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# FLOOD IN LA CAÑADA VALLEY CALIFORNIA

## JANUARY 1, 1934

BY

HAROLD C. TROXELL AND JOHN Q. PETERSON

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# FLOOD IN LA CAÑADA VALLEY, CALIFORNIA

By Harold C. Troxell and John Q. Peterson

## ABSTRACT

Heavy rainfall at the end of December 1933, following an earlier storm about the middle of the month, caused a disastrous flood in La Cañada Valley, near Los Angeles, Calif. As a result of this flood over 600,000 cubic yards of debris was moved from the mountain area to the foothill region and the valley floor, devastating buildings, citrus groves, vineyards, villages, and highways. The reported property damage exceeded $5,000,000, and more than 40 lives were lost.

About 7.5 square miles of mountain area tributary to La Cañada Valley was burned over by a fire in November 1933, and from this burned-over area came practically all the run-off that produced the debris movement in the La Crescenta-Montrose district. Damage was suffered at many places in the vicinity of Los Angeles outside La Cañada Valley. The discharge of water into Glendale and Burbank from canyons draining the southern and western slopes of the Verdugo Mountains and San Rafael Hills was torrential and heavily loaded with debris, although these slopes have a normal forest cover.

The Pickens Creek drainage area was selected for a study of the debris movement from the several mountain canyons, as it is reasonably typical of the areas draining into La Cañada Valley. Pickens Creek drains the short and steep Pickens Canyon, crosses La Cañada Valley, and flows into Verdugo Creek. Pickens Canyon has very steep slopes, from which much debris was delivered to the stream channel during the heavy rainfall of the New Year's storm. Large debris deposits had accumulated in the canyon during years prior to 1933 in which there had been only minor floods. Many check dams in the stream bed were destroyed by the flood, thereby releasing large quantities of debris. Numerous slides from the sides of the channel also contributed to the amount of debris. The addition of greater than normal debris loads to the channel of Pickens Creek caused deposition among the boulders in the channel, thereby smoothing its bed and increasing its carrying capacity. The deposition also tended to increase the gradient and thereby the capacity, until an adjustment was reached between velocity, slope, and capacity. With an increase in the discharge of the stream because of the high rate of storm run-off, the velocity and capacity were increased, causing a downstream movement of the accumulated debris in the canyon.

The debris cone in Pickens Canyon begins at an altitude of about 2,800 feet. Under conditions existing prior to the New Year's flood deposits of new debris on the cone began at an altitude of 2,100 feet, with a tendency for the initial point of deposition to move farther downstream with each successive flood. Because of the deep channel that had been cut down in the upper part of the debris cone the flood discharge of Pickens Creek at the time of the New Year's flood could not spread out over the cone until it had passed the Foothill Boulevard, thereby bringing the flood flow and debris movement about 13,000 feet nearer the developed sections of La Cañada Valley than they would have come if the energy could have been dissipated by the spreading and meandering channels of the older cone.

Only in Haines Canyon was it possible to measure accurately the amount of debris. There a gravel pit in the upper end of the debris cone had been converted into a debris basin, and it was found from surveys that 28,500 cubic yards of debris coming from an area of less than 1 1/2 square miles was deposited in the pit.

Profiles of Pickens Canyon made before and after the New Year's flood indicated that about 72,000 cubic yards of debris was removed from the canyon during the flood. The tributary area was 1.6 square miles.

The river-measurement stations in Haines, Cooke, and Blanchard Canyons were destroyed or put out of operation before the time of maximum discharge, and records of discharge in these canyons are not available.

From the records of rainfall it is estimated that the maximum discharge from Pickens Canyon may have been as much as 645 second-feet to the square mile. By using Kutter's formula estimates have been made of the discharge in Verdugo Creek near the lower end of La Cañada Valley, where the tributary area is about 19 square miles. These estimates indicate a maximum discharge of about 320 second-feet to the square mile at that place.

## INTRODUCTION

Over certain portions of southern California 1934 began with catastrophe. Shortly after midnight on New Year's eve a flood and debris wave[1] originating from the small group of mountains that form the western extension of the San Gabriel Range swept across La Cañada Valley, within the suburbs of Los Angeles. In this valley are situated several populous communities, chief among which are Montrose, Verdugo City, La Crescenta, and La Cañada. Heavy storm run-off brought down great quantities of mud and boulders from the several short, steep, deeply entrenched canyons that dissect this group of mountains. Upon reaching the valley the flood waters spread with unconfined fury toward Verdugo Creek, the main drainage channel, and, accumulating additional volume from tributaries in that vicinity, swirled through Glendale, a city of some 60,000 inhabitants, finally reaching the Los Angeles River and thence passing to the sea. This disaster is known locally as the New Year's flood, and it seems probable that in southern California this name will afford adequate definition of it for a long time to come. (See pl. 19, A.)

In La Cañada Valley there was a reported property damage exceeding $5,000,000, including 400 houses demolished or rendered uninhabitable, and more than 40 lives were lost. Streets, highways, and yards were strewn with wreckage and debris; automobiles and garages were rolled and piled in a conglomerate mass; bridges were destroyed; culverts and drains were clogged. The flood ravage was concentrated in the La Cañada and Glendale areas to a much greater degree than elsewhere in this foothill region.

The flood was caused by a 3-day storm that began moderately on the afternoon of December 30, 1933, and increased in intensity on the following day. Rainfall records indicate that the heaviest precipitation occurred over an area of intermediate altitude (ranging from about 1,000 to 3,000 feet) extending inland from Santa Monica to Claremont, a distance

1 For a description of this "debris wave" see Eaton, E. C., Flood and erosion control problems and their solution: Am. Soc. Civil Eng. Trans., vol. 101, pp. 1319-1321, 1936.

of about 50 miles. An earlier storm, on December 14 and 15, when about 4 inches of rain fell, undoubtedly had considerable effect in preparing conditions favorable to a high rate of run-off from the storm that continued through Deeember 31 and January 1.

For many years recurring floods have been filling La Cañada Valley with material eroded from the tributary mountain areas. Until comparatively recent time there has been little human occupancy in this foothill region, and thus this natural process of erosion and deposition had not particularly affected man's activities. The New Year's flood of 1934 found buildings, citrus groves, vineyards, villages, and several main arteries of motor travel occupying the alluvial cones that are the product of past floods and are subject to periodical future floods. As a result of this storm, material of a character similar to the earlier valley deposits, aggregating well over 600,000 cubic yards, was moved from the mountain area onto the alluvial cones and the valley floor.

The flood water with the accompanying debris came in the main from the mountainous tributary area north of the valley. Just a little over a month earlier, in November 1933, a forest fire had almost completely denuded much of this tributary area of its vegetative cover. This denudation, the intensity of the New Year's rainfall, and the effect of the rain earlier in December caused the enormous debris movement that was so disastrous. The purpose of this report is to describe and analyze this debris movement and to explain its causes and the method of its behavior.

## ACKNOWLEDGMENTS

In the preparation of this report the authors have been aided by R. Stanley Lord, junior engineer, and L. R. Brooks, associate classifier, both of the United States Geological Survey. They are indebted also to D. A. Lane, of the Department of Water and Power, City of Los Angeles, for his vivid account of the flood in the vicinity of Glendale; to the Los Angeles County Flood Control District for data furnished; and to the Los Angeles County surveyor for airplane pictures of Pickens Canyon and vicinity. Many helpful suggestions have been received from other members of the Geological Survey who have reviewed the report. The collection of field data and some of the preliminary work were carried on jointly by the two authors. The assignment of the junior author to duty elsewhere prevented his further participation except on general features of the report. The preparation of the manuscript in its final form and conferences with various reviewers fell to the senior author, and thus his responsibility for the report in its final form is predominant.

## LA CAÑADA VALLEY AND VICINITY

### Topography and drainage

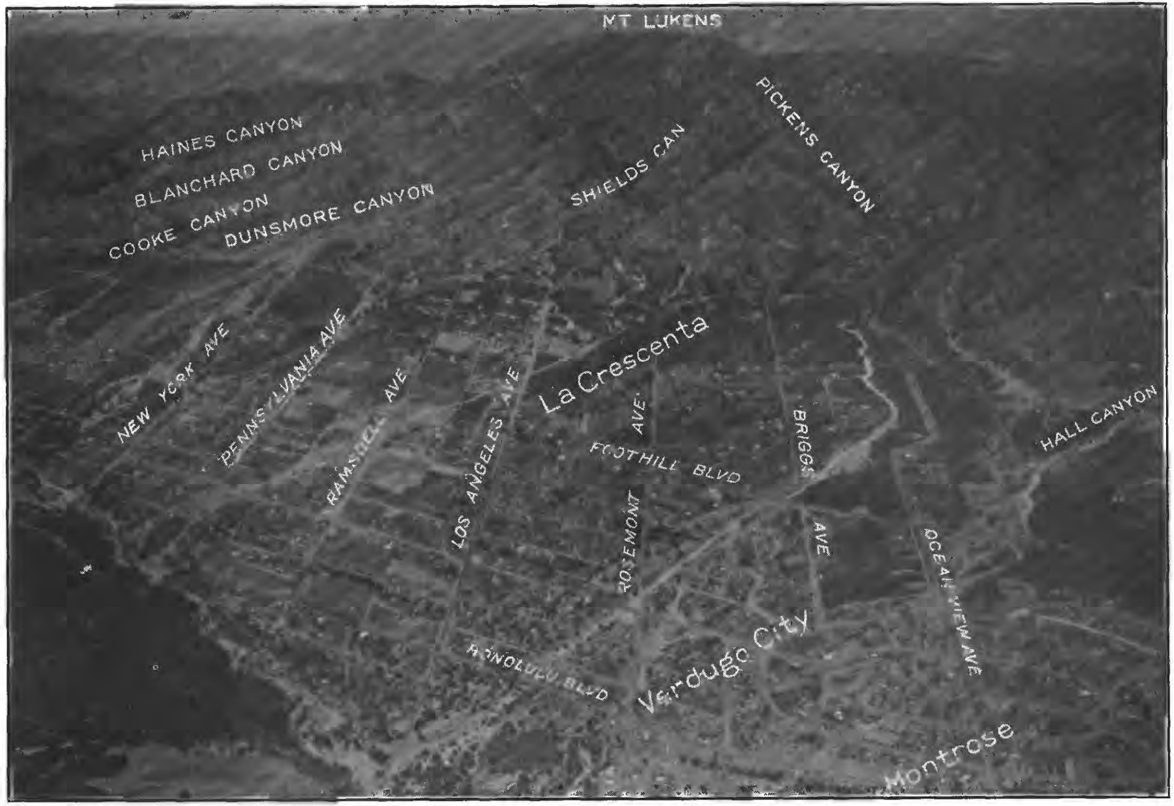
La Cañada Valley is near the north limits of the city of Glendale, about 12 miles north of downtown Los Angeles. The valley is a southward-sloping piedmont plain formed at the foot of the San Gabriel Range. It is flanked on its southeastern border by the San Rafael Hills and on its southwestern border by the Verdugo Mountains. The northern boundary is the south front of the San Gabriel Mountains for a distance of about 6 miles. The average width of the valley is about 2 miles. (See pls. 16, 17, and 18 and fig. 7.)

The drainage of La Cañada Valley except in flood stage is mainly underground, or through poorly defined surface channels converging to Verdugo Creek. This creek flows southeastward along the northeast front of the Verdugo Mountains to the south end of La Cañada Valley, where it is turned abruptly south by the interposition of the San Rafael Hills. Thence it follows the east side of the Verdugo Mountains through a narrow gap known as Verdugo Wash to the city of Glendale, where it turns west and flows through that city to its junction with the Los Angeles River near Griffith Park, at the east front of the Santa Monica Mountains.

The Foothill Boulevard, a main highway, parallels the San Gabriel Range, approximately bisecting La Cañada Valley. Between this boulevard and Verdugo Creek lie Montrose and Verdugo City, the two most thickly settled communities of the valley. The smaller communities La Crescenta and La Cañada are at opposite ends of the valley near the Foothill Boulevard. Outlying developments consist mainly of residential, agricultural, and recreational properties.

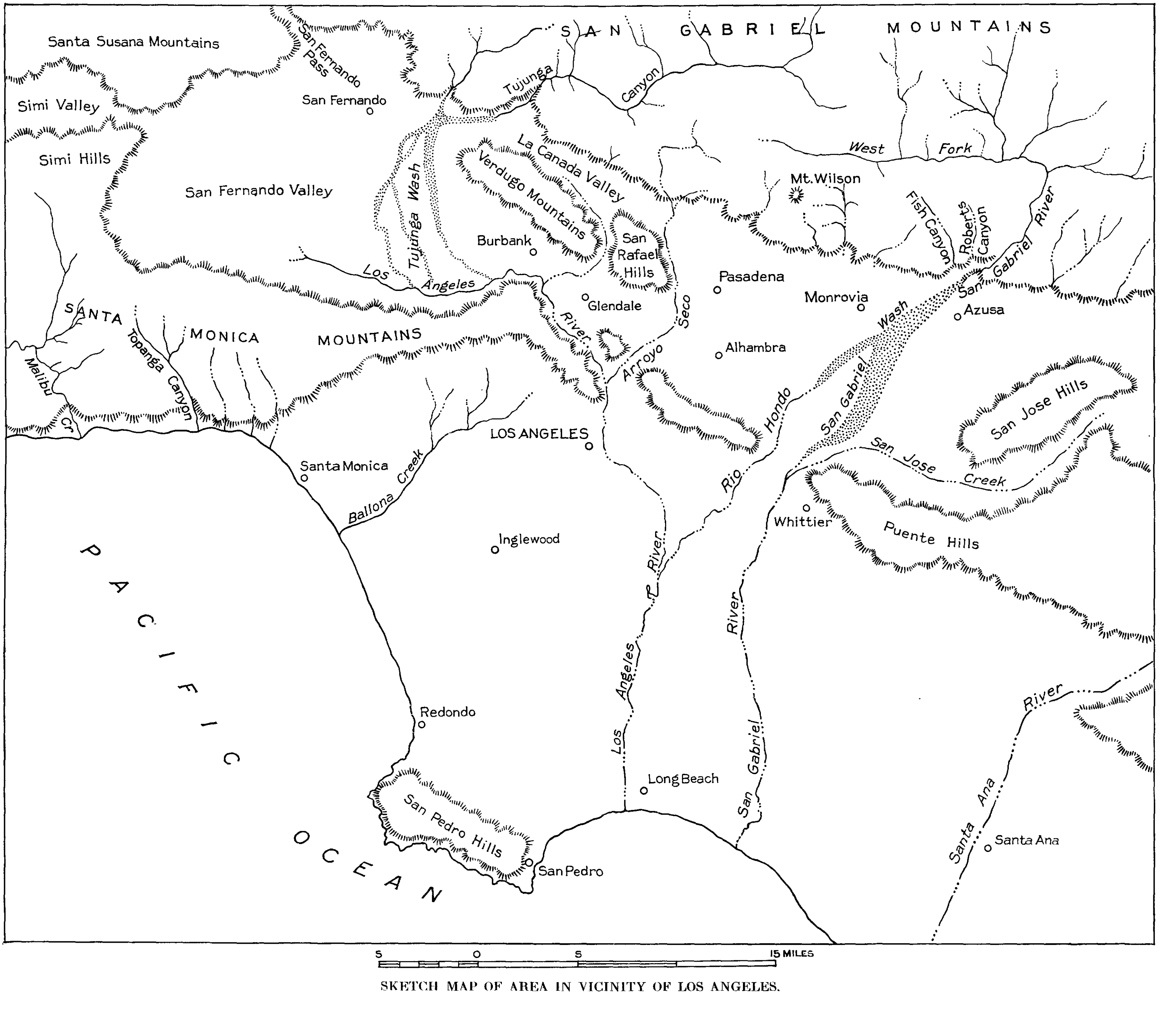
The altitude of the valley ranges from about 1,200 feet at the south end to 2,100 feet at the foot of the San Gabriel Mountains. These mountains rise in this vicinity 3,000 feet above the valley floor within a horizontal distance of 2 miles to the common divide between Arroyo Seco, Tujunga Creek, and Verdugo Creek and culminate in Mount Lukens (Sister Elsie Peak) at an altitude of 5,050 feet.

