Flow of Springs and Small Streams in the Tecolote Tunnel Area of Santa Barbara County California

GEOLOGICAL SURVEY WATER-SUPPLY PAPER 1619-R

Prepared in cooperation with the Santa Barbara County Water Agency

Flow of Springs and Small Streams in the Tecolote Tunnel Area of Santa Barbara County California

By S. E. RANTZ

CONTRIBUTIONS TO THE HYDROLOGY OF THE UNITED STATES

GEOLOGICAL SURVEY WATER-SUPPLY PAPER 1619-R

Prepared in cooperation with the Santa Barbara County Water Agency

UNITED STATES GOVERNMENT PRINTING OFFICE, WASHINGTON : 1962

UNITED STATES DEPARTMENT OF THE INTERIOR

STEWART L. UDALL, *Secretary*

GEOLOGICAL SURVEY

Thomas B. Nolan, *Director*

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

CONTENTS

ILLUSTRATIONS

TABLES

CONTRIBUTIONS TO THE HYDROLOGY OF THE UNITED STATES

FLOW OF SPRINGS AND SMALL STREAMS IN THE TECOLOTE TUNNEL AREA OF SANTA BARBARA COUNTY, CALIFORNIA

By S. E. RANTZ

ABSTRACT

This report presents the results of an investigation to determine the effect of the construction of Tecolote Tunnel in southern Santa Barbara County, Calif., on the flow of springs and spring-fed streams in the tunnel area. A program of monthly measurement of discharge for this purpose began in late 1948 at 125 springs and streams; tunnel construction started in March 1950 and was completed in January 1956. By late 1951 an appreciable amount of seepage was entering the tunnel.

Incidental to the primary objective of this study, but necessary to the investigation, were a study of the discharge pattern of the springs and streams of the region and an evaluation of the effect on flow of both the Arvin-Tehachapi earthquake of July 21, 1952 and the Refugio brush fire of early September 1955. The most striking characteristic of the flow regimen in the area is the rapid response of discharge to precipitation. An interesting effect was observed in July 1952 when the Arvin-Tehachapi earthquake abruptly increased the flow at 18 measuring sites. At 15 of these sites this effect was felt for only several months, but at three of the sites the effect remained for several years. As for the effects of the Refugio fire, there is some reason to believe that the summer flow of many springs and streams may have increased in succeeding years as a result of decreased evapotranspiration losses, but the evidence is inconclusive.

The many complex and interrelated factors that influence the discharge of springs and spring-fed streams make it exceedingly difficult to isolate the effect of Tecolote Tunnel on the flow. Another major difficulty in an evaluation of the effect of the tunnel stems from the fact that the calibration period for this study was only 3 years, lasting from late 1948 to late 1951, during which time the precipitation was uniformly deficient. Furthermore, these inadequacies of the calibration period in regard to short length of record and limited range in precipitation, cannot be overcome by the collection of additional discharge information in the years to come. From the data available, however, the following conclusions were reached concerning the effect of Tecolote Tunnel:

1. The failure of one spring can be attributed to construction of the tunnel. This spring, designated as site 110b, is the source of Hot Springs Creek.

2. There is no evidence that construction of the tunnel affected the flow of any other spring or stream.

INTRODUCTION

PURPOSE AND SCOPE

The study of the flow of springs and small streams in southern Santa Barbara County was conceived in March 1948, when the Bureau of Reclamation received authorization for immediate construction of the Cachuma Project. The principal features of the Cachuma Project are the Cachuma Dam and storage reservoir on Santa Ynez River, and the Tecolote Tunnel for diversion of water from Cachuma Reservoir through the Santa Ynez Mountains to the water-deficient coastal region south of the mountains (fig. 1). The users of the

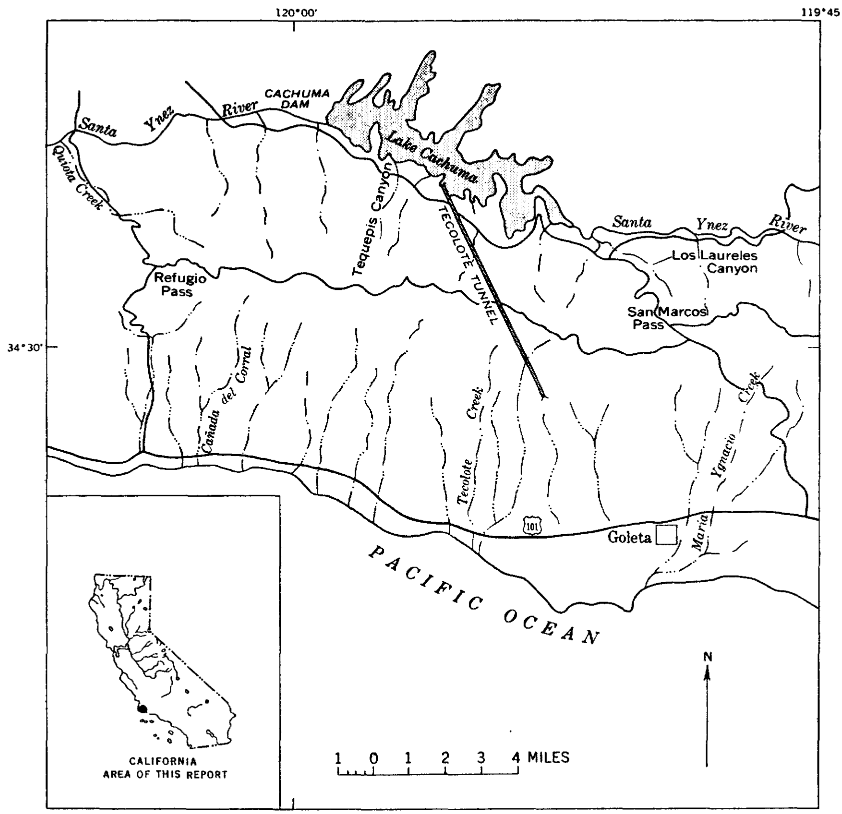

FIGURE 1.—Map of Tecolote Tunnel area.

mountain springs and streams in the vicinity of the tunnel site were concerned over the possibility that tunnel construction might reduce their water supply, as it appeared likely that the completed tunnel would intercept and develop appreciable flows of water. Because of this concern, the Santa Barbara County Water Agency requested the

Geological Survey to establish an observational program which would provide for the systematic measurement of the flow of developed springs and headwater streams in the Tecolote Tunnel area. The program was started in late 1948 and was continued into late 1961.

The primary purpose of this report is to evaluate the data collected and to determine which springs and streams, if any, have been affected by the construction of Tecolote Tunnel. Monthly measurements of discharge began in late 1948; tunnel construction started in March 1950 and was completed in January 1956. Incidental to the primary objective, but necessary to the investigation, were a study of the discharge pattern of the springs and streams of the region, and an evaluation of the effect on flow of both the Arvi-Tehachapi earthquake of July 21, 1952 and the Refugio brush fire of early September 1955.

ACKNOWLEDGMENTS

This study was authorized by a cooperative agreement between the U.S. Geological Survey and the Santa Barbara County Water Agency. The report was prepared under the immediate supervision of Walter Hofmann, district engineer of the Surface Water Branch of the Geological Survey. Preliminary studies by the Geological Survey were made by H. C. Troxell, Walter Hofmann, and W. C. Peterson, who prepared the eight progress reports of the investigation that have been released to the open file during the past 12 years.

Valuable assistance was also rendered by the California Department of Water Resources and the Bureau of Reclamation, Sacramento, Calif.

DESCRIPTION OF THE AREA

For the purpose of this study, the Tecolote Tunnel area is defined as the north and south slopes of the Santa Ynez Mountains that are bounded approximately on the west by Refugio Road and on the east by San Marcos Pass Road (pl. 1). The area is rectangular in shape and is about 16 miles from east to west, and about 7 miles wide from north to south. About two-thirds of the area lies west of Tecolote Tunnel. The tunnel passes through the mountain range in a southeasterly direction for a distance of 6.4 miles, with a slope of 0.00025. The inlet portal, at an altitude of 660 feet, is about 3 miles upstream from Cachuma Dam, and the outlet portal at the upper end of the west fork of Glen Anne Canyon, is about 10 miles west of the city of Santa Barbara.

The principal ridge line of the Santa Ynez Mountains has an east-west trend, and an average altitude of 3,000 feet in the tunnel area. The brush-covered north and south mountain flanks have a slope of about 800 feet to the mile, and are sparsely populated. Numerous canyons, drained by spring-fed streams, are incised in the mountain sides; most of the ranches and residences of the area are found in the bottoms of these canyons.

