UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

OCCURRENCE OF GROUND WATER NEAR ANA SPRINGS, SUMMER LAKE BASIN, LAKE COUNTY, OREGON

By

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Open-file report
Not reviewed for conformance with standards
and nomenclature of the Geological Survey

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ABSTRACT

Ana Springs are near the north end of Summer Lake Basin, a closed fault-block basin in Lake County Oregon. The water of the springs rises by artesian pressure from lava-rock aquifers through about 150 feet of overlying thinly bedded lake deposits to discharge at the bottom of an impounding reservoir, the spring orifices being beneath 30 to 36 feet of water. On the valley floor less than a mile south and southwest of the reservoir artesian wells appear to tap the same lava rock from which the waters of the springs arise.

Observations of the piezometric surface of the artesian water during flow tests show that three artesian wells, 30/16-1R1, 30/17-7D1, and -7F1, are hydraulically connected with a fourth, 30/16-1R2, and that well 30/16-1R2 is hydraulically connected with Ana Springs. A fifth artesian well, 30/16-12A1, did not show hydraulic connection with the other four wells during the short-term tests made.

Mathematical constants derived from the tests permit calculations which indicate that the four wells, 30/16-1R1, -1R2, 30/17-7D1, and -7F1, when flowing at a combined rate of 4,600 gpm for 100 days, may lower the pressure head on Ana Springs by an amount equal to 2.7 feet of water. This lowering in pressure may cause a decrease in the rate of discharge of Ana Springs by about 4.4 cubic feet per second, or about 5 percent of the present wintertime rate of discharge. This diversion (5 percent) would be within the limit of error of single measurements of the spring discharge. Chemical and temperature characteristics of the Ana Springs water indicate it is similar to the water of the five lava-rock wells.

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INTRODUCTION

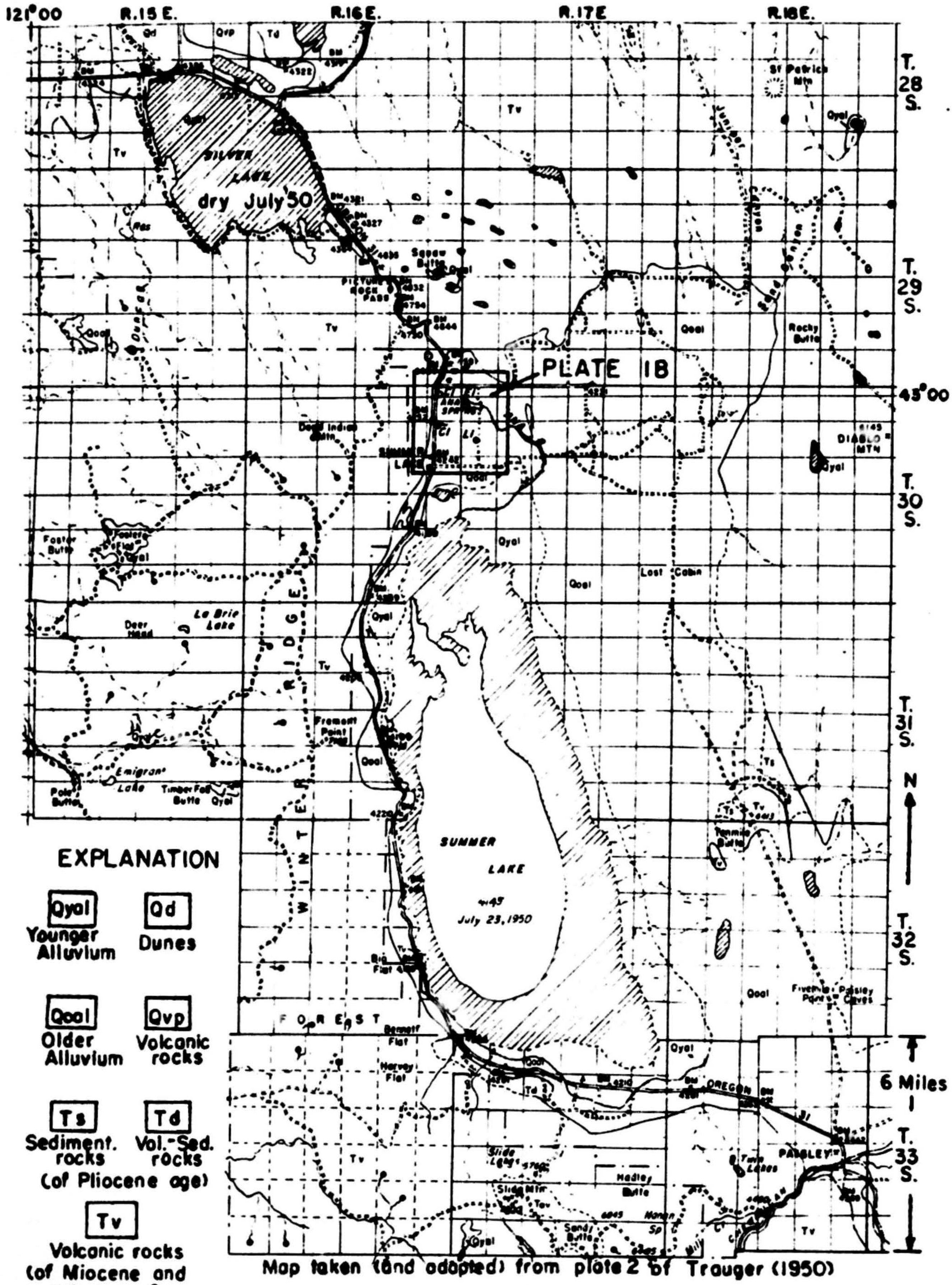
Purpose of the Investigation

As a part of the investigation in cooperation between the office of the State Engineer of Oregon and the U. S. Geological Survey for the evaluation of the ground-water resources of Oregon, the Geological Survey undertook an investigation to determine the immediate origin of the water of Ana Springs, which are the principal source of Ana River. The river is the main tributary feeding Summer Lake in Lake County, in south-central Oregon (pl. 1A). Distribution of the main geologic units is given in earlier reports covering Lake County (Waring, 1908; Trauger, 1950).

The extent and boundaries of the ground-water body feeding Ana Springs have not been determined. This investigation was intended to shed some light on the immediate source of Ana Springs and to determine the relation between the water discharging from the springs and that pumped or flowing from certain wells.

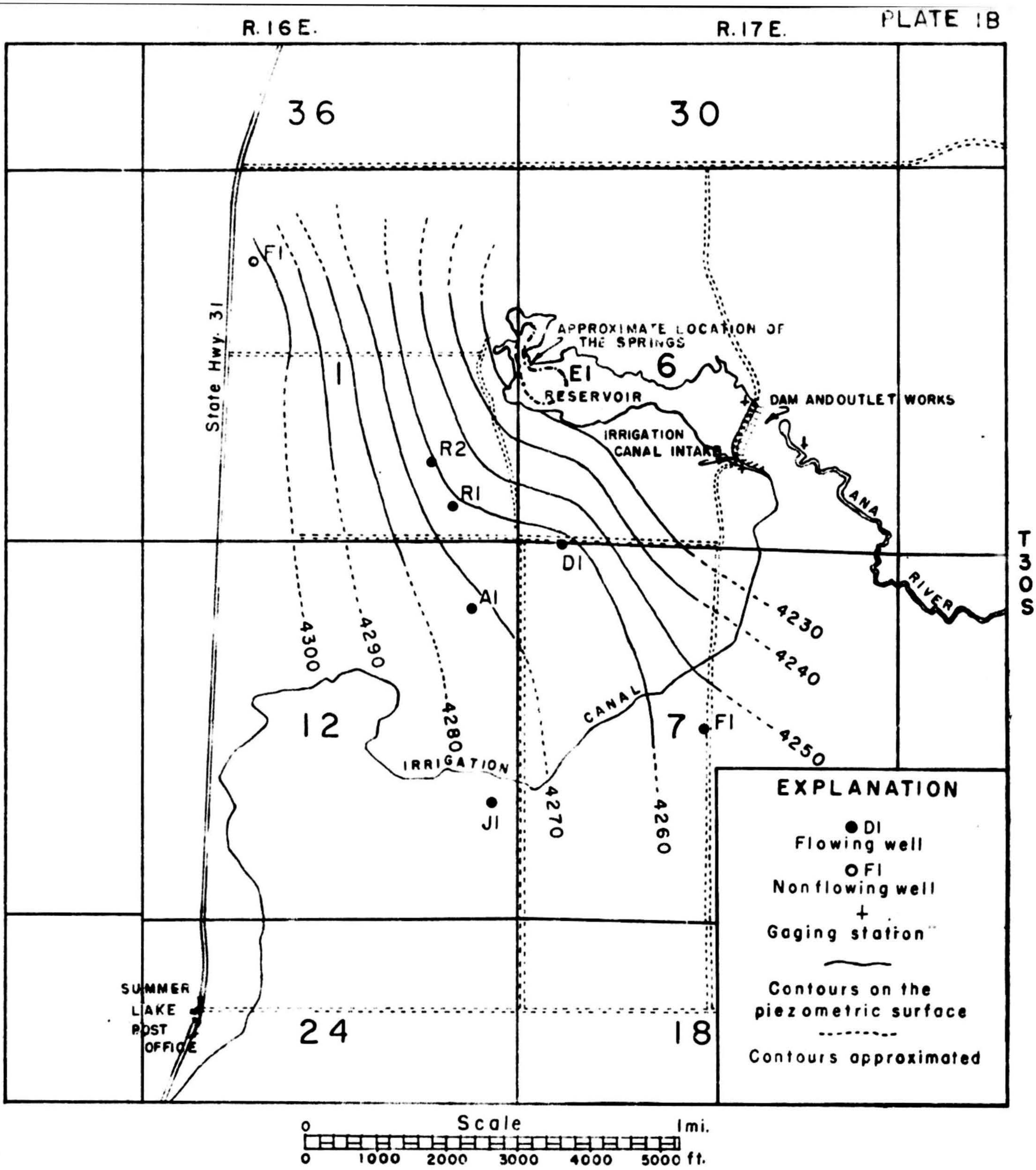
Ana Springs and the impounding reservoir into which they discharge, lie mostly within sec. 6, T. 30 S., R. 17 E. (pl. 1B). The reservoir is formed by an earthen dam about half a mile east of the two main spring orifices. The 60-foot-high dam raises the water surface to an altitude of approximately 4,220 feet, a level which is about 30 feet below the surrounding plain, and an average of about 36 feet above the orifices of Ana Springs. The dam and reservoir are owned and operated by the Summer

PLATE-1A



Map taken (and adapted) from plate 2 of Trauger (1950)

MAP OF THE AREA AROUND SUMMER LAKE BASIN IN LAKE COUNTY, OREGON



MAP SHOWING LOCATION OF ANA SPRINGS RESERVOIR, NEARBY WELLS, AND CONTOURS ON THE PIEZOMETRIC SURFACE.

