HYDROLOGIC EFFECTS OF SUBURBAN DEVELOPMENT NEAR PALO ALTO, CALIFORNIA

OPEN—FILE REPORT

U.S. DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY
Water Resources Division
Menlo Park, California, 1969

UNITED STATES
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By

J. R. Crippen and A. O. Waananen

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January 23, 1969

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ABSTRACT

Data were gathered for 7 years in 3 small basins in the foothills west of San Francisco Bay near Palo Alto, Calif., to detect changes in the hydrologic regime caused by suburban development. One basin (Los Trancos Creek tributary) remained in a natural state throughout the study period while another (Sharon Creek) remained natural for the first 3 years, then suburban homes, offices, and a golf course were established during the fourth year; the basin remained relatively stable for the following 3 years. The third basin (San Francisquito Creek tributary) was unchanged for the first 4 years of the study, but from then on construction activity was continuous and no stable relation existed between basin parameters and hydrologic characteristics.

Streamflow in Sharon Creek changed from ephemeral to perennial because of the introduction of imported water and an associated rise in the ground-water table. Runoff increased from 5 or 10 percent of annual precipitation to more than 30 percent. Flow peaks of magnitudes that occurred only once or twice a year under natural conditions occurred with much greater frequency after development, while the frequency of peaks of greater magnitude increased to a lesser degree. Sediment production was markedly increased during times of construction activity, but returned to predevelopment magnitude after the developed area became stable. Downstream from the developed area brush and weeds became established in the channel and on the streambanks and formed a dense, lush zone of vegetation where only seasonal grasses and herbage had existed previously. There was an increase in concentrations of dissolved solids, and the total load borne by the stream increased about tenfold.

San Francisquito Creek tributary experienced marked changes in its regimen of streamflow, with peaks becoming higher and more frequent and flow becoming perennial. However, these changes could not be related to any set of stable conditions in the basin and therefore no analysis was attempted.

INTRODUCTION

The past 50 years have seen rapid population growth throughout the Nation, and even more rapid increase in the population of urban regions. Each metropolitan core area has become surrounded by many square miles of suburbs. Transportation of people and goods has become faster and more flexible, allowing dispersed, outlying centers of commerce and light industry to arise; these new centers, in turn, have spawned initially scattered new residential developments which eventually tend to merge. This trend portends an increase in problems concerning water supply, waste disposal, and storm-drainage facilities. Public leaders, engineers, ecologists, and conservationists are increasingly aware of the need for careful planning. The development of solutions for the problems of the future must proceed within the context of a changing environment in each urban region. Hydrologic data on the effects of urbanization are scarce, and some available data have not been fully evaluated. As a result, designers and planners have had only rule-of-thumb criteria with which to deal with those problems.

To obtain information on the character and magnitude of some of the hydrologic changes that occur as lands are converted from rural to urban-residential use, the San Francisquito project was begun in 1958. The project included two small basins tributary to San Francisquito Creek (San Francisquito Creek tributary and Los Trancos Creek tributary) and the adjacent small basin of Sharon Creek, all about 3 miles southwest of Palo Alto. At that time the basins of San Francisquito Creek tributary and Sharon Creek were scheduled for suburban-type development.

Trends in Population and Urban Development in the Vicinity of Palo Alto

Problems associated with urban and suburban development are expected to grow at a fast pace during the next few decades. This expectation is based on projections of three existing trends, expressed in terms of population growth and movement:

1. Increasing density of population in regions already developed.
2. Development of lands not previously occupied, which frequently are more problem-prone than those involved in early development.
3. Increase in the size of unified areas of development, whereby problem situations may interact.

These trends exist in San Mateo and Santa Clara Counties, which contain the study area, and their future course can be visualized by inspection of table 1. Although the projected population growth (table 1) may seem large, estimates for 1970 and 1980 by the California Department of Finance (1965) are about 50 percent greater than those cited.

Table 1.--Estimated population and area of developed land, San Mateo and Santa Clara Counties, 1960-2020

[From the 1960 census and from projections of land use and population by the U.S. Department of Commerce (1959)]

Year	Population (thousands)	Area of developed lands (sq mi)	
		Residential and commercial	Industrial
1960	1,087	198	28
1970	1,280	238	36
1980	1,730	290	50
1990	2,260	367	62
2000	2,960	446	74
2010	3,780	563	84
2020	4,700	647	96

Total land area, 1,759 sq mi

Purpose and Scope

The purpose of the San Francisquito project was to detect changes in the hydrologic regime as lands were converted from rural to urban-residential use, to document hydrologic parameters before, during, and after suburban development, to define the changes caused by development, and to relate the nature and degree of changes to their causes, if possible.

Prior to, and for a short time during the study, all three basins were in a state of relative hydrologic equilibrium, with runoff, ground water, and plantlife following a regime established by the natural environment. Indications in 1958 were that two of the basins would become suburban, with broad streets, individual homes, and small reservations of park land. The third basin was to be reserved from development and was therefore chosen as a control area.

The timetable of development was rather uncertain. This was recognized in planning the hydrologic study and the program of study was therefore flexible. At this time (1966) the control basin (Los Trancos Creek tributary) remains unchanged. Sharon Creek basin has been developed over much of its area, and the degree of development remained almost stable for more than 3 years. However, additional development has started in this basin, and drainage facilities are being altered in a way that will make continued study of the hydrologic regime of doubtful value. The basin of San Francisquito Creek tributary is being partly developed for light industry. This report presents a description of the hydrologic, physiographic, and climatic environment, and summaries of data collected in the three basins through September 1965. Emphasis is on analysis of the data from the Sharon Creek basin during the 3 years of relative stability following its development. Selected basic data are presented in an appendix.

Acknowledgments

This report was prepared by the Water Resources Division of the Geological Survey under the supervision of Walter Hofmann, former chief of the California district, and his successor, R. Stanley Lord. Prior to October 1963 fieldwork and data collection were under the supervision of the Chief, Branch of General Hydrology.

Personnel of the Menlo Park, Calif., subdistrict of the Survey, especially John Limerinos, aided materially in all aspects of data collection, and other coworkers furnished helpful advice and guidance. Owners of property in and near the study basins, including officials of Stanford University, were wholeheartedly cooperative in permitting the installation of equipment on their lands. Data from test borings, soil studies, vegetation surveys, and infiltration studies were made available by D. A. Morris, R. F. Miller, F. A. Branson, and I. S. McQueen, all of the Geological Survey. C. T. Snyder, also of the Geological Survey, abstracted information concerning the geology of the study basins from data provided by Dr. F. W. Atchley and personnel of the Atomic Energy Commission.

THE SAN FRANCISQUITO PROJECT

Physiography

The San Francisquito project area is on the inland slopes of the San Francisco Peninsula (figs. 1 and 2), about 12 miles from the Pacific Ocean. The basins are tributary to San Francisco Bay near its southern end, at a distance of about 5 miles. A ridge of low mountains forming the backbone of the San Francisco Peninsula lies between the study area and the Pacific, with altitudes as high as 2,500 feet. The basins themselves are in a gently rolling foothill region, and their altitudes range from 145 to 532 feet. Some of the physical characteristics of the basins are listed in table 2.

The San Andreas Rift zone lies 2 or 3 miles southwest of the study basins. The area was violently shaken during the great San Francisco earthquake of 1906, but only minor tremors have been experienced since that time. Landforms and drainage patterns in the region have a predominantly northwest to southeast trend, reflecting the importance of large-scale uplift along fault zones paralleling the San Andreas Rift in establishing present-day topography.

Table 2.--Selected characteristics of the study basins

FEATURE	BASIN		
	Sharon Creek	Los Trancos Creek tributary	San Francisquito Creek tributary
Area, acres	245	302	170
Altitude, feet,			
mean	255	395	280
lowest point	145	270	175
10-percentile[1]	195	310	225
25-percentile	220	340	255
50-percentile	255	395	280
75-percentile	295	455	310
90-percentile	320	485	330
highest point	375	532	410
Circularity ratio (Rc)[2]	0.585	0.568	0.703
Longest dimension, feet	4,500	4,250	3,100
Basin perimeter, miles	2.87	3.23	2.18
Coordinates of center of area of basin[3]			
Latitude: 37° +	25' 30"	24' 07"	24' 25"
Longitude: 122° +	12' 46"	10' 44"	12' 12"

[1]For example, 10 percent of the land surface in the Sharon Creek basin is lower than 195 ft.

[2]Rc = (area of basin) / (area of circle with same perimeter).

[3]One second of latitude is about 101 ft; one second of longitude is about 80 ft.

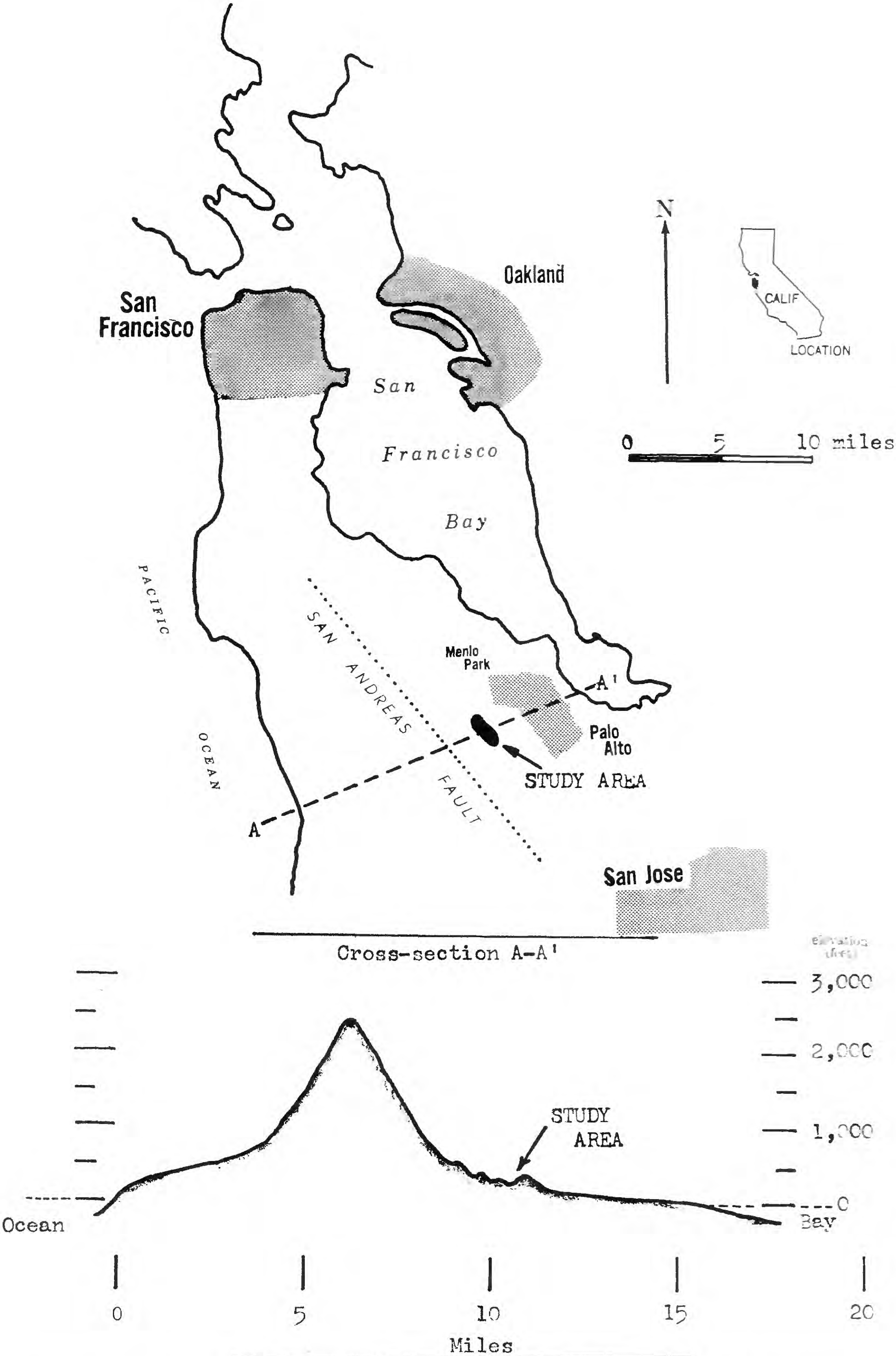


FIGURE 1.--Sketch map and profile showing location of study basins.

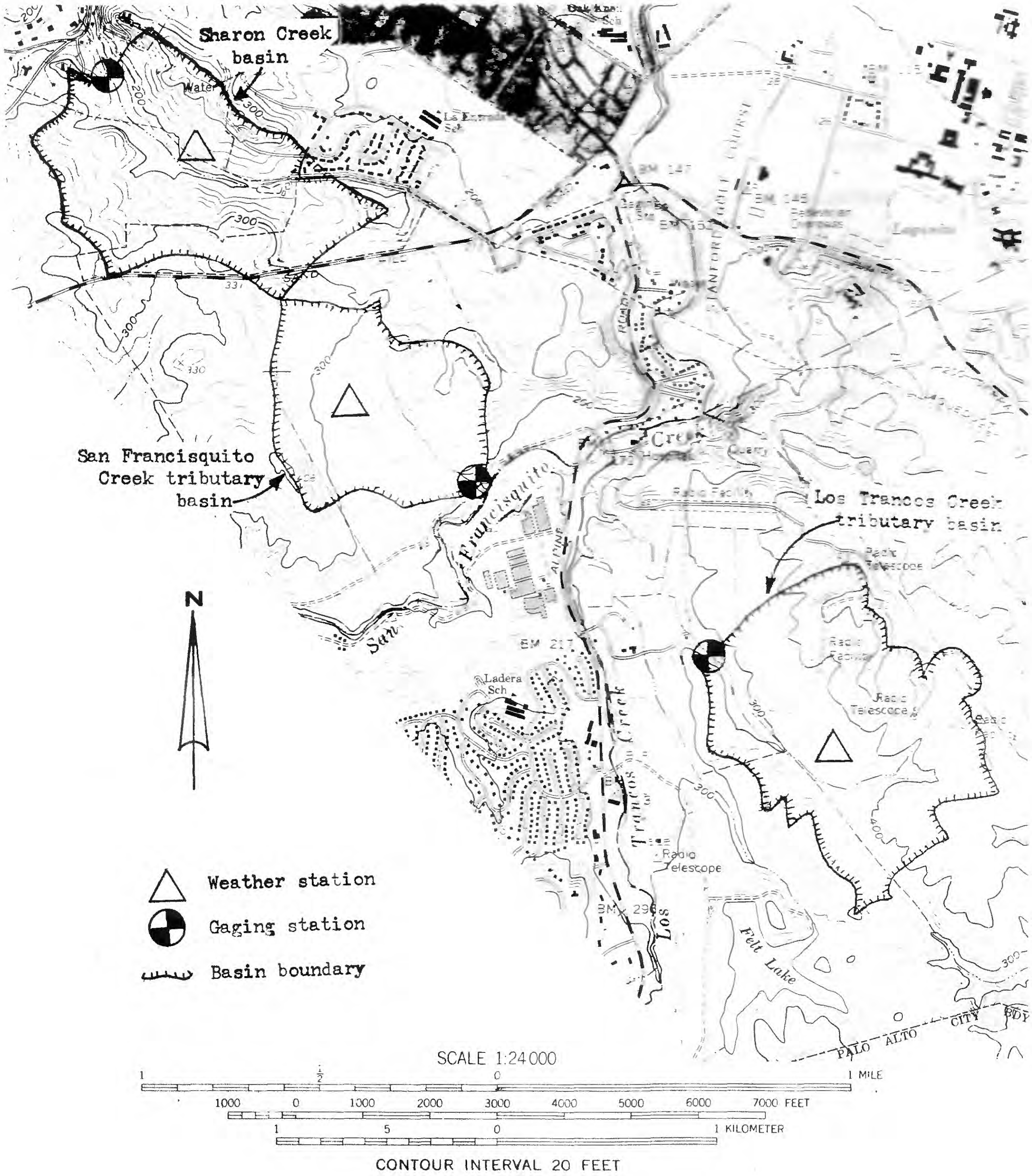


FIGURE 2.--Topographic map showing the study basins.

Instrumentation and Project Operations

The study basins were equipped with standard streamflow-measurement stations at or near the outlets of the basins; recording rain gages, hygrothermographs and anemometers at a weather station in each basin to record humidity and the temperature and movement of air; a pyrheliograph in the central basin to measure incoming solar radiation; networks of small precipitation-storage gages around the basin peripheries; and ground-water observation wells.

The operating program for the project, in addition to the maintenance of the recording instruments and gaging stations, included weekly observations of water levels in wells, prompt inspection of precipitation gages following rains, and soil-moisture observations at intervals of a month or less. Water samples were collected from the streams at various intervals, and were analyzed for chemical quality and sediment content. Test borings were made in March 1959 to determine depth to water and obtain subsurface data. In June 1959 the soils in the study areas were mapped, the vegetation was surveyed, and infiltrometer studies were made.

Climate

The climate in the study area is Mediterranean. Winters are warm and moist, and summers are mostly cool and dry.

Long-term weather data describing conditions in the study area have been assembled from official and unofficial weather records at Palo Alto, 3 miles east of the study area. Average monthly values from 37 years of temperature and 50 years of precipitation records at Palo Alto are summarized in the following table. The study basins are 200 to 400 feet higher than the Palo Alto station and are free of the moderating influence of the city; temperatures therefore average about two degrees lower than those of Palo Alto. Early morning frosts occur perhaps 15 or 20 times a year in December, January, and February. On rare occasions the temperature may drop to -7°C (20°F) or slightly lower, and in the summer months the maximum occasionally exceeds 40°C (104°F). Daily mean temperatures are seldom below 0°C (32°F) or above 30°C (86°F). The diurnal temperature range is least in midwinter and greatest in midsummer--the maximum ranges likely to be encountered during the two seasons are about 17° and 31°C (30° and 55°F).

Month	Precipitation (inches)	Temperature		Month	Precipitation (inches)	Temperature	
		(°C)	(°F)			(°C)	(°F)
July	0.01	36.6	65.8	January	3.38	26.2	47.2
August	.02	36.2	65.2	February	2.89	28.0	50.4
September	.26	35.8	64.5	March	2.04	29.6	53.2
October	.65	33.4	60.1	April	1.07	31.2	56.3
November	1.41	29.7	53.5	May	.49	33.4	60.1
December	3.21	26.9	48.4	June	.11	35.6	64.1

(Precipitation data from records 1911-60; temperature data from records 1923-60).

The general pattern of precipitation in the study area can best be described by a review of U.S. Weather Bureau data and other records collected at Palo Alto. The station location has been changed several times, but all sites have been within a small area some 3 to 4 miles east of the Sharon Creek basin and at altitudes from 20 to 100 feet above mean sea level. Because of the changes in location, an accurate analysis of time trends in precipitation is not possible. However, the data define the general characteristics of precipitation in the region. The Palo Alto record consists of data on daily precipitation since 1911, and hourly data for a shorter period. The 50-year record for the period 1911-60 has been studied to provide estimates of the long-term pattern of annual, seasonal, and daily precipitation. The information on hourly rates at Palo Alto, data from the study area, and analyses by the Weather Bureau have all been used to define short-period intensity and frequency characteristics.

Almost all precipitation within the project basins occurs as rain. Some years, snow may whiten the ground for a few minutes. Perhaps two or three times during the 50 years snow cover of as much as 2 inches, remaining for a day or so, has been observed. Such small, infrequent amounts are negligible in the hydrologic regime, and all precipitation data can be treated as rainfall. The ground surface is never frozen. Frequency and magnitude of annual precipitation for the period 1911-60 are shown in figure 3. The annual average at Palo Alto for the period was 15.2 inches. The extreme high and low annual precipitation amounts were 26.6 and 7.1 inches.

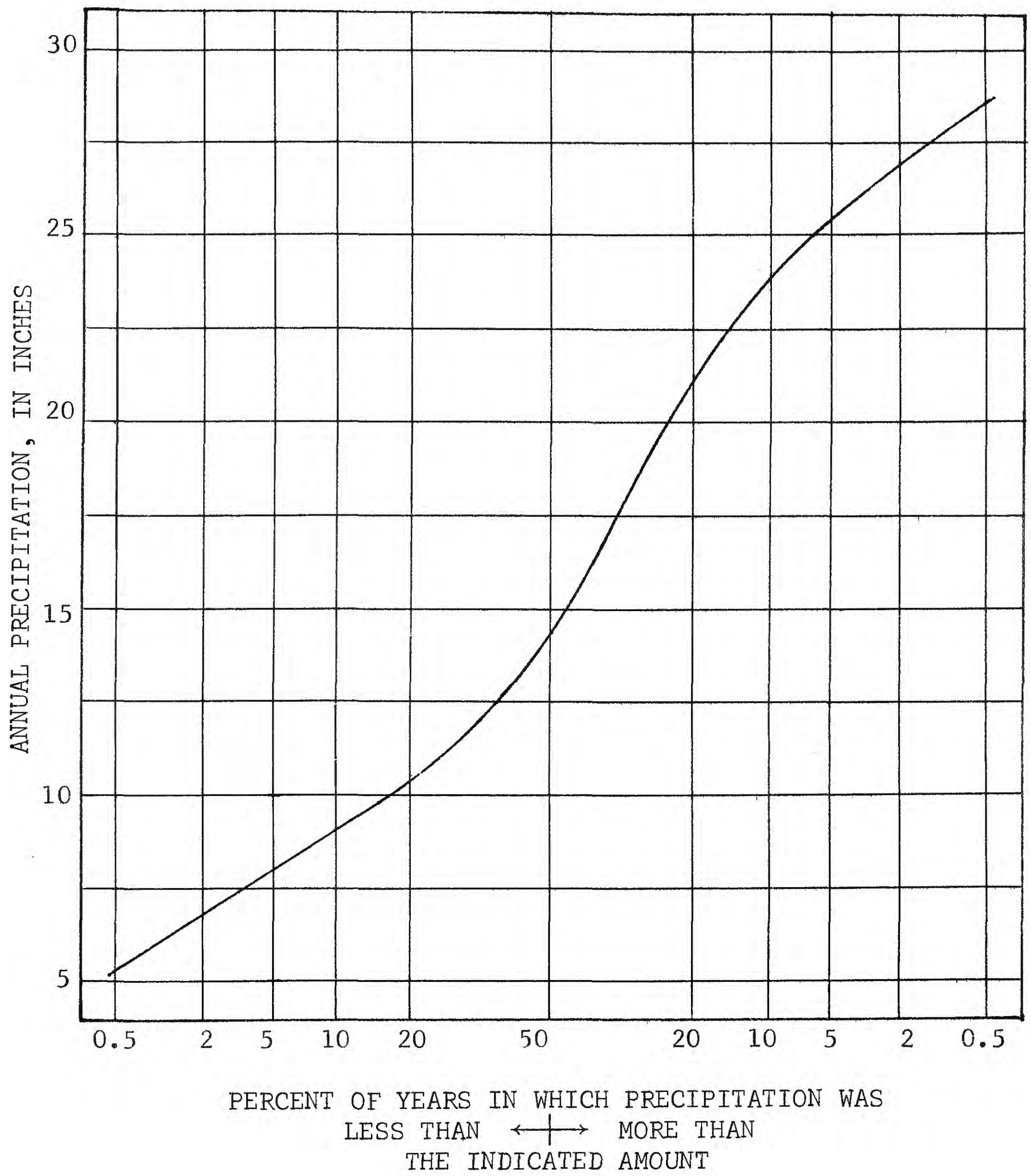


FIGURE 3.--Frequency distribution of annual precipitation at Palo Alto, 1911-60.

The distribution of precipitation is highly seasonal, as shown in figure 4. About 75 percent of the precipitation, including most of the major storms, occurs during the 4-month period December through March. However, there have been exceptions to this rule. In September 1959 an early winter-type storm produced 2.25 inches of rain in 1 day in Palo Alto (3.21 inches at Sharon Creek), and a 1-day rainfall of more than 1 inch has occurred in May. Midsummer is invariably dry; during the 50-year period only 8 days in July had measurable precipitation.

There are usually several days with more than 1 inch of rainfall during the 4 months of heaviest precipitation. The curve of figure 5 illustrates the percentage of days in the entire 50-year period during which precipitation equaled or exceeded observed values. Of course, the number of days within a given range of intensity, particularly the number of days of relatively heavy rainfall, varies from year to year. Figure 6 shows the number of days of more than 1 inch of rainfall and the percentage of years during which they occurred. The bar graph in figure 6 represents cumulative frequency; for example, 38 percent of years had 2 or more days of precipitation in excess of 1 inch.

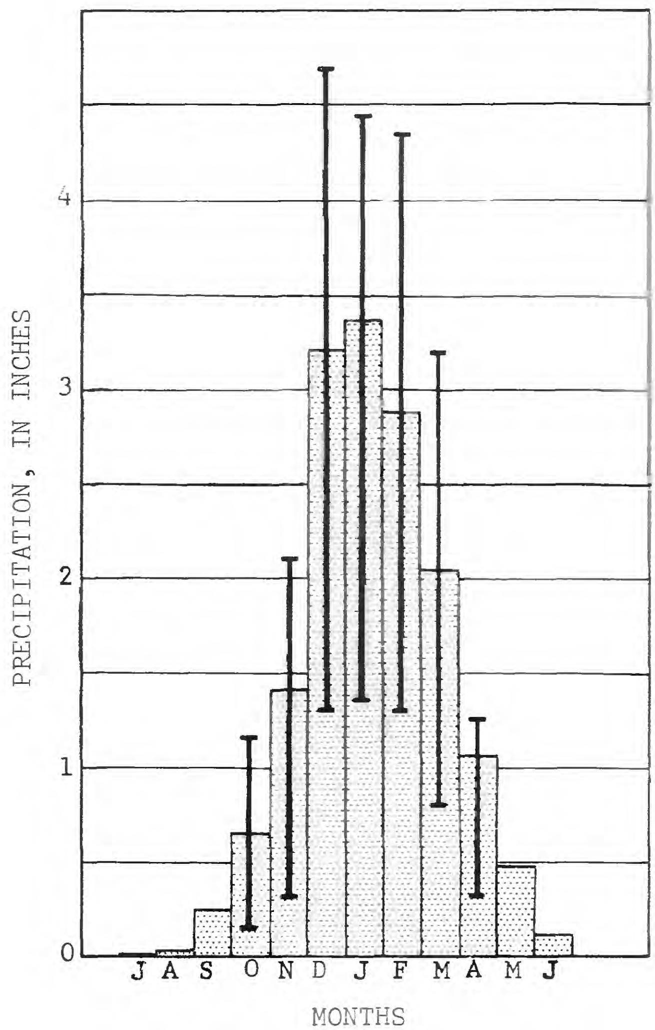


FIGURE 4.--Mean monthly precipitation at Palo Alto, 1911-60. Narrow vertical bars extend from the 25 to the 75 percentile points and thereby show the range within which precipitation occurred during 50 percent of wet-season months.

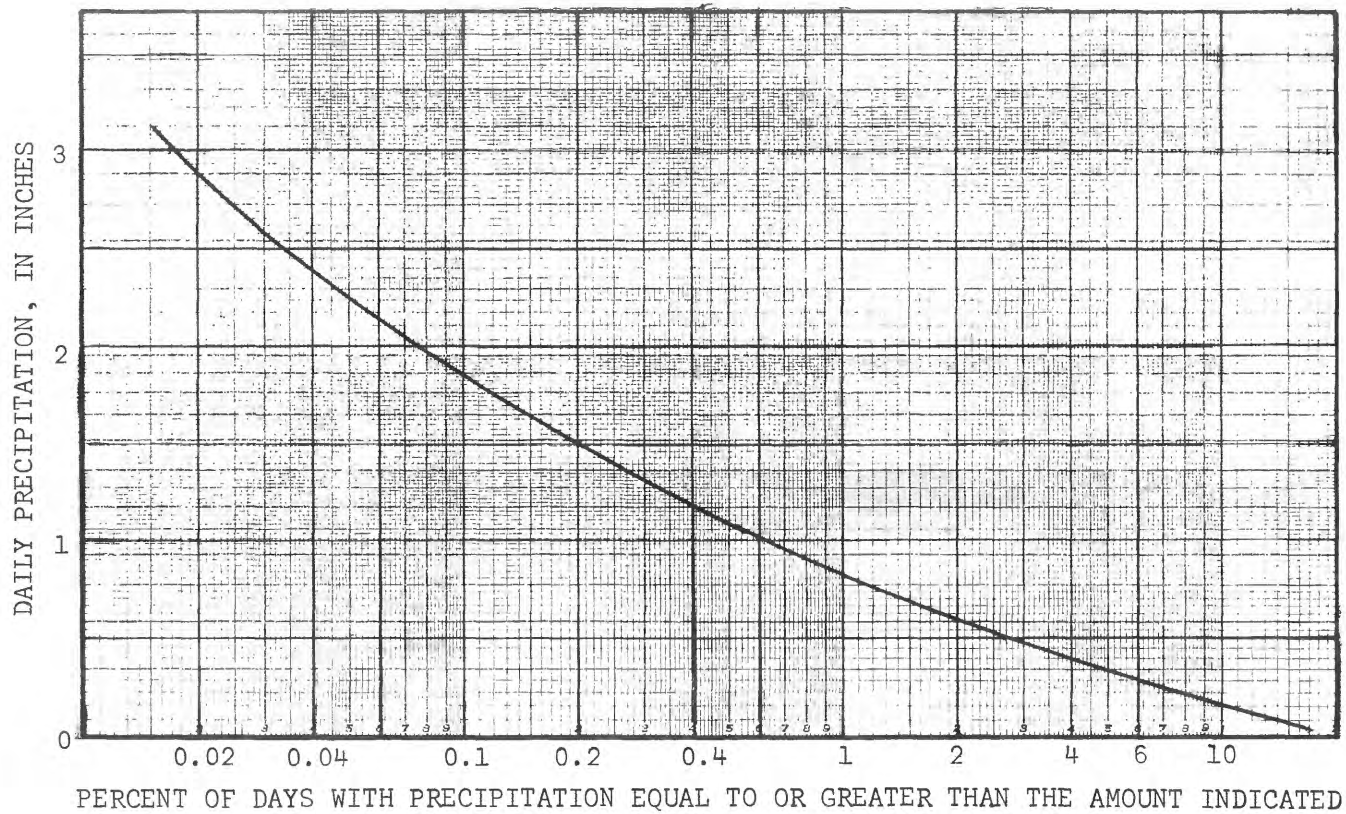


FIGURE 5.--Cumulative probability curve of daily precipitation at Palo Alto, 1911-60.

