UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY
Water Resources Division

# FLOOD OF DECEMBER 1964 IN REDWOOD AREAS OF NORTH COASTAL CALIFORNIA

Saul Edward Rantz, 1911-



OPEN-FILE REPORT
# [65-130]

Menlo Park, California
March 1965

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# FLOOD OF DECEMBER 1964 IN REDWOOD AREAS OF NORTH COASTAL CALIFORNIA

By S. E. Rantz

## ABSTRACT

The flood of December 1964 in the redwood areas of north coastal California was the most damaging in the history of the area. The flood resulted from a series of storms in late December, but primarily from the warm torrential rainfall of December 21-23. This rainfall reflected the combined effect of moist unstable airmasses, strong west-southwest winds, and mountain ranges oriented nearly at right angles to the flow of air. The magnitude of the rainfall over much of the mountainous area was equal to or greater than that estimated to have an average return period of 100 years. Precipitation totals in excess of 10 inches in 24 hours and 15 inches in 48 hours were commonplace in the mountains and interior valleys. The peak discharge of streams draining these drenched areas was extremely high and also had a return period estimated to be greater than 100 years. By contrast, some of the areas immediately adjacent to the Pacific Ocean had maximum 24-hour rainfalls of only 2 inches and the small streams draining these low-altitude basins experienced rises that were little greater than those that occur during the usual winter storms.

A somewhat sketchy analysis of peak runoff rates indicates that the variation of peak discharge in the areas of heavy rainfall can be explained by variation in drainage area size and variation in volume and intensity of precipitation. Because the rainfall was fairly uniform for at least 24 hours during the height of the storm, the maximum 24-hour basinwide precipitation provided an index of both volume and intensity of precipitation. The equation relating these variables is

$$Q = 2.96 P^{2.8} A^{-0.255}$$

where Q = peak discharge, in cubic feet per second per square mile

P = maximum 24-hour basinwide precipitation, in inches

A = drainage area, in square miles

This equation also fits closely the few observed events in small basins that had relatively light rainfall. However, there were too few data of this kind to define the equation reliably for areas with light rainfall.

Suspended-sediment concentrations and loads were high in most streams in the redwood area. However the quantitative data available are sparse (as of March 1, 1965) because many samples that were collected are still awaiting analysis and sediment loads are still to be computed. It is highly probable that some of the small streams near the ocean, that had relatively low runoff, also had relatively low sediment concentrations.

The available streamflow and suspended-sediment data are inadequate to evaluate the effect of logging on runoff and sediment production during the flood. However, the analysis of peak runoff rates leaves one with the impression that logging had little effect on the peak discharge of streams whose watersheds received heavy rainfall.

## INTRODUCTION

Intense rainfall during late December 1964 produced record-breaking floods in Oregon, northern California, western Nevada and Idaho, and southern Washington. The redwood areas in the coastal basins of Califoria north of San Francisco Bay were particularly hard hit. This paper describes the flood in these coastal areas (fig. 1), and briefly analyzes the peak runoff rates that occurred.

The report was prepared by the Geological Survey under the supervision of Walter Hofmann, district chief, at the request of L. B. Leopold, Chief Hydrologist of the Water Resources Division.

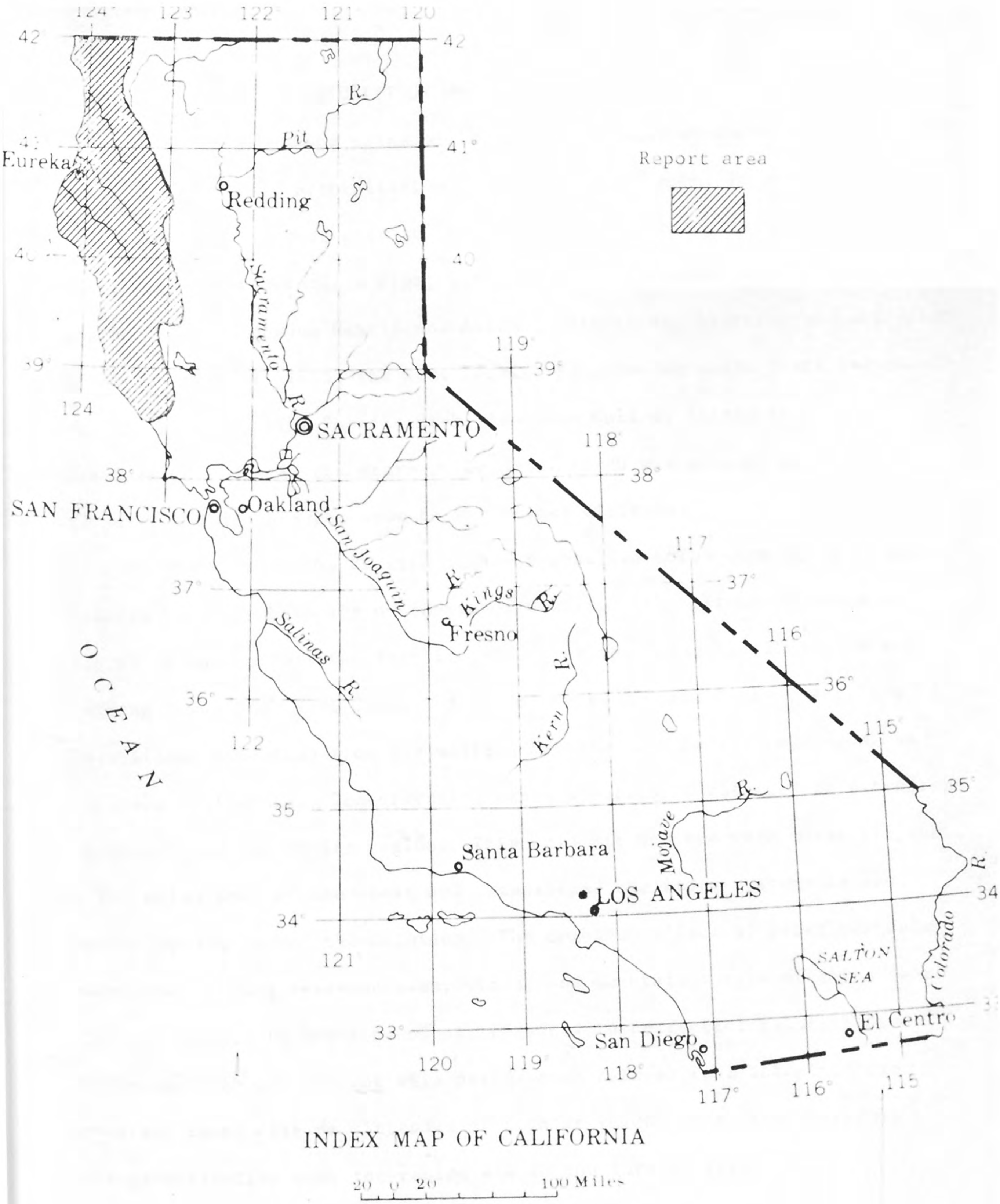


Figure 1.--Location of report area.