The part of the southern slope of the San Gabriel Mountains that is tributary to La Cañada Valley has an area of about 10 square miles and is roughly bounded by Haines Creek on the west and Arroyo Seco on the east. Haines Creek is a tributary of Tujunga Creek, which ultimately reaches the Los Angeles River in San Fernando Valley, north of the Santa Monica Mountains. Arroyo Seco skirts the east side of the San Rafael Hills




VIEW OF LA CAÑADA VALLEY, LOOKING NORTH.

WESTERN PART OF PICKENS CREEK DRAINAGE AREA.




SKETCH MAP OF AREA IN VICINITY OF LOS ANGELES.

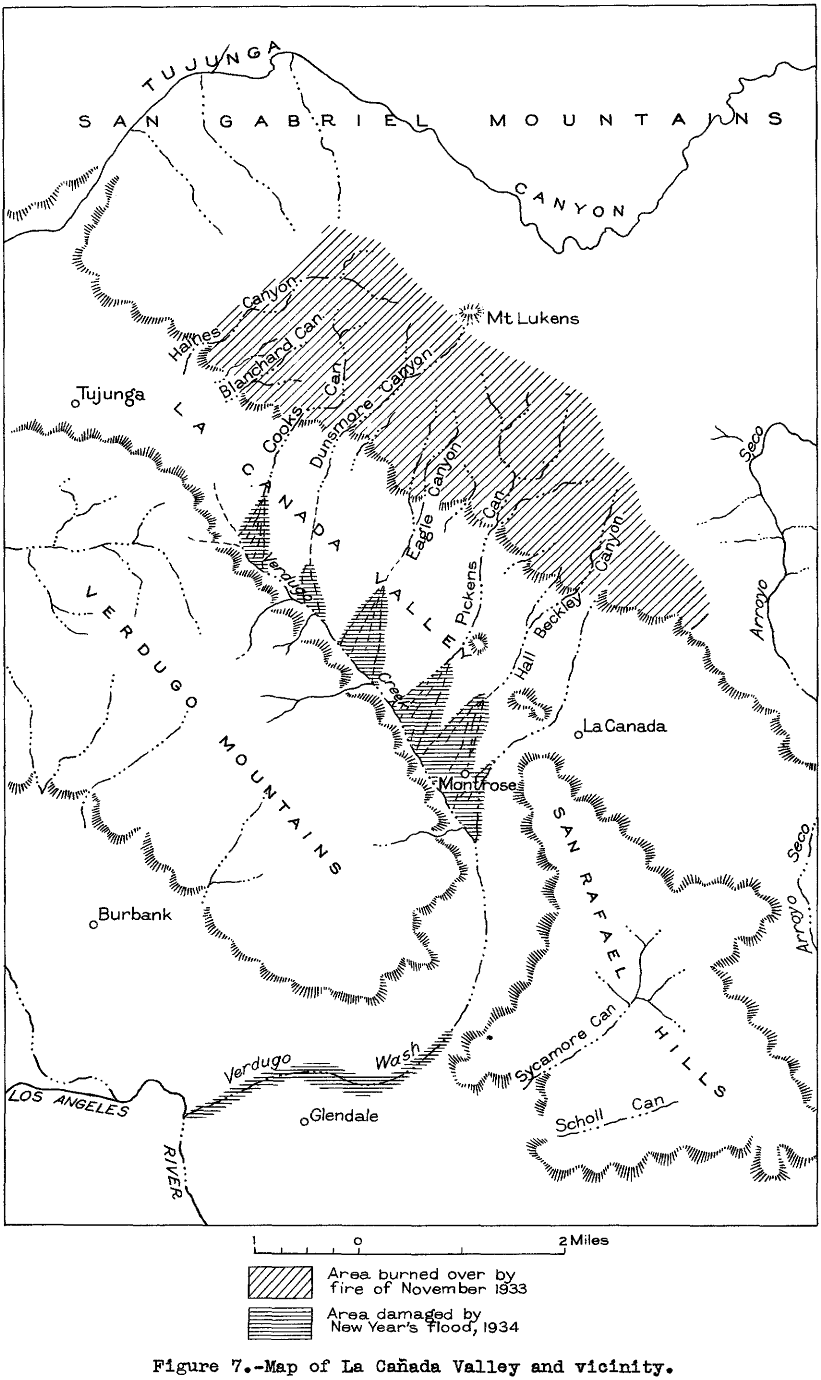



Figure 7.-Map of La Cañada Valley and vicinity.

and joins the Los Angeles River near Elysian Park, in Los Angeles. Between Haines Creek and Arroyo Seco are 15 short, deeply entrenched canyons that empty into La Cañada Valley and contribute to the deposition of debris in the valley. Practically no run-off from these canyons enters Verdugo Creek as surface water, except after periods of very intense rainfall, when the canyons become torrents laden with debris ranging from fine silt to large boulders.

## Soil

On the steeper slopes of the mountain area soil depths range from less than 3 inches to 24 inches or more in some localities. In the deepest parts of shallow gullies on some of the steeper slopes all finer material has been removed, and the underlying rock is exposed. In some places there are massive outcrops of granite, and in others large granite boulders are mingled with sand, gravel, and silt. Most of the alluvial fans merge with one another to form a fairly uniform foothill slope, which extends almost unbroken from the base of San Gabriel Mountains to the San Rafael Hills and Verdugo Mountains. The alluvial material is composed of sand, gravel, silt, and boulder deposits, generally of great depth. The finer material at the surface is strewn with granite boulders. It is on this type of soil that the towns of La Cañada, La Crescenta, Verdugo City, and Montrose are situated.

The principal agricultural soil types are described as Holland loam, Holland stony loam, Altamont clay loam, Hanford fine sandy loam, Hanford gravelly sandy loam, and Hanford stony sandy loam.[2]

## Climate

The climate of the region is characterized by a wet season and a dry season. The wet season extends usually from October to May or June. About 58 percent of the annual precipitation occurs during the three winter months, and its occurrence is very erratic, varying widely from year to year. In adjacent valleys where records for relatively long periods are available there have been years when the winter precipitation was barely 2 inches, although in one year the rainfall in one month exceeded the long-time yearly average.

The average seasonal rainfall in La Cañada Valley for the last 15 years has ranged from 22 to 24 inches for different parts of the valley.

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2 Soil survey of the San Fernando Valley area, California: U. S. Dept. Agr., Bur. Soils, 17th Rept., for 1915, pp. 2471-2481, 1919.

Just over the divide, on the headwaters of the San Gabriel River at Opids Camp (altitude 4,250 feet), the average seasonal rainfall for the last 15 years has been 38.23 inches. For the city of Los Angeles (altitude 417 feet) the average seasonal rainfall for the past 55 years has been 15.00 inches.

## Vegetation

The vegetation native to the valley and to the surrounding hills consists principally of chaparral of medium to dense growth. Chaparral is a general term applied to the mountain brush of the Southwest, consisting of stiff woody plants or shrubs, mostly evergreen, many of them with thick leathery leaves and sharp spinelike thorns. Succulent herbaceous plants sometimes form an undergrowth that is more noticeable in open than in dense stands of chaparral.

In contrast with most other regions of the temperate zone, the growing season is here reversed from summer to winter, because of the long, hot, arid summers and the short, mild winters with considerable moisture. The brief period of growth and the long dormant period, with excessively high temperatures, undoubtedly account for the dwarfed and woody condition of the vegetative growth and its general hardness and spinelike character.

The composition of the chaparral varies within certain limits with altitude, topography, slope, and soil, but in any one place the species remain practically the same from year to year. Chaparral ranges in altitude from sea level up to 5,000 to 8,000 feet, giving way to coniferous forest at the upper limit. Chaparral includes about 100 species of shrubs and semiwoody plants, a very large percentage of which is made up of various species of Ceanothus, scrub oaks, and manzanitas.

Fires can occur in chaparral during any month of the year. During the summer dormant period from May to October, however, fires are especially severe, and often all of the plant is consumed. A chaparral fire is very difficult to control, because of the high rate of spread. especially when it is burning uphill with the wind.

Chaparral usually regenerates readily after a fire, either from sprouts or from seeds that survived the fire. However, sprouting is often weak, and the stand reinvades the site slowly. As a rule, 10 years is required to get a complete stand of chaparral on burned-over ground, but a dense cover may not be fully reestablished for 20 to 50 years.

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## GENERAL FEATURES OF THE NEW YEAR'S FLOOD

### The fire of November 21-24, 1933

The fire that swept the slopes of the western end of the San Gabriel Mountains for the greater part of 4 days in November 1933 is commonly referred to as the Pickens Canyon fire, because it began in that canyon. The fire started at about 8 p.m. November 21, immediately outside the boundary of the Angeles National Forest, and during the night, fanned by warm breezes from the interior, it spread rapidly to the north and west. The next day it was brought under partial control, but during the night of the 22d adverse weather operated to thwart heroic fire-fighting efforts, and most of Haines, Dunsmore, and Pickens Canyons and much of the Halls Canyon drainage basin were burned over. On the third day the Halls Canyon firebreak east of the fire was widened and backfiring attempted, but this proved futile, owing to a change in the direction of the wind during the night of November 23. On the morning of November 24 the fire began spreading into the Arroyo Seco area, but it was finally brought under control on the Gould Canyon firebreak and the Angeles Crest Highway. The fire denuded 4,830 acres of mountain drainage area, most of which was tributary to La Cañada Valley. It was doubtless one of the contributing causes of the enormous debris movements that took place in La Cañada Valley as a result of the New Year's storm.

### Rainfall of the New Year's storm

About mid-afternoon of December 30, 1933, light rain began to fall over the valleys and foothills of southern California. For a period of 12 to 18 hours thereafter intermittent or steady showers of moderate intensity occurred. During the forenoon of December 31 heavy rain with fluctuating but generally increasing intensity became general throughout the southern California region.

From a description of this storm prepared by Lawrence H. Daingerfield,[3] of the United States Weather Bureau office in Los Angeles, the following description is quoted:

> Under this pressure distribution the rather localized but moisture-bearing warm front advanced northeastward or northward from its tropical or semitropical origin and crossed the coast line of Los Angeles, Orange, and the upper extremity of San Diego Counties.

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3 Excessive rain and flood in the Los Angeles, Calif., area: Monthly Weather Rev., vol. 62, no. 3, pp. 91-92, March 1934.

The precipitation, generally, was only moderately heavy over the coastal area named, ranging from 2 to 4 inches, except from Santa Monica westward, where the abrupt, steep southerly slope of the Santa Monica Mountains, dropping sharply to the sea, exerted a profound influence on the rain-bearing wind.

Before the moist air reached the slopes of the San Gabriel and San Bernardino Mountains, however, it was underrun by a cold easterly wind, which, obviously, largely increased the rainfall over the valley lands and lower foothill regions between the coast and mountains. In this connection Floyd D. Young, in charge of the Pacific coast fruit-frost work of the bureau, with head office in Pomona, Calif., says:

"So far as the local area around Pomona is concerned, I believe the general conditions which prevailed here throughout the storm period were practically the same as those in Los Angeles. The outstanding feature of the storm here, or at least the feature which impressed me most forcibly, was a strong, relatively cool, sustained surface wind, which continued from an easterly direction throughout the rainfall period. Most of the time this wind was from the east or northeast, but shifted to the southeast for short periods. This fact, as well as the fact that the rainfall was heaviest along the lower foothills, with, in many cases, considerably lighter rainfall in the higher mountains, leads me to believe that the orographic influences, except in so far as they may have affected the surface wind direction, were considerably less important in this storm that in most other rainstorms which have occurred here in the past. In other words, it appears to me that the strong and sustained southerly and southwesterly air currents, which prevailed from moderate to high elevations, as shown by pilot-balloon observations, began to rise over the relatively cold easterly currents at lower elevations considerably before the mountains were reached, and that the precipitation of the moisture was due not only to the rising of the southerly air currents, but also to a certain extent at least to the mixing with the relatively cold surface easterly wind."

Examination of the isohyetals for the storm shows centers of heaviest total rainfall at Hegees Camp, San Gabriel Mountains, elevation 2,650 feet, 19.91 inches; Opids Camp, same mountains, elevation 4,254 [4,250][3a] feet, 17.93 inches; Squirrel Inn, San Bernardino Mountains, elevation 5,700 feet, 12.55 inches; Lytle Creek, in Lytle Creek Valley, between the mountain ranges named, elevation 2,250 feet, 13.44 inches; Malibu Headquarters, Topunga Canyon, Santa Monica Mountains, elevation 747 feet, 16.03 inches; Mount Wilson, loftiest reporting station in the San Gabriel Mountains, elevation 5,850 [5,725][3a] feet, 15.58 inches; and Big Bear Lake Dam, loftiest reporting station in the San Bernardino Mountains, elevation 6,800 feet, 10.30 inches. Further examination of the isohyetals, however, shows that there were local areas of heavy rainfall in the valley and foothill regions adjacent to the San Gabriel Mountains, the Verdugo Hills, and Griffith Park in Los Angeles. Some of the wet-center, lower-elevation stations are, in the San Gabriel foothill area, Flintridge, above Glendale, 14.92 inches; Sunset Reservoir, above Pasadena, 14.95 inches; Azusa, 16.29 inches; Griffith Park Nursery, Los Angeles, 14.72 inches. Riverside, shadowed by the Box Springs Mountains on the east and southeast, received a total of only 1.74 inches, while Long Beach, San Pedro, Palos Verdes Estates, on the immediate coast, received only 2.87, 2.20, and 2.25 inches, respectively.

New 24-hour high-precipitation records were established at many points over the rain area; Los Angeles, as an example, with a period covering 56 years, was raised from 5.12 inches (on Feb. 23-24, 1913) to 7.36 inches (Dec. 31, 1933-Jan. 1, 1934), at the height of the storm. While the amount of rainfall for the whole storm was phenomenal, time and area considered, its short-period intensity for any particular station does not appear to have been outstanding, especially when compared with the remarkable 1-minute record of 1.02 inches, measured in two Fergusson gages, exposed side by side, at Opids Camp (elevation 4,254 [4,250][3a] feet) back of Mount Wilson, near the headwaters of the west fork of the San Gabriel River, at 4:48 a.m. April 5, 1926.

Figure 8 shows the average rates of rainfall in inches per hour for each 5-minute period throughout the storm at a few typical stations in or near La Cañada Valley. This information was in the main collected and compiled by the Los Angeles County Flood Control District and the United

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3a The altitudes given in brackets are taken from the latest United States Geological Survey maps.