GEOLOGY

The Santa Ynez Mountains are eroded from a great thickness of folded and faulted sedimentary rocks of Tertiary and Cretaceous age elevated from below sea level by great compressive forces. The sedimentary rocks are well-stratified hard sandstones and shales; individual beds range in thickness from a few feet to several hundred feet.

In this part of the range the sedimentary strata are compressed into an anticlinal fold and elevated on a southward-dipping thrust fault, the Santa Ynez fault, near the north base of the range. The axis of the anticline is parallel and just north of the crest of the range; the strata dip steeply on the south flank and dip at low angles near the axes and on the north flank. The strike of the dipping strata is variable but within 20° of west. This anticlinal fold is transverse to the tunnel which is oriented S. 18° E. from the inlet portal. The Santa Ynez fault crosses the tunnel 2.2 miles from the inlet portal. North of the fault the Tertiary strata are tilted steeply northward and locally folded and faulted. The principle water-bearing localities in the tunnel are in zones of fracturing and shearing in and near the Santa Ynez fault, at other minor faults, and at bedding-planes of steeply dipping strata found especially on the south flank of the anticline.

HYDROLOGY

The long-term average annual precipitation over the Tecolote Tunnel area ranges from about 18 inches at the lower altitudes to about 30 inches at the crest of the mountains. The precipitation is distinctly seasonal and very little rain falls from June through September. More than 90 percent of the precipitation normally occurs in the 6-month period, November through April. Precipitation also shows a definite cyclic trend, and since the start of the current dry period in 1944, there have been only 2 years, 1952 and 1958, when precipitation was well above average.

Precipitation is only one of the many complex and interrelated factors that influence the discharge of springs and spring-fed streams in the area. Recharge to the ground-water bodies that supply the flow depends not only on the volume and time distribution of precipitation but also on the infiltration rate, the soil-moisture deficiency, and the evapotranspiration rate. Also important in affecting the discharge rate of springs are the hydraulic characteristics of the aquifer, the proximity of the recharge area to the discharge site, pumping from the aquifer, and the methods used in developing and maintaining individual springs.

DATA AVAILABLE

Observations of the discharge of a few springs and streams began in late 1948, but it was not until January 1949 that monthly observations began at all measuring sites in the network. These discharge measurements have been made each year at about 125 sites, but occasional revision of the network has resulted in measurements at 164 sites at one time or another. As of March 1960, monthly discharges were reported for 120 sites; 40 sites were discontinued; and 4 others were paired with nearby sites for reporting purposes. Each measured discharge was considered to be indicative of the flow for the month in which the measurement was made. For the occasional months when measurements were not obtained, discharges interpolated between measured flows were assumed to be representative of the flow. The location of each measuring site, along with its identifying number, is shown on plate 1.

Site numbers, rather than site names, are used in this report for simplicity; the springs would otherwise have to be designated by the names of the present property owners and many streams would have no names. Descriptions of the sites and the results of all discharge measurements made during the investigation are presented in an open-file report titled "Flow of Springs and Small Streams in the Tecolote Tunnel Area of Santa Barbara County, California", by S. E. Rantz, October 1960. Also listed in the open-file report are water temperatures observed at the time of each measurement.

In addition to the measurements of the springs and streams, measurements of seepage into Tecolote Tunnel were made as tunnel-drilling operations progressed. Drilling began at the north, or inlet, portal in March 1950 and at the south, or outlet, portal in May of the same year. Seepage first appeared at the north portal (site 128a) in April 1950, and at the south portal (site 36a) a month later. The tunnel was "holed through" in January 1955, and thereafter all seepage was measured at the south or outlet portal.

In January 1955 the California Department of Water Resources prepared an unpublished report titled, "Tecolote Tunnel Water Quality." That report presented the results of an analysis of water samples obtained by engineers of the U.S. Geological Survey and Bureau of Reclamation during the period October 1953 to May 1954. The waters of 23 springs were sampled as were the inflows from 18 sites within the tunnel. The results of the chemical analyses are summarized on page R20–R23.

643868—62——2

FLOW REGIMEN OF SPRINGS AND STREAMS

Because of the many complex and interrelated factors that influence the flow, differences in magnitude, timing, and variability of discharge exist among the measured springs and spring-fed streams. Some springs respond almost immediately to precipitation while others lag, which indicates possible differences in distance to recharge areas, in water-table gradients, or in the permeability of the aquifers. The flow of some springs is well sustained, but the flow of many others is intermittent and the spring goes dry during the summer. Examination of all discharge records is necessary for an appraisal of the effect of the construction of Tecolote Tunnel on the flow of individual springs and streams, but there is much to be learned concerning the general discharge pattern by studying groups of selected springs and streams that are representative of the area. For example, the selection of only those sites that flow perennially simplifies the problem of determining the trend of summer discharge, because springs that go dry early in the season are eliminated from consideration. Furthermore, by use of the median of the monthly discharge measurements at a group of measuring sites as the pattern for the group, it is possible to avoid the many inconsistent discharges that appear in the records for individual sites. These inconsistencies account for the jagged appearance of many of the individual discharge hydrographs during the dry months when flows are receding. For example, in the absence of any summer rain the August discharge measurement at a given site may indicate greater flow than was measured there in July. The quantities of water involved during these dry periods are extremely small, and measured discharge may fail to be indicative of the average natural flow for the day, much less the month, for the following reasons: 1. Pumping from the aquifer at the time of measurement. 2. Variable evapotranspiration draft, depending on the time of day when the measurement was made. 3. Changes made to the outflow works by the owner of the spring.

The 18 springs and 10 spring-fed streams listed in table 1 were selected for the purpose of investigation of the areal pattern of runoff. As mentioned before, one criterion used in the selection of measuring sites was that the flow be nearly or consistently perennial. The chosen sites also represent a wide areal distribution, which is shown on plate 1, where each site is indicated by a special symbol. Other criteria for selection of sites were that they sample a wide range of altitude, average discharge, and variability of flow.

In the Tecolote Tunnel area, land surface altitudes range from sea level to 3,000 feet. Column 3 of table 1 indicates that virtually this entire range of altitude is sampled by the selected group of measuring

TABLE 1.—*Discharge characteristics of selected springs and spring-fed streams*

Measurement site No.	Classification	Altitude of measurement site (feet)	Median measured discharge (gpm)	P_{10} (gpm)	P_{90} (gpm)	Ratio P_{10}/P_{90}
1	2	3	4	5	6	7
2	Spring	2,700	5.4	17	1.1	15
18	do	1,900	7.2	10	3.2	3
20 and 21 *	do	1,700	7.2	13	3.7	3.5
28	do	1,250	12	37	3.3	11
31	do	425	39	94	28	3.5
33	Stream	500	33	64	15	4
35	Spring	800	54	158	25	6
36	do	600	3.2	15	1.3	12
49	Stream	425	4.9	28	.51	55
50	do	520	425	1,410	149	9.5
59	do	1,100	58	331	1.0	331
61	do	190	31	90	7.6	12
65	do	800	162	830	21	40
70	Spring	100	94	630	2.7	233
85	Stream	400	111	260	42	6
93	Spring	2,320	6.7	15	3.1	5
94	do	2,350	1.4	2.7	.6	4.5
100	do	2,025	3.8	34	.32	106
106a	do	1,100	.75	2.5	.29	8.5
110a	Stream	950	28	176	4.5	39
122	do	1,600	6.7	45	1.1	41
132	Spring	1,250	2.6	10	.43	23
136	do	970	1.5	6.4	.36	18
140	do	1,150	47	262	6.2	42
142	do	980	.15	.41	†.001	†410
143	Stream	2,200	45	130	17	7.5
147	Spring	1,750	.85	1.25	.40	3
153	do	1,150	.56	2.0	.044	45

* Combined.
† Estimated; low discharges are measured in drops per minute.

