Scour and Fill in Tujunga Wash— A Fanhead Valley in Urban Southern California—1969

GEOLOGICAL SURVEY PROFESSIONAL PAPER 732-B

Prepared in cooperation with the California Department of Water Resources

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By KEVIN M. SCOTT

PHYSIOGRAPHIC AND HYDRAULIC STUDIES OF RIVERS

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An analysis of well-documented large and destructive changes of a stream channel in an urbanized area subject to floods

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SCOUR AND FILL IN TUJUNGA WASH—A FANHEAD VALLEY IN URBAN SOUTHERN CALIFORNIA—1969

By Kevin M. Scott

ABSTRACT

A unique combination of substantial channel change and documentation of the changes by high-order photogrammetry was studied in Tujunga Wash in southern California. Extensive scour and fill occurred during the recordbreaking 1969 floods in this 3-mile-long, partly urbanized fanhead valley. Maxima of 20±2 feet of net scour and 35±2 feet of net fill were measured on 31,000 scale-feet of cross sections plotted to illustrate changes in distributary channels of the wash. Net elevation change of the channel thalweg varied from as much as 14±2 feet of scour to as much as 16±2 feet of fill.

The most dramatic causes of scour and fill in Tujunga Wash were (1) the unexpected yet possibly natural diversion of floodflow to a major distributary channel of the wash in which urbanization had progressed, (2) local reduction in base level which occurred when floodflow in both of the main distributary channels entered a large gravel pit, and (3) lateral scour of an aggradational surface within the wash because of natural adjustment of a distributary channel to flood discharge. Additional scour and fill were due to locally raised base level and to the natural lateral shift characteristic of channels in the broad, ephemeral washes of arid and semiarid regions.

Scour proceeded upstream from the edge of the gravel pit probably as much as 3,000 feet and was instrumental in the failure of three highway bridges. An entire residential street and seven homes built on an unstabilized cutback of the channel were destroyed by lateral scour. Damage at most, if not all, of the localities could be indirectly ascribed to man's disregard of natural geomorphic processes on alluvial fans and in fanhead valleys.

The textural similarity of the bed material of the active channels and the deposits exposed within the wash by the 1969 floods suggests that all the deposits were formed under the present, or a similar, hydrologic regime. Thus, rapid lateral shifts of channel position as a result of major floods should not be unexpected anywhere in the wash. During long intervals of dry weather, however, the memories of previous flood disasters become dim, and building sites in the washes and on bordering terraces prove irresistible to developers and home buyers. Urban development on the unstabilized cutbank of a natural flood channel on an alluvial fan or fanhead valley is generally a poor risk.

Comparing preflood and postflood profiles downstream from the point of a fanhead jump, it is apparent that channel diversion locally resulted in scour of one major channel which corresponded in amount with fill in the other major channel. Not only were scour and fill comparable in amount, but the postflood profiles of both channels became nearly parallel, after smoothing of pronounced preflood irregularities in the channel which were both natural and the result of the works of man. Analogies with mechanisms active in the maintenance of a long-term equilibrium in the formation of alluvial fans are possible.

Analysis of the photogrammetric data indicated that accuracy of design mapping (contour interval, 2 feet; scale, 1: 600) is sufficient to define net changes in scour and fill throughout a flood course, in parts of the channels to the nearest foot of elevation. Detection of minor gullying outside the main distributary channels was possible on low slopes.

INTRODUCTION AND ACKNOWLEDGMENTS

Many urban areas in southern California are bounded by rugged mountain ranges. Streams draining the mountains flow initially through steep bedrock channels, then debouch during floods from the steep fronts of the ranges to rapidly deposit debris on broad, semicircular cones known as alluvial fans.

Streams that drain the frontal watersheds of the San Gabriel and San Bernardino Mountains form alluvial fans directly at the mountain front. Larger streams that drain the interior of the mountain ranges, although confined to deep V-shaped canyons throughout much of their courses, make the final 1–5 miles of their departure from the mountain front through broad, expanding valleys hydrologically similar to the pie-shaped segment of a fan. These valleys, here described as fanhead valleys, are the intermountain extensions of fan alluviation. Such upper fan embayments also have been described as fanbay areas which, however, are generally features of a smaller scale.

In their natural state, channels both on the fans and in the fanhead valleys are unstable washes like those of desert regions—ephemeral and capable of shifting rapidly in response to changes in flow.

It was on the fans, particularly in fanhead areas, where stream processes were most active and where the greater part of the damage caused by the recordbreaking floods of January and February 1969 was concentrated. It was also on the upper parts of the fans where the conflict between urbanization and the natural environment was most dramatically illustrated. Such areas are often the last land available in southern California in a pattern of urbanization moving upward from the level land of the basins toward the mountain front. Individual flood-control facilities for every major fan-forming drainage have not kept pace with urban development. Well-planned flood-control facilities in older developed sections held damage to a minimum in basin areas and on most of those fans where facilities were complete.

Several indirect factors contribute to the local destructive intensity of floods in southern California. One is the ephemeral nature of stream channels on fans and in fanhead valleys. Little or no surface flow occurs during most of the year, and in many years storm runoff is of small magnitude and short duration. During the long intervals of dry weather, memories of previous flood disasters become dim, and building sites in the washes and on bordering terraces prove irresistible to developers and home buyers. This problem was magnified by a prolonged dry period, lasting from the mid-1940's to 1965, that coincided with a time when the population of southern California multiplied explosively. In addition, urban planners have not been uniformly cognizant of the geomorphic setting and the nature of floodflows on alluvial fans. At the heart of this aspect of the problem, as noted by Rantz (1970), is the lack of a direct central planning authority to exercise uniform control over the 78 municipalities that exist in Los Angeles County alone.

The problem of flooding on fans generally was not one simply of damage from rising flood waters; rather, it was largely one of rapid lateral shift in channel position, either by erosion of the banks of stream terraces supporting structures seemingly safe from the greatest flood or by the seemingly random jump of the flow to old or completely new channels radiating from the fan apex. Property destruction from this cause occurred on fans throughout southern California in 1969.

This report treats an example of flood effects on both channel morphology and the activities of man in a fanhead valley—Tujunga Wash (fig. 1). The purpose of the study is to (1) provde urban planners with a case history of the changes in channel morphology in a fan environment; (2) analyze these changes in terms of scour and fill; (3) indicate the causes of scour and fill wherever possible; and (4) show how high-order photogrammetry can detect such channel changes. The circumstances connected with scour and fill in Tujunga Wash are examples that apply in principle to innumerable other fanhead valleys that may become urbanized in a similar manner throughout the Southwestern United States.

The changes in Tujunga Wash were of two general kinds: changes that would have occurred under natural conditions, and changes that were interrelated with human modification of the channel. In the first, if destruction in similar geomorphic settings is to be avoided in the future, planners must appreciate the potential magnitude of the natural changes—the way in which ephemeral fan channels adjust to changing flow conditions—before making zoning decisions. Secondly, with knowledge of the harmful effects of a few of man's activities in the channels, control of such activities must be exercised, or compensating protective measures planned in the event of economic justification.

The study was made in cooperation with the California Department of Water Resources. Agencies that provided information are acknowledged in the body of the report; individuals who provided assistance are too numerous to mention, but lack of space does not reflect the lack of the author's gratitude.

THE STORMS

PRECIPITATION AND RUNOFF

The storms of late January and late February 1969 caused floods approaching or exceeding the previous flows of record at many localities (Waananen, 1969). Moist tropical air moved strongly out of the Pacific as a series of storms during the periods January 18–22, January 24–27, and February 22–25. The pattern of precipitation for the February storm, which caused the greatest damage in Tujunga Wash, is shown in figure 1.

Distribution of rainfall in the upstream drainage basin of Tujunga Creek generally was similar in the January 18–22 and February 22–25 periods. During the January 24–27 storm, greater quantities of precipitation, 18–20 inches, fell in the central part of the basin near Big Tujunga Reservoir. Totals for the January 18–22 and February 22–25 storms ranged from 12 to 14 inches in the same area. Precipitation during February maintained saturated-soil conditions that permitted the runoff from the storm of February 22–25 to compare with that of the more intense storm of January 24–27.

The January 1969 floods in southern California were comparable to those of March 1938, the greatest since the legendary flooding of 1862. This was not true in the Tujunga Canyon area, however, where peak discharges were less than in 1938 (table 1), in part because the 1938 storm was unusually intense in the Tujunga

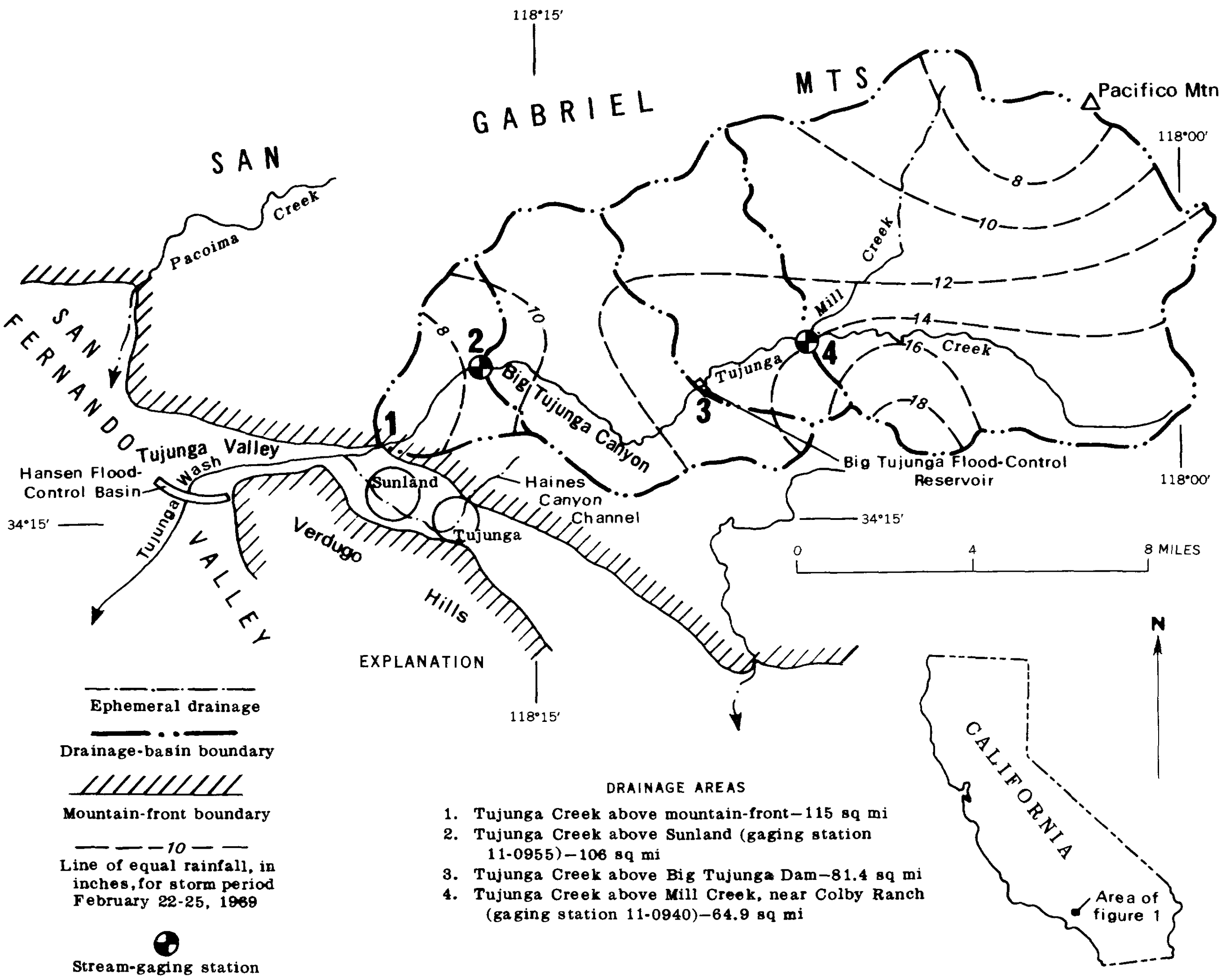

FIGURE 1.—Index map of study area. The stream-gaging stations shown are operated by the Los Angeles County Flood-Control District. Isohyetals compiled by the Los Angeles County Flood-Control District.

Creek watershed. Although renewed flooding in February 1969 produced peak discharges in Tujunga Creek comparable to those of January (table 1), the February flows proved to be more devastating in their effects on urbanization in the area studied because of factors described below.

Values of peak discharges through Tujunga Wash are not well defined. Maximum mean hourly inflow into Hansen Flood-Control Basin (fig. 1) during the February storm period was 26,000 cfs (cubic feet per second) from 0700 to 0800 hours on February 25 (Simpson, 1969b, pl. 86). Inflow from an additional drainage area of 21 square miles is included in this figure. Discharge in the wash is estimated to have reached a maximum of more than 17,000 cfs during the predawn hours of February 25 (Simpson, 1969a, p. 40).

TABLE 1.—*Summary of flood discharges at gaging stations in Tujunga Creek drainage*

Station No.	Stream and place of determination	Drainage area (square miles)	Period of record	Date	Maximum discharges: Cfs	Maximum discharges: Recurrence interval (ratio to 50-year flood)
11–0940	Tujunga Creek below Mill Creek, near Colby Ranch.	64.9	1948–69	1–23–43	[1] 14,800	1.2
				12–29–65	6,550	.42
				1–25–69	12,900	1.02
				2–25–69	13,500	1.1
11–0955	Tujunga Creek near Sunland.	106	1916–69	3– 2–38	[2,3] 50,000	2.6
				1–25–69	[3] 20,600	1.1
				2–25–69	[3] 20,000	1.05

[1] Exceeded by March 1938 flood. Peak inflow to Big Tujunga Reservoir (drainage area 81.4 sq mi) 35,000 cfs, Mar. 2, 1938.
[2] Estimated.
[3] Affected by storage in Big Tujunga Reservoir (constructed 1931).

RECURRENCE INTERVALS OF THE 1969 FLOODS

A perspective of the relative significance of the 1969 floods in the Tujunga Creek basin is indicated by their recurrence intervals—the number of years, on the average, in which a given peak flow will be equaled or exceeded once by the annual peak discharge. A 50-year flood, for example, has one chance in 50 of being equaled or exceeded in any one year. Such a flood need not recur only once every 50 years; because of the irregularity of climatic trends, it could occur several times in a shorter time interval.

