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Mass Movement in the Redwood Creek Basin, Northwestern California

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

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ABSTRACT

Mass movement has played a dominant role in the geomorphic history of the Redwood Creek basin. Areas of active mass movement presently occupy approximately 16 percent of the total area of the watershed, and sites of inactive mass-movement features occupy an additional 15 percent. Most of these features are earthflows. Although debris slides and avalanches occupy less than 2 percent of the basin area, these landslides, particularly those adjacent to stream channels, are important sediment sources. Since the late 1950's, the amount of sediment derived from landslides adjacent to tributaries of Redwood Creek has been similar to the amount derived from landslides adjacent to the main channel.

Photointerpretive studies of landslide history document dramatic increases in the number of streamside landslides since 1947. Debris slides and avalanches have shown the greatest increase in activity; earthflow activity has not increased significantly since 1947. Most of the increased landsliding occurred between 1962 and 1966. The causes for the increase were the 1964 flood, destabilization of hillslopes by earlier storms, and intensive timber harvesting and road construction in the late 1950's and early 1960's. Since 1970, landslide activity in the basin has apparently decreased, but the lesser impact of the 1972 and 1975 floods on slope stability may partly be explained by the failure of most unstable slopes in the earlier 1964 flood.

INTRODUCTION

Mass movement has been a dominant geomorphic agent shaping the Redwood Creek basin (fig. 1), and both active and inactive landslides are common on most of the landscape. In addition, bowl-shaped basins, convex-upward hillslopes, and benched slopes throughout the basin suggest that mass movement has been responsible for much of the morphology of hillslopes, even in areas where discrete landslide features are absent. The presence of well-developed relict soils on many of these latter slopes suggests that they have not experienced landslides for thousands or even tens of thousands of years. However, these slopes are probably affected by active creep (Harden and others, 1978). The extent of active landslides (Nolan and others, 1976) attests to the continuing importance of mass movement as an erosional agent in the basin. Mass movement is also a significant contributor to the high fluvial sediment loads of Redwood Creek and its tributaries.

The number of streamside landslides increased by a factor of four between 1947 and 1976 (Colman, 1973; Nolan and others, 1976). This increase was a major concern to those responsible for protecting the resources of Redwood National Park (Janda, 1978). The degree to which the increase in streamside landslides resulted from the intensive clearcut timber harvesting that occurred between 1955 and 1975, rather than from the destabilizing influence of major floods of the same period, was a subject of considerable public debate during the course of our studies (Janda, 1978). Our photointerpretive studies of landslide history and landslide monitoring within the basin were begun as a result of this controversy. Results of these studies also have provided insights into the evolution of the drainage basin, as well as an understanding of the interactions between hillslope and channel processes in the basin.

ACKNOWLEDGMENTS

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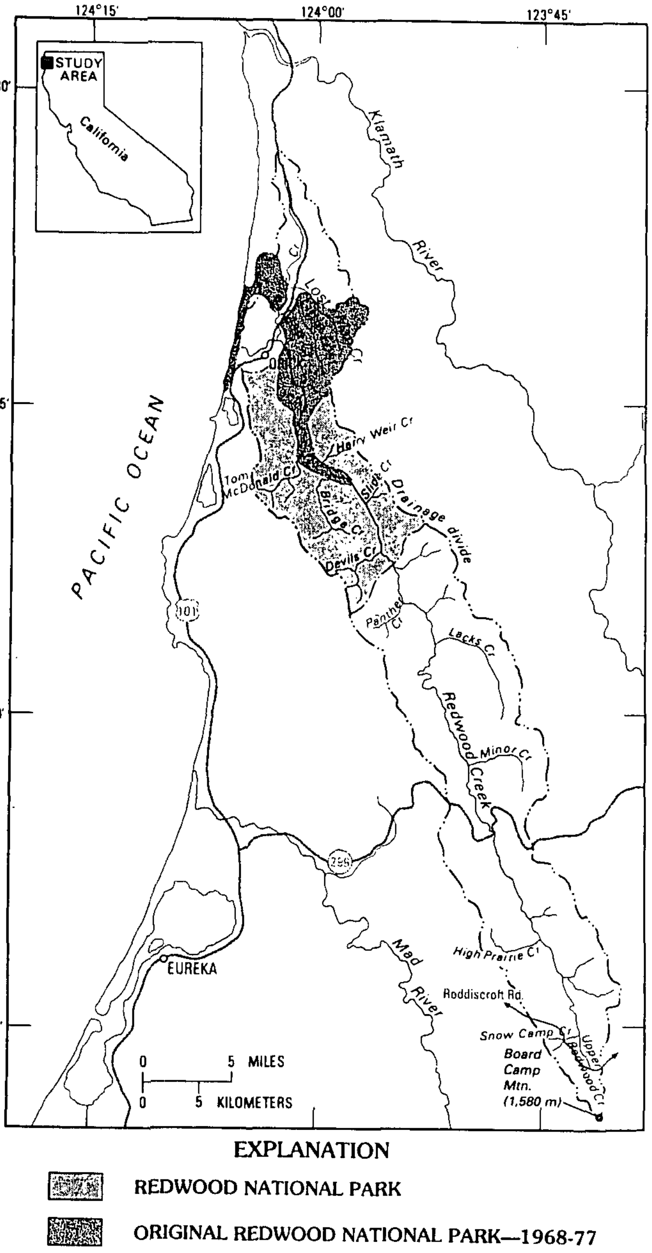


FIGURE 1.—Redwood Creek basin.

PREVIOUS WORK

Much of the U.S. Geological Survey's effort in the Redwood Creek basin from 1973 to 1976 was devoted to the characterization of mass movement on the basin's hillslopes. Study of recent streamside landslides was begun by Colman (1973) and expanded by Nolan and others (1976) and Harden and others (1978). This report draws heavily on the results of those studies, and the reader is referred to those reports for complete presentations of data. More recent unpublished studies by the U.S. Geological Survey and studies by the National Park Service (chap. J, this volume) have provided additional descriptions of mass movement in the basin. Finally, the general report by Janda and others (1975) provided considerable background information for this paper.

SETTING

The strongly elongate Redwood Creek basin, in the Coast Ranges of northwestern California (fig. 1), has an area of 725 km^2 in steep terrain. Redwood Creek flows approximately 102 km northwestward from its headwaters at Board Camp Mountain to the Pacific Ocean near the town of Orick (fig. 1). The total basin relief is approximately 1,615 m, and the relief normal to the basin axis is between 610 and 915 m (Janda and others, 1975). The average hillslope gradient is 26 percent; hillslopes in the basin are commonly steepest along their lower segments adjacent to steam channels.

Redwood Creek has a gravelly inner flood plain that is inundated during periods of high discharge. Along reaches in lower Redwood Valley and within Redwood National Park (fig. 1), a higher outer flood plain is underlain by 2 to 5 m of sandy loam and silt loam. Channel gradients range from 0.15 m/m (meters per meter) in the headwaters to 0.003 m/m in lower Redwood Creek, and the average gradient above Orick is 0.014 m/m (Janda and others, 1975). Tributaries are generally steep and lack flood plains.

Sheared and fractured bedrock of the Franciscan assemblage of Late Jurassic and Cretaceous age underlies most of the basin (Harden and others, 1981). Unmetamorphosed sandstone and shale, together with associated small bodies of greenstone, crop out in the eastern half of the basin. The western half and the southwestern corner of the basin are underlain by fine-grained quartz-mica schist. Rocks transitional in texture and degree of metamorphism crop out between these two units in portions of the basin. Weakly consolidated sedimentary rocks of probable Pliocene and Pleistocene age crop out in the northern part of the basin (chap. B, this volume).

The Redwood Creek basin receives about 2,000 mm of rain annually, and average precipitation ranges from about 1,525 mm near Orick to over 2,540 mm in the basin headwaters. Most of the rain falls between October and April during moderately intense regional storms that commonly produce as much as 500 mm of precipitation in 72 hours. During the last 30 years, the basin has had six floods that had instantaneous peak discharges of about 1,400 m^3/s (cubic meters per second) at Orick. Redwood Creek transports one of the highest sediment loads in the conterminous United States (Janda and Nolan, 1979). The long-term average annual total sediment load is about 2,350 Mg/km^2.