Lake Irrigation District. The wells directly involved are located in secs. 1 and 12, T. 30 S., R. 16 E., and sec. 7, T. 30 S., R. 17 E. These wells are described in tables 1 and 2. Plate 1B shows the location of the wells and springs for which data were obtained, the Ana Springs Reservoir, and the upper part of Ana River.

Physiographic and Geologic Setting

General Physiographic Environment

The structural framework of the Summer Lake Basin is that of a typical downdropped fault block of the Basin and Range physiographic province (Fenneman, 1917). The basin is 25 miles long in a general north-south direction and about 13 miles wide. A prominent fault escarpment forms the west side of the basin and its crest is known as Winter Ridge; it rises from the 4,145-foot altitude of the valley floor to a general altitude of about 7,000 feet. The surrounding upland is cut by many other faults, some of which disappear beneath the alluvium of the Summer Lake basin. The downdropped block has received a deep alluvial fill and the valley floor is a wide, flat plain that rises slightly toward the edges. The central part of the valley floor is occupied by Summer Lake, a shallow but perennial lake which has no surface outlet. The gently sloping alluvial plain at the north end of the lake is trenched by a sharp ravine in which the Ana River flows from its origin in Ana Springs southward about 3 miles to Summer Lake.

Valley Alluvium

The valley plain o f the Summer Lake basin is underlain by lake deposits which consist of finely bedded silt, clay, and fine sand. The maximum thickness of these lake and alluvial deposits may be more than 1,000 feet at some places. A 1,200-foot well at the State Wildlife Refuge, 2 miles south of Ana Springs, is reported to have been drilled entirely within these materials. In the vicinity of Ana Springs the valley alluvium is about 200 feet thick, and well logs indicate that it becomes progressively thinner toward the north and west, where it can be seen to feather out against the bedrock slopes about a mile from Ana Springs. About 70 feet of these horizontal beds of silt, clayey silt, and sandy silt are exposed in the V-shaped ravine through which the Ana River flows.

Consolidated Rocks

Several thousand feet of rudely layered rock consisting most of lava flows, volcanic-sedimentary deposits, and a few intrusive masses of igneous rock are exposed in the Winter Ridge escarpment.

In the escarpments on the north, east, and south of the lake basin several hundred feet of basaltic lava flows and other volcanic rocks similar to those in the upper part of the Winter Ridge escarpment are exposed. Similar lava rocks underlie the lake beds and other valley fill deposits in the Ana Springs vicinity. The volcanic rocks were encountered beneath the silty lake-bed deposits at a depth of 380 feet in well -7F1, 205 feet in -7D1, 181 feet in -1R1, 185 feet in -1R2, and about 370 feet in -12J1.

The volcanic rocks are mostly basaltic and andesitic lava flows. There are some beds of tuff and some autobrecciated lavas. The brecciated lavas are the most permeable units of the bedrock and are called "cinders" by well drillers. The five wells listed above obtain ground water from such breccia or from lava flows which are moderately well jointed even though more massive than the breccia.

Characteristics of Ana Springs and Ana River

The valley plain of Summer Lake basin is interrupted by the youthful steep-walled ravine of the Ana River. This is about 70 feet deep and leads from the drowned upper orifice of Ana Springs to the north end of Summer Lake. For most of its length the ravine is less than 600 feet wide at its top, though in two parts of the reservoir it reaches greater widths. The ravine has only a faint and shallow continuation northward from the uppermost orifice of the springs. Southward the depth and width of the ravine decrease progressively as the plain, into which the ravine has been cut, descends to the level of the present bed of Summer Lake.

The main spring orifices are now drowned in the reservoir. Reports on the pre-reservoir appearance of the orifices agree that the water issued from irregularly shaped, but generally vertical, shafts in the lake beds. Waring (1908) recorded the water temperature as 66°F and the fact that the springs issued " through the sediments." He described the spring's orifices as "five or more in number," though residents generally refer to the springs as having had two main orifices, or orifices clustered in two main groups (see table 1).

The Ana River Dam

About 1915 a small dam was constructed across a narrow part of the Ana River ravine between the two main clusters of springs. This old dam is reported to have raised the water to a depth of 20 or 30 feet over the orifice of the "upper spring." The dam fell into disrepair and is reported to have been largely out of use by 1920.

In 1920 a report was prepared (Baar and Cunningham, 1920) on the feasibility of an irrigation project in the Summer Lake Valley. It describes five springs as ranging in altitude from 4,198.1 to 4,175.2 feet. The base-level datum used in that report is not known, but it is assumed to be the sea-level datum used prior to the 1929 adjustment. The report proposed a dam to raise the water level to an altitude of 4,220.6 feet, drowning the springs beneath an average of 36 feet of water.

The dam was constructed in 1922-23, with the spill into the irrigation canal at an altitude of 4,220.6 feet and the pipe outlet at about the original grade of the Ana River. Later, movement of the earth fill caused the original outlet pipe to be collapsed and thereby permanently blocked. A new, but higher, outlet was constructed and now allows the reservoir to be lowered to an altitude of about 4,213.2 feet. At the present time the only overflow spillway is the canal of the irrigation district. The outlet pipe permits the reservoir to be lowered only about 7 feet below the spillway.

In order to lessen the seepage losses and the strain on the dam, the reservoir level is kept at spillway level only during the irrigation season--May through September. During the period October through April the reservoir level is kept at the level of the outlet pipe.

Plan of the Investigation

The general plan of the investigation was based on the assumption that, if a hydraulic connection exists between the ground water which feeds Ana Springs and that which feeds nearby artesian wells, that fact could best be ascertained by manipulating the pressure head at one place and measuring the effect on pressure head at the other place. Thus, increasing the flow of the springs would result in an expansion of the cone of depression produced by the springs, and water levels would be lowered in nearby wells. Likewise, if hydraulic connection exists, pumping or allowing the wells to flow would decrease the discharge pressure head and thus the flow of the springs. Of the two possible methods of measuring an induced change, the wells were believed to offer the most readily measurable possibilities. All available information concerning the wells was collected, and Bourdon-type pressure gages were attached to wells. Also, well 30/16-1R2, Withers no. 2, was fitted with a standpipe on which an automatic water-stage recorder was placed (see pl. 6). The level of the water in the reservoir was assumed to be at an altitude of 4,220 feet and a staff gage--with zero 1 foot below the water surface--was placed on the reservoir to measure changes in its level. Levels were run between the gage staff on the reservoir and the pressure gages and measuring points on the wells. Maintenance men of the Summer Lake Irrigation District assisted in stabilizing the water level in the reservoir several days before the tests began.

As a first step in the study, controlled-flow tests were run on each of the wells to determine if each affected the others hydraulically, and to obtain values for coefficients of the transmissibility and storage of the aquifer. These coefficients would permit mathematical evaluation of the theoretical effects of discharge from the flowing wells on the pressure levels of the water in the aquifer. During the period of operation of the recorder and the pressure gages on the various wells, a recording barometer was operated in an attempt to determine the influence of the changes in atmospheric pressure upon the artesian pressures in the wells.

Samples of the water from the wells and springs were obtained and the temperature of the water was measured, chemical analyses were made. The results of the analyses are presented in table 3.

The last phase of the field work involved the opening of the outlet gate to the Ana Springs reservoir and the observation of the water levels in the wells during the subsequent 2 weeks. During a part of this period the recorder on well 30/16-1R2 was operating.

Well-Numbering System

In this report, wells and springs are designated by symbols which indicate their locations according to the official rectangular survey of public lands. For example, in the symbol for well 30/16-1R2, the part written as a fraction before the hyphen indicates township and range south and east of the Willamette baseline and meridian (T. 30 S., R. 16 E.); the number after the hyphen indicates the section (sec. 1); the letter denotes the 40-acre subdivision of the section, according to the following diagram; the final digit is the serial number of the well

D	C	B	A
E	F	G	H
M	L	K	J
N	P	Q	R

or spring in that particular 40-acre tract. Thus, well 30/16-1R2 is in the SE$\frac{1}{4}$SE$\frac{1}{4}$ sec. 1, T. 30 S., R. 16 E., and it is the second well in that tract to be listed.

In table 1, these location symbols are not given in full for each well. Rather, the symbols are grouped by townships under appropriate subheads and only that part of the symbol is tabulated which indicates the section, 40-acre tract, and serial number. All wells and springs listed in the tables are located on plate 1.

THE OCCURRENCE OF GROUND WATER IN THE ANA SPRINGS AREA

Confined and Unconfined Ground Water

In general, ground water occurs in one or the other of two types of hydraulic situations: confined (artesian), and unconfined (water-table). Confined or artesian water occurs where an aquifer is overlain by a less permeable layer which confines the water, preventing it from escaping freely upward. Confined water is under pressure greater than the atmosphere and rises above the level at which it is encountered by a well or natural opening, whereas the pressure at the top of unconfined water (the water table) is atmospheric.

Ground water occurs under both unconfined and confined conditions in the Ana Springs area, but the confined water is the only water of which any economic use is made. The possibility of encountering artesian water by drilling in the northern part of Summer Lake Valley was recognised by Waring (1908, p. 56-57), and many flowing wells have been drilled in that area since 1910. All except one of the flowing irrigation wells near Ana Springs have been drilled since 1948.

The outflow at Ana Springs is an example of the discharge of confined water. Meinzer (1927, p. 77) states:

> "There are five vents close together that are now at times flooded by water impounded by a dam. They issue from Pliocene lake beds at the north end of the great fault valley occupied by Summer Lake. The origin of the springs has not been definitely determined, but, as suggested by Waring, the water probably comes from permeable lava rock and is brought to the surface through the agency of the fault. A temperature of 66°F reported by Waring suggests a deep origin of the water."