NOTE.—P_{10} refers to measured discharge that is equaled or exceeded 10 percent of the time. P_{90} refers to measured discharge that is equaled or exceeded 90 percent of the time.

sites. The discharges listed for each site in columns 4 to 6 were obtained by arranging the measured flows in order of magnitude and selecting the discharges corresponding to the percentiles indicated in the column headings. No great precision is claimed for these listed values. The discharges were not measured at equally spaced intervals of time during the 12-year observational period, and during the 12 years the total number of measurements made at the individual sites ranged from 100 to 127. Nevertheless these tabulated discharges are of the proper order of magnitude and provide a reliable basis for comparison of the discharge characteristics of the selected springs and streams. Column 4 shows the wide range of median discharge, 0.15 to 425 gpm (gallons per minute), at these sites. The median is used because it is a more representative average than the arithmetic mean, being unaffected by either the extremely high or extremely low flows observed. It has already been mentioned that individual low-flow measurements may not be representative of the average discharge for a particular month. This is also true of the high-flow measurements made at monthly intervals during the winter, because winter discharges change rapidly with respect to time, and only by chance can a measured flow be indicative of the discharge for a particular month.

Column 7 of table 1 indicates the range in flow at the individual sites. The index of variability used for this purpose is defined as the ratio of observed discharge that is equaled or exceeded 10 percent of the time (P_{10}) to the observed discharge that is equaled or exceeded 90 percent of the time (P_{90}). This index, as tabulated in column 7, ranges from 3 to 410. It might be inferred that the selection of 10 streams in the sample of 28 measuring sites would result in too heterogeneous a sample, since streams are normally more variable in discharge than are springs. However, figure 2 depicts the statistical distribution of the indexes of variability for springs and streams and shows that there is homogeneity in the composite sample of springs and spring-fed streams insofar as flow variability is concerned.

After the selection of a satisfactory sample of the measuring sites in the region, the first step in the analysis of the general flow pattern was to express all discharges in dimensionless units to facilitate discharge comparisons. This was accomplished by dividing the measured discharges at each site by the median discharge for that site. All discharges, now expressed as dimensionless ratios, were tabulated, and the median values for each month of each year were selected. These median values were plotted on figure 3, and the resulting graph represents the average pattern of flow for all springs and spring-fed streams in the Tecolote Tunnel area during the period 1949–60. The reliability of the extreme high and low flows in each year is still uncertain, but plotting of the medians of the 28 measured flows in each

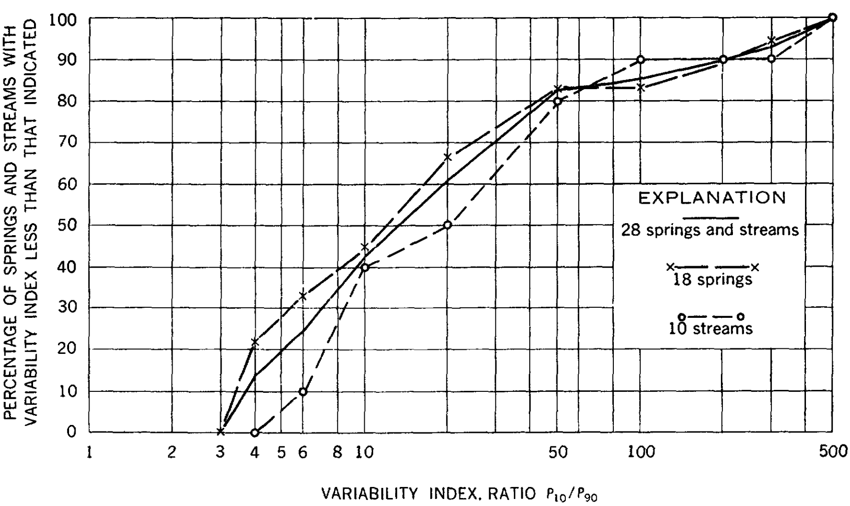

FIGURE 2.—Cumulative frequency curves of variability indexes for springs and streams.

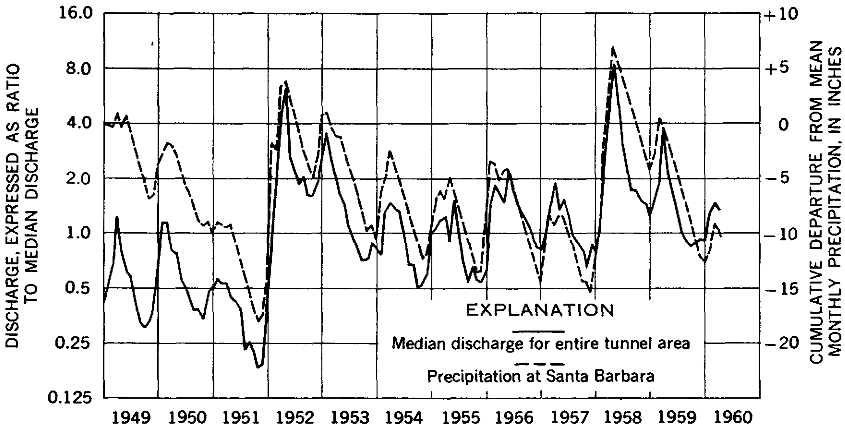

FIGURE 3.—Comparison of precipitation pattern and average pattern of discharge.

month tends to minimize the errors. A logarithmic discharge scale was used in figure 3 to provide a scale sufficiently expanded at the lower discharges to show fluctuations in low flow. Logarithmic plotting also tends to make the graph of discharge recession linear during the drier months.

The next step was to compare this average pattern of discharge with the rainfall pattern. The precipitation record for Santa Barbara, 10 miles east of Tecolote Tunnel, was selected as an index of rainfall over the tunnel area. Table 2 lists monthly precipitation at Santa Barbara from July 1948 to March 1960. Because most of the precipitation occurs during general storms, there is probably a fairly constant ratio between precipitation at Santa Barbara and that which occurs over the entire Tecolote Tunnel area. Obviously, a simple relationship cannot be obtained between monthly precipitation and concurrent monthly flow, because effluent ground water continues to be discharged during the 5 months of each year when rainfall is negligible or even zero. A graphic comparison can be obtained, however, by the use of cumulative departures of monthly precipitation from the mean. The long-term mean annual precipitation at Santa Barbara is 18.0 inches, and therefore the mean monthly precipitation is 1.5 inches. This latter figure is a fictitious one in the sense that a rainfall of 1.5 inches is never attained during the 5 dry months of each year, but when this figure of monthly precipitation is used to obtain a graph of cumulative departures, one of the results is a linear recession curve during the dry season that is similar to the runoff recession hydrograph. The precipitation graph of cumulative departures has been plotted on figure 3. There is no significance to the relative positioning of the two graphs in this figure; the vertical scales were alined to facilitate visual comparison of the trends of the graphs.

TABLE 2.—*Monthly and annual precipitation, in inches, at Santa Barbara, Calif.*

[T, Trace, an amount too small to measure]

Year	July	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	Annual
1948-49	0.00	0.00	T	0.08	0.00	2.64	1.40	1.35	2.78	0.24	2.43	0.03	10.95
1949-50	T	T	.00	.02	1.72	4.16	2.54	2.76	1.29	.61	.05	.01	13.06
1950-51	.81	.02	.41	1.21	1.88	.50	2.53	1.21	1.20	1.45	.01	.01	11.24
1951-52	.00	.06	.00	.49	2.04	4.80	13.89	.71	7.37	1.79	T	.08	31.23
1952-53	.03	.01	.04	.10	3.60	5.26	1.78	.03	.71	1.42	.17	.29	13.44
1953-54	.00	.00	.01	.00	2.08	.09	5.98	2.95	3.81	.44	.06	.02	15.44
1954-55	.00	.02	.00	.03	2.03	3.60	4.39	2.29	.70	3.45	.40	.01	16.92
1955-56	.00	.01	.00	.00	1.36	6.07	7.19	1.15	.00	2.42	1.64	.00	19.84
1956-57	.00	.00	.00	.11	.00	.14	5.39	3.74	.54	2.31	1.57	.06	13.86
1957-58	.00	.00	.00	1.41	.51	4.51	3.71	9.84	6.20	5.43	.33	.00	31.94
1958-59	.00	T	.27	T	.11	.04	2.68	5.05	.00	.89	.02	.00	9.06
1959-60	.00	.00	.01	.01	.00	1.01	3.12	3.39	.63	------	------	------	--------

It can be seen from figure 3 that the patterns of discharge and precipitation are similar. There is little time lag between precipitation and discharge, which probably indicates that there is close proximity between the area of recharge and the point of discharge, or possibly that there exist steep water-table gradients or highly permeable aquifers. The difference in vertical displacement of the two curves before and after December 1951 reflects the effects of the long dry period from 1944 to 1951 and the more humid period that followed. Thus, despite the rapid response of discharge to precipitation, a certain amount of deep percolation of rainfall influences the discharge for some time after the occurrence of precipitation. By way of illustration, either table 2 or the graph of figure 3 shows that total precipitation from January 1952 to June 1958 was greater than average, with rainfall during the last 12 months being especially excessive. Precipitation during the climatic year that followed (July 1958 to June 1959) was the lightest since 1944. Nevertheless, discharge during 1959 never approached the low values of the period 1949–51, which demonstrates the "carryover" effect of precipitation from 1 or more previous years. It is not possible to make a quantitative study of the rainfall-discharge relationship for individual sites, primarily because the bulk of the discharge occurs during the high winter flows, and monthly discharge measurements at a site provide insufficient data for a determination of the volume of this winter flow.

