Geomorphic Processes and Aquatic Habitat in the Redwood Creek Basin, Northwestern California

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A Comparison of Flood-Producing Storms and Their Impacts in Northwestern California

By DEBORAH R. HARDEN

GEOMORPHIC PROCESSES AND AQUATIC HABITAT IN THE REDWOOD CREEK BASIN, NORTHWESTERN CALIFORNIA

U.S. GEOLOGICAL SURVEY PROFESSIONAL PAPER 1454-D

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A COMPARISON OF FLOOD-PRODUCING STORMS AND THEIR IMPACTS IN NORTHWESTERN CALIFORNIA

By DEBORAH R. HARDEN[1]

ABSTRACT

Major floods resulting from relatively infrequent, intense winter storms are an important geomorphic agent affecting hillslopes and stream channels in the Redwood Creek basin and throughout northwestern California. A series of six flood-producing storms between 1953 and 1975 and an earlier storm series in the late 1800's in northwestern California are documented by precipitation data and historic records. Reconstruction of regional rainfall and runoff patterns for these storms is an important step in analyzing the causes of the observed variability in the impacts of the storms.

The six storms between 1953 and 1975 produced similar instantaneous peak discharges estimated at about 1,400 m^3 at Redwood Creek at Orick, the downstreammost gaging station on Redwood Creek, 3 km from its mouth. The distribution of rainfall, antecedent moisture conditions, and rainfall amounts varied within the basin. However, the amount of precipitation recorded during the 1964 storm does not alone account for the extensive regional damage to hillslopes and channels during the 1964 flood. Likely causes for the disproportionate impacts of this storm include small-scale destabilization of hillslopes by the 1953 and 1955 storms; concentration of rainfall in the upper basin, where streamside slopes are less densely vegetated and also unprotected by flood plains; and intensive road construction associated with logging in the upper basin between 1955 and 1964.

Comparison of the series of 1953-75 storms with major regional storms in northwestern California during the late 19th century, patterns of which were reconstructed from newspaper accounts and other published information, indicates that major storms of 1861-62 and 1890 were at least as intense in the Redwood Creek basin as the 1964 storm. The fact that the earlier flood series had a dramatically smaller erosional impact in the basin is probably attributable to changes in runoff regimes and hillslope stability caused by human disturbance of the basin during the second half of this century.

INTRODUCTION AND SCOPE OF WORK

Regional storms during the winter months are largely responsible for the high rainfall that characterizes north coastal California. The storms are generated when an anticyclonic cell moves north to the Gulf of Alaska during the winter months in the Pacific Ocean. Moderately intense rain falls as a result of orographic and frontal lifting of the air masses as they are carried landward and intersect the Coast Ranges (Coghlan, 1984). The Redwood Creek basin receives about 200 mm of precipitation annually, most of which falls during these regional winter storms within the basin; annual precipitation varies from about 1,525 mm near Orick to over 2,540 mm in the headwaters (Iwatsubo and others, 1975).

During the period of historic records, two series of years with a high incidence of major storms have occurred in the north coast region (northwestern California). Between 1953 and 1975, six storms generated runoff with peak flows greater than 1,282 m^3/s at Redwood Creek at Orick (table 1), 3 km from the mouth of Redwood Creek. These floods have a long-term recurrence interval of about 25 years (Janda and others, 1975).

TABLE I. — *Instantaneous peak discharges for Redwood Creek near Blue Lake and at Orick during recent major floods*
[From Harden and others (1978)]

Date	Redwood Creek near Blue Lake (drainage area 175 km^2) (m^3/s)	[m^3/s)/km^2	Redwood Creek at Orick (drainage area (m^3/s)	[m^3/s)km^2
Jan. 18, 1953	(')	([1])	1,416	1.97
Dec. 22, 1955......	342.7	1.96	1,416	1.97
Dec. 22, 1964......	464.4	[2]2.66	1,430	1.99
Jan. 22, 1972	195.4	[3]1.11	1,282	1.78
Mar. 3, 1972.	388.0	[3]2.22	1,407	1.96
Mar. 18, 1975.	345.5	1.97	1,422	1.98

[1] Floodmarks for this event were at a stage of 4.66 m, whereas floodmarks for the 1955 event were at a stage of 4.18 m. No discharge value has been assigned to the 1953 event.
[2] Discharge estimated from floodmarks and stage discharge relations in effect when operation of station was discontinued in 1958. If any channel aggradation occurred in the interval between 1958 and 1964, as seems to be the case, the estimated peak discharge for the 1964 flood would be too high.
[3] At the time of these floods, this station was being operated only as a flood-warning station. Peak discharges were estimated from peak stages and a periodically revised stage-discharge relation.

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An earlier series of flood-producing storms is documented by historic records and limited rainfall data from northwestern California. During the late 19th century, major regional storms occurred during 1861-62 and in 1890. Additional, less extensive storms affected many north coast basins in the intervening years. The years between 1890 and 1953 were relatively free of major flood-producing storms.

The purpose of comparing storms that generated major floods in the Redwood Creek basin was to account for the fact that the December 1964 storm produced the most damaging flood of the period of record throughout the north coast. The effects of this storm on hillslopes and stream channels are still discernible in the Redwood Creek basin (chap. G, this volume). I have compared the magnitude, intensity, and distribution of the six 20th century storms to evaluate their impact on different portions of the basin. I have also attempted to reconstruct the distribution and magnitude of the storms of the 19th century to see whether that storm series was of comparable magnitude.

