The Drainage Problem in the Draper Area, Utah

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THE DRAINAGE PROBLEM

IN THE DRAPER AREA, UTAH

by

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INTRODUCTION

As a rule, in the practice of irrigation, more water is delivered to a project than is used by the plants, evaporated, or removed by natural drainage. It is now generally accepted that, in the West, irrigation and drainage are necessary complementary practices. With comparatively good irrigation practice the efficiency is about 34 percent; that is, approximately one-third of the water is actually used by the crops. With rather poor irrigation practice the efficiency may drop as low as 12 percent. (5)

The increase in irrigation practice of higher lands in Utah has resulted in an increased need for drainage in the bottom lands of the valleys. This need for drainage influenced the Utah Agricultural Experiment Station and the Utah Power & Light Company to set up a cooperative experimental drainage project (Ut. Agr. Exp. Sta. Project 285, The Drainage of Irrigated Lands). The objectives of this project were:*

1. To develop new and improved methods of design, operation, and maintenance of drainage systems; both gravity and pumping.

2. To develop improvements in the design, the placing and maintenance of drainage tile, with special reference to prevention of inflow of excessive sand, silt, and clay which clogs tile drains and necessitates very costly cleaning or abandonment.

3. To develop a clear understanding, by field inspection and experimentation, of the reason for successful drainage of 100,000 acres of Utah irrigated land, now well drained, and of the reasons for failures of the drainage systems covering an additional 100,000 acres.

4. To find the conditions under which, and the extent to which, drainage by pumping is preferable to drainage by gravity systems and to design, locate, drill and develop drainage wells so as to obtain maximum yield per foot of drawdown, and thus decrease drainage cost.

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* From the outline of Project 285, which is on file in the office of the Utah Agricultural Experiment Station.

The Utah Power & Light Company also provided, as part of its cooperation, a fund for research fellows. The cooperating agencies adopted the policy of assigning a specific drainage problem area for study by each research fellow. The first study undertaken was made by Mr. Sterling Davis in the Lewiston area, which is located in the north end of Cache Valley, south of the Idaho State line, between the Bear and Cub rivers.

The second study undertaken, which is reported in this thesis, covered the Draper area, Utah, located approximately 20 miles south of Salt Lake City and east of State street (Fig. 1). This study was carried on cooperatively by the Draper Irrigation Company, Utah Agricultural Experiment Station, and Utah Power & Light Company.

Special consideration was given to various costs involved in drainage in the Draper area, with particular reference to initial costs and the costs of operation and maintenance. For the study in the Draper area, drainage by pumping was selected because:

1. Through the years, tile drains have not provided sufficient drainage.
2. Drainage by pumping provides additional water for irrigation.
3. Pumping ground water for irrigation in San Joaquin valley, California and in the Salt River valley, Arizona, has lowered the water table enough to provide ample drainage.

The drainage research in the Draper area consisted of:

1. Preliminary investigation of ground water, with special reference to the depth and slope of the water table;

2. Drilling and testing of two 3-inch diameter wells No. 1 and No. 2;
3. Drilling, gravel packing, developing and testing 8-inch gravel envelope well No. 3 and
4. Long-time testing and pumping of well No. 3.

Early History

The Indians, many years previous to the coming of the white man, named the Draper area "Sivagah",* and mountain streams clear and cold spread out over the area as they left the foothills north and east of the town and flowed westward toward the river. Willows grew profusely along the banks of the creeks near the eastern and higher parts of the area. In the western part of the area, cattails and native grasses grew in and near the streams. The first white settlers herded their cattle along the banks of the creeks during the winters of 1848 and 1849. Two boys, Norman Brown** and Joseph F. Smith,*** brought cattle, mules, and horses to feed where the snow had been swept from the high places by the wind.

Land claims were staked out late in 1850 and early 1851. Ebenezer Brown, of Mormon Battalion fame, moved his family into the area and built the first house in the spring of 1851. Henry Day worked his claim during the summer of 1851, and in the fall of that year built the second house in the new settlement, which then was known as South Willow Creek. Later it was named Draperville, and later again changed to Draper.

In the autumn of 1851, several families joined the Brown's and the Day's. Andrew Jackson Allen, Andrew Burnham, Perry Fitzgerald, and a few others settled on their claims in the area. In the early part of 1852, Jacob Terry, Joel E. Terry and Absolom W. Smith came with their families.

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* Sivagah - An Indian name meaning a place of many willows.

** Norman Brown, a few years later, plowed the first furrow in the new settlement and began the farming industry in what is now Draper.

*** Joseph F. Smith, 5 decades later, became sixth president of the Church of Jesus Christ of Latter Day Saints.

Thomas V. Williams came to Utah in 1855 and settled in Draperville. Mr. Williams worked out a system for the farmers to divide the irrigation water. Each farmer was granted so many shares of water, depending upon the size of his farm and also upon the amount of money and work he contributed to making ditches, digging canals, and building reservoirs. Important questions were: How often should each man take the water? How many hours should the water be used? How many acres will a certain stream irrigate, and the time required to irrigate an acre?

Mr. Williams figured that crops in the area would need water about every 8 or 9 days. He proposed the ingenious method of having each farmer take his water turn every 8 days and 6 hours. This arrangement provided every man an equal number of daylight hours to water his crops. This system is in use today. (4)

Location and Extent of Area

The Draper area herein considered is that area which is provided water by the Draper Irrigation Company. Special consideration is given to that part under which a high water table exists.

The town of Draper is mainly in the S. W. quarter of Sec. 29, T. 3 S., R. 1 E., but the area under consideration takes in all, or parts of, sections 27, 28, 29, 32, 33, 34, T. 3 S., R. 1 E., and part of Secs. 4 and 5, T. 4 S., R. 1 E. The area needing drainage is shown on the map (Fig. 1).

The area served by the Draper Irrigation Company at the present time is nearly 4000 acres; of this, approximately 600 acres are in need of drainage.*

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* These figures were given by Mr. R. Carlquist, President of the Draper Irrigation Company, and are only approximate.

Irrigation

The first settlers diverted the mountain stream and irrigated their farms in the same manner as in other areas settled by the pioneers. They built ditches and canals the best they could and in this particular case they did a very good job. Near the mountain, the canal with hand-placed granite and rock lining, placed by the early pioneers, is still in good condition.

An entry in the journal of William R. Terry indicates that they were irrigating as early as 1853.

> Closed school the 12 of Feb., 1853. Comens ditching and fencing a farm of 24 acres put in seed and raised a crop. (4)

On March 19, 1888, the Draper Irrigating Corporation was incorporated with 85 "stockholders". On January 18, 1913, the name was changed to the Draper Irrigation Company.

The objects of incorporating the Draper Irrigation Company were:

> The business and pursuits of this corporation shall be the controlling of the water brought from Big Willow Creek, Rockymouth, Middle and South Dry Creeks and springs, Little Willow Creek and Bear Canyon; also one-half of North Dry Creek until July 20 of each year and two-thirds thereafter each year; all situated in Salt Lake County school district No. 22 of said county in a ditch built for that purpose.*

In the early days the farmers had trouble losing the water in sinks and sand banks of Big Willow Creek. Nearly all of the upper section of canal is now lined either with rock masonry or concrete. The lined section is to the N. E. of Sec. 28 and so is not shown on the map. The Draper Irrigation Company does not have a map showing the exact location of the upper land and the lined section of the canal.

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* Taken from records of the Draper Irrigation Company, Draper, Utah.

Individual efforts

A few short tile drain lines were placed by W. B. Enniss, A. Nielson, and John H. Garfield, as early as 1900.

Groups of landowners

A closed tile drain located in Secs. 29 and 32, T. 3 S., R. 1 E., Salt Lake Base and Meridian, was constructed in April and May, 1922 and was known as the Cove Drainage System. The Soil Conservation Service has recently been interested and has helped in the solution of the drainage problem in the area. No records or maps were available showing more detailed information in this area.

Draper Irrigation Company

The cooperative work undertaken in this study has been the first drainage work or investigation in which the Draper Irrigation Company has taken an active interest.

Several days were spent in Draper searching the records of the late Mr. Enniss, who for many years was president of the Draper Irrigation Company. However, no detailed records or maps of the drains in the Draper area were found.

General

The Draper area lies in a valley, or one time bay, of historic Lake Bonneville. Weathering and stream and lake action have combined to graduallywear down the mountains and deposit some of the material in this valley. The valley is a structural valley caused by a movement of the earth's crust leaving an escarpment on the east and a dike or spit formation on the south.*

Lake Deposits

The clays and fine material were undoubtedly deposited when Lake Bonneville was at its highest level. The fine material, because it stayed in suspension longer, was carried farther out in the lake. Coarse material was deposited close to the shore due to the fact that the streams carrying the material were small and thereby lost their carrying power soon after entering the lake.

Stream Deposits

The streams entering Lake Bonneville deposited the heavier material close to the lake shore. As the lake level lowered the stream carried this material farther down the valley and deposited the sands on top of the clays, thus leaving the valley floor deposit as shown in the logs of the wells (Figs. 6 and 11). West of the Draper area, the deposit of sand decreases. Near the Jordan river the clays are on the surface.

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* Dr. William Peterson, Director Emeritus, Utah State Extension Service, was helpful in giving information concerning the geology of the Draper area.

INVESTIGATIONS FOR WELL LOCATION

Preliminary Investigations of Area

Water table studies

The first work was putting down test holes with soil augers to obtain profiles of the water table. The profiles were determined by measuring the depth from the ground surface to the water in the test holes, then drawing a profile showing the ground surface and the distance to the water surface at each test hole.

On September 20, 1947, Line A, holes 7 to 14, north and south, and Line B, holes 1 to 6, east and west were drilled and the depths to water were measured and recorded. On September 27, the east-west line was extended farther to the east to include holes 15 to 23 as Line C. On October 4, Line D, holes 24 to 28, north and south, and other test holes were drilled to obtain additional information concerning the ground water in the area. All test holes are shown in Fig. 1.

Profiles of water table

Profiles of the water table and the ground surface, on Lines A, B, C, and D, are plotted in Figs. 2, 3, 4, and 5, respectively. The depths of the water table, below ground surface, are also shown in Table 1. Measurements were made on September 20, September 27, October 4, and November 1.

Plan for drilling test wells

Well drillers in the Salt Lake area were contacted in connection with the proposed test wells to be drilled at Draper, but they all had other obligations. Mr. Robert Johnson, well driller, of Logan, Utah, was employed. He drilled two 3-inch diameter test wells during November, 1947, to depths of 126 feet and 77 feet respectively. Well

No. 1 was started November 17, 1947 and completed November 21, 1947. Well No. 2 was started November 24, 1947 and completed November 25, 1947.

Sources of ground water

The older inhabitants of the area believe that the principal source of ground water is the heavy snowfall on nearby mountains and percolation into the ground from canyon streams. The road along the base of the delta, east of Draper, was always wet before a drain was constructed on the north side of the road, about 1925. A continuous stream has been discharging from this drain since its construction.

The amount of ground water which might be contributed by the Draper Irrigation Company Jordan river canal has not been fully determined. However, the late Mr. Vawdrey, a former secretary of the Draper Irrigation Company, said that a record had been kept of measurements of the inflow and outflow in the canal every two weeks during the irrigation season, for many years. On the basis of Mr. Vawdrey's report and measuring all of the stream flows in cubic feet per second, the following definitions and relations of inflow, outflow, and losses are presented:

Q_p = the pump delivery of water at the head of the canal, measured each 2-week period, designated the c.f.s. inflow.

Q_d = the sum of the streams delivered to stockholders.

Q_s = the stream delivered to the Sandy Irrigation Company.

Q_l = loss in the 9 miles of canal section.

Then $Q_p = Q_d + Q_s + Q_l$

and $Q_l = Q_p - (Q_d + Q_s)$

These records showed that after the banks were thoroughly soaked the loss of water by seepage was approximately one cubic foot per second along the 9 miles of canal. If this was true, the canal contributed very little to to the ground water. For example:

If average Q = 45 c.f.s. and the loss was one-ninth of a c.f.s. per mile; then, the percent loss per mile =

$$= 100\left(\frac{\frac{1}{9}}{45}\right) = \frac{100}{405} = 0.25 \text{ percent per mile.}$$

From the information gathered, it is assumed that the main sources of ground water are:

1. Water lost in sinks or faults near the sources of mountain streams, northeast of the water logged lands.

2. Deep percolation water losses from excessive irrigation of the upper lands.

Test Well No. 1

Location

Draper area test well No. 1 was located on the Henry Ballard farm (Fig. 1) 296 feet north, 49 feet east of the S. W. corner Sec. 28, T. 3 S., R. 1 E., Salt Lake Base and Meridian.

Drilling

Test wells No. 1 and No. 2 were put down by a jet type well drilling machine. Water was pumped down a 3/4-inch pipe at approximately 15 g.p.m. Soil materials loosened by the drill were washed to the surface by the water pumped down the well.

Log of well

The log of test well No. 1 (Fig. 6) shows that the thickness of the different materials encountered varied from 2 feet to 20 feet. Drilling was stopped at 126 feet depth, in sandstone. The sandy soil stratum, between the depths of 28 and 36 feet, absorbed the entire jet stream of 15 g.p.m. This indicated that this stratum was the most permeable drilled through. Casing was required to a depth of 70 feet. After drilling was completed, the casing was pulled back so as to leave 40 feet of casing in the well. The casing was pre-perforated for 10 feet from the 26-foot to the 36-foot level.

Piezometer installation

Piezometers were put down in pairs, approximately 9 inches apart, to depths of 14 and 32 feet below the ground surface. The pipes were installed along the fence line, west of wells, at stations 25 feet, 50 feet, 100 feet, 200 feet, and 400 feet, north and south on Line E (Fig. 7).

Piezometers of one-half inch black pipe and the equipment for driving and flushing were furnished by the Utah Agricultural Experiment Station. Installations were made by the U. S. Soil Conservation Service of Murray, Utah.

Testing

The air lift pump used for testing the well consisted of a 3/4-inch air discharge pipe connected to a nozzle, and an air compressor. The nozzle, which was designed to break up the air jet into small bubbles with an initial upward velocity component, was placed near the bottom of the well for maximum submergence. A 1/4-inch pipe was put down the well to a depth below the air nozzle to measure the water level during the pumping test. A calibrated gage was connected to the 1/4-inch pipe to measure the distance from the ground level to the water surface before and during pumping. The difference in the level of the water surfaces was the drawdown of the well.

For the first two days, during testing operations of the well, a large quantity of blue quicksand was brought up with the water. On the third day, about 3 cubic feet of gravel was poured down the 3-inch casing. The gravel seemed to stabilize the formation, because when pumping was resumed the water cleared in a short time. Drawdown was measured at the well and the discharge was measured with a 3-inch Parshall flume in the 96 hours of continued pumping from the well. Readings were taken every hour during the test.

Piezometer readings were taken each morning and evening. The morning readings are recorded in Table 2 and plotted in Fig. 8.

Permeability

Since no large gravel-bearing stratum was encountered, pumping was from the water-bearing sandy material above the clay layer. The method used to determine the permeability of this material is described by Wenzel (11, p. 78).