≈ 10.5 T/Ac.

TYPES OF MASS MOVEMENT

Discrete erosional landforms occupy approximately 30 percent of the Redwood Creek landscape (Nolan and others, 1976; Harden and others, 1978) (table 1). Tilted trees, midslope depressions, and ground cracking in many of the remaining areas attest to the activity of less clearly defined landslides even in more stable portions of the basin. In addition, creep processes are active on almost all basin hillslopes. The types and rates of mass movement operating on hillslopes in the basin appear to be influenced by the underlying bedrock, slope aspect, vegetation, and land use (Harden and others, 1978). The type of mass movement operating on a given hillslope influences the rate of sediment supply to adjacent stream channels (chap. J, this volume). Our landslide classification scheme (Nolan and others, 1976) closely follows that of Varnes (1978).

DEBRIS SLIDES

Debris slides produce well-defined, nearly planar failure surfaces as a result of discrete, episodic failures. Movement is dominantly translational and generally involves the upper 2 to 4 m of colluvium and fractured bedrock (Marron, 1982) (fig. 2). Debris slides in the Redwood Creek basin are concentrated on streamside hillslopes (Colman, 1973; Nolan and others, 1976) and adjacent to roads and log-loading decks. Examination of time-sequential aerial photographs indicates that most slides are initiated during major winter storms, sometimes in conjunction with human disturbance. Although partial stabilization of streamside debris slides may occur within several years, activity on portions of many failures persists for decades.

DEBRIS AVALANCHES

Debris avalanches produce long, narrow scars that are straight to slightly sinuous and generally shallow (<4 m) (fig. 3). Movement is rapid and produces a chaotic mixture of disrupted vegetation, soil, and colluvium. Debris avalanche chutes are common on the steepest upper hillslopes in the basin and are also a common result of road failure. Like debris slides, debris avalanches occur in response to a single disruptive influence such as a major storm. Once initiated, these shallow scars may remain unvegetated for years but do not tend to enlarge significantly. Debris avalanche chutes at the heads of stream channels may carry debris flows during extremely wet periods; through geologic time, the chutes may evolve to form parts of stable drainage networks on steep upper slopes.

TABLE 1.—*Abundance of mass-movement landforms in the Redwood Creek basin as of 1974*

[Sources: Nolan and others (1976) and Harden and others (1978)]

Category	Percent of basin area above Prairie Creek
Active features:	
Debris slides	1
Debris avalanches	.2
Earthflows[1]	12
Unstable streambanks	3
Total	16.2
Inactive features:	
Old and questionable landslides	10
Amphitheater-shaped basins	5
Total	15

[1] Very active earthflows, which display unvegetated areas, open cracks, and bulbous toe slopes, occupy 2 percent of the basin area.

FIGURE 2.—Streamside debris slide, about 20 m in height, along the main channel of Redwood Creek about 6 km upstream from State Highway 299.

EARTHFLOWS

Earthflows occupy more area within the Redwood Creek basin than all other types of mass failure combined (Nolan and others, 1976) (table 1). Movement by both translational and rotational sliding, as well as by flowing, produces characteristic hummocky and lobate topography (fig. 4). Measured depth of one earthflow, near the mouth of Minor Creek (fig. 1), ranges from 4.5 to 7.7 m (Richard Iverson, U.S. Geological Survey, written commun., 1983). Earthflows typically bear grassland prairie vegetation and associated oak and madrone. They are commonly dissected by discontinuous gullies, which are important sediment sources in the basin (chap. F, this volume).

Movement of earthflows is variable but tends to be continuous rather than episodic. Active earthflows generally move during every rainy season, and the amount of seasonal movement varies with both rainfall amount

FIGURE 3.—Debris avalanche in the Prairie Creek basin approximately 2 km from the town of Orick.

and distribution (Harden and others, 1978). Movement rates also depend on the distribution of mass within the earthflow (chap. F, this volume). Repetitive surveys of stake lines indicate that a period of prolonged rainfall that saturates earthflows at depth is required before earthflows begin to move. High annual movement rates have occurred during winters such as that of 1973–74, when persistent heavy rains fell during November (Harden and others, 1978). Brief intense storms do not necessarily trigger deep-seated earthflow movement, but they can result in gullying and other surface erosion from earthflows. Average movement rates on four monitored earthflows in the basin ranged from 0 to 2.5 m/yr (meters per year) between 1974 and 1982 (Harden and others, 1978).

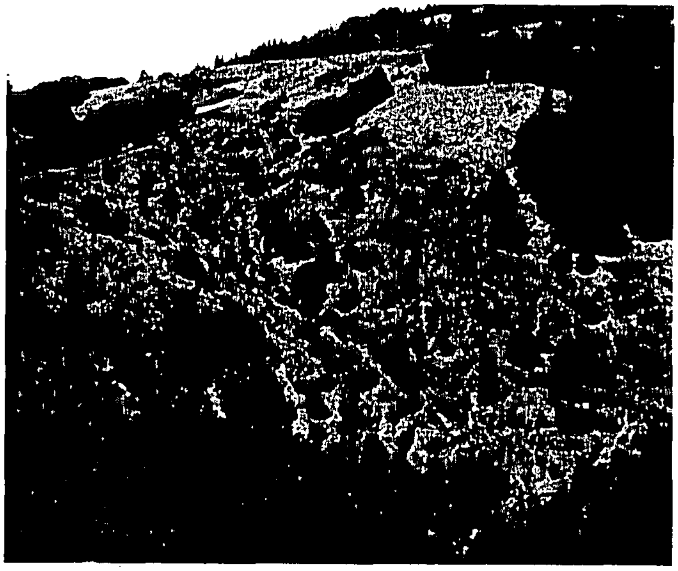


FIGURE 4.—Typical earthflow in the Redwood Creek basin adjacent to the downstream end of Minor Creek. View is toward north; local relief is about 200 m.

Large areas of bowl-shaped basins having characteristic earthflow topography indicate that earthflow movement has been a major geomorphic process in the basin during recent geologic time. Many of these features bear stands of trees that indicate stability for at least the past 50 to 100 years. Prairies lacking earthflow topography and recently forested areas adjacent to earthflows suggest that active earthflows may presently be less widespread in the basin than at some time in the past. However, the relationship between prairie vegetation and inactive earthflows is not clearly established.

SLUMPS

Slumps are uncommon in the Redwood Creek basin except as components of complex earthflows (Nolan and others, 1976). Slumps involve rotational movement of intact colluvial masses and produce concave-upward failure surfaces. Movement rates are probably similar to, or less than, those of debris slides. Slumping in the basin is generally confined to streamside hillslopes and along roads.

SOIL CREEP

Soil creep is probably active on most slopes in the basin but produces no discrete erosional landforms. Creep is probably a continuous mass-movement process. Rates vary from site to site within the basin and with fluctuations in rainfall. Swanston and others (chap. E, this volume) discuss soil creep in the basin.

INFLUENCE OF BEDROCK TYPE ON MASS-MOVEMENT PROCESSES

The underlying bedrock exerts a strong influence on both the type and rate of mass movement processes operating in the basin. A comparison of landslide distribution (Nolan and others, 1976) within different lithologic units (Harden and others, 1981) shows that most discrete, active mass failures are located on hillslopes underlain by unmetamorphosed and partially metamorphosed rocks of the Franciscan assemblage. Fewer mapped landslides lie within the schist terrain, although the existence of unmapped forested earthflows and other probable landslides in areas underlain by schist would weaken the observed relationship between landsliding and bedrock type.

Earthflow distribution shows strong correlation with lithologic type. Large, deep-seated earthflows are almost entirely restricted to areas underlain by unmetamorphosed argillaceous deposits of the Franciscan assemblage. Furthermore, the bedrock observed in active earthflow areas is apparently finer grained and more intensely sheared than that in surrounding areas. Earthflows bearing prairie vegetation are generally restricted to south- and west-facing hillslopes; this condition indicates that slope aspect, as well as lithology, influences earthflow distribution.