## DESCRIPTION OF THE STORM

The flood-producing rains of late December were of unprecendented intensity. Fairly heavy precipitation began late on December 18 under meteorological conditions that gave no indication that storms of unusual intensity would follow. The Pacific High, a high-pressure airmass, occupied most of the ocean area between Hawaii and Alaska, effectively blocking the migration of moist tropical air to the West Coast. Because the storm track lay around the north side of the Pacific High, from the Gulf of Alaska to northern California, the storm of December 18-20 was accompanied by low temperatures and brought snow to the higher altitudes.

On December 20 the Pacific High was observed to be undergoing progressive erosion in the subtropics northeast of Hawaii. This allowed subsequent storms to move across the Pacific at successively lower latitudes before turning toward the West Coast. A storm track, 500 miles wide, was thus established extending from the western Pacific near Hawaii to Oregon and northern California. Concurrently, there occurred an outbreak of extremely cold air from the Arctic region. This cold air met the warm moist air about 1,000 miles west of the coast and intensified the storm systems as they moved rapidly toward the mainland. The combined effect of moist unstable airmasses, strong west-southwest winds, and mountain ranges oriented nearly at right angles to the flow of air resulted in torrential rainfall from December 21 to 23. During this period temperatures rose sharply. The freezing level rose to altitudes as high as 10,000 feet, and therefore all precipitation over the region was in the form of rain.

During the period December 24-31, a surge of rising pressure moved into the ocean area northeast of Hawaii. This changed the weather pattern drastically by cutting off the flow of warm moist air to the mainland, and for several days there was heavy snow which extended down to low altitudes, and intermittent rain and hail near sea level. These weather conditions effectively reduced the immediate hazard of additional flooding, but seriously hampered rescue work in the flood-stricken area.

Table 1 presents precipitation data for the storms of late December for selected precipitation stations in the redwood belt (fig. 2). At most of these stations the gages are read once daily, generally at 0700 hours. Consequently the tabulated figures generally represent the precipitation catch between gage readings, and not the greatest catch in a designated number of hours without regard to clock time. The pronounced orographic influence on precipitation is evident on examination of table 1. At Fort Bragg on the coast, the maximum 24-hour rainfall totaled 3.5 inches, while at Branscomb 2NW (altitude, 1,480 feet), less than 20 miles to the northeast of Fort Bragg and only 8 miles from the coast, the maximum 24-hour precipitation totaled 10.7 inches. Fort Ross on the coast had a maximum 24-hour precipitation of 1.4 inches, and the coastal city of Eureka, popularly considered a storm-wracked city, had a maximum 24-hour precipitation of only 2.2 inches. By comparison, precipitation was extremely heavy in the mountains that occupy most of the coastal basins. Table 1 shows that 24-hour precipitation totals in excess of 10 inches and 48-hour totals in excess of 15 inches were commonplace. In the Eel River basin, Harris had a 24-hour precipitation total of 13.2 inches and Laytonville had a 48-hour precipitation total of 22.7 inches. In general the magnitude of the maximum 24-hour precipitation in mountain areas and interior valleys was equal to or greater than the 24-hour rainfall whose average return period is estimated to be 100 years (U.S. Weather Bureau, 1961). The rainfall totals for 48-hour and 120-hours generally exceeded the average once-in-100 year totals (U.S. Weather Bureau, 1964).

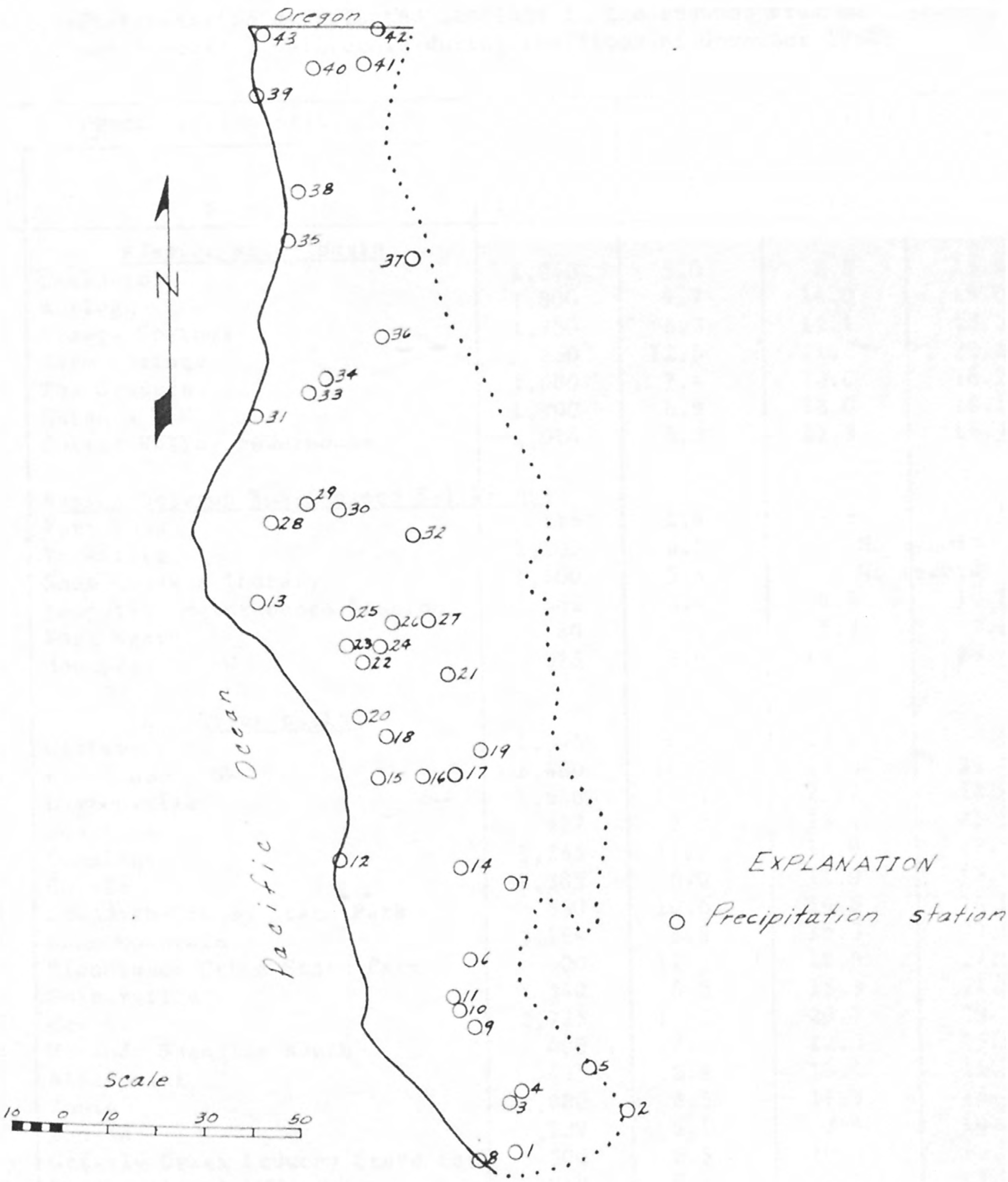


Figure 2.--Location of selected precipitation stations.