For steady flow in a water-bearing material where the water is not confined under artesian pressure, (Fig. 9) the permeability is equal to

$$k = \frac{2.3\,Q \log_{10}\frac{r_2}{r_1}}{\pi (h_2 - h_1)(S_1 - S_2)} \quad \ldots\ldots\ldots\ldots\ 1$$

in which Q is in c.f.s., r_1 and r_2 in ft., h_2 and h_1 in ft. and S_1 and S_2 are in ft. giving k = ft./sec. or $\frac{L}{T}$

Dimensional analysis $\frac{L}{T} = \frac{\frac{L^3}{T} \times 1}{L \times L} = \frac{L^3}{L^2 T} = \frac{L}{T}$

The values for calculating permeability are recorded in Table 3.

Test Well No. 2

Location

Draper area test well No. 2 was located on the Richard Carlquist farm (Fig. 1) 1322 feet south, 54 feet west from the N. E. corner of Sec. 32, T. 3 S., R. 1 E., Salt Lake Base and Meridian.

Log of well

Test well No. 2 was drilled through numerous strata of sand and clay which varied in thickness from 0.5 feet to 18 feet. Some gravel was found mixed with the sands, but no large stratum from which to pump was encountered. A picture of the drilling of test well No. 2 is shown in Fig. 10 and a detailed log of the well is shown in Fig. 11.

Piezometer installation

Piezometers were installed, Line F, (Fig. 12) the same as well No. 1.

Testing

Well No. 2 was tested by the same methods as well No. 1. The average discharge for the test was 0.053 c.f.s. = 23.78 g.p.m., and the average drawdown = 22.17 feet. Piezometer readings are recorded in Table 2 and shown in Fig. 13.

Permeability

Permeability was calculated by using the measured discharge Q, and the average values of h, r, and S on the north and south lines in Equation 1. These values are recorded in Table 5.

Introduction

The information obtained at test well No. 1 and No. 2 indicated that it would be impossible to get a large flow of water at either location. However, the effectiveness of lowering the water table could only be determined by experimenting. By gravel packing and developing the well, it was hoped to get a discharge substantially greater than that of test well No. 1.

Specifications and Construction Contract

Specifications* for the large diameter well were written during the month of January, 1947. The principal features of the specifications were:

1. The well shall be a double-cased gravel-envelope type. Inside casing not less than 12-inch diameter, outside casing 24-inch diameter, and depth of well not greater than 40 feet.
2. Outside casing shall be installed vertically by driving or jacking the casing and bailing the material from inside with cable tool equipment. Hydraulic rotary method of drilling shall not be used.
3. Other items covered in detail in specifications are, inside casing, gravel envelope, perforations, driving shoe, development and testing of the well.

There were some minor changes made in the field, but for the most part the original specifications have been followed.

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* Specifications are on file in the office of Dr. O. W. Israelsen, Research Professor of Irrigation & Drainage, Utah Agricultural Experiment Station

Bids received from three drillers, were opened and read at the county agent's office, Federal Building, Salt Lake City, at 3:00 p.m. on February 20, 1948. The bid of Mr. L. W. Dalton, of the Dalton Well Drilling Company, Salt Lake City, was accepted and a contract was signed on March 8, 1948.

Location of Well

Draper area large diameter experimental well (No. 3) was located on the Richard Carlquist farm (Fig. 1) 748 feet north, 40 feet west of the S. E. corner of Sec. 29, T. 3 S., R. 1 E., Salt Lake Base and Meridian.

Piezometers

Location

In the spring of 1948, piezometers of 3/8-inch pipe were installed, by the driving method, in pairs located on Lines G and H (Fig. 14) running at approximately right angles to each other. Piezometer stations were located at distances of 5, 10, 25, 50, 100, 200, 400, and 550 feet nearly west of well; and 5, 10, 20, 85, 200, 400, and 500 feet nearly east of well on Line G. They were located at distances of 5, 10, 25, 50, 75, and 280 feet north 18° east of well; and 5, 10, 25, 50, 100, 255, and 335 feet south 18° west of well on Line H.

Use

Piezometers are used for measuring the elevation of the water table during the pumping and the non-pumping periods. Measurements taken during pumping (Fig. 17) may be used for calculating soil permeability.

Water table profiles

The readings* of the water surface elevations (converted to mean sea level) in the 14-foot piezometers near well No. 3 and the water surface elevation (converted to mean sea level) at well No. 2, taken at approximately 7-day intervals, are recorded in Table 6. The profiles of the water table before pumping and at specified times during the pumping period, are shown in Figs. 15 and 16.

Control piezometers

Piezometers at test well No. 2 were used to check the water table fluctuations due to hydrographic conditions.

Well Construction

Outside casing

The outside casing was rolled from 1/4-inch steel plate by the Provo Foundry and Iron Works, Provo, Utah. Each rolled section was 24 inches inside diameter and 6 feet in length.

Inside casing

The 34 feet of inside casing was 8-inch inside diameter black pipe. Braces were welded 5 feet from the top and 6 feet from the bottom of the casing. The braces were necessary to keep the inside casing centered in the outside casing (Fig. 18). The lower 16 feet of the inside casing was pre-perforated and a plate welded to the bottom (Fig. 19).

Perforations

The 8-inch casing was perforated with an acetylene torch, which was held so that the slots were made wider on the inside than outside. Each

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* Readings of piezometers were taken daily for the first three weeks (except weekends), then twice weekly for four weeks, then weekly. These records are on file in the office of Dr. O. W. Israelsen, Utah Agricultural Experiment Station.

row of holes was staggered with the row above (Fig. 20). Outside dimensions were 5/32 x 3/2 inches. In the 16 feet of casing there were 128 rows and in each row there were 10 perforations. The area of each perforation was 15/64 of a square inch, thus making the total area of the perforations 300 square inches, or 2.08 square feet. Using 8.6 inches as the outside diameter of the casing, the outside circumference is 2.25 feet, and the area is 36.0 square feet. The ratio of perforated area to total area is therefore 5.8 percent.

Gravel envelope

Gravel for the envelope was obtained from the Salt Lake Valley Sand and Gravel Company. The 1/4-inch pea gravel, (mechanical analysis of gravel No. 2, Fig. 21) due to being damp, contained a considerable amount of sand and had to be hand-screened over a 1/4-inch mesh before being used.

Power supply and pump

The Utah Power & Light Company, Midvale office, installed transformers and brought 60-cycle, 220-volt, 3-phase electric service to the site. The power line from the control box to the well was only a temporary installation. The pump used in the development of the well was a submersible pump, 5 hp., 3-phase, 60-cycle, 220-volt, 15-amp. a.c. current, and had a capacity of 140 g.p.m. at a 70-foot head (Fig. 22).

Drilling the well

Drilling of the 8-inch gravel envelope well was started on April 14, 1948. A 20-inch bit was connected to the string of tools for the drilling operations (Figs. 23A and 23B). The bit churned up the soil material and water and a bailer was used to remove this mixture (Figs. 24A and 24B). To drive the outside casing a driving head of 1500 pounds was dropped at an average height of 3 feet. As the depth increased the driving of the casing became slower due to skin friction (Figs. 25A and 25B). The minimum time to drive a 6-foot section was 15 minutes and the maximum time to drive a 6-foot section was 90 minutes. Blue clay was reached at a depth of 33 feet. The outside casing was driven to a depth of 35 feet, and drilling (Fig. 26) was stopped at a depth of 38 feet. The inside casing was installed and the bottom rested on the gravel at a depth of 33 feet below the ground surface. Gravel was placed in layers of approximately 6-foot depths, in the annular ring between the two casings, at different intervals. After placing each gravel layer, the outside casing was jacked back a length of 6 feet (Fig. 27). Each 6-foot section of the well was developed by pumping, surging and bailing.

The process of gravel packing, jacking back the outside casing, and developing was continued until 13 feet of the outside casing remained as part of the completed well. The remaining space in the annular ring was filled with gravel and development by pumping, surging and bailing was continued (Fig. 28).

Development of Well

Pilot gravel tubes

In order to try to get more gravel in the space below the 24-inch casing, five 5-inch pilot tubes (1, p. 269) were placed around the outside of the 24-inch casing at a distance of approximately 6 inches. Two were driven to a depth of 20 feet and three to a depth of 13 feet (Fig. 29).

Surging and bailing

As the surging and bailing operation continued, very little gravel settled in the tubes or annular ring. Caving occurred around the outside of the 24-inch casing and approximately 20 cubic yards of gravel was used to fill up the hole.

On June 19, 1948, the driller was released and further development of the well was accomplished without the use of the well-drilling equipment.

Backwashing

A special cap with two connections was made so that water could be forced down the 8-inch casing under pressure and out through the perforations into the water bearing material (Fig. 30). To force water down to the bottom of the 8-inch casing, a 2-inch line 33 feet long was connected on the inside of the cap. By closing the valve from the canal supply line, starting the other pump and opening the discharge valve, water was pumped through the 2-inch line from the bottom of the 8-inch casing, thus drawing out any sediment that might accumulate. When the water was pumped into the 8-inch casing it rose to the ground surface through the gravel in the annular ring and also around the outside, and carried considerable quantities of fine material. The process of pumping into the well and then out of it was continued until very little fine material was evident.

Underground Formation

The material below the top soil was dark brown in color to a depth of 18 feet. Mechanical analysis showed a medium to fine sand with some fine gravel as well as a small percent of silt (Fig. 21). From 18 feet to 32 feet the material was light yellow in color. Mechanical analysis showed this to be medium to fine sand also but with less gravel and more silt, although the gravel was of larger particles. Blue clay was encountered at 33 feet (Fig. 31).

Initial pumping

Initial pumping was with a 5 hp. submersible pump, which was lowered to approximately 2 inches from the bottom of the 8-inch casing. The pump was operated at maximum discharge, for the five-day test period, except when the stream was reduced by partly closing the valve on the discharge hose.

Drawdown and discharge curve

During the initial pumping test with the submersible pump, the well was tested at different drawdowns and discharges. For each test, a setting was made on the valve and the pump was allowed to operate at this discharge rate for 2 hours; then drawdown was measured. Five drawdown discharge curves showing the results of measurements on July 15, 19, 21, 27, and August 3 are plotted in Fig. 32. The well discharge at the beginning of the tests on July 15, was much higher than for later tests at the same drawdown. For example, pumping 30 g.p.m. on July 15, caused a drawdown of 22.5 feet, whereas, on July 19, pumping only 16.5 g.p.m. caused the same drawdown of 22.5 feet.

Long-Time Pump Test

Drawdown-discharge curve

The period from the shutting down of the submersible pump and the starting of the turbine pump, (Figs. 33A and 33B) except for 5 minutes to check operation, was approximately 48 hours. Considering the low permeability of the soil, it is doubtful if this time was sufficient to allow the water to stabilize at the well.

Drawdown-discharge tests were made each week for 3 weeks. The discharge for the first week of pumping was approximately 20 g.p.m.

However, the discharge gradually decreased during the first month to approximately 16 g.p.m. This rate has been maintained to date at a drawdown of approximately 20.5 feet.

Effect on water table

The effect of pumping on the water table to date has been small, except in the area very close to the well. The water table fluctuates with the irrigation of the upper lands and since the quantity being pumped is so small, considerable time is necessary to lower the water table appreciably.

Permeability Measurements

Field measurements

The permeability of the soil measured in the field was calculated by using Equation 1. The piezometers used were the 10-and 100-foot radii on the west and south lines, 10-and 85-foot radii on the east line and 10-and 75-foot radii on the north line. The water surface elevations in the 14-foot-depth piezometers at the end of one month of pumping, presented in Table 7, were used in the calculations. A depth of 33 feet was used between ground surface and the clay material. The average value of permeability of the material was calculated as follows:

$k = 3.27 \times 10^{-5}$ ft./sec.

Laboratory measurements

Laboratory measurements of permeability were made in the college soil mechanics laboratory, using a constant-head permeameter. The soil used was a combined sample of the materials from all the depths. These samples were taken during the drilling operations and were not sufficiently large for testing each depth of sampling. However, the permeability of the material opposite the perforations was the chief concern; for this reason, samples of the soil material were taken at 6 different times from the 17-foot depth to the 33-foot depth (Fig. 21).

Using formula derived from Darcey's Law Q = kai. For the constant head permeameter $k = \frac{VL}{HAT}$

Where k is the permeability in ft./sec.

V = volume of water flow in a given time in cu. ft.

H = the loss in hydraulic head in ft.

A = area of the sample in sq. ft.

L = depth of the soil sample in ft.

T = time in secs.

The permeability of this material as tested in the laboratory gave $k = 1.49 \times 10^{-5}$ ft./sec.

Effectiveness of Well

The effectiveness of a well can be ascertained by an application of the equilibrium formulas for determining permeability according to Wenzel. (14, p. 148)

$$E_W = \frac{100 S_c}{S_1} \quad . \; . \; . \; . \; . \; . \; . \; . \; . \; . \; . \; . \; 2$$

and

$$S_c = H - \sqrt{\frac{h_2^2 - 2.3\,Q \log_{10} \frac{r_2}{r_1}}{\pi k}} \quad . \; . \; . \; . \; . \; . \; . \; 3$$

in which E_w is the effectiveness of the discharging well in percent, S_c is the theoretical or computed drawdown of the water level in the well, in feet; and S_1 is the observed drawdown in the well in feet. The symbols used in Equation 3 are defined graphically in Fig. 9, except H which is the thickness of the saturated material before pumping began.

The values are presented in Table 8, using the average value of the permeability of 3.3 x 10^{-5} ft./sec. The average effectiveness was found to be 19.2 percent.

Specific capacity

The specific capacity of the well was very low and somewhat variable. Using the last drawdown test, a discharge of 17.5 g.p.m., the drawdown was 19.96 feet giving a specific capacity of 0.877 g.p.m. per foot of drawdown. At a discharge of 12.75 g.p.m. the drawdown was 11.16 feet, giving a specific capacity of 1.143 g.p.m. per foot of drawdown.

Mechanical Analysis of Soil

Representative curves resulting from the mechanical analysis of samples from the various depths have been recorded in Fig. 21. Soils are sometimes classified, from mechanical analysis curves, on the basis of the 20 percent size; that is, 20 percent of the sample is finer and 80 percent is coarser. On the basis of U. S. Bureau of Soils Classification (8, p. 649), the material for the 2-to 18-foot depth is in the medium to fine sand range. Likewise, the 18-to 21-foot depth is classified as medium sand and the 31-to 33-foot depth classified as coarse sand. The gradation of coarse to fine material (Fig. 21) was rather uniform at each depth. The fine particles filled the pore spaces and thus decreased the area through which the flow took place and partly reduced the permeability. This imposed serious limitations on the water yield.

The size of the gravel used in the filter was determined from the mechanical analysis curves of the natural material (8, p. 688).

Cost of Well Unit

The cost of the 24-inch well, the cost of the pump unit designed for the capacity and lift of the well, and the assumptions noted, were used as the basis for the following cost analysis:

Capital cost:

1.	Well and extras	$1750.50
2.	$1\frac{1}{2}$ hp. Little Chief turbine pump unit, to discharge 3120 g.p.h. or 52 g.p.m. at 20 feet head, and switches	364.30
	Total	$2114.80

Annual costs:

1.	Power costs for pumping 12 months at $7.70 per 30-day month*. .	$92.40
2.	Maintenance, at $10 per year	10.00
3.	Capital costs reduced to uniform annual cost on basis of 20-year life and 4 percent interest (2114.80) (0.0736)	155.65
	Total	$258.05

Costs Per Acre

It is assumed that pumping will continue throughout the year, that the pump will maintain a 16 g.p.m. discharge, and that 1 acre-foot of water per acre must be removed by artificial drainage. One g.p.m. is equal to 1.61 acre-feet per year; therefore 16 g.p.m. is equivalent to

* Rate as figured from schedule #24, irrigation and drainage pumping power service of the Utah Power & Light Company.

the excess water from 25.76 acres of land. Using the values above as a basis, the well unit will furnish drainage for 25.76 acres at an annual cost of $258.05 or at an annual cost of $10.02 per acre.

