Storms, Floods, and Debris Flows in Southern California and Arizona 1978 and 1980

Overview and Summary of a Symposium, September 17-18, 1980

by Norman H. Brooks

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PREFACE

On September 17-18, 1980, the Committee on Natural Disasters of the National Research Council joined with the Environmental Quality Laboratory of the California Institute of Technology in sponsoring a symposium on the storms and floods of 1978 and 1980 in southern California and Arizona. This symposium provided an opportunity for 300 people interested in storms and flood control systems to exchange views on the events of 1978 and 1980 and their effects on future flood hazard mitigation policies.

A volume containing the proceedings of the symposium was produced as a joint effort of the Committee on Natural Disasters and the Environmental Quality Laboratory. This overview and summary, here reprinted separately, appears as Chapter 1 in the full proceedings volume. Also included in this separate publication is an Appendix A that provides reprints of 24 figures from the proceedings. Appendices B and C list the members of the Committee on Natural Disasters and the National Research Council reports of postdisaster investigations, respectively. The entire proceedings volume is available from the Committee on Natural Disasters or the Environmental Quality Laboratory.

The program committee for the symposium consisted of:

Norman H. Brooks, Director, Environmental Quality Laboratory, California Institute of Technology (Director)
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The California Department of Water Resources, the U.S. Army Corps of Engineers, the U.S. Geological Survey, and many other organizations (shown by the affiliations of the authors) also contributed significantly to the symposium through participation of their staff members.

This overview and summary was prepared by Norman H. Brooks at EQL with secretarial help by Debra Brownlie, Patricia Rankin, and Marcia Nelson. At the NRC the final editing was done by the Committee on Natural Disasters staff: O. Allen Israelsen, Executive Secretary; Steve Olson, Consultant Editor; Joann Curry and Lally Anne Anderson, Secretaries.

We gratefully acknowledge all of the various contributions of the authors, the staff, and the sponsors who made the symposium possible.

Symposium Co-Chairmen

Paul C. Jennings, Chairman, 1980
Committee on Natural Disasters

Norman H. Brooks, Director
Environmental Quality Laboratory

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On burned watersheds debris production during floods increases dramatically. In La Crescenda a mudflow from Shields Canyon on March 4, 1978, carried cars along with large boulders down a street into this house; just the roof is showing. (See the paper by Daniel Davis in Section 4 of the full proceedings.)

OVERVIEW AND SUMMARY

by Norman H. Brooks

INTRODUCTION

Following the floods of 1978 and 1980 in southern California and Arizona a symposium was convened at the California Institute of Technology in September 1980 to document the significant events of these floods and to exchange information and evaluations. The symposium laid the groundwork for a volume of proceedings, which serves as a compact permanent source of information on these floods for not only local readers but national readers as well.

Special attention is given in the proceedings to documenting problems--some engineering, some institutional--and to drawing conclusions and making recommendations for research. The papers included are not intended to be research papers or to replace the much more detailed reports of individual agencies. The emphasis was on preparing and presenting the papers soon after the event in such a way as to emphasize the regional nature of floods and flood control problems.

The proceedings are organized into several sections, with 35 papers altogether. Following the overview and summary, Section 2, STORM METEOROLOGY, which consists of four papers, describes the long-range weather patterns that affect the southwestern United States; the relationship of these patterns to sea surface temperatures in the North Pacific Ocean; the short-term synoptic meteorology of the storms under consideration, showing the importance of multiple storm sequences; and statistical analyses of return periods, based on historical data, for precipitation at a point.

Section 3, DOWNSTREAM RIVER FLOODING, consisting of nine papers, gives an overview of the floods on the larger rivers, how the flood control works responded, and what damages occurred. Section 4, UPLAND FLOODS AND SEDIMENT TRANSPORT (five papers), focuses on the unique aspects of sedimentation in regional floods. Section 5, LANDSLIDES, with four papers, explains the problems of landslides, both large and small, that were triggered by the prolonged periods of heavy rainfall.

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Section 6, CASE STUDIES OF ENGINEERING PROBLEMS (four papers), gives detailed analyses of three particular engineering problems: the failure of levees on the San Jacinto River, the uncontrolled filling of Lake Elsinore to damaging stages, and the severe streambed scour threatening to undermine the Interstate 10 highway bridge over the Salt River at Phoenix, Arizona. The experiences and analyses described in these papers should be useful to engineers who deal with similar structures and situations in the future.

Section 7, EFFECTS ON THE SHORELINE, consisting of two papers, illustrates the damaging effects of the high storm waves and high tides that occurred in 1978 and 1980. Beach profiles shifted very rapidly, with sand being moved temporarily offshore, which exposed many shoreline structures to direct wave attack, causing severe damages.

Section 8, POLICIES FOR FLOOD CONTROL AND HAZARD MITIGATION (six papers), focuses on institutional issues. Four of these papers advocate a strong new emphasis on hazard mitigation, better flood warning systems, and other nonstructural approaches as part of the mix of society's activities to deal with floods.

About 300 people participated in the symposium, and many contributed to the questions and discussion. In the closing session there was a panel discussion by Russell Campbell, Engineering Geologist with the U.S. Geological Survey; John F. Kennedy, Director of the Iowa Institute on Hydraulic Research at the University of Iowa and member of the Committee on Natural Disasters of the National Research Council; Dale Peterson, Director of Community Services with the Federal Emergency Management Agency (FEMA) in San Francisco; and Richard Wainer, Los Angeles City Engineer's Office in Van Nuys. The writer served as moderator. Since it was not feasible to digest and record all of these discussions, I am attempting in this summary to capture the main conclusions and issues.* Nonetheless, the following conclusions and recommendations are solely the responsibility of the author and do not necessarily represent a consensus by the participants at the symposium.

For the record it should be noted that the following papers included in the proceedings were not presented at the symposium: "Geotechnical Origin and Repair of the Bluebird Canyon Landslide, Laguna Beach, California" by Beach Leighton and "Levee Failures and Distress, San Jacinto River Levee and Bautista Creek Channel, Riverside County, Santa Ana River Basin, California" by Joe Sciandrone, Ted Albrecht, Jr., Richard Davidson, Jacob Douma, Dave Hammer, Charles Hooppaw, and Al Robles, Jr. The latter paper is a shortened version of the official Corps of Engineers report on the San Jacinto River levee failure, which was not available in time for presentation at the conference.

Numerous brief discussions at the symposium are gratefully acknowledged, although very few are included in the proceedings.

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*The entire symposium was recorded on 10 audio cassette tapes, which are available from the Environmental Quality Laboratory for the cost of duplicating.

HYDROLOGIC PERSPECTIVE

This section gives some general background on the flood hydrology of southern California and Arizona for those who may be unfamiliar with the area. An overview of the 1978 and 1980 floods is then presented in the next section, followed by discussion of nonstructural approaches and recommendations for research.

Flood Potential in the Southern California Coastal Region

Climate and Geology

The climate in the southwestern United States is arid, except for the California coastal strip and mountainous areas that receive orographic increases in precipitation. The main focus of this volume is the southern California coastal strip between Point Conception on the north and the Mexican border on the south, extending inland to the drainage divide between the streams flowing to the ocean and those flowing to the desert. The principal drainages are shown in Figure 1, and the identifications and areas are listed in Table 1. The elevation of the highest peak is about 3,500 m (11,500 ft) above sea level, and several are higher than 3,000 m (9,800 ft). The geology of the region, especially in relation to erosion and deposition, has been summarized by Fall (1981).

The mountain ranges are responsible for giving this strip a semiarid Mediterranean climate with considerably higher rainfall (an annual average of 10 to 25 in. or 250 to 630 mm in the valley areas and up to twice as much in the mountains) than on the desert side of the mountains (with less than 8 in. or 200 mm). The mean annual rainfall distribution for California is shown in Figure 2. The large variation of the annual rainfall at Los Angeles for the period 1877-1980 is shown in Figure 3 of the paper by James Slosson and James Krohn in Section 5. The precipitation falls almost entirely during the winter months, with long dry hot summers that generally inhibit the development of forest cover below about 1,500 m elevation except on some north-facing slopes. Below this level the slopes are covered with chaparral (native brush), a few trees, grasses, or bare soil. The soils in the mountains are quite thin and rapidly erode or slide down the slopes; the underlying rocks decompose fairly rapidly, yielding an overall long-term erosion rate of the order of 1 m per thousand years (Taylor, 1981). The vegetation and soils of the area are described in more detail by Wells and Palmer (1981). A comprehensive summary of a wide range of hydrologic and geologic characteristics for a part of the San Bernardino Mountains has been lucidly presented with excellent maps and graphics by Troxell et al. (1954).

Flood Factors

Several factors make this region susceptible to severe floods and storm damage:

1. Steep slopes in the mountains, with many slopes at the angle of repose (or steeper) for loose material. Landslides and mudflows are common during heavy and prolonged rainfall, and landslides may occur up to a year later.

