U. S. DEPARTMENT OF AGRICULTURE
AGRICULTURAL RESEARCH SERVICE
SOIL AND WATER CONSERVATION RESEARCH BRANCH
WESTERN SECTION

ANNUAL REPORT
1956

Colorado A and M College
Fort Collins, Colorado

By

A. R. Robinson,
Agricultural Engineer (General)
R. W. Nelson,
Agricultural Engineer (Conservation)

CER56AAR18

U. S. Department of Agriculture
Agricultural Research Service
Soil and Water Conservation Research Branch
Western Section

ANNUAL REPORT
1956

Colorado A and M College
Fort Collins, Colorado

By
A. R. Robinson,
Agricultural Engineer (General)
R. W. Nelson,
Agricultural Engineer (Conservation)

TABLE OF CONTENTS

INTRODUCTION

During the calendar year 1956 there were changes in personnel in the Fort Collins office. Mr. R. W. Nelson, Agricultural Engineer, was transferred to Fort Collins from Boise, Idaho to conduct drainage research. Mr. W. W. Sayre who was employed half-time while completing a Master's degree resigned to accept other employment.

Progress has been made during the year on three approved projects. These are: (1) Laboratory and Field Investigations of the Vortex tube sand trap, (2) Measuring Devices for Small Canals, (3) Development of Drainage Design Criteria for Irrigated Lands. Another project, Performance Tests of Well Screens and Gravel Filters, was inactive during the year. This project will be reactivated at an early date and carried to completion. Preliminary studies were made on a proposed project using an electrical analogue for the study of drainage problems.

(1) Laboratory and Field Investigation of the Vortex Tube Sand Trap

A. Experiment Colorado - FC-5 Line Projects SWC-c9-4

B. Location of Experiment: Colorado A & M College
Fort Collins, Colorado

C. Personnel involved: A. R. Robinson, D. F. Peterson, Chief, Civil Engineering Section, Experiment Station, Colorado A & M College

D. Date of initiation and expected duration:

Initiated: February 1, 1956

Duration: 2 years

E. Objectives:

1. To make an analysis of existing data on the vortex tube which were taken previously but never analyzed.
2. To make a detailed study in the laboratory of the Vortex Tube sand trap using a sloping flume and a recirculating sediment system. Under laboratory conditions many of the variables which should affect the operation of the device can be controlled.
3. To conduct a field study of existing installations of sand traps to determine their effectiveness.
4. To check the operation of the field installations with the laboratory findings.
5. To develop generalized criteria for the design of vortex tubes which may be applied with confidence by designing engineers.
6. To publish a general report on the entire study including the previous studies.

F. Need for study:

In some parts of the United States, one of the most important problems in water transport is the removal of sediment and bed load from irrigation and power canals. This sediment usually has its origin in the main stream and is diverted by the headworks into the canal. A properly designed diversion works will exclude much of this sediment from canals. However, many diversion works were constructed before much was known about the proper design for removing or bypassing sediment, thus, many dams act as sediment traps so that much more sand enters the canals than is necessary. This sediment needs to be removed before it silts up the canals, deposits on the irrigated lands, or reaches power plants where considerable damage could be done to impellers and penstocks.

A considerable amount of work has been done in India on sediment excluders and ejectors. Two highly effective types of sediment ejectors were developed at Fort Collins by Mr. Ralph Parshall and Mr. Carl Rohwer, Senior Irrigation Engineers, retired. There are a number of successful installations of these ejectors in existance which were designed by Mr. Parshall. However, there are also installations which were not successful. Reasons which have been advanced for failure of these installations are that the velocity in the canal was too low or that the tube was set below grade in the channel. In some cases, no specific reason for failure could be assigned.

Considerable experimental work has been done to develop the vortex tube for specific installations. Information from these studies has aided materially in providing design information. However, general design information is lacking for assisting the field engineer in designing a vortex tube sand trap. No publications have been issued that give general design information for this type of ejector. Much of the previous research was based on visual observations rather than quantitative measurements.

G. Design of experiment and procedure followed:

The flume used in this experiment was available in the Hydraulics Laboratory at Colorado A & M College. The slope of the flume is adjustable by jacks to cover a range of slopes normally encountered in canals. The flume has a length of 160 feet, a width of 8 feet and is equipped with a recirculating system so that the suspended sediment can be circulated with the water.

The only major modification of the existing facilities was the construction of a test section (See figure 1). This section was constructed to contain a vortex tube, the shape and size of which was determined from previous data. The total water discharge through the flume was measured through a pipe orifice with the flow from the tube measured by a 6-inch Parshall flume and by weighing. The sediment discharge in the channel was determined using a traversing sampler across the overfall from the flume.

A diverter and weighing tank was used to measure the sediment discharge from the tube. The concentrations of sediment were determined in parts per million by weight. The water surface profile was measured using a movable point gage.

The procedure followed in conducting the experiments was:

1. The flume was filled with sand of a predetermined size to a level which was 2-inches lower than the test section.
2. The flume was adjusted to a constant slope.
3. A quantity of water was circulated through the flume for a period of 2 - 4 hours until equilibrium conditions were established. The depth of water was regulated using an adjustable tail gate.
4. After the 2 - 4 hour period, the total water discharge and the discharge through the vortex tube were determined.
5. Water surface profiles were made using the traveling point gage.
6. Samples for sediment concentration measurements were taken.
7. Sediment weights were determined by decanting the water and weighing the dry sediment.
8. The depth of water on the discharge was then changed to introduce a new situation.
9. The data was obtained so that a range of Froude numbers (ratio of kinetic to potential energy) from 0.4 to 1.4 were covered.

H. Experimental data and observations:

Some experimental work has been done in the past on the design and operation of the vortex tube sand trap. An analysis was first made of previous data and conclusions were made regarding the proper shape and angle to place the tube. The design of the tube was based on these findings and the performance was checked under a range of operating conditions.

Figures 2 and 3 are the results of the analysis of flow from the vortex tube. From the previous work, a relationship was determined:

$$100 \frac{Q_T}{Q_F} = \frac{10}{\left(\frac{d}{D}\right)^{1.16} Fr^{0.62} \left(\frac{d}{D}\right)^{0.4}} \quad (1)$$

for relating the total flow and depth in the channel to the flow from the vortex tube. In this relationship Q_T is the flow in the tube, Q_F the flow in the flume, d the depth of flow 0.5 feet upstream from the tube, D the width of the tube opening and Fr is the Froude number $\frac{V}{\sqrt{gd}}$. This relationship is plotted on figure 2.

It can be seen that the relationship is fairly well determined for the data taken in 1935 and 1950. However, the data which was taken in this study to extend the scope showed considerable scatter. The 1935 data was taken using a tube of similar shape and dimensions as the one presently used with the exception that the 1935 tube was tapered.

A simple relationship of depth versus the discharge from the tube is shown in figure 3. Here again there is considerable deviation between the two sets of data.

Figure 4 gives some idea on the sediment removal qualities of the vortex tube. Shown are the removal efficiencies (E) versus the Froude Number (Fr). The efficiency is defined as the ratio in percent of sediment moving in the channel to that removed by the tube. The efficiencies are plotted as an overall efficiency considering the total sediment load and are also shown for four size fractions. Also shown, is the efficiency assuming that the sediment removed is in direct proportion to the amount of water removed. Shown above each set of data is the total load of sediment (ppm by weight) which was flowing in the channel at the time that the test was made.

I. Comments and interpretations:

The inconsistancies in the flow analysis which are shown in figures 2 and 3 cannot be explained at this time. The tube used in 1935 and the present one are similar except that the 1935 tube was tapered, but Jack had the same average dimensions. The discharge from each was measured through small Parshall flumes.

Generally the efficiency of trapping was very good for the coarser fractions of the material as shown in figure 4. For the range of material sizes greater than 0.295 mm (0.012 inches) an efficiency of trapping of approximately 80% is indicated. As would be expected the efficiency in trapping the finer fraction (in this case less than 0.295 mm) is much less than the coarser. Even for this material some trapping was accomplished over and above the percentage of water which was removed by the tube.

J. Summary:

Tests were made on a laboratory installation of a vortex tube sand trap to supplement data which were previously obtained. Data taken to determine the relationship of water discharge from the vortex tube to the velocity and depth of flow in the channel were generally inconclusive.

Very good results related to the efficiency of trapping were obtained for the coarser material. For material finer than 0.295 mm the efficiency was reduced. The total sediment load varied from 300 to 5400 ppm by weight and the size range was from 0.1 to 2.3 mm (0.004 - .09-inch)

The tests are to be continued using higher concentrations of sediment and different sizes of tubes. Field tests will also be made on existing vortex tube installations.

(2) Measuring Devices for Small Canals

A. Experiment: Colorado-FC-2 Line Project SWC-c9-4

B. Location of Experiment: Colorado A & M College
Fort Collins, Colorado

C. Personnel involved: A. R. Robinson

D. Date of initiation & expected duration:

Initiated: July 1, 1955

Duration: Indefinite

E. Objective:

The objectives of this study are to develop and calibrate water measuring devices and to improve existing devices.

F. Need for study:

The need for good water measuring devices cannot be over emphasized. Although some progress has been made in developing measuring equipment, there is still a need for devices which can be adapted for which they were never intended. These need to be calibrated to fit the general situation. This phase of the study had as its purpose the standardization of design and calibration of small Parshall flumes.

G. Design of Experiment and Procedure:

A standard design for 1 and 2 inch Parshall flumes was developed using larger flumes as a pattern. Flumes were constructed and calibrations made in the Hydraulics Laboratory. The calibrations were made utilizing a small flume. The flumes were attached to the end of the flume and accurate determinations made of depth of flow and discharge. The depths were measured using hook gages and wells and the discharge determined by weighing.

H. Experimental data and observations:

At least two flumes of each size were calibrated. In addition to determinations of free flow discharges the flumes were also calibrated for submerged flow conditions. Submerged flow exists when the depth of water downstream exceeds approximately 50 percent of the depth upstream from the throat.

I. Comments and interpretations:

Small Parshall flumes were found to be accurate devices for measuring small flows of water. Care must be exercised in the construction of the flumes as well as in the installation. Accurate discharge measurements can be made even under submerged flow conditions.

J. Summary

A standard design was developed for 1 and 2 inch Parshall measuring flumes. These flumes were calibrated for both free flow and submerged flow conditions. The results of this study are presented in detail in the Colorado Experiment Station Technical Bulletin No. 61.

(3) Performance Tests of Well Screens and Gravel Filters

A. Experiment Colorado FC: Line Project SWC-c9-4

B. Location of Experiment: Colorado A & M College
Fort Collins, Colorado

C. Personnel involved: A. R. Robinson,
Carl Rohwer

D. Date of initiation and expected duration:

Initiated: May 15, 1947

Expected duration: Indefinite

E. Objectives: Reference, Annual Report, CY 1953

F. Need for Study: Reference, Annual Report, CY 1953

G. Design of experiment and procedure to be followed:

Reference, Annual Report, CY 1953

H. Experimental data and observations:

There was no progress on this project during the past year. A review was made of past studies in the preparation of a report which was presented at the Joint A.R.S.-S.C.S. conference in January, 1957. It is anticipated that the work will be reactivated at an early date and carried to completion. A revised experimental outline will be prepared at the time that the project is reactivated.

(4) Development of Drainage Design Criteria for Irrigated Lands

A. Experiment: Colorado-FC-1(Revised) Line Project SWC-c9-3

B. Location of experiment: Colorado A & M College
Fort Collins, Colorado

C. Personnel involved: A. R. Robinson, N. A. Evans, Chief, Agricultural Engineering Section, Experiment Station, Colorado A & M College

D. Date of Initiation and Expected Duration:

Initiated: September, 1954

Expected Duration: Indefinite

E. Objectives:

The general objective is to provide drainage engineers with dependable criteria upon which to base the design of new drains on irrigated lands in Colorado. The following specific objectives amplify the general objective.

1. To determine if a relationship between measured discharge, farm water supply, physical features of the drain system and drainage characteristics of the soils can be used to predict water yields to be expected from new drains.
2. To check by field data the theoretically derived relationships between soil drainage properties, shape of the water table draw down and boundary conditions.
3. To determine by field observation the applicability of the findings from the previous interceptor drain model study to actual field conditions.

F. Need for Study:

Drainage design in the irrigated regions of the Western States has not been given adequate research attention. The criteria developed in Eastern humid regions for relief drains has practically no application in the Western region. As irrigation progresses to new lands and as older irrigated lands develop drainage problems, the demand and need for design criteria increases.

In the case of tile drains, the estimation of water yield from a drain system is necessary in order to specify the size of tile to be used. An under-estimate of yield results in failure of the drain to function efficiently, while over-estimation results in oversized tile and undue cost of installation. Since the cost of tile increases rapidly with size, an accurate prediction of water yield is economically important.

In the case of open drains in flat lands, where slope is a limiting factor, an accurate estimate of yield is necessary to properly design the drain cross section.

In addition to the need for estimates of drain yield, there is need for information to better design the tile system. Information is also needed on the location and depth of the tile system for maximum benefit.

G. Design of Experiment and Procedure:

Tile drain systems were selected on nine farms in northeastern Colorado for study the first season. These nine systems are of the interceptor type and were chosen to best represent the most prevalent drainage problems. The Soil Conservation Service personnel assisted in the selection of drains to be studied.

The discharge from the drains were collected by means of automatic recorders attached to small measuring flumes. The physical features and the soils data were assembled from S.C.S. records. Ground water data were collected from cased observation holes installed in lines normal to drain lines. Hydraulic conductivity measurements employing the auger hole method were made.

Procedure to be Followed in Conducting the Experiment

After installation of measuring flumes and recorders, the sites were visited once a week to remove the charts and to service recorders. The farmers were consulted relative to time or irrigation and rainfall and the effect of these occurances noted on the charts. The ground water levels as indicated by the test holes were measured at two week intervals or at shorter periods if rainfall or irrigation occurs. Hydraulic conductivity tests were made during the irrigation season. Measurement of tile discharge were made during winter months by visual observation of gage heights made once each week.

The tests will be conducted on each farm for at least one year so that a complete record of flow and ground water levels may be secured.

H. & I. Experimental data and observations:

Maps of the nine farms which were studied during 1956 are shown in figures 5 through 13. These systems generally utilize 6 inch lateral lines placed with an envelope of filter materials. Their pickup lateral lines varied in length from 600 to 2600 feet. The location of observation holes, measuring flumes and hydraulic conductivity measurements are shown. In some cases, the source of ground water was a canal, while on others the source was from both irrigation and canals or just from irrigation.

Continuous records of discharge from the drains given in average daily flows are shown in figures 14 to 22. There was a considerable range of discharges from the drains for different farms and also a wide fluctuation in discharge for a given farm. As would be expected, irrigation, heavy rains or stage of water in a nearby canal were the cause of these fluctuations. In many cases, the peak flow exceeded the average flow for a period by several times.

In order to have some method of classifying the drainage condition for each farm, a classification index was adapted from the S.C.S. system. This index is shown in table 1. As an example in using this table, a drain system given the code of 232AF would mean moderately stratified, moderate hydraulic conductivity, the thickness of soil over a barrier layer of from 48-72 inches, the surface slope is from 0 to 1 percent and a canal is the probable source of seepage. Table 2 summarizes the indexes for the farms as well as length of line, hydraulic conductivities, and discharges.

A plot of the relationship of hydraulic conductivity to maximum flow for the systems studied is given on figure 23. Also shown are the farm classification index for each point. A relationship developed by G. B. Bradshaw, S.C.S. for determining interceptor drain yield is also shown on figure 23. From this plot it seems there is no defined relationship between the two variables, discharge and hydraulic conductivity. as shown by Bradshaw. However, only limited data are available.

The ground water profiles for the systems are shown in figures 24 through 31. As would be expected the shape of the drawdown curve was dependent on times of irrigation, rainfall and water being in or out of a canal. The flow from the drain was dependent on the shape of the drawdown curve in that a steeper or flatter gradient induced a greater or smaller outflow.

No analysis has been made regarding the location of the interceptor drain on the resulting flow and shape of the drawdown curve.

J. Summary

Measurements were made on nine farms in the Northern Colorado of tile discharge, water table positions, and hydraulic conductivity. The purpose is to study typical interceptor drains in order to predict tile discharge in future installations with a further objective of developing design criteria.

On the farms studied there seemed to be no relationship between the peak flows and hydraulic conductivity. There was a considerable fluctuation from most of the drains during the season. The shape of the ground water profile varied depending on irrigation, rainfall and flow in a nearby canal.

(5) Preliminary Work Upon a Regional Approach to Quantitatively Obtain the Relative Hydraulic Conductivity of Non-homogeneous Soils over an Entire Area Requiring Drainage

A. Experiment: Line Project SWC-c9-3

B. Location of Experiment: Colorado A & M College
Fort Collins, Colorado

C. Personnel involved: Claude H. Pair, R. William Nelson and Warren W. Rasmusson of the Western Soil and Water Conservation, Research Branch, A.R.S.; Zimri E. Mills, John E. Renard and Claude Swerthout of the Soil Conservation Service

D. Date of initiation:

Exploratory work was started in the spring of 1956 and based upon these results an experimental outline is currently being prepared to examine the approach in more detail.

E. Objectives:

1. Obtain a method of quantitively characterizing the water transmitting ability of variable soils in the saturated zone.
2. Develop a method or methods of utilizing the piezometric head distribution to determine the relative salient changes in hydraulic conductivity over an area.
3. Devise an orderly procedure of changing the potential distribution on a uniform sheet of electrical conductance paper to the distribution desired (analog approach).
4. Examine the feasibility of a finite difference solution of the piezometric head distribution to obtain relative hydraulic conductivity.

F. Need for Study:

The more consideration given to Interception Drainage of irrigated lands, the more vital appears the need for some way of rationally selecting the best drain location. Such a procedure would seem to require measuring those variables acting to provide a basis from which beneficial results after drainage could be predicted. A procedure to have wide application must consider the time and expenditure required to measure these variables.

In working with soils and after all drainage is a soils problem, two factors stand out as paramount:

1. Soils as found in nature are variable and non-homogeneous.
2. Flow in soils and soils themselves make up a dynamic system.

Realizing these facts the present need is to devise a method of quantitively characterizing the water transmitting ability of variable soils over the entire area affected by poor drainage. Such a characterization must be accomplished within the limits of justifiable engineering costs.

Consideration of the overall saturated flow problem seems to indicate that salient changes in hydraulic conductivity over the area can be found through an analysis of the piezometric head distribution. However, this possibility must be examined in further detail before a high degree of sureness can be expressed regarding its validity.

Once the inherent transmitting properties of the variable system have been cataloged, then solutions in the non-homogeneous system are required if predictions of conditions after drainage are to be made. Solutions for variable cases are not presently available so possibilities for relaxation must be examined.

G. Design of experiment and procedures:

This is being worked out in conjunction with preparing the experimental outline.

