PEAK FLOW, VOLUME, AND FREQUENCY OF THE JANUARY 1982 FLOOD, SANTA CRUZ MOUNTAINS AND VICINITY, CALIFORNIA

U.S. GEOLOGICAL SURVEY
Open-File Report 84-583

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By J. C. Blodgett and K. R. Poeschel

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CONTENTS

ILLUSTRATIONS

TABLES

CONVERSION FACTORS

For readers who prefer the International System of Units (SI) to inch-pound units, the conversion factors for the terms used in this report are listed below.

Multiply	By	To obtain
acre-feet (acre-ft)	1233	cubic meters
inches (in)	2.540	centimeters
feet (ft)	0.3048	meters
miles (mi)	1.609	kilometers
square miles (mi^2)	2.590	square kilometers
cubic feet per second (ft^3/s)	0.02832	cubic meters per second
cubic feet per second per square mile ((ft^3/s)/mi^2)	0.01093	cubic meters per second per square kilometer

WATER YEAR

A water year is a 12-month period that begins October 1 and ends September 30 and is designated by the calendar year in which it ends. References to years in this report are by water year unless otherwise noted.

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ABSTRACT

In many parts of the Santa Cruz Mountains, flooding and landslides caused by the storm of January 3-5, 1982, were the most severe since December 1955. To establish the severity of the January 1982 flood, this report compares the January 1982 flood with historical floods, including the December 1955 flood.

The areal distribution of precipitation during the January 1982 storm in the Santa Cruz Mountains and vicinity was influenced by the orographic effect of the mountains. On the west side near Boulder Creek, the 1-day precipitation depth reached 12.2 inches, which has a recurrence interval of 67 years. In the rain shadow of the mountains, by contrast, the 1-day precipitation depth at San Jose was 1.33 inches, which has a recurrence interval of less than 2 years. The rain shadow of the Santa Cruz Mountains also influenced flooding during the January 1982 storm. For example, the flow, calculated as unit peak discharge, ranged from 626 cubic feet per second per square mile for a tributary on the San Lorenzo River near Boulder Creek on the west side to 82.9 cubic feet per second per square mile for Pescadero Creek near Chittenden on the east side. The median recurrence interval for the peaks on the west side of the mountains is 26 years, whereas on the east side it is 7 years.

During the January 1982 flood, peak flows of many streams were similar to those observed during the December 1955 flood. Although precipitation and flood magnitude for both the December 1955 and January 1982 floods are similar, damages caused by landslides, inundation, and channel changes during the January 1982 storm and flood are considered more severe.

A study of historical floods and precipitation characteristics in the San Lorenzo River basin suggests that major floods in the area are the product of (1) greater-than-normal antecedent precipitation for up to 60 days prior to the flood and (2) subsequent intense frontal-type storms immediately prior to the peak.

INTRODUCTION

During the period January 3-5, 1982, an intense storm system passed through the coastal area of central California and produced record amounts of precipitation, which resulted in flooding in the Santa Cruz Mountains and vicinity. The storm was the product of the merger of a cold front from Alaska with another storm originating in the warmer midlatitudes. Rainfall rates of more than 1 inch per hour for more than 8 hours were recorded in the Santa Cruz Mountains south of San Francisco. The 1-day rainfall of 11.47 inches at the Ben Lomond precipitation station on January 5, 1982, was the highest daily rainfall total since the beginning of record in 1938. Heavy runoff, together with landslides and debris flows in steep terrain, brought large amounts of sediment and debris into the waterways, which resulted in reduction in channel capacity, logjams, blockage of bridges, channel scour and fill, changes in channel alinement, and overflow of the banks. High water levels caused inundation of the floodplain and damaged residences, commercial establishments, roadways, and bridges.

On the west side of the Santa Cruz Mountains, only the peak flows of the December 19-26, 1955, flood exceeded those of January 1982. Flooding on the east side of the mountains during January 1982 was less severe; peak flows there were comparable to floods of January 1952 and April 1958. Normally, a frequency analysis of historical peak flows of streams in the flood area provides a good indication of the severity of the event. During the January 1982 flood, however, peak flows of many streams were similar to those observed during the December 1955 flood, but damage resulting from landslides, mudflows, and channel changes was considered much more severe. The increased severity of damage from the 1982 storm compared to that of previous events may be due to antecedent (prestorm) conditions and to the storm duration and intensity. In addition, increased cultural development of the area, including construction of buildings, roads, fills, and benching in hillside areas, may have contributed to increased damages from the January 1982 storm.

In this report, data for 5 precipitation stations and 37 streamflow sites located in the Santa Cruz Mountains, along the coast north to San Francisco, and inland east to San Francisco Bay and the Santa Clara Valley (fig. 1) are used to compare the January 1982 and December 1955 floods. The chosen area includes basins with major flooding and adjacent basins both east and west of the Santa Cruz Mountains divide and south of the major areas of flooding. Areas north and east of San Francisco Bay were also subject to extensive flooding by this storm, but these areas are not discussed in this report. Gaging stations are located in mountainous terrain, except those on terraces directly adjacent to the coast. Most stations east of the divide are located near the base of the Santa Cruz Mountains and in the Santa Clara Valley.

Data for the January 1982 flood were compared with historical precipitation and streamflow records to assess the magnitude of this storm. Specific objectives were as follows:

1. Evaluate the effects of prestorm conditions, such as antecedent precipitation, on runoff.
2. Document peak flow and runoff volume for selected durations.
3. Estimate the frequency of occurrence of peak flows and runoff volume.
4. Indicate the areal variation of flooding.
5. Compare magnitudes of the January 1982 and December 1955 floods.

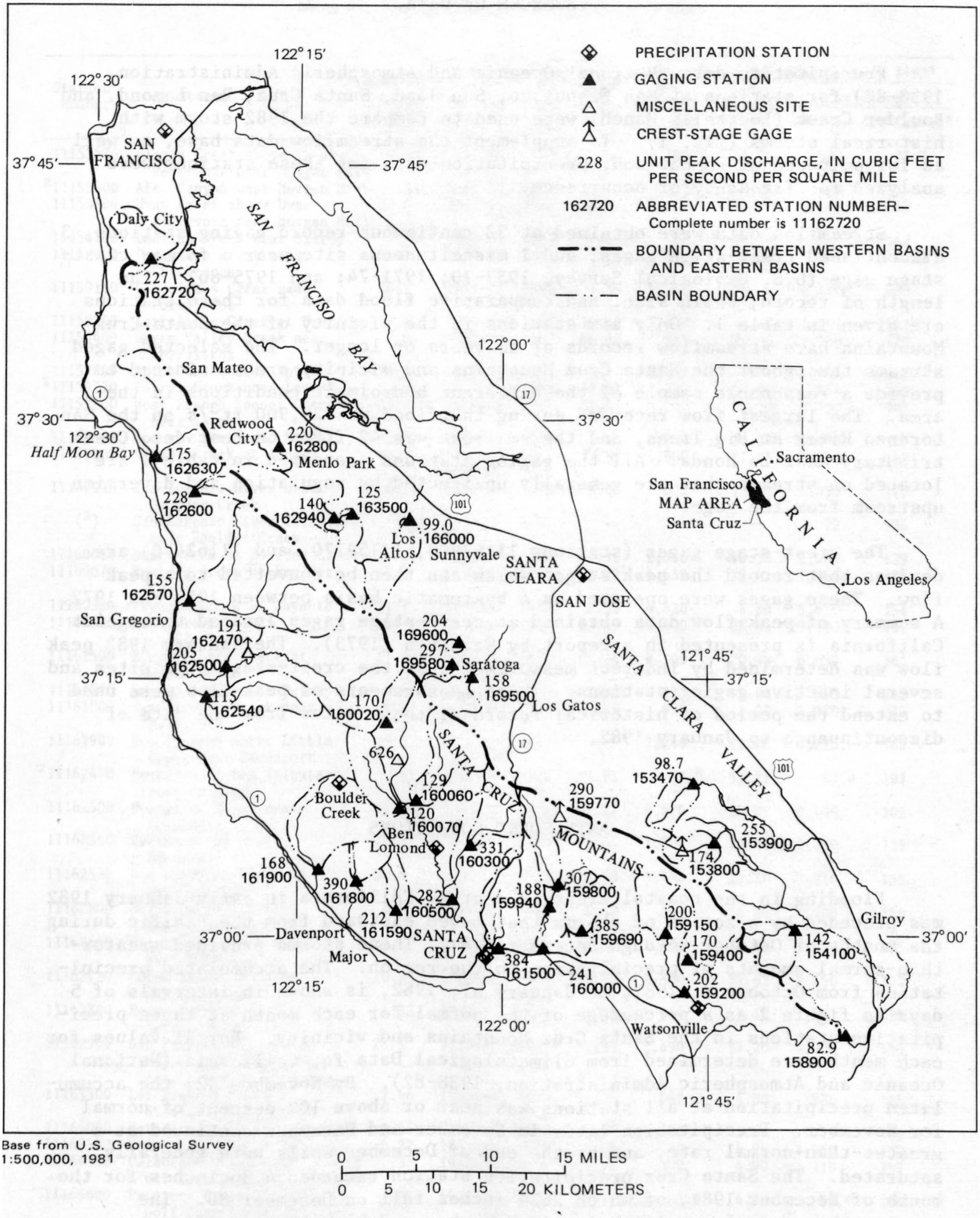

FIGURE 1. — Location of data-collection sites and areal distribution of unit peak discharge for the flood of January 1982.

