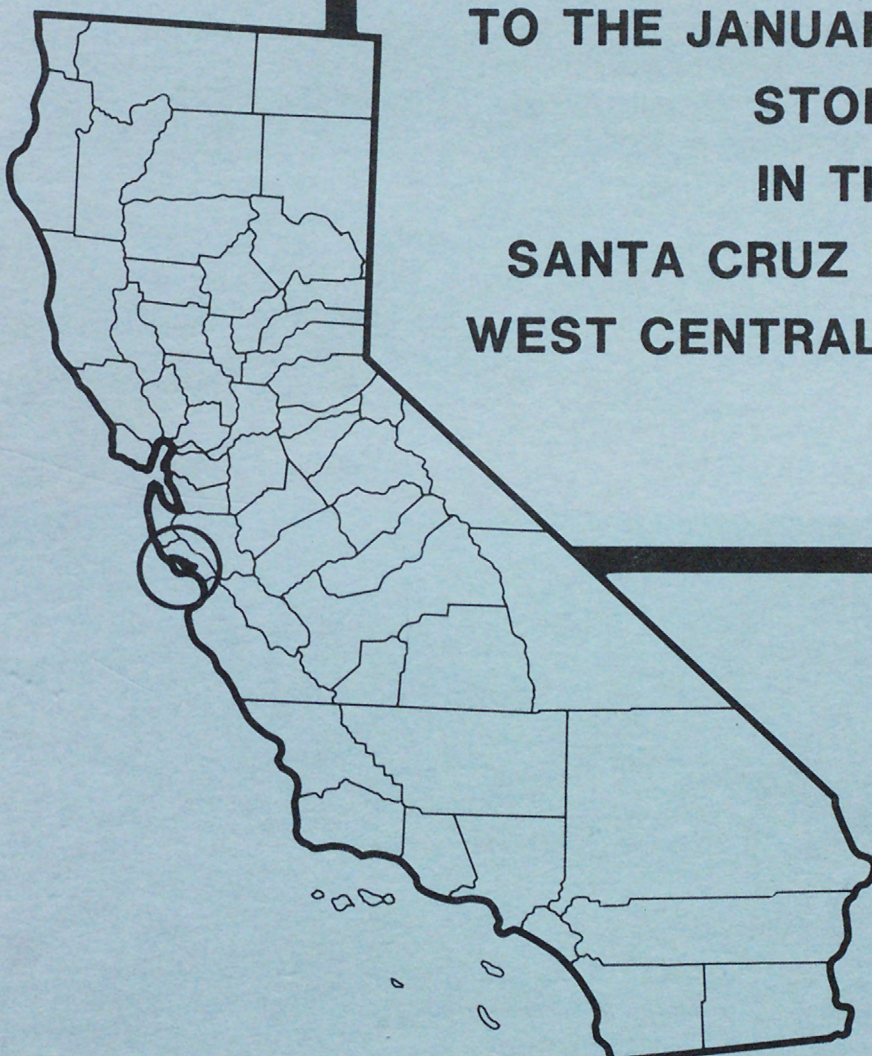
STREAM-CHANNEL RESPONSE TO THE JANUARY 3-5, 1982 STORM IN THE SANTA CRUZ MOUNTAINS WEST CENTRAL CALIFORNIA



U.S.GEOLOGICAL SURVEY

Open-File Report 84-248

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By K. M. Nolan, D. C. Marron, and L. M. Collins

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UNITED STATES DEPARTMENT OF THE INTERIOR

WILLIAM E. CLARK, Secretary

GEOLOGICAL SURVEY

Dallas L. Peck, Director

For additional information
write to:

District Chief
U. S. Geological Survey
Federal Building, Room W-2235
2800 Cottage Way
Sacramento, California 95825

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CONVERSION FACTORS

For readers who prefer to use inch-pound units, conversion factors for terms used in this report are listed below.

Multiply	By	To obtain
millimeters (mm)	0.03937	inches
meters (m)	3.281	feet
kilometers (km)	0.6214	miles
square meters (m^2)	0.0002471	acres
square kilometers (km^2)	0.3681	square miles
cubic meters (m^3)	35.31	cubic feet
cubic hectometers (hm^3)	810.7	acre-feet
megagrams (Mg)	1.102	tons, short
grams per cubic centimeter (g/cm^3)	62.428	pounds, avoirdupois per cubic foot
megagrams per square kilometer (Mg/km^2)	2.994	tons, short, per square mile
meters per meter (m/m)	1.000	feet per foot
square meters per square kilometer (m^2/km^2)	27.868	square feet per square mile

STREAM-CHANNEL RESPONSE TO THE JANUARY 3-5, 1982,

STORM IN THE SANTA CRUZ MOUNTAINS, WEST CENTRAL CALIFORNIA

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by K. M. Nolan, D. C. Marron, and L. M. Collins

ABSTRACT

Intense rainfall on January 3-5, 1982, in the Santa Cruz Mountains caused high streamflow and widespread landsliding. In the watersheds studied, recurrence intervals for peak streamflows were as much as 50 years, and recurrence intervals for maximum rainfall intensities were in excess of 100 years. Generalized channel response in these basins included scour in steep, low-order channels and moderate fill in higher order channels. Large volumes of channel fill were noted along some channels, but this was limited to reaches that received large volumes of colluvium from debris flows and streamside debris slides. Such major effects were generally local and did not extend great distances upstream or downstream. The local nature of these effects on channel geometry contrasts with widespread depositional effects observed following major storms in steep terrain in other parts of California. This contrast may be related to the manner in which channel and hillslope processes interact.

Storm-related changes in channel morphology coupled with frequency analysis of sediment transport indicate that the morphology of most intermediate and high-order channels are formed at least as much by events with moderated recurrence intervals as by extreme events. Along low-order channels that were scoured and along isolated reaches of some intermediate and high-order channels where fill was severe; however, storm effects will probably persist for long periods of time. Individual high magnitude storms are therefore effective in modifying channel geometry, but only in some locations. Since the localized effects of high magnitude storms can persist longer than the recurrence interval of the storms themselves, channel morphology throughout the area probably reflects the effects of a number of storms.

INTRODUCTION

The rainstorm of January 3-5, 1982, produced more than 600 mm of rain in a 36-hour period in steep drainage basins of the Santa Cruz Mountains. This intense rainstorm produced record or near record flood peaks throughout the area and caused widespread shallow-seated landsliding. This report assesses the effects of high streamflow on stream-channel geometry and sediment transport in three drainage basins within this steep terrain and relates effects to hillslope processes operating during the storm. Data presented have been collected from sites of previously established stream-gaging stations as well as from postflood field investigations. Land use does not appear to have altered the natural response of stream channels to the storm event. Storm effects on manmade structures, though locally extensive, have therefore been described only briefly.

DESCRIPTION OF THE STUDY AREA

Location and Physical Characteristics

Effects of the January 1982 storm were studied in the drainage basins of Soquel Creek, San Lorenzo River, and Pescadero Creek. These streams drain 500 km^2 in the Santa Cruz Mountains and are located approximately 50 km southeast of San Francisco and 25 km west of San Jose (fig. 1). Elevations in the study basins range from sea level to more than 800 m along the crest of Ben Lomond Mountain. The San Lorenzo watershed, which encompasses much of the study area, is highly asymmetric with short, steep tributaries feeding the main channel from the west, and longer, more gently sloping tributaries feeding the main channel from the northeast. Several levels of marine terraces extend along some coastal sections of the study area.

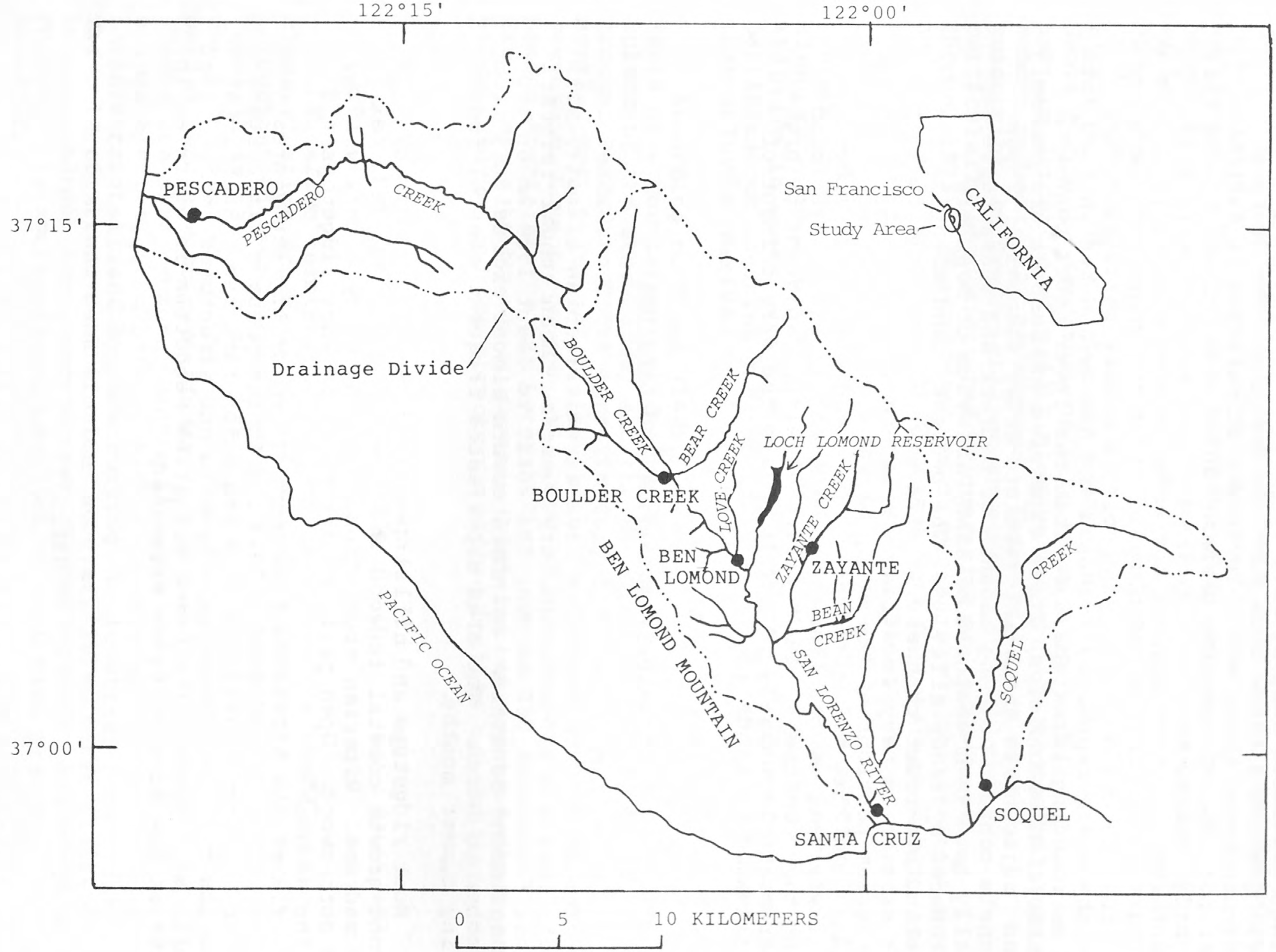

Figure 1. - Location of the study area.

Hillslopes within the study basins are relatively steep with average gradients ranging from 30 percent to over 50 percent. Stream gradients range from 0.003 to 0.2 m/m. The steepest gradients occur along small low-order tributaries in extreme upper portions of drainage basins. These small channels are only slightly incised into surrounding hillslopes, and bedrock is common along such channels. Low-order channels usually contain a relatively thin deposit of alluvium over the underlying bedrock. Larger, intermediate-order channels in middle portions of the watersheds are typically V-shaped and narrow and are incised into the surrounding landscape more than the lower order channels. Because of this incision, steep expansive hillslopes are commonly found adjacent to these intermediate-order channels. These channels contain varying amounts of bedrock and characteristically have beds composed of sandy alluvium or boulders surrounded by sandy alluvium. The bedrock found along intermediate-order channels is effective in reducing the rate of bank erosion in many locations. High-order channels in downstream portions of the study basins flow through alluviated valleys and show well-defined meander and point-bar morphology. The lowest stream gradients within the study basins are found along these channels. Floodplains developed adjacent to high-order channels usually buffer them from the direct input of colluvium from landslides.

Climate, Vegetation, and Land Use

The Santa Cruz Mountains have a Mediterranian climate, with moist, cool winters and warm, dry summers. Mean annual rainfall ranges from about 500 mm near the coast to about 1500 mm on top of Ben Lomond Mountain. Rainfall occurs almost exclusively from November to March. The area experiences frequent coastal fog during summer months.

Most ridgetops and hillslopes are densely vegetated by second-growth coastal redwood and associated Douglas-fir, oak, and madrone. Riparian vegetation is dominated by alder, willow, and cottonwood. Open prairies are found on some ridgetops and marine terraces.

Timber was harvested from most slopes in the study area during the early and middle 1900's. At the present time, low-density suburban development is the major land use. Artificial flow constrictions in stream channels and structures on low-flood plains are common. The Santa Margarita Sandstone is quarried in parts of the Zayante Creek watershed.

Geology

Bedrock in the study area is dominated by a thick sequence of Tertiary marine arkosic sandstone, mudstone, and interbedded volcanic units (Clark, 1981). Weathered materials from most units are predominately sand to gravel in size, and are readily transported by streams. The most common rock types are bedded mudstones, and sandstones with abundant mudstone interbeds. These stratigraphic units, which include the Santa Cruz Mudstone of late Miocene age and the Monterey Formation of middle Miocene age, are highly susceptible to landsliding and typically produce colluvium and alluvium that consist mostly of sand and gravel with some boulders. Massive sandy units such as the Santa Margarita Sandstone of late Miocene age and the Lompico Sandstone of middle Miocene age contribute predominately sand-sized material to streams. These units are highly susceptible to dry ravelling, sheetwash, and gullying, particularly when disturbed by quarrying and road-building (Brown, 1973). The combination of regionally subhorizontal dips and substantial local relief causes most tributary drainages to be underlain by several of the Tertiary marine units.

Stratigraphically beneath the Tertiary marine section are Cretaceous granitic and metasedimentary rocks, which crop out along the summit and on the flanks of Ben Lomond Mountain. Alluvium in creeks draining these rocks is rich in sand-sized particles but contains greater amounts of cobbles and boulders than alluvium derived from overlying Tertiary sediments.

According to Clark (1981), major active faults in the Santa Cruz Mountains include the San Andreas Fault, which lies inland of the study area, and the San Gregorio Fault, which crosses Pescadero Creek approximately 5 km upstream from its mouth. Most folds and faults in the study area trend northwest-southeast. Some ridgetops and stream channels, particularly Ben Lomond Mountain, the San Lorenzo River downstream from Boulder Creek, and a tributary of Zayante Creek called Mountain Charlie Gulch, follow bedrock structures alined in this orientation.