The terrain formed by shallow debris avalanches contrasts sharply with earthflow terrain in the basin (fig. 5). Debris avalanches are restricted to steep slopes underlain by massive, resistant sandstone units within the unmetamorphosed Franciscan assemblage (Harden and others, 1981). The upper portions of Lost Man and Little Lost Man Creeks and the northwest-trending part of the Lacks Creek basin are two prominent examples of debris-avalanche terrain in the basin.

The location of large debris slides also appears to be partly controlled by bedrock lithology. Streamside debris slides, particularly those adjacent to upper Redwood Creek, seem to be preferentially developed in unmetamorphosed rocks. Streamside debris slides are also concentrated along the linear zones of sheared rocks parallel to the Grogan fault in the lower basin (Harden and others, 1981). Northwest-trending linear zones of slope instability also mark other shear zones along Bridge and Devils Creeks.

FIGURE 5.—Contrast between earthflow terrain (foreground) and steeper debris-avalanche terrain (background). Area shown is in the Lacks Creek basin. Local relief is about 300 m.

The concentration of mappable landslides in areas underlain by unmetamorphosed rocks of the Franciscan assemblage (Nolan and others, 1976) suggests that these terranes contribute more sediment to Redwood Creek than do areas underlain by schist. However, hillslopes are steeper in areas underlain by unmetamorphosed and partially metamorphosed Franciscan assemblage rocks (Janda and others, 1975); thus, hillslopes shaped by rapid creep or less well defined landslides may be eroding more rapidly over geologic time to produce the gentler slopes of the schist terrane. Alternatively, the schist slopes may indeed represent a more mature and thus more stable landscape; more gentle slopes created by reduced relief are less susceptible to active mass movement. We do not have conclusive evidence to support either hypothesis, but the presence of deep ultisols on early Pleistocene(?) gravels that cap the schist on divides in the lower Redwood Creek basin (Harden and others, 1981) suggests that at least the upper parts of the schist landscape are relatively old. In addition, the predominance of unmetamorphosed clasts in the gravel bed of Redwood Creek (chap. N, this volume) may indicate that the schist terrain is eroding less rapidly; however, the fine-grained schist cobbles are less resistant to abrasion than the sandstone clasts.

RELATION OF PHYSIOGRAPHY TO MASS MOVEMENT

Approximately 80 percent of the 551 mapped active landslides in the basin (Nolan and others, 1976) occur on hillslopes having average gradients between 30 and 70 percent (table 2). Earthflows generally occur on gentler slopes than do debris slides and avalanches. Slopes having debris slides and debris avalanches show similar average gradients (table 2).

The incidence of mass failure other than earthflows on slopes less than 30 percent (table 2) is relatively low. The low incidence of landslides on slopes having dominant

TABLE 2.—*Selected data for sites of active mass movement related to dominant hillslope gradient*

[Number of features is given outside parentheses; percentages of total are shown in parentheses. Modified from Harden and others (1978). Hillslope gradients were measured from a photomechanically generated slope map of the basin, scale 1:62,500]

Slope class (gradient in percent)	Total percent of basin area in slope class	Type of mass movement feature				Total	Percent features in slope class weighted by basin area in slope class
		Debris slides and small mass failures	Debris avalanches	Slumps	Active earthflows		
0–15	8.6	2 (0.5)	2 (2.3)	0 (0)	0 (0)	4 (0.7)	0.9
15–30	35.3	48 (13.2)	11 (12.4)	2 (28.6)	41 (45.6)	102 (18.5)	5.5
30–50	50.2	222 (60.8)	56 (62.9)	4 (57.1)	48 (53.3)	330 (59.9)	13.0
50–70	5.5	85 (23.3)	19 (21.3)	1 (14.3)	1 (1.1)	106 (19.3)	37.3
>70	.4	8 (2.2)	1 (1.1)	0 (0)	0 (0)	9 (1.6)	43.3
Total	100	365 (100.0)	89 (100.0)	7 (100.0)	90 (100.0)	551 (100.0)	100.0

TABLE 3.—*Selected data for sites of active mass movement related to steepest hillslope gradient*

[Number of features is given outside parentheses; percentages of total are shown in parentheses. Modified from Harden and others (1978). Hillslope gradients were measured from a photomechanically generated slope map of the basin, scale 1:62,500]

Slope class (gradient in percent)	Total percent of basin area in slope class	Type of mass movement feature				Total	Percent features in slope class weighted by basin area in slope class
		Debris slides and small mass failures	Debris avalanches	Slumps	Active earthflows		
0–15	8.6	2 (0.5)	1 (1.1)	0 (0)	0 (0)	3 (0.5)	0.1
15–30	35.3	13 (3.6)	3 (3.4)	0 (0)	3 (3.3)	19 (3.5)	.2
30–50	50.2	151 (41.4)	43 (48.3)	4 (57.1)	72 (80.0)	270 (49.0)	1.8
50–70	5.5	120 (32.9)	26 (29.2)	3 (42.9)	8 (8.9)	157 (28.5)	9.5
>70	.4	79 (21.6)	16 (18.0)	0 (0)	7 (7.8)	102 (18.5)	88.4
Total	100	365 (100.0)	89 (100.0)	7 (100.0)	90 (100.0)	551 (100.0)	100.0

gradients steeper than 70 percent reflects the fact that these slopes occupy only 0.4 percent of the total basin area. That these steep slopes are highly susceptible to mass failure is demonstrated by the incidence of landslides on hillslopes where the steepest gradient exceeds 70 percent (table 3).

Slope aspect also apparently exerts a controlling influence on earthflow distribution. Earthflows bearing prairie vegetation are confined to south- and west-facing slopes in the basin. Greater insolation on these slopes apparently affects at least the vegetation type. However, the number of unmapped forested earthflows in the basin is unknown, and the influence of slope aspect on earthflow distribution may be less than is apparent.

Flood plains play an important role in controlling streamside landslides in the basin (Janda and others, 1975). The wide alluvial flats in lower Redwood Creek and in Redwood Valley (Harden and others, 1981) (fig. 6) protect the toes of streamside hillslopes from undercutting. Slopes along these reaches of Redwood Creek are therefore less susceptible to the destabilizing effects of flood-induced aggradation (chap. N, this volume).

RECENT INCREASES IN STREAMSIDE LANDSLIDES

The number of active streamside landslides in the basin increased dramatically between 1947 and 1975 (Colman, 1973; Nolan and others, 1976; Harden and others, 1978). About 100 unvegetated landslides, mainly debris slides, can be seen along the Redwood Creek channel on 1947 aerial photographs, whereas 415 active landslides appear on the 1976 photographs. The erosional landform map of Nolan and others (1976) documents a similar dramatic increase for many tributaries in the basin.

Widespread landsliding along many north coast rivers is often attributed to the flood of December 1964 (Dwyer and others, 1971; Kelsey, 1977; Harden and others, 1978). The degree to which intensive timber harvesting exacerbated these landslides has been a subject of controversy (U.S. House of Representatives, 1976). The disturbances caused by the 1964 storm were probably increased by the destabilizing effects of earlier major storms in the basin, as well as by timber harvesting. As Colman (1973) and Harden and others (1978) have pointed out, the combined impact of timber harvesting and the floods between 1953 and 1975 probably was greater than if either disturbance had occurred alone. The impact of the 1964 storm on north coast hillslopes appears to have been unusually severe relative to that of other similar storms of the past 120 years (chap. D, this volume).