Precipitation data (National Oceanic and Atmospheric Administration, 1938-82) for stations at San Francisco, San Jose, Santa Cruz, Ben Lomond, and Boulder Creek (Locatelli Ranch) were used to compare the 1982 storm with historical storms (fig. 1). To supplement the streamflow-data base, as well as for purposes of comparison, precipitation data for these stations were analyzed for frequency of occurrence.

Streamflow data were obtained at 33 continuous-record gaging stations, 3 discontinued crest-stage gages, and 1 miscellaneous site near a former crest-stage gage (U.S. Geological Survey, 1937-70; 1971-74; and 1975-80). The length of record, basin size, and comparative flood data for these stations are given in table 1. Only six stations in the vicinity of the Santa Cruz Mountains have streamflow records of 25 years or longer. The selected gaged streams throughout the Santa Cruz Mountains and vicinity are considered to provide a reasonable sample of the different hydrologic conditions in the area. The largest flow recorded during the flood was 29,900 ft^3/s on the San Lorenzo River at Big Trees, and the smallest was 42 ft^3/s on Pescadero Creek tributary near La Honda. All the gaging stations presented in table 1 are located on streams that are generally unaffected by regulation and diversion upstream from the gage.

The crest-stage gages (stations 11153800, 11159770, and 11162470) are devices that record the peak stage, which can then be converted to a peak flow. These gages were operated on a systematic basis between 1958 and 1972. A summary of peak-flow data obtained at crest-stage gages located throughout California is presented in a report by Waananen (1973). The January 1982 peak flow was determined by indirect measurements at the crest-stage gage sites and several inactive gaging stations. These measurements of peak-flow were used to extend the period of historical record at these sites from the date of discontinuance to January 1982.

ANTECEDENT CONDITIONS

Flooding in the coastal areas in central California in early January 1982 was preceded by a series of storms that moved eastward from the Pacific during the months of October through December 1981. These storms provided greater-than-normal amounts of precipitation to the region. The accumulated precipitation from October 1, 1981, to January 31, 1982, is shown in intervals of 5 days in figure 2 as a percentage of the normal for each month at three precipitation stations in the Santa Cruz Mountains and vicinity. Normal values for each month were determined from Climatological Data for California (National Oceanic and Atmospheric Administration, 1938-82). By November 12, the accumulated precipitation at all stations was near or above 100 percent of normal for November. Precipitation later in November and December continued at a greater-than-normal rate, and by the end of December soils were generally saturated. The Santa Cruz precipitation station recorded 4.36 inches for the month of December 1981, of which 2.29 inches fell on December 30. The greater-than-normal precipitation in November and December significantly increased the potential for flooding during the subsequent winter months.

TABLE 1.--Summary of flood stages and discharges

Station number	Stream	Drainage area (mi^2)	Maximum previously known				Maximum, January 1982[1]		
			Period	Year	Gage height (ft)	Discharge (ft^3/s)	Gage height (ft)	Discharge ft^3/s	Discharge $(ft^3/s)/mi^2$
11153470	Llagas Creek above Chesbro Reservoir near Morgan Hill	9.63	1971-81	1978	7.50	969	6.86	950	98.7
[2]11153800	Alec Canyon near Morgan Hill	.91	1961-73	1963	--	367	58.95	158	174
11153900	Uvas Creek above Uvas Reservoir near Morgan Hill	21.0	1961-81	1962	13.18	6,580	11.99	5,360	255
11154100	Bodfish Creek near Gilroy	7.40	1959-81	1963	8.25	1,240	8.78	1,050	142
11158900	Pescadero Creek near Chittenden	10.2	1970-81	1981	6.06	425	8.15	846	82.9
11159150	Corralitos Creek near Corralitos	10.6	1957-72	1958	7.55	1,970	10.37	2,120	200
11159200	Corralitos Creek at Freedom	27.8	1955-81	1955	15.60	3,620	16.66	5,610	202
11159400	Green Valley Creek near Corralitos	7.05	1961-73	1963	56.62	925	57.65	1,200	170
11159690	Aptos Creek near Aptos	10.2	1959-81	1963	--	1,920	--	3,930	385
[2]11159770	Laurel Creek near Laurel	.93	1961-73	1963	32.31	290	31.92	270	290
11159800	West Branch Soquel Creek near Soquel	12.2	1959-72	1967	11.47	4,530	12.50	3,750	307
11159940	Soquel Creek near Soquel	32.0	1968-72	1969	9.03	2,700	16.37	6,000	188
11160000	Soquel Creek at Soquel	40.2	1937, 1951-81	1955	22.33	15,800	21.85	9,700	241
11160020	San Lorenzo River near Boulder Creek	6.17	1968-81	1973	9.10	672	11.48	1,050	170
([3])	San Lorenzo River Tributary near Boulder Creek	.115	--	--	--	--	--	72	626
11160060	Bear Creek at Boulder Creek	16.0	1977-81	1980	10.36	2,080	10.50	2,060	129
11160070	Boulder Creek at Boulder Creek	11.3	1976-81	1978	8.03	1,630	22.45	1,360	120
11160300	Zayante Creek at Zayante	11.1	1957-81	1978	8.52	4,620	8.86	3,670	331
11160500	San Lorenzo River at Big Trees	106	1936-81	1955	22.55	30,400	28.85	29,900	282
11161500	Branchiforte Creek at Santa Cruz	17.3	1940-43, 1952-68	1955	22.04	8,100	20.95	6,650	384
11161590	Laguna Creek near Davenport	3.07	1969-76	1974	3.68	283	5.04	650	212
11161800	San Vicente Creek near Davenport	6.07	1969-81	1974	5.83	937	8.90	2,370	390
11161900	Scott Creek above Little Creek near Davenport	25.1	1937-41, 1958-73	1940	--	7,240	10.08	4,220	168
[2]11162470	Pescadero Creek Tributary near La Honda	.22	1961-73	1973	51.75	51.0	51.21	42.0	191
11162500	Pescadero Creek near Pescadero	45.9	1951-82	1955	21.27	9,420	20.93	9,400	205
11162540	Butano Creek near Pescadero	18.3	1961-74	1962	10.04	1,600	22.46	2,100	115
11162570	San Gregorio Creek at San Gregorio	50.9	1969-81	1973	17.50	3,730	21.28	7,910	155
11162600	Purisima Creek near Half Moon Bay	4.83	1958-69	1967	5.42	343	6.80	1,100	288
11162630	Pilarcitos Creek at Half Moon Bay	27.2	1966-81	1968	11.20	1,290	13.08	4,750	175
11162720	Colma Creek at South San Francisco	10.8	1963-81	1973	11.80	2,880	11.63	2,450	227
11162800	Redwood Creek at Redwood City	1.82	1959-81	1963	9.36	644	7.10	401	220
11162940	San Francisquito Creek below Ladera Damsite, near Stanford University	28.5	1961-70	1967	14.81	2,890	17.20	4,000	140
11163500	Los Trancos Creek at Stanford University	7.46	1931-41	1940	4.07	647	4.30	930	125
11166000	Matadero Creek at Palo Alto	7.26	1952-81	1973	5.57	1,380	3.66	719	99.0
11169500	Saratoga Creek at Saratoga	9.22	1933-81	1955	6.40	2,730	6.75	1,460	158
11169580	Calabazos Creek Tributary at Mt. Eden Road near Saratoga	.37	1972-78	1978	5.50	120	4.90	110	297
11169600	Prospect Creek at Saratoga Golf Course near Saratoga	.27	1972-78	1978	5.12	63.0	4.98	55.0	204

[1]This maximum occurred on January 4 for all stations except 11160500, for which the maximum occurred on January 5.
[2]Crest-stage gage.
[3]Miscellaneous site.