Table 1.--Precipitation at selected stations in the redwood area of north coastal California during the flood of December 1964

| Precipitation station | | | Precipitation, in inches | | |
|---|---|---|---|---|---|
| No. on fig. 2 | Name | Altitude (feet) | 24-hour maximum | 48-hour maximum | 120-hour maximum |
| | Russian River basin | | | | |
| 1 | Cazadero | 1,040 | 5.0 | 8.8 | 15.4 |
| 2 | Kellogg | 1,800 | 9.7 | 14.0 | 19.0 |
| 3 | Skaggs Springs | 1,930 | 6.3 | 12.1 | 18.5 |
| 4 | Warm Springs | 660 | 12.6 | 21.3 | 29.1 |
| 5 | The Geysers | 1,600 | 7.4 | 13.0 | 18.2 |
| 6 | Ukiah 4 WSW | 1,900 | 6.9 | 13.0 | 18.1 |
| 7 | Potter Valley powerhouse | 1,014 | 8.3 | 12.3 | 16.9 |
| | Basins between Russian and Eel Rivers | | | | |
| 8 | Fort Ross | 116 | 1.4 | 2.5 | 4.4 |
| 9 | Yorkville | 1,100 | 6.2 | No record | |
| 10 | Soda Creek tributary | 1,600 | 5.4 | No record | |
| 11 | Boonville Maintenance Station | 342 | 5.4 | 9.5 | 14.5 |
| 12 | Fort Bragg | 80 | 3.5 | 5.2 | 7.8 |
| 13 | Honeydew 2 WSW | 375 | 8.0 | 15.8 | 23.6 |
| | Eel River basin | | | | |
| 14 | Willits 1 NE | 1,345 | 8.8 | 13.6 | 20.9 |
| 15 | Branscomb 2 NW | 1,480 | 10.7 | 17.3 | 29.9 |
| 16 | Laytonville | 1,640 | 12.4 | 22.7 | 27.9 |
| 17 | Dos Rios | 927 | 9.3 | 16.6 | 21.5 |
| 18 | Cummings | 1,265 | 11.2 | 18.0 | 27.9 |
| 19 | Covelo | 1,385 | 6.0 | 11.0 | 15.4 |
| 20 | Standish-Hickey State Park | 850 | 10.6 | 14.8 | 24.0 |
| 21 | Lake Mountain | 3,164 | 8.8 | 15.3 | 20.5 |
| 22 | Richardson Grove State Park | 500 | 11.3 | 18.5 | 27.4 |
| 23 | Garberville | 340 | 8.3 | 15.3 | 21.4 |
| 24 | Harris | 2,225 | 13.2 | 20.7 | 29.2 |
| 25 | Miranda Spengler Ranch | 400 | 7.5 | 12.3 | 15.6 |
| 26 | Alderpoint | 435 | 5.9 | 10.4 | 15.7 |
| 27 | Zenia | 2,880 | 6.5 | 11.5 | 18.7 |
| 28 | Scotia | 139 | 5.1 | 7.4 | 10.2 |
| 29 | Grizzly Creek Redwood State Park | 500 | 6.5 | 10.0 | 13.1 |
| 30 | Bridgeville 4 NNW | 2,050 | 5.5 | 10.8 | 17.2 |
| 31 | Eureka WB City | 43 | 2.2 | 3.0 | 4.3 |

Table 1.--Precipitation at selected stations in the redwood area of north coastal California during the flood of December 1964 (continued)

| Precipitation station | | | Precipitation, in inches | | |
|---|---|---|---|---|---|
| No. on fig. 2 | Name | Altitude (feet) | 24-hour maximum | 48-hour maximum | 120-hour maximum |
| | Mad River and Redwood Creek basins | | | | |
| 32 | Mad River Ranger Station | 2,775 | 7.9 | 14.8 | No record |
| 33 | Korbel | 145 | 4.2 | 6.8 | 9.7 |
| 34 | Blue Lake 8 NE | 1,875 | 7.0 | 11.1 | 18.0 |
| 35 | Orick Prairie Creek Park | 161 | 3.0 | 5.1 | 9.1 |
| | Klamath River basin | | | | |
| 36 | Hoopa | 345 | 8.5 | 14.4 | 19.4 |
| 37 | Orleans | 403 | 7.4 | 11.1 | 15.3 |
| 38 | Klamath Glen | 20 | 4.0 | 8.0 | 14.2 |
| | Smith River basin | | | | |
| 39 | Crescent City 1 N | 40 | 3.4 | 5.2 | 8.2 |
| 40 | Gasquet Ranger Station | 384 | 6.4 | 10.4 | 20.0 |
| 41 | Idlewild Highway Maintenance Station | 1,250 | 10.7 | 17.5 | 27.1 |
| 42 | Elk Valley | 1,711 | 9.3 | 18.1 | 29.0 |
| 43 | Lopez Creek | 60 | 3.2 | 4.5 | 8.3 |

## DESCRIPTION OF THE FLOOD

Antecedent conditions in the coastal basins were favorable for heavy runoff from the storm of late December 1964. Rainfall in November and the first half of December had brought soil moisture to a high level, and the following rains of December 18-20 saturated the soil and caused modest rises in the streams. When the torrential rains of December 21-23 arrived, the response of runoff to the rainfall was dramatic. Streams rose quickly and spilled over their banks bringing destruction and tragedy to the area. Exactly nine years earlier, in December 1955, these same streams had rampaged wildly to create unprecedented disaster. The 1964 floods generally were more intense and the peak stages not only exceeded those in 1955, but closely approached or were even greater than those that occurred during the almost legendary floods of 1861-62.

An exception to this general runoff pattern occurred in some of the small streams tributary to or adjacent to the Pacific Ocean. These streams drain low-elevation basins in the western foothills of the Coast Ranges and because the rainfall over these basins was relatively light, these streams experienced rises that were little greater than those that occur during the usual winter storms. Two such streams, Prairie Creek tributary and Lopez Creek, are discussed in a later section of this report.

Table 2 lists peak discharge figures that are available, as of March 1, 1964, for gaging stations in the study area (fig. 3). No gaging stations in the Klamath River basin were used because peak discharge figures for that basin are available only for streams draining the larger tributary watersheds, most or all of whose areas lie outside the redwood belt. Peak discharge figures are not shown for the Eel River stations upstream from Dos Rios, because peak discharges there were affected by storage in Lake Pillsbury, and this effect has not yet been evaluated.

The floods in each of the major basins in the report area are briefly described on the pages that follow.