Landslides

Landslide terminology used in this paper is based on the classification scheme of Varnes (1959). Landslides are numerous throughout the study area. Steep hillslopes combine with friable regolith in many locations to produce a high susceptibility to debris flows. Where the dip surfaces of bedding planes parallel hillslopes, the susceptibility to block slides is great. Debris slides are also common. Debris flows, block slides, and debris slides are triggered both by high pore-water pressures induced by intense rainfall and by undercutting due to stream-bank erosion. The role of stream-bank erosion, however, is somewhat limited because bedrock along many stream channels limits bank erosion. Persistently active landslides such as earthflow are not abundant.

The storm of January 3-5, 1982, produced short-lived flood peaks on the study streams. Recurrence intervals of peak flows ranged from 4.8 to 50 years (J. C. Blodgett, U. S. Geological Survey, written commun., 1982). The recurrence intervals of flood peaks varied as a result of the distribution of rainfall. Reported storm rainfall totals ranged from 152 mm to 629 mm (R. K. Mark, U.S. Geological Survey, written commun., 1982). Maximum 24-hour precipitation intensities recorded during the storm were associated with recurrence intervals of greater than 100 years (J. Monteverdi, San Francisco State University, written commun., 1982). Maximum recorded precipitation values were found along a northwest-southeast line running through the lower two-thirds of basins draining into the San Lorenzo River from the northeast.

The storm triggered numerous landslides throughout the area. The most common features were debris flows and debris slides that were caused by high pore-water pressures induced in soils during the storm. Variation in precipitation intensity resulted in considerable variation in the spatial distribution of landslides and hence in the amount of colluvium introduced to different stream systems. Storm-related landslides have been mapped by E. L. Harp (U.S. Geological Survey, written commun., 1982).

General effects of the January storm on channel morphology included scour in small first- and second-order channels and fill in larger, higher order channels. In most locations, effects from channel fill were either not particularly severe or are not likely to persist for a long period of time. However, in localized reaches deposition caused severe decreases in stream cross-sectional area that have the potential to persist for long periods of time. This deposition occurred in areas adjacent to large individual streamside debris slides and in areas where small-scale landsliding was particularly abundant. Landsliding was most abundant in areas that received the most intense rainfall.

Methods Used To Assess Channel Changes

Effects of the January 3-5 storm on stream channels in the San Lorenzo River, Soquel Creek, and Pescadero Creek watersheds were assessed using field and air photo observations and measurements in addition to information from U.S. Geological Survey stream-gaging stations. In order to assess basinwide effects of the storm, stream reaches were described at sites chosen to represent a range in stream size, bedrock type, and impact severity (fig. 2). The length of channel studied at each site was approximately equal to five channel widths. Sediment accumulation and scour were estimated in each reach using botanical and physical evidence. Botanical evidence included burial of vegetation and exposure of roots in stream banks. Physical evidence included burial of preflood surfaces by alluvium, burial of culverts and bridge aprons, and exposure of fresh bedrock, water pipes, drains, and drainage lines.

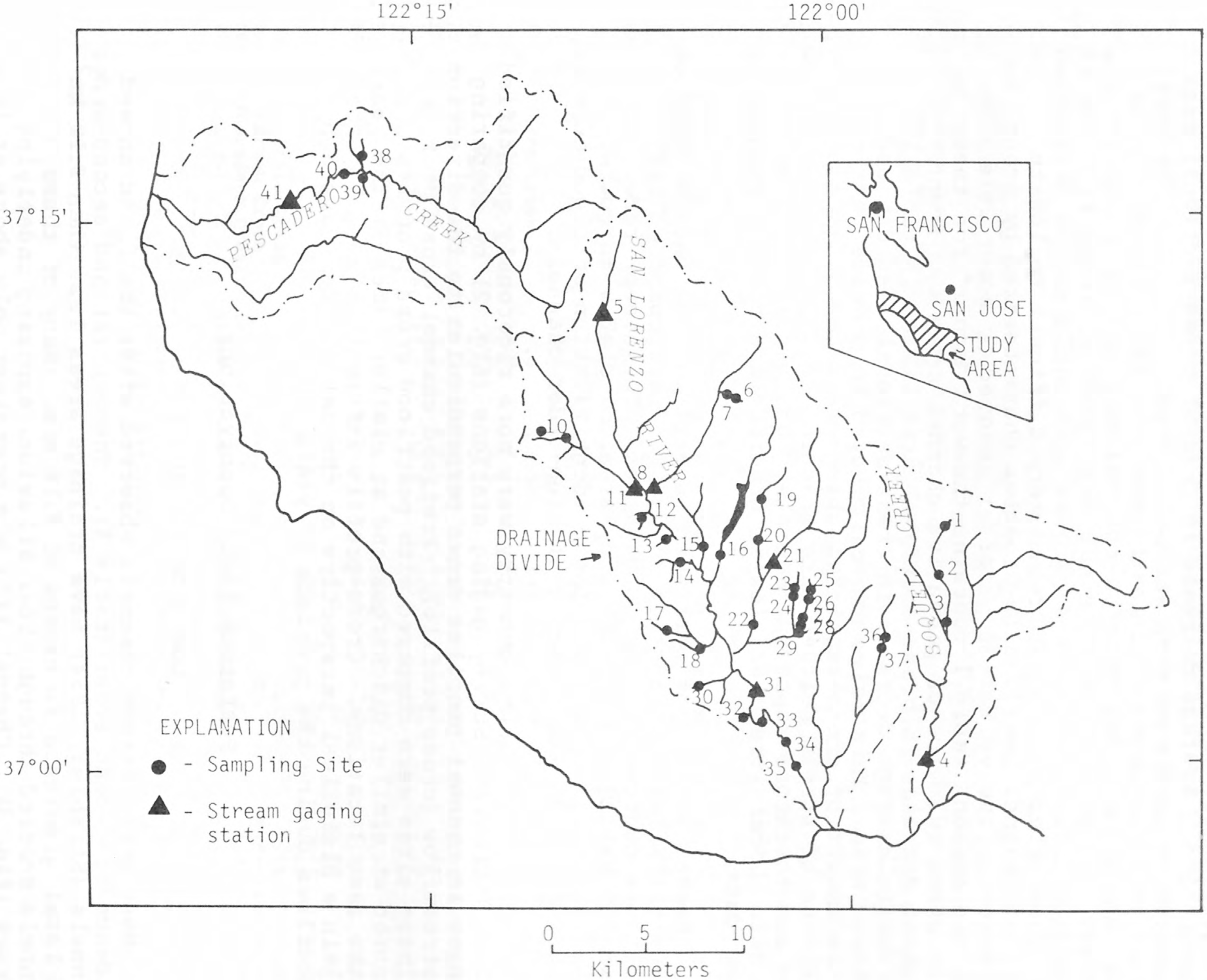

Figure 2. - Location of study sites.

Measured channel changes and basic physiographic variables of study sites are given in table 1. Measures of channel change in table 1 include average fill within the active channel, average decrease in cross-sectional area, and weighted sediment accumulation. Average decrease in channel cross-sectional area, presented in square meters, was calculated by dividing the total volume of flood deposits in each reach, by reach length. This area change includes both in-channel and overbank deposition. Because stream reaches were not described at sites 4, 5 and 13 average decreases in cross-sectional area could not be determined for those sites. Since it proved very difficult to locate preflood channel levels along reaches characterized by scour, no estimates of the volume of material removed by scour were made. For this reason, table 1 contains the word "scour" for those sites where evidence of pervasive channel scour was found. Weighted decrease in cross-sectional area listed in table 1 represents average decrease in cross-sectional area divided by drainage area. This value was calculated to provide perspective on the amount of cross-sectional change relative to channel size. Gradients of stream reaches were measured on 1:24,000 topographic maps and therefore represent average gradients above study reaches. Local irregularities in gradient are not represented in these data.

Channel conditions portrayed on vertical air photos taken on February 15, 1982, at a scale of 1:8,000 were compared with conditions depicted on preflood photos. The steep, redwood-dominated hillslopes in the study area, coupled with low mid-winter sun angles, made air-photo identification of flood effects possible only at wide reaches of high-order channels.

Changes in channel geometry were more rigorously quantified at U.S. Geological Survey gaging stations (fig. 2) by comparing changes in channel profiles drawn perpendicular to the direction of streamflow (cross profile). Preflood channel cross profiles at these sites were compared with postflood cross profiles measured at similar discharges and at similar times of the year at the same locations. Cross-profile information was also used to gain a historical perspective on channel changes caused by floodflows during the previous 42 years.

Poststorm Field Observations

Low-Order Channels

Most small stream channels observed after the flood showed evidence of recent scour (table 1). These first and second-order channels (Strahler, 1954) have drainage areas less than 0.10 km^2 and local gradients in excess of 0.10 m/m. Many of these channels scoured through older alluvium, exposing underlying bedrock (fig. 3). Channel fill was prevalent only above artificial constrictions such as culverts blocked by sediment and by organic debris such as trees and bushes. Most accumulations of organic debris in unconstricted channel reaches formed open frameworks that were not effective in trapping sediment (fig. 4).

Table 1. - Summary of physiographic variables and channel scour and fill due to the January 1982 storm at study sites

[Station numbers correspond with locations in figure 2]

Station	Drainage basin	Drainage area (km^2)	Average bankfull width (m)	Channel gradient (m/m)	Average depth of channel fill (m)	Average decrease in cross-sectional area (m^2)	Weighted decrease in cross-sectional area[1] (m^2/km^2)
1	Hester Creek	.3	1.3	0.15	0.06	0.09	0.30
2	do.	2.8	5.5	.023	.23	3.19	1.14
3	do.	5.3	4.1	.0033	.08	.33	.06
4[2]	Soquel Creek	104.1	-	.0050	.39	-	-
5[2]	San Lorenzo River	16.0	-	.021	.41	-	-
6	unnamed tributary	.3	1.2	.20	.08	.38	1.27
7	do.	.4	.9	.11	0	-----scour----	
8[2]	Bear Creek	38.5	.2	.0070	.31	.26	.01
9	unnamed tributary	.2	-	.20	0	-----scour----	
10	Jamison Creek	3.4	4.2	.050	.16	.73	.21
11[2]	Boulder Creek	29.3	8.4	.16	.03	.55	.02
12	unnamed tributary	.1	-	.36	0	-----scour----	
13	do.	.1	-	.20	-	-	-
14	Marshall Gulch	2.8	3.5	.011	.07	.99	.35
15	Love Creek	7.3	4.0	.025	.15	.92	.13
16	Newell Creek	23.2	7.6	.015	0	.30	.01
17	South Fall Creek	1.1	1.1	.73	0	-----scour----	
18	Bennett Creek	1.0	1.2	.011	.04	.06	.06
19	Lompico Creek	2.8	2.9	.033	.22	2.33	.83
20	do.	5.5	2.2	.029	.42	2.82	.51
21[2]	Zayante Creek	28.7	7.9	.017	.05	.78	.03
22	do.	32.9	6.9	.010	.31	3.27	.10
23	Lockhart Gulch	1.7	2.8	.040	.49	1.53	.90
24	do.	2.0	2.0	.022	.84	11.97	5.99
25	Ruins Creek	.8	1.5	.030	.51	4.19	5.24
26	do.	1.0	1.7	.039	.08	.92	.92
27	do.	1.9	2.5	.029	.72	3.09	1.63
28	do.	2.0	2.4	.023	.17	.65	.33
29	Bean Creek	13.7	4.6	.010	.30	5.34	.39
30	Gold Gulch	2.2	2.1	.043	.09	.90	.41
31[2]	San Lorenzo River	288.8	19.0	.017	.47	8.67	.03
32	unnamed tributary	.1	-	.82	0	-----scour----	
33	San Lorenzo River	291.8	15.2	.0050	.46	40.02	.14
34	do.	297.4	25.9	.0030	.46	23.04	.08
35	do.	300.8	18.6	.0020	.46	21.88	.07
36	Branciforte Creek	5.8	5.2	.013	.20	2.32	.40
37	do.	7.3	5.4	.0090	.11	.68	.09
38	McCormic Creek	2.9	3.8	.034	.13	.59	.20
39	Hoffman Creek	.8	1.2	.10	0	-----scour----	
40	Pescadero Creek	107.8	12.6	.003	.07	2.81	.03
41[2]	do.	118.9	13.9	.004	.22	8.60	.07

[1] Average decrease in cross-sectional area divided by drainage area.
[2] U.S. Geological Survey gaging stations.

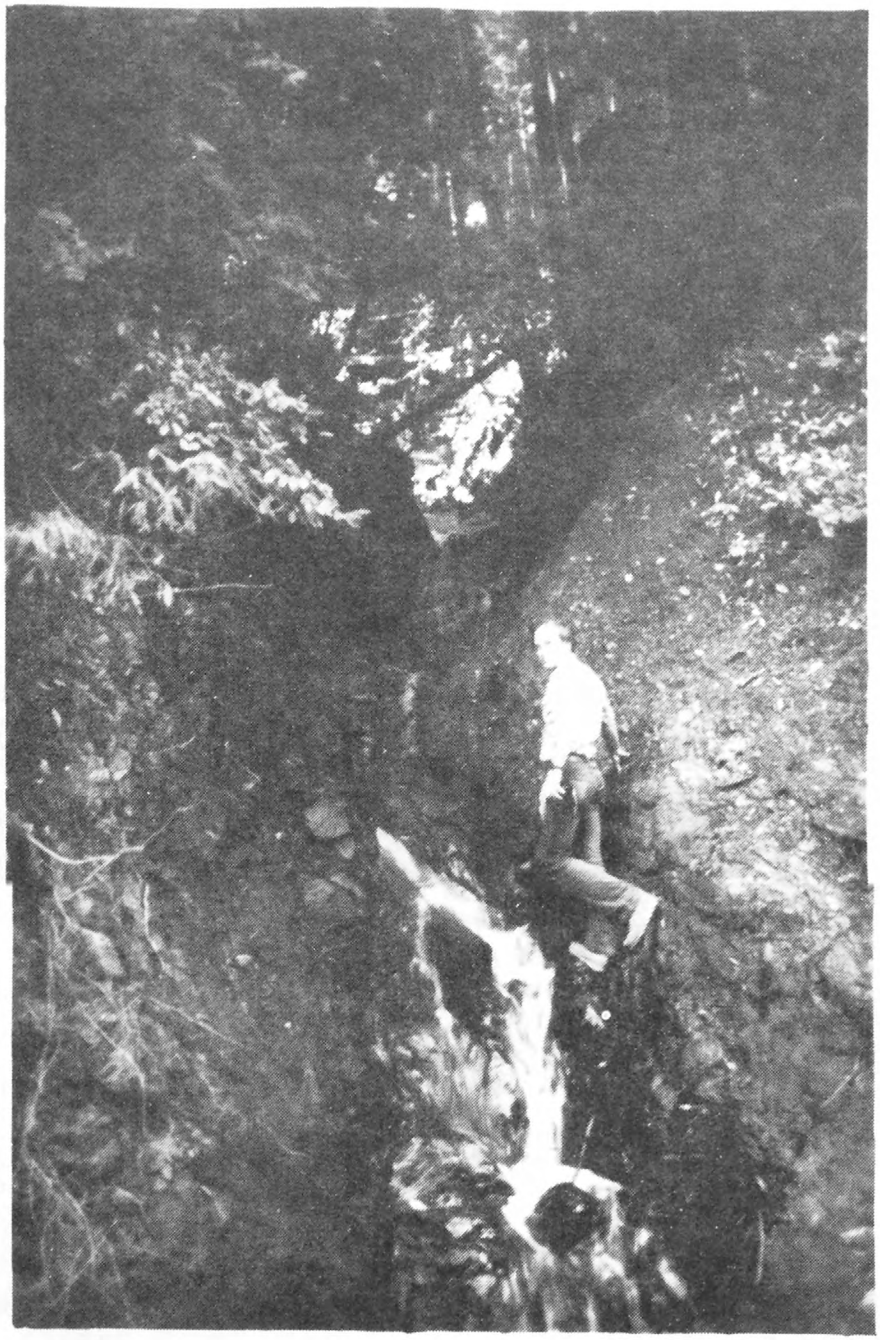

Figure 3. - Scour in second-order channel, near Ben Lomond.