The most uncertain figure in the analysis is the amount of water that must be removed annually by artificial drainage. The general value used is 8 inches, but because of the extremely high water table in the Draper area throughout the year, the one-foot figure is a reasonable estimate of the amount to be removed by artificial drainage.

Quality of Water as a Factor in Pumping Costs

An important element in the cost of drainage by pumping is the value of the pumped water for irrigation purposes. In the Draper area the water pumped from the well, as analyzed by Mr. James Thorne, Soil Conservation Service, Soil Scientist, at the Utah State Agricultural College, was found to be in Class 1 on the basis of its electrical conductance, boron content, and sodium percentage.*

In a 5-month irrigation season the quantity of water pumped at the rate of 16 g.p.m. would be 10.6 acre-feet. The value of 10.6 acre-feet of water at $3.00 per acre-foot** would be $31.80. This amount would pay 34.4 percent of the annual power bill.

---

* The official report of the water, as made by Mr. James Thorne, is filed in the office of Dr. O. W. Israelsen, Utah Agricultural Experiment Station.

** The $3.00 per acre-foot is an approximate average value for the State of Utah as stated by Mr. J. R. Barker, Irrigation Specialist, Utah State Extension Service.

Drill more test wells

More test wells in the area are necessary for giving sufficiently detailed information about the underground formation and ground water movement. Solution of the drainage problem may be found by using the data already gathered and by putting down more test wells.

Locate existing drains

If all existing drains were definitely located, a thorough study of the ground water flow could determine which drains were located for maximum effectiveness. Other drains might be placed so as to intercept the ground water flow; they could be connected to existing drains in order to reduce drainage costs.

Check condition of existing drains

After all existing drains are located, they should be checked to find out which ones are operating efficiently and which ones need repair. The water now being discharged from the drain on the north side of the highway (Fig. 14) should be diverted into the canal instead of being allowed to empty into a slough. The present discharge into the slough adds greatly to the excess ground water.

Measure water delivered to upper lands from mountains

Water measuring devices, or water recorders, should be installed on all of the mountain streams so as to obtain a record of the amount of water applied to the upper land. An estimate of the amount of excess water could be made by subtracting the amount of water used by plants and evaporation from the amount of irrigation water applied. Excess water applied to land contributes to the ground water. Increasing the amount of water applied increases the amount of ground water and thereby raises the water table to a point where drainage is necessary.

Control early irrigation of upper lands

If the amount of irrigation water applied to the upper lands were controlled, especially in the early spring when the supply is large and demand low, land owners in the lower areas would not suffer the excessive losses due to high water table that they do now.

Build reservoirs to store spring run-off

If a reservoir, or series of reservoirs, could be built in the canyons or on the upper lands to store the spring run-off it would do two things:

1. Provide a supply of water in the latter part of the irrigation season, when the supply is usually low.
2. Reduce the quantity of water annually flooded onto the upper lands. This excess water contributes to the ground water which raises the water table of the lower lands.

The need for drainage in certain areas influenced the Utah Agricultural Experiment Station and the Utah Power & Light Company to set up a cooperative experimental drainage project. Under this project drainage research in the Draper area, Utah, was undertaken in cooperation with the Draper Irrigation Company.

The Draper area comprises about 4000 acres; of this, approximately 600 acres need drainage. Information gathered in this research indicates that the main sources of ground water are:

1. Water lost in sinks or faults near the sources of mountain streams, northeast of the water-logged lands.
2. Deep percolation water losses from excessive irrigation of the upper lands.

The first work consisted of putting down test holes to obtain profiles of the water table. From these profiles the depth and slope of the water table and the direction of the flow of the ground water were determined.

Two 3-inch test wells were then put down to obtain information about the soil formation of the area and to determine the feasibility of drainage by pumping. The average quantity of water pumped from well No. 1 was 30 g.p.m.; from well No. 2 the average was 25 g.p.m. Piezometers were installed to measure drawdown at various distances from each well. Permeability was calculated for each area using Equation 1.

The information obtained at these two test wells indicated that it would be impossible to get a large flow of water at either location. However, the effectiveness of lowering the water table could be determined only by experimenting.

Drilling of the 8-inch gravel envelope well was started on April 14,

1948. A 20-inch bit was connected to the string of tools for the drilling operations. The bit churned up the soil material and water, and a bailer was used to remove this mixture. To drive the outside casing, which was 24 inches inside diameter, a driving head of 1500 pounds was dropped at an average height of 3 feet. Blue clay was reached at a depth of 33 feet. The outside casing was driven to a depth of 35 feet, and drilling was stopped at a depth of 38 feet. The inside casing, which was 8-inch diameter black pipe, was installed and bottom rested on the gravel at a depth of 33 feet below the ground surface. The lower 16 feet of the 8-inch casing was pre-perforated with 5/32 x 3/2-inch slots. Gravel was placed in layers of approximately 6-foot depths, in the annular ring between the two casings, at different intervals. After placing each gravel layer, the outside casing was jacked back a length of 6 feet. Each 6-foot section of the well was developed by pumping, surging and bailing.

The process of gravel packing, jacking back the outside casing, and developing was continued until 13 feet of the outside casing remained as part of the completed well. The remaining space in the annular ring was filled with gravel and development by pumping, surging and bailing was continued.

In the development work three methods were used: namely, pilot gravel tubes, surging and bailing, and backwashing.

Initial pumping was with a 5 hp. submersible pump, which was lowered to approximately 2 inches from the bottom of the 8-inch casing. During this initial pumping two complete tests were made at different drawdowns and discharges. A turbine pump was then installed and three drawdown-discharge tests were made each week for 3 weeks. The discharge for the first week of pumping was approximately 20 g.p.m. However, the discharge gradually decreased during the first month to approximately 16 g.p.m.

This rate has been maintained to date at a drawdown of approximately 20.5 feet.

The effect of pumping on the water table has been small except in the area very close to the well.

The permeability at well No. 3 was lower than at wells No. 1 and No. 2 as shown by the following values:

Well No.	Permeability - ft./sec.
1	9×10^{-5}
2	20×10^{-5}
3	3×10^{-5}

The effectiveness of a well can be ascertained by an application of the equilibrium formulas for determining permeability. The average effectiveness of well No. 3 was found to be 19.2 percent.

Using certain assumed values and reducing capital costs to annual costs, the cost of drainage, using well No. 3, was $10.02 per acre per year.

The author's recommendations for further work in the area briefly summarized are:

1. Drill more test wells.
2. Locate and map existing drains.
3. Check condition and effectiveness of existing drains.
4. Measure the water delivered to upper lands from mountains.
5. Build reservoirs to store spring run-off.
6. Reduce the amounts of water applied in early irrigation of upper lands.

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(2) Christiansen, J. E. Some permeability characteristics of saline and alkali soils. Agr. Engr. 28 (4): 147-150. Apr. 1947.

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(4) Fitzgerald, J. W. One hundred years of education in a Utah community. Unpublished manuscript. Palo Alto, Calif.: Graduate School of Education, Stanford University, 1948.

(5) Israelsen, O. W. Irrigation principles and practices. New York: John Wiley & Sons, 1932.

(6) Israelsen, O. W. Pumping ground water has twin benefits. Farm & Home Science. 8 (3): 1 . Sept. 1947.

(7) Jessop, L. T. The discharge of drains serving irrigated lands. U. S. Dept. Agr. Bureau of Agr. Engr., 1933.

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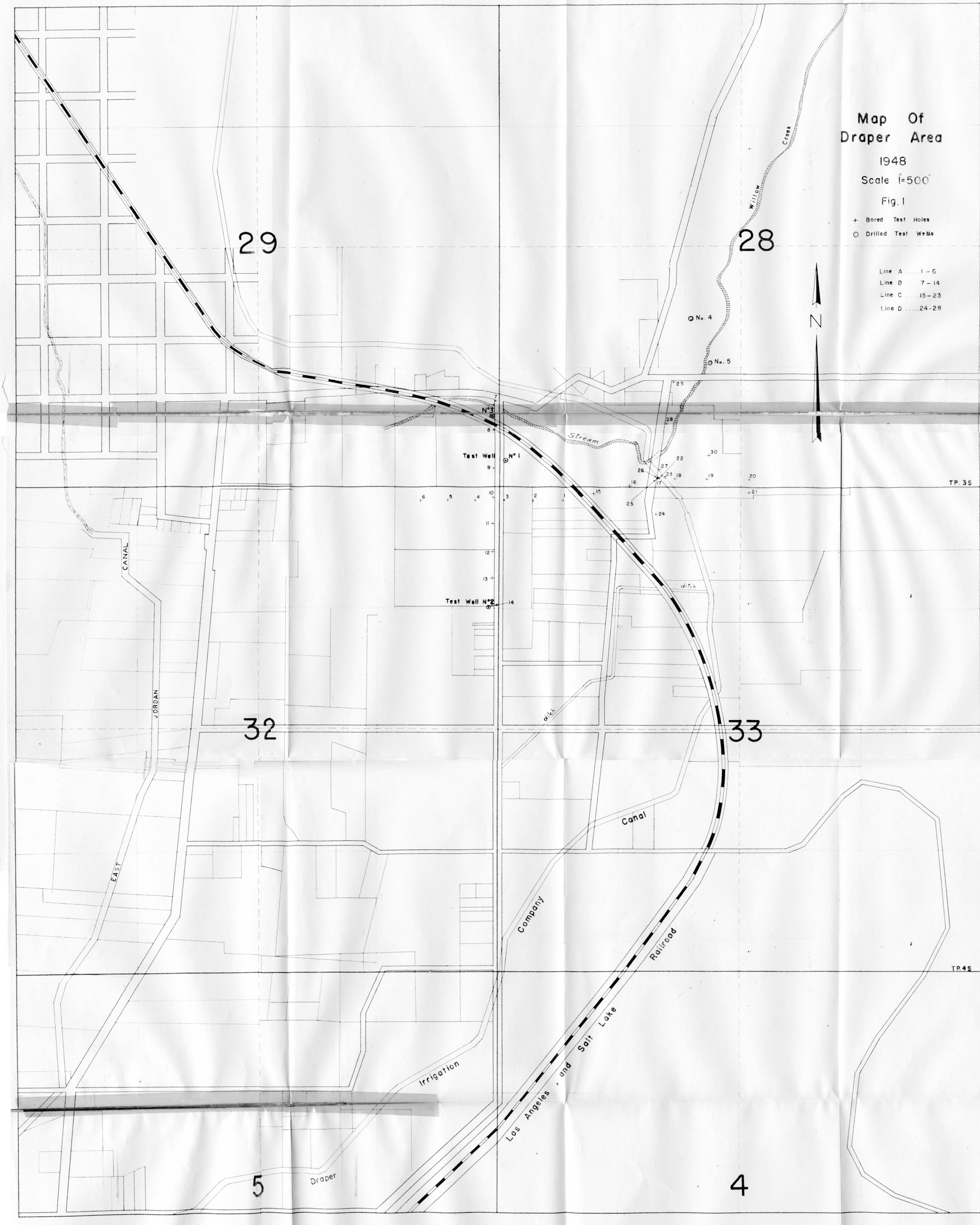
(12) Rohwer, Carl. Putting down and developing wells for irrigation. U. S. Dept. Agr. Circular 546. 1940.

(13) Tolman, C. F. Ground water. New York: McGraw-Hill Book Co., 1937.

(14) Wenzel, L. K. Methods of determining permeability of water-bearing materials. U. S. Geological Survey, Water Supply Paper 887. 1942.

FIGURES


Map Of
Draper Area
1948
Scale 1"=500'
Fig. 1
+ Bored Test Holes
○ Drilled Test Wells
Line A ..... 1 - 6
Line B ..... 7 - 14
Line C ..... 15 - 23
Line D ..... 24 - 28
N
29
28
32
33
5
4
TP. 3S
TP. 4S
Willow Creek
Stream
No. 4
No. 5
No. 3
Test Well No. 1
Test Well No. 2
ditch
Canal
East Jordan Canal
Company
Irrigation
Draper
Los Angeles, and Salt Lake Railroad