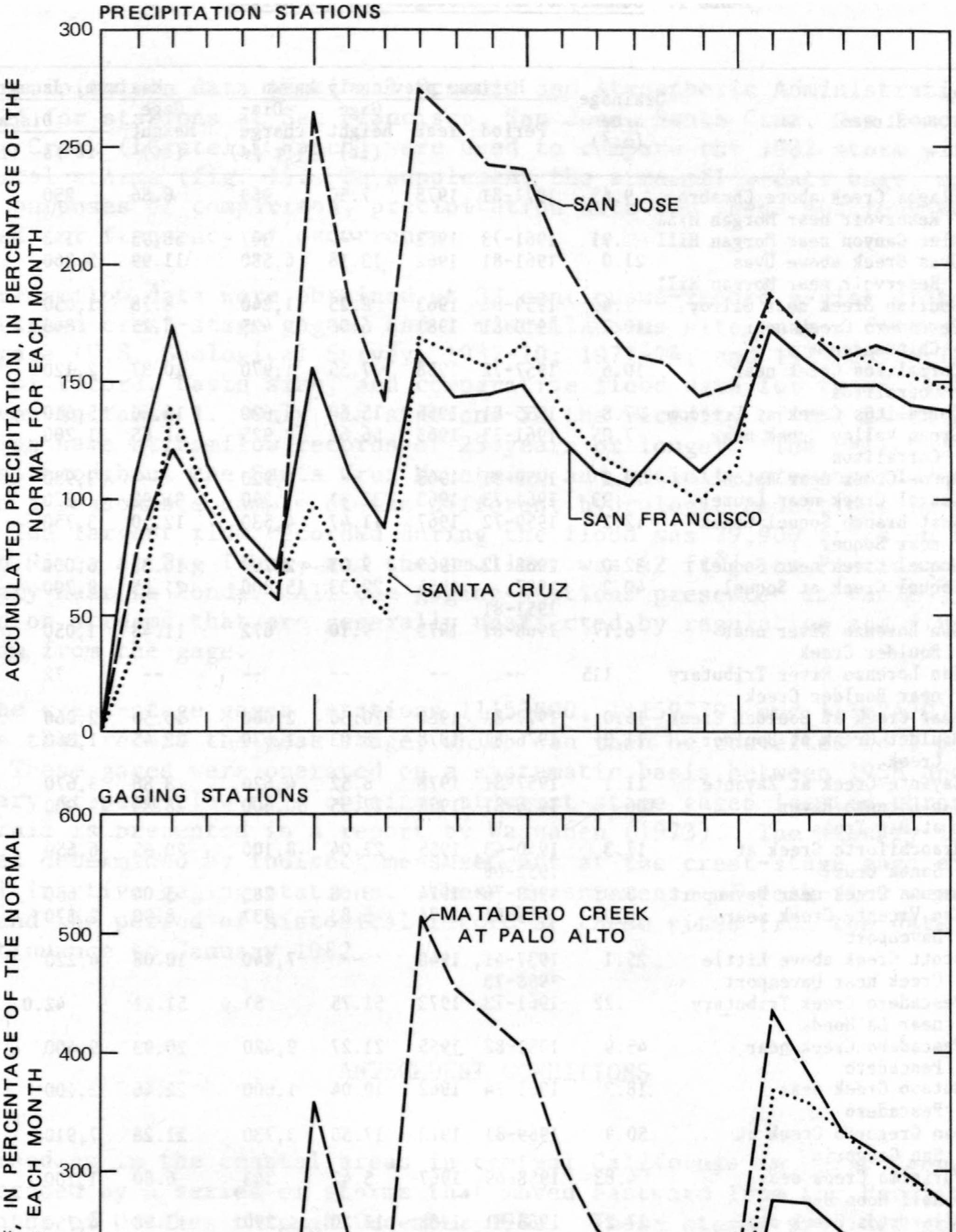

FIGURE 2. — Accumulated precipitation and runoff from October 1, 1981, to January 31, 1982, for stations in the Santa Cruz Mountains and vicinity.

Streamflow in the study area responded to the greater-than-normal rainfall during the 3 months preceding the January storm with a rapid increase in accumulated flow (fig. 2) following the storms of October 25 to November 12. Runoff was near or above normal for the three stations shown in figure 2 during part of November and all of December. During the first 4 days of January, runoff increased rapidly to peak flows, from about 120 percent to 400 percent of normal for January.

DESCRIPTION OF STORM

Regional Characteristics of Precipitation

About 85 percent of the annual precipitation in the Santa Cruz Mountains and vicinity occurs from November through March (Rantz, 1971). Mean annual precipitation in the area ranges from about 14 inches at San Jose to more than 58 inches at the town of Boulder Creek. This range from east to west results from the orographic influence of the Santa Cruz Mountains, which rise abruptly from the coastline to more than 4,000 feet, causing high annual depths of precipitation in some areas of the mountains and creating a rain shadow on the leeward side. The location of the divide between the west and east sides of the Santa Cruz Mountains is shown in figure 1. The orographic effect of the Santa Cruz Mountains is reflected in the precipitation during the 1955 and 1982 storms. The 1-day precipitation at Boulder Creek during the 1955 and 1982 storms was more than six times the amount recorded in the valley at San Jose (table 2).

Precipitation Depth-Duration-Frequency

To compare the intensity, duration, and frequency of the storms of December 1955 and January 1982, precipitation-depth data at the five stations in table 2 were assembled for 1-, 3-, and 8-day intervals. The 1-day depth was selected as an indicator of maximum rainfall associated with peak flows. The 3- and 8-day precipitation depths were selected to identify the largest segment of precipitation during a storm that can be related to runoff for a typical flood. Many major storms in the vicinity of the Santa Cruz Mountains last for 8 or 9 days, as did the December 1955 and January 1982 storms (fig. 3). The data from table 2 suggest that the maximum 1-day precipitation of the December 1955 storm averaged 1 inch less than that of the January 1982 storm, but the average amount of precipitation measured in 3- and 8-day periods was about 1.5 inches greater for the December 1955 storm than for the January 1982 storm.

TABLE 2.--Precipitation depth, duration, and frequency, for selected precipitation stations,
December 19 to 26, 1955, and December 29, 1981 to January 5, 1982

Station	Length of record (years)	Mean annual precipitation (inches)	Year	1-day precipitation: Inches	1-day precipitation: Recurrence interval (years)	3-day precipitation: Inches	3-day precipitation: Recurrence interval (years)	3-day precipitation: Ratio to 1-day	8-day precipitation: Inches	8-day precipitation: Recurrence interval (years)	8-day precipitation: Ratio to 1-day
Boulder Creek at Locatelli Ranch near Boulder Creek	36	52.28	1955	12.12	63	19.53	46	1.61	26.61	53	2.19
			1982	12.2	67	13.1	5.3	1.07	20.9	11	1.71
Ben Lomond	43	[1]52.3	1955	10.42	43	16.97	35	1.63	23.82	55	2.29
			1982	11.47	95	16.12	25	1.41	22.20	32	1.94
Santa Cruz	105	31.37	1955	4.39	5	8.91	16	2.03	11.05	10	2.52
			1982	6.91	70	9.44	23	1.37	13.00	26	1.88
San Francisco	133	20.66	1955	2.26	2	4.21	3.7	1.86	5.82	3.9	2.58
			1982	4.22	27	4.73	5.5	1.12	6.68	6.7	1.58
San Jose	109	13.65	1955	1.90	3.3	3.34	7.8	1.76	5.80	32	3.05
			1982	1.33	<2	1.97	<2	1.48	3.38	2.5	2.54
Average ----------------------------			1955	6.22		10.59		1.78	14.62		2.53
			1982	7.23		9.07		1.29	13.23		1.93
Standard deviation -----------------			1955	4.75		7.36		.17	9.95		.33
			1982	4.64		5.82		.18	8.36		.37