The recurrence intervals of peak discharges on both January 25 and February 25 were slightly in excess of 50 years at both the upstream station, Tujunga Creek below Mill Creek, near Colby Ranch, and at the station only 3 miles above the canyon mouth, Tujunga Creek near Sunland (table 1). The back-to-back occurrence of two 50-year floods in the basin does not lengthen the odds against another major flood in the near future, however.

THE ENVIRONMENT

CHARACTERISTICS OF THE DRAINAGE BASIN

Tujunga Creek above the mountain front drains 115 square miles of the western San Gabriel Mountains. Big Tujunga Flood-Control Reservoir (fig. 1) acts as catchment for 71 percent of the basin, but its capacity is small (3,819 acre-ft in 1966) in relation to its drainage area (81.4 sq mi). Large flows, such as those of January and February 1969, may pass the spillway only slightly attenuated.

The area is one of normally erosion-resistant rocks which, because of geologically recent faulting and fracturing, supply large quantities of debris to drainage courses through processes of mass movement, as well as normal runoff-erosion mechanisms. Annual debris yields to Big Tujunga Reservoir, in 39 seasons (1930–31 to and including 1968–69), have averaged 2,500 cu yd per sq mi per yr (cubic yards per square mile per year), or 1.56 acre-ft per sq mi per yr. Debris inflow between October 1966 and March 1969 was 7,550 cu yd per sq mi per yr, or 4.68 acre-ft per sq mi per yr. Most of the debris represented by the 1966–69 figure was deposited during the 1969 storms.

Geologically recent uplift of the basin is indicated by steep, dissected slopes, which average 40 percent throughout the watershed, and convexity in parts of the stream profile (fig. 2). Other explanations of a convex profile are possible, but the nearness of a convexity to the range front suggests that change of base level by uplift relative to the San Fernando Valley is the most probable cause. The rift zone of the San Gabriel fault, a major lateral-slip fault with many miles of displacement, controls the stream-channel

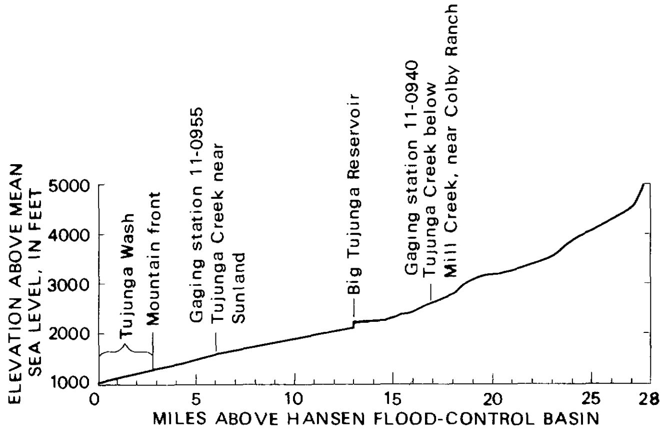

FIGURE 2.—Longitudinal profile of Tujunga Creek.

alinement in the northwest-southwest reaches upstream from the gaging station, Tujunga Creek near Sunland. Relative uplift of the upper part of the basin may have been accompanied by lateral movement on this fault. The continuing nature of tectonic activity in the watershed was illustrated by the major earthquake of February 9, 1971, during which as much as 4 feet of vertical displacement occurred along a faultline of thrusting at the north side of Tujunga Wash.

Basin relief is more than 5,000 feet, ranging from elevations of 7,124 feet at the summit of Pacifico Mountain to 1,290 feet where Tujunga Creek leaves the mountain front and enters Tujunga Wash. Valleys are V-shaped, except for parts of the main channel in which bedrock constrictions have acted as natural debris dams to form flat areas of alluviation. The average slope of the main channel over most of its 25-mile course is 135 feet per mile.

Hillslopes throughout the basin are covered with a dwarf forest of chaparral, an association of xerophytic shrubs and stunted tree forms that reflect the semiarid, Mediterranean climatic pattern—one of summer drought and winter rains. Such vegetation is highly inflammable during the dry season. Loss of watershed cover by fire can greatly increase runoff and erosion in the basin, but this was not a factor in 1969.

CHARACTERISTICS OF TUJUNGA WASH

Downstream from the mountain canyon Tujunga Creek enters a reach, Tujunga Wash, which can best be described as a fanhead valley (fig. 3). The contrast with the mountain canyon is sharp. When viewed from the air, the wash appears as a sinuous white ribbon of coarse alluvium poured from the mountain front, and is the most striking physiographic feature in San Fernando Valley. The wash forms the floor of Tujunga Valley and is 3 miles long and half a mile wide in the interval before surface flows reach the spillway eleva-

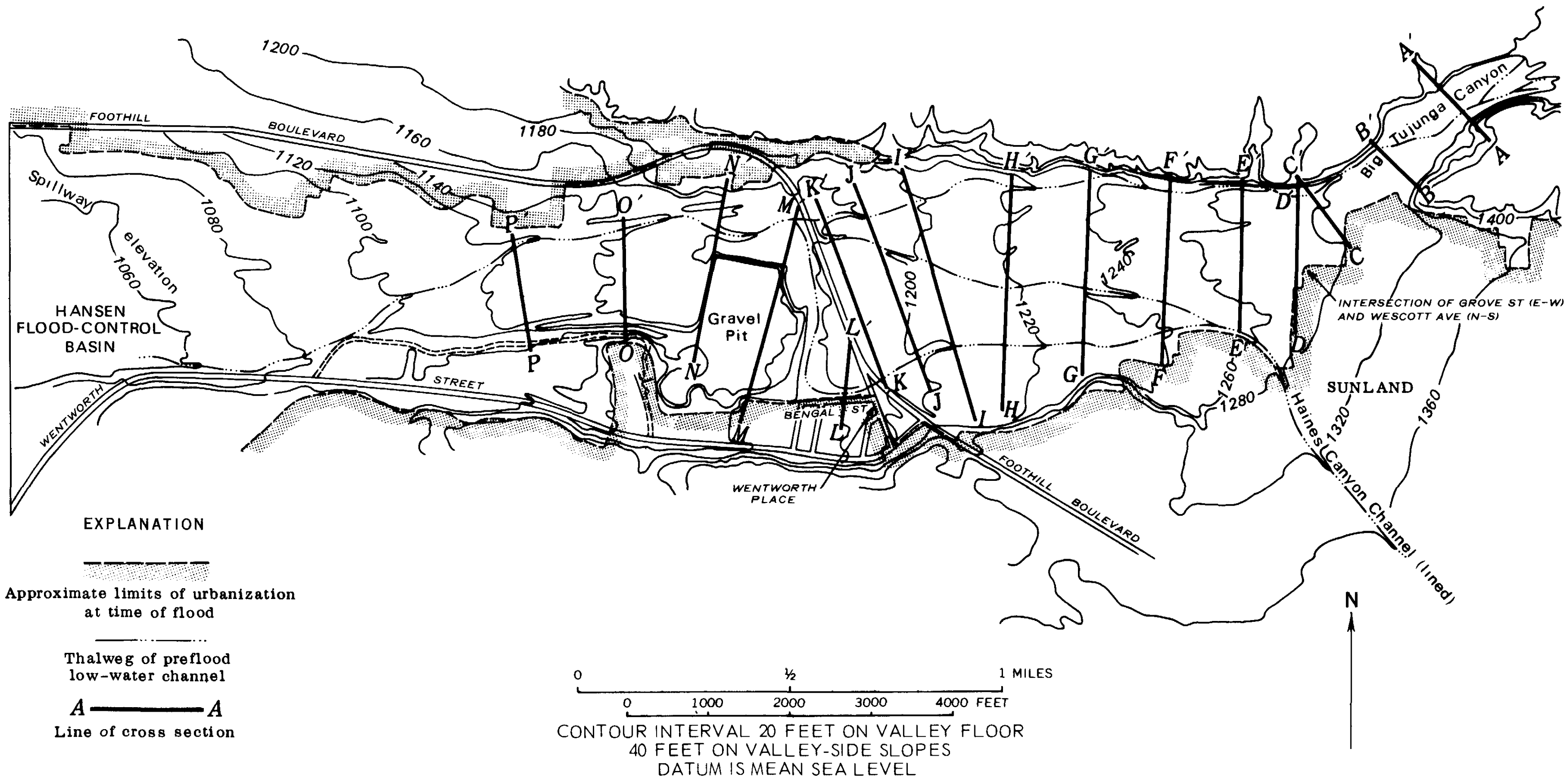

FIGURE 3.—Limits of urbanization and location of cross sections of channels in Tujunga Wash. Cross sections are shown in figures 6, 7, 9, 10, 11, 13, 15, and 16. Topography is from U.S. Geological Survey 1:24,000 quadrangle map (Sunland quadrangle) and is not comparable with elevation data used to plot the cross sections.

tion of the Hansen Flood-Control Basin. It was in this reach that large quantities of scour and fill occurred, and along which property damage was most severe.

Tujunga Wash is a complex of active and abandoned channels. It resembles an alluvial fan in that it likewise is an alluvial fill formed by deposition from a stream whose competence is suddenly reduced as it leaves the confining reaches of its mountain course. Rather than an abrupt change in slope of the channel where it meets the fan apex, it is the change in hydraulic factors associated with flow through noncohesive materials— an increase in width and a decrease in depth of flow— that generally causes deposition of debris on fans and in fanhead valleys such as Tujunga Wash. Infiltration of flow in permeable valley deposits is an additional factor which causes the concentration of deposition in fan-shaped loci at mountain fronts.

The stream channel of Tujunga Wash in an unmodified state is free to migrate laterally through bed material of boulder gravel, but only floodflows have the competence to transport material of that size. The main active channel on the north side of the wash (fig. 3) has a nearly constant slope marked by small irregularities, both natural and man-made. A second, historically less-active, major channel branches from the main channel at the mountain front and runs along the south side of the wash. As on an alluvial fan or delta, the tendency is one of formation of distributaries at the point where flow leaves the mountain front, but in Tujunga Wash this tendency is restricted by the bedrock side slopes of Tujunga Valley.

The channels, though typical of ephemeral desert washes, do not readily fit the systems of channel nomenclature that were developed in humid regions. Channel patterns include a spectrum of types, depending on flow regime. At low flow each sand-floored distributary meanders in a bar-braided pattern with low sinuosity (less than 1.3) within its individual wash. Little lateral cutting of the boulder-gravel banks takes place. Pools and riffles are not well defined by bed relief. Features possibly analogous to riffles appear during periods of no flow as concentrations of boulders spaced at regular intervals along the channel (Leopold, Emmett, and Myrick, 1966, p. 207); similarly, features that may correspond to pools are seen as sand-covered reaches underlain by gravel apparently less coarse than that in the riffles. At high discharges (fig. 4), flow fills the main drainage courses, and the flow pattern becomes complexly braided with multiple bars. Rapid lateral shift of individual channels is common, although, during the floodflows of 1969, this occurred within the confines of the two large-scale braided channels discussed above.

TERRACE LEVELS OF TUJUNGA WASH

The most widespread of the depositional surfaces in Tujunga Valley is the central floor of Tujunga Wash into which the present natural channels have been entrenched, to a preflood depth of 8–10 feet near the Foothill Boulevard crossing. This surface is similar to that of undissected alluvial fans elsewhere in southern California—undulating, broadly convex upward in lateral profile, covered with mature desert vegetation. It is the most conspicuous surface on each side of the valley and is that upon which urbanization has encroached most extensively. The preflood location of the destroyed Bengal Street (fig. 3) was on this surface.

Other terraces observed were a level sporadically present 7–8 feet above the channel on the south side of the wash, and two higher levels, one 10–15 feet and another 70–90 feet above the natural channel along the north side of Tujunga Valley. The lower of the latter two levels has been extensively urbanized; the higher is an old surface, also aggradational, grading to a former, higher level of valley fill.

BED MATERIAL OF TUJUNGA WASH

The gravel underlying the most widespread surface of the wash is similar in all sedimentological respects to the bed material of the channels. There was no significant difference in the size distributions of four samples of material underlying the main surface and five samples of bed material from the active channels. All samples were boulder gravel of bimodal distribution with the primary mode in the phi-classes −6.0 to −7.0 (64–128 mm) or −7.0 to −8.0 (128–256 mm).[1] Mean size of the samples ranged from phi values of −5.3 to −6.6 (40–100 mm). Sorting, nearly equivalent to standard deviation of the size distribution, was between 1.8 and 2.5 phi units, ranges commonly characterized as poorly sorted.

It is clear, considering the similarity in size distributions, that all the deposits exposed within the wash were formed under the present, or a similar, hydrologic regime. The significance of this conclusion is that there is no basis for assuming that any part of the main depositional surface of Tujunga Wash, because of greater coarseness of material, is immune to destruction by lateral shift of the channels. As noted above, it was this main depositional surface upon which new urbanization was progressing most rapidly prior to the 1969 flooding.

SCOUR AND FILL

Scour as discussed in this report is the removal of sediment from the channel and overbank areas of a stream by the action of fluid flow, virtually the defi-

[1] The phi (ϕ) grade scale may be compared with size in millimeters by the relation, mm = $\frac{1}{2}^{\phi}$.

FIGURE 4.—Looking upstream along the south channel of Tujunga Wash to the point where the floodflow of February 25, 1969, branched near the head of the wash. The lined channel from Haines Canyon is visible in the foreground. Wescott Avenue is seen from lower right to upper center where its intersection with Grove Street, upper right, is inundated. Photograph by Harold Morby, Golden West Broadcasters.

nition of Culbertson, Young, and Brice (1967, p. 1). Conversely, fill is the deposition of material on bed or banks.

The connotation of scour is related to the method of measurement. For example, scour recorded by scour chains or ribbons buried vertically in a bed is the maximum depth of dilation of the grain bed during a flood. The net amount of scour, determined from preflood and postflood surveys of Tujunga Wash, is not the maximum depth of scour that existed in much of the wash during passage of the 1969 flood peaks. However, the large magnitude of channel changes in Tujunga Wash as well as the extreme coarseness of the bed material precluded study with scour chains. Values of scour and fill as measured by means of preflood and postflood surveys are the net subtraction or addition, respectively, of sediment on the valley floor.