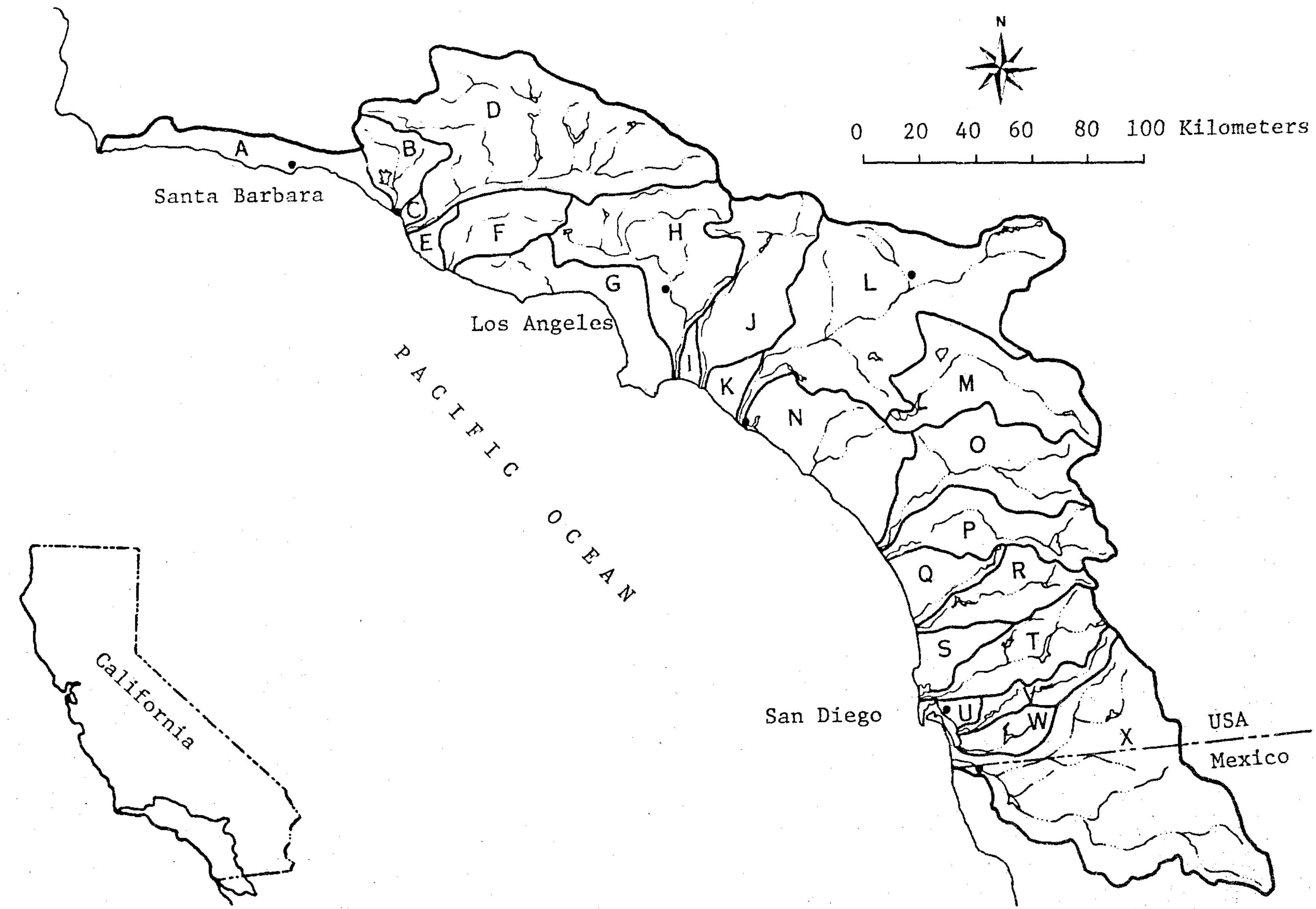

FIGURE 1 Southern California coastal area showing the principal drainage units, identified by letter code and listed in Table 1. Source: Taylor (1981).

TABLE 1 Major Drainage Units in the Southern California Coastal Area (as shown in Figure 1)

Map Symbol	Principal Basin or Group of Small Basins	Controlled Drainage Area of Principal Basins[a] (sq km)	Area (sq km)	Percent of Area Controlled in Principal Basins
A	Santa Ynez Mountains group	--	901	--
B	Ventura River basin	243	585	42
C	Ventura group	--	52	--
D	Santa Clara River basin	1,527	4,219	37
E	Oxnard group	--	159	--
F	Calleguas Creek basin	--	837	--
G	Santa Monica Mountains group	166	1,493	11
H	Los Angeles River basin	866[b]	2,155	40
I	Long Beach group	--	120	--
J	San Gabriel River basin	1,400	1,663	84
K	Huntington Beach group	--	234	--
L	Santa Ana River basin	3,950	4,406[c]	90
M	Lake Elsinore basin	1,989	1,989[d]	100
N	Laguna Hills group	--	1,737	--
O	Santa Margarita River basin	958	1,927	50
P	San Luis Rey River basin	531	1,450	37
Q	Escondido Creek group	--	568	--
R	San Dieguito River basin	785	896	88
S	San Clemente Canyon group	--	437	--
T	San Diego River basin	686	1,119	61
U	San Diego group	--	157	--
V	Sweetwater River basin	471	567	83
W	Otay River basin	255	370	69
X	Tijuana River basin	3,175	4,483	72
Totals		17,002	32,524	53

[a]Calculated by adding the drainage areas controlled by the major water retention structures that are farthest downstream in each basin.

[b]Whittier Narrows flood control basin controls both Los Angeles and San Gabriel rivers. This estimate assumes that 35 sq km of the drainage area controlled by the Whittier Narrows structure lies within the Los Angeles River drainage basin.

[c]Excludes Lake Elsinore basin (M).

[d]Closed interior basin. Overflow into Santa Ana River basin did not occur between 1916 and 1980.

Source: Brownlie and Taylor (1981).

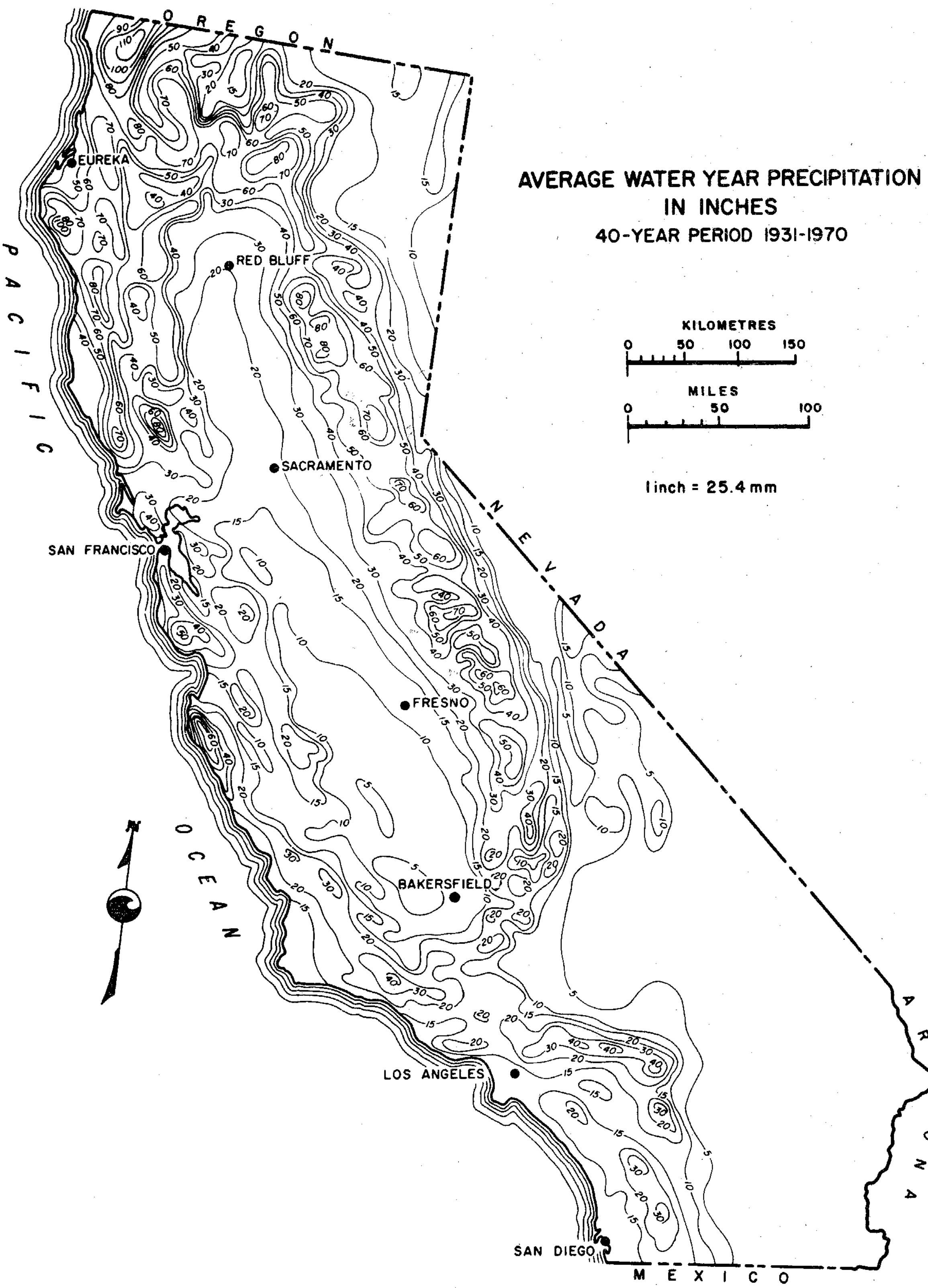

FIGURE 2 Annual precipitation map for California. Source: California Department of Water Resources (1980), p. 16.

2. Intense winter storms, often in groups (such as six in nine days in February 1980), with strong orographic increases in precipitation with elevation.

3. Snowfall generally above 2,000 to 2,500 m, an area that is a minor fraction of the total area. Floods are therefore caused by rapid rain runoff, not by snowmelt.

4. Naturally high erosion rates (or sediment yields), causing very high sediment transport out of the canyons onto alluvial fans and floodplains.

5. Burned watersheds, producing flood peaks that are several times higher and sediment outflows that are an order of magnitude greater than for unburned watersheds.

The fire-flood sequence is the most devastating and least well controlled of the flood phenomena of southern California and contributed significantly to the damages to the foothill areas in the 1978 and 1980 storms (see the papers by Wade Wells and Daniel Davis in Section 4). The chaparral on the lower slopes burns fiercely when fires start accidentally in the dry weather of late summer or early fall, often whipped by Santa Ana winds from the north off the desert. Many residents of southern California living next to the foothills have luckily escaped the damage of the summer fires only to see their property buried by sediments pouring out of the canyons or sliding down slopes in the winter floods.

The inhabitable land on the coastal strip naturally lies between the mountains and the shoreline. Before human development these lands were largely depositional areas; although the alluvial fans at the mouths of many canyons were the most rapidly aggrading features, many have nonetheless become urbanized areas (such as Altadena, shown in Figure 3). The fans may have slopes of up to 0.08 to 0.1. The main rivers in the valleys still are relatively steep, with slopes of 0.001 to 0.01--large values for major rivers that make them flow at relatively high velocities, often with wavy surfaces. Before human intervention the gravel and coarse sands were all deposited on the alluvial fans and the river valleys, while much of the fine sand, silt, and clay was carried through to the ocean in large uncontrolled floodflows. This flow of sand has been the principal source of nourishment for southern California's extensive beaches (Brownlie and Taylor, 1981).

Flood Control

The early settlers in the coastal areas of southern California quickly discovered how brutal uncontrolled streams and rivers could be. The earliest flood control efforts were accelerated by the formation of the Los Angeles County Flood Control District in 1915, which had as its mission not only flood control but also water conservation. Since that time the district, along with the Corps of Engineers (starting in the 1930s), has built one of the most intensive systems of flood control structures in the world. Outside Los Angeles County the flood control systems are less developed, with more works in the planning stages to protect growing developments.

In the early years the flood control systems in the Los Angeles area focused on major flood control dams and channel improvements, most with

FIGURE 3 The San Gabriel Mountains drain from steep canyons directly onto alluvial fans, such as this large one underlying Altadena and the northern part of Pasadena (northeast of Los Angeles). The developed areas on this fan are protected by debris basins at the mouths of the canyons (see Figure 4).

permanent concrete linings. However, after the New Year's Day flood in 1934 it became apparent that extraordinary measures would be needed to control the huge and damaging outpourings of sediment (or debris) from the many smaller canyons onto the urban areas in the foothills. A system of 105 debris basins was conceived, and most of them have now been built. The longest period of operation is now over 40 years, so some statistics on rates of filling are becoming established (see the paper by Daniel Davis in Section 4 and Brown and Taylor (1981)).