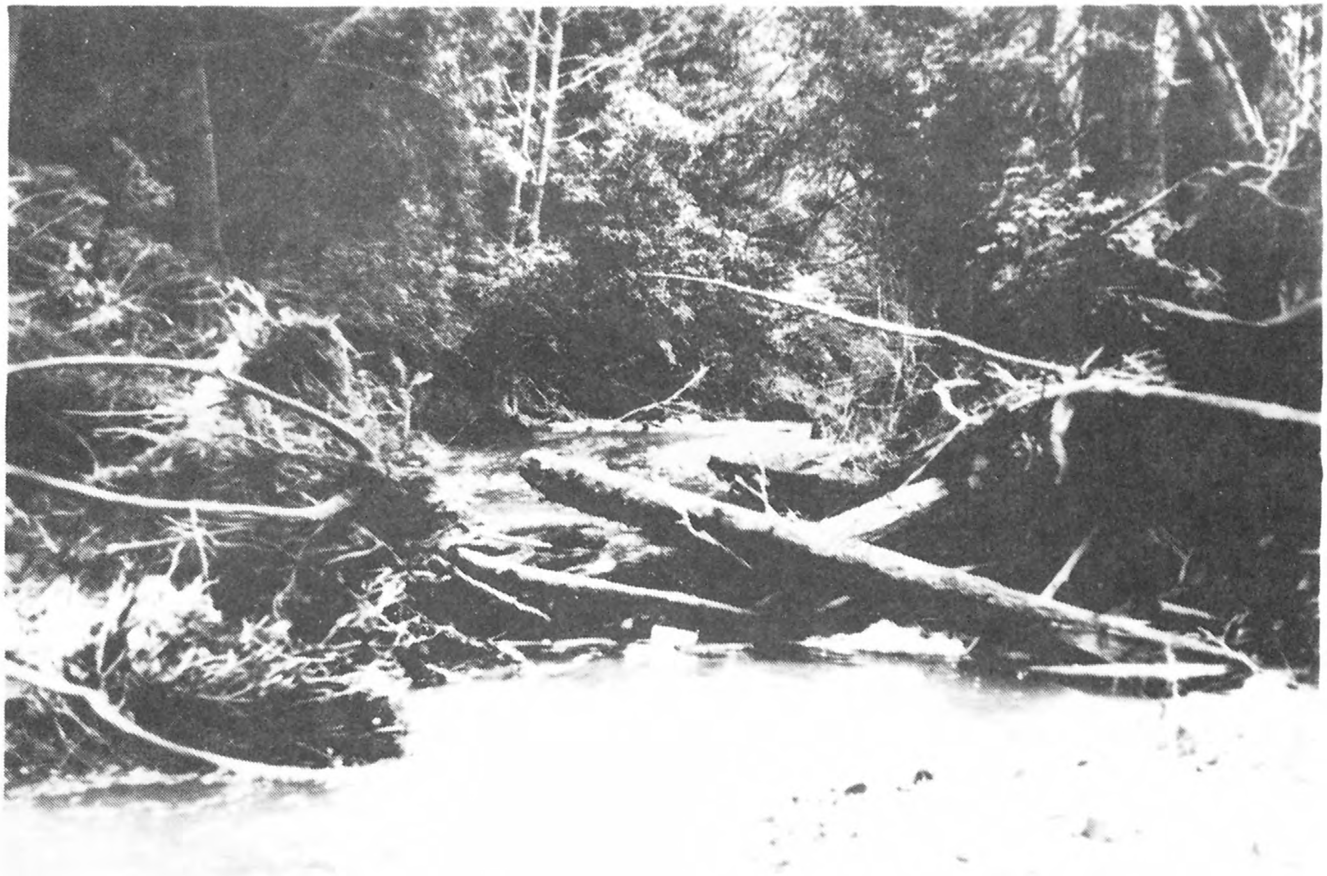

Figure 4. - Open framework of debris jam near Ben Lomond. Note lack of deposition behind debris.

Sediment was removed and transported through these steep channels by both high streamflow and debris flows. Effects of debris flows on channel morphology resembled those described by Campbell (1975) and Swanston and Swanson (1976). Some flows were apparently very fluid, and, although they transported large volumes of sediment through steep reaches, they caused only minimal channel scour (fig. 5). In contrast, other in-channel debris flows stripped large amounts of alluvium and colluvium from steep reaches, commonly exposing bedrock and leaving much more obvious scars on the landscape (fig. 6). These effects closely resemble scouring debris flows described by Campbell (1975) as well as debris torrents described by Swanston and Swanson (1976). Campbell (1975) attributed variations in the erosive potential of debris flows to gradient steepness, and therefore flow velocity, and to the moisture content of the moving material. Along low-gradient reaches at the mouths of some channels that experienced debris flows, large volumes of channel fill were spread over wide areas (fig. 7).

Figure 5. - Minor channel changes resulting from debris flow near town of Boulder Creek. Note that most soil and vegetation remains in place upstream of house on left. Downstream deposition resulting from this activity can be seen in figure 7.

Figure 6. - Scouring debris flow in the San Lorenzo River basin near Ben Lomond. Note removal of large amounts of vegetation and colluvium.

Figure 7. - Deposition and damage found in low-gradient slopes below channel shown in figure 5. Despite lack of major channel changes upstream, large quantities of debris were transported through the channel and deposited on low-gradient slopes shown here.

Intermediate-Order Channels

Flood effects on intermediate-sized channels varied considerably. The observations included in this group were made primarily along third and fourth-order channels with drainage areas between 1 and 5Ø km2. Although many reaches along these streams showed little or no effects from the storm, significant channel modification was found along some reaches (table 1). Most of these channel modifications resulted when input of colluvium from large streamside debris slides or large debris flows overwhelmed the sediment-transport capacity of the affected channel (fig 8). These effects were generally confined to the immediate area of colluvial input. In most cases, large volumes of the introduced colluvium were removed by streamflow with little or no effect on downstream reaches (fig. 9).

Figure 8. - Streamside debris slide, Soquel Creek. This slide, which entered Soquel Creek from the left side, produced locally severe channel changes typical of those found in many locations subjected to exceptionally intense rainfall.

Figure 9. - Lack of channel effects downstream of streamside landslide shown in figure 8. This photograph shows the channel of Soquel Creek 1.4 kilometers downstream of severe channel changes shown in figure 8. The lack of burial of preflood bouldery alluvium and minimal effects on riparian vegetation indicate a general lack of channel change in this reach.

The most numerous and severe channel modifications were found along midbasin locations of Zayante and Bean Creeks, as is illustrated by figure 10, which shows the distribution of weighted change in cross-sectional area found at study sites. Comparing this figure to a map of the locations of maximum rainfall intensities (R. K Mark, U.S. Geological Survey, written commun., 1982) and maps displaying the locations of storm-related landslides (E. L. Harp, U.S. Geological Survey, written commun., 1982), indicates that the most numerous and most severe channel modifications occurred in areas that were also characterized by the most numerous landslides and the greatest rainfall intensity.

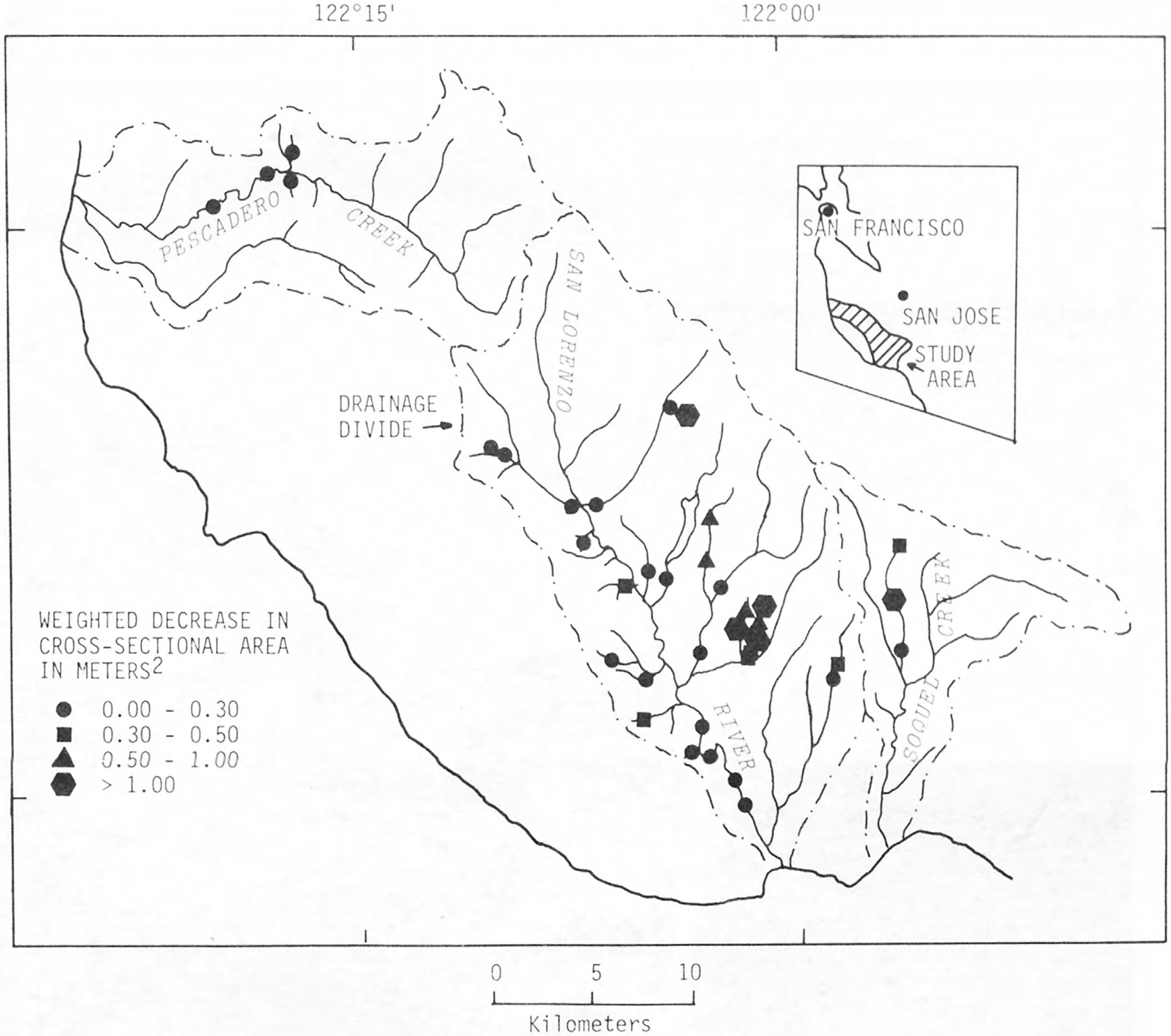

Figure 10. - Distribution of measured sediment accumulation. Weighted decrease in cross-sectional area at each site was calculated by dividing the volume of flood deposits by the reach length, and then dividing by the drainage area.

In a few areas, such as at study sites 19, 23, and 24, major channel modifications extended beyond the areas immediately adjacent to individual landslides. Deposits in these areas were characterized by poorly sorted angular to subangular cobbles and gravel and were suggestive of in-channel debris-flow activity (figs. 11 and 12). These deposits were commonly found overlying well-sorted sandy deposits that were interpreted to be water-worked alluvium that was deposited prior to the occurrence of debris flows. Debris-flow deposits were found only at higher locations along stream channels, such as in overbank areas or on tops of point bars. Post-debris flow streamflow probably obscured evidence of debris-flow deposits in lower stream channel positions.