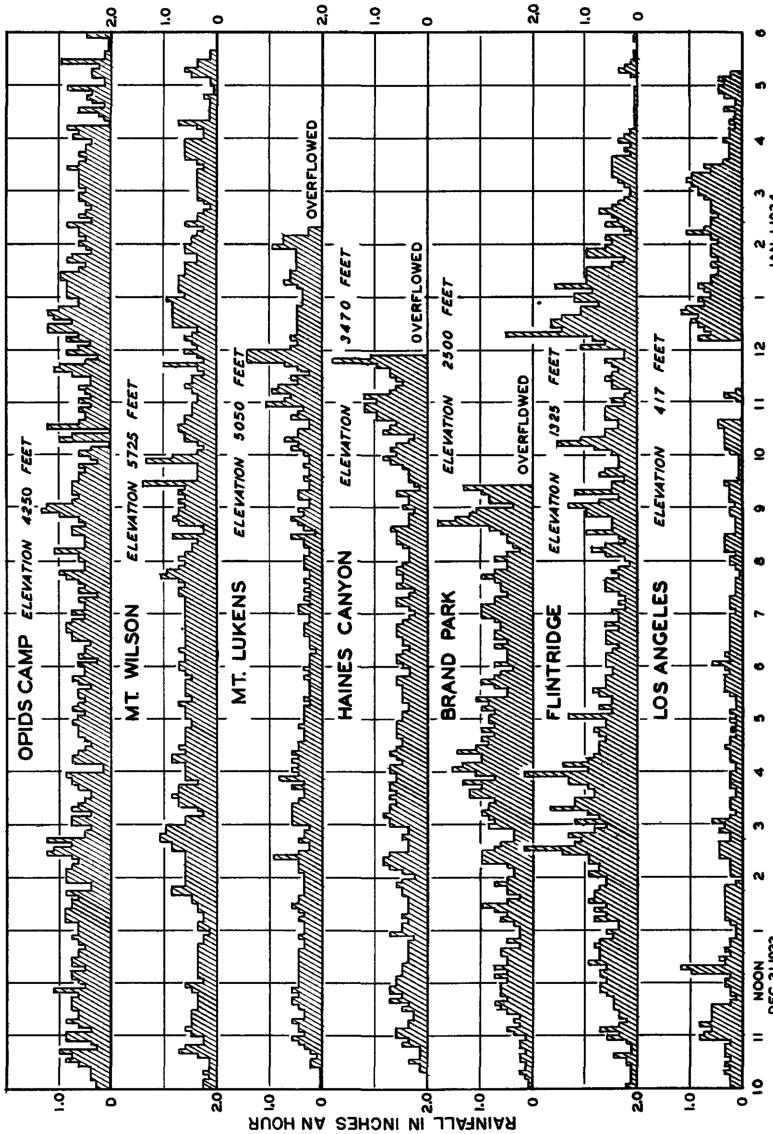


Figure 8.—Mean rate of rainfall for 5-minute periods.

States Weather Bureau from records of recording rain gages. Most of these rain gages have a limited capacity, and as they were unattended, some of them became full and inoperative before the storm was over, a fact which accounts for the incomplete records at the Brand Park, Haines Canyon, and Mount Lukens stations.

As indicated by the data shown in figure 8 the storm period was punctuated at the different rainfall stations by very intense short showers. The localized character of the showers is shown by the fact that the intensities at stations separated by short distances varied widely at the times of the major showers. The progressive mean rates of rainfall for each three 5-minute periods from 10 a.m. December 31 to 2 a.m. January 1 have been computed for three of the stations and plotted on figure 9 to show the characteristics of rainfall intensity. The records of the Flintridge and Mount Lukens stations were used to show the distribution of the rainfall in La Cañada Valley. The distribution of the rainfall at higher altitudes in the back country is indicated by the record at Opids Camp. Short periods when the intensities were outstandingly large are marked on the Flintridge and Mount Lukens records by numbers to designate specific showers.

On figure 10 is shown a general profile of the ground surface from the Pacific Ocean through Los Angeles and Pasadena to Mount Wilson and Opids Camp. On this profile the altitude of the several rain gages is indicated. A similar profile through Glendale and La Cañada Valley indicates the positions of recording rain gages in that region.

As reported by Daingerfield and Young, this storm differed from many of the usual storms of the region in that the higher rates of rainfall occurred at the lower altitudes. On figure 10 the average rates of rainfall for 15-minute periods during the seven most severe showers indicated by numbers on figure 9 have been plotted against altitude. In the preparation of these graphs the rainfall records at Los Angeles, Flintridge, Brand Park, Haines Canyon, and Mount Lukens have been used in order to show differences in precipitation at places of different altitudes, although it is recognized that the inclusion of the Los Angeles and Brand Park records might be questioned, because both stations are outside La Cañada Valley and because the altitude of the Los Angeles station is much below that of the valley. Moreover, the intervening Verdugo Mountains may have affected precipitation in such a way as to destroy similarities between these two records and the valley records.

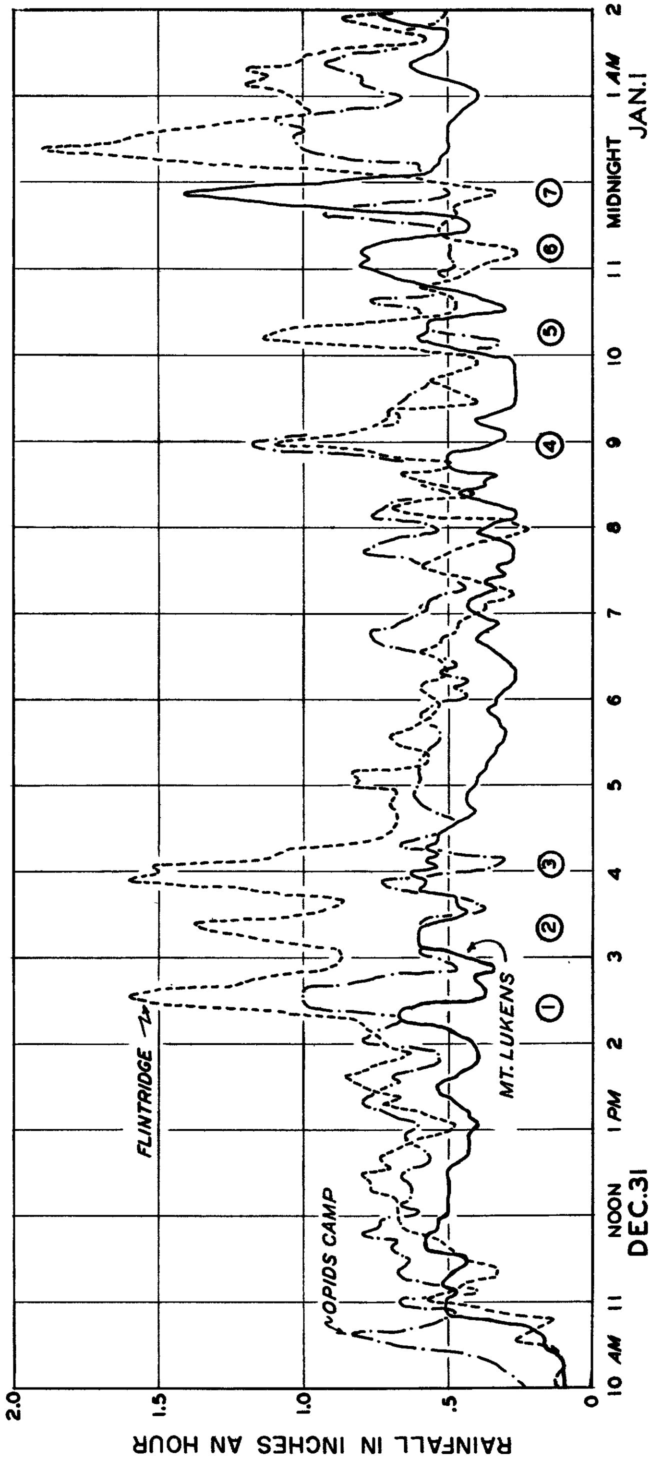


Figure 9.-Rainfall records for Opids Camp, Mount Lukens, and Flintridge stations.

The sharp shower (no. 1 on figures 9 and 10) which occurred between 2:15 and 2:30 p.m. December 31 was the first of the heavier showers during the New Year's storm. As indicated by the graph the hourly rates of rainfall in this shower ranged from 0.5 inch at Los Angeles to about 1.6 inches at Flintridge. The average hourly rainfall rate in this shower at Brand Park, altitude 2,500 feet, was less than 1.0 inch, at Haines Canyon 0.8 inch, and at the divide on Mount Lukens only about 0.6 inch. Showers 2, 3, 4, and 5 agree in general with the distribution of the rainfall of shower 1, except for some irregularity of shower 4 at the Brand Park station.

During the later part of the New Year's storm the showers had an entirely different distribution of intensity with respect to altitude. In shower 6 at about 11 p.m. December 31 the heavier rates of rainfall were recorded at the higher altitudes. In shower 7, the very disastrous midnight shower, much greater intensities were recorded for the high altitudes at Haines Canyon and on Mount Lukens than for the lower altitude at Flintridge.

## Rates of discharge

In the area denuded by fire the Geological Survey was maintaining at the time of the flood only one river-measurement station - that in Haines Canyon. During the flood the water carried large quantities of debris, and the record obtained at the station was not satisfactory - in fact, there appears to be no known method by which the movement of water and debris at this station could have been reliably measured. Within the burned-over area the Los Angeles County Flood Control District was maintaining two river-measurement stations, in Cooke and Blanchard Canyons, each equipped with a Venturi flume and a water-stage recorder. Unfortunately both of these stations were destroyed by the flood during the afternoon of December 31.

Thus, with no reliable records of run-off in the denuded area, it is necessary to rely largely on rainfall records for estimating rates of discharge. The graphs in figure 10 showing the variation of rainfall with altitude indicate that for showers 1 to 5 the highest rates of discharge probably occurred from the lower mountain areas and the valley floor. However, as the floor of La Cañada Valley is in the main composed of debris of recent origin and hence is unconsolidated and absorptive, it is possible that the run-off from that area may have been comparatively light.

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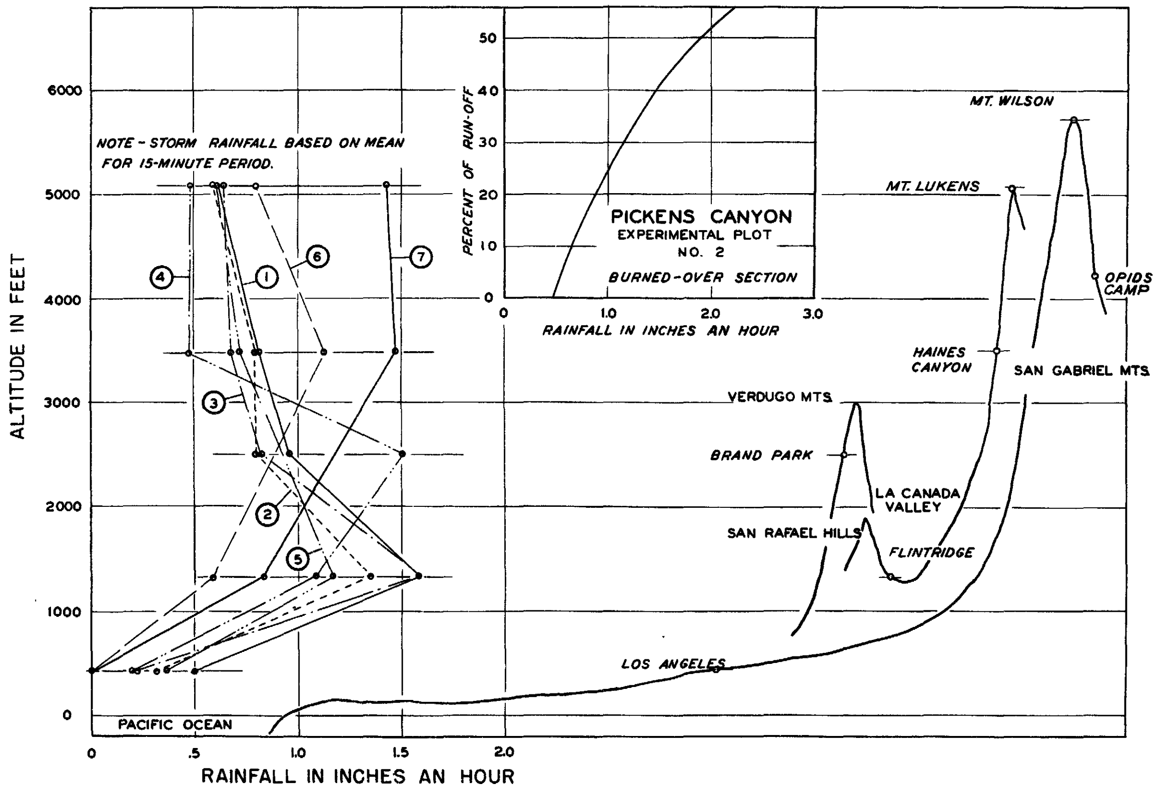


Figure 10.-Graphs showing rainfall of New Year's storm, profile showing location of rain gages, and relation between rates of rainfall and run-off on an experimental plot in Pickens Canyon.

Although the run-off from the mountain area resulting from showers 1 to 5 may have been comparatively light, it was of sufficient magnitude when accompanied by the heavy load of debris to destroy or stop operation of the three river measurement stations in Haines, Cooke, and Blanchard Canyons.

Shower 6 does not seem to have produced the discharge that might have been expected, as there was no indication of discharge of exceptional intensity until after the midnight shower (no. 7). It was the midnight shower, climaxing over 12 hours of continuous rainfall, that appears to have been the immediate cause of the great flood which did practically all the damage in La Cañada Valley. Eyewitnesses gave descriptions, of which the following are typical:

At Blanchard Canyon, - All day long water was about 15 feet wide and 2 feet deep, but keeping to channel. At midnight a regular wall of water. All damage was done in a couple of minutes.

At Shields Canyon, - The big peak came at 12:15 a.m. (Jan. 1). Wall of water 8 to 10 feet high. Lasted not over 5 minutes. Heavy roar.

At Pickens Canyon, - A wall of water 20 feet high on the Foothill Boulevard. Estimated from height of power-line guide pole.

Eyewitnesses testify to extraordinarily large peak discharges at or near midnight from each of the burned-over canyons and from several that had not been burned over for a number of years. The flood was so violent and was accompanied by so much debris that reliable estimation of discharge was impossible. However, its great magnitude and its lack of similarity to ordinary floods stimulate a study of the causes and methods by which water and debris could be delivered in such great quantity to the Montrose area. These aspects are considered in a later part of this report.

A rough estimate of the maximum discharge from Pickens Canyon may be made from the records of rainfall. On the assumptions that in the midnight shower the rate of rainfall was 1.5 inches an hour for 15 minutes throughout the drainage area of Pickens Canyon, that the hourly rate of run-off from this shower was 1 inch in depth over the basin, and that the water from the farthest point of the drainage area reached the mouth of the canyon within the 15 minutes of the shower, the maximum discharge would have been 645 second-feet to the square mile. Temporary damming of the flow by slides might have materially affected the results, but it is the authors' opinion that the maximum rate of discharge of water alone did not exceed this figure.

By using Kutter's formula numerous estimates have been made of the discharge in Verdugo Creek at the crossing of the street called Wabasso Way, near the lower end of La Cañada Valley. With reference to these estimates,

E. W. Kramer,[4] regional engineer of the United States Forest Service, states:

> The most reliable estimates of the magnitude of the flood from the burned area can be obtained by deduction from estimates made of the flow in Verdugo Canyon at Wabasso Way. As you know, nearly all of the small canyons and watersheds which were burned over drain into Verdugo Canyon. Included in the Verdugo Canyon drainage are also the towns of La Crescenta and Montrose. For a distance of something over 500 feet in the vicinity of Wabasso Way the creek channel is enclosed by pilings. The area of the cross section of the channel and the slope is very uniform for this distance. Furthermore, there is a debris basin in the Verdugo Canyon above this section. Very nearly all of the silt which came from the upper drainage was deposited in this debris basin. Therefore, the flow below the debris basin was almost entirely water. For this reason it is believed that an accurate estimate of flow can be made at Wabasso Way. The drainage area above Wabasso Way is about 19 square miles, of which roughly about 6 1/2 square miles were burned. Estimates made from the slope, area of the cross section, and high-water marks in this section indicate a flood flow of 6,100 second-feet, which is equivalent to a run-off of about 320 second-feet per square mile. When it is taken into consideration that the peak was taken off this flow in the debris basin and most of the silt removed also, and the further fact that only a part of the drainage area above this point was burned over, it is evident that the maximum flow from the burned areas was not less than 500 second-feet per square mile of water, which was probably laden with twice its bulk of silt.