One of the major controversies surrounding the Redwood Creek basin has centered on the contribution of major storms to the widespread landsliding and channel aggradation that began in the late 1950's (Janda and others, 1975). The erosional impacts of the storms of 1953 through 1975 on hillslopes in north coastal California are well documented (chap. G, this volume, 1978; Stewart and LaMarche, 1967; Kelley and LaMarche, 1973; Kelsey, 1977, for example). Extensive damage to stream channels, in the form of bank erosion and aggradation, is also well documented. The December 1964 storm, which produced the most damaging and widespread floods of this century, has been particularly credited with long-term destabilization of hillslopes and channels in northwestern California. The record of flood-induced damage during the late 19th century storms is far less conclusive. Historic records, aerial photographs taken when landslide scars of the late 19th century were still discernible, and information gained from coring of flood-plain trees show far less evidence of damage to hillslopes and stream channels than was produced during the later storm series (Kelsey, 1977; Harden and others, 1978).

METHODOLOGY

I have reconstructed the regional precipitation and runoff patterns for each of the 20th century storms by using available records. Temperature and snowpack records also were used to evaluate antecedent moisture conditions. A search of newspaper accounts and other historic documents was made to reconstruct the late 19th century storms, and limited precipitation records supplemented these accounts. A brief description of data sources and quality of data is given below; a more complete discussion of methodology can be found in Harden and others (1978).

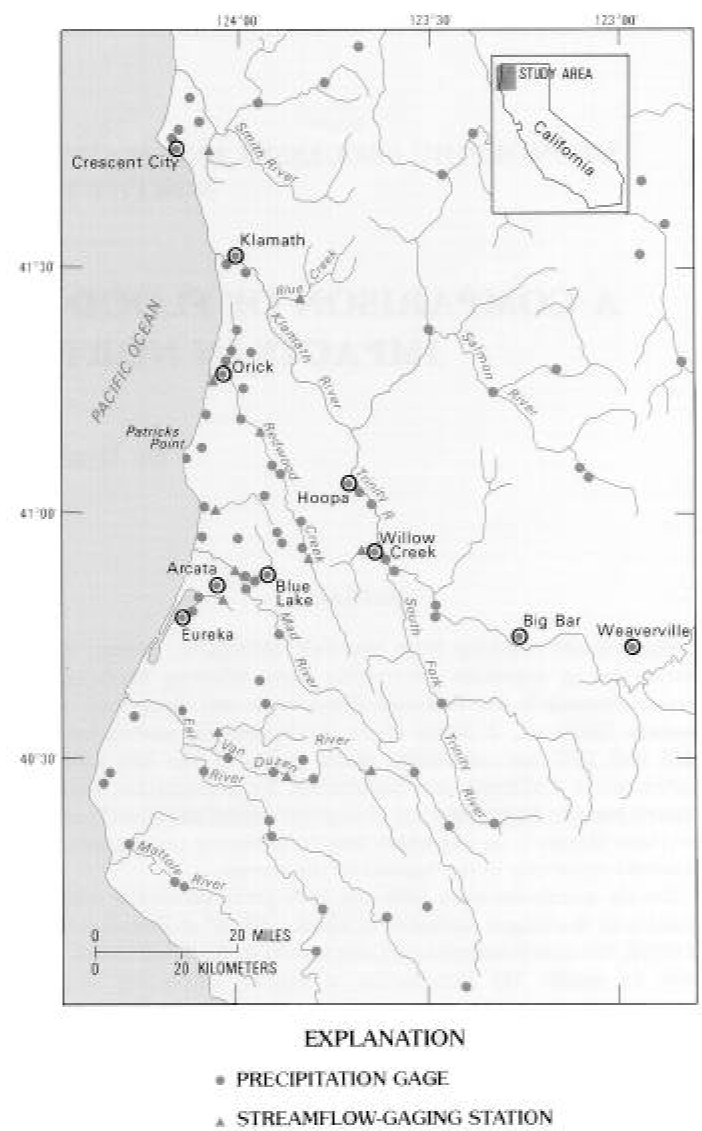


FIGURE 1.—Location of precipitation and streamflow-gaging stations in northwestern California.

PRECIPITATION RECORDS

For the 20th century storms, daily precipitation records from 81 rain gages in northwestern California were used to reconstruct storm rainfall totals (fig. 1; Harden and others, 1978). Only 16 gages were in operation during all six storms, and records from many stations are available for only one storm (fig. 2). However, many discontinued stations were replaced by nearby gages, and many of the stations with only one storm recorded were those installed during studies in the Redwood Creek basin (Harden and others, 1978). The

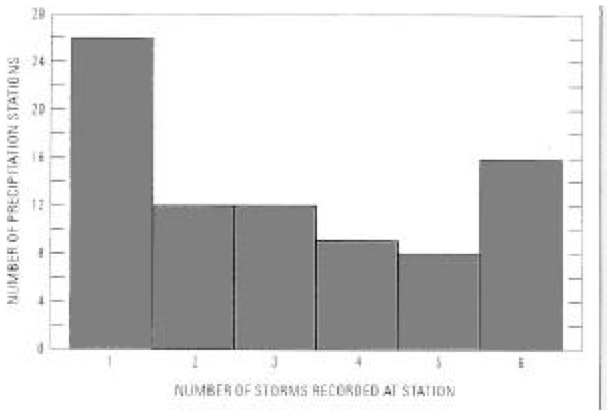


FIGURE 2.—Histogram showing number of precipitation stations operating during storm events.

areal and elevational distribution of gages for each of the six storms is therefore quite good, with 31 (1953) to 53 (1964) records available for each storm. The scarcity of gages near the inland portions of the Redwood Creek basin prior to 1975 necessitates extrapolation of records from adjacent Mad and Trinity River basins (fig. 1) to estimate storm impacts in the upper portion of the basin.