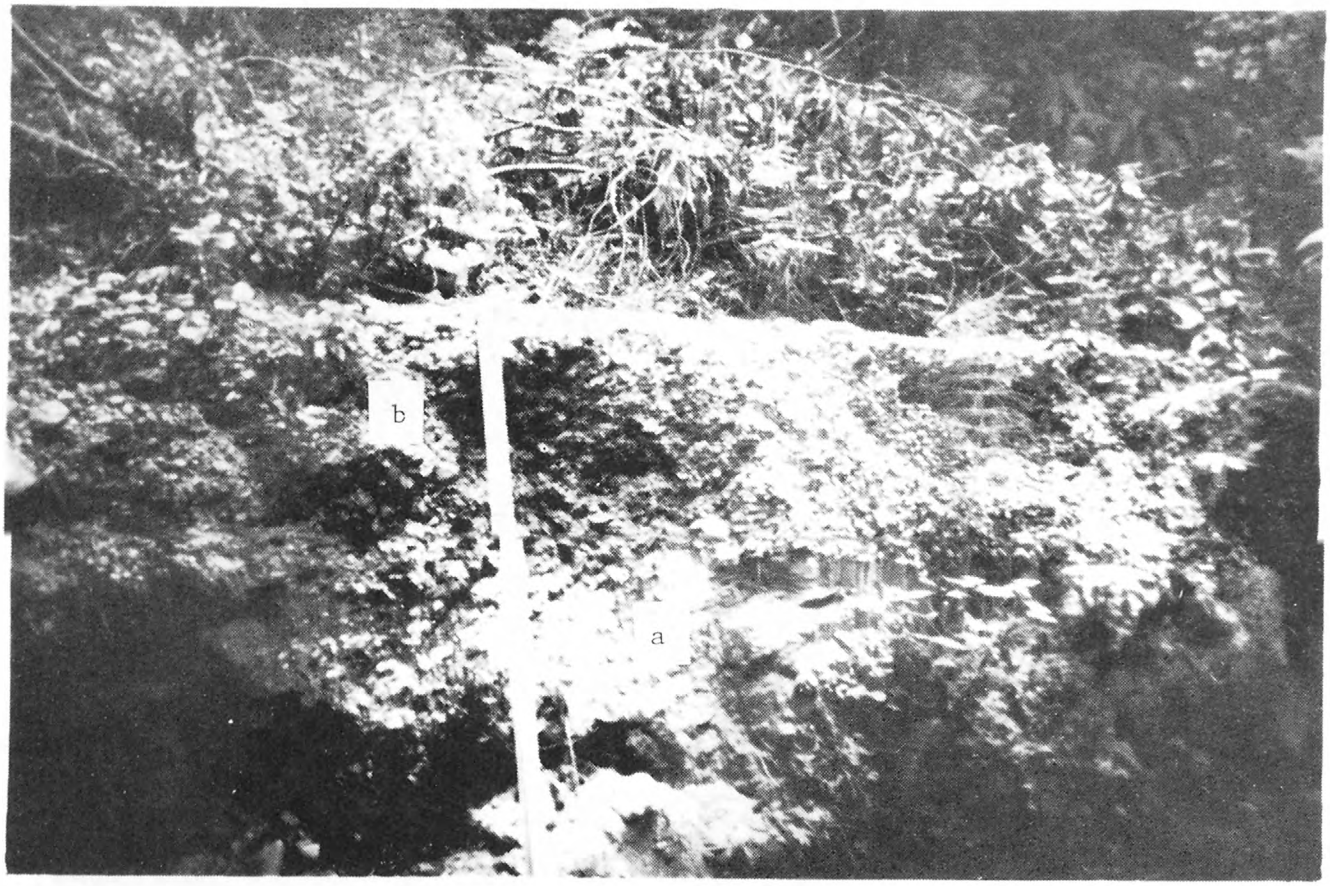

Figure 11. - Debris-flow deposit in Lockhart Gulch, site 25. This deposit consisted of approximately 0.25 meter of well-sorted sand (a) overlain by approximately 0.50 meter of poorly sorted debris-flow deposits (b) which consisted predominantly of sand and gravel.

Figure 12. - Massive flood berms in Lockhart Gulch, site 24. The sedimentology of deposits at this site and that of deposits immediately upstream (fig. 11) suggest that the massive deposits found along this reach were the result of in-channel debris flow activity.

Debris-flow deposits were found only along reaches adjacent to the most abundant landsliding. The mechanisms for formation of these in-channel debris flows is not clear. They may have been down-channel continuations of flows which started high in steep tributaries (Takahashi, 1980), or they may have been formed within intermediate-order channels due to sudden large increases in sediment loads from abundant streamside debris slides and debris flows (Ashida and others, 1981). There appeared to be some lithologic control on the occurrence of in-channel debris flows. Debris-flow deposits were found only in reaches receiving colluvium derived predominately from well-consolidated mudstones, siltstones, and sandstones. Well-sorted, noncohesive, sandy colluvium introduced from the Santa Margarita Formation, although exceptionally voluminous in some locations, either was not conducive to debris-flow initiation or did not produce deposits that were easily recognizable as resulting from debris flows. As much as 0.84 m of average channel fill was observed in reaches subjected to debris flows.

Where landslides were numerous but evidence of in-channel debris flows was lacking, the reworking of colluvium and alluvium by floodwaters caused as much as 0.72 m of average channel fill. The most extensive and voluminous channel fill and overbank-flood deposits in these areas were found at or near study sites 20, 25, 27, and 29 (figs. 13 and 14). Fluvially reworked deposits consisted predominantly of well-sorted sand and gravel. Naturally extensive deposition appeared to have been augmented by the blocking or overloading of artificial flow constrictions (bridges and culverts) by organic and inorganic debris (fig. 15). Some local bank erosion occurred in these areas as a result of deflection of flow by colluvial deposits and (or) organic debris (fig. 16).

Figure 13. - Channel fill in Bean Creek, site 29. Note stream banks are buried and riparian vegetation is missing.

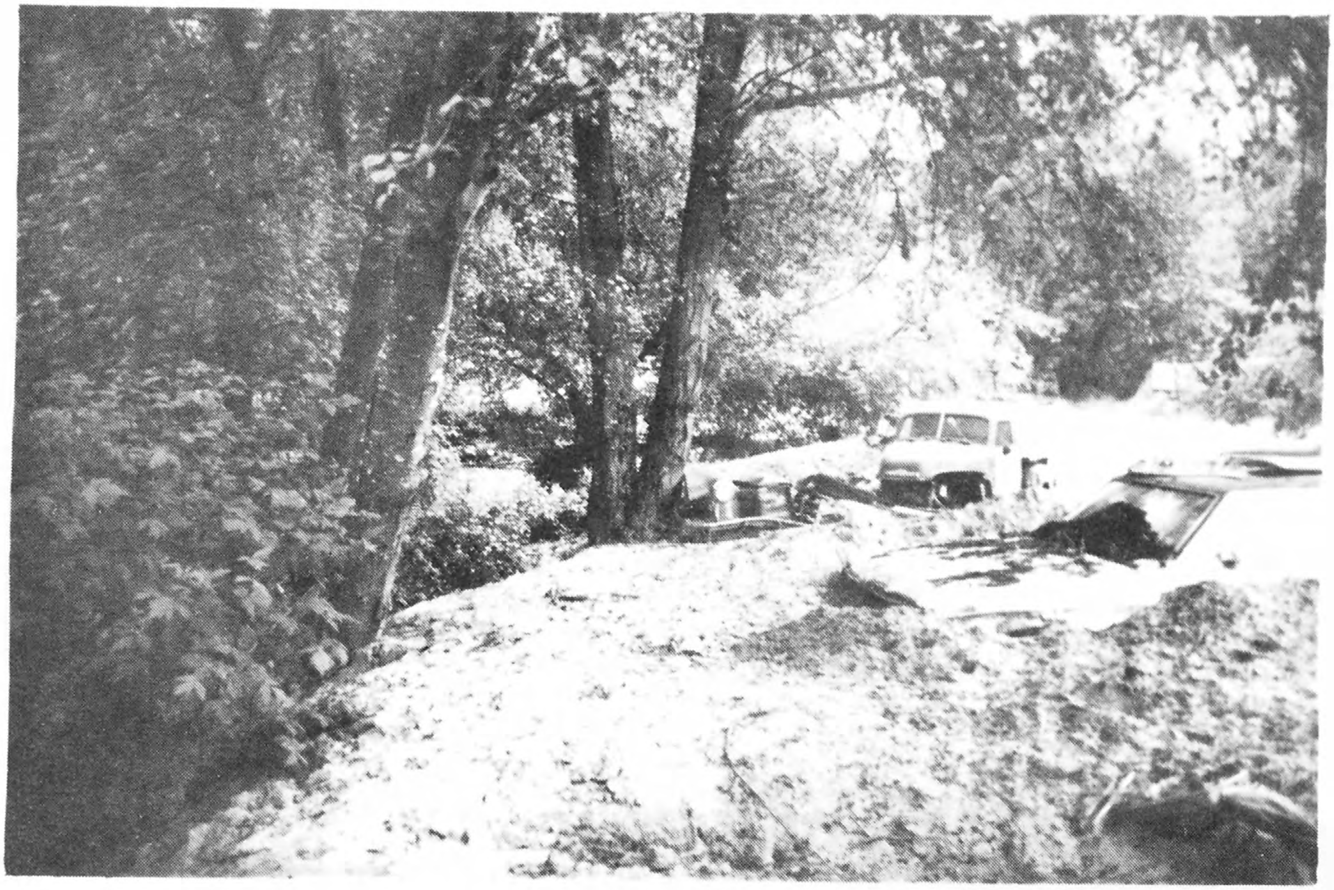

Figure 14. - Overbank deposits in Bean Creek near site 29.
This area contained some of the thickest over-
bank deposits found in study area.

Figure 15. - Damage to manmade structures along tributary to Lockhart Gulch. The volume of water and debris transported during the storm totally overwhelmed the small box culvert (arrow) and destroyed some streamside structures.

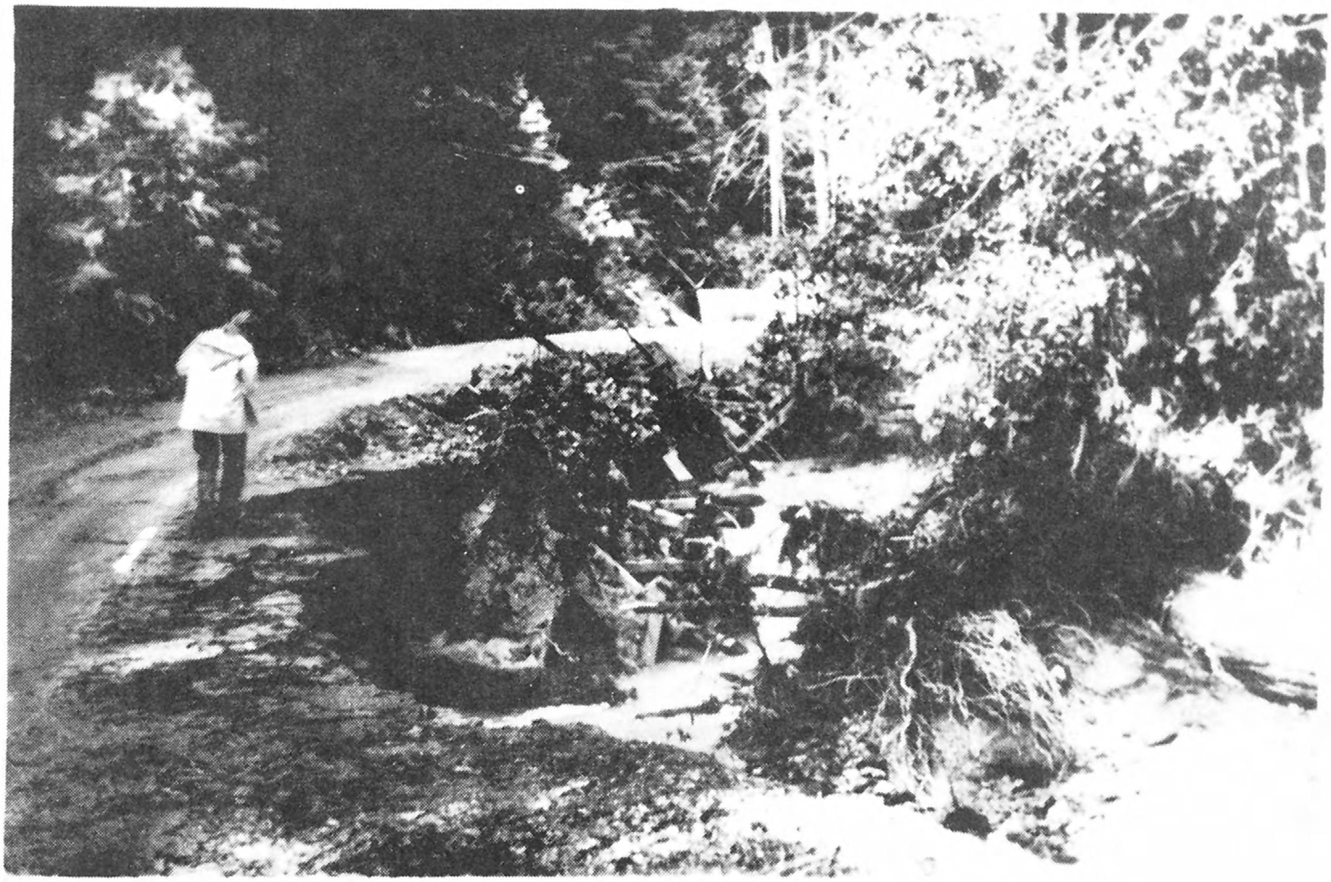

Figure 16. - Streambank erosion caused by deflection of streamflow by organic debris in Love Creek.

Changes in intermediate-order channels throughout the remainder of the study area were caused predominantly by deposition of moderate amounts of well-sorted alluvium. Average channel fill ranged from 0.00 to 0.30 m. Hydrologists who have a longterm familiarity with gaging sites in the area have noticed a postflood increase in the amount of sandy alluvium filling interstices between cobbles and boulders in many channels (S. H. Hoffard, U.S. Geological Survey, oral commun., 1982). Although such changes may be pervasive throughout the study area, they are generally too subtle to be documented by available data. Although streambank scour was evident in both highly and moderately affected reaches, major changes in bank-to-bank channel width were not common. Stream banks in the study area are typically quite stable owing to bedrock control and buttressing by riparian vegetation (fig. 17).

Figure 17. - Channel widening limited by bedrock along streambanks in Zayante Creek. Although high water along this and many other reaches reached bank-to-bank and removed riparian vegetation, it did not cause streamside instability.

High-Order Channels

Moderate channel filling was common in larger high-order channels as a result of the storm. Observations were made along channels with drainage areas of between 100 and 300 km^2. Average channel fill recorded at these sites ranged between 0.07 and 0.47 m. Much of this sediment was transported from upstream reaches and deposited in wide low-gradient reaches characteristic of these channels. Point-bar and overbank deposits of well-sorted sand, although not always particularly thick, were extensive (figs. 18 and 19). Direct colluvial input to the reaches was minimal because floodplains were wider than those of smaller streams and prevented most landslide material from directly entering stream channels. Large amounts of organic debris were removed from infrequently occupied floodway areas in many reaches (fig. 20). Since the last major flood to occupy many such areas occurred in 1955, vegetation had 27 years to become established in these locations.

Figure 18. - Flood berm in downstream reach of Pescadero Creek, near site 40. This berm was typical of many found along downstream reaches of high-order channels.