During this investigation, an unsuccessful attempt was made to locate and sound the spring orifices. Longtime residents of the area pointed out that Buckhorn Springs, which rise farther east in the NW$\frac{1}{4}$NW$\frac{1}{4}$ sec. 8, T. 30 S., R. 17 E., on the Carlin Ranch, are similar in appearance to the now submerged Ana Springs. The waters of Buckhorn Springs arise through a circular pipelike vertical conduit which terminates in an elliptical-shaped orifice in the lake beds. Chemical analyses of the water of both Buckhorn Springs and Ana Springs are given in table 3.

Character of the Artesian Aquifer

All the flowing wells near Ana Springs obtain their water from "lava rock" or "cinders" at depths ranging from 135 feet to 380 feet below the land surface. The static (nonflowing) pressure head at the wells ranges from 18 feet to 50 feet above the land-surface datum. The logs in table 3 indicate that the confining layer is a silt or clay, and in part possibly a layer of tufa, directly on top of the "cinders" or "broken lava rock" from which the wells obtain their water.

Relation of the Flow of the Ana River to Precipitation

From 1904 until 1929 the only measurements of the discharge of Ana Springs were a few measurements of instantaneous discharge made at random intervals of time. In 1930, gaging stations were established on the diversion canal and on the river a short distance below the dam. These were maintained until 1939, then discontinued until the summer of 1951. From 1904 to 1929, 44 individual measurements of discharge were made. The values for the total flow ranged from a high of about

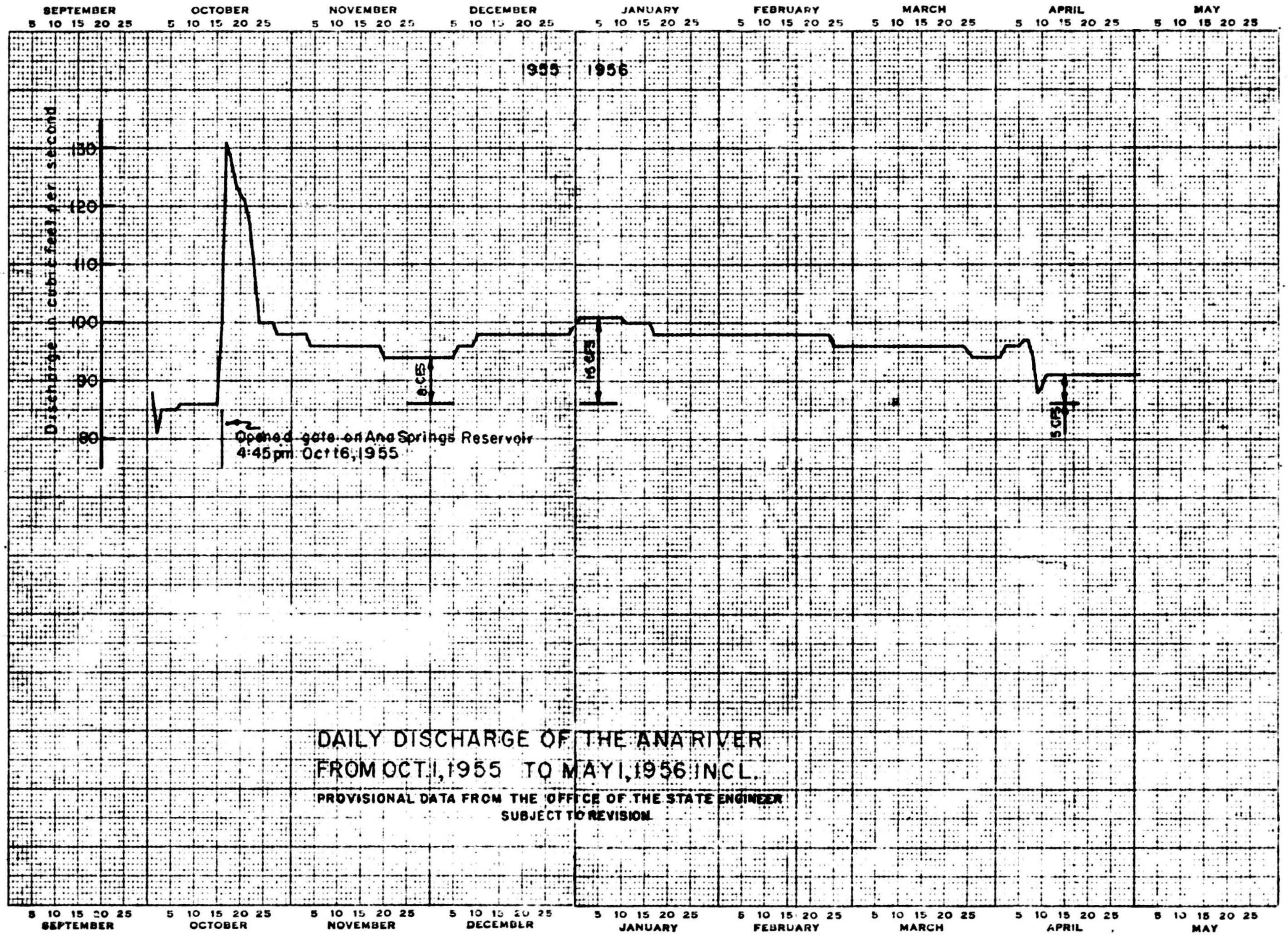
165 cubic feet per second to a low of 75 cfs (see pl. 3). Commencing in 1930 the average daily discharge was computed for every month of the periods of record. These values range from a daily average of 120 cfs during the month of November 1930 to 40 cfs during the month of May 1939. These data are presented graphically on plate 3. The flow of the Ana River in acre-feet was computed for the period of water years 1931 to 1941, and 1952 to 1954, and is shown graphically on plate 2, in comparison with the precipitation at Paisley and Fremont (respectively 23 miles southwest and 30 miles northwest of Ana Springs).

The weather records show that precipitation at Paisley has ranged from as little as about 4 inches for the water year 1924 to as much as about 14 inches for the water year 1952, the average for the 25 water years 1921 through 1945 being 8.80 inches per year. At Fremont the 25-year base-period average is 9.45 inches per water year, with extremes of about 4.5 inches in 1929 and about 19 inches in 1927. The graph (pl. 2) showing the accumulated deviation from the average is a curve plotted so that the accumulated excesses and deficiencies of precipitation are shown as rising or falling lines. Thus, the period from 1916 through 1920 was one of generally below-average precipitation at Fremont, as was also the period from 1930 to 1935. In general, the period from 1930 to 1939 was deficient in precipitation at both Paisley and Fremont, and by inference the accretion to ground water was deficient during this period. During the years 1931 through 1939 the flow of Ana Springs declined. In 1936 and in 1940 and 1941 the discharge showed a slight increase. From visual comparison of the graphs on plate 2, it appears that the flow of Ana Springs parallels the trends indicated by the accumulated-deviation curve at least for the years 1931 through 1936.

The period from 1936 through 1955 has been a period of net gain in accumulated precipitation. However, the annual discharge of the Ana River has not increased proportionately. To the end of 1954 there has been only a slight increase in discharge for the water year. At present, data are not sufficient to indicate the relation between the precipitation and the discharge of Ana Springs.

A factor that would affect the flow of the springs is the raising of the water behind the dam an average of as much as 36 feet over the spring orifices. This increases the head against which the springs must flow, thereby decreasing the rate of discharge. Not only is a lesser pressure differential present where the water discharges at the flooded orifices of the springs, but the decreased velocity of flow through the spring orifices is less efficient in keeping the vents open. These factors, coupled with the yearly raising and lowering of the reservoir, further mask the relationship between the annual discharge of the springs and the amount of precipitation on the recharge area which feeds the ground water.

The discharge of the springs is smaller during the irrigation season when the water level in the reservoir is raised. The record is not adequate to permit determination of the exact natural relation between precipitation and annual flow prior to the construction of the dam, or to permit determination of the exact effect of the dam on that relationship. However, it is certain that increasing the head against which the springs



DAILY DISCHARGE OF THE ANA RIVER
FROM OCT. 1, 1955 TO MAY 1, 1956 INCL.

PROVISIONAL DATA FROM THE OFFICE OF THE STATE ENGINEER
SUBJECT TO REVISION

must discharge decreases the flow from the springs themselves. How much this decrease in head has contributed to the long-term decline in annual discharge from the springs (pl. 3) cannot be fully evaluated at this time.

AQUIFER TESTS

Procedure

Levels were run to relate the elevation of water levels in each of the wells to the water surface of the reservoir. Pressure gages were installed at each well and an automatic water-stage recorder was installed on a standpipe erected on well 30/16-1R2, Withers no. 2.

In performing the aquifer test, one well at a time was allowed to flow. The flow was held at a constant rate and was measured by means of an orifice meter. Frequent observations were made of the pressure head at the remaining wells.

During the tests a recording barometer was maintained at Summer Lake (post office). The air pressure recorded there could not be correlated with apparent barometric effects observed in the wells. Consequently, the barometric effects could not be removed from the water-level records observed in the wells.

The coefficient of transmissibility, T, is defined as the number of gallons per day, of water at the prevailing temperature, that will pass through a strip of aquifer 1 foot wide extending the full depth of the aquifer under a hydraulic gradient of 100 percent. The coefficient of storage, S, of an aquifer is the volume of water that is released from or taken into storage per unit surface area of the aquifer per unit change in the component of head normal to that surface.

