface. This highly-permeable gravel fill which extends 6 inches on either side of the pipe and 6 inches below serves both to cut off horizontally-moving ground water and to convey surface water rapidly to the drains. Since construction, the system has apparently been highly effective. Mr. Floyd Hansen, the airport manager, states that to survey the initial tile lines it was necessary to wade through swampy water. In 1951, 175 acres of alfalfa and grasses were seeded at the airport so that now patches of alfalfa, rather than tules and cattails, grow between the landing strips and taxiways.

## Economics of drainage

Economics, as in all projects, is a prime consideration of land drainage. However, land which may be economically drained for an airport site may not be economically drained for agricultural purposes only. Much of the undrained soil within Cache County Drainage District No. 2 after being reclaimed for irrigation agriculture would fall into classes 1 and 2 (15). Therefore, at present prices this area could economically carry an average of $80 per acre for reclamation. On the other hand, the total cost of the existing airport drainage system which drains nearly 200 acres was estimated at $50,000, or approximately $250 per acre. However, since airport drainage systems must be designed with very large capacity lines to carry quick runoff, the 2 projects, airport and agriculture, cannot be compared with precision.

## Study area

This investigation was confined to an area near the center of the airport where poor drainage was very apparent. This area is located by figure 2 and shown in detail by figure 3. Data on the 3 drains within this area are recorded in table 1. The evidences of inadequate drainage are briefly listed:

1. A longitudinal cracking of the asphalt-covered taxiway along the wheel lines. The portion of the taxiway surface adjacent to the study section (see figure 2) was very badly broken.

2. A high moisture content in the clay soil directly beneath the taxiway and runway foundation even during the hottest portion of the summer.

3. A dispersal of the gravel subgrade or asphalt foundation. The gravel particles had apparently moved downward into the clay.

4. Depressions, or sump holes, in the soil near the tile drains. These holes were between 1 and 2 feet in diameter at the top and were as much as 3 feet deep.

# OBJECTIVES

The 7 major objectives of this study were to:

1. Determine the function of the airport tile drains.

2. Observe and study fluctuations in both the ground-water table level and the pressure head within the 40-foot artesian aquifer during the 3 seasons, fall, winter, and spring. (Throughout this entire report pressure head is measured in feet of water.)

3. Study the upward hydraulic gradient from the 40-foot artesian aquifer through the overlying clay layer.

4. Estimate the effective vertical permeability of the clay aquiclude.

5. Compare the upward hydraulic gradient and the effective vertical permeability of the clay aquiclude with those values reported by Israelsen and McLaughlin (9).

6. Check from the upward hydraulic grade line and soil boring observations the assumption that the clay aquiclude is homogeneous throughout its entire thickness.

7. Study the inadequate drainage problem that exists near the center of the airport.

## PREVIOUS DRAINAGE RESEARCH IN THE AIRPORT AREA

### Israelsen and McLaughlin

In 1929 and 1930 Israelsen, McLaughlin, Gardner, and Jennings conducted a drainage study of this area. The results of this study were reported by Israelsen and McLaughlin (8, 9). Their major objective was to drain and reclaim the area for agricultural purposes. By piezometric and pumped well studies they arrived at some very important conclusions. Many of their procedures and conclusions are related very closely to the airport-drainage problem, and so they are briefly mentioned here.

Water-table depths were measured along a north-south line just west of a large open drain on the east boundary of the airport tract. The measurements showed a depth of as much as 5 feet. However, it is probably that the water table was influenced by the open drain. Israelsen and McLaughlin also reported water-table depths measured on an area of land known as the Bell Tract, immediately south of the airport (see figure 2). These readings, a summary of which has been included as table 2 in this report, were not taken in the vicinity of any drains. Note that the average of their water-table depths for the years 1930-1932 was 2.5 feet, which is too shallow for successful agricultural production.

At the Bell Tract piezometers of varying lengths were used to establish the average magnitude of the hydraulic gradient in the saturated clay layer or aquiclude overlying the artesian aquifer to a depth of 40 feet. From a laboratory test with a constant-head permeameter the soil permeability for vertical flow of the overlying clay layer was estimated. Two assumptions were made: (a) Since the hydraulic gradient is essentially in a vertical direction, the horizontal flow in the clay is negligible. For this reason the horizontal permeability was not measured. (b) The vertical permeability is nearly constant throughout the whole depth of the caly layer.

Using their measured values for the vertical permeability and the hydraulic gradient, Israelsen and McLaughlin calculated the velocity of upward flow from the artesian aquifer by using Darcy's equation for steady-flow velocity, $V = ki$.

$k_v = 1.71 \times 10^{-7}$ feet per second

$= 1.71 \times 10^{-7} \times 12 \times 3600 \times 24 = 0.177$ inches per day of 24 hours

Average $i = 0.39$ foot per foot

$V = ki$

$= 0.177 \times 0.39$

$= 0.0691$ inches per day

Assume that May 7 to October 11 is the average growing period. Therefore, the calculated total upward flow during this time is $0.0691 \times 157 = 10.9$ inches.

An experimental well was drilled to the 40-foot artesian aquifer and a well pump installed. The pumping caused a marked lowering of the piezometric surface at a distance of 1,500 feet from the well; an appreciable lowering at a distance of 3,000 feet; and no lowering at a distance of 10,000 feet.

The most important conclusion of the Israelsen-McLaughlin report was that deep drains to drain and reclaim the soil for agricultural purposes would not be successful because of 2 existing conditions: (a) The upward hydraulic gradient from the gravel aquifer would reduce the effective gradient toward a deep gravity drain. (b) The low permeability of the clay soil would, for a given gradient, reduce the flow toward a gravity drain. To illustrate this conclusion Donnan's formula (4) will be used to calculate the rate at which water would be removed from the soil by tile drains spaced at 200 feet.

$$Q = \frac{\pi\ k\ L(H - h)}{2.3\ \log_{10} S/d}$$

where,

$Q$ = the flow in cfs removed from the soil by the drain,

$k$ = the effective soil permeability in feet per second,

$L$ = the length of drain in feet.

The remaining quantities in the foregoing equation are illustrated in figure 4. Assume the following numerical values for these quantities:

$H$ = 6 feet

$h$ = 3 inches

$d$ = 6 inches

$S$ = 200 feet

$k = 1.71 \times 10^{-7}$ feet per second (9)

$L$ = 1 foot

Therefore,

$$Q = \frac{\pi \times 1.71 \times 10^{-7} \times 1(6 - 0.25)}{2.3\ \log_{10} 200/0.5}$$

$$= \frac{\pi \times 5.75 \times 1.71 \times 10^{-7}}{5.98} = 5.16 \times 10^{-7} \text{ cfs}$$

From the equation of continuity, $Q = AV$, Israelsen and McLaughlin estimated the upward flow from the artesian aquifer to be $0.67 \times 10^{-7}$ cfs per square foot. The area influenced by one of the drains shown in figure 4 is 200 square feet per foot of drain length. Therefore, the upward flow over this area is $200 \times 0.67 \times 10^{-7} = 1.34 \times 10^{-5}$ cfs, or more than 20 times the flow removed by the drains. A closer spacing would increase the flow into the drains, but, at a 7-foot tile depth, 200 feet is approximately the minimum economical spacing even for grade 1 agricultural land.

On those areas of land overlying the artesian aquifer, excess water in the surface soil may come from 1 or more of 4 sources: (a) upward flow from the water-bearing gravel, (b) rainfall and snowfall, (c) irrigation water, (d) surface runoff from higher lands. The experimental work reported by Israelsen and McLaughlin was for the most part performed with a view to finding ways of preventing the flow to the land surface from source (a). They concluded that the upward flow could be considerably reduced by drilling numerous wells through the clay layer to the gravels.

### Gardner, Israelsen, and others

The physical concepts underlying such a drainage system of pumped wells were first published by Gardner and Israelsen (5). Recently, Peterson, Israelsen, and Hansen (13) have provided valuable information on the hydraulics of pumped wells. These publications all suggest that the artesian pressure which causes the upward flow can be relieved by pumping large quantities of water from the aquifer. By lowering the piezometric surface measured at the artesian aquifer to a depth of 6 feet or more below the ground surface, much of the land could be reclaimed by leaching of the salts through downward percolation of the irrigation water. Since the soil of the valley floor is very fertile, high yields could be expected. Of course, the existing upward hydraulic gradient prevents any downward movement and subsequent leaching by irrigation and rain water.

### Bisal

In 1948 Bisal (2) suggested that siphon drains be constructed to relieve the hydrostatic pressure in the artesian aquifer underlying the area. By lowering the piezometric surface with respect to the artesian aquifer to some depth below the ground surface, the siphon drains would, he reasoned, reduce upward flow through the clay aquiclude and at the same time permit irrigation water to penetrate the soil and move downward. Pumping on a large scale would accomplish the same results, but at considerably more cost than siphon drains.

Bisal included in his report a suggested location and design for 2 siphon wells in the vicinity of the airport. He constructed a map showing the influence of the 2 wells upon the streamline pattern in the aquifer. The depth to which the piezometric surface with respect to the artesian aquifer can be lowered by siphon drains depends directly upon the elevation of the drain outlet. Bisal, therefore, proposed that one well discharge directly into an irrigation canal and that the other well discharge into a nearby deep ravine.

## Moser

Shortly before the first tile lines were installed at the airport, E. U. Moser, then Logan City Engineer, also conducted water-table depth determinations along a north-south line just west of a large open drain on the east boundary of the airport tract. The results were very similar to those reported by Israelsen and McLaughlin (8, 9). Again, Moser is of the opinion that the water table was strongly influenced by the proximity of the deep, open drain.

## Results of drainage recommendations

Even through the preceeding studies and recommendations by Bisal, Israelsen, and others were made some years ago, the problem still apparently remains unsolved. The results of research reported by these men indicate that the problem of draining the area is simple from a physical or engineering standpoint. Israelsen (6) suggests that water could be pumped from the aquifer with the expenditure of very little power because of the artesian pressure. Water could then be stored on the surface and used when needed for irrigation purposes. This solution was also found to be feasible from an economic standpoint. Therefore, properly used, the aquifer would provide an ideal water-storage reservoir.

The principal reason for the delay is one of human or public relations. In spite of the fact that inadequate drainage and the resulting salinity problems have caused many acres to be abandoned, farmers are yet unwilling to lose the apparent conveniences of flowing wells. This human relations problem is, however, not restricted to Cache Valley but is encountered in many of the Utah valleys where artesian pressure exists. The courts still uphold the ruling that a water right in an area of artesian pressure also entitles the user to this pressure, even though a lowering of the artesian pressure would not necessarily deprive the users of any existing ground-water rights.

## PROCEDURE

### Piezometric studies

Piezometer tubes in this study were used for 2 distinct purposes: (1) to obtain the hydraulic grade line between the artesian aquifer and the water table by measuring the static ground-water pressure or hydraulic head at various depths in the soil profile, and (2) to indicate the depth of the ground-water table beneath the soil surface. These purposes will both be discussed in turn.

Since it was thought that the distance from a given drain may influence the static water level in any piezometer, 3 lines of piezometers, A, B, and C, each at a greater distance from drain 12, were installed. As can be noted from figure 3, line C is midway between drains 11 and 12. In each of the 3 lines, 9 three-eights inch diameter pipes were forced into the clay soil to different depths from 5 feet to approximately 45 feet as illustrated in figure 5.

Installing piezometers by machine. The pipes were inserted into the clay be means of a portable jetting rig. This equipment, originally designed as an orchard sprayer, was complete with a 500-gallon capacity water tank. The pump, driven by a 1 horse power Wisconsin air-cooled 2 cycle gasoline engine, was capable of developing a maximum water pressure of 700 psi. Each pipe in turn was jetted to its desired depth by this high-pressure stream of water delivered from the pump. An important observation was that even though each piezometer was jetted completely to its assigned depth the wet clay which quickly adhered to the outside surface of the pipe prevented any upward leakage of the artesian water along the outside diameter of the pipe. It was first proposed to extend each pipe above the ground surface to a height great enough to prevent overflow of the artesian water. However, airport safety regulations restricted the maximum projection of these pipes above the ground surface to 1 foot.

The use of pressure gages. A number of mercury manometers, or pressure gages, were then constructed to solve the problem of measuring the hydrostatic pressure head in those pipes where the static water level stood at a level greater than 1 foot above the ground surface. One of the mercury gages is illustrated in figure 6. A 6-inch length of 2-inch cast iron pipe threaded and capped at each end made up the body of the gage. One of the end caps was tapped and fitted with 2 brass connections. One connection sealed a length of plastic tubing into the cap, while the other held a one-fourth inch rubber hose. The top of each piezometer to be equipped with a mercury gage was threaded and fitted with a valve. The rubber hose connected the mercury gage to the valve. As the ground water under pressure entered the cast iron cylinder through the rubber hose, the mercury was forced upward through the plastic tubing until the weight of the column of mercury was equal to the static water pressure. Equilibrium conditions were then established. Since the height of the column of mercury is directly proportional to the static hydraulic pressure head, the mercury pots were easily calibrated in the laboratory before being set out in the field. Thus, for any given height of mercury column the equivalent head in feet of water above the bottom of the pot was obtained by placing a calibrated stick adjacent to the mercury column. Figure 6 illustrates the manner in which the calibrated stick was used to obtain directly from the height of the mercury column the hydraulic head in feet of water above the ground surface. A mercury gage was permanently attached to all piezometers in which the static water level stood at a height greater than 1 foot above the ground surface. To provide stability each pot was sunk to a depth of 6 inches in the clay soil. Figure 7 shows 3 mercury pots in place in the field. In any one of the 3 piezometer lines, A, B, or C, the decrease in hydrostatic pressure with an increase in height above the artesian aquifer was clearly depicted by the differences in the heights of the mercury columns in adjacent mercury pots.

Piezometer measurements in tubes where the static water level stood at less than 1 foot above the ground surface were obtained by means of the electric sounder illustrated in figure 8. These tubes were left open at the top. All pressure-head readings were taken at 3-day intervals and are recorded in tables 3 to 8, inclusive. Each table contains the measurements for a single month. These data are summarized in table 9. Data could not be obtained during periods of extreme cold. Readings for piezometer 1, line A, were not included because the proposed location of this piezometer was within the minimum distance from the edge of the taxiway considered safe by airport regulations. This pipe was, therefore, not installed.

Draw-down conditions. To approximately locate the water table by direct measurements piezometers were laid out along the 3 lines, $D_4$, $D_{11}$, and $D_{12}$ shown in figure 3. The numerical subscripts refer to the drains to which the lines were perpendicular. For example, a line of piezometers perpendicular to drain 12 was designated $D_{12}$.

When piezometers are used to study the draw-down conditions adjacent to a drain, it is important that they be spaced not only for accuracy in plotting the draw-down curve, but also for economy in numbers. Near the drain where the water table may be relatively steep the spacing should be close, while farther from the drains where the water table is comparatively flat the piezometers should be wide-spread. An exponential or logarithmic spacing as illustrated in figure 9 was therefore used for each of the 3 lines.

Test holes were dug to determine the depth of the water table (see table 10). The piezometers were then cut at a length slightly greater than the water-table depth as indicated by the test holes. The lower 2½ feet of each tube was perforated with small drill holes, and the top of each was threaded to permit capping. Because of the low air temperatures prevailing when the piezometers were installed, the jetting apparatus was not used. Fortunately, a thick snow cover had prevented the top soil from freezing so that the piezometers were readily driven into place with a piezometer hammer. As shown by figure 9, they were all set at a depth of approximately 7½ feet below the ground surface. A steel rivet was placed in the bottom of each tube before it was placed in the soil. The rivet not only acted as a driving point but also prevented soil from entering the pipe during the driving process. A long steel rod was thrust down each piezometer to force out the rivet. Finally, the piezometers were flushed with a hand jetting pump and capped. All readings were taken at 3-day intervals with an electric piezometer sounder and recorded as shown in tables 11 to 16, inclusive. Here again each table contains the measurements for a single month.

Levelling. The elevation of the ground surface at all piezometers with respect to an arbitrary point was obtained. The results of these level measurements are shown in tables 17a and 17b.

### Further tests

In order to study the soil profile 3 test holes were sunk to a depth of 12 feet. The locations of these holes is stated on table 10.

The flow in each of the drains, 4, 11, and 12, was periodically checked through manholes in the vicinity of the study area. Table 18 records observations made during the rapid snowmelt period from March 29 to April 10. At this time both the high capacity of the system and its quick disposal of surface water were demonstrated. More than 6 inches of snow melted between March 29 and April 3, leaving large pools of water standing between the landing strips. However, by April 10 the entire airport area was free from surface water. During the peak of the runoff all drains were completely full. Throughout the remainder of the entire investigation there was no appreciable flow in any of the 3 drains at the study area and very little flow from the outlet of the entire drainage system.

## DISCUSSION

### Relation of the airport drains to soil-water conditions

The ground-water table. The water table is the surface of atmospheric pressure within the soil. At this surface the piezometric or pressure head, p/w, is therefore equal to zero. For this reason, where ground-water conditions are influenced by an upward hydraulic gradient it is almost impossible, in a clay soil of low permeability, to accurately locate the water table by direct piezometer measurements. A piezometer, as the name implies, is a pressure gage which indicates the ground-water pressure head existing at the lower end of the tube. Therefore, if, for example, the bottom of a given tube extends 1 or 2 feet below the water table, an upward hydraulic gradient will cause the water surface in the pipe to rise above the line of atmospheric pressure in the soil profile. The difference between the 2 levels is, of course, equal to the friction head lost by the water in moving through the soil from the bottom of the piezometer tube to the ground-water table. This difference, therefore, increases as the depth of the piezometer below the water table is increased. Theoretically, for correct water-table depth measurements the lower end of the piezometer should coincide exactly with the water-table surface. However, under actual field conditions a fluctuating water table may rise as much as 2 feet or more above the lower end of any one piezometer. The resulting problem of obtaining a piezometer reading which is approximately equal to the depth from the ground surface to the water table or surface of atmospheric pressure is often partially overcome by perforating the lower portion of each piezometer tube with small drill holes. However, in the tight clay soil encountered at the airport the value of such a procedure is doubtful.

In soil of low permeability even auger holes may not accurately measure the depth of the water table. If driven by an upward hydraulic gradient, the water in the hole tends to reach an equilibrium somewhere above the level of the water table. Here also for a given soil and upward hydraulic gradient the equilibrium water level depends directly upon the depth of the auger hole. On the other hand, unlike a metal tube, the sides of the hole permit water to escape slowly into the soil above the water table. Because of these dynamic conditions, the water depth within the hole is less than the ground-water pressure head at the bottom of the hole. Thus, under the conditions existing at the airport the value of auger holes to measure either the depth of the water table or the pressure head at the bottom of the hole is questionable.

As the 2 preceding paragraphs suggest, under certain conditions direct water-table measurements are not entirely satisfactory. On the other hand, for any set of soil conditions the water table may be located more indirectly by plotting the soil-moisture pressure head readings against the distance above or below a given datum. Tensiometers may be used to yield data in the region of negative pressure or soil moisture tension above the water table. The point of intersection of the resulting curve with the line of zero piezometric head represents the surface of atmospheric pressure within the soil water. If only piezometric data are available, it may be possible to extrapolate the curve to cross the zero pressure head line.

The extrapolation procedure is illustrated in figures 10 to 15, inclusive, which were plotted from the data recorded in tables 3 to 8. Each figure illustrates the average relationship between the pressure head and depth of piezometer within the overlying clay layer for 1 month during the study period. The lines were fitted to the data by eye rather than by more refined statistical methods. The reason for this approximation is obvious. Both the slope of the pressure gradient and its point of intersection with the line of zero pressure head, are, of course, influenced by location or position in the field. Therefore, when extended from the small area over which they were obtained to a large area occupied by a proposed drainage project, approximate values of the hydraulic gradient and water-table depth are as significant as more exact values. These approximate values are, therefore, considered from a practical field engineering point of view. As was expected, the level of the water table as estimated by a monthly average of the readings from piezometer line $D_{12}$ was for each month slightly higher than the level of the line of atmospheric pressure, $p/w = 0$, as determined by extending the line of pressure head versus depth below datum to cross the line of zero pressure head. This difference is clearly illustrated by comparing the line which represents water-table depth on figure 16 with line $D_{12}$ on figure 19. Figure 16 is a summary of the quantities obtained from the figures 10 to 15, inclusive.

Another very interesting observation from figures 10 to 15 is that although the average monthly readings from each piezometer line, A, B, and C were plotted separately, for any given month a single straight line closely fits the 3 sets of data. This phenomenon suggests that the upward hydraulic gradient from the aquifer is not related to the horizontal distance from drain 12.

Influence of the tile drains upon water flow within the soil. The observation stated in the preceding paragraph implies immediately that drain 12 apparently has no direct influence upon water movement within the soil profile below the water table. This conclusion is also supported by figure 18 which was plotted from table 9. This figure illustrates the mean piezometric heads over a 6-month period at 3 radial distances from drain 12 for 8 depths ranging from 10 to 46 feet below the soil surface. At each depth the horizontal gradient perpendicular to the drain axis is shown. At no depth, however, does a significant gradient exist either toward or away from the tile. It might be argued that the mean conditions for a 6-month period would not necessarily show the influence of the drain. Actually, however, the mean conditions for any single month during this period were almost identical to the overall mean conditions shown.

A further check of figures 10 to 15 explains the apparent ineffectiveness of drain 12. The tile was at all times situated in the region of negative pressure head above the surface of atmospheric pressure, $p/w = 0$, and therefore was unable to remove water directly from the soil. This statement may require a brief explanation.

It is a well-known fact that water will rise in soils above the water table. The maximum height of capillary rise is governed by the minimum soil pore size, while the minimum height of capillary rise is dependent upon the maximum pore size. The average of these 2 heights is known as the capillary fringe. Below the minimum height of rise the soil is essentially saturated, so that the water moves freely within the soil. However, in rising above the water table or atmospheric pressure surface, the water enters a zone of negative or sub-atmospheric pressure and is, therefore, under tension. The minimum pressure that can exist within a drain is, of course, zero or atmospheric. Thus for a drain that is situated in the zone of negative pressure above the ground-water table the pressure gradient is out of rather than into the tile. Briefly, because the gradient is in the opposite direction, water under tension will not cross an air-water interface. This fact is sometimes stated as the second law of moisture movement. The above statements should emphasize why the lines of a ground-water drainage system must be placed below the maximum desired depth of the atmospheric pressure surface, $p/w = 0$.

The average water-table depths for each month during the study period at the 3 piezometer lines, $D_4$, $D_{11}$, and $D_{12}$, are plotted as 3 separate curves in figure 19. The overall average depth of the water table within the 1951-1952 study area appears to be comparatively deep, with the top of the permanently-saturated soil zone at approximately 6.5 feet below the ground surface. As would be expected, the fluctuations in the water-table level for the months January to

June were very consistent for the 3 piezometer lines. Data for July and August were estimated from a few scattered readings, and since they were not taken within the investigation period have not been tabulated.

The water-table profile at its maximum and minimum monthly average depths as measured by the 3 piezometer lines, $D_4$, $D_{11}$, and $D_{12}$, are shown in figures 20 and 21. As previously explained, since these curves are based upon direct piezometer readings, they are in all probability shown at shallower depths than the true profile of the atmospheric pressure surface which existed at the same time within the soil. The maximum observed water-table depth occurred in January with the spring runoff from the melting snow producing a peak elevation of between 4 and 5 feet below the ground surface in early April. The water table then fell slowly during May and June, until in early July it again approached the average maximum depth of approximately 6.5 feet.

Previously in this section it was suggested that drain 12 is ineffective as a sub-surface drain. An important observation from figures 19, 20, and 21 is that not only drain 12 but also both drains 4 and 11 at the sections illustrated were well above the level of the water table throughout the entire study period. Under these conditions it was also impossible for soil water to enter either of these drains. Rather, the sharp upward curve of the water-table profile for April almost directly beneath the 3 tile lines suggests that a small portion of the surface water which had entered the drains actually again escaped and moved on downward through the soil. The unexpected draw-down for January under drains 11 and 12, when there was no observed flow in any of the 3 drains, probably was produced by small amounts of surface water which had percolated down through the gravel back-fill and by-passed the tile.

Because the drains are backfilled with gravel, the low permeability of the surrounding clay has no influence upon their effectiveness as surface drains. It should be noted that surface water which enters the airport drains through the gravel backfill is not under tension. The large pores in the gravel eliminate all capillary forces so that the water moving downward largely under the influence of gravity enters the drains.

Water entering the soil from the drains would, of course, contribute to the ground-water reservoir, and, in fact, may have been partially responsible for the marked rise of the ground-water level during the rapid spring snowmelt period. It has already been noted under the heading of "Procedure" that only during the spring snowmelt period was there an appreciable flow in any of the 3 drains at the study area. Any very slight flow during the remainder of the investigation period was largely surface runoff from higher lands. This water is caught by a shallow gutter extending along the east and north boundaries of the airport. Small quantities of water flowed almost continuously from the gutter into the tile drainage system.