By using sequential sets of aerial photographs of the Redwood Creek channel (table 4), Colman (1973) and Harden and others (1978) have documented the history of basinwide landslide activity since 1947. Colman (1973) supplemented landslide inventories made from aerial photographs with field mapping and descriptions. Because of the variable scale of the photographs (table 4), we estimate that the smallest discernible landslides

FIGURE 6.—Protective influence of flood plains on streamside hillslopes. Streamside landslides are numerous where Redwood Creek abuts hillslopes directly (1). On opposite bank, landslides (2) are separated from the active channel by a low flood plain. The photograph depicts the main channel of Redwood Creek immediately below the mouth of Minor Creek.

discussed in the following paragraphs are about 30 m in width. We have inventoried landslides primarily by number of features, although volumes were crudely estimated by Colman (1973). However, we include brief discussion of National Park Service volumetric measurements of landslides where appropriate.

Not surprisingly, periods having major flood-producing storms showed the greatest increases in streamside landslides (fig. 7). During the interval from 1947 to 1958, the two major storms of 1953 and 1955 apparently triggered numerous streamside slides. However, the impacts of these storms on hillslopes were much less severe than the impacts of the 1964 and 1972 storms, even though storm intensity and flood runoff were similar to those of the 1953 and 1955 storms (chap. D, this volume). The lesser impact of the earlier storms may reflect the fact that they occurred before extensive streamside logging took place (fig. 8). However, streamside slopes may have also been more susceptible to landsliding during the later storms because of channel aggradation and small-scale destabilization during the 1953 and 1955 events.

The period of maximum streamside landsliding (1962–66) includes the December 1964 flood (fig. 7). The concentration of new and increased landslide activity from 1962 to 1966 would be even more pronounced if volumes rather than numbers of landslides were compared (Colman, 1973). Pitlick (chap. K, this volume) has estimated that more than half of the volume of landslide debris delivered to tributary channels between 1947 and 1978 was supplied during this interval, specifically during the 1964 flood. Streamside timber harvesting was most intense from 1958 to 1966, especially in the upper watershed where precipitation was also greatest during the 1964 storm.

The impact of the 1972 and 1975 floods on streamside hillslopes was significantly less dramatic than that of the 1964 storm (fig. 7). Rainfall intensities were probably lower for the 1972 storms (chap. D, this volume), and streamside logging lessened from 1970 to 1974 (fig. 8).

TABLE 4.—*Aerial photograph coverage of the main channel of Redwood Creek*

Date	Scale	Area of main channel covered[1]	Source
1936	1:30,000	Prairie Creek to Lupton Creek	T. Hatzimanolis, Redwood National Park.
1947	1:45,000	About 0.8 km below Copper Creek to Roddiscroft Road.	U.S. Geological Survey.
1958	1:12,000	Prairie Creek to Roddiscroft Road	Humboldt County.
1962	....do....	....do....	Do.
1966	....do....	....do....	Do.
1970–71	....do....	....do....	Do.
1972	1:36,000	....do....	National Park Service.
1973	1:10,000	Prairie Creek to 0.8 km below Snow Camp Creep	U.S. Geological Survey.
1974	....do....	Prairie Creek to Roddiscroft Road	Do.
1974	1:12,000	Prairie Creek to Roddiscroft Road	Humboldt County.
1975	1:10,000	Prairie Creek to about 1.6 km above Pardee Creek	National Park Service.
1976	....do....	Prairie Creek to Roddiscroft Road	Do.

[1] Localities are shown on figure 1.

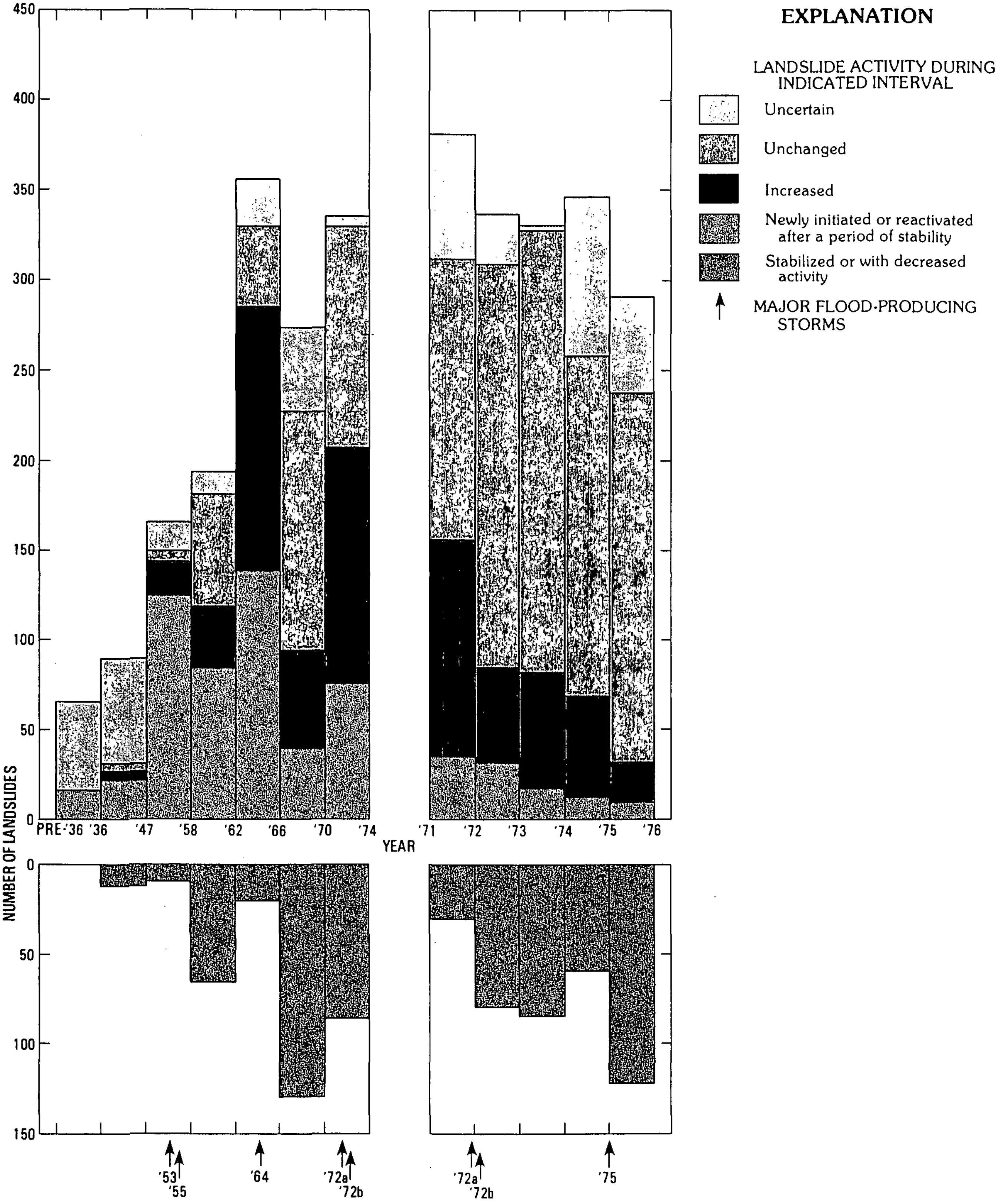


FIGURE 7.—Activity of streamside landslides adjacent to Redwood Creek between Roddiscroft Road and Prairie Creek, 1936–76. Data are based on interpretation of aerial photographs (from Harden and others, 1978). Note that time periods are not even. They represent times of available aerial photography.