The following summary of the causes of scour and fill is not comprehensive but includes the dominant processes that account for most scour and fill in ephemeral streams. It describes those processes most active in fanhead valleys and on alluvial fans.

FACTORS THAT INFLUENCE SCOUR AND FILL IN FANHEAD VALLEYS AND ON ALLUVIAL FANS

CHANGES IN WATER DISCHARGE AND SEDIMENT LOAD

The flow of water and sediment in alluvial channels is complex and involves the mutual adjustment of a number of variables—water discharge, sediment discharge, size of bed material, the fall velocity of a characteristic sediment particle, width, depth, velocity, slope, and a characteristic of the pattern of streamflow (Maddock, 1969).

The adjustment of channels to changes in flow variables can be partly illustrated by the channel changes that accompany the passage of a flood. Width, mean depth, and mean velocity each increase as power functions with increasing discharge at a cross section, part of the set of relations described as the hydraulic geometry of channels by Leopold and Maddock (1953). Shear stress on the bed increases, and sediment is scoured. If a large debris load is introduced on the rising stage, however, deposition may occur, associated with a decrease in flow resistance, or roughness, a change in bed form, and a reduction in depth. On the falling stage, competence of the flow to transport sediment is reduced, and fill generally occurs, most commonly back to the same or a similar level as that which existed before the flood. Similarly, temporary episodes of scour, also related to changes in debris load, and contrary to the trend toward fill, are possible on the falling stage.

Few studies have been able to define the variation in scour and fill due to change in flow factors longitudinally along a stream. In general, the ephemeral channels of semiarid areas have been found to scour temporarily during floods (Leopold, Wolman, and Miller, 1964, p. 235). Lane and Borland (1954) concluded, from sediment yield to a reservoir, that the substantial scour in a few cross sections must be balanced by fill elsewhere in the same section of channel. Studies of perennial streams in humid areas suggest that scour and fill alternate in certain reaches.

MOVEMENT OF BED FORMS AND DEBRIS FLOWS

Large-scale gravel waves representing either dune forms or the snouts of debris flows were associated with 1969 flood discharges in other canyons along the front of the San Gabriel Mountains. Cessation in movement of concentrations of gravel formed by either process caused substantial quantities of fill at points along some expanding reaches. In Tujunga Wash and other large drainages the receding stages of water discharge were sufficiently prolonged to destroy dune forms characteristic of a high flow regime.

No gravel dunes or debris-flow snouts were visible during field inspection of all reaches of Tujunga Wash. Dune movement doubtless occurred during the peak flows, however, and caused small, temporary quantities of scour and fill.

LATERAL SHIFT OF CHANNEL

The position of the type of channel found on alluvial fans may change either by sudden redirection, or jump, of the flow, such as when distributaries form at the fan apex, or by the lateral migration of a single channel that will occur under constant flow conditions in most channels formed in noncohesive materials. In truly braided flow, the multiple channels are subject to continuous shift and splitting. Much the same mechanism is responsible for the major changes in direction that occur at the apex of a fan or fanhead valley when the bedrock-confined flow first enters an environment where flow is unconfined and bed material is noncohesive. Fahnestock (1959) illustrated the manner in which braided streams flowing through glacial-outwash debris change their channels: As flow increases the channel widens and in some places depth decreases, until competency is not sufficient to transport bed material; a bar is then formed, commonly near the middle of the channel, and flow divides into two channels. This process is repeated as flow increases and the channels anastomose in the constantly changing pattern characteristic of braided flow. Figure 4 shows the major division of flow that occurred near the apex of Tujunga Valley, top-center part of photograph, and the anastomosing of braided flow in the south channel, left of center.

The thalweg of alluvial channels may undergo lateral shift without a similar shift in overall channel position. In humid-region streams, this shift commonly is temporary during high discharges. In ephemeral washes, the changes are greater and are more likely to survive the runoff event.

CHANGE IN CHANNEL SLOPE

A major channel shift in a fanhead valley or on an alluvial fan is commonly associated with a change in slope. Diversion of the channel at a fan apex is generally to a radial path with a steeper slope, temporarily increasing the ability of the stream to scour. However, over a longer interval, deposition will build on the new segment of the fan until another channel shift occurs along a path of greater slope. It is this occasional shifting of the watercourse and the locus of deposition at the fan apex that gives the alluvial fan its symmetrical, conical form. Such change is a natural, expectable phenomenon.

CHANGE IN BASE LEVEL

The level of the body of water into which a stream flows, its base level, affects the gradient of the stream channel. If the base level of a stream changes, scour or fill is induced in the channel upstream from the new base level.

If a new and higher base level is introduced, by construction of a dam, for example, fill will occur throughout a length of the upstream reach. The distance to which fill will extend in such a case cannot be well defined and varies for different types of streams; Leopold, Wolman, and Miller (1964, table 7-6) reviewed a number of case histories. In general, introduced base levels affect only limited sections of upstream reaches. A similar, unknown degree of fill could be expected to have occurred in Tujunga Wash above the Hansen Flood-Control Basin (fig. 1).

A reduction in base level, on the other hand, will increase the erosive ability of a stream through increase in gradient. A steep headcut formed at the point of lowered base level may move upstream, commonly flattening with time and extending the increase in slope over a greater length of channel. Such a lowered base level occurred in Tujunga Wash when floodflows from both main channels poured into a large gravel pit (fig. 3).

TECTONIC EFFECTS AND LONG-TERM AGGRADATION OR DEGRADATION

If there is a trend toward fill lasting over a period of years, the change represents aggradation; if the change is one of net long-term scour, it is called degradation.

Plainly, the fan or fanhead valley itself is the site of net aggradation over geologic intervals at the same time the channels of the watershed that supply the sediment to the fan are being degraded. Periods of aggradation and degradation can affect channels in both geomorphic settings, however, generally because of climatic and human effects on the hydrologic regimen of the drainage basin. The trend of the changes at present is helpful in the practical considerations of scour and fill—bridge siting and design, lined-channel construction, allowance for sediment supply in the design of impoundments, to name a few.

In southern California the picture is complicated by tectonic changes—raising or lowering of the mountain masses relative to the depositional areas. Uplift, geologically recent and continuing at present in some areas, has greatly increased the sediment supply and rate of fan construction along the fronts of many ranges, including the San Gabriel Mountains. The effect is that of lowering the base level or locally increasing the slope of the stream channel within the mountains.

Yet another factor to consider in the interpretation of available data is the difference in effects on channels of a large floodflow as opposed to a period of low and moderate flows. A single catastrophic flood in California streams often has resulted in extensive fill in most areas (Stewart and LaMarche, 1967; Scott and Gravlee, 1968), followed by degradation during successive periods of lower flows if discharges remain sufficient to transport bed material deposited by the flood. Unfortunately, it is exceedingly difficult to generalize on this subject because of the other variables that affect scour and fill.

In few places is there more topographic diversity to affect the variables controlling scour and fill than in southern California. Consequently, it is not surprising that an unpublished survey of 1968–69 changes in streambed elevations at gaging stations in the region by R. P. Williams of the Geological Survey showed no significant overall trend toward either scour or fill. Study of Williams' data with reference to physiographic position of the gaging stations showed a probably significant trend toward aggradation in settings similar to Tujunga Wash.

Differences in long-term trends of scour and fill, that is, aggradation or degradation, on parts of the same river system in southern California are illustrated by the channel of the Santa Ana River prior to the construction of major dams. At the station Santa Ana River near Mentone, in a fanhead reach, fill occurred during, and for years previous to, the major flood of 1938. Downstream, at the station Santa Ana River near Prado, scour occurred progressively over the same period (Troxell and others, 1942, fig. 40). Firm conclusions obviously cannot be based on data from single stations. Every study of scour and fill based on cross sections at gaging station sites must note that such locations are likely to be unrepresentative of the stream as a whole. And, even though a trend toward scour or fill may be recorded at a particular section for years, there is no assurance that the trend will continue, or that it could not be reversed in the future.

More uniform results were presented by Hickey (1969) for gaging-station sites in coastal northern California, an area more humid and less physiographically diverse than southern California. Streambed-elevation changes at 42 of 51 sites represented fill in response to the 1964 flood, the largest of record at most stations in that region. No regional trends toward aggradation or degradation were evident from yearly measurements during the periods of record at the stations.

There can be little doubt, however, that trends toward both aggradation and degradation are occurring in streams in southern California. Regionally, the area shows evidence of what may be the same long-term alluviation noted by Leopold, Emmett, and Myrick (1966, p. 194) in the Southwest. Also, as in the Southwest, deposits of this period of alluviation are now undergoing dissection in southern California.

MANMADE CHANGES

Most of the above causes of scour and fill can be related to the works of man, and, as will be seen below, this was true of many of the channel changes in Tujunga Wash.

Not previously discussed were the effects of manmade obstacles, such as bridge piers and constrictions of the channel. Culbertson, Young, and Brice (1967) summarized the effects of construction of river structures on channels, generally those of humid regions, and the principles clearly extend to the ephemeral channels of semiarid areas.

A specific aspect is the effect of a dam on the downstream channel. One common effect of a reservoir is to reduce flood discharges, increase base flow, and, by trapping most sediment, cause the release of clear-water flows downstream. With the change in discharge and change in sediment load relative to discharge, the downstream channel is scoured and may change its cross-sectional configuration. Or, fill may occur in response to large sediment contributions from tributaries, increased vegetation due to reduction of peak discharges, or approximately uniform releases. The effects of Big Tujunga Flood-Control Reservoir (fig. 1) on the morphology of Tujunga Wash expectably are minor because of the small capacity of the reservoir and the channel distance between the dam and the mountain front that allows the sediment load of floodflows to readjust to discharge.

METHODS OF STUDY—PHOTOGRAMMETRIC DETERMINATION OF SCOUR AND FILL

A study of scour and fill in Tujunga Wash was possible because of the unique combination of large-magnitude channel changes and the availability of high-order photogrammetry. Preflood and postflood photogrammetry of nearly the entire reach of interest was included in four sets of maps: two derived from aerial photography before both floods and two from photography flown within a short time after the February flood.

The photography was flown on the following dates, and maps were constructed with the following scales and contour intervals:

Date of photography	Scale of map	Contour interval of map (feet)	Source
Preflood			
9–13–66	1 in. = 100 ft (1:1,200)	5	City of Los Angeles.
6–10–68	1 in. = 50 ft (1:600)	2	California Division of Highways.
Postflood			
3– 6–69	1 in. = 50 ft (1:600)	2	Do.
3–15–69	1 in. = 100 ft (1:1,200)	5	City of Los Angeles.

Dates on the cross-section lines in the following figures indicate the photography from which each was derived. Maps at the smaller scale (1:1,200) and larger contour interval (5 ft) covered the upstream end of the wash where changes from flood-induced scour and fill were relatively minor. Where scour and fill could be defined only by overlap of data at the two differing scales, the smaller scale was expanded computationally two times during the section-plotting process to match the larger scale. Fortunately, however, the area of greatest changes was covered by the larger scale maps. Because flow of sufficient competence to move boulder gravel did not occur between September 1966 and June 1968, it was assumed that the 1966 photography recorded conditions virtually constant through 1968. Both sets of photography define the configuration of Tujunga Wash at the start of the 1968–69 storm season.

TYPES AND ACCURACY OF PHOTOGRAMMETRIC MAPPING

Two types of mapping are common in highway-engineering practice in California—reconnaissance mapping and design mapping (Kulhan and Slavoj, 1969, p. 58–61). Both types may include extensive reaches of important channels, thus lending themselves to study of channel morphology, and both are illustrative of the techniques and accuracy available in photogrammetry which can be specifically applied to studies of channel morphology.

Reconnaissance mapping is primarily for route planning. Terrain factors control the combination of scales and contour intervals, which range from 1:1,200 to 1:4,800 and 5 to 20 feet, respectively.

Design maps commonly are prepared at a scale of 1:600 with a 2-foot contour interval and include spot elevations at locations where interpolation between contours will not give a correct elevation. Such maps are of an accuracy that permits their use in many cases as a substitute for a final location survey and as the basis for calculation of earthwork volumes. Katibah (1968) noted that maps of this scale commonly are plotted by the 5-diameter direct projection plotter and that, with this instrument, as relief increases, the practical mapping width possible with each photograph decreases in proportion to the total relief. If there is no relief, the practical mapping width is 1,500 feet, using a width of 6 inches on the photographs. With as much as 200 feet of relief, for example, a channel survey with photography at the design scale could be included in a single flight line with a practical mapping width of 1,300 feet.

Both types of maps conform to the National Map Accuracy Standards. The standards, among other requirements, state that 90 percent of all contours must be accurate to within one-half of the contour interval and that all shall be within one interval of their true elevation, except where terrain is hidden by brush. No less than 90 percent of the spot elevations should be within one-fourth of the contour interval from true elevation. In addition, present specifications for design maps in California state that the arithmetic mean shall not exceed:

± 0.40 foot for 20 points tested,

± 0.30 foot for 40 points tested, and

± 0.20 foot for 60 or more points tested.

Tolerances for the mean are based on a standard deviation of 0.60 foot and a 99 percent probability. Amounts of scour and fill measured in this report are based on differences in elevations of two maps with the above standards of accuracy. Although, as will be seen below, the accuracy of the maps used surpasses these standards, critical values of scour and fill are described as approximate, with the above error factors understood to apply.

Standards for horizontal control are rigorous to the point that horizontal-control error has less effect on accuracy of the data than does scale-change or section-plotting error.

CONSTRUCTION OF CROSS SECTIONS

Tujunga Wash was initially studied in the field to select representative sites. Cross sections then were located on the topographic maps, and individual points on cross sections were plotted at the map scale before reduction to publication size.

Emphasis in plotting was placed on accurate determination of slope inflections and thalweg depths; at such points, elevations were determined by graphical interpolation between contours and between spot elevations and contours. Points so located are marked on the sections as questionable. Other points on the cross sections that do not coincide with contour elevations and that are not marked as questionable indicate close proximity (at map scale) of section lines to spot elevations.

Finally, the cross-section locations were reexamined in the field to assess the degree of artificial modification of the channel that occurred in the short interval between the time of the floods and the postflood photography.