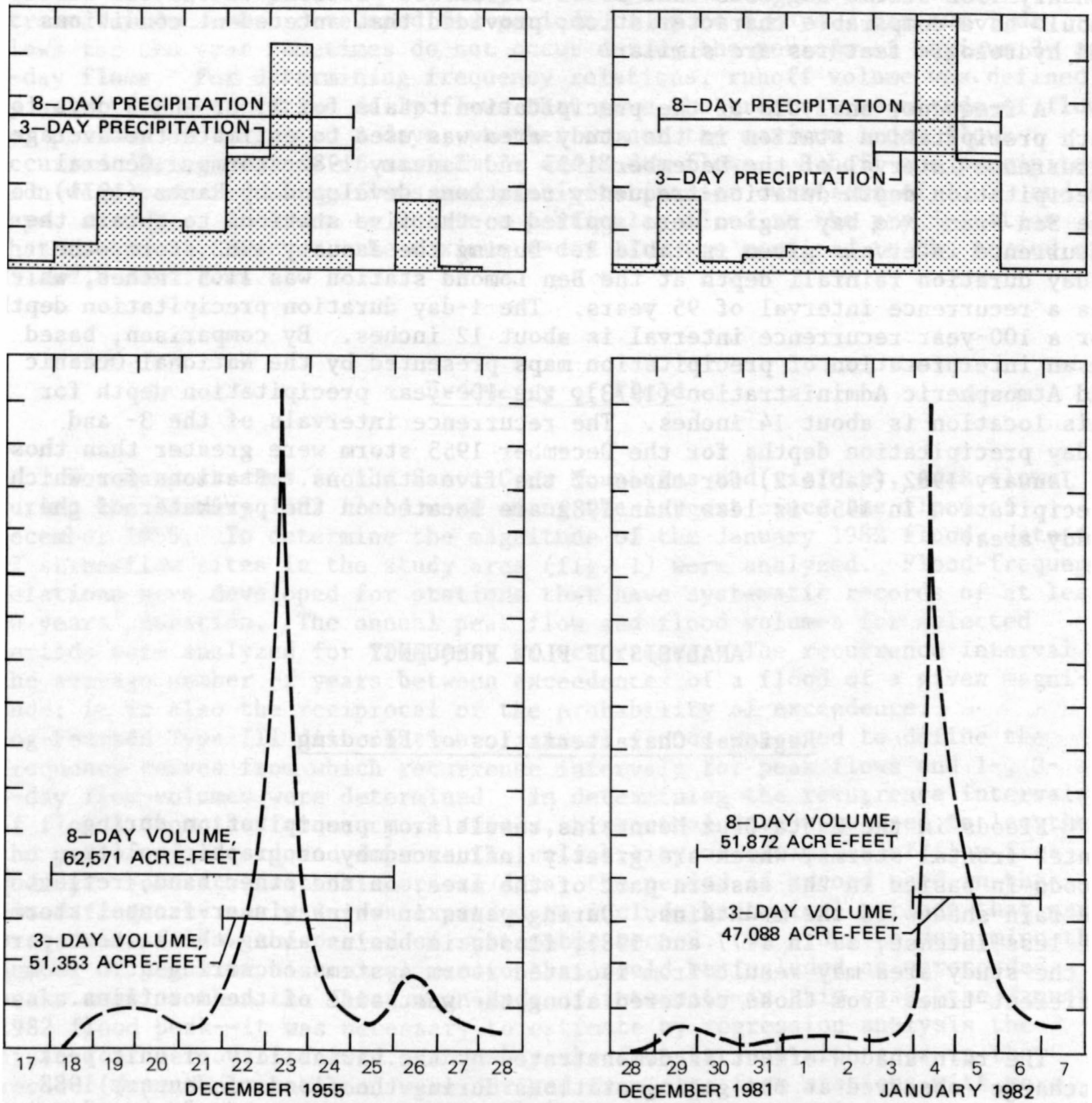

FIGURE 3. — Precipitation histogram at Ben Lomond and discharge hydrograph of San Lorenzo River at Big Trees for storms of December 1955 and January 1982.

The areal variation of precipitation for a given storm can be described by the standard deviation of observed precipitation at various locations. For example, the standard deviations of 1-day rainfall of the December 1955 and January 1982 storms at selected stations in the region (table 2) differed by about 2 percent. This small difference indicates that both storms had a similar areal variation in precipitation. The standard deviations of the ratios of 3-day and 8-day rainfall to 1-day rainfall of the two storms differed by 6 and 12 percent, respectively, which indicates that both storms also had a similar areal variation of precipitation over the longer period. The similarity of precipitation intensity and duration for the December 1955 and January 1982 storms suggests that areal streamflow patterns of the two floods should have comparable characteristics, provided that antecedent conditions and hydrologic features are similar.

A frequency analysis of the precipitation totals for 1, 3, and 8 days for each precipitation station in the study area was used to estimate the average recurrence interval of the December 1955 and January 1982 storms. General precipitation depth-duration-frequency relations developed by Rantz (1971) for the San Francisco bay region were applied to the five stations to obtain the recurrence intervals given in table 2. During the January 1982 storm, the 1-day duration rainfall depth at the Ben Lomond station was 11.5 inches, which has a recurrence interval of 95 years. The 1-day duration precipitation depth for a 100-year recurrence interval is about 12 inches. By comparison, based on an interpretation of precipitation maps presented by the National Oceanic and Atmospheric Administration (1973), the 100-year precipitation depth for this location is about 14 inches. The recurrence intervals of the 3- and 8-day precipitation depths for the December 1955 storm were greater than those of January 1982 (table 2) for three of the five stations. Stations for which precipitation in 1955 is less than 1982 are located on the perimeter of the study area.

ANALYSIS OF FLOW FREQUENCY

Regional Characteristics of Flooding

Floods in the Santa Cruz Mountains result from precipitation during winter-frontal storms, which are greatly influenced by orographic uplift. Floods in basins in the eastern part of the area, on the other hand, reflect the rain shadow of the mountains. During years in which winter-frontal storms are less intense, as in 1977 and 1981, floods in basins along the eastern part of the study area may result from isolated storm systems occurring at different times from those centered along the west side of the mountains.

The rain-shadow effect is demonstrated by the variability of unit peak discharge[1] observed at the gaging stations during the flood of January 1982 (fig. 1). For example, the unit peak discharge value is 390 $(ft^3/s)/mi^2$ for San Vicente Creek near Davenport (11161800), but on the east side of the mountains (due east of San Vicente Creek) it is 98.7 $(ft^3/s)/mi^2$ for Llagas Creek above Chesbro Reservoir, near Morgan Hill (11153470) (fig. 1). The 1982 flood also suggests a north-south trend in the magnitude of unit peak discharge. Unit peak discharge on streams near the northern part of study area is about 200 $(ft^3/s)/mi^2$, compared with about 300 $(ft^3/s)/mi^2$ near the southwestern part of the area. The highest unit peak discharge measured is

626 $(ft^3/s)/mi^2$ at the miscellaneous site San Lorenzo River Tributary near Boulder Creek. This site, which is near a former crest-stage gage, was selected to indicate the peak flow of a very small basin.

Although some snow falls in the winter at altitudes above 2,000 feet, it does not remain on the ground for more than a few days. Snowmelt was not a significant factor during the January 1982 flood.

Flows for durations of 1, 3, and 8 days and the peak flow were used to define the magnitude of the flood and to compare the precipitation and streamflow data. The bulk of the storm runoff occurs within an 8-day period for streams in the study area. To analyze a complete storm system, therefore, streamflow data were developed for periods of up to 8 days. Maximum 1-day flows for the year sometimes do not occur during the periods of maximum 3- and 8-day flows. For determining frequency relations, runoff volume was defined by selecting consecutive daily flows that gave the greatest magnitude of flow for periods of 1, 3, and 8 days, whether or not the maximum 1-day flows occurred during periods of maximum 3- and 8-day flows. Runoff and precipitation were compared using flows and precipitation for durations of 1, 3, and 8 days, as well. In order to relate a particular flood to the precipitation that caused it, however, the maximum 1-day flow was confined to the period of 3- and 8-day flows.

Frequency of Flood

For many streams in the Santa Cruz Mountains and vicinity, peak flows during the January 1982 flood were among the largest since the flood of December 1955. To determine the magnitude of the January 1982 flood, data for 37 streamflow sites in the study area (fig. 1) were analyzed. Flood-frequency relations were developed for stations that have systematic records of at least 10 years' duration. The annual peak flow and flood volumes for selected periods were analyzed for frequency of occurrence. The recurrence interval is the average number of years between exceedences of a flood of a given magnitude; it is also the reciprocal of the probability of exceedence. A log-Pearson Type III distribution of annual floods was used to define the frequency curves from which recurrence intervals for peak flows and 1-, 3- and 8-day flow volumes were determined. In determining the recurrence intervals of floods from the frequency relations, historical data were used to lengthen the period of record and improve the reliability of estimates of flow frequency. For sites with historical data, the period of record used in the flood frequency analysis was expanded to include historical periods that may precede or follow the period of systematic record. In order to determine the number of years of historical record that could be included as unrecorded peaks smaller than the flood magnitude of interest--in this case, the January 1982 flood peak--it was necessary to estimate by regression analysis the historical period of record. Annual peaks for stations with gaps in the record (dependent stations) were derived from data from stations with more complete records (independent stations). Independent stations were selected that yielded the highest coefficient of correlation when correlations with several stations were attempted.