The discharge hydrograph of figure 3 represents the average flow pattern of all springs and streams in the Tecolote Tunnel area. There still remained the likelihood of differences in the flow regimen of groups of springs and streams located in widely separated sectors of this area. To investigate this probability the area was divided into four sectors, with the tunnel as the divide between east and west zones, and the principal ridge of the Santa Ynez Mountains as the divide between north and south zones. The 28 sites under consideration were apportioned between the four sectors as follows:

Northeast sector	*Northwest sector*	*Southwest sector*	*Southeast sector*
Site 2	Site 122	Site 49	Site 18
93	132	50	*20 and 21
94	136	59	28
100	140	61	31
106a	142	65	33
110a	143	70	35
	147	85	36
	153		

*Combined.

Monthly median discharges were obtained for each of the four groups for the purpose of hydrographic comparison. In determining these group median discharges, the procedure followed was that used in obtaining monthly median discharges for all 28 sites. Graphs of median discharge for the northeast and northwest sectors were plotted on figure 4 along with the hydrograph of median discharge for all 28 sites. Figure 5 is a similar graph for the southeast and southwest sectors.

Comparison of the average discharge patterns shown on figures 4 and 5, for the four sectors and for the entire area, indicates little difference in the timing of discharge. There is a difference in the variability of discharge, however. The flow of springs and streams in the southwest sector shows a much greater range in discharge than the flows from the other sectors, whereas the flow of springs in the southeast sector shows the least variability. It has already been

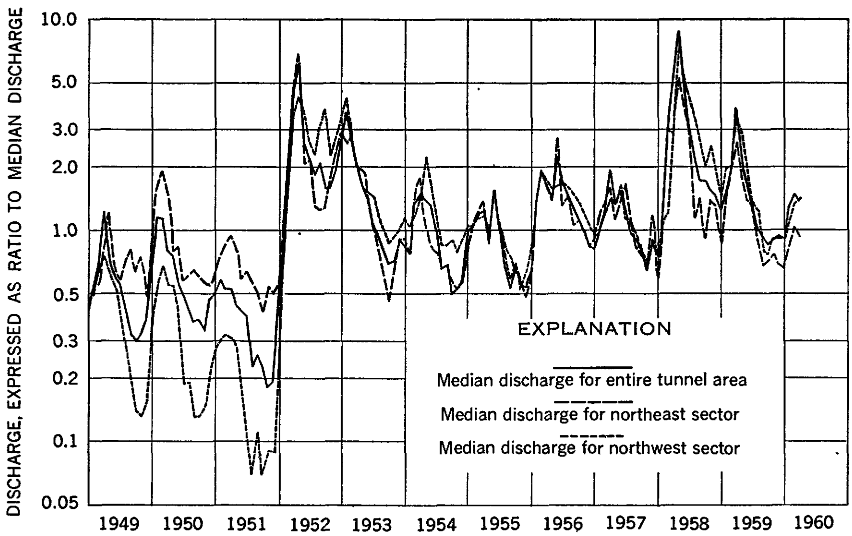

FIGURE 4.—Comparison of discharge hydrographs for the northeast and northwest sectors and for the entire tunnel area.

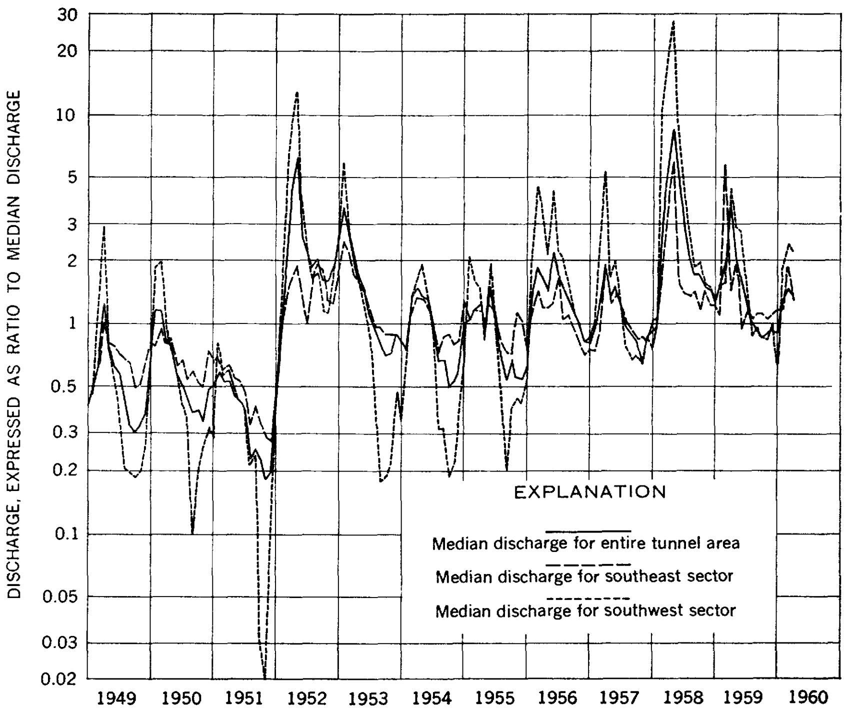

FIGURE 5.—Comparison of discharge hydrographs for the southeast and southwest sectors and for the entire tunnel area.

mentioned that flows were sustained at higher levels after December 1951 than they had been before that date. The graphs show that this difference in discharge before and after December 1951 is most marked in the northwest sector.

EFFECT OF THE ARVIN-TEHACHAPI EARTHQUAKE OF JULY 21, 1952

Analysis of the flow regimen of springs and spring-fed streams in the Tecolote Tunnel area reveals that the Arvin-Tehachapi earthquake affected the flow at 18 of the 125 sites measured in 1952. The epicenter of this damaging quake, which occurred on July 21, 1952, was located near Wheeler Ridge, about 65 miles northeast of Tecolote Tunnel. The 18 sites affected were:

	Sites	
13	33	142
18	85	143
19	98	147
*20 and 21	110a	151
23	135	153
31	136	156

* Combined.

At each of these 18 sites the flow increased, but at 15 of them the increase was temporary, lasting only several months. At sites 31, 136, and 142, however, the effect of the earthquake on discharge remained for several years. This is evident from the graphs of figures 6 and 7,

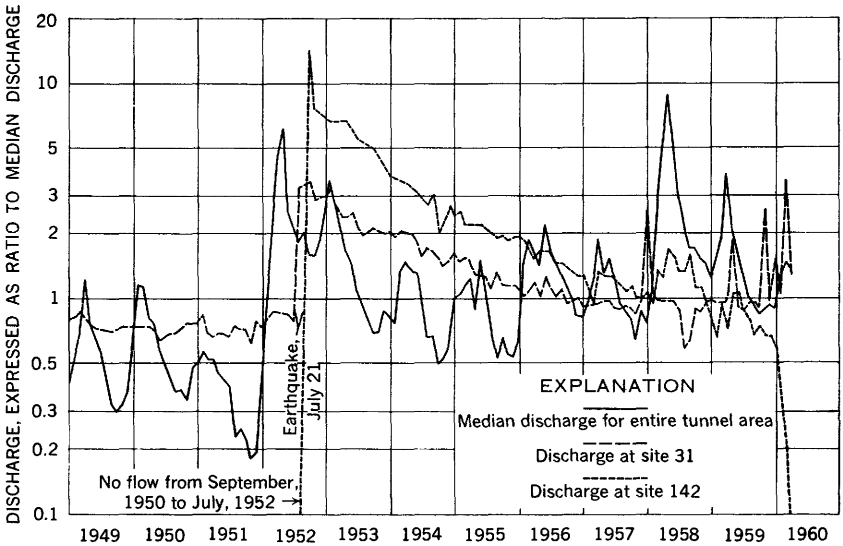

FIGURE 6.—Discharge hydrographs showing effect of the Arvin-Tehachapi earthquake at sites 31 and 142.