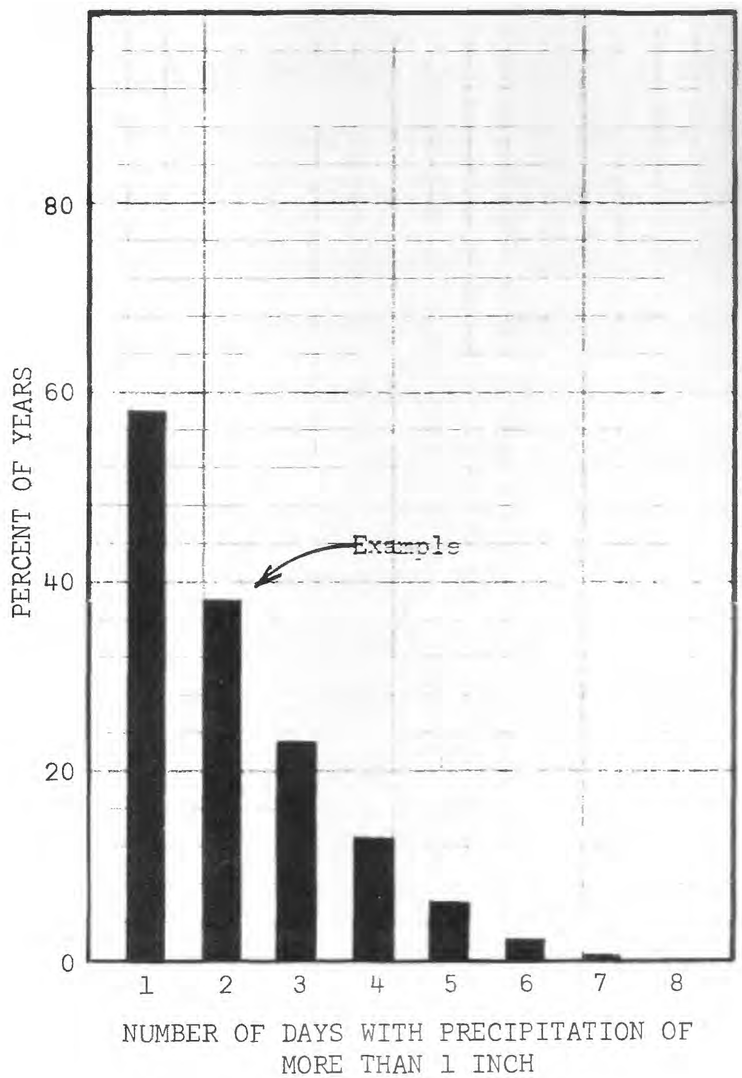


FIGURE 6.--Probability of daily precipitation of more than 1 inch at Palo Alto, 1911-60. Example: During 38 percent of years there were 2 days of precipitation in excess of 1 inch.

Most winter storm periods are from 2 days to as much as a week in duration. During unusually wet years, one rain-producing situation may follow another so closely that there is no clearly defined break between storms, and rain may fall almost every day for 3 or 4 weeks or even longer. The storm centers are usually characterized by relatively heavy rainfall and high winds. The combination of topography and air movement produces short fluctuations in intensity which can be best characterized as a series of storm cells following one another so as to produce the heavy precipitation for periods of 5-15 minutes with lulls between.

Very few thunderstorms occur in the region and intense, short bursts of precipitation such as are experienced in most other parts of the nation are almost unknown. The U.S. Weather Bureau has prepared rainfall intensity-duration-frequency curves for stations throughout the country (U.S. Department of Commerce, 1955), and inspection of these curves reveals that all Pacific Coast locations, from Seattle to San Diego, have less intense precipitation than do most other regions. Figure 7 presents intensity-duration-frequency curves for the San Francisquito project area, derived from the Weather Bureau analysis and local data. Daily precipitation data for the study basins are tabulated in the appendix.

Selected statistics relating to observed storms in the study area are shown in table 3.

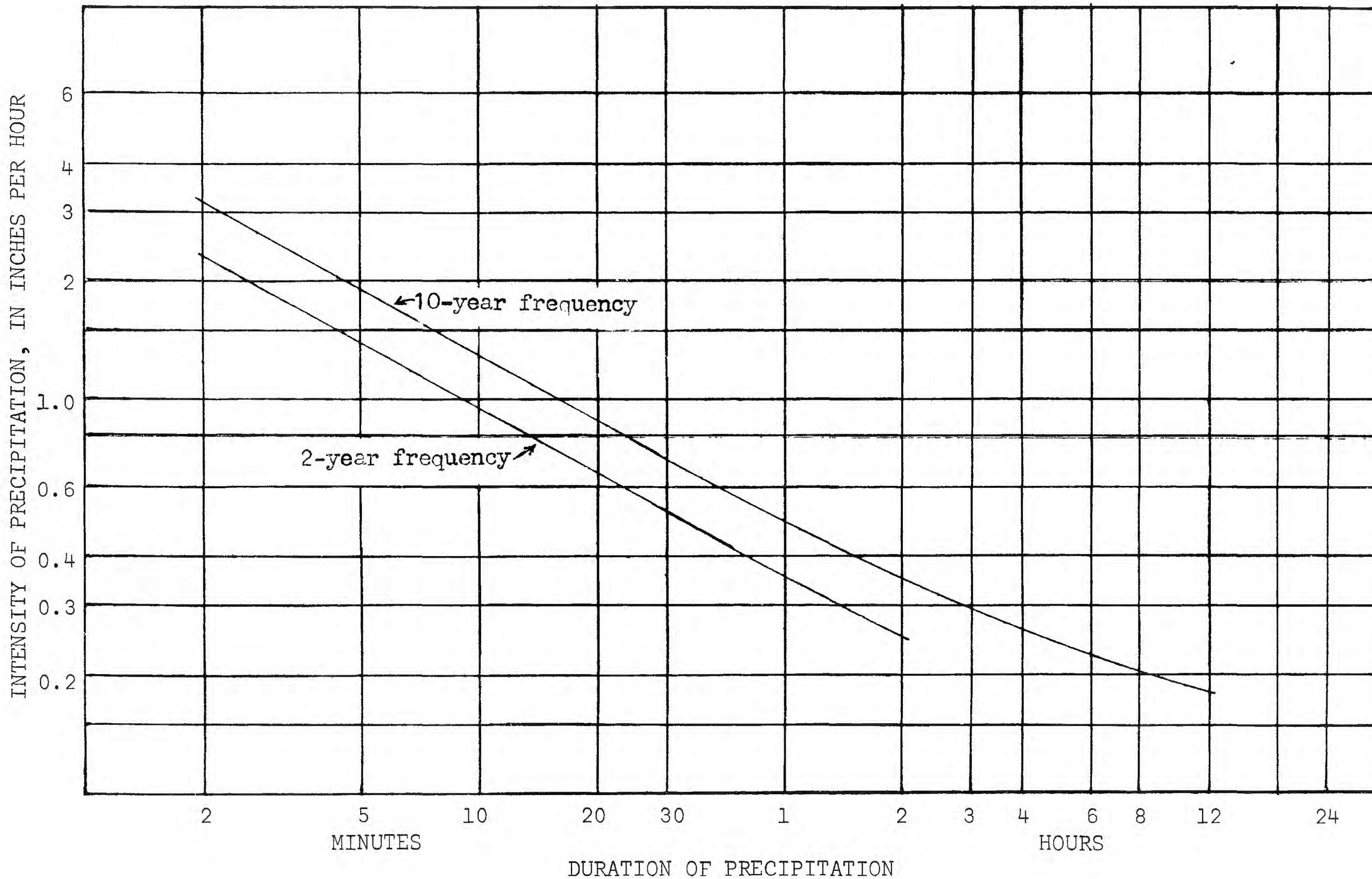


FIGURE 7.--Estimated frequency, intensity, and duration of precipitation in the study basins.

Table 3.--Statistics of precipitation of storm events recorded in Sharon Creek basin

	Year ending September 30						
	1959[1]	1960	1961	1962	1963	1964	1965
Maximum precipitation (inches):							
1 hour	0.45	0.32	0.27	0.43	0.42	0.41	0.32
2 consecutive hours	.90	.55	.47	.59	.65	.70	.51
4 consecutive hours	1.63	.78	.87	.98	.97	1.23	.91
12 consecutive hours	3.13	1.20	1.51	1.61	2.22	1.60	1.08
24 consecutive hours	3.22	1.26	1.52	1.62	3.73	1.99	1.75
2 consecutive days	3.22	1.57	1.55	2.30	4.22	2.45	2.62
5 consecutive days	3.45	2.47	1.57	2.91	4.68	3.01	3.79
15 consecutive days	3.84	3.90	2.37	6.42	6.48	3.34	6.22
Number of:							
Storm events[2]	4	4	3	5	7	2	5
Storm days[3]	12	15	7	23	15	7	31
Precipitation:							
Total (inches)	10.3	8.3	4.0	13.0	16.5	4.9	15.1
Percent of annual	83	71	39	82	78	44	82

1. Record starts December 12, 1958. No noteworthy storm occurred from October 1 to December 12.

2. Storm events arbitrarily defined by amount of precipitation during separate periods of consecutive or closely spaced days, with at least 1 inch of precipitation during each event.

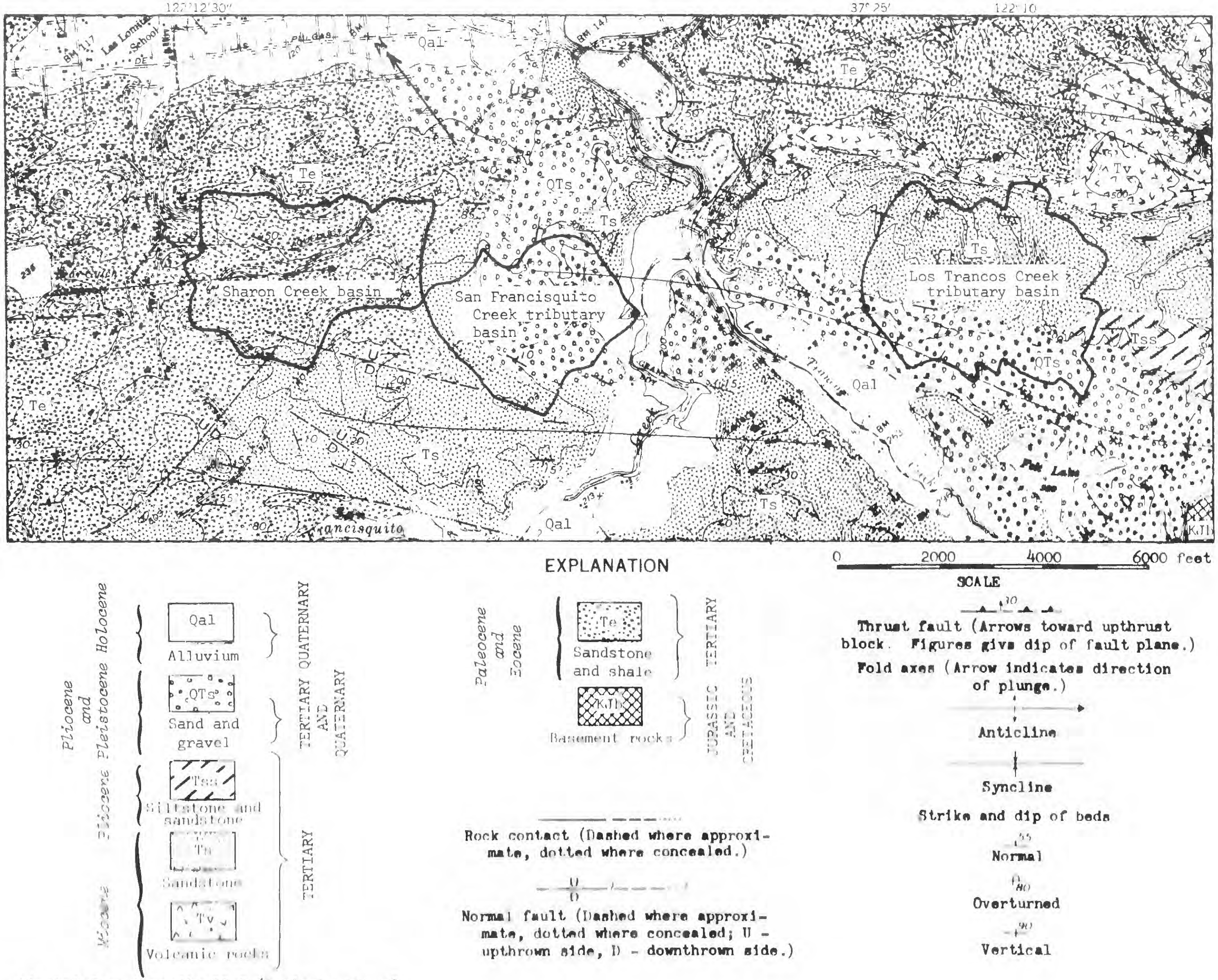
3. Days having 0.10 inch or more of precipitation during storm events.

Geology

Geologic formations in the study basins are shown in figure 8. The area is in the California Coast Range section of the Pacific Border physiographic province, and has been described by Fenneman (1931, pl. 1) as "Parallel ranges and valleys on folded, faulted and metamorphosed strata; with rounded crests of subequal height."

The project area consists of three distinct drainage basins, enclosed by low divides. Each basin seems to have been developed by headward erosion of an intermittent stream. Two of the basins have been formed by the development of tributaries to San Francisquito and Los Trancos Creeks, while the Sharon Creek basin has been developed by erosion of a small stream system that drains to the northwest. No evidence suggests that control has been imposed by the underlying rocks except for the dominant directional trend parallel to the San Andreas fault, in common with many drainage patterns in coastal regions of central California.

Seven formations have been identified in the general area and are shown in figure 8. However, only six crop out in the project area. Table 4 shows the percentage distribution of geological formations in each of the three study basins.



Adapted from Appendix II-B (Geologic map of the Stanford Foothills, by R. O. Dobbs and C. F. Forbes), Atchley and Dobbs, 1960.

FIGURE 8.--Geologic map of the study area.

Table 4.--Distribution of geologic formations and soil types in study basins, by percent

Formation or soil type	Sharon Creek	Los Trancos Creek tributary	San Francisquito Creek tributary
Formations: (symbols in parentheses refer to fig. 8)			
Holocene alluvium (Qal)	-	-	5
Pliocene and Pleistocene sand and gravel (QTs)	-	27	55
Pliocene siltstone and sandstone (Tss)	-	3	-
Miocene sandstone (Ts)	5	69	35
Miocene volcanic rocks (Tv)[1]	-	1	-
Paleocene and Eocene sandstone and shale (Te)	95	-	5
Soil types derived from individual formations:			
Qal: Sandy alluvium	-	-	100
QTs: Sand	-	1	25
Sandy loam	-	68	51
Silty clay	-	31	1
Silty clay loam	-	-	2
Sandy alluvium	-	-	9
Gravel, sand, loam	-	-	12
Tss: Sandy loam	-	100	-
Ts: Sandy loam	75	89	53
Silty clay	25	10	8
Silty loam	-	-	18
Silty clay loam	-	-	5
Sand	-	1	2
Gravel, sand, loam	-	-	14
Tv: Sandy loam	-	100	-
Te: Sand	30	-	-
Sandy loam	5	-	41
Silty loam	-	-	59
Silty clay loam	15	-	-
Silty clay	50	-	-
Soil types, without regard for origin:			
Sandy loam (SL)	9	82	48
Sand (S)	29	1	15
Silty loam (SiL)	-	-	9
Silty clay (SiC)	48	17	4
Silty clay loam (SiCL)	14	-	3
Gravel, sand, loam (GrSL)	-	-	11
Sandy alluvium (SAl)	-	-	5
Alluvium (Al)	-	-	5

The geologic map (fig. 8) shows an anticlinal axis in the central part of the Sharon Creek basin. Intersecting faults near the western edge of that basin bring a block of Miocene sandstone opposite beds of Paleocene and Eocene age. Other faults occur throughout the general area but have not been mapped in the project basins.

The San Francisquito Creek tributary basin lies along the northeastern flank of an anticline whose beds dip northeastward into a syncline. The Los Trancos Creek tributary basin, further to the southeast, is on the eastern flank of the same syncline. There the westward-dipping beds on the flank of the syncline form the western flank of an anticline which lies east of the study areas.

The most pronounced effect of structure is its influence over the exposure of formations. Flat-lying beds usually are uniform over a whole area, therefore the soil tends to be uniform. Where formations are elevated, depressed, or tilted by folding or faulting, various beds may be exposed, thus yielding a greater variety of soil types.

The structure does not seem to have had great influence on the drainage pattern, as the principal streams have cut across the structures rather than conforming to the structural trends. It is likely, however, that the slopes at which formations now lie and the nature of formations exposed to erosion have influenced channel and hillside slopes to some extent. The interplay of eroding forces and the resisting qualities of the various formations is extremely complex. Analysis of these features of landscape morphology is beyond the scope of this report.

The geology of the basins very likely exerts some influence upon the chemistry of the water that comes into contact with the soil or rocks. This conclusion is supported by the fact that water from the Sharon Creek basin, which is chiefly underlain by geological formations differing from those predominant in the other two basins, had chemical characteristics that differed from those of the other basins before development occurred. After development, the chemical characteristics of water from the Sharon basin appeared to become more similiar to those of water from the other basins. The reason for this is not apparent, but it may be associated with the disruption, during development, of the natural placement of substances in the upper soil horizons.

The Soil Mantle

Regions such as the study area having a complex pattern of outcrops usually possess a complex pattern of soil types, and because of soil movement the locations of the soils may not bear a close relation to the location of the parent rock. The distribution of soils in the study basins is shown in figure 9. Comparison of the outcrop areas shown in figure 8 with the locations of soil types in figure 9 does not reveal any obvious relation.

Soil depths range from less than 1 foot on some of the exposed crest areas to more than 10 feet in swales and valley bottoms. The contact between soils and the underlying rock is often indistinct, as the zone of weathering may penetrate rather deeply where structural fractures occur. Deep-rooted vegetation may also create local areas of deep weathering.

The proportions of soils and formation outcrops lying in the three basins are shown in table 4.

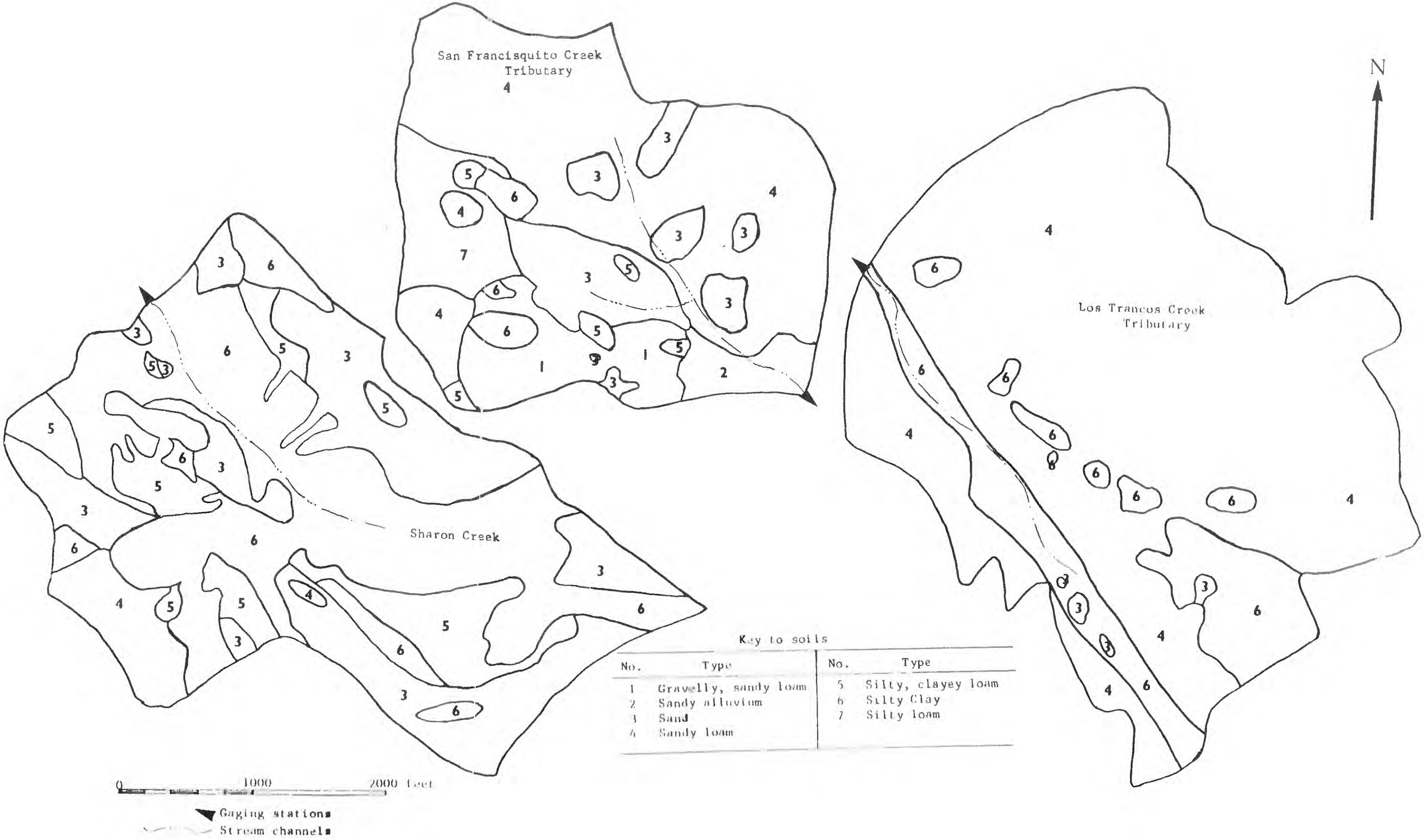


FIGURE 9.--Distribution of soil types in the study basins.

Vegetation

The study basins of the San Francisquito project were used principally for grazing when the project investigations were started. Annual grasses and scattered deciduous and live oaks formed the principal vegetative cover. The basins of the Los Trancos and San Francisquito Creek tributaries were almost completely open grasslands, and woody plants covered less than 10 percent of the area. Woody plants, both native and exotic, covered about 30 percent of the surface in the Sharon Creek basin.

Branson, in a survey of vegetation in the study basins in 1959 (Branson, Miller and McQueen, 1961), found differences in the abundance and kind of plants growing on different soils. The soils in the basins are principally sandy or clayey (table 4 and fig. 9), generally with sharp boundaries between types, and medium-textured soils occur only in small areas. The species more abundant on clayey than on sandy soils included wild oat, Italian ryegrass, bellardia, tarweed and bur clover. Purple star thistle occurred on clayey soil only. The sandy soils supported greater amounts of vegetation and a greater variety of plant species; soft chess and red-stem filaree were more abundant on sandy than on clayey soils. Species found only on the sandy soils were ripgut brome, California oatgrass, foxtail fescue, mouse barley, needlegrass, agoseris, bindweed, Spanish clover, two species of lupine, California poppy, and fiddle dock.

Branson found that the percent moisture at saturation and at field capacity were considerably greater in the clayey soil than in sandy soil. He estimated that the field capacity in the clayey soil was approximately double that of the sandy soil in the upper 2 feet of the two soils, and that lineal shrinkage was nearly four times greater in the clayey soils than in the sandy soils. He concluded that in the study basins, one of the chief determinants of the kinds and amounts of vegetation found is the quantity of water stored in the soil and available for plant growth during the growing season.

Valley oak, blue oak and coast live oak were the principal trees common to the three areas, and these did not appear to be affected by the different soil textures. In the Sharon Creek basin about 50 percent of the woody vegetation consisted of small plantations of introduced species such as eucalyptus, pine, a pear orchard, olive trees and miscellaneous small trees. A part of the woody vegetation in the Sharon Creek basin was removed as a result of construction and development.

HYDROLOGIC BUDGET OF THE STUDY AREA UNDER NATURAL CONDITIONS

Computation of the Budget

The long-term hydrologic budget of an undeveloped small basin in the study area can be described by analysis of four processes: An input of precipitation, and outputs of evapotranspiration, streamflow, and deep percolation. As here defined, the basin is limited by topographic drainage divides on the surface, and at depth by the regional water table. Therefore the relatively small amount of water that percolates to the zone of saturation (deep percolation) is considered to have left the hydrologic system being studied. The amount of ground water moving in or out of the basin by underflow is considered negligible. If the budget is to be evaluated over a period of several days or weeks, or by the year, the amount of water in storage in the basin must also be considered. Open-water surface storage is negligible and changes in storage in the perched ground-water bodies in the study basins are small; however, storage in the upper soil horizons must be considered because accretions from precipitation and depletions by evapotranspiration and deep seepage cause relatively rapid changes. Accordingly, provision was made in 1960 for the collection of soil-moisture data using a neutron-scattering probe in access tubes.

The magnitudes of components of the hydrologic budget of the Los Trancos Creek tributary basin have been estimated from information accumulated for the period July 1961 to October 1965 from precipitation records, streamflow records, and periodic measurements of soil moisture.

Data on evapotranspiration and deep percolation are not available; however, computed rates of potential evapotranspiration together with precipitation data provide limits within which actual transpiration must lie. Air-temperature and solar-radiation data from San Francisco and San Jose have been used to compute potential evapotranspiration rates, as suggested by Lane (1964). The rates are shown in figure 10, and are consistent with evaporation data from standard pans at Burlingame, 12 to 14 miles northwest of the study area, and at Stanford University. The pan data at both locations, when adjusted by a coefficient of 0.78 in accord with findings of the U.S. Weather Bureau, indicate daily evaporation of about 0.04 inch in late December and 0.25 inch in late June.

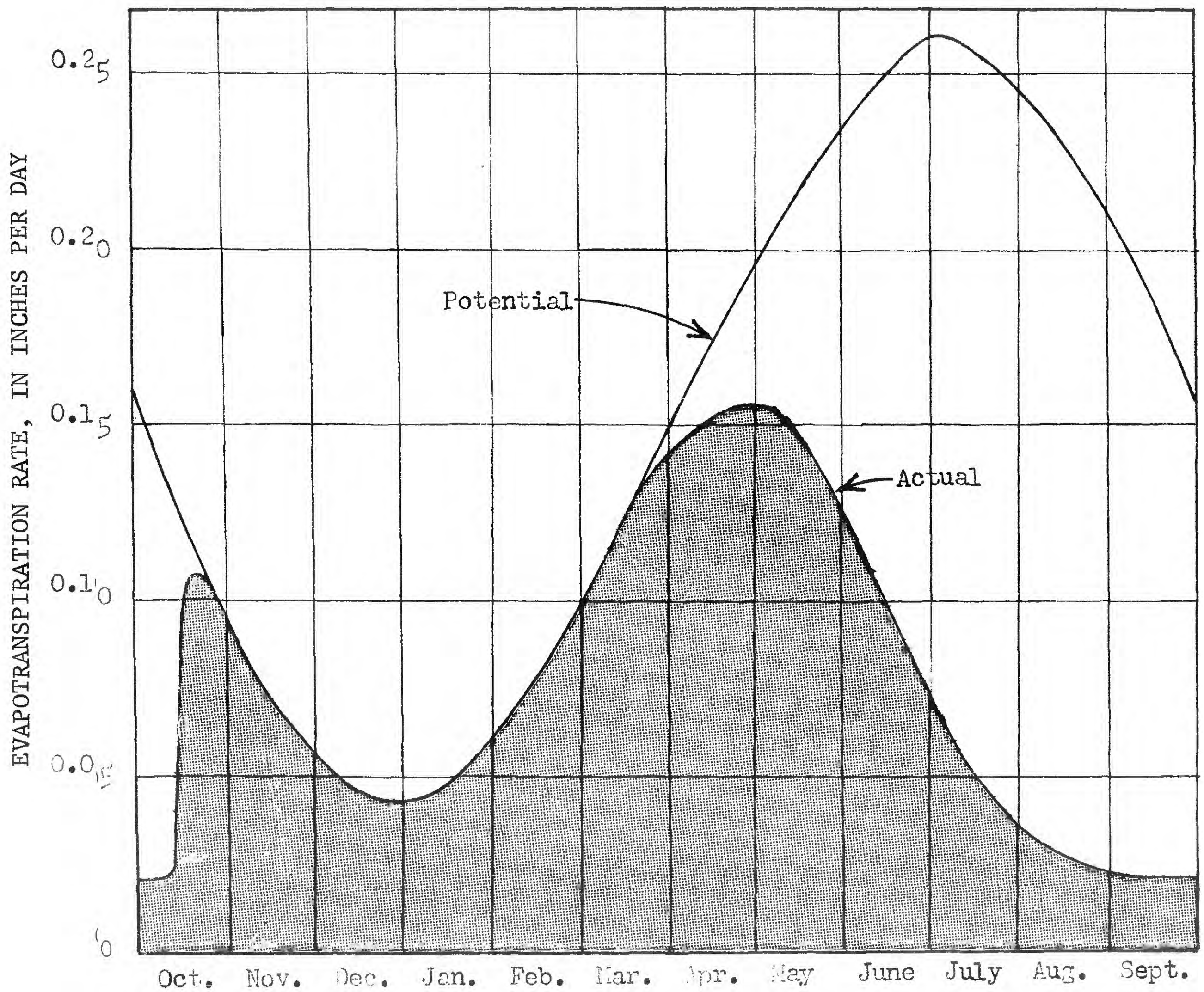


FIGURE 10.--Typical rates of potential and actual evapotranspiration in the study area.

Periodic changes in the moisture content of the uppermost 33 inches of the soil, as shown by measurements at three selected access tubes in the Los Trancos Creek tributary watershed, were computed. These changes were considered to be an index of basin-wide changes in soil moisture with time. The quantities of rainfall and streamflow for each period between soil-moisture measurements were determined; as were the estimated losses by evapotranspiration, limited by potential evapotranspiration as shown on figure 10 and by the available soil moisture. By trial and error, an empirical constant multiplier for the changes in soil moisture was found that produced a set of input and output values that were almost balanced for the entire period July 19, 1961 to October 18, 1965, except for small residuals immediately after periods of heavy precipitation. These residuals (totaling 5.9 inches while precipitation totaled 61.3 inches and evapotranspiration 50.4 inches) were considered to represent deep percolation. The data are shown in table 5 and constitute the estimated water budget for the basin of Los Trancos Creek tributary for the period.

The summary (table 5) shows that during the water years 1962-65 annual precipitation averaged slightly more than 15 inches. Streamflow averaged 10 percent of precipitation, percolation to the deep regional ground-water table, where the water is lost to the study basin, also averaged 10 percent, and evapotranspiration averaged 80 percent of precipitation. All values are expressed as depth of water over a unit area. Annual precipitation ranged from 11.0 to 20.6 inches. Evapotranspiration ranged from 79 to 81 percent of precipitation except during the driest year, when it was 91 percent. Streamflow and deep percolation each ranged from 3 to 15 percent of precipitation.