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[1]Because discharge in cubic feet per second varies according to basin size, peak flow is expressed as unit peak discharge, in cubic feet per second per square mile, to discount this effect.

Estimated values of annual peak flow were not incorporated in the flow record but were used solely as an indication of the historical period in which peaks were less than the January 1982 flood peak. There are 14 stations for which the systematic data base was extended up to 8 years on the basis of estimated historical information. In order to estimate frequency relations of peak flows, a generalized skew of peak flows, -0.78, was derived using procedures described by the U.S. Water Resources Council (1981). To estimate the frequency of flow volumes for the selected durations using comparable procedures, it was necessary to determine values of the generalized skew applicable for flow volumes as well as flood peaks. The U.S. Water Resources Council (1981) does not present methods for estimating the generalized skew of flow volumes. For the present report, it was assumed that the appropriate generalized skew coefficients are -0.73, -0.80, and -0.84, which were derived from flow volumes of 1-, 3-, and 8-day duration in the same way as for peak flows.

The peak flow and 1-, 3-, and 8-day volumes of the January 1982 flood and their associated recurrence intervals for selected gaging stations in the Santa Cruz Mountains and vicinity are presented in table 3. Estimates of flood recurrence intervals are rounded to two significant figures, and values of more than 100 years are given as greater than 100 (>100). Where available, the recurrence interval of peak flow and flood volumes for the December 1955 flood are included in the table for comparison. The median recurrence interval of the January 1982 peak for 33 stations in the study area is 12 years. Based on six stations, the median recurrence interval for the December 1955 flood is 36 years. Only one of the seven sites with comparable data, Corralitos Creek at Freedom (11159200), had a higher peak in January 1982 than in December 1955.

The peak flows of the January 1982 flood for San Vicente Creek near Davenport (11161800) and Purisima Creek near Half Moon Bay (11162600) (table 3) indicate return periods greater than 100 years, but flows expressed as unit runoff are comparable with flow values for nearby basins. Most of the other basins that were located in areas of high flow had peaks with recurrence intervals of about 40 to 50 years.

Flood volumes during January 1982 for a 1-day duration had a higher recurrence interval than peak flows at 10 of the 15 stations. Recurrence intervals of flows for a 3-day duration, however, were greater than those for the peak flow at only 6 of the 15 stations. In terms of flow volumes (table 4), the median recurrence intervals of the January 1982 flood for 1-, 3-, and 8-day durations are 8, 10, and 7.1 years, respectively. Recurrence intervals of the December 1955 flood are 62, 22, and 30 years. By comparison, runoff volumes for durations of 1, 3, and 8 days on the west side of the Santa Cruz Mountains had lower recurrence intervals than the recurrence intervals of peak flows, as indicated in table 4. On the east side, the recurrence intervals of the 1-, 3-, and 8-day durations were greater than recurrence intervals of peak flows.

The median recurrence intervals of peaks for selected stations presented in table 4 indicate that the December 1955 flood was much larger and longer in duration than the January 1982 flood. Although precipitation records (table 2) indicate that 1-day precipitation during the January 1982 storm generally was greater than that recorded during the December 1955 storm, the magnitude of this flood in terms of peak flow and runoff for 1, 3, and 8 days is less than that of the December 1955 flood. This difference in flow characteristics of the two floods may be attributed to differences in total precipitation.

TABLE 3.--Peak flow, volume, and recurrence interval during various durations of flow at selected gaging stations, December 19 to 26, 1955, and December 30, 1981 to January 6, 1982

Station No.	Station name	Side[1]	Peak flow: Date (month-day-year)	Peak flow: Amount (ft^3/s)	Peak flow: Recurrence interval (years)	1-day volume: Amount (acre-ft)	1-day volume: Recurrence interval (years)	3-day volume: Amount (acre-ft)	3-day volume: Recurrence interval (years)	8-day volume: Amount (acre-ft)	8-day volume: Recurrence interval (years)
11153470	Llagas Creek above Chesbro Reservoir near Morgan Hill	E	1-4-82	950	4.4	--	--	--	--	--	--
[2]11153800	Alec Canyon near Morgan Hill	E	1-4-82	158	4.0	--	--	--	--	--	--
11153900	Uvas Creek above Uvas Reservoir near Morgan Hill	E	1-4-82	5,360	8.0	5,430	15	9,990	22	11,600	8.5
11154100	Bodfish Creek near Gilroy	E	1-4-82	1,050	9.1	916	12	1,360	8.7	1,710	6.7
11158900	Pescadero Creek near Chittenden	E	1-4-82	846	9.5	--	--	--	--	--	--
11159150	Corralitos Creek near Corralitos	W	1-4-82	2,120	10	--	--	--	--	--	--
11159200	Corralitos Creek at Freedom	W	12-22-55	3,620	12	--	--	--	--	--	--
			1-4-82	5,610	40	1,980	6.3	4,060	6.7	4,890	4.1
11159400	Green Valley Creek near Corralitos	W	1-4-82	1,200	22	--	--	--	--	--	--
11159690	Aptos Creek near Aptos	W	1-4-82	3,930	40	3,310	37	4,130	21	4,840	14
[2]11159770	Laurel Creek near Laurel	W	1-4-82	270	5.6	--	--	--	--	--	--
11159800	West Branch Soquel Creek near Soquel	W	1-4-82	3,750	9.5	--	--	--	--	--	--
11159940	Soquel Creek near Soquel	W	1-4-82	6,000	50	--	--	--	--	--	--
11160000	Soquel Creek at Soquel	W	12-23-55	15,800	62	17,500	>100	28,300	>100	35,200	>100
			1-4-82	9,700	14	8,530	18	12,100	11	14,200	6.3
11160020	San Lorenzo River near Boulder Creek	W	1-4-82	1,050	11	1,000	8.3	1,690	7.3	1,860	5.1
11160060	Bear Creek at Boulder Creek	W	1-4-82	2,060	--	3,630	--	5,300	--	6,200	--
11160070	Boulder Creek at Boulder Creek	W	1-4-82	1,360	4.8	1,810	6.3	3,570	6.3	4,460	3.7
11160300	Zayante Creek at Zayante	W	1-4-82	3,670	6.9	3,390	16	4,400	9.5	4,790	5.6
11160500	San Lorenzo River at Big Trees	W	12-23-55	30,400	36	33,700	62	51,400	30	69,700	30
			1-5-82	29,900	33	29,200	36	47,100	24	51,900	11
11161500	Branciforte Creek at Santa Cruz	W	12-22-55	8,100	77	--	--	--	--	--	--
			1-4-82	6,650	29	--	--	--	--	--	--
11161800	San Vicente Creek near Davenport	W	1-4-82	2,370	>100	1,690	38	2,280	27	2,560	10

See footnote at end of table.

TABLE 3.--Peak flow, volume, and recurrence interval during various durations of flow at selected gaging stations, December 19 to 26, 1955, and December 30, 1981 to January 6, 1982 Continued

Station No.	Station name	Side[1]	Peak flow: Date (month-day-year)	Peak flow: Amount (ft³/s)	Peak flow: Recurrence interval (years)	1-day volume: Amount (acre-ft)	1-day volume: Recurrence interval (years)	3-day volume: Amount (acre-ft)	3-day volume: Recurrence interval (years)	8-day volume: Amount (acre-ft)	8-day volume: Recurrence interval (years)
11161900	Scott Creek above Little Creek near Davenport	W	1-4-82	4,220	29	--	--	--	--	--	--
[2]11162470	Pescadero Creek Tributary near La Honda	W	1-4-82	42	43	--	--	--	--	--	--
11162500	Pescadero Creek near Pescadero	W	12-23-55	9,420	21	11,000	62	17,300	8.3	25,400	56
			1-4-82	9,400	21	6,940	14	10,000	7.4	12,100	5.7
11162540	Butano Creek near Pescadero	W	1-4-82	2,100	11	--	--	--	--	--	--
11162570	San Gregorio Creek at San Gregorio	W	1-4-82	7,910	43	--	--	--	--	--	--
11162600	Purisima Creek near Half Moon Bay	W	1-4-82	1,100	>100	--	--	--	--	--	--
11162720	Colma Creek at South San Francisco	E	1-4-82	2,450	28	1,630	>100	2,170	>100	2,770	>100
11162800	Redwood Creek at Redwood City	E	1-4-82	401	5.6	341	29	428	9.2	598	9.1
11163500	Los Trancos Creek at Stanford University	E	1-4-82	930	21	--	--	--	--	--	--
11166000	Matadero Creek at Palo Alto	E	12-22-55	854	6.8	664	17	1,080	18	1,440	17
			1-4-82	719	5.0	682	18	861	10	1,090	8.6
11169500	Saratoga Creek at Saratoga	E	12-22-55	2,730	>100	1,190	14	2,680	22	4,590	20
			1-4-82	1,460	12	1,410	25	2,640	21	3,170	7.1
11169580	Calabazas Creek tributary at Mt. Eden Road near Saratoga	E	1-4-82	110	3.4	--	--	--	--	--	--
11169600	Prospect Creek at Saratoga Golf Course near Saratoga	E	1-4-82	55	4.6	--	--	--	--	--	--
Median values, 1982											
Study area				--	12	--	18	--	10	--	7.1
West side				--	26	--	16	--	9.5	--	5.7
East side				--	6.8	--	22	--	16	--	8.6
Median, 1955				--	36	--	62	--	22	--	30

[1]Indicates which side of the Santa Cruz Mountains drained by the stream, as follows: E = east side; W = west side.