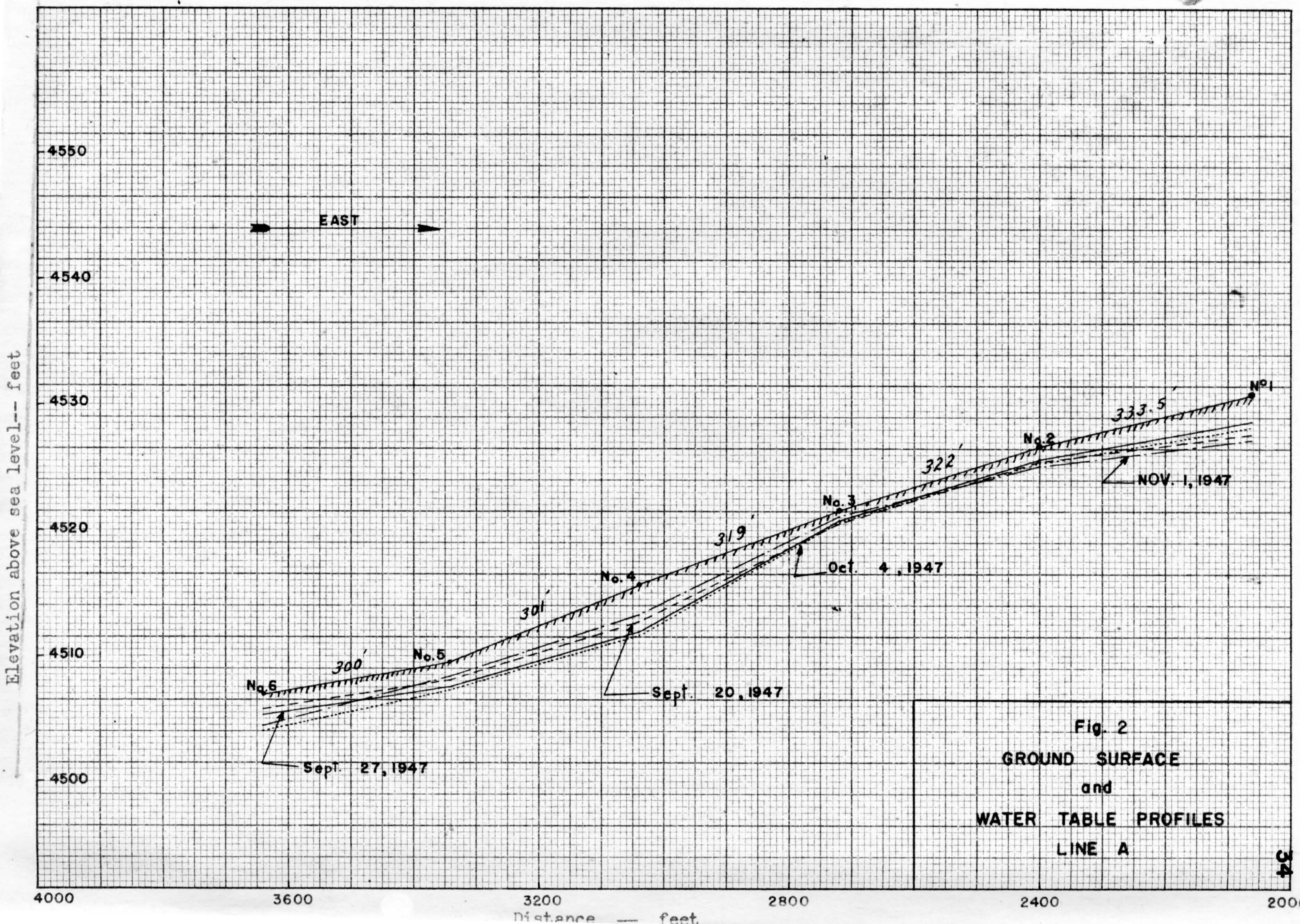


Fig. 2
GROUND SURFACE
and
WATER TABLE PROFILES
LINE A

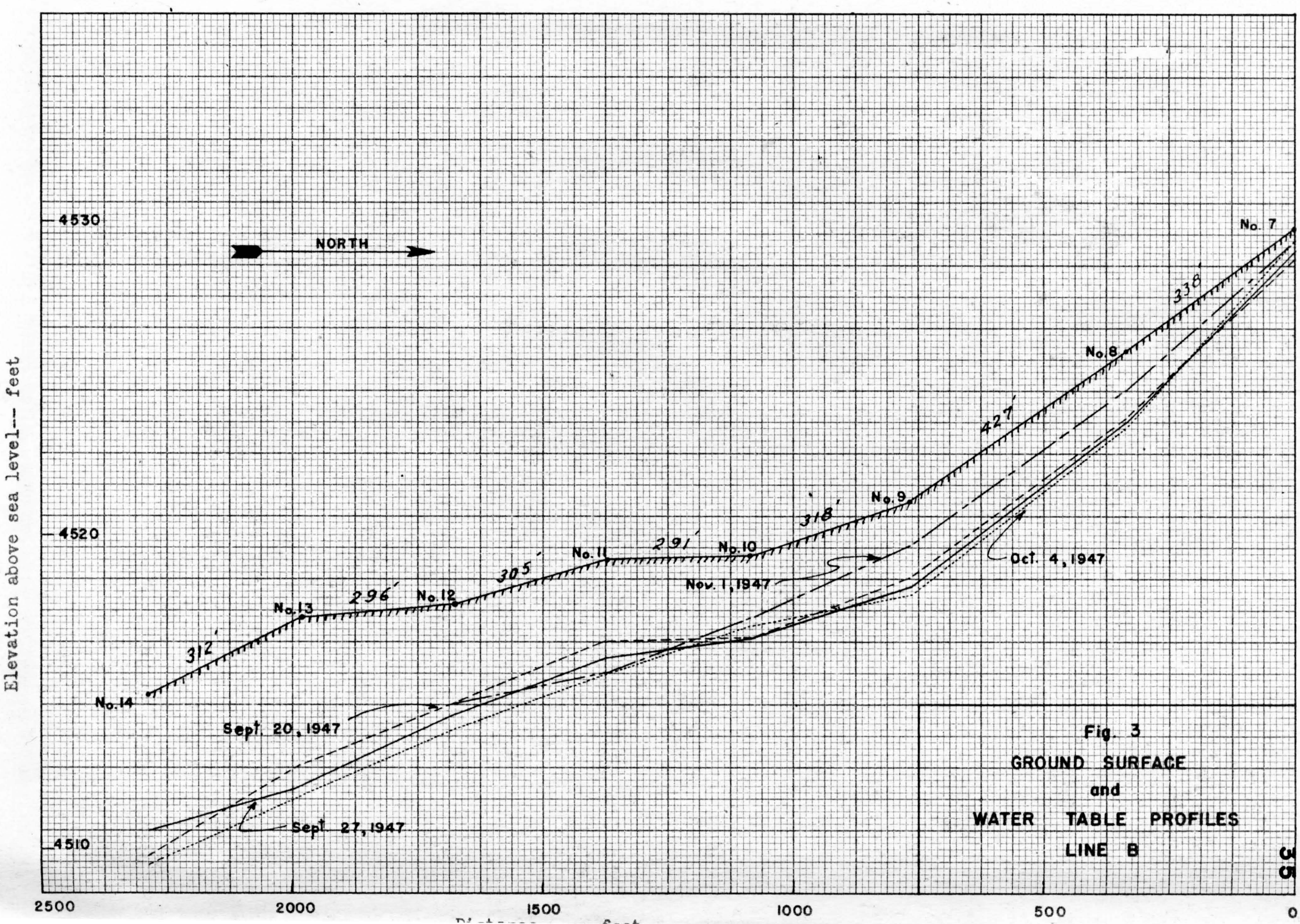


Fig. 3
GROUND SURFACE
and
WATER TABLE PROFILES
LINE B

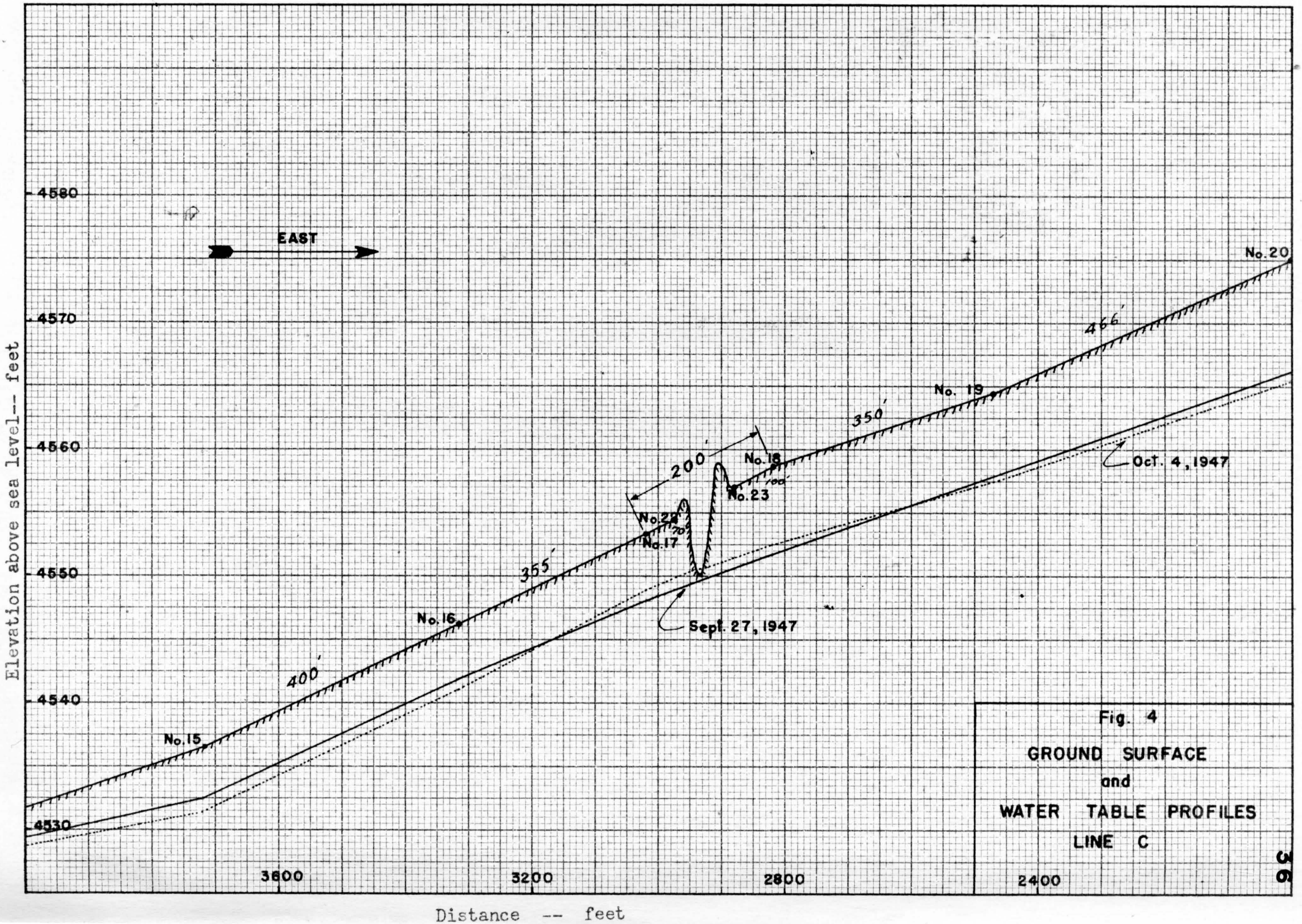


Fig. 4

GROUND SURFACE and WATER TABLE PROFILES LINE C

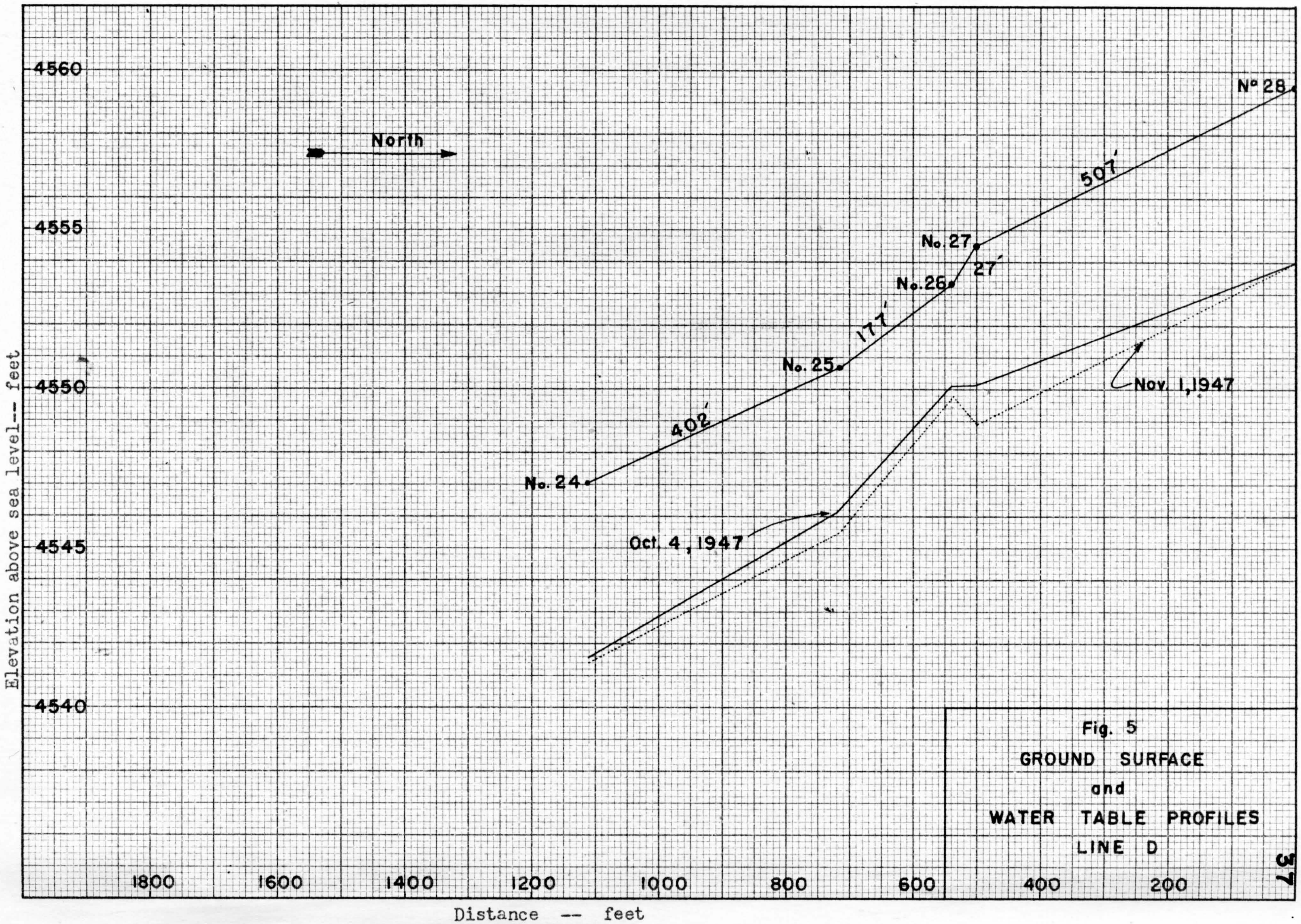


Fig. 5
GROUND SURFACE
and
WATER TABLE PROFILES
LINE D

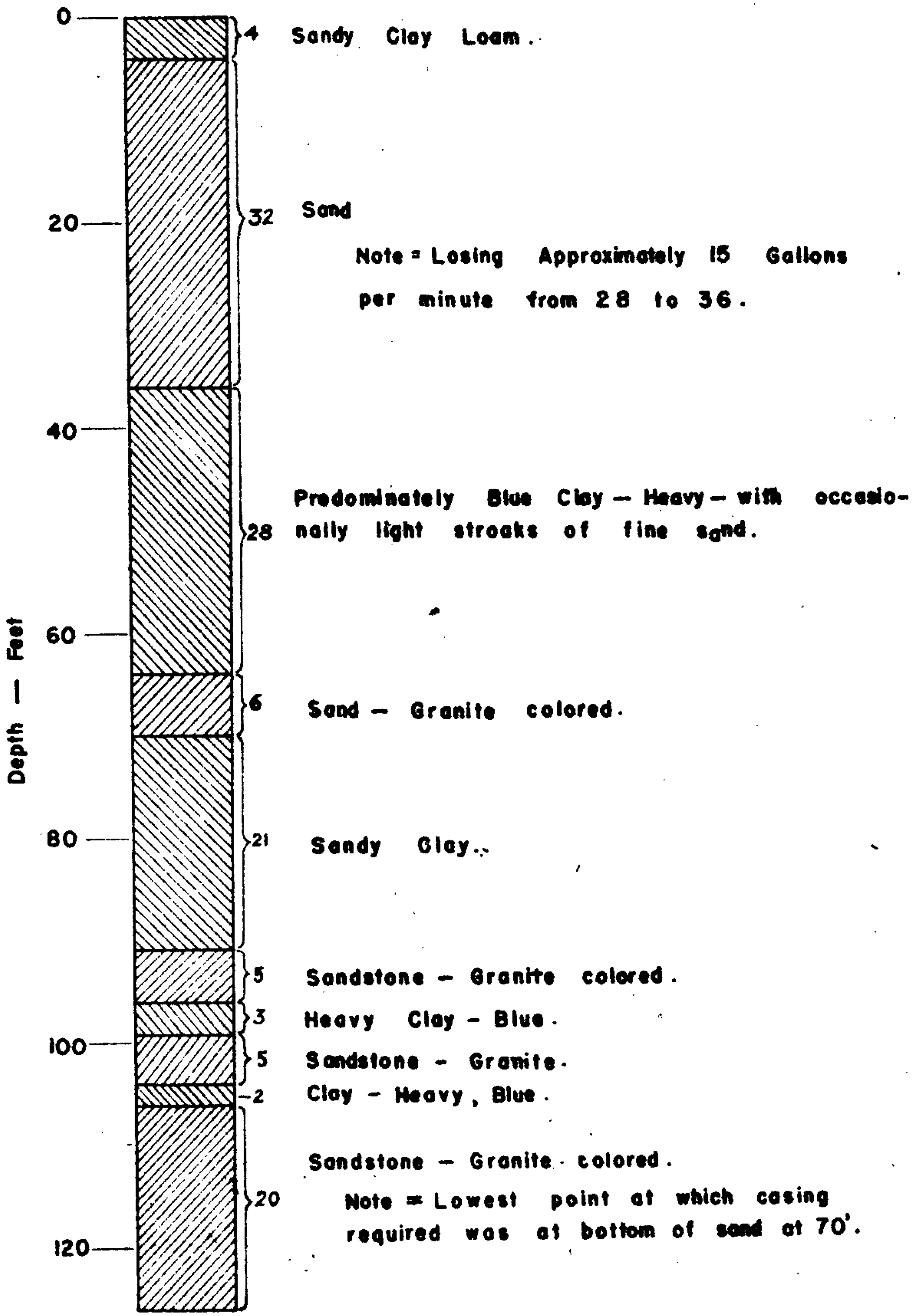


Fig. 6
TEST WELL — No. 1-LOG
Draper area, Utah
Nov. 1947
Scale 1" = 15'