Table 5.--Water budget of Los Trancos Creek tributary basin, July 1961-October 1965

(By periods between soil-moisture readings)

(Water-budget data expressed as depth of water over a unit area)

	Input	Change in storage	Output, in inches		
	Precipitation (inches)	Decrease in soil moisture (inches)	Streamflow	Evapotranspiration	Deep percolation
July 19, 1961-Aug. 31	0.08	0.06	0.00	0.14	0.00
Sept. 1-Nov. 7	.32	.41	.00	.73	.00
Nov. 8-Dec. 5	3.82	-2.77	.00	1.05	.00
Dec. 5-Jan. 4, 1962	.13	.74	.00	.87	.00
Jan. 5-Feb. 20	6.87	-2.46	.60	2.10	1.71
Feb. 21-Mar. 14	2.18	.58	.54	1.80	.42
Mar. 15-Apr. 18	.42	1.87	.00	2.29	.00
Apr. 19-May 21	.16	1.58	.00	1.74	.00
May 22-June 20	.00	.46	.00	.46	.00
June 21-July 27	.00	.17	.00	.17	.00
July 28-Sept. 7	.00	.14	.00	.14	.00
Sept. 8-Oct. 4	.00	.04	.00	.04	.00
Oct. 5-Oct. 15	4.27	-4.02	.00	.25	.00
Oct. 16-Nov. 2	.00	1.04	.00	1.04	.00
Nov. 3-Dec. 5	.44	.91	.00	1.35	.00
Dec. 6-Jan. 7, 1963	2.64	-1.14	.00	1.15	.35
Jan. 8-Feb. 6	4.37	-.98	1.64	1.30	.45
Feb. 7-Mar. 7	2.02	.70	.57	2.15	.00
Mar. 8-Apr. 11	4.24	-.72	.14	3.38	.00
Apr. 12-May 14	2.34	1.25	.03	3.56	.00
May 15-June 14	.01	1.63	.00	1.64	.00
June 15-June 26	.00	.22	.00	.22	.00
June 27-July 17	.00	.10	.00	.10	.00
July 18-Aug. 16	.01	.11	.00	.12	.00
Aug. 17-Sept. 12	.21	.14	.00	.35	.00
Sept. 13-Nov. 13	1.75	-.88	.00	.87	.00
Nov. 14-Nov. 22	2.22	-1.85	.00	.37	.00
Nov. 23-Dec. 11	.76	.28	.00	.92	.12
Dec. 12-Jan. 6, 1964	.07	.59	.00	.66	.00
Jan. 7-Jan. 29	3.45	-1.53	.27	.80	.85
Jan. 30-Feb. 18	.15	.76	.00	.91	.00
Feb. 19-Mar. 12	.26	.09	.00	.35	.00
Mar. 13-Apr. 3	1.10	1.04	.00	2.14	.00
Apr. 4-Apr. 25	.00	.92	.00	.92	.00
Apr. 26-May 28	.57	.31	.00	.88	.00
May 29-July 1	.53	.27	.00	.80	.00
July 2-July 27	.00	.05	.00	.05	.00
July 28-Sept. 3	.21	.11	.00	.32	.00
Sept. 4-Oct. 1	.00	*.10	.00	.10	.00
Oct. 2-Nov. 6	.95	-.25	.00	.70	.00
Nov. 7-Nov. 19	2.46	-1.51	.00	.82	.13
Nov. 20-Dec. 11	.37	.44	.00	.81	.00
Dec. 12-Jan. 12, 1965	7.13	-2.36	1.90	1.00	1.87
Jan. 13-Feb. 24	1.54	1.00	.41	2.13	.00
Feb. 25-Mar. 19	.39	.75	.00	1.14	.00
Mar. 20-Apr. 12	2.52	-.73	.05	1.74	.00
Apr. 13-May 13	.76	1.86	.00	2.62	.00
May 14-June 10	.00	1.16	.00	1.16	.00
June 11-July 20	.00	.39	.00	.39	.00
July 21-Sept. 11	.00	.27	.00	.27	.00
Sept. 11-Oct. 18	.00	.09	.00	.09	.00
By water years					
1962	13.6	0.5	1.1	10.9	2.1
1963	20.6	-.7	2.4	16.7	.8
1964	11.0	.2	.3	10.0	1.0
1965	16.1	1.1	2.4	12.8	2.0
Water year average	15.35	+.28**	1.54	12.62	1.48
Percentage distribution					
(Long term)	100.0	0.0	10.1	80.3	9.6

*Estimated; faulty data.

**In the long term this value would be zero, and output would equal input.

Hydrologic Processes as Related to the Climatic Regime

In the climatic environment of this study, the period between heavy rainfall events is usually sufficiently long to allow the uppermost layers of the soil to dry and thus recover infiltration capacity; in this manner surface runoff is limited to those few periods when antecedent conditions have primed the upper horizons. The loss of soil moisture is in two directions, upward by evapotranspiration and downward by percolation. Movements in both directions are controlled by physical limitations having attributes that are beyond the scope of this study. However, a few of the more obvious ones may be mentioned. Downward percolation is limited by the size and number of available pore spaces within the soil, although the long drying process during summer and early fall modifies this limitation by introducing large, deep, shrinkage cracks in the heavier clays and clay loams. Therefore most overland flow from unusually early and heavy rainfall soon enters the cracks, some of which may be as much as 4 inches wide at the surface and more than 2 feet deep. As the clay becomes saturated, it swells and the cracks disappear until the next dry season.

Transpiration loss is limited by potential evapotranspiration, so that water arriving as heavy or sustained precipitation during the months November to February, when the demands by evapotranspiration are least, is retained in the soil, leaves the basin as streamflow, or percolates to the regional water table. During the 4 years covered by table 5, 40 of the 61 inches of precipitation fell during the combined November-February periods, while 5.4 of the 6.2 inches of streamflow and 5.6 of the 5.9 inches of deep percolation occurred during the months December-February. About 24 inches of the total of 50 inches of evapotranspiration was in March, April, and May, although only 13 inches of precipitation fell during those months. The difference, as well as the 4.8 inches of evapotranspiration during the almost rainless months June to September, was withdrawn from soil-moisture storage.

The distribution of soil moisture and the variations in water content of the soils in the Los Trancos Creek tributary basin are demonstrated by the selected profiles for the 1962 and 1963 water years shown in figure 11. These profiles illustrate the more significant changes that occurred during the two seasons. Data are presented for three sites, representing conditions at the hilltop along the northeastern drainage divide (elevation, 515 feet), at the weather station at mid-basin (elevation, 354 feet), and on the valley floor near mid-basin (elevation, 326 feet). These sites identify conditions in representative soil types and the valley data also demonstrate the relation when the soil materials are at or near full saturation. Soil moisture at the valley site was observed in an open-bottom access tube that was also used as a ground-water observation well, so the depth of the profile sampled was limited by the depth to water. Lithologic logs of the access holes are shown in figure 11 to identify the soil types at the sites.

The water content of the soils varies during the year in response to infiltration from rain and subsequent withdrawal by evapotranspiration and percolation downward and, at many sites, by lateral translocation. The profiles shown in figure 11 illustrate the normal seasonal range. In most years the moisture levels in the autumn decline to consistently low values, but in wet years such as 1963, the heavier soils may retain more moisture at the end of the summer than after dry years; this is demonstrated by comparison of the profiles for September 12, 1963, with those for October 4, 1962.

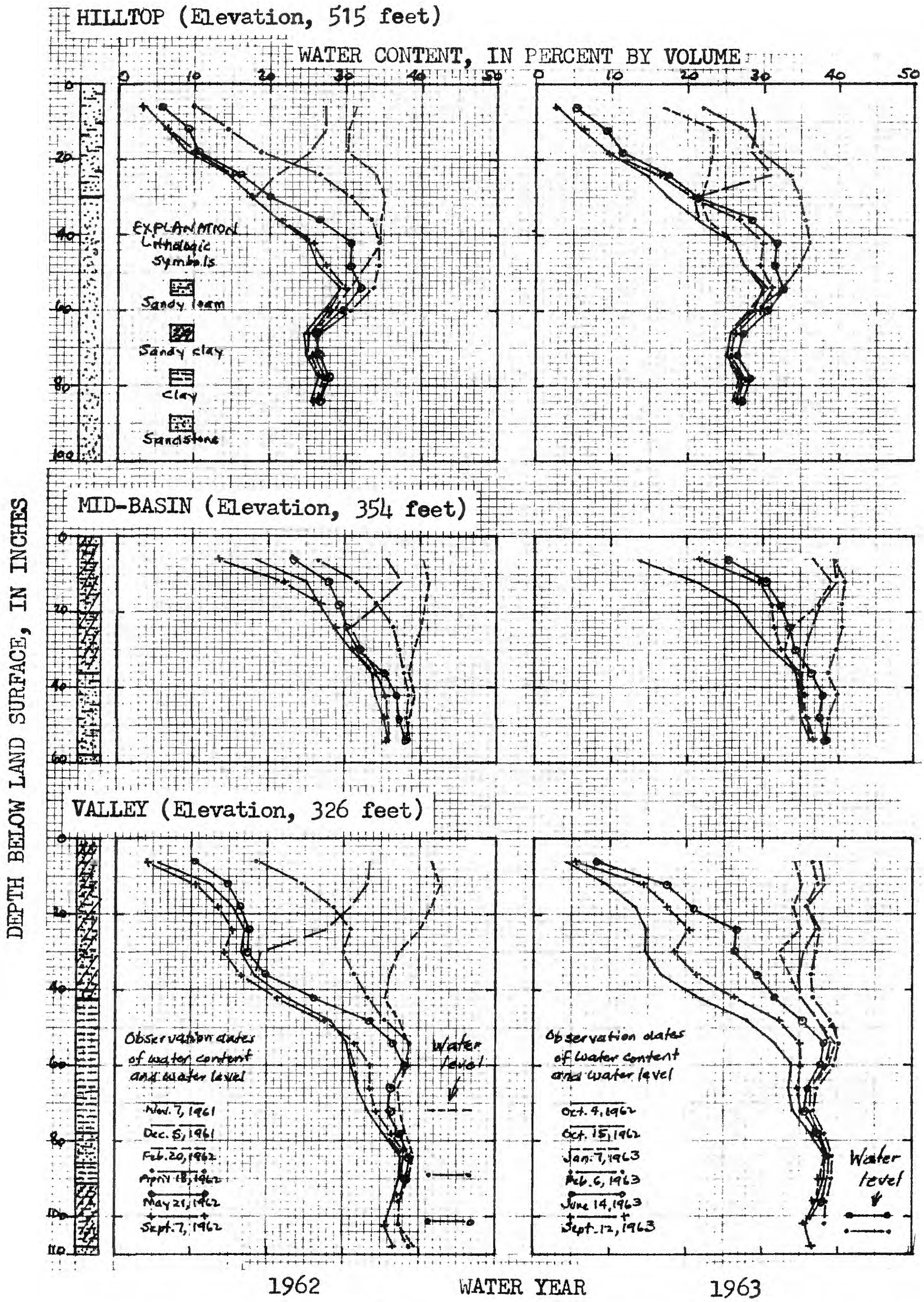


FIGURE 11.--Water content and access-hole logs at three sites in the Los Trancos Creek tributary basin during water years 1962 and 1963.

The increases in soil moisture at the hilltop and mid-basin sites were caused by infiltration from direct precipitation only, but the increases at the valley site include infiltration from overland flow and possibly some interflow that reaches the valley floor. The ground water at the valley site normally was lower than the bottom of the soil-moisture access tubes, but late each winter, the water table rose to the depths shown in figure 11. The valley floor area constitutes only about 5 percent of the total basin area, and the average changes in water content of the soil throughout the basin are more nearly approximated from the data obtained at other locations.

Soil-moisture data obtained in the Sharon Creek and San Francisquito Creek tributary basins showed comparable variations in the areal and seasonal distribution of water content in the soils.

GROUND-WATER CONDITIONS

The ground-water conditions in the study areas and the nearby foothill areas are deduced on the basis of data from observation wells and water-supply wells, and from borehole data. Ground water occurs in alluvium along the perennial streams and in tributary valleys, in bedrock, and in terrace deposits. Water is available to wells generally in the valleys of San Francisquito Creek and its principal tributaries that have perennial flow, such as Los Trancos Creek. In the foothill areas and in smaller tributary basins the ground-water levels in the dry season may average about 40 feet below the land surface on the higher hills, 20 to 25 feet on the lower slopes, and 5 to 15 feet in the valleys and ravines. Only small quantities of water can be obtained from wells in these latter areas.

Small perched bodies of ground water exist here and there in the study basins, but in general the sediments are tight and except for very short periods after heavy rain all ground-water outflow becomes surface flow and the unmeasured ground-water outflow is slight. For this reason, lateral outflow of ground water was not segregated as a separate component of the hydrologic budget.

In the Sharon Creek basin auger holes drilled in 1959 indicated the probable zone of moisture penetration (delineated by the color change in the clays and sandstones from tan and brown to gray) to be about 40 feet below the surface on the peripheral hills but only about 11 feet below the surface in the valley area. However, the quantity of water was so slight, and its movement so slow, that an observation well 15 feet deep near the gaging station at the outlet of the basin remained dry for several years.

Boreholes in the San Francisquito Creek tributary basin indicated similar depths to the zone of saturation in the hill and valley areas. Many large boreholes and smaller drilled holes along the Stanford Linear Accelerator site, crossing the upper part of the basin, penetrated the saturated zone; water accumulated in most of those holes and rose to levels that ranged from 20 to 30 feet below the land surface. In the lower part of the basin a 47-foot augered hole on the flood plain about 360 feet from the stream channel indicated silt and clay soils, and sand and gravel overlying gray weathered siltstone to a depth of 19 feet. The water table in this flood plain was above the siltstone.

Hand-augered holes in the Los Trancos Creek tributary basin near the gaging station, indicated loam, clay, sand and some stones overlying sandstone to depths of 6 to 7 feet, and showed that dry-season water levels were below the upper surface of the sandstone. Upstream in the basin the overlying materials on the valley floor are thicker, and water levels are as much as 10 feet below the land surface during the dry season.

Water levels observed in selected wells in the three basins for the period March 1959-September 1965 are shown in figure 12. These wells were established on the flood plains near the outlets of each of the study basins. Infiltration and percolation of water from precipitation provides the principal natural recharge of the ground water. The underlying bedrock is generally impervious and most of the ground-water movement is through fractures. Low permeabilities in the sandstones along the linear accelerator were indicated by slow recoveries of water levels after bailing of boreholes. Low transmissibilities in the valley alluvium were also indicated by tests in small observation wells. The values obtained ranged from about 0.4 gallons per day per foot width of aquifer in the heavy clays and clay loams in the Sharon Creek basin to 2.1 to 28 gallons per day per foot in the Los Trancos Creek tributary basin. The tests are crude but are indicative of the relative rates, and illustrate the very low transmissibilities in the alluvium in the valleys.

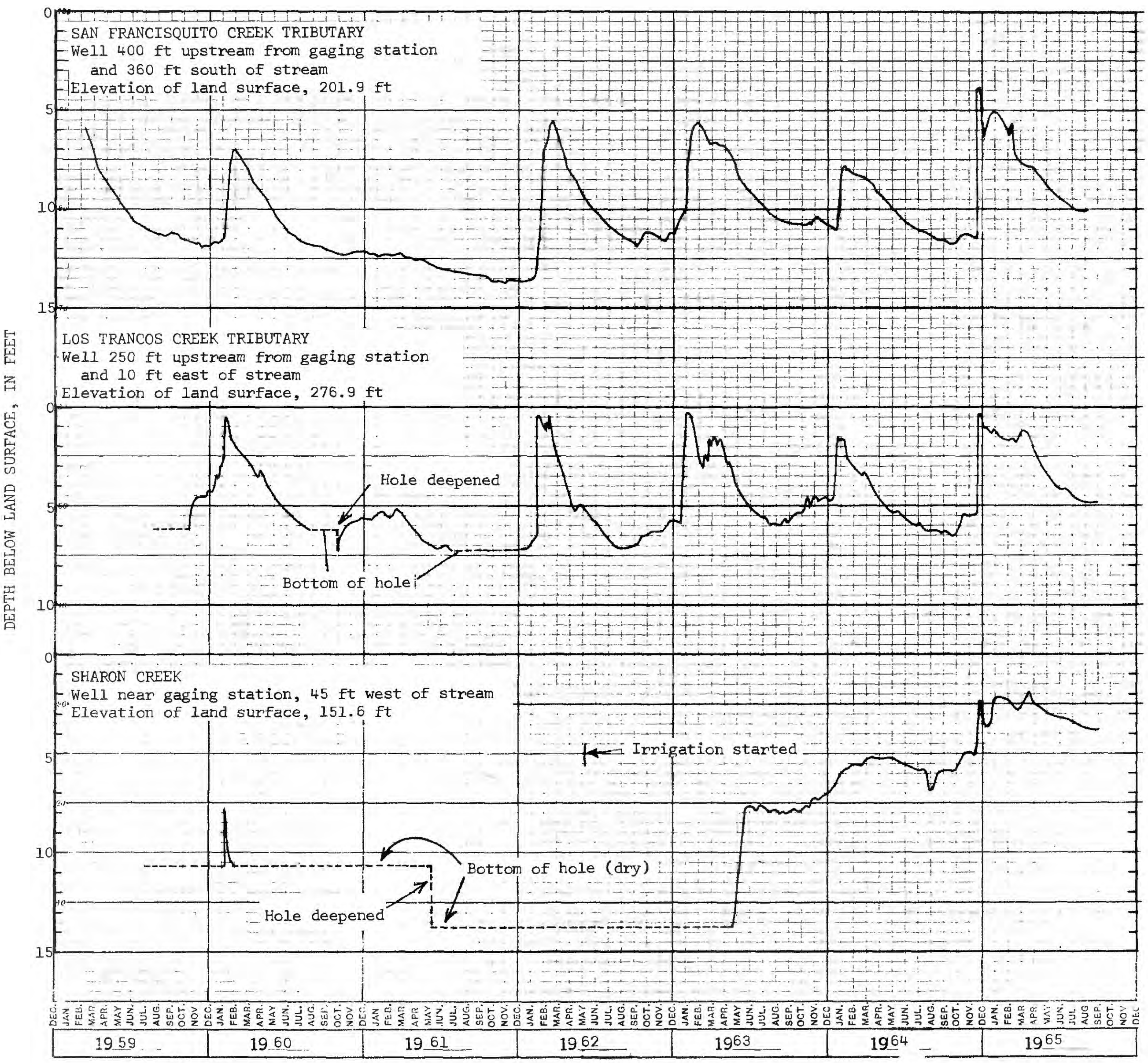


FIGURE 12.--Hydrographs of water levels in representative wells in the project basins, March 1959-September 1965.

Surface Water-Ground Water Relation

Flow in the streams in the three study basins under natural conditions is ephemeral. Early season precipitation is almost completely retained as soil moisture, although on rare occasions early storms are heavy enough to saturate the upper layers of the soil profile and cause overland flow and runoff for short periods. Storms that occur after soil-moisture deficiencies have been satisfied raise the level of ground water by percolation, interflow, and seepage from the stream channels. In all except extreme drought years the water tables occasionally rise to levels that cause flow in the San Francisquito Creek tributary and Los Trancos Creek tributary, and effluent ground water may continue to drain out as streamflow for periods of several weeks after storms and at the end of the runoff season. However, the volume of runoff that enters the stream by these subsurface routes is usually very small compared to the volume of storm runoff. A simplified section of a tributary valley such as that of the Los Trancos Creek tributary is shown in figure 13. The typical relations among the land surface, sandstone horizon, zone of saturation, and water-table surface in wet and dry seasons are indicated.

After winter storms have ceased, in the spring, the ground-water levels decline and streamflow ceases. Perennial ground-water seepage occurs in the San Francisquito Creek tributary basin, as is indicated by visible trickles over the sandstone into which the receiving channels are incised, and the presence of damp spots in the otherwise dry streambed.

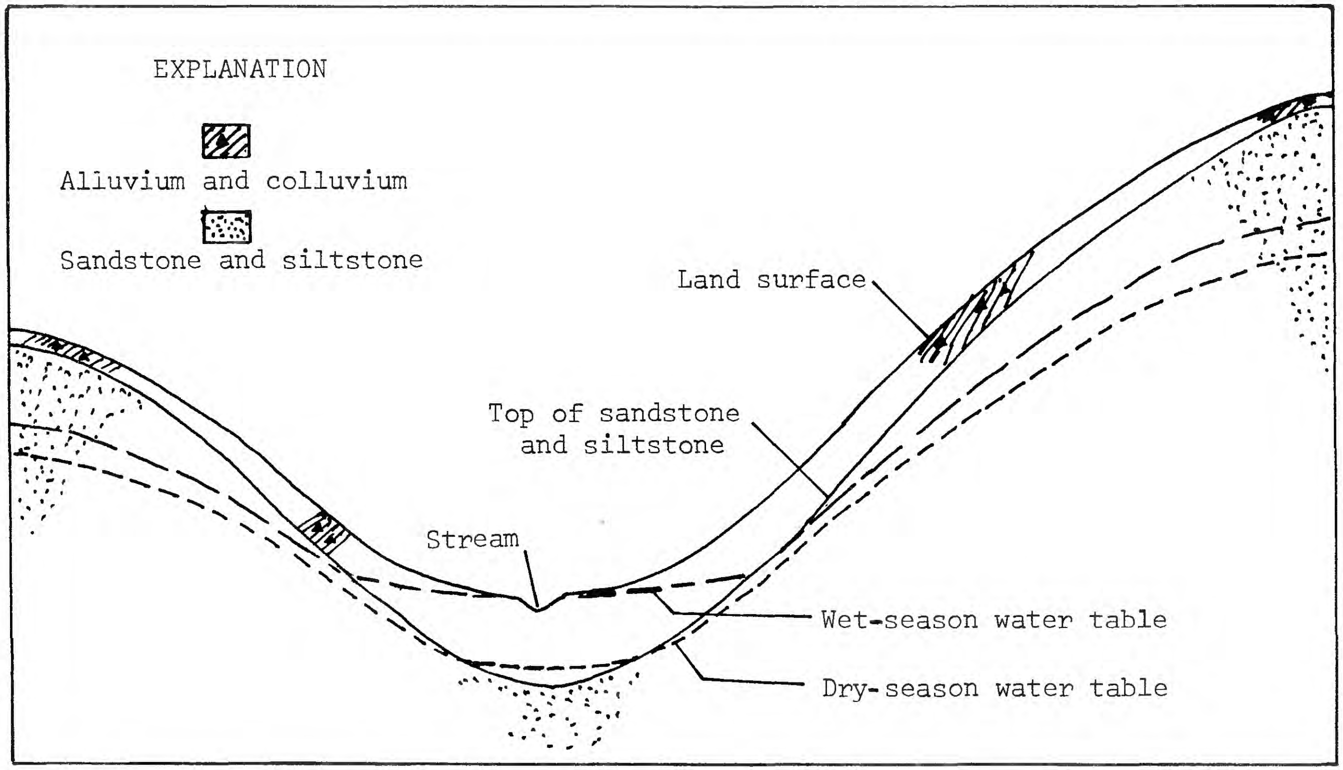


FIGURE 13.--Generalized basin section indicating relation of geology to ground-water conditions.

Under the natural regime in the Sharon Creek basin, however, the clays and clay loams were of sufficient thickness that the full depth of the materials overlying the sandstones did not become completely saturated, and runoff occurred only when precipitation rates exceeded the infiltration rates of the upper layers of soil. The runoff was sometimes heavy and was comparable in peak rates to that from other saturated areas or from nearly impervious surfaces, but the streamflow was sustained only for a short period after precipitation ended.

Hydrographs from selected periods showing typical streamflow patterns are shown in the appendix.

LAND USE IN THE STUDY REGION

The study region remained wild and little known until the middle of the 19th century. The city of San Francisco, about 25 miles to the northwest, developed very slowly after the establishment of the early Spanish Mission of St. Francis in 1776 until the "gold rush" days of 1849. As the city grew after that period, settlements were established along the peninsula and there was logging in the hills lying west of present-day Palo Alto. The first meaningful invasion of the study area was the establishment in the middle of the 19th century of a logging road roughly paralleling San Francisquito Creek.

Although there was a stage road along the western shore of San Francisco Bay since perhaps the 1820's, travel was slow and arduous and only scattered ranches existed in the Palo Alto (then Mayfield) region. In the 1860's, however, a railroad was built connecting San Francisco with San Jose, about 15 miles southeast of the study area. "The Peninsula," as the region is locally called, became a desirable residential region. The improved transportation also caused a mild boom in farming activity and the population of the Palo Alto region increased moderately from that time to the 1940's. Stanford University was established in 1885, and was deeded several thousand acres of land, which included two of the study basins. Use of the basins as pasture-land probably began not earlier than the 1870's, and small level areas have been plowed and planted from time to time. However, crop farming in any large part of the study basins has never been continuous or intensive.

During and after World War II, the need for land for light industry coupled with the improved highway network caused a rapidly mounting influx of population and industry into the entire San Francisco Bay region, and especially along the Peninsula. By 1960 there were few breaks in a band of industrial, commercial, and residential development extending from San Francisco to San Jose. The level alluvial plains between the bayside lowlands and the foothills were the first to be occupied, but as congestion increased on the level ground, construction of scattered houses began in the hills to the west. The development recorded in this study reflects this recent trend. The general population increase and movement to urban areas indicates that the settlement of these foothill regions will likely accelerate.

The thickly settled region lies between the foothills and the undeveloped bayside lowlands. It includes small cities ranging in population from 24,000 to 58,000, with population densities averaging about 5,000 per square mile. Densities range from about 24,000 per square mile in apartment areas to less than 1,000 per square mile where there are suburban-type estates. This urban-suburban region is characterized by a fairly regular grid of streets, with shopping centers, business areas, schools, small parks, and light industrial plants.

The rural-suburban region is mostly in the foothills, and the population density is less, averaging about 650 per square mile. Streets generally resemble country roads, although they form a fairly close net in some areas. In much of the rural-suburban region, little provision is made for storm drainage, and domestic sewage is led to septic tanks and drain fields. Vacant areas of many acres may alternate with other regions having perhaps two or three houses per acre.

The unsettled rural areas are of three types: Foothill regions susceptible to development but withheld thus far; steep foothill and mountain areas not suitable for large-scale development under present circumstances; and the bayside lowlands. These lowlands range in altitude from sea level, at the edge of tidal flats and evaporation ponds, to about 10 feet, and on them are scattered industrial facilities. Pressure has recently arisen to make more use of the lowlands, with some favoring rather dense industrial and apartment development, and other advocating public ownership with large areas preserved in their natural state.

PHYSIOGRAPHY AND DEVELOPMENT IN THE STUDY BASINS

The basin lands first came into private ownership at the time of the Mexican issuance of land grants during the period 1830-45. The basins remained unoccupied until about 1910, when the Sharon Creek basin became part of the large Sharon estate. The other two basins remained unoccupied until the development observed during this study, and still remain in the possession of Stanford University. Figures 14-17 are views of the basins in their undeveloped state.

In 1958, when data collection started, the basins of Los Trancos Creek tributary and San Francisquito Creek tributary were virtually in their natural state. There may have been slight changes caused by several decades of intermittent light cattle grazing, and inspection of enlarged aerial photographs indicated that small patches may have been cultivated at some earlier time. The Sharon Creek basin had a half-acre unused pond, an orchard of a few acres, a few nonnative decorative trees, 4,000 or 5,000 feet of unpaved lanes, and about 1,000 feet of paved highway (Sand Hill Road) across the southeast corner of the basin. These modifications are believed to have been negligible in their effect on the hydrology of the basin.

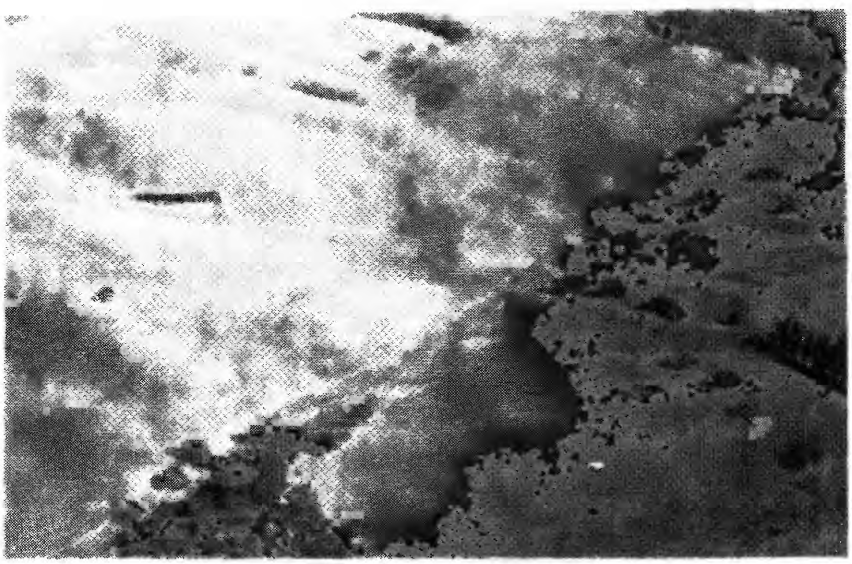
FIGURE 14.--Aerial view of project basins in September 1948. Basins outlined are: A, Sharon Creek; B, San Francisquito Creek tributary; and C, Los Trancos Creek tributary. Basin conditions were about the same in September 1958.

A

B

FIGURE 15.--Sharon Creek basin prior to development showing (A) character of land and vegetative cover in the middle of the basin and (B) infrequent flow, grassy channel, and head cuts upstream from the gaging station.

A



B

FIGURE 16.--Los Trancos Creek tributary basin showing (A) conditions near the gaging station (left foreground) in May 1959 and (B) oblique aerial view of the basin in September 1965. Gaging station among trees in lower left center.

FIGURE 17.--San Francisquito Creek tributary basin, looking up channel from flood-plain area near gaging station. Photograph taken March 29, 1960, prior to development in the basin.

The first recent work in the Sharon Creek basin began in 1957-58, when a section of Sharon Park Drive was built for a distance of about 1,000 feet along the eastern end of the northeast basin boundary. Significant development within the basin began in May 1961. At that time large-scale landscaping started, and by the fall of 1962 development had reached a stage at which it remained relatively stable until the fall of 1965. Land use during this period of stability is shown in figure 18. About 14 acres was occupied by single-family residences, 12 acres by offices and two apartment buildings, and 85 acres, including the area immediately upstream from the gaging station, was a golf course. In addition to these 111 acres, there were about 8½ acres of streets and roads. Within the area devoted to the golf course, offices, apartments, and residences the total area covered by roofs, drives, and patios was about 16½ acres. One hundred and twenty-five acres, about half of the basin, remained unchanged. The state of development existing in September 1967 is shown in figure 19.

Plans for the additional development of the Sharon Creek basin indicate that more commercial-type buildings, with large parking lots, may be erected along Sand Hill Road, and construction of additional streets and houses along the hillside forming the northeast side of the basin started in the early spring of 1966. An area of about 11 acres at the eastern end of the basin, including the old Sharon Estate pond, is reserved for a public park. Dwelling units in the basin totaled about 110 in the autumn of 1965, and others will be built eventually. Thus, the development will be a version of the cluster type, with an average population density of slightly more than 1,000 persons per square mile in pleasant, open surroundings. Such density can be called rural-suburban.

Sharon Creek, before intensive development started in the basin, had formed a channel which was little more than a grass-covered trough (fig. 15), with tributary flow concentrated in wide, sloping, grass-covered valleys. The stream had only two or three short reaches of incised channel, which had steep, raw-earth sides. The stream is now conducted beneath the golf course for about 2,200 feet in a 2-foot diameter concrete pipe, and several side drains enter it. The stream leaves the pipe about 530 feet upstream from the gage and flows for about 250 feet in a straight channel 6 feet wide, incised about 3 feet at its upper end, with vertical sides of raw earth. The channel is almost level in this reach, while the valley floor slopes downward so that the banks fade out. For perhaps another 150 feet, the channel has incised itself very slightly into the valley floor, then it drops into a channel 6 or 8 feet deep. The gaging station was established about 100 feet downstream from the point where this deeper channel begins. Sharon Creek continues for about 600 feet downstream from the gage, then joins the Atherton drainage channel.