H. & I. Experimental Observations and Interpretations:

In the spring of 1956 field work was started on the Grandview, Idaho area for which the Soil Conservation Service was developing a drainage plan. Banks of four piezometers (¼" pipes) with each terminating at a different depth were installed on approximately a 500 foot grid on about 600 acres. These piezometers were read about once a week during the 1956 growing season and are currently being read at longer intervals. On the same area the Soil Conservation Service had readings for the two previous years on piezometers located at the corners of each 40 acres, thereby providing some information on whether the 1956 season was a representative year insofar as the drainage problem was concerned.

Upon comparing the water levels in the piezometers, it was found that the levels stood at approximately the same elevation in each of the four or five piezometers which made up a particular bank. This indicated the flow was essentially lateral under the area. It was further found that four times during the season a steady state condition was approached sufficiently close to allow comparison of values of hydraulic conductivity to be found by the suggested method. Since the flow was found to be essentially lateral, a two dimensional analog can be used thereby simplifying the procedure considerably.

Conductance paper can be used for the two-dimensional case, but since it is a uniform material, it will not be a true model of the field problem until it is modified sufficiently to represent the non-uniformity in field hydraulic conductivity. Accordingly the need for an orderly method of making the initially uniform conductance paper into a variable medium. It is proposed to vary the potential distribution by selecting a circular cut of 1/8" diameter as the shape to be used. Using this circular cut, sufficient holes must be placed in the conductance paper and at such a location that the potential distribution obtained on the conductance paper is identical to that measured in the field.

In order to specify a cut location consider a hydrodynamic source and sink of equal strength and axially separated by a distance d . If the source and sink are moved closer and closer together, then in the limit as d approaches zero there would be no resulting flow as the sink would absorb all the flow from the source. Yet no flow from an exterior field could move across the combined source and sink of adequate strength. It is realized then that a circular cut in the uniform conductance paper is a doublet (i.e. combined source and sink) for which the potential function ϕ in polar form is:

$$\phi = U \frac{a^2}{r} \cos \theta \qquad (1)$$

where:

ϕ = complex potential at any point

$\Delta\varphi$ = change in potential due to introducing the doublet

U = unit velocity potential

a = radius of doublet

r = distance from center of doublet to any point

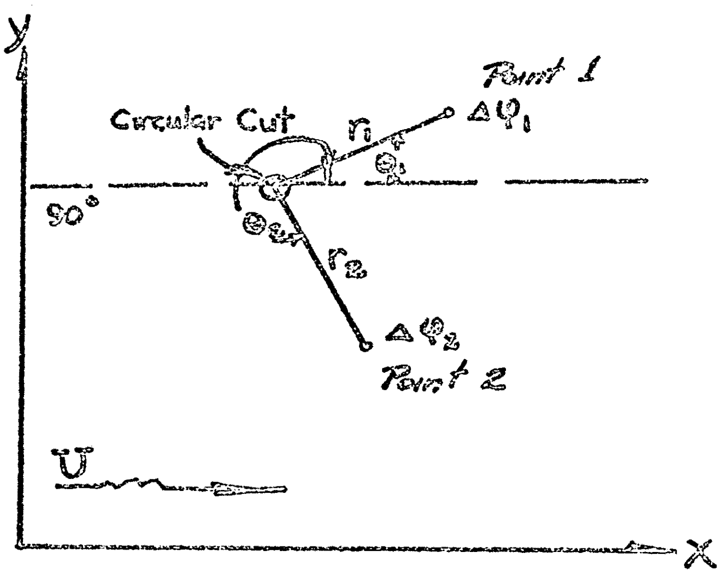
θ = angle from polar coordinate axis

Taking any two adjacent points in a uniform field and inserting a circular cut will result in changing the potential at each of the points in accordance with Equation 1.

$$\Delta\varphi_1 = U \frac{a^2}{r_1} \cos \theta_1 ,$$

and

$$\Delta\varphi_2 = U \frac{a^2}{r_2} \cos \theta_2 ,$$



Taking the ratio of ϕ's

$$\frac{\phi_1}{\phi_2} = \frac{U \frac{a^2}{r_1} \cos \theta}{U \frac{a^2}{r_2} \cos \theta_2} = \frac{r_2}{r_1} \frac{\cos \theta_1}{\cos \theta_2} \quad (2)$$

For every other surrounding point which can be paired with point 1, an equation similar to equation 2 can be written. Each equation will specify a cut location such that the incremental change at each of the surrounding points is in the correct proportion to the total change desired at each of the points considered.

Having obtained an equation to specify the cut location there remains a need for an over-all program to direct the manner in which to proceed to cut over the entire conductance model. The following approach has been devised:

Take the difference between the measured voltage V_m and the voltage wanted V_w, thereby giving the required change in voltage $\Delta\phi$ for every reference point on the conductance paper. Adopt the convention that if $V_m > V_w$ then $\Delta\phi$ is negative and conversely if $V_m < V_w$ then $\Delta\phi$ is defined as positive. Select the point requiring the greatest negative change $(-\Delta\phi = \text{maximum})$. Calculate $\frac{\Delta\phi \text{ one point}}{\Delta\phi \text{ adjacent point}}$ for all adjacent points on the conductance paper. Take two ratios of $\frac{\Delta\phi \text{ one point}}{\Delta\phi \text{ adjacent point}}$ and solve for the location to cut out a circular hole using Equations 2.

This procedure as described above must be repeated over and over again until the voltages have been reduced to the values desired. Although extremely time consuming to work out manually, a set procedure is available which can be used for machine programming. Further, by gaining more experience short cuts undoubtedly can be devised to simplify this procedure.

J. Summary

Ideas and suggestions have been presented based upon present experience with a regional approach to studying ground water problems. The approach includes:

(1) A method of taking into account variability of hydraulic conductivity over an area through the use of an electrical analog procedure.

(2) The piezometric head distribution in the field is utilized for constructing the model.

(3) For the Grandview Area, the problem is a two-dimensional one, which simplifies the electrical analog.

(4) Procedures have been worked out for obtaining the desired potential distribution for the two-dimensional case.

V. Summation of Significant Findings by Line Projects

SWC-c9-3: From limited data available it seems that the flow from a tile interceptor drain cannot be predicted using the hydraulic conductivity alone. Other important factors such as location and depth of drain and source of ground water also determine the amount of flow.

Present indications are that relative hydraulic conductivities can be found for non-uniform, saturated soils over an entire area having drainage problems. This can be accomplished by an analysis of the piezometric head distribution over the area using an approach similar to relaxation techniques.

SWC-c9-4: Small Parshall measuring flumes offer a means of accurate measurement of small flows of water. These flumes will measure flows under submerged conditions where there is a very small amount of head loss.

The Vortex Tube sand trap is efficient in removing sand from a channel under most operating conditions for particle sizes greater than 0.012". Efficiencies of about 80% were observed for the larger size particles. The amount of water removed by the tube varied from 10 to 20 percent depending on the depth and velocity of flow.

VI. List of Publications and Research Reports

1. R. W. Nelson - "Difficulties in Field Methods of Measuring Hydraulic Conductivity", Presented at the Annual Meeting, American Society of Agricultural Engineers, December, 1956.

2. R. W. Nelson - "Interception Drainage with Ideas on a Design Method", Presented at Joint A.R.S.-S.C.S. Conference, Colorado Springs, Colorado, January, 1957.

3. R. W. Nelson - "Report on Inspection Tour on San Luis Valley, Colorado", July, 1956.

4. A. R. Robinson, "Seepage Measurement and its Relation to Drainage and Canal Lining Programs", Journal of Soil and Water Conservation, March, 1956.

5. A. R. Robinson, "Parshall Flumes of Small Sizes", Colorado Experiment Station Technical Bulletin No. 61, January, 1957.

6. A. R. Robinson, "Model Studies of Interceptor Drains", A.R.S.-S.C.S. Conference, January, 1957.

7. A. R. Robinson, "Research on Well Screens and Gravel Packs, A.R.S.-S.C.S, January, 1957.

8. A. R. Robinson, Closing Discussion of "Measurement of Canal Seepage", A.S.C.E. Transactions, 1956.

Table 1
Farm Classification Scheme
for Characterizing the Drainage Situation

Stratification or uniformity of soil:

No. 1	highly stratified -	>50% of profile is unlike material
2	moderately stratified -	10 - 50% of profile is unlike material
3	uniform -	<10% of profile above rock is unlike material

Hydraulic Conductivity - average value by auger hole method:

No. 1	very slow	<0.06 inches/hr.
2	slow	0.07 - 0.29 inch/ hr.
3	moderate	0.30 - 3.0 inch/hr.
4	rapid	3.1 - 6.0 inch/hr.
5	very rapid	>6.0 inch/hr.

Thickness of soil material over barrier:

No. 1	<48 inches
2	48 - 72
3	72 - 120
4	>120

Slope of land (in vicinity of effective drain line):

A	0 - 1%
B	1 - 3
C	3 - 6
D	>6

Probable source of ground water:

F	Canal
G	Canal and irrigation
H	Irrigation

Table 2—Summary of Tile Interceptor Drain Study, 1956

Farm No.	Farm	Farm #1 Classification	Length of Pickup Line Feet	Hydraulic #2 Conductivity in./hr.	Maximum Flow date	Maximum Flow cfs	Maximum Flow cfs/1000 ft	July cfs	July cfs/1000 ft	August cfs	August cfs/1000 ft	September cfs	September cfs/1000 ft
1	Aranci	2-3 BG	1539	- -	7-21	1.13	0.74	0.71	0.46	0.57	0.37	0.47	0.31
2	EPH Corp.	343 BF	1045	4.6	7-12	0.042	0.040	0.026	0.025	0.029	0.028	0.015	0.014
3	Foote	353 AG	2645	9.8	8-17	0.60	0.23	0.35	0.13	0.36	0.14	0.30	0.11
4	Kluver	333 BG	1200	1.8	- -	- -	- -	- -	- -	0.22	0.18	0.20	0.17
5	McCormick	242 AH	1436	4.8	7-30	0.51	0.35	0.025	0.017	0.013	0.009	0.035	0.024
6	Ragan	243 CH	600	5.6	8-19	0.28	0.47	0.12	0.20	0.15	0.25	0.10	0.17
7	Spangler	232 AH	1990	2.0	8-21	0.047	0.024	0.022	0.011	0.028	0.014	0.029	0.015
8	Sprenger	353 AF	600	6.4	7-27	0.095	0.158	0.026	0.043	0.030	0.050	dry	—
9	Stewart	333 BG	1570	2.6	8-25	0.068	0.043	0.039	0.025	0.048	0.030	0.037	0.024

#1 See Table 1 for explanation of classification system

#2 Determined by auger hole method.

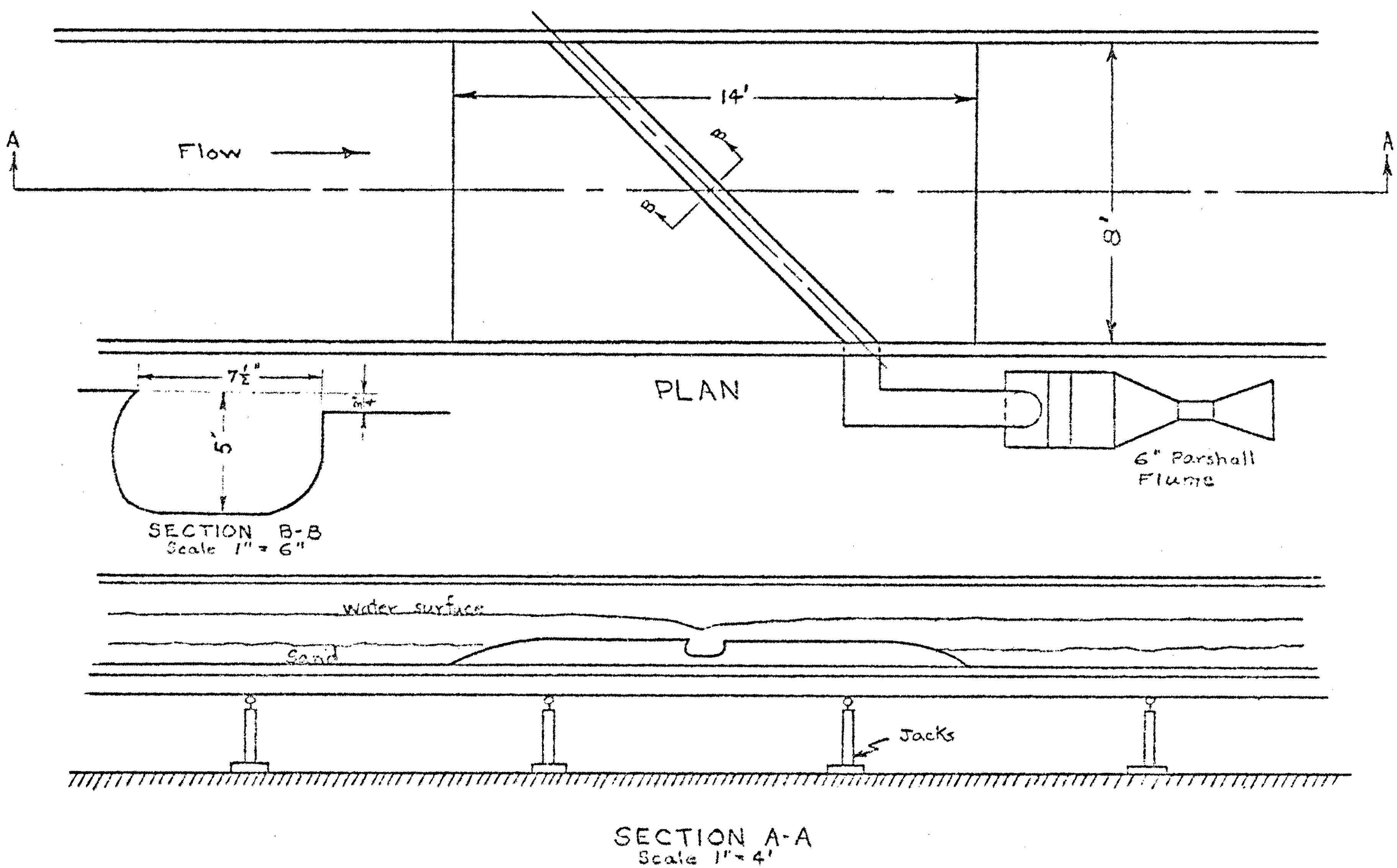


Figure 1 Layout of Vortex tube sand trap.

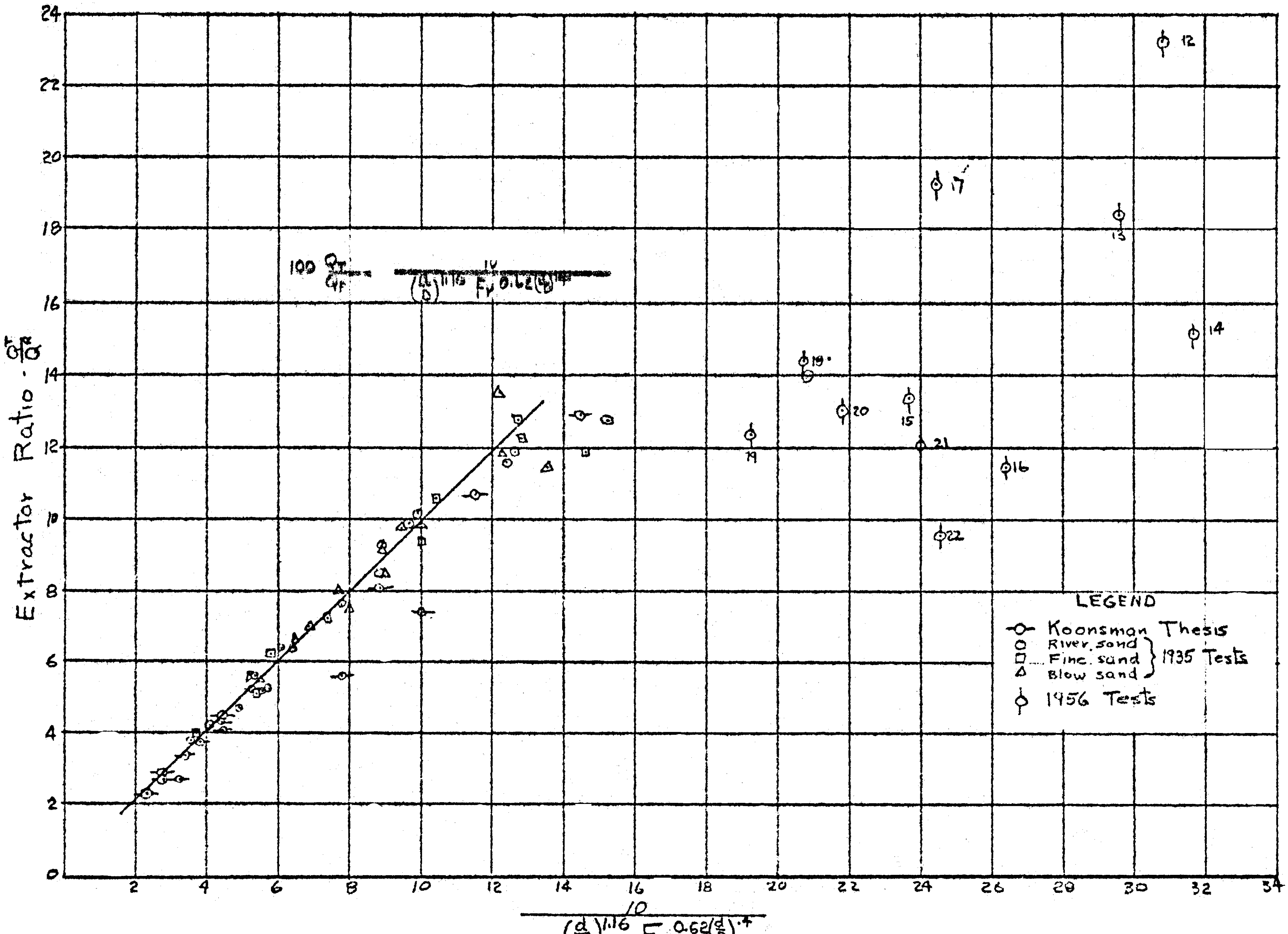


Figure 2 Flow analysis for vortex tube sand trap 1956

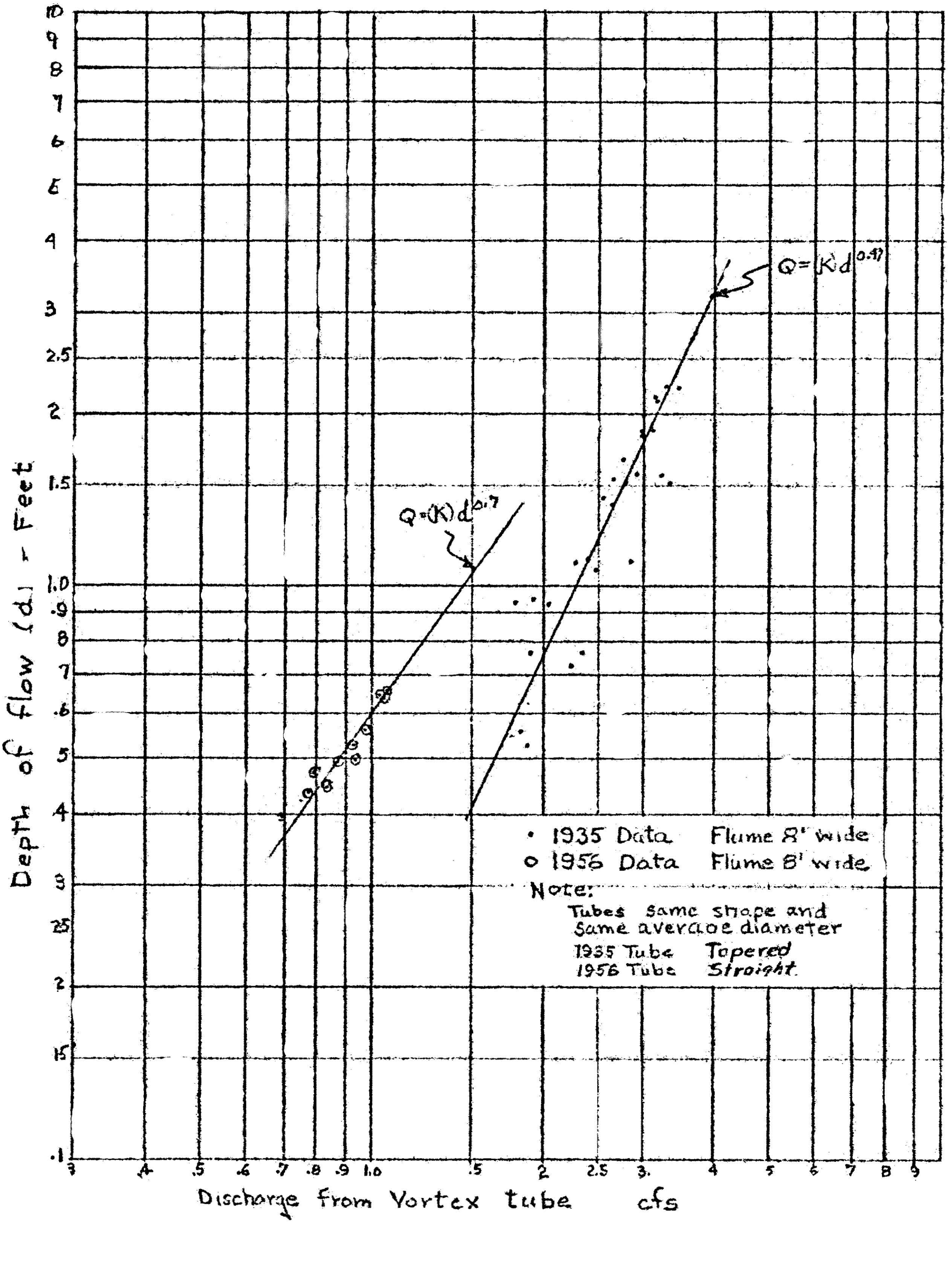


Figure 3 Discharge From Vortex Tube as a function of the depth of water above the tube.