## Profile of the overlying clay layer

Test-hole data. The soil survey test-hole data are recorded in table 10. Each of these borings yielded the following factual information: Hard, heavy Logan clay, light gray in color, extended from near the land surface to a depth of 4 feet. Below this depth lay a soft, silty clay loam 4 or 5 feet thick, which carried the red and yellow mottled effects of ferric oxide, indicating a fluctuating or periodic saturation of the soil. At 6.5 feet a blue silty clay began to appear. The blue color caused by ferric oxide signifies permanent saturation. At 11.5 feet the silty clay gradually gave way to a very soft, silty blue mud, which extended to a depth of 12 feet where the boring was stopped. The first level of the blue silty clay at a depth of 6.5 feet below the ground surface obviously signifies the minimum water-table elevation. The maximum water-table elevation is indicated by the beginning of the mottled clay at a depth of between 4 and 5 feet. As shown by figure 21, these estimates agree fairly closely with those obtained at the same point from piezometric data.

Piezometric data. It was mentioned earlier that all points plotted on figures 10 to 15, inclusive, fall very close to a straight line drawn from approximately the 10-foot depth to the 40-foot depth below the ground surface. This line immediately implies that below the top 10 feet of surface soil there extends downward 30 feet of material having exceptionally uniform permeability. This homogeneous soil material is undoubtedly the soft, blue mud found near the bottom of the test holes.

At a piezometer depth of approximately 40 feet the hydraulic gradient deviates from a straight line as indicated by the curved dotted portions of the curves. This phenomenon suggests that the layer of material approximately 5 feet thick and immediately overlying the gravel aquifer is relatively less permeable than the clay in the remaining soil profile.

### Pressure within the artesian aquifer

**Average total pressure.** The average pressure head in the artesian aquifer during the period of study as recorded by piezometers 1, lines B and C, was approximately 61 feet of water. Piezometers 1 in lines B and C were both jetted to the aquifer. As table 9 illustrates, a slight difference was found between the average of the 2 piezometer readings for the entire study period. With only 1 replication, however, this difference cannot be said to indicate a trend; rather, it probably can be accounted for by experimental error, such as differences between the 2 mercury gages, or differences between the entrance conditions at the bottom of the 2 piezometers. Justin, Hinds, and Creager (11) list $1 \times 10^{-7}$ feet per second as an average figure for the permeability of coarse clay. Israelsen and Morgan (10) have presented data which indicate that the permeability of the gravel aquifer is approximately 0.016 feet per second. The permeability of the gravel aquifer may, therefore, be at least 100,000 times greater than that of the overlying clay layer. Under these conditions the gradient within the aquifer would be imperceptible so that the piezometric surface at any point within the aquifer should be essentially a constant.

**Pressure variations.** Fluctuations of the monthly average artesian pressure head were only slight during the entire period of study. As shown by both figures 16 and 22 the maximum variation during the 8-month period, November to June, inclusive, was 4 feet of water.

However, rather than reaching a maximum as expected in the spring, the average pressure head dropped sharply in May. Uncontrolled flow from the 40-foot aquifer through a nearby artesian well probably produced this decline. In the fall of 1951 a well was drilled at the airport to provide water for a newly constructed fire-control tank. During the drilling process the static pressure at the 40-foot aquifer forced water to the surface around the outside of the well casing. For approximately 3 months an estimated 0.5 cfs flowed from the well. This flow was eventually stopped by forcing mud to the bottom of the well shaft. The water carried the mud upward around the outside of the casing, thus sealing the leak. However, with the coming of spring, the pressure within the aquifer began to rise. On April 28, 1952, this rising pressure burst the mud seal and water again flowed in an uncontrolled stream from the well. Almost immediately the average artesian pressure head recorded by piezometers at a distance of 1,600 feet from the well dropped approximately 2 feet of water (see figure 17). After this sudden drop the pressure head continued to fall very slowly so that by July 10 it was approximately 4 feet below the piezometric head, as recorded on April 27, of more than 62 feet of water. While compared with the total piezometric head of approximately 60 feet of water this decline is relatively small, it actually represents nearly 20 percent of the excess or driving head which forces the water upward through the soil.

It is evident from the previous paragraph that pressure changes are readily transmitted through the highly-permeable artesian aquifer.

Therefore, it seems feasible to assume that by locating pumped wells at strategic points the piezometric surface with respect to the 40-foot artesian aquifer could be lowered to any desired level. However, it should be noted that although no drawdown data were obtained for the uncontrolled well, the water-table elevation at the study area was not noticeably affected.

### Upward hydraulic gradient through the clay

Israelsen and McLaughlin (9) measured the average upward hydraulic gradient from the gravel aquifer to be 0.39. The average gradient as measured from figure 16 for the 1951-1952 study period was 0.53 with a low of 0.43 in April and a high of 0.60 in February. It appears from the figure that this variation was not dependent upon corresponding changes in the aquifer pressure head. For instance, the hydraulic gradient for both November and May was 0.5, yet the average artesian aquifer pressure heads for these same 2 months were 63 and 58.8 feet of water respectively. Again, figure 22 shows no definite correlation between the pressure within the artesian aquifer and that of the soil moisture at any given depth within the clay aquiclude. As mentioned previously, there appears to be a thin layer of clay soil immediately above the aquifer which is relatively less permeable than the rest of the profile. Such a layer may tend to reduce the affects of short-time pressure variations in the aquifer upon the hydraulic gradient. However, changes in the average pressure head during the investigation period were fairly small for all piezometer depths. Therefore, it is possible that the correlation mentioned above, if present, was not detected by the experimental procedures employed.

The apparently high degree of correlation between the depth of the water table and the upward hydraulic gradient suggested by figure 16 is to be expected because curves 2 and 3 are not independent plots. The values of the water-table depth plotted as curve 2 were derived directly from the pressure head lines of figures 10 to 15, the slopes of which yielded the values for curve 3. However, curve $D_{12}$ of figure 19 is a plot of the water-table depth for the same area measured by an independent method. This curve when compared with line 3 of figure 16 indicates an almost direct variation between the upward hydraulic gradient and the depth of the ground-water table. Other conditions being equal, this relationship, of course, is natural. A comparatively higher water table means a longer flow distance from the aquifer, and so a decreased hydraulic gradient.

The gradient apparently deviates from a straight line only within a few feet of the aquifer. Therefore, the permeability of the homogeneous blue silty mud is taken as the effective permeability of the entire soil layer above the gravel stratum.

### Computing the effective permeability of the clay aquiclude

**Permeability measurements.** In permeability measurements the large experimental errors must be reduced by statistical analyses. Hence, considerable time is required to obtain an accurate permeability measurement of a single soil layer. Now, as previously stated, the aquiclude appears to consist of at least 3 layers of varying permeabilities. Therefore, the amount of work involved in finding the effective vertical permeability of the aquiclude by Kirkham's field method (12, 16) would be too great for this project. Actually, a procedure which would measure the rate of upward flow from the aquifer over a given area would be more satisfactory. Having determined the average hydraulic grade line for this same area by means of piezometric clusters, the effective vertical permeability could then be calculated not only for each individual layer but also for the entire thickness of the aquiclude by Darcy's equation, $V = ki$, where $V$ = velocity of flow in distance per unit of time, $k$ = the soil permeability in distance per unit of time, and $i$ = the hydraulic gradient (dimensionless). Of course, in order to apply this equation, a condition of steady flow from the artesian aquifer to the ground-water table must be assumed. If this experiment were replicated for several areas within the same vicinity, a statistical analysis could be applied to the results.

One of the most satisfactory means of obtaining V is to measure the increment of flow for a given length of drain. However, such a drain must be situated below the water table so that the drain is removing primarily underground water. Under these conditions there is a definite draw-down of the atmospheric pressure surface to the drain.

The consumptive-use basis. V may also be obtained from an estimate of the crop consumptive use for any given period. This method will be employed here. Refer to figure 23 where a section of the aquiclude is shown. To approximate actual field conditions the ground-water table has been slightly inclined so that there is movement along this surface. Actually, lateral movement in the clay soil of the bottom lands of Cache Valley is probably exceptionally slow. The upward hydraulic gradient from the aquifer is 0.5, while for water which enters the soil surface and flows vertically downward to the water table the hydraulic gradient is approximately 1. As has already been stated, even driven by these comparatively high gradients, both the upward flow of water from the gravels and the downward percolation of water from the land surface are very small. Now assume, for example, that the slope of the water table is 1/500 and that the horizontal and vertical permeabilities of the soil are equal. Under these conditions the flow of water laterally within the clay would be 250 times less than the upward flow from the artesian aquifer, and 500 times less than the downward flow from the ground surface. Test-hole data presented by Rasmussen (14) and shown in table 10 indicate that horizontal thin sand layers exist at various depths in the surface profile. However, as far as can be determined, these veins are discontinuous, so that unless they are intercepted by a drain or ditch lateral movement, even within the sand, is almost negligible.

Assuming steady-flow conditions, the inflow to the section shown in figure 23 must equal the outflow. Therefore, it is reasonable to assume that the upward flow from the artesian aquifer for any given period is approximately equal to the crop consumptive use minus the total amount of precipitation for that period. The airport lands are not irrigated. Changes in the average water-table depth reflect changes in both the consumptive use and the hydraulic gradient and should be taken into account.

Determination of consumptive use. Consumptive use has been mathematically expressed by Blaney and Criddle (3) on the basis of temperatures and available heat as in the following equation:

$$U = KF$$

where

$U$ = consumptive use of crop (or evapo-transpiration) in inches for any period,

$F$ = sum of the monthly consumptive-use factors for the period (sum of the products of mean monthly temperature and monthly percent of daytime hours of the year), and

$K$ = empirical consumptive-use coefficient (irrigation season or growing period).

Blaney and Criddle list K values for alfalfa of 0.80 to 0.85, with the lower values for the coastal areas and the higher values for areas with an arid climate. Cache Valley is situated in an arid region. However, because the alfalfa growing at the airport was relatively sparse and also showed signs of drought, its consumptive use would undoubtedly be lower than average. Therefore, the lowest given value of K was used in the following calculations.

Blaney and Criddle state that the average growing season for alfalfa in Cache Valley is the period from May 7 to October 11, and list the values shown in the following table as the normal monthly consumptive-use factors, f, for Logan, Utah. The total monthly precipitation in inches for each month during the growing season of 1952 is listed under "r" in the table. These values were taken from meteorological data recorded at the Greenville Experimental Farm in North Logan, Utah.

| Month | No. of Days | r | f |
|---|---|---|---|
| May | 24 | 1.25 | 4.23 |
| June | 30 | 1.75 | 6.53 |
| July | 31 | 0.31 | 7.53 |
| Aug. | 31 | 0.44 | 6.86 |
| Sept. | 30 | 0.15 | 5.19 |
| Oct. | 11 | -- | 1.29 |
| Total | 157 | 3.90 = R | 31.63 = F |

$$\therefore \quad U = KF = 0.80 \times 31.63 = 25.3 \text{ inches of water}$$

Therefore, total crop requirements from the ground water = 25.3 - 3.90 = 21.4 inches.

Growing-season water-table depth constant. As mentioned above, a change in the water-table depth during the growing season must be considered in estimating both the upward hydraulic gradient and the water consumed by the crop. The water table in the vicinity of piezometer lines A, B, and C as measured by piezometer line $D_{12}$ will be considered in these calculations. As may be inferred from line $D_{12}$, figure 19, there was essentially no change in the average depth of the water table between the beginning and end of the growing season.

Upward flow equals consumptive use less precipitation. Since the average water-table level remained constant during the growing season, the total upward flow from the artesian aquifer between

May 7 and October 11 was, therefore, approximately equal to the difference between the consumptive use and the precipitation during this same period. This value has already been calculated to equal 21.4 inches of water for the 1952 growing season. Expressed in inches per 24-hour day:

$$V = \frac{21.4}{157} = 0.136 \text{ inches per 24 hours}$$

As feet per second:

$$V = \frac{0.136}{12 \times 24 \times 3600} = 1.31 \times 10^{-7} \text{ feet per second}$$

The average upward hydraulic gradient has previously been found to equal 0.53.

Now, applying Darcy's formula, $V = ki$,

$$k = \frac{V}{i} = \frac{1.31 \times 10^{-7}}{0.53} = 2.78 \times 10^{-7} \text{ feet per second}$$

To obtain a truly representative estimate of k which could be applied to the whole area it would be necessary to replicate this experiment many times. In 1930 Israelsen and McLaughlin (9) estimated from permeameter studies the effective vertical permeability of the clay aquiclude to be $1.7 \times 10^{-7}$ feet per second. Justin, Hinds, and Creager (11) quote $1.0 \times 10^{-7}$ feet per second as an average value for coarse clay. Considering the great variation that exists in permeability determinations, the agreement between these 3 estimates of the effective vertical permeability of the clay aquiclude is reasonably close.

## Effects of the airport drains

**New drain.** As previously stated, the asphalt surface of taxiway 1-A adjacent to the study area had failed many times under load. Therefore, in the spring of 1952, 2 parallel 8-inch diameter drains were placed along each side of the taxiway. The drains were set at depths ranging from 6 to 9 feet below the ground surface and were spaced 50 feet apart. During the trench excavation it was observed that even though the water table stood at an average depth of 6 feet below the ground surface, when the shovel cut through the asphalt surface into the clay soil below, large quantities of water poured from the gravel subgrade into the trench. It was reasoned, therefore, that the high moisture content of the clay soil directly beneath the asphalt subgrade of taxiway 1-A was caused by inadequate surface drainage rather than by a high water table. Water which had collected beneath the asphalt could not evaporate readily, and the clay subsoil restricted percolation to the water table below. The water, entrapped between the soil surface and the asphalt, softened the clay so that under periodic loading particles of the gravel subgrade moved slowly downward. The asphalt then having insufficient support cracked longitudinally along the wheel lines where the load was applied. The new drains placed below the taxiway in the spring of 1952 were backfilled with gravel to a level with the clay surface, so that water which now flows beneath the asphalt is not entrapped but flows downward through the gravel backfill to the drain. The clay surface soil is thus stabilized. A thick gravel subgrade was placed to permit ready water movement beneath the asphalt surface.

Since the airport was first constructed, this taxiway had been repaired many times. However, 6 months after the installation of these new drains no longitudinal cracks had appeared in the surface of the taxiway and there had been no apparent dispersion of the gravel subgrade. Adequate drainage seems to have been provided and solved the problem.

Sump holes or depressions near the drains. The depressions or sump holes in the soil near the drains were caused by a washing of clay particles into the drains. When the drains were installed, a graded gravel filter was not placed at the joints in the tile. M. M. Marler, Assistant Logan City Engineer, stated that during a heavy rainstorm shortly after completion of the airport the entire earth backfill around a particular manhole was washed into the drain. During periods of rapid runoff, the water in the drains is very muddy. It has also been suggested that these holes were caused by the oxidation of peat situated near the soil surface. However, during the construction of the airport all peat beds that existed within the area were dug out completely and the holes backfilled with gravel. No peat was observed in the shallow soil-boring investigations conducted during this study. Part of the break-up of the taxiway in the vicinity of drain 12 may probably be attributed to the formation of these sump holes.

Water-table depth. Throughout the year 1951-1952 the water table within the study area remained at a sufficient depth for the satisfactory growth of most crops. Therefore, because no irrigation water was applied, by June the clay surface soil had become cracked and hard, and much of the alfalfa growing between the runways showed signs of drought. Both pictures shown in figure 24 illustrate shrinkage cracks in the clay soil which resulted from an inadequate moisture supply in the plant root zone.

In marked contrast to this situation were the drainage conditions in fields adjacent to the airport fence. For instance, at the Bell Tract it can safely be assumed that the average water-table level is still very near the ground surface. Here the surface soil was wet and boggy and supported largely only marsh grass and cattails. Figure 25 illustrates these contrasting conditions. Note the clear line of demarkation between the marsh grass which appears in the upper left hand corner of the picture and the forage grasses seen in the remainder of the picture. The marsh grass, of course, growing in undrained soil, indicates an excess water supply. The thin line of silver shown in the upper right hand corner of the picture is not water but reflected light from the asphalt surface of a landing strip.

The condition, or set of conditions, which produce the apparently large difference between the water-table depth at the 1951-1952 study area and that at the Bell Tract only 0.9 miles to the south are still not definitely established. The deep water table may be produced by natural underground conditions existing in the vicinity. However, soil borings and hydraulic gradient measurements show that the profile of the clay layer beneath both areas is almost identical. The artesian pressures at both locations are approximately equal. In the vicinity of the airport the entire land surface slopes gently to the north and west so that the average elevation of the Bell Tract is approximately 5 feet greater than that of the 1951-1952 study area.

The surface drainage system at the airport is also a possible explanation for the comparatively low water table within the study area. E. U. Moser, Cache County Surveyor, Ray C. Hugie, Logan City Engineer, and M. M. Marler, Assistant Logan City Engineer, all support this suggestion. These men state that before the system was installed almost the entire area was occupied by peat bogs and swamps in which water continuously lay. True, by carrying off excess surface water the drains have reduced the amount of water entering the surface soil. As has previously been observed, the upward flow from the artesian aquifer during the growing season is actually less than that required to support satisfactory crop growth. Hence, crop consumptive use may have slowly reduced the amount of water in the surface soil and so lowered the water table until an equilibrium level between the upward flow and the consumptive use was reached.

Surface drains essential. A prime objective of this investigation was to determine the function of the airport drainage system. Evidence now indicates that the system is in the main effective only for surface drainage.

However, irregardless of the water-table elevation, it is possible that a surface drainage problem would exist within the airport area. Before the tile lines were installed, precipitation and runoff from higher lands may have accumulated on the ground surface, even though some distance above the water table. For instance, during the rapid snowmelt period in the spring of 1952 large pools of water lay on the land surface nearly 6 feet above the level of the water table. Assuming that the vertical permeability of the surface soil is equal to that of the clay layer beneath the water table, the volume of deep percolation from the soil surface to the water table for a given unit of time is only twice the volume of flow upward from the artesian gravels.

Therefore, it appears that drains to intercept and carry away the surface water are an essential part of a system to adequately drain the lower lands of Cache Valley. Beauchamp (1) in considering the drainage of clay soils with a low permeability writes that shallow drains to intercept excess surface water provide the only practical solution to the problem. In his discussion, however, he did not consider clay soils overlying an artesian basin. Certainly, subgrade drainage for all asphalt surfaces seem to be essential at the airport. Whether surface drainage alone would completely solve the problem for agriculture by indirectly lowering the water table to a sufficient depth for economical crop production is a question not yet definitely answered.

Permanent agriculture. To insure continuously good crop yields it is imperative not only that the water table be maintained at an adequate depth but also that irrigation water be applied in sufficient quantities to prevent an accumulation of salt within the soil. As stated by Israelsen (7), these practices are the very foundation of permanent agriculture in arid regions. Shallow surface drains 2 or 3 feet deep and spaced at 200 feet or more by removing the surface water might indirectly lower the water table to a sufficient depth for satisfactory crop production. Also, alfalfa could be grown to build up the soil structure and so aid the downward movement of leaching water.

However, even assuming that these practices were at first successful, it is still indefinite whether permanent agriculture would be established. First, because all movement below the water table is upward, salts may accumulate within the capillary fringe, causing the plant roots to retract and subsequent rise in the water table. Second, any downward movement of leaching water either to reclaim the soil or to prevent salt accumulation would again upset the equilibrium conditions and produce a rise in the level of the water table. It is possible, therefore, that the water-table level can be effectively controlled only be reducing the rate of upward flow through pumped drainage from the artesian aquifer. Pumps in conjunction with surface drains would, of course, eliminate all uncontrolled water flow to the surface soil. Because of the low permeability of the surface soil, it is doubtful whether pumping alone would solve the problem, but the irrigation water derived from the deep gravel would probably more than pay the expenses incident to a large-scale drainage system. Unfortunately, the landowners in the area, who are upheld in their views by the courts, will not tolerate pumping on the grounds that the artesian aquifer provides them with a ready source of water under pressure. For this reason pumped wells to lower the piezometric surface will be developed slowly. Therefore, even considering that they would only partially solve the drainage problem, shallow surface drains would be the first step toward revolutionizing the agriculture in the bottom lands of Cache Valley.

# SUMMARY AND CONCLUSIONS

## Function of the airport drains

The airport drains act only to dispose of surface water; no water is removed directly from the clay soil. Throughout the entire period of investigation the ground-water table remained well below the level of the 3 tile lines, drains 4, 11, and 12. Also, at any given depth below the water table, there was no measureable hydraulic gradient toward drain 12.

## Water-table depth at the 1951-1952 study area

Within the 1951-1952 study area the average water table is comparatively deep. The top of the permanently-saturated soil zone is approximately 6.5 feet below the ground surface. Apparently, excess surface water from the melting snow caused the water table to rise until it reached its peak elevation of between 4 and 5 feet below the ground surface in early april. The water table then fell slowly until in late June or early July it had again returned to the 6.5-foot level.

Thus, during most of the year the water table at the study area was sufficiently deep for satisfactory crop growth; yet at the Bell Tract only 0.9 miles to the south the average water table stood very near the ground surface. It is not definitely established, however, whether this marked difference has been produced by the airport drainage system or by natural underground conditions existing in the vicinity of the study area.

## Profile of the clay aquiclude

Test hole and piezometric data indicate that the complete soil profile between the artesian aquifer and the ground surface probably consists in general of 3 distinct classes of material. The top 10 feet of soil range from a soft silt loam at the surface through 4 feet of hard Logan clay to a layer of soft silty loam nearly 6 feet in thickness. Immediately overlying the artesian gravel there is apparently a 5-foot layer of clay which is relatively less permeable than the rest of the profile. Sandwiched in between these 2 thin layers of material are 30 feet of blue silty mud having exceptionally uniform permeability.

## Artesian aquifer pressure head

The total average pressure head in the 40-foot artesian aquifer during the study period was 61 feet of water. Although pressure head changes were relatively small, there appears to have been a general decline from the beginning to the end of the period. This decline may have been produced by uncontrolled flow from a nearby well which burst its seal late in April. The maximum observed pressure head difference was 4 feet of water, or nearly 20 percent of the driving head which produces the upward flow from the aquifer.

Since pressure head changes appear to be readily transmitted through the highly-permeable gravels, it seems feasible to assume that pumped wells placed at strategic points could lower the piezometric surface with respect to the aquifer to any desired level.

### Upward hydraulic gradient

The average upward hydraulic gradient through the clay aquiclude was 0.53 for the study period, with a low of 0.43 in April and a high of 0.60 in February. In 1929 and 1930 Israelsen and McLaughlin (9) measured this gradient to be 0.39. The gradient was apparently not influenced by small variations in the artesian aquifer pressure head. On the other hand, evidence indicates that almost a direct relationship exists between the upward hydraulic gradient and the depth of the water table.

### The permeability of the clay aquiclude

With the aid of precipitation and consumptive-use data the effective vertical permeability of the overlying clay layer was estimated in this report to be 2.78 x $10^{-7}$ feet per second. In 1930 Israelsen and McLaughlin (9) from permeameter studies measured this permeability at 1.7 x $10^{-7}$ feet per second.

### Landing strip and taxiway design

The failure of taxiway No. 1-A in the vicinity of the study area was the result of both inadequate subgrade drainage and the formation of sump holes adjacent to drain 12. These depressions or sump holes were apparently caused by drainage water carrying clay soil particles into the drain. A graded gravel filter placed at the tile joints would have prevented this problem.

All asphalt landing strip and taxiway surfaces constructed at the Logan-Cache Airport should be provided with sufficient subgrade drainage to prevent water from being entrapped and held between the asphalt and the soil surface. A thick gravel subgrade must, of course, be provided for all asphalt surfaces.

## Surface drains and agricultural production

To be economically applicable to agricultural land, smaller tile and in general a wider drain spacing than were used at the airport would be necessary. Also, if the drains are installed to remove surface water entirely, the minimum depth need be determined only by normal cultivation practices. It may be noted that even though the airport drainage system was designed with very large-capacity lines to carry quick runoff, the total annual drainage volume per acre from irrigated land within the same area would be considerably larger than that carried by the present airport tiles.

Irregardless of whether they alone would establish permanent crop production, drains to intercept and carry away the surface water appear to be an essential part of a system to adequately solve the drainage problem in the lower lands of Cache Valley.

# LITERATURE CITED

(1) Beauchamp, Keith H. Surface drainage of tight soils in the midwest. Agr. Engin. 33:208-212. 1952.

(2) Bisal, Frederick. Siphon drainage in the Hyde Park-Benson area, Cache Valley, Utah. Soil Sci. 67(5):395-401. 1949.

(3) Blaney, Harry F., and Criddle, Wayne D. Determining water requirements in irrigated areas from climatological and irrigation data. U. S. Dept. Agr., Soil Conservation Service. 1950 (Mimeo.)

(4) Donnan, W. W. Model tests of the tile-spacing formula. Proc. Soil Sci. Soc. Am. 11:131-136. 1946.

(5) Gardner, Willard, and Israelsen, Orson W. Design of drainage wells. Utah State Engin. Exp. Sta. Bul. 1. 1940.

(6) Israelsen, O. W. Drainage of land overlying an artesian basin. Utah Acad. Sci. Proc. 8:35-37. 1931.

(7) ______________ Irrigation science; the foundation of permanent agriculture in arid regions. Logan, Utah: Utah State Agr. College Faculty Assn. 1943.