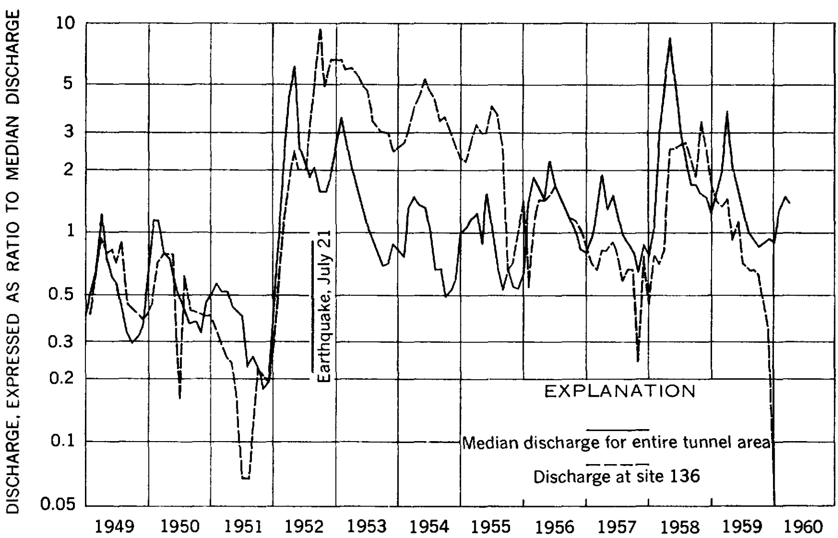

FIGURE 7.—Discharge hydrographs showing effect of the Arvin-Tehachapi earthquake at site 136.

where the discharge hydrographs for these three sites are plotted along with the previously derived average discharge hydrograph for the entire tunnel area. All discharges on these graphs are expressed as ratios to the median flow. It can be seen that a marked increase in discharge occurred at the three sites in July, during the usual summer drought, and that the effect persisted for several years.

It is extremely doubtful that the Arvin-Tehachapi earthquake had any permanent effect on recharge areas or on the permeability of any of the aquifers. The increases in discharge were more likely due to disturbance of the unconsolidated material in the discharge areas, resulting in the clearing of existing ground-water outlets and the opening of new ones.

EFFECT OF THE REFUGIO BRUSH FIRE OF SEPTEMBER 1955

A complicating factor in the study of the flow regimen of the Tecolote Tunnel area was the severe fire of early September 1955. The map (pl. 1) shows that the burn extended over about 80 percent of the tunnel area. The heavy natural brush cover was completely destroyed by the fire except for small isolated areas in the bottoms of canyons. Later in the year the area was reseeded by the U. S. Forest Service and the ensuing winter rains established a satisfactory grass cover. In succeeding years the grass cover deteriorated until it is now very sparse, but a large amount of brush has reappeared. Forest Service estimates now indicate a full recovery of brush on the canyon bottoms and a 50-percent recovery on the slopes and summits.

It would be reasonable to expect an increased summer flow of springs in the burned-over area during the years that followed the fire. The substitution of shallow-rooted grasses for much of the deeper rooted brush that had been destroyed by fire, could have reduced total evapotranspiration losses. Because the springs discharge extremely low flows in summer, even a minor decrease in the transpiration rate could cause a large percentage increase in discharge.

A quantitative hydrologic study is necessary if the effect of the Refugio burn on summer flow is to be isolated. Because the discharge data collected consists entirely of monthly measurements, there is inadequate information available for a study of the type needed. However, the discharge measurements at the individual measuring sites may be used in a double mass curve analysis for a cursory investigation of the trend of summer flow. In performing this analysis, cumulative precipitation at Santa Barbara was plotted against the accumulated sum of measured discharges for August and September at individual sites. The purpose of using the sum of August and

September discharges, rather than just a single monthly discharge, was to minimize the error in the event that a nonrepresentative discharge measurement had been obtained for either month. It was realized that the results obtained might be biased because the variation in summer flow from year to year will be influenced, to a degree, by the date of the last significant storm of the preceding rainy season, and annual precipitation at Santa Barbara may not be a satisfactory index of the precipitation on the recharge area of a specific spring.

A double-mass curve analysis was performed for 20 springs and streams of the representative group of 28 listed in table 1. The eight sites that were not considered are listed below, along with the reasons for their elimination from consideration.

Sites 2, 143, 147, 153	Outside the burned area.
31, 136, 142	Affected by earthquake.
110a	Affected by construction of Tecolote Tunnel (tunnel effect is discussed in a following section of this report).

Of the 20 sites investigated, 6 showed no apparent change in the trend of summer discharge. These 6 are sites 18, 20 and 21 (combined), 36, 49, 85, and 106a. One stream, site 33, indicated decreased summer flow, and the remaining 13 sites indicated an increase in summer discharge following the Refugio burn.

Figure 8 illustrates the double-mass curve analysis for three selected sites. For purposes of comparison the plotted discharge for each site is expressed as a ratio to its median monthly discharge. A change in the slope of a graph indicates a change in the relationship of precipita-

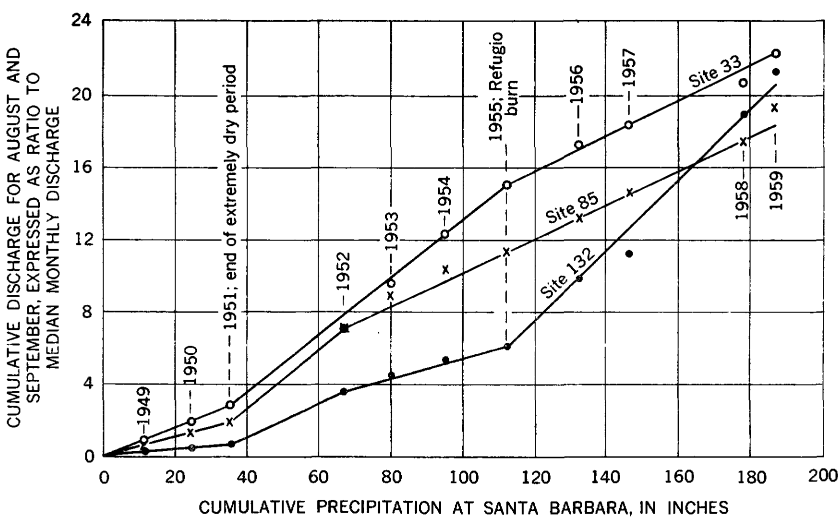

FIGURE 8.—Double-mass curves of summer flow at selected sites.

tion to summer discharge. If the slope becomes steeper, an increase in summer discharge is indicated. Conversely, if the slope flattens, a decrease in summer flow is indicated. An increased slope is expected after 1951 as a result of the change from an extremely dry period to a more humid one. Any change in slope after 1955 is attributed to the effect of the Refugio burn. From the graphs of figure 8 it would appear that the effect of the burn increases summer discharge at site 132, decreases discharge at site 33, and produces no change at site 85.

It should be recognized that this double-mass curve analysis is inconclusive because of the inadequacy of the basic data. It is of interest, for example, that a similar anaylsis performed for sites 2 and 143, both located outside the burned area, also indicated increased summer discharge after 1955. Probably the only conclusion that may be safely drawn from this study is that there is a likelihood that the summer flow of many of the springs and streams may have increased as a result of the Refugio burn.

EFFECT OF TECOLOTE TUNNEL ON DISCHARGE

Construction of Tecolote Tunnel commenced on March 1, 1950, when drilling began at the north or inlet portal. Two months later drilling began at the south or outlet portal, and excavation advanced from each end toward the center. Seepage first appeared in the tunnel at the north excavation in April 1950 and at the south excavation a month later. The tunnel was "holed through" in January 1955, and thereafter all seepage was removed at the south or outlet portal and measured there. The concrete lining of the tunnel was completed in late January 1956, with weep holes provided to drain the seepage.