For most of the six storms, the dates of each storm period were clearly defined by the daily precipitation records. However, the complex storm periods of December 1964 and March 1975 were less easily delineated. Even by using flood hydrographs to separate that rainfall contributing directly to the flood peak and its recessional limb, the main flood-producing precipitation could not be isolated.

Three-day precipitation values for the days preceding, including, and following the flood peak for each storm provide a measure of storm intensity. In cases where flood peaks occurred on different days on different streams, the date of the peak at Redwood Creek at Orick was used to define the 3-day period for all stations. Unfortunately, daily rain-gage readings are not taken at the same time at all rainfall stations; this variability produces some misleading differences in 3-day totals at different stations.

Reconstruction of the storm patterns of the late 19th century was more difficult due to the scarcity of rainfall and runoff records. At the time of the 1890 flood, six precipitation stations were operating in northwestern California. However, none of these was located near the Redwood Creek basin. Limited records are also available for the 1888 storm. At the time of the 1861-62 storm, the major flood-producing storm of the 19th century series, only one precipitation gage was operating, at Fort Gaston in the Hoopa River valley. The record from this station is somewhat questionable due to the recording method used at that time (see Harden and others, 1978, p. 62). Reconstruction of the late 19th century flood records therefore relied heavily on the accounts of newspapers (Arcata Union, Humboldt Weekly Times, Humboldt Times, Weaverville Trinity Journal) and other published accounts of the floods (Brewer, 1930; McGlashan and Briggs, 1939).

ANTECEDENT CONDITIONS

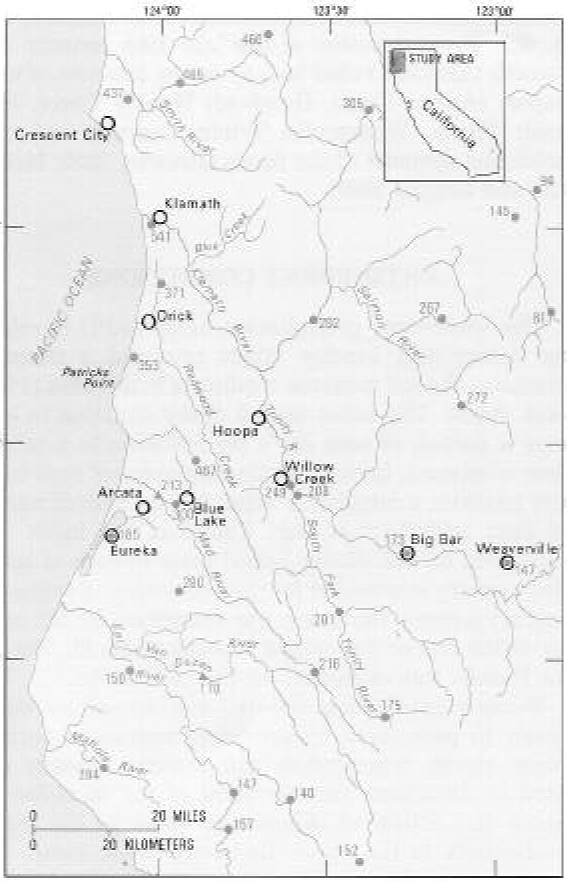
The antecedent precipitation index (API) developed by Kohler and Linsley (1951) provided a means of assessing the soil moisture conditions in this area prior to each storm. The index uses a decay equation to carryover a portion of each day's precipitation to a selected date of interest, in this case the beginning of each storm, and provides a cumulative value for the desired number of days prior to that day. Values of the index were calculated for the 60-day period prior to each of the six 20th century storms and for the 1890 storm. For the 20th century events, the index was computed for Orick and for either one or two inland stations (table 2). The API for Eureka was calculated for the 1890 storm.

Because preexisting snowfall can contribute significantly to peak flows by providing meltwater during a warm storm, temperature and snowfall records were used to determine the elevation of the snowline and hence the extent of preexisting snow in the region, particularly in the upper Redwood Creek basin. Cold temperatures during each storm period, at the beginning when snow could accumulate and later contribute to flood peaks, were also noted. Conversely, snowfall at the end of each storm period was considered to have a dampening effect on storm runoff.

RUNOFF

Streamflow records from 12 U.S. Geological Survey gaging stations are available for portions of the period of interest, with from two to five records available for each storm. The daily discharge records (U.S. Geological Survey, 1964, 1972, 1975; Waananen and others, 1971) were used to generate flood hydrographs for each event at the operating stations. In addition to providing storm runoff totals, the hydrographs aided in isolating the storm periods. The average storm total runoff, in inches, for the area above each station was used as the chief measure of flood magnitude.