(8) Israelsen, O. W., and McLaughlin, W. W. Drainage of land overlying an artesian ground-water reservoir. Utah Agr. Exp. Sta. Bul. 242. 1932.

(9) ______________________________ Drainage of land overlying an artesian ground-water reservoir. Utah Agr. Exp. Sta. Bul. 259. 1935.

(10) Israelsen, O. W., and Morgan, Elmo R. Specific water conductivity of an artesian aquifer. Trans. Am. Geophys. Union 18:568-574. 1937.

(11) Justin, Joel D., Hinds, Julian, and Creager, William P. Engineering for dams. Vol. 3. New York: Wiley, 1944.

(12) Kirkham, D. Proposed method for field measurement of permeability using auger holes. Proc. Soil Sci. Soc. Am. 10:58-69. 1945.

(13) Peterson, Dean F., Israelsen, O. W., and Hansen, Vaughn E. Hydraulics of wells. Utah Agr. Exp. Sta. Tech. Bul. 351. 1952.

(14) Rasmussen, W. W. Logan-Benson drainage area study: airport soils survey. (Unpublished report. Dept. of Irrigation and Drainage) Utah State Agricultural College, 1952.

(15) U. S. Dept. Interior. Irrigated land use. Bureau of Reclamation Manual. Vol. 5. 1951.

(16) Van Bavel, C. H. M., and Kirkham, D. Field measurement of permeability using auger holes. Proc. Soil Sci. Soc. Am. 13:90-96. 1948.

Table 1. Data on the sections of drains 4, 11, and 12 within the study area*

| Drain No. | Study Section, Manholes | Diameter | Slope | Point of Observation | Station | Depth of Bottom of Tile Below Ground Surface (feet) | Depth of Bottom of Tile Below Datum** (feet) |
|---|---|---|---|---|---|---|---|
| 4 | 42 -43 | 10" concrete | 0.002545 | Manhole 42 | 34+67 | 5.0 | -- |
| | | | | Manhole 43 | 37+42 | 5.5 | -- |
| | | | | Study point*** | 36+52 | 5.3 | 5.1 |
| 11 | 44 - 73 | 8" concrete | 0.003423 | Manhole 44 | 9+08 | -- | -- |
| | | | | Manhole 73 | 12+88 | 4.9 | -- |
| | | | | Study point | 12+13 | 4.7 | 4.8 |
| 12 | 43 - 85 | 12" concrete | 0.003401 | Manhole 43 | 10+03 | -- | -- |
| | | | | Manhole 85 | 12+97 | 5.1 | -- |
| | | | | Study point | 12+27 | 5.0 | 5.6 |

*From original plans of airport drainage system

**See Table 17a

***Portion of drain 4 on piezometer line $D_4$ (see figure 3)

Table 2. Summary of water-table depths (inches below land surface) on the Bell Tract (1930 to 1932)*

| Land Surface Elevation** | 51.6 | 51.4 | 51.6 | 52.9 | 51.5 | 51.3 | 51.5 | 52.5 | 51.4 | 54.2 | Avg. |
|---|---|---|---|---|---|---|---|---|---|---|---|
| No. of Hole | R1 | R2 | R3 | R4 | R5 | R6 | R7 | R8 | R9 | A1-1 | |
| Year | | | | | | | | | | | |
| 1930 | 20 | 26 | 26 | 23 | 25 | 21 | 19 | 29 | 24 | — | 23.7 |
| 1931 | 28 | 48 | — | 40 | 39 | 31 | 31 | 33 | 54 | 34 | 37.6 |
| 1932 | 21 | 27 | 54 | 46 | 43 | 21 | 25 | 40 | 24 | 26 | 32.7 |

*From Israelsen and McLaughlin (9)

**Add 4400 feet to each elevation given to obtain elevation above sea level.

Table 3. Piezometer readings at Logan-Cache Airport in feet of water above the ground surface, November 1951*

| Line No. | Date | Reading No. | Piezometer Number | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
| A | 14 | 1 | - | 11.2 | 8.0 | 2.1 | 0.1 | 0 | -3.4 | -4.6 | dry |
| | 17 | 2 | - | 11.2 | 8.0 | 2.1 | 0.1 | 0 | -3.5 | -4.7 | " |
| | 20 | 3 | - | 11.6 | 8.2 | 2.1 | 0.1 | 0 | -3.3 | -4.5 | " |
| | 23 | 4 | - | 12.0 | 8.7 | 2.3 | 0.1 | 0 | -3.5 | -4.8 | " |
| | 26 | 5 | - | 12.1 | 8.9 | 2.5 | 0.1 | 0 | -3.8 | -5.0 | " |
| | 29 | 6 | - | 12.2 | 9.0 | 2.6 | 0.1 | 0 | -3.0 | -5.1 | " |
| Average | | | - | 11.7 | 8.5 | 2.3 | 0.1 | 0 | -3.6 | -4.8 | " |
| Pressure Head, p/w** | | | - | 53.2 | 44.0 | 33.3 | 25.6 | 20.5 | 11.9 | 5.2 | - |
| B | 14 | 1 | 18.4 | 10.0 | 5.7 | 5.1 | 2.9 | -1.3 | -4.8 | -6.2 | dry |
| | 17 | 2 | 18.4 | 10.0 | 5.7 | 5.1 | 2.9 | -1.3 | -4.8 | -6.1 | " |
| | 20 | 3 | 18.4 | 10.0 | 6.9 | 5.1 | 3.2 | -1.3 | -4.8 | -6.1 | " |
| | 23 | 4 | 17.8 | 11.1 | 7.3 | 5.4 | 3.6 | -0.5 | -4.8 | -6.1 | " |
| | 26 | 5 | 16.5 | 13.3 | 8.0 | 6.1 | 3.8 | -1.3 | -4.9 | -6.2 | " |
| | 29 | 6 | 16.2 | 13.4 | 8.2 | 6.5 | 3.8 | -1.3 | -5.0 | -6.3 | " |
| Average | | | 17.6 | 11.3 | 7.0 | 5.6 | 3.4 | -1.2 | -4.9 | -6.2 | " |
| Pressure Head, p/w | | | 61.6 | 52.8 | 43.5 | 36.0 | 28.9 | 19.3 | 10.6 | 3.8 | - |
| C | 14 | 1 | 18.6 | 14.7 | 7.8 | 4.9 | 0.2 | -0.1 | -6.2 | -6.5 | dry |
| | 17 | 2 | 18.6 | 14.7 | 7.8 | 4.9 | 0.1 | 0 | -6.1 | -6.5 | " |
| | 20 | 3 | 18.6 | 14.7 | 7.8 | 4.9 | 0.1 | 0 | -6.1 | -6.5 | " |
| | 23 | 4 | 18.4 | 14.9 | 8.3 | 5.0 | 0.1 | -0.1 | -6.1 | -6.4 | " |
| | 26 | 5 | 16.7 | 13.8 | 8.5 | 5.0 | 0.1 | 0 | -6.1 | -6.3 | " |
| | 29 | 6 | 16.2 | 13.7 | 8.4 | 5.1 | 0.1 | 0 | -6.1 | -6.3 | " |
| Average | | | 17.9 | 14.4 | 8.1 | 5.0 | 0.1 | 0 | -6.1 | -6.4 | " |
| Pressure Head, p/w | | | 64.4 | 55.9 | 44.6 | 36.0 | 25.6 | 20.5 | 9.4 | 3.6 | - |
| Average Lines A,B,C | | | 17.8 | 12.5 | 7.5 | 4.3 | 1.2 | -0.4 | -4.9 | -5.0 | dry |
| Pressure Head, p/w | | | 63.0 | 54.0 | 43.0 | 35.3 | 26.7 | 20.1 | 10.6 | 5.0 | - |

Average monthly weather conditions: warm, fair
Average monthly ground-surface conditions: dry, no plant growth

*Piezometer depths in feet below the ground surface are shown in table 17b

**Feet of water

Table 4. Piezometer readings at Logan-Cache Airport in feet of water above the ground surface, December 1951*

| Line No. | Date | Reading No. | Piezometer Number 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| A | 6 | 7 | - | 12.5 | 9.3 | 3.2 | 0.1 | 0 | -4.0 | -5.3 | dry |
| Pressure Head, p/w** | | | - | 54.0 | 45.8 | 34.2 | 25.6 | 20.5 | 11.5 | 4.7 | - |
| B | 6 | 7 | 16.3 | 13.4 | 8.3 | 6.5 | 3.9 | -1.5 | -4.9 | -2.7 | dry |
| Pressure Head, p/w | | | 60.3 | 54.9 | 44.8 | 37.5 | 29.4 | 19.0 | 10.6 | 7.3 | - |
| C | 6 | 7 | 16.2 | 13.7 | 8.4 | 5.1 | 0.1 | 0 | -6.0 | -6.1 | dry |
| Pressure Head, p/w | | | 62.7 | 55.2 | 44.9 | 36.1 | 25.6 | 20.5 | 9.5 | 3.9 | - |
| Average Lines A,B,C | | | 16.2 | 13.2 | 8.7 | 4.9 | 1.7 | -0.5 | -5.0 | -4.7 | dry |
| Pressure Head, p/w | | | 61.4 | 54.7 | 45.2 | 35.9 | 27.2 | 20.0 | 10.5 | 5.3 | - |

Average monthly weather conditions: cold, cloudy

Average monthly ground-surface conditions: snow-covered in the latter part of the month

*Piezometer depths in feet below the ground surface are shown in table 17b

**Feet of water

Table 5. Piezometer readings at Logan-Cache Airport in feet of water above the ground surface, February 1952*

| Line No. | Date | Reading No. | Piezometer Number 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| A | 1 | 8 | - | 11.1 | 8.5 | 2.4 | 0 | -0.4 | -4.6 | -5.6 | dry |
| Pressure Head, p/w** | | | - | 52.6 | 45.0 | 33.4 | 25.5 | 20.1 | 10.9 | 4.4 | - |
| B | 1 | 8 | 15.9 | 13.0 | 8.0 | 5.5 | 3.2 | -1.4 | -4.2 | -5.0 | dry |
| Pressure Head, p/w | | | 59.9 | 54.5 | 44.5 | 36.5 | 28.7 | 19.1 | 11.3 | 5.0 | - |
| C | 1 | 8 | 16.0 | 13.4 | 7.5 | 4.8 | 0 | -0.3 | -6.2 | -6.4 | dry |
| Pressure Head, p/w | | | 62.5 | 54.9 | 44.0 | 35.8 | 25.5 | 20.2 | 9.3 | 3.6 | - |
| Average Lines A,B,C | | | 16.0 | 12.5 | 8.0 | 4.2 | 1.1 | -0.7 | -5.0 | -5.7 | dry |
| Pressure Head, p/w | | | 61.2 | 54.0 | 44.5 | 35.2 | 26.6 | 19.8 | 10.5 | 4.3 | - |

Average monthly weather conditions: cold, intermittent snow
Average monthly ground-surface conditions: snow-covered

*Piezometer depths in feet below the ground surface are shown in table 17b

**Feet of water.

Table 6. Piezometer readings at Logan-Cache Airport in feet of water above the ground surface, April 1952*

| Line No. | Date | Reading No. | Piezometer Number | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
| A | 1 | 9 | - | 10.7 | 9.0 | 2.1 | 0 | -0.8 | -3.6 | -3.0 | -5.4 |
| | 4 | 10 | - | 10.7 | 9.0 | 2.1 | 0 | -0.8 | -3.6 | -2.8 | -5.3 |
| | 7 | 11 | - | 10.8 | 9.1 | 2.2 | 0 | -0.7 | -3.7 | -2.7 | -5.2 |
| | 10 | 12 | - | 10.8 | 9.1 | 2.2 | 0 | -0.7 | -3.7 | -2.5 | -5.2 |
| | 13 | 13 | - | 13.0 | 9.3 | 2.4 | 0.2 | -0.8 | -3.6 | -3.1 | -5.4 |
| | 16 | 14 | - | 13.0 | 9.3 | 2.5 | 0.1 | -0.8 | -3.6 | -3.3 | -5.3 |
| | 19 | 15 | - | 13.4 | 9.6 | 2.6 | 0.2 | -0.8 | -3.6 | -3.6 | -5.3 |
| | 22 | 16 | - | 13.0 | 8.5 | 2.6 | 0.2 | -0.8 | -3.6 | -3.8 | dry |
| | 25 | 17 | - | 11.9 | 9.0 | 2.6 | 0.2 | -0.8 | -3.6 | -4.2 | " |
| | 28 | 18 | - | 11.7 | 8.8 | 2.4 | 0.1 | -0.9 | -3.6 | -4.2 | " |
| Average | | | - | 11.9 | 9.1 | 2.4 | 0.1 | -0.8 | -3.6 | -3.3 | -5.4 |
| Pressure Head, p/w** | | | - | 53.4 | 45.6 | 33.4 | 25.6 | 19.7 | 11.9 | 6.7 | 0.1 |
| B | 1 | 9 | 16.5 | 12.0 | 4.4 | 2.7 | 2.4 | -1.7 | -3.7 | -5.1 | -5.1 |
| | 4 | 10 | 16.5 | 12.0 | 4.5 | 2.8 | 2.5 | -1.6 | -3.6 | -5.0 | -5.0 |
| | 7 | 11 | 16.5 | 12.0 | 4.5 | 2.8 | 2.6 | -1.6 | -3.6 | -5.0 | -4.9 |
| | 10 | 12 | 16.5 | 12.0 | 4.5 | 2.8 | 2.7 | -1.5 | -3.6 | -5.1 | -4.9 |
| | 13 | 13 | 16.5 | 12.0 | 6.0 | 3.8 | 2.8 | -1.5 | -3.7 | -5.1 | -5.2 |
| | 16 | 14 | 16.5 | 11.5 | 6.6 | 4.3 | 3.0 | -1.5 | -3.6 | -5.0 | -5.0 |
| | 19 | 15 | 16.7 | 13.3 | 7.0 | 5.0 | 3.2 | -1.5 | -3.7 | -5.0 | -5.2 |
| | 22 | 16 | 16.8 | 11.6 | 7.0 | 5.0 | 3.3 | -1.5 | -3.7 | -5.0 | -5.3 |
| | 25 | 17 | 16.6 | 12.0 | 5.5 | 3.6 | 3.1 | -1.6 | -3.9 | -5.0 | -5.3 |
| | 28 | 18 | 16.5 | 11.3 | 4.6 | 3.2 | 2.9 | -1.7 | -4.0 | -5.0 | dry |
| Average | | | 16.6 | 12.0 | 5.5 | 3.6 | 2.9 | -1.6 | -3.7 | -5.0 | -5.1 |
| Pressure Head, p/w | | | 60.6 | 53.5 | 42.0 | 34.6 | 28.4 | 18.9 | 11.8 | 5.0 | 0.4 |
| C | 1 | 9 | 16.7 | 13.6 | 7.0 | 5.2 | 0 | -0.2 | -4.4 | -4.8 | -4.8 |
| | 4 | 10 | 16.7 | 13.6 | 7.1 | 5.2 | 0 | -0.1 | -4.4 | -4.7 | -4.8 |
| | 7 | 11 | 16.8 | 13.7 | 7.2 | 5.3 | 0.1 | -0.1 | -4.3 | -4.6 | -4.7 |
| | 10 | 12 | 16.8 | 13.7 | 7.2 | 5.3 | 0.1 | -0.1 | -4.3 | -4.6 | -4.6 |
| | 13 | 13 | 16.9 | 13.7 | 7.8 | 5.5 | 0.3 | -0.3 | -4.5 | -4.9 | -4.9 |
| | 16 | 14 | 16.9 | 14.0 | 7.9 | 5.6 | 0.3 | 0 | -4.6 | -4.9 | -4.7 |
| | 19 | 15 | 17.0 | 15.1 | 8.0 | 5.6 | 0.3 | -0.1 | -4.4 | -4.8 | -4.7 |
| | 22 | 16 | 17.2 | 15.9 | 7.4 | 5.5 | 0.2 | -0.2 | -4.7 | -5.1 | -5.0 |
| | 25 | 17 | 16.9 | 13.6 | 7.3 | 5.5 | 0.2 | -0.2 | -4.8 | -5.2 | -5.2 |
| | 28 | 18 | 17.2 | 12.7 | 5.9 | 5.5 | 0 | -0.2 | -5.0 | -5.4 | -5.3 |
| Average | | | 16.7 | 13.8 | 7.3 | 5.4 | 0.2 | -0.2 | -4.5 | -4.9 | -4.9 |
| Pressure Head, p/w | | | 63.2 | 55.3 | 43.8 | 36.4 | 25.7 | 20.3 | 11.0 | 5.1 | 0.6 |
| Average Lines A,B,C | | | 16.6 | 12.6 | 7.3 | 3.8 | 1.1 | -0.9 | -3.6 | -4.4 | -5.1 |
| Pressure Head, p/w | | | 61.8 | 54.1 | 43.8 | 34.8 | 26.6 | 19.6 | 11.9 | 5.6 | 0.4 |

Average monthly weather conditions: warm, intermittent rain.
Average monthly ground-surface conditions: wet, little plant growth

*Piezometer depths in feet below the ground surface are shown in table 17b

**Feet of water

Table 6. Piezometer readings at Logan-Cache Airport in feet of water above the ground surface, May 1952*

| Line No. | Date | Reading No. | Piezometer Number 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| A | 1 | 19 | - | 12.0 | 8.7 | 2.4 | 0.1 | -0.9 | -3.6 | -4.4 | dry |
| | 4 | 20 | - | 12.4 | 8.5 | 2.3 | 0.1 | -0.9 | -3.6 | -4.6 | " |
| | 7 | 21 | - | 12.3 | 8.4 | 2.3 | 0.1 | -0.9 | -3.7 | -4.7 | " |
| | 10 | 22 | - | 12.2 | 8.2 | 2.3 | 0.1 | -0.9 | -3.7 | -4.7 | " |
| | 13 | 23 | - | 12.1 | 8.1 | 2.3 | 0.1 | -0.9 | -3.7 | -4.8 | " |
| | 16 | 24 | - | 12.0 | 8.0 | 2.3 | 0.1 | -0.9 | -3.7 | -4.9 | " |
| | 19 | 25 | - | 12.0 | 8.2 | 2.3 | 0.2 | -0.9 | -3.8 | -4.9 | " |
| | 22 | 26 | - | 12.0 | 8.3 | 2.3 | 0.3 | -0.9 | -3.8 | -5.0 | " |
| | 25 | 27 | - | 12.0 | 8.4 | 2.3 | 0.3 | -0.9 | -3.9 | -5.0 | " |
| | 28 | 28 | - | 11.8 | 8.6 | 2.3 | 0.3 | -0.9 | -3.8 | -5.0 | " |
| Average | | | - | 12.1 | 8.3 | 2.3 | 0.2 | -0.9 | -3.7 | -4.8 | " |
| Pressure Head, p/w** | | | - | 53.6 | 44.8 | 33.3 | 25.7 | 19.6 | 11.8 | 5.2 | - |
| B | 1 | 19 | 15.5 | 11.2 | 5.7 | 3.7 | 2.9 | -1.8 | -4.1 | -5.0 | dry |
| | 4 | 20 | 14.5 | 11.1 | 6.2 | 4.4 | 3.0 | -1.8 | -4.2 | -5.1 | " |
| | 7 | 21 | 13.7 | 10.8 | 6.6 | 5.2 | 3.1 | -1.9 | -4.3 | -5.1 | " |
| | 10 | 22 | 13.7 | 10.9 | 6.6 | 5.3 | 3.1 | -1.9 | -4.5 | -5.1 | " |
| | 13 | 23 | 13.7 | 11.0 | 6.8 | 5.5 | 3.1 | -1.9 | -4.8 | -5.1 | " |
| | 16 | 24 | 13.7 | 11.1 | 6.9 | 5.6 | 3.1 | -2.0 | -4.9 | -5.1 | " |
| | 19 | 25 | 13.5 | 11.1 | 7.0 | 5.6 | 3.1 | -2.0 | -4.8 | -5.2 | " |
| | 22 | 26 | 13.3 | 11.2 | 7.1 | 5.7 | 3.2 | -2.0 | -4.7 | -5.2 | " |
| | 25 | 27 | 12.9 | 11.3 | 7.2 | 5.8 | 3.2 | -2.0 | -4.5 | -5.2 | " |
| | 28 | 28 | 12.7 | 11.7 | 7.6 | 6.2 | 3.2 | -2.1 | -4.5 | -5.2 | " |
| Average | | | 12.7 | 11.1 | 6.8 | 5.3 | 3.1 | -1.9 | -4.5 | -5.1 | " |
| Pressure Head, p/w | | | 56.7 | 52.6 | 43.3 | 36.3 | 28.6 | 18.6 | 11.0 | 4.9 | - |
| C | 1 | 19 | 16.0 | 12.4 | 7.0 | 5.4 | 0 | -0.2 | -5.0 | -5.5 | dry |
| | 4 | 20 | 14.8 | 12.2 | 7.2 | 5.3 | -0.1 | -0.2 | -5.0 | -5.7 | " |
| | 7 | 21 | 14.2 | 12.0 | 7.4 | 5.3 | 0.1 | -0.2 | -5.5 | -5.8 | " |
| | 10 | 22 | 14.2 | 12.0 | 7.4 | 5.3 | 0.1 | -0.2 | -5.5 | -5.8 | " |
| | 13 | 23 | 14.2 | 12.0 | 7.5 | 5.3 | 0.2 | -0.2 | -5.6 | -5.9 | " |
| | 16 | 24 | 14.1 | 12.0 | 7.6 | 5.3 | 0.2 | -0.2 | -5.6 | -5.9 | " |
| | 19 | 25 | 14.1 | 12.1 | 7.6 | 5.4 | 0.2 | -0.1 | -5.6 | -5.8 | " |
| | 22 | 26 | 14.2 | 12.2 | 7.7 | 5.5 | 0.3 | -0.1 | -5.5 | -5.8 | " |
| | 25 | 27 | 14.3 | 12.2 | 7.7 | 5.5 | 0.3 | -0.1 | -5.4 | -5.8 | " |
| | 28 | 28 | 12.9 | 12.4 | 8.1 | 5.5 | 0.3 | -0.1 | -5.5 | -5.8 | " |
| Average | | | 14.3 | 12.2 | 7.5 | 5.4 | 0.2 | -0.2 | -5.4 | -5.8 | " |
| Pressure Head, p/w | | | 60.8 | 53.7 | 44.0 | 36.4 | 25.7 | 20.3 | 10.1 | 4.2 | - |
| Average Lines A,B,C | | | 14.0 | 11.8 | 7.5 | 4.3 | 1.2 | -1.0 | -4.5 | -5.2 | dry |
| Pressure Head, p/w | | | 59.2 | 53.3 | 44.0 | 35.3 | 26.7 | 18.5 | 11.0 | 4.8 | - |

Average monthly weather conditions: warm, fair

Average monthly ground-surface conditions: dry, beginning of plant growth

*Piezometer depths in feet below the ground surface are shown in table 17b

**Feet of water

Table 9. Piezometer readings at Logan-Cache Airport in feet of water above the ground surface, June 1952*

| Line | | Reading | Piezometer Number | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| No. | Date | No. | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
| | 4 | 29 | - | 11.3 | 8.4 | 1.6 | 0.2 | -0.6 | -2.9 | -5.0 | dry |
| | 7 | 30 | - | 11.8 | 8.4 | 2.3 | 0.2 | -0.1 | -3.0 | -5.0 | " |
| | 10 | 31 | - | 11.3 | 8.3 | 2.3 | 0.5 | -0.2 | -1.2 | -5.0 | " |
| A | 13 | 32 | - | 11.3 | 8.2 | 2.6 | 0.2 | -0.8 | -3.8 | -5.3 | " |
| | 16 | 33 | - | 11.3 | 8.3 | 2.6 | 0.4 | -0.8 | -3.8 | -5.3 | " |
| | 19 | 34 | - | 11.5 | 7.8 | 2.6 | 0.2 | -1.0 | -3.8 | -5.3 | " |
| | 22 | 35 | - | 11.5 | 8.0 | 2.4 | 0.1 | -1.3 | -3.2 | -5.6 | " |
| Average | | | - | 11.4 | 8.2 | 2.3 | 0.3 | -0.7 | -3.1 | -5.2 | " |
| Pressure Head, p/w** | | | - | 52.9 | 44.7 | 83.3 | 25.8 | 19.8 | 12.4 | 4.8 | - |
| | 4 | 29 | 12.5 | 10.0 | 6.0 | 4.3 | 3.3 | -2.1 | -2.3 | -3.6 | dry |
| | 7 | 30 | 13.5 | 11.5 | 5.5 | 4.9 | 3.3 | -2.2 | -3.6 | -4.5 | " |
| | 10 | 31 | 13.8 | 10.7 | 6.0 | 4.7 | 3.2 | -2.1 | -2.0 | -4.5 | " |
| B | 13 | 32 | 13.5 | 10.7 | 6.9 | 5.0 | 3.2 | -2.1 | -4.5 | -5.3 | " |
| | 16 | 33 | 14.1 | 11.1 | 6.8 | 5.4 | 3.3 | -1.9 | -4.4 | -5.3 | " |
| | 19 | 34 | 14.0 | 11.1 | 6.9 | 5.4 | 3.2 | -1.9 | -4.4 | -5.3 | " |
| | 22 | 35 | 14.3 | 12.4 | 7.5 | 5.8 | 3.3 | -2.2 | -3.8 | -5.3 | " |
| Average | | | 13.7 | 11.1 | 6.5 | 5.1 | 3.3 | -2.1 | -3.6 | -4.8 | " |
| Pressure Head, p/w | | | 57.7 | 52.6 | 43.0 | 36.1 | 28.8 | 18.4 | 11.9 | 5.2 | - |
| | 4 | 29 | 12.9 | 10.5 | 5.4 | 4.8 | 0 | -0.1 | -4.7 | -5.0 | dry |
| | 7 | 30 | 13.8 | 12.5 | 5.4 | 4.8 | 0 | 0 | -4.6 | -5.0 | " |
| | 10 | 31 | 14.0 | 12.4 | 5.4 | 5.4 | 0.1 | -0.3 | -5.5 | -5.7 | " |
| C | 13 | 32 | 13.9 | 12.4 | 6.1 | 5.4 | 0.2 | -0.5 | -5.5 | -5.8 | " |
| | 16 | 33 | 14.5 | 12.3 | 6.8 | 5.2 | 0.1 | -0.5 | -5.7 | -5.9 | " |
| | 19 | 34 | 14.6 | 12.2 | 6.8 | 5.2 | 0.1 | -0.5 | -5.6 | -6.1 | " |
| | 22 | 35 | 14.5 | 12.2 | 7.0 | 5.4 | 0 | -0.7 | -5.8 | -6.3 | " |
| Average | | | 14.0 | 12.1 | 6.1 | 5.2 | 0.1 | -0.4 | -5.3 | -5.7 | " |
| Pressure Head, p/w | | | 60.5 | 53.6 | 42.6 | 36.2 | 25.6 | 20.1 | 10.2 | 4.3 | - |
| Average Lines A,B,C | | | 13.8 | 11.5 | 6.9 | 4.2 | 1.2 | -1.1 | -4.0 | -5.2 | dry |
| Pressure Head, p/w | | | 59.0 | 53.0 | 43.4 | 35.2 | 26.7 | 19.4 | 11.5 | 4.8 | - |