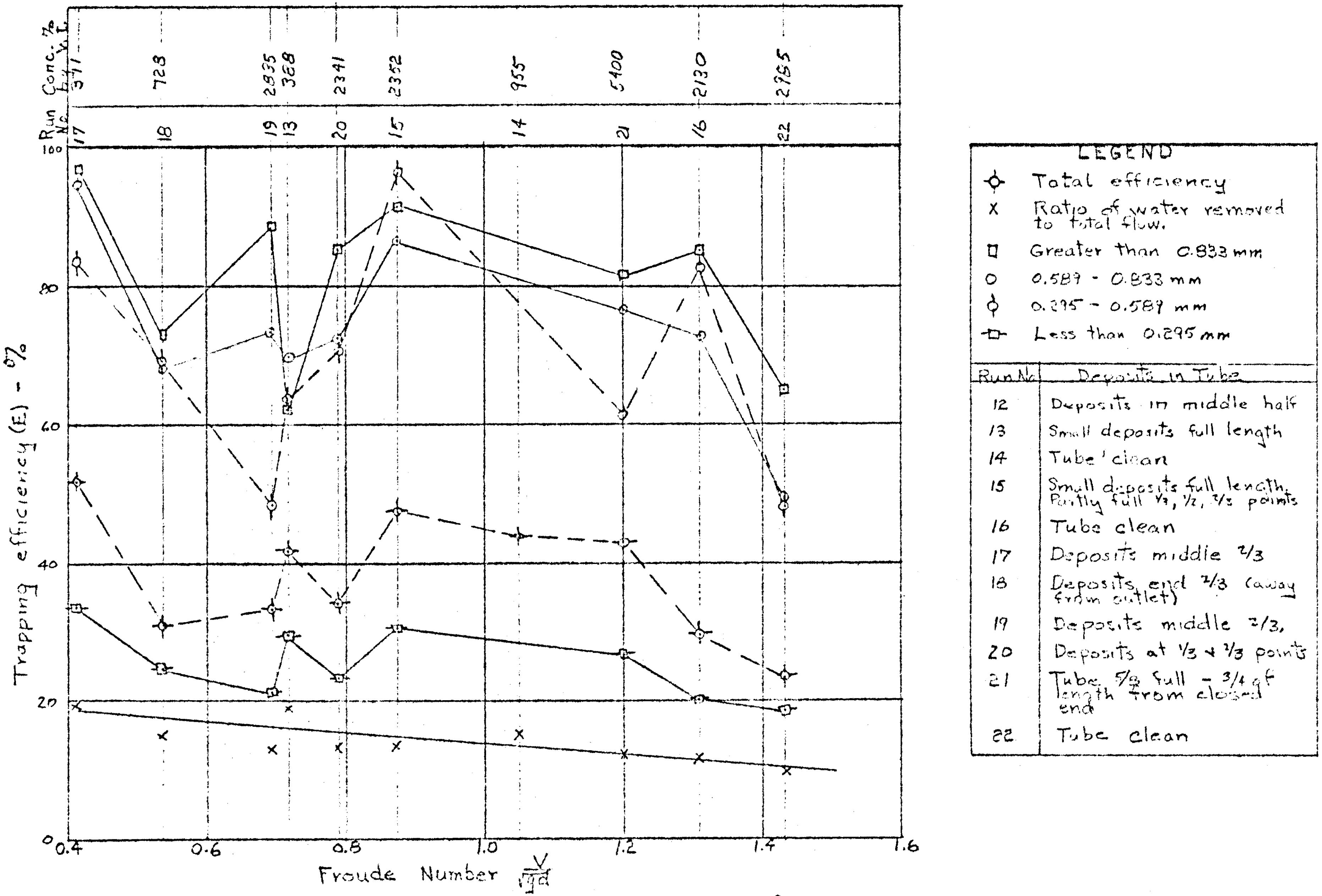


Figure 4 Trapping efficiency of the Vortex tube sand trap.