[2]Crest-stage gage.

TABLE 4.--Precipitation at Ben Lomond and annual flood discharge of San Lorenzo River at Big Trees, Calif.

Water year	Date of flood	Precipitation 1-day	Precipitation 3-day	Precipitation 8-day	Antecedent precipitation 15-day	Antecedent precipitation 45-day	Antecedent precipitation 60-day	Discharge (ft^3/s)	Volume (acre-ft) 1-day	Volume (acre-ft) 3-day	Volume (acre-ft) 8-day
38	1-31-38	5.43	7.49	11.91	4.79	--	--	13,800	9,620	17,772	32,446
39	3-9-39	3.16	4.66	4.83	1.41	9.92	9.92	678	1,055	2,007	2,938
40	2-27-40	6.25	11.82	14.43	14.10	20.97	52.37	24,000	27,174	43,597	55,584
41	2-9-41	3.91	8.20	13.99	5.65	16.73	31.70	15,500	14,638	30,526	44,040
42	1-24-42	7.15	10.98	14.67	1.72	21.97	24.73	13,400	14,817	22,592	34,340
43	1-21-43	6.73	11.82	15.84	4.39	10.87	17.45	13,900	14,737	23,306	28,915
44	3-4-44	2.47	3.91	6.70	7.69	19.60	20.52	1,890	3,094	5,375	9,630
45	2-2-45	10.27	16.54	19.54	3.03	7.45	7.48	13,200	14,380	26,262	32,466
46	12-27-45	3.00	4.90	12.13	7.27	17.61	22.72	2,810	3,055	6,758	12,690
47	11-22-46	6.37	5.09	11.88	3.58	3.69	4.62	1,450	1,047	1,799	3,005
48	4-29-48	2.55	4.46	4.49	2.44	12.59	14.62	1,390	1,089	2,680	4,066
49	3-10-49	3.74	7.10	8.26	6.81	14.00	17.59	3,880	4,661	12,179	16,987
50	2-6-50	5.33	9.41	10.01	3.13	15.49	21.54	6,190	5,098	13,049	17,604
51	11-18-50	7.10	14.48	21.69	6.95	12.52	12.56	10,600	8,668	19,141	24,691
52	1-12-52	6.30	8.85	14.52	13.34	31.48	35.84	14,900	12,694	24,179	39,710
53	12-7-52	7.74	9.45	10.09	6.75	22.39	27.59	9,250	6,546	7,906	9,344
54	1-17-54	4.87	5.66	5.71	4.73	15.46	15.46	2,710	2,103	2,588	3,110
55	12-2-54	5.22	7.87	10.45	2.30	11.01	11.13	3,300	1,984	4,741	7,196
56	12-23-55	10.42	16.97	26.39	9.28	19.23	19.23	30,400	33,719	51,353	66,737
57	2-24-57	3.00	6.33	8.75	2.59	11.24	14.36	2,560	2,539	5,639	7,188
58	4-2-58	4.90	8.27	11.65	10.34	25.84	40.00	17,200	12,456	26,143	41,431
59	2-16-59	3.00	4.86	7.75	8.18	16.58	20.78	6,690	5,316	8,844	14,188
60	2-1-60	4.59	5.44	7.19	9.98	18.96	22.29	2,990	2,083	3,306	5,349
61	11-26-60	3.52	4.19	4.19	1.42	5.57	8.68	639	536	724	966
62	2-14-62	5.10	8.80	12.56	11.34	16.39	16.39	6,090	4,701	12,258	19,264
63	1-31-63	9.72	19.17	19.52	.35	2.32	5.81	13,000	14,678	29,554	34,933
64	1-21-64	2.48	5.73	8.45	.74	12.97	12.97	2,660	2,281	4,526	6,044
65	1-5-65	2.70	4.53	8.28	5.80	12.98	18.97	8,450	5.970	12,992	23,332
66	12-29-65	--	--	--	4.14	6.17	6.24	1,080	1,137	2,644	4,229
67	1-21-67	10.83	12.58	16.04	.87	1.15	13.80	10,400	12,595	19,030	28,443
68	1-30-68	4.93	7.67	8.01	3.76	7.28	11.23	8,720	7,160	9,515	11,199
69	2-15-69	4.72	5.04	6.34	7.27	17.37	17.78	11,500	11,068	16,404	24,978
70	1-16-70	4.03	7.86	9.80	4.13	13.05	13.05	8,190	7,418	14,618	21,243
71	11-29-70	2.77	5.36	10.13	7.41	13.39	13.39	2,530	2,717	5,415	10,997
72	12-27-71	2.19	3.47	7.24	5.45	11.52	11.54	1,060	1,269	2,644	4,399
73	1-16-73	3.50	5.41	5.92	6.75	10.26	10.44	11,800	9,104	18,427	24,536
74	3-28-74	3.30	5.67	10.08	1.67	3.19	7.95	4,220	4,165	9,733	11,455
75	3-21-75	2.30	3.72	4.95	1.27	12.94	13.98	5,040	2,955	6,204	10,951
76	2-29-76	3.00	4.59	4.81	.00	3.95	4.87	458	321	732	1,055
77	3-15-77	1.34	2.65	2.85	.37	2.36	2.36	263	254	438	645
78	1-14-78	5.49	11.29	15.70	10.72	21.24	26.03	11,300	11,881	26,638	37,433
79	2-13-79	4.56	5.78	8.18	1.06	13.10	14.72	5,080	3,293	6,474	9,170
80	2-19-80	5.40	9.50	19.00	16.70	30.19	40.30	10,500	12,675	23,385	41,761
81	3-21-81	3.23	5.04	5.68	4.97	5.45	11.38	2,410	2,955	4,671	6,909
82	1-5-82	11.47	16.82	22.90	9.98	15.61	25.39	29,900	29,157	47,088	53,915
Mean		5.00	7.94	11.00	5.48	13.50	17.54	8,177	7,797	14,130	20,033

EFFECT OF ANTECEDENT PRECIPITATION ON FLOODING OF THE SAN LORENZO RIVER AT BIG TREES

Streamflow-related damages in the Santa Cruz Mountains and vicinity caused by the January 1982 storm were the greatest since the December 1955 flood. Precipitation data at Ben Lomond and flood data for San Lorenzo River at Big Trees indicate that the amount of precipitation and corresponding runoff for these two floods are similar (table 4). For comparison, it should be noted that both the January 1963 and February 1945 floods, which had similar amounts of precipitation, had similar-size peaks and volumes of runoff (table 4). These comparisons suggest that for certain precipitation patterns, the resulting floods are of similar magnitude and volume; however, this is not always the case. The storm in Jauary 1963 was more severe (in terms of 3-day duration) than either the 1955 or 1982 storms (table 4), yet the resulting runoff was about half as much as that recorded during the 1955 and 1982 floods. Since it has been established that locally intense convective-type storms and snowmelt are not factors in causing floods in the Santa Cruz Mountains (Rantz, 1971), the variation in runoff volumes of a flood for a given amount of storm precipitation is attributed to antecedent precipitation.

A review of the dates of annual peaks of the San Lorenzo River at Big Trees (table 4) indicates that all the floods occurred during the winter months of November through March, except for two floods that occurred in April, the largest of which occurred very early in the month. October and November are the only 2 months with storm activity that precedes the period of major precipitation and flooding, December through March (fig. 4); September is not included in the analysis of antecedent precipitation because it is a low-precipitation month (fig. 4).

The data on figure 3 indicate that most runoff for two of the major floods on the San Lorenzo River at Big Trees occurred during a 3-day period. In order to compare precipitation at Ben Lomond and corresponding runoff of the San Lorenzo River for different floods, the 3-day period that includes the annual peak has been selected. Using the precipitation and runoff data in table 4 for the 3-day duration, the variation in runoff for given amounts of precipitation at Ben Lomond is indicated in figure 5.