Tables 3 and 4 present a summary of monthly seepage discharge from the tunnel. The hydrographs of tunnel outflow are presented in figure 9, along with a graph that depicts the progress of tunnel construction. With the advance of the tunnel headings, additional seepage flows were found in the tunnel, but these flows were controlled to a degree by grouting. The effect of grouting is seen in the hydrographs as a sharp reduction in flow following an increase in discharge, and this explains the irregular shape of the graphs. Discharge from the north portal has at all times been relatively insignificant, but there has been significantly large seepage discharge from the south portal since late 1951. Most of the seepage apparently enters the tunnel between the faults at tunnel stations 161 and 244. (Tunnel stationing, expressed in hundreds of feet, starts at the north portal with station 0; the south portal is at station 336.) The seepage discharge from the south portal reached a peak of 16.7cfs (cubic feet per second) in September 1954, and has shown a steady decline ever since. The high

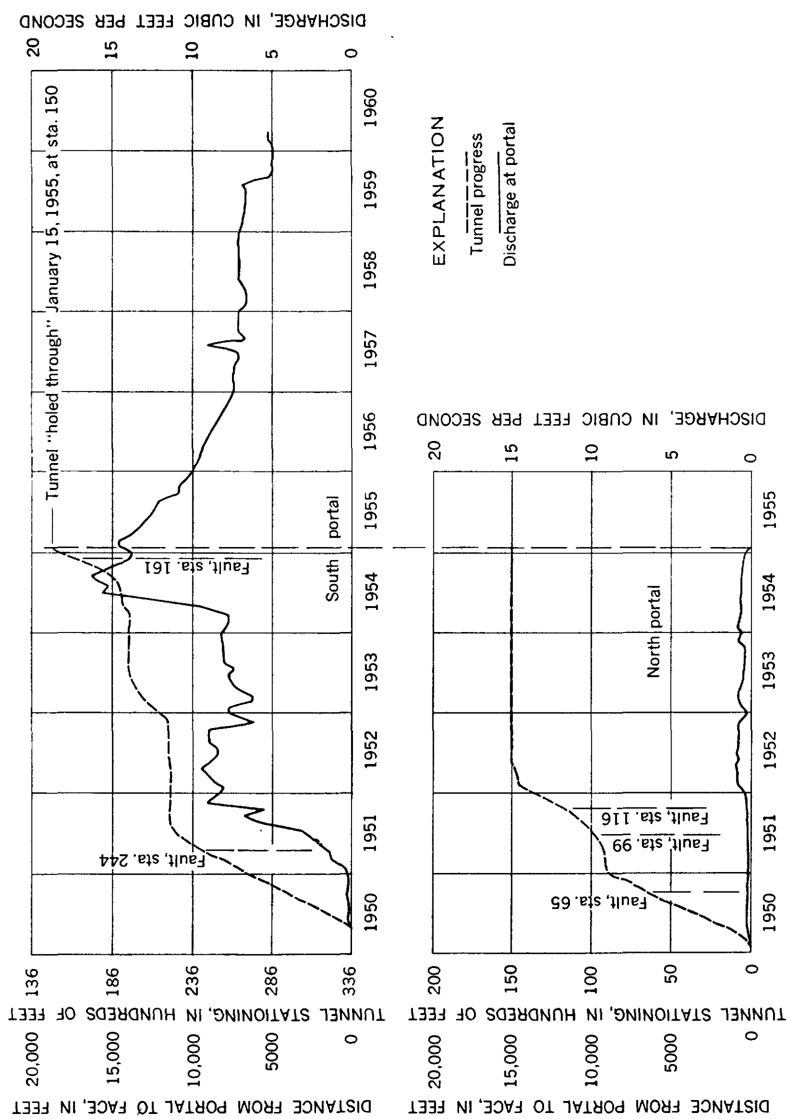

FIGURE 9.—Heading progress and outflow hydrographs of Tecolote Tunnel.

temperature of most of this seepage, observed as high as 113°F, may be a result of heating caused by active faults in the area, or it may be an indication that the flows originate at great depth. The large volume of water discharged seems to indicate that an underground water reservoir of considerable magnitude had been tapped. The chemical quality of the water and the decline of inflow into the tunnel strongly suggest that the ground water is meteoric in origin.

TABLE 3.—*Monthly seepage discharge, in cubic feet per second, from north portal of Tecolote Tunnel*

Water year	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.
1949-50	------	------	------	------	------	0	0.011	0.057	0.15	0.092	0.059	0.091
1950-51	0.11	0.13	0.12	0.22	0.19	.13	.23	.176	.164	.170	.172	.212
1951-52	.196	.236	.266	.33	.74	.77	.80	.82	.80	.79	.75	.71
1952-53	.78	.51	.24	.45	.77	.69	.54	.41	.36	.28	.32	.35
1953-54	.42	.59	.53	.67	.62	.59	.56	.59	.55	.51	.52	.39
1954-55	.37	.41	.44	.34	------	------	------	------	------	------	------	------

NOTE.—Tunnel "holed through" in January 1955. All seepage subsequent to that date was measured at the south portal.

TABLE 4.—*Monthly seepage discharge, in cubic feet per second, from south portal of Tecolote Tunnel*

Water year	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.
1949-50	------	------	------	------	------	------	0	0.005	0.023	0.073	0.094	0.19
1950-51	0.20	0.064	0.077	0.18	0.64	1.26	1.33	2.00	2.50	2.90	5.65	6.88
1951-52	5.27	9.05	8.48	7.95	8.64	8.71	9.29	8.92	8.35	8.36	8.96	8.94
1952-53	8.90	5.80	7.72	7.75	6.12	6.15	7.03	7.39	7.70	7.24	7.91	8.01
1953-54	7.95	8.05	8.20	8.06	7.52	7.74	9.03	11.6	15.5	15.2	16.6	16.7
1954-55	15.3	14.4	14.0	14.5	14.5	13.7	13.2	12.8	12.4	12.2	11.8	10.7
1955-56	10.8	10.2	9.9	9.8	9.5	9.4	9.2	9.0	8.8	8.5	8.2	8.0
1956-57	7.8	7.6	7.4	7.3	7.5	7.4	7.3	7.1	7.2	9.0	6.6	7.1
1957-58	7.1	7.1	7.1	6.6	6.6	6.6	6.8	7.1	7.1	7.1	7.1	7.1
1958-59	7.1	7.1	7.1	6.8	6.8	6.6	6.6	6.6	6.6	6.9	5.2	4.9
1959-60	5.0	4.8	4.9	4.9	5.5	5.5	------	------	------	------	------	------

NOTE.—Tunnel "holed through" in January 1955. Discharges subsequent to that date represent total seepage into tunnel.

It is exceedingly difficult to evaluate the effect of Tecolote Tunnel on the flow of springs and spring-fed streams in the area. The evaluation must be based on a comparison of measured discharge before and after the tunnel began draining off appreciable quantities of water. It has been pointed out that the measuring program began in the fall of 1948, and that 3 years later the tunnel began draining off significantly large quantities of water. These first 3 years of record represent the calibration period for an evaluation study; that is, the period when the flow of springs is known to have been unaffected by tunnel construction. It also happens that these 3 years represent a period of extremely deficient precipitation. In 7 of the 8 years that followed, 1952 through 1959, precipitation was greater than it had been during any year of the calibration period, and the effect of the

1 dry year, 1959, was offset, to a degree, by the fact that it followed 1 of the 2 extremely wet years in the 8-year period. Because the measured springs respond rapidly to changes in precipitation, it is not surprising that the flow of almost all springs and streams has been greater each year since 1951 than it had been in the preceding 3 years. Furthermore, because the 3 years of the calibration period were uniformly very dry, no conclusions can be drawn as to whether or not the tunnel has affected the degree of response of the flow to large quantities of precipitation.

The deficiencies of the calibration period in length of record and variability of flow cannot be overcome by the collection of additional discharge information in the years to come. There are data available, however, concerning water quality and temperature that are helpful in an evaluation of the effect of tunnel construction. In November 1953, samples of the discharge from 23 springs were chemically analyzed. The results of the chemical analysis are found in table 5. In May 1954, the Bureau of Reclamation obtained samples of inflow from 18 sites within the south half of the tunnel. These tunnel inflows were found to be under a static head of about 500 feet. The results of the chemical analysis of the tunnel samples are found in tables 6 and 7. All three tables of water quality have been abstracted from an unpublished report by the California Department of Water Resources, dated January 1955, and titled, "Tecolote Tunnel Water Quality."