For the 19th century floods, reports of flood stages provided a qualitative estimate of flood magnitude. Although these values could not be converted to a volume of runoff for a given drainage basin, the stage records aided in reconstructing the patterns of storm

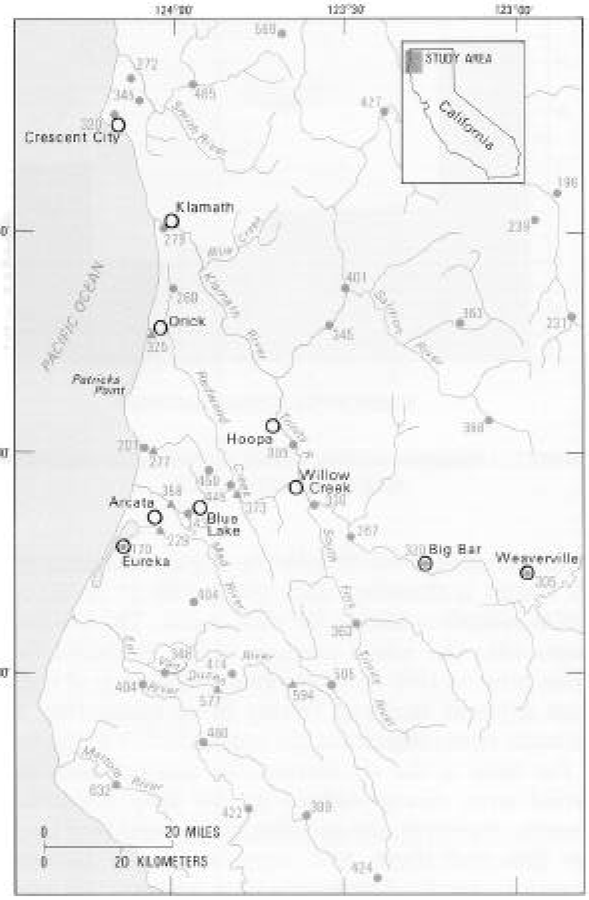


EXPLANATION

140 ● PRECIPITATION GAGE—Location, and precipitation value in millimeters

170 ▲ STREAMFLOW-GAGING STATION—Location, and runoff value in millimeters

FIGURE 3.—Precipitation and runoff for January 16 to 20, 1953.



EXPLANATION

383 ● PRECIPITATION GAGE—Location, and precipitation value in millimeters

594 ▲ STREAMFLOW-GAGING STATION—Location, and runoff value in millimeters

FIGURE 4.—Precipitation and runoff for December 15 to 23, 1955.

distribution. The reports of stream stages also provided documentation that the storms indeed produced major flooding.

STORMS OF 1953 TO 1975

The available climatologic and hydrologic data for the storms occurring from 1953 to 1975 were compiled in a series of maps that show the regional distribution of rainfall and runoff for each storm (figs. 3-9). The following comparisons of precipitation totals, rainfall intensity, storm distribution, antecedent moisture conditions, and runoff provide a basis for comparing storm magnitudes with the erosional impact of each storm.

The regional pattern of precipitation suggests that two contrasting storm tracks are typical of northwestern California. Storms such as the January 1953 and January 1972 events are centered to the north of the Redwood Creek basin and produce intense, heavy rainfall in coastal areas from Patrick's Point northward. These storms have lesser effects along the southern portion of the study area and in the inland portions of the Redwood Creek basin, and they produce only moderate precipitation in the eastern and southern inland portions of the region. The second type of storm track passes directly over the inland portion of the Redwood Creek basin, or even south of it. These storms, typified by the 1955, 1964, and 1975 events, produce high rainfall at inland sites and are frequently more prolonged than the coastal storms. Although the second storm type produces extensive regional flooding, the coastal storms may be more important geomorphic agents in the lower Redwood

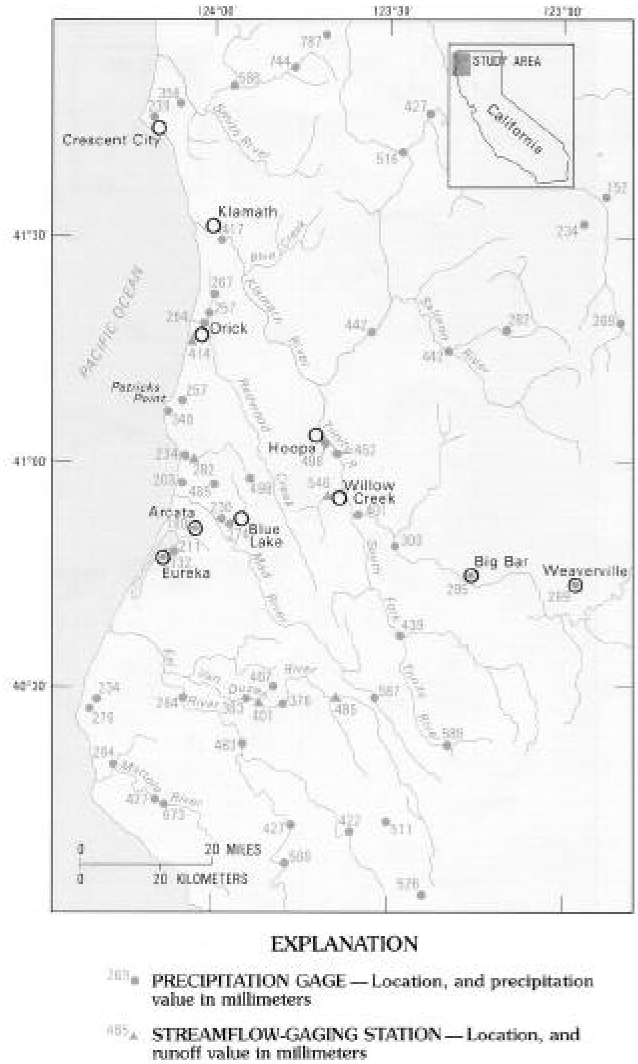


FIGURE 5.—Precipitation and runoff for December 18 to 24, 1964.