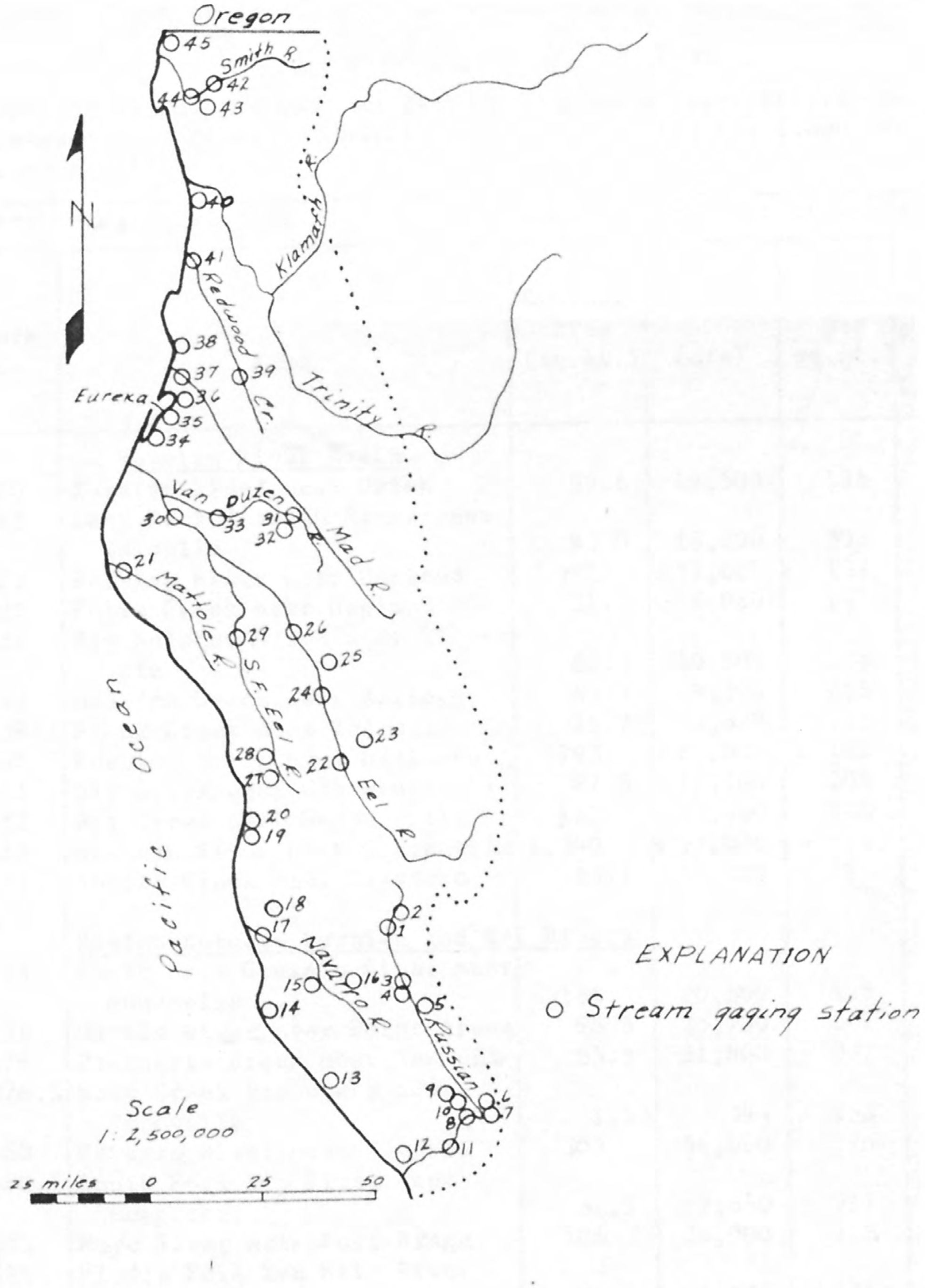


Figure 3.--Location of stream-gaging stations.

Table 2.--Peak discharge and maximum 24-hour basinwide precipitation in the redwood area of north coastal California during the flood of December 1964

| Stream-gaging station | | | | Peak discharge | | |
|---|---|---|---|---|---|---|
| No. on fig. 3 | Network no. | Name | Drainage area (sq.mi.) | (cfs) | (cfs per sq.mi.) | Estimated maximum 24-hour basinwide precipitation (inches) |
| | | Russian River basin | | | | |
| 1 | 4610 | Russian River near Ukiah | 99.6 | 19,500 | 196 | 7 |
| 2 | 4615 | East Fork Russian River near Calpella | 93.0 | 18,800 | 202 | 7 |
| 3 | 4625 | Russian River near Hopland | 362 | a 57,000 | a 157 | 7 |
| 4 | 4627 | Feliz Creek near Hopland | 31.1 | 6,080 | 195 | 7 |
| 5 | 4632 | Big Sulphur Creek near Cloverdale | 82.3 | 10,500 | 128 | 7 |
| 6 | 4639 | Maacama Creek near Kellogg | 43.4 | 9,370 | 216 | 7 |
| 7 | 4639.3 | Franz Creek near Kellogg | 15.7 | 3,620 | 231 | 7 |
| 8 | 4640 | Russian River near Healdsburg | 793 | a 80,000 | a 101 | 7 |
| 9 | 4645 | Dry Creek near Cloverdale | 87.8 | 18,100 | 206 | 7 |
| 10 | 4652 | Dry Creek near Geyserville | 162 | 33,400 | 206 | 7 |
| 11 | 4670 | Russian River near Guerneville | 1,340 | a 97,000 | a 72 | 6 |
| 12 | 4672 | Austin Creek near Cazadero | 63.1 | 12,000 | 190 | 7 |
| | | Basins between Russian and Eel Rivers | | | | |
| 13 | 4675 | South Fork Gualala River near Annapolis | 161 | 20,600 | 128 | 6 |
| 14 | 4676 | Garcia River near Point Arena | 98.5 | 25,700 | 261 | 7 |
| 15 | 4678 | Rancheria Creek near Boonville | 65.6 | 21,800 | 332 | 7 |
| 16 | 4678.5 | Soda Creek tributary near Boonville | 1.53 | 394 | 258 | 5.4 |
| 17 | 4680 | Navarro River near Navarro | 303 | 54,000 | 178 | 6 |
| 18 | 4680.7 | South Fork Big River near Comptche | 36.3 | 7,650 | 211 | 6 |
| 19 | 4685 | Noyo River near Fort Bragg | 106 | 24,000 | 226 | 7 |
| 20 | 4686 | Middle Fork Ten Mile River near Fort Bragg | 32.9 | 5,670 | 172 | 6 |
| 21 | 4690 | Mattole River near Petrolia | 240 | 78,200 | 326 | 9 |