Figure 10 presents information obtained by the Los Angeles County Flood Control District showing the relation of rainfall and run-off from 1 square-foot of burned-over area in Pickens Canyon. If used with proper caution, data collected from so small an area may furnish significant information. For this particular small plot there was no run-off at rates of rainfall less than half an inch an hour. When the rate of rainfall on this 1-foot plot increased to 1 inch an hour, 25 percent of the rainfall ran off. If it were possible that a larger drainage area would have soil and topography exactly like those of the 1-foot plot and that the concentration of the run-off could be such that particles of water from the farthest point of the drainage area would reach the point of outflow from the area within the period of the shower, then the rate of run-off per square mile would be 160 second-feet so long as the rate of rainfall continued at 1 inch an hour. Because of lack of synchronization in flow from different parts of the basin, however, 1 square mile of drainage area similar to that of Pickens Canyon would produce a much smaller rate of run-off than 160 second-feet from a rate of rainfall of 1 inch an hour, unless the discharge were modified by slides that would produce temporary channel storage to be released during the period.

## Flood damage

Sources of information on the number of fatalities due to the flood are vague and unreliable, but 39 known deaths were reported as a direct result of the flood, and 45 persons were reported missing. Most of the deaths

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[4] Proceedings of the Flood Control Conference, Los Angeles, March 23, 1934.

occurred in Montrose. The number of houses completely demolished was reported at 198, and the number rendered totally uninhabitable at 401. In addition there was complete or partial destruction of garages, automobiles, roads, bridges, streets, railroads, gardens, lawns, water systems, and other property, the full value of which can never be known.

Engineers have recognized that La Cañada Valley is so situated as to be particularly vulnerable to the ravages of flashy floods, as is shown by a report submitted December 31, 1925, to the Los Angeles County Board of Supervisors by J. A. Bell and H. Hawgood, consulting engineers for the Flood Control District, the first paragraph of which reads as follows:

> La Cañada Valley exhibits to an unusual degree the effects of violent flood action. The whole area, ringed about by steep mountains, is boulder-strewn virtually down to the main drainage channel, the Verdugo Wash. The character of this boulder-strewn alluvium is significant. Its great size, at least half a mile down the slope from the mouths of the canyons, is clearly indicative of but one thing - periodic flood discharges of extremely violent nature.

The damage due to the New Year's flood was not confined entirely to La Cañada Valley. At many points in the vicinity of Los Angeles and in Venice, Culver City, and adjacent areas considerable damage was suffered. Although the Verdugo Mountains and San Rafael Hills, immediately south of La Cañada Valley, have a normal forest cover, much of which has not been disturbed by fire during the last 10 or 20 years, the discharge of water into Glendale and Burbank from the canyons draining their southern and western slopes was torrential and heavily loaded with debris.

## DEBRIS MOVEMENT

The New Year's flood deposited over 600,000 cubic yards of debris in the Montrose area.[5] Eaton[6] states: "As an indication of the extent of the debris flows, over 20 percent of the gross area included in La Crescenta-Montrose district was subject to covering with debris and erosion from the storm." This is of particular interest when it is remembered that 20 percent of this area is about 3 square miles, and that practically all the run-off that produced the debris movement in this district came from about 7.5 square miles of burned-over area.

With a view to the possible determination of proper precautions against a recurrence of a similar disaster, a somewhat detailed analysis was made of the causes and mechanics of this debris movement. While such causes and mechanics are not exactly the same over all of the area draining

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5 Eaton, E. C., Flood and erosion control problems: Am. Soc. Civil Eng. Trans., vol. 101, p. 1322, 1936.

6 Eaton, E. C., Proceedings of the Flood Control Conference (Conservation Association of Los Angeles County), March 23, 1934.

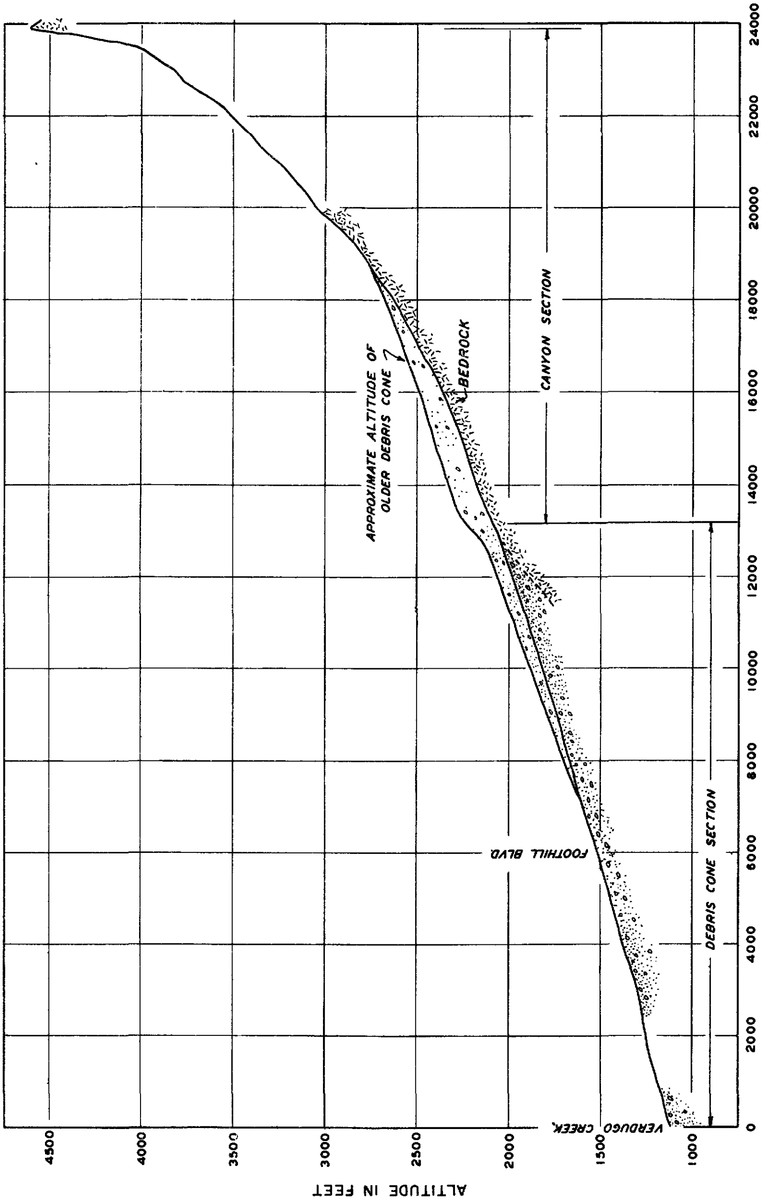


Figure 11.-Profile of Pickens Creek.

into La Cañada Valley, the debris movement from the several mountain canyons had many common characteristics. The Pickens Creek drainage area is reasonably typical and was therefore selected for study of the debris movement. The following statements give the authors' interpretations of the physical conditions, and it is believed that they are either based upon good evidence or are generally accepted.

## Pickens Creek

Pickens Creek drains the short and very steep Pickens Canyon, crosses La Cañada Valley, and flows into Verdugo Creek. Pickens Canyon is almost in the center of the burned-over mountain area. The main stream channel from the divide at an altitude of 4,600 feet to its junction with Verdugo Creek at 1,120 feet is about 24,000 feet (4 1/2 miles) in length. The following table gives the altitude and average slope of successive reaches of the stream channel from the divide to Verdugo Creek. The profile of the channel is shown in figure 11.

Altitude and average slope in the stream channel of Pickens Creek

| Distance from Verdugo Creek (feet) | Altitude above mean sea level (feet) | Average slope (percent) |
|---|---|---|
| 0-2,000 | 1,120-1,248 | 6.4 |
| 2,000-4,000 | 1,248-1,375 | 6.4 |
| 4,000-6,000 | 1,375-1,518 | 6.6 |
| 6,000-8,000 | 1,518-1,665 | 7.4 |
| 8,000-10,000 | 1,665-1,816 | 7.6 |
| 10,000-12,000 | 1,816-1,981 | 8.2 |
| 12,000-14,000 | 1,981-2,175 | 9.7 |
| 14,000-16,000 | 2,175-2,362 | 9.4 |
| 16,000-18,000 | 2,362-2,625 | 13.2 |
| 18,000-20,000 | 2,625-3,052 | 21.4 |
| 20,000-21,000 | 3,052-3,256 | 20.4 |
| 21,000-22,000 | 3,256-3,507 | 25.1 |
| 22,000-23,000 | 3,507-3,840 | 33.3 |
| 23,000-24,000 | 3,840-4,600 | 76.0 |

The drainage area of Pickens Creek is shown in plates 16 and 17, airplane photographs of the area. For further description the channel of Pickens Creek is considered in two parts - Pickens Canyon and the debris cone.

Like all other canyons in the burned-over area, Pickens Canyon has very steep slopes, as indicated by the profile in figure 11. The character of the channel varies somewhat between the divide and the point where it reaches the debris cone. Plates 20, A, 21, A, and 21, B, from photographs taken at points above an altitude of 3,200 feet, illustrate the type of channel in the upper part of the main canyon. Except for the damaged check dams and the burned chaparral the appearance of the channel shown in these photographs probably differs but little from its appearance prior to the fire of November and the subsequent New Year's flood.

In the area shown in plate 20, A, the underlying bedrock is largely uncovered. The condition of the exposed rock might indicate that the uncovering had taken place fairly recently. In contrast plate 21, A, shows no exposure of the underlying rock formation.

The character of the sides of the canyon is shown in plate 21, B. (See also pl. 17.) The presence of large quantities of easily erodible material is evident on these slopes - a condition which, however, is not uniform throughout Pickens Canyon, as parts of the canyon slopes are composed of almost bare rock walls, as shown in plate 20, B.

Downstream in the main channel the underlying granite bedrock is more and more conspicuous. Throughout the last 5,000 feet of canyon above the debris cone the channel is cut deeply into the rock, as shown by plate 22, A. Like the sections of channel farther upstream, these sections of canyon that are entrenched in solid rock contained large debris deposits as well as many check dams prior to the New Year's flood. Such deposits had undoubtedly accumulated during a series of years in which there had been only minor floods. Only occasionally and at irregular intervals are there floods of sufficient size to carry these canyon deposits onto the debris cone.

Below the bedrock section just described the channel of Pickens Creek passes onto the debris cone. As indicated by plate 22, B, the channel across the debris is wider and of lesser slope than that in the canyon section. (See fig. 11.) The side walls or banks of the channel across the cone range in height from about 150 feet at an altitude of 2,400 feet to practically zero just below the Foothill Boulevard. From the boulevard to Verdugo Creek the channel of Pickens Creek meanders over the top of the cone with no banks to confine it (pl. 19, B), and as this section is within the lower part of the debris cone, the slopes are less steep and the soil less rocky than in the higher part. This part of the cone was therefore considered desirable for residential uses and was the most highly developed part of La Cañada Valley.

Generally, under normal conditions, the stream after discharging its debris load on the debris cone breaks up into several channels, which meander down the cone. (See pl. 16.) As these channels are wide and lack well-defined banks, the water generally travels in thin sheets over the debris. The stream flow passing from the steep mountain canyon into these broad, relatively flat and meandering channels loses much of its transporting capacity, and as a result most of the load of debris carried by floods is deposited on the upper part of the cone, leaving the water comparatively

*A*. TYPICAL SCENE OF DESTRUCTION.

A section of Montrose most severely affected by Pickens Creek flood.

*B*. ENCROACHMENTS ON CHANNEL OF PICKENS CREEK.

View looking north.

*A*. CONDITION OF CHECK DAM AND CHANNEL IN CANYON SECTION OF PICKENS CREEK.

Altitude about 3,200 feet.

*B*. AREA ON PICKENS CREEK SPARSELY COVERED BY CHAPARRAL.

Altitude about 2,900 feet.

*A.* CONDITION OF CHANNEL OF PICKENS CREEK ABOVE ALTITUDE OF 3,200 FEET.

*B.* MATERIAL FROM ADJACENT SLOPES SLUMPED INTO THE BED OF PICKENS CREEK.

*A.* PICKENS CREEK AT ALTITUDE OF ABOUT 2,300 FEET.

Prior to the storm this part of the channel contained large deposits of debris in which a heavy growth of water-loving plant life had developed.

*B.* CHANNEL OF PICKENS CREEK ON DEBRIS CONE AT ALTITUDE OF ABOUT 2,000 FEET.

clear, and in this condition it flows in an orderly manner across the valley floor.

During periods of small storm run-off the streams reach the top of the cone with little or no debris load. As they have additional carrying capacity under these conditions they pick up debris at the upper end of the cone, the result being the gradual deepening of the channels across this part of the cone. If the periods of heavy run-off, with their large contributions of debris, are several years apart, the intervening flow of relatively clear water often excavates well-defined channels across the cone that are capable of confining flood flows of considerable magnitude. Because of these confining channels the load of debris may be carried much farther down the slope of the cone and nearer the valley floor below. With each storm a channel across the upper part of the debris cone may be cut deeper, until in some places bedrock may be reached.

The Pickens Canyon debris cone heads at an altitude of about 2,800 feet. Because, perhaps, of the underloaded condition of the stream in recent years, a deep channel has been cut into the cone. In places this channel has been cut more than 150 feet into the debris deposits and has reached the underlying granite. (See pl. 22, A.) Under the conditions that existed prior to the New Year's flood the deposits of new debris began at an altitude of about 2,100 feet, or 700 feet lower than the head of the cone as indicated in figure 12. So long as this condition persists the tendency is for the initial point of deposition to move farther downstream with each successive flood. These characteristics of the development and behavior of the channel through the debris cone are illustrated in plate 23. The photograph reproduced in plate 23, B, taken in November 1934, about 11 months after that of plate 23, A, shows that during the intervening period the stream had lowered its bed at the point photographed by about 7 feet. Practically all debris deposited in the Montrose area during the later storm in October 1934 is believed to have originated from sources such as are indicated by these photographs.

Plate 16 shows that, until the flood discharge of Pickens Creek had passed the Foothill Boulevard, it could not spread out in the manner usually found on debris cones. Thus above this point the debris cone could not become effective in dissipating the energy of the stream flow, thereby causing a deposit of the debris. Unfortunately the cone below this point was the most highly developed part of the valley. Only slight semblances of stream channels, such as are indicated on plate 19, B, passed through this section. Thus, the head of deposition on the debris cone, formerly at an altitude of 2,800 feet, was temporarily moved down to the Foothill Boulevard.

Flood flows and debris movement that, in the past, might have been dissipated by the spreading and meandering channels of the older cone were at the time of the New Year's flood brought, by a confining channel, about 13,000 feet nearer the developed sections of La Cañada Valley than the head of the cone, and this was still true at the time of writing this report, (April 1935).

## Factors influencing movement of debris

The factors influencing debris movement have been summarized by Gilbert[7] as follows:

> The quantity of debris which a given stream transports is its load; the quantity it can transport may be called its capacity. The load may be less than the capacity but not greater.
>
> Capacity varies with slope. The greater the slope the greater the capacity; and the change in capacity is always larger than the change in slope.
>
> Capacity varies with discharge. When discharge is increased the resulting increase in capacity is greater than the increase in discharge; the capacity per unit of discharge is increased. But an increase in discharge does not enhance capacity so much as the same ratio of increase in slope.
>
> Capacity varies with the character of the debris transported. The lower the specific gravity of the debris the greater the capacity -- that is, the greater the weight of load which may be transported. The finer the debris the greater the capacity.
>
> The ratio in which capacity is modified by a change in slope, discharge, fineness of debris, or depth of current is greater when the conditions are near competence than when they are far above competence. In other words, capacity is most sensitive to changes in the conditions which control it when near its lower limit.
>
> If a stream which is loaded to its full capacity reaches a point where the slope is less, it becomes overloaded with reference to the gentler slope, and part of the load is dropped, making a deposit. If a fully loaded stream reaches a point where the slope is steeper, its enlarged capacity causes it to take more load, and the taking of load erodes the bed. If the slope of a stream's bed is not adjusted to the stream's discharge and to the load it has to carry, then the stream continues to erode or deposit, or both, until an adjustment has been effected and the slope is just adequate for the work.
>
> In another paper Gilbert[8] says: If slope be the constant, in which case velocity changes with discharge, capacity varies on the average with the 3.2 power of velocity. If discharge be the constant, in which case velocity changes with slope, capacity varies on the average with the 4.0 power of velocity. If depth be the constant, in which case velocity changes with simultaneous changes of slope and discharge, capacity varies on the average with the 3.7 power of velocity.