According to the nonequilibrium formula of Theis (1935)

$$T = \frac{114.6\ Q\ W(u)}{s} \quad \text{and}$$

$$u = \frac{1.87 r^2 S}{T\ t}$$

It is possible to determine T and S graphically. In the above formulas

T, S, and u have been previously defined

r = the distance, in feet, from the flowing well to the observation well

Q = the discharge, in gallons per minute

s = the drawdown of the water pressure surface, in feet

t = the time, in days, since flow began

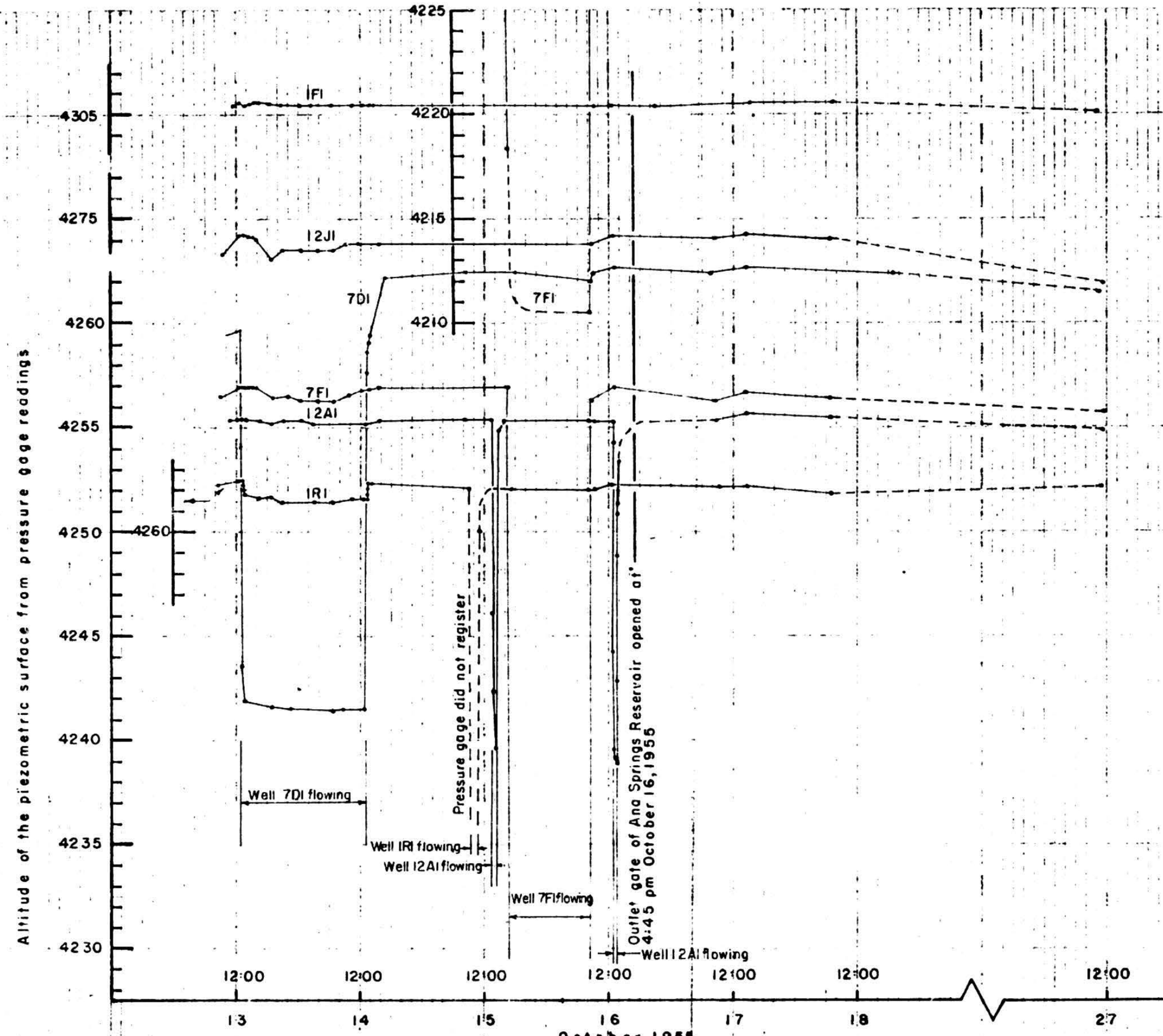
$$W(u) = \int_u^\infty \frac{e^{-u}}{u}\, du$$

After the aquifer tests were completed on the wells, the outlet gate of the previously stabilized Ana Springs Reservoir was opened and the water surface in the reservoir was allowed to decline until it again became stabilized.

Hydraulic Data Obtained

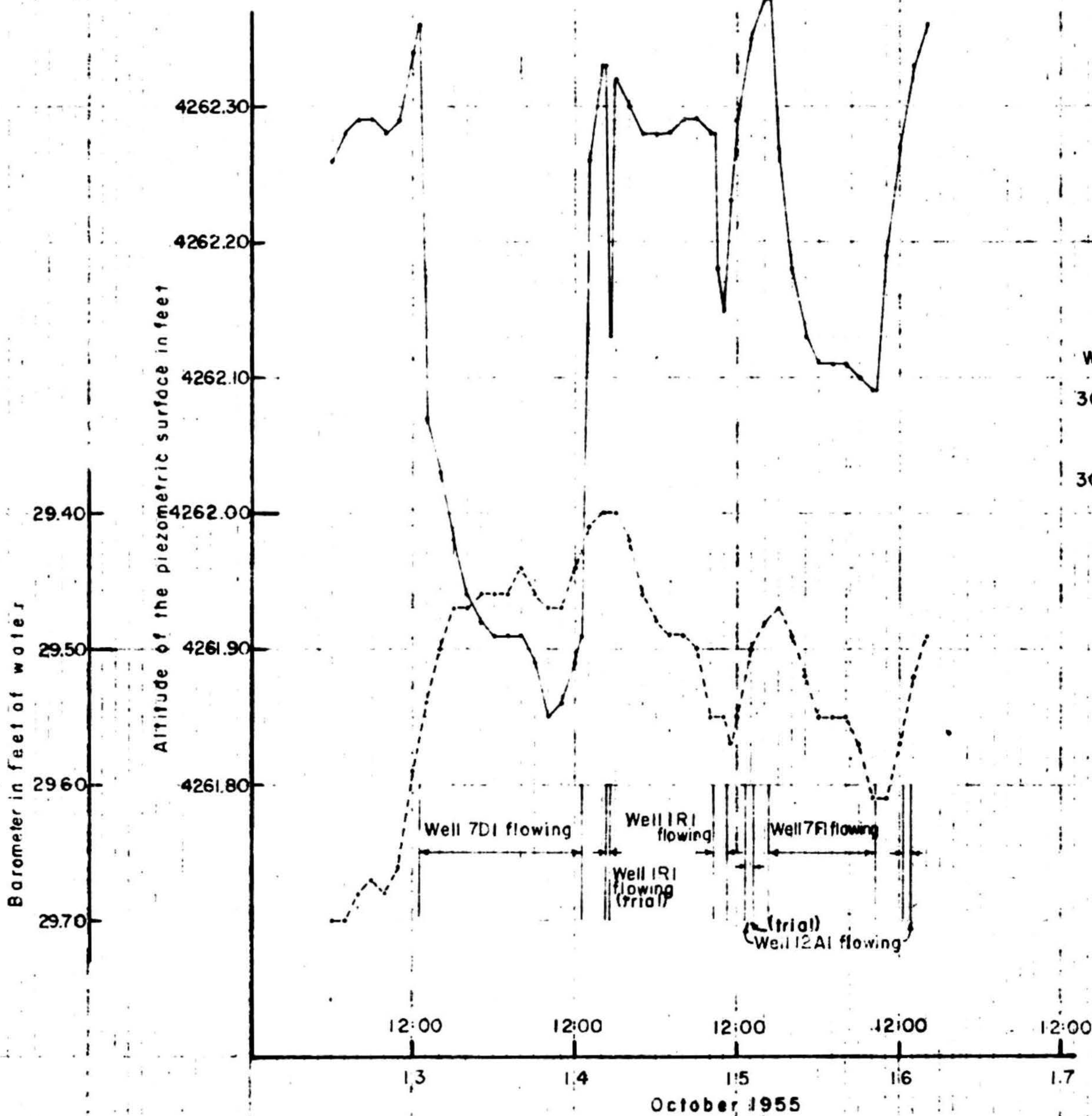
Plates 4, 5, 6, and 7 present graphically the hydraulic data obtained from the investigation. Plate 4 shows the daily discharge of the Ana River for the period October 1, 1955 to May 1, 1956. Plates 5 and 6 show the altitude of the piezometric surface at the wells during the period of the tests, as taken from the pressure gages and the automatic water-stage recorder. The Bourdon-type pressure gages were not sufficiently sensitive to show accurately the changes in pressure of less than 1 foot of water (equal to about 0.433 pound per square inch). The water-stage recorder was sensitive to changes in water level of

PLATE 5



ALTITUDE OF THE PIEZOMETRIC SURFACE AT SIX WELLS NEAR ANA SPRINGS IN OCTOBER, 1955 DURING THE AQUIFER TESTS

PLATE 6



Well number	Distance to well 30/16-1R2	Discharge in gpm
30/16-1R1	714 feet	650
12A1	1,500 feet	315
30/17-7D1	2,160 feet	1,320
7F1	5,380 feet	1,500

ALTITUDE OF THE PIEZOMETRIC SURFACE AT WELL 30/16-1R2 COMPARED WITH THE BAROMETER DURING THE AQUIFER TEST NEAR ANA SPRINGS, OREGON

0.01 foot, equal to a water-pressure change of about 0.0043 pound per square inch. For that reason, values for T and S were calculated by using the water levels as recorded by the automatic water-stage recorder on well 30/16-1R2. Plate 6 shows the elevation of the piezometric surface at well 30/16-1R2, and the atmospheric pressure expressed in feet of water. Also shown on this plate are the periods during which wells were flowing, the amount of discharge of these wells, and their distance from the recorder. Plates 8 and 9 are the graphical solutions of the nonequilibrium equation. The average value obtained for the transmissibility was 1.95×10^6 gpd/ft and for the coefficient of storage was 2.9×10^{-4}.

Plate 7 presents graphs showing the altitude of the piezometric surface at well 30/16-1R2, the altitude of the water surface of Ana Springs Reservoir, and the atmospheric pressure in feet of water during the time that Ana Springs Reservoir was allowed to drain to a lower level.

The draining began on October 16 when the gates of the reservoir were opened. As the discharge of the springs is directly related to the height of water in the reservoir, the discharge of the springs increased gradually as the surface of the reservoir lowered. Before the reservoir was stabilized at the new, lower level, the discharge of the Ana River, as shown in plate 4, was not related to the discharge of Ana Springs. The reservoir level, and discharge of the river, did not stabilize until about October 30. Because the discharge varied continuously throughout the period of the test, the data could not be analyzed by means of the Theis nonequilibrium formula.

On April 8, 1956, an attempt was made to close the outlet gate and raise the water surface in the reservoir in order to observe the recovery in well 30/16-1R2. The gate stuck when only partly closed and recovery could not be obtained, but the closure apparently was sufficient to cause the decline in discharge from the reservoir shown for April 8-10 on plate 4.