Table 2.--Peak discharge and maximum 24-hour basinwide precipitation in the redwood area of north coastal California during the flood of December 1964 (continued)

| Stream-gaging station | | | Drainage area (sq.mi.) | Peak discharge | | Estimated maximum 24-hour basinwide precipitation (inches) |
|---|---|---|---|---|---|---|
| No. on fig. 3 | Network no. | Name | | (cfs) | (cfs per sq.mi.) | |
| | | Eel River basin | | | | |
| 22 | 4722 | Outlet Creek near Longvale | 161 | 67,400 | 419 | 9 |
| 23 | 4730 | Middle Fork Eel River near Covelo | 367 | 160,000 | 436 | 10 |
| 24 | 4740 | Eel River below Dos Rios | 1,484 | 446,000 | 301 | 10 |
| 25 | 4745 | North Fork Eel River near Mina | 250 | 130,000 | 520 | 10 |
| 26 | 4750 | Eel River at Alderpoint | 2,079 | 561,000 | 270 | 10 |
| 27 | 4755 | South Fork Eel River near Branscomb | 43.9 | 19,900 | 453 | 10 |
| 28 | 4757 | Tenmile Creek near Laytonville | 50.3 | 14,500 | 288 | 9 |
| 29 | 4765 | South Fork Eel River near Miranda | 537 | 199,000 | 371 | 10 |
| 30 | 4770 | Eel River at Scotia | 3,113 | 752,000 | 242 | 10 |
| 31 | 4775 | Van Duzen River near Dinsmores | 85.1 | 27,000 | 317 | 8 |
| 32 | 4777 | South Fork Van Duzen River near Bridgeville | 36.2 | 13,600 | 376 | 8 |
| 33 | 4785 | Van Duzen River near Bridgeville | 216 | 48,700 | 225 | 7 |
| | | Elk River basin | | | | |
| 34 | 4797 | Elk River near Falk | 44.5 | 3,430 | 77 | 4 |
| | | Jacoby Creek basin | | | | |
| 35 | 4800 | Jacoby Creek near Freshwater | 6.1 | 1,530 | 252 | 6 |
| | | Mad River basin | | | | |
| 36 | 4808 | North Fork Mad River near Korbel | 40.5 | 15,400 | 380 | 8 |
| 37 | 4810 | Mad River near Arcata | 484 | b85,000 | b 176 | 8 |
| | | Little River basin | | | | |
| 38 | 4812 | Little River at Crannell | 44.3 | 7,550 | 170 | 6 |

Table 2.--Peak discharge and maximum 24-hour basinwide precipitation in the redwood area of north coastal California during the flood of December 1964 (continued)

| Stream-gaging station | | | Drainage area (sq.mi.) | Peak discharge | | Estimated maximum 24-hour basinwide precipitation (inches) |
|---|---|---|---|---|---|---|
| No. on fig. 3 | Network no. | Name | | (cfs) | (cfs per sq.mi.) | |
| | | Redwood Creek basin | | | | |
| 39 | 4815 | Redwood Creek near Blue Lake | 67.5 | 16,400 | 243 | 8 |
| 40 | 4824 | Prairie Creek tributary near Klamath | .40 | 36 | 90 | 3.0 |
| 41 | 4825 | Redwood Creek at Orick | 278 | 50,500 | 182 | 8 |
| | | Smith River basin | | | | |
| 42 | 5310 | Middle Fork Smith River at Gasquet | 130 | 41,100 | 316 | 9 |
| 43 | 5320 | South Fork Smith River near Crescent City | 295 | 138,000 | 468 | 10 |
| 44 | 5325 | Smith River near Crescent City | 609 | 228,000 | 374 | 10 |
| | | Lopez Creek basin | | | | |
| 45 | 5330 | Lopez Creek near Smith River | .93 | 79 | 85 | 3.2 |

a Estimated natural peak discharge; observed peak discharge has been adjusted for effect of storage in Lake Mendocino.

b Estimated natural peak discharge; observed peak discharge has been adjusted for effect of storage in Ruth Reservoir.

In the Russian River basin peak discharges were generally slightly higher than those that occurred in 1955. The operation of Lake Mendocino, a flood-control and water-conservation reservoir built in 1958 on the East Fork Russian River, was instrumental in preventing damage from mounting higher than it did along the middle and lower reaches of the Russian River. For example, at the gaging station at Hopland a peak discharge of 41,500 cfs (cubic feet per second) was recorded. Closure of the gates of Lake Mendocino during the height of the flood prevented the peak discharge from reaching a probable value of about 57,000 cfs at the gaging station; by comparison the peak discharge in 1955 was 45,000 cfs. On the lower river where the greatest damage occurred, operation of the reservoir is believed to have reduced peak stages by about 2 feet. Despite this reduction in stage, record-breaking peak discharges occurred on the Russian River near Healdsburg (71,300 cfs) and near Guerneville (93,400 cfs).

The greatest damage in the Russian River basin occurred in the town of Guerneville and the surrounding resort area, where 500 persons were left homeless and an estimated 1,000 summer homes were either damaged or destroyed. The business district of Guerneville was flooded to depths of as much as 4 feet. Highway transportation was completely disrupted during the height of the flood. In the upper basin the principal damage was to agricultural lands. Thousands of acres were inundated and many acres were lost as a result of streambank erosion.

The small coastal basins between the Russian and Eel Rivers were also hard hit. The Noyo River near Fort Bragg crested at a record-breaking discharge of 24,000 cfs. The Mattole River near Petrolia, cresting at 78,200 cfs, approached its 1955 record discharge of 90,400 cfs. Because the area is very sparsely settled, practically all damage was confined to roads and bridges. Only in the Mattole River basin was there any appreciable loss of private property. Agricultural losses consisted mainly of silted pastures and loss of livestock.

In the Eel River basin river stages reached unprecendented heights in response to the heavy rainfall which amounted to as much as 22 inches in 48 hours. On the lower reaches of the South Fork Eel River peak stages exceeded those attained in the 1955 flood by only a few feet, but along the mainstem of the Eel River and its right-bank (eastern) tributaries the record peaks of 1955 were greatly exceeded. At the gaging station on the Eel River below Dos Rios the river crested 12.6 feet above the 1955 level at a discharge of 446,000 cfs; at Alderpoint the Eel River exceeded its 1955 peak stage by 14.7 feet and had a peak discharge of 561,000 cfs; at Scotia the Eel River exceeded its 1955 peak stage by 10.1 feet and discharged a phenomenal 752,000 cfs. Almost every gaging station in the basin was damaged or destroyed. Unprecedented peak discharges also occurred throughout the Van Duzen River basin, the principal tributary basin of the Eel River downstream from Scotia.

Damage in the Eel River basin was catastrophic. Because commercial and residential development is concentrated along U.S. Highway 101, which parallels the South Fork Eel River and the Eel River mainstem downstream from the junction with South Fork, this part of the basin suffered the greatest damage. The town of Pepperwood, rebuilt after being demolished by the 1955 flood, was obliterated. Almost as completely devastated were the communities of South Fork, Meyers Flat, Stafford, and Weott. The high velocity flow carrying heavy debris either flattened buildings or swept them from their foundations. The chief industrial damage was to the lumber industry, as facilities were destroyed and large stacks of logs and finished lumber were swept away. Agricultural damages in the delta area were tremendous. Numerous farm homes and out-buildings were destroyed or damaged and 4,000 head of cattle were lost. The damage to highways and bridges throughout the basin isolated many communities. Helicopters were used extensively both for rescue work and to carry supplies to isolated areas. Slides, washouts, and trestle losses shut down the Northwestern Pacific Railroad and many months will elapse before service can be resumed. Because this railroad normally carries about 75 percent of the lumber shipped from the area, activities in the lumber industry will of necessity be curtailed for months, adding to the economic hardship in the basin.