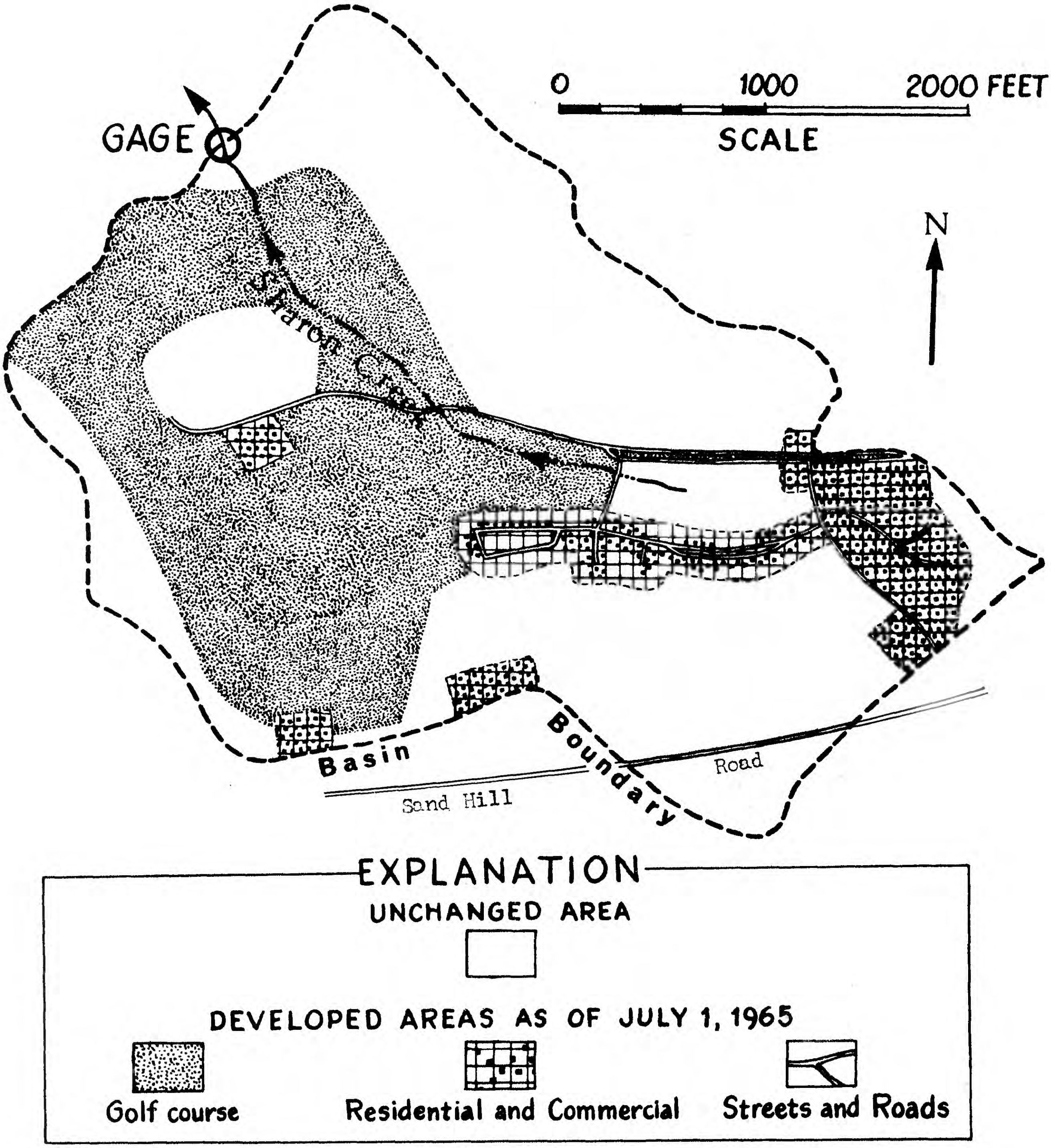


FIGURE 18.--Sketch map of Sharon Creek basin showing development.

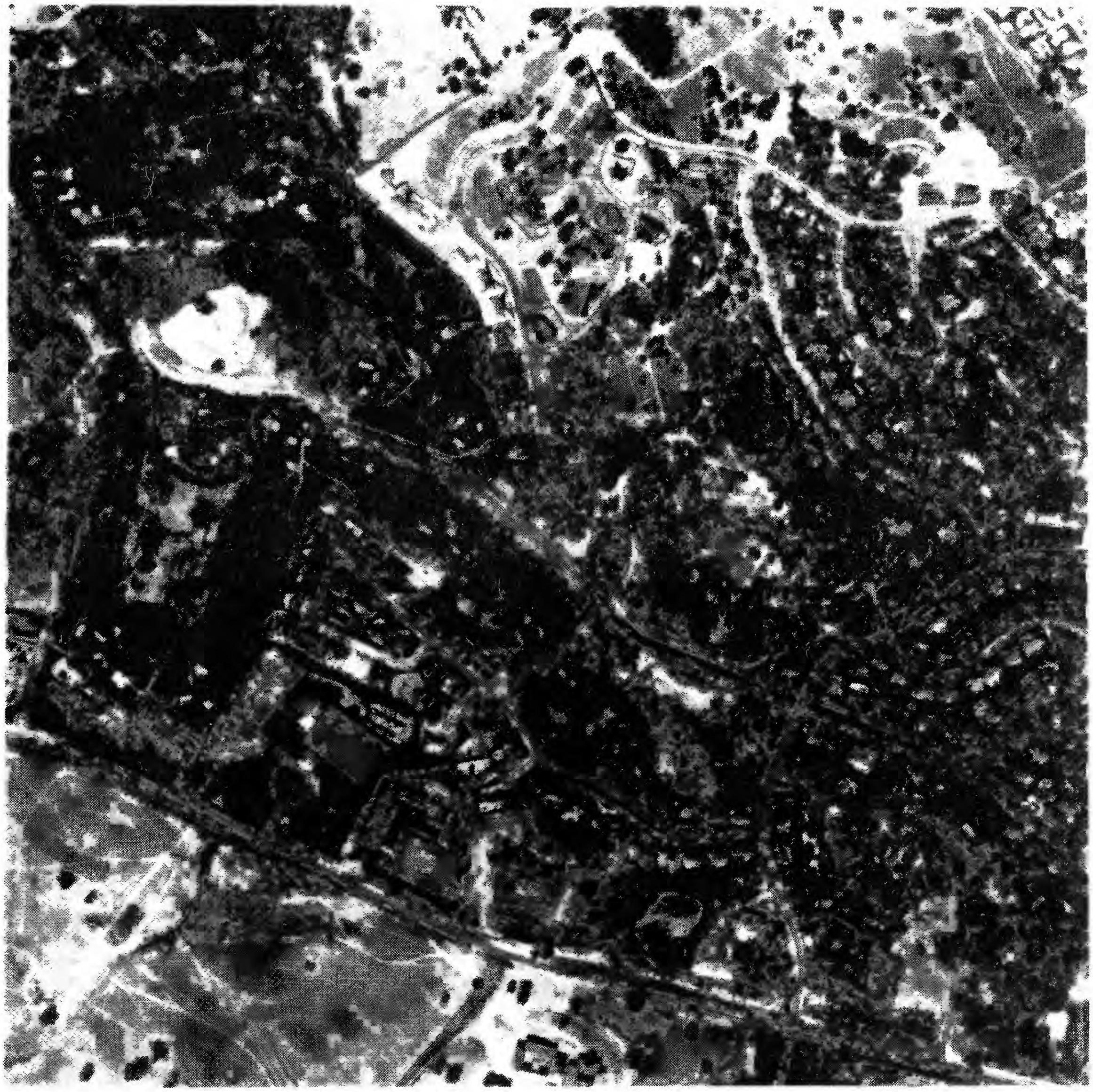


FIGURE 19.--Aerial view showing development in Sharon Creek basin as of September 1967. Streets and about 30 houses shown in northern part of area (top of photograph) were established subsequent to the period of study covered in this report.

The basin of Los Trancos Creek tributary (fig. 16) has three well-defined channels. The main channel is fairly straight, trends to the northwest, and is parallel to and only a few hundred feet from the southwestern basin boundary. Two subtributaries drain much of the northeastern side of the watershed. The northernmost tributary, with a contributing area of about 83 acres, joins the main channel 1,200 feet upstream from the gage and the other, draining about 74 acres, joins the main channel about 1,200 feet further upstream. These two tributaries thus drain about one-half the total area contributing to flow past the gage, and their drainage collects the runoff from almost all of the relatively high and steep northeastern side of the basin.

Aerial photographs of the Los Trancos Creek tributary basin show evidence of past cultivation of a small area near the southwest corner. A 50-foot diameter radio telescope and access road had been constructed on a hilltop at the southeast corner of the basin. No other uses, except grazing, were evident prior to the erection of poles supporting antenna systems used in radar and radioastronomy studies by Stanford University and Stanford Research Institute personnel. In 1960-61 an area of about one acre, partially within the basin, atop a hill at the northern corner of the basin, was paved and a 150-foot diameter steerable radio telescope mounted. A smaller radio telescope was erected and about 800 feet of single-lane pavement placed along the northeastern ridge at about the same time. No change in streamflow was apparent as a result of this work, and the basin was considered to be in its natural state through the winter of 1963-64.

During the late summer and fall of 1964 another small radio telescope was erected downslope from the large telescope, in the head of a small natural trough leading into the main channel just upstream from the gage. The pavement (roadway, parking, and working areas) totals about one-half acre in extent. The site is about 2,300 feet from the gage and about 200 feet higher. During the heavy storms of December 1964-January 1965 and December 1965, flow from this paved area entered Los Trancos Creek tributary near the gage, bringing with it much sand carried from the fresh cuts left by construction. Flow of this type had not resulted from earlier storms during the study period, and it occurred only after sustained prior precipitation had saturated the upper soil horizon. Maximum inflow from this source is estimated to be less than 5 percent of the flow from the remainder of the basin, and the flow was not included in the Los Trancos Creek tributary data used to define the natural regime.

Construction of a six-lane freeway with a center mall, following the alinement of Los Trancos Creek tributary for 2,000 feet or more within the study basin, is scheduled to begin in 1967.

San Francisquito Creek tributary has two well defined subtributaries. One drains the northeastern corner of the basin, and another the western side. The two tributaries drain areas of roughly 66 acres and 52 acres respectively (about 70 percent of the basin above the gage) and unite about 1,000 feet upstream from the gage (figs. 20 and 21).

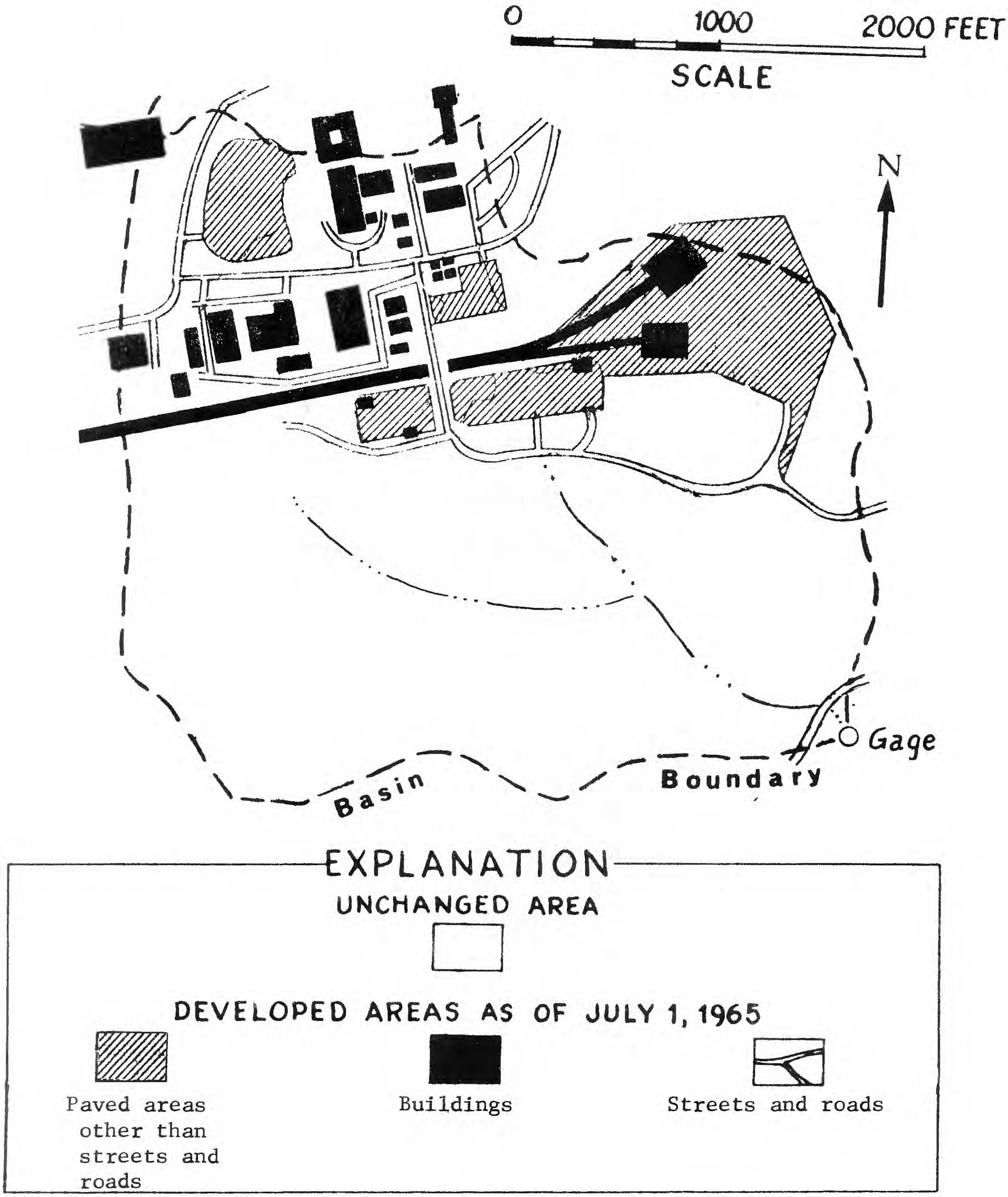


FIGURE 20.--Sketch map of San Francisquito Creek tributary basin showing development.

FIGURE 21.--Aerial view of San Francisquito Creek tributary basin in September 1967. Development shown consists of administrative offices and facilities of the Stanford Linear Accelerator Center including east (target) end of the accelerator.

The northeastern tributary has no well defined channel until it reaches a point about 600 feet upstream from its junction with the western channel, where there is a vertical headwall dropping into a narrow, steep-walled, fairly straight channel which continues downstream almost to the gage (fig. 17). In many places this channel has cut below the soil mantle and into the underlying sandstone.

The western tributary has no clearly defined channel until it reaches a point about 1,000 feet upstream from the junction, where it drops over a headwall into a narrow V-shaped channel from 6 to 10 feet deep and about 500 feet long. The channel cut then becomes broader, shallower, and is grass covered for another 500 feet, where it meets the northeastern tributary. This lower 500-foot reach of the western channel proceeds downward in steps with vertical scarps or headwalls of 1 to 2 feet in height forming the risers. During flow recession, water has been seen entering gopher holes 5 to 10 feet upstream from these headwalls and spouting out from the faces of the walls. The scarps tend to move upstream by means of erosion.

Below the junction, the stream flows southeastward for about 1,000 feet before passing under an unpaved farm road, then about 220 feet farther to the gaging station. The slope of the incised channel from the junction to the road is about 100 feet per mile. Downstream from the road the stream has eroded to bedrock, and the channel is shallower, broader, and descends at about 240 feet per mile until it debouches into the channel of San Francisquito Creek about 150 feet southeast of the gage.

The only interference in the natural regime of the basin of San Francisquito Creek tributary known to have occurred prior to the study period was the use of a small area near Sand Hill Road for military training during World War I. Remains of a small network of underground trenches were revealed during accelerator construction. The land was otherwise unused except for grazing until March 1961, when a field that included about two-thirds of an acre in the west side of the basin was prepared for the raising of garden crops. During and after the summer of 1961 a moderate amount of irrigation water was applied to this field as dictated by crop requirements, but evapotranspiration from the field itself probably consumed almost all the imported water; the hydrologic regime of the basin as a whole was unaffected.

In December 1961 a trench was cut along the alinement selected for the Stanford Linear Accelerator. Little more was done until heavy equipment started large-scale earthmoving operations in July 1962. Little or no change occurred in the low-flow regime until the late spring of 1964, when substantial quantities of water were imported, chiefly for use in curing large masses of concrete. Since May 1, 1964, outflow of imported water has been almost continuous with daily amounts ranging from 0.01 to 0.5 cfs. Peak flows appeared to be affected by construction at times during the winter storms of 1962-63 and 1963-64 (see hydrograph in appendix), and were markedly changed in 1964-65, but channel modifications, topsoil stripping, and paving operations were changing from day to day. Thus, no two runoff periods provided data relating to the same changes, therefore no quantitative comparison of hydrographs has been attempted.

The Stanford Linear Accelerator runs from east to west across the northern end of the basin and separates about 43 acres of the western and northeastern tributary drainage areas from the lower part of the basin. The accelerator structure acts as an impervious barrier based in sandstone. Runoff, interflow, and the slight ground-water outflow from the 43 acres thus isolated is led into the original main channel at about midbasin by a drainage collector system. Drainage from some 3 acres of the south side of the accelerator roof and service roadway flows into the head of a small tributary draining the west side of the basin, and surface drainage from about 14 acres of impervious surfaces in the target area, at the east end of the accelerator, enters a poorly defined natural channel leading southward near the east side of the basin. About 83 acres are included in the developed part of the basin, of which 3 acres have been added by the shifting of drainage boundaries resulting from construction. About 50 acres of the 83 are paved or roofed and about 20 acres are irrigated by imported water, while 13 acres have been changed but little or not at all. The 90 acres at the south (lower) end of the basin remained unchanged through 1965.

The freeway construction scheduled to begin in 1967 in the basin of Los Trancos Creek tributary will also affect the basin of San Francisquito Creek tributary. The road will extend for about 2,000 feet across the southwest part of the basin and will cross the Linear Accelerator a few hundred feet west of the western boundary.

CHANGES IN THE HYDROLOGIC REGIME

Infiltration and Runoff during a Sustained Storm

Infiltration rate varies with soil type and depth, and with the amount of water already in the upper horizons of the soil. For these reasons, the average infiltration rates in the study basins can only be approximated for the natural state. Data from unit-hydrograph studies and from mass curves of rainfall and runoff indicate that the infiltration rate in the basins stabilizes in the range from 0.10 to 0.20 inch per hour during periods of sustained runoff-producing rainfall, and is more than 0.5 inch per hour in early autumn when the soil is at its lowest moisture content and large cracks are present to divert overland flow. Infiltrometer tests in 1959 (Branson, Miller and McQueen, 1961) indicated infiltration rates averaging 6.4 inches per hour in dry sandy soils in the study basins and as low as 0.18 inch per hour in dry uncracked clay-loam soil. The infiltrometer data may be representative of the characteristics of the individual soil types when dry, but extrapolations for basinwide evaluations are probably not reliable, particularly for use under the varying degrees of saturation that occur normally during the rainy season.

Runoff is a resultant of the combined characteristics of precipitation intensity, infiltration rates, and surface detention. After the major features of surface detention are filled runoff is determined by precipitation intensity and infiltration, integrated in both time and location. Short, intense bursts of precipitation may bring more water onto a small area than the soil can absorb. The longer the duration of excess precipitation and the larger the proportion of the basin receiving rainfall at a high rate, the larger the peak.

Variations in infiltration rates and in precipitation intensities are usually more influential in their effect on runoff from small basins than from large basins. The greater natural storage and the longer transit time of runoff in the larger basins tend to damp the effect of these variations. In small basins, such as those in the study area, where there is little damping effect caused by natural storage, runoff responds rapidly to changes in precipitation intensity, and a rather complex relation exists among precipitation, infiltration, and runoff. The number of physical measurements necessary to define the several factors is much greater than was obtained in this study. The ideal procedure is to analyze precipitation data and runoff data for a period when precipitation intensity is fairly constant over a length of time that permits a concentration of runoff from all parts of the basin to reach the measuring point. If the infiltration rate is assumed to be the same throughout the entire basin during this ideal precipitation, then the variation in infiltration rate with time remains as the only variable. Precipitation intensities during storm periods, however, are usually not constant and the infiltration rate may also vary from place to place. These variations complicate the analysis of the rainfall-runoff relation.

The interaction between precipitation and infiltration is illustrated by the curves of cumulative precipitation and cumulative runoff of Sharon Creek and Los Trancos Creek tributary during the storm period January 29-31, 1963, shown in figure 22. A rain of less than 0.10 inch on December 31, was the only precipitation after December 16, so fairly dry conditions existed until late afternoon of January 29.

Sharon Creek, where the impervious areas and the irrigated golf course prevented infiltration, responded very quickly. By 0200 hours on January 30, only 0.17 inch of precipitation had occurred but Sharon Creek runoff had totaled about 0.02 inch. By 0900 hours January 30, precipitation totaled 0.73 inch and Sharon Creek runoff was 0.12 inch, or about 16 percent of precipitation. From 0900 to 1800 hours on January 30, precipitation was 0.88 inch and runoff was 0.45 inch, 51 percent of the precipitation. During the longest period of sustained heavy precipitation, from 1500 to 2100 hours January 31, the rain totaled 1.27 inches and the runoff 0.95 inch, or 75 percent of the precipitation. By 2400 hours January 31, 2.53 inches of runoff had left the Sharon Creek basin, representing 58 percent of the precipitation.

During periods of relatively intense precipitation that occurred between about 0400 hours January 30 and 2400 hours January 31, Sharon Creek experienced 11 separate rises to discharges greater than 0.01 cfs per acre, with the first rise at 0430 hours January 30.

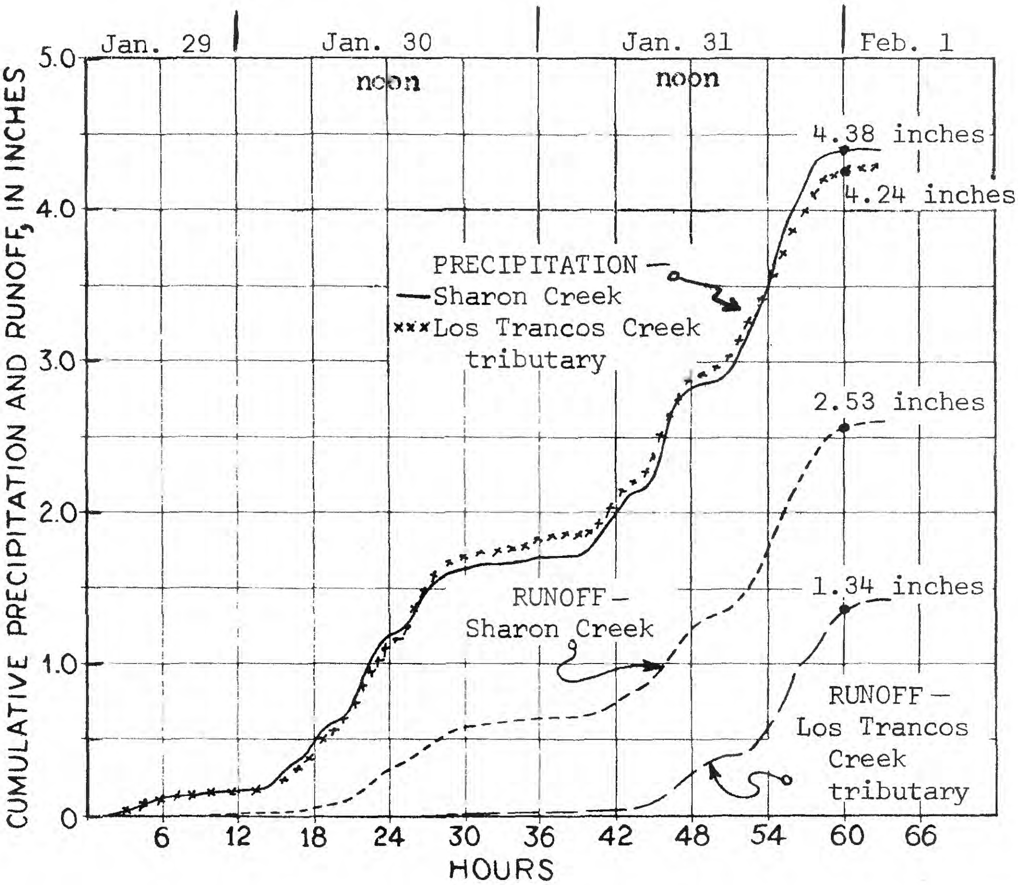


FIGURE 22.--Cumulative precipitation and runoff, natural and developed basins during storm of January-February 1963.

Los Trancos Creek tributary, with no modifications by man, responded very differently to the early stages of the storm. There was almost no response in runoff until late afternoon of January 30, although 1.70 inches of precipitation had occurred. In the same period Sharon Creek had yielded 0.57 inch of runoff. By 0900 hours January 31, after additional heavy rainfall, the upper soil horizons were approaching saturation and the response of Los Trancos Creek tributary from that time to the end of the storm was similar to the response of Sharon Creek. During the 6-hour period of most intense precipitation, the Los Trancos Creek tributary basin received 1.10 inches of rain and yielded 0.64 inch of runoff, or 58 percent. By 2400 hours January 31, 1.34 inches of runoff (32 percent of precipitation) flowed from the basin. Peak flow occurred a few minutes later than in Sharon Creek, and was 0.22 cfs per acre while the peak flow in Sharon Creek was 0.28 cfs per acre. The flow rose to five separate peaks of greater than 0.01 cfs per acre.

Detailed hydrographs of the streamflow from the three study basins on January 30 are shown in the appendix.

A summary of the reaction of the two basins to the January 1963 storm includes these observations:

1. Response of the developed basin to rainfall was much quicker than that of the undeveloped basin.

2. During the storm, Sharon Creek experienced 11 peaks of more than 0.01 cfs per acre. Los Trancos Creek tributary had only 5 such peaks.

3. As the storm progressed the soil surfaces in the undeveloped basin approached saturation. The response of the undeveloped basin to additional precipitation then became more like that of the developed basin.

4. The heaviest rainfall of 20 to 30 minutes duration followed a 48-hour period with about 3 inches precipitation; the ensuing peak-discharge rates between developed and undeveloped basins did not differ greatly. If the period of heavy precipitation had occurred early in the storm the undeveloped basin would have experienced a much lower peak rate.

5. Two hours after precipitation stopped, 58 percent of storm rainfall had left the developed basin, but only 32 percent had left the undeveloped basin.

Effect of Development on the Ground Water

The change in infiltration and runoff characteristics of Sharon Creek basin following development results in part from a change in the capacity of the soils to accept water. Prior to development the water table in the basin was 11 feet or more below the land surface, as mentioned on page 42. Most of the precipitation in the basin was retained as soil moisture and only a small part was discharged by surface runoff after saturation of the upper layers of soil.

The golf course in the Sharon Creek basin occupies the principal part of the valley floor. Irrigation of the course with imported water in the early period of development provided water in excess of actual consumptive requirements. Percolation of the excess water into the underlying soils eventually saturated these soils and raised the water table to or near the level of tile drains installed to carry off surplus irrigation water and provide drainage for the course. During periods of precipitation the already wet soil on the valley floor is filled quickly and from then on water flows over the surface or accumulates in the drains. During the dry season surplus water from periodic sprinkler irrigation also flows into the drains and thence to the stream channel. The combination of high water table and periodic replenishment of water in the upper soil horizons results in perennial flow in Sharon Creek.

Runoff of imported water began in Sharon Creek on October 21, 1961. The golf course irrigation was put on a regular schedule in May 1962 and the flow in the creek became perennial by August 1962. Observations in a well 45 feet from the Sharon Creek channel at the gage indicated that the deeper clay materials were becoming saturated in May 1963, and there was water in the well in June 1963, as shown in figure 12. The long time interval between the start of nearly continuous flow in Sharon Creek in October 1961 and the accumulation of water in the well illustrates the low rate of lateral movement of water in the soils overlying the bedrock in this basin. In May 1965 observations adjacent to the outlet of the concrete conduit about 530 feet upstream from the gaging station indicated that ground water was above the invert of the drain and close to the land surface; water levels upstream in the basin undoubtedly were higher.

The near saturation of the soils on the valley floor produces a situation comparable to that of a basin that has been well primed by antecedent rain, so that even minor rains cause some streamflow. The basin might be compared also with an area having a high degree of imperviousness and a fairly large surface detention capacity.

Increase in Yield Associated with Change from Ephemeral to Perennial Flow

Development in the basin of Sharon Creek has produced a marked increase in the total runoff. Such an increase has been noted in other studies, and is probably more pronounced in the semiarid California climate than in more humid regions. A reasonable postulation is that the amount of increase is related to the amount of precipitation and to the effects of development on the regime of runoff. Such a relation with precipitation appears to be roughly defined by the data from Sharon Creek. Annual precipitation of about 10 inches has been observed to occur with no appreciable runoff from either Sharon Creek (before development) or Los Trancos Creek tributary basin, while precipitation of 11 inches or more during the study period has invariably been accompanied by some streamflow. Obviously, the duration and intensity characteristics of precipitation during the year are a factor, but apparently these characteristics and the total annual amount are so interdependent that a 10- to 11-inch threshold exists.

During the seven water years 1959-65, Sharon Creek flowed for 20 days, 21 days, 1 day, 288 days, 355 days, 366 days, and 350 days, respectively. In 1962, when flow occurred on 288 days, landscaping operations were in progress and irrigation of the golf course was started, therefore that year is not comparable to either the predevelopment or the postdevelopment regime. Inspection of the number of days of flow for the periods before and after 1962 indicates a significant change in the regime of flow. Analysis of the magnitude of change is complicated by the fact that both 1963 and 1965 were rather wet years, with greater intensity of precipitation and more frequent periods of precipitation than occurred during other years of the study. However, 1964 was dry and thus is directly comparable to the predevelopment years.

Precipitation and runoff data from the study basins are summarized in table 6, and figure 23 shows the relative percentage of precipitation that left the basins of Los Trancos Creek tributary and Sharon Creek as streamflow. Outflow of imported water is not included in the Sharon Creek runoff shown in figure 23.

Table 6.--Summary of annual precipitation and runoff, in inches

Water year (Oct. 1-Sept. 30)	Sharon Creek			Los Trancos Creek tributary		San Francisquito Creek tributary		
	Precipitation	Runoff		Precipitation	Runoff	Precipitation	Runoff	
		Natural	Imported				Natural	Imported
1959	a12.4	0.52	0	a12.7	0.85	a12.2	0.50	0
1960	11.7	.90	0	10.9	.43	11.5	.48	0
1961	10.3	.003	0	10.2	.004	10.0	.01	0
1962	15.8	2.47	.72	13.6	1.14	14.5	2.07	0
1963	21.3	7.04	.88	20.6	2.41	20.9	4.58	.09
1964	11.1	2.80	.91	11.0	.27	11.5	2.01	3.38
1965	18.4	6.66	1.07	16.1	2.38	17.6	-	-

a. Partially estimated from Palo Alto record.