## Adaptation of stream bed to discharge and debris movement

Gilbert has demonstrated that if the discharge and type of debris remain constant the slope of a stream channel increases by deposition as the debris load increases. This condition results from nature's attempt to maintain a balance between slope, debris load, and discharge.

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7 Gilbert, G. K., Hydraulic-mining debris in the Sierra Nevada: U. S. Geol. Survey Prof. Paper 105, p. 26, 1917.
8 Gilbert, G. K., The transportation of debris by running water: U. S. Geol. Survey Prof. Paper 86, p. 11, 1914.

The Gilbert experiments were carried on during 1907-9 at the University of California, in Berkeley. For the principal experiments a straight flume or trough with horizontal bottom was used. Gilbert's description[9] of the operation of this flume is as follows:

> Through this a stream of water was run, the discharge being controlled and measured. Near the head of the trough sand was dropped into the water at a uniform rate, the sand grains being of approximately uniform size. At the beginning of an experiment the sand accumulated in the trough, being shaped by the current into a deposit with a gentle forward slope. The deposit gradually extended to the outfall end of the trough, and eventually accumulation ceased, the rate at which sand escaped at the outfall having become equal to the rate at which it was fed above. The slope was thus automatically adjusted and became just sufficient to enable the particular discharge to transport the particular quantity of the particular kind of sand.

Holding the discharge constant, the rates at which the debris was added to the flume were increased. As a result deposition continued at a relatively greater rate in the upper end of the flume until the new slope was just sufficient to transport the debris. These experiments were continued with various widths of flume, with various discharges and various types of material. For the purpose of illustration typical results selected from the report of these experiments are given in the following table:

Adjusted values of capacity for debris grade B (13,400 particles to the gram) for given rates of discharge and variable slope 1/
(Width of flume 1.0 foot)

| Slope (percent) | Capacity (grams per second) for different rates of discharge | | | |
|---|---|---|---|---|
| | 0.182 sec.-ft. | 0.363 sec.-ft. | 0.545 sec.-ft. | 0.734 sec.-ft. |
| 0.6 | 10.8 | 35.3 | -- | 86 |
| .8 | 19.5 | 58.5 | 99 | 138 |
| 1.0 | 30.1 | 85 | 143 | 199 |
| 1.2 | 42.8 | 116 | 193 | 268 |
| 1.4 | 57 | 149 | 247 | 344 |
| 1.6 | 73 | 186 | 305 | 422 |
| 1.8 | 90 | 225 | 368 | 507 |
| 2.0 | 108 | 266 | 435 | -- |
| 2.2 | 129 | 310 | 505 | -- |
| 2.4 | 150 | 356 | -- | -- |
| 2.6 | 173 | -- | -- | -- |
| 2.8 | 197 | -- | -- | -- |
| 3.0 | 224 | -- | -- | -- |

1/ Gilbert, G. K., op. cit. (Prof. Paper 86), pp. 77-78.

The initial slope of the bed of the flume was zero. With the addition of a debris load of 30.1 grams per second of the designated material at a rate of discharge of 0.182 second-foot deposition in the flume took place until a slope of 1.0 percent was developed. The development of this 1.0 percent slope was necessary to produce sufficient velocity to move the debris

9 Gilbert, G. K., The transportation of debris by running water: U. S. Geol. Survey Prof. Paper 86, p. 17, 1914.

load of 30.1 grams per second under the given conditions of rate of discharge and width of flume. This slope remained constant as long as the debris load remained 30.1 grams per second and the rate of discharge was unchanged. As the debris load was gradually increased the corresponding slopes increased by deposition until with a debris load of 224 grams per second a 3 percent slope was developed. In other words, for the nature of the load used in this experiment a 3 percent slope was necessary to produce sufficient velocity or transporting capacity to move the 224 grams per second. If the channel were long such a change in slope would signify a considerable deposition of debris in the bed. If the rate of discharge were increased to 0.734 second-foot with the slope at 3 percent the transporting capacity would be greatly in excess of the 224 grams per second, and previously accumulated debris would then be eroded until a new balance was established at a slope of about 1.1 percent. A wedge-shaped deposit of material between the slopes at 1.1 and 3.0 percent would represent the volume of debris moved downstream as an incident of the adjustment of the stream bed to changing rate of discharge and debris movement.

Bends in the canyon channel have a considerable effect on the transportation of debris. In mountain canyons where the slopes are steep and the velocities high the stream loses velocity in passing around sharp bends. This loss in velocity reduces the capacity of the stream to carry debris. When the debris load is small the loss in capacity is relatively slight. However, as the debris load above the bend is increased to the point where it approaches the capacity of the stream the loss of capacity around the bend causes the deposition of debris there. Deposition will continue until the slope at and below the bend is sufficient to produce transporting capacity equal to that above the bend. Equilibrium, once established, would continue as long as the debris load and rate of discharge remained constant. When the stream above the bend became underloaded the condition and the correspondingly increased slope around the bend would start the removal of the recently deposited debris.

Any influence in the channel that affects the velocity of the water will also affect the capacity. In addition to the width and slope of the channel, the channel roughness influences the velocity and consequently the debris movement. In general, most of the stream channels in mountain canyons contain deposits of coarse material and boulders ranging from medium to large sizes, the finer material having been carried off from time to time as suspended load. These boulder-filled stream beds naturally offer considerable obstruction to the movement of the water and thereby materially reduce the transporting capacity that would be normal for the slopes and rates of discharge involved.

With the addition of greater than normal debris loads to the channel of Pickens Creek as a result of the New Year's storm, deposition took place among the boulders, tending to smooth out the channel and to increase its capacity. Plate 24, A, shows a rough boulder-filled section of the creek, in which the boulders were buried by a normal process of deposition of finer material until the transporting capacity was increased sufficiently to transport the debris load.

In the light of the foregoing explanation, it is evident that the slope and general condition of the channel of Pickens Creek would tend to reflect the presence or absence of debris in the water carried by it during recent years. For several years Pickens Creek has brought practically clear water to the debris cone, and consequently there has been a tendency to maintain the flattest possible stream-bed slope that the alinement of the canyon and the roughness of the channel would permit. This normal condition was modified somewhat by the construction of numerous check dams in the stream-bed.

In a deep, irregular canyon such as that of Pickens Creek the normal balancing of debris deposits and channel slopes that might be suitable for the movement of the usual small debris loads develops a channel that is unsuitable and out of balance for the infrequent large flows with their attendant debris movements. With the continuous and heavy rainfall that characterized the New Year's storm, much debris was delivered to the stream channel. In order to transport this abnormally large debris load the stream had to increase its transporting capacity, either by smoothing its bed or by increasing its gradient or by a combination of the two processes.

A typical section of Pickens Canyon is schematically shown in figure 12 to illustrate the authors' interpretation of the features of debris movement that are discussed above. The upper part of this diagram shows the alinement of the channel, including the water and debris in it, when high-water marks were made. The arrows represent the courses taken by the main part of the stream flow. The lower part of the diagram shows the profiles of the stream bed and of the water surface. In the center of the diagram are four typical cross sections of the stream showing the authors' ideas as to the distribution of stream flow and debris deposits.

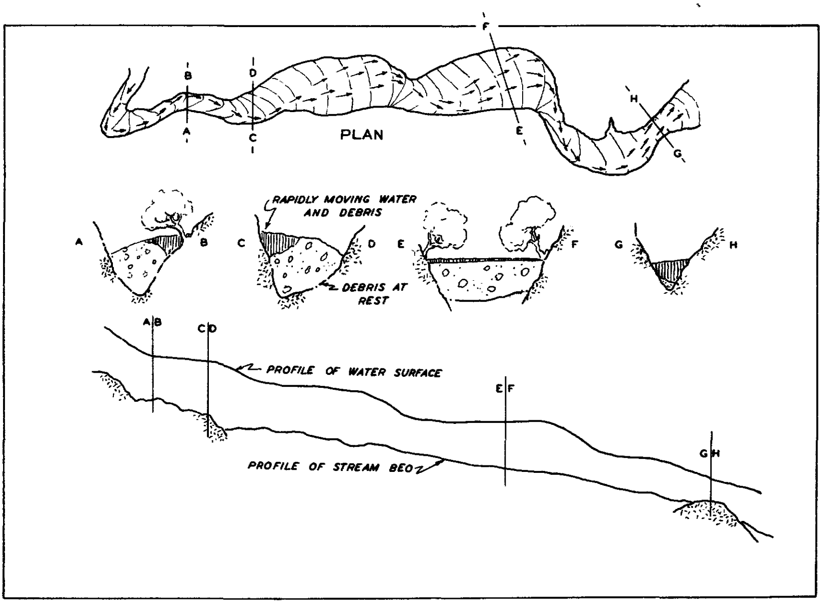



Figure 12.-Movement of debris in Pickens Canyon.

Cross section E-F is drawn at a point just above a reach in which the capacity of the stream for moving debris is largely controlled by a sharp bend in the channel. Because of the reduction in the velocity, debris will be deposited at this point until the slope of the stream in the narrow channel below the bend has been so increased that its capacity equals the capacity above the bend. The result is the development of a very steep gradient below the bend, with the greatest depth of debris deposited at the bend. The appearance of the channel of Pickens Creek indicates that the depth of such stream-bed deposits exceeded 25 or 30 feet at some of the sharp bends.

The debris deposit at a bend would tend to control the altitude of the channel immediately upstream. Thus at cross section E-F the altitude of the channel deposits was governed by the conditions at the bend downstream and not by the conditions immediately adjacent to the section itself. For this reason the slopes of the high-water marks at wide cross sections above sharp bends may be flatter than the normal stream-bed slopes at those places.

Plate 24, B, illustrates a channel immediately below a sharp bend in Pickens Canyon. A rope has been stretched across the channel at the level of the high-water mark as indicated by abrasion marks on trees. Directly below the rope is a 12-foot level rod, which indicates that at one time during the flood the surface of water in the stream was about 20 feet above the present bed of the stream. There is, of course, the possibility that this high-water mark may not have been made at the time of the maximum discharge, but at some time when the bed was much higher and the discharge far less than the peak.

The depth of the deposits of debris in the cross section over which the moving debris and water passes depends upon a relationship, always temporary and changing, that exists between the debris movement and the transporting capacity of the stream. It is in fact entirely possible that the maximum discharge of the New Year's storm period might have occurred after most of these temporary debris deposits had been removed. Thus it is evident that large cross-sectional areas such as shown by plate 24, B, may have no relationship to flood discharge and therefore no value for use in connection with slope formulas as a means for estimating peak discharge.

The abrasion marks on the tree at the left in plate 24, B, are shown in more detail in plate 25, A. The condition of the bark on the tree and the embedded debris testify to the high velocity of the moving debris load.

Plate 25, B, reproduced from a photograph taken near the mouth of Pickens Canyon, gives some indication as to the method of formation of abrasion marks on small trees. The abrasion marks shown in this view were apparently made by a rapidly moving debris-laden stream that was passing over the debris deposits shown. Below the surface of the debris deposits the trees are undamaged, indicating practically no movement of debris after deposition took place or after a channel had been cut in the valley filling that concentrated the discharge below the old level. The marks on these trees tend to indicate that the flowing debris and water were comparatively shallow. The depth of the debris deposit at this place was largely determined by the presence of a check dam and a sharp bend in the channel a short distance below. It is believed that the trees shown in plates 24, B, and 25, A, were marked in much the same way as those shown in plate 25, B, except that the debris deposits over which this thin sheet of rapidly moving debris passed were probably much less stable.

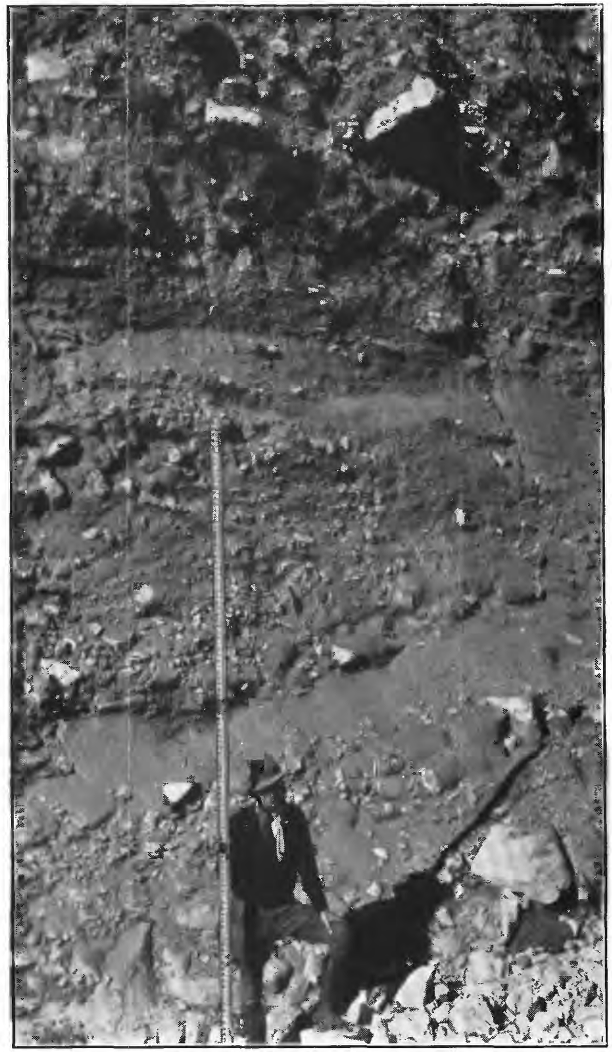
Plate 25, B, appears to show that when the stream became underloaded, not only were the recent debris deposits removed but a large section of the former stream bed was eroded. It will be readily seen that the large cross section now indicated at this point may have had no relation to the cross section of the flowing debris and water at any stage of the flood.

At points such as indicated by cross section G-H, figure 12, are usually to be found the minimum flood-channel cross sections. Such sections are immediately above small waterfalls, where because of the free fall in the stream the velocities are nearly always sufficient to keep the crest of the falls fairly clear of debris. A small falls section of Pickens Canyon is shown in plate 26, A. The rope stretched across the canyon represents approximately the peak stage at this place but, of course, not necessarily the stage at the time of maximum discharge. This flood cross-section may be compared with that shown in plate 24, B, a view taken several hundred yards downstream. There is no tributary inflow between these two cross sections and consequently the same quantity of debris passed both. Owing to the alinement of the canyon the stream could not move an abnormally large debris load until sufficient slope to create the necessary transporting capacity had been developed by deposition of debris in the vicinity of the bend shown by plate 24, B.