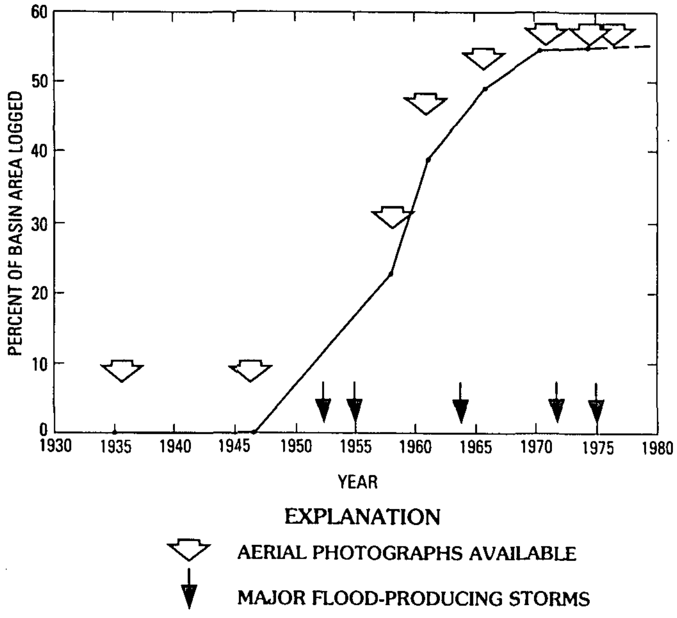
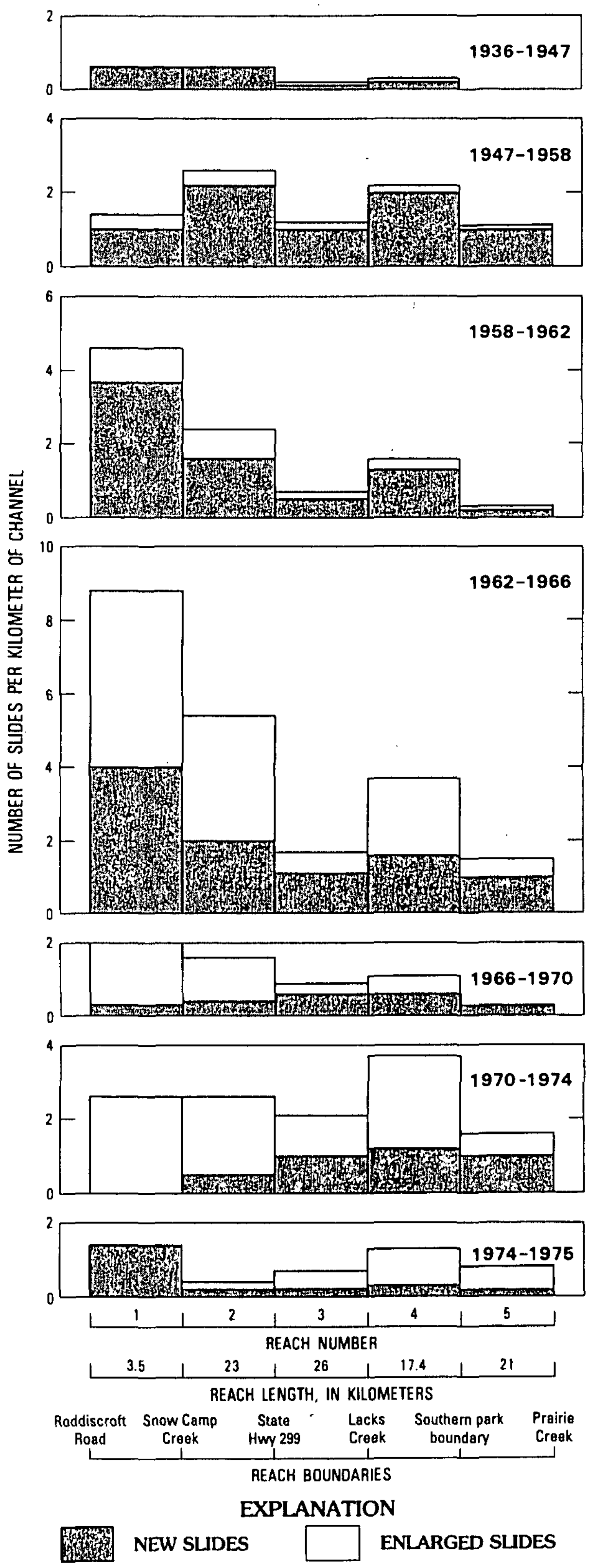


FIGURE 8.—Cumulative percent of Redwood Creek streamside hillslopes logged between 1936 and 1976.

FIGURE 9.—Distribution and occurrence of landslides adjacent to ▶ selected reaches of Redwood Creek. Boundaries between reaches are shown at bottom and on figure 1. Note that time periods are not even. They represent times of available aerial photography.



New timber harvest practices involving less ground surface disruption were also in force from 1974 to 1975 (Janda, 1978), and these new practices may have lessened the impacts of timber harvest on streamside hillslopes. Nevertheless, the number of new or enlarged slides below State Highway 299 (fig. 9, reaches 3–5) for both 1970–74 and 1974–75 was almost as great or greater than for the 1962–66 interval, although these slides were generally much smaller than the massive slides triggered during 1962–66 along the upper channel.

The flood-free periods of 1958–62 and 1966–70 were characterized by only minor increases in streamside mass movement in most reaches. Many features stabilized or decreased in activity, and few new slides were initiated. The lesser amount of slide activity between 1958 and 1962 indicates that the absence of major storms was the main reason for the decreased number of landslides, because streamside timber harvest was most intense during this period (fig. 8). However, those increases in slide activity that did occur from 1958 to 1962 were concentrated in areas where timber harvest was active (fig. 9, reaches 2 and 4). The additional harvesting combined with the lingering effects of pre-1958 logging, including root decay and poorly maintained roads, were probably responsible for many of the additional landslides.

Between 1966 and 1970, many slides along the Redwood Creek channel healed to some extent, and very few new slides were initiated (fig. 7). Most preexisting features remained active to some extent, however, particularly in the upper basin. Many of the massive debris slides initiated in 1964 along reaches 1 and 2 showed little if any vegetation by 1970.

The locus of maximum landslide activity along the channel has migrated downstream since 1947 (fig. 9). New and increased slide activity was generally concentrated above State Highway 299 (reaches 1 and 2) prior to 1966. After 1966, the number of new and enlarged slides per kilometer of channel increased in the lower reaches and generally decreased proportionately upstream from State Highway 299 (fig. 1). Several factors may have contributed to this shift. First, most unstable slopes in upper reaches already may have failed by 1966, presumably during the intense rainfall of 1964. Second, streamside timber harvesting was concentrated in the lower Redwood Creek basin after 1966. Finally, sediment deposited in the upper reaches during the 1964 flood has migrated to the lower channel since that time (chap. N, this volume). The increased sliding in lower reaches since 1966 may be partly a response to the channel widening and undercutting of slopes that resulted from the massive influx of sediment related to the 1964 flood.

The damage to streamside hillslopes by the 1964 flood persisted for at least 15 years, and many of the massive debris slides in the upper basin showed only minor revegetation by 1976. However, these slides are presently contributing much less sediment to Redwood Creek than they did during the 1960's (chap. J, this volume); as a result, major channel aggradation has presently ceased in upper Redwood Creek (chap. N, this volume). Nevertheless, these massive, unvegetated debris slides in the upper basin may be remobilized during major storms comparable to the storm of December 1964. Continuing slope failures triggered by aggradation in downstream areas are in part another legacy of the 1964 flood-induced landslides in the upper basin.

CONTRIBUTION OF TIMBER HARVEST TO STREAMSIDE LANDSLIDES

The series of flood-producing storms during the period 1953 to 1975 (chap. D, this volume) was undoubtedly a major cause of the observed increases in streamside landslides. The 1964 storm was the most damaging of the series and resulted in massive landslides and channel aggradation that can still be observed along most north coast rivers. The magnitude of this storm, its concentration in the upper watershed where streamside slopes are highly susceptible to failure, and the destabilizing effects of the 1955 flood probably all contributed to the severity of the 1964 flood impact. However, the intensive streamside timber harvest in those reaches where the storm was most intense was also an important factor in triggering slope failures. The tendency, during any given interval, for streamside reaches having active logging to show concurrent landslides during flood years (Harden and others, 1978) reflects the destabilizing effects of logging.

One of the most conclusive lines of evidence that points to timber harvest as a factor for the increased streamside landslides since the 1950's is the dramatically smaller impact of the floods of the late 1800's compared to those between 1953 and 1975. Despite the apparent similarity between the two storm series (chap. D, this volume), streamside landslides were much less widespread during the earlier events time period.