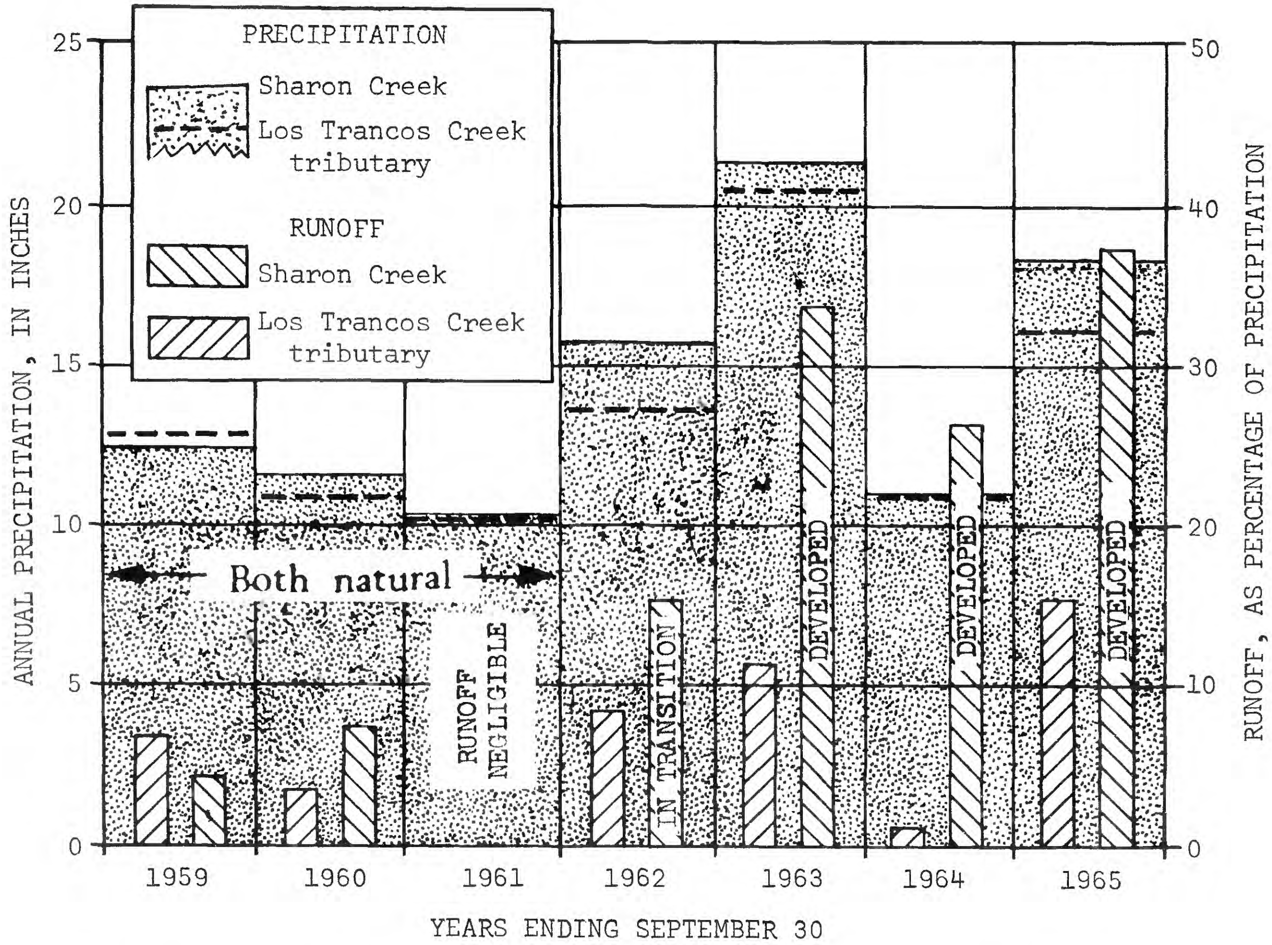


FIGURE 23.--Precipitation, in inches, and runoff, as percentage of precipitation, Sharon Creek and Los Trancos Creek tributary basins (outflow of imported water deducted).

The amount of imported water contributing to outflow can be estimated rather closely by inspection of the hydrograph during periods of low flow (see hydrograph in appendix). Imported water reaches the stream by two routes: Irrigation return flow intermixed with some effluent ground water seeps into a network of tile drains and thence is carried to the stream, and a larger amount of water is fed directly into a small regulating pond that in turn overflows to the concrete conduit carrying the creek through the golf course. The pond also has a drain at its bottom, discharging to the conduit, that is occasionally opened when the pond must be emptied. All flow in the creek throughout the dry summer period and during much of the remainder of the year is from these two sources. Imported water first appeared in Sharon Creek on October 21, 1961. Table 7 shows the monthly amount of imported water included in the flow.

Both table 6 and figure 23 indicate that, for a given amount of precipitation, more water now flows from Sharon Creek than would have been discharged under predevelopment conditions. The short period of record available for each condition provides too few data to justify formal statistical analysis, with the assignment of limits to determine the acceptance or rejection of a hypothesis of significant change. Nevertheless, it is evident that the change in the streamflow regime of Sharon Creek is strongly associated with the development within the basin.

Table 7.--Contribution of imported water to Sharon Creek discharge in cfs-days

Month	Water year			
	1962	1963	1964	1965
Oct.	1.26	0.87	0.30	0.35
Nov.	1.82	.45	.85	3.84
Dec.	.01	1.79	2.71	.94
Jan.	.14	.74	1.52	1.58
Feb.	.00	1.30	.51	.89
Mar.	.46	1.21	.31	.37
Apr.	.39	.53	.49	.49
May	.25	.60	.72	.41
June	.86	.51	.34	.42
July	.46	.28	.63	.65
Aug.	.85	.40	.37	.50
Sept.	.95	.42	.59	.58
Total, year	7.45	9.10	9.34	11.02
Total, in inches	.72	.88	.91	1.07
Direct release	6.32	7.31	8.03	10.18
Irrigation return	1.13	1.79	1.31	.84

To convert cfs-days to runoff in inches, multiply by 0.0971.

Data estimated from inspection of Sharon Creek gage-height record.

The relation between annual runoff (R), in inches, and annual precipitation (P), in inches, for natural conditions, can be approximately expressed thus:

$$R = 0.33\ (P-10)$$

and for Sharon Creek after development, thus:

$$R = 0.45\ (P-5.1)$$

The relations are probably valid for estimating runoff for years with precipitation between 10 and 26 inches. The increase in total runoff ranges from about 2.2 inches during a year of 10-inch total precipitation to about 3.4 inches when annual precipitation is about 20 inches. For the rare years of heavier precipitation, runoff may be greater than that computed using the equations. Natural water loss in the area is probably limited to a maximum of 22 to 28 inches, therefore runoff during very wet years will constitute a larger proportion of precipitation.

Figure 24 presents flow-duration curves illustrating five regimes of streamflow within the study basins: (1) The natural flow regime observed during the three water years 1959-61 at Los Trancos Creek tributary; (2) the natural regime for the same period at Sharon Creek; (3) the flow regime during water years 1963-65 at Los Trancos Creek tributary; (4) Sharon Creek during 1963-65 with imported water outflow deducted; and (5) Sharon Creek during 1963-65 with outflow of imported water included. The curves of figure 24 show the duration of flow (in percentage of days) when discharge was between 0.04 and 4 cfs.

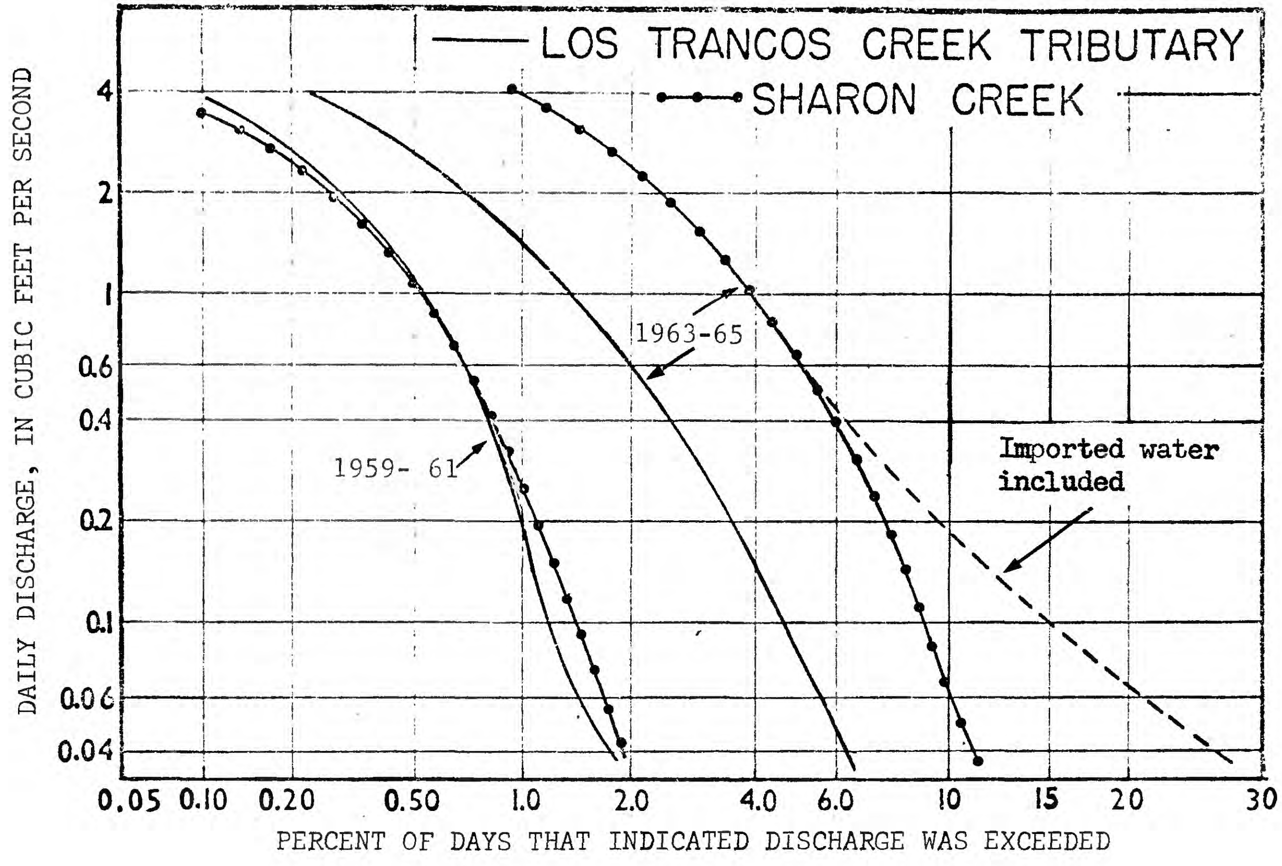


FIGURE 24.--Duration of daily flow from study basins.

The two curves for the predevelopment years are very close, showing that the regime of flow of appreciable magnitude differed but little between the basins. The curves for natural flow during the postdevelopment years 1963-65 are both shifted to the right, indicating a greater number of days of flow of all magnitudes within the range shown; this is to be expected in view of the heavier precipitation. However, the curve for Sharon Creek is much farther to the right than that for the Los Trancos Creek tributary. The curves show that in the years 1959-61 flows of 0.04 cfs or more occurred in Los Trancos Creek tributary on 19 days, and in Sharon Creek on 21 days. In the years 1963-65, the comparable numbers of days were 67 and 124, respectively. The greater number of days of flow of this magnitude in Sharon Creek is not entirely because of better-sustained base flow, but is principally caused by the more rapid response of the streamflow, after development in the basin, to precipitation during light storms.

The schedule of irrigation of the golf course is adjusted to the needs of the grass cover, as decided by the managers of the course. Water is applied by means of rotating sprinklers; at very low rates or not at all during the months December to March and at higher rates during the dry summer months. Inspection of hydrographs indicates that irrigation return flows for the water years 1963-65 were about 0.17, 0.13, and 0.08 inch. Chaotic landscaping and drainage conditions during the construction period in the 1962 water year, together with the different irrigation pattern required for the early establishment of the turf, prohibit meaningful comparison of 1962 data with those for earlier or later years.

To summarize: Development and associated importation of water in the Sharon Creek basin have resulted in perennial flow from the basin, whereas flow before development was ephemeral, occurring only a few days each year. Much of the additional low flow is imported water; however, if the outflow of imported water is deducted, the total runoff from precipitation still is much greater than would have occurred had the basin remained in its natural state.

Effect on the Unit Hydrograph

The relation between excess precipitation and runoff within a basin can be expressed by use of the unit hydrograph, a plot of the time distribution of runoff resulting from 1 inch of excess precipitation falling evenly throughout the basin during a unit of time.(Excess precipitation is that which leaves the basin as surface flow with little delay by residence in the ground.) The time unit is usually expressed in minutes or hours and may be a few minutes or several hours. It generally is chosen as some fraction of the time of concentration; that is, of the time required for water to flow from the most remote spot in a basin to the point of measurement. According to unit-hydrograph theory, any occurrence of excess precipitation will result in an outflow hydrograph that is proportional to the unit hydrograph. The following commonly used parameters of the unit hydrograph were measured in this study:

Q_p, peak discharge, in cubic feet per second;

q_p, unit peak discharge, in cubic feet per second per square mile of basin area;

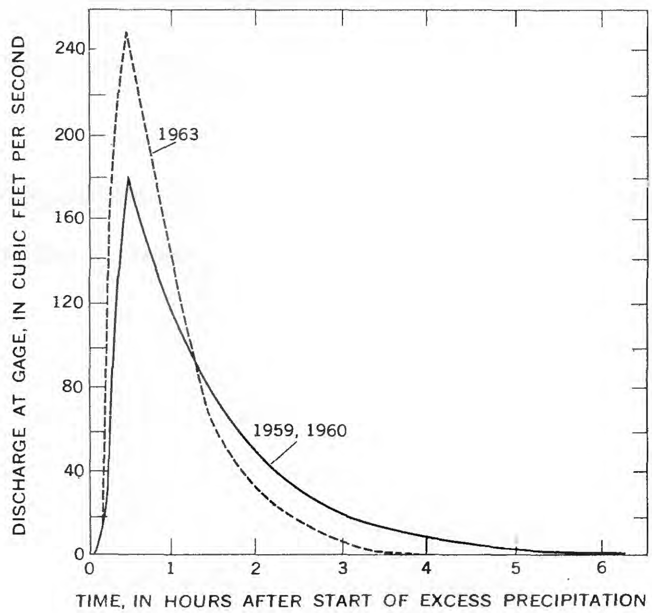
t_p, time from centroid of excess precipitation to occurrence of peak discharge;

T_{50}, time from centroid of excess precipitation to passage of 50 percent of runoff;

T_c, time between centroids of excess precipitation and the resulting runoff; and

T_{90}, time from centroid of excess precipitation to passage of 90 percent of runoff.

Average 15-minute unit hydrographs for Sharon Creek have been derived from storms of 1959-60, before development began, and from storms of 1963, after about a year of fairly stable land use with the development previously described. The two unitgraphs, with selected parameters, are shown in figure 25.



Hydrograph parameter		*1959, 1960*	*1963*
Q_p	cfs	180	250
t_p	min	22	22
T_{50}	min	54	38
T_c	min	69	54
T_{90}	min	145	92

FIGURE 25.--Average 15-minute unit hydrographs of Sharon Creek. Parameters are as defined in text.

The parameters of the two unitgraphs reflect basin characteristics under the regime of the stream before and after development, respectively. The magnitude of peak discharge from a small basin usually increases as a result of the construction of paving and drainage facilities that accompanies the urbanization process. This occurred in Sharon Creek; Q_p increased from 180 cubic feet per second to 250 cfs. Expressed in cubic feet per second per square mile (q_p), the increase was from 470 to 653.

In Sharon Creek basin, t_p did not change appreciably during basin development, but Q_p increased and produced a corresponding increase in q_p of about 40 percent.

Carter (1961, p. B10), studying basins near Washington, D.C., that ranged in area from 4 to 550 square miles, used indexes of channel length (L) and slope (S) as a measure of T_{50}. He found that for natural basins $T_{50} = 3.10\ (L/\sqrt{S})^{0.6}$, and for partially sewered basins $T_{50} = 1.20\ (L/\sqrt{S})^{0.6}$. In Sharon Creek before development $T_{50} = 3.70\ (L/\sqrt{S})^{0.6}$, and after development $T_{50} = 2.60\ (L/\sqrt{S})^{0.6}$. The difference between Carter's coefficient for natural basins and that for Sharon Creek before development is no greater than the scatter of points used by Carter in deriving his relationship, and therefore is not significant. The difference between the coefficients 1.20 and 2.60 has little quantitative meaning, as the definitions of "partially sewered" and of the degree of development in Sharon Creek basin are not precise. The change in the Sharon Creek coefficient accompanying the change in development is consistent with the difference found by Carter.

Flood hydrographs were inspected to determine whether a relation existed between any of the unit-hydrograph lag times (T) and the magnitude of peak flow (Q_p). The existence of such a relation has been postulated by some workers upon the basis of data which included a wide range of magnitude. However, the variation in magnitude of peaks available for this study was not great, and no relation was detected.

Effect of Development on Frequency of Flood Peaks

The reduced infiltration capacity resulting from development leads not only to a quicker response of runoff to precipitation, but also to the more frequent production of minor flood peaks. Data from Sharon Creek and from Los Trancos Creek tributary (table 8) illustrate this characteristic. The number of peaks of selected magnitudes in the two basins for 3-year periods both before and after development in the Sharon Creek basin are tabulated. Data for the 1962 water year are shown separately because construction activities were in progress and the data then were not representative of stable conditions. Data for the unusual 17-day storm period, December 21, 1964-January 6, 1965, are also shown separately in the table. Despite greater precipitation during the years after development, the changes in relation between the two basins is obvious.

The peaks are not all independent one from the other in the usual hydrologic sense, but are the result of short periods of excess precipitation separated by periods of lesser intensity; thus several of the peaks may be superposed upon one general rise of several hours duration. The same arbitrary criteria of separation were used for both basins.

Table 8.--Summary of peak flows in excess of 0.01 cfs per acre, in developed and undeveloped basins

Year	Range in peak discharge (cfs/acre)	Number of peaks	
		Sharon Creek (developed)[1]	Los Trancos Creek tributary (undeveloped)
1959-61	More than 0.15	0	0
	0.10-0.15	3	1
	.05-.10	1	0
	.03-.05	1	1
	.01-.03	3	6
1962	More than 0.15	2	1
	0.10-0.15	1	0
	.05-.10	1	2
	.03-.05	6	0
	.01-.03	15	3
1963-65	More than 0.15	3	2
	0.10-0.15	12	2
	.05-.10	32	4
	.03-.05	17	6
	.01-.03	104	11
Storm period Dec. 21, 1964- Jan. 6, 1965	More than 0.15	0	0
	0.10-0.15	3	0
	.05-.10	12	2
	.03-.05	2	2
	.01-.03	36	7

[1]Development started during 1962, and was fairly stable during the years 1963-65.

The data illustrate two characteristics of flood-peak frequency: A greatly increased number of peaks of relatively low magnitude--those that are to be expected several times during the average year--and a much smaller change in the number of higher peaks. The 7 years of available record do not include any peaks of rare magnitude, but the data of table 8 together with the illustrations previously discussed, showing the increased similarity between responses as the basins approach saturation, suggest that flood peaks of great magnitude may be quite similar in terms of discharge per unit of area for small basins lying in the same climatic region, regardless of differences in development.

Most planning for alleviation of the undesirable effects of floods is based on the relation between magnitude and frequency of annual peak flows. This relation is often shown, and is perhaps most concisely expressed in graphic form. Figure 26 has two hypothetical flood-frequency curves illustrating the nature of change resulting from basin development. The magnitude of the flood at which the curves converge is arbitrarily shown at about the 25-year frequency. The true frequency of convergence is not known and probably varies from basin to basin, depending on basin size and topography and on the climatic regime of the area.

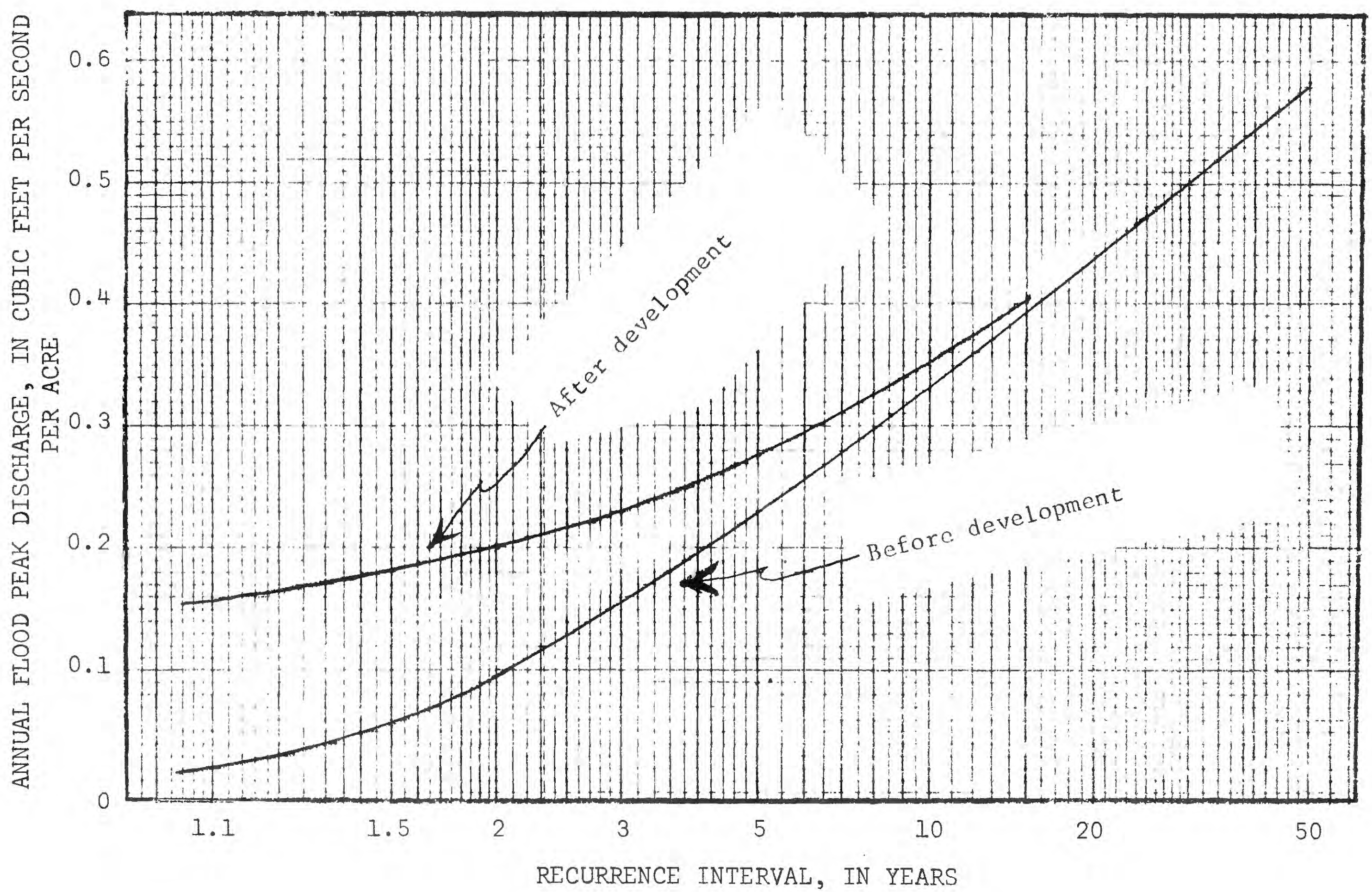


FIGURE 26.--Hypothetical flood-frequency curves for a small basin before and after development.

The limited data from Los Trancos Creek tributary indicate that peaks up to 0.03 cfs per acre are to be expected several times a year from small basins in the foothills near Palo Alto, and that peaks of 0.15 cfs per acre or greater may be expected in almost half the years. Data from Sharon Creek suggest that after development in that basin there were several times as many peaks of 0.03 cfs per acre as would occur under natural conditions, and a few more peaks of 0.15 cfs per acre or greater.

The change in a flood-frequency relation depends upon the degree and nature of development and also varies with basin size, topography, and the climatic regime. Even though the priming of the soil by irrigation of the golf course increases the number of small peaks to an appreciable degree, it probably causes less change than would be caused by complete paving of the same area.

Increase in Storm Runoff

The effect of urbanization upon flood peaks and upon storm runoff have probably received more attention than any other hydrologic aspect. In addition to increased numbers of small flood peaks and increases in magnitude, there has been an increase in the percentage of precipitation that runs off during and immediately after storm periods. Table 9 shows runoff as percentage of precipitation for various situations.

Table 9.--Storm associated precipitation and runoff in study basins

	Sharon Creek (developed after 1962)			Los Trancos Creek tributary (undeveloped)		
	Precipitation (inches)	Runoff		Precipitation (inches)	Runoff	
		Inches	Percent		Inches	Percent
Total						
1959-61	34.4	1.42	4.1	33.8	1.28	3.8
1963-65	50.8	16.50	32.5	47.7	5.06	10.6
Storm[1]						
1959-61	22.4	1.35	6.0	22.4	1.09	4.9
1963-65	40.4	15.23	37.8	37.3	4.63	12.4
Storm[2]						
1959-61	11.7	1.34	11.5	11.8	1.09	9.2
1963-65	29.2	13.29	45.5	27.2	4.63	17.0

[1]Precipitation criteria as described on the following page.

[2]Storms meeting the precipitation criteria and also yielding 0.002 inches or more runoff from the Los Trancos Creek tributary basin.

The choice of criteria for this comparison requires consideration of the climatic regime of the study area. The magnitude of storms producing appreciable runoff varies greatly with antecedent conditions in most environments, but the pronounced annual cycle of precipitation on the Pacific coast results in an extremely high infiltration rate at the time of the first autumn rains, and heavy storms early in the year can yield little or no runoff under natural conditions while the developed basin responds with runoff from all storms, whenever they occur. If the occurrence of runoff from the developed basin were used to select periods for comparison of storm runoff, then every occurrence of rain, even the many light early autumn and late spring rains that have no effect under natural conditions, would constitute storm events. If runoff from the undeveloped basin were used, heavy out-of-season rains that are important contributors to storm runoff from the developed basin would be ignored. For these reasons, the magnitude and intensity of precipitation is probably the most valid basis for selection of periods.

The criteria for selection of storm periods were: There must be 3 consecutive days with a total precipitation of 0.60 inch, 1 day of the 3 must have precipitation of 0.25 inch or more, the first day of the storm period must have 0.20 inch or more of precipitation, and a daily precipitation of less than 0.10 inch is considered as zero. In determining storm runoff, the flow for the first day after the end of the period meeting these criteria was included. Outflow of imported water, determined by inspection of the record, was deducted; however, the difference between total flow and storm flow for the periods selected was slight. By the criteria used, there were 15 storm events with a total of 41 days of precipitation during the period 1959-61, and 25 events with 59 days of precipitation in 1963-65. Storm runoff was about 90 percent of total runoff in both basins for the entire 6 years, and the difference between the two basins in percentage of annual runoff appearing as storm runoff is probably not significant. However, the difference in percentage of both total and storm precipitation appearing as runoff under natural versus developed conditions is significant.

The first set of storm-runoff data shown in table 9 is from periods meeting the criteria described in the preceding paragraph. Several of the periods thus selected produced very little runoff from the undeveloped basin, therefore data from periods meeting another condition are also shown; this added condition includes only those periods that meet the first criteria and also yield 0.002 inch or more runoff in Los Trancos Creek tributary. As shown in table 9, the difference in runoff using the two criteria is sizeable for the developed basin (15.23 inches and 13.29 inches) but is almost zero for the natural basin (4.63 inches by either criterion).

Table 9 indicates that under undeveloped conditions, and varying with the criteria used and the period involved, storm runoff ranged from 4.9 percent of storm precipitation to 17.0 percent. Under developed conditions the corresponding ratios for the two criteria were 37.8 percent and 45.5 percent. Changes of this nature, although of different magnitudes, have been observed in other studies, as reported by Harris and Rantz (1964), and Waananen (1961). Wiitala (1961), on the other hand, found no detectible change in storm runoff after urban development of a larger basin near Detroit.

Changes in Rate of Sediment Transport

The basins and channels of the three project streams do not normally produce large quantities of suspended sediment or bedload. From the description of the Sharon Creek channel, on p. 72, it is evident that little sediment is likely to be picked up by the stream from its own channel except in the short reach leading from the golf course drain outlet to the gage. In the winter of 1961-62, however, sediment was eroded from fresh fill surrounding the newly laid concrete pipe placed in the original channel through the golf course and from other areas where grading and earthmoving were in progress. During the winter of 1963-64, some sediment was contributed by exposures of loosened earth and by channel erosion in the reach immediately above the gage, where construction was underway.

Most of the sediment load in the Los Trancos Creek tributary basin has its origin in several groups of small scarps, or headwalls. The scarps occur in groups along the lower 600- to 800-foot reaches of the two main tributaries, with a few smaller cuts further upstream. They appear to be moving slowly upstream by headwall erosion. Except for these scattered centers of erosion, stream channels are grass-covered and indistinct.

San Francisquito Creek tributary also carries sediment derived from headwall erosion. However, the presence of loosened soil during construction, the advent of perennial flow that accompanied the construction, and the increased number and intensity of flow peaks caused by the presence of large paved areas increased the outflow of sediment greatly.

Tables 10, 11, and 12 show the results of analyses of samples taken from the three basins during high flows. The variation in rate of transport (that is, discharge in tons per day) is very large, because the concentration increases as the discharge increases; the rate of transport may rise from 0.01 ton per day to 100 tons per day in a few hours. The heavy load carried at and near peak discharge is not a good indicator of the total volume carried. For example, the total load of suspended sediment carried by San Francisquito Creek tributary on March 16, 1963, was about 6 or 8 tons, but the rate of transport at the time of peak flow was about 82 tons per day.

Selected samples of sediment from the basins were analyzed for particle-size distribution. The results of some of the analyses are listed in the appendix.

The amount of sediment measured at a basin outlet during one flood period, or even during an entire flow season, is not always indicative of the actual amount of sediment movement within the basin. In a basin unchanged by man there may be localized regions where, because of differences in degree of consolidation, or differences in slope or in channel characteristics, sediment production and local movement rates are more than or less than the rates over the basin as a whole. The location of these anomalous regions with respect to the sampling site in any one storm or one year may result in the collection of data not truly representative of long-term averages.