In the Mad River basin flooding was severe, but the operation of Ruth Reservoir in the headwaters was instrumental in preventing record-breaking peak discharges from occuring downstream. Nine miles downstream from the reservoir, the peak discharge at the Mad River gaging station near Forest Glen was 20,100 cfs on December 22, as compared with a peak discharge of 39,200 cfs in December 1955, prior to the construction of Ruth Reservoir. However, extremely heavy runoff in the lower part of the basin resulted in a peak discharge of 70,400 cfs at the downstream gaging station on the Mad River near Arcata. This peak flow is only 7,400 cfs less than that in 1955. Highway damage in the basin was severe, as was the damage to agricultural lands from erosion and the deposition of silt and debris. In the Blue Lake area a flood-weakened levee was responsible for minor flooding.

In the Redwood Creek basin, the peak discharge of Redwood Creek at Orick, 50,500 cfs, was slightly greater than that attained in the flood of December 1955. The creek rose rapidly and nearly every home and business establishment in the town of Orick was flooded. All residents were evacuated to higher ground. About 900 acres of agricultural land were inundated and roads were damaged.

The heavy rains in the Klamath River basin culminated in a tremendous peak discharge of 557,000 cfs on December 22 at the Klamath River gaging station near Klamath. This peak discharge is 107,000 cfs greater than the peak flow that occurred during the almost-legendary floods of the winter of 1861-62, and 132,000 cfs greater than the peak flow in December 1955. The town of Klamath was virtually obliterated, and two-thirds of the buildings in Klamath Glen, about 3 miles upstream, were destroyed. Farther upstream, at the junction of the Klamath and Trinity Rivers, the town of Weitchpec was destroyed as floodwaters rose to a stage that was 13.7 feet higher than that of 1861-62, and 19.5 feet higher than that of 1955. In the lower Trinity River basin the towns of Willow Creek and Hoopa were severely damaged. The economy of the lower Klamath and Trinity River basins, which is based on the production of lumber and lumber products, was dealt a severe blow. Several lumber mills were damaged or destroyed and the loss of stocks of finished lumber and logs was very high. In the delta area of the Klamath River more than 1,000 acres of agricultural land were inundated. In Hoopa Valley in the Trinity River basin several lumber mills were severely damaged, but the principal losses involved very extensive damage to roads and bridges. Only the fact that the Klamath River basin in California is sparsely settled prevented monetary damage from reaching astronomical figures.

In the Smith River basin, as in the Klamath River basin, peak discharges exceeded those attained in the flood of December 1955. At the gaging station on Smith River near Crescent City the peak discharge was 228,000 cfs, compared to a peak flow of 165,000 cfs in 1955. Particularly hard-hit was the Middle Fork Smith River. In the delta area of the river several thousand acres of pasture and agricultural land were inundated, with consequent damage from scouring and the deposition of silt and debris. Damage to roads and bridges was severe as a result of rain and high water which caused slides and washouts. Most notable was the loss of a bridge 2-1/2 miles east of Gasquet which closed U.S. Highway 199. The principal industrial damage was the inundation of lumber mills and the attendant loss of finished lumber and logs.

## ANALYSIS OF PEAK RUNOFF RATES

Peak runoff rates resulting from heavy storms depend primarily on drainage area size and on volume and intensity of precipitation. Other factors such as basin shape, land slope, land use, and the time distribution or sequence of rainfall also affect peak rates, but to a lesser degree. Therefore the rather sketchy analysis of peak runoff rates that was made for this report was based on drainage area size and on an index of volume and intensity of precipitation. The selection of a suitable precipitation index was based on an examination of the few available records for recording precipitation gages in the area. This examination showed that the rainfall was fairly uniform for at least 24 hours during the height of the storm, indicating that the maximum 24-hour basinwide precipitation would be a suitable index of both precipitation volume and intensity.

The maximum 24-hour basinwide values of precipitation that were used are shown in table 2. For the small basins of Soda Creek tributary (sta. 16) Prairie Creek tributary (sta. 40), and Lopez Creek (sta. 45), none of which are greater than 1.6 square miles, the basinwide precipitation was considered equal to the precipitation recorded in or near the basin. For the other 42 basins listed in table 2, the basinwide precipitation values were computed from the maximum 24-hour station values given in table 1, by use of the assumption that the ratio of basinwide precipitation to station precipitation for the 24-hour rainfall is equal to the ratio of basinwide precipitation to station precipitation for the long-term mean annual precipitation. Long-term mean annual precipitation values for both stations and basins had been computed previously. Those for the northern part of the report area have been published (Rantz, 1964); those for the southern part will appear in a later report (Rantz, in preparation). There is a degree of error involved in the computation of maximum 24-hour basinwide precipitation, but the computed values shown in table 2 are believed to be within ±1 inch of their true values. They were used in the analysis of peak discharge described below.

Data from table 2 were used in a graphical multiple correlation relating peak discharge per square mile of drainage area to drainage area and maximum 24-hour basinwide precipitation (fig. 4). The ranges of variables for the 45 gaging stations are as follows:

Peak discharge -- 77 to 520 cubic feet per second per square mile

Drainage area -- 0.4 to 3,113 square miles

Maximum 24-hour basinwide precipitation -- 3 to 10 inches

The family of curves on figure 4 consists of 8 lines of relationship, each representing an integer value of basinwide precipitation. The equation for this family of curves is

$$Q = 2.96\ P^{2.8} A^{-0.255}$$

where Q = peak discharge, in cubic feet per second per square mile

P = maximum 24-hour basinwide precipitation, in inches

A = drainage area, in square miles

The lower lines are poorly defined, there being only four basins that have precipitation values smaller than 6 inches. One would hardly expect the equation to be valid for a range of drainage area size from 0.4 to 3,113 square miles. Nevertheless, all but 4 of the 45 stations -- nos. 5, 17, 27, and 28 -- plot within 1 inch of precipitation from their respective relationship lines; the other 4 stations plot within 1 1/2 inches of precipitation from their respective lines. The small stations, nos. 16, 40, and 45, whose basinwide precipitation figures are observed values, plotted very close to their respective lines.