Average monthly weather conditions: warm, fair
Average monthly ground-surface conditions: dry, rapid plant growth

*Piezometer Depths in feet below the ground surface are shown in table 17b

**Feet of water

Table 9 . Average monthly pressure heads in feet of water at Logan-Cache Airport*

| Line No. | Month | Piezometer Number | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
| A | Nov. | - | 53.2 | 44.0 | 33.3 | 25.6 | 20.5 | 11.9 | 5.2 | - |
| | Dec. | - | 54.0 | 45.8 | 34.2 | 25.6 | 20.5 | 11.5 | 4.7 | - |
| | Feb. | - | 52.6 | 45.0 | 33.4 | 25.5 | 20.1 | 10.9 | 4.4 | - |
| | Apr. | - | 53.4 | 45.6 | 33.4 | 25.6 | 19.7 | 11.9 | 6.7 | 0.1 |
| | May | - | 53.6 | 44.8 | 33.3 | 25.7 | 19.6 | 11.8 | 5.2 | - |
| | June | - | 52.9 | 44.7 | 33.3 | 25.8 | 19.8 | 12.4 | 4.8 | - |
| Average | | - | 53.3 | 45.0 | 33.3 | 25.6 | 20.2 | 11.7 | 5.2 | - |
| B | Nov. | 61.6 | 52.8 | 43.5 | 36.0 | 28.9 | 19.3 | 10.6 | 3.8 | - |
| | Dec. | 60.3 | 54.9 | 44.8 | 37.5 | 29.4 | 19.0 | 10.6 | 7.3 | - |
| | Feb. | 59.9 | 54.5 | 44.5 | 36.5 | 28.7 | 19.1 | 11.3 | 5.0 | - |
| | Apr. | 60.6 | 53.5 | 42.0 | 34.6 | 28.4 | 18.9 | 11.8 | 5.0 | 0.4 |
| | May | 56.7 | 52.6 | 43.3 | 36.3 | 28.6 | 18.6 | 11.0 | 4.9 | - |
| | June | 57.7 | 52.6 | 43.0 | 36.1 | 28.8 | 18.4 | 11.9 | 5.2 | - |
| Average | | 59.5 | 53.5 | 43.5 | 36.2 | 28.8 | 18.9 | 11.2 | 5.2 | - |
| C | Nov. | 64.4 | 55.9 | 44.6 | 36.0 | 25.6 | 20.5 | 9.4 | 3.6 | - |
| | Dec. | 62.7 | 55.2 | 44.9 | 36.1 | 25.6 | 20.5 | 9.5 | 3.9 | - |
| | Feb. | 62.5 | 54.9 | 44.0 | 35.8 | 25.5 | 20.2 | 9.3 | 3.6 | - |
| | Apr. | 63.2 | 55.3 | 43.8 | 36.4 | 25.7 | 20.3 | 11.0 | 5.1 | 0.6 |
| | May | 60.8 | 53.7 | 44.0 | 36.4 | 25.7 | 20.3 | 10.1 | 4.2 | - |
| | June | 60.5 | 53.6 | 42.6 | 36.2 | 25.6 | 20.1 | 10.2 | 4.3 | - |
| Average | | 62.3 | 54.7 | 44.0 | 36.2 | 25.6 | 20.3 | 9.9 | 4.1 | 0.1 |

*The readings are taken from tables 3 to 8, inclusive.

Table 10. Airport soil survey

| Depth (feet) | 3 Test Holes at Airport* | | Notes by Rasmussen (14)** | |
|---|---|---|---|---|
| | Soil Type | Color | Soil Type | Color |
| 0 – 0.5 | Silt loam (soft) | Dark brown | Silty clay loam | Dark brown |
| 1.0 | Heavy Logan clay (hard) | Light grey | Clay loam | Light greyish brown |
| 2.0 | Heavy Logan clay (hard) | Light grey | Clay loam | Brown |
| 3.0 | Heavy Logan clay (hard) | Light grey | Clay | Greyish brown, mottled |
| 4.0 | Silty clay loam (softer) | Start of mottling | Clay | Slate colored, mottled |
| 5.0 | Silty clay loam (softer) | Red and yellow mottled | Silty clay loam | Light greyish brown |
| 6.0 | Silty clay loam (softer) | Red and yellow mottled | Fine sand | Grey |
| 6.5 (Water Table) | Silty clay loam (softer) | Red and yellow mottled | | |
| 9.5 | Silty clay (soft) | Blue | | |
| 12.0 | Silty mud (soft) | Blue | | |

*Location of test holes:
1. 1.5 feet west of piezometer 1, line $D_{12}$; 1 foot north of drain 12.
2. 5 feet west of piezometer 1, line $D_{12}$; 1 foot north of drain 12.
3. 2 feet north of piezometer 1,line B,on a line perpendicular to drains 11 and 12.

**(14) refers to literature cited; hole 8, line 7S, one-eighth mile west in airport.

Table 11. Piezometer readings at Logan—Cache Airport in feet from the ground surface down to the water table, January 1952

| Line No. | Date | Reading No. | Piezometer Number | | | | | | | | | Overall Average |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | |
| D4 | 12 | 1 | 5.7 | 5.9 | 5.9 | 5.9 | 5.9 | 5.9 | 6.6 | 6.1 | 5.6 | |
| | 15 | 2 | 6.0 | 6.0 | 6.1 | 5.9 | 6.0 | 5.9 | 6.6 | 6.1 | 5.6 | |
| | 17 | 3 | 5.8 | 5.8 | 5.9 | 5.8 | 5.9 | 5.8 | 6.6 | 6.1 | 5.6 | |
| | 20 | 4 | 5.8 | 5.8 | 5.9 | 5.7 | 5.9 | 5.8 | 6.6 | 6.3 | 5.7 | |
| | 23 | 5 | 6.2 | 5.9 | 5.9 | 5.7 | 6.1 | 6.2 | 6.6 | 6.1 | 6.1 | |
| | 26 | 6 | 6.2 | 5.8 | 6.0 | 5.6 | 6.0 | 6.0 | 6.5 | 6.1 | 6.1 | |
| | 29 | 7 | 6.2 | 5.8 | 6.0 | 5.6 | 6.0 | 6.0 | 6.5 | 6.1 | 6.1 | |
| Average | | | 6.0 | 5.9 | 6.0 | 5.7 | 6.0 | 6.0 | 6.6 | 6.1 | 5.8 | |
| Distance Below Datum* | | | 6.6 | 6.4 | 6.6 | 6.2 | 6.3 | 6.2 | 6.7 | 6.1 | 5.4 | 6.3 |
| D11 | 12 | 1 | 7.0 | 7.5 | 7.7 | 7.0 | 7.0 | 7.0 | 6.5 | 6.5 | 6.6 | |
| | 15 | 2 | 6.4 | 7.5 | 7.6 | 7.0 | 7.0 | 7.0 | 6.5 | 6.5 | 6.6 | |
| | 17 | 3 | 5.7 | 6.1 | 6.1 | 6.6 | 6.6 | 6.7 | 6.7 | 6.5 | 6.6 | |
| | 20 | 4 | 5.6 | 6.0 | 6.1 | 6.6 | 6.6 | 6.7 | 6.7 | 6.3 | 6.4 | |
| | 23 | 5 | 5.5 | 6.0 | 6.1 | 6.4 | 6.5 | 6.5 | 6.6 | 6.2 | 6.3 | |
| | 26 | 6 | 5.5 | 6.0 | 6.1 | 6.4 | 6.5 | 6.5 | 6.6 | 6.2 | 6.3 | |
| | 29 | 7 | 5.5 | 6.0 | 6.1 | 6.4 | 6.5 | 6.5 | 6.6 | 6.2 | 6.3 | |
| Average | | | 5.9 | 6.5 | 6.5 | 6.6 | 6.7 | 6.7 | 6.6 | 6.3 | 6.4 | |
| Distance Below Datum | | | 6.0 | 6.6 | 6.8 | 6.8 | 6.9 | 6.9 | 6.8 | 6.8 | 7.1 | 6.7 |
| D12 | 12 | 1 | 6.4 | 6.7 | 7.4 | 6.8 | 6.5 | 7.0 | 6.5 | 6.5 | 6.6 | |
| | 15 | 2 | 6.4 | 6.7 | 7.6 | 6.8 | 6.2 | 7.0 | 6.6 | 6.6 | 6.6 | |
| | 17 | 3 | 6.4 | 6.7 | 6.7 | 6.7 | 6.4 | 6.7 | 6.7 | 6.4 | 6.6 | |
| | 20 | 4 | 6.4 | 6.6 | 6.5 | 6.6 | 6.5 | 6.5 | 6.5 | 6.4 | 6.4 | |
| | 23 | 5 | 6.4 | 6.5 | 6.5 | 6.6 | 6.3 | 6.4 | 6.5 | 6.3 | 6.3 | |
| | 26 | 6 | 6.4 | 6.5 | 6.5 | 6.6 | 6.3 | 6.4 | 6.5 | 6.3 | 6.3 | |
| | 29 | 7 | 6.4 | 6.5 | 6.5 | 6.6 | 6.3 | 6.4 | 6.5 | 6.3 | 6.3 | |
| Average | | | 6.4 | 6.6 | 6.8 | 6.7 | 6.4 | 6.6 | 6.5 | 6.4 | 6.4 | |
| Distance Below Datum | | | 7.0 | 7.1 | 7.3 | 7.3 | 7.1 | 7.3 | 7.2 | 7.1 | 7.1 | 7.2 |

Average monthly weather conditions: cold, intermittent snow
Average monthly ground—surface conditions: snow covered

*See table 17a

Table 12. Piezometer readings at Logan-Cache Airport in feet from the ground surface down to the water table, February 1952

| Line No. | Date | Reading No. | Piezometer Number | | | | | | | | | Overall Average |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | |
| $D_4$ | 1 | 8 | 5.9 | 5.7 | 5.9 | 5.4 | 5.5 | 5.6 | 6.3 | 5.8 | 5.8 | |
| | 4 | 9 | 5.9 | 5.7 | 5.9 | 5.4 | 5.5 | 5.6 | 6.3 | 5.8 | 5.8 | |
| | 7 | 10 | 5.9 | 5.7 | 5.9 | 5.4 | 5.5 | 5.6 | 6.3 | 5.8 | 5.8 | |
| | 10 | 11 | 5.9 | 5.7 | 5.9 | 5.4 | 5.5 | 5.6 | 6.3 | 5.8 | 5.8 | |
| | 13 | 12 | 5.9 | 5.7 | 5.9 | 5.4 | 5.5 | 5.6 | 6.3 | 5.8 | 5.8 | |
| | 16 | 13 | 5.9 | 5.7 | 5.9 | 5.4 | 5.5 | 5.6 | 6.3 | 5.8 | 5.8 | |
| | 19 | 14 | 5.9 | 5.7 | 5.9 | 5.4 | 5.5 | 5.6 | 6.3 | 5.8 | 5.8 | |
| | 22 | 15 | 5.9 | 5.7 | 5.9 | 5.4 | 5.5 | 5.6 | 6.3 | 5.8 | 5.8 | |
| | 25 | 16 | 5.9 | 5.7 | 5.9 | 5.4 | 5.5 | 5.6 | 6.3 | 5.8 | 5.8 | |
| | 28 | 17 | 5.9 | 5.7 | 5.9 | 5.4 | 5.5 | 5.6 | 6.3 | 5.8 | 5.8 | |
| Average | | | 5.9 | 5.7 | 5.9 | 5.4 | 5.5 | 5.6 | 6.3 | 5.8 | 5.8 | |
| Distance Below Datum* | | | 6.5 | 6.2 | 6.5 | 5.9 | 5.8 | 5.8 | 6.4 | 5.8 | 5.4 | 6.0 |
| $D_{11}$ | 1 | 8 | 5.6 | 6.0 | 6.1 | 6.0 | 6.1 | 6.1 | 6.1 | 5.7 | 6.0 | |
| | 4 | 9 | 5.6 | 6.0 | 6.1 | 6.0 | 6.1 | 6.1 | 6.1 | 5.7 | 6.0 | |
| | 7 | 10 | 5.6 | 6.0 | 6.1 | 6.0 | 6.1 | 6.1 | 6.1 | 5.7 | 6.0 | |
| | 10 | 11 | 5.6 | 6.0 | 6.1 | 6.0 | 6.1 | 6.1 | 6.1 | 5.7 | 6.0 | |
| | 13 | 12 | 5.6 | 6.0 | 6.1 | 6.0 | 6.1 | 6.1 | 6.1 | 5.7 | 6.0 | |
| | 16 | 13 | 5.6 | 6.0 | 6.1 | 6.0 | 6.1 | 6.1 | 6.1 | 5.7 | 6.0 | |
| | 19 | 14 | 5.6 | 6.0 | 6.1 | 6.0 | 6.1 | 6.1 | 6.1 | 5.7 | 6.0 | |
| | 22 | 15 | 5.6 | 6.0 | 6.1 | 6.0 | 6.1 | 6.1 | 6.1 | 5.7 | 6.0 | |
| | 25 | 16 | 5.6 | 6.0 | 6.1 | 6.0 | 6.1 | 6.1 | 6.1 | 5.7 | 6.0 | |
| | 28 | 17 | 5.6 | 6.0 | 6.1 | 6.0 | 6.1 | 6.1 | 6.1 | 5.7 | 6.0 | |
| Average | | | 5.6 | 6.0 | 6.1 | 6.0 | 6.1 | 6.1 | 6.1 | 5.7 | 6.0 | |
| Distance Below Datum | | | 5.6 | 6.1 | 6.4 | 6.2 | 6.3 | 6.3 | 6.3 | 6.2 | 6.7 | 6.2 |
| $D_{12}$ | 1 | 8 | 6.3 | 6.4 | 6.4 | 6.4 | 6.4 | 6.1 | 6.2 | 6.0 | 6.0 | |
| | 4 | 9 | 6.3 | 6.4 | 6.4 | 6.4 | 6.4 | 6.1 | 6.2 | 6.0 | 6.0 | |
| | 7 | 10 | 6.3 | 6.4 | 6.4 | 6.4 | 6.4 | 6.1 | 6.2 | 6.0 | 6.0 | |
| | 10 | 11 | 6.3 | 6.4 | 6.4 | 6.4 | 6.4 | 6.1 | 6.2 | 6.0 | 6.0 | |
| | 13 | 12 | 6.3 | 6.4 | 6.4 | 6.4 | 6.4 | 6.1 | 6.2 | 6.0 | 6.0 | |
| | 16 | 13 | 6.3 | 6.4 | 6.4 | 6.4 | 6.4 | 6.1 | 6.2 | 6.0 | 6.0 | |
| | 19 | 14 | 6.3 | 6.4 | 6.4 | 6.4 | 6.4 | 6.1 | 6.2 | 6.0 | 6.0 | |
| | 22 | 15 | 6.3 | 6.4 | 6.4 | 6.4 | 6.4 | 6.1 | 6.2 | 6.0 | 6.0 | |
| | 25 | 16 | 6.3 | 6.4 | 6.4 | 6.4 | 6.4 | 6.1 | 6.2 | 6.0 | 6.0 | |
| | 28 | 17 | 6.3 | 6.4 | 6.4 | 6.4 | 6.4 | 6.1 | 6.2 | 6.0 | 6.0 | |
| Average | | | 6.3 | 6.4 | 6.4 | 6.4 | 6.4 | 6.1 | 6.2 | 6.0 | 6.0 | |
| Distance Below Datum | | | 6.9 | 6.9 | 6.9 | 7.0 | 7.0 | 6.8 | 6.9 | 6.7 | 6.7 | 6.9 |

Average monthly weather conditions: cold, intermittent snow
Average monthly ground-surface conditions: snow covered

*See table 17a

Table 13. Piezometer readings at Logan-Cache Airport in feet from the ground surface down to the water table, March 1952

| Line No. | Date | Reading No. | Piezometer Number | | | | | | | | | Overall Average |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | |
| $D_4$ | 2 | 18 | 5.9 | 5.7 | 5.9 | 5.4 | 5.5 | 5.6 | 6.3 | 5.8 | 5.8 | |
| | 5 | 19 | 5.9 | 5.7 | 5.9 | 5.4 | 5.5 | 5.6 | 6.3 | 5.8 | 5.8 | |
| | 8 | 20 | 5.9 | 5.7 | 5.9 | 5.4 | 5.5 | 5.6 | 6.3 | 5.8 | 5.8 | |
| | 11 | 21 | 5.9 | 5.7 | 5.9 | 5.3 | 5.4 | 5.5 | 6.3 | 5.7 | 5.7 | |
| | 14 | 22 | 5.8 | 5.6 | 5.8 | 5.3 | 5.4 | 5.4 | 6.7 | 5.6 | 5.6 | |
| | 17 | 23 | 5.8 | 5.6 | 5.8 | 5.2 | 5.3 | 5.4 | 6.2 | 5.4 | 5.5 | |
| | 20 | 24 | 5.7 | 5.6 | 5.7 | 5.1 | 5.2 | 5.3 | 6.1 | 5.3 | 5.4 | |
| | 23 | 25 | 5.7 | 5.5 | 5.7 | 5.1 | 5.2 | 5.2 | 6.1 | 5.2 | 5.2 | |
| | 26 | 26 | 5.6 | 5.5 | 5.6 | 5.0 | 5.1 | 5.0 | 6.0 | 5.0 | 5.0 | |
| | 29 | 27 | 5.5 | 5.5 | 5.6 | 4.9 | 5.1 | 4.9 | 6.0 | 4.8 | 4.8 | |
| Average | | | 5.8 | 5.6 | 5.8 | 5.2 | 5.3 | 5.4 | 6.2 | 5.4 | 5.5 | |
| Distance Below Datum* | | | 6.4 | 6.1 | 6.4 | 5.7 | 5.6 | 5.6 | 6.3 | 5.4 | 5.1 | 5.8 |
| $D_{11}$ | 2 | 18 | 5.6 | 6.0 | 6.1 | 6.0 | 6.1 | 6.1 | 6.1 | 5.7 | 6.0 | |
| | 5 | 19 | 5.6 | 6.0 | 6.1 | 6.0 | 6.1 | 6.1 | 6.1 | 5.7 | 6.0 | |
| | 8 | 20 | 5.6 | 6.0 | 6.1 | 6.0 | 6.1 | 6.1 | 6.1 | 5.7 | 6.0 | |
| | 11 | 21 | 5.6 | 6.0 | 6.1 | 5.8 | 6.0 | 5.9 | 6.0 | 5.6 | 5.9 | |
| | 14 | 22 | 5.6 | 6.0 | 6.1 | 5.8 | 6.0 | 5.9 | 6.0 | 5.6 | 5.9 | |
| | 17 | 23 | 5.5 | 6.0 | 6.0 | 5.7 | 5.9 | 5.8 | 5.9 | 5.5 | 5.8 | |
| | 20 | 24 | 5.5 | 6.0 | 6.0 | 5.6 | 5.9 | 5.7 | 5.8 | 5.4 | 5.8 | |
| | 23 | 25 | 5.5 | 6.0 | 6.0 | 5.4 | 5.8 | 5.5 | 5.7 | 5.2 | 5.7 | |
| | 26 | 26 | 5.5 | 6.0 | 6.0 | 5.3 | 5.8 | 5.4 | 5.6 | 5.0 | 5.7 | |
| | 29 | 27 | 5.5 | 6.0 | 6.0 | 5.1 | 5.7 | 5.3 | 5.4 | 4.9 | 5.6 | |
| Average | | | 5.6 | 6.0 | 6.1 | 5.7 | 5.9 | 5.8 | 5.9 | 5.4 | 5.8 | |
| Distance Below Datum | | | 5.7 | 6.1 | 6.4 | 5.9 | 6.1 | 6.0 | 6.1 | 5.9 | 6.5 | 6.1 |
| $D_{12}$ | 2 | 18 | 6.3 | 6.4 | 6.4 | 6.4 | 6.4 | 6.1 | 6.2 | 6.0 | 6.0 | |
| | 5 | 19 | 6.3 | 6.4 | 6.4 | 6.4 | 6.4 | 6.1 | 6.2 | 6.0 | 6.0 | |
| | 8 | 20 | 6.3 | 6.4 | 6.4 | 6.4 | 6.4 | 6.1 | 6.2 | 6.0 | 6.0 | |
| | 11 | 21 | 6.3 | 6.4 | 6.4 | 6.4 | 6.4 | 6.1 | 6.2 | 6.0 | 6.0 | |
| | 14 | 22 | 6.3 | 6.4 | 6.4 | 6.4 | 6.3 | 6.1 | 6.1 | 6.0 | 5.9 | |
| | 17 | 23 | 6.3 | 6.3 | 6.3 | 6.3 | 6.3 | 6.1 | 6.1 | 5.9 | 5.9 | |
| | 20 | 24 | 6.3 | 6.3 | 6.3 | 6.3 | 6.3 | 6.1 | 6.1 | 5.9 | 5.8 | |
| | 23 | 25 | 6.3 | 6.3 | 6.3 | 6.3 | 6.2 | 6.1 | 6.0 | 5.9 | 5.8 | |
| | 26 | 26 | 6.3 | 6.3 | 6.3 | 6.3 | 6.2 | 6.1 | 6.0 | 5.9 | 5.7 | |
| | 29 | 27 | 6.3 | 6.3 | 6.3 | 6.3 | 6.1 | 6.1 | 6.0 | 5.9 | 5.6 | |
| Average | | | 6.3 | 6.4 | 6.4 | 6.4 | 6.3 | 6.1 | 6.1 | 6.0 | 5.8 | |
| Distance Below Datum | | | 6.9 | 6.9 | 6.9 | 7.0 | 6.9 | 6.8 | 6.8 | 6.7 | 6.5 | 6.8 |

Average monthly weather conditions: cold, intermittent snow
Average monthly ground-surface conditions: snow covered