SCOUR AND FILL IN TUJUNGA WASH

Cross sections were located to show the most significant changes due to scour and fill, and to be representative of changes within each section of reach. Sites that would overemphasize the magnitude of local changes were avoided. Location of the sections had to conform to the overlap areas of the different sets of maps, and the selected sites utilize the maximum coverage. In the upper half of the wash, section lines are the grid lines of the California coordinate system. Flow in the rest of the wash was oblique to the coordinate system; sections located there were referenced to permanent structures or topographic features whenever possible. Coordinate-section line intersections are shown on the sections for reference in possible future studies.

Profiles showing change in elevation of the channel thalwegs (fig. 5) were constructed from the cross-section data to illustrate the longitudinal variation in scour and fill diagrammatically. Conclusions regarding the general behavior of ephemeral channels on alluvial fans will be based on these profiles following the description of the changes at individual sections.

Specific aspects of each preflood and postflood cross section are discussed in the following section.

SCOUR AND FILL PORTRAYED ON CROSS SECTIONS

SECTION *A–A′*

Little change that is not artificial is evident in section *A–A′* (fig. 6), in the confined channel within the mountain front. The fill indicated on the south bank (left bank in the cross sections) is a riprapped highway embankment. Scour or fill that might have occurred in the thalweg as a result of constriction of the natural channel by the highway embankment did not take place. The north bank (right bank in the cross sections) is bedrock. Close correspondence of photogrammetrically oriented points on this steep slope

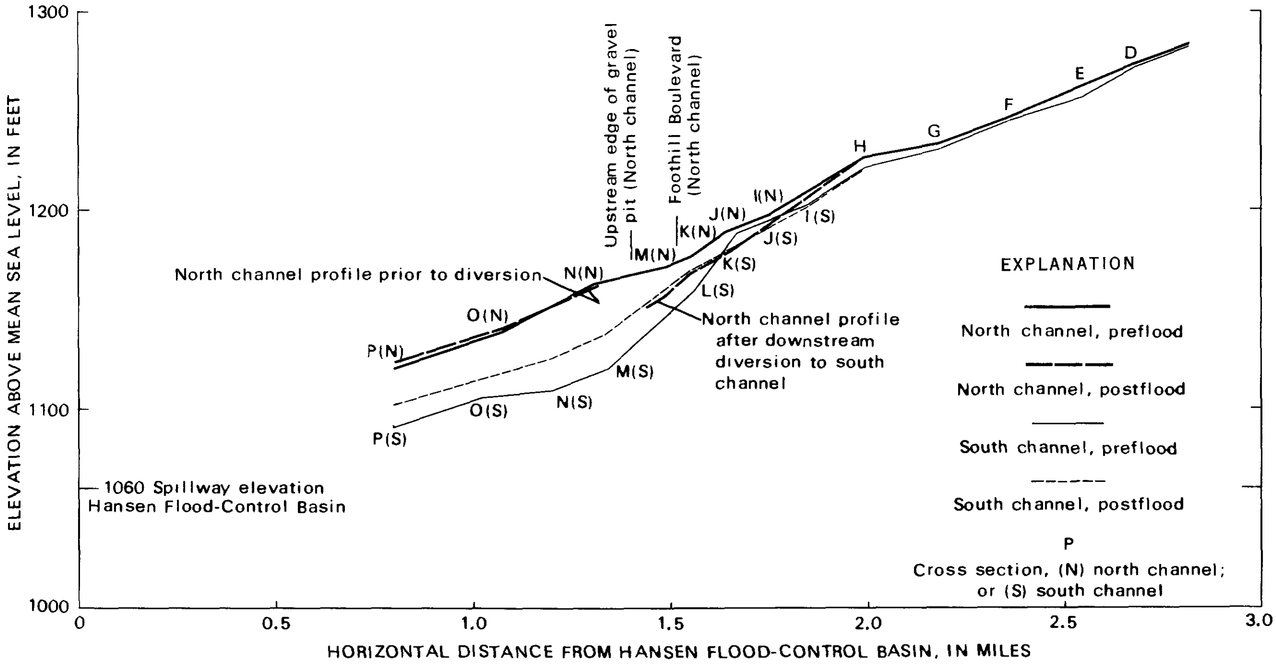

FIGURE 5.—Longitudinal profiles of the main channels of Tujunga Wash illustrating scour and fill.

testifies to the accuracy of the mapping from which the sections were constructed.

SECTION *B–B′*

Fill across the entire channel apparently occurred at site *B–B′* (fig. 6) and cannot definitely be ascribed to any one cause. The section is at the point Tujunga Creek leaves the mountain front and enters Tujunga Wash.

Downstream from this section, between the January and February storms, a causeway embankment was constructed in place of a private bridge destroyed by the flow of January 25. The bridge previously provided the sole access for about 200 residents living on the north side of Tujunga Valley. Culverts through the causeway were designed to transmit flows substantially larger than those of January, but in the early morning hours of February 25 the causeway acted as a temporary impoundment and failed, releasing a surge of unknown, but probably small, magnitude into the valley. The fill at section *B–B′* may represent debris trapped behind this temporary impoundment. Again, apparent fill on the left bank is a highway embankment.

SECTION *C–C′*

No significant change occurred at section *C–C′* (fig. 6), located just below the point where Tujunga Creek enters Tujunga Wash. Near this point, floodflows were split into two main channels, one on each side of the valley, and the beginning of the south channel can be seen in this cross section. Splitting of the main flow near the valley apex can be seen at the top center of figure 4.

Although splitting of the flow may have been influenced by the temporary causeway, the important point is that formation of single or multiple distributaries at the apex of the fanhead valley was a phenomenon to be expected under natural conditions. Preflood topographic maps reveal that the course of the south channel had a thalweg similar in elevation to that of the normal low-water channel adjacent to the north bank, and therefore virtually equivalent in its ability to capture flow under natural flood conditions. It can be seen in this section and downstream sections that the medial part of the wash actually had the highest elevation.

SECTION *D–D′*

The convex-upward shape of the floor of the wash is well illustrated in sections *D–D′* and *E–E′* (fig. 7), supporting the basic analogy of Tujunga Wash to an alluvial fan.

The left 500 feet of cross section *D–D′* corresponds closely with the rear property line of houses on the west side of Wescott Street (figs. 4, 8). The line of section *D–D′* is along the fence separating the houses on Wescott Avenue from the abandoned orchard shown in figure 4 and along the remnants of fence behind the inundated homes shown in the left-center part of figure 8.

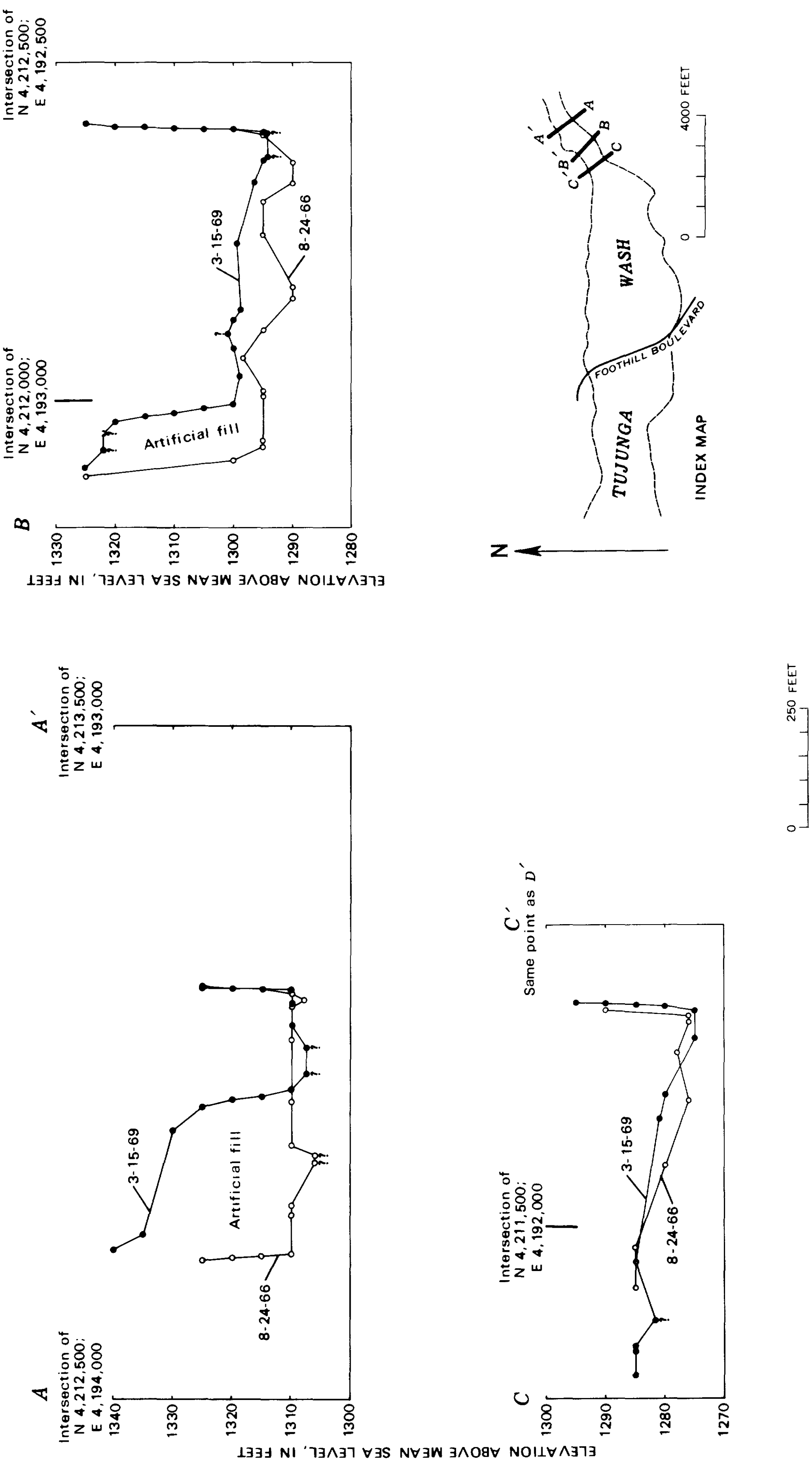

FIGURE 6.—Sections *A–A′*, *B–B′*, and *C–C′*. Locations of these and all following sections are shown in figure 3.

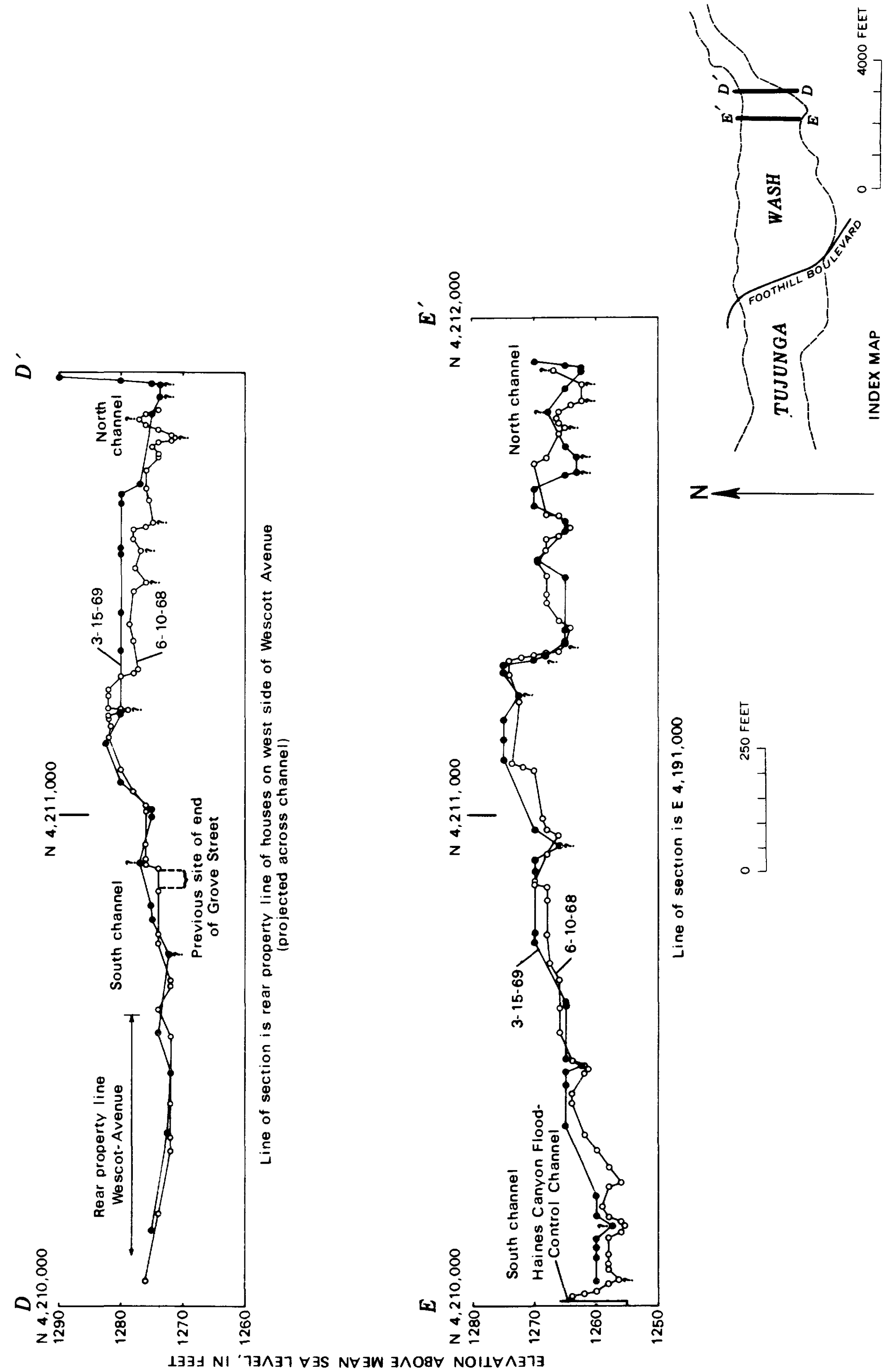

FIGURE 7.—Sections *D–D′* and *E–E′*.