A typical basin is shown in Figure 4, and design details are shown in Figure 1 of the paper by John Tettemer in Section 4. As sediments accumulate these basins are supposed to be excavated, sometimes even between storms (see the paper by Daniel Davis in Section 4). They are intended only to catch the coarser sediments, with the finer sediments flowing through the outlet tower (see Figure 1 in the paper by John Tettemer). They have insignificant water

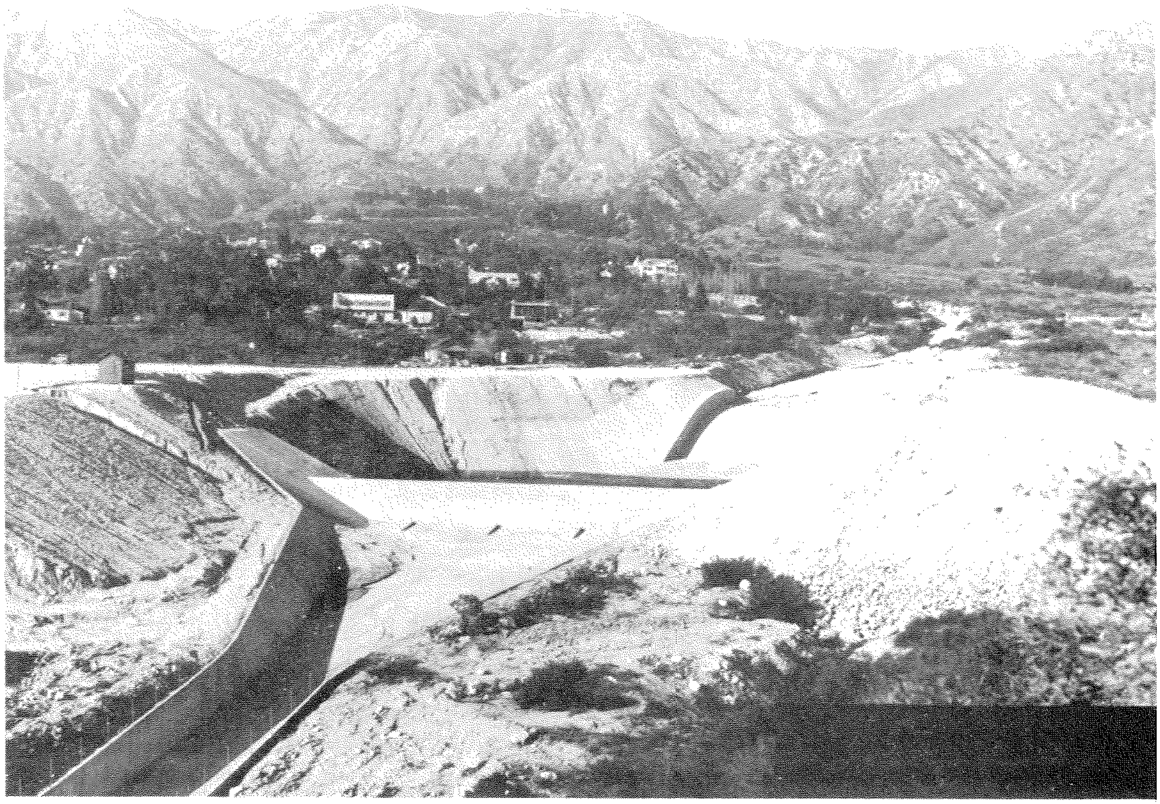

FIGURE 4 Pickens debris basin in La Crescenta, California, shortly after it was constructed by the Los Angeles County Flood Control District in 1936. Flow enters from upper right, and after coarse sediments are captured the outflow passes into a lined channel (lower left).

storage volumes and do not appreciably change the water discharges. These flows can then be carried in lined concrete channels without danger of the channels being filled by debris. Earlier efforts to convey canyon floodflows across alluvial fans without removing the debris met with quick and unequivocal failure--channels simply filled right up with sediments, allowing the water to flow over the fan as before (see the photograph in Figure 5, taken after the 1938 flood).

Large flood storage dams have also been filling up at a rapid rate, and many of them have had to be cleaned out about once every 30 to 50 years. Disposing of all of the sediments from the major dams and the debris dams is posing an increasing problem for the Los Angeles County Flood Control District and other agencies because there are few available places to store this material safely for the long run. The historical data on cleanouts of major reservoirs, debris basins, and channels (before the 1978 and 1980 floods) have been summarized for the southern California coastal region by Kolker (1981).

FIGURE 5 Concrete flood channel on an alluvial fan in Monrovia, completely filled with sediment in the 1938 flood (only a short length of the very tops of the channel walls is visible). Without an upstream debris basin a channel like this is useless in a flood.

Flood Potential in Arizona

In Arizona the rainfall from winter storms from the Pacific Ocean is generally less than in coastal portions of California. On the other hand, short-duration intense rainfall from thunderstorms is more frequent. Occasionally, Arizona is also hit with intense rain from tropical storms that come from the south off the Gulf of California and Pacific Ocean during the fall. The primary area of interest in this volume is the vicinity of Phoenix and the upstream tributary areas of the Gila River system as shown in Figure 1 of the paper by B. N. Aldridge, Section 3. In these areas, as well as in California, erosion and sediment transport increase the flood hazards.

As urbanization spreads around Phoenix and other areas in the arid Southwest (e.g., Palm Springs, California, or Tucson, Arizona), developers will be looking for choice building sites and will think that many alluvial fans are attractive for development. In his two papers in this volume, John Tettemer describes the urgency of adopting a flood mitigation policy for floodplain zoning in order to keep developments off those alluvial fans that are active, hazardous, and entail exorbitant costs of protection. The development of floodplain hazard maps along with the implementation of the National Flood Insurance Program by FEMA will be very useful in forcing communities to pay more attention to sediment hazards.

OVERVIEW OF THE 1978 AND 1980 FLOODS

The notable flood events of 1978 and 1980 are discussed in the papers that follow. Our job here is to ask "What did we learn?" and "How can we improve our systems for flood control and damage mitigation?" This subject will be discussed in the next several sections; since this is an overview and evaluation, the reader is referred to the papers for detailed information. A discussion of nonstructural approaches and recommendations for research will be presented in later sections.

The Natural Events--How Well Do We Understand Them?

The storms and floods of 1978 and 1980 have each been judged to be of the size that can be expected approximately once in 25 years (although the severity of these events varied considerably with location). Precise frequencies cannot be determined because our data base is too short and different stations and criteria give different answers. Whether the number is 10, 25, or 50 years, these floods were well within the range of frequencies for which the flood control systems have been designed. They were definitely not of disastrous proportions (say, once-in-several-thousand-years frequency) that would exceed the capacity of the control structures. Therefore, without minimizing the loss of life, property damage, and general disruption and psychological impacts that <u>did</u> occur, it is important to realize that these storms were far from the worst that <u>could</u> occur.

In 1978 the two major storms occurred separately (in February and early March) on watersheds well saturated with previous rainfall. In 1980 the biggest floods were caused primarily by an unusual sequence of six storms in the eight and a half day period February 13-21. Figure 6 shows the hourly distribution of the 19.71 in. (501 mm) of rainfall that fell in that period at Caltech, while Figure 7 shows the accumulative amounts. For short-term durations the amounts were generally far from record-breaking (see the paper by Wade Wells in Section 4), thereby indicating that the main flooding problems in 1980 were not associated with small drainages or culverts but rather with the larger-scale flood control dams and channels of the bigger systems. The exceptions were those watersheds that had been burned within a few years prior to 1980 (see the paper by Daniel Davis in Section 4).

The meteorology of these situations is now much better understood than it was before, both on short and long time scales. Satellite observations help greatly in understanding the sequences of storms (such as occurred in 1980)

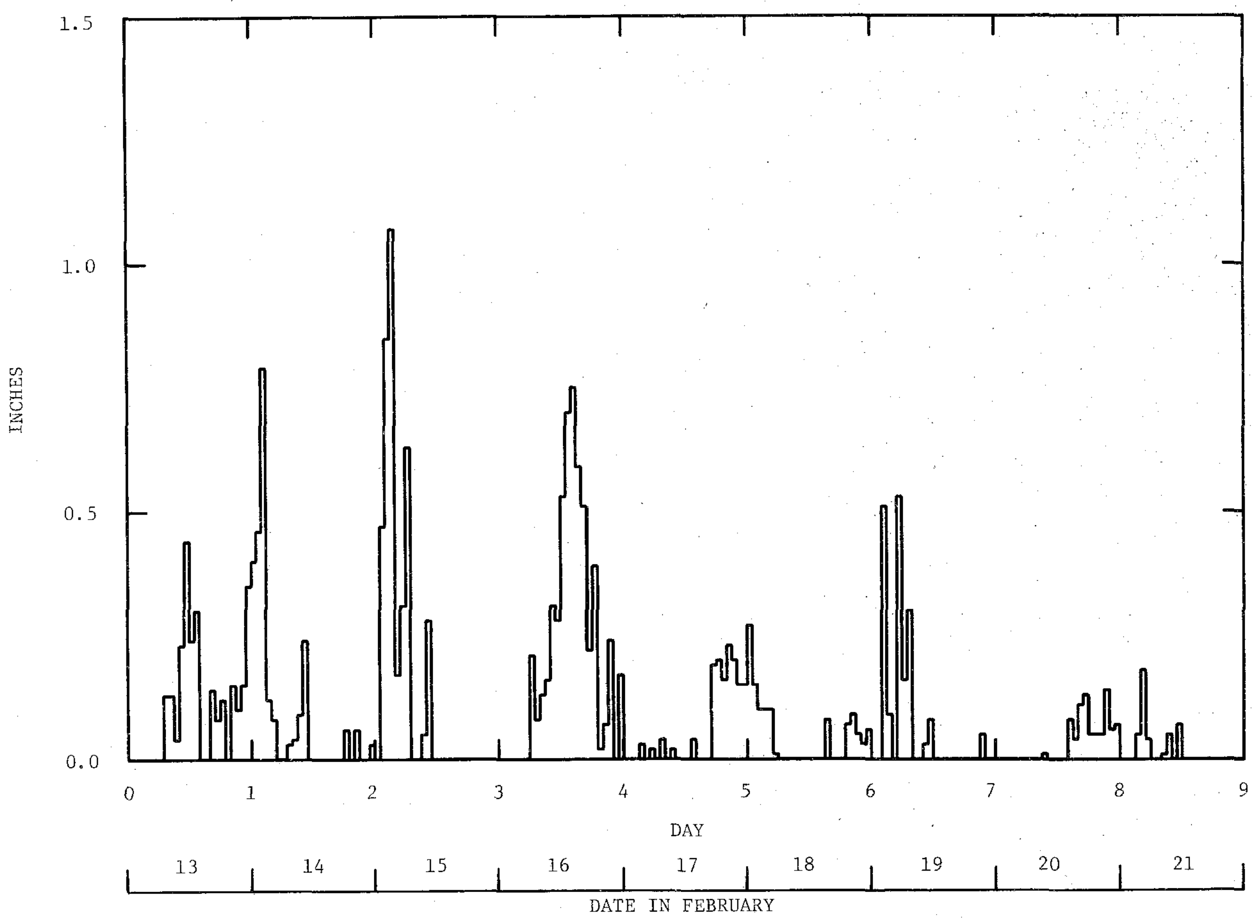

FIGURE 6 Hourly rainfall at the California Institute of Technology in Pasadena for the six storms in the period February 13-21, 1980 (from the recording gage record of Station 303F operated by Caltech for the Los Angeles County Flood Control District).

and in predicting their arrival times and approximate intensities. The regular "clear water" hydraulics of stream runoff is well in hand, except for the sharper and higher peaks coming from urbanized areas as more surfaces get paved or roofed (see the paper by Philip Pryde in Section 3).