*See table 17a

Table 14. Piezometer readings at Logan-Cache Airport in feet from the ground surface down to the water table, April 1952

| Line No. | Date | Reading No. | Piezometer Number | | | | | | | | | Overall Average |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | |
| $D_4$ | 1 | 28 | 5.4 | 5.4 | 5.6 | 4.2 | 4.7 | 4.4 | 5.9 | 4.4 | 4.4 | |
| | 4 | 29 | 5.2 | 5.4 | 5.6 | 4.3 | 4.7 | 4.4 | 5.9 | 4.4 | 4.4 | |
| | 7 | 30 | 4.8 | 5.3 | 5.5 | 4.6 | 4.5 | 4.2 | 5.7 | 4.5 | 4.4 | |
| | 10 | 31 | 4.8 | 5.2 | 5.5 | 4.8 | 4.8 | 4.7 | 5.7 | 5.0 | 4.8 | |
| | 13 | 32 | 4.9 | 5.1 | 5.5 | 5.2 | 5.0 | 5.0 | 5.7 | 5.3 | 5.3 | |
| | 16 | 33 | 4.9 | 5.2 | 5.5 | 4.9 | 5.0 | 5.0 | 5.7 | 4.9 | 4.8 | |
| | 19 | 34 | 4.8 | 5.2 | 5.4 | 4.9 | 4.9 | 4.8 | 5.6 | 4.9 | 4.8 | |
| | 22 | 35 | 4.9 | 5.2 | 5.4 | 5.1 | 5.1 | 5.0 | 5.6 | 5.3 | 5.3 | |
| | 25 | 36 | 5.1 | 5.2 | 5.4 | 5.3 | 5.2 | 5.3 | 5.6 | 5.6 | 5.6 | |
| | 28 | 37 | 5.1 | 5.2 | 5.4 | 5.3 | 5.2 | 5.2 | 5.6 | 5.6 | 5.6 | |
| Average | | | 5.0 | 5.2 | 5.5 | 4.9 | 4.9 | 4.8 | 5.7 | 5.0 | 4.9 | |
| Distance Below Datum* | | | 5.6 | 5.7 | 6.0 | 5.4 | 5.2 | 5.0 | 5.8 | 5.0 | 4.5 | 5.4 |
| $D_{11}$ | 1 | 28 | 5.3 | 5.8 | 5.8 | 4.6 | 5.3 | 4.8 | 4.8 | 4.5 | 5.0 | |
| | 4 | 29 | 5.3 | 5.8 | 5.8 | 4.6 | 5.2 | 4.7 | 4.8 | 4.5 | 4.9 | |
| | 7 | 30 | 5.4 | 5.7 | 5.6 | 4.7 | 4.9 | 4.5 | 4.7 | 4.5 | 4.7 | |
| | 10 | 31 | 5.4 | 5.6 | 5.5 | 4.9 | 4.9 | 4.9 | 5.0 | 4.7 | 5.0 | |
| | 13 | 32 | 5.5 | 5.6 | 5.5 | 5.3 | 5.3 | 5.1 | 5.4 | 5.1 | 5.3 | |
| | 16 | 33 | 5.4 | 5.6 | 5.5 | 5.1 | 5.0 | 5.2 | 5.4 | 5.0 | 5.3 | |
| | 19 | 34 | 5.5 | 5.6 | 5.5 | 5.1 | 5.1 | 5.2 | 5.3 | 5.0 | 5.3 | |
| | 22 | 35 | 5.5 | 5.6 | 5.5 | 5.4 | 5.0 | 5.5 | 5.5 | 5.3 | 5.4 | |
| | 25 | 36 | 5.8 | 5.6 | 5.5 | 5.7 | 5.2 | 5.7 | 5.7 | 5.4 | 5.6 | |
| | 28 | 37 | 5.8 | 5.6 | 5.5 | 5.9 | 5.2 | 5.9 | 5.8 | 5.7 | 5.9 | |
| Average | | | 5.5 | 5.7 | 5.6 | 5.1 | 5.1 | 5.2 | 5.2 | 5.0 | 5.2 | |
| Distance Below Datum | | | 5.6 | 5.8 | 5.9 | 5.3 | 5.3 | 5.4 | 5.4 | 5.5 | 5.9 | 5.6 |
| $D_{12}$ | 1 | 28 | 4.2 | 4.5 | 6.1 | 5.7 | 4.6 | 5.7 | 5.3 | 5.5 | 5.0 | |
| | 4 | 29 | 4.5 | 5.0 | 6.4 | 6.0 | 4.7 | 5.6 | 5.3 | 5.4 | 4.9 | |
| | 7 | 30 | 6.2 | 6.2 | 6.0 | 6.1 | 4.9 | 5.3 | 5.5 | 5.1 | 4.7 | |
| | 10 | 31 | 6.3 | 6.4 | 6.3 | 6.3 | 5.3 | 5.5 | 5.9 | 5.4 | 5.0 | |
| | 13 | 32 | 6.5 | 6.6 | 6.5 | 6.5 | 5.6 | 5.6 | 6.2 | 5.7 | 5.3 | |
| | 16 | 33 | 6.4 | 6.5 | 6.4 | 6.4 | 5.7 | 5.7 | 6.0 | 5.6 | 5.3 | |
| | 19 | 34 | 6.5 | 6.5 | 6.5 | 6.5 | 5.9 | 5.8 | 6.1 | 5.7 | 5.3 | |
| | 22 | 35 | 6.5 | 6.6 | 6.5 | 6.5 | 6.0 | 5.9 | 6.2 | 5.8 | 5.4 | |
| | 25 | 36 | 6.5 | 6.6 | 6.6 | 6.6 | 6.4 | 6.0 | 6.3 | 6.2 | 5.6 | |
| | 28 | 37 | 6.7 | 6.8 | 6.7 | 6.8 | 6.3 | 6.1 | 6.5 | 6.2 | 5.9 | |
| Average | | | 6.0 | 6.2 | 6.4 | 6.3 | 5.5 | 5.7 | 5.9 | 5.7 | 5.2 | |
| Distance Below Datum | | | 6.6 | 6.7 | 6.9 | 6.9 | 6.1 | 6.4 | 6.6 | 6.4 | 5.9 | 6.5 |

Average monthly weather conditions: warm, intermittent rain
Average monthly ground-surface conditions: wet, little plant growth

*See table 17a

Table 15. Piezometer readings at Logan-Cache Airport in feet from the ground surface down to the water table, May 1952

| Line No. | Date | Reading No. | Piezometer Number 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | Overall Average |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| $D_4$ | 1 | 38 | 5.2 | 5.2 | 5.4 | 5.4 | 5.3 | 5.2 | 5.6 | 5.7 | 5.7 | |
| | 4 | 39 | 5.2 | 5.2 | 5.4 | 5.4 | 5.4 | 5.3 | 5.6 | 5.7 | 5.7 | |
| | 7 | 40 | 5.2 | 5.3 | 5.4 | 5.4 | 5.4 | 5.4 | 5.7 | 5.7 | 5.7 | |
| | 10 | 41 | 5.2 | 5.3 | 5.4 | 5.4 | 5.4 | 5.4 | 5.7 | 5.7 | 5.7 | |
| | 13 | 42 | 5.3 | 5.3 | 5.4 | 5.4 | 5.4 | 5.4 | 5.7 | 5.7 | 5.7 | |
| | 16 | 43 | 5.3 | 5.3 | 5.4 | 5.4 | 5.4 | 5.4 | 5.7 | 5.7 | 5.7 | |
| | 19 | 44 | 5.3 | 5.3 | 5.4 | 5.4 | 5.4 | 5.4 | 5.7 | 5.8 | 5.8 | |
| | 22 | 45 | 5.4 | 5.3 | 5.4 | 5.4 | 5.4 | 5.4 | 5.7 | 5.8 | 5.8 | |
| | 25 | 46 | 5.4 | 5.3 | 5.4 | 5.4 | 5.4 | 5.4 | 5.7 | 5.8 | 5.9 | |
| | 28 | 47 | 5.4 | 5.3 | 5.5 | 5.5 | 5.5 | 5.5 | 5.7 | 5.8 | 5.8 | |
| Average | | | 5.3 | 5.3 | 5.4 | 5.4 | 5.4 | 5.4 | 5.7 | 5.7 | 5.8 | |
| Distance Below Datum* | | | 5.9 | 5.8 | 5.9 | 5.9 | 5.7 | 5.6 | 5.8 | 5.7 | 5.4 | 5.7 |
| $D_{11}$ | 1 | 38 | 6.0 | 5.7 | 5.6 | 6.1 | 5.4 | 6.1 | 6.0 | 5.8 | 6.1 | |
| | 4 | 39 | 6.2 | 5.7 | 5.6 | 6.1 | 5.4 | 6.2 | 6.2 | 5.9 | 6.2 | |
| | 7 | 40 | 6.4 | 5.7 | 5.7 | 6.3 | 5.5 | 6.4 | 6.3 | 6.1 | 6.3 | |
| | 10 | 41 | 6.4 | 5.7 | 5.7 | 6.3 | 5.5 | 6.4 | 6.4 | 6.1 | 6.3 | |
| | 13 | 42 | 6.5 | 5.8 | 5.7 | 6.4 | 5.5 | 6.5 | 6.4 | 6.2 | 6.3 | |
| | 16 | 43 | 6.6 | 5.8 | 5.7 | 6.4 | 5.5 | 6.5 | 6.5 | 6.2 | 6.3 | |
| | 19 | 44 | 6.4 | 5.8 | 5.8 | 6.3 | 5.6 | 6.4 | 6.4 | 6.1 | 6.2 | |
| | 22 | 45 | 6.1 | 5.9 | 5.8 | 6.2 | 5.6 | 6.3 | 6.3 | 6.1 | 6.2 | |
| | 25 | 46 | 5.9 | 5.9 | 5.9 | 6.1 | 5.7 | 6.2 | 6.3 | 6.0 | 6.2 | |
| | 28 | 47 | 6.0 | 5.9 | 5.8 | 6.2 | 5.7 | 6.3 | 6.4 | 6.0 | 6.3 | |
| Average | | | 6.2 | 5.8 | 5.7 | 6.2 | 5.5 | 6.3 | 6.3 | 6.0 | 6.2 | |
| Distance Below Datum | | | 6.3 | 5.9 | 6.0 | 6.4 | 5.7 | 6.5 | 6.5 | 6.5 | 6.9 | 6.3 |
| $D_{12}$ | 1 | 38 | 6.7 | 6.9 | 6.8 | 6.8 | 6.3 | 6.3 | 6.6 | 6.3 | 6.1 | |
| | 4 | 39 | 6.7 | 6.9 | 6.8 | 6.8 | 6.3 | 6.3 | 6.7 | 6.4 | 6.2 | |
| | 7 | 40 | 6.8 | 6.9 | 6.8 | 6.8 | 6.6 | 6.4 | 6.7 | 6.6 | 6.3 | |
| | 10 | 41 | 6.8 | 6.9 | 6.8 | 6.8 | 6.6 | 6.4 | 6.7 | 6.6 | 6.3 | |
| | 13 | 42 | 6.7 | 6.9 | 6.9 | 6.9 | 6.6 | 6.3 | 6.8 | 6.5 | 6.3 | |
| | 16 | 43 | 6.7 | 6.9 | 6.9 | 6.9 | 6.6 | 6.3 | 6.8 | 6.5 | 6.3 | |
| | 19 | 44 | 6.8 | 6.9 | 6.9 | 6.9 | 6.6 | 6.4 | 6.8 | 6.5 | 6.2 | |
| | 22 | 45 | 6.7 | 6.9 | 6.9 | 6.9 | 6.6 | 6.5 | 6.8 | 6.5 | 6.2 | |
| | 25 | 46 | 6.8 | 6.9 | 6.9 | 6.9 | 6.6 | 6.5 | 6.8 | 6.5 | 6.2 | |
| | 28 | 47 | 6.8 | 6.9 | 6.9 | 6.9 | 6.6 | 6.6 | 6.8 | 6.5 | 6.3 | |
| Average | | | 6.8 | 6.9 | 6.9 | 6.9 | 6.5 | 6.4 | 6.8 | 6.5 | 6.2 | |
| Distance Below Datum | | | 7.4 | 7.4 | 7.4 | 7.5 | 7.1 | 7.1 | 7.5 | 7.2 | 6.9 | 7.2 |

Average monthly weather conditions: warm, fair
Average monthly ground-surface conditions: dry, beginning of plant growth

*See table 17a

Table 16. Piezometer readings at Logan-Cache Airport in feet from the ground surface down to the water table, June 1952

| Line No. | Date | Reading No. | Piezometer Number |  |  |  |  |  |  |  |  | Overall Average |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
|  |  |  | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |  |
| $D_4$ | 4 | 48 | 4.0 | 4.0 | 3.9 | 4.7 | 4.8 | 4.7 | 4.6 | 4.6 | 4.6 |  |
|  | 7 | 49 | 7.0 | 5.8 | 5.8 | 5.8 | 5.7 | 5.7 | 5.6 | 5.6 | 5.6 |  |
|  | 10 | 50 | 5.6 | 5.6 | 5.6 | 5.7 | 5.7 | 5.8 | 5.8 | 5.8 | 5.8 |  |
|  | 13 | 51 | 5.4 | 5.2 | 5.2 | 5.3 | 5.3 | 5.4 | 5.7 | 5.6 | 5.7 |  |
|  | 16 | 52 | 5.4 | 5.3 | 5.1 | 5.3 | 5.3 | 5.3 | 5.6 | 5.7 | 5.7 |  |
|  | 19 | 53 | 5.1 | 5.1 | 5.0 | 5.1 | 5.1 | 5.3 | 5.6 | 5.5 | 5.5 |  |
|  | 23 | 54 | 5.6 | 5.6 | 5.6 | 5.4 | 5.3 | 5.2 | 5.1 | 5.2 | 5.2 |  |
| Average |  |  | 5.4 | 5.1 | 5.2 | 5.3 | 5.3 | 5.3 | 5.4 | 5.4 | 5.4 |  |
| Distance Below Datum* |  |  | 6.0 | 5.6 | 5.8 | 5.8 | 5.6 | 5.5 | 5.5 | 5.4 | 5.0 | 5.6 |
| $D_{11}$ | 4 | 48 | 6.0 | 6.2 | 6.1 | 6.2 | 5.8 | 5.8 | 6.1 | 5.8 | 6.6 |  |
|  | 7 | 49 | 5.9 | 6.1 | 6.1 | 6.1 | 5.8 | 5.8 | 5.8 | 5.7 | 6.5 |  |
|  | 10 | 50 | 6.9 | 6.7 | 6.7 | 6.7 | 6.4 | 6.2 | 6.3 | 6.2 | 6.4 |  |
|  | 13 | 51 | 6.7 | 6.6 | 6.5 | 6.5 | 6.3 | 6.2 | 6.3 | 6.3 | 6.0 |  |
|  | 16 | 52 | 6.4 | 6.5 | 6.5 | 6.5 | 6.1 | 6.2 | 6.4 | 6.1 | 6.1 |  |
|  | 19 | 53 | 6.4 | 6.6 | 6.5 | 6.4 | 6.3 | 6.2 | 6.4 | 6.1 | 6.0 |  |
|  | 23 | 54 | 6.6 | 6.7 | 6.7 | 6.8 | 6.5 | 6.5 | 6.4 | 6.4 | 6.0 |  |
| Average |  |  | 6.4 | 6.5 | 6.4 | 6.5 | 6.2 | 6.1 | 6.2 | 6.1 | 6.2 |  |
| Distance Below Datum |  |  | 6.5 | 6.6 | 6.7 | 6.7 | 6.4 | 6.3 | 6.4 | 6.6 | 6.9 | 6.6 |
| $D_{12}$ | 4 | 48 | 6.7 | 5.1 | 5.1 | 6.6 | 5.0 | 6.7 | 6.8 | 6.4 | 6.6 |  |
|  | 7 | 49 | 6.6 | 5.1 | 5.1 | 6.6 | 5.0 | 6.6 | 6.7 | 6.7 | 6.5 |  |
|  | 10 | 50 | 6.2 | 5.6 | 5.5 | 6.1 | 5.5 | 6.1 | 6.2 | 6.1 | 6.4 |  |
|  | 13 | 51 | 6.2 | 5.6 | 5.6 | 6.2 | 5.6 | 6.2 | 6.3 | 5.9 | 6.0 |  |
|  | 16 | 52 | 6.3 | 5.7 | 5.7 | 6.3 | 5.6 | 6.3 | 6.3 | 6.0 | 6.1 |  |
|  | 19 | 53 | 6.3 | 5.6 | 5.6 | 6.2 | 5.6 | 6.2 | 6.4 | 6.0 | 6.0 |  |
|  | 23 | 54 | 6.5 | 5.9 | 5.9 | 6.4 | 5.9 | 6.5 | 6.6 | 6.0 | 6.0 |  |
| Average |  |  | 6.4 | 5.5 | 5.5 | 6.3 | 5.5 | 6.4 | 6.5 | 6.2 | 6.2 |  |
| Distance Below Datum |  |  | 7.0 | 6.0 | 6.0 | 6.9 | 6.1 | 7.1 | 7.2 | 6.9 | 6.9 | 6.7 |

Average monthly weather conditions: warm, fair

Average monthly ground-surface conditions: dry, rapid plant growth

*See table 17a

Table 17a. Levelling data for piezometer lines $D_4$, $D_{11}$, and $D_{12}$*

| Piezo. No. | Line $D_4$ | | Line $D_{11}$ | | Line $D_{12}$ | |
|---|---|---|---|---|---|---|
| | Elev. at G.S. | Distance from G.S. to Datum | Elev. at G.S. | Distance from G.S. to Datum | Elev. at G.S. | Distance from G.S. to Datum |
| 1 | 99.4 | 0.6 | 99.9 | 0.1 | 99.4 | 0.6 |
| 2 | 99.5 | 0.5 | 99.9 | 0.1 | 99.5 | 0.5 |
| 3 | 99.4 | 0.6 | 99.7 | 0.3 | 99.5 | 0.5 |
| 4 | 99.5 | 0.5 | 99.8 | 0.2 | 99.4 | 0.6 |
| 5 | 99.7 | 0.3 | 99.8 | 0.2 | 99.4 | 0.6 |
| 6 | 99.8 | 0.2 | 99.8 | 0.2 | 99.3 | 0.7 |
| 7 | 99.9 | 0.1 | 99.8 | 0.2 | 99.3 | 0.7 |
| 8 | 100.0 | 0 | 99.5 | 0.5 | 99.3 | 0.7 |
| 9 | 100.4 | -0.4 | 99.3 | 0.7 | 99.3 | 0.7 |

Table 17b. Levelling data for piezometer lines A, B, and C*

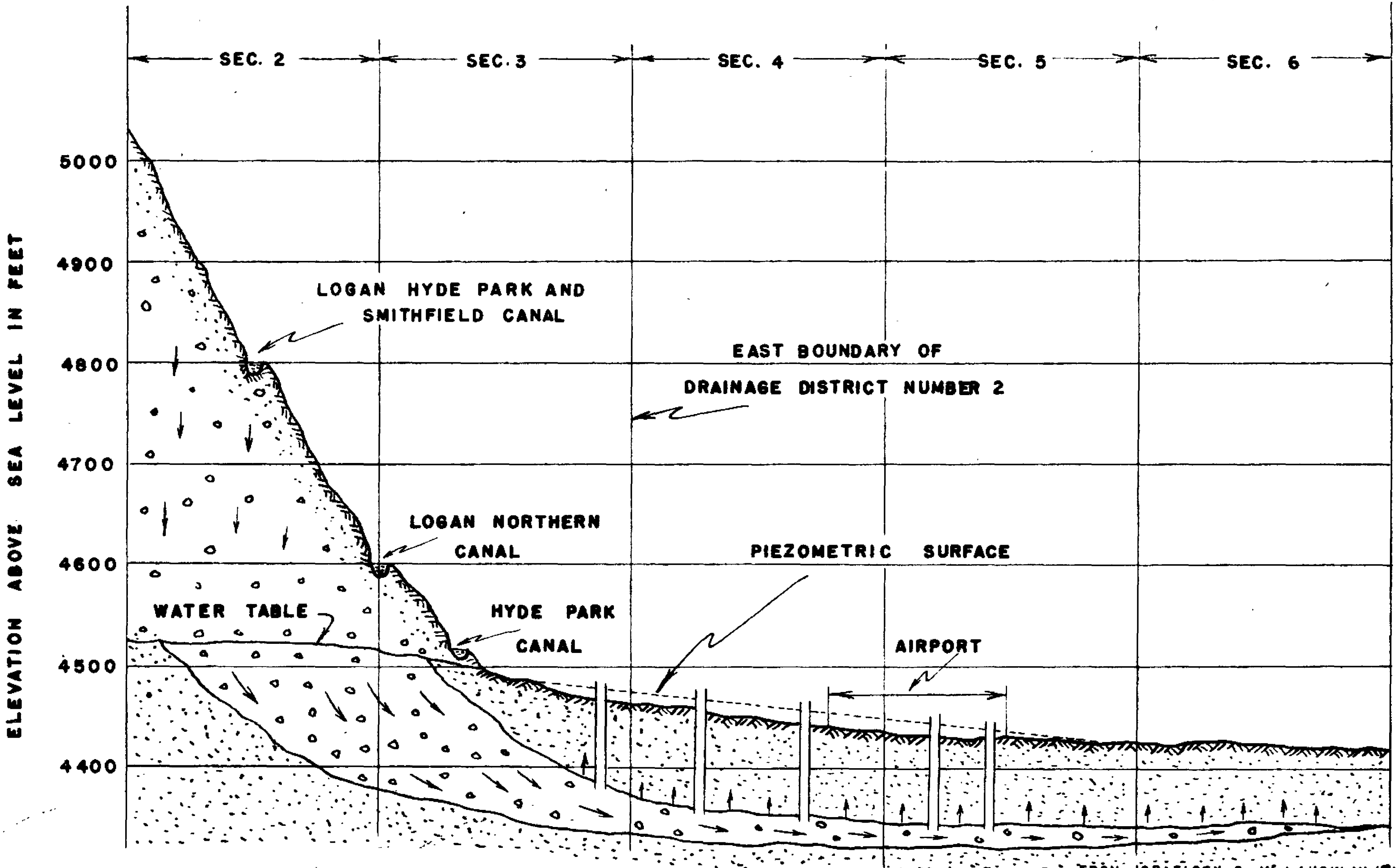
| Piezo. No. | Line A | | | Line B | | | Line C | | |
|---|---|---|---|---|---|---|---|---|---|
| | Elev. at G.S. | Piezo. Depth Below G.S. | Piezo. Depth Below Datum | Elev. at G.S. | Piezo. Depth Below G.S. | Piezo. Depth Below Datum | Elev. at G.S. | Piezo. Depth Below G.S. | Piezo. Depth Below Datum |
| 1 | - | - | - | 99.3 | 44.0 | 44.7 | 99.3 | 46.5 | 47.2 |
| 2 | 99.4 | 41.5 | 42.1 | 99.3 | 41.5 | 42.2 | 99.3 | 41.5 | 42.2 |
| 3 | 99.4 | 36.5 | 37.1 | 99.2 | 36.5 | 37.3 | 99.2 | 36.5 | 37.3 |
| 4 | 99.3 | 31.0 | 31.7 | 99.2 | 31.0 | 31.8 | 99.3 | 31.0 | 31.7 |
| 5 | 99.3 | 25.5 | 26.2 | 99.2 | 25.5 | 26.3 | 99.3 | 25.5 | 26.2 |
| 6 | 99.2 | 20.5 | 21.3 | 99.1 | 20.5 | 21.4 | 99.2 | 20.5 | 21.3 |
| 7 | 99.1 | 15.5 | 16.4 | 99.1 | 15.5 | 16.4 | 99.2 | 15.5 | 16.3 |
| 8 | 98.6 | 10.0 | 11.4 | 99.0 | 10.0 | 11.0 | 99.2 | 10.0 | 10.8 |
| 9 | 98.8 | 5.5 | 6.7 | 99.1 | 5.5 | 6.4 | 99.2 | 5.5 | 6.3 |

*Assumed elevation of datum at manhole 73 is 100 feet. All distances are in feet.

Table 18. Drain-flow observations during the rapid snowmelt period, March 29 to April 10, 1952

| Date | Flow in Drains* | | | | | | | | Notes |
|---|---|---|---|---|---|---|---|---|---|
| | Drain 4 10" Diameter | | Drain 11 8" Diameter | | Drain 12 12" Diameter | | | | |
| | Depth | Flow | Depth | Flow | Entering Manhole | | Leaving Manhole | | |
| | | | | | Depth | Flow | Depth | Flow | |
| | (Inches) | (cfs) | (Inches) | (cfs) | (Inches) | (cfs) | (Inches) | (cfs) | |
| March 29 | 2 | 0.10 | 0 | 0 | 6 | 1.12 | 9 | 1.84 | Surface water from snowmelt entering drains through catch basins and manholes. Approximately 6 inches of rapidly-melting snow. |
| April 1 | 10 | 1.20 | 8 | 0.77 | 12 | 2.25 | 12 | 2.25 | Considerable water lying on land surface entering drains through catch basins and manholes. Approximately 2 inches of rapidly-melting snow. |
| April 4 | 10 | 1.20 | 8 | 0.77 | 12 | 2.25 | 12 | 2.25 | |
| April 7 | 1 | 0.20 | 1/4 | - | 3 | 0.30 | 4 | 0.53 | Snow melted; most surface water disappeared either through drains or through infiltration. |
| April 10 | 1/4 | - | 0 | 0 | 3 | - | 3 | - | The water in drain 12 was stationary (no appreciable flow). No water entering manhole 85 from the catch basin. |
| April 13 | 0 | 0 | 0 | 0 | 3 | - | 3 | - | |

*Water from a surface catch basin entered drain 12 at manhole 85. Drain 4 was inspected at manhole 42; drain 11 at manhole 73; and drain 12 at manhole 85.