Evidence of streamside landslides during floods of the late 1800's is preserved in the form of landslide-shaped, streamside areas of young, even-aged vegetation visible on 1936 and 1947 aerial photographs. These young stands are interpreted as revegetated landslide scars, and they occur to a limited extent along all major north coast streams. Scars of large landslides initiated by the 1890 flood would bear vegetation not more than 57 years old in 1947; scars of slides initiated by the 1861–62 floods would bear vegetation not more than 85 years old in 1947. Arboreal vegetation populating the scars of late-19th-century landslides in 1947 can clearly be distinguished from old-growth forest on aerial photographs, but only a limited number of streamside landslide scars can be identified on 1936 and 1947 aerial photographs. Conclusive evidence of landsliding during the late 1800's was provided by coring of trees on two landslides along Redwood Creek near the former southern boundary of Redwood National Park (fig. 1). The tree-ring records revealed that nearly all of the trees were established immediately after the 1861–62 floods (S. Veirs, Jr., U.S. National Park Service, written commun., 1977). One slide showed evidence of continued movement until after the 1890 flood.

Evidence of aggradation that was presumably triggered by landslides during the 19th-century floods is also visible in parts of the Redwood Creek basin and other areas, but evidence for aggradation before 1960 appears localized and inconsistent from valley to valley. Even-aged stands of conifers on some gravel bars near Redwood Valley were about 100 years old in 1974 (Janda and others, 1975). Other sites having evidence of major aggradation during the late 19th century include Blue

Creek (Helley and LaMarche, 1973) and Bald Mountain Creek (Kelsey, 1977). Evidence also exists for older major episodes of aggradation (Helley and LaMarche, 1973; Kelsey, 1977). Along the upper reaches of the Redwood Creek channel, the age of riparian trees buried and killed by the 1964 flood was estimated at 200 to 300 years. Many streamside redwoods that have been toppled by recent bank erosion or buried by recent gravel deposits along parkland reaches of Redwood Creek are more than 1.8 m in diameter and probably more than 150 years old.

SUMMARY

Studies of mass movement in the Redwood Creek basin document the importance of landslides both as long-term landscape-forming processes and as major factors in the ongoing denudation of the area. The fourfold increase in streamside debris slides adjacent to the Redwood Creek channel between 1947 and 1975 can be attributed to the combined impacts of major floods, particularly the flood of 1964, and to intensive timber harvesting. Over geologic time, persistently active earthflows and creep processes, which have not been significantly affected by recent storms and timber harvesting, have been at least as important as episodic mass failures in the sculpting of basin of hillslopes.

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Harden 1995

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

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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).

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TABLE 1.—*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)		Redwood Creek at Orick (drainage area 720 km^2)	
	(m^3/s)	[m^3/s)/km^2]	(m^3/s)	[m^3/s)km^2]
Jan. 18, 1953	(1)	(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; Helley 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

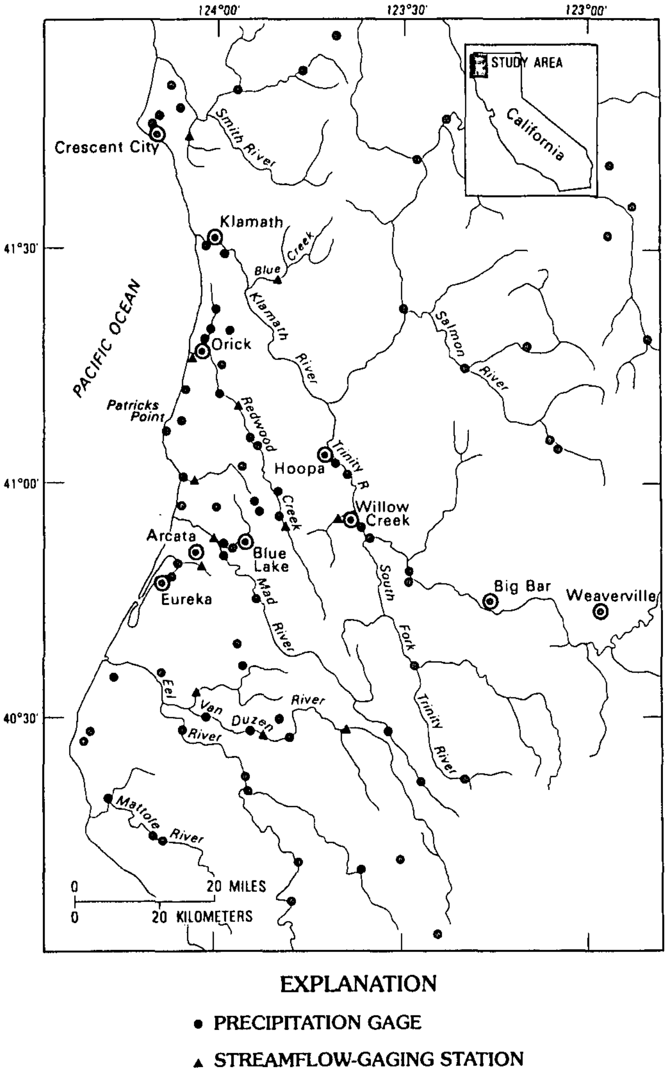


FIGURE 1.—Location of precipitation and streamflow-gaging stations in northwestern California.

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).

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

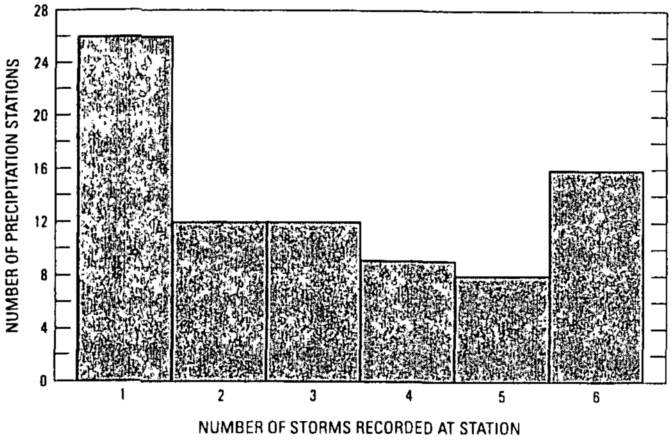


FIGURE 2.—Histogram showing number of precipitation stations operating during storm events.

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

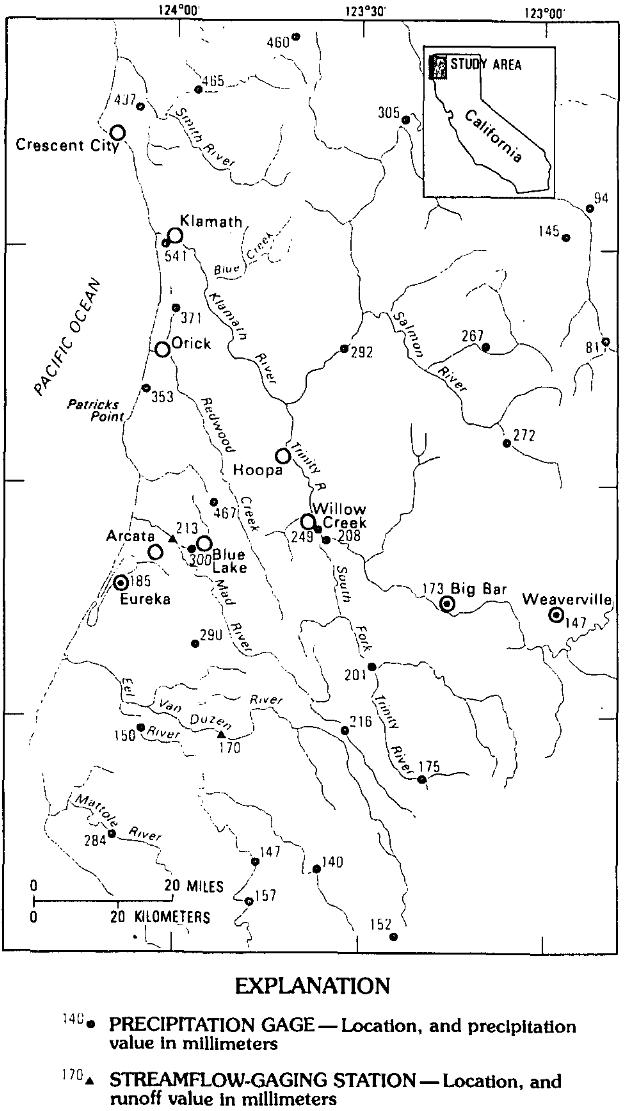
The antecedent precipitation index (API) developed by Kohler and Linsley (1951) provided a means of assessing the soil moisture conditions in this area prior to each storm. The index uses a decay equation to carry over a portion of each day's precipitation to a selected date of interest, in this case 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