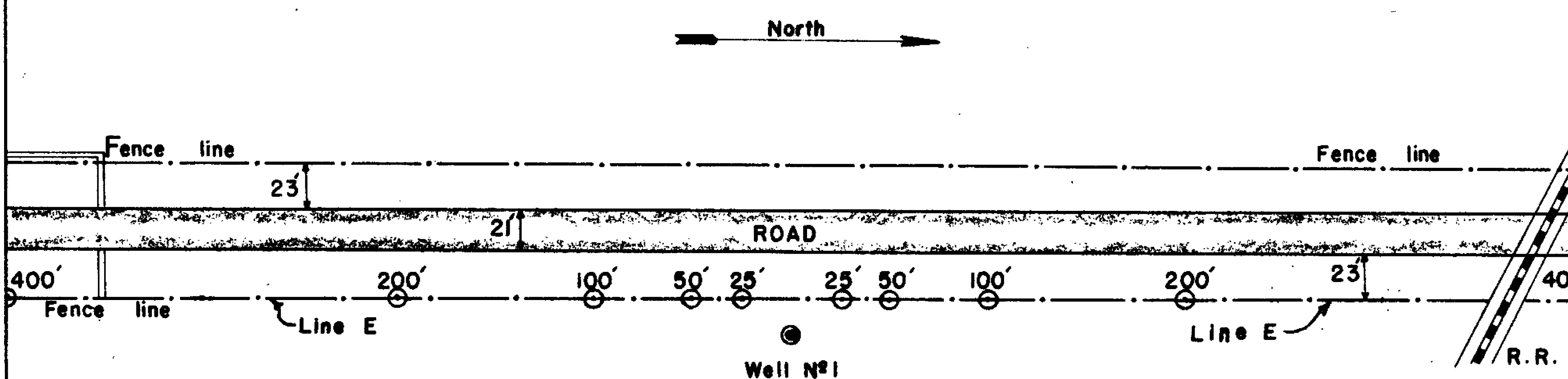


Fig. 7
PIEZOMETER LOCATION

TEST WELL No 1

● - Indicates a set of 2 piézometers

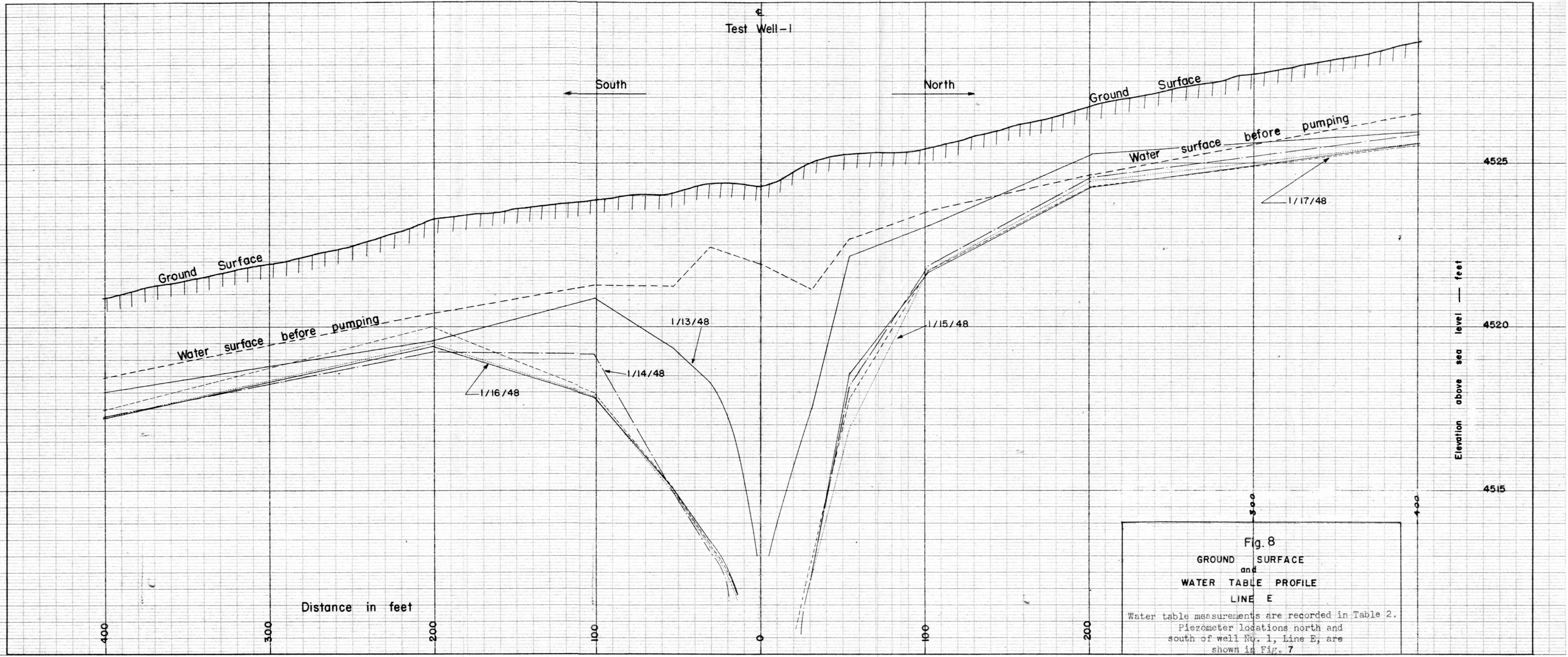
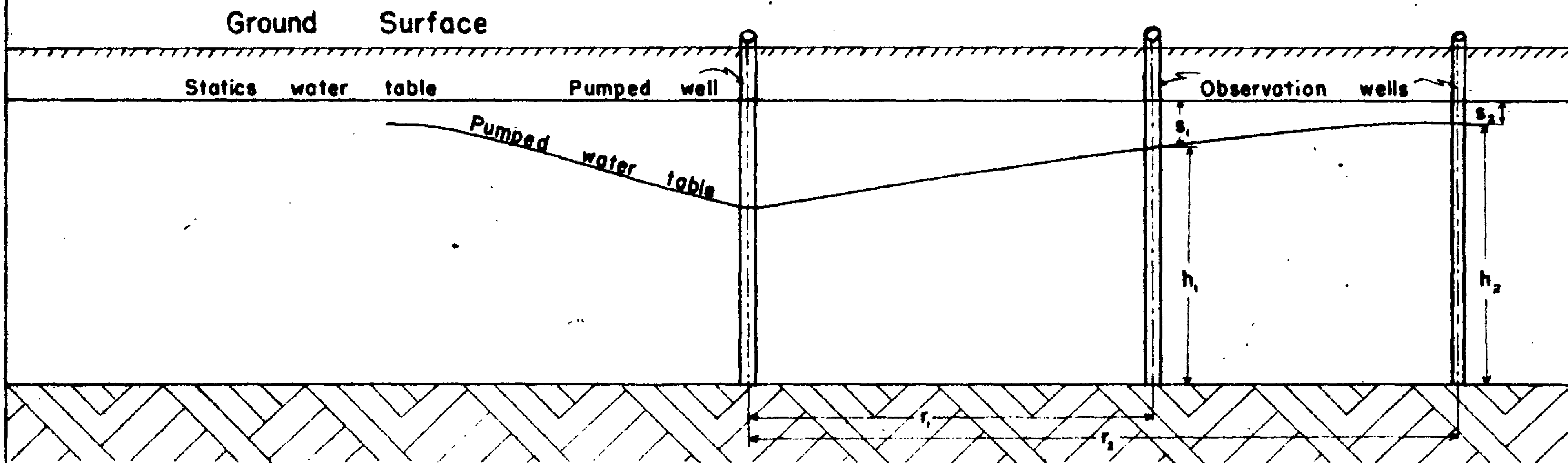


Fig. 8
GROUND SURFACE and WATER TABLE PROFILE
LINE E

Water table measurements are recorded in Table 2. Piezometer locations north and south of well No. 1, Line E, are shown in Fig. 7



$$Q = \frac{\pi k (h_2^2 - h_1^2)}{\log_e \frac{r_2}{r_1}} \qquad \text{From which} \qquad k = \frac{Q \log_e \frac{r_2}{r_1}}{\pi (h_2 + h_1)(s_1 - s_2)}$$

Q = Discharge of pumped well.

k = Coefficient of permeability.

r_1 and r_2 = Distances from pumped well to two observation wells.

h_1 and h_2 = Depth of water in two observation wells during pumping.

s_1 and s_2 = Length of drawdown in the observation wells.

Note: The units for the above symbols are given under equation 1.

Fig. 9

Pumping from Surface Stratum

Fig. 10 Examining Material at Test Well No. 2

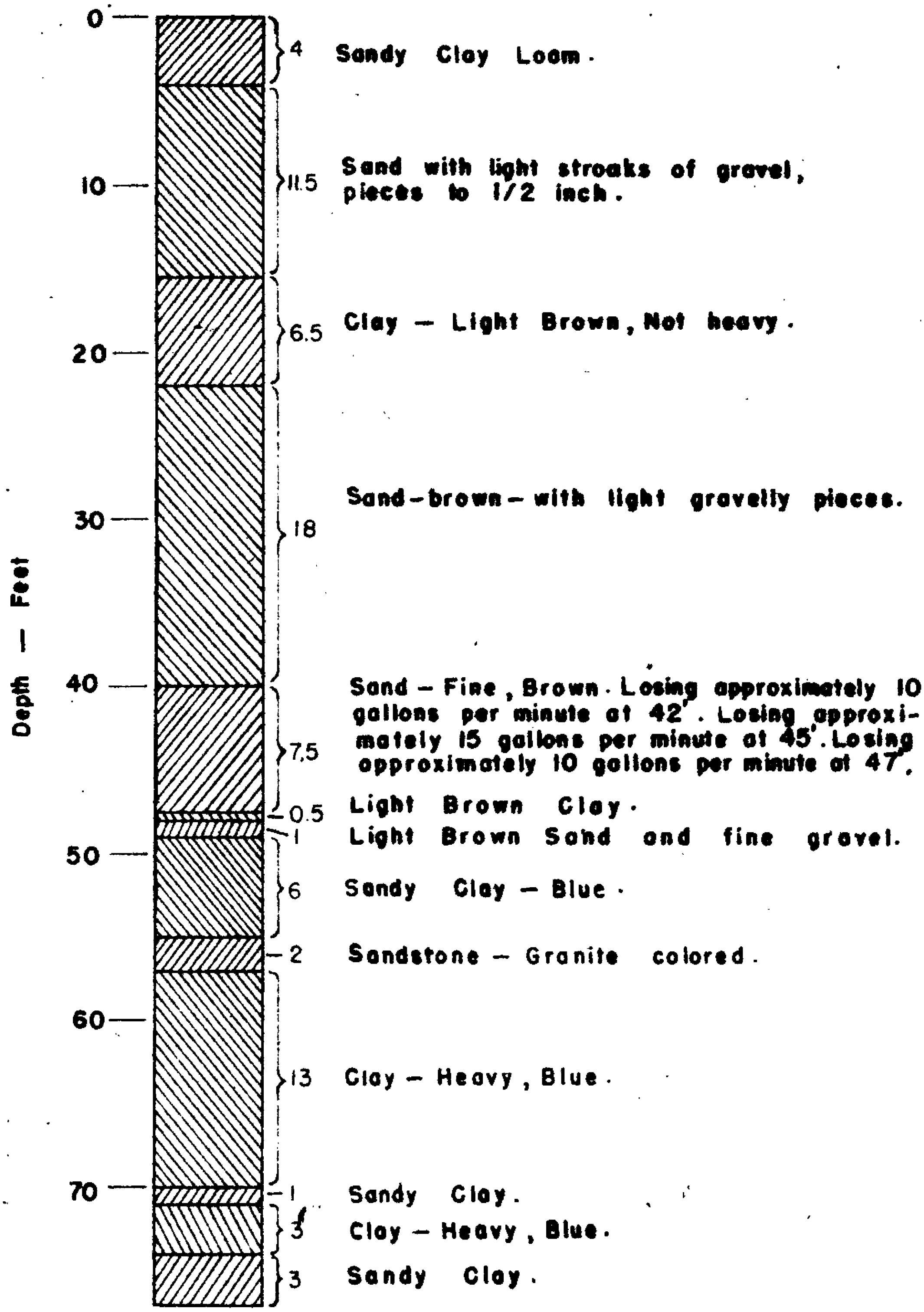


Fig. 11
TEST WELL-No. 2-LOG
Draper area, Utah
Nov. 1947
Scale 1"=10'

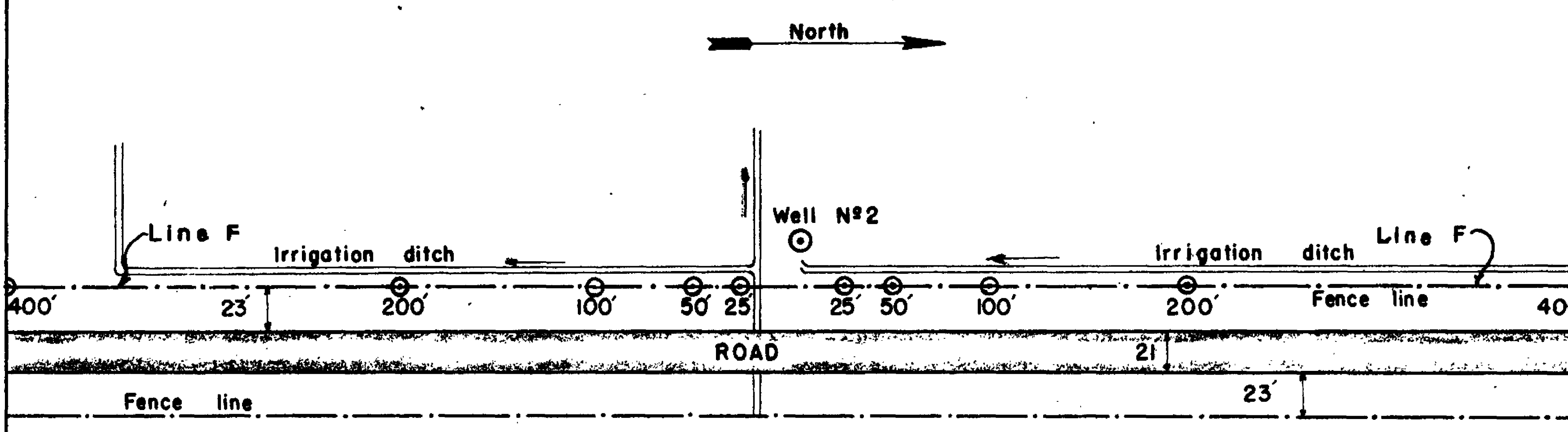


Fig. 12
PIEZOMETER LOCATION
TEST WELL Nº 2

⊖ - Indicates a set of 2 piezometers.