FROM ISRAELSEN & Mc LAUGHLIN (8)

Figure 1. Profile on East-West line through Hyde Park on south boundary of sections 2, 3, 4, 5, and 6 of Township 12 North, Range 1 East, Salt Lake Meridian, showing the piezometric head within the artesian aquifer

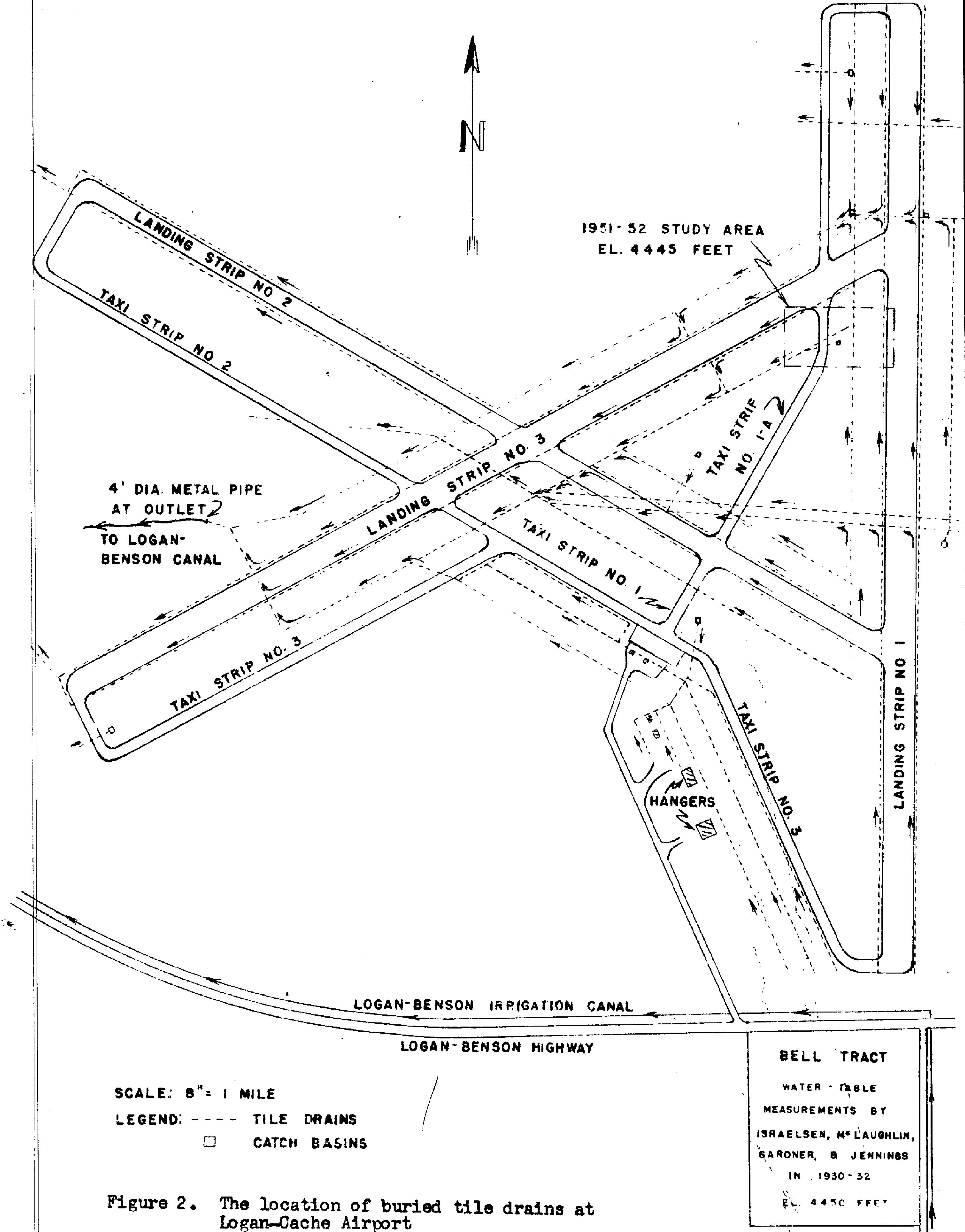


Figure 2. The location of buried tile drains at Logan-Cache Airport

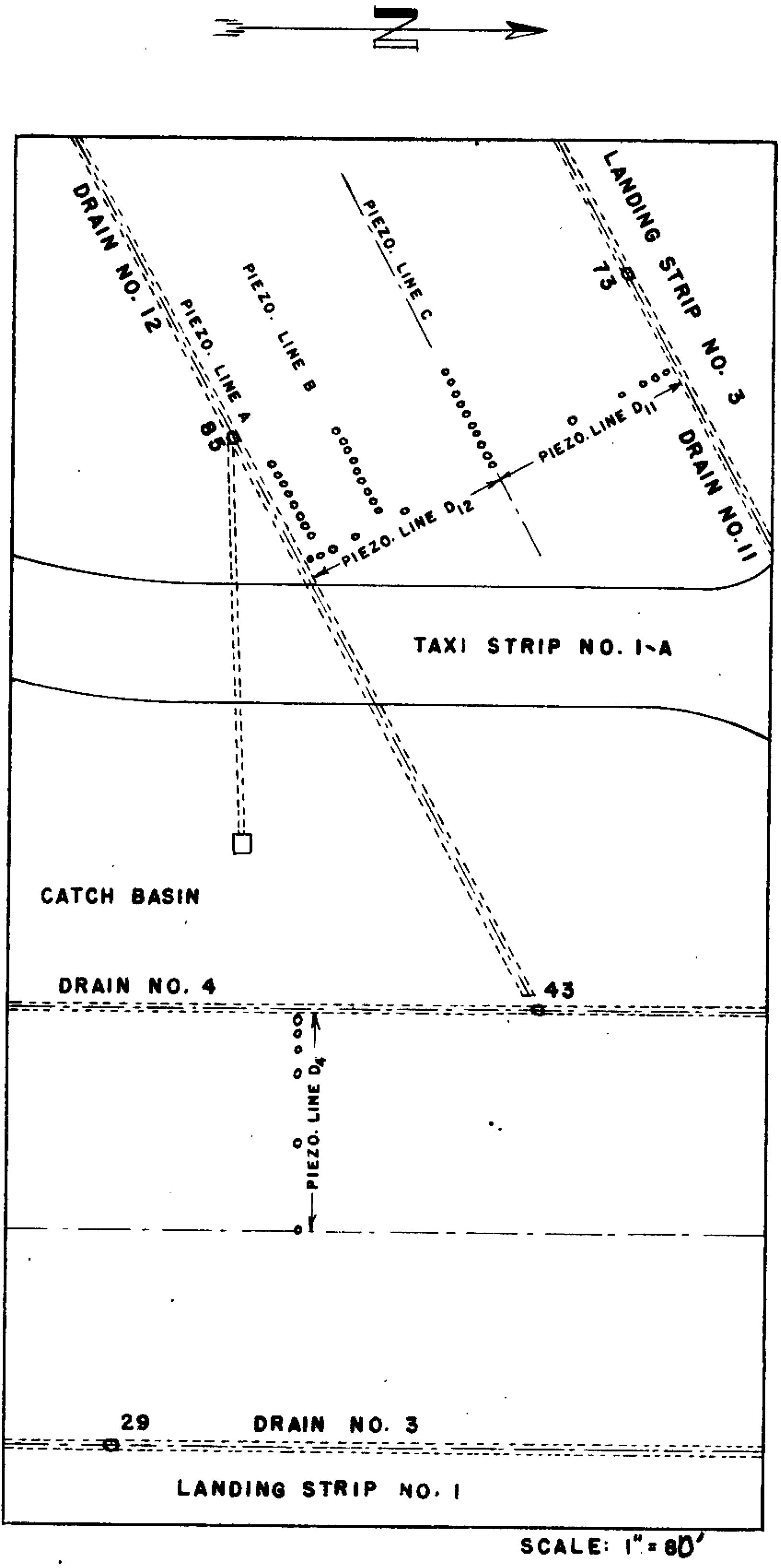


Figure 3. Detail of the study area including all piezometer lines

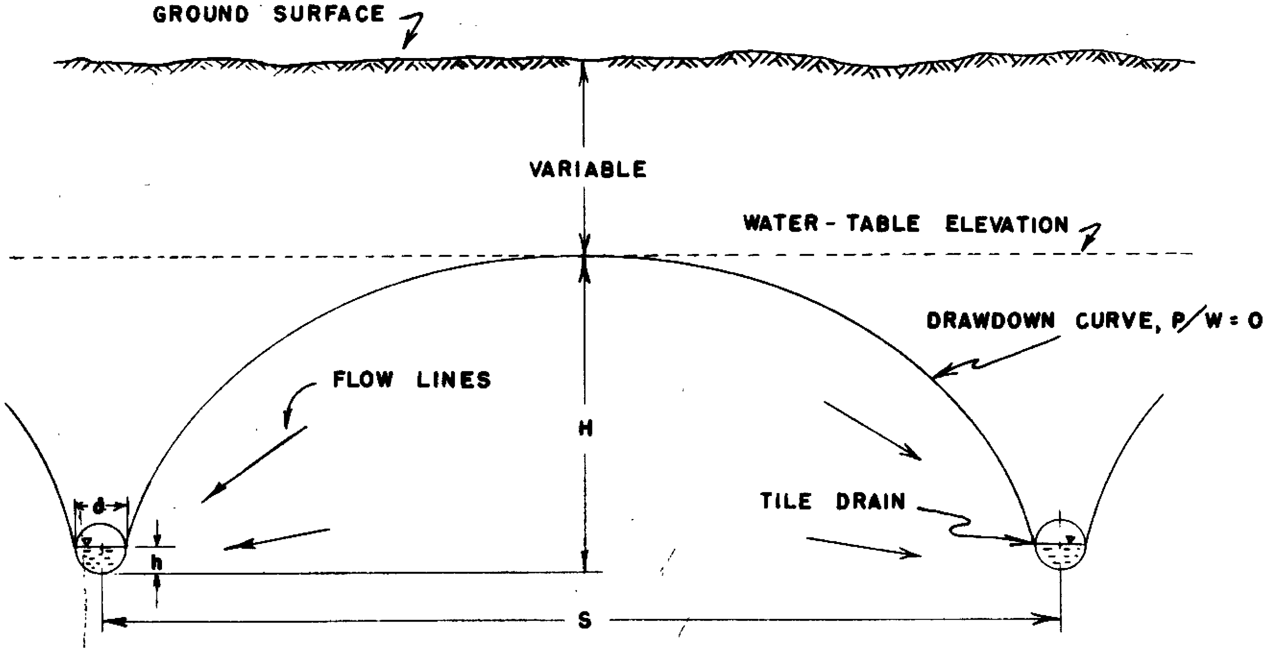


Figure 4. Radial flow toward tile drains in deep, uniform soil

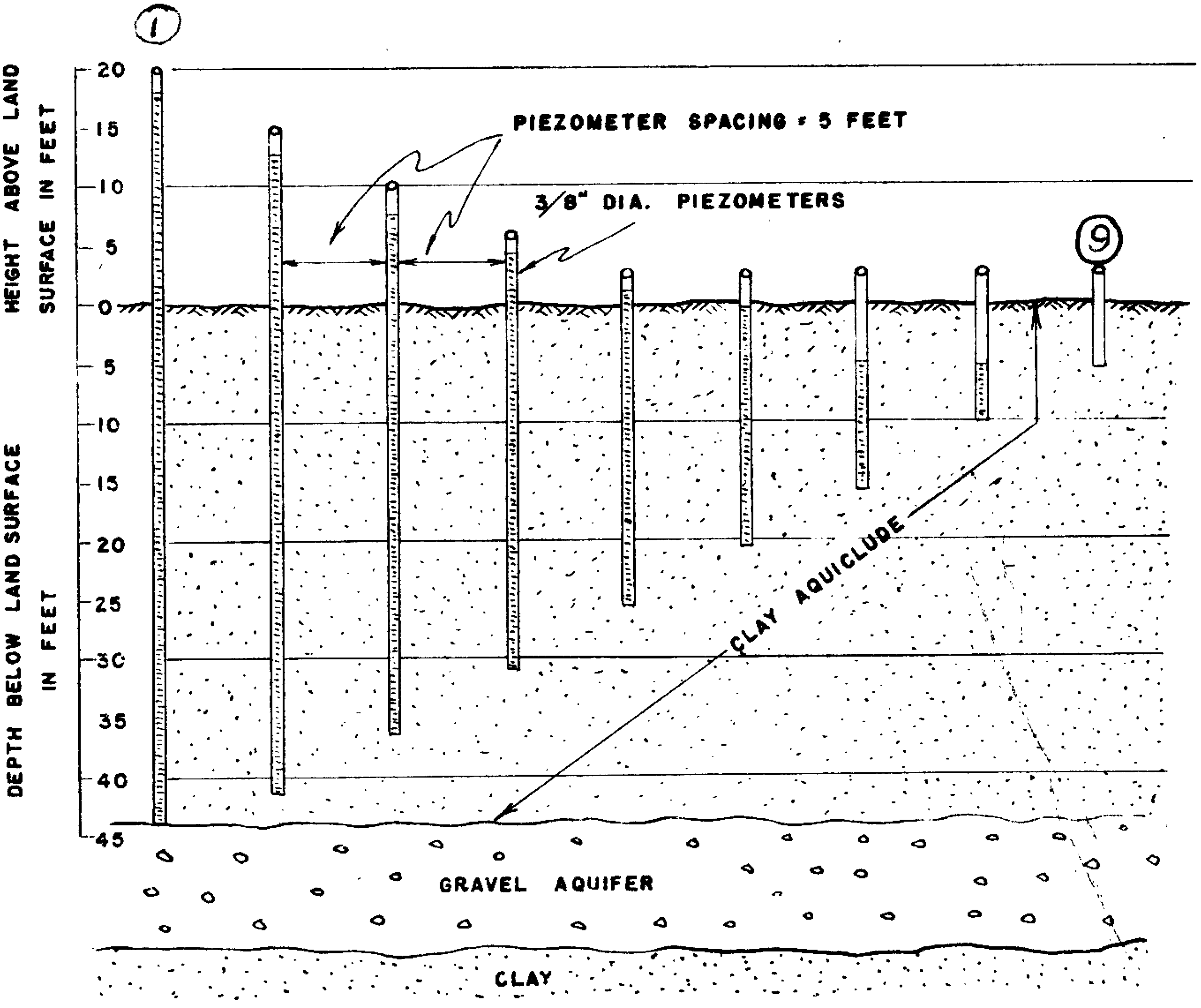


Figure 5. **Measuring piezometric surface elevations in clay aquiclude at 8 different distances above the artesian aquifer.**
Piezometer levelling data are shown in figure 17b

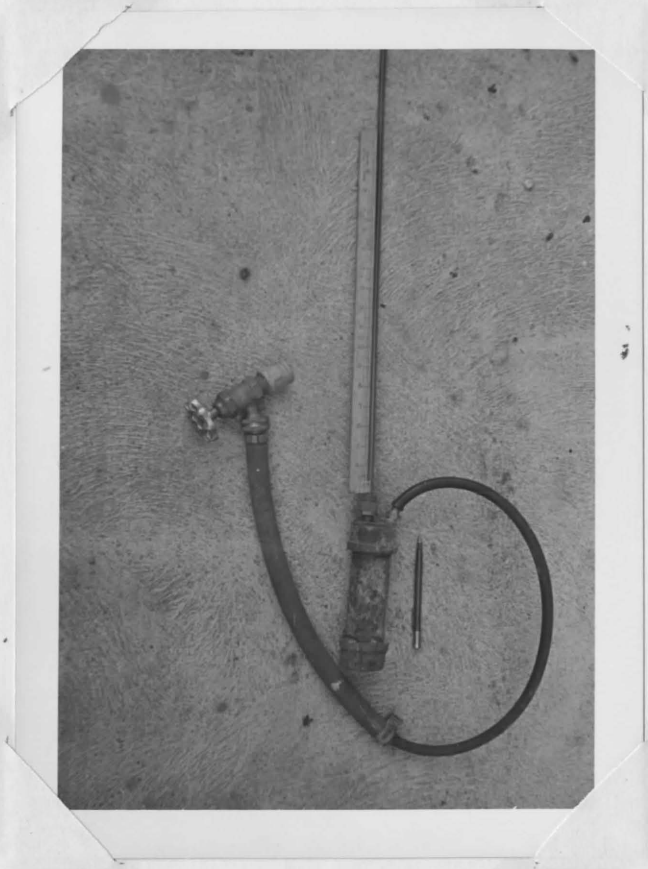


Figure 6. Mercury pot close-up and calibrated stick

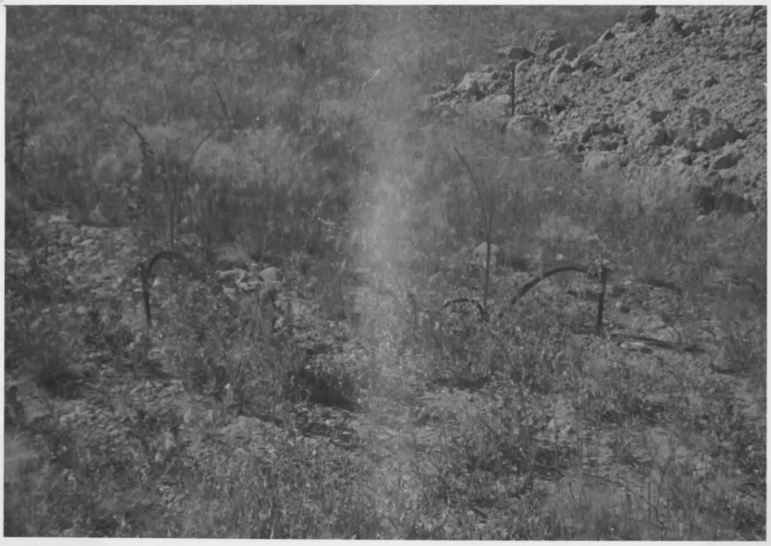


Figure 7. Mercury pots in the field

Figure 8. Electric sounder

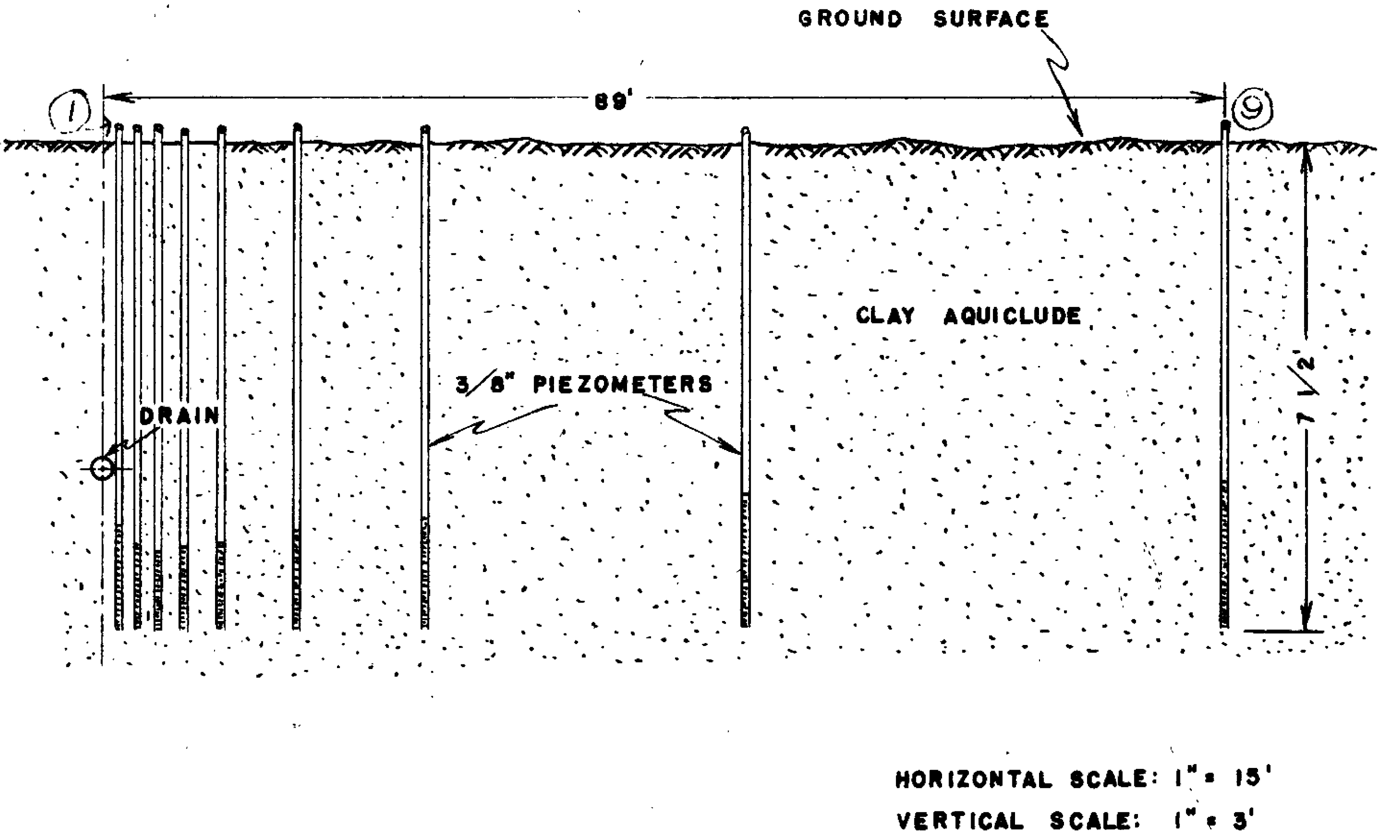


Figure 9. Piezometers showing water-table depths, or profile in a vertical plane, normal to the drains. Piezometer levelling data are shown in table 17a

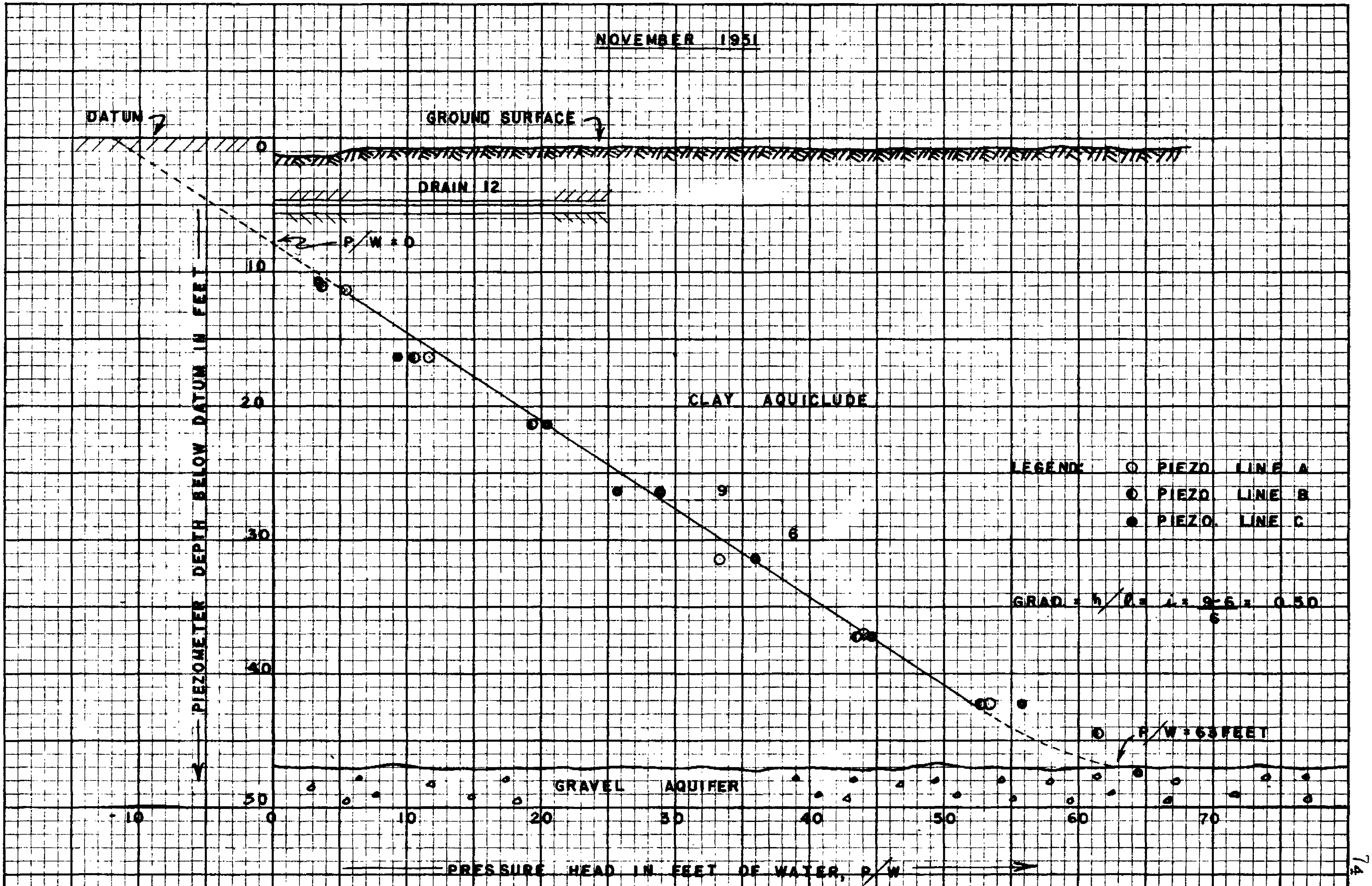


Figure 10. The relation between pressure head and depth of piezometer within the clay aquiclude, November, 1951