The enveloping lines for minimum and maximum 3-day runoff on figure 5 indicate that runoff for a given amount of precipitation may vary up to 18:1, depending on antecedent conditions. For example, with a 3-day precipitation of 4.5 inches, the flow of the San Lorenzo River may vary between 730 and 13,000 acre-ft. The water years in which the runoff was minimal for a given amount of precipitation, 1963 and 1976 (fig. 5), had antecedent-precipitation amounts for the 15 days prior to the flood that were the lowest of record (table 4). Water years with maximum runoff, 1965, 1969, 1973, and 1975, had average amounts of antecedent precipitation for a 15-day duration, but the 60-day antecedent precipitation amounts were above average (table 4). It is interesting to note that major floods during the years 1940, 1955, and 1982 are midway between the enveloping curves on figure 5. Even though these floods were larger than average, an even greater flood might occur, given the right combination and storm intensity. For example, with antecedent conditions observed prior to the 1940 flood and a 3-day precipitation similar to the 1982 storm (table 4), a flood greater than any observed to date is likely.

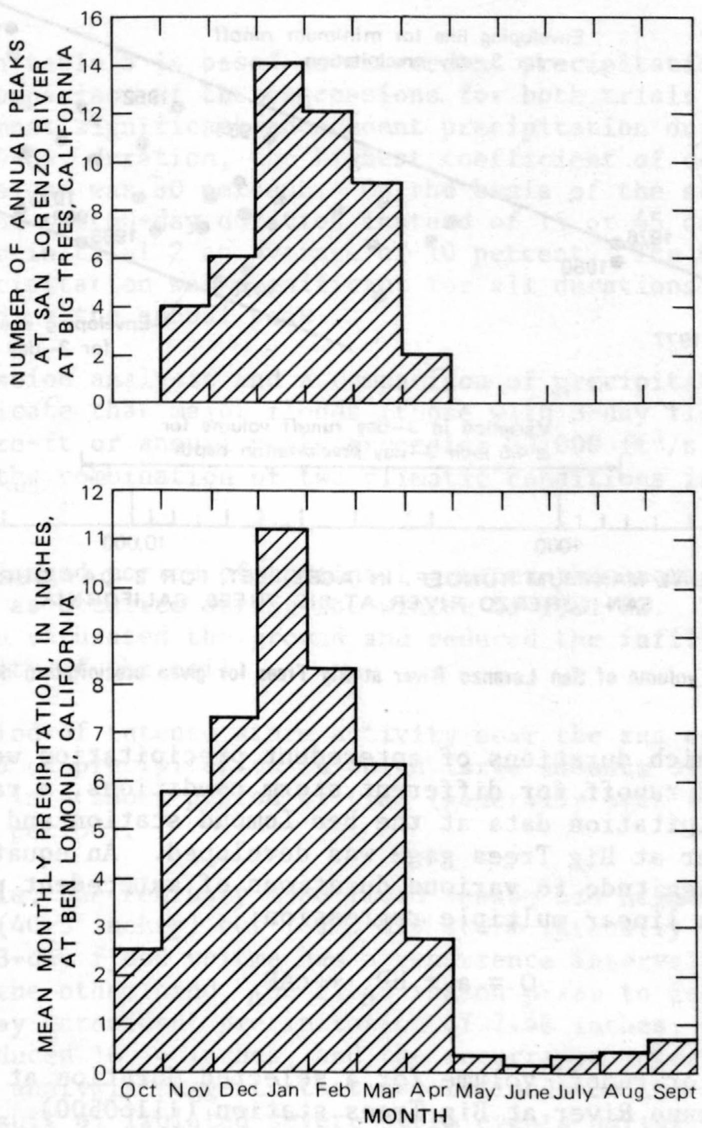

FIGURE 4. — Monthly distribution of annual peaks for San Lorenzo River at Big Trees (for period 1938–82) and mean monthly precipitation at Ben Lomond, California (for period 1968–82).

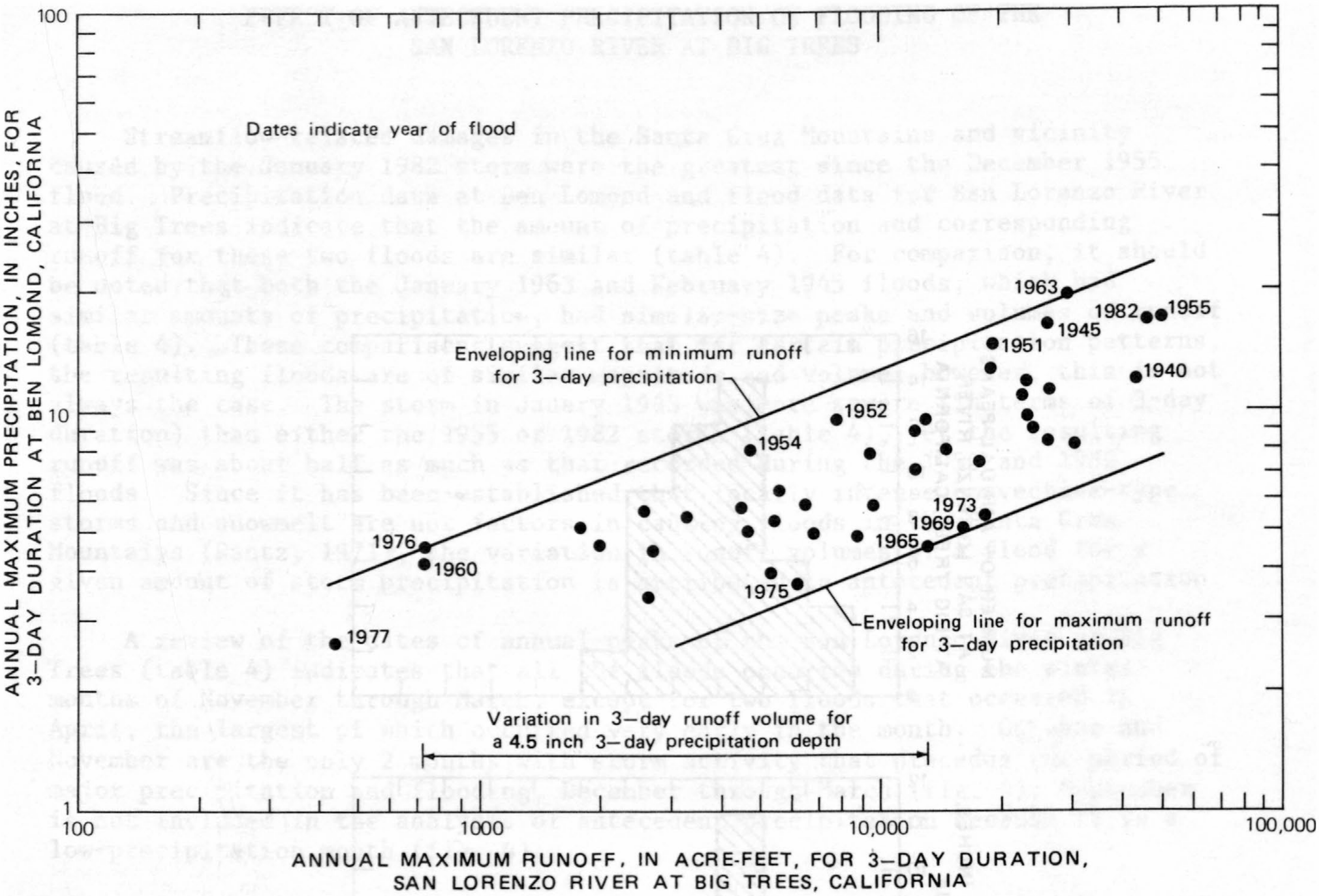

FIGURE 5. — Variation in 3–day volume of San Lorenzo River at Big Trees for given precipitation depth at Ben Lomond, California.

To determine which durations of antecedent precipitation were most influential on subsequent runoff for different storm conditions, a rainfall-runoff model based on precipitation data at the Ben Lomond station and flow data for the San Lorenzo River at Big Trees gage was developed. An equation that related the flood magnitude to various durations of antecedent precipitation was developed from a linear multiple regression:

$$Q = a + bP_n + cAP_n \qquad (1)$$

where

Q = peak flow or runoff volume for a selected duration at the San Lorenzo River at Big Trees station (11160500). Volumes of runoff are expressed in acre-feet.

P_n = precipitation depth in inches for the selected duration, concurrent with the annual maximum volume of flow of similar duration.