## Movement of debris across the debris cone

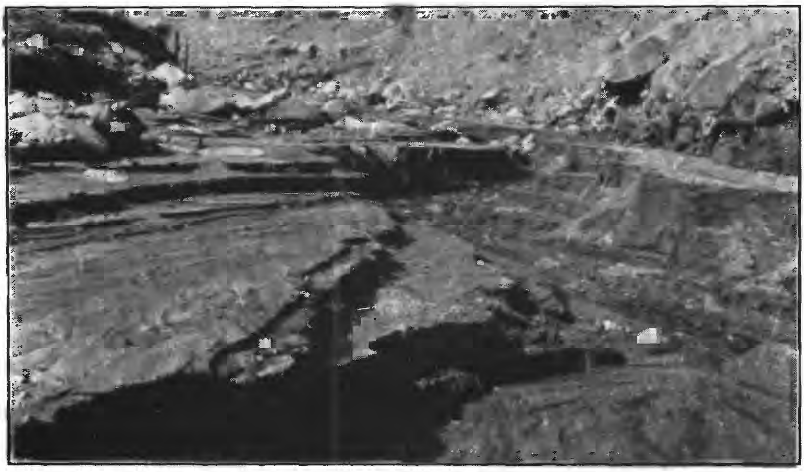
The debris movement through the wider, less crooked channels across the debris cone, with their much flatter gradients, is believed to have

*A*



*B*

STREAM-BED EROSION ON DEBRIS CONE IN PICKENS CREEK ABOUT ONE-FOURTH MILE ABOVE ORANGE AVENUE.
*A*. Photograph taken in January 1934. *B*. Photograph taken at same locality in November 1934. Bed about 7 feet lower than as shown in *A*.



*A*. DEBRIS DEPOSITED IN PICKENS CREEK DURING STORM OF OCTOBER 1934.
The eroded channel in the debris was caused by underloaded run-off from a subsequent small storm.

*B*. CANYON SECTION OF PICKENS CREEK IMMEDIATELY BELOW A SHARP BEND.
The position of the rope represents the peak stage of the flood of January 1, 1934, several hundred yards downstream from section shown in plate 26, *A*.

*A*. ABRASION MARKS ON TREE TRUNK IN PICKENS CANYON.

Tree is shown at left in plate 24, *B*.

*B*. DAMAGED CONDITION OF TREES CAUSED BY SWIFTLY MOVING DEBRIS AND WATER IN CANYON SECTION OF PICKENS CREEK.

Altitude about 2,200 feet.

*A*. SMALL FALLS IN PICKENS CANYON.

The position of the rope represents the peak stage of the flood of January 1, 1934, several hundred yards upstream from the section shown in plate 24, *B*.

*B*. DEBRIS IN CHANNEL OF FISH CREEK, APRIL 2, 1925.

Compare with plate 27, *A*.

had slightly different characteristics from those within the canyon sections described above.

Cecil[10] in his paper on the Montrose disaster said that "according to the statement made by local observers, the early run-off carried but little mud and silt. The first loss of life reported occurred in Montrose at about 9 p.m. (Dec. 31, 1933). At this time the flood is reported to have been comparatively free of detritus." Thus, after almost 12 hours of continuous rainfall there was very little movement of debris down the debris cone. During this period there were several sharp showers, which were capable of producing some mountain-area run-off, as indicated by observations in nearby Cooke and Blanchard Canyons. This run-off undoubtedly removed some of the more easily eroded material from the mountain slopes. It would seem that prior to about 9 p.m. most of the material thus moved in the basin of Pickens Creek was still held in the canyon sections.

After each shower of greater than average intensity there was a sharp storm run-off of short duration. The transporting capacity of the moving water would decrease rapidly after the passing of these sharp peaks. As a general rule, the material in the bed of the stream would move more slowly than the water flowing near the bed of the stream. Thus the particles, especially the larger ones set in motion at the time of a peak discharge, would soon fall behind the water that started them on their way and would gradually come to rest because of lack of transporting capacity.

As the storm peaks during the afternoon of December 31 were of short duration, each one moved the main body of the canyon debris only a short distance at most. This type of run-off would give the debris a jerky movement in its journey downstream. Under the influence of a peak the debris would move rapidly, and as soon as the peak had passed it would slow down to a considerable extent. As a result the debris would tend to collect at the lower end of the canyon section or at the upper end of the alluvial cone, where the slopes of the bed became flatter, until a succeeding peak gave the stream sufficient capacity to move it farther.

Plates 26, B, and 27, A, illustrate conditions near the mouth of the canyon of nearby Fish Creek after that area had been denuded by fire during the fall of 1924. Plate 26, B, shows the conditions April 2, 1925, and 27, A, the conditions 16 days later. Both pictures were taken from the same point. During the intervening time a rainfall of 2 to 4

10 Cecil, G. H., Fire and flood, Conservation Assoc. Los Angeles County, 1934.

inches had occurred on the drainage basin, and the deposit of debris that was originally well below the footbridge had increased in depth until it was only a foot or two below the water pipe that spanned the creek above the footbridge. The deposition of debris at this time was caused in part by the widening of the channel and a reduction in the gradient of the stream bed. On passing from the narrow canyon section above the debris deposit, the stream was split up into several channels, which meandered over the newly deposited debris as indicated in plate 26, B. The increase in cross-sectional area was accompanied by a loss of velocity and transporting capacity, with a resulting increase in deposition of debris. The deposit continued to increase in depth until there was a storm discharge of sufficient magnitude to transport the material downstream. This evidence supports the belief of the authors that somewhat similar conditions existed in Pickens Canyon and that prior to midnight on December 31 there was a tendency for the debris to accumulate in the lower reaches of the canyon and at the head of the debris cone.

From available information it appears that practically all the debris was moved across the debris cone and deposited in La Cañada Valley as a result of the very heavy rain (shower 7, fig. 10) that occurred about midnight. Several descriptions of the debris movement as it occurred in Pickens Creek and adjacent canyons are given in the following paragraphs. Most of these descriptions were collected by the Los Angeles County Flood Control District.

A resident at the mouth of Blanchard Canyon reported that a wall of water came down the canyon at about 11:56 p.m. December 31. He described the water surface at the peak of the flood as being greatly raised in the center of the cross section. Twelve minutes after the initial heavy flow he was able to walk across the canyon.

A resident in Shields Canyon, an area burned over by the recent fire to the west of Pickens Canyon, stated that the big peak occurred about 12:15 a.m. A wall of water 8 to 10 feet high accompanied by a very loud roar traveled down the channel. Within 5 minutes it was all over.

A resident on the Foothill Boulevard testified that he saw the peak of the flood from Shields Canyon as it crossed the boulevard at about 12:09 a.m. in the form of a wall of water 10 feet high. Three minutes later the floor of his residence, about 600 feet west of the channel, was flooded to a depth of about 2 1/2 inches. At 12:15 a.m. the wave had passed and the roar ceased.

A resident at the mouth of Deer Canyon, an area which had not been burned over in many years, had been at the mouth of the canyon throughout the storm. Shortly before midnight he crossed the canyon from his home to the opposite side. At that time the water in the creek was about 2 feet deep. About midnight he heard a loud roar. What appeared to him to be a wall of water came down the stream channel, crowned about 8 to 10 feet in the center. The boulders riding along the top of the wave seemed to leap clear of the water. He compared the mixture to concrete with boulders. Practically all the larger rocks came down within 20 minutes after the peak. At about 12:20 a.m. he was able to wade back across the stream to his home on the other bank.

A resident of Montrose who saw the peak from Pickens Canyon cross Foothill Boulevard estimated the wall of water to be 20 feet high, by comparison with the height of the power-line poles. The wall flattened out immediately after it crossed the boulevard.

Another resident was helping to free several automobiles that had been caught in the debris where the flood from Shields Canyon crossed the Foothill Boulevard. When the flood wave struck the boulevard he was held by the current against the upstream side of one of these cars. The car and he were carried across the boulevard and held from further travel by the pipe handrail of the crossing. He reported that he was held in an upright position and that the flow was just over his head. The flow quickly dropped. When the peak had passed the debris had settled around his body up to his shoulders.

From the foregoing reports of eyewitnesses it is evident that the entire debris movement occurred in a very short interval of time. In less than 20 minutes over 600,000 cubic yards of debris was transported from the small canyons of the mountain area and deposited in La Cañada Valley.

Each of the great flood and debris waves that issued from the canyons appeared to be caused by the very heavy shower that occurred about midnight in the mountain areas. As indicated on figure 10, the rates of rainfall for this shower (no. 7) were considerably higher in these areas than those for any of the previous showers. The excessive stream flow from this midnight shower had a capacity for debris movement far greater than that of any of the earlier showers. It was the run-off from this shower that moved the large quantities of debris concentrated in the canyon stream beds out on to the debris cones and left it in the developed areas of Montrose and vicinity. If this last shower had been of less intensity the capacity of the streams to move debris would have been less, and these debris deposits might, in the main, have remained in the canyons.

Figure 13, based on an inspection of the channel of Pickens Creek across the debris cone and the testimony of eyewitnesses, has been prepared to show the method by which the authors believe the debris moved downstream. The dimensions of the debris wave pictured in this figure are selected for effective presentation and are not made to scale. In the center of the figure is given the plan of the debris wave, and in the upper part are a series of cross sections at the points indicated on the plan. Typical progressive longitudinal profiles are shown at the bottom of the figure. The debris wave as illustrated is very similar to a group of much smaller waves that were noted in another canyon nearby. The longitudinal profile agrees very closely in shape with sand waves that have been examined in the Santa Ana River.

This large debris deposit was in general transported down the debris cone in a manner similar to that in Fish Creek, illustrated in plate 26, B. At the upper end of the deposit in Fish Creek a fairly swift stream of clear water of several second-feet discharged from the canyon onto the debris cone. This stream quickly picked up a load for movement downstream. In progressing downstream the deposit became deeper. With increasing depth the surface area of the deposit increased and at the same time the surface slope became much flatter. After leaving the canyon the stream is broken up into several channels, which meander across the cone. As a result of the flatter slope and the separation of the stream into several channels much of the transporting capacity is lost, and deposition takes place. Thus the deposit was gradually moved by scouring the particles from the upper end and depositing them farther downstream. A cross section of the debris deposit showing movement of this type is shown at the bottom of figure 13. The movement of the debris deposits down the Pickens Creek debris cone is believed to have been similar to that described above, except that it took place more rapidly.

The passage of this heavily loaded stream over stream-bed deposits, in the manner indicated by sections A, B, C, figure 13, could do little more than smooth the surface of the channel. Extensive erosion would be impossible at this stage because of the loaded condition of the stream. In contrast, the rear part of the wave was characterized by erosion not only of the debris deposits but of the stream channel as well.

The influences of these two parts of the debris wave on the stream channel are illustrated in plate 27, B. This picture of the debris cone

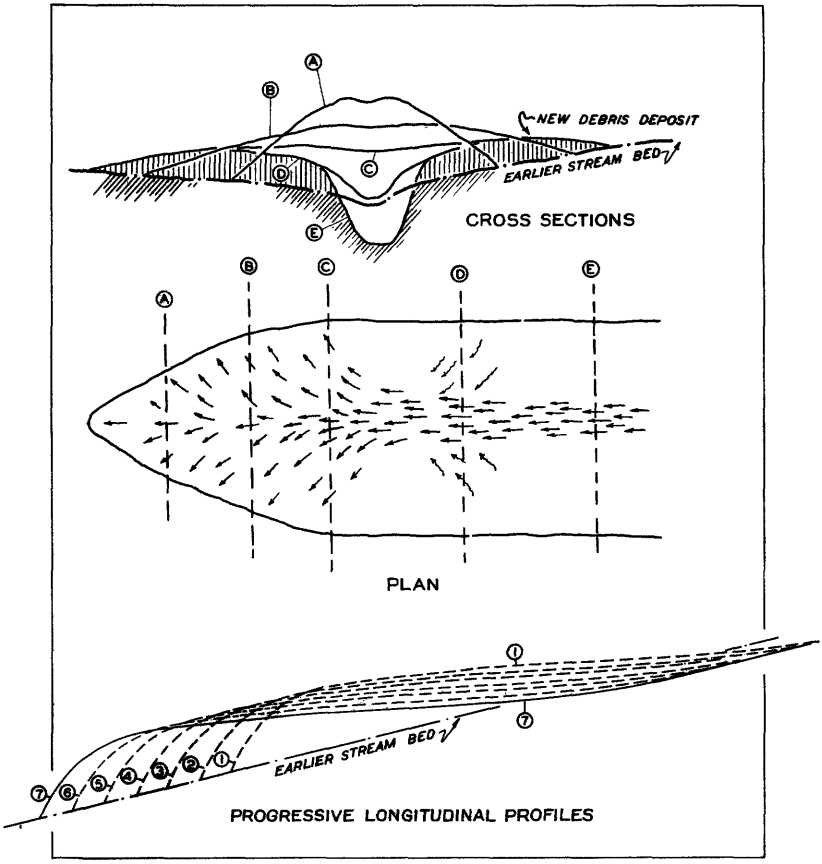



Figure 13.-Movement of debris wave across debris cone of Pickens Creek.

of Dunsmore Creek, which shows how both banks have been smoothed off - in fact, almost polished - by a loaded stream, indicates that the loaded condition continued until practically the entire debris deposit in the stream channel had been removed. Then followed a period in which the stream was underloaded and as a result scoured deeply into the bed of the channel, undercutting both banks.

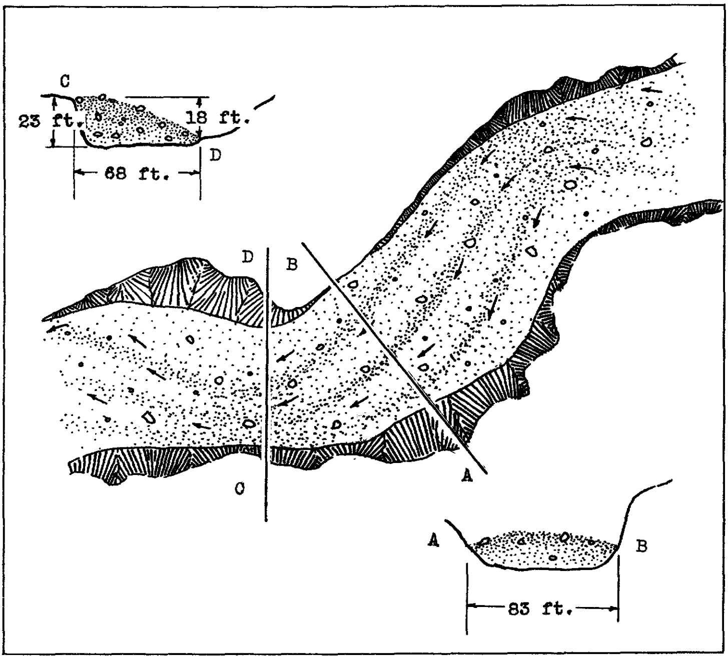



Figure 14.-Debris wave on Pickens Creek debris cone.

The channel of Pickens Creek across the debris cone was equally well marked by the passage of the debris wave. For example, at the end of Orange Avenue at an altitude of about 1,800 feet, an interesting record of debris behavior was left at a slight bend in the channel. The east bank of the creek (C, fig. 14 ) was completely overtopped by the debris wave. This bank, which is 23 feet high, is shown in plate 28,B. On the opposite bank the debris deposit was only 3 feet above the normal stream bed as shown by plate 29, A. As indicated in figure 14 the debris deposit on the east bank was 18 feet higher than that on the west bank. The high-water marks, such as they were, practically coincided with the debris deposits.

It has been suggested that this difference in height between the marks on the two sides of the creek might be due to high velocity at the bend in the channel. All channel evidence, however, indicates that high velocity did not occur at this stage of debris movement. The loaded condition of the stream would probably cause a velocity much less than for water alone. Gilbert[11] has stated that "The imperfect liquid constituted by the combination of water and debris is more viscous and therefore flows more slowly than the water alone. The solid particles do not partake of the internal shearing involved in the differential movement of the current, and by their rigidity they restrain the shearing of water in their immediate vicinity." The smooth side walls of the channel as indicated by plate 28, B, indicate that the stream was probably loaded to capacity. If the stream had not been so loaded the bank would have been undercut and eroded. As indicated in plate 27, B, it was only in the final stages of the flood that the stream had capacity to erode the bed and banks.