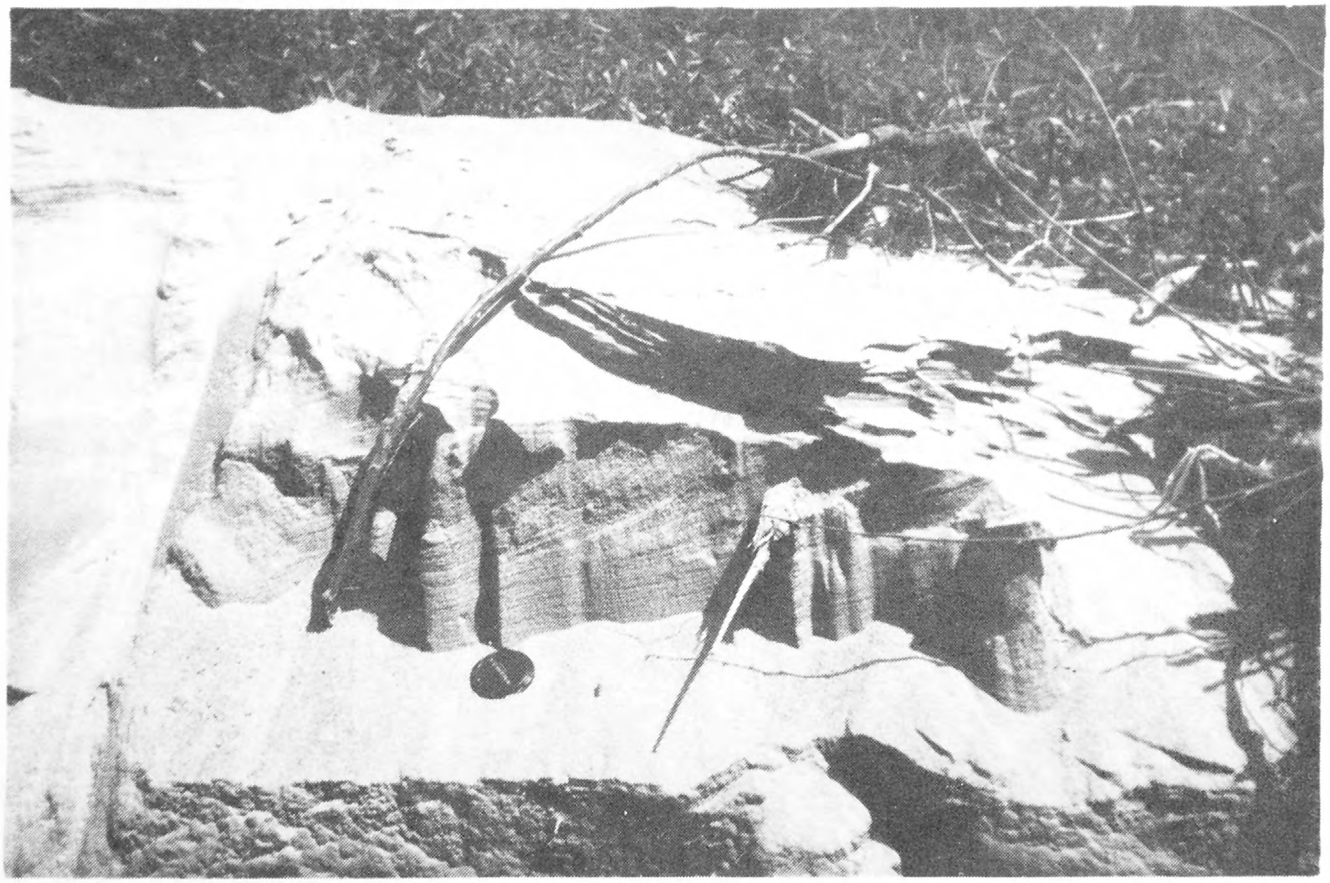

Figure 19. - Detail of flood berm shown in figure 18. This and most other such deposits found along high-order channels consisted of well sorted cross-bedded sand.

Figure 20. - Organic debris deposited along downstream reach of Soquel Creek.

Channel-Geometry Changes at Gaging Stations

Storm-related changes in the geometry of intermediate-and high-order channels were also assessed at seven stream-gaging stations operated by the U.S. Geological Survey using techniques similar to those used by Hickey (1969) and Lisle (1981). Changes in channel cross profiles and median streambed elevations were assessed at five of these sites using data collected during water-discharge measurements made at fixed locations, such as bridges and cable ways, and during level surveys conducted during indirect measurements of water discharge. When cross-profile data collected during water-discharge measurements made at fixed locations were used, preflood data were selected to conform as closely as possible to the time of year and the rate of water discharge associated with available postflood data. This selection limited possible ambiguities caused by scour and fill associated with variations in the rate of water discharge or seasonal variations in bed elevations. Median streambed elevations were used rather than mean values to deemphasize the effects of extreme elevations associated with streambanks. Lisle (1981) gives a more complete discussion of ambiguities caused by scour and fill and the use of median streambed elevations.

At two gaging stations the fixed location for highwater measurements was inappropriate for assessing changes in channel geometry. Discharge measurements on the San Lorenzo River near Boulder Creek were made at a culvert, and those at Zayante Creek were made at a bridge that severely constricted the channel. At these two sites, changes in channel geometry were assessed by using mean streambed elevations, which were determined during lowflow measurements made by wading. This technique introduces additional error because the locations of wading measurements are not precisely fixed in space. Hickey (1969) suggested that an error of $\pm$ 0.15 m is associated with such comparisons. Mean streambed elevations, rather than median elevations, were used for these comparisons because of the limited streambank heights associated with these low-flow wading measurements. These elevations were calculated by subtracting the mean depth during the discharge measurement from the gage height associated with the measurement. Elevations of the thalweg (the deepest part of the channel) were also calculated for all sites by subtracting the greatest depth during a given discharge measurement from the gage height associated with that measurement. Stream-gaging stations used in the study are shown in figure 2. Summary data on channel geometries are given in table 2. Figures 21 and 22 show examples of preflood and postflood cross profiles from Boulder Creek and the San Lorenzo River.

Table 2. - Prestorm and poststorm streambed elevations at gaging stations

Gaging station name and number	Study Site	Date	Median bed elevation[1] (m)	Mean bed elevation[1] (m)	Thalweg elevation (m)	Water Discharge (m^3/sec)	Type of Measurement	Location
Soquel Creek at Soquel (11160000)	4	1-15-80	0.52	-	0.32	10.5	Cable	Cable
		2-17-82	0.91	-	0.84	10.2		
San Lorenzo River near Boulder Creek (11160020)	5	12-16-81	-	0.50	0.41	0.04	Wading	15 m above gage
		1-07-82	-	0.56	0.35	1.09		
Zayante Creek at Zayante[2] (1160300)	21	11-25-81	-	0.31	0.21	0.15	Wading	55 m above gage
		1-19-82	-	0.31	0.24	0.30		
Boulder Creek at Boulder Creek (11160070)	11	3-24-78	1.49	-	0.94	([3])	Survey	8 m above gage
		3-10-82	1.34	-	0.92	([3])		
Pescadero Creek near Pescadero (11162500)	41	2-21-80	-0.27	-	-0.40	30.6	Bridge	At bridge
		1-06-82	0.29	-	-0.14	15.6		
San Lorenzo River at Big Trees (111605000)	31	1-11-80	0.45	-	0.33	29.2	Bridge	At bridge
		1-06-82	1.30	-	0.90	40.8		
		3-16-82	0.98	-	0.68	15.0		
Bear Creek near Boulder Creek (11160060)	8	3-21-78	1.18	-	-0.15	([3])	Survey	60 m above gage
		1-15-82	0.72	-	-0.21	([3])		

[1]Above gage datum.
[2]Bed elevation controlled by concrete wier with dropoff on downstream side.
[3]Not available.

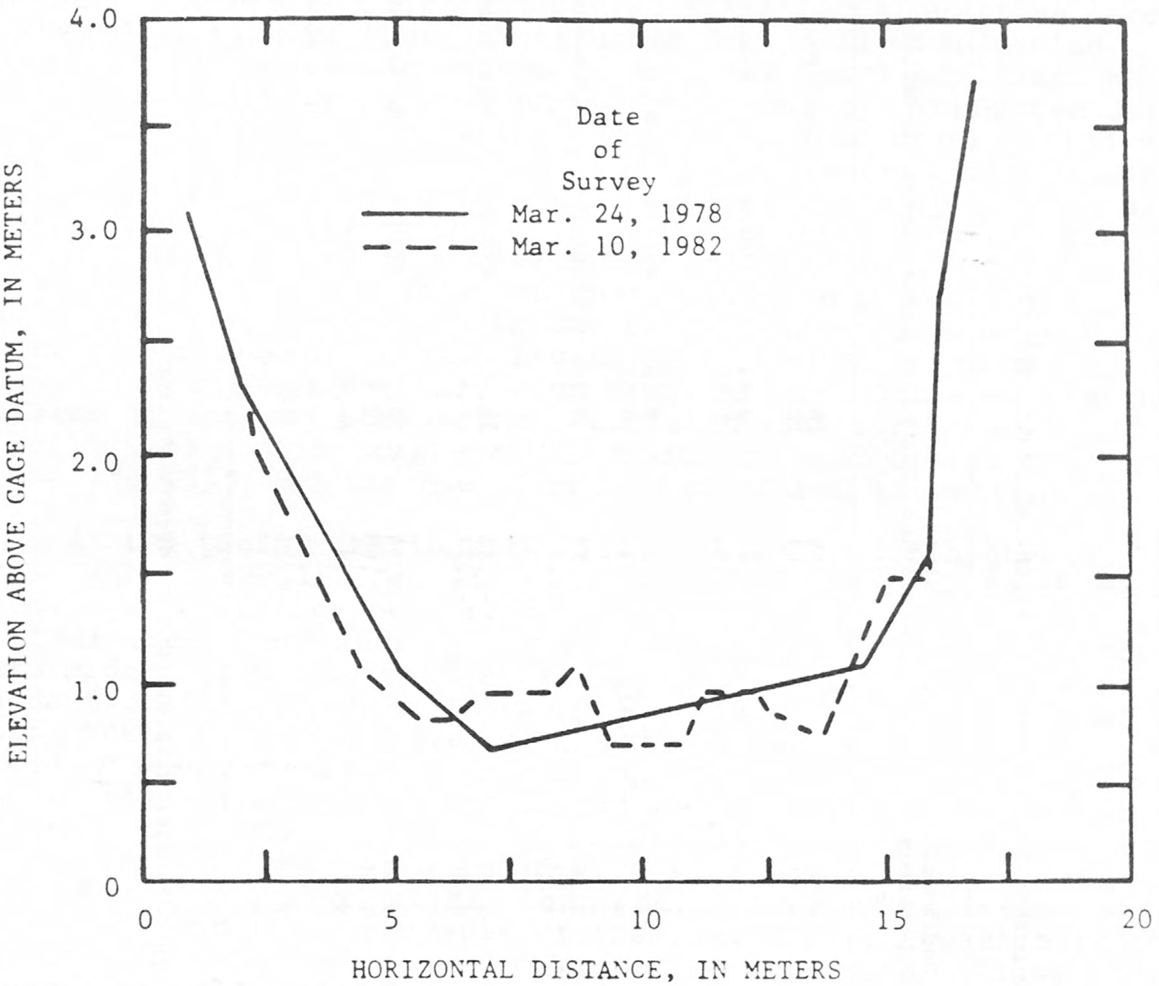

Figure 21. - Cross profiles of Boulder Creek, study site 11, before and after the flood of January 3-5, 1982.

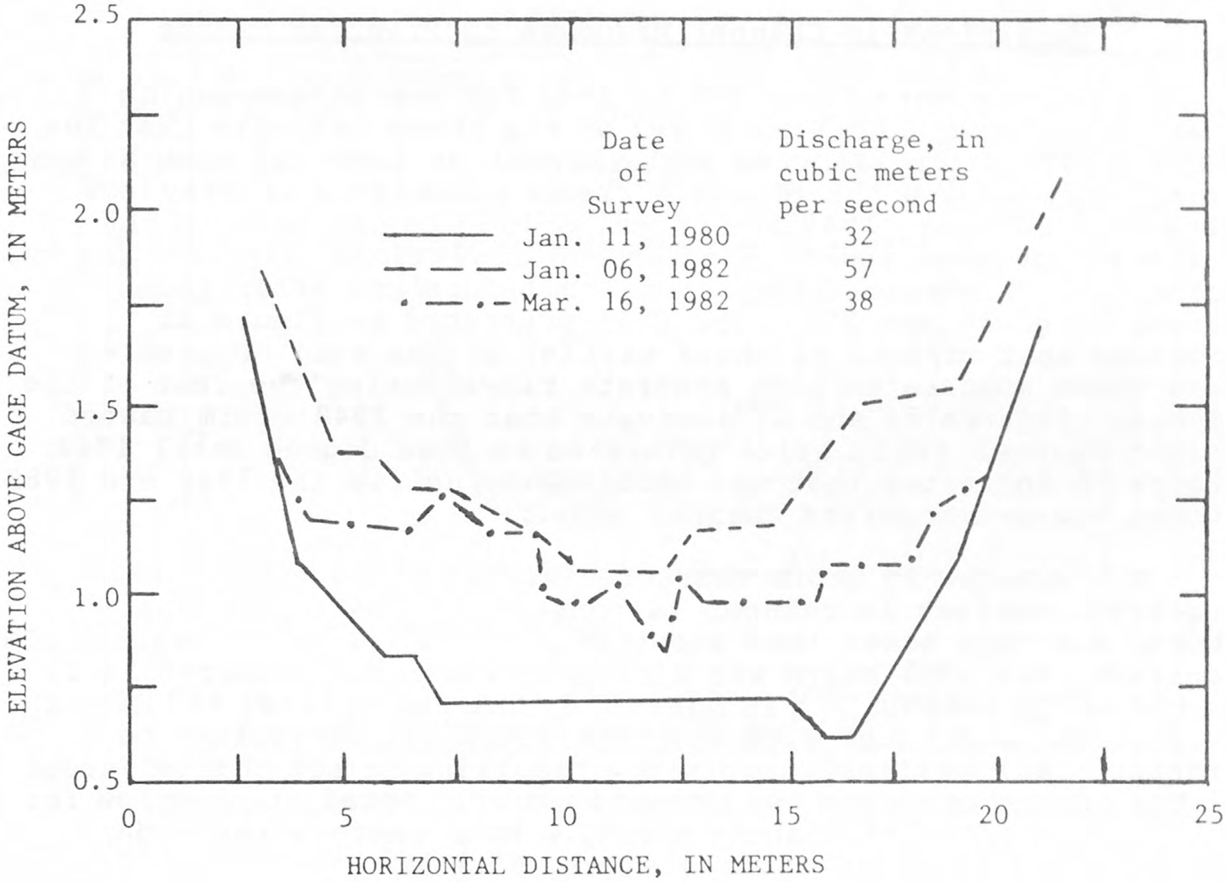

Figure 22. - Cross profiles of San Lorenzo River at Big Trees, study site 31, before and after the flood of January 3-5, 1982.

Five of the seven gaging sites showed some degree of channel fill following the storm. The greatest measured changes were on the San Lorenzo River at Big Trees, on Pescadero Creek, and on Soquel Creek. The mean streambed elevation of the San Lorenzo River rose 0.85 m, and the bed of Pescadero Creek rose 0.56 m, and the bed of Soquel Creek rose 0.39 m. Changes in streambed elevations at the remaining sites ranged from 0.46 m of scour on Bear Creek to 0.06 m of fill on the San Lorenzo River near Boulder Creek.

Variations in Channel Response to Previous Storms

Available data from 1936 to 1982 for the stream-gaging station on the San Lorenzo River at Big Trees indicate that the January 1982 storm affected that channel at least as much as any other storm during the period of record. Effects of previous floods in February 1940 and December 1955 can be seen in the variation of mean low-flow streambed elevations (fig. 23) and by comparison of channel cross profiles before and after those floods (fig. 24 and 25). The data presented in figure 23 indicate that effects of these earlier storms were no greater than those associated with moderate flows during the rest of the record. Figures 23 and 24 indicate that the 1940 storm caused slight channel fill, which persisted to some degree until 1943. Figure 25 indicates that the 1955 storm, unlike the 1940 and 1982 storms, caused moderate channel scour.