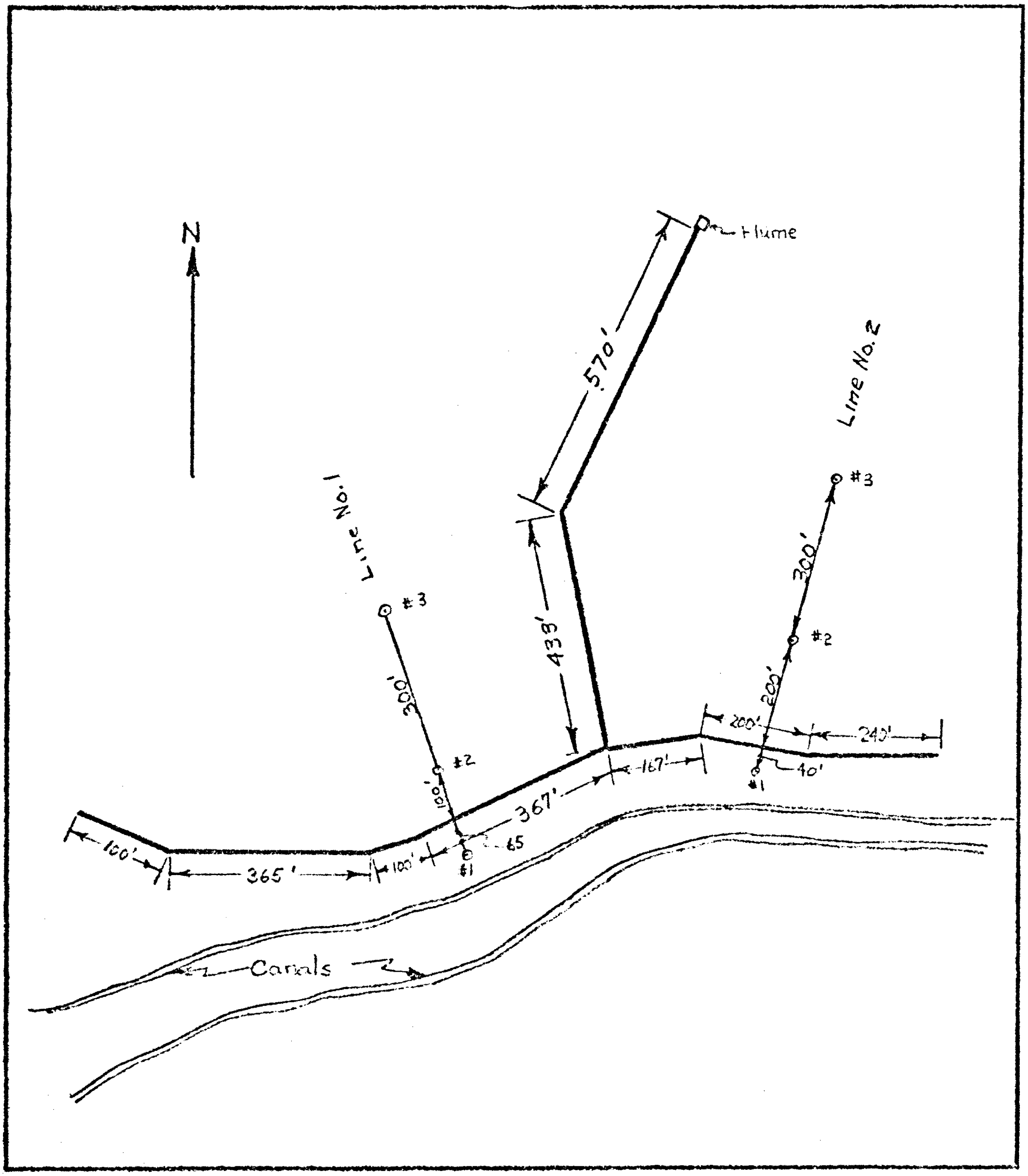


Figure 5 Map of tile interceptor drain Aronci Farm 1956

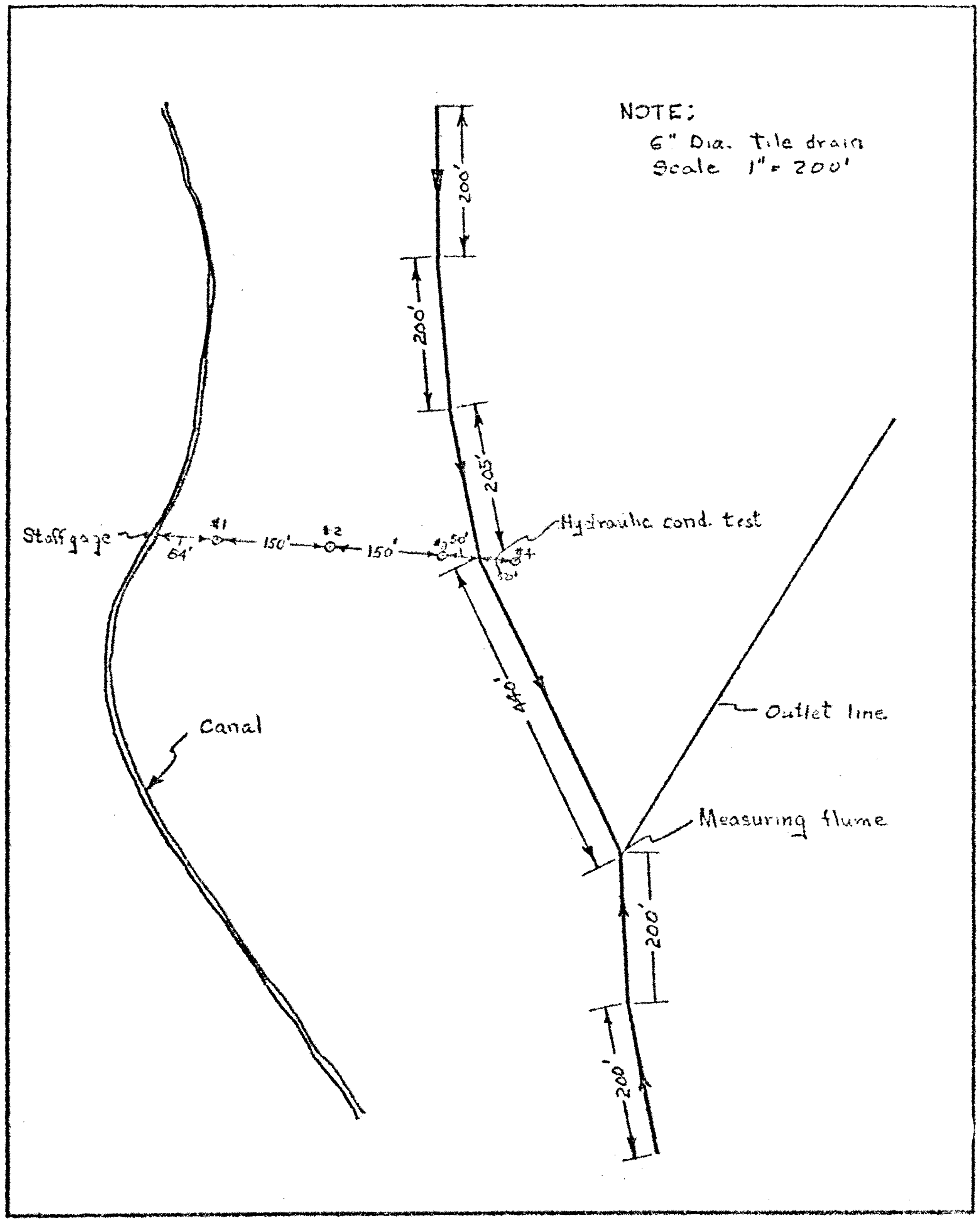


Figure 6 Map of Interceptor Tile Drain E.P.H. Corp. Farm

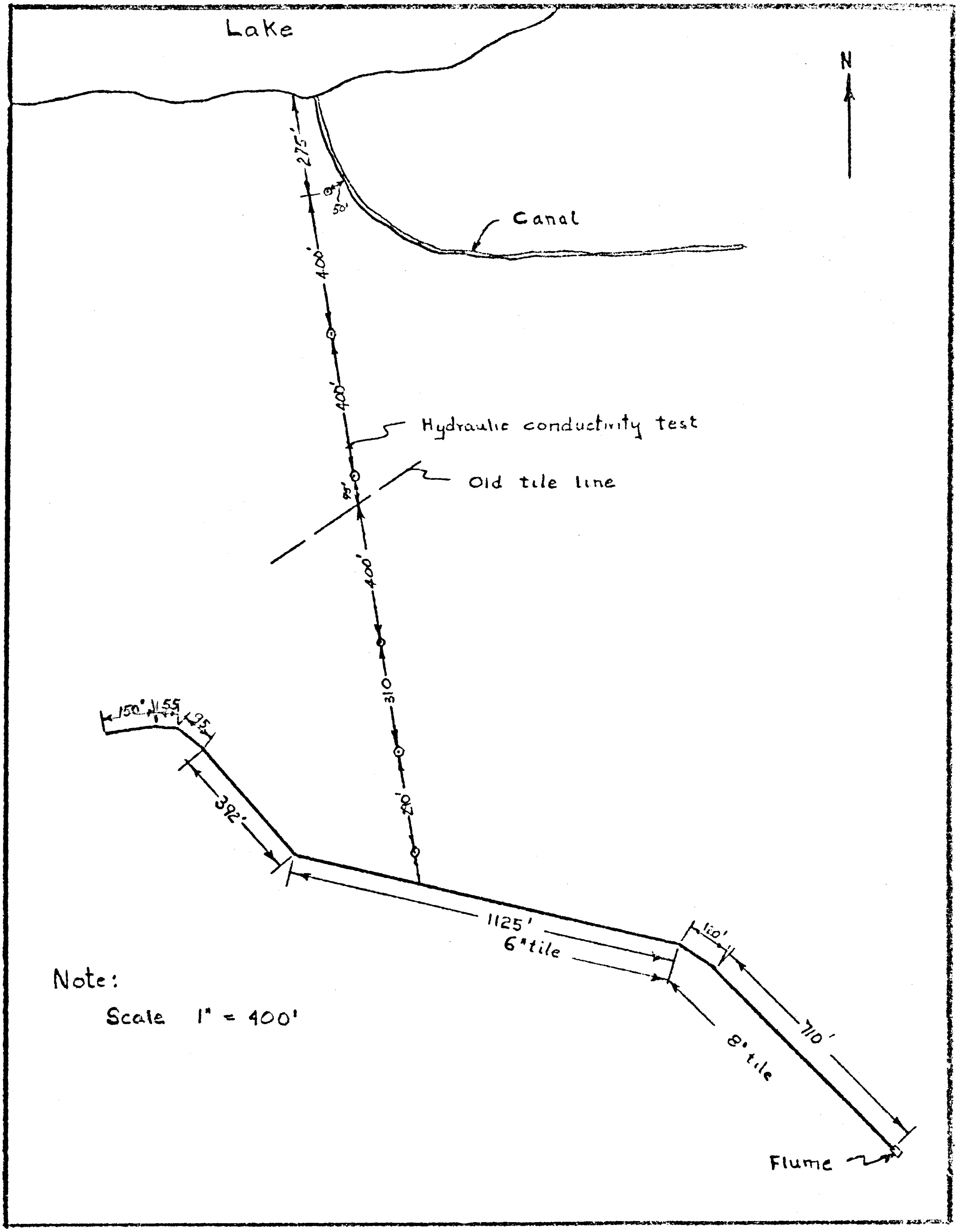


Figure 7 Map of tile drain - Foote Farm 1956

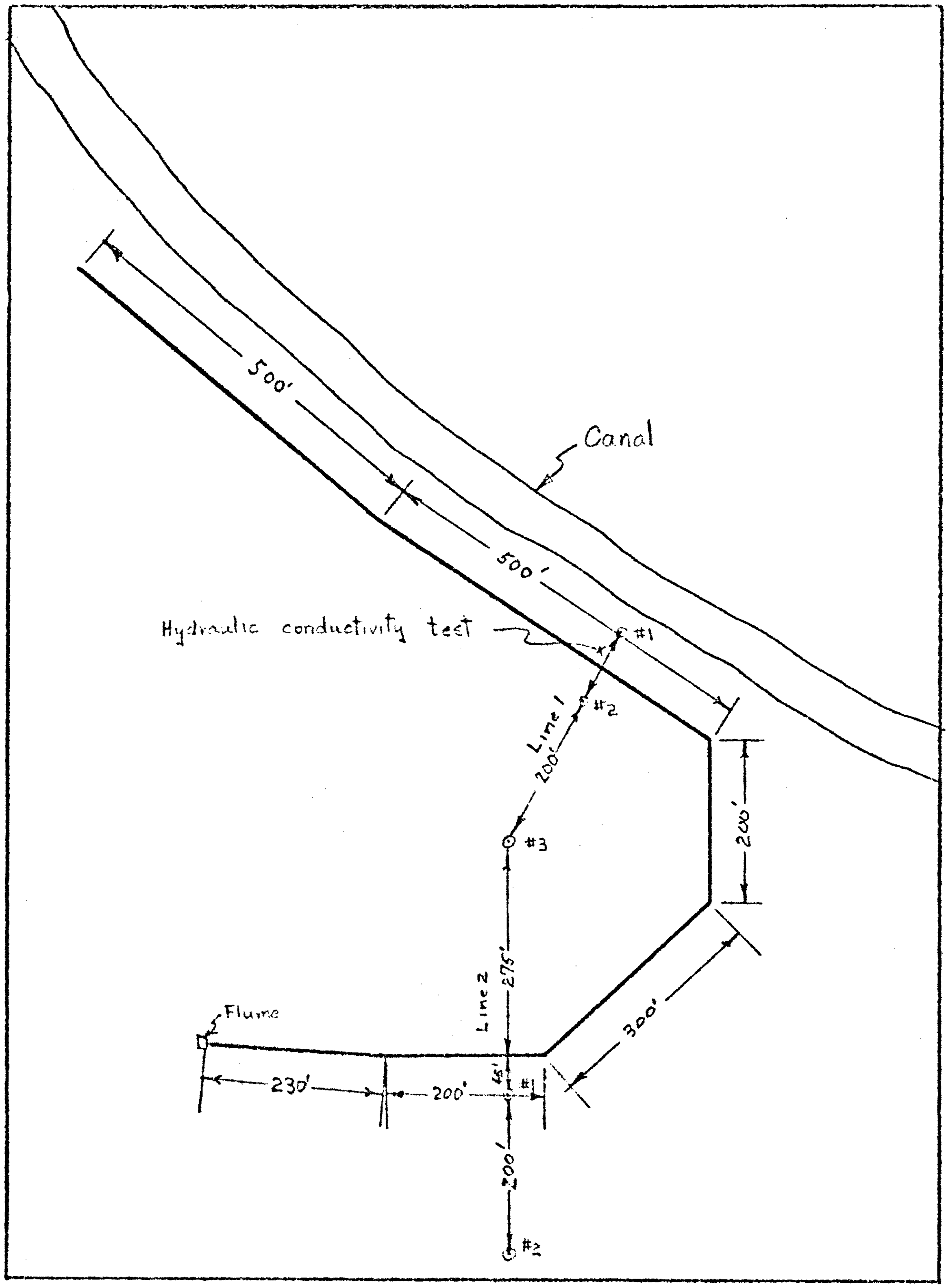


Figure 8 Map of tile interceptor drain Kluver Farm 1956:

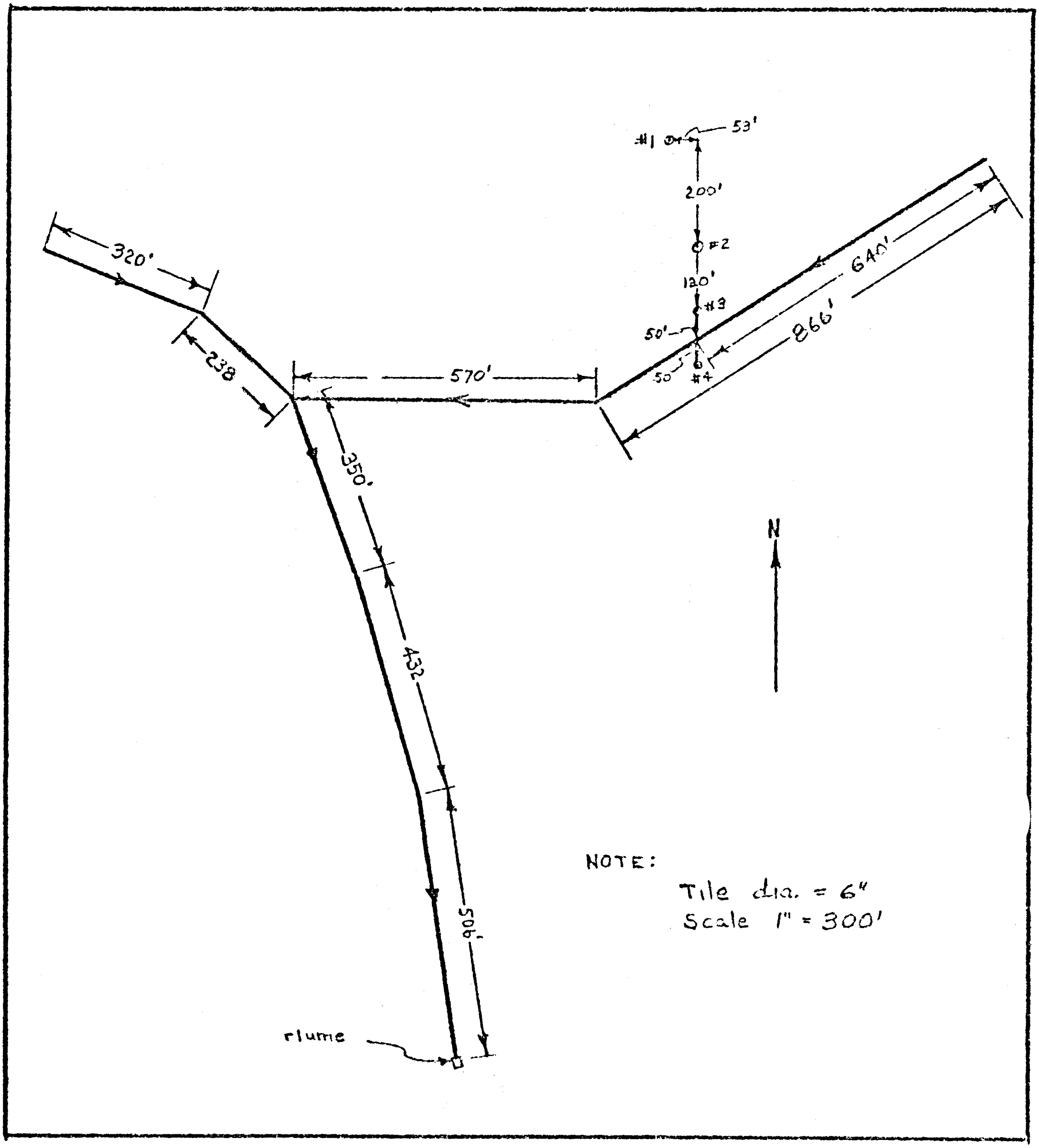


Figure 9 Map of tile drain McCormick Farm 1956

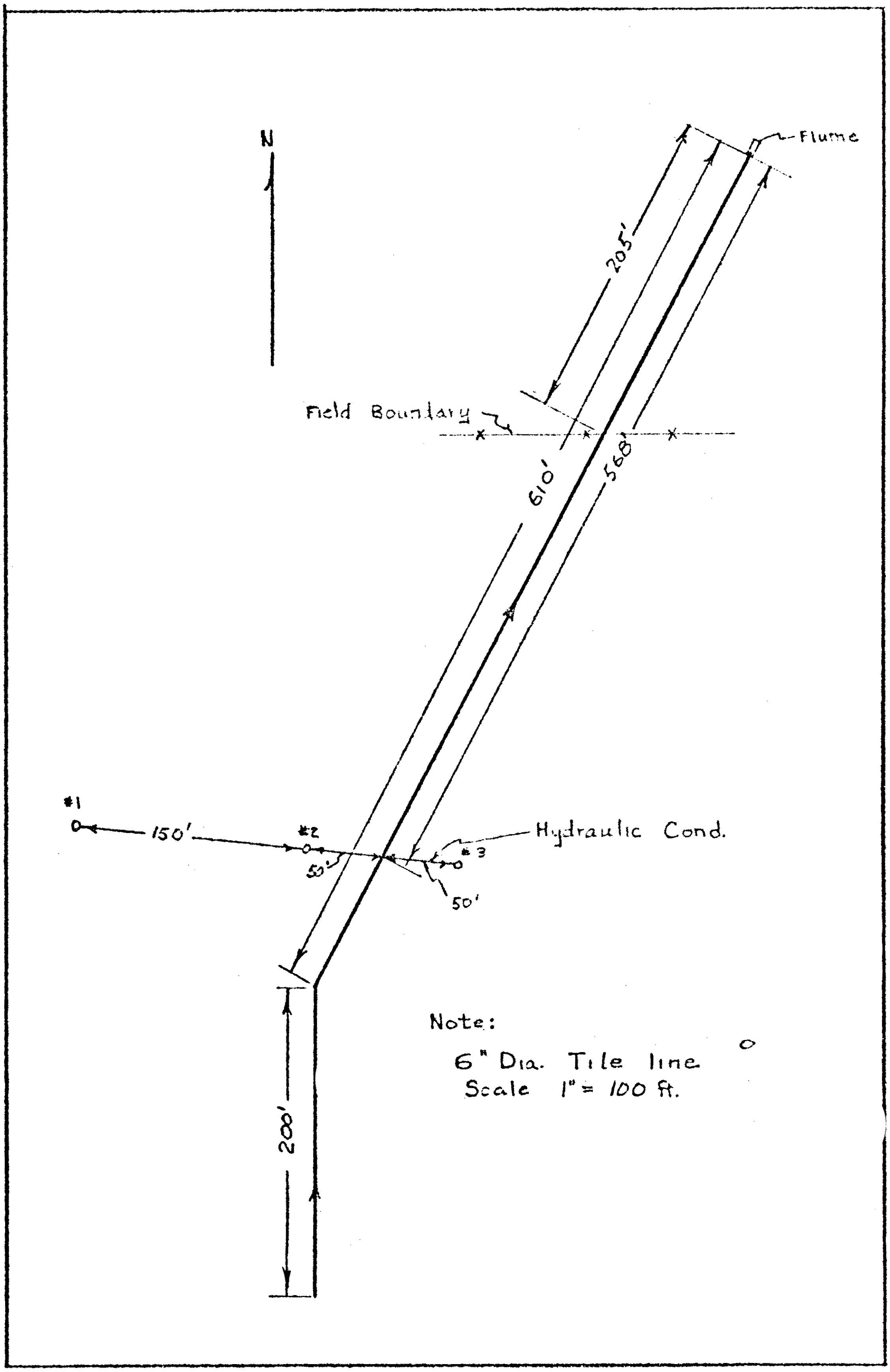


Figure 10 Map of Interceptor Tile Drain Rogan Farm

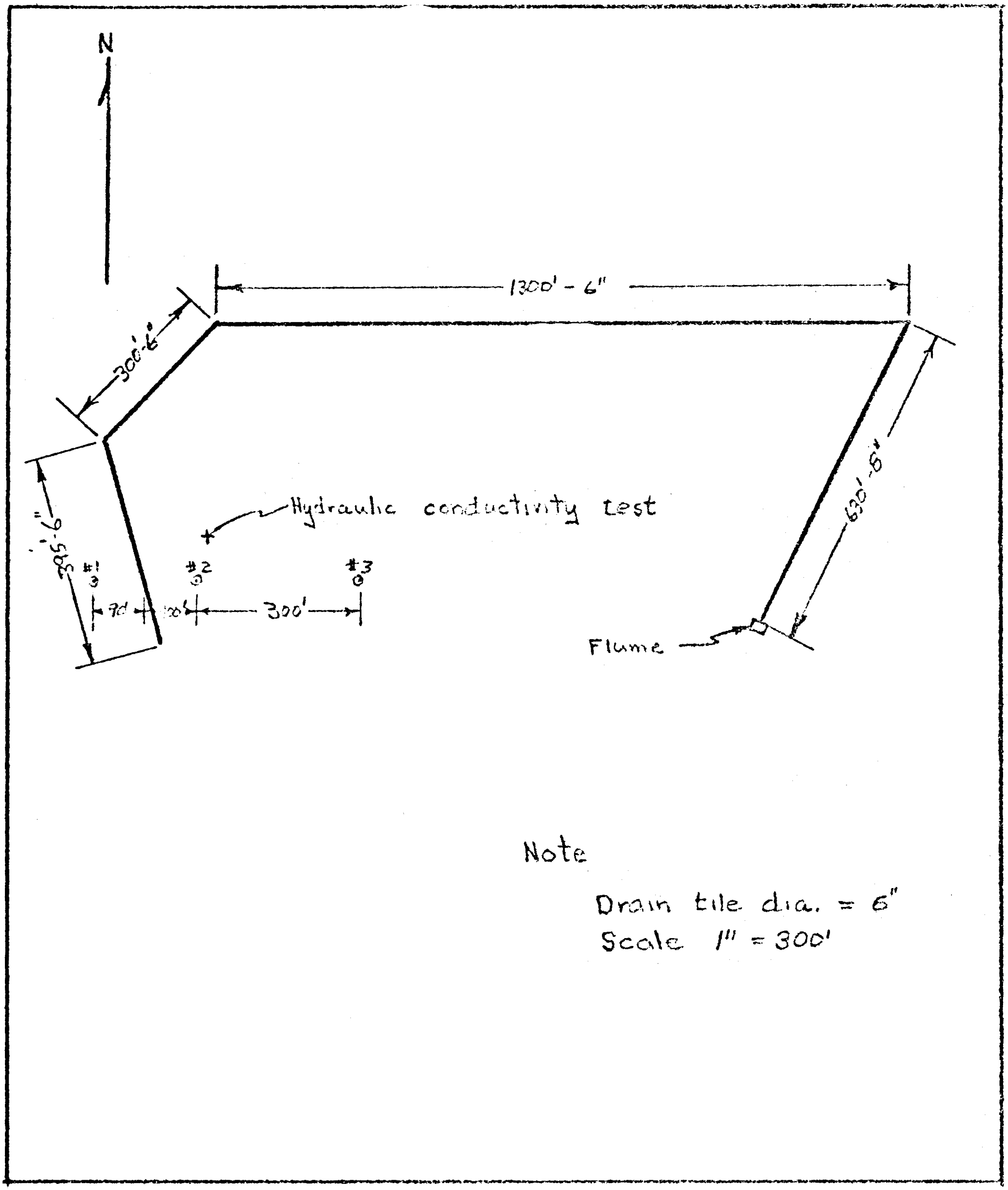


Figure 11 Map of tile interceptor drain Spangler Farm 1956

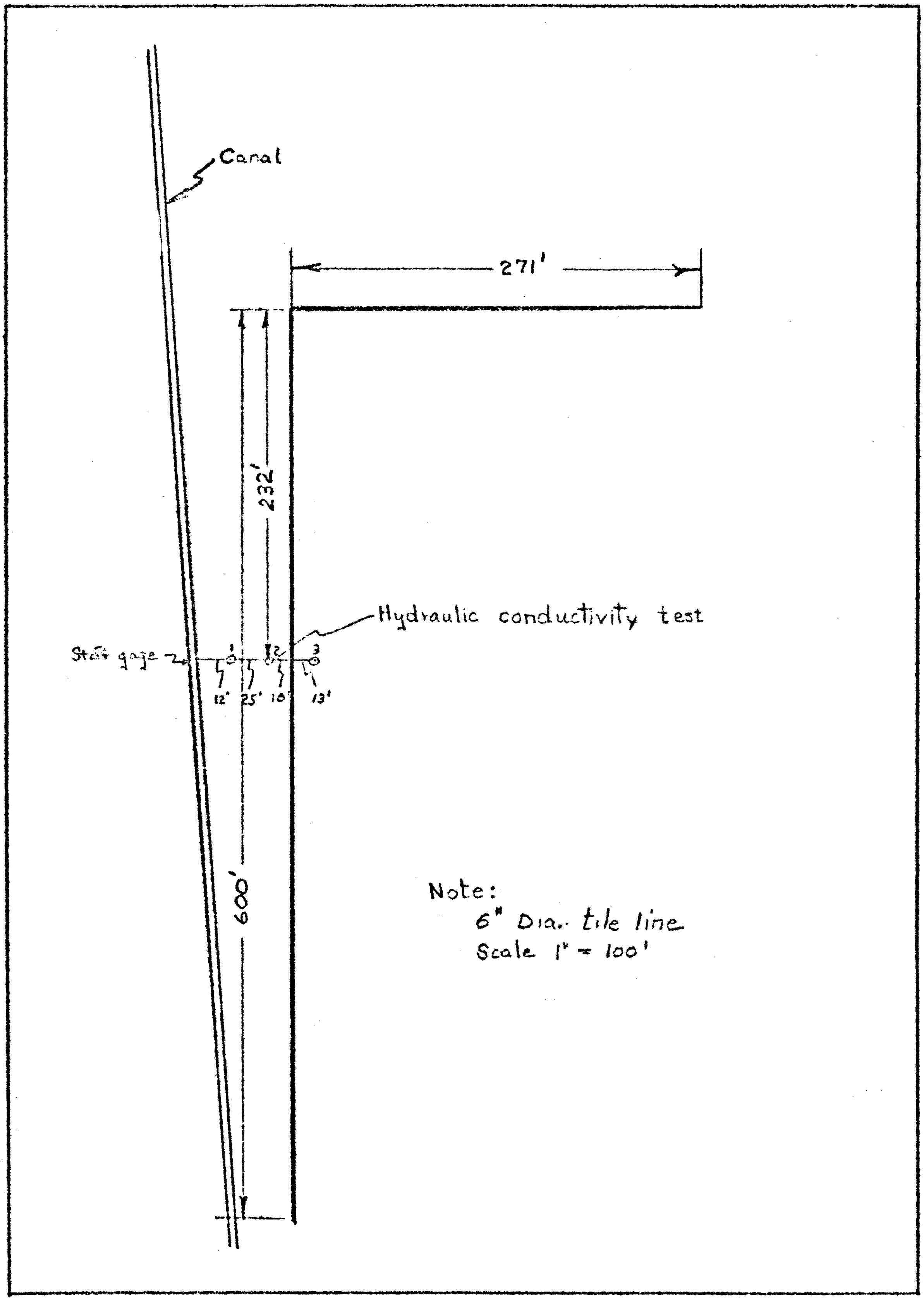


Figure 12 Map of Interceptor Tile Drain Sprenger Farm

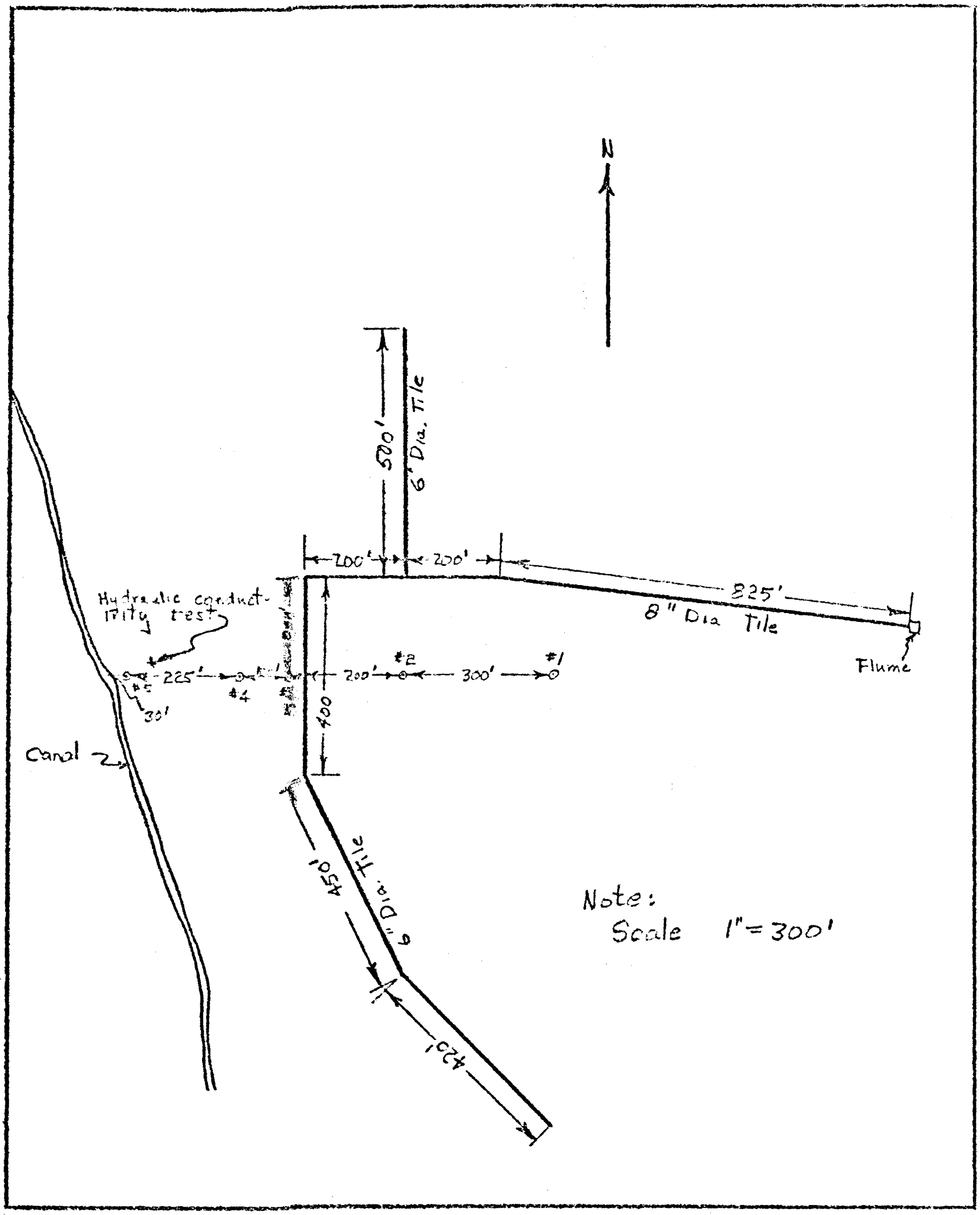


Figure 13 Map of interceptor tile drain Stewart + Adams Farm.