Plates 10 and 11 give curves obtained by solution of the non-equilibrium formula. Plate 11 shows the theoretical decrease in the pressure head at Ana Springs orifice caused by a well flowing at 1,000 gpm. The drawdowns were calculated successively for distances (from well to spring) up to 10,000 feet from the springs and for lengths of time up to 100 days. Thus, it is possible to estimate graphically the effect of a well located at a particular distance from the spring and flowing for any given length of time. The drawdown for a well, at a given distance from the springs, flowing 2,000 gpm would be twice as much as that shown on the graphs, and conversely, one flowing 500 gpm would produce only half as much drawdown as that shown on plate 11.

Computed Effect of the Wells on the Discharge from the Springs

Because the reservoir at spillway level raises the water level above the orifices of the springs an average of 36 feet, the pressure head producing discharge from the springs must exceed the water level in the reservoir by an amount 'h' feet. If the discharge is all true laminar flow, the discharge is directly proportional to the head producing discharge. Knowing the change in discharge produced by a known change in head, it should be possible to approximate h. On plate 7 the total change in water level of the reservoir in the period October 16, 1955 to April 8, 1956, is shown as 6.8 feet. Then $\frac{Q_1}{Q_2} = \frac{h_1}{h_2}$, and if $Q_1 = 86$ cfs, and $Q_2 = 97$ cfs, h_1 = the head producing discharge before the reservoir gate is opened.

Also, $h_2 = h_1 + 6.8$ ft $\qquad \frac{86}{97} = \frac{h_1}{h_1 + 6.8} \qquad h_1 = 54$ ft

4,220 + 54 = 4,274 ft, the computed static pressure of the ground water which issues from Ana Springs.

The effect on the pressure head at the spring orifices, if wells 30/16-1R1, -1R2, 30/17-7D1, and -7F1 were allowed to flow simultaneously, was approximated mathematically by solving the nonequilibrium equation for the drawdown in each of the wells. Such a solution is shown graphically on plate 10. This set of curves shows the solution of the nonequilibrium equation for each of the wells flowing at a fixed rate for a length of time up to and including 100 days. At the end of the 100-day period the sum of the drawdowns on the pressure surface at the orifices of Ana Springs should be approximately 2.7 feet.

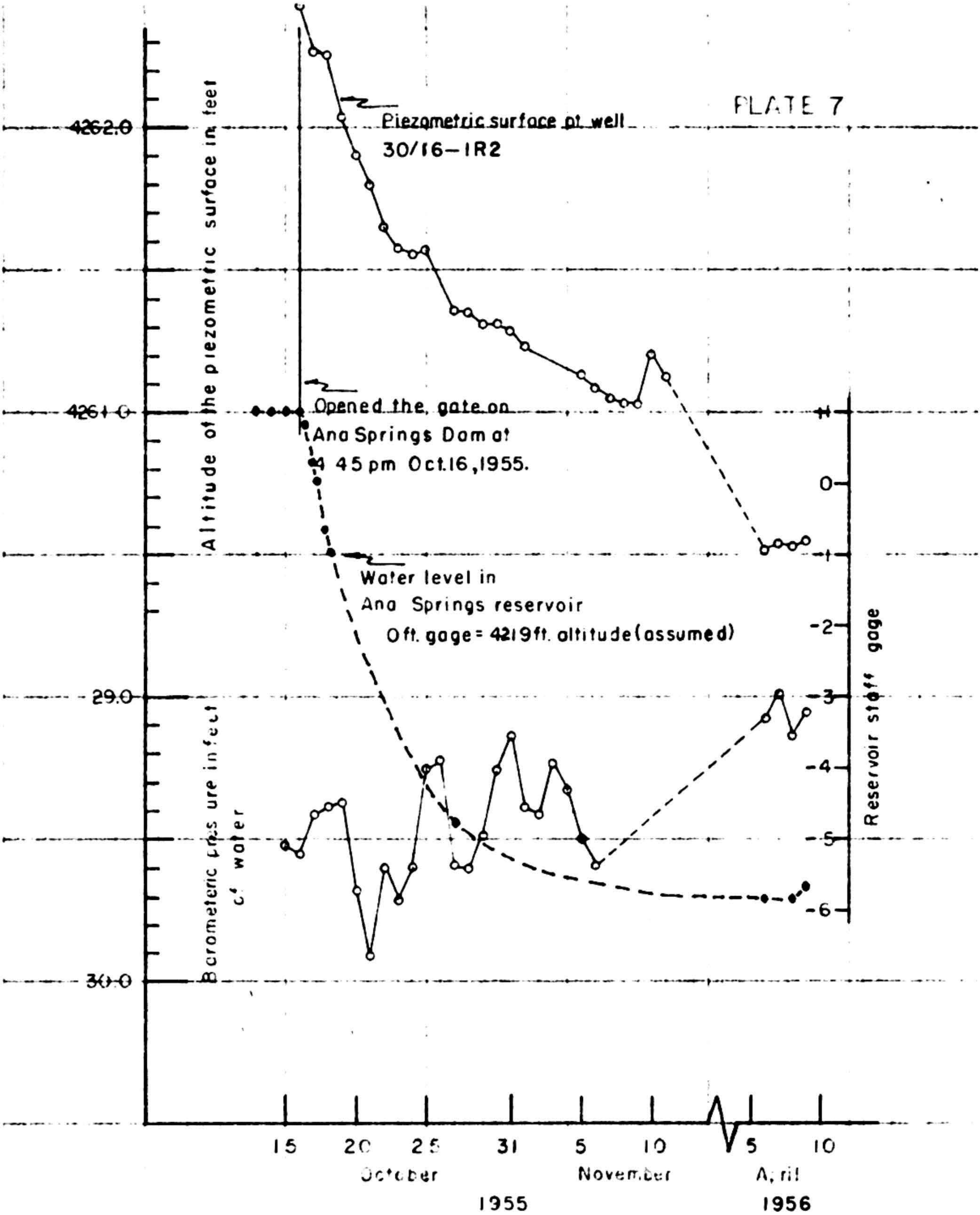
If at the end of 100 days' pumping the wells 30/16-1R1, -1R2, 30/17-7D1 and -7F1 are discharging a total of 4,600 gpm (about 10.2 cfs), the discharge head at the spring orifices would theoretically be lowered about 2.7 feet. If it is supposed that the springs were flowing about 90 cfs at the start of this hypothetical situation and the discharge is proportional to the head producing discharge, then:

$$\frac{Q_1}{Q_2} = \frac{h_1}{h_2} \qquad Q_2 = \frac{h_2 Q_1}{h_1}$$

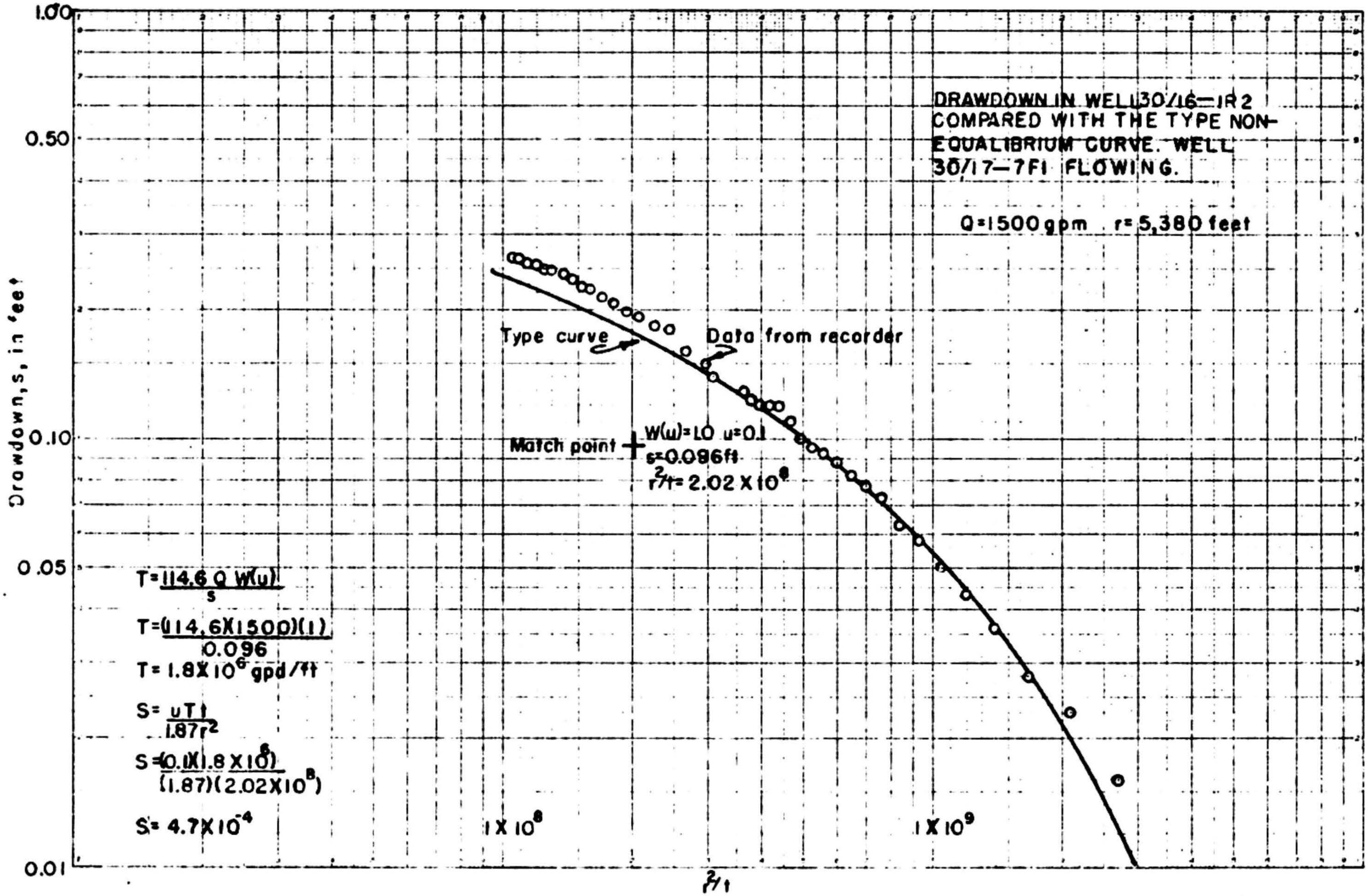
$$h_2 = 54 - 2.7 = 51.3$$

$$Q_2 = \frac{51.3}{54}(90) = 85.6 \text{ cfs}$$

The change in discharge $(Q_1 - Q_2)$ = 4.4 cfs, or about 5 percent.