Differences in storm characteristics may have caused the observed contrast in channel response. The 1940 storm was a short, discrete event that occurred late in the rainy season. In contrast, the 1955 storm was a longer event that occurred early in the rainy season. It is possible that the greater volume of streamflow associated with the 1955 storm was sufficient to transport all available sediment, resulting in net channel scour at the gage site on the San Lorenzo River. Total streamflow for 7 days during the 1955 storm was 81.4 hm^3, whereas the 7-day total during the 1940 storm was only 65.3 hm^3.

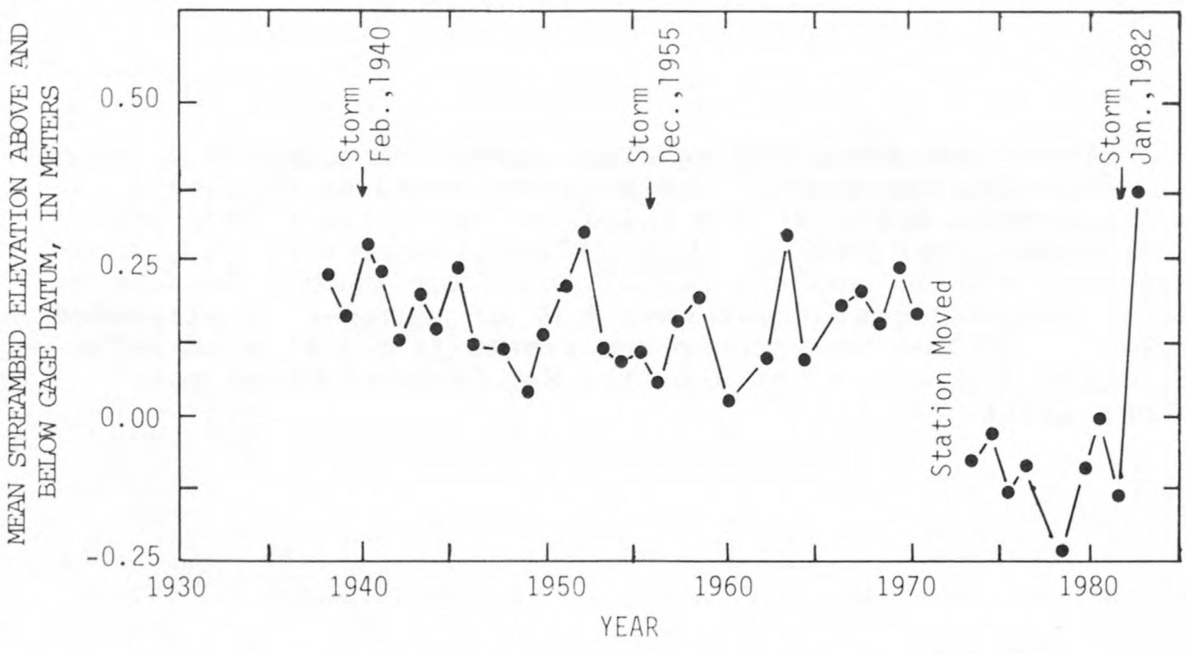

Figure 23. - Variations in mean streambed elevation of the San Lorenzo River at Big Trees. Note that station was moved in 1973. Mean streambed elevation was determined from low-flow, water-discharge measurements made between the months of April and October at sites between 30 and 60 meters above the old gage between 0 and 10 meters below the new gage.

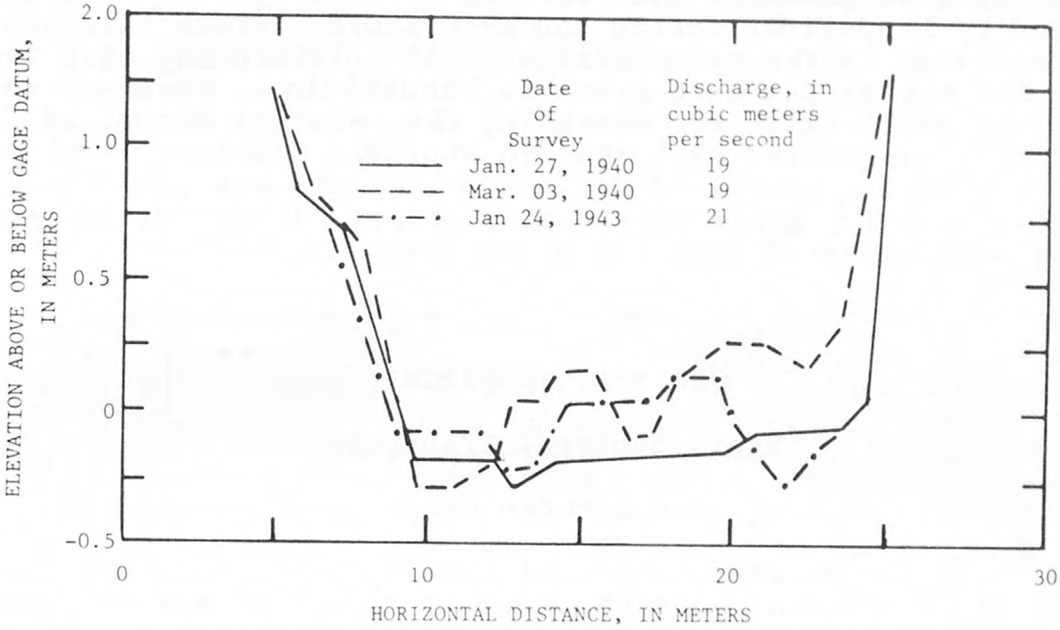

Figure 24. - Cross profiles of San Lorenzo River at Big Trees before and after the flood of February 27, 1940. Note tendency toward channel fill as a result of the flood. Profiles were determined during discharge measurements at the stream-gaging station.

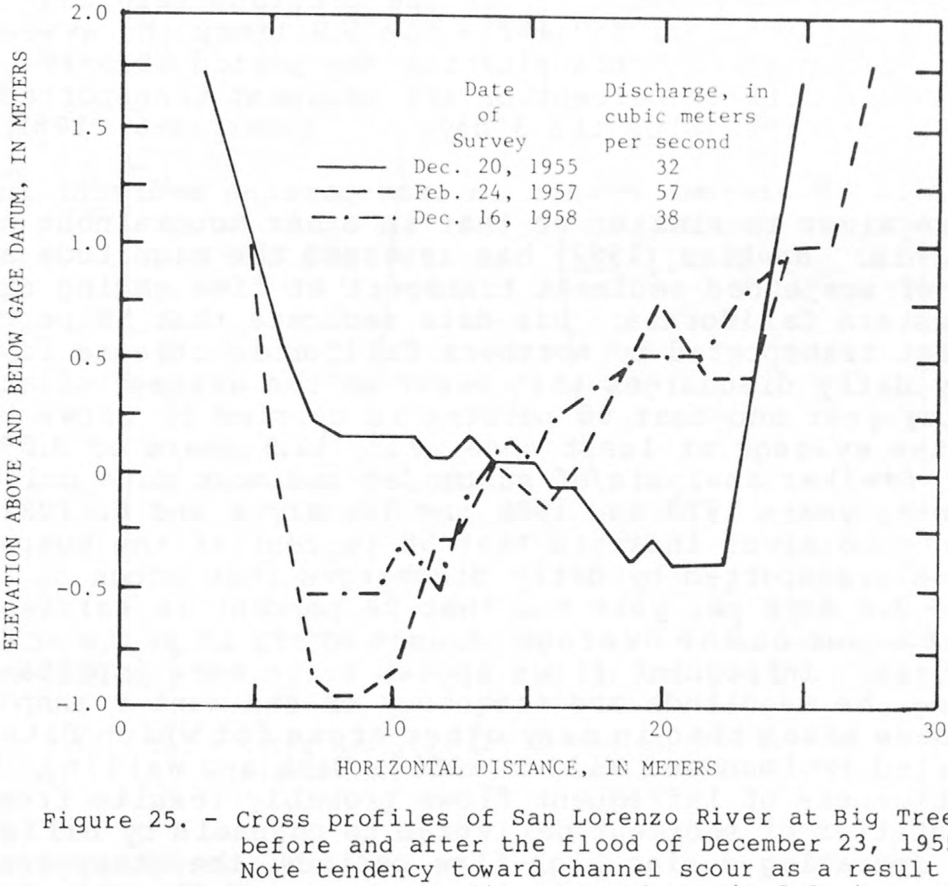

Figure 25. - Cross profiles of San Lorenzo River at Big Trees before and after the flood of December 23, 1955. Note tendency toward channel scour as a result of the flood. Profiles were determined during water discharge measurements at the stream-gaging station.

It is also possible that streams carried additional sediment supplied by landslides during the 1940 storm. Since this storm occurred later in the rainy season, soil moisture may have been higher and hillslopes more prone to landsliding. However, no definitive means exist for assessing the relative amount of landsliding associated with the two storms. Examination of available preflood and postflood aerial photography was inconclusive, owing to the small scale of the photography, dense vegetal cover, and the small size of most landslide features.

SEDIMENT TRANSPORT

Storm Sediment Transport

San Lorenzo River

Despite the short duration of the January 1982 storm, large quantities of sediment were transported by all stream systems throughout the study area. Total suspended-sediment transport of the San Lorenzo River at the Big Trees gaging station from January 4 to January 6 was 853,400 Mg or 3,100 Mg/km^2. Bedload discharge for these 3 days has been estimated at 3,320 Mg or 12.1 Mg/km^2 (L. F. Trujillo, U.S. Geological Survey, written commun., 1982). Water and sediment hydrographs for this event are shown in figure 26. The importance of these data is perhaps best viewed from the perspective of the previous record at this site. The 3-day total of 853,400 Mg is 5.9 times the average annual sediment yield at this site for the period 1973-80 (table 3) and equals 40 percent of all sediment transported between 1973 and 1980 plus the 3 days of January 4-6, 1982.

The role of extreme events in transporting sediment in the San Lorenzo River is similar to that in other mountainous areas of California. Hawkins (1982) has assessed the magnitude and frequency of suspended sediment transport at five gaging stations in northwestern California. His data indicate that 50 percent of the sediment transported by northern California streams is carried by daily discharges that occur on the average of at least 1.9 days per year and that 90 percent is carried by flows that occur on the average at least once every 12.5 years or 0.08 days per year. Similar analysis of suspended-sediment data collected between water years 1973 and 1980 and January 4 and 6, 1982, on the San Lorenzo River indicate that 50 percent of the suspended sediment is transported by daily discharges that occur on the average of 2.0 days per year and that 90 percent is carried by flows that occur on the average of once every 15 years or 0.07 days per year. Infrequent flows appear to be more important in determining the magnitude and frequency of sediment transport in both of these areas than in many other areas for which data have been reported (Wolman and Miller, 1960; Webb and Walling, 1982). The effectiveness of infrequent flows probably results from the large quantities of sediment delivered to channels by hillslope processes operating during high-flow periods, the steepness of stream channels in these mountainous areas, and the effects of highly variable flow as described by Baker (1977).

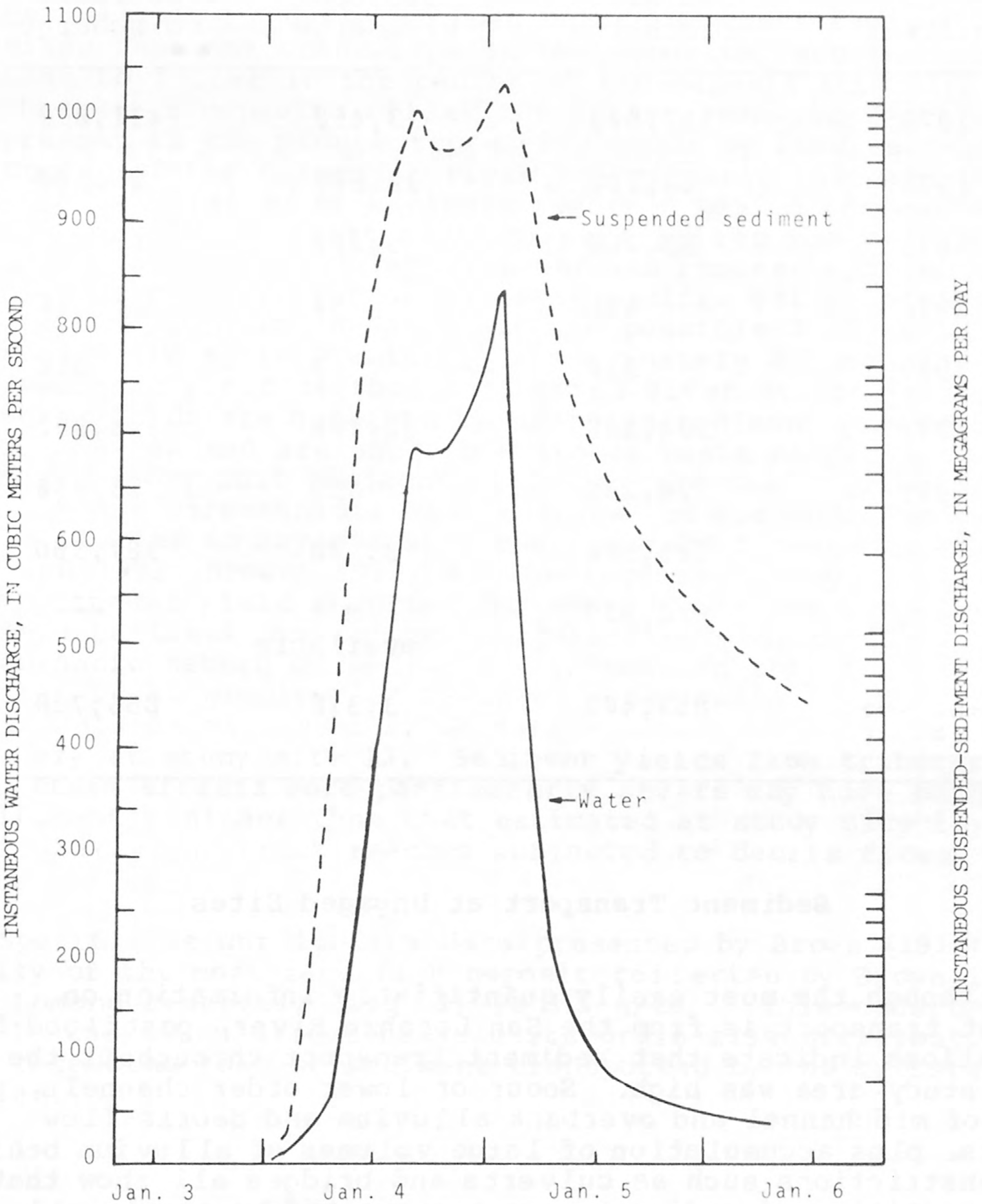

Figure 26. - Water and sediment discharge, San Lorenzo River at Big Trees, storm of January 1982.