AP_n = antecedent precipitation depth in inches preceding the beginning of the selected flood duration. Generally, the beginning day of a 60-day period is 62 to 64 days prior to the date of the peak.

Various transformations, such as $\log_{10}$ or use of a polynomial expansion in the regression analysis, did not improve the accuracy of the regression. The inclusion of other hydrologic variables, such as those that tend to define the shape of the precipitation hydrograph, also did not improve the regression.

Precipitation data for the Ben Lomond station were used to regress with streamflow data for the San Lorenzo River at Big Trees station because the Ben Lomond station is located near the center of the basin. The first set of regressions (trial 1 in table 5) used antecedent precipitation for durations of 15, 30, and 45 days. It was found that antecedent precipitation for a 30-day duration was statistically insignificant. The highest correlation coefficient (r^2) for trial 1 was about 77 percent using a 15-day antecedent period. Since the largest floods of record occurred either in late December or in January and February (table 4), a duration of antecedent precipitation longer than 45 days was therefore considered a possible influence on the flood magnitude.

Trial 2 in table 5 is based on antecedent precipitation for a 60-day duration. A comparison of the regressions for both trials in table 5 indicates the most significant antecedent precipitation duration is 60 days. Based on the 60-day duration, the highest coefficient of correlation of the various regressions was 80 percent. On the basis of the standard error of estimate, use of the 60-day duration instead of 15 or 45 days improved all of the regressions in trial 2 an average of 10 percent. The 60-day duration of antecedent precipitation was significant for all durations of floods given in table 5, including the annual peak.

The regression analysis and a comparison of precipitation and flood data in table 4 indicate that major floods (those with 3-day flood volumes greater than 40,000 acre-ft or annual peaks exceeding 20,000 ft^3/s) on the San Lorenzo River reflect the combination of two climatic conditions in the following sequence:

1. A prolonged period of continual greater-than-normal storm activity, as occurred during the winter of 1981-82. This precipitation saturated the ground and reduced the infiltration capacity of the soil.

2. A period of intense storm activity near the end of the prolonged period of precipitation in which large amounts of precipitation occur in a short period of time (generally over 10 inches in a 3-day period).

For example, the February 1980 flood season had high 60-day antecedent precipitation (40.3 inches) but low 3-day storm intensity (9.50 inches), and the resulting 3-day flood volume has a recurrence interval of 5 years (fig. 6). On the other hand, the flood season prior to February 1945, which had a low 60-day antecedent precipitation of 7.48 inches, had a strong 3-day storm that produced 16.54 inches, and the recurrence interval of this flood is 7 years. This analysis suggests that major floods on the San Lorenzo River are not the result of isolated severe storm events during winter months but instead are the combined effect of greater-than-normal antecedent precipitation and subsequent intense frontal-type storms.

TABLE 5.--Regression of discharge of San Lorenzo River at Big Trees and precipitation at Ben Lomond, Calif., to determine effect of antecedent precipitation on streamflow

[Form of equation: $Q = a + bP_n + cAP_n$][1]

Flood duration (Q)	Trial	Mean flow for period 1938-82	Intercept of equation (a)	Precipitation for selected periods (inches): Coefficient b for duration of flood (P_n)[1]			Coefficient c for antecedent period (AP_n)[2]			Statistical measure of regressions: Coefficient of correlation (r^2)	Standard error of estimate (S_e)
				1-day	3-day	8-day	15-day	45-day	60-day		
Peak (ft^3/s)	1	8,177	-4,977	1,899	--	--	671.2	--	--	0.65	4,838
	2		-6,640	1,855	--	--	--	--	314.1	.71	4,403
1-day runoff (acre-ft)	1	7,797	-6,157	2,089	--	--	658.2	--	--	.66	4,481
	2		-7,787	2,046	--	--	--	--	308.1	.71	4,138
3-day runoff (acre-ft)	1	14,130	-9,834	--	2,307	--	1,050	--	--	.77	6,050
	2		-12,117	--	2,254	--	--	--	477.9	.80	5,642
8-day runoff (acre-ft)	1	20,033	-13,153	--	--	2,212	--	659.0	--	.73	8,632
	2		-13,772	--	--	2,027	--	--	654.2	.80	7,430

[1]Duration of flood includes day of peak and represents period of major runoff.
[2]Antecedent precipitation for period prior to day of peak or duration of flood, where n equals number of days.

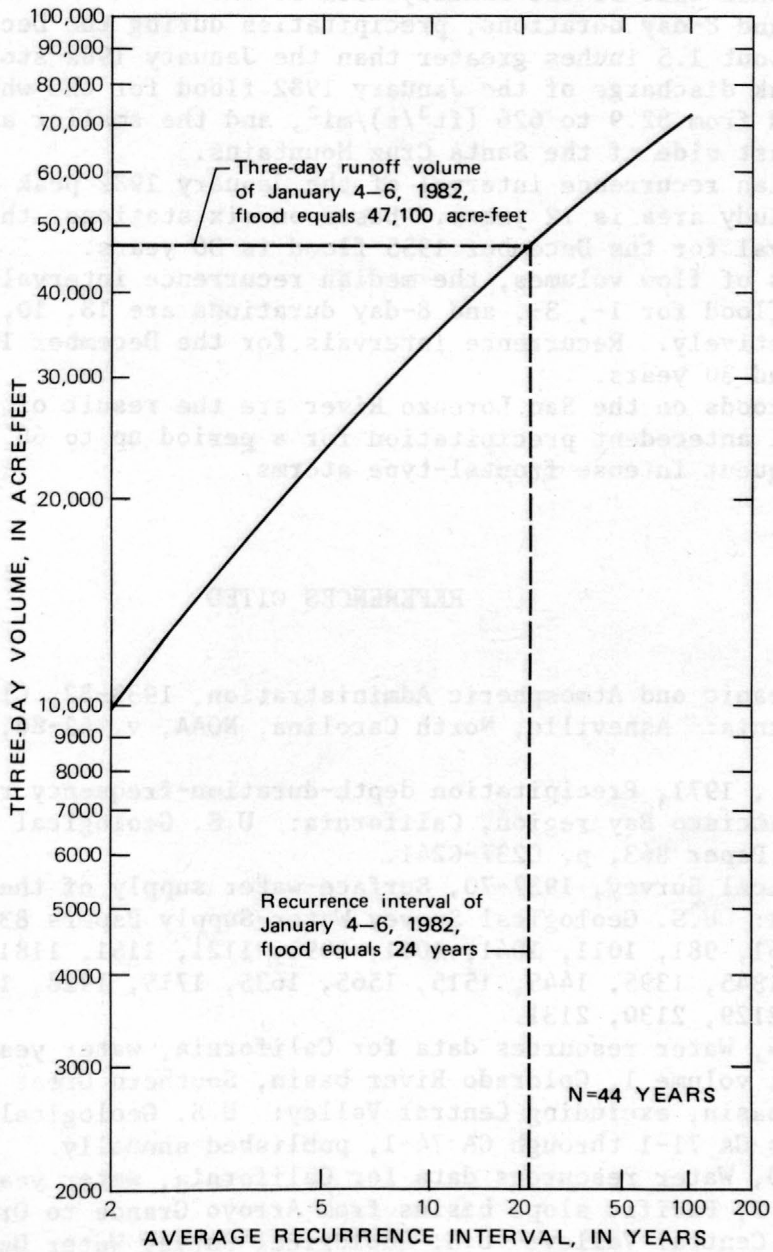

FIGURE 6. — Flood-frequency relation of 3–day runoff, San Lorenzo River at Big Trees, California.

SUMMARY

The significant results of this study are summarized as follows:

1. Antecedent precipitation for 2 months prior to the January 1982 storm was more than 100 percent of normal.
2. The maximum 1-day precipitation of the December 1955 storm averaged 1 inch less than that of the January 1982 storm.
3. For 3- and 8-day durations, precipitation during the December 1955 storm was about 1.5 inches greater than the January 1982 storm.
4. Unit peak discharge of the January 1982 flood for the whole study area ranged from 82.9 to 626 $(ft^3/s)/mi^2$, and the smaller amounts were on the east side of the Santa Cruz Mountains.
5. The median recurrence interval of the January 1982 peak for 33 stations in the study area is 12 years. Based on six stations, the recurrence interval for the December 1955 flood is 36 years.
6. In terms of flow volumes, the median recurrence intervals of the January 1982 flood for 1-, 3-, and 8-day durations are 18, 10, and 7.1 years, respectively. Recurrence intervals for the December 1955 flood are 62, 22, and 30 years.
7. Major floods on the San Lorenzo River are the result of greater-than-normal antecedent precipitation for a period up to 60 days combined with subsequent intense frontal-type storms.

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