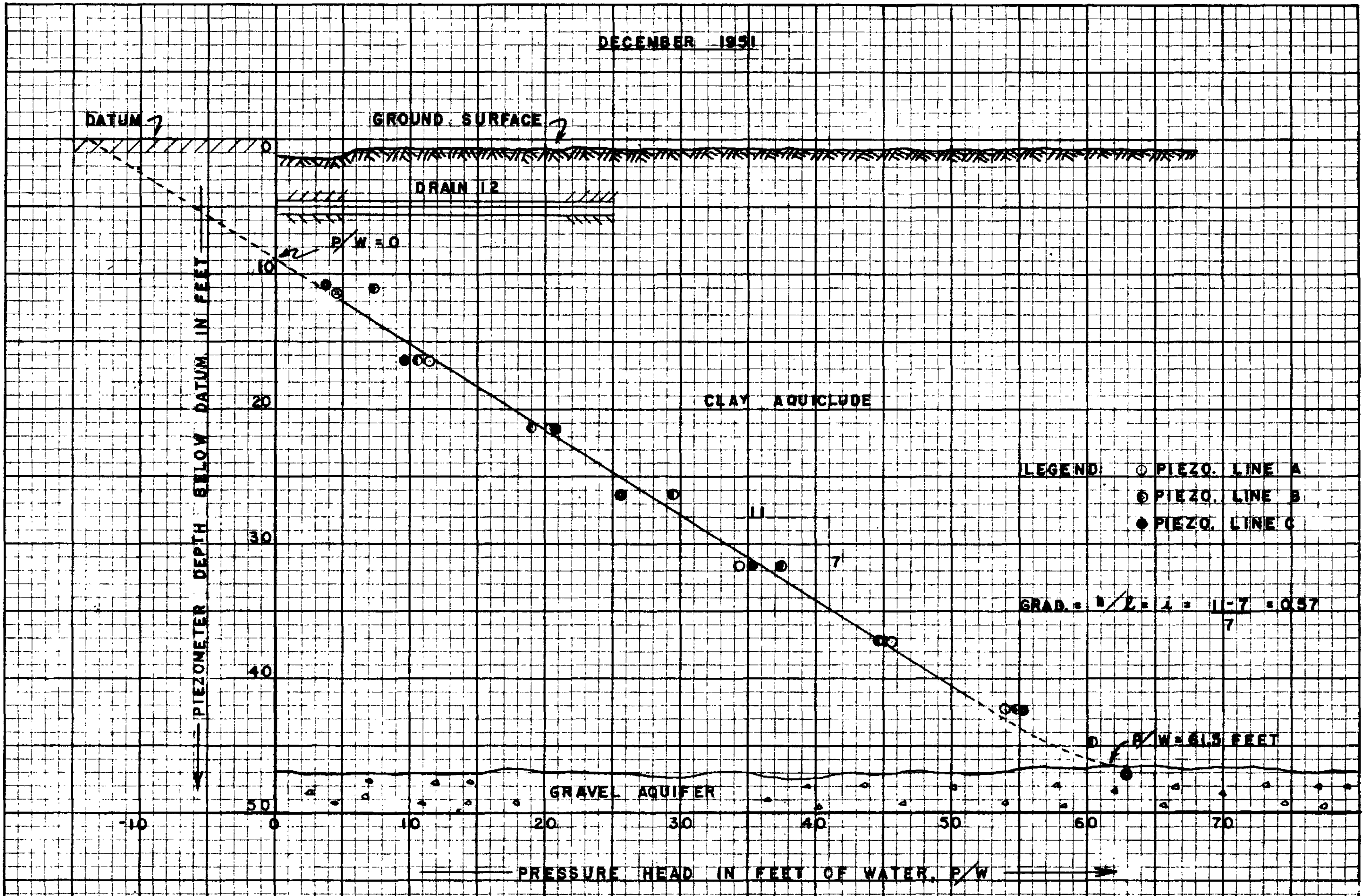


Figure 11. The relation between pressure head and depth of piezometer within the clay aquiclude, December 1951

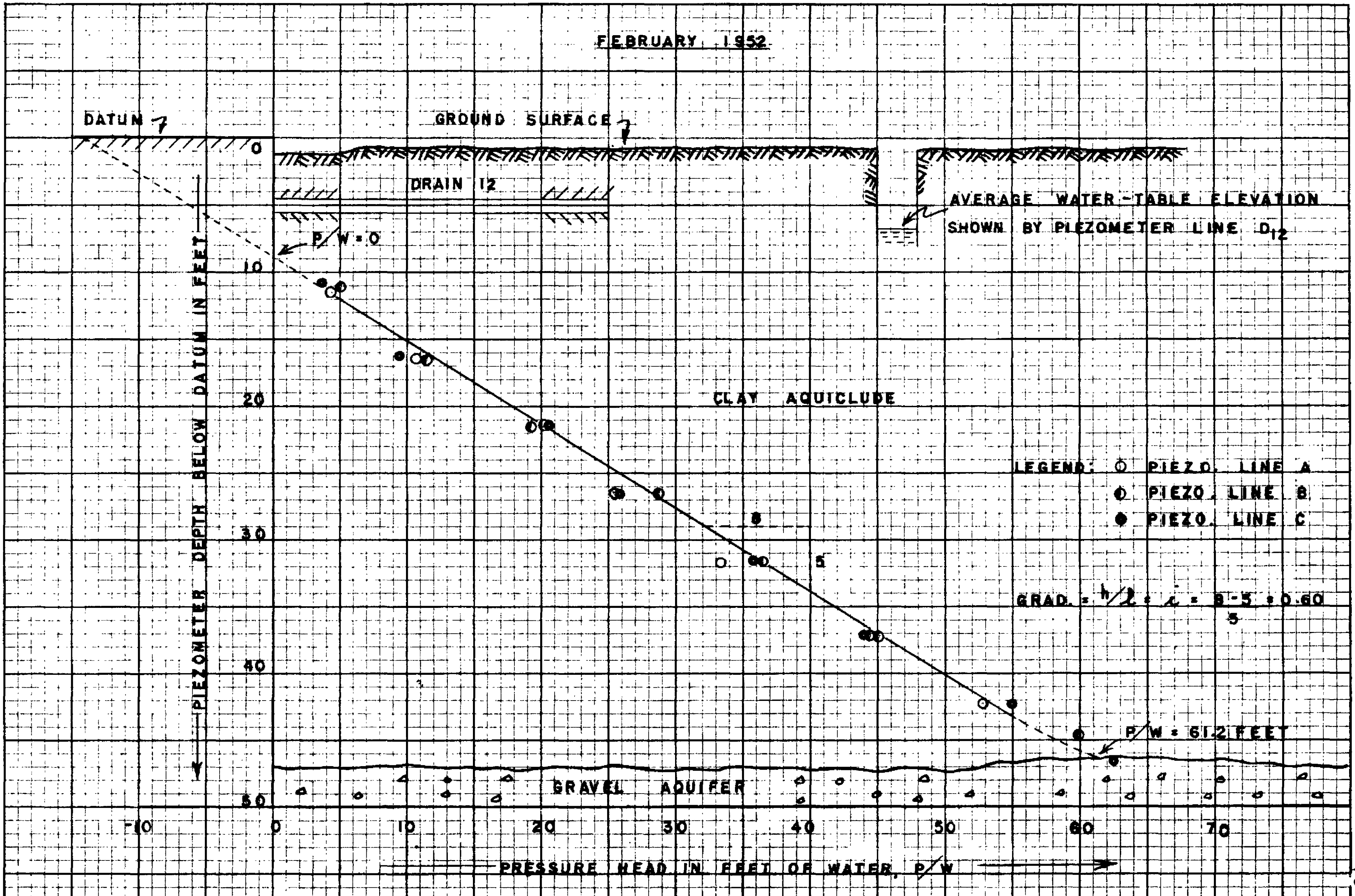


Figure 1[illegible]. The relation between pressure head and depth of piezometer within the clay aquiclude, February 1952

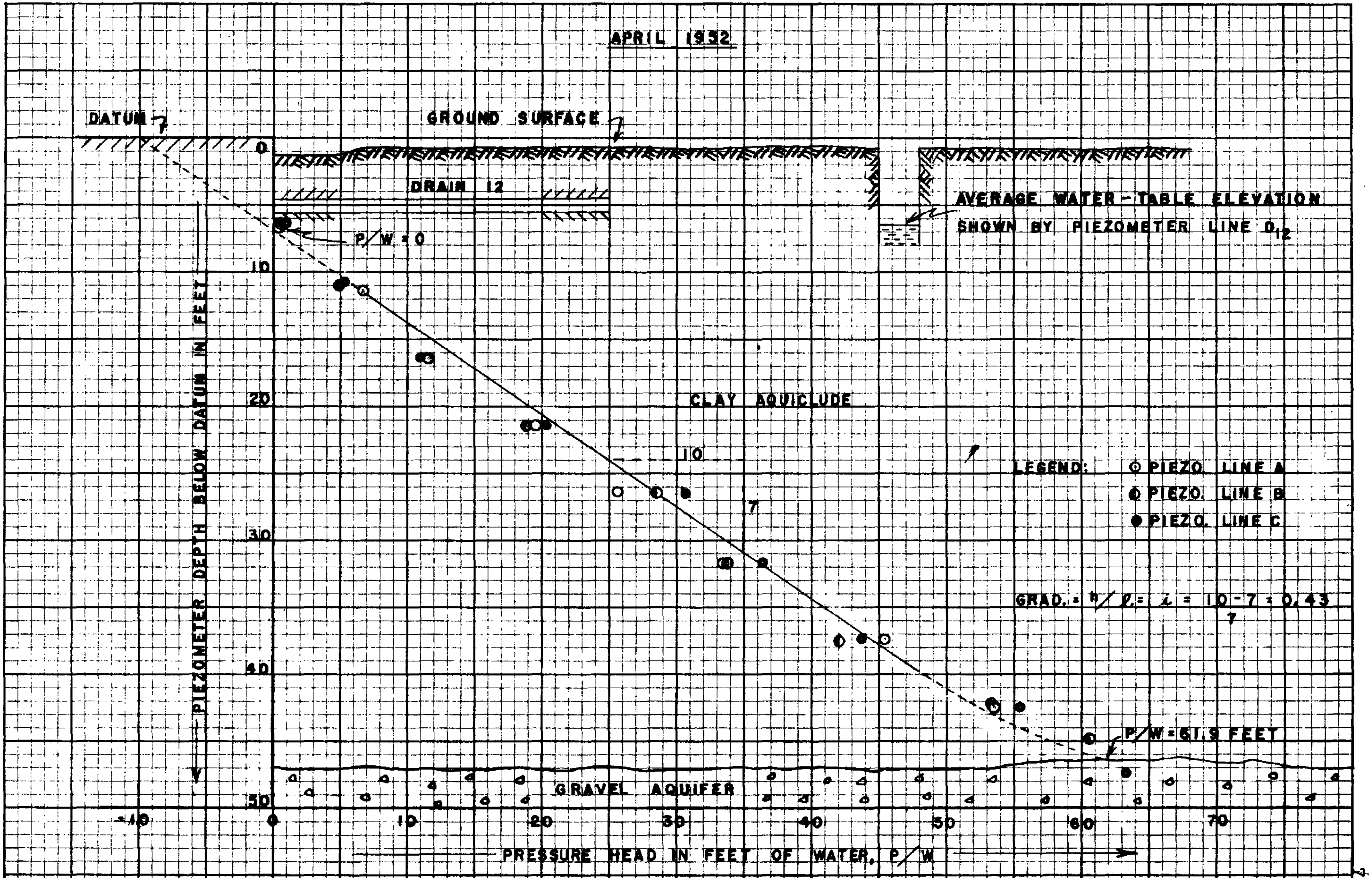


Figure 13. The relation between pressure head and depth of piezometer within the clay aquiclude, April 1952

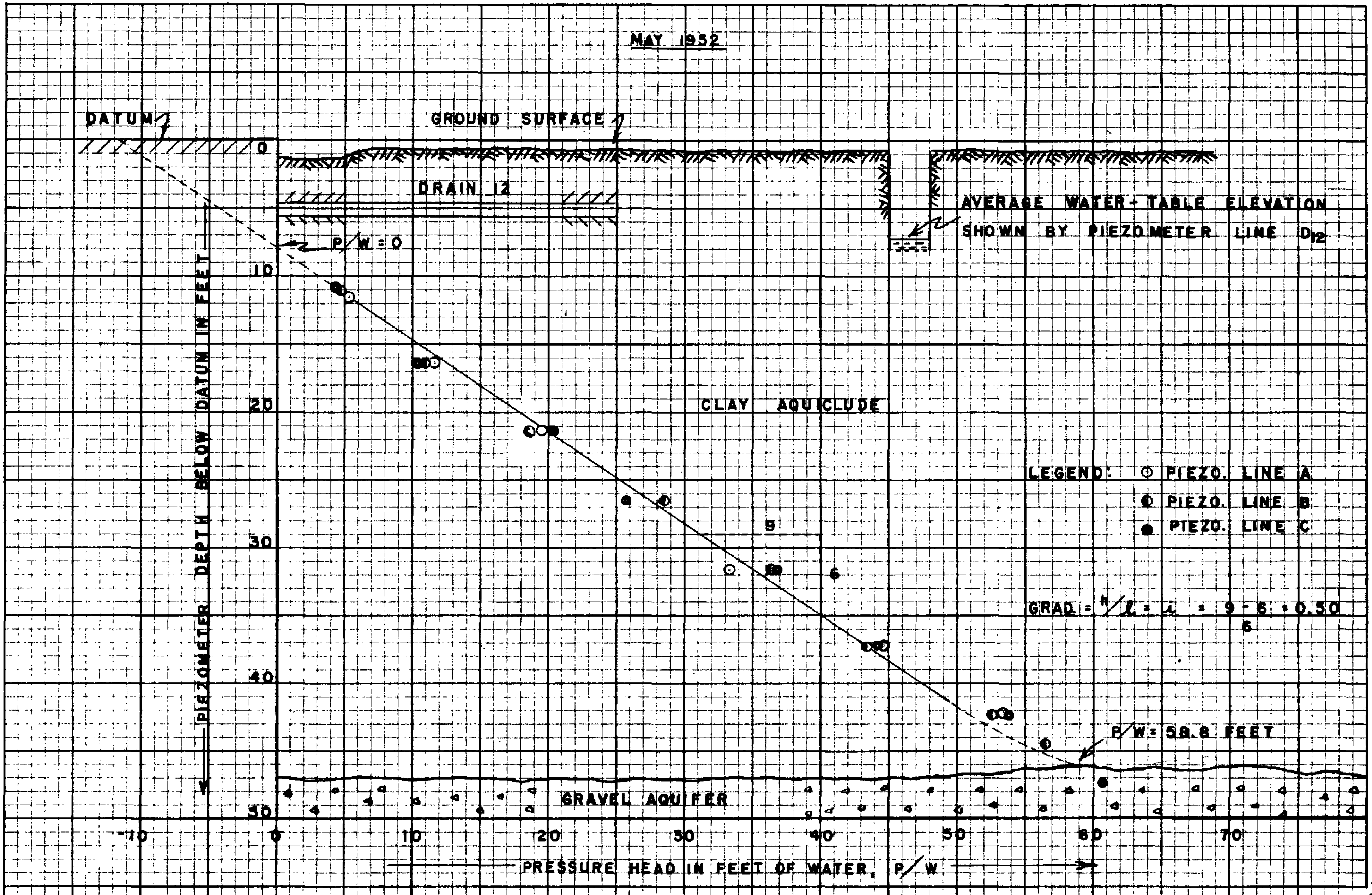


Figure 14. The relation between pressure head and depth of piezometer within the clay aquiclude, May 1952

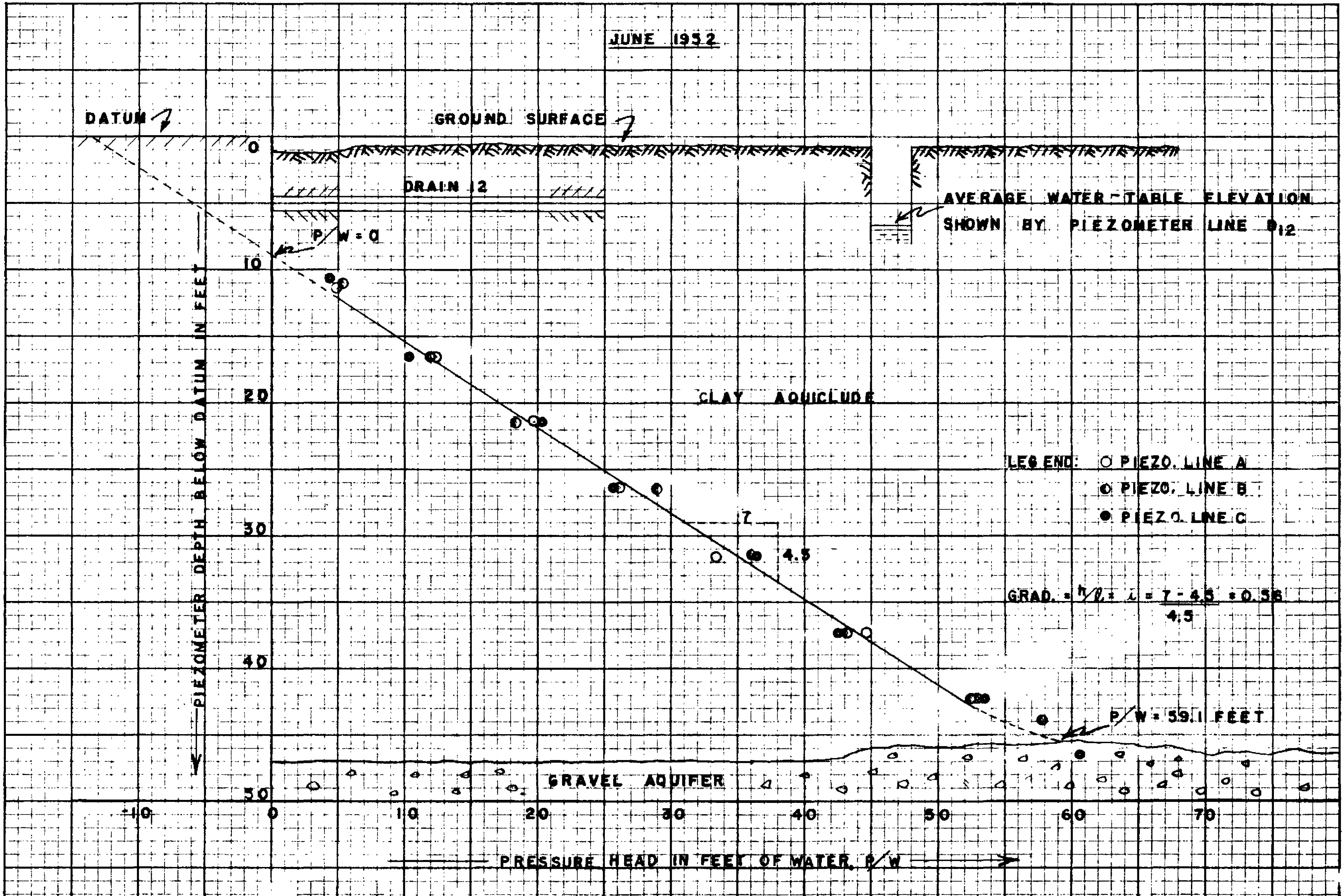


Figure 15. The relation between pressure head and depth of piezometer within the clay aquiclude, June 1952

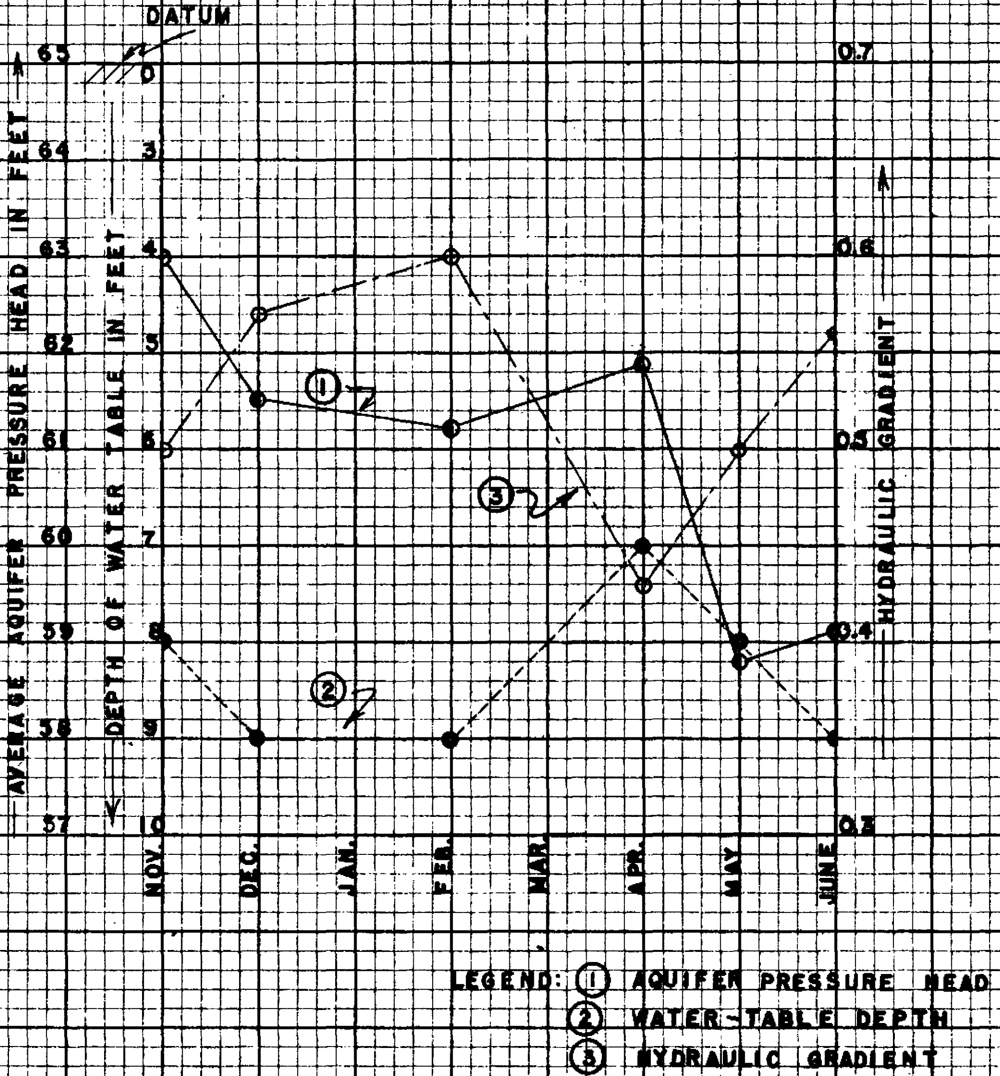
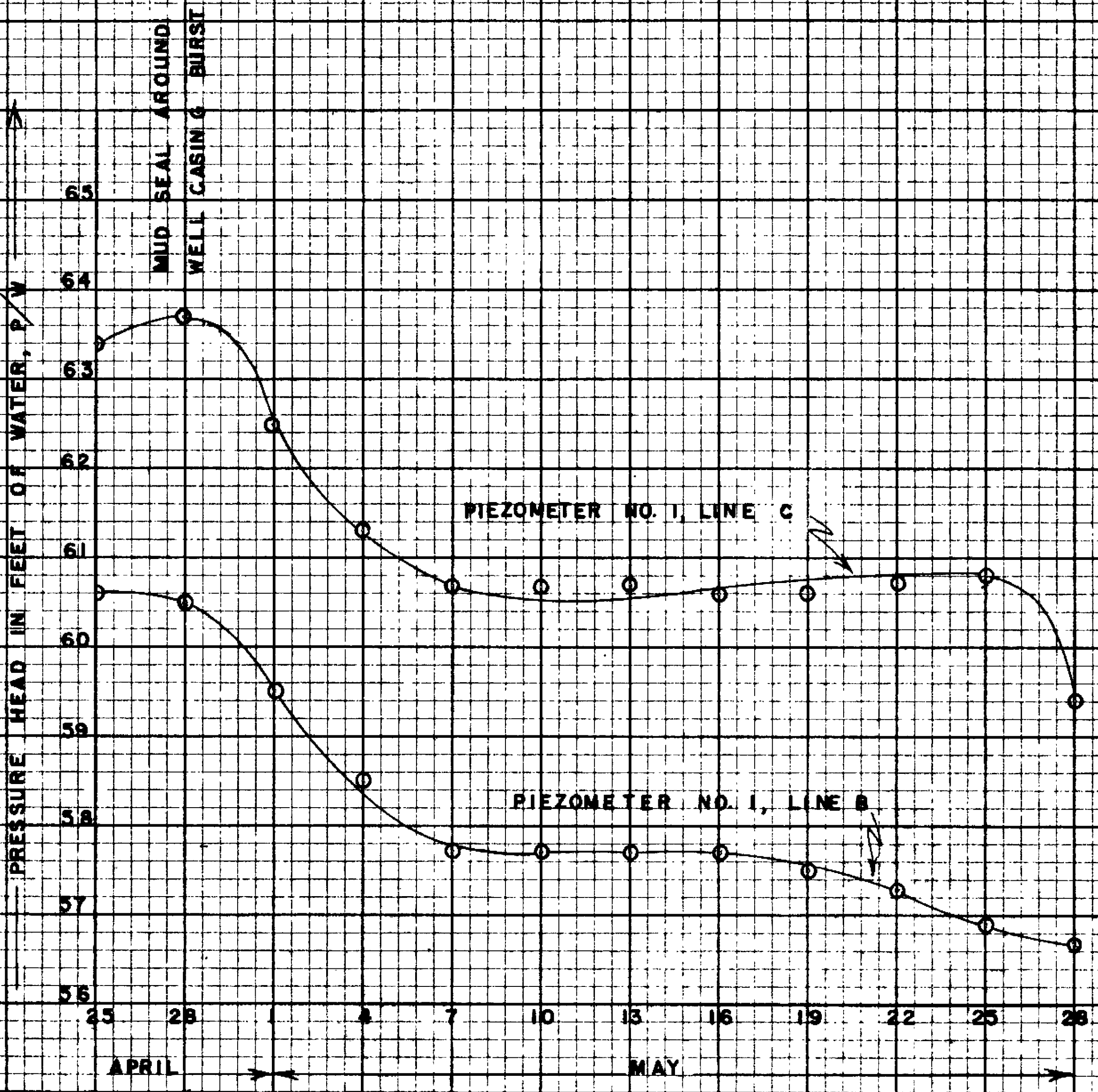