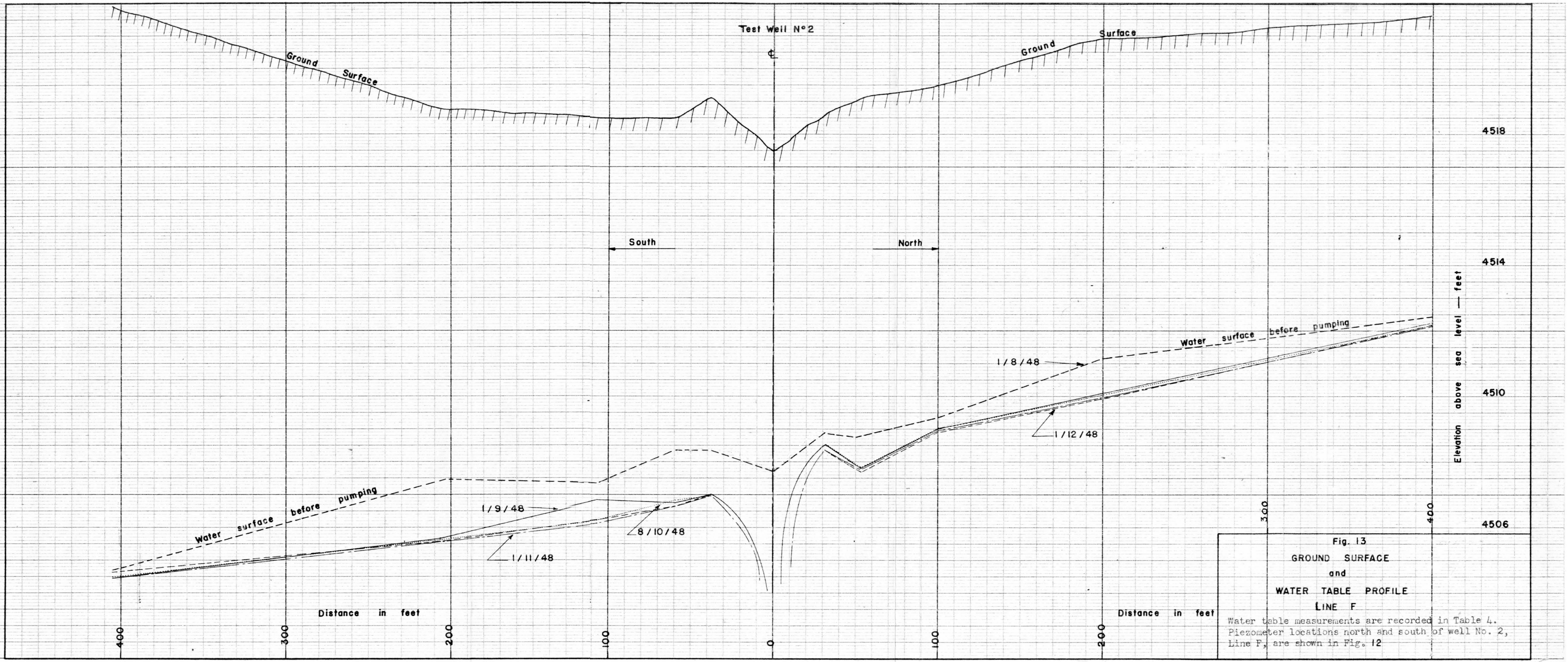


Fig. 13
GROUND SURFACE
and
WATER TABLE PROFILE
LINE F

Water table measurements are recorded in Table 4. Piezometer locations north and south of well No. 2, Line F, are shown in Fig. 12

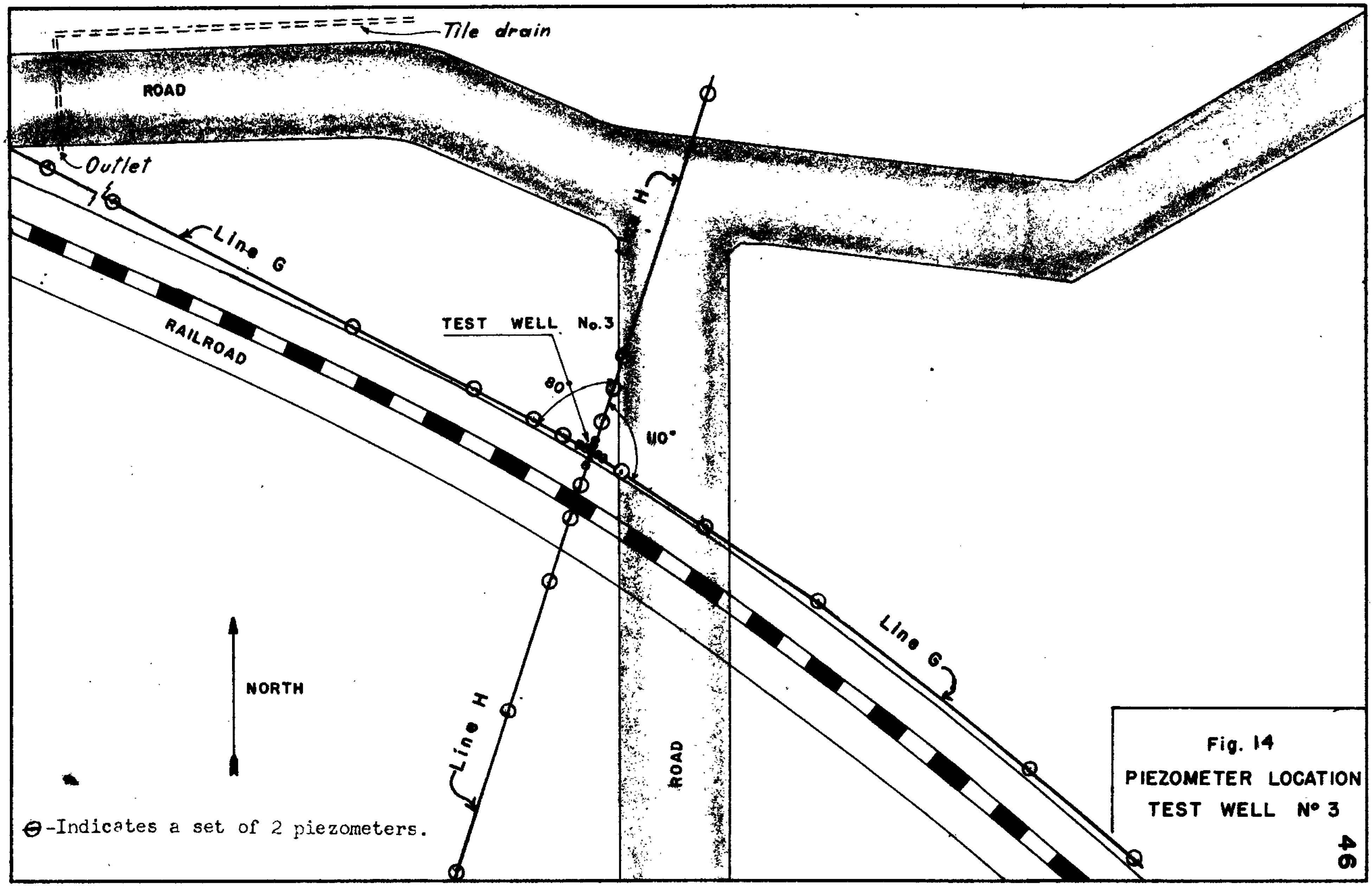


Fig. 14
PIEZOMETER LOCATION
TEST WELL Nº 3

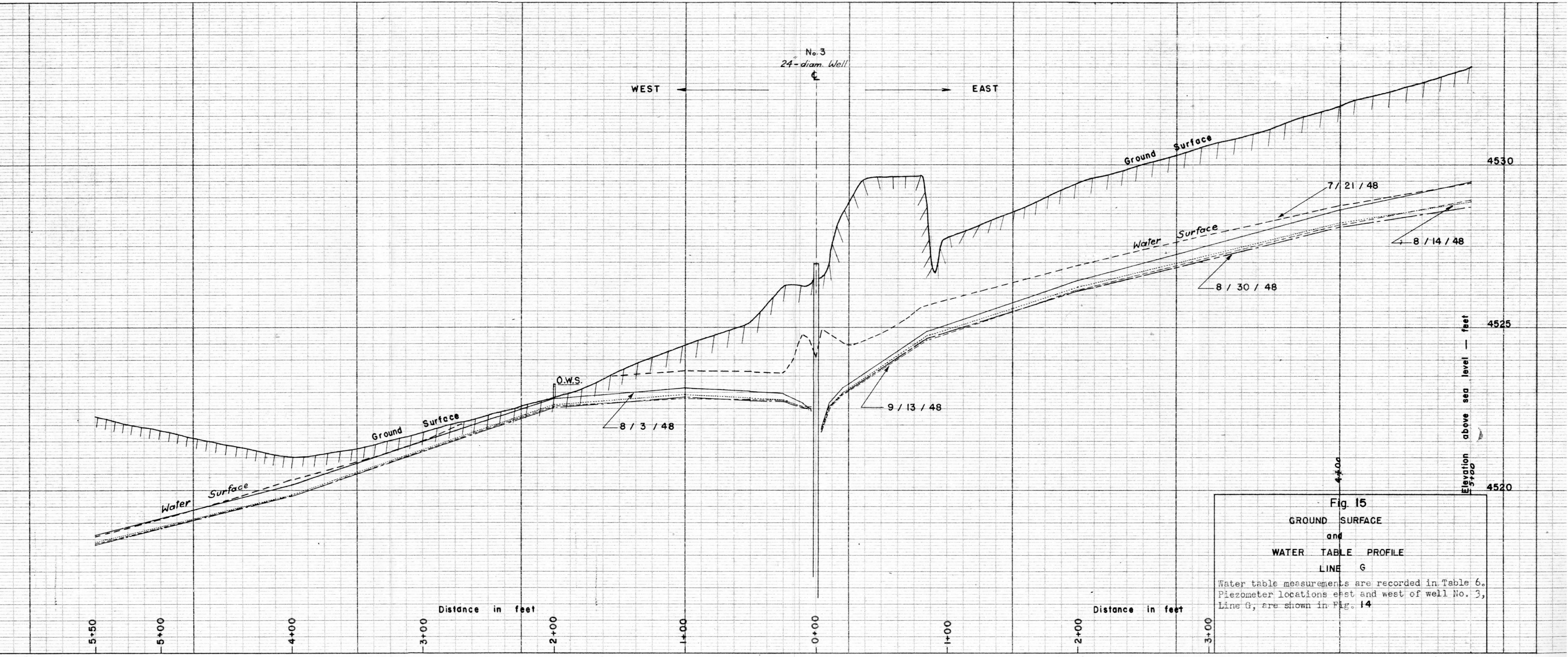


Fig. 15
GROUND SURFACE
and
WATER TABLE PROFILE
LINE G

Water table measurements are recorded in Table 6. Piezometer locations east and west of well No. 3, Line G, are shown in Fig. 14

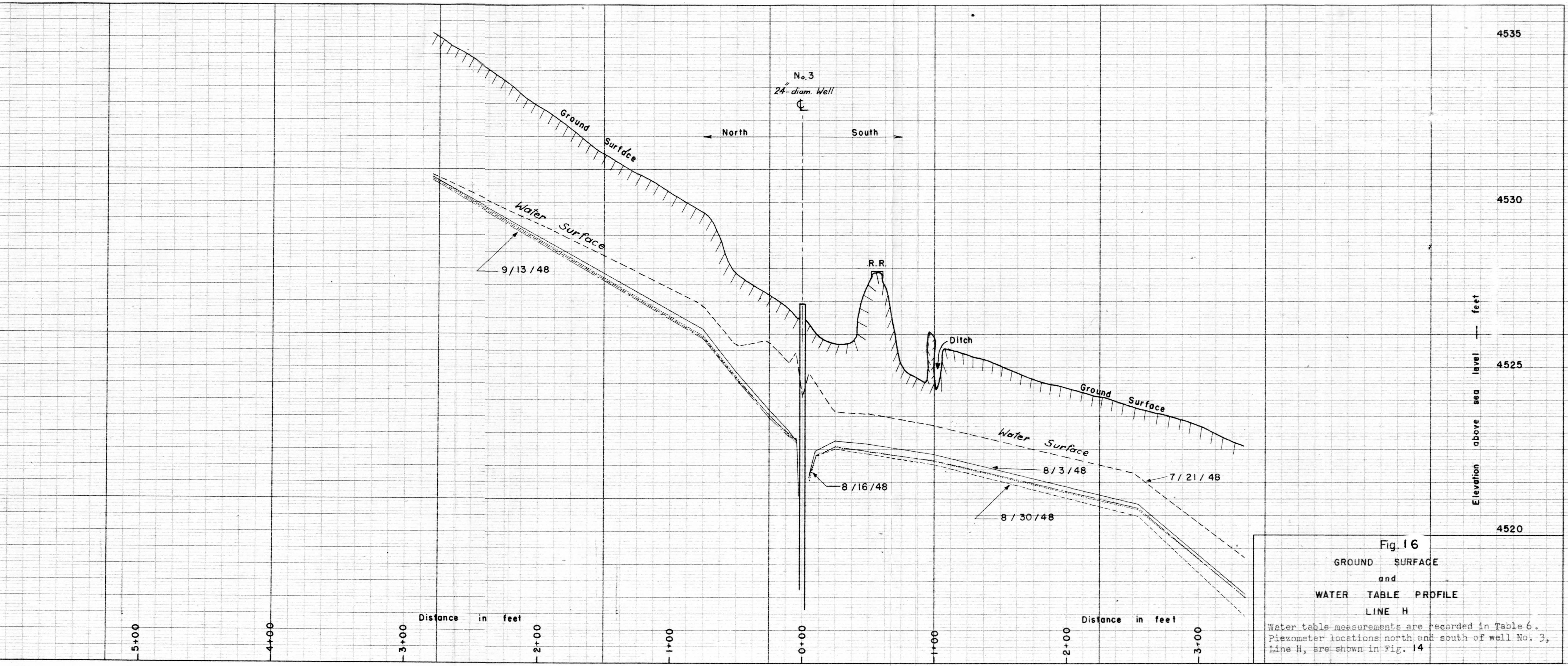


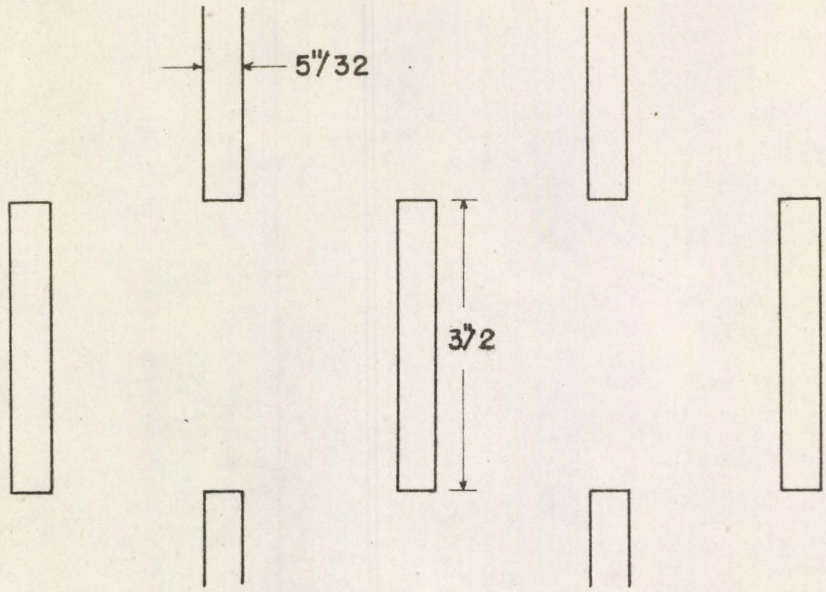
Fig. 16
GROUND SURFACE
and
WATER TABLE PROFILE
LINE H