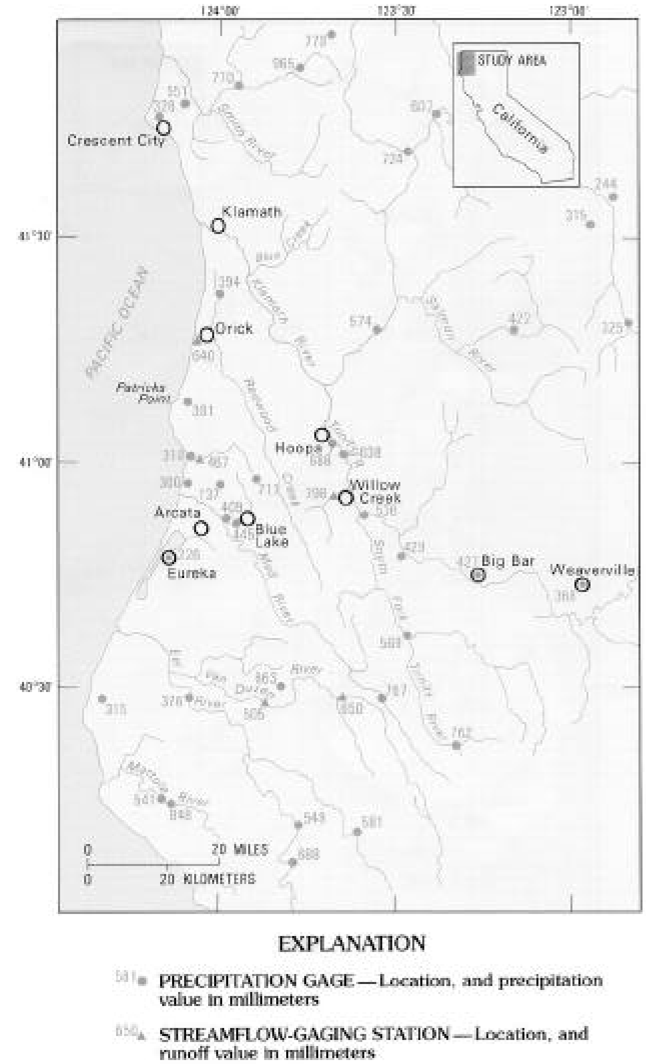


FIGURE 6.—Precipitation and runoff for December 18 to 30, 1964.

Creek and Klamath River basins and in smaller coastal streams.

PRECIPITATION TOTALS

On the basis of available records, the December 1964 storm apparently produced the greatest precipitation totals in the inland portions of the basin (figs. 3-9). Rainfall totals for the complex storm period between December 18 and 30, 1964 (fig. 6), were far greater than storm totals for the other five periods, and totals for the main storm period, December 18-24 (fig. 5), were also generally higher than those for other storms. However, precipitation in the coastal portion of the basin near Orick was greater during the 1953 (fig. 3) and 1975 (fig. 9) storms than during December 18 to 24, 1964 (fig. 5). The December 1955 storm generally produced the second highest precipitation totals for inland and southern portions of the Redwood Creek basin (fig. 4). Like the 1964 storm, this storm was less intense in the vicinity of Orick.

Both the 1955 and 1964 storms produced prolonged periods of rainfall, in contrast to the 1953 and 1972 storms. The March 1975 storm period included both a brief, intense storm similar to the 1953 and 1972 events and a subsequent, prolonged period of lesser rainfall. The 1972 storms were regionally less extensive than the other events, but they produced high rainfall totals in the northern coastal portions of the region (figs. 7 and 8).