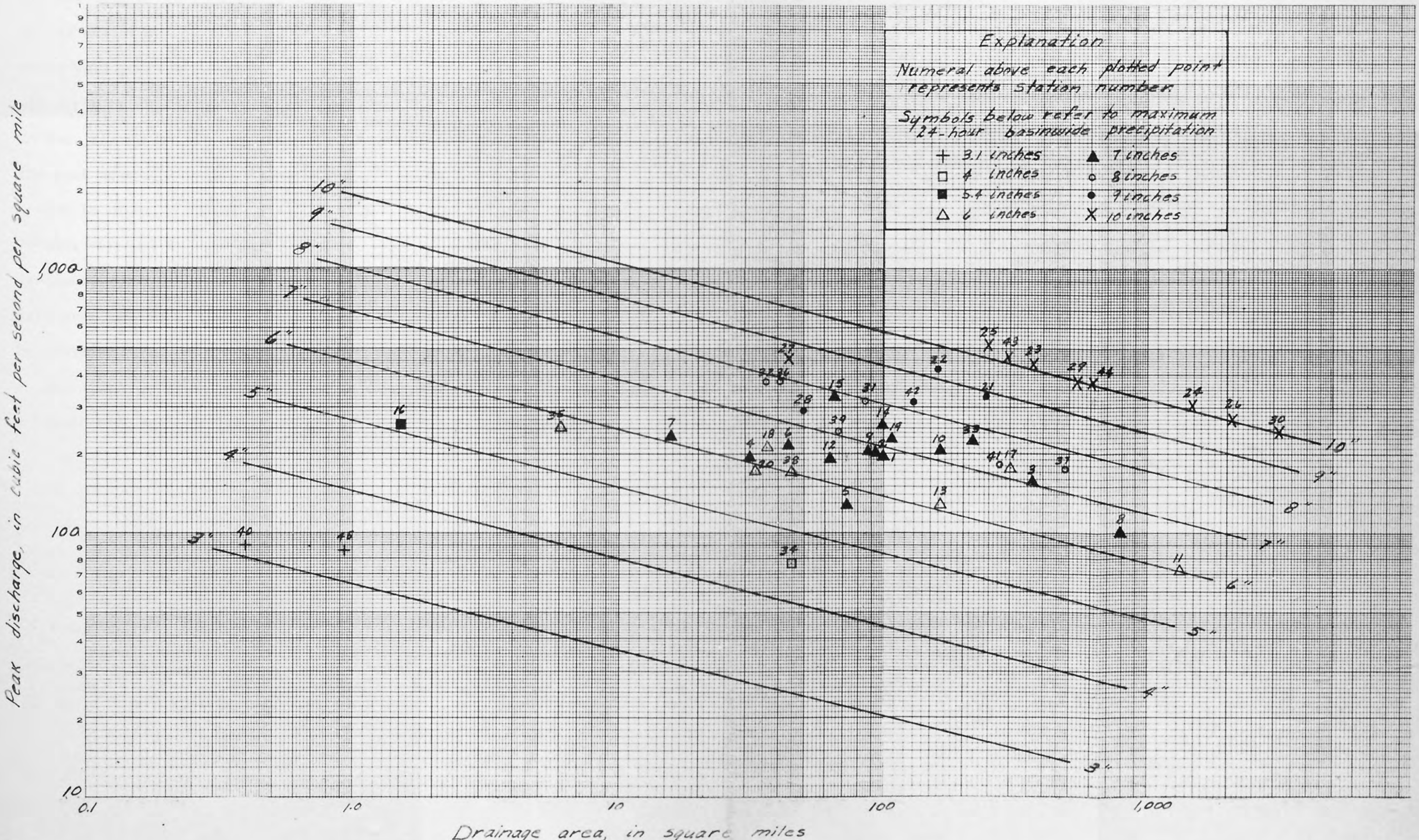


Figure 4.-- Relation of peak discharge to drainage area and maximum 24-hour basinwide precipitation in north coastal California, December 1964.

Because the departures from the relationship lines are generally within the accuracy of the computed basinwide precipitation, ±1 inch, investigation of the effect of other basin and climatic factors was not warranted. In other words, the variation in peak discharge of streams in the study area appears to be adequately explained by differences in basin size and maximum 24-hour precipitation. Figure 4 shows that for a given drainage area size, the peak discharge of a basin receiving a maximum 24-hour rainfall of 10 inches is almost 30 times the peak discharge of one receiving a maximum 24-hour rainfall of 3 inches. On the basis of precipitation magnitude-frequency studies by the U.S. Weather Bureau (1961, 1964), it is concluded that rainfall over many of the basins had a return interval of more than 100 years. Preliminary flood-frequency analysis for some of these same basins indicates a return period of about 150 years for the peak discharges that occurred, a result that is consistent with the rainfall-frequency studies.

## SUSPENDED SEDIMENT

Visual observation and the rather sketchy quantitative data that are available indicate that suspended-sediment concentration and load were high in most streams in the study area. Erosion occurred not only in areas with steep slopes and sparse vegetation, but there was also considerable erosion from cultivated lands on flood plains when streams overtopped their banks or changed their courses. However, part of the sediment transported by the streams was derived from their beds and banks as channels were scoured and widened by the floodwaters. Severe bank caving occurred in most streams when the floodwaters undercut their banks. This was especially damaging to the embankments of highways and railroads that closely parallel the streams, as along the Eel River, and to many buildings that were built on or near stream banks. Landslides, as in the Smith River basin, were another source of sediment. Floating debris combined with high sediment loads to clog the channels at many bridge and culvert sites. Most of the floating debris was of forest origin and consisted of trees, logs, brush, slash, and finished lumber. Many bridges had insufficient capacity to pass the floodflows and their approaches were overtopped and eroded away. Some bridges were lost when their abutments or piers were undermined by scour. It is likely, however, that several of the small streams draining low-altitude basins tributary to or adjacent to the Pacific Ocean, had light sediment loads because their peak runoff rates were not excessively high.

Corollary to the transport of sediment by streams is the deposition of sediment when the transporting capacity of the streams decreases. Therefore, as streams receded from their flood peaks and velocities decreased, deposits of sediment several feet thick were often left on the flood plain, on flooded highways, and in inundated homes. Large quantities of sediment were also deposited in the lower reaches of rivers and in reservoirs.

Table 3 is a summary of maximum suspended-sediment concentrations observed in the study area. Where two entries are listed under the heading, "Maximum observed concentrations," the second entry refers to the maximum concentration previously observed during the period of record. Table 3 is not complete because many samples that were collected are still awaiting analysis and sediment loads are still to be computed (as of March 1, 1965). Three of the stations listed in the table are on the Russian River, and for these stations there is little information on suspended-sediment concentrations in previous years. Little could be done, therefore, in comparing sediment transport in December 1964 with that in previous years. The maximum concentration observed in the Russian River during the 1964 flood period was 10,600 ppm (parts per million) on December 22 at the station near Ukiah. In the South Fork Eel River near Branscomb the maximum concentration observed was 2,760 ppm on December 21; the previous maximum observed was 2,420 ppm on January 31, 1963. The highest concentration observed in the Mad River near Arcata, 21,800 ppm, was more than 3 times as great as the previous maximum in February 1960. The suspended-sediment discharge at the Arcata station for the period December 18-31, 1964 was estimated to be about 10 million tons, or 7 times the average annual sediment discharge during the 5-year period 1958-62.

Table 3.--Summary of maximum observed suspended-sediment concentrations in the redwood area of north coastal California during the flood of December 1964.

| Sampling site | | Drainage area (sq.mi.) | Period of record | Maximum observed concentration | |
|---|---|---|---|---|---|
| Net-work no. | Name | | | Date | Concentration (ppm) |
| | Russian River basin | | | | |
| 4610 | Russian River near Ukiah | 99.6 | 1964 | Dec. 22, 1964 | 10,600 |
| 4620 | East Fork Russian River near Ukiah a/ | 105 | 1964 | Dec. 26, 1964<br>Jan. 16, 1954 | 1,050<br>7,300 |
| 4630 | Russian River near Cloverdale | 502 | 1963-64 | Dec. 22, 1964 | 3,920 |
| | Eel River basin | | | | |
| 4755 | South Fork Eel River near Branscomb | 43.9 | 1962-64 | Dec. 21, 1964<br>Jan. 31, 1963 | 2,760<br>2,420 |
| | Mad River basin | | | | |
| 4810 | Mad River near Arcata | 484 | 1957-64 | Dec. 23, 1964<br>Feb. 8, 1960 | 21,800<br>6,600 |

a. The two concentrations shown for this station are not comparable; a flood-control reservoir, Lake Mendocino, was constructed just upstream from the station in 1958.