Heavy sediment transport in floods from the canyons is always expected and is part of the long-term geologic process that downcuts the mountains at a rate of about 1 m per thousand years (while tectonic processes uplift them at a rate several times higher). In fact, much of the development in southern California lies on active or historical depositional areas. In the extensive recently burned areas the sediment erosion rates were increased as much as tenfold over unburned areas (see the paper by Daniel Davis in Section 4); floodflows were also sharply increased due to bulking (high sediment loads), less infiltration, and faster flows (Wells, 1981). Practically all the flood damage in the foothill areas in 1978 and 1980 was associated with burned watersheds.

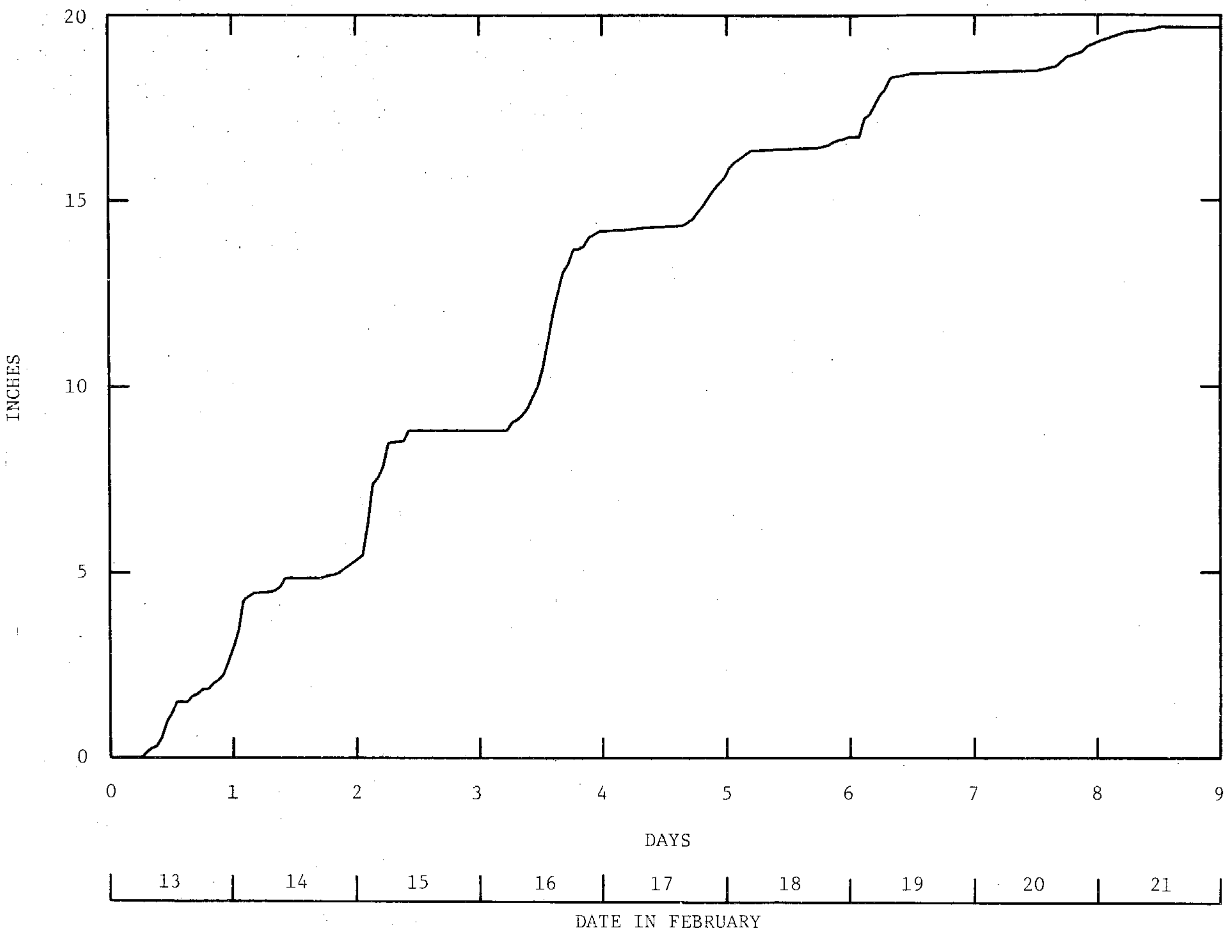

FIGURE 7 Cumulative rainfall at the California Institute of Technology for February 13-21, 1980.

Fires, which are natural for the southern California mountains, occurred before humans developed the area and recur in spite of our efforts at suppression (see Wells (1981) for a discussion of fires). Available fuel in the chaparral stand builds up between fires so that after several decades without a burn, it is practically impossible to stop a wildfire before it covers tens of square kilometers. In the long-term geologic sense the heavy erosion following fires (which also occurred before man's arrival) may be considered part of the normal process of downcutting. The fire-flood sequence will continue to be a threat to foothill communities, and the risks of these events are probably underestimated by the public.

Although the most spectacular sediment transport by streams is in the mountain canyons, even the downstream rivers can produce staggering rates of transport of suspended sediment. For example, data in Kenneth Wahl's paper in Section 3 for the Santa Clara River, the region's largest, show instantaneous sediment transport rates of over one million tons per day and sediment concentrations ranging up to 32 grams per liter.

Landslides and mudslides are predictable general consequences of wet winters in southern California. Small landslides occur as soon as the ground is saturated, while larger slides do not occur until months later because of the time required for the deep percolation of moisture to the weak shear zones. One example is the Bluebird Canyon landslide in Laguna Beach, which destroyed 25 homes on October 2, 1978, seven months after the end of the rainy season (see the paper by Beach Leighton in Section 5). An even longer delayed response was the large Malibu rock slide that occurred on April 13, 1979, blocking Pacific Coast Highway more than a year after the heavy rains (see the paper by Raymond Forsyth and Marvin McCauley in Section 5). We can identify areas that are prone to landslides and mudflows, but we do not have the ability to predict just when any particular slide might occur. Strict controls on hillside developments, such as the ordinances adopted by the City of Los Angeles (see the paper by James Slosson and James Krohn, Section 5), can significantly mitigate the hazards from these natural phenomena.

The shoreline in southern California, especially in the vicinity of Malibu, received heavy wave attacks during the 1978 and 1980 storms. George Armstrong in his paper in Section 7 describes the shore erosion of 1978 as the worst in the past 40 years, but he still calls the 1978 storm season "exceptional but not unusual." As a predictable natural process during winter storms, the large waves caused a major realignment of beach profiles, shifting sand from the beach to the offshore berm and leaving many structures unduly exposed to the breaking of waves. The seasonal coming and going of beaches is a normal phenomenon, as described in the paper by Martha Shaw in Section 7. She observed that during the February 1980 storms over 150 cubic meters of sand per meter of beach were removed in a few days from the nearshore region of Leadbetter Beach at Santa Barbara; this is equivalent to the removal of an area of 150 sq m in the vertical cross section. Again, these are normal well-understood phenomena, but the risks due to shifting beach profiles during storms are probably generally underestimated.

Flood Control Structures--How Well Did They Work?

In California the floods caused 38 deaths in 1978 and 18 deaths in 1980; estimated property damages were $220 million in 1978 and $270 million in 1980 (see the paper by Carlos Garza and Craig Peterson in Section 2 and Jacob Angel's paper in Section 8). However, Joseph Evelyn in his paper in Section 3 estimates that the Corps of Engineers projects alone in the Los Angeles-San Gabriel-Santa Ana River systems in southern California prevented more than $4 billion in damages. In Arizona the flood damages were $70 million in March 1978 and $90 million in December 1978; no estimates were given for 1980 (see the paper by B. N. Aldridge in Section 3).

In general, the main flood control systems in southern California and Arizona performed very well. Yet there were some failures and problems with engineered systems, in spite of the highly favorable operating experience.

Levee Failures

Levee failures on the San Jacinto River flooded the town of San Jacinto; other failures on Calleguas Creek flooded the Point Mugu Naval Air Station.

At San Jacinto the levee failed due to toe erosion, while at Calleguas Creek the levee was overtopped.

The levee failures on the San Jacinto River are fully described in the papers by Kenneth Edwards and Joe Sciandrone et al. in Section 6. The apparent cause of the failure was undermining of the levee toe due to very deep scour. The location of the scour was associated with the confluence of Bautista Creek and the San Jacinto River, which caused a poor alignment of the main stream of flow with respect to the levee. The peak flow in the channel (25,000 cu ft/s) was only 29 percent of the design flow (86,000 cu ft/s). The median size of the riprap rock that was specified at the time of construction of the levee was 130 lb (12 in.), whereas present Corps of Engineers criteria would have called for 2,000-lb (30-in.) rock (for details see the paper by Joe Sciandrone et al. in Section 6).

These examples illustrate that channels having sand beds with levees may not be as safe as the designers expected. Even grade control structures, such as those in the Santa Ana River in Orange County, may not control degradation in cases where the stream is starved for sediment (see the paper by Carl Nelson in Section 3). The failure of such drop structures can be followed by undermining of levees.

Bridge Piers Undermined by Channel Scour

The undermining of bridge piers is another recurring engineering problem, as illustrated by several failures in San Diego County, the problems with the Interstate 10 bridge at Phoenix, and near failures on the Santa Ana River in Orange County. During floods, scour may reach considerable depths, often much more than the depth of the water itself. The depth of scour is dependent on the amount of sediment load of sand and gravel sizes entering the channel with the water discharge. Channels with sand beds downstream of storage dams (e.g., the Santa Ana River below Prado Dam; see the paper by Carl Nelson in Section 3) are especially vulnerable to severe degradation because almost all of the sand load is probably deposited in the reservoir. The discharge of water without a sand load attacks the bed as it seeks to establish a new equilibrium rate of transport. Urbanization may also lower the input of sand in valley and hill areas below previous natural rates.