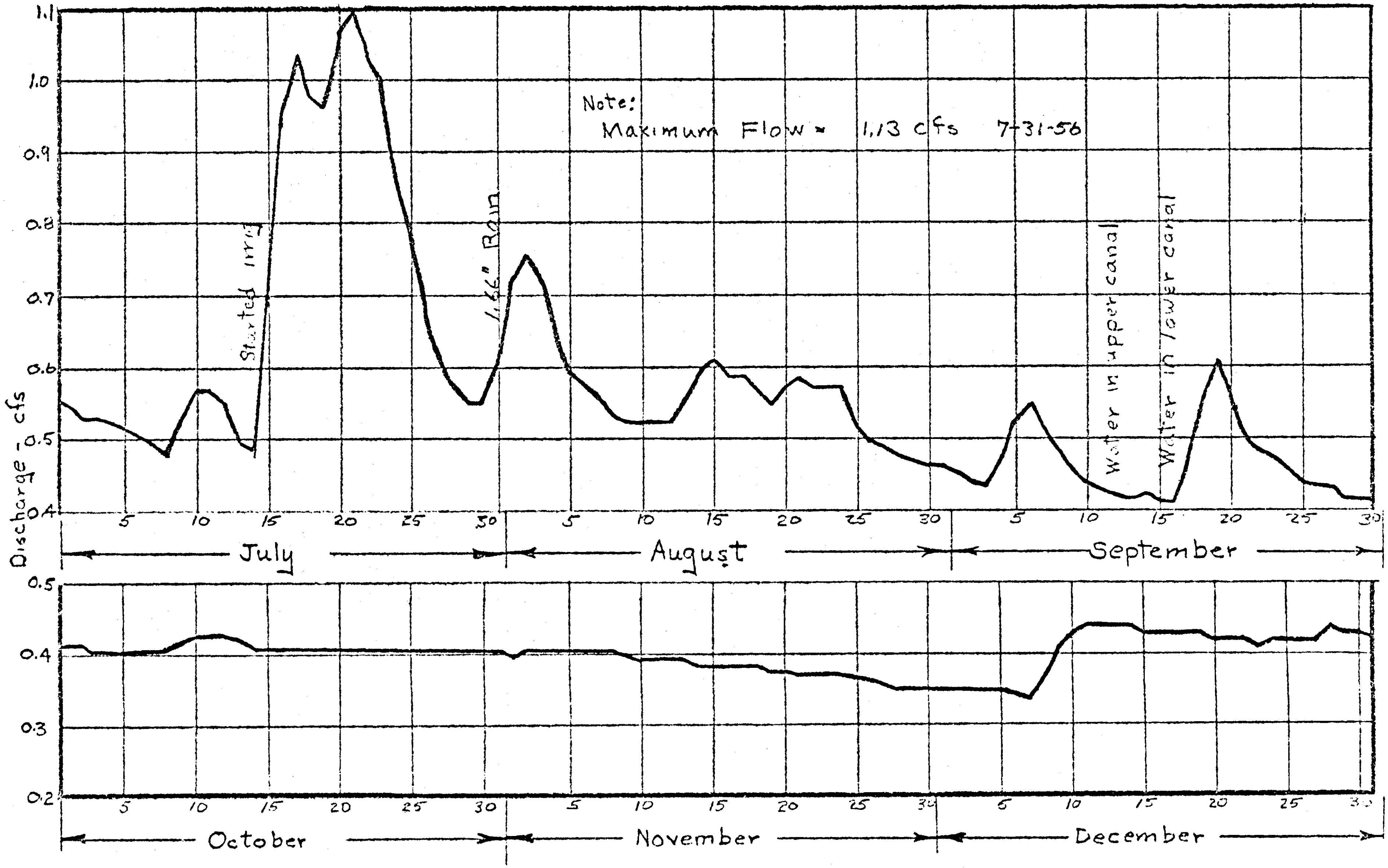


Figure 14 Average daily discharge Aronci Drain 1956

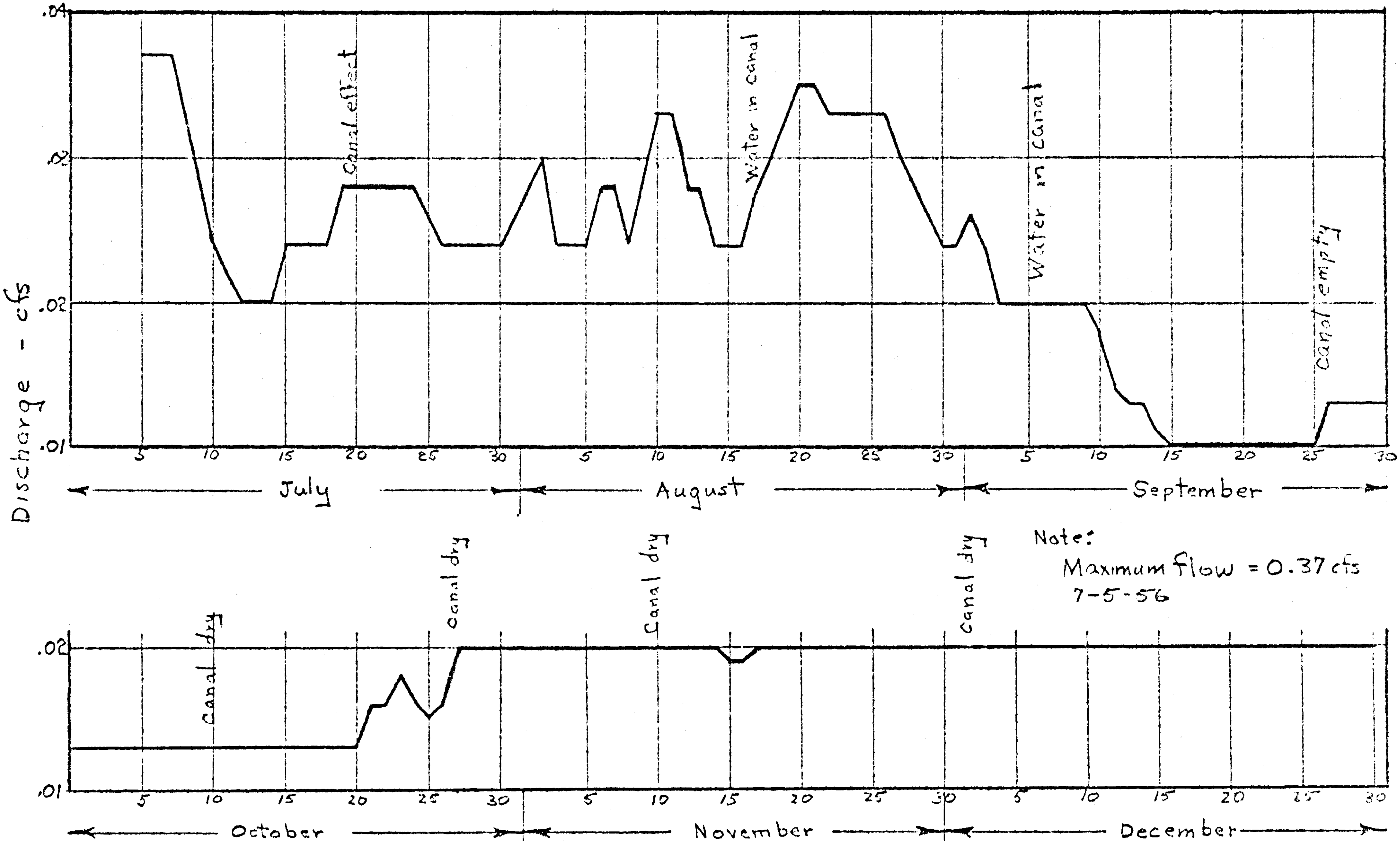


Figure 15 Average daily discharge E. P. H. Corp. Farm 1956

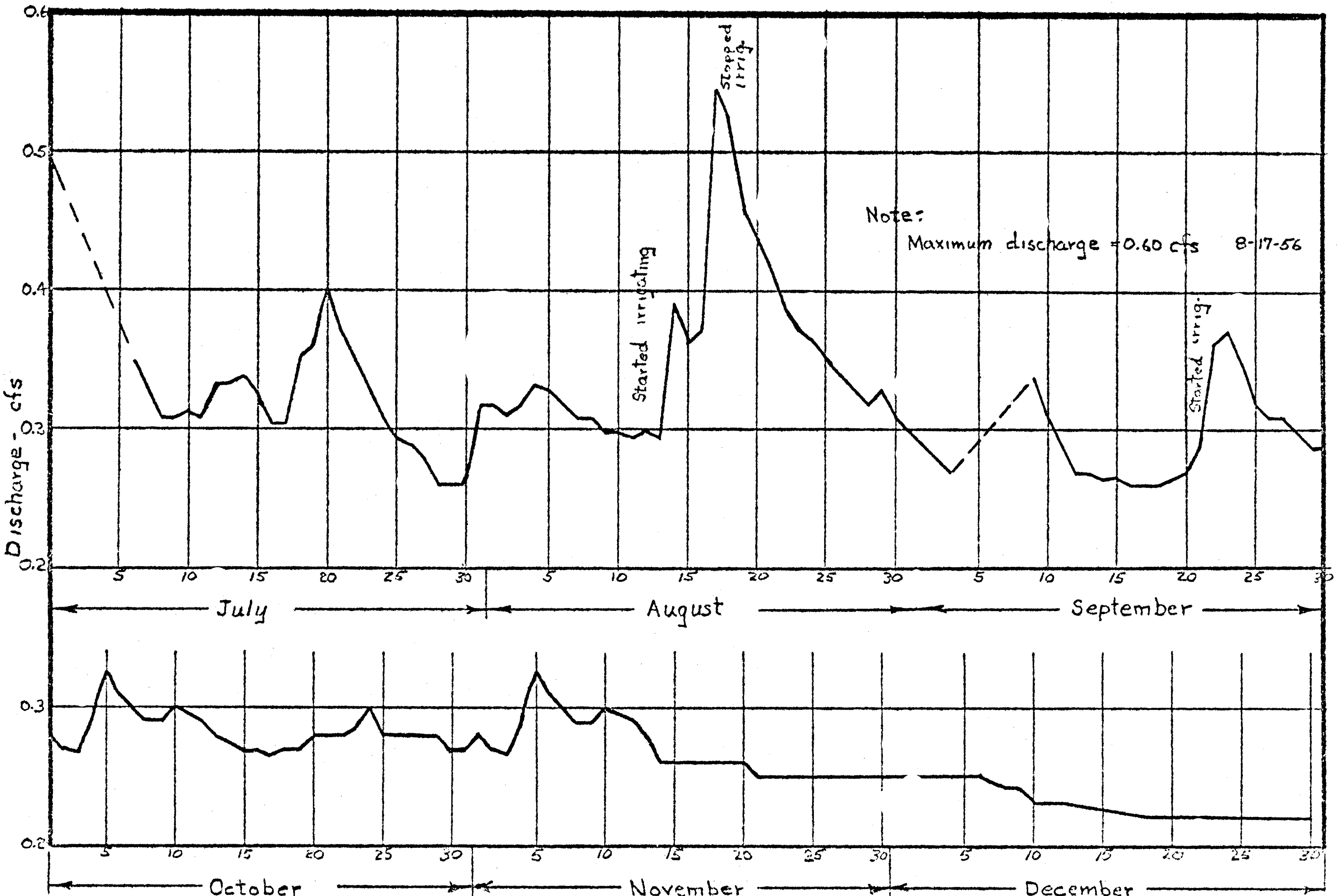


Figure 16 Average daily discharge Foote drain 1956

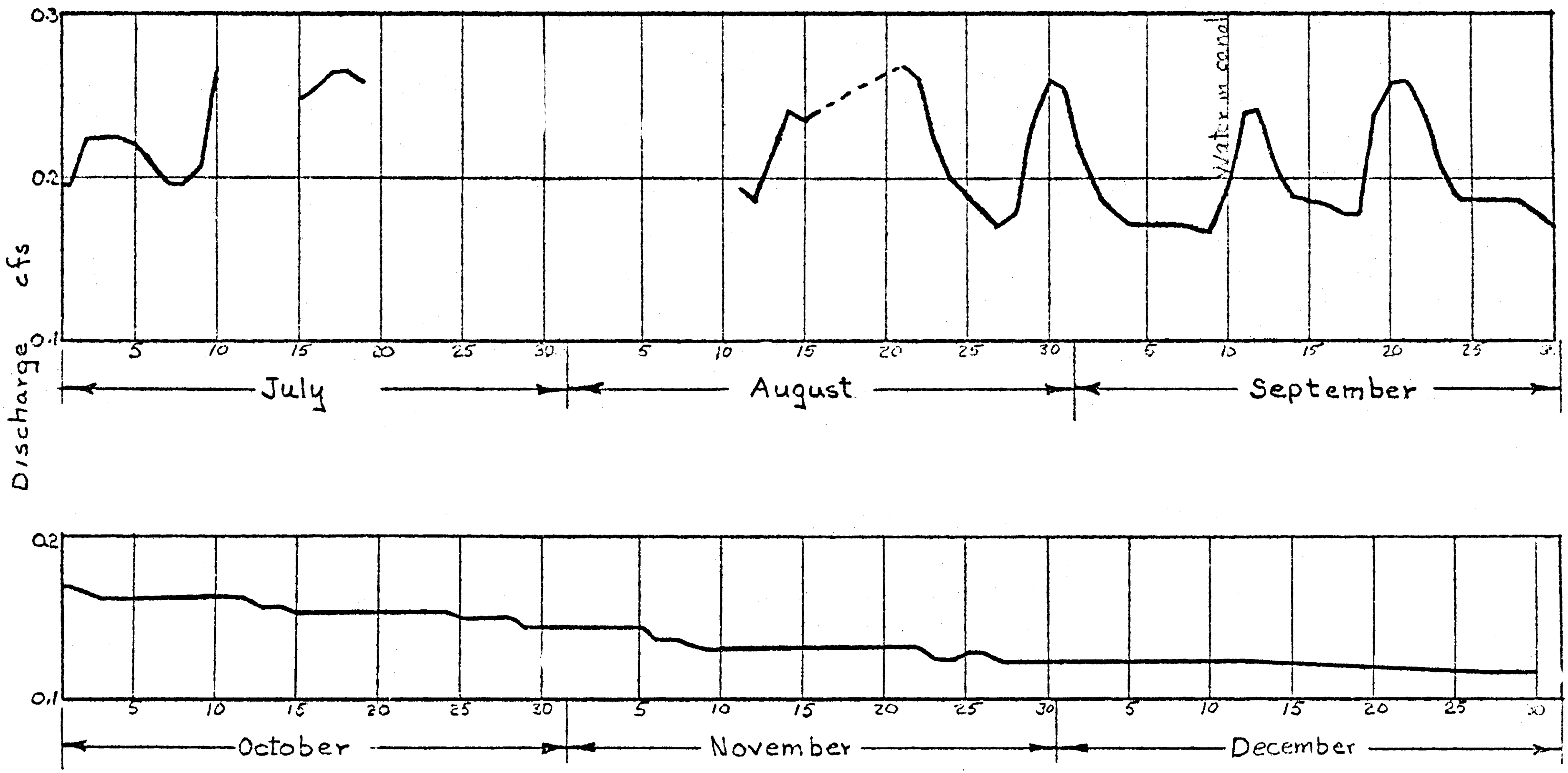


Figure 17 Average daily discharge Kluver Drain 1956

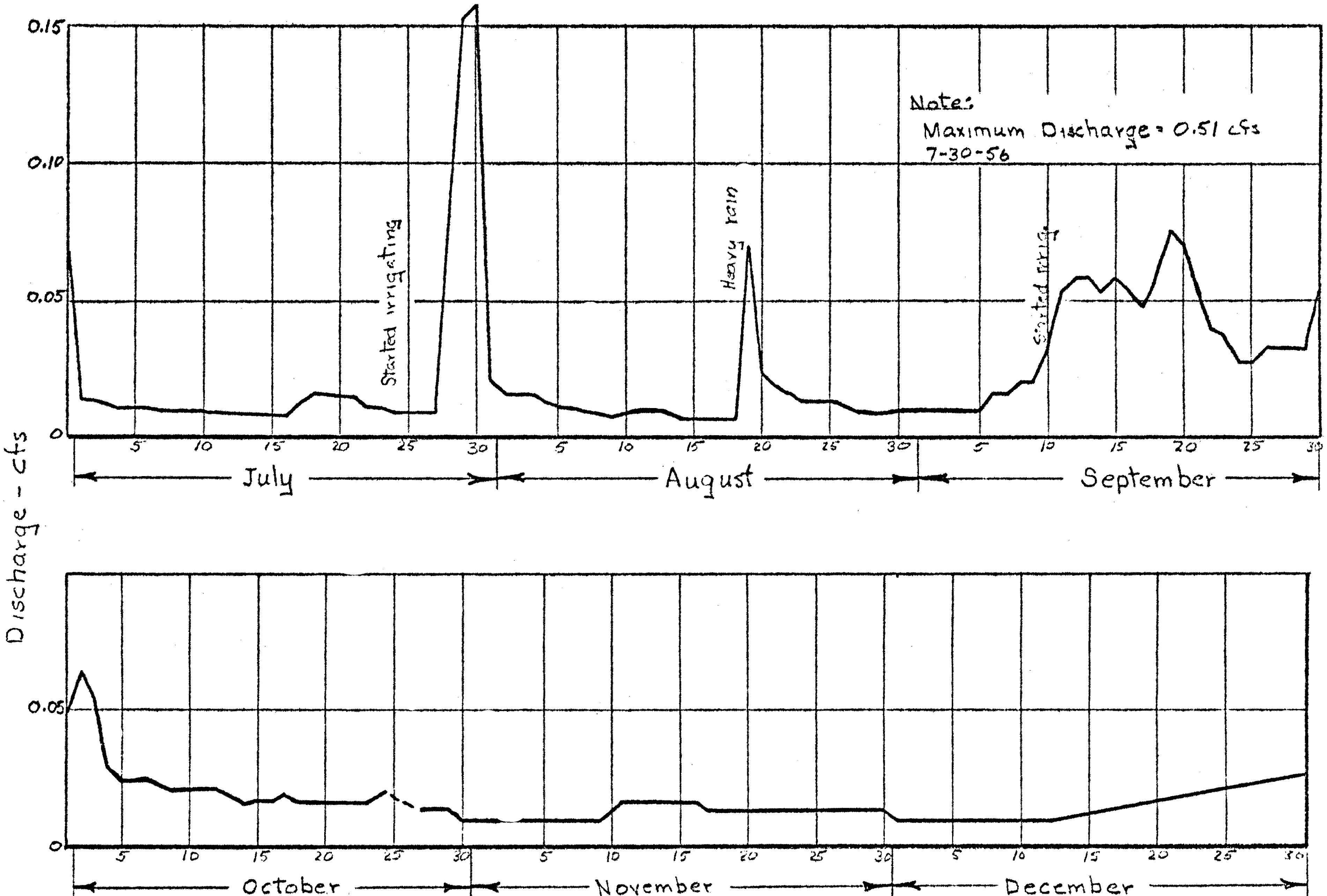


Figure 18 Average daily discharge McCormick Drain 1956

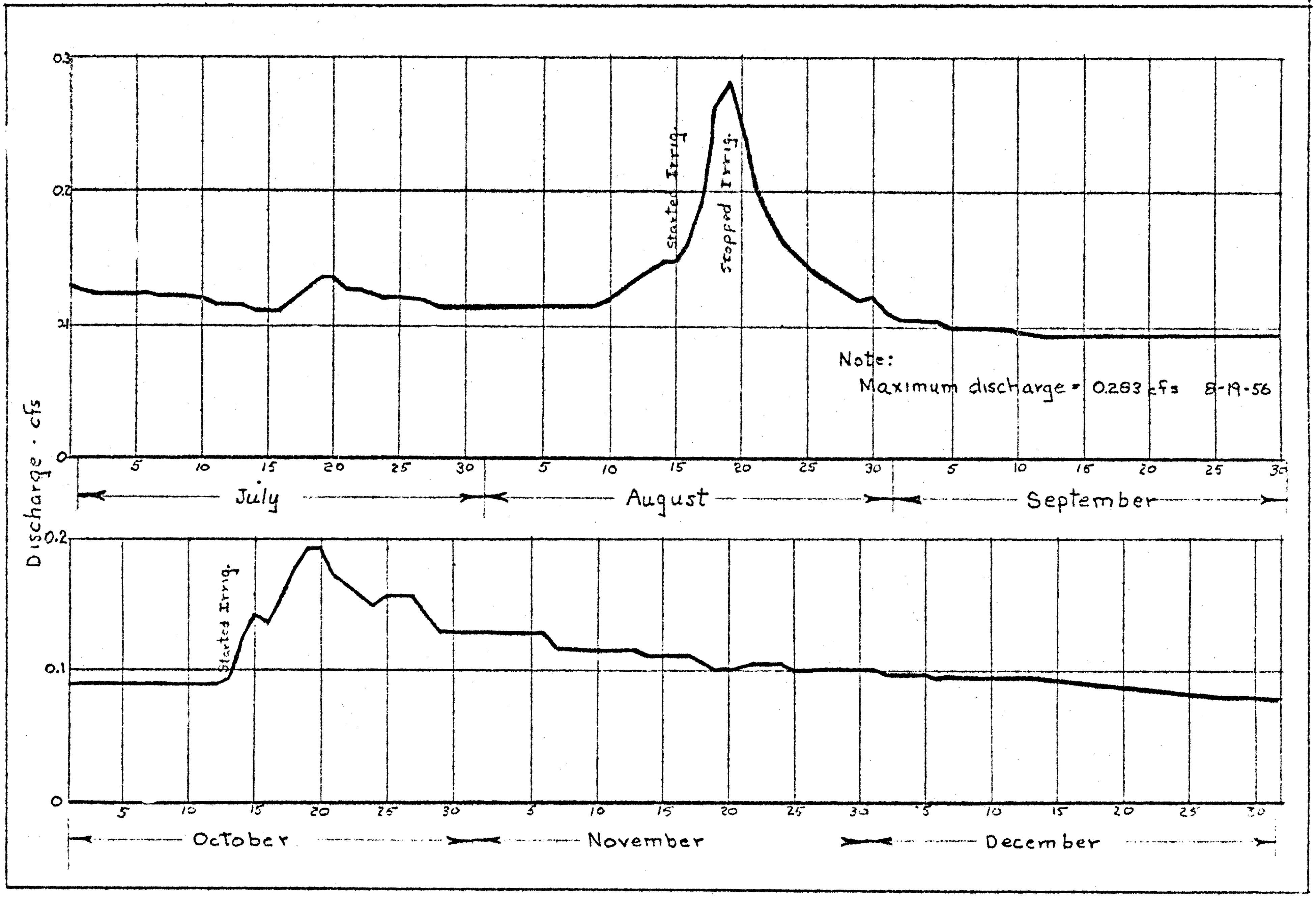