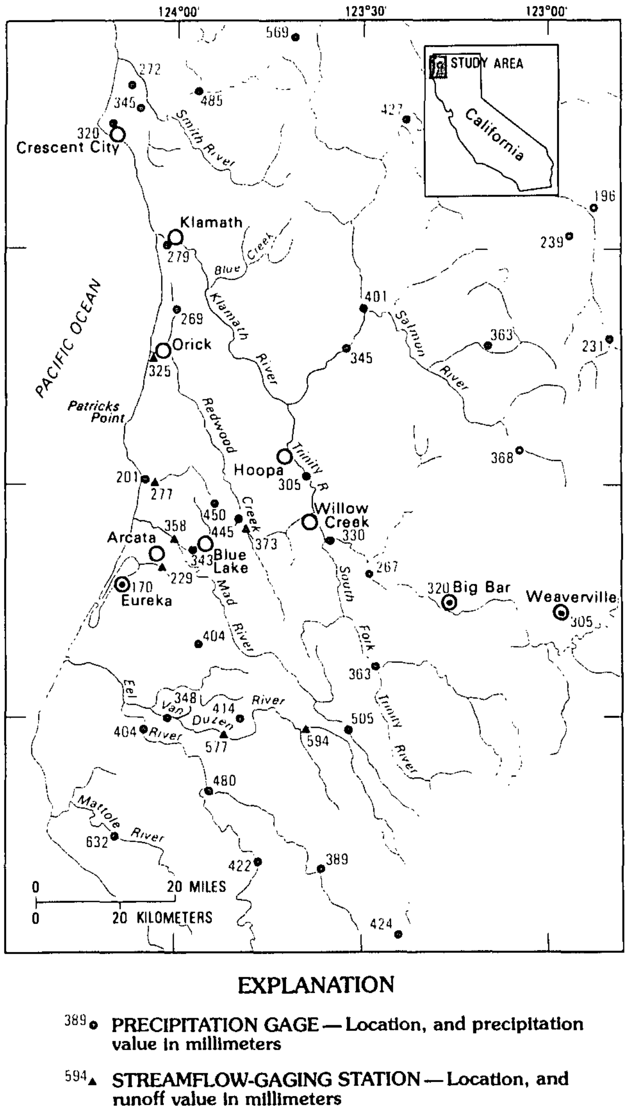


EXPLANATION

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

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

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

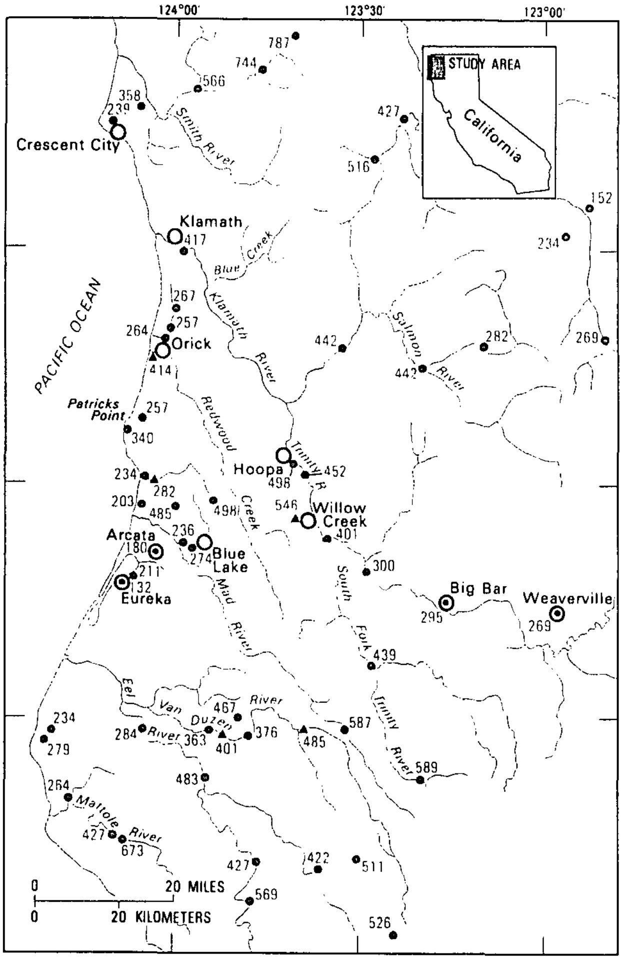
FIGURE 4.—Precipitation and runoff for December 15 to 23, 1955.