TABLE 5.—*Analyses of springs, Santa Barbara County, Calif.*

[Reproduced by courtesy of California Dept. Water Resources]

Spring No.	Date collected	Flow (gpm)	Temperature (°F)	Altitude	Odor[1]	EC×10[6] at 25°C	pH	Parts per million (upper number) and equivalents per million (lower number) for indicated cations and anions								F (ppm)	B (ppm)	Total dissolved solids (ppm)	Total hardness as $CaCO_3$ (ppm)
								Ca	Mg	Na	K	CO_3	HCO_3	SO_4	Cl				
16	Nov. 18, 1953	0.35	55	2,230	------	365	7.5	34.0 1.70	17.4 1.44	20.5 0.89	0.8 0.02	0 0	151 2.47	39.3 0.82	23.4 0.66	0.1	0.0	220	157
30	Nov. 23, 1953	52.0	49	400	------	534	8.25	61.0 3.05	14.6 1.21	30.2 1.32	1.0 0.03	1.5 0.05	234 3.84	54.3 1.13	22.4 0.63	.1	.05	302	213
31	do	79.0	63	425	Cs	664	7.8	70.0 3.50	14.0 1.16	56.1 2.44	1.0 0.03	0 0	274 4.49	99.0 2.06	21.3 0.60	.3	.15	425	233
33	do	29.0	52	500	------	631	8.1	78.0 3.90	17.4 1.44	32.2 1.40	1.0 0.03	0 0	254 4.17	97.5 2.03	23.4 0.66	.1	.0	327	267
35	do	19.0	53	800	------	593	8.1	70.8 3.54	21.2 1.75	24.8 1.08	0.8 0.02	0 0	258 4.24	79.0 1.68	19.2 0.54	.1	.05	333	264
35b	do	(2)	61	700	Cs	769	7.5	74.4 3.72	29.4 2.42	49.7 2.16	1.4 0.04	0 0	301 4.94	131 2.72	27.7 0.78	.0	.10	493	307
36	do	2.83	61	600	------	1,070	8.0	141 7.04	36.9 3.05	44.2 1.92	2.0 0.05	0 0	358 5.88	246 5.13	43.8 1.23	.1	.0	728	504
50b	Nov. 20, 1953	110.0	59	1,985	------	462	7.5	67.2 3.36	13.6 1.12	14.0 0.61	0.8 0.02	0 0	174 2.75	88.6 1.96	9.6 0.27	.1	.05	312	224
50c	do	203.0	58	1,950	------	438	7.6	62.8 3.14	12.0 0.99	12.4 0.54	0.8 0.02	0 0	151 2.47	88.2 1.95	12.8 0.36	.1	.0	287	206
50d	do	96.0	62	1,800	Cs	444	7.6	62.8 3.14	13.1 1.08	24.6 1.07	0.8 0.02	0 0	207 3.40	63.8 1.41	14.9 0.42	.1	.05	312	211
62	Nov. 19, 1953	7.8	63	130	------	755	7.45	125 6.23	18.5 1.53	24.8 1.08	1.0 0.03	0 0	272 4.47	182 3.79	25.6 0.72	.4	.10	518	388
66	do	.83	52	300	------	474	8.2	86.2 4.31	1.1 0.09	12.4 0.54	0.8 0.02	0 0	210 3.45	41.8 0.87	19.1 0.54	.1	.10	257	220
95	Nov. 18, 1953	(3)	54	2,900	M	57	5.7	8.2 0.41	1.1 0.09	4.4 0.19	1.2 0.04	0 0	7.3 0.12	16.3 0.34	9.6 0.27	.2	.10	82	25

100	do	2.07	52	2,025		835	7.4	122 6.09	26 6 2.20	21.2 0.92	2.0 0.05	0 0	294 4.82	199 4.15	13.8 0.39	.0	.0	578	414
101 and 102[4]	do	.13	56	(5)		1,590	7.8	230 11.48	67.3 5.56	47.8 2.08	2.1 0.05	0 0	330 5.42	629 13.1	28.7 0.81	.3	.15	1,225	852
103	do	1.2	56	1,100		817	7.6	106 5.28	29.3 2.42	25.8 1.12	0.8 0.02	0 0	300 4.91	159 3.32	19.2 0.54	.2	.10	527	385
110b	Nov. 17, 1953	80.0	>[6] 110	1,050	Cs	762	8.2	4.4 0.22	0 0	163 7.10	1.2 0.04	Tr.	226 3.72	36 0 0.75	101 2.85	2.8	2.95	542	11
120	Nov. 19, 1953	(7)	44	1,190	Cs	2,730	7.3	238 11.90	40.2 3.32	310 13.50	7.0 0.18	0 0	410 6.71	620 12.90	345 9.72	1.2	7.20	1,771	761
121	do	.44	60	1,185	Cs	1,105	7.1	173 8.65	9.2 0.76	50.5 2.20	3.6 0.09	0 0	360 5.92	223 4.65	39.6 1.11	.5	.80	760	470
124 and 125[3]	do	1.67	52	850		710	7.9	89.6 4.48	19.0 1.57	33.1 1.44	1.0 0.03	0 0	302 4.95	78.7 1.64	34.0 0.96	.2	.25	366	302
129	Nov. 18, 1953	12.1	49	1,900		523	7.8	79.8 3.99	11.9 0.98	14.1 0.61	0.9 0.03	0 0	242 3.98	64.9 1.35	10.6 0.30	.1	.10	267	248
131	do	3.75	54	1,550		423	7.3	44.0 2.20	12.5 1.03	26.7 1.16	0.8 0.02	0 0	221 3.63	13.5 0.28	19.2 0.54	.3	.05	165	162
172	Nov. 19, 1952	2.31	44			668	7.95	95.0 4.75	19.7 1.63	21.6 0.94	1.0 0.03	0 0	286 4.70	106 2.20	12.8 0.36	.1	.0	308	319

1 Cs Chemical, sulfuretted. M, Musty.
2 Flow was cut off at time of sampling. 1 month previously the flow was 60 gpm.
3 No flow, sample dipped from spring box.
4 Sample taken from junction box of two springs.
5 Spring 101 at 1,280 ft and spring 102 at 1,100 ft.
6 Subsequently temperature measured 114°F.
7 No flow, sample taken from pool.
9 Sample taken from common collection tank.

TABLE 6.—*Analyses of tunnel inflows, Tecolote tunnel, Santa Barbara County, Calif.*

[Reproduced by courtesy of California Dept. Water Resources]

Stationing from north portal (feet)	Date collected	Estimated flow (gpm)	Temperature (°F)	EC×10⁶ at 25°C	pH	Parts per million (upper number) and equivalents per million (lower number) for indicated cations and anions								Sulfide (ppm)	F (ppm)	B (ppm)	Total dissolve solids (ppm)	Total hardness as $CaCO_3$ (ppm)
						Ca	Mg	Na	K	CO_3	HCO_3	SO_4	Cl					
193+40	May 12, 1954	±50	113.5	398	9.1	0 0	0 0	105 4.57	0.8 0.02	34 1.12	127 2.08	43 0.90	17 0.48	10.3	3.0	0.40	281	0
199+00	do	±100	109	417	9.1	0 0	0 0	105 4.57	0.8 0.02	34 1.12	163 2.68	17 0.35	18 0.51	10.4	3.0	.40	280	0
205+15	do	±100	104	461	9.1	0 0	0 0	115 5.0	0.8 0.02	36 1.20	163 2.68	32 0.66	21 0.59	10.3	3.0	.44	316	0
210+55	do	±10	96	472	8.7	0 0	0 0	115 5.0	0.8 0.02	17 0.56	178 2.92	57 1.19	18 0.51	5.9	3.0	.44	300	0
213+00	do	±10	94	442	8.9	0 0	0 0	115 5.0	0.8 0.02	29 0.96	163 2.68	50 1.04	20 0.56	6.9	3.0	.46	291	0
219+78	do	1–2	90	450	8.7	4 0.20	2 0.16	105 4.57	0.8 0.02	26 0.88	166 2.72	43 0.89	18 0.51	10.5	2.5	.42	277	18.2
221+38−223+83 [1]	do	varies	88	391	8.4	6 0.30	3 0.25	95 4.13	0.8 0.02	10 0.32	176 2.88	43 0.90	17 0.48	7.6	1.0	.32	259	27.3
224+64	do	±5	87	485	9.1	0 0	0 0	115 5.0	0.8 0.02	34 1.12	151 2.48	71 1.47	16 0.45	6.6	.2	.16	312	0
231+12	do	±10	82	585	7.7	81 4.04	27 2.22	31 1.35	0.8 0.02	0 0	281 4.60	131 2.73	8 0.23	0	.2	.06	456	313
235+80	do	±2	80	585	9.3	0 0	0 0	137 5.96	0.8 0.02	46 1.52	129 2.12	109 2.28	9 0.25	0	.2	.18	358	0
244+60	do	drips	77	555	8.0	5 0.25	3 0.25	130 5.66	0.8 0.02	0 0	217 3.56	116 2.42	10 0.28	0	.6	.26	385	24.8
250+05	do	drips	75	546	8.7	0 0	0 0	137 5.96	0.8 0.02	22 0.72	217 3.56	53 1.11	16 0.45	1.3	3.0	.36	333	0
259+43	do	1–2	78	602	8.5	6 0.30	3 0.25	148 6.44	1.4 0.04	22 0.72	312 5.12	20 0.42	23 0.65	6.3	3.0	.68	396	27.3
262+10	do	2–3	81	575	8.5	3	1	148	1.4	22	312	15	18	9.9	3.5	.92	365	11.6