Figure 19 Average daily discharge - Tile drain · Ragan Farm 1956

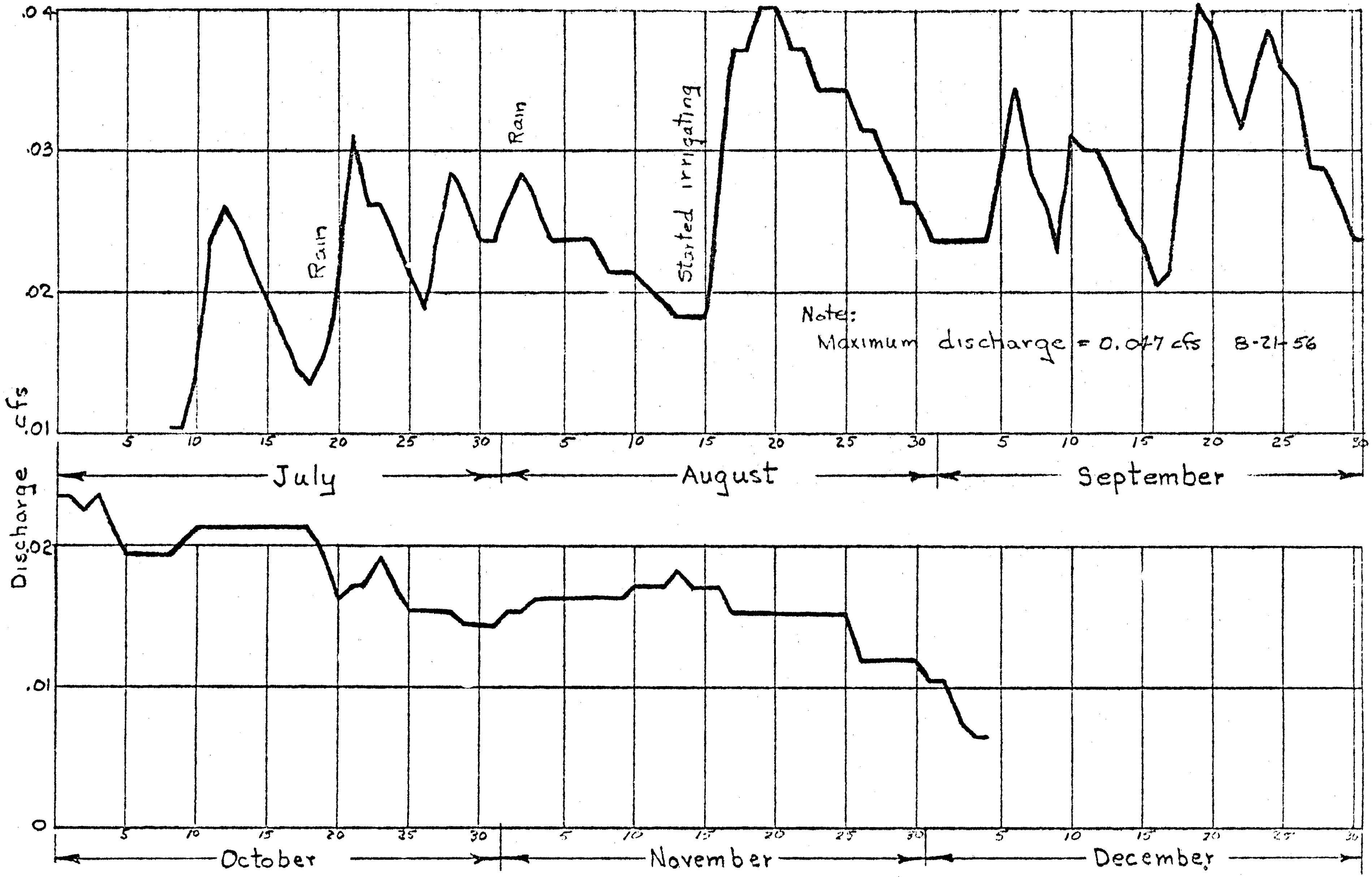


Figure 20 Average daily discharge Spangler Drain 1956

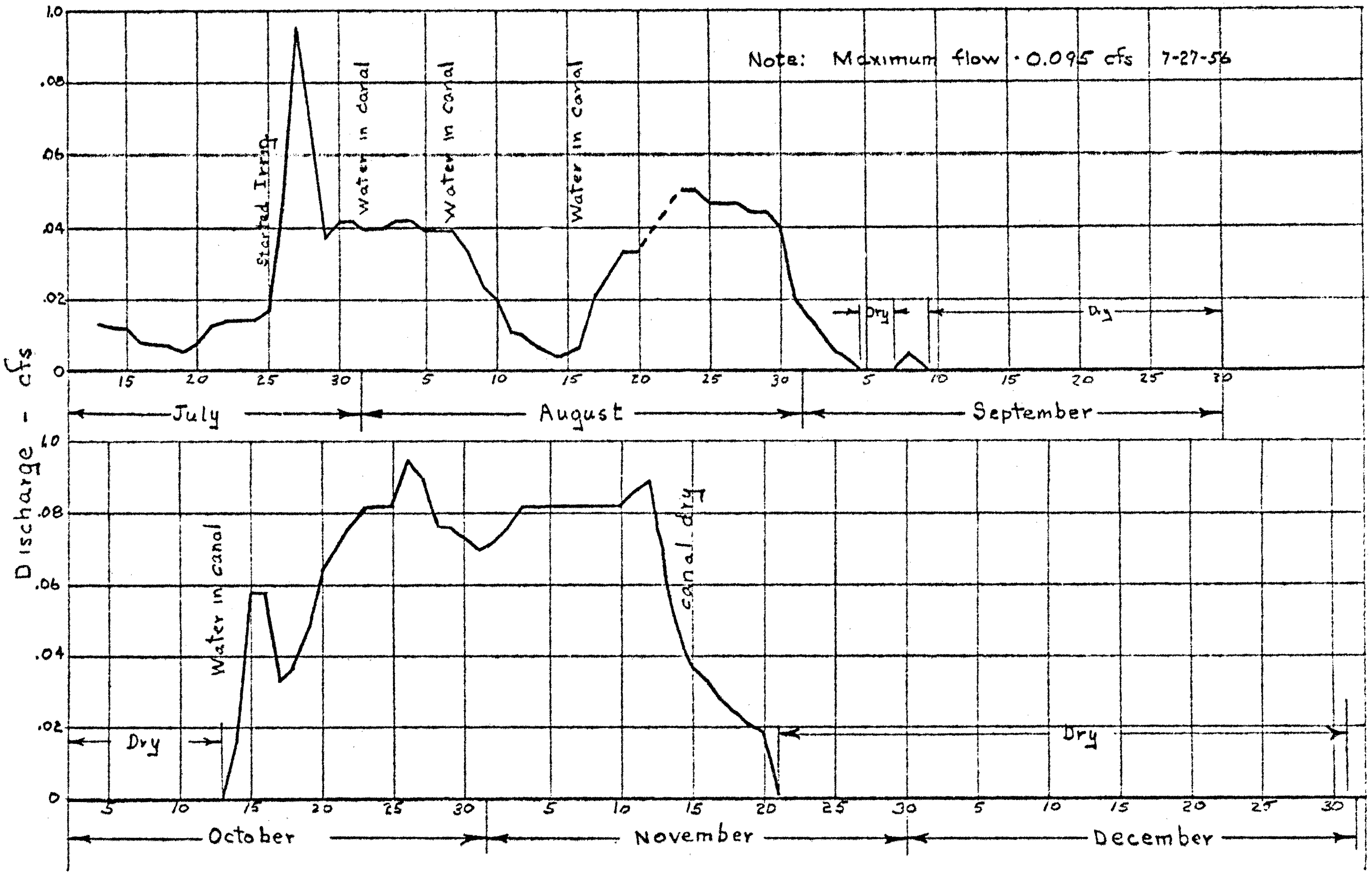


Figure 21 Average daily discharge Sprenger Farm 1956

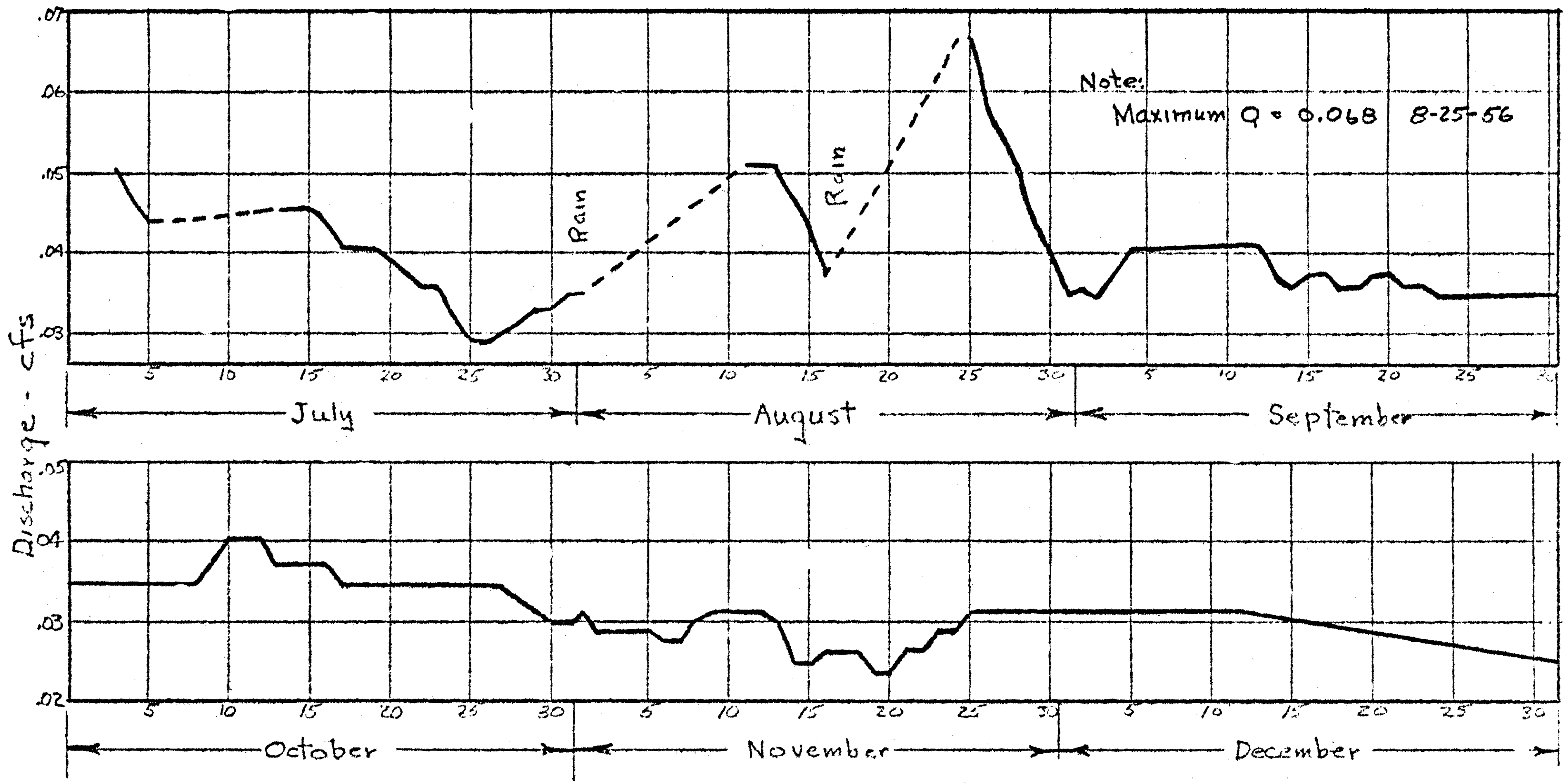


Figure 22 Average daily discharge - Tile Drain - Stewart + Adams Farm 1956

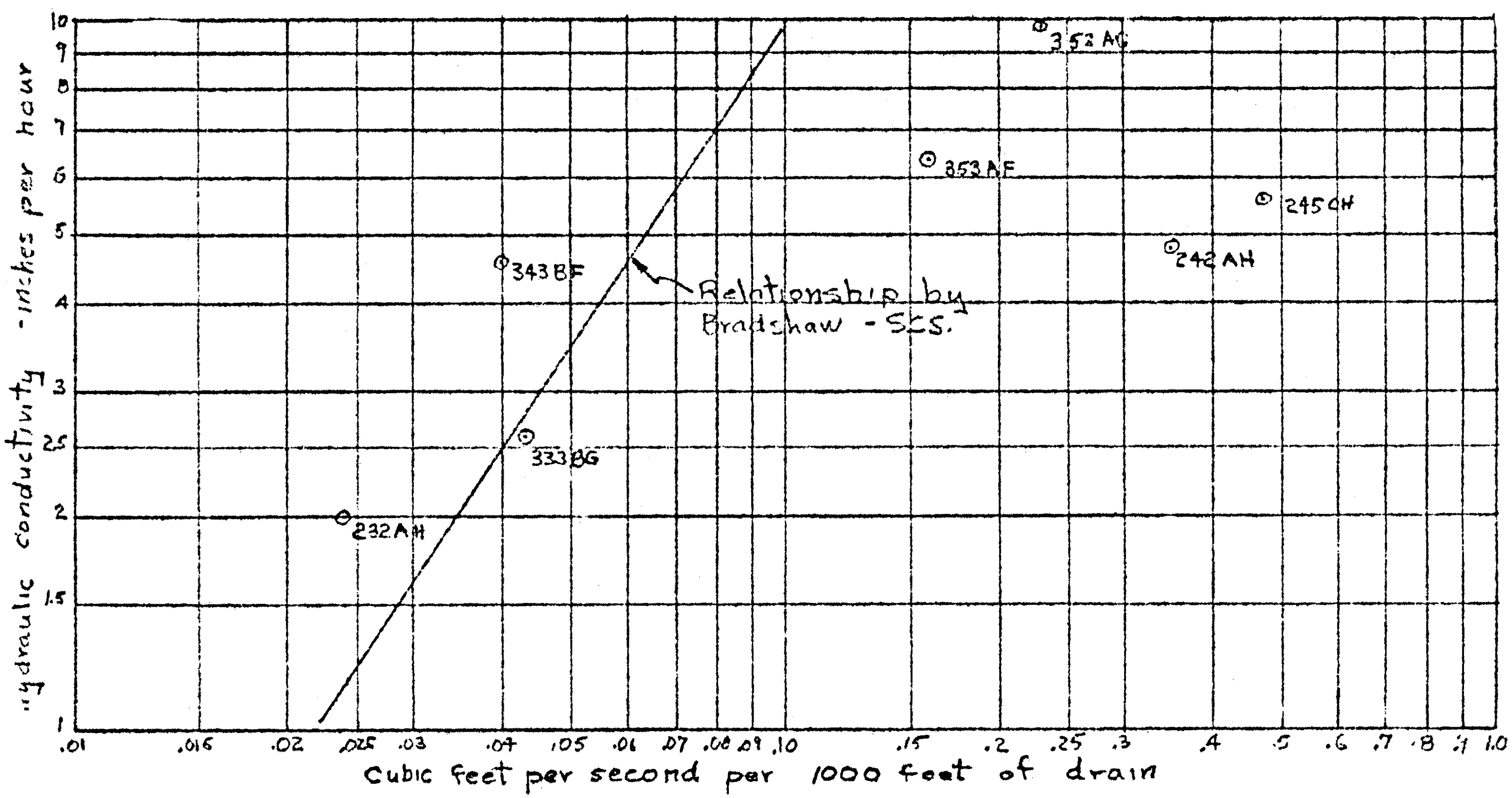


Figure 23 Interceptor drain peak discharge as a function of hydraulic conductivity for different farm classifications.