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

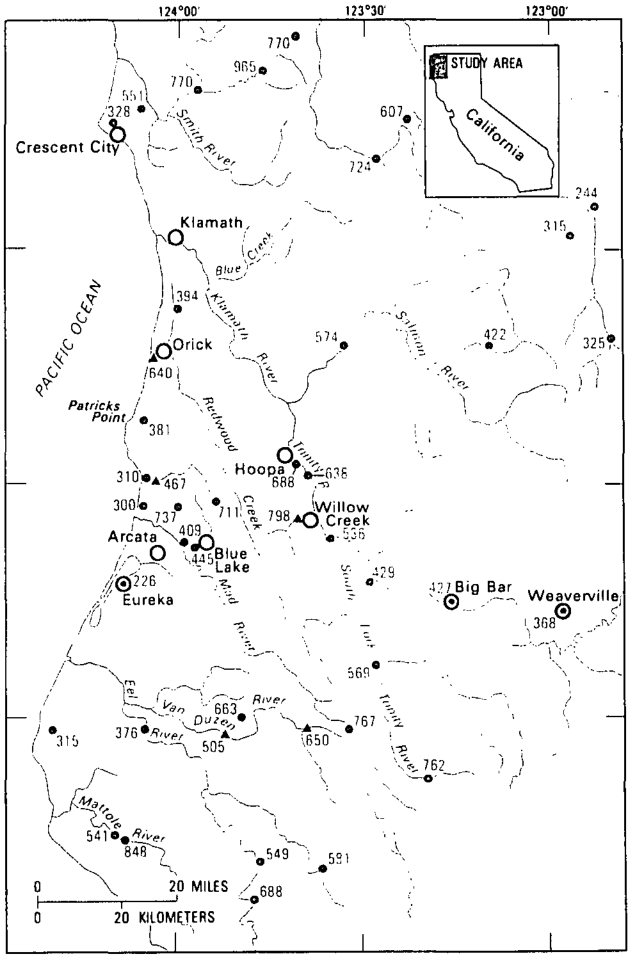


EXPLANATION

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

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

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



EXPLANATION

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

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

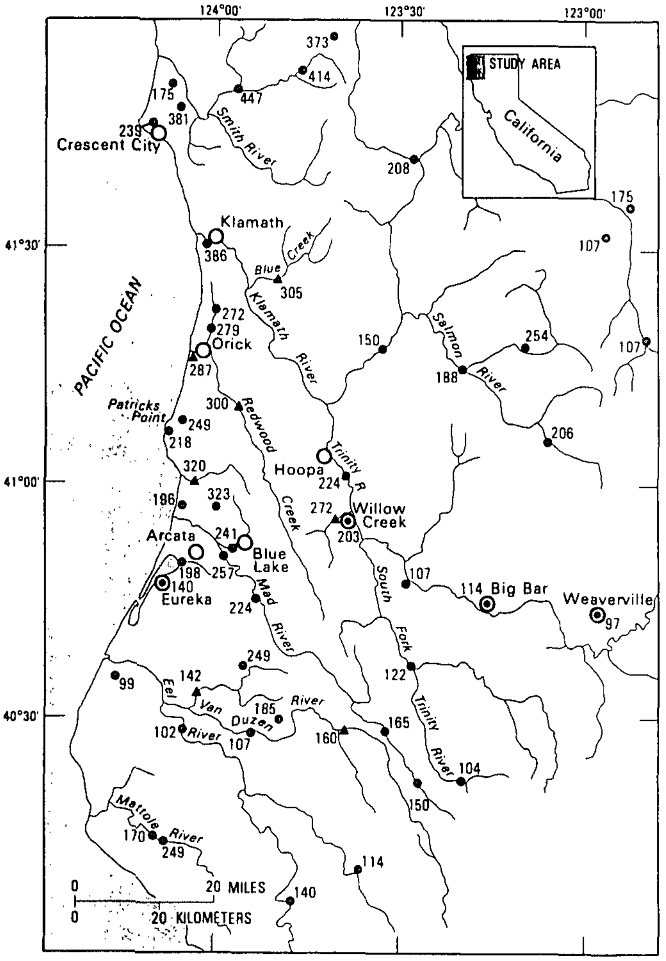
FIGURE 6.—Precipitation and runoff for December 18 to 30, 1964.

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).

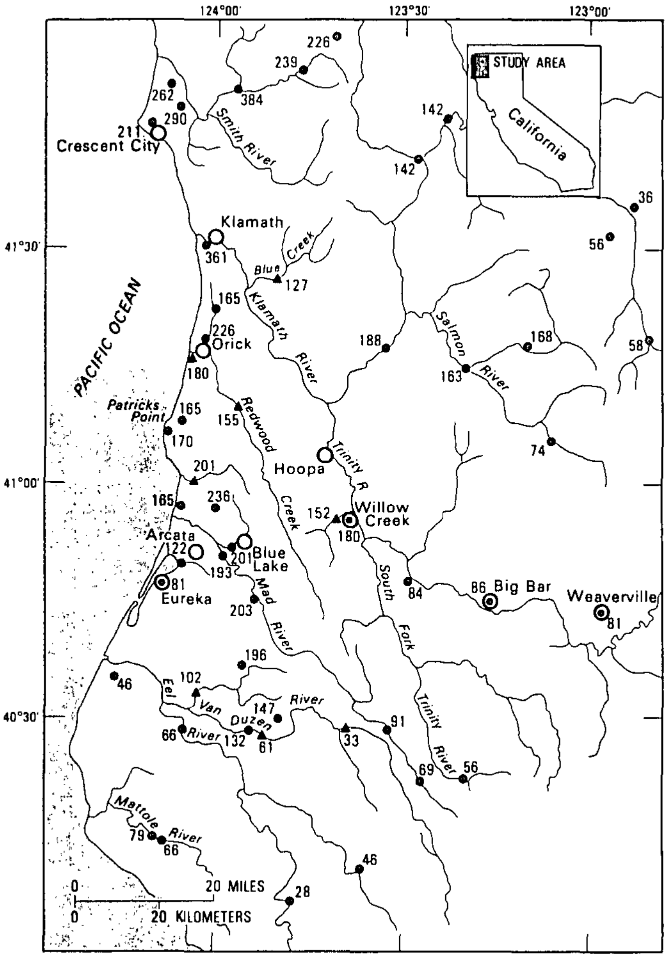


EXPLANATION

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

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

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



EXPLANATION

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

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

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*

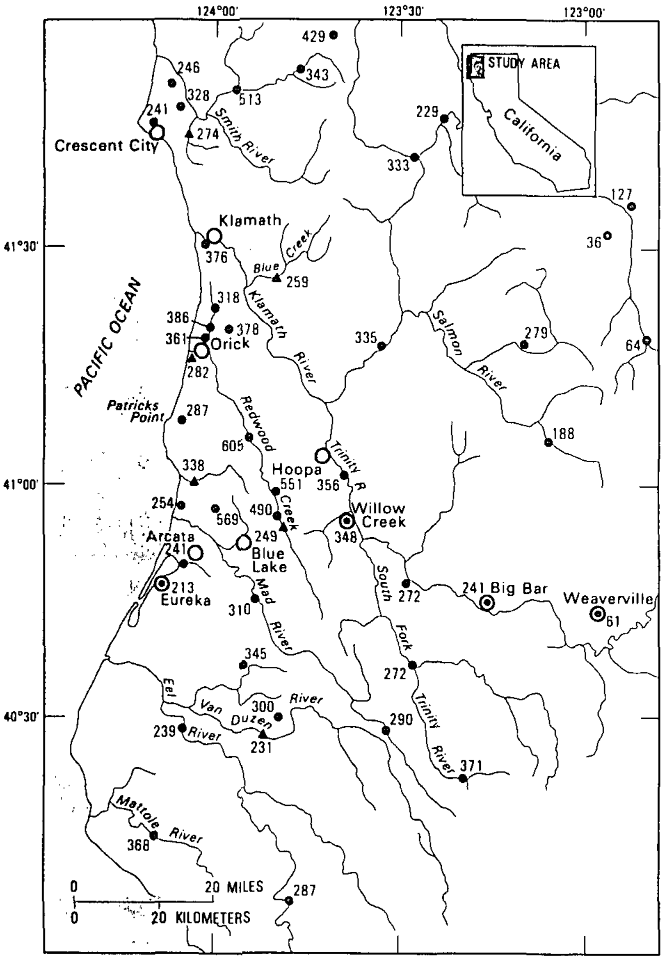
[—, no data]

	API, in millimeters			
Year	Orick	Hoopa	Big Bar	Willow Creek
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



EXPLANATION

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

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

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.

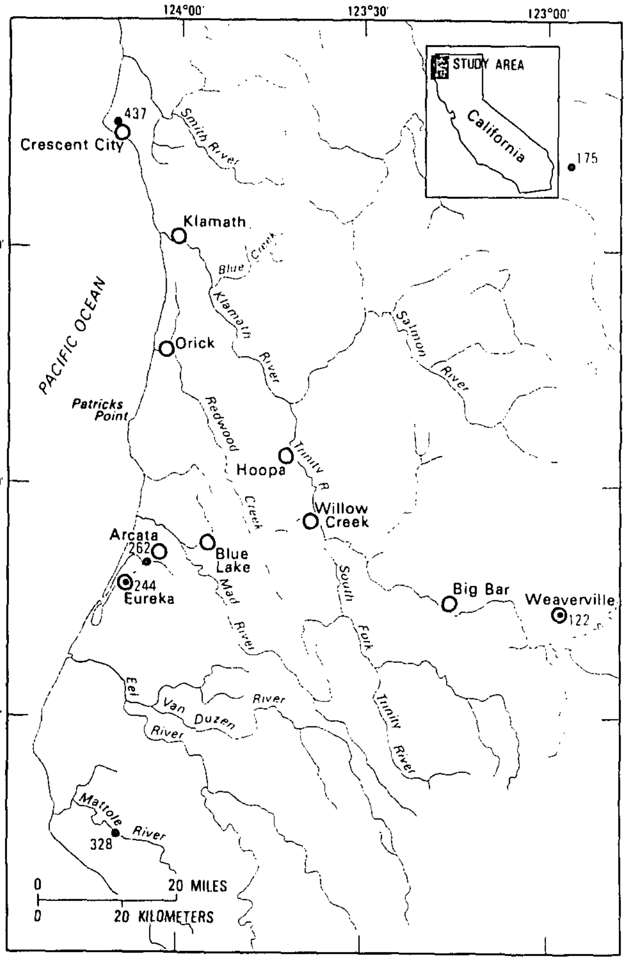
PRECIPITATION TOTALS

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

328● 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, Helley 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 Helley 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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