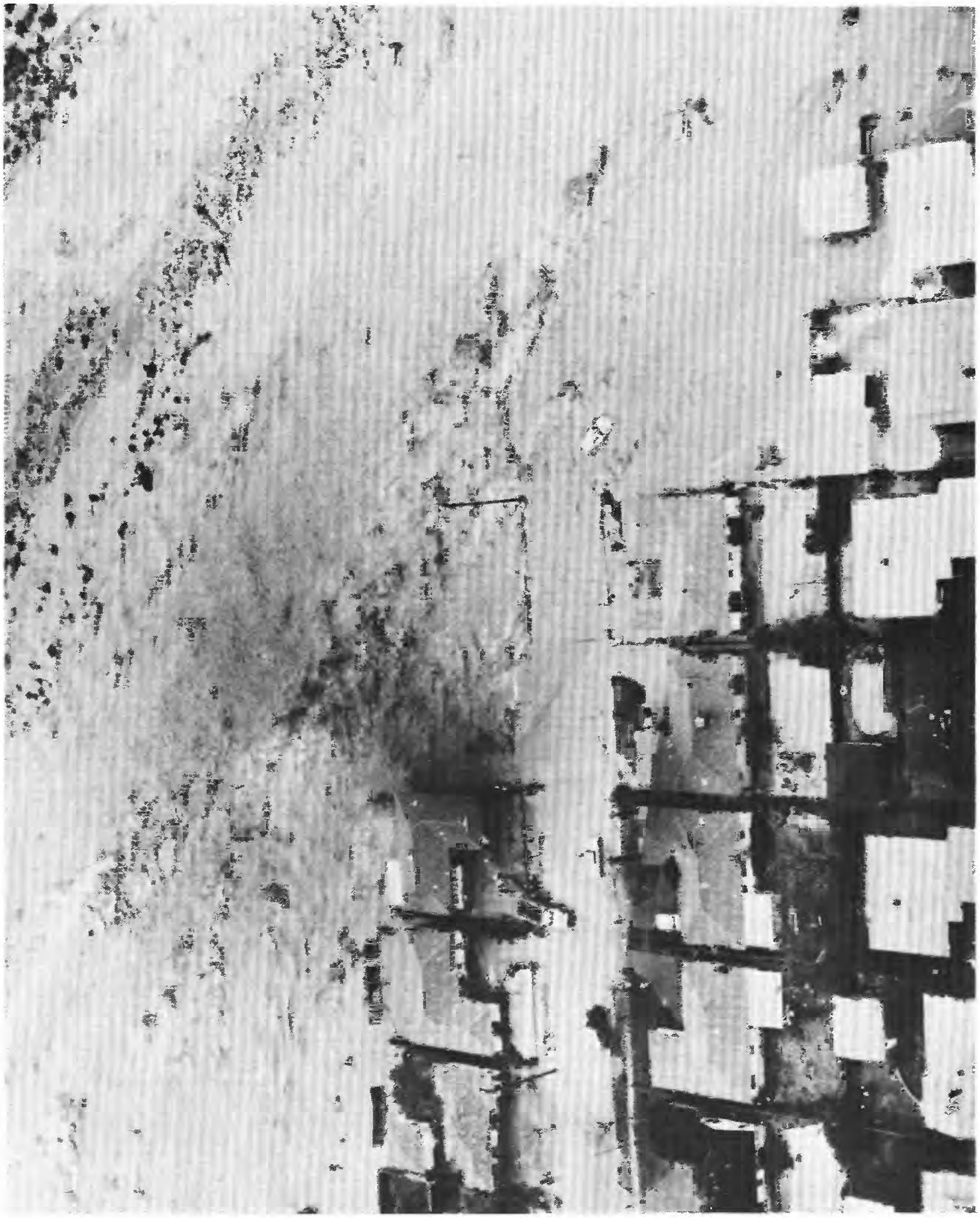

FIGURE 8.—Inundation along south channel of Tujunga Wash, February 25, 1969. Wescott Avenue is visible at left center. Grove Street is inundated along lower right side of photograph. Section *D–D'* profile is near rear fences of homes on far side of Wescott Avenue. Photograph by Harold Morby.

The west end of Grove Street was covered by flood-deposited sediment, shown as fill in section *D–D′*. At the time of the 1969 floods, urbanization, as represented by Grove Street, was spreading rapidly across the channel on the south side of the valley (figs. 4, 8). Fill shown in the vicinity of Grove Street on section *D–D′*, about 2 to 3 feet, is slightly less than that observed at nearby points in the field by means of buried automobiles and other debris.

Fill occurred in the north channel, but not to any significant degree.

SECTION *E–E′*

Little change is evident in section *E–E′* (fig. 7). The broadly convex-upward shape of the valley floor stands out plainly. Flow did not overtop the central part of the valley in this reach, and some of the differences in elevation in the central part of the valley more likely are due to bulldozing than to error in the method or in plotting, although error is a possibility. Poor correspondence of some elevations on this section is due to the fact that postflood control is less accurate, being derived from the 1:1,200-scale mapping.

The left bank in this reach is the outside of the concrete Haines Canyon Flood-Control Channel, which fortuitously diverted the south channel flows away from a highly urbanized part of the wash and stopped lateral scour that might have damaged many more homes.

Fill apparent in the south channel is natural and may reflect normal aggradation near the apex of a fan or fanhead valley.

SECTION *F–F′*

Fill near the left bank of section *F–F′* (fig. 9) is similar to that on section *E–E′* and can be ascribed to the same origin. Concomitant scour and fill, typical of the lateral migration of ephemeral channels, occurred in the north channel. Lateral scour was restricted there by the steep valley-side slope.

Surprisingly close correspondence of the preflood and postflood surveys in the middle section of the wash, which was not inundated, verifies the accuracy of the changes seen in the channels. Again, some of the small apparent differences are due to the difference in scale and level of accuracy between the preflood and postflood maps. Also, the connection of widely spaced control points with straight lines does not necessarily portray the actual shape of the section between control points.

SECTION *G–G′*

From section *G–G′* (fig. 9) and those preceding, it is clear that the south channel was a major natural drainage of the wash, having actually a lower thalweg elevation than the north channel in this section of the wash. It is not surprising, therefore, that a substantial part of the floodflow entered this channel in spite of levees intended to contain flow from Tujunga Creek in the north channel.

As in the upstream sections, there is evidence of fill in the south channel and shift in position of the north channel.

SECTION *H–H′*

At this point in Tujunga Wash (fig. 10), the pattern of fill in the south channel ceased. Section *H–H′* may be the possible upstream limit of the effects of locally reduced base level which occurred at a large gravel pit, 2,600–3,000 feet downstream.

Note the beginning of enlargement and an apparent slight deepening of the north channel.

SECTION *I–I′*

A pronounced increase in the amount of net vertical scour can be seen to have occurred in the north channel at section *I–I′* (fig. 10). The south channel also was deepened, and in both, the scour represented net removal of bed material from the cross section. There is little corresponding fill as was true in the simple lateral shift of a channel seen in sections *F–F′*, *G–G′*, and others upstream. These changes, in both channels, point incontestably to the effects of lowered base level further downstream.

SECTION *J–J′*

Net vertical scour of the thalweg increased to more than 10 feet in the north channel and to about 4 feet in the south channel at section *J–J′* (fig. 11). Again, there is little corresponding fill. The above figures probably approach the maximum amounts of scour that occurred at this point during peak flow because, in these oversteepened channels, scour may have continued on the receding stage of the flood. In other words, most of the scour that occurred at this section constituted net removal of bed material from the reach.

Minor gullying from local runoff in the central part of Tujunga Wash is detectable in this cross section. Section *J–J′* and all sections downstream are direct comparisons of design maps at the highest order of accuracy (contour interval: 2 ft).

SECTION *K–K′*

The section line of *K–K′* is parallel to Foothill Boulevard (fig. 3) and 150 feet upstream (fig. 11). Net scour that occurred at this section is representative, on the conservative side, of the net scour that took place at the two Foothill Boulevard bridges and the single span, downstream from Foothill Boulevard, of Wentworth Place (fig. 3). The large Foothill Boulevard bridge over the north channel did not fail during the

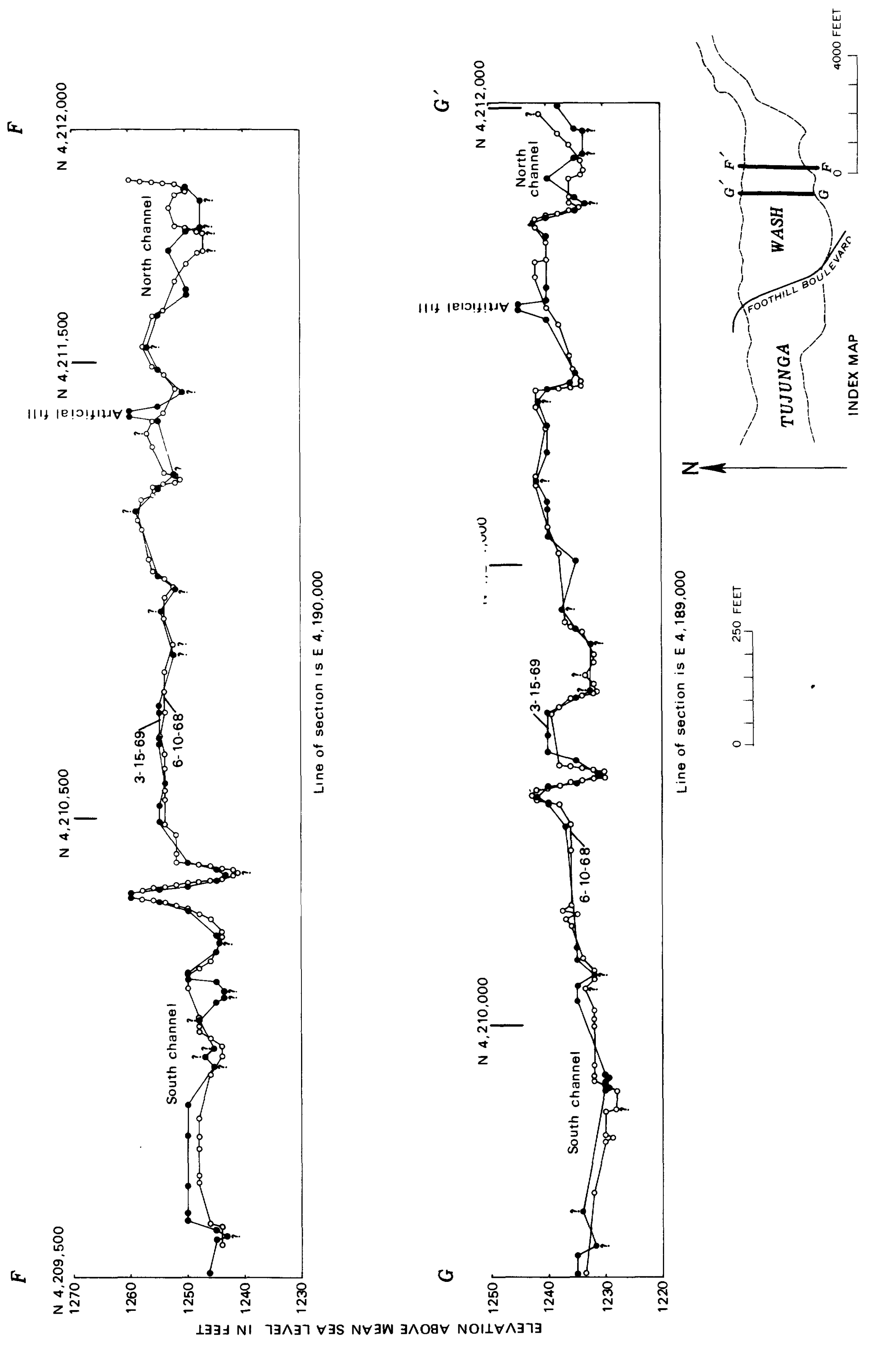

FIGURE 9.—Sections *F–F′* and *G–G′*.

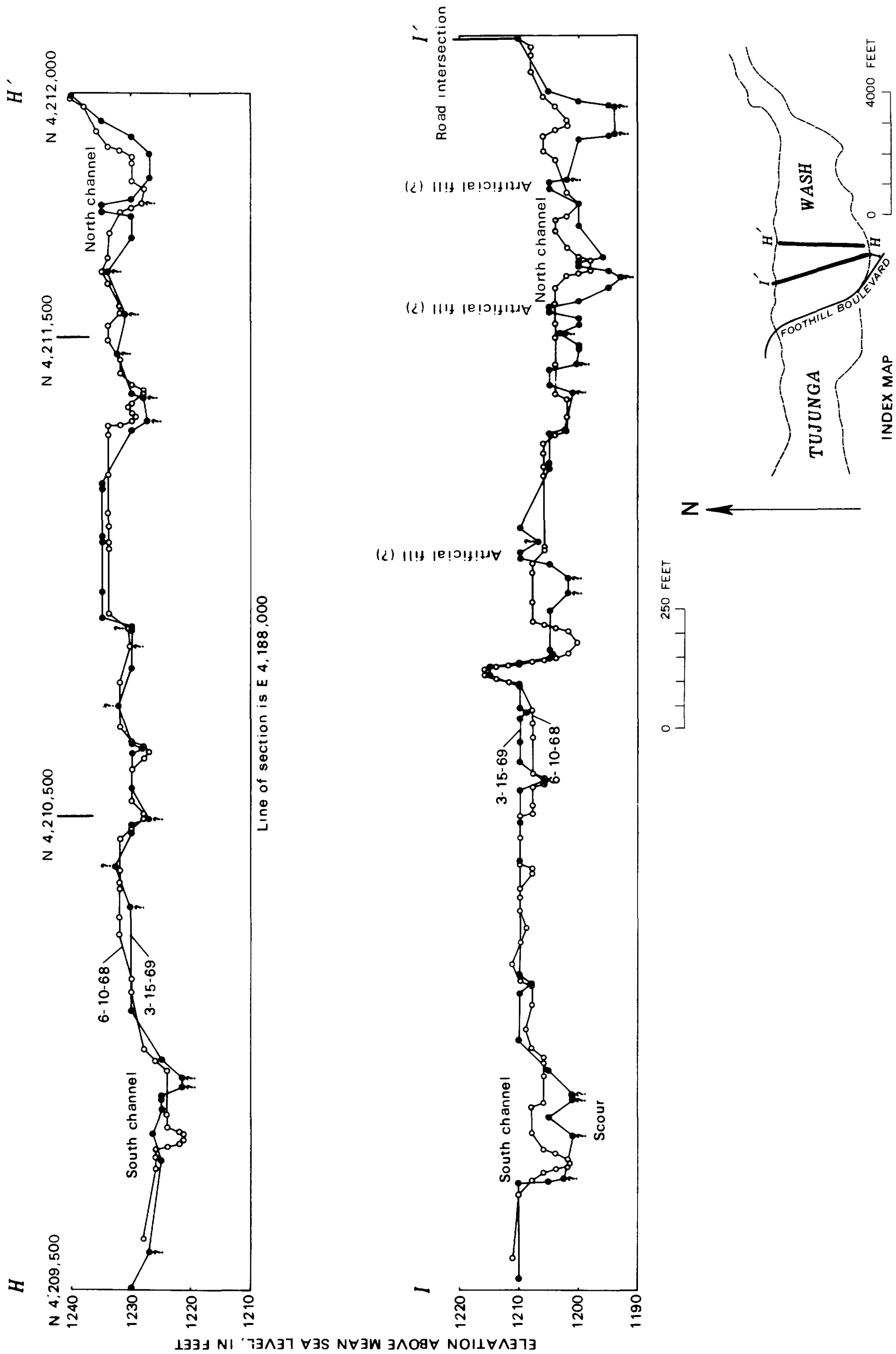

FIGURE 10.—Sections *H–H′* and *I–I′*.