Water table measurements are recorded in Table 6. Piezometer locations north and south of well No. 3, Line H, are shown in Fig. 14

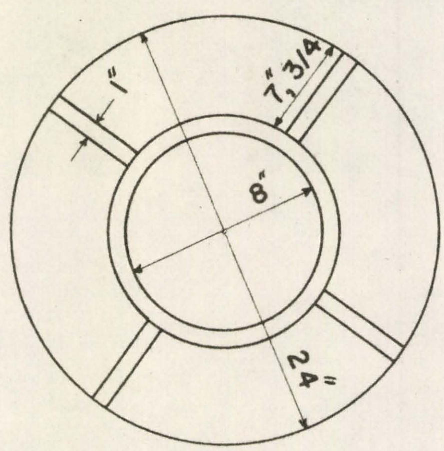
Fig. 17 Taking Piezometer Readings Near Well No. 3

Fig. 18 Spacers Welded to 8-inch
Casing

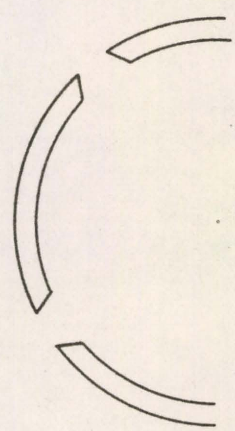
Fig. 19 Perforated 8-inch Casing
Showing Perforations and Plate
Welded at Bottom



Templet for perforating
8-inch casing



View showing spacers
on 8" casing inside
24" casing



Top view of perforation

Fig. 20
DESIGN SHOWING
DETAILS FOR PERFORATING 8"
CASING AND SPACER ARRANGEMENT

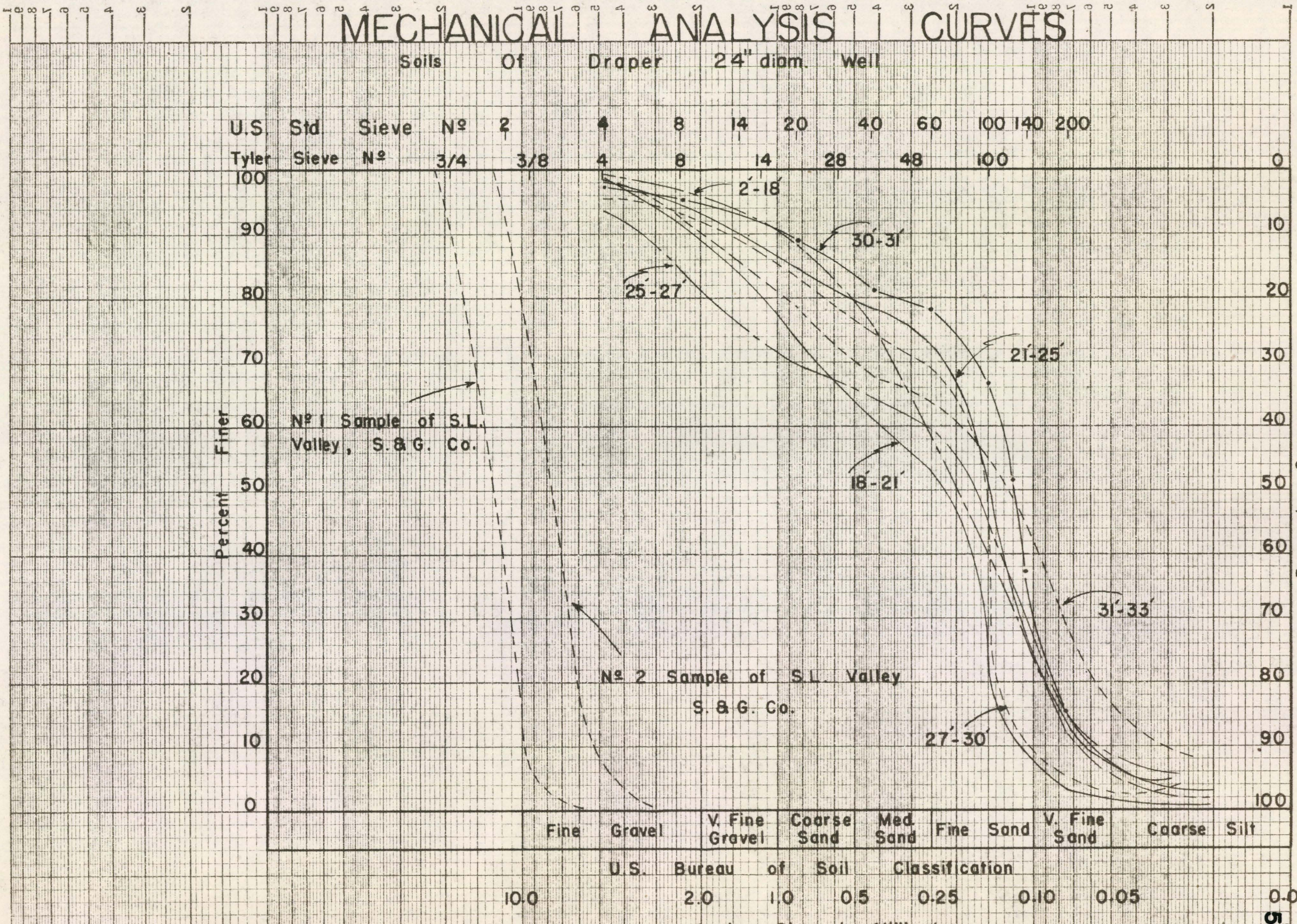

MECHANICAL ANALYSIS CURVES
Soils Of Draper 24" diam. Well
U.S. Std. Sieve No 2 4 8 14 20 40 60 100 140 200
Tyler Sieve No 3/4 3/8 4 8 14 28 48 100
Percent Finer
Percent Coarser
2'-18'
30'-31'
25'-27'
21'-25'
No 1 Sample of S.L. Valley, S.&G. Co.
18'-21'
31'-33'
No 2 Sample of S.L. Valley S.&G. Co.
27'-30'
Fine Gravel
V. Fine Gravel
Coarse Sand
Med. Sand
Fine Sand
V. Fine Sand
Coarse Silt
U.S. Bureau of Soil Classification
10.0
2.0
1.0
0.5
0.25
0.10
0.05
0.01
Grain Size in Millimeters

Fig. 21

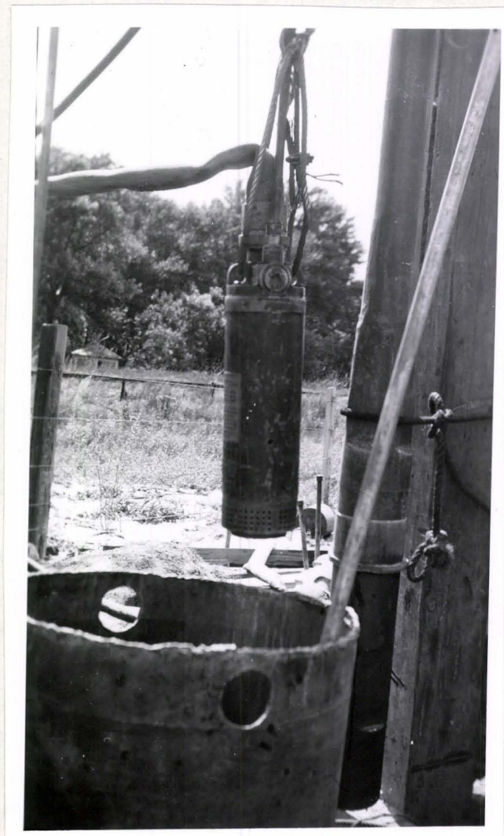


Fig. 22 Submersible Pump Ready to be Lowered into Well No. 3

Fig. 23A The 20-inch Bit Being Raised From Well

Fig. 23B The 20-inch Bit Being Connected to Drilling Tool

Fig. 24A Bailer Being Raised From Well

Fig. 24B Bailer Being Dumped

Fig. 25A Driving Head on the 24-inch Casing

Fig. 25B Driving Head Ready to Drop

Fig. 26 Drilling in Progress

Fig. 27 Jacking Back 24-inch
Casing

Fig. 28 Surge Block Used for
Developing Well

Fig. 29 Installing the 5-inch Pilot
Tube by Jetting and Driving

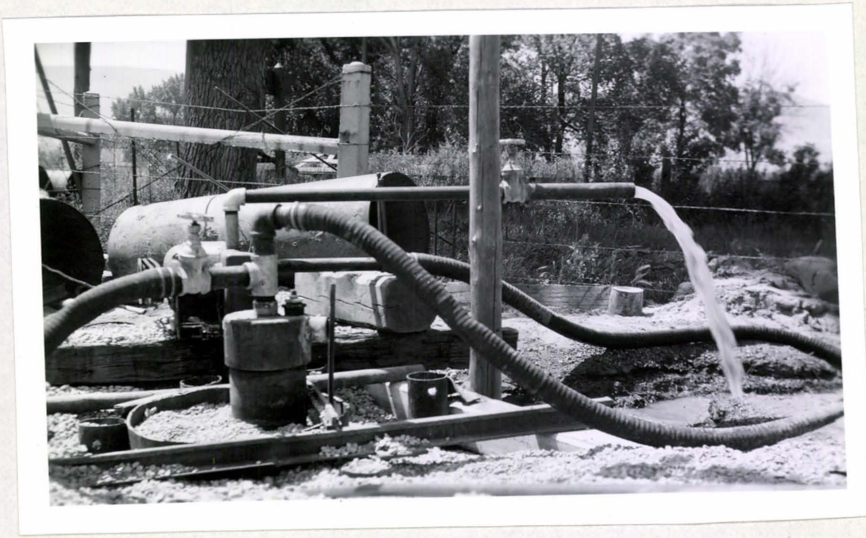


Fig. 30 Backwashing by Pumping out of Well

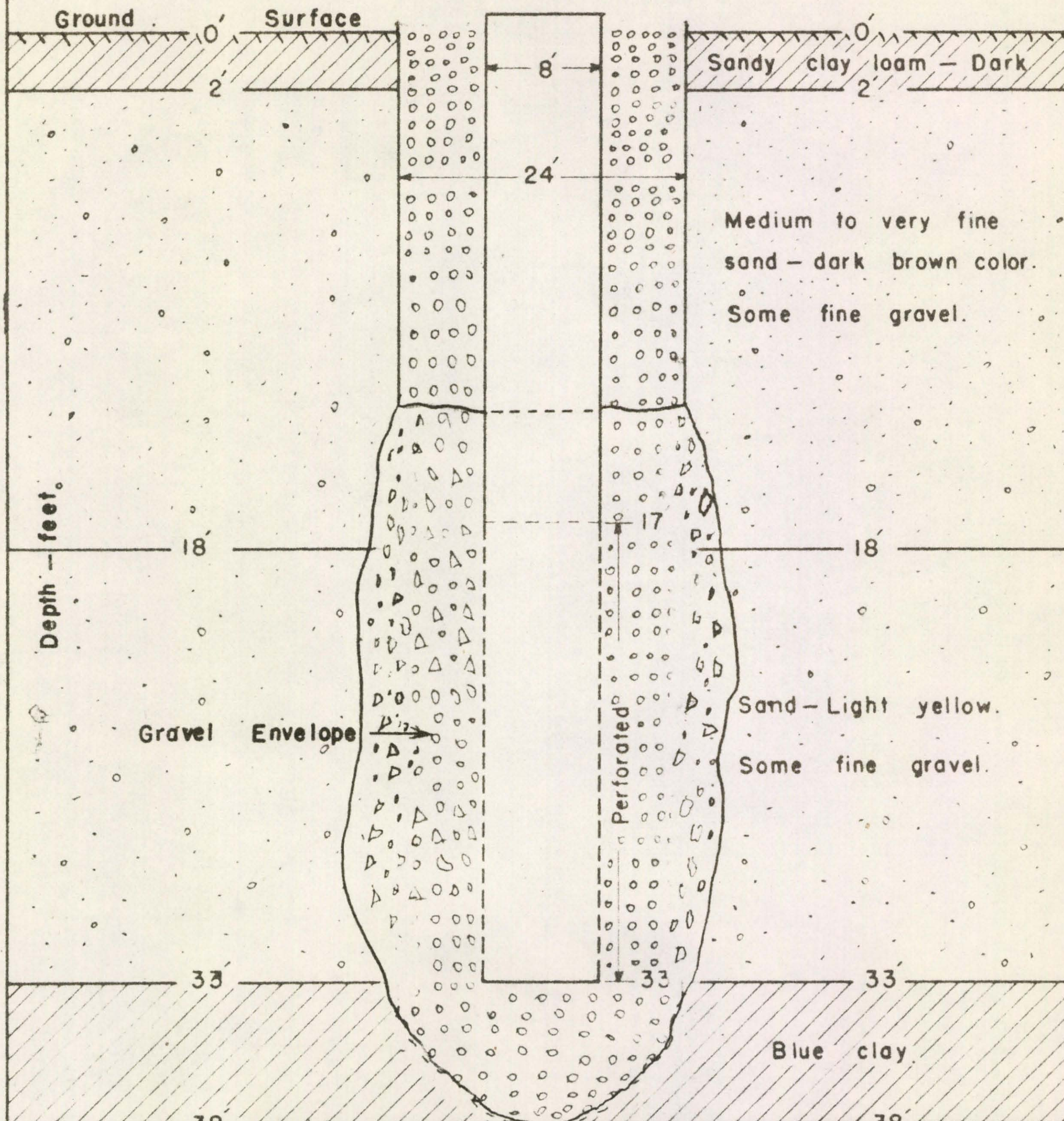


Fig. 31
WELL No. 3
24-inch Experimental Well
Draper area, Utah
April, 1948
Scale 1" = 6'