Plate 29, B, illustrates a similar effect of the debris wave on the banks of the channel across the Pickens Creek debris cone. Here is shown a rather sharp bend in the channel where the debris wave passed completely over the top of a 22-foot bank about a quarter of a mile above Orange Avenue. Here also the smoothness of the surface of the bank indicates that there was no undercutting. This bend in the channel is very much sharper than that shown in figure 14.

A lack of undercutting of the banks is associated with a heavily loaded stream and reduced velocities. The statement of the man who aided in freeing automobiles caught in the debris at the Foothill Boulevard that the car at which he was standing was held from overturning by a light guard-rail indicates that the debris in that portion of the stream was not moving with great velocity. The fact that he could hold on to the car while the debris and water were up to his neck or higher certainly shows that the nearby material was moving slowly. If this stream had been unloaded, as it usually is in these channels, and if it had had the depth indicated, he would have been carried rapidly downstream in the rolling wreckage of the car.

In contrast to the debris-laden stream as indicated by the polished side walls of the channels, there developed in the rear of the wave a devastating, underloaded, eroding stream. In the main it was this part of the flood and debris movement that caused most of the damage. This later phase of the flow turned entrapped automobiles into masses of wreckage and rolled large boulders through the house shown in plate 19, A, while adjacent houses were buried up to the roof with debris but not otherwise damaged.

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11 Gilbert, G. K., The transportation of debris by running water: U. S. Geol. Survey Prof. Paper 86, p. 225, 1914.

## Composition of debris and its influence on debris movement

The debris load of running water is made up of two parts - the suspended load and the bed load. As the velocity of a stream increases, the turbulence throws first the finer particles, then larger particles into suspension. In this process the specific gravity and the buoyancy of the fluid are increased. In addition to the suspended load, material known as bed load is moved along the bed of the stream by the tractive force of the moving water and its suspended load. There is no clear line of demarcation between the suspended load and the bed load, as many of the particles pass from one load to the other and back again. As the transporting capacity increases, the particles usually move from the bed to the suspended load; as the capacity decreases the movement is reversed. Under ordinary conditions only the finer particles are to be found in the suspended load.

The debris movement during the New Year's storm was undoubtedly largely in the form of bed load. The mechanical analyses of several samples of this bed load are shown in figure 15. The Pickens Creek samples 1 and 3 were collected just above the Foothill Boulevard at an altitude of about 1,600 feet. Sample 2 was collected at the lower end of the canyon section, at a point about 2,100 feet above sea level. Plate 25, B, illustrates the debris deposits from which this sample was taken.

The analyses of two samples of the suspended load collected in the burned-over drainage areas of Roberts Canyon (Rogers Creek)[12] and Sawpit Creek in 1924 and 1925 have been plotted on the same diagram (fig. 15). Both of these samples were taken on streams very similar to Pickens Creek, and they are believed to be representative of suspended load from burned-over areas in this region.

Analyses of samples of the bed load collected on the Santa Ana River have also been plotted on figure 15 to afford a comparison with a typical bed load. In these samples the absence of the finer material is most marked. On the Santa Ana River the annual high water scours and redeposits this stream-bed material and carries off the finer particles as suspended load.

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12 Hoyt, W. G., and Troxell, H. C., Forest and stream flow: Am. Soc. Civil Eng. Trans., vol. 99, p. 27, 1934.

*A*. DEBRIS IN CHANNEL OF FISH CREEK, APRIL 18, 1925.
Compare with plate 26, *B*.

*B*. CHANNEL OF DUNSMORE CREEK AT END OF NEW YORK AVENUE.
The two large boulders on the left bank are those shown in plate 28, *A*. Note the erosion of the channel which occurred during falling stages of the flood.


*A*. TWO BOULDERS ON PAVEMENT AT END OF NEW YORK AVENUE.

These boulders were brought down Dunsmore Creek by the flood. Estimated weight over 60 tons each.

*B*. EAST BANK OF PICKENS CREEK AT ORANGE AVENUE.

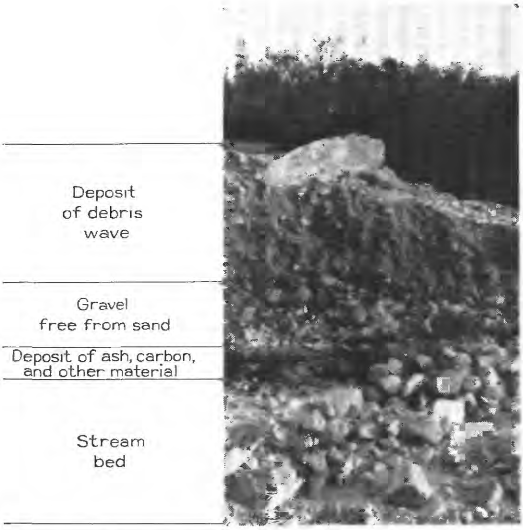
Material from the debris wave passed over the top of this 23-foot bank. Compare with view of opposite bank shown in plate 29, *A*.

*A*. WEST BANK OF PICKENS CREEK AT ORANGE AVENUE.

The high-water mark of the flood was 18 feet lower on this bank than on the opposite bank shown in plate 28, *B*.

*B*. PICKENS CREEK ABOUT A QUARTER OF A MILE ABOVE ORANGE AVENUE.

At this bend in the channel, near the upper end of the debris cone, the crest of the debris wave passed over the top of the 22-foot bank.




*A*. COMPOSITION OF DEBRIS DEPOSITS IN CHANNEL OF PICKENS CREEK.
Altitude about 1,590 feet.

*B*. DEBRIS BASIN IN HAINES CANYON.

The extent of the debris deposited by the flood is indicated by this photograph. Steam shovels and trucks are at work removing the debris. The depth of the debris can be compared with the height of the trucks. The spillway section is in the right foreground.

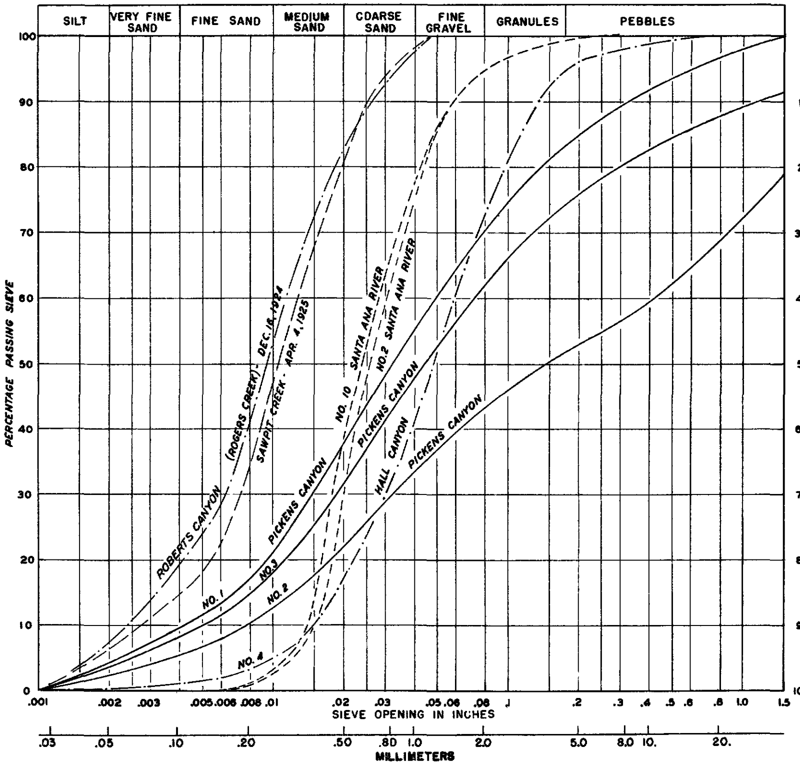



Figure 15.-Sieve analyses of debris.

Gilbert[13] states that "the packing together of larger and smaller grains which tends toward a smooth stream bed tends also toward the reduction of interstitial spaces within the bedded debris, thus reducing the percentage of voids. It was suggested in the laboratory that the percentage of voids, used inversely, might serve as a sort of index of mobility." The analysis of the debris deposits left in the Pickens Creek channel disclosed that the mixture contained a large percentage of very fine material. It is possible that the mere addition of sufficient water to such material might reduce the friction enough to allow internal sliding between the particles, which, under the action of gravity, might promote a downstream movement of the debris deposits. Newly mixed concrete, containing as a rule a much smaller percentage of fine material, travels under the force of gravity down chutes of even less slope than those encountered in parts of Pickens Canyon. Thus it is not unreasonable to suppose that this debris in the presence of sufficient water would act somewhat like freshly mixed concrete.

The composition of the debris wave is well shown also in plate 30, A. In the foreground is shown the regular channel of Pickens Creek, taken at an altitude of about 1,590 feet. Just over this surface can be seen a layer of charcoal and ash brought from the burned-over area by an earlier storm. Directly above this black deposit is a layer of water-washed gravel. Apparently during the period when this gravel was being laid down most of the finer particles were carried off as suspended load. Immediately above the gravel deposit may be seen the deposit from the debris wave. This deposit contains a large percentage of the finer particles. It is not unreasonable to suppose that the deposit, including the larger boulder on top, had a certain degree of down-stream movement, due to the mobility of the mass, which was not imparted to the coarse underlying water-washed gravel.

Besides the influence of the smaller particles on the mobility of the bed load as a whole, Gilbert found that the addition of the finer material to the stream flow increased its capacity to move the larger particles. He states:[14] "When a finer grade of debris is added to a coarser the finer grains occupy interspaces among the coarser and thereby make the surface of the stream bed smoother. * * * One of the coarser grains, resting on a surface composed of its fellows, may sink so far into a hollow as not to be

13 Gilbert, G. K., op. cit. (Prof. Paper 86), p. 179.
14 Gilbert, G. K., op. cit. (Prof. Paper 86), p. 178.

easily dislodged by the current, but when such hollows are partly filled by the smaller grains its position is higher and it can withstand less force of current."

Because at sometime during the New Year's flood the channel of the stream in Dunsmore Canyon was bank full of debris, it was possible for the two large boulders shown in plate 28,A, at the upper end of the debris cone to travel downstream, either by rolling or sliding over a smooth bed, until they finally came to rest on top of one of the banks. These boulders can be seen in the background in plate 27, B. The movement of such boulders for any great distance down a very irregular stream bed containing other large stones and boulders and many rapids, such as existed prior to the New Year's storm, would be difficult to conceive were it not for the presence of a heavy debris load to smooth out the stream bed. It is doubtful whether in the absence of the debris load and the consequent effect of viscous flow boulders of this size could have moved more than a very short distance.

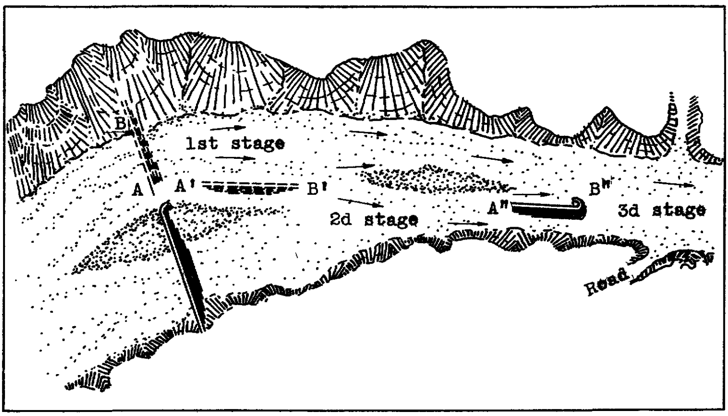



Figure 16.-Action of debris wave on check dam in Haines Canyon.

The influence of the smaller debris on the transporting capacity of a stream is illustrated at a point about 0.8 mile above the United States Geological Survey's gaging station in Haines Canyon, where a check dam of the rock and wire type was moved downstream about 150 feet. On figure 16 has been plotted the authors' conception of the action that took place at this point. The check dam was somewhat longer than the usual structure, with its center section resting on an island in the channel. This center section constituted a point of weakness. At the point marked B, the dam was resting on the bare rock of the canyon wall, being held in place mainly by its weight. Earlier flows had evidently weakened the bond between the dam and bedrock. A-B, A'-B', and A"-B" show successive positions of section of dam that failed.

As a result of this weakening the first part of the New Year's flood swept the B end of the dam downstream. The strain placed on the wire fencing caused it to break, releasing the section A-B. The debris wave moved this section of the structure to a point about 150 feet downstream, where it was left but slightly damaged, in a longitudinal position and right side up. The wire enclosing the rock mattresses was in good condition, only a small percentage of it being broken, indicating that this section had received practically no battering from rolling boulders, and that it had not rolled over in its 150-foot journey.

The movement of this structure 150 feet down a boulder-laden and bedrock channel without complete destruction of the wire-bound rock mattresses would seem to indicate that it practically floated or slid over a channel completely filled with smaller debris. It seems evident that under no condition could such a movement as this have taken place in the clear or nearly clear flood waters that have usually been discharged from these canyons in recent years.

It therefore appears probable that the capacity of the streams to move debris from Pickens Canyon and the adjacent burned-over areas was greatly enhanced by the presence of large quantities of the smaller debris.

## Measurements of debris

Only in Haines Canyon was it possible to measure the amount of debris that left the mountain area. In order to obtain building material a local company had operated a gravel pit in the upper end of the Haines Canyon debris cone, and prior to the New Year's flood considerable material had been removed, leaving a large pit in the bed of the canyon. The Los Angeles County Flood Control District had converted this pit into a debris basin by constructing a spillway section on the downstream edge and diverting the creek into the pit. By midnight of December 31 this basin was nearly filled with water and debris. When the flood or debris wave poured into the debris basin, shortly after midnight, it displaced the water in the basin and forced it out over the spillway. The water flowing from the basin contained very little debris and traveled down the channel, spreading over the valley floor in an orderly manner. A view of this debris basin, still containing part of the debris entrapped during the New Year's flood, is shown in plate 30, B. From topographic surveys made before and after the New Year's flood it has been found that 28,500 cubic yards of debris was deposited in the pit. This debris came from a drainage area of less than 1 1/2 square miles. The general conditions of the canyon and the conclusions reached in preceding pages indicate that most of this debris was supplied by the canyon stream-bed deposits and the general regrading of the channel caused by the debris basin itself.

In October 1934 the Los Angeles County Flood Control District made a profile of Pickens Canyon, and the results were compared with a profile made in January 1930 by the same organization. The comparison showed that the stream bed in 1934 was very much lower than it was in 1930, except at the extreme upper end of the canyon section and the extreme lower end of the debris cone. At several points the differences were as much as 20 feet. These differences indicate that when the check dams were built there was a much greater amount of debris in the stream bed than there was after the passage of the New Year's flood. It is known also that between the date of the 1930 profile and the time just prior to the New Year's storm most of the original storage space above these dams had become entirely filled with debris.

The profile of the main channel shows also that between altitudes 2,100 and 2,800 feet, the bed was lowered an average of 6.5 feet through a distance of 6,200 feet. If the stream bed was 30 feet wide and the average depth of scour in the cross section was one-half of the 6.5 feet, the removal of bed material would amount to about 3.6 cubic yards per linear foot of channel. On a reasonable assumption that the total length of channel in the 1.6 square miles of drainage area of Pickens Creek and its tributaries subject to the removal of material at this average rate was 20,000 feet, the volume of deposits removed from the canyon would have been about 72,000 cubic yards. This mountain drainage area of Pickens Creek may therefore have delivered material to the debris cone from this source at the rate of about 45,000 cubic yards to the square mile.