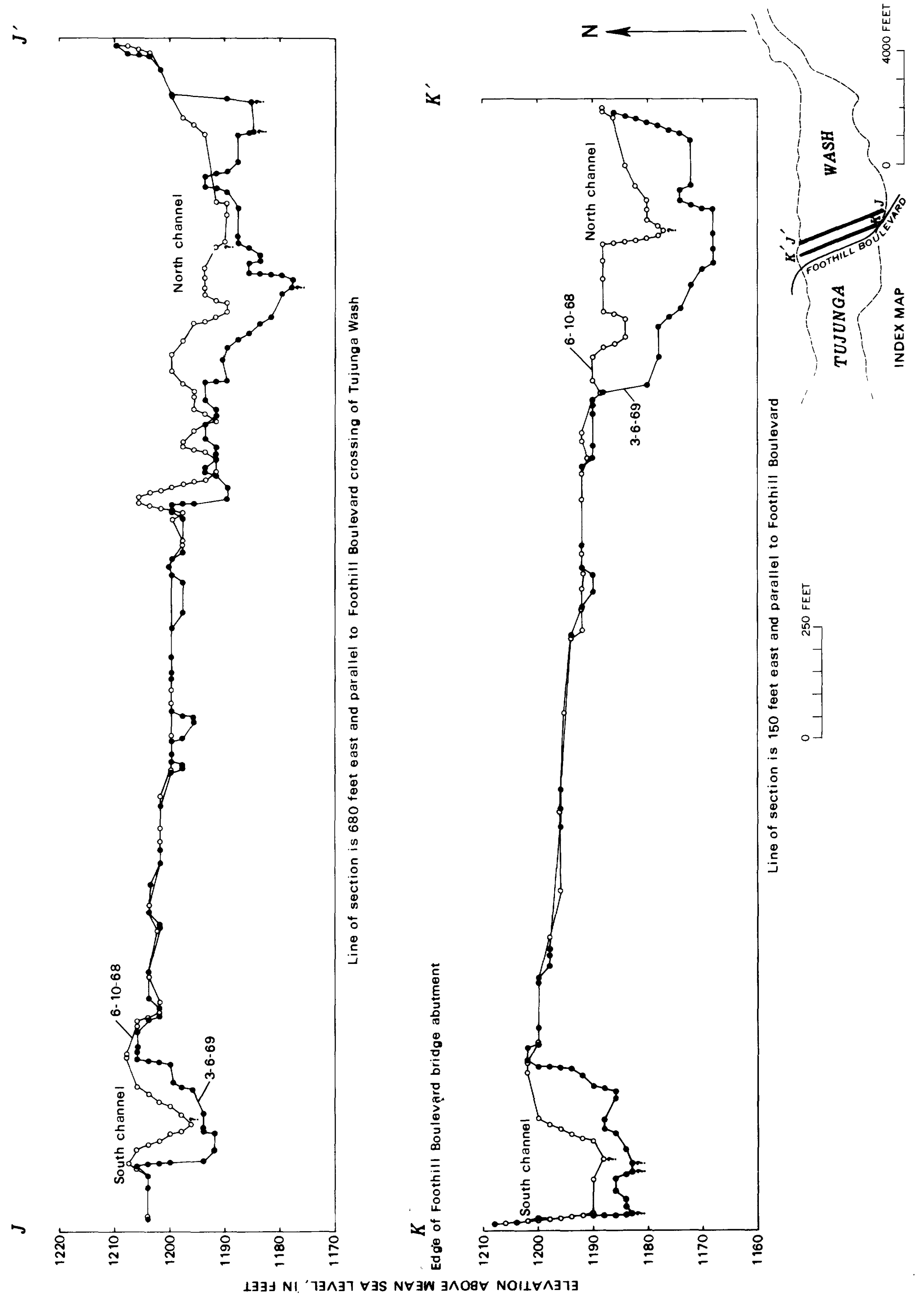

FIGURE 11.—Sections J–J′ and K–K′.

January flows, although the Los Angeles Fire Department reported erosion around pier supports and considerable vibration on the span. Failure of the structure, built in 1937, occurred during the peak February flow by scour around the piers.

It was surprising that the bridge stood as long and as well as it did. Net thalweg scour was about 9 feet in the north channel and 5 feet in the south channel at this section; these figures do not approach the maximum net scour that occurred at specific points in the section—about 20 feet in the north channel and 15 feet in the south channel. The large amounts of debris from both lateral and vertical scour were uncompensated by any significant degree of fill in either channel.

Figure 12 shows the south channel upstream from the Foothill Boulevard bridge. The incision of the main part of the south channel is clearly evident in the steep sides of the wash and the knickpoint and plunge pool formed where tributary flow, as shown at the bottom of the photograph, joins the larger channel.

The accuracy of the photogrammetry is such that minor gullying in the central part of the wash also is detectable in section *K–K′*.

SECTION *L–L′*

Only the south channel is shown in cross section *L–L′* (fig. 13) because of a gap in the photogrammetry. The line of section transects the Bengal Street terrace which, before the floods, was the site of middle-class suburban homes with lots extending to the edge of the terrace. Before the floods, the terrace level at this point was 8 feet above the south channel. Postflood, however, the remnant of the terrace is 19 feet above the bottom of the channel. Net vertical scour of about 11 feet took place in the channel thalweg during the 1969 floods at this site.

Of more practical concern was the lateral scour that removed 75 feet of the terrace at this line of section, including all of Bengal Street and seven of the homes that bordered Bengal Street. A comparable amount of scour occurred on the right bank of the south channel. Channel change at this site basically was one of incision and enlargement of the old channel without much tendency of the channel to shift laterally. The cause of the incision was the lowering of local base level which took place when flow entered the gravel pit a short distance downstream combined with adjustment of the channel configuration to the large flood discharge. That the scour at this site was primarily a function of the reduced base level, however, is proved by corresponding scour in the north channel and an increase in scour in both channels in a downstream direction.

Figure 14 shows the incision of the wash into the residential area and the remnant of the Bengal Street terrace early on the morning of February 25, shortly after most of the lateral scour had already taken place.

SECTION *M–M′*

Section *M–M′* (fig. 13) crosses the upstream end of the gravel pit into which both north and south channels flowed. Earthen embankments intended to channel flow around the pit were not effective, particularly in the south channel where flow was much greater than expected, primarily due to branching of the flow at at the valley apex.

Sand and gravel were mined sporadically at this site from 1925 until the mid-1960's when, after failure of the lessee to obtain appropriate zoning on additional acreage, the operation became inactive. Estimates by the landowner of the amount of debris added to the main pit were 200,000–300,000 tons for the January period and 2–3 million tons for the February storm, the latter figure presumably including the earlier total. Mining of the newly added debris began in 1969.

The cross section shows that about 20 feet of fill occurred uniformly across the bottom of the pit. The north channel, seen at the right end of the section, entered the pit a short distance downstream. About 14 feet of net vertical scour took place in the north-channel thalweg, and as much as 24 feet of scour occurred at a single point. The steepness of the north-channel thalweg, indicated here by its still considerable elevation above the pit bottom, suggests that erosion of channels upstream from the pit would have continued, had large discharges continued for a longer period of time.

SECTION *N–N′*

A greater quantity of fill, as much as 35 feet, is shown near the downstream end of the gravel pit in section *N–N′* (fig. 15). At this point, flows from both the north and the south channels had entered the pit and rejoined, the total flow then exiting through an old channel along the south side of the valley where desilting ponds had been constructed.

Visible on the right side of this section is the riprapped berm against which the main channel was apparently intended to be confined downstream from Foothill Boulevard. Construction of a small levee to confine the low-water channel against the riprapped berm can be seen near the right end of the section. The berm itself was undamaged by the floodwaters which, unfortunately, were diverted away from the berm through both natural and manmade causes.

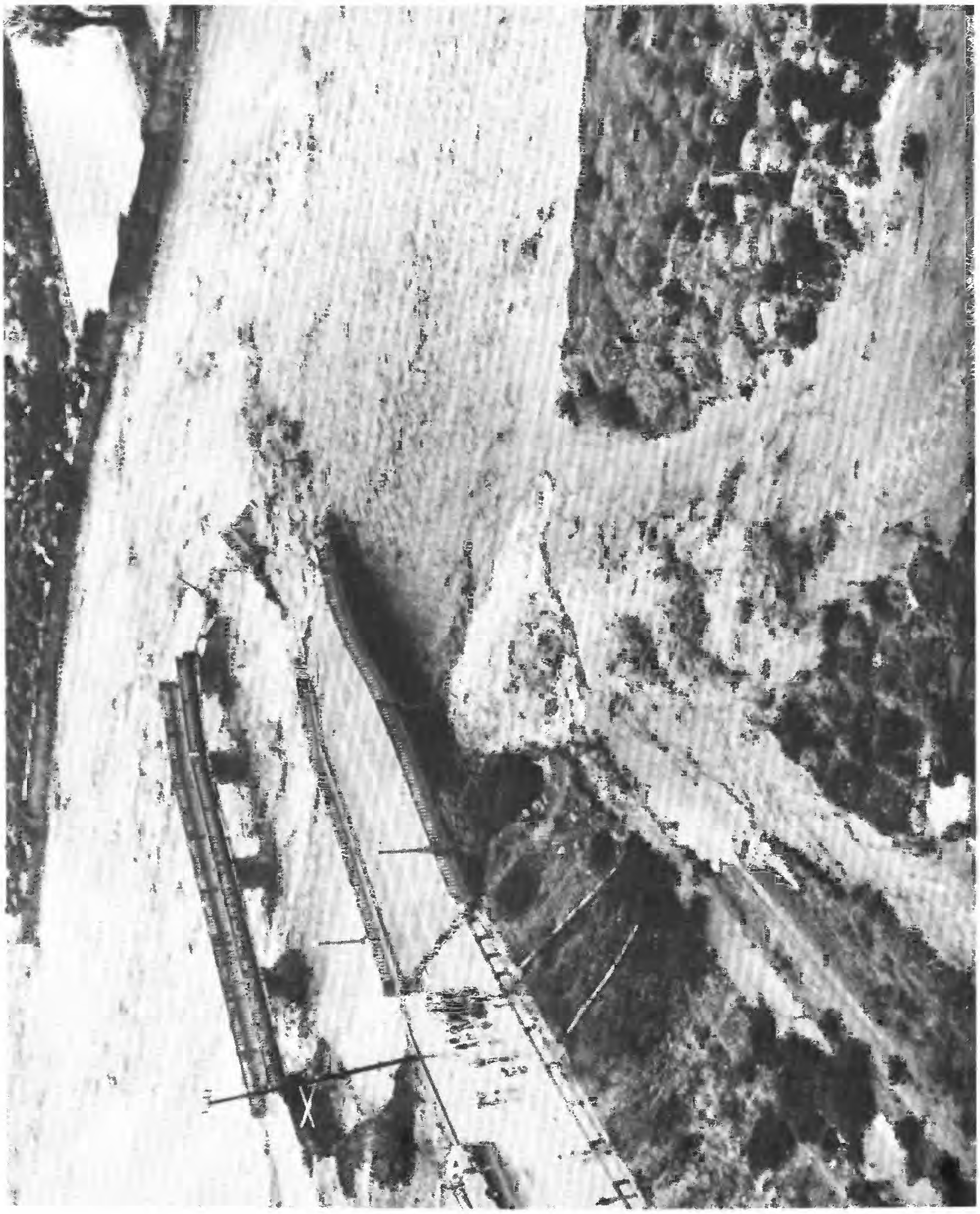

FIGURE 12.—South channel of Tujunga Wash showing destruction of the south-channel Foothill Boulevard bridge, upstream on the right, and the smaller Wentworth Place bridge. The left end of section K–K' is the embankment supporting the Foothill Boulevard bridge abutment, left of center. Photograph by Harold Morby.