Sediment-control structures like debris basins, which are absolutely essential for preventing severe aggradation on alluvial fans, may create a hazard of severe degradation unless they feed into lined channels or unless the channels have other sources of sediment to keep them in reasonable balance.

Increased Flood Peaks from Urban Areas

Spreading urbanization is tending to reduce the concentration time (or the time from peak rainfall to peak streamflow) and to increase the peak flood discharge for a given storm (see the paper by Dolores Taylor in Section 3, which indicates that this factor contributed to the overtopping of the Calleguas Creek levee). This effect is reducing the protection of the existing set of improved channels, inasmuch as they will not be able to carry floods of lesser frequency than originally thought (see Philip Pryde's paper in Section 3).

Overflow of Debris Basins in Fire Areas

In Los Angeles County the severe floods and debris transport from burned areas exceeded the capacity of some debris control structures (Daniel Davis gives examples in his paper in Section 4). The present design criterion of 200,000 cubic yards of capacity per square mile (or 59,000 cu m/sq km, which is equivalent to 5.9 cm of depth over the watershed area) appears to be adequate for the storms that occurred, according to Davis, who shows no measured values exceeding 50,000 cu m/sq km. However, some of the debris basins were built with smaller volumes in earlier years and can be expected to overflow more often (e.g., upper Shields Canyon). For watersheds that were not recently burned, the debris basins in the Los Angeles County system proved to be very sufficient, with no problems during the 1978 and 1980 floods.

Flooding and Sediment Damages in Unprotected Areas

Streams and Canyons

Other flood problems occurred in flood-prone areas unprotected by flood control structures, such as areas upstream of debris basins and dams or houses built in canyons in the Santa Monica Mountains and elsewhere. There the pattern of development of many houses along the canyon bottoms makes flood control impossible. When these streams are aggraded during floods because of heavy sediment loads (later the deposits will be cut out again), flooding of roadways and dwellings is almost inevitable. Here the problem is not with the flood control system but rather with a lack of control of development in areas of extreme flood hazard.

Lake Elsinore--Flooding of Developments Encroaching on the Historical Lake Area

A unique flood event in southern California was the record high level that Lake Elsinore reached in March 1980, which caused extensive flooding and threatened the developments that had gradually encroached on the historical lake area (see the paper by Charles White in Section 6). Lake Elsinore is the sink for the San Jacinto River and has a relatively high overflow channel to the Santa Ana River system. In geological time this channel undoubtedly carried overflows a number of times. However, it had been so long since Lake Elsinore had filled up (not since 1916) that the perception of a flood hazard had all but faded away! Damage prevention would have been easy with proper zoning control of the developments around the lake. Present zoning controls, stringently enforced, will reduce flood damages in the future.

Landslides and Mudflows

Landslides

Landslides were widely scattered during and after the storms, threatening loss of life as well as property. There is no practical way to stop a landslide once it starts, so all countermeasures must be preventive. During a storm, individual troublesome slopes can be protected from additional rainfall by plastic sheeting or by deflecting concentrated surface runoff away from weak slopes, if possible. But only vigorous zoning and grading ordinances, such as in the City of Los Angeles, can permanently reduce the potential for landslide damage. Hazards can come either from natural slopes or from improperly constructed earth embankments. Structures at both the tops and bottoms of the slopes are in jeopardy.

James Slosson and James Krohn report in their paper in Section 5 that the City of Los Angeles has been keeping detailed statistics of landslide damages within the city and relating these to the ordinances in effect at the time of development. Total damages within the city were estimated to be $50 million in 1978 and $70 million in 1980. Their Table 3 (showing 3,000 failures for 1978) gives a slope failure rate of 7.5 percent for pre-1963 construction (before the modern code) versus only 0.7 percent for post-1963 construction. Damages in 1978 to developments under the new code are estimated to have been reduced 95 percent from what they would have been had the new code not been adopted in 1963.

The essence of the code is to require proper geologic investigations of natural slopes and avoid building where there are significant hazards. For man-made embankments it requires proper soil mechanics engineering regarding materials to be used, choice of slopes, and methods of construction. Furthermore, geologists and soil mechanics engineers must inspect grading projects while they are in progress and certify them upon completion as meeting the safety standards.

While the present codes effectively prevent construction of new possible sources of damage, houses built before 1963 could still be subject to heavy damage in future wet years under the right circumstances. According to Harold Weber, Jr., in his paper in Section 5, shallow slides may be triggered by special sequencing of rainfalls. For instance, over 100 homes were damaged in Monterey Park on February 16, 1980 (the day of heaviest rain--see Figure 6 above), although there had been no previous damage in over 40 years since development of the area started. In other areas damage regularly occurs in any very wet year, and for some areas damage was much worse in 1978 than in 1980.

Mudflows

When a saturated landslide begins to liquefy and flow like a viscous fluid, it is called a mudflow. In the mountains, landslides often fall into streams in the canyon bottoms and may start mudflows, which surge down the natural stream channels. These mudflows have the consistency of wet sloppy concrete, with large boulders and gravel included in the matrix. They stop as soon as they spread out laterally or the grade flattens, and the water and fine sediments drain away from larger sediments as they stop.

Mudflows at the base of hillslopes can flow out with flatter surface slopes than landslides per se. Since the National Flood Insurance Program covers <u>mudflow</u> damage but not <u>landslide</u> damage, there is a difficult problem of definitions. Physically, however, a sharp distinction is often not possible--who can say exactly where a landslide turns into a mudflow? Mudflows may also start as a surface or streambed erosion process on very steep slopes during periods of exceptionally heavy rainfall without being triggered by a landslide. A committee of the National Reseach Council has prepared a report for the Federal Emergency Management Agency on methodologies to define and clarify mudflow hazards and distinguish them from landslides for insurance purposes (National Research Council, 1982). For an excellent description and explanation of landslides and mudflows in the Santa Monica Mountains, see Campbell (1975).

Mudflows should not be confused with heavy sediment transport and deposition by streams during floods. Mudflows are special, distinct episodes and are not continuous like floodflows. The alluvial fans at the mouths of mountain canyons are mainly the result of stream transport and deposition, not of mudflows. Although sediment concentrations in mudflows may be over 1,000 grams per liter, much more sediment transport occurs in alluvial floods (with sediment concentrations only very rarely exceeding 100 grams per liter) because of the latter's high volume. Again, there may be instances where the distinction is unclear.

NONSTRUCTURAL APPROACHES TO DAMAGE REDUCTION--WERE THEY USEFUL IN THE 1980 FLOODS?

Risks and Benefits

There is a growing awareness that flood control structures (dams, lined channels, storm drains, pump stations, etc.) are necessary but not sufficient to provide for safety and prevent damage (e.g., see California Department of Water Resources (1980) and the paper by Ronald Robie in Section 8). Nonstructural approaches, which are getting increased attention, will be discussed in this section. There are several compelling reasons for this shift in attitudes toward flood control:

1. Flood control structures can be designed to handle floods only up to a certain size, usually expressed as a flood frequency. For floods exceeding this size the structures may no longer be effective or, in case of failures, the damages can be worse than if there had been no structures at all. For example, a levee designed for a 25-year flood may create confidence that encourages development next to the levee; then if a 50-year flood causes the levee to fail the damage might be extensive. Although spillways of major dams may be designed for very large floods (the maximum possible as determined by hydrometeorological methods), the channels downstream often cannot feasibly be built to carry such extraordinary floods. Acceptance of some risk is inevitable and economically sensible. At some point on the scale of risk reduction, flood insurance and disaster assistance provide a way to share the remaining risk at annual costs to society that are less than the costs of additional structural measures.

2. The cost of public works has increased sharply in the last decade. Not only has the cost of construction increased by a factor of about three

over the last decade, but the cost of borrowing (expressed as the interest rate paid by government) has also tripled. Therefore the annual cost could have increased between three and nine times, depending on the length of the repayment period. Thus there are strong economic incentives to consider and use other approaches.

3. The environmental impacts of flood control works are being viewed with more sensitivity than they were 15 to 20 years ago.

4. Experience, including that with the floods of 1978 and 1980, is showing that nonstructural methods can be used effectively to save lives and reduce property damage for reasonable costs.

5. Some nonstructural measures, such as better flood forecasting and better flood channel maintenance, enhance the protection afforded by structures already built.

In this section we shall discuss some nonstructural measures of flood control, both as they were used in 1980 and as they might be used effectively as a more significant part of an overall response to floods in the future.

The 1980 Experience with Nonstructural Approaches

Flood Predictions and Warnings

With satellite imagery the National Weather Service was able to make better storm predictions in 1980 than ever before. However, since the intensity of rainfall and small-scale variations are still difficult to predict, it is useful to instrument the key larger watersheds with real-time telemetry to transmit rainfall amounts and stream stages from upstream locations to a central operations center. Using computer simulation, downstream hydrographs can be predicted in time to warn residents and mobilize flood fighting forces. In their paper in Section 3, Ira Bartfeld and Dolores Taylor describe the development of such a system for the unregulated Sespe Creek in Ventura County after the 1978 floods. In 1980 the system was operational and was instrumental in saving Fillmore from a repeat of the damaging flood and the frantic evacuation it experienced in 1978.

Operation of Flood Control Systems

Although all major reservoirs performed well and prevented millions of dollars in damage (see the paper in Section 3 by Joseph Evelyn), there is still need for a more systematic approach to reservoir operations to get the most benefit from the overall system of reservoirs and channels. Although the storms of 1978 and 1980 were not a truly great series of storms, the larger flood control dams and channels were used in many cases to near capacity in 1980. In a system of storms with a return period of approximately 100 or more years, the writer believes that there would be some significant uncontrolled spillway releases, with some downstream channels likely to overflow since they generally have less capacity than do the spillways of large dams.

With telemetry of flood data to a computer during a flood, the best strategies for releases on multidam systems could be calculated while considering the limitations of the downstream channels.

Flood Fighting

Flood damages can be reduced by carefully patrolling flood channels, levees, debris dams, and other flood control works. In case of trouble, fast responses can often be vital--for example, in removing trash that plugs an outlet or channel. In Santa Barbara County a diligent patrol of levees on the Santa Maria River probably averted a levee failure when deteriorating sections were discovered and emergency reinforcement procedures were instigated immediately (see James Stubchaer's paper in Section 4).