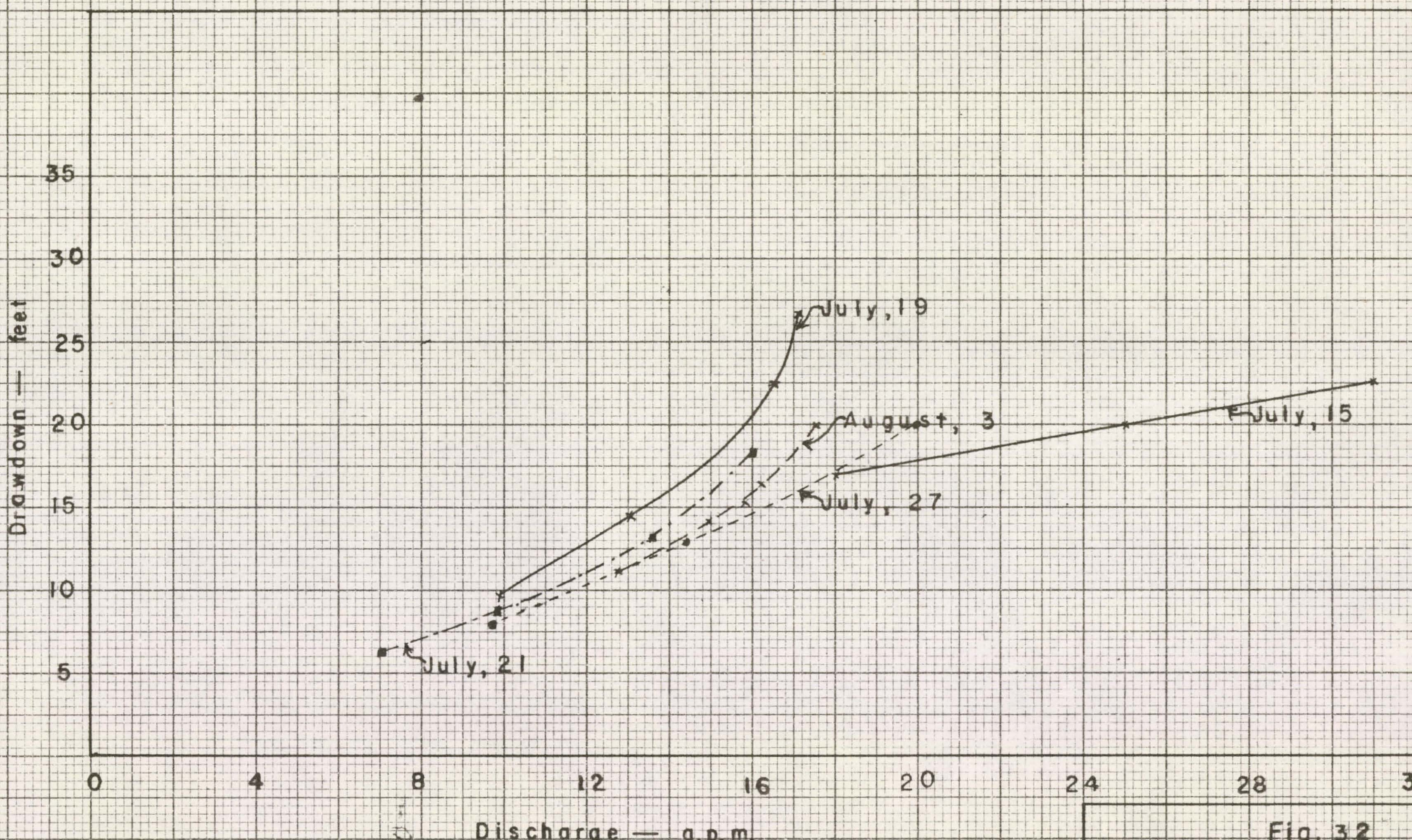


Fig. 32

Drawdown — Discharge Curves

1948

Test Well No. 3

Fig. 33A Adjusting Bowls of
New Turbine Pump

Fig. 33B Testing New Turbine Pump

TABLES

Table 1. Water table depths measured in feet at different time period - 1947

Test Hole	Dates of measurement			
	September 20	September 27	October 4	November 1
1	3.0	2.0	2.6	3.4
2	0.8	0.9	1.1	1.0
3	1.2	0.8	0.9	0.3
4	2.9	3.8	4.0	3.7
5	1.7	1.8	2.2	2.0
6	1.5	1.7	2.4	1.6
7	1.2	1.0	0.9	0.7
8	2.1	2.3	2.4	1.5
9	2.3	2.8	2.8	1.2
10	2.3	2.3	2.2	2.0
11	2.5	3.1	3.3	3.8
12	3.2	3.7	---	---
13	4.9	5.5	---	---
14	4.8	4.5	---	---
15	Drilled on Sept. 27	3.8	---	---
16		4.1	---	---
17		4.6	4.5	5.1
18		6.7	6.4	---
19		6.7	7.0	---
20		8.6	9.2	---
21		8.1	11.0	---
22	Drilled on Oct. 4		4.8	---
23			6.0	---
24			5.8	---
25			4.5	5.1
26			3.5	3.7
27			4.4	5.2
28			5.5	---
29			dry at 12 feet	
30			8.1	---
31			Rocks at 10 feet - dry	

Table 2. Elevations of the ground surface and ground water surface, north and south of well No. 1, in feet above mean sea level - 1948

Station	Length of pipe in feet	Date / Elevation ground surface	January 6	January 13	January 14	January 15	January 16	January 17
			Ground water surface elevation					
North 25	14	4525.0	4521.8	4518.4	4514.8	4514.8	4514.3	4514.7
	32		21.1	17.5	12.3	12.3	12.3	12.8
50	14	25.3	22.9	22.3	21.4	21.2	21.3	21.1
	32		22.7	22.2	18.2	16.9	18.6	17.8
100	14	25.5	22.8	23.3	22.9	22.6	22.4	22.5
	32		23.5	23.1	21.8	21.7	21.7	21.7
200	14	26.8	24.9	24.5	24.4	24.3	24.4	24.2
	32		24.6	25.3	24.6	24.4	24.2	24.3
400	14	28.8	26.7	26.0	26.0	25.9	26.0	26.0
	32		26.5	25.9	25.9	25.6	25.6	25.6
South 25	14	24.4	22.2	17.8	13.9	14.7	14.7	14.3
	32		22.4	18.3	13.1	13.3	13.5	13.4
50	14	24.1	20.8	17.2	13.4	13.9	13.8	13.1
	32		21.2	19.3	15.0	15.0	15.1	15.7
100	14	24.0	22.1	21.5	20.3	18.3	17.7	17.8
	32		21.3	20.9	19.2	17.9	17.8	18.0
200	14	23.3	20.9	20.4	20.9	21.4	21.6	21.7
	32		20.4	19.8	19.2	19.5	19.4	20.0
400	14	22.0	19.9	19.4	19.5	19.8	20.3	20.2
	32		18.5	18.0	17.3	17.2	17.2	17.5

Table 3. Elevations above datum and drawdowns at different distances from well No. 1 during pumping used in calculating the permeability of the soil. An average discharge of 0.07 c.f.s. was used for all calculations

Horizontal distance from axis of well feet		Height of drawdown curve above datum plane - feet		Distance from water surface before pumping, to drawdown curve -- feet		Permeability of soil formation ft./sec.
r_1	r_2	h_1*	h_2*	S_1*	S_2*	k
25	50	21.68	26.22	10.32	5.78	7×10^{-5}
25	100	21.68	29.44	10.32	2.56	8×10^{-5}
25	200	21.68	31.63	10.32	0.37	9×10^{-5}
50	100	26.22	29.44	5.78	2.56	9×10^{-5}
50	200	26.22	31.63	5.78	0.37	10×10^{-5}
100	200	29.44	31.63	2.56	0.37	11×10^{-5}
					Average	9×10^{-5}

*Values recorded are the average of the north and south piezometers. The 32-foot piezometer readings were used. The readings at r_2 - 400 gave negative values for (S_1-S_2) so they were not used. The symbols are described in Fig. 9 .

Assumptions: (1) That the original water surface and clay layer are parallel.

(2) That the thickness of the saturated material is 32 feet.

Table 4. Elevations of the ground surface and ground water surface, north and south of well No. 2, in feet above mean sea level - 1948

Station	Length of pipe in feet	Date elevation ground surface	January 8	January 9	January 10	January 11	January 12
			Ground water surface elevation				
North 25	14	4518.5	4508.1	4507.8	4507.8	4507.7	4507.6
	32		08.9	08.5	08.5	08.5	08.4
50	14	19.1	08.4	08.0	08.0	07.9	07.9
	32		08.8	07.8	07.8	07.8	07.7
100	14	19.5	08.9	08.5	08.6	08.5	08.4
	32		09.4	09.0	09.0	09.0	08.9
200	14	20.4	09.6	09.5	09.5	09.4	09.4
	32		11.2	10.1	10.0	10.0	09.9
400	14	21.6	12.4	12.5	12.5	12.4	12.5
	32		12.4	12.3	12.2	12.2	12.2
South 25	14	19.1	07.3	07.1	07.1	07.0	06.9
	32		07.3	07.0	07.0	07.0	06.8
50	14	18.5	06.8	06.7	06.6	06.5	06.5
	32		07.3	06.8	06.8	06.6	06.6
100	14	18.5	06.2	06.1	06.1	06.0	06.0
	32		06.3	06.9	06.2	06.1	06.2
200	14	18.7	05.5	05.5	05.4	05.4	05.4
	32		06.4	05.7	05.6	05.6	05.6
400	14	19.1	Dry	---	---	---	---
	32		04.8	04.5	04.5	04.5	04.6

Table 5. Elevations above datum and drawdowns at different distances from well No. 2 during pumping used in calculating the permeability of the soil. An average discharge of 0.05 c.f.s. was used for all calculations

Horizontal distance from axis of well feet		Height of drawdown curve above datum plane - feet		Distance from water surface before pumping, to drawdown curve - feet		Permeability of soil formation ft./sec.
r_1	r_2	h_1*	h_2*	S_1*	S_2*	k
25	50	24.55	30.62	7.45	1.38	3×10^{-5}
25	100	24.55	31.19	7.45	0.81	6×10^{-5}
25	400	24.55	31.82	7.45	0.18	1×10^{-4}
50	100	30.62	31.19	1.38	0.81	3×10^{-4}
50	400	30.62	31.82	1.38	0.18	5×10^{-4}
					Average	2×10^{-4}

* Averages of the north and south piezometers. The 32 foot piezometer readings were used. The piezometer reading r_2 = 200 ft. gave a negative value for (S_1-S_2) so it was not used. The symbols are described in Fig. 9.

Assumptions: (1) That the original water surface and clay layer are parallel.

(2) That the thickness of the saturated material is 32 feet.

Table 6. Elevations in the 14-foot piezometers of the ground water surface in the four directions from well No. 3; feet above mean sea level - 1948

Station Direction	Station Distance feet	July 21*	July 26	Aug. 3*	Aug. 9	Aug. 16*	Aug. 23	Aug. 30*	Sept. 6	Sept. 13*
		Water Surface Elevations								
North	5	4525.5	4522.7	4522.8	4523.1	4522.7	4522.9	4522.8	4522.7	4522.8
	10	25.2	23.0	23.1	23.3	22.9	23.1	22.9	22.9	23.0
	25	25.8	23.6	23.7	23.9	23.5	23.7	23.5	23.5	23.5
	50	25.7	24.7	24.8	25.0	24.7	24.8	24.6	24.6	24.6
	75	26.8	26.1	26.1	26.2	25.9	26.0	25.8	25.9	25.9
	280	30.8	30.8	30.8	30.9	30.8	30.8	30.7	30.7	30.7
South	5	24.8	21.6	21.7	21.8	21.5	21.8	21.6	21.6	21.7
	10	24.6	22.4	22.5	22.7	22.3	22.6	22.3	22.3	22.3
	25	23.6	22.7	22.9	22.6	22.8	22.6	22.6	22.5	22.5
	50	23.6	22.7	22.7	22.9	22.5	22.7	22.5	22.5	22.4
	100	23.2	22.4	22.3	22.6	22.1	22.4	22.1	22.1	22.0
	255	21.8	21.0	20.8	21.2	20.7	21.1	20.7	20.6	20.5
	335	19.2	18.5	18.1	18.6	18.0	18.6	18.0	17.7	17.4
East	5	24.9	21.8	21.9	22.1	21.8	22.0	21.8	21.8	21.8
	10	24.8	22.6	22.7	22.9	22.6	22.8	22.6	22.6	22.6
	20	24.5	23.1	23.1	23.4	23.0	23.2	23.0	22.0	23.0
	85	25.6	24.8	24.9	25.1	24.7	24.9	24.7	22.7	24.6
	200	26.9	26.1	26.4	26.6	26.2	26.4	26.1	26.1	26.1
	400	28.7	28.4	28.6	28.6	28.2	28.3	28.1	28.1	28.2
	500	29.4	29.2	29.5	29.3	28.9	28.9	28.7	28.8	28.9
West	5	24.6	22.6	22.5	22.8	22.4	22.6	22.5	22.4	22.6
	10	24.8	22.6	22.7	22.9	22.5	22.7	22.5	22.5	22.6
	25	23.6	22.9	23.0	23.1	22.8	23.0	22.7	22.8	22.8
	50	23.6	22.8	23.0	23.2	22.8	23.0	22.7	22.8	22.8
	100	23.7	23.0	23.1	23.3	22.9	23.1	22.9	22.9	22.8
	200	23.2	22.8	22.8	22.9	22.6	22.8	22.6	22.6	22.6
	400	20.3	20.0	20.1	20.1	19.9	20.0	19.8	19.9	19.8
	550	18.6	18.4	18.6	18.8	18.4	18.4	18.3	18.5	18.4
Well No.2	—	13.7	12.8	12.8	13.6	13.1	12.8	12.2	11.7	11.4

*These dates and values are plotted on Fig. 15 and 16. No. 2 well values are not plotted.

Table 7. Elevations above datum and drawdowns at different distances from well No. 3 during pumping used in calculating the permeability of the soil. An average discharge of 0.0036 c.f.s. was used for all calculations

Horizontal distance from axis of well feet		Height of drawdown curve above datum plane - feet		Distance from Water surface before pumping, to drawdown curve - feet		Permeability of soil formation ft./sec.
r_1	r_2	h_1	h_2	S_1	S_2	K
N - 10	N - 75	28.01	29.27	1.99	0.73	3×10^{-5}
E - 10	E - 85	28.05	29.38	1.95	0.62	3×10^{-5}
S - 10	S - 100	28.04	29.29	1.96	0.71	4×10^{-5}
W - 10	W - 100	28.04	29.50	1.96	0.50	3×10^{-5}
					Average	3×10^{-5}

N - north line, E - east line, S - south line, W - west line,
The symbols are described in Fig. 9 .

Assumptions: (1) That the original water surface and clay layer are parallel.

(2) That the distance between the clay layer and original water surface is 30 feet for calculation purposes.

Table 8. Elevations above datum and drawdown at different distances from well No. 3 used in calculating the theoretical drawdown. This in turn with the actual drawdown are used in calculating the efficiency. An average discharge of 0.0036 c.f.s. and average permeability of 3.3×10^5 are used for calculating the theoretical drawdown.

Horizontal distance from axis of well feet		Elevation of drawdown curve above datum feet	Theoretical drawdown at the well computed from equation (3) feet	Actual drawdown at the well as measured feet	Efficiency of the well as computed using equation (2) percent
r_1	r_2	h_2*	S_e	S_1	E_w
1	N - 75	29.27	3.40	17.91	19
1	E - 85	29.38	3.40	17.91	19
1	S - 100	29.29	3.60	17.91	20
1	W - 100	29.50	3.35	17.91	18.7

* The value used for drawdown in well and observation well are the end of 1 month of pumping.

Assumption: (1) That the original water surface and clay layer are parallel.

(2) That the thickness of the saturated material is 30 feet.

(3) That r_1 due to gravel envelope is equal to 1 foot.