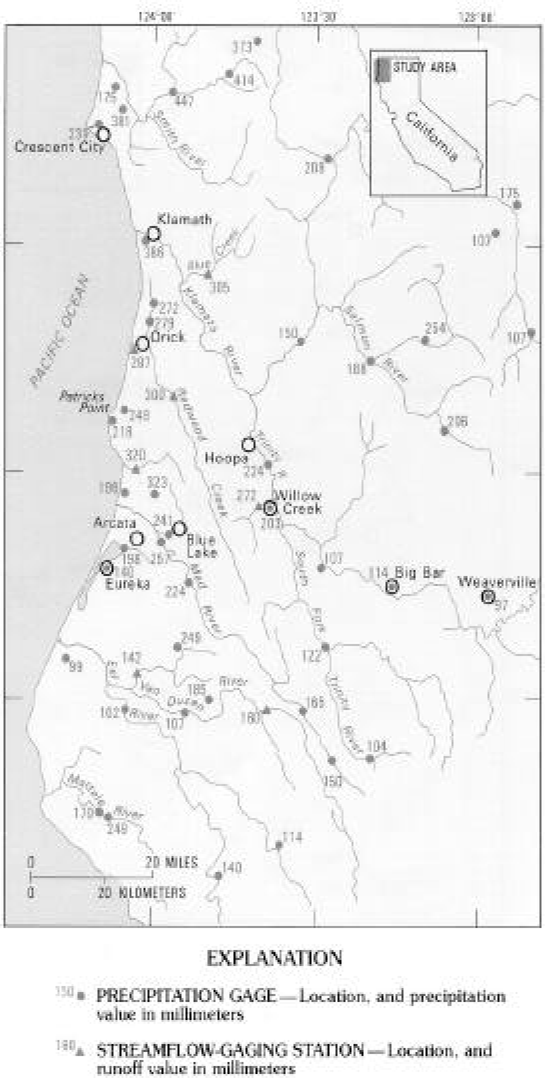


FIGURE 7.—Precipitation and runoff for January 19 to 24, 1972.

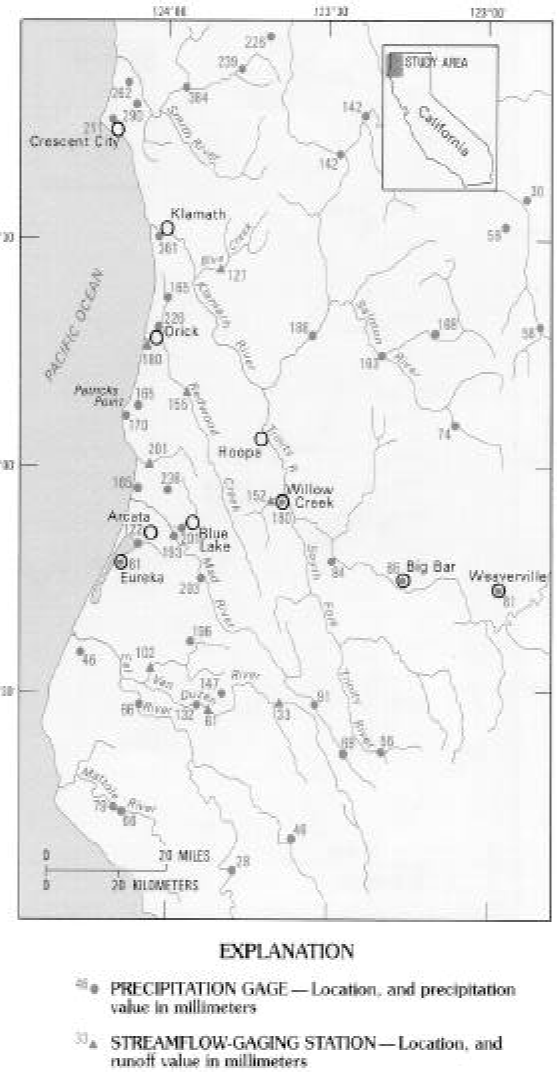


FIGURE 8.—Precipitation and runoff for March 1 to 4, 1972.

TABLE 2.—*Values of 60-day antecedent precipitation index (API) for flood-producing storms*

[—, no data]

	API, in millimeters			
Year	Orick	Hoopa	Big Bar	Willow
1953	225	—	167	—
1955	171	—	117	—
1964...............	174	144	86	—
1972 (January)......	114	—	57	—
1972 (March)	218	—	129	206
1975...............	125	106	68	—
1890	API at Eureka was 259			

ANTECEDENT MOISTURE CONDITIONS

Comparisons of values of the 60-day antecedent precipitation index for each of the six storm periods indicate that flooding would have been most enhanced by antecedent moisture conditions during the 1953 storm (table 2). Both coastal and inland portions of the basin had high precipitation prior to that storm. Antecedent moisture was apparently lowest during the January 1972 and March 1975 storms (table 2). The low antecedent moisture conditions in 1975 probably diminished the erosional impact of that storm.

The presence of snow in the upper portions of the basin at the time of a major storm also could contribute to peak runoff values for the storm period. Examination of temperature records and recorded snowfall occurrence prior to the six major storms revealed that melting snow may have augmented peak flows during the 1964, March 1972, and 1975 events (Harden and others, 1978). The low temperature during the end of the complex storm