						0.15	0.08	6.44	0.04	0.72	5.12	0.32	0.51					
272+22	do	1–2	79	943	8.7	2 0.10	0 0	275 11.96	2.4 0.06	31 1.04	559 9.16	68 1.41	23 0.65	15 3	2.0	.56	690	5.0
287+75	do	drips	75	1,220	8.8	0 0	0 0	330 14.36	2.6 0.07	53 1.76	644 10.56	47 0.97	49 1.38	13.8	2.0	.38	803	0
300+60	do	drips	74	699	7.8	93 4.64	25 2.06	44 1.91	1.2 0.03	0 0	322 5.28	145 3.02	15 0.42	0	.2	.02	524	335
305+50	do	±3	74	714	7.8	81 4.04	22 1.81	48 2.09	1.4 0.04	0 0	310 5.08	113 2.36	18 0.51	0	1.2	.04	465	292
336+07 [2]	Oct. 8, 1953	3,500	94	488	8.0	6 0.30	3 0.25	100 4.35	0.9 0.02	0 0	215 3.52	53 1.10	9 0.25	-------	2.0	.34	299	28
336+07 [2]	do	3,500	94	490	7.8	6.5 0.32	2.4 0.20	104 4.52	0.4 0.01	0 0	210 3.44	58 1.21	10 0.28	-------	2.5	.42	313	26

[1] Section of tunnel 245 ft in length lined with concrete; flow from behind which is controlled by a valve.

[2] South portal stationing; sample is of total flow.

TABLE 7.—*Trace-metal and silica analyses of tunnel inflows, Tecolote Tunnel, Santa Barbara, Calif.*

[Reproduced by courtesy of California Dept. Water Resources]

Stationing from north portal (feet)	Date collected	Mineral constituents in parts per million														SiO_2 (ppm)
		Sr	Ba	B	Fe	Al	Cr	Cu	Mn	Ni	Sn	Ti	V	Li	Zr	
199+00	May 12, 1954	0.005	0.01	0.5	0.01	0.1	0.0006	0.01	0	0	0	0.03	0	0	0.006	35
213+00	do	.005	.07	.8	.04	.2	.002	.009	0	.005	0	.02	0	0	.009	30
235+80	do	.5	.03	1.	.02	.3	0	.01	0	.01	0	0	0	0	.02	25
259+43	do	.005	.2	1.	.02	.2	.0006	.004	0	0	0	.01	0	0	.009	25
272+22	do	.005	.4	1.	.07	.4	.007	.02	0	0	0	.02	0	0	.02	15
305+50	do	2.	.04	.05	.04	.04	.0006	.002	.2	0	.01	0	.009	0	-------	35
336+07 [1]	Oct. 8, 1953	.4	.2	.03	.04	.2	-------	.002	.004	-------	.002	.001	.002	.08	-------	25

[1] South portal stationing; sample is of total flow.

NOTE.—Trace-metal concentration determined by spectrographic analysis.

For Tecolote Tunnel to affect the flow of a spring adversely, it is necessary that the tunnel inflow and the spring discharge be supplied from the same aquifer. To decide positively on the existence of a common aquifer for both flows is most difficult, but from the available data, it would appear that the spring at site 110b, now dry, was affected by construction of the tunnel. Spring 110b, located about 1.8 miles east of the tunnel, had water similar in many respects to the majority of the tunnel inflows, but dissimilar to the water discharged from the other springs in the area. The tunnel flows are predominantly sodium waters, whereas the springs other than spring 110b discharge calcium waters. Because most of the tunnel inflow occurs between tunnel stations 161 and 244, it is reasonable to assume that this inflow has the characteristics found in the first three tunnel samples listed in table 6. The discharge from spring 110b and the tunnel inflow had a low degree of hardness, 11 ppm (parts per million) for the spring water and 0 ppm for the tunnel seepage. It is true that a difference existed in the total dissolved solids, 452 ppm for the spring flow and 290 ppm for the tunnel inflow, but many other characteristics of the two waters were closely similar. Fluoride concentrations, for example, were 2.8 ppm for spring 110b and 3.0 ppm for the tunnel. Sulfides were present in both flows, the tunnel flow having had a content of 10.3 ppm. The water of spring 110b was not analyzed for sulfides, but had a definite hydrogen sulfide odor at the time of sampling. Hypothetically, the principal dissolved-mineral constituent of both of these waters was $NaHCO_3$.

Spring 110b was the only spring in the measuring network of 164 sites that had high-temperature flows. Observed temperatures ranged from 105° to 112°F, whereas at the other measuring sites the temperature ranged from about 45° to 75°F. Water temperatures observed at the three tunnel-sampling sites in the region of heavy inflow ranged from 104° to 113.5°F. Although the elevation of spring 110b is 400 feet above the tunnel, it will be remembered that the tunnel inflows were under a static head of about 500 feet.

The flow of spring 110b was first measured in July 1954, when a flow of 29 gpm was observed. By March 1955 the spring was dry and failed to be recharged by the storms of the following years. It seems that the failure of the spring may have been a result of drainage into Tecolote Tunnel between tunnel stations 161 and 244, where most of the seepage enters. In the preceding paragraphs various premises have been presented to support this conclusion. No one premise is decisive by itself, but the combined weight of the evidence leaves little doubt that spring 110b was adversely affected by the construction of the tunnel.

It has been mentioned previously that the flow of almost all springs and streams has been greater each year since December 1951, when the extremely dry period ended, than it had been in the preceding 3 years. The only exceptions to this trend were found at springs 110b and 136, and at Hot Springs Creek (sites 110 and 110a). The failure of spring 110b has already been discussed. The decline of Hot Springs Creek is attributed to the decline and final cessation of flow of spring 110b, which is a principal contributor to the flow of the creek. Spring 136, an earthquake-affected spring whose flow was well sustained in the years following 1951, inexplicably declined rapidly in flow after the summer of 1959 and became dry in December of that year. A comparison of the hydrograph of this spring (fig. 7) with the hydrograph of tunnel outflow (fig 9.) reveals no connection between the decline of spring 136 and the existence of the tunnel.

All the above considerations lead to the following conclusions concerning the effect of Tecolote Tunnel on the flow of springs and spring-fed streams:

1. From all indications, the failure of spring 110b can be attributed to the effect of the tunnel.

2. There is no evidence that construction of the tunnel affected the flow of any other spring or stream.

SUMMARY AND CONCLUSIONS

1. The most striking characteristic of the flow of springs and spring-fed streams in the Tecolote Tunnel area is the rapid response of discharge to precipitation.

2. The Arvin-Tehachapi earthquake of July 1952 increased the flow at 18 measuring sites. At 15 of these sites this effect was felt for only several months, but at sites 31, 136, and 142, the effect remained for several years.

3. The summer flow of many springs and streams may have increased as a result of decreased evapotranspiration losses following the Refugio brush fire of September 1955, but the evidence is inconclusive.

4. The many complex and interrelated factors that influence the discharge of springs and spring-fed streams make it exceedingly difficult to isolate the effect of Tecolote Tunnel on the flow. Another major difficulty in evaluation of the effect of the tunnel stems from the fact that the calibration period is inadequate for the purpose. The calibration period is defined as that period of observed discharge prior to the time when the tunnel began to develop appreciable inflow. The calibration period for this study was only 3 years, lasting from late 1948 to late 1951, and was uniformly deficient in precipitation. Fur-

thermore, these inadequacies in regard to short length of record and limited range in precipitation cannot be overcome by the collection of additional discharge information in the years to come.

5. A study of all available data resulted in the following conclusions concerning the effect of Tecolote Tunnel: (a) The failure of spring 110b, the source of Hot Springs Creek, can be attributed to construction of the tunnel; (b) There is no evidence that construction of the tunnel affected the flow of any other spring or stream.