Table 3. - Sediment discharge of San Lorenzo River at Big Trees (station 11160500)

[Data are in megagrams. Time interval is water year unless otherwise noted]

Time interval	Suspended-sediment discharge	Bedload Discharge	Total sediment discharge
1973	397,500	13,450	411,000
1974	84,700	10,600	95,300
1975	58,200	5,000	63,700
1976	481	94	576
1977	510	7	518
1978	304,400	12,400	316,800
1979	26,200	655	26,850
1980	383,500	3,740	387,300
1981	16,900	Not available	---
Jan. 4-6, 1982	853,400	3,320	856,720

Sediment Transport at Ungaged Sites

Although the most easily quantifiable information on sediment transport is from the San Lorenzo River, postflood field observations indicate that sediment transport throughout the entire study area was high. Scour of lower order channels, deposition of midchannel and overbank alluvium and debris-flow deposits, plus accumulation of large volumes of alluvium behind flow constrictions such as culverts and bridges all show that large quantities of sediment were transported by nearly all stream systems.

The massive accumulations of sediment behind flow constrictions such as culverts and debris jams attest to the fact that large amounts of sediment were transported through reaches where the flood caused minimal effects on channel geometry or riparian conditions. The amount of sediment transported by one small, steep tributary (site 13, fig. 2) was estimated by measuring the amount of sediment deposited behind a small-diameter (1 m) culvert that plugged during the storm (fig. 27). High-water marks indicate that the wing wall surrounding this culvert was overtopped by flow and that water was ponded 40 meters upstream of the culvert. The flat-topped nature of the backwater deposits, the concordant tops of the deposits, and the sediment adhering to a tree in the center of the deposit (fig. 27) suggest that backwater deposits filled the entire area and that the void now present in the middle represents scour by flow subsequent to unplugging of the culvert. Field measurements indicate that approximately 145 m^3 of sediment remained behind the culvert, and that, if one assumes that sediment once filled the void between the flat-topped lateral berms, scour has removed approximately 575 m^3 of sediment. If one uses a specific weight of sediment[1] of 1.3 g/cm^3, the above data indicate possible 3-day unit sediment yield of 9,400 Mg/km^2, which is approximately 4 times the 3-day unit sediment yield of the San Lorenzo River at Big Trees. Unit sediment yields are obtained by dividing sediment yields by drainage area, and are used in drainage basin comparisons. The estimated 3-day unit sediment yield for the small tributary seems high but not unreasonable when compared to suspended-sediment data collected on Zayante and Newell Creeks between water years 1970 and 1973 (Brown, 1973; U.S. Geological Survey, 1975). The maximum annual yield reported for these two sites was 2,760 Mg/km^2 for Zayante Creek during the moderate-flow year of 1973. The episodic nature of sediment transport in this terrane and the somewhat lower gradient of Zayante Creek (table 1) indicate that yields well in excess of 2,760 Mg/km^2 can be expected from the tributary at study site 13. Sediment yields from tributaries in which storm effects were particularly severe may have been significantly higher than that estimated at study site 13, particularly in stream reaches subjected to debris flows.

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[1]Specific weight is from data presented by Brown (1973). The density of the most sand-rich deposit collected by Brown in the Loch Lomond Reservoir (fig. 1) is 1.3 g/cm. This density was used in the calculations because its grain size distribution most resembles that of sediment transported by the tributary studied.

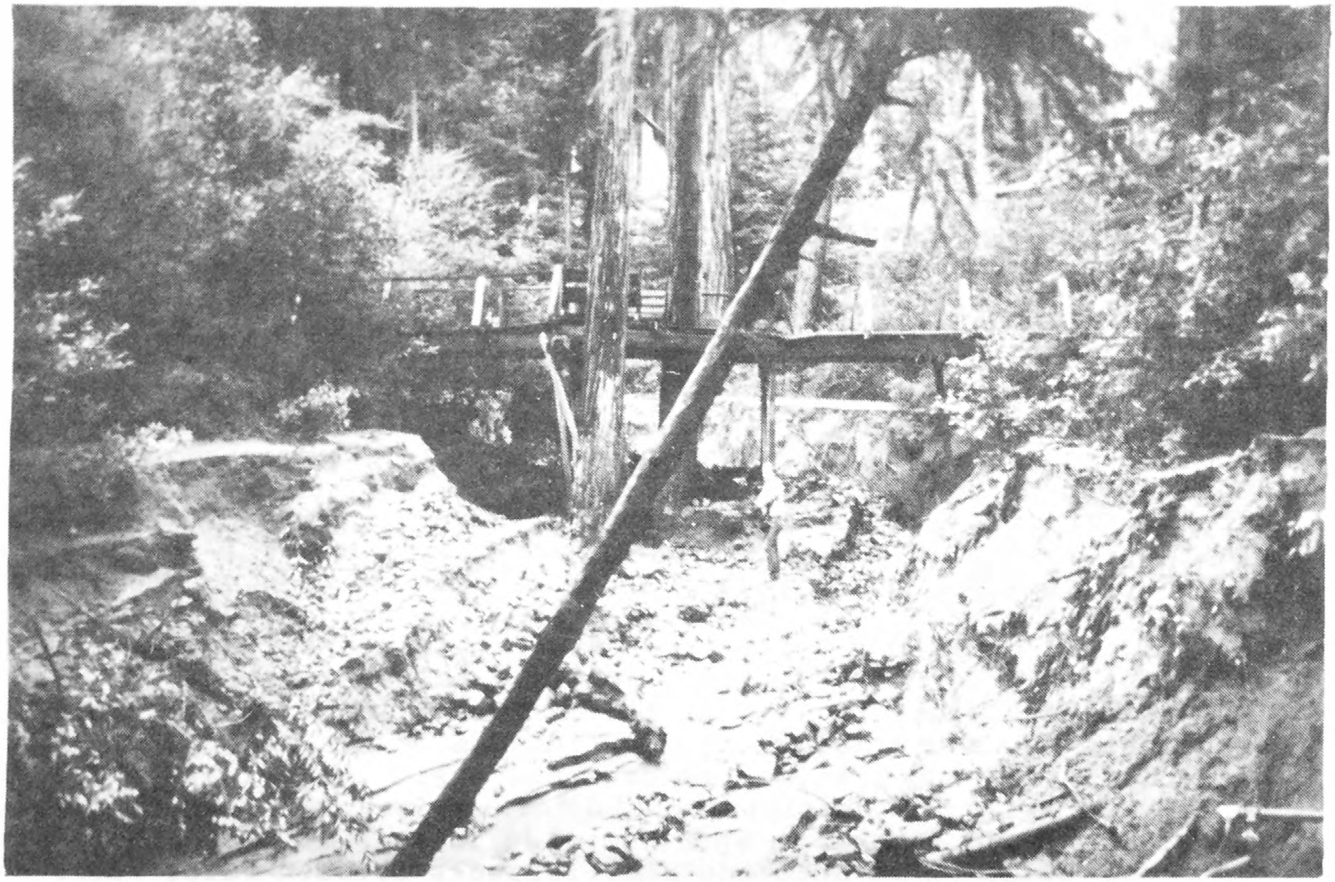

Figure 27. - Backwater deposits resulting from plugging of culvert at site 13.

Regional Comparison of Sediment Transport

Despite apparently high sediment yields during storms in the Santa Cruz Mountains, from a regional perspective, annual unit-sediment yields of the San Lorenzo River are not exceptionally high. Low average annual runoff, rather than sediment-transport capacity, accounts for this discrepancy. By comparison, the 720 km^2 Redwood Creek watershed in northwestern California has one of the highest annual unit sediment yields in the conterminous United States (Janda and Nolan, 1979b). The San Lorenzo River's suspended-sediment transport curve, which relates volume of water to suspended-sediment discharge, is similar to that of Redwood Creek (fig. 28). Although the San Lorenzo River has the potential for high annual sediment transport, annual unit sediment yields are limited by the amount of annual runoff. For example, the average annual runoff for Redwood Creek between water years 1973 to 1980 was 1,200 mm, whereas the average annual runoff from the San Lorenzo River during the same period averaged 420 mm. Average annual unit sediment yields of the San Lorenzo River and Redwood Creek reflect the difference in average annual runoff. The average annual unit sediment yield between 1973 and 1980 for Redwood Creek was 1,333 Mg/km^2, whereas that from the San Lorenzo was only 571 Mg/km^2.

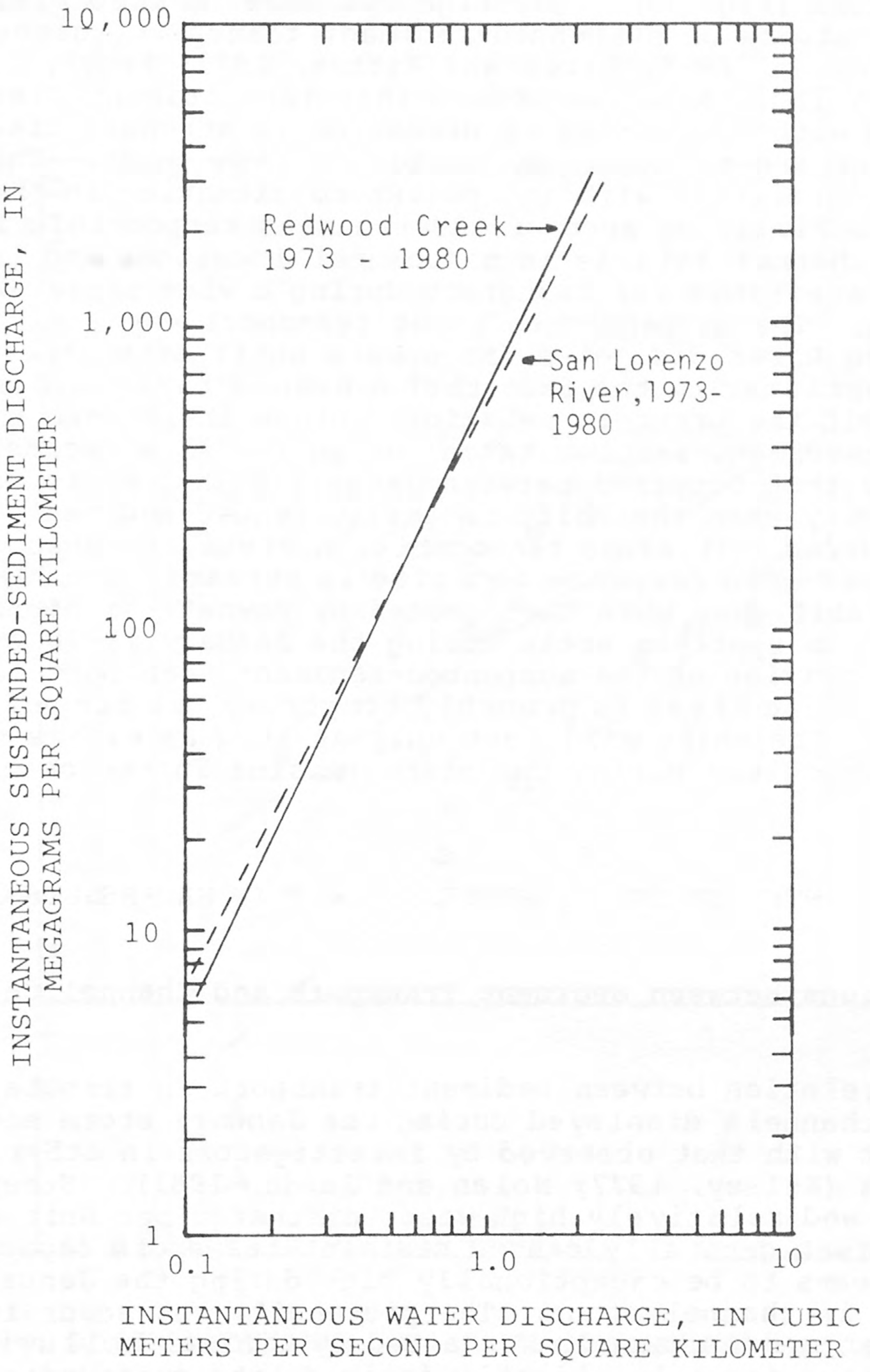

Figure 28. - Suspended-sediment transport curves for San Lorenzo River at Big Trees and Redwood Creek at Orick. Lines were fitted to data using regression analysis. The coefficient of determination was 0.94 for the San Lorenzo River data and 0.95 for the Redwood Creek data.

The suspended-sediment discharge associated with a given water discharge on the San Lorenzo River increased following the January storm (fig. 29). Investigators have noticed similar effects of storms on suspended-sediment transport curves elsewhere (Anderson, 1968; Brown and Ritter, 1971; Knott, 1971). Janda and Nolan (1979a) suggested that the sediment discharge associated with a given water discharge is strongly tied to the amount of sediment readily available for transport. This observation is consistent with the poststorm situation in the San Lorenzo River, as much of the sediment responsible for poststorm channel fill is in midchannel locations and is therefore available for transport during a wide range of flow conditions. The suspended-sediment transport curve of the San Lorenzo River did not shift upward until after the storm. This is confirmed by the fact that a sample taken on January 6 falls within the prestorm relation. Since there were no suspended-sediment samples taken during the slow recession in streamflow that occurred between January 6 and 20, it is not known exactly when the shift in the suspended-sediment transport curve occurred. It seems reasonable, however, to assume that the shift occurred in response to a rise in streamflow on January 19-20. This shift may have been caused by downstream migration of sediment from upstream areas during the January 19-20 event. The elevated position of the suspended-sediment transport curve of the San Lorenzo River is probably temporary, as has been the case elsewhere. The shift will last only as long as excessive sediment deposited during the storm remains in the channel.

INTERACTIONS OF PROCESSES WITHIN WATERSHEDS

Relations Between Sediment Transport and Channel Changes

The relation between sediment transport in tributary and mainstem channels displayed during the January storm seems consistent with that observed by investigators in other steepland watersheds (Kelsey, 1977; Nolan and Janda, 1981). Steep stream gradients and relatively high water discharge per unit area from smaller areas generally caused sediment-transport capacity of small streams to be exceptionally high during the January storm, resulting in channel scour. The propensity for scour in these steep first-order channels was aided by minimal colluvial input. These streams are only slightly incised into surrounding hillslopes, hillslope segments adjacent to them are not particularly expansive or steep, and streamside landslides are relatively scarce. The sediment removed from these steep streams was transported to higher order channels, which generally have less steep gradients and lower unit runoff. Where sediment delivery from tributaries exceeded the transport capacity of higher order channels, fill resulted.