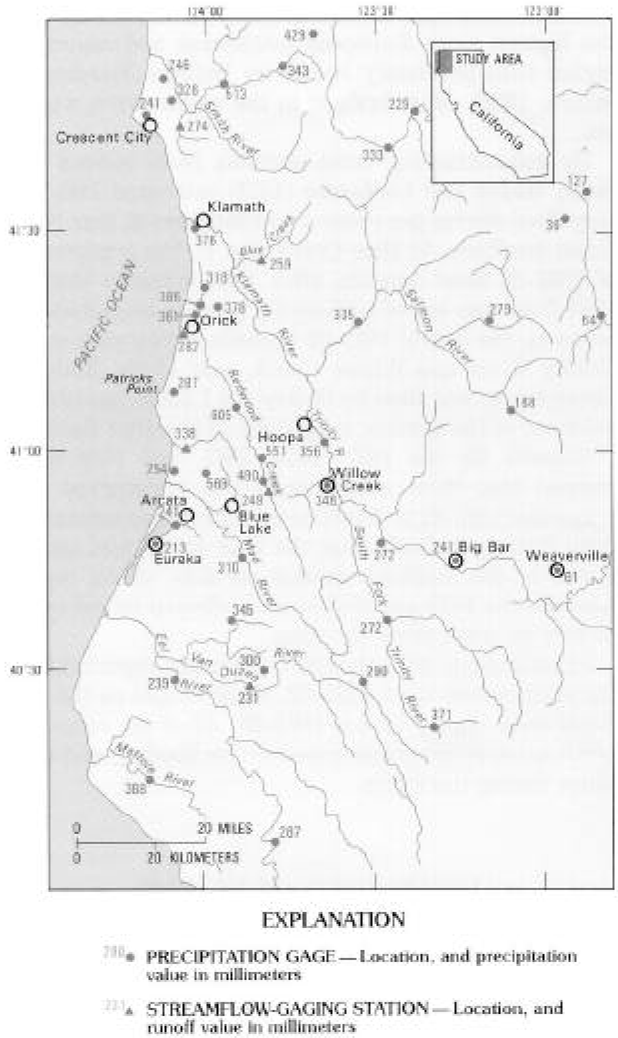


FIGURE 9.—Precipitation and runoff for March 15 to 24, 1975.

period in December 1964 caused precipitation in high areas to fall as snow and therefore not to contribute to the main flood peaks except where the snow fell directly into channels.

RUNOFF

Runoff at Redwood Creek at Orick was greater for the December 1964 storm (fig. 6) than for any of the other four events for which records are available. Peak discharges at Orick were similar for all six floods (table 1). The 1955 flood produced the second highest runoff total (fig. 4), and the 1975 flood produced slightly less runoff than 1955 (fig. 9).

LATE 19TH CENTURY STORMS

Northwestern California experienced at least five flood-producing storms between 1861 and 1890. From December 1861 to January 1862, several storms produced major floods throughout the region. Many north coast basins experienced more localized floods in 1879, 1881, and 1888 (McGlashan and Briggs, 1939). The 1890 flood was apparently as widespread as the 1861 event, although precipitation totals were probably not as high.

Information about the earlier storms is qualitative and scanty. By the time of the 1890 flood, however, daily precipitation records were kept at several stations in northwestern California. The information for each flood is presented in Harden and others (1978). Only summary data are presented in the following paragraphs.

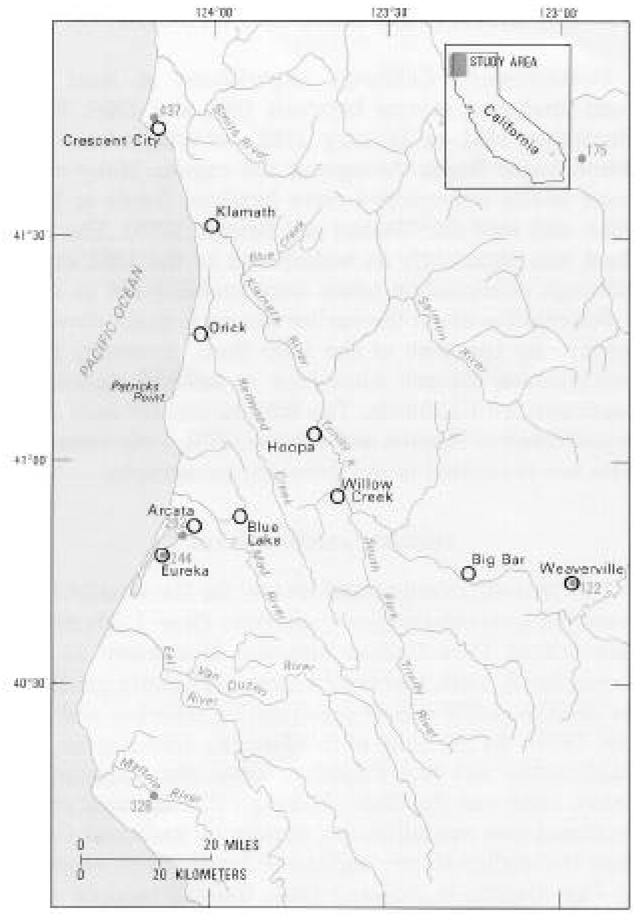
PRECIPITATION TOTALS

The 1861-62 storm period was by far the wettest ever recorded in northwestern California. Over 1,270 mm of rain fell at Fort Gaston between November 24 and December 8, 1861, and the January 8-11 storm produced an additional 305 mm of precipitation (Harden and others, 1978). At the time of the January 1862 storms, the Sacramento and San Francisco areas also experienced heavy rains and flooding. Although this January storm produced less rainfall in the vicinity of Redwood Creek than the earlier storm, additional flooding was reported at Fort Gaston in January 1862. Rainfall records were not available for the 1867, 1879, 1881, and 1888 floods. The Eureka Humboldt Times reported that over 787 mm of rain fell at the Upper Mattole station during the storm of January 27-31, 1888, storm.

The storm of January 31-February 4, 1890, is the best documented of the 19th century storms. Rainfall totals at Crescent City, Arcata, and Eureka exceeded those during the 20th century storms (fig. 10). However, at the operating inland stations, rainfall totals were less than during 1955 and 1964 (figs. 4 and 5). This precipitation pattern suggests that the 1890 storm was concentrated in northern coastal areas.