## SOURCES OF DEBRIS

### Soil erosion

Plates 17 and 21 show large quantities of debris in the headwaters of Pickens Creek. The movement of this debris from the side walls of the canyon varies with type of soil, vegetation cover, and topography, but it is dependent primarily on the medium of transportation, which is water. If other things remain constant, erosion will, as a rule, vary with the rate of run-off, which in turn varies with the rate of rainfall.

As indicated in figure 10 the first five major showers at the higher altitude of Pickens Canyon were well below a rate of 1 inch an hour. In this basin only showers 6 and 7 had rates of rainfall in excess of 1 inch an hour, and it appears probable that most of the erosion from the canyon walls followed these two showers.

Vegetation, with the accumulation of litter, tends to retard surface run-off on steep slopes like those of Pickens Canyon, and its removal may permit a great increase in the rapidity with which the water passes over the surface of the ground. As the capacity of flowing water to carry debris varies as about the 3.2 power of the velocity if the slope remains the same, the increase in velocity caused by removal of the vegetative cover will greatly increase the transporting capacity.

Minute rivulets passing over the surface of the soil unite, and their union reduces the aggregate wetted perimeters of their channels. This union by increasing the quantity of water in a channel increases the velocity and carrying capacity of the water. As a result, "shoestring" gullies such as those shown in plate 31, A, are formed. These gullies unite farther down the steep slope and cause the development of larger gullies, as shown in plate 31, B. Thus, the small surface rivulets unite to form "shoestring" gullies, then larger gullies, and the material eroded in the formation of these surface channels is carried into the stream channels below.

## Slides

In addition to the debris derived from surface and gully erosion there have been numerous slides from the sides of the channel of Pickens Creek. Plate 22, A, shows that in the canyon section between altitudes of 2,100 and 2,800 feet the stream has cut through the older debris deposits. At places along 6,000 linear feet of channel the steep walls of the earlier deposits towered as much as 150 feet above the bed of the creek after the New Year's flood. Long continuous rainfall, such as occurred during this storm and other great storms of the past saturates the soil or brings it to a condition approaching saturation. The addition of water moistens and lubricates the soil particles, thereby lessening friction and inducing instability. As a result, quantities of soil move slowly from the side walls into the stream channel below. This is the familiar phenomenon of soil creep, exhibited on many soil-covered slopes. Many of these slides have moved so slowly and so intermittently through so long a time that trees and other plants have grown in the slowly moving material. Such a slide is shown in plate 32, A, with its lower end resting on the bedrock over which it has advanced and partly removed by the flood water of the New Year's storm.

In contrast with such slow movements there are more active and violent movements that are usually designated landslides. A continuous heavy rain may saturate the soil mantle and induce such easy slippage that the whole soil cover of the canyon slopes moves into the stream practically in a mass. A slide of this character is shown in plate 32, B. It is not unlikely that some such slides may have been large enough to dam the stream temporarily.

Stream-channel deposits

The main source of the debris carried by Pickens Creek during the New Year's storm was probably the material deposited in the stream channel by earlier storms. Gilbert found that "If a stream which is loaded to its full capacity reaches a point where the slope is less, it becomes overloaded with reference to the gentler slope, and part of the load is dropped, making a deposit."[15] The mountain sides in this area, being much steeper than the stream channels, produce a surface run-off capable of transporting material from the mountain slopes, but this run-off is unable to move the material down the channels, and thus stream-bed deposits are formed.

At irregular intervals the Pickens Canyon area has been visited by storms of very high rainfall intensity. The discharge from an occasional storm has been of sufficient magnitude and duration to move much of the accumulated stream-bed deposits downstream to the debris cone.

In order to reduce the movement of debris from the stream channels to the developed debris cone during storm periods, numerous check dams had been built in the stream bed of Pickens Canyon, and many of these check dams were less than 100 feet apart. Check dams in many of the Los Angeles County mountain canyons were the rule rather than the exception and were accepted by the public as having a controlling influence on floods. The dams were adapted from European practice and were built with the idea that they would reduce the rapidity of storm run-off.[16] The most common type of check dam in general use was that shown in plate 33, A. These structures served their intended purpose for floods of moderate discharge. However, the reduced velocity of the stream flow caused the deposition and accumulation behind the dams of debris that had been brought down from the mountain slopes. Such a

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15 Gilbert, G. K., Hydraulic-mining debris in the Sierra Nevada: U. S. Geol. Survey Prof. Paper 105, p. 26, 1917.

16 See Reports of the Board of Engineers Flood Control to the Board of Supervisors, Los Angeles County, Calif., July 27, 1915.

deposit is illustrated in plate 33, B. The deposits back of the check dams supported thrifty growths of vegetation, which offered additional obstruction to the movement of the flood water, thus further reducing the capacity of the stream to transport debris.

The size of one of these debris deposits back of a check dam in Haines Canyon is shown in plate 34, A. This dam, like most of the others, rested on deposits of canyon debris. The water from the New Year's storm eroded debris below the dam, leaving the bottom of the structure about 5 feet higher than the stream-bed immediately downstream from it. Inspection of this photograph shows clearly the large quantity of debris that would have been released to travel downstream had the structure failed completely. The check dams on Pickens Creek were, in general, much smaller than the one shown in plate 34, A, but nearly all of them were completely destroyed.

## EFFECTS OF THE NEW YEAR'S STORM ON OTHER DRAINAGE AREAS

La Cañada Valley was not the only area that experienced a severe flood as a result of the New Year's storm. All rivers and watercourses from the Ventura River on the west to the San Gabriel River on the east were at flood stages. On some of these - for example, Ballona Creek near Culver City - there was damage, but La Cañada Valley was the greatest sufferer, both in lives lost and in property destroyed.

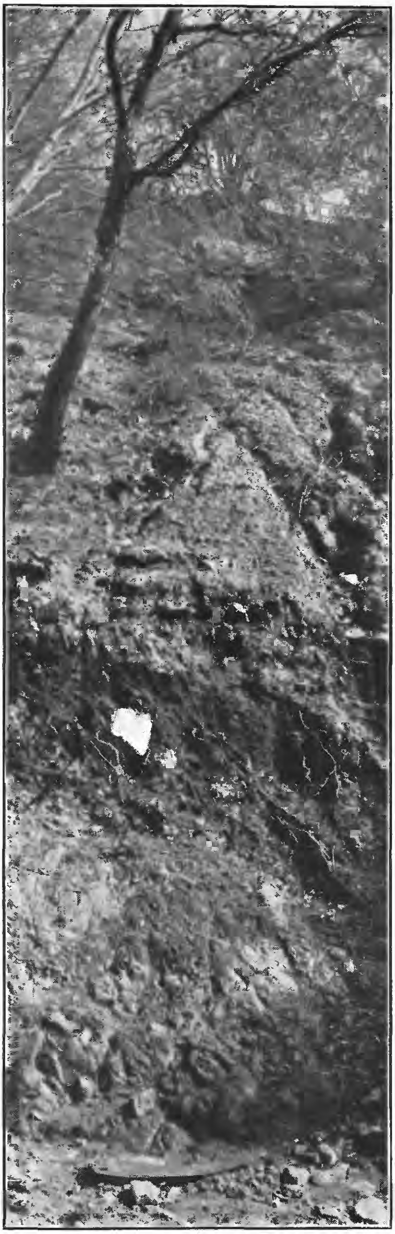
Many of these areas have not been burned over in recent years. It may be seen, therefore, that heavy rainfall will produce flood run-off, whether the area is forested or nonforested, although forest cover may tend to reduce the flood discharges.

The drainage basin of Topanga Creek is situated within the boundaries of the area where the highest rates of rainfall occurred during this storm period. The creek is in Topanga Canyon in the Santa Monica Mountains, a short distance west of the city of Santa Monica. Except for several peaks the drainage area is below an altitude of 2,000 feet. As indicated in figure 10 this range of altitude was within the range of maximum rainfall intensity of December 31. The drainage area yielded a discharge of 4,510 second-feet[17] on December 31 at the Topanga Beach gaging station, corresponding to an average discharge of 252 second-feet per square mile for 17.9 square miles of forested drainage area. The total storm run-off for December 31 and several days thereafter was 5,900 acre-feet, equivalent to 330 acre-feet per square mile, or 6.18 inches in depth over the basin.

17 U. S. Geol. Survey Water-Supply Paper 766, p. 100, 1936.

*A*. EXAMPLE OF SOIL EROSION.
Showing shoestring gullies on a burned-over area.

*B*. EXAMPLE OF GULLY EROSION.



*A*

*B*

TYPICAL LANDSLIDES.

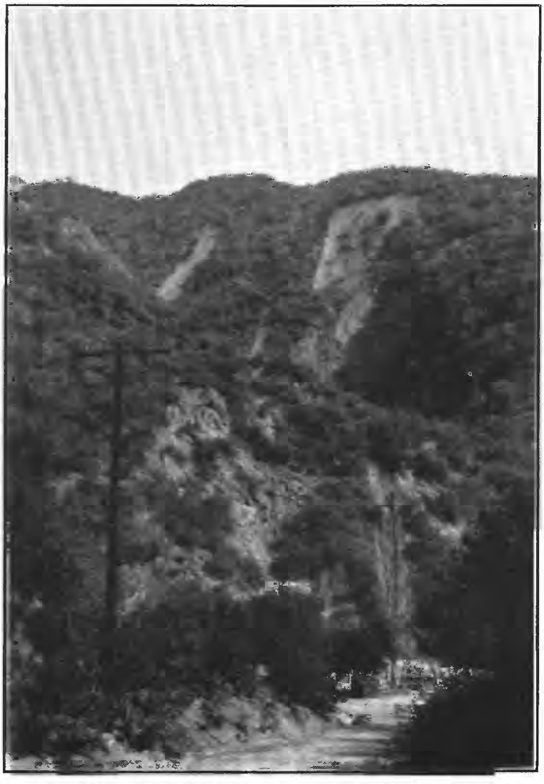
*A*. Slide on upper end of the debris cone in Pickens Creek. Note that the lower portion of the slide has been removed by the flood.
*B*. Landslide in Brand Park, Glendale Highlands. Slides like this one were found in the unburned area from Topanga to Pomona.

*A*. CHECK DAM IN HAINES CANYON
Typical wire-and-rock mattress check dam.

*B*. DEBRIS ABOVE A CHECK DAM IN PICKENS CANYON.
The condition of this debris indicates that the storage capacity had been filled for several years. The root systems show the development of plant life in the channel deposit.

*A*. DEBRIS ABOVE A CHECK DAM IN HAINES CANYON.

Note the condition of the wire and the collection of debris above the dam, also the erosion downstream from the dam.



*B*. LANDSLIDES ON FOREST-COVERED SLOPES OF VERDUGO MOUNTAINS NEAR GLENDALE.

At the Malibu Headquarters, Topanga Canyon (altitude 747 feet), the storm rainfall was 16.03 inches. This figure may or may not represent the average rainfall over the entire drainage area, but it indicates that a fairly large percentage of the rainfall left the basin in the form of surface run-off.

The drainage basin of Santa Paula Creek, covering 39.8 square miles, ranging in altitude from about 700 to 6,000 feet, produced on December 31 a flood peak of about 10,000 second-feet. This basin is in the Santa Barbara Mountains of Ventura County, in the western edge of the area affected by the New Year's storm. The peak discharge represents an average run-off of 251 second-feet per square mile. The run-off from this area during the storm period and a short time immediately afterward was about 140 acre-feet per square mile, equivalent to 2.6 inches in depth over the area.

The larger drainage area of Sespe Creek, 257 square miles, east of Santa Paula Creek, produced a peak discharge of about 34,000 second-feet or 132 second-feet per square mile.

To the east of La Cañada Valley, in the San Gabriel River drainage area, San Jose Creek had a peak discharge of 13,100 second-feet on January 1. This corresponds to an average discharge of 154 second-feet per square mile from the 85.2 square miles of drainage area of fairly low altitude. The run-off for the storm period was about 88 acre-feet per square mile, or about 1.7 inches in depth over the basin.

In the San Gabriel Mountains, Fish and Rogers Creeks and Arroyo Seco, with more or less similar characteristics, produced storm discharges of 98.5, 129, and 57.9 second-feet per square mile, respectively. The respective drainage areas are 6.5, 6.4, and 16.4 square miles.

On the valley floor area, the Los Angeles River at Los Angeles, the Rio Hondo near Montebello, and the San Gabriel River at Pico had peak discharges of 22,000, 11,800, and 22,000 second-feet respectively, representing flood stages in all three rivers.

The following interesting description of the run-off from the New Year's storm is taken from a letter prepared by a hydraulic engineer residing on the southern slopes of the Verdugo Mountains, La Cañada Valley:

> Brand Canyon, which is in the Verdugo Hills between Glendale and Burbank, immediately above my place, kicked out about as much water in proportion to its size as any stream I have ever heard of. This area was burned off in 1928. The winter of 1928-29 resulted in a run-off which carried debris, principally mud, from the canyon down over several streets extending as far as San Fernando Road. Subsequent to that flood numerous check dams of rock and wire had been constructed throughout both branches of the drainage area.

The flood of January 1 (1934) left the canyon about midnight. Boulders weighing several tons were carried down a distance of over 1 mile from the mouth of the canyon. Automobiles parked on Western Avenue were rolled over and over until they were a mass of wreckage. At Kenneth Road and Western, two automobiles stuck in the mud early in the evening were buried in debris until only 6 inches of the top was visible. Houses abutting my place were filled from 1 to 3 feet deep with mud. I helped dig out the front door of one place and found boulders from 1 to 2 feet in diameter wedged against the door clear up on the front porch. A 4 or 5 room frame house located about 1 mile from the canyon was washed a distance of about 300 feet from its foundation. The street car tracks on Glenoak Boulevard were buried from 2 to 3 feet deep for a distance of several thousand feet on either side of Western Avenue. Neighbors to whom I talked, as well as the woman who was staying with my children, stated that the flood hit slightly after midnight with a terrible roar.

On January 7 I went up the west branch of Brand Canyon. Out of a total of 19 check dams which I counted on the main canyon and the west branch, 17 had either partially or completely failed. Many of them had been so completely obliterated that it was necessary to look for pieces of pipe or wire that had caught on a granite outcrop.

My conception of what took place is that the continuous heavy rain, which started about 2 p.m. (December 31) to be of serious intensity, gradually increased the stream flow and began the movement of the debris in the canyon fill until the check dams were filled up. After filling behind the dam, the movement of the granite boulders gradually hammered the wire to pieces and allowed the dam to fail. The result was that not only was the velocity of the water increased by a straight slope, but the debris which had been stored up behind the dam was immediately eroded and added to the torrent.

The intense rainfall occurring around midnight eventually caused the landslides that deposited tremendous amounts of debris into the stream channel, which, added to the debris carried from the stored-up check dams, created the tremendous havoc when it spilled onto the debris cone. At one point I found where the bark had been entirely removed from a tree at least 9 feet above the ground surface. The width of the stream channel at this point was approximately 40 feet, and I believe the velocity of the stream could not have been less than 15 feet per second, and possibly more.

The following is quoted from the paper prepared by L. H. Daingerfield:[18]

In this connection, however, it is well to call attention to the fact that the west end of the Verdugo Hills,[19] which was burned over by the fire of December 1927, failed to show phenomenal run-off, while the east end of the same range, with a good chaparral cover and unaffected by material fires during the last 25 years, had a very high run-off.

It appears that the presence of a vegetative cover, while it may tend to reduce landslides and debris movement, is in nowise a guaranty against soil movement if the rainfall is heavy and continuous. For example, many slides occurred in the forest-covered slopes of the Verdugo Mountains, as illustrated in plate 34, B. In addition, the forested drainage basin of Deer Creek produced a sizable debris wave, as described on page 83.

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18 Monthly Weather Rev., vol. 162, no. 3, p. 93, March 1934.
19 Mr. Daingerfield undoubtedly refers to the extreme western end of the Verdugo Mountains.

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