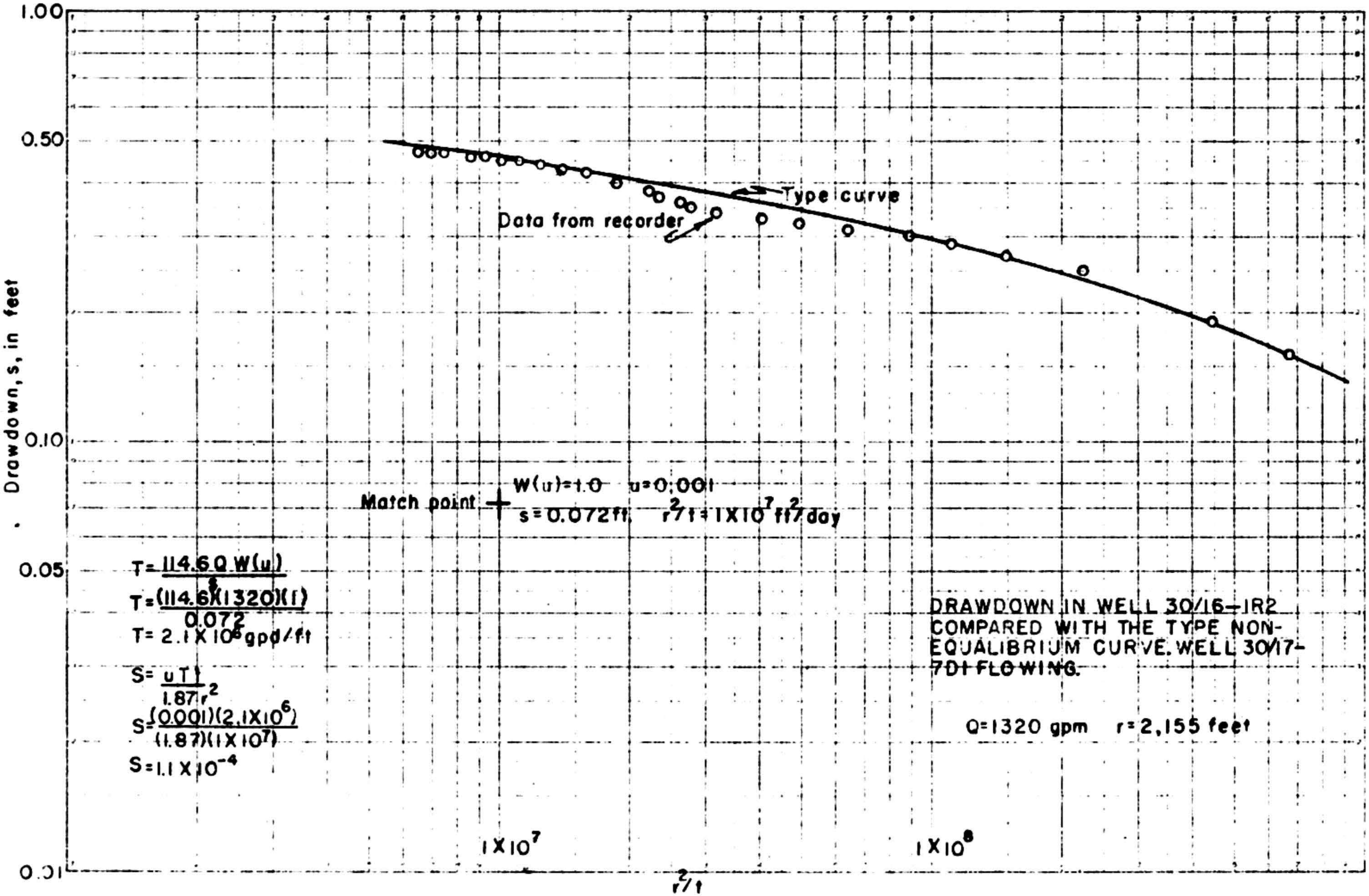


GRAPHS SHOWING SHOWING NOON WATERSTAGE RECORDER READINGS, NOON BAROMETER READINGS AND THE WATER LEVEL IN THE ANA SPRINGS RESERVOIR



DRAWDOWN IN WELL 30/16-1R2 COMPARED WITH THE TYPE NON-EQUALIBRIUM CURVE. WELL 30/17-7F1 FLOWING.
Q=1500 gpm r=5,380 feet
Type curve
Data from recorder
Match point
W(u)=1.0 u=0.1
s=0.096ft
r²/t=2.02 X 10⁸
T=114.6 Q W(u) / s
T=(114.6)(1500)(1) / 0.096
T=1.8 X 10⁶ gpd/ft
S= uTt / 1.87r²
S=(0.1)(1.8 X 10⁶) / (1.87)(2.02 X 10⁸)
S= 4.7 X 10⁻⁴
1.00
0.50
0.10
0.05
0.01
1 X 10⁸
1 X 10⁹
Drawdown, s, in feet
r²/t

PLATE 8



DRAWDOWN IN WELL 30/16-1R2 COMPARED WITH THE TYPE NON-EQUALIBRIUM CURVE. WELL 30/17-7D1 FLOWING.

It is apparent that turbulent flow is present in the conduit tubes of the springs. However, calculations based on the hydraulic coefficients determined in this report indicate that much of the drawdown at the springs is due to loss of head under conditions of laminar flow in the aquifer. The loss of head due to turbulent flow in the spring conduits is believed to be equivalent to only a few feet.

QUALITY OF GROUND WATER

Chemical analyses are given in table 3 for water from five of the six wells listed in table 1 as deriving water from lava rocks. Two analyses for water from Ana Springs also are given. The analyses were made on samples taken from the discharging stream of each well. The 1955 sample for Ana Spring was bailed from a boat located as near as possible over the main orifices. The temperature of 60°F for the Ana Spring water may indicate the sample had undergone some cooling in the reservoir above the actual orifice.

The chemical similarity between the dissolved solids in the water of Ana Spring and those in the water of the wells 30/16-1R1, -12A1, -12J1, 30/17-7D1 and -7F1 can be seen readily. An analysis of the spring water is compared with averaged results of analysis of the water of the five wells:

(All results, except specific conductance and pH, in parts per million)

Constituents	Source	
	Ana Springs	Five wells averaged
Silica (SiO_2)	36	39
Calcium (Ca)	4.4	3.8
Magnesium (Mg)	3.5	1.6
Sodium (Na)	36	76
Potassium (K)	3.6	5.8
Bicarbonate (HCO_3)	106	174
Chloride (Cl)	5	18
Hardness	25	16
Specific conductance	194	337
pH	8.3	8.4

The chief difference between the waters lies in the greater sodium, bicarbonate, and chloride content of the well waters.

The temperature of water from four of the wells is 66° or 67°F and that of a fifth is recorded as 60°F. These compare favorably with the 66°F recorded by Waring (1908) for the temperature of the water of Ana Springs prior to the impoundment over the orifices. The average, or normal, values accepted by geologists and geophysicists for the increase of earth temperature with depth below the land surface lie between 1° and 2°F per hundred feet of depth below the first one hundred feet. The average annual temperature recorded at Fremont for the years 1921-32 was 42.2°F. Thus, the maximum earth temperature at a depth of 200 to 300 feet might be expected normally to be 44° to 47°F. Well water temperature of 66° to 67°F indicates that the temperature of the rocks in the area is considerably above normal or the water has circulated to greater depth to acquire its higher temperature.

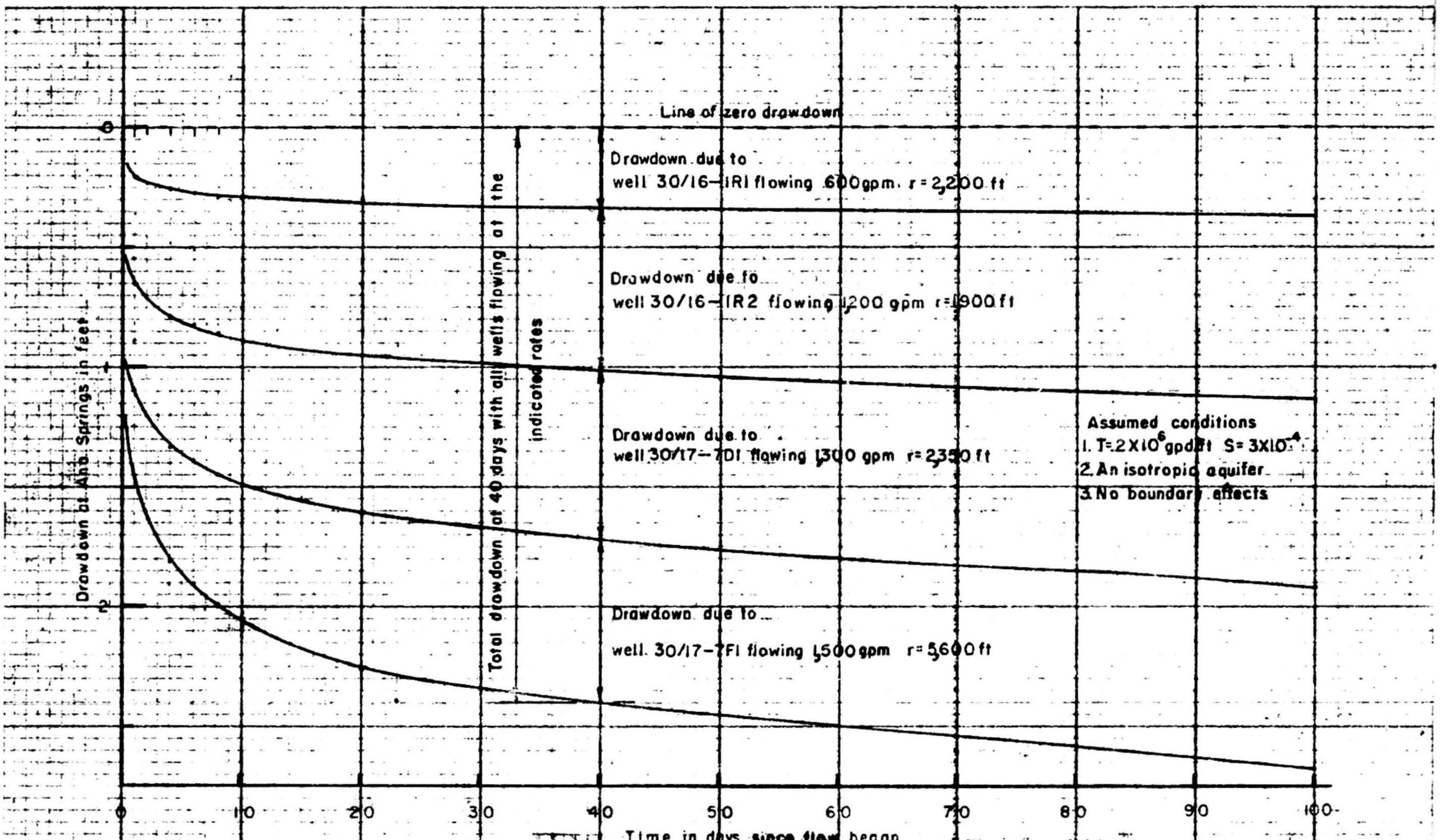
CONCLUSIONS

Evidence bearing on one question in particular was desired from this investigation: Is the flow of Ana Springs decreased by the flowing artesian wells in question, and, if so, by how much?