Figure 16. The relation between the artesian aquifer pressure head, the water-table depth, and the hydraulic gradient



**NOTE:** THE WELL WAS LOCATED AT A DISTANCE OF APPROXIMATELY 1600 FEET FROM THE PIEZOMETERS.

Figure 17. The effect of flow from a well on the pressure head in the artesian aquifer

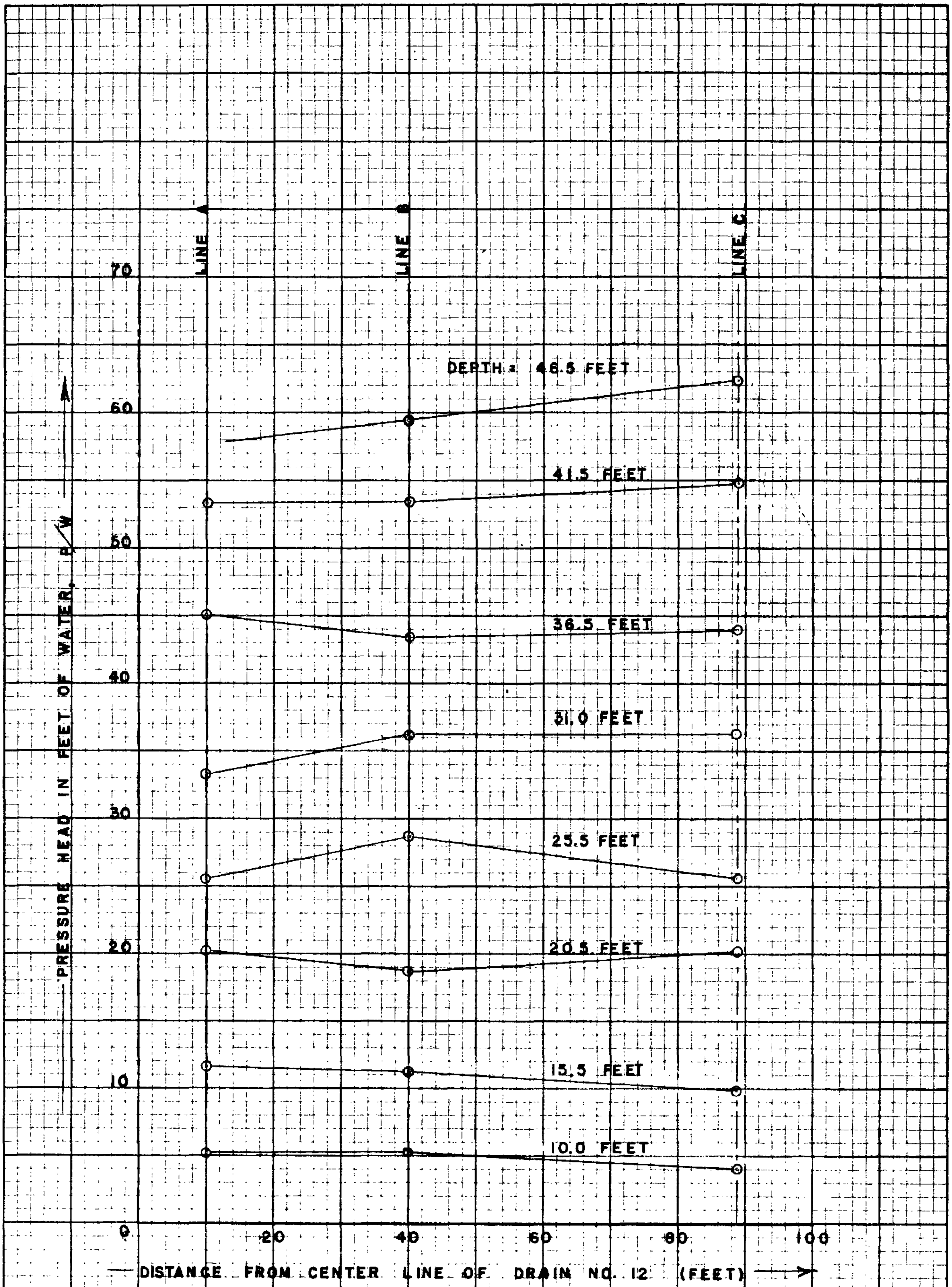
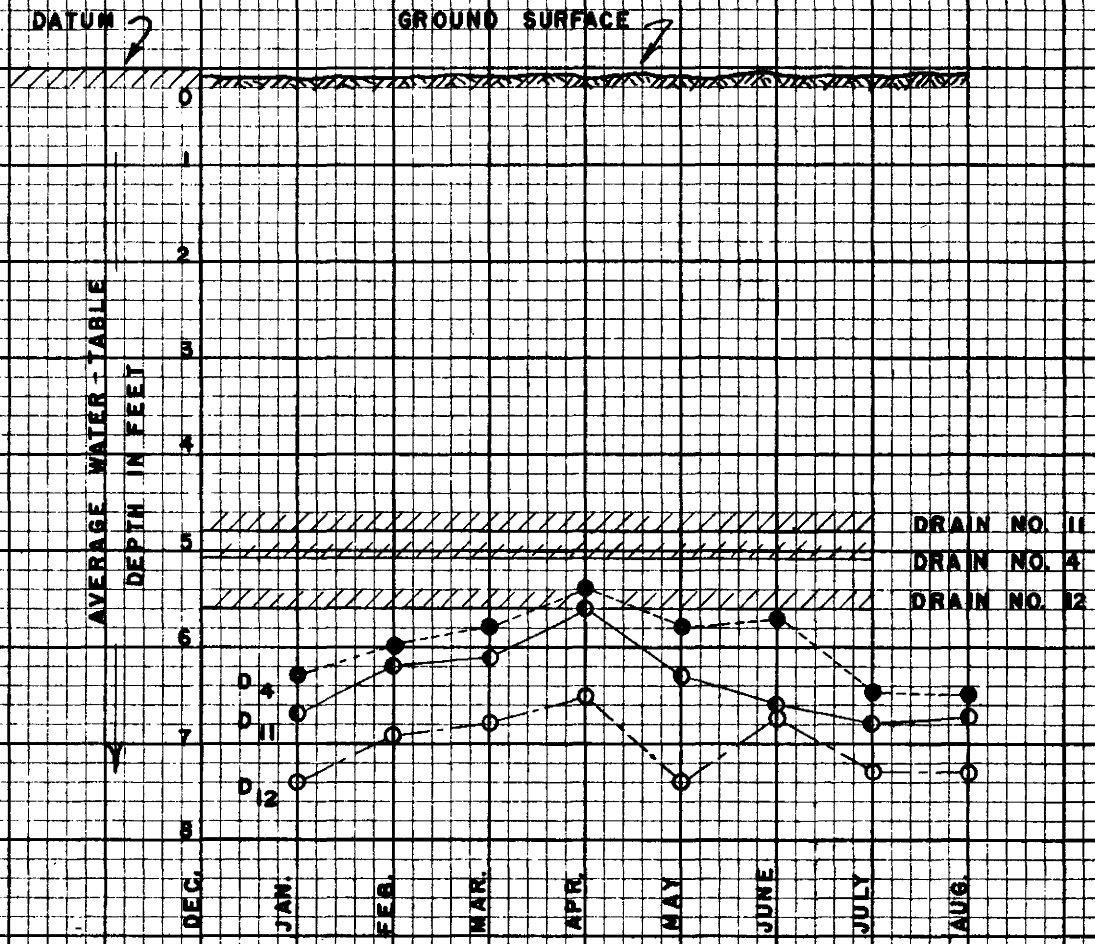


Figure 18. The relation between the pressure head at 8 depths within the clay aquiclude and the distance from the center line of drain 12



**NOTE:** 1. THE BOTTOM ELEVATION OF DRAINS SHOWN.

2. WATER TABLE READINGS OBTAINED FROM PIEZOMETER LINES $D_4$, $D_{11}$, AND $D_{12}$.

3. READINGS FOR JULY AND AUGUST WERE TAKEN BY GORDON H. FLAMMER.

Figure 19. The average water-table depths (below datum) for the 3 piezometer lines, $D_4$, $D_{11}$, and $D_{12}$, for each month during the investigation period

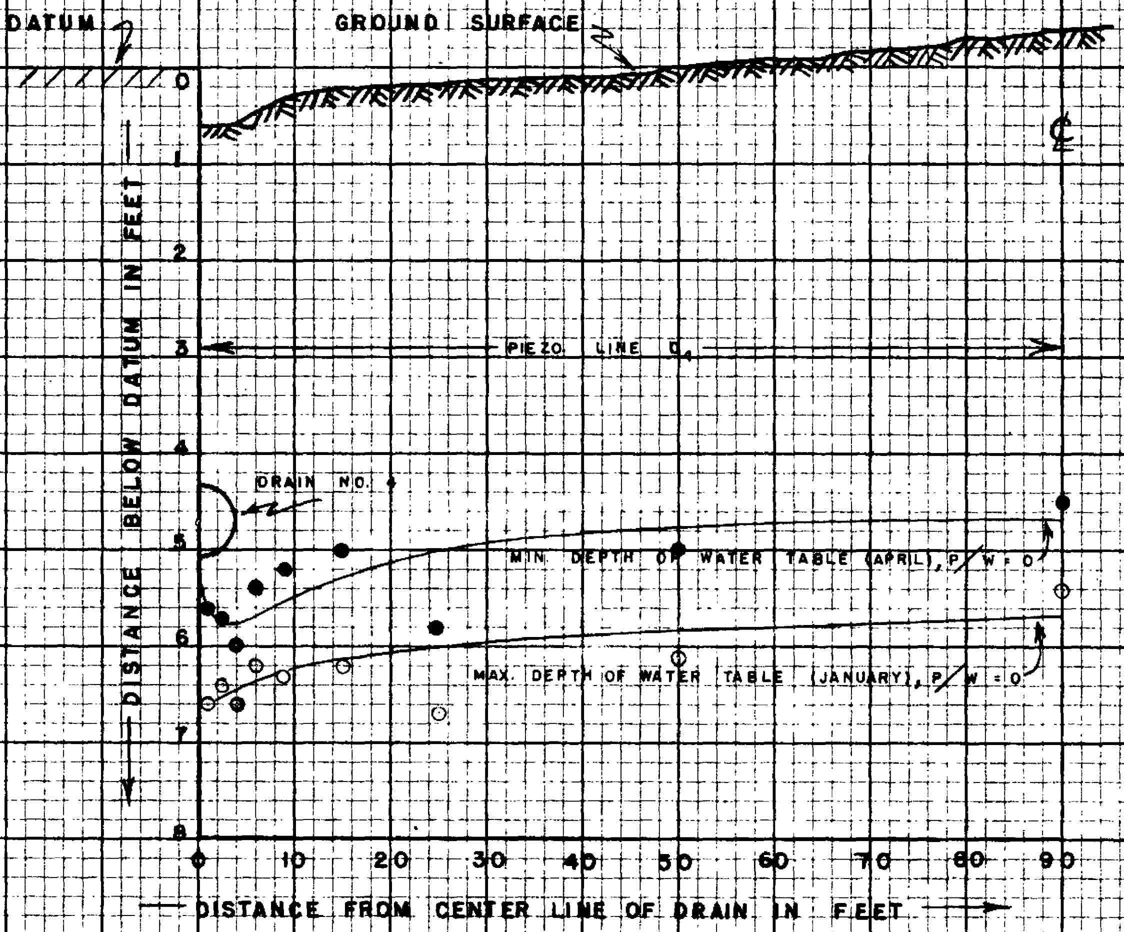


Figure 20. The maximum and minimum monthly average water-table depths adjacent to drain 4

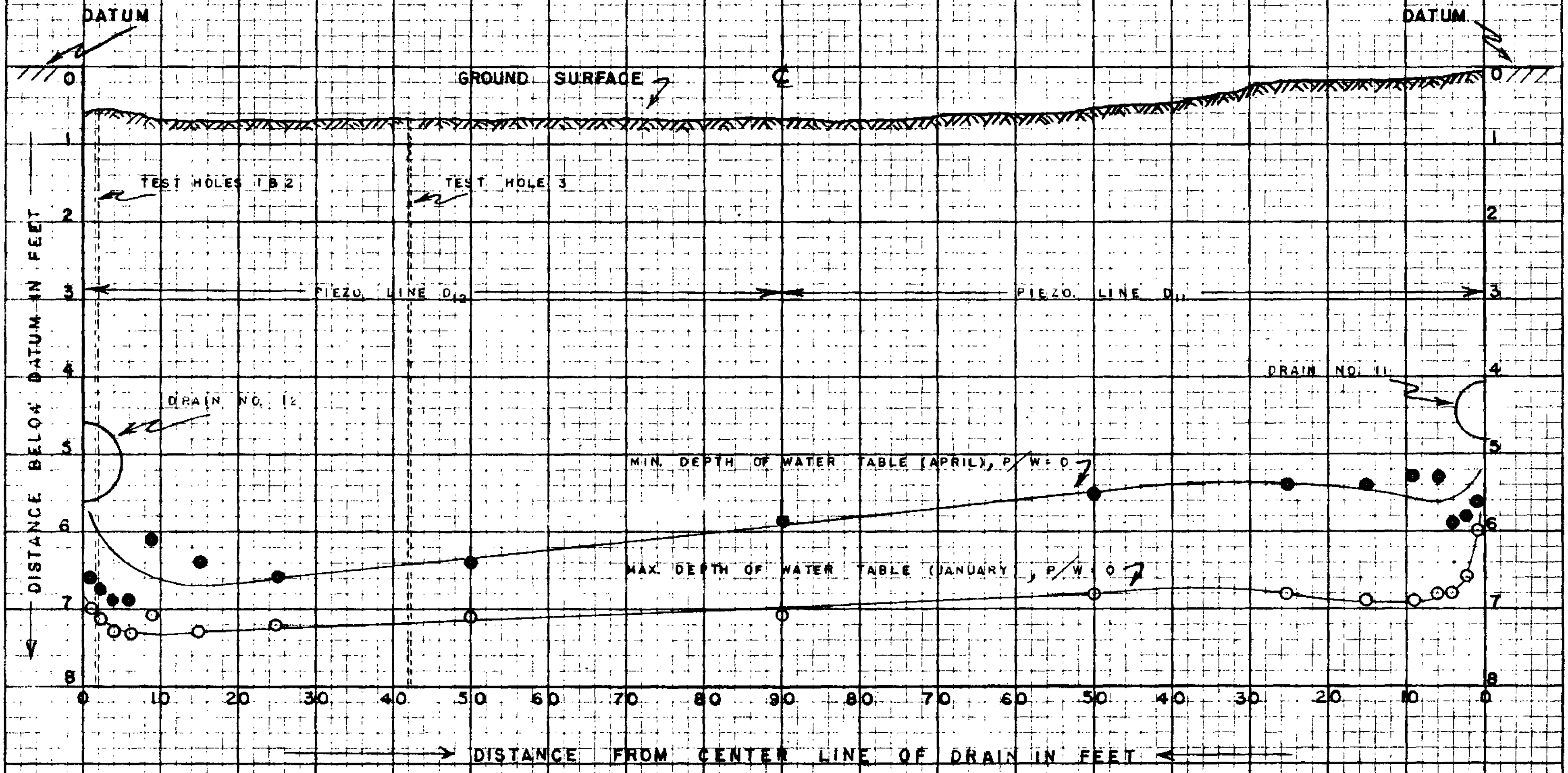


Figure 21. The maximum and minimum monthly average water-table depths between drains 11 and 12

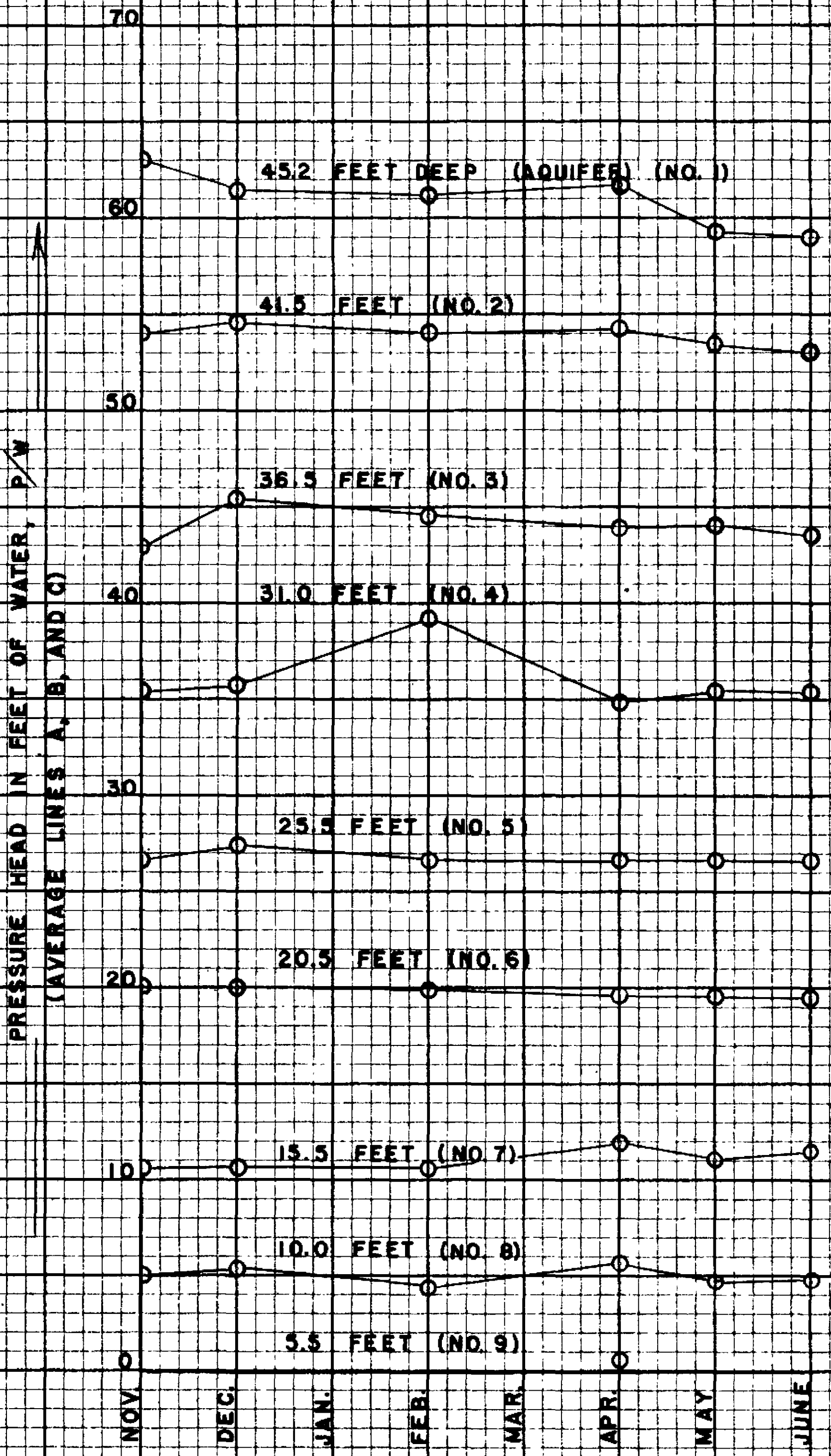


Figure 22. The average pressure head at 9 different depths within the clay aquiclude for each month during the investigation period

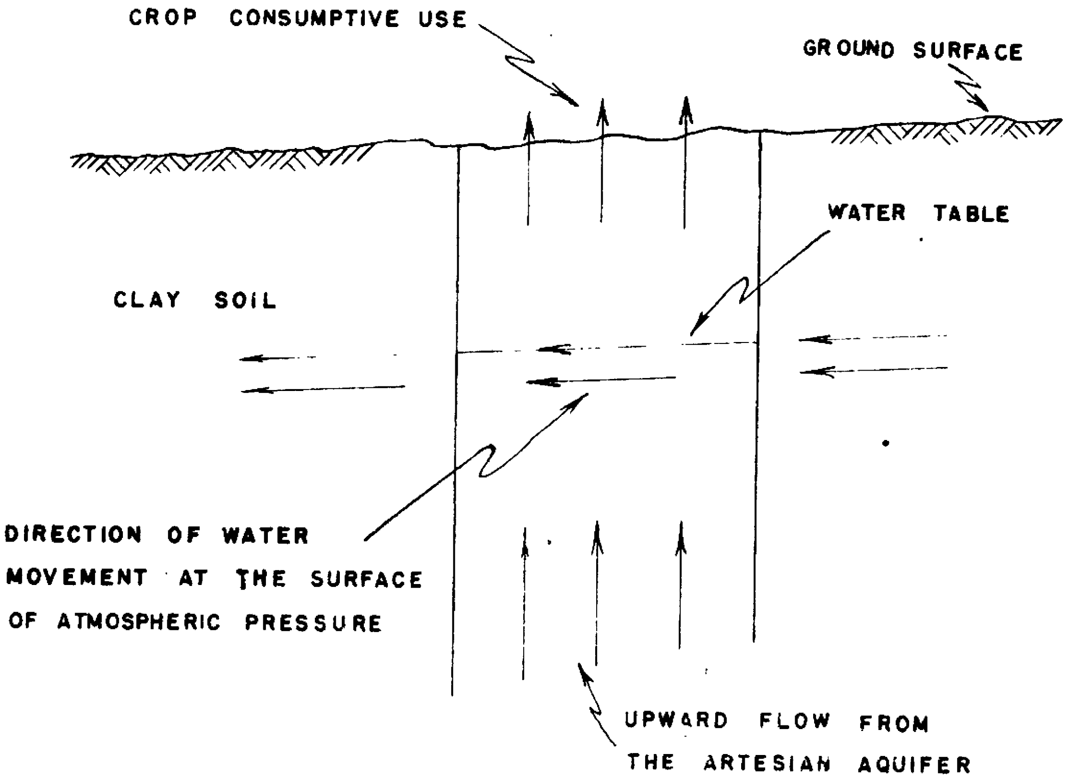


Figure 23. An illustration of steady-flow conditions through a section of the aquiclude

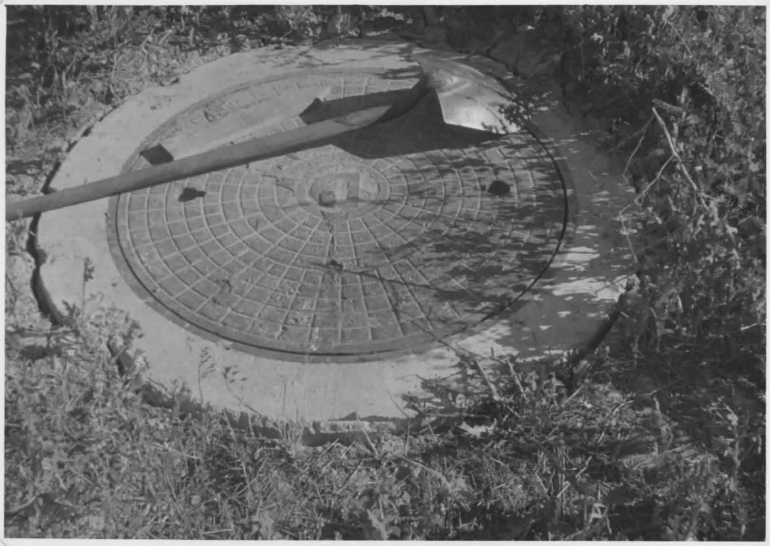


Figure 24. Shrinkage cracks in the clay soil

Figure 25. Forage grasses on drained land in the foreground and marsh grass on waterlogged soils in upper left of picture