ANTECEDENT MOISTURE CONDITIONS

No mention of preexisting snow was made in newspaper accounts for the 1861 through 1888 storms. However, the winter of 1889-90 was characterized by unusually heavy snowfall prior to the February flood. According to newspaper accounts, January snowfall was the heaviest since European settlement of the area, and the trail from Arcata to Hoopa, which traversed the Redwood Creek basin near Minor Creek, was passable only with snowshoes in late January.



EXPLANATION

PRECIPITATION GAGE—Location, and precipitation value in millimeters

FIGURE 10.—Precipitation for January 31 to February 4, 1890.

At the start of the 1890 floods, warm rains melted the snow at lower elevations in the Mad River basin. Newspaper accounts and the marked rise in temperature at Eureka at the end of January suggest that significant snowmelt probably occurred early in the storm. In fact, snowmelt from high areas was cited as causing the 1890 flood stage on the Mattole River to equal that of 1881. It therefore seems likely that the 1890 flood peaks were augmented by snowmelt from at least some of the high areas.

RUNOFF

Newspaper descriptions of the 1861-62 storms indicate that flooding was widespread in northwestern California, including in the Redwood Creek basin. Flood damage was reported from all of the settled areas, both in the Trinity River mining districts and in coastal ranching areas. Flood stages on the Mad and Trinity rivers were the highest since European settlement and reportedly higher than previously known by Indians (Harden and others, 1978). Most bridges in the region were washed out.

By reconstructing cross sections from terrace surfaces, Kelley and LaMarche (1973) estimated 19th century flood discharges relative to 1964 flows at four North Coast localities. At Blue Creek (fig. 1), the preservation of 1861-62 flood deposits after 1964 indicates that the 1964 flood was not of sufficiently greater magnitude. In contrast, the lack of 1861-62 deposits at two sites on the Trinity River and Willow Creek, east of the Redwood Creek basin, was cited by Kelley and LaMarche (1973) as evidence of the greater magnitude of the 1964 flood.

Records for the 1867, 1879, 1881, and 1888 floods suggest that these events were less widespread than either the 1861-62 or 1890 floods. Newspaper accounts of flood damage indicate that the 1888 storm was concentrated in the southern coastal portions of the region, whereas the 1879 and 1881 storms affected inland areas, as well as areas along the coast.

Flood damage from the 1890 storm was reported to be the most severe since 1861-62. Flood stages on the Mad River were higher than in 1861-62. All of the remaining north coast rivers experienced major flooding and landslides during the storm.

COMPARISON OF STORMS

The amount of precipitation during December 18 to 24, 1964, does not alone account for the high runoff and the extensive regional damage to hillslopes and stream channels caused by the 1964 flood. The flood-producing storms of the late 19th century were probably comparable to those from 1953 to 1975 in amounts of rainfall and in the occurrence of a succession of natural events that could have preconditioned unstable hillslopes and stream channels to augment the impacts of floods late in each series. In fact, considering the apparently unprecedented magnitude of the 1861-62 floods, the recurrence of major flooding in 1867, 1879, 1881, and 1888, and the intense precipitation along the coast during the 1890 storm, it appears that the series of floods in the late 19th century could have been more damaging than the more recent floods.

The 1890 flood had several factors in common with the 1964 flood. First, at least two major floods immediately preceded both events. Second, flood peaks from both storms were probably augmented by snowmelt. Third, both storms were apparently concentrated in the area north of Eureka. Rainfall records indicate that the coastal portions of the Redwood Creek basin probably received more precipitation in 1890 than in 1964 and that rainfall totals in the upper basin may have been comparable.

The erosional impacts of the two storms could therefore be expected to be similar. The fact that the 19th century floods had a dramatically smaller erosional impact in the Redwood Creek basin than did the floods of the past 25 years is logically attributable to changes caused by human activities in the second half of this century. No other major changes in drainage basin conditions have occurred. The impacts of human activities in the basin are discussed elsewhere in this volume by Harden and others (chap. G) and Nolan and Janda (chap. L).

The greater impact on channels and streamside hillslopes of the 1964 storm relative to those of the other storms occurring from 1953 to 1975 is partly attributable to the greater magnitude of the December 18-24 precipitation. A second storm immediately following the peak 1964 flood discharges sustained near-bank-full stages in many coastal streams. However, even if this late December 1964 precipitation is added to the December 18-24 totals, the precipitation values are still comparable to 1955 totals at some stations. Moreover, in many intensively damaged areas, the second phase of the 1964 storm occurred as snow, which would not have contributed to the flood peaks. Rainfall totals during the 1964 storm do appear to have been greater in the upper basin than in the lower basin. The concentration of flood damage in the upper Redwood Creek basin in 1964 may partly reflect rainfall distribution.

Some weakening or small-scale destabilization of hillslopes and stream channels may have occurred during the 1953 and especially the 1955 storms. However, destabilization by early floods alone cannot account for the disproportionately large erosional impact of the 1964 flood in the upper Redwood Creek basin because the rainfall patterns of the 1953 and 1955 storms suggest that hillslopes in the lower basin would presumably have received at least as much preconditioning by earlier storms as the upper basin. Moreover, if preconditioning was a major factor, the succeeding 1972 and 1975 storms should have been even more damaging than the 1964 storm, especially in the lower basin.

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