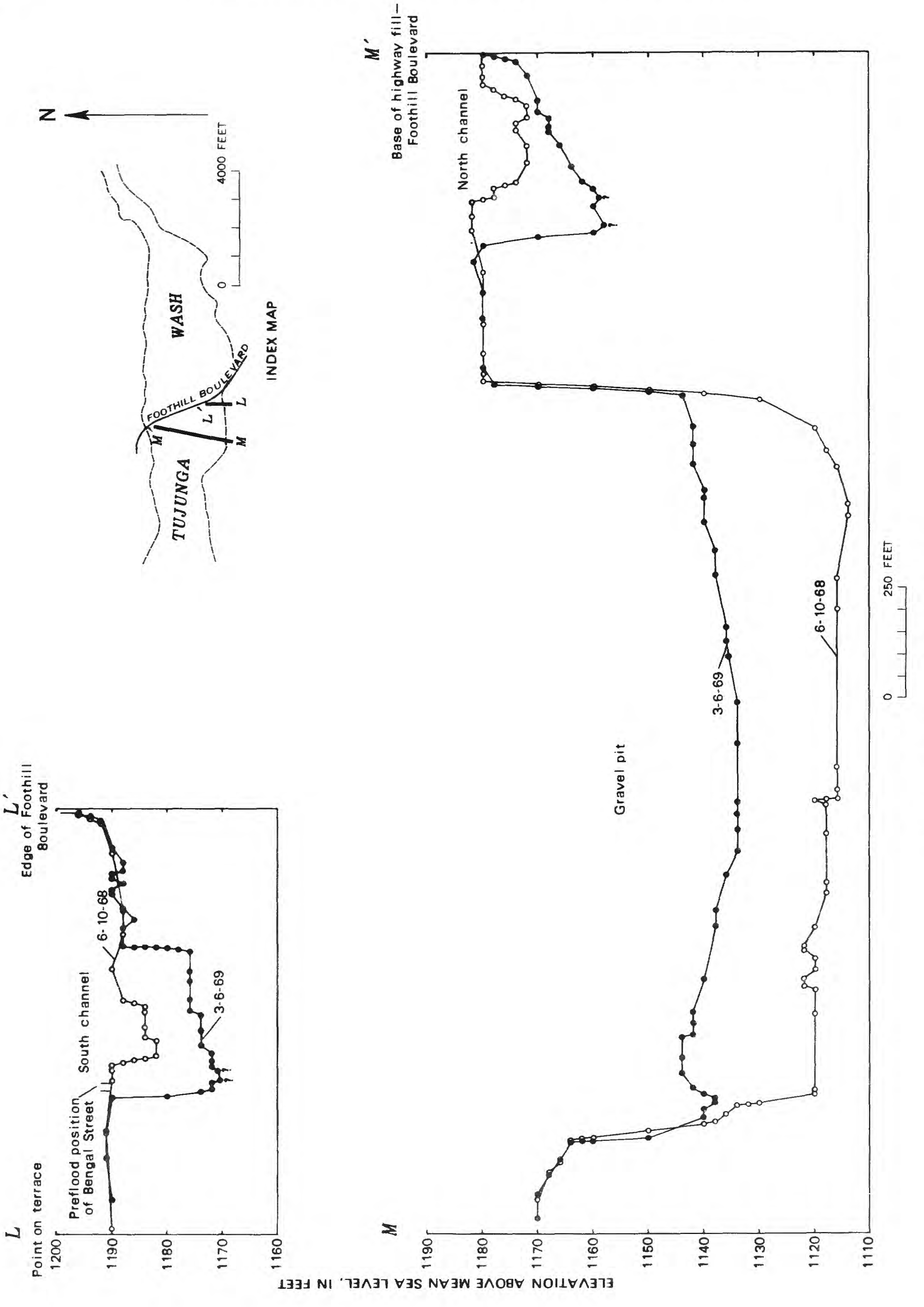

FIGURE 13.—Sections L–L′ and M–M′.

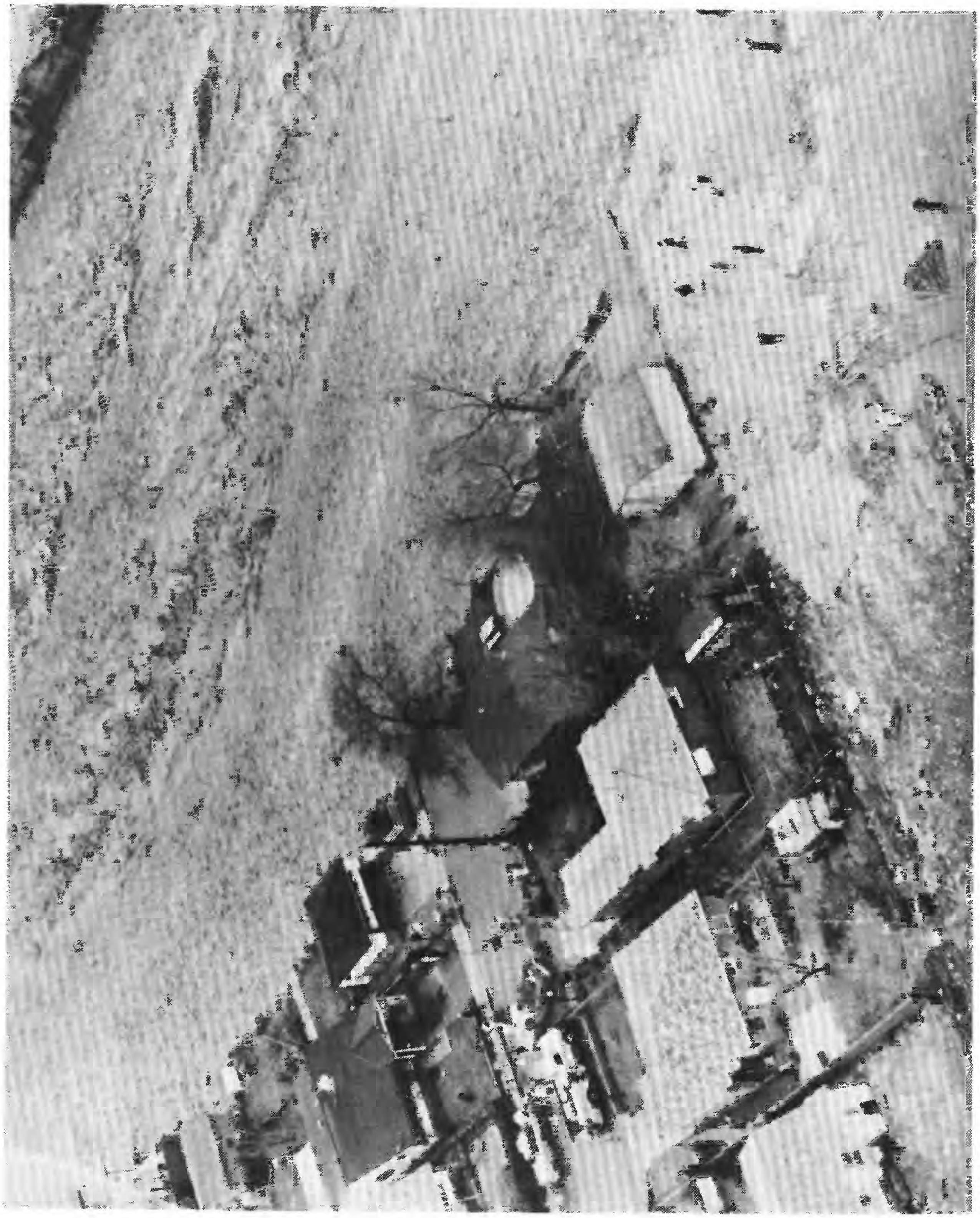

FIGURE 14.—View looking northwest of what remained of the Bengal Street terrace shortly after the February 25 flood peak. Bengal Street originally ran east-west (upper left to lower right in photograph) across the area now occupied by the south channel of Tujunga Wash and intersected the street shown at left center. Height of the cutbank at the edge of the terrace is 18 feet. Photograph by Harold Morby.

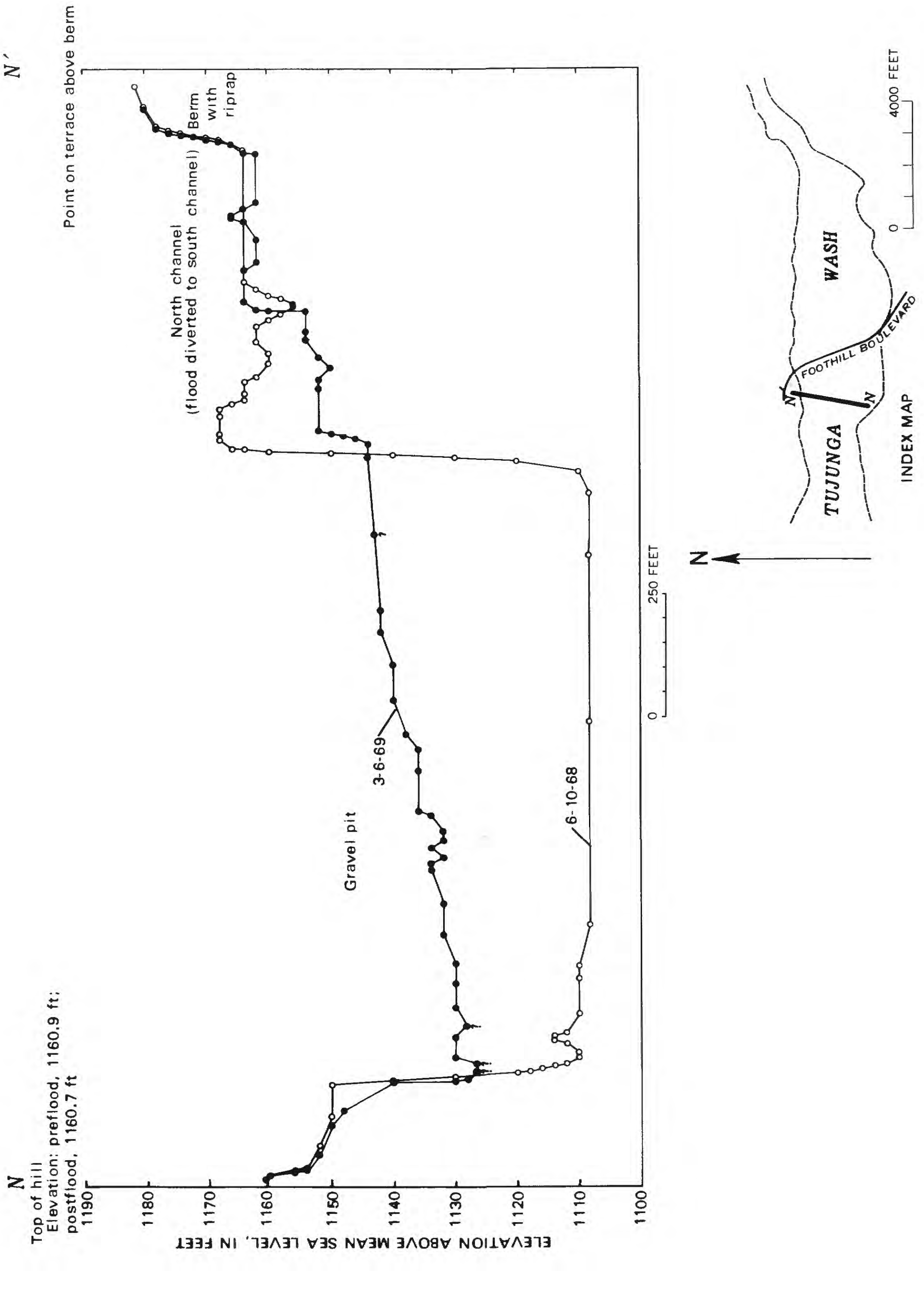

FIGURE 15.—Section N–N′.

SECTION *O–O′*

That most of the floodflow was in the south channel is readily apparent in cross section *O–O′* (fig. 16); little scour and fill occurred in the north channel during the period before flow entered the gravel pit upstream from this section. The scour that proceeded upstream from the pit edge captured all the subsequent floodflow in the north channel.

The most significant change in the south channel was one of fill—net vertical deposition in the thalweg of about 10 feet. The channel widened by some 60 feet to accommodate the unusually high discharge, but no marked net erosion of the main terrace level occurred. It is difficult to assign an exact cause to the thalweg fill that occurred at this point; upstream effects of the Hansen Flood-Control Basin, or deposition in the preflood channel which apparently was deepened to drain the gravel pit, are likely explanations.

Note the extremely close correspondence of the topography outside the flood channels.

SECTION *P–P′*

A similar quantity of fill—about 12 feet in the south-channel thalweg—occurred at section *P–P′* (fig. 16). About 3 feet of fill also occurred in the north-channel thalweg, lending support to the idea that channel fill here and at the preceding site was due in part to the backwater effects of the reservoir. The spillway elevation of the reservoir is reached 4,100 feet downstream from this section.

Not evident at this section line and undocumented by the photogrammetric coverage was a severe quantity of lateral erosion that occurred just downstream. There, south-channel flow was directed strongly against the bedrock wall of the canyon and removed a two-block section of Wentworth Street, previously a major, four-lane arterial highway. Similar destruction of Wentworth Street at the same locality occurred during the 1938 flood; this damage went unrepaired and Wentworth Street remained impassable until the early 1960′s.

SUMMARY AND CONCLUSIONS

Changes in the channels of Tujunga Wash and the resulting property damage caused by the 1969 floods were great because of both natural and manmade causes. The effects of man were significant, not necessarily because of incomplete flood-control measures, but because of man's failure to recognize the true character of the natural landscape—in this area, the fact that Tujunga Wash is similar in most respects to an alluvial fan and that its natural ephemeral channels can be expected to change dramatically during floods. The chief difference between Tujunga Wash and an alluvial fan is that the wash continues to be partly constricted by bedrock valley-side slopes for a considerable distance after surface flow leaves the mountain front. The practical significance of this difference is that flood effects, such as channel changes, are concentrated in a smaller radial segment, centered at the mountain front, than is typical of an alluvial fan.

Scour or fill due to a variety of specific causes occurred in Tujunga Wash. The causes included possible natural channel aggradation, lateral movement of distributaries, local decrease in base level, local increase in base level, and natural adjustment and shift of the channel in response to changes in flow parameters. However, several major changes in the channel and the resultant property damage serve as especially graphic examples of what can be expected to occur under similar conditions—the combination of a major flood and an urbanized alluvial fan. These major changes are summarized in the following sections.

FLOW DIVERTED TO DISTRIBUTARY CHANNEL

Although attempts had been made to contain all expected flow in the north channel of Tujunga Wash, a significant part (about one-half) of the flood discharge entered the south channel (figs. 4, 8; sections *C–C′*, *D–D′*, and *E–E′*). No judgment can be made as a result of this study as to whether or not the causeway created as an access road to the north side of Tujunga Valley was the cause of this diversion. A significant point, however, is that formation of distributaries at the apex of a fan or fanhead valley was a natural, expectable occurrence. Splitting of the February 1969 floodflow occurred where and when it likely would have done so under entirely natural conditions. The south channel was nearly as probable a natural flood course within Tujunga Wash as was the north channel.

The question as to why urbanization was allowed to proceed within the south channel (fig. 8) before completion of adequate flood-control measures is one that must be left to others. Damage along the south channel farther downstream (between sections *D–D′* and *F–F′*) would have been high were it not for the fortunate protection afforded by the concrete outlet channel from Haines Canyon.