The graphs on plates 5 and 6 show that when well 30/17-7D1 is allowed to flow, the water-pressure levels decline in wells -7F1, 30/16-1R1, and -1R2, and that flow from well 30/16-1R1 similarly reduces the water-pressure level of well -1R2, while flow from well 30/16-12A1 showed no effects on the water-pressure levels of the other wells. Water-pressure levels in wells 30/16-1F1 and -12J1 appear to be affected only slightly, if at all, by the flow of any other of the tested wells. Plate 7 shows that lowering the reservoir and thereby increasing the discharge of the springs, lowered the water-pressure surface in well 30/16-1R2, and, as the aquifer and interference tests showed that 30/16-1R2 was affected by the flow of -1R1, 30/17-7D1 and -7F1, it can be inferred that increasing the discharge of Ana Springs will lower the head of water causing discharge at all four of these wells.

Plate 4 shows the change in flow of the springs as calculated from the continuous water-stage recorder on the Ana River. As shown on plate 4, the river received an abnormally high flow for the first ten days after the reservoir gates were opened, followed by a stabilizing period to December 5, an increased flow during the barometric low period of storms thereafter to January 2, and a long equalizing period to April 8.

The amount by which the 100-day flow of 4,600 gpm from wells 30/16-1R1, -1R2, 30/17-7D1, and -7F1 would decrease the average flow from Ana Springs (assumed to be 90 cfs) was calculated as being about 5 percent, or 4.4 cfs.



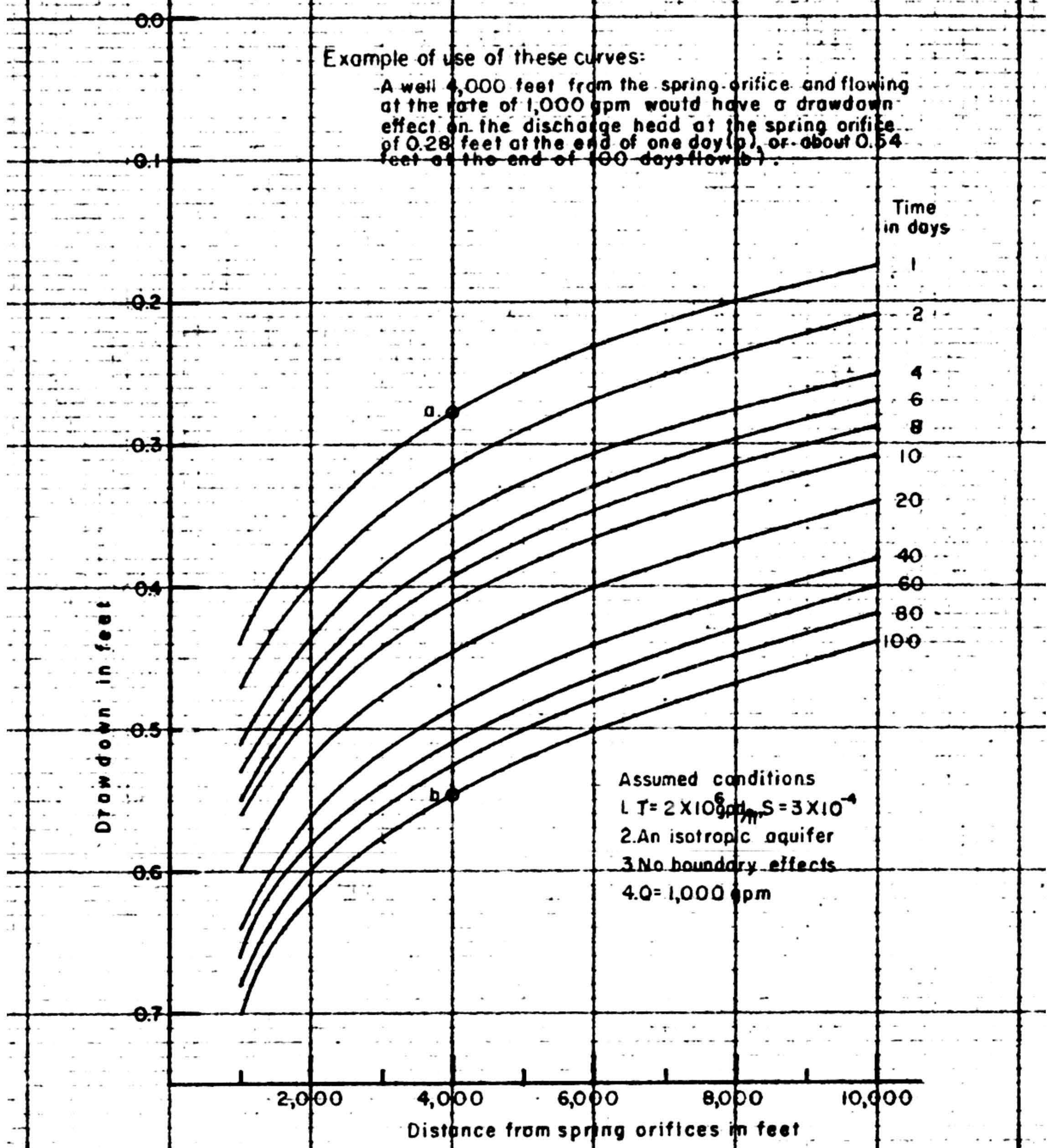
MATHEMATICAL APPROXIMATION OF THE DRAWDOWN CAUSED BY FOUR FLOWING WELLS ON THE HYDRAULIC HEAD WHICH PRODUCES DISCHARGE FROM THE ORIFICES OF ANA SPRINGS

The compiled records of the gaging stations on the Ana River and the irrigation canal give measurements rated as "good" by the U. S. Geological Survey. This means that the measurement of flow at the station is considered to be accurate to plus or minus 10 percent. The calculated reduction in flow caused by the well interference would be smaller than the limits of accuracy of the measurements. In an oral communication, Mr. Albert Moore, Assistant District Engineer of the Surface Water Branch of the Geological Survey in Portland, stated that a consistent decrease of 2 percent might possibly be picked up by statistical comparison over a long-term series of measurements each made with equal care and precision and a decrease of 4 percent should be discernible in a series of 5 or 6 measurements of similar quality.

The hydraulic constants derived for the aquifer indicate that a well 4,000 feet from the Ana Springs and discharging at the rate of 1,000 gpm should have a theoretical drawdown effect on the discharge head of the springs orifice of 0.28 foot at the end of 1 day and of 0.54 foot at the end of 100 days. Other projections of these calculations are given on plate 11.

The chemical character and the temperature of the water from Ana Springs are very similar to those of wells 30/16-1R1, -12A1, -12J1, 30/17-7D1, and -7F1. The main difference is in a greater content of sodium, bicarbonate, and chloride in the well waters.

PLATE 11



MATHEMATICAL APPROXIMATION OF THE DRAWDOWN OF THE HEAD CAUSING DISCHARGE AT THE ORIFICES OF ANA SPRINGS BY A WELL FLOWING AT A RATE OF 1,000 GPM

Table 2.- Logs of Wells in the Vicinity of Ana Springs

30/16-1R1. Withers no. 1. Drilled by Frank Williams about 1953

Materials	Thickness (feet)	Depth (feet)
Clay, gray	40	40
Unreported	90	130
Clay, black	40	170
Sand, black	10	180
Cinders, red and black	29	209

30/16-1R2. Withers no. 2. Drilled by Frank Williams about 1953

Clay, gray	30	30
Clay, black	52	82
Unreported	30	112
Rock, broken, and sand	26	138
Rock, red	47	185
Rock, hard, black	37	222

30/17-7F1. Mr. Williams, Sr. Drilled by owner about 1939

Silt, unconsolidated	315	315
Chalky, white, porcelainous tufa(?)	70	385
Lava rock, spongy, pumiceous, red, water-bearing	60	445