Table 10.--Sediment-load data from Sharon Creek

Date	Time	Discharge (cfs)	Sediment	
			Concentration in mg/l	Discharge in tons/day
1960				
Jan. 25	1645	0.68	130	0.24
Feb. 8	1017	10.4	106	2.97
1961				
Nov. 29	0950	.078	1,730	.36
Nov. 29	0954	.077	1,660	.34
Nov. 29	1012	.054	1,330	.19
Dec. 1	0858	.910	16,800	41.6
Dec. 1	0859	.880	16,300	39.0
Dec. 1	0915	.628	13,900	23.8
Dec. 1	0917	.620	13,400	22.6
Dec. 1	0941	.303	7,670	6.32
Dec. 1	0942	.319	9,070	7.88
1962				
Jan. 22	1510	.068	3,260	.60
Feb. 9	1400	1.20	13,500	44.1
Feb. 9	1420	6.70	19,600	359
Feb. 9	1500	5.06	12,700	173
Dec. 16	1450	12.1	1,480	48.3
Dec. 17	1455	5.64	1,810	27.5
1963				
Feb. 21	1403	5.00	769	10.4
Mar. 16	1007	5.42	599	8.75
Mar. 16	1055	3.12	411	3.46
Mar. 28	0955	1.27	296	1.01
Nov. 5	2105	.51	159	.22
Nov. 15	1300	.032	356	.031
Nov. 19	1433	27.8	1,240	92.9
Nov. 19	1455	24.2	1,760	115
Nov. 19	1530	28.7	1,320	102
Nov. 19	1640	18.8	708	35.9
Nov. 19	1950	2.28	608	3.74
Nov. 20	0815	.095	15	.004
1964				
Jan. 20	2110	27.3	616	45.3
Jan. 20	2155	17.8	432	20.7
Jan. 20	2206	17.0	468	21.4
Jan. 21	0830	.469	17	.021
Jan. 21	1416	4.62	227	2.83
Jan. 21	1957	6.38	346	5.95
Jan. 22	1316	4.90	482	6.37

Table 11.--Sediment-load data from Los Trancos Creek tributary

Date	Time	Discharge (cfs)	Sediment	
			Concentration in mg/l	Discharge in Tons/day
1962				
Feb. 13	1245	2.90	369	2.88
Feb. 13	1325	5.87	854	13.5
1963				
Mar. 16	1145	.420	280	.32
Mar. 16	1220	.300	331	.27
1964				
Jan. 21	0902	1.45	71	.28
Jan. 21	1450	1.35	155	.56
Jan. 22	1420	.498	41	.55

Table 12.--Sediment-load data from San Francisquito Creek tributary

Date	Time	Discharge (cfs)	Sediment	
			Concentration in mg/l	Discharge in Tons/day
1962				
Feb. 9	1055	0.023	588	0.036
Feb. 13	1055	.285	384	.29
Feb. 13	1455	2.45	305	2.01
Oct. 13	1515	1.84	5,620	27.9
Dec. 17	1610	.940	1,020	2.58
1963				
Jan. 31	1135	13.1	2,530	89.3
Jan. 31	1220	10.5	2,110	59.7
Mar. 16	0845	5.22	5,850	82.3
Mar. 16	0913	4.70	5,730	72.6
Mar. 16	0927	3.48	6,010	56.4
Mar. 16	0947	2.26	5,380	32.8
Mar. 16	1125	.940	2,300	5.83
Mar. 16	1237	.362	2,130	2.08
Mar. 16	1312	.235	1,920	1.22
Nov. 5	2045	.470	882	1.12
Nov. 15	1400	.008	113	.002
Nov. 19	1500	10.5	5,100	144
Nov. 19	1510	13.6	6,190	227
Nov. 19	1540	10.7	6,070	175
Nov. 19	1905	.442	1,190	1.42
Nov. 20	0840	.013	232	.008
1964				
Jan. 20	2124	10.7	3,730	108
Jan. 20	2140	8.13	3,850	84.4
Jan. 20	2310	4.16	2,070	23.2
Jan. 21	0857	.275	215	.159
Jan. 21	1433	2.26	1,050	6.40
Jan. 21	2033	2.35	1,320	8.36
Jan. 22	1400	.632	592	1.01
Jan. 23	1038	.210	37	.021
Jan. 24	1521	.181	1,260	.615

Construction and landscaping operations accompanying development within a basin increase the likelihood of obtaining non-typical data. Slopes of land surfaces are changed; some are steepened, and some lessened. Loose, easily erodible accumulations of soil and gravel are formed and provide high-yielding sediment sources which may be either temporary or relatively permanent. While outflow is generally expedited, local areas of ponding and deposition may occur. The relative locations of flow modifications, sediment sources, and sampling sites form a complex system which must be studied in its entirety before meaningful interpretation of data from one specific site is possible.

Despite these complications, many studies have furnished incontrovertible evidence that development activities frequently result in at least a temporarily increased rate of movement of solids from the basin undergoing change (Guy and Ferguson, 1962, 1963; Savini and Kammerer, 1961). The total amount of artificially induced movement is related to the characteristics noted in the preceding paragraphs and may also be affected by the timing and methods of construction and the timing of precipitation. If care is taken to avoid unnecessary exposure of loose, steep slopes, and if precipitation and streamflow remain low during the critical periods of erosion potential, sediment transport may not be excessive. On the other hand, if large, unstable fills are carelessly placed and intense storms occur at inopportune times, tremendous quantities of sediment may be carried away; often to create problems at some downstream location where deposition occurs.

Net loss of sediment by stream transport from the gaged basin of Los Trancos Creek tributary ranged from practically none in 1961 when there was very little outflow, to an estimated 1,000 cubic feet between October 1964 and May 1965. Most of the sediment originated during periods of high flow, and came from the erosion of headwalls, the deepening of plunge pools below the headwalls, and the collapse of undercut banks. Rates of erosion from land surfaces in the basins were not directly measured; however, it must be assumed that such erosion occurs in both natural and developed basins. From the data collected in this study, total erosion rates under natural conditions are roughly estimated to be equivalent to overall basin degradation of 50 to 80 feet in one million years.

The effect of development upon sediment movement in the Sharon Creek basin has been slight with respect to predevelopment and postdevelopment concentrations. Heavy concentrations of sediment load were observed at times when construction was in progress, but once the environment had become stable under developed conditions, sediment concentration was low; perhaps even less than under the predevelopment regime. It is probable, however, that sediment movement in the channel below the area of development has increased somewhat. Flow is perennial, peaking occurences are more frequent, and peaks are somewhat higher and sharper than previously. All these changes tend to erode the banks and bed more rapidly and to carry sediment more efficiently.

Chemical Quality of the Water and Increase in Transport of Dissolved Minerals

During its movement through the soil and to a lesser extent in its passage over the ground, water dissolves most earth substances and converts many of the soil and rock constituents into ions of the more common elements and compounds. Moving water thus transports large quantities of dissolved minerals in addition to its load of suspended sediment. The chemical constituents most commonly abundant in fresh water which has passed through soil or rock are bicarbonate, sulfate, chloride, calcium, sodium, silica, and magnesium.

Water flowing in the three streams under study has been analyzed, and the results of these analyses are shown in the appendix. The specific conductance of the water and the pH, or hydrogen ion concentration (a measure of acidity), were measured at more frequent intervals, and these data too are tabulated in the appendix. Detailed discussion of the characteristics and significance of the chemical constituents of water can be found in Hem (1959); only aspects thought to be pertinent to this study are discussed in this report.

Chemical concentrations in most streams tend to be higher when discharge is slight, but streams carry a larger total load when discharge is high although concentrations are low. This generalization appears to hold true for the study basins. The relations among rate of discharge, rate of change of discharge, and dissolved-solids concentration are complex and are affected by other factors; however, frequent readings of conductance can sometimes be translated into a record of the approximate transport rate of dissolved solids. The relations involved are not precise enough to justify moment-by-moment analysis, but the rather broad scatter about the assumed relation trend seems to be almost random and the computation of quantities on a daily basis can be used to estimate the annual load reasonably well. Water from the study basins was analyzed and the proportions of the principal constituents of dissolved solids were found to be fairly constant within each basin. Figure 27 shows the nature of these constituents. In addition to the constituents shown in figure 27, 2 to 3 percent of the calculated dissolved solids was silica, and combined nitrate and phosphate ions constituted less than 1 percent. The calculated dissolved solids shown in the appendix make up about 95 percent of the total dissolved solids present in the study stream, and the constituents shown in figure 27 represent about 90 percent of the total. There were undoubtedly small quantities of other materials in solution. Samples were not analyzed for such substances as phenols and pesticides and no statement can be made concerning the presence or possible change in quantity of substances that were not studied.

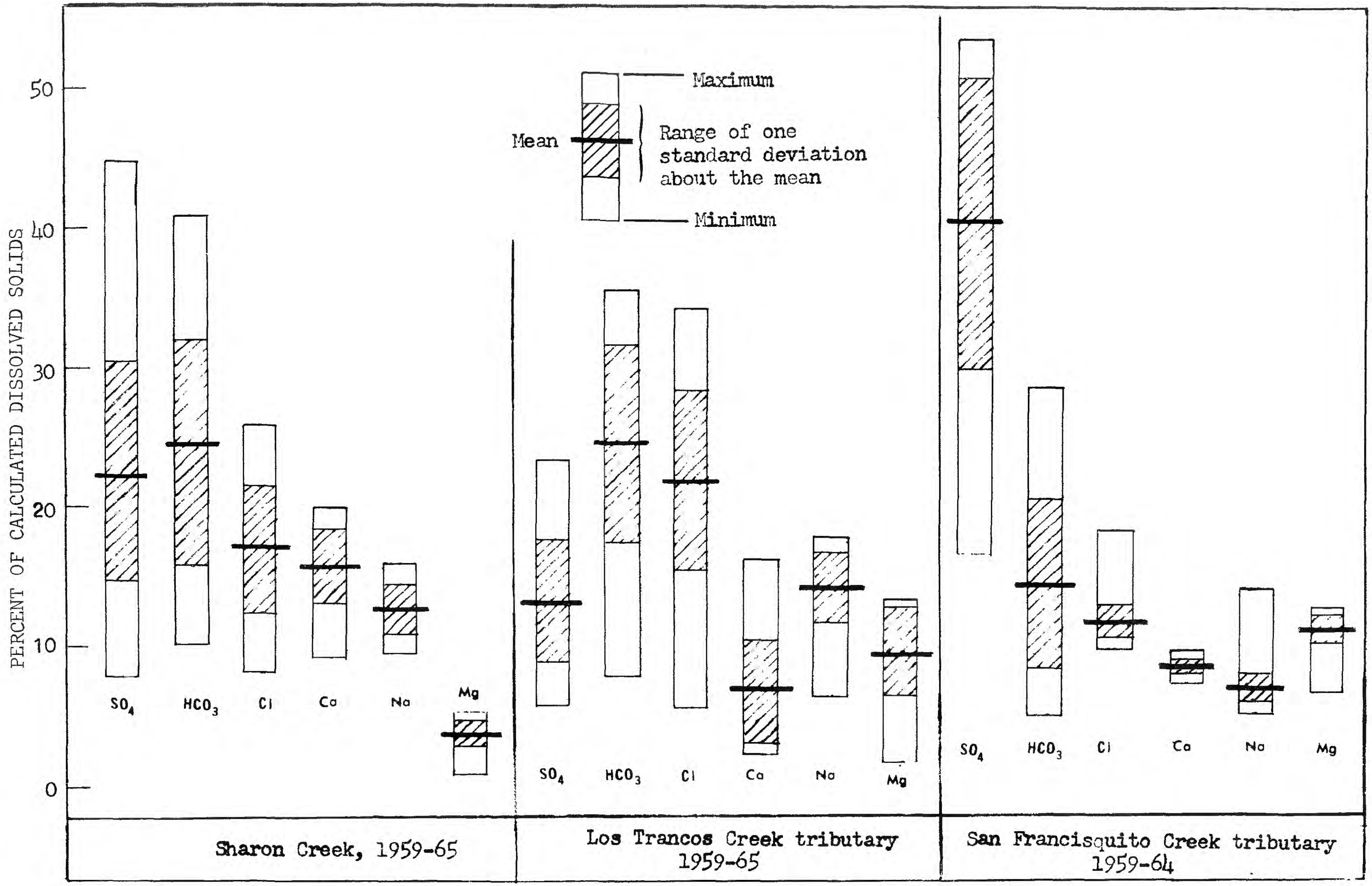


FIGURE 27.--Principal constituents of dissolved solids in study streams.

In the Sharon Creek basin, both concentration and total load of dissolved solids increased materially after development. The control basin, Los Trancos tributary, showed no change. There are variations that appear to be related to antecedent flow conditions and others that appear to occur randomly in time. Table 13 shows the estimated yearly loads of dissolved solids carried from the Sharon Creek and Los Trancos Creek tributary basins. Specific conductance and discharge were determined in Sharon Creek during periods of flow before developme and biweekly when flow became perennial, after development. Measuremen were made in Los Trancos tributary basin when flows occurred. These data provide a basis for estimates of the annual loads of dissolved solids removed from the two basins by streamflow.

Table 13.--Annual input and outflow of dissolved solids, Sharon Creek and Los Trancos Creek tributary, 1959-65

Water year (Oct. 1-Sept. 30)	Precipitation at Sharon Creek (inches)		Estimated quantity of dissolved solids (tons)					
			Sharon Creek				Los Trancos Creek tributary	
			Total outflow		Input to basin		Total outflow	Input from precipitation[2]
	Total	Storm	Natural[1] conditions	Developed conditions	From precipitation[2]	From imported water		
1959	12.4	10.3	2.0		3.4		3.8	4.4
1960	11.7	8.3	2.9		3.2		3.6	3.7
1961	10.3	4.0	.02		2.9		.12	3.5
1962	15.8	13.0	4.8	28	4.4	7.1	3.9	4.7
1963	21.3	16.5	6.6	55	5.9	7.2	6.5	7.0
1964	11.1	4.9	.7	33	3.1	7.3	1.1	3.8
1965	18.4	15.1	5.8	56	5.1	7.5	9.3	5.5

[1] 1962-65 estimated from the relation of figure 28.

[2] See discussion, page 113.

The estimates of annual loads of dissolved solids transported from the Sharon Creek basin before development and from the Los Trancos Creek tributary basin during the entire period, in tons per acre, have been plotted against an index of effective precipitation, in figure 28. The relation shown between the two can be expressed as

$$L = 0.00208\ P_S - 0.00756$$

with L the annual load in tons per acre and P_S the index, storm precipitation (see table 3), during each year. The equation cannot be considered indicative of relations in other areas nor for years when annual storm precipitation greatly exceeds the observed upper limit of about 16 inches or is less than the lower limit of 4.0 inches. Storm precipitation in the study basins is probably within these limits during more than 80 percent of years. Most years having less than 10 inches of total precipitation have less than 3.6 inches of storm precipitation and therefore no runoff in this region, although the time distribution of occurrence of precipitation varies and occasionally even a very dry year produces small amounts of streamflow. Yearly total and storm precipitation at Sharon Creek are shown in table 13. Precipitation depths in the Sharon Creek and Los Trancos Creek tributary basins are almost identical. Precipitation at Palo Alto, 4 miles from Sharon Creek, during the study period totaled only about 85 percent of the 1911-65 mean.

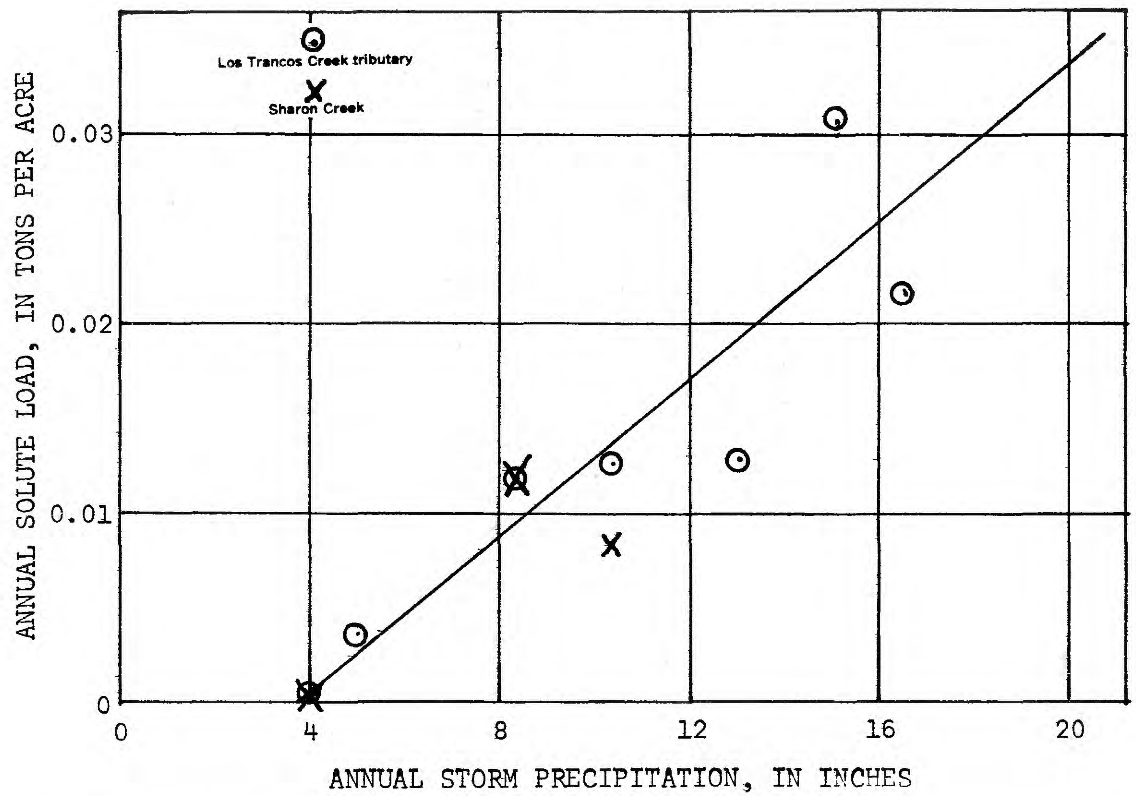


FIGURE 28.--Relation between annual outflow of dissolved solids and annual storm precipitation, Sharon Creek (1959-61) and Los Trancos Creek tributary (1959-65).

The relation between L and P_S has been used to estimate the load of dissolved solids that would have been carried from the Sharon Creek basin by streamflow if conditions had remained natural in the period 1962-65. The estimates are listed in table 13, and indicate the magnitude of the difference between natural and developed conditions rather well. They show that the combined effects of increased flow and increased concentration of dissolved solids resulted in a much greater load of solutes being carried from the basin under developed conditions than under natural conditions. Thus, under natural conditions in the 3 years 1963-65 there would have been about 13 tons of dissolved solids transported from the basin; however, the actual quantity totaled about 144 tons--more than 10 times that estimated for natural conditions.

The large variation in load during the years 1960, 1961, and 1964, despite a variation during the same years of less than 1.5 inches in annual precipitation, reflects the fact that precipitation amounts during those years were very close to the threshold below which no runoff is likely. Runoff of Los Trancos Creek tributary for the 3 years was 10.8 acre-feet, 0.09 acre-foot, and 6.8 acre-feet, respectively.

Table 13 also shows the estimated amounts of dissolved solids introduced into the basins by precipitation and into the Sharon Creek basin by imported water. The amount of dissolved solids brought by precipitation was estimated as high as possible (10 parts per million) from the data of Whitehead and Feth (1964) because no allowance has been made for the input from dry fallout. A 7-year summation of the estimates under natural conditions shows an excess of input of solutes over outflow. This should not be construed as typical over a long period; the flushing action is probably greater during normal or wet periods than it was during the relatively dry years of the study.

The higher concentrations of dissolved solids and the large excess of outflow of dissolved solids over input that was observed in Sharon Creek during 1962-65 may be attributed to several factors. Under natural conditions most of the precipitation was retained as soil moisture and subsequently was lost to the atmosphere by evapotranspiration. Chemicals in solution were carried into the soils by the infiltrating waters and remained in the soils when the water was transpired. Similarly, water rising from the water table by capillarity and lost by evapotranspiration also deposited chemical residues in the soils. These processes were repeated over a long time span and undoubtedly resulted in substantial concentrations of chemicals in the soils. After development, the rise of the water table (associated with golf course irrigation) to levels near the land surface provided opportunity for leaching of the chemicals. The basin outflows after development are combinations of effluent ground water containing large concentrations of dissolved solids mixed with runoff from precipitation or irrigation return flow, and thus the runoff of dissolved solids is high.

Other probable causes of the higher dissolved solids concentration and the larger load include: (1) Alteration of the natural soil distribution during development, especially where extensive cuts and fills were necessary for establishment of the desired golf-course topography, and exposure of material that had not been thoroughly leached in the past; and (2) normal planned application of irrigation water to lawns and the golf course at rates approximating the consumptive need, resulting in retention of dissolved solids in the irrigated soil and subsequent leaching by runoff from precipitation or from occasional surplus irrigation water. Possibly the year-round active growth in the irrigated areas produces carbon dioxide in volumes sufficient to cause some increase in the solvent power of the water in the soils.

Data in tables of chemical analyses (appendix) show that, prior to development, water in Sharon Creek was generally lower in mineral concentrations than water from the other two basins. After development, concentrations in Sharon Creek more nearly resembled those at equivalent flows in the other basins. The concentrations of sulfate and chloride and values of both hardness and noncarbonate hardness show especially striking increases following development in Sharon Creek basin.

The geologic map (fig. 8) shows that Sharon Creek basin is underlain almost entirely by Tertiary sandstone and shale, whereas both other basins are underlain by a mixture of rock types, including sand and gravel of Tertiary and Quaternary age. The differences in geology may explain the differing water qualities observed prior to development. The change in Sharon Creek after development--especially the increased concentrations of sulfate and chloride--cannot be explained on the basis of any information on rock types that is available. Inasmuch as little if any fill was brought into Sharon Creek basin during development, the changes cannot be explained on the basis of materials introduced from outside the basin. It appears, therefore, that the mineral matter was present in the native rock, and merely was made available by disturbance of the original surface. A return to predevelopment quality may eventually occur when new equilibrium conditions are established.

Increase in Streambed and Channel Vegetation

The change of regime in the flow of Sharon Creek below the developed area has encouraged plant growth in at least two ways: Moisture is now available the year around, and pockets of loose, well-sorted sediment are deposited in new areas where they support plant growth. Suburban development, as observed in the Sharon Creek basin, has not been found thus far to introduce contaminants that hinder plant growth. It was earlier assumed that fertilization of lawns and of the golf course would cause a significant increase in the concentration of nutrients in the water of the stream and that plant growth would thereby be stimulated. The expected enrichment has not been detected. Chemical analyses of water samples from Los Trancos Creek tributary and Sharon Creek have shown that both streams contained from 0.1 to 5.0 ppm of combined nitrates and phosphates during the years 1960-65, and no significant change in these proportions was noted. However, the total amount of dissolved materials carried by Sharon Creek has increased greatly, as described in previous paragraphs, and the amount of nutrient in the form of nitrate and phosphate ions has increased accordingly. These substances make up about 1 percent of the total dissolved minerals in Sharon Creek water; the amount of nutrients removed from the basin was therefore about 100 pounds during the years 1959-61, and was almost 3,000 pounds in 1963-65. Most of this material was carried throughout the length of the stream to distant destinations, of course, but it is highly probable that biological activity, including plantlife, has been encouraged by the presence of increased amount of nutrients.

Plant growth in the streambed and along the banks of Sharon Creek has increased greatly in the years since development began, especially in the reach between the golf course and the gaging station where the slope is gentle. Prior to development there was a cover of wild meadow grasses and weeds that became green and grew actively only after autumn rains began, then dried out and became dormant in April or May. By the autumn of 1965 reeds and brush grew thickly in much of the channel and brush, weeds, and grass were lush along the banks all through the year. Downstream from the gaging station the channel slope is somewhat steeper than upstream, and the increase in vegetation is less pronounced. It is likely that the effects of changes in Sharon Creek that induce biological activity decrease in relative magnitude with distance from the developed basin, and with the combining of the altered flow with natural outflow from undeveloped lands.

POSTULATED CHANGES NOT OBSERVED IN THIS STUDY

There are many concomitant effects of urbanization upon hydrology that have been postulated by investigators, but that have not been observed in this study. Some of them may actually have taken place but may not have been recognized because of inadequacies in the data, while some may not occur because of local conditions that differ from conditions in other basins.

Urbanization has been found responsible for localized climatic changes in some regions (Mitchell, 1961; Woolum, 1964; Chagnon, 1968; Landsberg, 1956). Climatic changes were not detected in the course of this study. The 7 years of data indicated variations that, within the limits of accuracy of the observations, are inherent in the natural variance of the climate of the region.

Pollution caused by the introduction of sewage wastes into the environment was not a factor in the study area itself, because a sanitary sewerage system diverts such contaminants from the basin.

The usual concomitants of urban and suburban development have been described as causing an increase in peak flow; however, other features of development may tend to cause a decrease. An example sometimes encountered is that of roadway construction that incorporates an embankment through which flow is conveyed by a culvert. Such a feature can modify the flood-frequency characteristics of a small basin by impounding some of the inflow and producing a retarded, moderated peak (Hathaway, 1945; Forrest and Aronson, 1959).

Changes in the stream channel downstream from the study area and changes in the flow regime of secondarily-affected streams were not explored in this study. Such changes undoubtedly occur, and their effect is determined by the nature and magnitude of changes in the primarily-affected basins. Waananen (1961) reported sharp, high flow peaks on a stream in New York caused by urban runoff superimposed on the more rounded peaks produced by larger natural basins upstream.

Discussion of the interplay of underground water and surface water is treated less extensively in this study than in many others. Several investigators have found that development has affected the quantity, movement or quality of underground water. Savini and Kammerer (1961) and Pluhowski and Kantrowitz (1964) relate specific instances of the effect of urbanization upon ground-water levels and upon the chemical quality of ground water, while the relation between coastal concentrations of population and the intrusion of saline waters into ground-water aquifers is described by Todd (1964).

SUMMARY

The impact of urban development and changes in land use in modifying the hydrologic regime has long been recognized, but the paucity of data has limited the evaluation of the full extent and the magnitudes of the resulting changes. Data obtained in the San Francisquito project study basins near Palo Alto, Calif., during the period 1958-65 indicate changes that resulted from conversion of rural lands to a suburban-residential, professional-light industrial, and recreational use. Though not typical of the normal large-scale suburban-residential development the results nonetheless appear to provide data that may be applicable to other situations in regions with a comparable hydrologic environment.

The development that occurred in the Sharon Creek basin caused changes in the hydrologic regimen that included a rise in ground-water level following importation of water for irrigation, and deterioration of the quality of the ground water and of the wastewater discharged from the basin. Changes in the characteristics of surface runoff and streamflow resulting from development included:

1. More rapid and greater response to precipitation (in terms of runoff) after development.
2. Change in flow from ephemeral to perennial following the commencement of irrigation.

3. More frequent floodflows from moderate rain that occur more quickly, reach higher peak discharges, and recede more rapidly than those under pre-development conditions. The number of peak flows at rates of 0.25 cfs per acre or less has increased markedly, but the magnitude and frequency of floods from more rare storms of greater intensity has changed to a lesser extent.

4. Increase in both storm and annual runoff. A much greater part of the storm precipitation leaves the basin as runoff. The data indicate that in years of near-normal precipitation the increase in annual runoff is about three-fold, from about 10 percent of the annual precipitation before development to more than 30 percent after development. Comparative estimates for typical amounts of annual precipitation are:

Annual precipitation, inches	Runoff, inches	
	Undeveloped	Developed
10	0	2.2
15	1.6	4.5
20	3.3	6.7
25	5.0	9.0

5. Large increase in sediment concentrations when raw land surfaces were exposed during rainy periods, but return to pre-development magnitudes or less after grasses and plantings were well established. However, total sediment discharge is somewhat greater than that before development.
6. Increase in outflow of dissolved solids during the three years after development to more than 10 times that to be expected if development had not taken place.
7. Occurrence of flourishing vegetation on the stream banks and in the channel where only grasses and scattered shrubs existed before development.

The quantitative descriptions of the results of suburban development upon the hydrologic regime that are presented in this study can be extrapolated loosely to other similar areas of development in a similar environment. Each region of development, however, is unique in some details and many regions have widely differing hydrologic environments. Depending upon the degree of variation, changes akin to those described in this report must be expected, perhaps in combination with other changes not noted here.