VERTICAL SCOUR DUE TO LOCAL REDUCTION IN BASE LEVEL

The thalwegs of both north and south channels were scoured from the vicinity of section *H–H′* to the point where both channels entered the gravel pit west of Foothill Boulevard, a distance of 2,600–3,000 feet. The net vertical scour of the channel thalweg increased progressively downstream to about 14 feet in section *M–M′*.

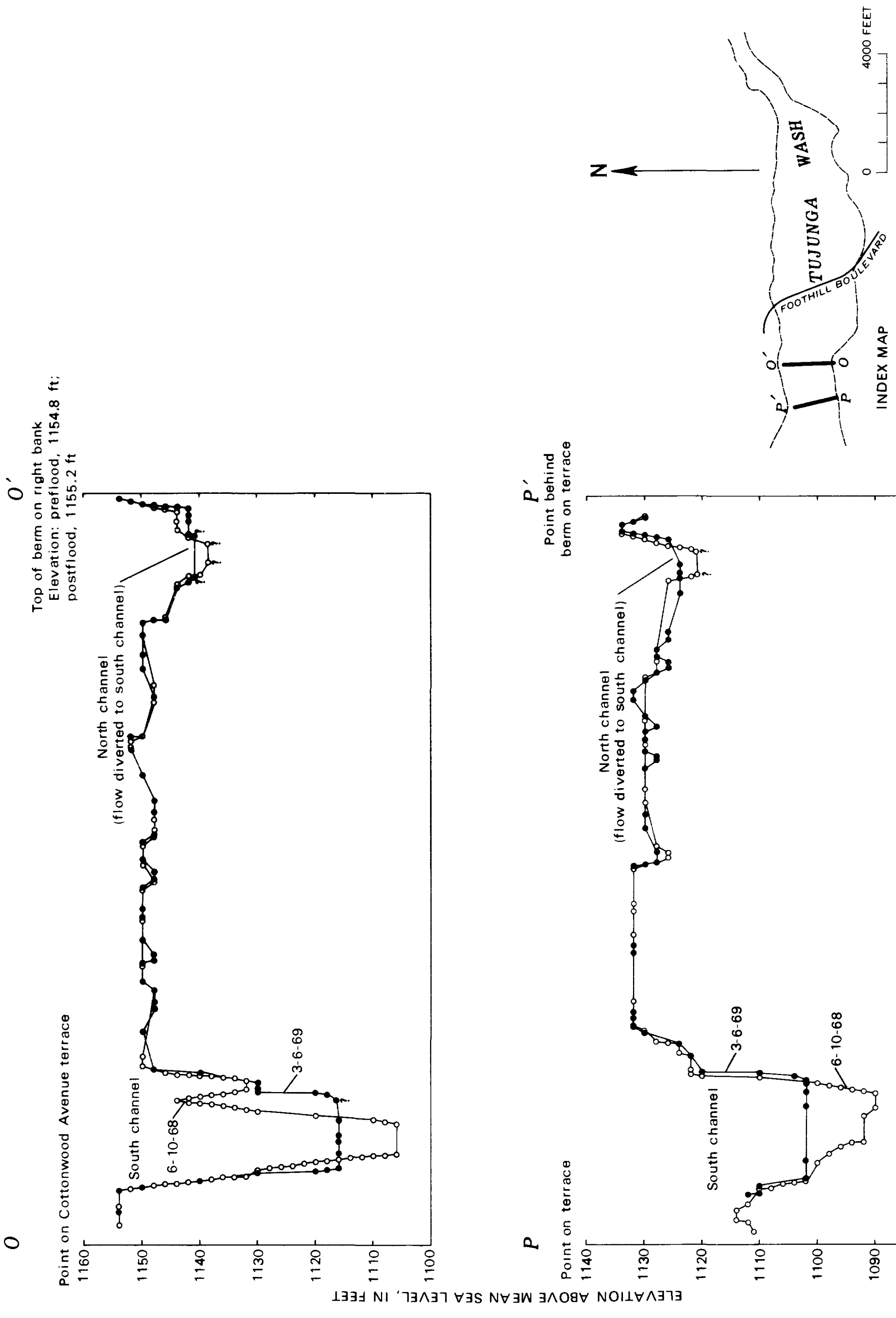

FIGURE 16.—Sections O–O′ and P–P′.

The vertical scour in this section of the channel was largely the direct result of the lowering of base level when flow broke through from each channel into the gravel pit. Scour then proceeded upstream and ceased in the oversteepened reaches only when flow was no longer competent to transport the bed material.

The failure of three bridges spanning this reach, two on Foothill Boulevard and one on Wentworth Place, was one result of the scour. This event emphasizes the need for hydrologic considerations in the issuance of future gravel-mining permits in streambeds without effective flood-control channels. Because sand and gravel constitute the most important inorganic mineral resource in southern California, plans for mining must be made in certain channels. Such planning could help forestall a potential shortage of aggregate as well as reduce the harmful effects of channel diversion and scour triggered by mining operations in active channels.

LATERAL SCOUR OF TERRACES

The most dramatic damage (fig. 14, section *L–L′*) was due to lateral scour of the main surface in Tujunga Wash. Bengal Street and seven homes bordering it disappeared shortly after 5:30 a.m. on February 25. Scour along the sides of the south channel removed 75 feet of land surface from the urbanized left bank and 125 feet from the right bank. This lateral scour was concomitant with net thalweg scour of 11 feet, caused basically by the change in base level discussed above. The effects of vertical scour combined with the lateral scour served to remove 18 feet of the land surface (net vertical scour) at the site of Bengal Street in section *L–L′*.

Basically what occurred in the south channel adjacent to the Bengal Street terrace was dimensional enlargement of the flooded channel cross section by a factor of two; shape and hydraulic parameters of the channel remained the same. The increased flow in the south channel was the result of the distribution of part of the flow from Big Tujunga Canyon at the apex of the wash combined with flow from Haines Canyon. A greater degree of impervious surface due to urbanization in the Haines Canyon drainage acted to increase peak discharge from that source which, however, was minor compared to flow within the wash. Generally, lateral change in the south channel was one of adjustment to the increased discharge. Added to this change was the increased scour due to reduced base level; this effect served to incise the channel and reduce its tendency toward lateral movement.

The equilibrium configuration toward which the stream with its lowered base level was tending is largely a matter of opinion, but it is probable that equilibrium would not have been attained even with continued high discharges for several days. Channel instability would probably have continued. What channel changes would have occurred with only the increased discharge, had not incision of the channel taken place, can only be surmised. Without the base-level effects of the gravel pit, thalweg scour of a lesser amount would have occurred and would have been in large part temporary during passage of the flood peaks. Lateral erosion locally would have been greater but also more subject to the vagaries of a constantly shifting, alluvial-fan drainage course; erosion of the Bengal Street terrace might have been greater or may not have occurred at all. Natural channel shift probably was the cause of the loss of Wentworth Street, downstream from the cross-section sites.

Once again, however, it is clear that the danger to homes on the terrace was evident before the flood from a consideration of the geomorphic setting of Tujunga Wash. Urbanization on the unstabilized cutbank of a natural flood channel on an alluvial fan or fanhead valley generally is a poor risk.

CHANGES IN LONGITUDINAL PROFILES

Inspection of figure 5 reveals some potentially significant conclusions regarding the general behavior of ephemeral channels on alluvial fans. Comparing preflood and postflood profiles downstream from where much of the flow left the north channel and entered the south channel, the point of fanhead jump, it is apparent that the diversion locally resulted in scour of the north channel that corresponded in amount with fill that occurred in the south channel. The correspondence is most notable in the reach from 1.7 to 1.4 miles above the spillway elevation of Hansen Flood-Control Basin (fig. 5). Not only was scour in the first channel matched by fill in the channel to which the fanhead jump occurred, but the postflood profiles of both channels became nearly parallel, after smoothing of pronounced preflood irregularities in the channel which were both natural and the result of the gravel pit and other works of man.

By analogy to a natural fan, the smoothing and similarity in gradient of the profiles may be functions in maintenance of a long-term trend toward equilibrium. Small floods or debris-flows and mudflows, both of the latter commonplace on many fans, may over the short term create distributary channels in the fanhead area with irregular profiles representing temporary inequilibrium. The preflood, largely manmade irregularities in Tujunga Wash may be considered analogous to these smaller, natural features. Thus, the jump of a major channel during a major flood, as seen in Tujunga Wash, will involve smoothing as well as steepening and through this action represents an essential mechanism by which the maintenance of an equilibrium is accomplished over geologic time.

It is probable that with sustained flow over a long period, this change in accord with long-term equilibrium would have been even more pronounced in Tujunga Wash, but,as noted above, the exact equilibrium profile is a matter of conjecture. In any event, the jump in flow from the north channel to the south channel at the apex of Tujunga Wash was a likely natural adjustment of the alluvial system.

PHOTOGRAMMETRIC METHODS APPLIED TO THE DETERMINATION OF SCOUR AND FILL

Photogrammetry of the order of that used for highway-design maps can be a valuable tool in the quantitative study of channel change. Comparison of four sets of design maps of Tujunga Wash, two compiled before and two after the 1969 floods, clearly allowed significant measurements of scour and fill. Most of the maps used had a contour interval of 2 feet and were plotted at a scale of 1 inch equals 50 feet (1:600). Others with a contour interval of 5 feet at a scale of 1 inch equals 100 feet (1:1,200) were used locally.

Accuracy standards by which such maps are prepared required that contour lines be accurate to within one-half of the contour interval, resulting in confidence limits of ± 1 foot for design maps. Specification accuracy of amounts of scour and fill derived from differences between two such maps is ± 2 feet. Empirically, however, comparing the elevations on design maps of points not affected by scour or fill, accuracy generally surpassed this figure. Even specification accuracy was acceptable in dealing in this study with scour of as much as 20 feet (section K–K') and fill of as much as 35 feet (section N–N').

APPLICATION OF RESULTS

The scour and fill that occurred in Tujunga Wash, although possibly unique in magnitude and diversity of cause, is a concentrated example of many of the changes that may occur under natural or urbanized conditions during floods on alluvial fans and in fanhead valleys. Such changes, before urbanization, went largely unnoticed except when catastrophic, and their widespread effects on urbanization in southern California became substantially more than academic for the first time during the 1969 floods.

An increasingly greater proportion of new urbanization is subject to the processes described in this report. Pressure is relentless for development of increasingly marginal areas in terms of danger from geologic and hydrologic hazards. Fanhead valleys similar to Tujunga Wash represent the last undeveloped areas not subject to slope-stability problems in much of urban southern California.

Solutions need not involve only the construction of engineering works in such areas. The flood-control structures in the Los Angeles County Flood-Control District functioned well during the 1969 floods. However, as programs of a scale to assure safe urbanization are applied to smaller areas, diminishing returns rapidly become evident. It is economically impractical to protect the area downstream from every frontal watershed in the mountains of southern California. The present program of debris-basin construction by the Los Angeles County Flood-Control District, for example, does not attempt to do this and is based on sound economic considerations made by the county, not by developers. What is generally needed is an increased focus on the natural realities of the environment before urbanization in arid and semiarid areas, followed by uniform zoning and planning in accord with those realities. It may even appear in some instances that the greatest eventual benefit-cost ratio will be achieved in fanhead washes through uses other than as additions to an existing sea of homesite congestion.

REFERENCES CITED

Culbertson, D. M., Young, L. E., and Brice, J. C., 1967, Scour and fill in alluvial channels, with particular reference to bridge sites: U.S. Geol. Survey open-file report, 58 p.

Emmett, W. W., and Leopold, L. B., 1965, Downstream pattern of river-bed scour and fill, *in* Proceedings Federal Inter-Agency Sedimentation Conference, 1963: U.S. Dept. Agriculture, Agr. Research Service Misc. Pub. 970, p. 399–409.

Fahnestock, R. K., 1959, Dynamics of stream braiding as shown by means of time lapse photography[abs.]: Geol. Soc. America Bull., v. 70, p. 1599.

Hickey, J. J., 1969, Variations in low-water streambed elevations at selected stream-gaging stations in northwestern California: U.S. Geol. Survey Water-Supply Paper 1879–E, 33 p.

Katibah, G., 1968, Photogrammetry in highway practice: California Div. Highways, p. 8–17.

Kulhan, E. F., and Slavoj, D. E., 1969, Photogrammetry: Berkeley, California Univ., Inst. Transp. and Traffic Eng., 70 p.

Lane, E. W., and Borland, W. M., 1954, River-bed scour during floods: Am. Soc. Civil Engineers Trans., v. 119, p. 1069–1089.

Leopold, L. B., Emmett, W. W., and Myrick, R. M., 1966, Channel and hillslope processes in a semiarid area, New Mexico: U.S. Geol. Survey Prof. Paper 352–G, p. 193–253.

Leopold, L. B., and Maddock, Thomas, Jr., 1953, The hydraulic geometry of stream channels and some physiographic implications: U.S. Geol. Survey Prof. Paper 252, 57 p.

Leopold, L. B., Wolman, M. G., and Miller, J. P., 1964, Fluvial processes in geomorphology: San Francisco, W. H. Freeman & Co., 522 p.

Maddock, Thomas, Jr., 1969, The behavior of straight open channels with movable beds: U.S. Geol. Survey Prof. Paper 622–A, 70 p.

Rantz, S. E., 1970, Urban sprawl and flooding in southern California: U.S. Geol. Survey Circ. 601–B, 11 p.

Scott, K. M., and Gravlee, G. C., 1968, Flood surge on the Rubicon River, California—hydrology, hydraulics, and boulder transport: U.S. Geol. Survey Prof. Paper 422–M, 40 p.

Simpson, L. D., 1969a, Summary report, storms of 1969: Los Angeles County Flood-Control District, 55 p.

——— 1969b, Hydrologic report on storms of 1969: Los Angeles County Flood-Control District, 286 p.

Stewart, J. H., and LaMarche, V. C., Jr., 1967, Erosion and deposition produced by the flood of December 1964 on Coffee Creek, Trinity County, California: U.S. Geol. Survey Prof. Paper 422–K, 22 p.

Troxell, H. C., and others, 1942, Floods of March 1938 in southern California: U.S. Geol. Survey Water-Supply Paper 844, 399 p.

Waananen, A. O., 1969, Floods of January and February 1969 in central and southern California: U.S. Geol. Survey open-file report, 233 p.

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