## EFFECT OF LOGGING ON STREAM AND SEDIMENT DISCHARGE

Most of the gaged basins have been or are being logged to some degree. However, the effect of logging on stream and sediment discharge cannot be determined with the present network of stations. Only by carefully controlled experiments will this be possible. The U.S. Forest Service is engaged in research of this kind in the Caspar Creek basin in the redwood area near Fort Bragg, but results will not be available for the flood of December 1964 because the control and test watersheds are still being calibrated and logging has not yet begun on the test watershed. It is therefore not possible to make any definitive statements concerning the effect of logging but a few general statements and impressions will be given.

It is the consensus among practicing hydrologists that land management practices affect the peak runoff rates resulting from minor storms, but there is little that man can do to affect the peak runoff rates resulting from catastrophic storms. Once the soil is saturated and depression storage is filled, almost all the rainfall runs off regardless of land management practices. Poor practices can reduce the retentive capacity of the soil and thereby increase the peak runoff from minor storms. The major storms in the redwood area, however, are usually of long duration and commonly the soil moisture and depression storage deficiencies, even of virgin forest land, are satisfied prior to the onset of the heaviest rainfall.

The lack of precision in estimating basinwide precipitation for the analysis shown on figure 4, introduces uncertainties in the relation of peak discharge to rainfall. Considering first only those basins with 6 or more inches of rainfall in 24 hours, these uncertainties are sufficient to mask any differences in peak discharge that might be attributed to differences in the degree of logging. In other words, the departures of the plotted points from the five well-defined upper curves on figure 4 may be due to any one or a combination of the following factors: inaccuracy in estimating basinwide precipitation, failure to consider some pertinent basin or climatic parameter, or differences in the amount of logging in the basin. However, one gets the impression from the random scatter of the plotted points, that the effect of logging is slight for the basins with heavy rainfall. It is interesting, for example, although not significant, that the basin of South Fork Eel River near Branscomb (sta. 27), which has the appearance of having been recklessly logged, shows a disproportionately low peak discharge on figure 4.

Only four of the stations on figure 4 have basinwide precipitations of less than 6 inches, and consequently the three lower curves on the graph are poorly defined. The precipitation values for three of these stations -- nos. 16, 40, and 45 -- are observed precipitation catches and are believed to accurately represent basinwide precipitation. The storm was relatively light over the basins of Prairie Creek tributary (sta. 40) and Lopez Creek (sta. 45), the maximum 24-hour rainfall being only about 3 inches. The peak runoff rates from these two basins, both of which are virtually in their natural state, were likewise low. Prairie Creek tributary has a timber-covered drainage area of 0.40 square miles, only about 5 acres of which have been logged. This logging took place about 30 years ago. Lopez Creek, which has a drainage area of 0.93 square miles, is not timber-covered except for some riparian trees. It is not unlikely that the low peak discharge of these two streams, about 90 cubic feet per second per square mile, may be due to the virgin state of the basins as well as to the comparatively light precipitation. However, the peak rainfall-runoff relation for a 24-hour basinwide precipitation of 3 inches is too poorly defined to prove anything concerning the effect of land management practices.

As for the effect of logging on sediment production, reason tells us that a denuded area will produce more sediment than a vegetated one. The suspended-sediment data available for the flood of December 1964 are inadequate, however, to provide quantitative information on the effect of logging. Another complication is the fact that streambanks in the redwood area are subject to erosion and caving during flood periods, and at those times provide a large but unknown proportion of the sediment that is transported by the streams. The futility of attempting to draw quantitative conclusions concerning suspended-sediment production from the available data is apparent from examination of table 3. The suspended-sediment concentration in the South Fork Eel River near Branscomb, whose drainage basin is small and relatively heavily logged, is less than that for any of the stations listed, with the exception of East Fork Russian River near Ukiah. The sampling station near Ukiah, however, is immediately downstream from a flood-control reservoir which traps much of the sediment it receives.

During major floods in the redwood area, the streams carry large loads of floating debris, consisting primarily of trees, logs, brush, and the slash from logging operations. Logging operations unquestionably are responsible for a large part of this load, but much of it also results from natural causes. Streambank erosion topples riparian trees into the streams and landslides contribute trees that formerly grew on the affected slopes. Even where slopes are stable, the rain-saturated soil loses some of its capacity to support tall shallow-rooted trees, such as redwoods, and numerous windfalls result from the strong winds that accompany the more severe storms. The following account reads very much like a description of the December floods of 1955 and 1964:

> "The floods brought down an immense amount of driftwood from all the rivers along the coast, and it was cast up along the (Del Norte County) coast in quantities that stagger belief. It looked to me as if I saw enough in 10 miles along the shore to make a million cords of wood. It is thrown up in great piles, often half a mile long, and the size of some of these logs is tremendous."

It was written by Dr. W. H. Brewer after the floods of 1861-62 in north coastal California and recently republished (1949). The California Historical Society (1929) has published the report of A. B. Duhaut-Cilly who visited the redwood region of California in 1827. This excerpt appears:

> "(The Russian River) in winter becomes terrible, and carries swiftly away the immense trunks uprooted by the storms; the water, in returning, has left enormous ones on the two banks."

These two accounts antedate any logging in the redwood belt.

## SUMMARY AND CONCLUSIONS

Intense rainfall during late December produced a record-breaking flood in the redwood areas of north coastal California. In a large part of the area, rainfall for durations of 1 or more days and peak discharge were of such magnitude that they indicate an average return period in excess of 100 years. Because of the strong orographic influence on precipitation, some of the low-altitude basins tributary to or adjacent to the Pacific Ocean had relatively light precipitation, and the peak discharges of streams draining these basins were scarcely greater than those that occur during the usual winter storms.

The streams whose watersheds had heavy rainfall and runoff had concentrations and total loads of suspended sediment that were high. It is believed that the concentration of suspended-sediment was low in some of the small streams that experienced only minor rises.

A peak rainfall-runoff relation was derived that fits all data rather well, although there were too few observations in small basins with light rainfall to define the relation equation reliably for such areas. The equation is

$$Q = 2.96 P^{2.8} A^{-0.255}$$

where Q = peak discharge, in cubic feet per second per square mile

P = maximum 24-hour basinwide precipitation, in inches

A = drainage area, in square miles.

The available streamflow and suspended-sediment data are inadequate to evaluate the effect of logging on runoff and sediment production during the flood. However, the analysis of peak runoff rates leaves one with the impression that logging had little effect on the peak discharge of streams whose watersheds received heavy rainfall.

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