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APPENDIX: SUMMARY OF DATA

Discharge, in cubic feet per second

(There was discharge only on the days listed)

SHARON CREEK NEAR MENLO PARK, CALIF., 1959-65

Date	Discharge	Date	Discharge	Date	Discharge	Date	Discharge	Date	Discharge
Jan. 9, 1959	0.21	Feb. 17, 1959	0.53	Feb. 25, 1959	0.01	Feb. 5, 1960	1.32	Feb. 13, 1960	0.03
10	.02	18	.19	26	.01	6	.04	14	.02
12	.03	19	.08	Jan. 15, 1960	.01	7	.01	15	.01
Feb. 10	.09	20	.76	25	.13	8	4.12	18	.01
11	.12	21	.57	26	.01	9	1.67	19	.01
12	.02	22	.09	Feb. 1	.46	10	1.28	Mar. 28	.01
15	.04	23	.04	2	.03	11	.10	Mar. 17, 1961	.03
16	2.49	24	.02	3	.02	12	.04		

Day	Year ending September 30, 1962											
	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.
1		0.13	0.27			0.32	0.01	0.01	0.01	0.01	0.06	0.04
2		.15	.06			.30	.16		.01		.01	.04
3		.12	.02			.09	.01		.01	.01	.01	.04
4		.10	.02			.05	.01		.01	.02	.01	.04
5		.08	.01			3.90	.01		.10	.02	.04	.04
6		.07	.01			1.89			.01		.01	.04
7		.06	.01		0.11	.27	.07		.01	.01	.02	.03
8		.06			.01	.06			.01	.01	.06	.02
9		.06			1.93	.03			.01	.01	.01	.02
10		.06		0.05	.42	.02			.01		.01	.02
11		.05		.01	.06	.02	.01		.01	.21	.02	.03
12		.05			.04	.02				.01	.01	.02
13		.04			2.00	.01				.01	.01	.03
14		.77			4.71	.01	.01			.01	.02	.04
15		.03			1.41	.05	.01		.03	.01	.02	.02
16					.60	.05			.18	.01	.03	.03
17					.28	.01				.01	.01	.04
18					2.00	.01	.01				.01	.03
19		.01		.95	.27	.01	.01		.01		.02	.04
20		.75		.20	.40	.01			.01		.02	.03
21	0.06	.02		.01	.07	.01	.01		.02	.01	.03	.03
22	.08	.02		.01	.03	.60	.01	.16	.01	.02	.03	.03
23	.10	.02			.02	.01	.01	.01	.10	.02	.04	.03
24	.10	.02			.02	.01	.01	.01	.19	.01	.03	.03
25	.12	.04		.04	.02	.01	.01	.01	.02	.02	.06	.03
26	.13	.01		.01	.01	.01		.01	.02	.01	.04	.05
27	.13	.01			.01	.01	.03		.02	.03	.05	.04
28	.12	.02		.01	.28	.01			.02		.03	.03
29	.14	.59				.02		.01	.02	.01	.04	.02
30	.14	.31				.01	.01	.01	.01		.04	.02
31	.14					.01		.01		.01	.04	

Day	Year ending September 30, 1963											
	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.
1	0.02	0.01	0.02	0.03	3.70	0.01	0.01	0.01	0.02	0.01	0.01	0.01
2	.02	.01	.02	.03	1.07	.01	.01	.01	.02	.01	.01	.01
3	.02	.02	.02	.03	.62	.01	.01	.01	.02	.01	.01	.01
4	.02	.02	.02	.03	.06	.01	.01	.01	.02	.01	.17	.01
5	.02	.02	.02	.02	.12	.01	.01	.02	.03	.01	.01	.01
6	.03	.02	.02	.02	.09	.04	2.25	.02	.02	.01	.01	.01
7	.03	.02	.02	.02	.09	.01	.21	.02	.02	.01	.01	.01
8	.02	.02	.02	.02	.05	.02	.02	.24	.04	.01	.01	.01
9	.02	.05	.02	.02	5.02	.01	.06	.02	.02	.01	.01	.01
10	.10	.01	.02	.03	.58	.01	.05	.06	.02	.02	.01	.01
11	.08	.01	.02	.35	.10	.01	.01	.02	.02	.01	.01	.04
12	1.94	.02	.02		1.86	.01	.01	.01	.01	.01	.01	.10
13	10.0	.01	.05		.54	.01	.04	.01	.01	.01	.01	.01
14	.13	.01	.02		.07	.05	1.83	.01	.01	.01	.01	.01
15	.03	.01	1.44		.04	.01	.24	.02	[illegible]	.01	.01	.01
16	.04	.01	3.23		.05	2.55	.02	.02	[illegible]	.01	.01	.01
17	.12	.02	.87	.01	.02	.01	.02	.02	.02	.02	.01	.02
18	.10	.01	.13	.01	.02	.01	.60	[illegible]	.07	.01	.01	.01
19	.06	.01	.04	.03	.09	.06	.95	.02	.01	.01	.01	.01
20	.02	.01	.03		.02	.02	1.14	.02	.01	.01	.01	.01
21	.02	.02	.04		.39	.01	.05	.03	.01	.01	.01	.01
22	.02	.02	.03		.02	.67	.03	.02	.01	.01	.01	.01
23	.01	.01	.03		.01	.18	.02	.02	.01	.01	.01	.01
24	.01	.01	.03		.01	.01	.02	.02	.01	.02	.01	.01
25	.02	.01	.02	.01	.01	.01	.12	.02	.01	.01	.01	.01
26	.03	.19	1.08	.01	.01	.01	.02	.02	.01	.01	.01	.01
27	.02	.04	.04	.01	.02	4.46	.01	.04	.01	.01	.01	.03
28	.02	.02	.03	.01	.01	.89	.01	.04	.01	.01	.01	.06
29	.02	.01	.03	.08		.06	.01	.02	.01	.01	.01	.01
30	.01	.02	.03	6.25		.02	.01	.02	.01	.01	.01	.01
31	.01		.04	19.2		.03		.02		.01	.01	

Day	Year ending September 30, 1964											
	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.
1	0.01	0.01	0.01	0.15	0.01	0.25	0.07	0.05	0.01	0.01	0.01	0.01
2	.01	.01	.01	.12	.01	.03	.01	.02	.02	.01	.01	.01
3	.01	.01	.01	.12	.01	.01	.02	.10	.01	.02	.01	.02
4	.01	.05	.01	.10	.01	.01	.01	.01	.01	.01	.01	.02
5	.01	1.19	.01	.01	.01	.01	.01	.01	.01	.01	.01	.02
6	.01	.02	.01	.01	.01	.01	.01	.01	.02	.01	.01	.02
7	.01	.01	.01	.01	.01	.01	.01	.01	.01	.01	.01	.03
8	.01	.01	.05	.08	.01	.01	.02	.01	.56	.01	.01	.02
9	.01	.01	.02	.12	.01	.01	.01	.01	.05	.01	.01	.01
10	.24	.01	.01	.11	.01	.01	.02	.01	.02	.01	.01	.02
11	.11	.01	.02	.01	.01	.55	.01	.02	.01	.01	.05	.01
12	.01	.01	.17	.01	.01	.14	.02	.02	.01	.03	.01	.03
13	.01	.01	.14	.03	.01	.02	.01	.02	.01	.11	.01	.01
14	.01	.49	.16	.01	.01	.01	.01	.01	.01	.01	.01	.03
15	.08	.07	.16	.01	.10	.01	.07	.02	.01	.01	.01	.02
16	.01	.01	.08	.09	.01	.01	.01	.15	.01	.02	.01	.02
17	.01	.01	.09	.45	.01	.01	.01	.02	.02	.01	.01	.02
18	.01	.01	.15	.31	.01	.01	.01	.02	.01	.08	.01	.02
19	.01	3.81	.20	.43	.01	.01	.01	.02	.01	.01	.02	.02
20	.01	.15	.16	6.92	.01	.01	.01	.02	.01	.01	.02	.03
21	.01	.57	.16	4.34	.01	.03	.01	.02	.01	.01	.01	.04
22	.01	.06	.16	3.81	.01	.38	.01	.02	.01	.01	.01	.01
23	.01	1.99	.05	1.60	.01	.12	.01	.01	.01	.01	.01	.02
24	.01	.08	.14	.06	.01	.09	.02	.02	.01	.05	.01	.02
25	.01	.02	.15	.04	.01	.01	.04	.12	.01	.01	.01	.02
26	.01	.01	.14	.03	.01	.01	.02	.02	.01	.01	.01	.02
27	.01	.01	.14	.02	.23	.01	.02	.27	.01	.02	.01	.02
28	.01	.01	.16	.02	.02	.01	.02	.02	.01	.02	.01	.02
29	.01	.01	.15	.02	.01	.01	.02	.02	.01	.05	.01	.02
30	.01	.01	.06	.02		.01	.02	.01	.01	.01	.02	.01
31	.01		.03	.01		.19		.02		.02	.08	

Day	Year ending September 30, 1965											
	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.
1	0.01	0.26	0.16	0.05	0.03	0.03	0.02	0.02	0.02	0.02	0.01	0.02
2	.01	.27	.15	1.12	.05	.02	.02	.01	.01	.02	.01	.02
3	.01	.11	.02	1.22	.12	.02	.01	.01	.01	.02	.01	.02
4	.01	.12	.02	1.72	.79	.02	.01	.01	.02	.02	.01	.03
5	.04	.12	.01	4.81	.70	.03	.01	.02	.01	.02	.01	.07
6	.01	.13	.01	3.79	.16	.02	.02	.02	.01	.04	.02	.06
7		.14	.01	.98	.05	.01	.08	.02	.01	.02	.02	.03
8		.68	.01	.15	.04	.02	.51	.02	.01	.02	.01	.02
9		1.24	.01	.09	.03	.02	3.19	.02	.01	.02	.02	.01
10	.02	2.98	.01	.06	.03	.01	.52	.02	.01	.01	.01	.01
11	.02	.84	.02	.07	.03	.01	.05	.02	.01	.01	.01	.02
12	.02	.75	.01	.06	.03	.02	.03	.02	.01	.02	.01	.04
13		.20	.01	.04	.03	.09	.02	.02	.01	.02	.01	.01
14		.15	.01	.04	.03	.01	.02	.01	.01	.02	.01	.02
15	.02	.14	.02	.04	.03	.01	.78	.01	.01	.01	.01	.02
16		.14	.01	.04	.02	.01	.65	.01	.02	.02	.02	.01
17		.15	.01	.04	.02	.01	.03	.01	.02	.01	.01	.02
18		.15	.03	.03	.03	.01	.03	.01	.01	.01	.02	.01
19		.15	.48	.48	.03	.01	.02	.01	.01	.02	.02	.01
20		.14	.37	.08	.03	.01	.32	.01	.01	.01	.02	.01
21		.25	3.68	.23	.03	.01	.05	.01	.02	.01	.02	.01
22		.16	8.01	.12	.03	.01	.02	.01	.02	.14	.02	.01
23		.11	6.15	3.67	.03	.01	.02	.01	.02	.03	.02	.02
24		.19	1.15	2.33	.02	.01	.01	.01	.02	.01	.03	.01
25	.01	.16	.10	.15	.02	.03	.01	.01	.01	.01	.02	.01
26	.01	.17	2.08	.08	.02	.08	.02	.01	.02	.01	.03	.01
27		.15	2.30	.06	.51	.74	.02	.01	.01	.01	.02	.01
28	.15	.15	2.61	.06	.10	.12	.01	.01	.02	.02	.02	.01
29	.24	.15	1.83	.05		.08	.01	.01	.02	.02	.02	.02
30	.06	.15	2.22	.05		.10	.02	.01	.02	.01	.02	.01
31	.09		.84	.04		.58		.01		.02	.01	

Discharge, in cubic feet per second--Continued

LOS TRANCOS CREEK TRIBUTARY NEAR STANFORD UNIVERSITY, CALIF., 1959-65

Day	Year ending September 30									
	1959					1960				
	Dec.	Jan.	Feb.	Mar.	Sept.	Dec.	Jan.	Feb.	Mar.	Apr.
1				0.02				0.02	0.01	0.01
2				.02				.01	.01	.01
3				.02				.01	.01	.01
4				.02				.01	.01	.01
5		0.03		.02				.02	.01	.01
6		.02		.01				.01	.02	.01
7		.01		.01				.01	.02	
8		.01		.01			0.01	1.49	.02	
9		.03		.01			.01	1.03	.02	
10		.01	0.02	.01			.01	1.72	.02	
11		.01	.04	.01			.01	.10	.02	.01
12		.02	.04	.01				.05	.02	
13		.01	.02	.01				.03	.02	
14		.01	.02	.01			.02	.02	.02	
15		.01	.04	.01			.01	.02	.01	
16		.01	4.15	.01			.01	.01	.01	
17		.01	.70	.01			.01	.01	.01	
18		.01	.62	.01	0.01		.01	.02	.01	
19			.24	.01			.01	.01	.01	
20			1.79	.01				.01	.01	
21			1.92	.01			.01	.01	.01	
22			.30	.01			.01	.01	.01	
23			.12	.01		0.01	.01	.01	.01	
24			.07	.01			.01	.01		.01
25			.05	.01			.01	.01		.01
26	0.01	.01	.04	.01			.01	.01	.01	.01
27	.01		.03	.01			.01	.01	.01	.01
28			.02	.01			.01	.01	.01	.01
29							.01	.01	.01	
30									.01	
31									.01	

Day	Year ending September 30, 1963						
	Oct.	Dec.	Jan.	Feb.	Mar.	Apr.	May
1				2.86			0.01
2				.20			.01
3				.07			.01
4				.02			.01
5				.01			.01
6				.01		0.20	.01
7				.01		.08	.01
8						.01	.01
9				4.51		.01	.01
10				.57		.01	.01
11				.30		.01	.01
12				.76			.01
13	0.05			.91		.01	.01
14				.09		.21	
15				.03		.09	
16		0.01		.02	0.16	.01	
17				.02		.01	
18				.01		.01	
19				.01		.17	
20				.01		.35	
21				.01		.06	
22					.01	.02	
23					.01	.01	
24						.01	
25						.02	
26						.01	
27					.67	.01	
28					.28	.01	
29					.01	.01	
30			0.29		.01	.01	
31			16.9		.01		

Day	Year ending September 30					
	1961			1962		
	Nov.	Dec.	Mar.	Jan.	Feb.	Mar.
1		0.01				0.02
2						.06
3						.01
4						.01
5						4.64
6						1.64
7						.23
8						.05
9					0.08	.02
10					.01	.01
11						.01
12						.01
13					.74	.01
14			0.01		3.61	
15			.01		1.19	
16					.62	.01
17			.01		.21	.01
18					.82	.01
19				0.02	.13	
20				.01	.16	
21					.04	
22					.02	.02
23					.01	.01
24					.02	
25	0.01				.01	
26	.01				.01	
27						
28					.01	
29						
30						
31						

Day	Year ending September 30								
	1964			1965					
	Nov.	Jan.	Mar.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.
1			0.01			0.19	0.01		
2						.61	.01		
3						1.70	.01		
4						1.02	.12		
5						5.54	.36		
6						3.55	.10		
7						1.28	.02		
8						.25	.01		0.03
9						.13	.01		.34
10				0.01		.09			.12
11						.07			.01
12						.05			
13						.02			
14						.02			
15						.02			.02
16						.02			.08
17						.02			
18						.02			
19	0.01					.15			
20		0.94			0.01	.07			.01
21		1.17			.02	.05			
22		.85			.17	.10			
23		.32			1.15	1.65			
24		.04			.42	1.98			
25		.02			.04	.17			
26		.01			.28	.07			
27		.01			.31	.04	.01	0.04	
28		.01			1.58	.03			
29		.01			1.35	.02			
30					2.69	.02			
31					1.49	.01		.06	

Discharge, in cubic feet per second--Continued

SAN FRANCISQUITO CREEK TRIBUTARY NEAR STANFORD UNIVERSITY, CALIF., 1959-64

Day	Year ending September 30								
	1959				1960			1961	
	Jan.	Feb.	Mar.	Sept.	Jan.	Feb.	Mar.	Nov.	Mar.
1			0.01			0.04			
2			.01						
3			.01						
4			.01						
5	0.04		.01			.15			
6			.01			.01	0.01		
7			.01			.01	.01		
8			.01			1.26	.01		
9	.04		.01		0.01	.85	.01		
10		0.02	.01			.79			
11		.03	.01		.01	.09			
12	.01	.01	.01			.04			
13			.01			.02			
14			.01		.02	.01			0.01
15		.01				.01			
16		1.02				.01			
17		.25				.01			
18		.19		0.02		.01			
19		.11				.01			
20		.66				.01			
21		.66							
22		.14							
23		.07	.01						
24		.03	.01						
25		.02	.01		.02			0.02	
26		.01	.01					.02	
27		.01							
28		.01							
29									
30									
31									

Day	Year ending September 30, 1963								
	Oct.	Dec.	Jan.	Feb.	Mar.	Apr.	May	Aug.	Sept.
1				2.56		0.04			
2				.41		.01			
3				.24		.01			
4				.14		.01			
5				.03		.01			
6				.02	0.01	.63			
7				.01	.01	.17			
8				.01	.02	.02	0.05		
9				3.46	.01	.03	.01		
10				.59		.02	.02		
11				.18		.01	.01		
12				1.45		.01			0.01
13	2.52			.71		.01			
14	.02			.18		.53			
15	.02	0.08		.07		.17			
16	.01	.70		.11	.54	.02			
17	.01	.26		.05	.01	.02			
18	.05	.01		.01	.01	.07			
19	.14			.01	.01	.49			
20				.01	.01	.49			
21				.01	.09	.06			
22				.01	.26	.01			
23				.01	.19	.01		0.01	
24				.01	.01	.01		.03	
25				.01	.01	.06		.02	
26				.01	.01	.01		.02	.02
27				.01	1.30	.01		.03	.01
28					.30	.01		.01	
29					.02	.01			
30			1.30		.01				
31			11.9		.01				

Day	Year ending September 30, 1962			
	Nov.	Jan.	Feb.	Mar.
1				0.15
2				.60
3				.03
4				.02
5				3.94
6				1.24
7				.33
8				.10
9			0.13	.02
10			.02	.01
11			.01	.01
12			.01	.01
13			1.16	.01
14			2.43	.01
15			1.01	.01
16			.68	.01
17			.31	.01
18			1.20	.01
19		0.01	.30	.01
20	0.12	.01	.48	.01
21			.10	.01
22			.05	.10
23			.02	.01
24			.02	.01
25			.01	.01
26			.01	
27			.01	
28			.10	
29				
30				
31				

Day	Year ending September 30, 1964											
	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.
1					0.01	0.12	0.04	0.04	0.32	0.29	0.08	
2					.01	.03	.01	.04	.29	.36	.11	
3		0.06			.01	.01	.01	.09	.28	.22	.08	
4		.01			.01		.01	.04	.33	.36	.07	
5		.55			.01		.02	.03	.28	.40	.06	
6		.02			.01	.01	.01	.02	.37	.44	.06	
7					.01	.01		.02	.48	.41	.05	
8					.01			.02	.83	.26	.13	0.01
9			0.02		.01		.05	.03	.29	.37	.05	.05
10	0.14				.01		.01	.02	.25	.36	.06	.05
11	.12				.01	.23	.02	.04	.36	.34	.05	.03
12					.01	.06	.01	.03	.37	.41	.05	.03
13						.01	.07	.02	.42	.34	.05	.03
14		.19				.01	.01	.11	.45	.36	.05	.03
15	.03	.14			.07	.01		.04	.41	.29	.03	.03
16					.01	.01		.02	.37	.31	.03	.03
17	.04			0.14	.01	.01		.04	.34	.28	.05	.04
18				.19	.01	.01		.04	.34	.31	.02	.04
19		1.96	.04	.25	.01	.01		.05	.40	.30	.02	.04
20		.04		3.00	.01	.01	.06	.03	.43	.25	.02	.14
21		.07		2.62	.01	.02		.04	.48	.26	.01	.04
22				1.61	.01	.18		.04	.38	.15	.01	.04
23		.81		.23		.06	.01	.03	.39	.10	.02	.03
24		.02		.07	.01	.09	.02	.03	.29	.18	.01	.03
25				.04	.01	.04	.03	.04	.40	.19	.01	.03
26		.01		.04		.01	.04	.04	.37	.21		.03
27		.07		.06	.02	.01	.05	.18	.40	.16		.03
28				.02	.01	.01	.06	.05	.49	.12		.04
29				.02	.01	.01	.03	.03	.40	.13		.03
30				.01		.01	.02	.18	.35	.10		.04
31				.01		.09		.39		.05	.08	

Precipitation, in inches

(There was precipitation only on the days listed)

SHARON CREEK NEAR MENLO PARK, CALIF., 1959-65

Day	Year ending September 30, 1959							
	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	Sept.
1								
2								
3								
4								
5				1.43				
6				.11				
7					0.08			
8				.55				
9				1.36	.32			
10		a0.06		.02	.62			
11					.31			
12			(b)	.37				
13								
14		a.03						
15		a.04			.40			
16					.98			
17					.32			0.01
18	a0.02				.06			3.21
19	a.02							
20	a.02				.54			
21			0.28		.07			
22						0.11		
23								
24				.08		.06		
25			.09	.11			0.08	
26			.64					
27								
28								
29								
30						.02		
31								
Total	a0.06	a0.13	1.01	4.03	3.70	0.19	0.08	3.22

Day	Year ending September 30, 1961										
	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	Aug.	Sept.
1			0.59		0.07			0.01	0.01		
2			.13		.20						
3		0.01									
4						0.15					
5	0.03	.08				.12		.10			
6	.06	.47						.12			
7											
8						.12					
9								.02			
10			.07					.09		c0.01	
11		.11			.34	.02					
12		.29					0.03				
13		.48									
14			.01			.88					
15					.15	.29					
16						.30					c0.25
17						.03					
18		.05						.01			
19						.03		.28		c.05	
20											
21							.42				
22						.02	.15				
23				0.15		.01	.08				
24						.18					
25		1.38		.77		.09					
26		.17		.25		.02		.01		c.02	
27						.03					
28											
29		.02		.30							
30		.01		.04							
31				.15							
Total	0.09	3.07	0.80	1.66	0.76	2.29	0.68	0.64	0.01	c0.08	c0.25

Day	Year ending September 30, 1960					
	Dec.	Jan.	Feb.	Mar.	Apr.	May
1			1.01			
2			.06			
3			.14			0.16
4			.03			
5			.88	0.04		
6				.21		
7		0.03	.02	.10		
8		.45	.99			
9		.74	.58			
10		.14	.19			
11		.85		.05	0.03	
12	0.02	.01		.05		
13		.13		.04		
14		.63				
15						
16						
17						
18		.02	.13			
19						
20						
21		.21				
22					.03	
23	1.26				.02	.07
24	.10	.40				.01
25	.11	.59				
26					.40	
27				.52	.14	
28						
29						
30				.14		
31						
Total	1.49	4.20	4.03	1.15	0.62	0.24

Day	Year ending September 30, 1962						
	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.
1			0.83			0.19	
2			.18			.39	
3						.04	
4							
5						1.22	
6					0.14	.23	
7					.30		
8					.26		
9					1.24		
10					.29		
11			.02		.17	a.04	
12				0.20	.07		
13					1.12		
14					1.18	.07	
15			.02		.25		
16					.25		
17			.01		.11		
18			.02		.79		
19		0.67	.01	1.24	.03		0.04
20		.97		.09	.22	.08	
21			.02	.11			
22						.45	
23					.03		
24					.05		
25	(d)	.40					
26							
27	0.03						.13
28					.59		
29		.65					
30		.37					
31							
Total	0.03	3.06	1.11	1.64	7.09	2.71	0.17

See footnotes at end of table.

SHARON CREEK NEAR MENLO PARK, CALIF., 1959-65--Continued

Day	Year ending September 30, 1963										
	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	Aug.	Sept.
1					0.28						
2											
3			0.01								
4											
5							0.02				
6						0.11	.89				
7							.04			0.01	
8	0.01				.02	.03		0.30			
9					1.20		.09				
10	.23				.04		.13	.12	0.01		
11	.37							.01			
12	1.11		.07		.54						0.32
13	2.82		.06		.07		.07				
14			.94			.14	.67				
15			1.19				.06				
16			.37		.05	1.08					.04
17		0.04									
18							.39				
19							.14				
20							.26				
21											
22						.53					
23						.06					
24											
25							.19				
26		.44									
27						1.13					
28						.06					
29				0.18		.06					
30				1.54							
31			.07	2.68		.07					
Total	4.54	0.48	2.71	4.40	2.20	3.27	2.95	0.43	0.01	0.01	0.36

Day	Year ending September 30, 1964									
	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	Aug.
1						0.21	0.03	0.05		
2								.03		
3								.11		
4		0.09								
5		.76								
6										
7										
8			0.06						0.55	
9										
10	0.63									
11	.05					.46				
12										
13				0.06						
14		.54								
15	.25	.08			0.13					
16										
17				.25						
18				.09						
19		1.66	.07	.12						
20				1.57						
21				.83		.07				
22				.35		.36				
23		.79		.02		.04				
24						.10				
25										
26										
27								.25		
28					.05					
29				.02						
30										
31						.22				0.13
Total	0.93	3.92	0.13	3.31	0.18	1.46	0.03	0.44	0.55	0.13

Day	Year ending September 30, 1965						
	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.
1		0.15					
2		.21	0.03	0.43			
3				.41			
4				.06	0.40	0.02	
5				.47	.17		
6				.58			
7				.02			0.15
8		.68					.41
9		.45					.93
10		1.22					.13
11		.44	.03				
12		.33					
13						.13	
14							
15							.57
16							.10
17							
18			.06				
19			.34	.12			
20			.17				.23
21		.14	1.08	.11			
22			1.54				
23			.66	.77			
24		.07	.05	.19			
25		.03					
26			.53		.06	.16	
27			.30		.25	.39	
28	0.45		.31				
29	.44		.36				
30	.05		.51			.15	
31			.04			.36	
Total	0.94	3.72	6.01	3.16	0.88	1.21	2.52

a. Estimated on basis of Palo Alto record.
b. Recording gage installed December 12, 1958.
c. Estimated; recording gage removed and weather station dismantled July 3, 1961.
d. Recording gage reinstalled October 25, 1961.

Precipitation, in inches--Continued

LOS TRANCOS CREEK TRIBUTARY NEAR STANFORD UNIVERSITY, CALIF., 1959-65

Day	Year ending September 30										
	1959					1960					
	Jan.	Feb.	Mar.	Apr.	Sept.	Dec.	Jan.	Feb.	Mar.	Apr.	May
1								0.87			
2								.05			
3								.11			0.18
4											
5								.73	0.01		
6									.19		
7		0.15					0.04	.03	.07		
8							.46	1.00			
9		.35					.66	.66			
10		.56					.10	.21			
11		.51					.56		.05	0.08	
12						0.03			.04		
13							.07		.03		
14							.81				
15		.45									
16	(a)	1.15									
17		.29			0.02						
18		.16			2.90		.05	.08			
19											
20		.66									
21		.14					.19				
22										.02	
23						1.09				.08	.06
24	0.08		0.06			.10	.34				.03
25	.15			0.04		.11	.54				
26			.03							.51	
27									.32	.25	
28											
29											
30			.03						.13		
31											
Total	0.23	4.42	0.12	0.04	2.92	1.33	3.82	3.74	0.84	0.94	0.27

Day	Year ending September 30, 1962						
	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.
1			0.58			0.09	
2			.23			.23	
3						.03	
4							
5						1.25	
6					0.11	.20	
7					.22		
8					.21		
9					1.29		
10					.28		
11			.02		.17	.04	
12				0.17	.07		
13					.90		
14					1.17	.04	
15			.02		.21		
16					.23		
17					.15		
18			.02		.35		
19		0.59	.02	1.00	.02		0.03
20		.96		.10	.14	.08	
21			.05	.08			
22						.34	
23					.05		
24					.05		
25		.41					
26							
27	0.06						.13
28					.20		
29		.61					
30		.44					
31							
Total	0.06	3.01	0.94	1.35	5.82	2.30	0.16

Day	Year ending September 30, 1961										
	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	Aug.	Sapt.
1			0.74		0.05			0.01	0.01		
2			.11		.21						
3		0.01				0.01					
4						.11					
5	0.04	.07				.06		.10			
6		.68				.02		.17			
7											
8						.08					
9								.03			
10			.06					.02		0.01	
11		.12			.33	.03		.01			
12		.38			.02		0.03				
13		.33									
14			.02			.83					
15					.16	.34					
16						.18					0.26
17						.08					
18		.06						.01			
19						.04		.20		.05	
20											
21		.01					.44				
22						.02	.14				
23				0.14		.02	.07				
24						.17					
25		1.43		.67		.04					
26		.20		.20		.02		.04		.02	
27						.03					
28											
29		.03		.30							
30				.02							
31				.07							
Total	0.04	3.32	0.93	1.40	0.77	2.08	0.68	0.59	0.01	0.08	0.26

Day	Year anding September 30, 1963										
	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	Aug.	Sept.
1					0.18						
2											
3			0.01								
4											
5							0.02				
6						0.08	.85				
7							.05			0.01	
8	0.01				.03	.03		0.28			
9					1.22		.08				
10	.17				.02		.14	.29	0.01		
11	.29						.02	.02			
12	1.04		.07		.53						0.21
13	2.76		.07		.06		.07				
14			.74			.16	.71				
15			1.16				.07				
16			.55		.08	1.05					
17		0.05									.04
18							.27				
19							.23				
20							.25				
21											
22						.55					
23						.07					
24											
25							.15				
26		.38									
27						1.04					
28						.04					
29				0.13		.07					
30				1.63							
31			.05	2.45		.07					
Total	4.27	0.43	2.65	4.21	2.12	3.16	2.91	0.59	0.01	0.01	0.25

See footnotes at end of table.

LOS TRANCOS CREEK TRIBUTARY NEAR STANFORD UNIVERSITY, CALIF., 1959-65--Continued

Day	Year ending September 30, 1964									
	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	Aug.
1						0.22	0.03	0.03		
2								.01		
3								.12		
4										
5		0.77								
6										
7										
8			0.06						0.53	
9										
10	0.61									
11	.11					.39				
12										
13				0.06						
14		.42								
15	.22	.09			0.15					
16										
17				.18						
18				.09						
19		1.71	.07	.12						
20				1.77						
21				.84		.03				
22				.34		.31				
23		.70		.03		.02				
24						.17				
25										
26										
27								.41		
28					.04					
29				.02						
30										
31						.15				0.21
Total	0.94	3.69	0.13	3.45	0.19	1.29	0.03	0.57	0.53	0.21

Day	Year ending September 30, 1965						
	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.
1		0.20					
2		.13	0.04	0.32			
3				.23			
4			.01	.03	0.34		
5				.62	.07	0.05	
6				.42			
7							0.13
8		.81					.30
9		.18					.79
10		1.10					.06
11		.23	.04				
12		.12					
13		.02					
14							
15			.01				.41
16							.09
17							
18			.09				
19			.41	.33			
20			.19				.26
21		.14	.57	.12			
22			1.37				
23			.86	.65			
24		.11	.04	.03			
25							
26		.03	.44			.20	
27			.25		.34	.45	
28	0.37		.25				
29	.23		.42				
30	.02		.56			.28	
31			.05			.31	
Total	0.62	3.07	5.60	2.75	0.75	1.29	2.04

a. Recording gage installed January 16, 1959.

SAN FRANCISQUITO CREEK TRIBUTARY NEAR STANFORD UNIVERSITY, CALIF., 1959-65

Day	Year ending September 30									
	1959				1960					
	Feb.	Mar.	Apr.	Sept.	Dec.	Jan.	Feb.	Mar.	Apr.	May
1							0.88			
2							.07			
3							.12			0.17
4							.04			
5							.78	0.03		
6								.18		
7						0.04	.04	.09		
8						.41	1.07			
9						.76	.59			
10						.12	.17			
11						.73		.05	0.08	
12					0.04			.07		
13						.16		.03		
14						.61				
15										
16										
17				0.01						
18				2.90		.01	.08			
19										
20										
21						.17				
22		b0.10							.04	
23					1.28				.08	.09
24		b.05			.10	.35				.03
25			0.06		.09	.52				
26	(a)								.63	
27								.46	.12	
28										
29										
30		.02						.10		
31										
Total	0	0.17	0.06	2.91	1.51	3.88	3.84	1.01	0.95	0.29

Day	Year ending September 30, 1961										
	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	Aug.	Sept.
1			0.57		0.06			0.01	0.02		
2			.16		.13						
3		0.01									
4						0.10					
5	0.02	.09				.10		.12			
6	.03	.51				.01		.10			
7											
8						.12					
9								.02			
10			.07					.04		0.01	
11		.12			.30	.02		.03			
12		.49			.01		0.03				
13		.37									
14			.02			.75					
15					.14	.25					
16						.27					0.25
17						.02					
18		.07						.04			
19						.05		.29		.04	
20											
21		.01					.40				
22						.01	.20				
23				0.12		.01	.10				
24						.19					
25		1.43		.69		.07					
26		.17		.22		.01				.02	
27						.03					
28											
29		.03		.29							
30				.02							
31				.10							
Total	0.05	3.30	0.82	1.44	0.64	2.01	0.73	0.65	0.02	0.07	0.25

See footnotes at end of table.

SAN FRANCISQUITO CREEK TRIBUTARY NEAR STANFORD UNIVERSITY, CALIF., 1959-65--Continued

Day	Year ending September 30, 1962						
	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.
1			0.74			0.14	
2			.21			.32	
3						.02	
4							
5						1.20	
6					0.11	.16	
7					.24		
8					.25		
9					1.12		
10					.35		
11			.02		.17	.04	
12				0.18	.07		
13					.95		
14					1.10	.06	
15			.02		.19		
16					.26		
17					.14		
18			.02		.49		
19		0.63	.01	.98	.02		0.03
20		1.04		.09	.22	.09	
21			.03	.11			
22						.40	
23					.04		
24					.05		
25		.44					
26							
27	0.06						.12
28					.50		
29		.64					
30		.44					
31							
Total	0.06	3.19	1.05	1.36	6.27	2.43	0.15

Day	Year ending September 30, 1964									
	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	Aug.
1						0.26	0.03	0.06		
2								.07		
3								.09		
4		0.05								
5		.69								
6										
7										
8			0.07						0.64	
9										
10	0.63									
11	.08					.43				
12										
13				0.06						
14		.49								
15	.21	.06			0.15					
16										
17				.25						
18				.12						
19		1.66	.12	.14						
20				1.71						
21				.94		.07				
22				.37		.31				
23		.75		.03		.05				
24						.11				
25										
26										
27								.36		
28					.02					
29				.02						
30										
31						.21				0.20
Total	0.92	3.70	0.19	3.64	0.17	1.44	0.03	0.58	0.64	0.20

Day	Year ending September 30, 1963										
	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	Aug.	Sept.
1					0.25						
2											
3			0.01								
4											
5							0.04				
6						0.13	.90				
7							.05			0.01	
8	0.01				.04	.07		0.31			
9					1.26		.12				
10	.23				.05		.09	.18	0.01		
11	.28						.02	.02			
12	1.02		.07		.58						0.40
13	2.51		.08		.04		.07				
14			.88			.13	.76				
15			1.17				.04				
16			.44		.10	1.01	.02				
17		0.05									.04
18							.45				
19							.14				
20							.24				
21											
22						.55					
23						.06					
24											
25							.28				
26		.45									
27						1.15					
28						.06					
29				0.18		.06					
30				1.35							
31			.08	2.29		.08					
Total	4.05	0.50	2.73	3.82	2.32	3.30	3.22	0.51	0.01	0.01	0.44

Day	Year ending September 30, 1965						
	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.
1		0.09	0.01				
2		.17	.06	0.30			
3				.26			
4			.02	.07	0.39	0.03	
5				.51	.12		
6				.45	.03		
7				.01			0.16
8		.68					.49
9		.30					1.04
10		1.13					.14
11		.35	.03				
12		.27				.03	
13						.08	
14							
15			.01				.52
16							.06
17							
18			.08				
19			.28	.30			
20			.17				.26
21		.14	.78	.15			
22			1.45	.02			
23			.67	.80			
24		.10	.06	.04			
25							
26		.02	.41		.11	.28	
27			.47		.22	.34	
28	0.38		.24				
29	.29		.53				
30	.02		.52			.27	
31			.08			.28	
Total	0.69	3.25	5.87	2.91	0.87	1.31	2.67

a. Recording gage installed February 26, 1959.
b. No trace; estimated on basis of records at Sharon Creek basin and observations at Ladera.