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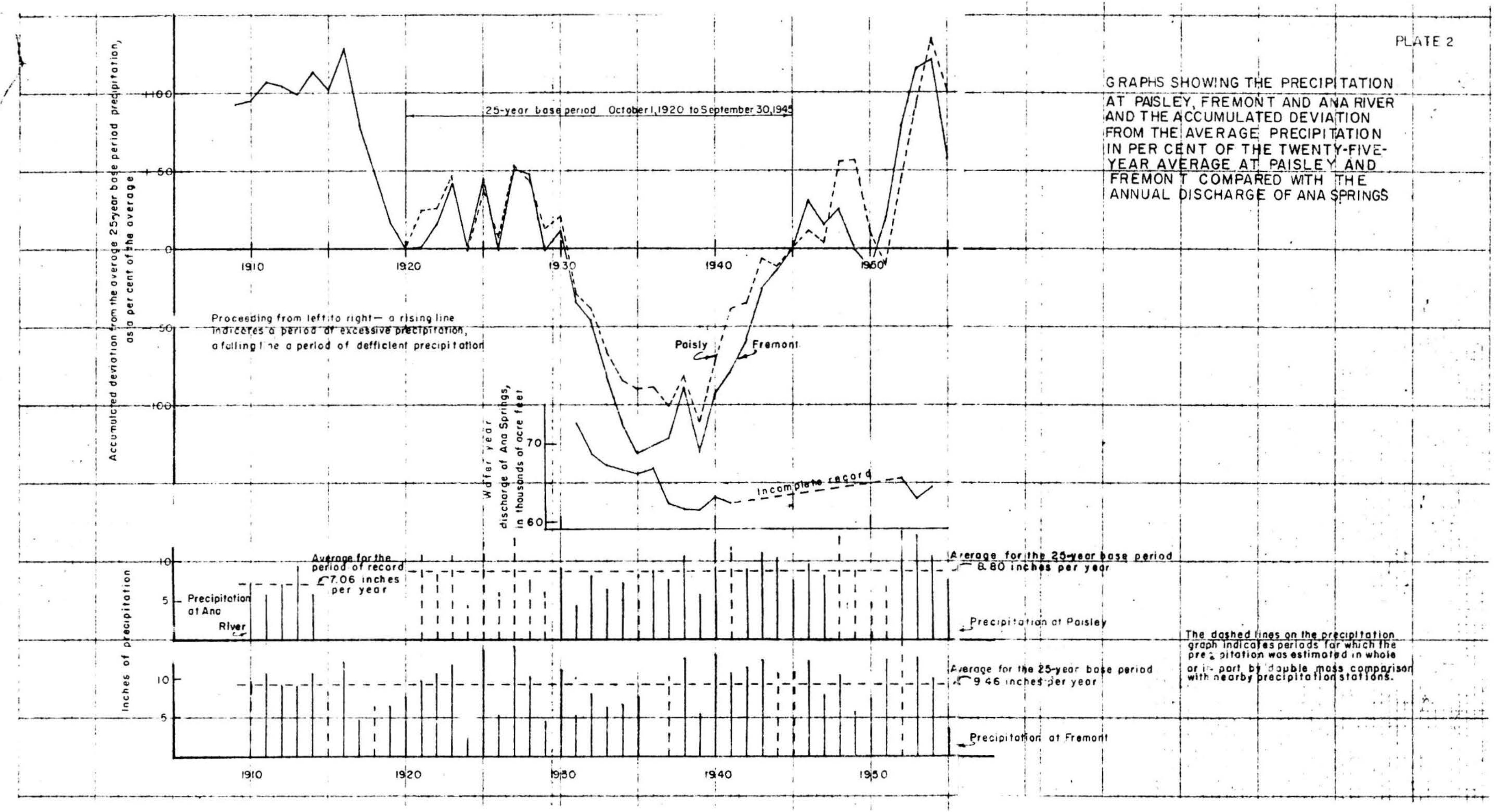
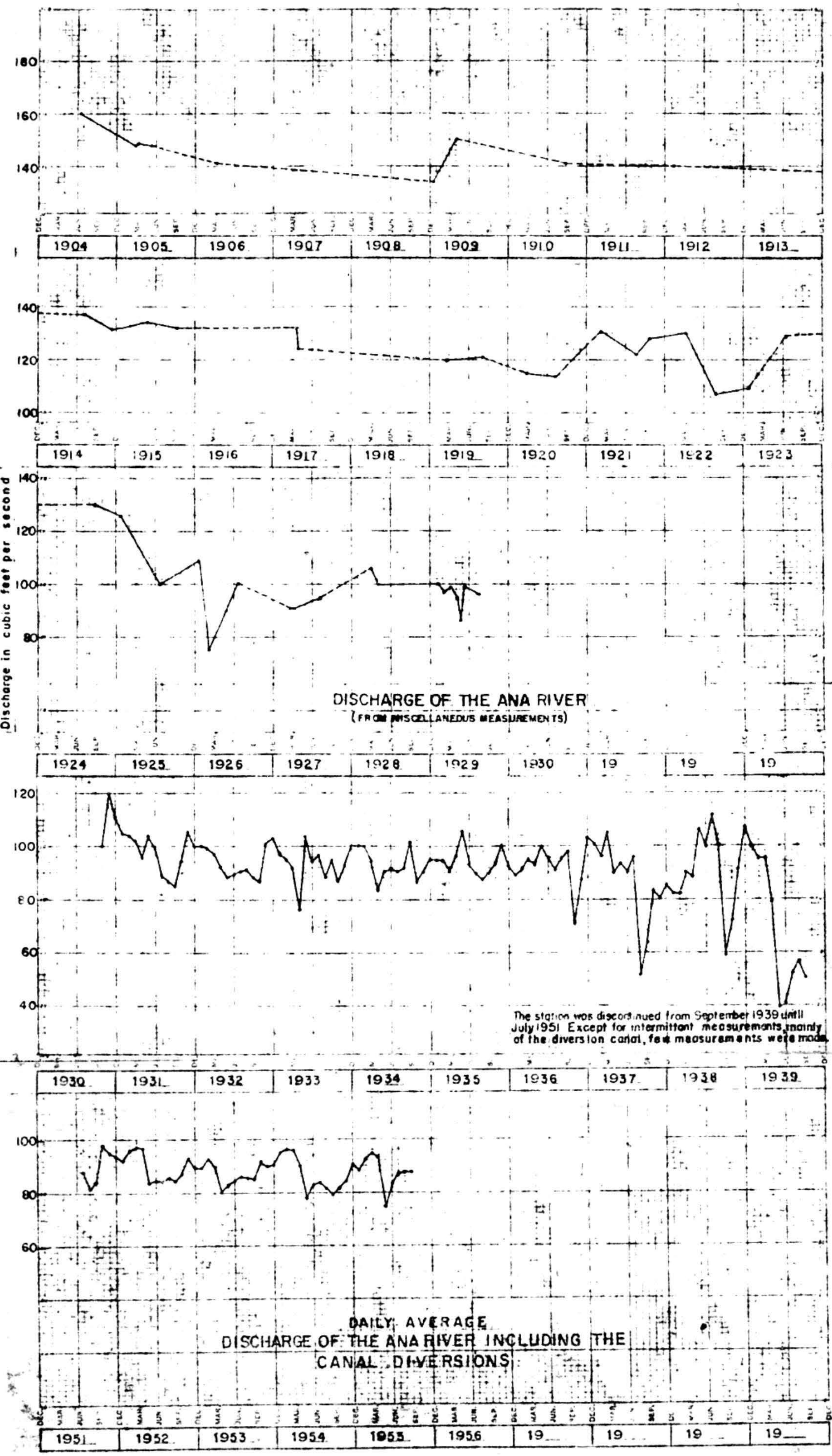
PLATE 2

GRAPHS SHOWING THE PRECIPITATION AT PAISLEY, FREMONT AND ANA RIVER AND THE ACCUMULATED DEVIATION FROM THE AVERAGE PRECIPITATION IN PER CENT OF THE TWENTY-FIVE-YEAR AVERAGE AT PAISLEY AND FREMONT COMPARED WITH THE ANNUAL DISCHARGE OF ANA SPRINGS





Discharge in cubic feet per second
DISCHARGE OF THE ANA RIVER
(FROM MISCELLANEOUS MEASUREMENTS)
1904
1905
1906
1907
1908
1909
1910
1911
1912
1913
1914
1915
1916
1917
1918
1919
1920
1921
1922
1923
1924
1925
1926
1927
1928
1929
1930
19
19
19
1930
1931
1932
1933
1934
1935
1936
1937
1938
1939
The station was discontinued from September 1939 until July 1951 Except for intermittent measurements mainly of the diversion canal, few measurements were made.
DAILY AVERAGE
DISCHARGE OF THE ANA RIVER INCLUDING THE CANAL DIVERSIONS
1951
1952
1953
1954
1955
1956
19
19
19
19

PLATE 3

Table 3.- Chemical Analyses of Water from Wells and Springs of the Ana Springs Area of the Summer Lake Basin

[Analyses by Geological Survey]

(Upper row of figures, parts per million; lower row, equivalents per million)

Well number	30/16-1F1	30/16-1R1	30/16-12A1	30/16-12J1	30/17-7D1	30/17-7F1	30/17-6F1*		30/17-8D1**
Date of collection	10/16/55	10/15/55	10/15/55	10/16/55	10/13/55	10/15/55	12/3/48	10/17/55	10/17/55
Temperature (°F)	69	67	60	66	67	66	--	60	60
Silica (SiO_2)	--	40	42	39	35	38	37	36	37
Calcium (Ca)	12	5.6	3.2	3.6	3.6	2.8	5.2	4.4	3.2
	0.599	0.279	0.160	0.180	0.180	0.140	0.259	0.220	0.160
Magnesium (Mg)	1.4	1.4	1.9	0.7	1.2	2.6	3.1	3.5	1.9
	0.115	0.115	0.156	0.058	0.099	0.214	0.255	0.288	0.156
Sodium (Na)	49	58	82	98	71	68	39	36	43
	2.132	2.523	3.567	4.263	3.088	2.958	1.696	1.566	1.870
Potassium (K)	6.0	4.8	9.7	5.8	4.7	4.8	3.2	3.6	3.6
	0.153	0.123	0.233	0.148	0.120	0.123	0.082	0.092	0.092
Bicarbonate (HCO_3)	41	[a]120	[b]184	[a]243	160	[c]165	108	[b]106	[a]115
	1.295	1.967	3.016	3.935	2.622	2.704		1.737	1.885
Carbonate (CO_3)	19								
	0.633								
Chloride (Cl)	44	22	24	19	11	12	13	5	6
	1.241	0.620	0.677	0.536	0.310	0.338		0.141	0.169
Nitrate (NO_3)	1.2	0.2	0.0	0.2	0.1	0.1	0.1	0.2	0.2
	0.019	0.003	0.000	0.003	0.002	0.002	0.002	0.003	0.003
Hardness as $CaCO_3$	36	20	16	12	13	18	26	25	16
Noncarbonate hardness	0	0	0	0	0	0	0	0	0
Percent sodium	71	83	87	92	89	86	74	72	82
Specific conductance (micromhos at 25° C.)	310	277	384	433	294	299	213	194	206
pH	9.2	8.4	8.4	8.5	8.2	8.6	8.4	8.3	8.4

a Contains the equivalent of 3 ppm CO_3.
b Contains the equivalent of 2 ppm CO_3.
c Contains the equivalent of 4 ppm CO_3.
* Spring; sample 12/3/48 contained 6.7 ppm sulfate.
** Buckhorn Spring, located 1.5 miles southeast of Ana Springs.