During the floods of 1978 and 1980 local officials received a great many calls for assistance from private property owners with problems of high water, deposition of debris, or erosion. Personnel of flood control agencies and public works organizations generally do not have the authority (or the time during floods) to provide emergency flood protection on private property, a fact that is not generally understood by the public. Since the City of Los Angeles had no way to respond to the numerous requests for help, callers were referred to the TreePeople, a private volunteer organization primarily dedicated to planting trees and other conservation projects (see the paper by Andrew Lipkis, Sherna Hough, and Lisa Geller in Section 8). In a very short time (without any advance planning) the TreePeople established a telephone hotline and mobilized hundreds of volunteers to help people protect their houses and property with sandbags and other small-scale emergency measures. The volunteer organization's response was so successful that it should serve as an example for flood fighting during the next flood and in other areas. Some advance organizational work and training of team leaders would be very useful to make the volunteer work as effective and safe as possible.

Temporary Defensive Measures in Fire Areas

When a watershed burns, the flood and sediment hazards are greatly increased. Flood control agencies can make special efforts to warn property owners of the extra hazards and advise them of temporary precautionary measures to take until vegetation reestablishes itself on the watershed over several years. Temporary public works can be erected to retain sediment, and flood fighting preparations and evacuation plans can be made. A program of this kind was successfully implemented following the Sycamore Canyon fire near Santa Barbara in 1977 (see James Stubchaer's paper in Section 4).

Cleanup and Maintenance

Agencies have learned that good maintenance of flood control facilities between floods is essential to keep the floodflow capacities of the structures up to design values. Such maintenance includes removal of sediment and debris from debris basins, reservoirs, and flood channels; repair of levees and other structures; and upkeep of outlet works and pump stations. Local agencies have the responsibility for maintaining flood channel projects built by the Corps of Engineers, but they may not have sufficient funds to do so until federal disaster assistance is received after the great floods.

Sand and Gravel Mining

Mining of sand and gravel from riverbeds must be closely regulated to be sure that the river regime is not unreasonably disturbed (e.g., by headcutting, levee undermining, or severe reduction of sand flux to the beach--see the paper by Vito A. Vanoni, Robert Born, and Hasan Nouri in Section 4). On the other hand, sand and gravel operators can help by removing unwanted sand and gravel from reservoirs and improved flood channels, although it may cost more than digging a large pit in a river bottom. Different institutional arrangements could well be used to encourage operators to use more surplus sediments and fewer riverbed excavations.

Flood Hazard Zoning and Proper Hillside Development Ordinances

Ordinances to control development are certainly worthy preventive measures, but they generally are used much too little. Ordinances to control developments in identified flood hazard areas that incorporate the federal requirements of FEMA would prevent or reduce damages from floods up to a 100-year flood.

As discussed above, the City of Los Angeles has adopted successful codes for controlling hillside development to prevent landslides. The National Flood Insurance Program strongly seeks to reduce hazards and discourages rebuilding of washed-out structures in the same hazardous locations. Communities must adopt and enforce meaningful hazard mitigation plans in order for their residents to be eligible for flood insurance (see Dale Peterson's paper in Section 8).

Flood Insurance

Flood insurance, administered by FEMA, provides a sharing of risks and pays for damages. The premiums will be based on the claims experienced over many years. The cost of further structural measures can then be compared with the money saved on insurance premiums (i.e., the benefits). The flood insurance program is growing, but the need to prepare maps of hazard zones, especially involving sediment or mudflow damage, has slowed it down.

Better Coordination of Local, State, and Federal Objectives and Activities

Coordination among the various levels of government would lead to improved flood control and faster settlement of intergovernmental transactions, such as for federal disaster assistance to local governments (see the papers by Ronald Robie, Dale Peterson, and Donald Tillman in Section 8).

RECOMMENDATIONS FOR RESEARCH

Although the region avoided a catastrophe of major proportions in the recent flood years, it would be worthwhile to continue research, using these recent flood experiences, on a variety of topics to improve our flood control systems and mitigate hazards. Topics for additional research are listed below.

1. Long-range weather forecasting.

2. Occurrence of cells of especially intense rainfall.

3. Effects of urbanization on flood peaks.

4. Computer programs for better real-time numerical flood forecasting for major rivers, using telemetered data.

5. Real-time determination of optimum reservoir release strategies during a flood.

6. Adequacy of the design criteria for levees, especially for scour protection at the toe.

7. Mechanics of landslides and mudflows, including evaluation of hazards for insurance and mitigation programs.

8. Detailed case studies of rainfall, runoff, and debris flow for selected small canyons in the San Gabriel and Santa Monica mountains in order to understand the responses of small watersheds better and to help assess risks on alluvial fans, manage the watersheds, and operate (or design) debris basins.

9. Controlled burning of small portions of watersheds on a rotating schedule as a means to reduce the severity of wildfires and ensuing floods and debris flows.

10. Techniques to control bed and bank erosion in streams with erodible beds when they are "starved" for sediment.

11. Benefits and costs of various combinations of structural and nonstructural components of an overall system for reducing damage, loss of life, and personal injury and for sharing the residual risks through insurance and disaster relief.

12. Governmental institutions and regulations needed to reduce hazards and future damages through mapping of areas subject to flooding, debris flows, and landslides and through controlling developments in these areas.

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APPENDIX A:

SELECTED FIGURES FROM THE FULL PROCEEDINGS

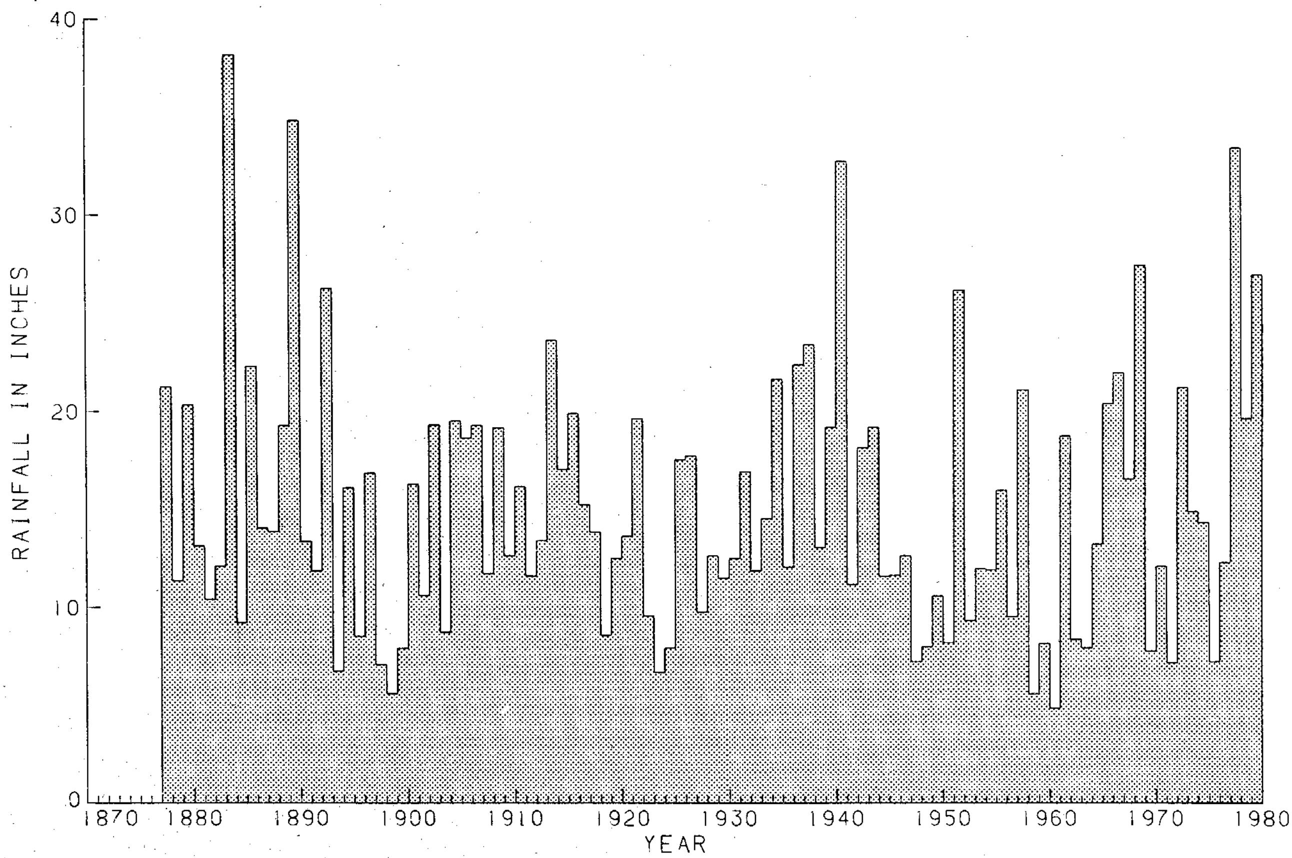


FIGURE A1 Annual rainfall in Los Angeles, 1877-1980. (Figure 3, James Slosson and James Krohn, Section 5.)

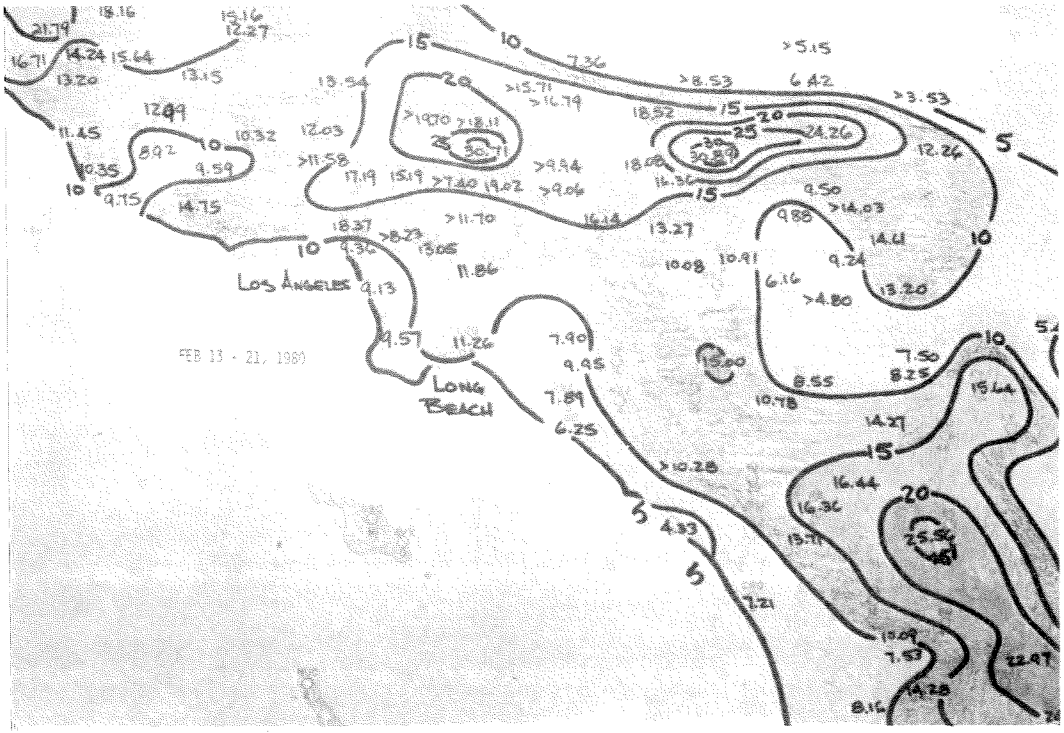


FIGURE A2 Total rainfall in the coastal region of southern California for the storms of February 13-21, 1980. (Figure 11, Carlos Garza and Craig Peterson, Section 2.)