Particle-size distribution of suspended sediment

Date	Tons per day	Percent finer than indicated size, in millimeters									
		0.002	0.004	0.008	0.016	0.031	0.062	0.125	0.250	0.500	1.000
Sharon Creek											
Dec. 1, 1961	39.0	61	65	80	85	94	99	100			
Jan. 22, 1962	.60		73		87		91	93	97	100	
Feb. 9, 1962	3,580		26		38		55	90	98	100	
Nov. 19, 1963	92.9						78	90	98	100	
Nov. 19, 1963	102						81	91	97	99	100
Nov. 19, 1963	3.74						99	100			
Los Trancos Creek tributary											
Feb. 13, 1962	13.5						94	100			
Jan. 21, 1964	.56						100				
San Francisquito Creek tributary											
Oct. 13, 1962	27.9	56	70	86	93	97	99	100			
Jan. 31, 1963	89.3	58	70	75	79	84	87	94	97	99	100
Mar. 16, 1963	72.6	67	87	92	93	99	100				
Nov. 19, 1963	227	49	62	75	84	89	93	98	100		
Jan. 20, 1964	108	40	49	57	65	73	82	96	100		

Results of chemical analyses of water

(Blanks indicate that analysis for constituent was not made. Analyses by U.S. Geological Survey except as indicated)

SHARON CREEK NEAR MENLO PARK, CALIF.

Date of collection	Water discharge (cfs)	Water temperature (°C)	Results in milligrams per liter (mg/l)																Dissolved solids			Specific conductance (micromhos at 25°C)	pH	Laboratory number
			Silica (SiO_2)	Aluminum (Al)	Iron (Fe)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Carbonate (CO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Orthophosphate (PO_4)	Boron (B)	Calculated (sum of determined constituents)	Hardness as $CaCO_3$	Noncarbonate hardness as $CaCO_3$				
1-25-60	0.5		13	0	0.02	26	5.8	21	3.6	79	0	41	24	0.2	2.1	0.3		176	88	25	297	6.6	1190
2- 9-60	1.1		18	0	.02	23	6.8	20	2.0	76	0	27	29	.2	2.0	.1		165	86	23	270	7.1	1208
3-18-61[1/]	a<.005		13		0	50	8.3	30	5.5	104	0	89	30	.2	4.5	.5	0.2	282	158	74	454	6.7	1463
11- 6-61	.03	16	7.0	0	0	18	4.4	12	.1	76	0	10	10	0	.4	.1	.1	99	63	1	173	7.5	38778
11-27-61	<.005		12	.1	0	36	43	48	2.1	274	0	67	48	.2	3.7	.2	.1	395	266	41	691	7.6	38782
2-12-62	.01	13	14	0	.01	95	23	59	2.6	299	0	93	72	.1	10	0	.2	516	330	85	862	7.9	39424
2-21-62	.06		15							190	0	125	45		1.6	0			220	65	725	7.8	
2-26-62[1/]	.02	8	14	0	0	91	22	60	2.5	307	0	96	68	.2	3.1	0	.21	508	318	66	855	7.6	1612
4-30-62	.03		19	0		76	16	73	6.0	230	0	42	122	.3	5.2	.4	.2	473	256	67	820	8.1	40326
9- 7-62	.01		32							128	0	16	18			0			95	0	272	8.2	
9-17-62	.05		.8	0	.05	36	6.7	17	3.8	116	2	14	21	.4	21	0	.2	180	118	20	323	8.3	42928
10- 3-62	.02		7							128	0	13	14			0			100	0	268	7.4	
11- 2-62	.01		8							150	0	22	17			0			115	0	319	7.8	
11-14-62	.01		6							170	0	34	21			0			145	5	391	7.7	
1- 9-63	.02		24	.1	.04	37	8.1	25	1.9	133	0	36	25	.2	2.1	0	.1	226	126	17	359	8.0	42925
1-23-63	.003		11							285	0	80	65			.1			265	30	811	7.4	
2- 8-63	.16		10							160	0	80	35			0			185	55	530	7.4	
2-18-63	.01	17	16	.1	0	123	29	96	2.6	352	0	191	120	.4	4.2	0	.4	756	425	136	1,210	8.1	42929
2-27-63	.01		7							315	0	165	130			0			360	100	1,200	7.9	
4-12-63	.01		8							355	0	210	150		1.0	0			450	160	1,390	8.1	
4-18-63	.02		11							296	0	205	125			0			390	150	1,220	7.9	
4-26-63	.01		10							258	0	145	90		.7	0			315	110	950	7.8	
4-29-63	.01		7							276	0	175	120		.1	0			360	140	1,130	8.0	
5-13-63	.01	14	11							145	0	165	90		.03	0			255	135	856	6.9	
5-17-63	.01		8							198	0	115	80			0			225	70	670	8.0	
5-24-63	.01		8.3	0	.02	68	14	76	1.7	196	0	122	82	.2	4.4	.1	.2	474	228	67	790	7.6	43577
6- 7-63	.01									195	0		52						225	65	696		
6-13-63	.007		13							290	0	185	120		.2	0			325	85	1,100	7.2	
6-20-63	.005									275	0		100						300	75	959	7.6	
6-26-63	.004	26	10							305	0	185	150		.1	0			310	60	1,320	8.1	
7- 5-63	.007	25											165								1,390		
7-12-63	.02											115	135			.5					1,180		
7-19-63	.007	22	17							270	0	170	120			.1			320	100	1,060	7.7	
7-26-63	.01	18								245	0										992	7.4	
8- 2-63	.01	22								330	0										1,380	8.0	
8-16-63	.01	17	19							255	0	130	85		0	0			260	50	880		
9- 6-63	.007	21	27							330	0	300	150		0				450	180	1,520		
9-11-63	.02	17	26							135	0	220	40		.1				350	240	825		
1-10-64	.16	12	29							230	0	80	115		.4	a0			290	100	862	7.4	
2- 7-64[1/]	.02	9	21	0	.01	208	86	232	6.8	360	0	536	398	.3	11	0	.5	1,680	874	579	2,630	7.5	45774
2-28-64	.10	11	58							170	0	240	200		.4	a0			390	250	1,440	8.2	
4- 3-64	.01	17	23							330	0	430	280		.2	a0			620	350	2,020	7.7	
5-14-64	.02	14	15	0	.02	99	27	84	5.2	270	0	119	128	.1	4.9	0	.5	616	358	137	1,070	7.6	49113
5-22-64	.01	17	12							280	0	205	135			0			390	110	1,280	7.2	
4- 2-65	.03	12	21	0		192	60	224	1.2	332	0	440	325	.1	6.3	0	.4	1,430	724	452	2,240	7.7	49109
7-11-61	(b)		2.7		.03	3.2	.6	2.9	.4	11	0	1.5	3.6	0	0			20	10	1	34	9.1	
4-26-63	(c)																				92		
5- 7-63	(c d)																				54		

1. Lithium: 3-18-61, 0.04 mg/l; 2-26-62, 0.08 mg/l. Manganese: 2-7-64, 0.18 mg/l. Other analyses show none.

a. Estimated.

b. Imported water. Determination by city of San Francisco.

c. Water in regulating pond for irrigation system in Sharon Creek basin.

d. Field determination.

LOS TRANCOS CREEK TRIBUTARY NEAR STANFORD UNIVERSITY, CALIF.

Date of collection	Water discharge (cfs)	Water temperature (°C)	Results in milligrams per liter (mg/l): Silica (SiO_2)	Aluminum (Al)	Iron (Fe)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Carbonate (CO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Orthophosphate (PO_4)	Boron (B)	Dissolved solids: Calculated (sum of determined constituents)	Hardness as $CaCO_3$	Noncarbonate hardness as $CaCO_3$	Specific conductance (micromhos at 25°C)	pH	Laboratory number
9-18-59[1]	<0.005		13	1.4	0.39	54	85	126	16	144	0	209	305	0.8	7.2	4.8	0.18	894	482	366	1,500	6.8	1120
2-11-60	.1		23	.1	.10	16	19	29	2.3	89	0	35	52	.3	2.1	.2		223	120	45	381	7.1	1212
3- 4-60	.01		30	.6	0	64	165	190	2.4	880	0	128	295	2.1	1.2	.4		1,310	840	117	2,240	7.7	1213
11-26-60[1]	<.005		7.2		.08	32	3.4	31	7.2	66	0	40	50	.2	4.8	2.6	.17	212	94	40	368	6.5	1461
3-15-61[1]			13		.29	60	6.6	58	7.4	152	0	55	87	.6	4.7	2.5	.26	370	176	52	626	6.6	1462
1-22-62		1	9.0	.2	.19	5.6	10	17	6.8	70	0	12	17	.7	2.9	1.8	.4	118	55	0	199	6.5	39428
2-12-62		12	12	.1	.01	8.8	15	19	6.4	110	0	13	20	.5	1.6	1.1	.4	152	84	0	258	7.8	39426
2-19-62	.14		16							85	0	37	25		.2	.3			90	20	254	7.2	
2-26-62[1]		11	20	.1	.04	34	72	100	5.2	276	0	110	182	.6	3.3	.3	.13	664	381	155	1,190	7.1	1609
3-19-62	.007		8		.05					635	0	220	385			.0			780	260	2,300	8.3	
3-29-62	.003		12	.4	.05	58	125	171	7.4	574	10	137	270	1.4	.9		.4	1,080	660	173	1,840	8.3	39735
10-13-62	.06		25	.1	.32	5.8	6.9	6.3	5.6	51	0	5.4	5.2	.4	5.5	1.8	.2	94	43	1	131	6.6	42934
2- 6-63	.003		13							245	0	65	80		2.0	.5			240	40	739	7.6	
2-18-63	.007	18	25	.2	.13	34	63	87	5.2	331	0	79	132	.8	1.8	.3	.2	592	342	71	1,010	7.9	42930
2-27-63	.003		10							730	0	210	280		.5	.1			780	180	2,080	8.1	
4-11-63	.007		13							660	0	150	265		.2	.4			680	140	1,900	8.3	
4-26-63	.01		13							635	0	170	325		.2	.3			720	200	2,090	8.2	
4-29-63	.004		14							830	0	210	335		.2	.4			860	180	2,360	8.2	
5-13-63	.005		21	.4	.05	70	202	230	4.5	940	47	184	338	2.0	3.5	1.0	.2	1,570	1,000	147	2,500	8.5	43579
1-31-64[1]	.004	9	27	.2	0	83	196	232	9.4	764	47	218	418	2.7	6.2	1.1	.3	1,620	1,010	305	2,650	8.7	45772
3-19-65	.001	21	14	.4	.04	30	153	226	4.4	824	63	130	298	2.1	4.5	.7	.5	1,330	705	29	2,120	8.7	49112

1. Lithium: 9-18-59, 0.06 mg/l; 11-26-60, 0.02 mg/l; 3-15-61, 0.03 mg/l; 2-26-62, 0.06mg/l. Manganese: 1-31-64, 0.21mg/l;other analyses show none.

SAN FRANCISQUITO CREEK TRIBUTARY NEAR STANFORD UNIVERSITY, CALIF.

Date of collection	Water discharge (cfs)	Water temperature (°C)	Results in milligrams per liter (mg/l): Silica (SiO_2)	Aluminum (Al)	Iron (Fe)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Carbonate (CO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Orthophosphate (PO_4)	Boron (B)	Dissolved solids: Calculated (sum of determined constituents)	Hardness as $CaCO_3$	Noncarbonate hardness as $CaCO_3$	Specific conductance (micromhos at 25°C)	pH	Laboratory number
9-18-59[1]	a0		11	1.2	0.96	55	89	50	8.9	112	0	370	95	0.3	0.5	0.4	0.08	737	503	411	1,100	6.6	1119
2-11-60	.1		21	.1	.05	23	30	22	1.5	87	0	105	30	.3	5.2	.4		282	182	110	459	7.0	1210
3- 4-60	.005		10	.5	0	110	181	92	1.5	403	0	674	165	.6	.8	.1		1,430	1,020	689	2,080	7.7	1211
11-26-60[1]	a0		8.1		0	84	98	62	7.1	94	0	493	119	.3	8.6	.7	.14	927	615	536	1,380	6.8	1460
3-15-61[1]	a0		8.7		0	50	63	38	5.9	92	0	298	64	.3	5.0	.8	.11	579	385	309	906	6.6	1464
11-29-61	.001		12	0	.97	20	27	16	7.4	95	0	83	24	.1	1.5	0	.3	239	160	82	411	6.7	38780
2-12-62	.004	17	15	.1	.01	51	65	34	3.5	130	0	232	56	.2	43	.2	.1	564	394	287	873	7.4	39422
2-19-62	.21		17							73	0	66	25		4.2	.4			135	75	357	7.2	
2-26-62[1]	a0		16	.1	.01	42	57	35	2.9	172	0	194	50	.3	4.1	.1	.08	486	340	199	786	7.5	1610
3-29-62	.004		3.1	.3	0	83	125	70	2.8	240	9	456	111	.4	.5		.1	979	720	494	1,460	8.5	39773
10-13-62	2.26		3.1	0	.06	9.0	6.4	13	1.8	53	0	15	14	.2	2.4	.2	.1	91	49	6	131	7.0	42931
2- 7-63	.01		17							165	0	185	38		1.1	0			290	155	647	7.6	
2-18-63	.02	17	17	.1	.05	42	52	31	1.5	189	0	163	44	.4	1.4	0	.2	446	319	164	712	8.2	42927
2-27-63	.005	7	13							295	0	320	90			0			640	400	1,330	7.8	
3-12-63	.003		8							245	0	330	90		0	0			580	380	1,150		
4-11-63	.02		10							220	0	185	52		0	0			390	210	875	7.9	
4-26-63	.01		15							195	0	185	48		.1	.2			345	185	795	8.0	
4-29-63	.02		16							245	0	270	70			0			510	310	1,130	8.3	
5- 7-63	.005	22	18							360	0	500	135		.1	0			870	575	1,800	8.3	
5-13-63	.004	19	20							315	0	390	95		0	.1			680	420	1,440	7.3	
5-24-63	.004		24	.3	.02	117	186	91	1.5	428	0	702	156	.6	2.3	.8	.1	1,490	1,060	709	2,040	8.0	43578
8-24-63	.025	21	35							122	0	75	31			1.8			180	80	402	7.1	
11-29-63	.001	14	16							220	0	190	38			.3			335	155	749	8.2	
1-24-64	.05	12	22							120	0	115	36			.5			230	130	508	7.1	
1-31-64[1]	.005	6	21	.1	.01	69	99	58	3.2	220	20	338	85	.5	4.8	.2	.1	807	578	365	1,220	8.7	45771
2-28-64	.003	12	12							230	0	400	78		0	.8			540	350	1,050		
4-10-64		15	27							185	0	170	105		.4	4			350	200	929		
5-22-64	.04	17	6							115	0	45	15		0	0			100	5	290		
5-27-64	.20	15	15							80	0	54				0			85	20	220	7.6	
6- 2-64	.22	26	12							73	0	72	12			.1			120	60	312	7.0	
6- 6-64	.27	18	16							85	0	54				0			95	25	245	7.9	
6-10-64	.27	17	15							80	0	72	11		0	0			100	35	283	7.7	
7-15-64	.25	28	10	0		24	8.3	12	1.3	68	0	55	7.6	0	.1	.1	.1	152	94	38	251	7.5	49108
3-19-65	.07	21	13	.1	.01	32	17	26	3.8	89	0	104	24	0	3.6	1.3	.3	269	149	76	428	8.1	49110

1. Lithium: 9-18-59, 0.04 mg/l;11-26-60, 0.05 mg/l;3-15-61, 0.01 mg/l; 2-26-62, 0.05 mg/l; Manganese: 1-31-64, 0.10 mg/l; none present in other analyses.

a. Sample representative of basin outflow shortly before collection time and after moderate to heavy precipitation.

SHARON CREEK NEAR MENLO PARK, CALIF.

Date of collection	Water discharge (cfs)	Water temperature (°C)	Specific conductance (micromhos at 25°C)	pH
1960				
Jan. 15	0.005		540	
Jan. 25	.5		297	6.6
Feb. 2	.02		591	7.2
Feb. 9	1.1		270	7.1
Feb. 16	<.005		1,150	8.0
1961				
Mar. 18	<.005		454	6.7
Nov. 6	.03	16	173	7.5
Nov. 27	<.005		691	7.6
Dec. 4	<.005	7	1,050	7.6
1962				
Jan. 22	<.005	7	222	7.8
Feb. 12	.01	13	862	7.9
Feb. 21	.06		725	7.8
Feb. 26	.02	8	855	7.6
Mar. 13	.02		739	
Apr. 30	.03		820	8.1
Sept. 7	.01		272	8.2
Sept. 17	.05		323	8.3
Oct. 3	.02		268	7.4
Nov. 2	.01		319	7.8
Nov. 14	.01		391	7.7
1963				
Jan. 9	.02		359	8.0
Jan. 23	.003		811	7.4
Feb. 8	.16		530	7.4
Feb. 18	.01	17	1,210	8.1
Feb. 27	.01		1,200	7.9
Apr. 12	.01		1,390	8.1
Apr. 18	.02		1,220	7.9
Apr. 26	.01		950	7.8
Apr. 29	.01		1,130	8.0
May 13	.01	14	856	6.9
May 17	.01		670	8.0
May 24	.01		790	7.6
June 7	.01		696	
June 13	.007		1,100	7.2
June 20	.005		959	7.6
June 26	.004	26	1,320	8.1
July 5	.007	25	1,390	
July 12	.02		1,180	
1963--Con.				
July 19	0.007	22	1,060	7.7
July 26	.01	18	992	7.4
Aug. 2	.01	22	1,380	8.0
Aug. 9	.007	23	986	8.1
Aug. 16	.01	17	880	
Aug. 24	.007	23	1,340	
Aug. 30	.01	20	1,320	
Sept. 6	.007	21	1,520	
Sept. 13	.01	21	750	
Sept. 27	.007	23	2,010	
Oct. 4	.03	14	1,540	
Oct. 11	.02	17	825	
Nov. 5	[1] .7		547	
Nov. 15	[1] .03		775	
Nov. 21	2.28		182	7.1
Nov. 30	.007	7	3,300	
1964				
Jan. 10	.16	12	862	7.4
Feb. 7	.02	9	2,630	7.5
Feb. 28	.10	11	1,440	8.2
Apr. 3	.01	17	2,020	7.7
May 14	.02	14	1,070	7.6
May 22	.01	17	1,280	7.2
May 27	.04	17	640	
May 29	.009	24	1,310	
July 8	.01	27	1,560	
July 15	.02	26	1,950	
July 27	.01	18	1,990	
July 31	.02	24	1,220	
Aug. 7	.01	23	1,830	
Aug. 21	.008	24	1,740	
Aug. 24	.008	21	1,020	
Aug. 31	.16	19	426	
Sept. 4	.01		1,270	
Oct. 28	[1] 1.0		296	
Nov. 9	[1] <1.0	17	458	
Nov. 10	[1] <1.0		738	
Nov. 12	[1] <1.0		976	
1965				
Apr. 2	.03	13	2,240	7.7

[1] Estimated.

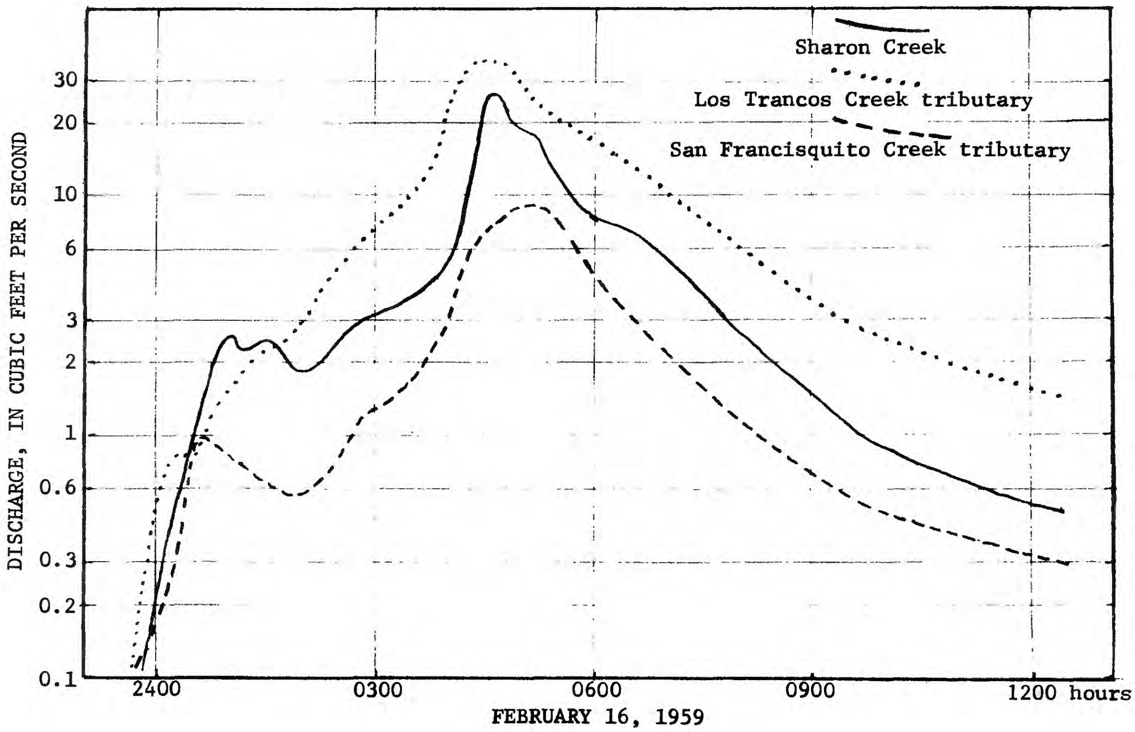
LOS TRANCOS CREEK TRIBUTARY NEAR STANFORD UNIVERSITY, CALIF.

Date of collection	Water discharge (cfs)	Specific conductance (micromhos at 25°C)	pH
1959			
Sept. 18	<0.005	1,500	6.8
1960			
Jan. 9	.02	1,130	6.7
Jan. 15	.005	1,980	
Jan. 26	.005	1,270	
Feb. 9	.6	262	6.9
Feb. 11	.1	381	7.1
Feb. 16	.02	1,980	7.9
Feb. 23	.01	2,610	7.9
Feb. 29	.01	2,410	8.0
Mar. 4	.01	2,240	7.7
Mar. 24	.01	2,010	8.2
Apr. 5	.005	2,040	8.1
Apr. 26	.005	1,790	8.7
May 4	.005	2,280	8.6
Nov. 26	<.005	368	6.5
Dec. 1	<.005	548	7.0
1961			
Mar. 15	<.005	626	6.6
Nov. 20	<.005	281	6.2
Nov. 29	<.005	334	6.2
1962			
Jan. 22	<.005	199	6.5
1962--Con.			
Feb. 9	0.01	221	6.8
Feb. 12	0	258	7.8
Feb. 19	.14	254	7.2
Feb. 26	<.005	1,190	7.1
Mar. 14	.003	1,930	8.1
Mar. 19	.007	2,300	8.3
Mar. 29	.003	1,840	8.3
Oct. 13	.06	131	6.6
1963			
Feb. 6	.003	739	7.6
Feb. 18	.007	1,010	7.9
Feb. 27	.003	2,080	8.1
Apr. 11	.007	1,900	8.3
Apr. 26	.01	2,090	8.2
Apr. 29	.004	2,360	8.2
May 7	.005	2,620	
May 13	.005	2,500	8.5
1964			
Jan. 31	.004	2,650	8.7
Feb. 19	<.005	1,560	
1965			
Mar. 19	.001	2,120	8.7

SAN FRANCISQUITO CREEK TRIBUTARY NEAR STANFORD UNIVERSITY, CALIF.

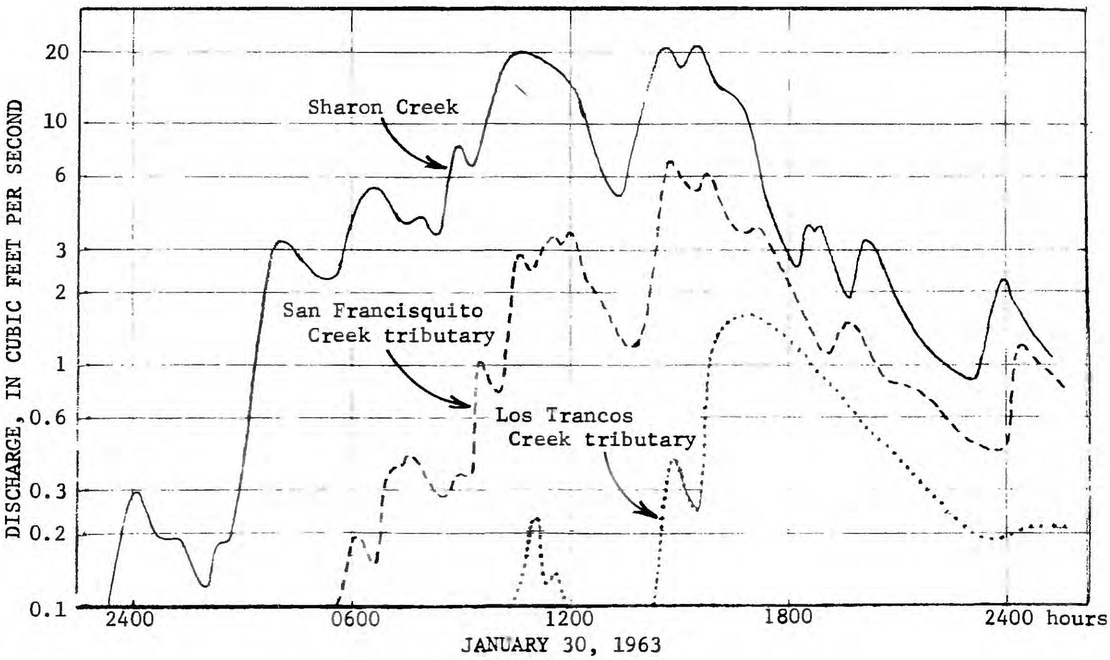
Date of collection	Water discharge (cfs)	Specific conductance (micromhos at 25°C)	pH
1959			
Sept. 18	0	1,100	6.6
1960			
Jan. 9		694	
Jan. 15	.001	1,510	
Jan. 26	.002	1,540	
Feb. 2	.005	1,730	7.6
Feb. 9	.2	330	7.1
Feb. 11	.1	459	7.0
Feb. 16	.007	1,060	8.0
Feb. 23	.004	1,680	8.0
Feb. 29	.004	1,860	8.2
Mar. 4	.005	2,080	7.7
Mar. 24	.004	2,650	8.2
Apr. 5	.001	2,970	7.9
Nov. 13	0	419	7.0
Nov. 26	0	1,380	6.8
Dec. 1	.007	630	6.9
1961			
Mar. 15		906	6.6
Nov. 20		390	5.5
Nov. 29	.001	411	6.7
1962			
Feb. 12	.004	873	7.4
Feb. 19	.21	357	7.2
Feb. 26		786	7.5
Mar. 29	.004	1,460	8.5
Oct. 13	2.26	131	7.0
1963			
Feb. 7	.01	647	7.6
Feb. 18	.02	712	8.2
Feb. 27	.005	1,330	7.8
Mar. 12	.003	1,150	
Apr. 11	.02	875	7.9
1963--Con.			
Apr. 26	0.01	795	8.0
Apr. 29	.02	1,130	8.3
May 7	.005	1,800	8.3
May 13	.004	1,440	7.3
May 24	.004	2,040	8.0
Aug. 24	.025	402	7.1
Nov. 5	.003	200	
Nov. 15		367	
Nov. 21	.003	750	7.7
Nov. 29	.001	749	8.2
1964			
Jan. 24	.05	508	7.1
Jan. 31	.005	1,220	8.7
Feb. 28	.003	1,050	
Apr. 10	.003	929	
May 22	.04	290	
May 27	.20	220	7.6
June 2	.22	312	7.0
June 6	.27	245	7.9
June 10	.27	283	7.7
July 1	.25	305	
July 8	.40	291	
July 15	.25	251	7.5
July 31	.04	297	
Aug. 7	.04	483	
Aug. 21	.03	537	
Aug. 31	.49	432	
Sept. 4	.01	2,110	
Oct. 13	.03	382	
Oct. 23	.03	388	
1965			
Mar. 19	.07	428	8.1

Selected hydrographs of study streams



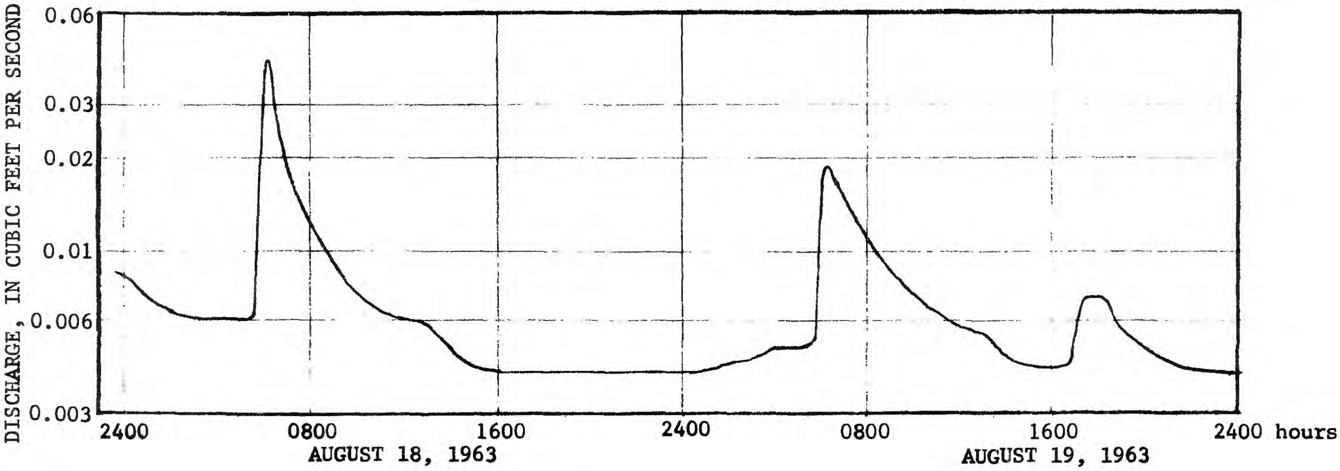
No development present. Highest hourly precipitation, about 0.3 inch, 0400-0500 hours.

Selected hydrographs of study streams--Continued



Development present in basins of Sharon Creek and San Francisquito Creek tributary. Highest hourly precipitation, about 0.2 inch, 1000-1100 hours and again 1500-1600 hours.

Selected hydrographs of study streams--Continued



Dry-season flow in Sharon Creek after development. The sharp rises coincide with times of sprinkler operation, and variations in magnitude and abruptness of the rises are related to rate of application of water and the location of the sprinkler being used.