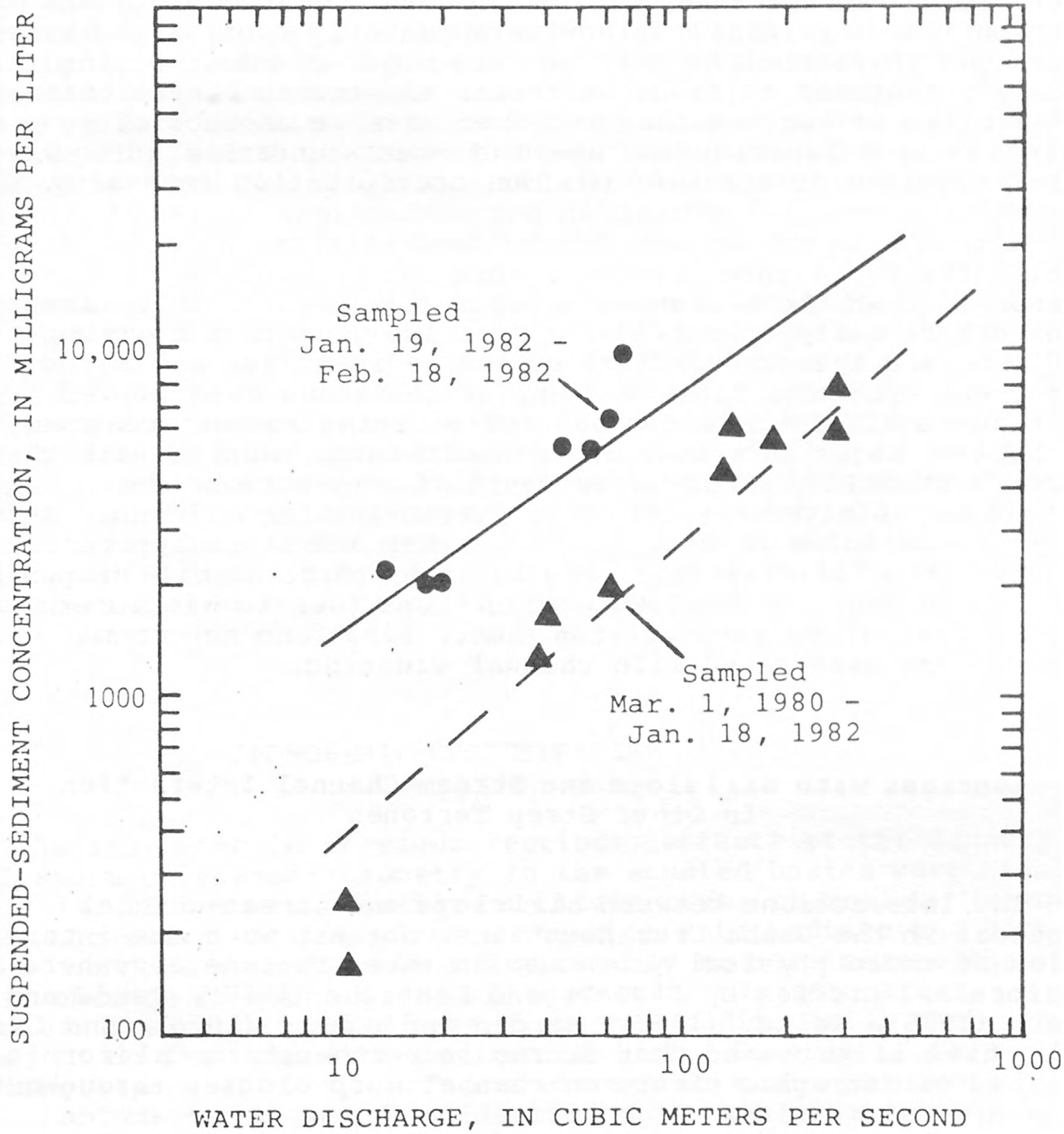

Figure 29. - Upward shift in the suspended-sediment transport curve of the San Lorenzo River at Big Trees. Note upward shift in the relationship subsequent to January 18, 1982. Lines were fitted by eye.

Interaction of Hillslope and Stream-Channel Processes

Although the link between channel processes in the Santa Cruz Mountains appears similar to that in steep terrane elsewhere, the interactions of physical processes in stream channels and on hillslopes contrast with such interactions in other areas. In the Santa Cruz Mountains, local geology and the distribution of rainfall intensity apparently control the extent of changes in channel geometry during major events. During the January 3-5 storm, major depositional effects on stream channels were limited to reaches that received massive amounts of colluvium from landslides. Areas of most abundant sliding were in turn limited to areas of maximum precipitation intensity.

Although large volumes of sediment were transported out of highly affected channel reaches, this sediment did not cause widespread downstream channel modification. The high sediment-transport capacity of streams, due at least in part to steep gradients and the sandy nature of the sediment load, limited downstream effects. Bedrock banks or dense and well-rooted riparian vegetation limited channel widening in most reaches. The lack of major increases in channel width, coupled with the relative stability of lower segments of many streamside hillslopes, limited the amount of streamside landsliding. Much of the landsliding related to the January 3-5 storm apparently resulted from failures initiated in upper parts of hillslopes in response to high soil moisture conditions (Gerald Wieczorek, U.S. Geological Survey, written comm., 1983) and not from undercutting associated with channel widening.

Contrast with Hillslope and Stream-Channel Interaction in Other Steep Terranes

The interactions between hillslope and stream-channel processes in the Santa Cruz Mountains contrast with the interaction of these physical processes in steep terrane elsewhere in California. Studies by Stewart and LaMarche (1967), Janda and others (1975), Kelsey (1977), Harden and others (1978), and Lisle (1981) have illustrated that storms in northwestern California have had catastrophic effect on channel morphologies throughout large drainage basins. High streamflow during these storms initiated large numbers of streamside debris slides by undercutting the toes of inherently unstable hillslopes found throughout the area (Harden and others, 1978). The large volumes of colluvium from these debris slides overloaded the transport capacity of most channels in the area, resulting in massive channel fill. Evidence has been reported for up to 4 m of fill, and channel widening in excess of 100 percent in the Redwood Creek drainage basin as a result of a major storm in 1964 (Harden and others, 1978).

Stream channels in the rapidly eroding terrain common in northwestern California are particularly prone to aggradation because they commonly contain large quantities of sediment even without the effects of storms. This sediment includes deposits from previous storms (Janda and others, 1975) in addition to yearly input from persistenly active mass movement (Harden and others, 1978, and Janda and Nolan, 1979a). When this terrane is subjected to major storm events, stream channels already contain large amounts of readily transportable alluvium, and unstable streamside hillslopes found throughout the area fail easily when undercut by streamflow. This set of conditions appears responsible for initiating a series of positive feedback loops during which colluvium from landslides causes channel aggradation and widening, which initiates further bank undercutting and streamside landsliding (Colman, 1973). This loop can result in widespread channel aggradation and hillslope failures even away from the locus of initial failure and channel fill.

Unlike stream channels in northwestern California, intermediate and high-order streams in the Santa Cruz Mountains can transport a high percentage of the sediment supplied to them during storms because of their high transport capacity, because sediments are commonly sand-sized, and because prior to major storms, channels do not contain exceptional amounts of sediment. Large volumes of storm-related sediment can be introduced to a channel before its transport capacity is reached. When channel modification does occur in the Santa Cruz Mountains, it is not propagated downstream. Bedrock along streambanks limits bank undercutting, which prevents the positive-feedback effects seen in northwestern California.

GEOMORPHIC EFFECTIVENESS OF EVENT

As indicated in previous sections, effects of the January 1982 storm on channel geometry in the studied basins were highly variable. Scour was pervasive in lower order channels. In most areas, however, effects of this storm on intermediate and high order channels were minimal and generally no more severe than those of more frequently occurring events. In some areas, however, the storm caused severe channel modification that can be expected to last for long periods of time. Because of this variability in effects, both the concept of geomorphic work suggested by Wolman and Miller (1960) and that of geomorphic effectiveness suggested by Wolman and Gerson (1978) seem relevant in assessing the role of the storm in shaping channel morphology throughout the study area.

Wolman and Miller (1960) suggested that the amount of geomorphic work done during individual events is measureable, at least in part, by the amount of sediment transported by such events. Data presented in their paper indicate that for such streams as the Rio Puerco in New Mexico and Brandywine Creek in Delaware daily discharges that recur more frequently than 6 and 11 times per year respectively transport 50 percent of the sediment and that these moderate flows control the shape of some fluvial landforms. Although the flows that transport 50 percent of the sediment in the Santa Cruz Mountains recur only 2 days per year and are therefore less frequent than in the study areas cited by Wolman and Miller, flows with such moderate recurrence intervals appear to have the potential to influence the morphology of channels in the Santa Cruz Mountains. Data presented in previous sections of this report indicate that channel morphology along most intermediate and high order reaches is probably shaped at least as much by frequently occurring flow events as by catastrophic events. The morphology of such reaches was either not modified significantly by the flood or is expected to return quickly to the preflood configuration. In such reaches the concepts of Wolman and Miller (1960) probably apply.

In other reaches, however, channel geometry was severely modified by the flood of January 1983. These were the reaches scoured to bedrock by exceptionally high runoff or subjected to severe deposition related to the influx of overwhelming volumes of colluvium. Although most of these severe changes will subsequently be modified during more moderate events, the imprint of the storm will remain for a long time. In these areas the concept of impact persistance proposed by Wolman and Gerson (1978) seems to apply. This concept suggests that if effects produced by a high magnitude storm persist longer than the recurrence interval of the storm itself, the storm has longterm geomorphic significance. In such cases the landscape always reflects effects of high-magnitude storms. Channel geometry in these areas cannot be totally attributed to effects of more moderate events.

Storm-related changes in highly affected reaches persist because the forces tending to restore channel geometries to pre-storm conditions either are not completely able to remove storm-related effects, act very slowly, or act only intermittently. The massive amounts of colluvium supplied to highly affected intermediate-order reaches by debris flows and debris slides totally rearranges channel morphologies. The effects of this large volume of material are probably visible in the cross profiles and longitudinal profiles of these channels for long periods. Channels incise through this debris, leaving colluvial remnants along channel margins. Filling of voids left by scouring debris torrents or by simple scour in some first-order channels depends upon slowly operating processes such as soil creep. Although most overbank deposits in the study area were not particularly massive, some of the more massive of these deposits may persist for a long time. The degree to which the less massive overbank deposits can resist weathering and subsequent overbank flooding is uncertain.

The long-term persistence of effects of previous storms was evident in the landscape prior to the January storm. Field observations revealed multiple locations along intermediate-order streams where channels are exceptionally wide and gently sloped and where colluvium mantles adjacent hillslopes. Channels in these reaches are lined with well established vegetation. These observations indicate that such reaches were probably depositional sites of ancient landslides. Channels upstream and downstream of these sites are typically much steeper and narrower and abut directly against steep hillslopes.

The persistence of storm-related effects also depends on the sequence of future events (Bevin, 1981). If the 1982 storm is followed by an exceptionally long storm-free period, effects of moderate events will become more obvious within the studied watersheds than effects of extreme events. The effects associated with future storms also depend somewhat on the sequencing of those storms. For example, effects of a storm that follows the one of January 1982 closely in time with maximum precipitation intensities located in similar locations may cause substantially less impact than one with maximum precipitation intensities located elsewhere, or one that occurs hundreds or even thousands of years in the future.

In areas such as the Santa Cruz Mountains, where debris slides and debris flows can contribute volumes of colluvium sufficient to modify channel geometries, it may be more appropriate to use recurrence intervals associated with precipitation intensity than those associated with streamflow to measure the likelihood of a given event. The occurrence of debris slides and debris flows similar to those observed in the studied watersheds depends more on short-duration precipitation intensities (Campbell, 1975) than on the volume of water necessary to produce exceptionally high streamflow. Recurrence intervals associated with peak rainfall intensities for the January storm were considerably higher than those associated with peak streamflow. Although 24-hour precipitation intensities recorded during the storm had estimated recurrence intervals in excess of 100 years (J. Monteverdi, San Francisco State University, written commun., 1982), recurrence intervals of peak streamflow in the area did not exceed 50 years (J. C. Blodgett, U.S. Geological Survey, written commun., 1982).

Because of the high precipitation intensities associated with the January 1982 storm, postflood observations of channel behavior probably permitted assessment of the effects of a particulary effective geomorphic event with a relatively rare frequency of occurrence. Observations of the response of stream channels to this event and of gross preflood channel morphology indicate that the morphology of stream channels in the Santa Cruz Mountains reflects effects of both moderate and catastrophic events. The morphology of most intermediate and high-order channels appear to reflect effects of moderate events at least as much as effects of catastrophic events. However, the morphology of most steep low-order channels and that of localized reaches along higher order channels strongly reflect effects of extreme events. This is because the scour found along these low-order channels and the filling found along these isolated reaches of larger channels have the potential to persist as long or longer than the recurrence interval of the storm itself. If such storm-related effects persist for periods of time exceeding the recurrence interval of the storm, there is reasonable chance that the effects of multiple storms could be found throughout the studied watersheds. This appears to be the case because the morphology of some reaches shows the influence of the deposition of colluvium during previous storms.

SUMMARY

In the majority of channels studied, channel changes resulting from the January 1982 storm in the Santa Cruz Mountains were not particularly severe and are not expected to persist for a long period of time. This lack of channel response occurred despite streamflow recurrence intervals that ranged up to 50 years, and the fact that large volumes of sediment were transported through most stream systems in the area. Significant channel changes did occur where low-order channels were scoured to bedrock and where colluvial input from debris slides and (or) debris flows was exceptionally voluminous. The depositional changes were mostly found in areas characterized by maximum precipitation intensities because high pore-water pressure induced by this intense precipitation was a dominant trigger mechanism of landsliding. These major channel changes were commonly local in nature because the positive feedback loop between hillslope and stream-channel processes (which is responsible for a downstream propagation of storm-related channel changes elsewhere in California) was not found to be effective in the Santa Cruz Mountains. In the Santa Cruz Mountains bedrock along many stream channels limits the importance of channel widening as a mechanism for triggering streamside debris sliding; stream transport capacities are high owing to steep gradients and sand-sized alluvium and colluvium; and channels are relatively clear of sediment before major storms owing at least in part to the lack of persistently active landslides.

Consideration of channel response to this and previous major storms suggests that channel morphology in the Santa Cruz Mountains is formed both by moderate and extreme events. For example, steep low-order channels tend to contain only small amounts of alluvium because alluvium is periodically flushed from them during major storms. Some intermediate-order channels flow through alluvial channels that are relatively wide and flat due to deposition related to the influx of overwhelming volumes of colluvium. Elsewhere, channels of this size tend to be V-shaped and relatively steep and appear to reflect the effects of moderate events at least as much as effects of extreme events. Since the localized effect of a high magnitude storm can persist longer than the recurrence interval of the storm itself, channel morphology throughout the area probably reflects the effects of a number of storms. These effects are probably scattered throughout the area as a result of variation in the spatial distribution of maximum precipitation intensities.

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