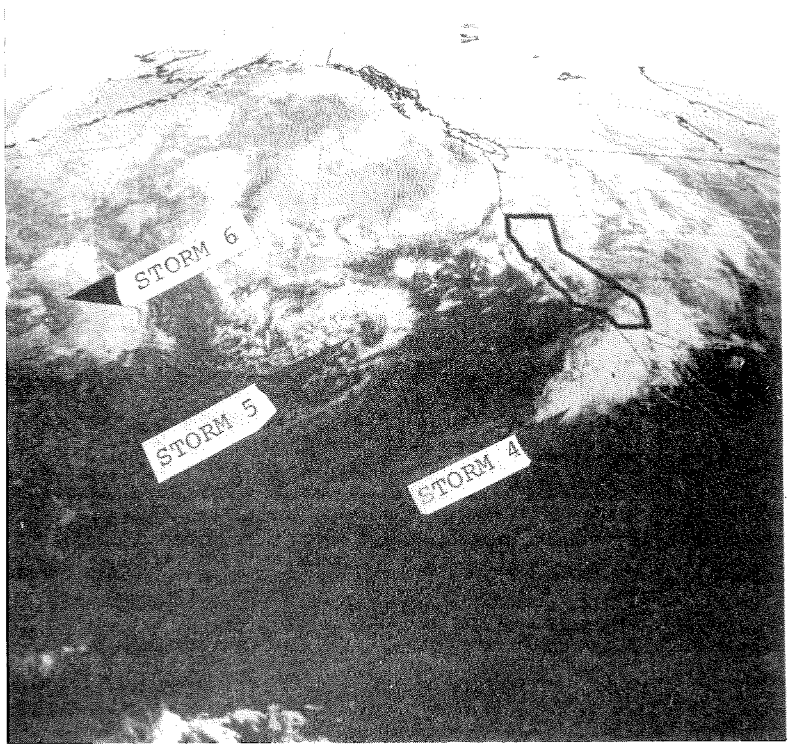


FIGURE A3 During the period February 13-21, 1980, six separate storms crossed southern California and Arizona in rapid succession. This satellite photograph shows storms 4, 5, and 6 moving eastward on February 18, 1980. (Figure 15, Carlos Garza and Craig Peterson, Section 2.)

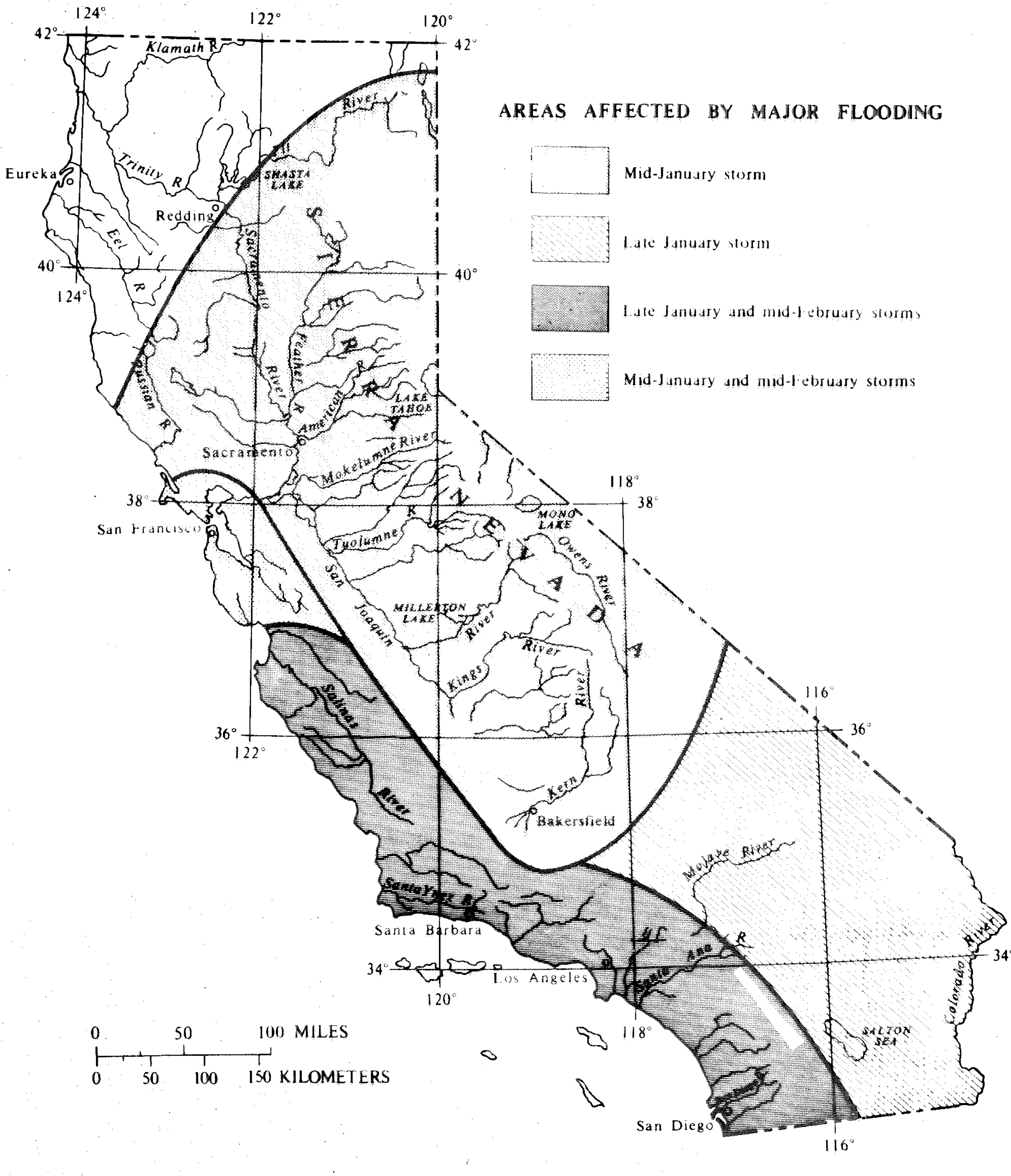


FIGURE A4 Approximate boundaries of areas in California affected by flooding in January and February 1980. (Figure 1, Kenneth Wahl, John Crippen, and James Knott, Section 3.)

FIGURE A5 Some lined flood channels in the Los Angeles area flowed near their capacities, as shown in the view looking downstream on the Los Angeles River near Kester Avenue (approximately 1 mile downstream of Sepulveda Dam) on February 16, 1980. Note the standing wave resulting from side weir overflow. Photograph courtesy of Los Angeles County Flood Control District. (Figure 10, Joseph Evelyn, Section 3.)

Figure A6 Flooding in Fillmore due to overflow of Sespe Creek, March 1978. (Figure 1, Ira Bartfeld and Dolores Taylor, Section 3.)

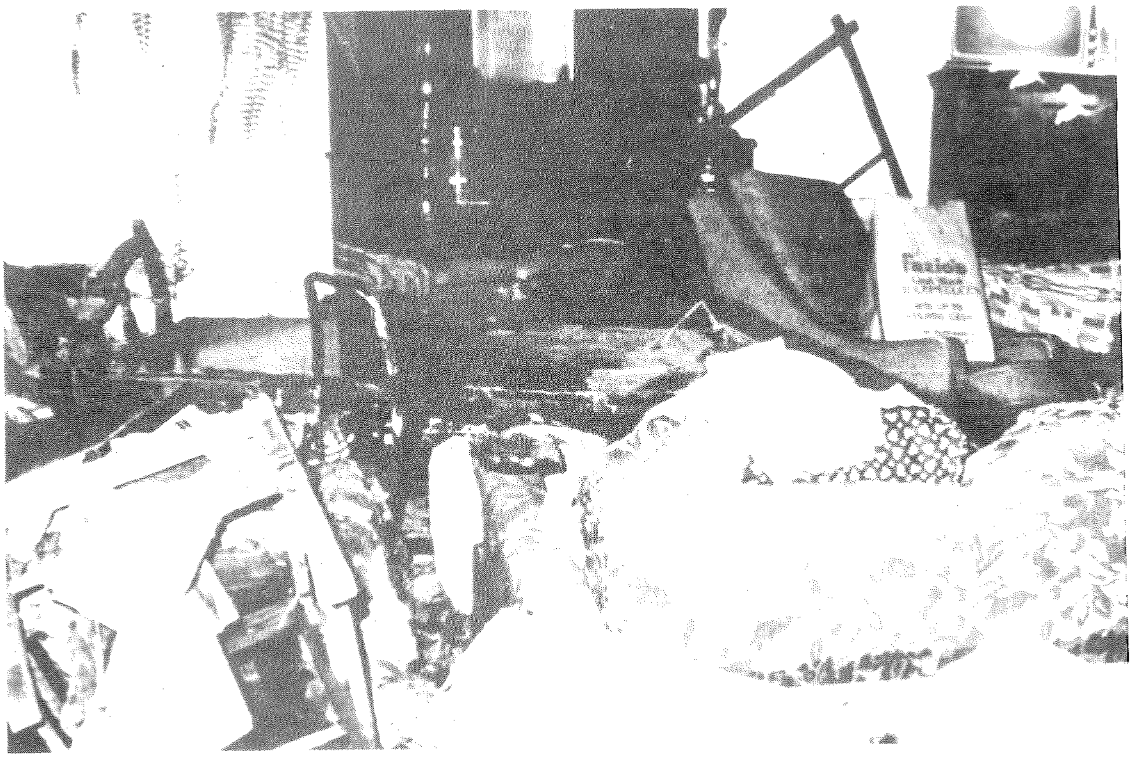


FIGURE A7 Residential flood damage in Fillmore due to overflow of Sespe Creek, March 1978. (Figure 2, Ira Bartfeld and Dolores Taylor, Section 3.)

FIGURE A8 Impingement of flow on Santa Maria River levee. Damage or failure may start at points of attack like this. (Figure 5, James Stubchaer, Section 4.)