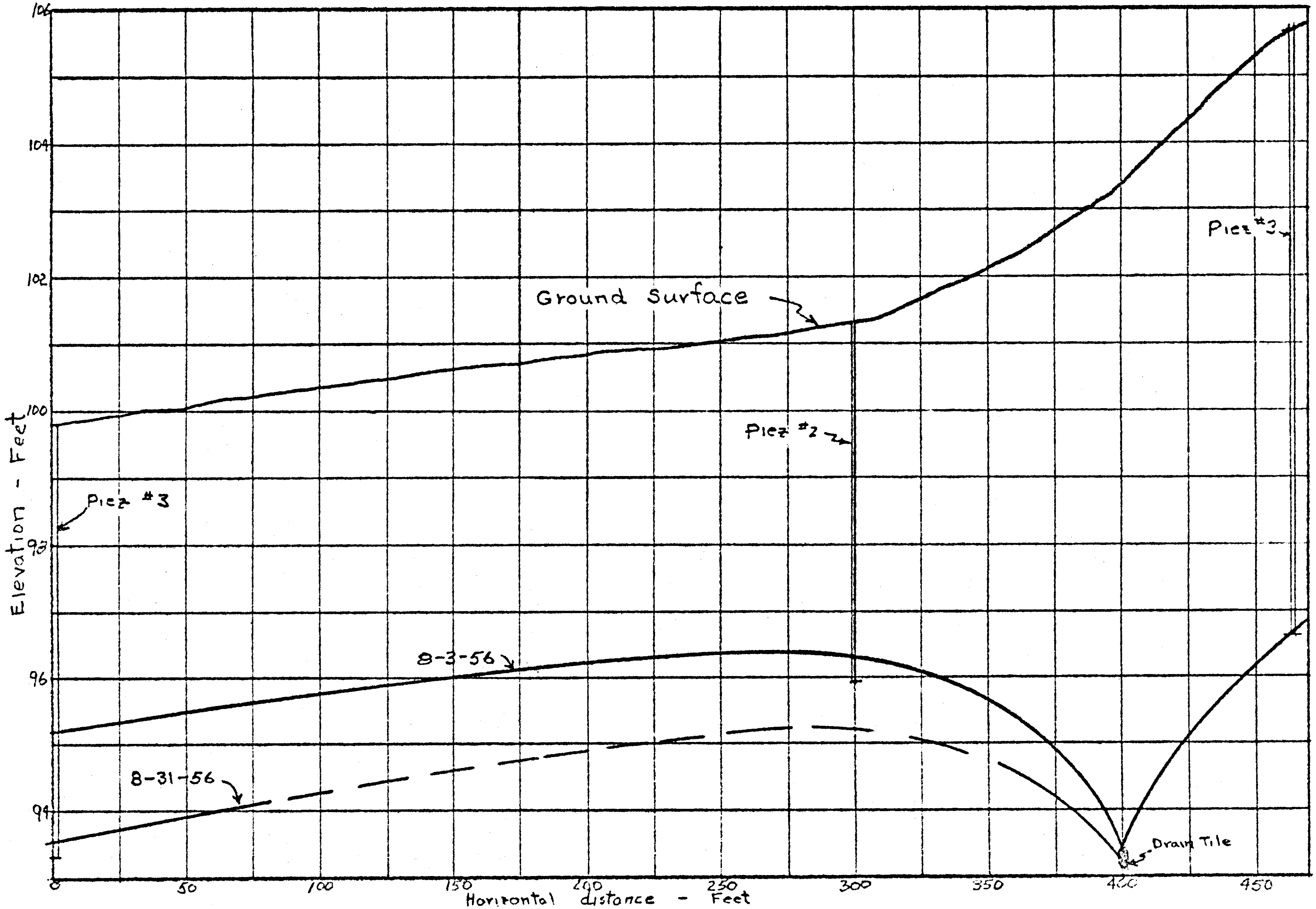


Figure 24-A Ground water profiles Aronci Drain Line 1 1956

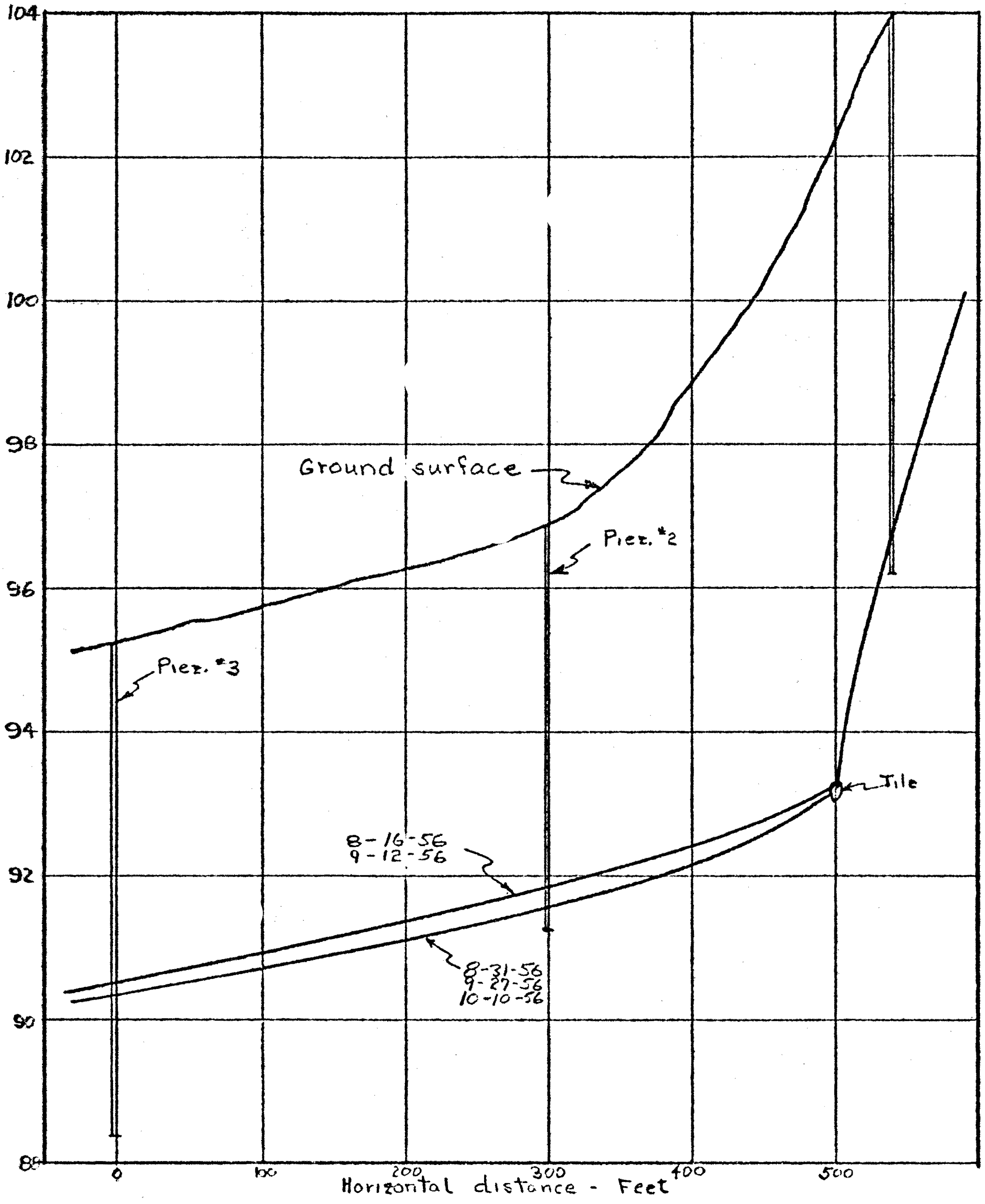


Figure 24-B Ground water profiles Aronci Drain - Line 2 1956

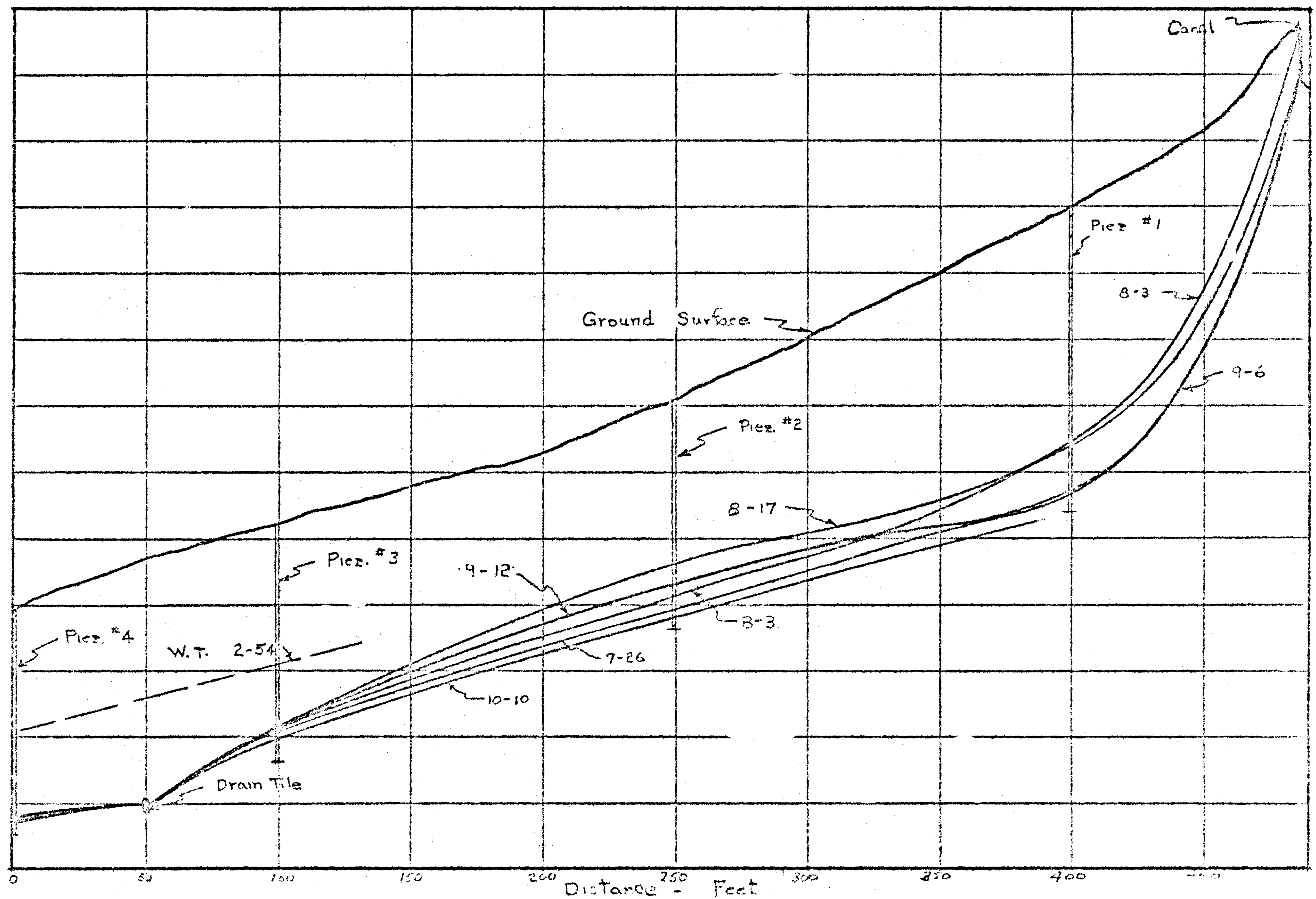


Figure 25 Ground water profiles E.R.H. Corp. Farm 1956

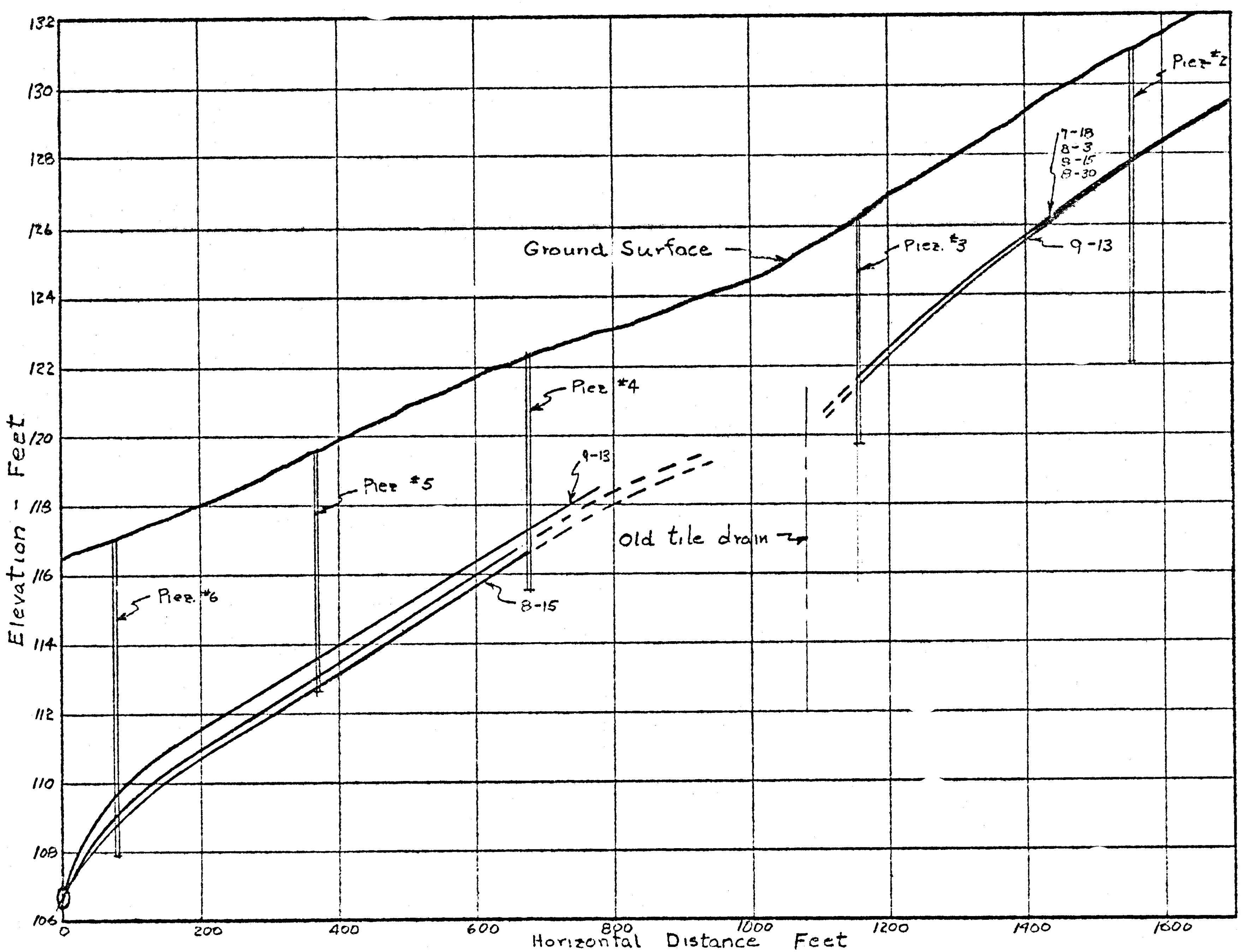


Figure 26 Ground water profiles Foote Farm 1956

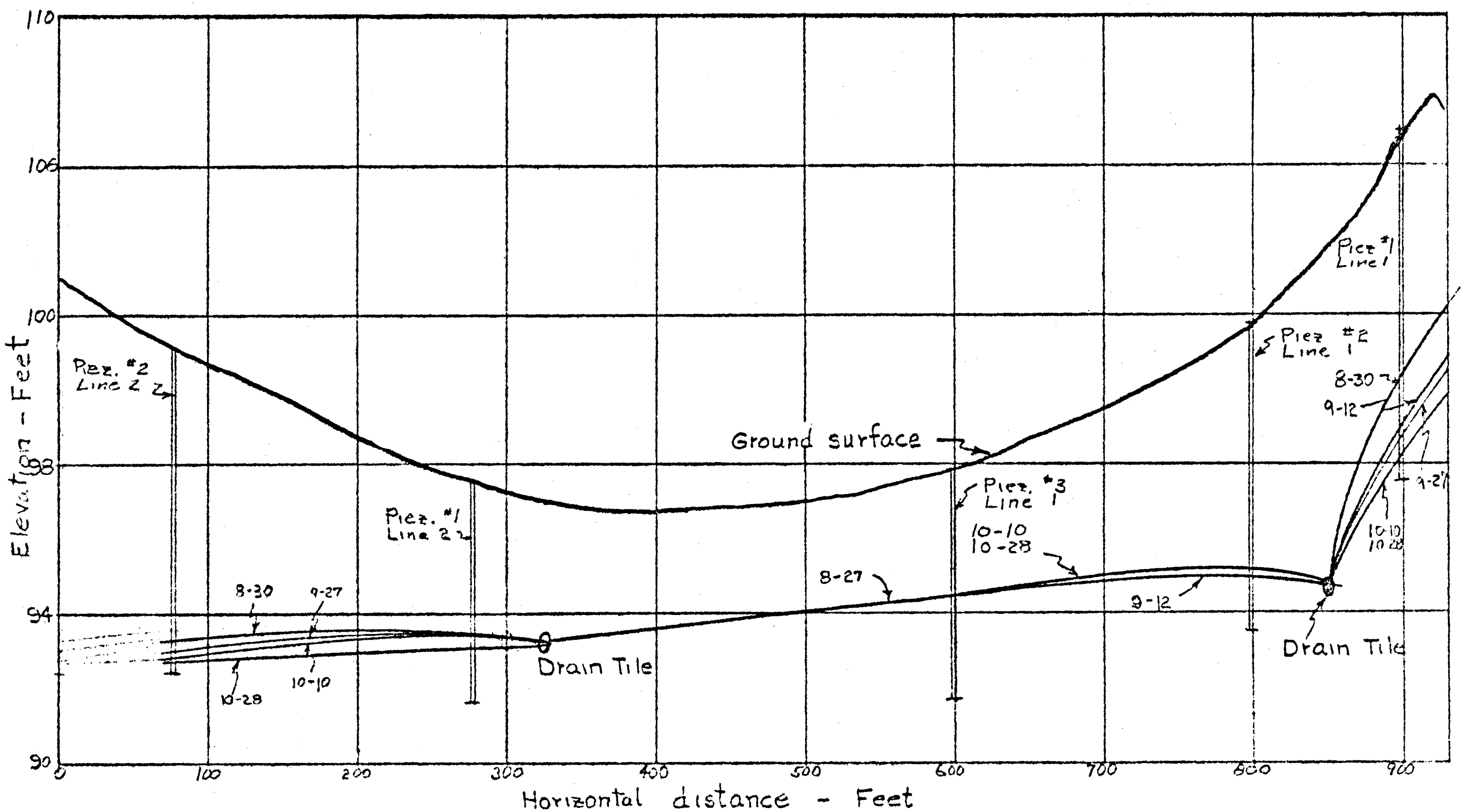


Figure 27 Ground water profiles Kluver Farm 1956

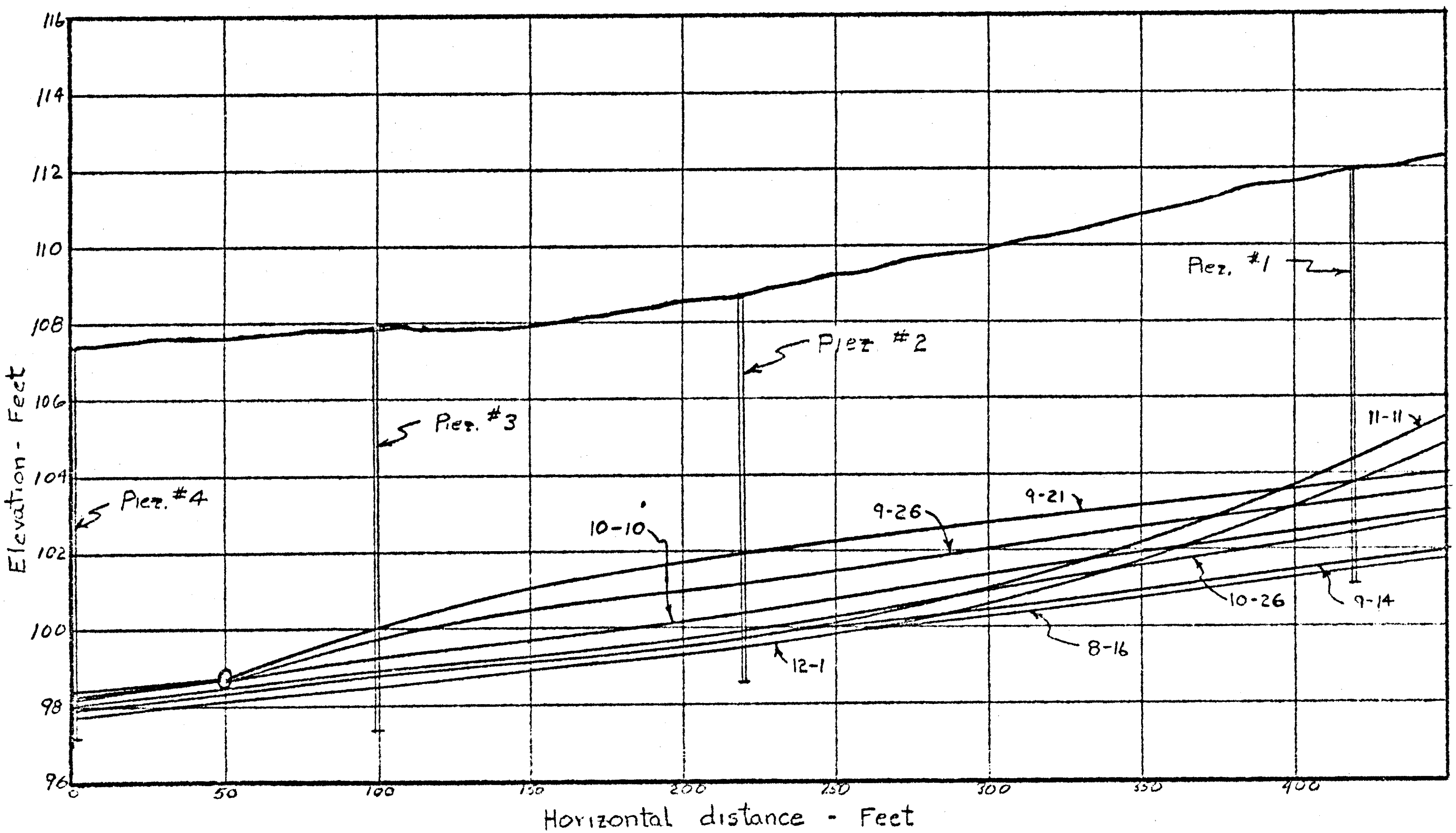


Figure 28 Ground water profiles McCormick Farm 1956

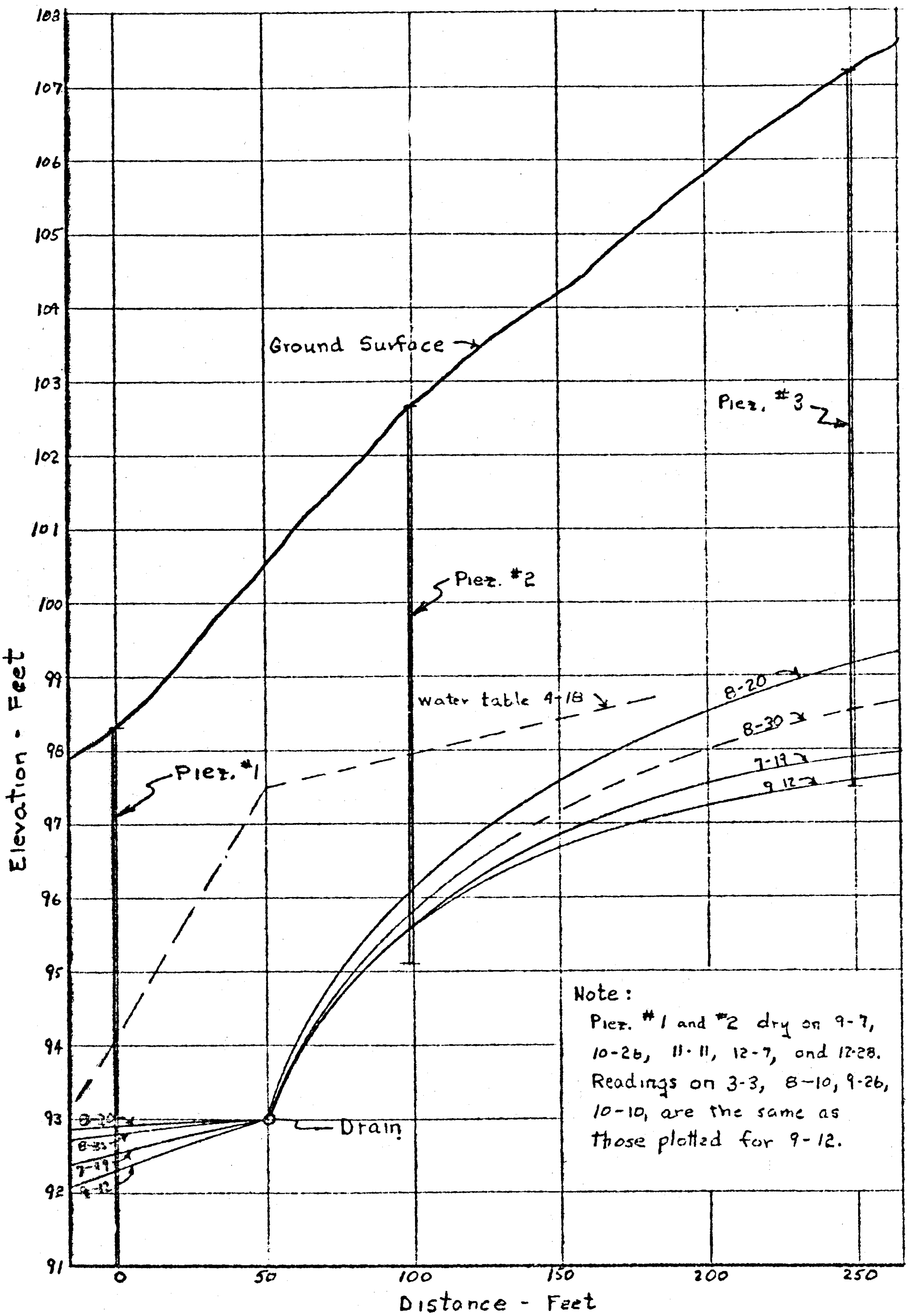


Figure 29 Ground water profiles - Ragan Farm - 1956

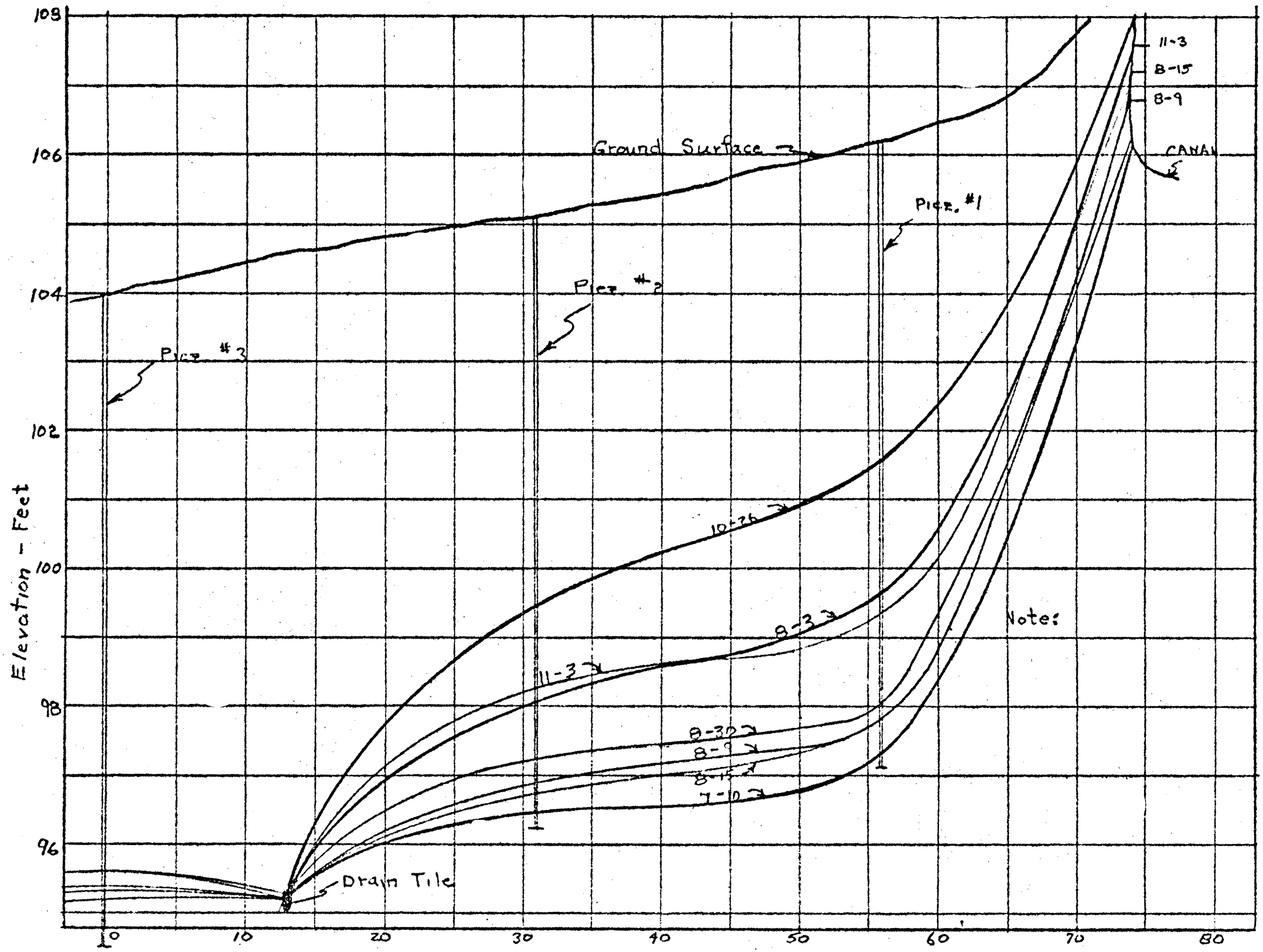


Figure 30 Ground water profiles Sprenner Farm 1956

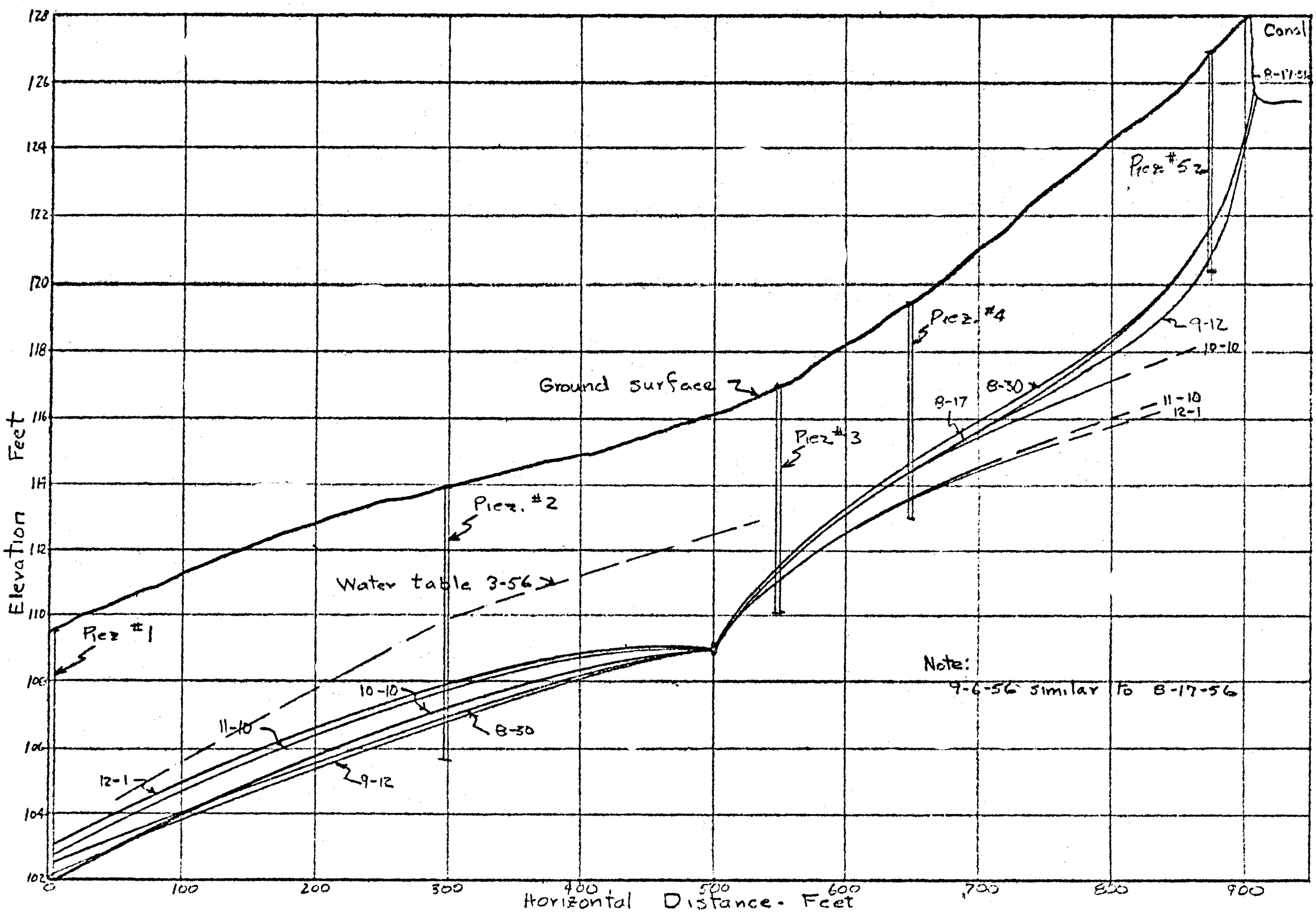


Figure 31 Ground water profiles Stewart + Adams Farm 1956