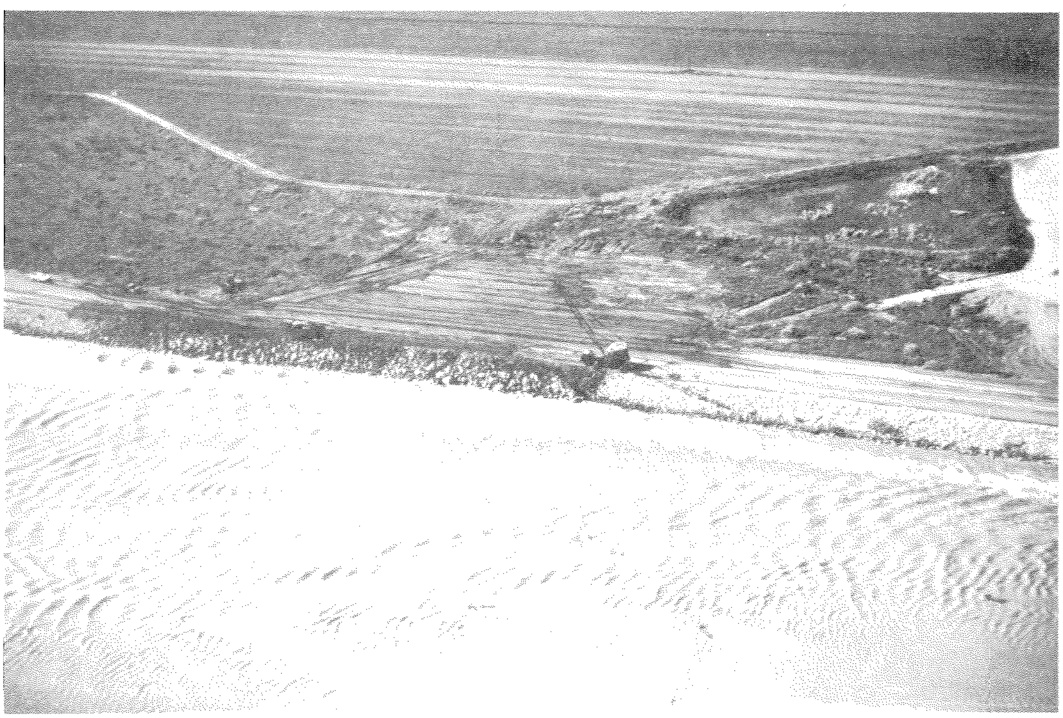
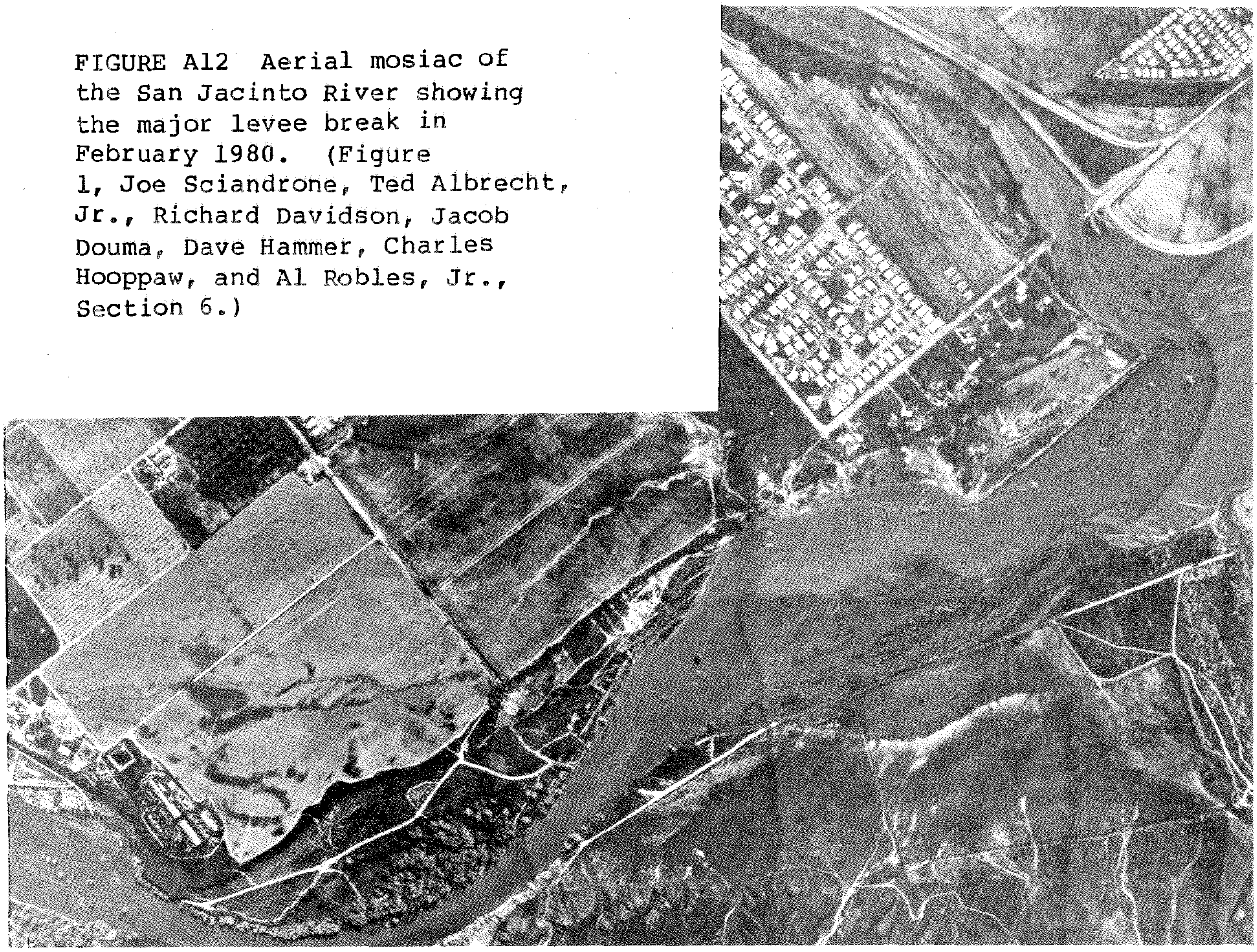


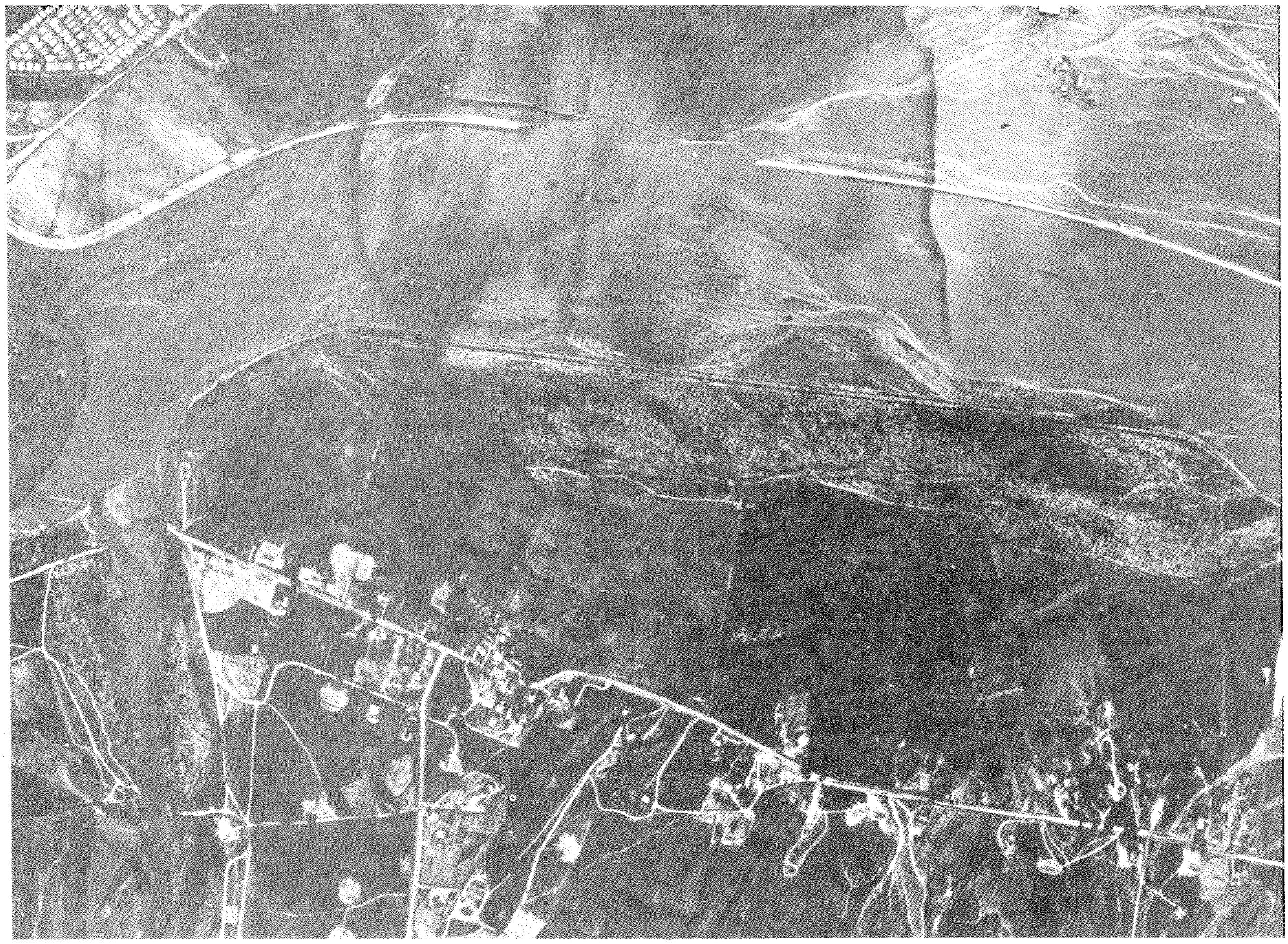
FIGURE A9 Rock being dumped on face of Santa Maria River levee just downstream of Bradley Canyon to prevent breakout and flooding of Santa Maria during 1969 flood. Careful surveillance for areas of damage and emergency repairs during the 1978 and 1980 storms prevented serious damage. (Figure 4, James Stubchaer, Section 4.)

FIGURE A10 Overflow of San Jacinto River into the City of San Jacinto. (Figure 4, Kenneth Edwards, Section 6.)

FIGURE A11 Eroded levee toe on the San Jacinto River (looking up-stream). (Figure 6, Kenneth Edwards, Section 6.)

FIGURE A12 Aerial mosiac of the San Jacinto River showing the major levee break in February 1980. (Figure 1, Joe Sciandrone, Ted Albrecht, Jr., Richard Davidson, Jacob Douma, Dave Hammer, Charles Hooppaw, and Al Robles, Jr., Section 6.)





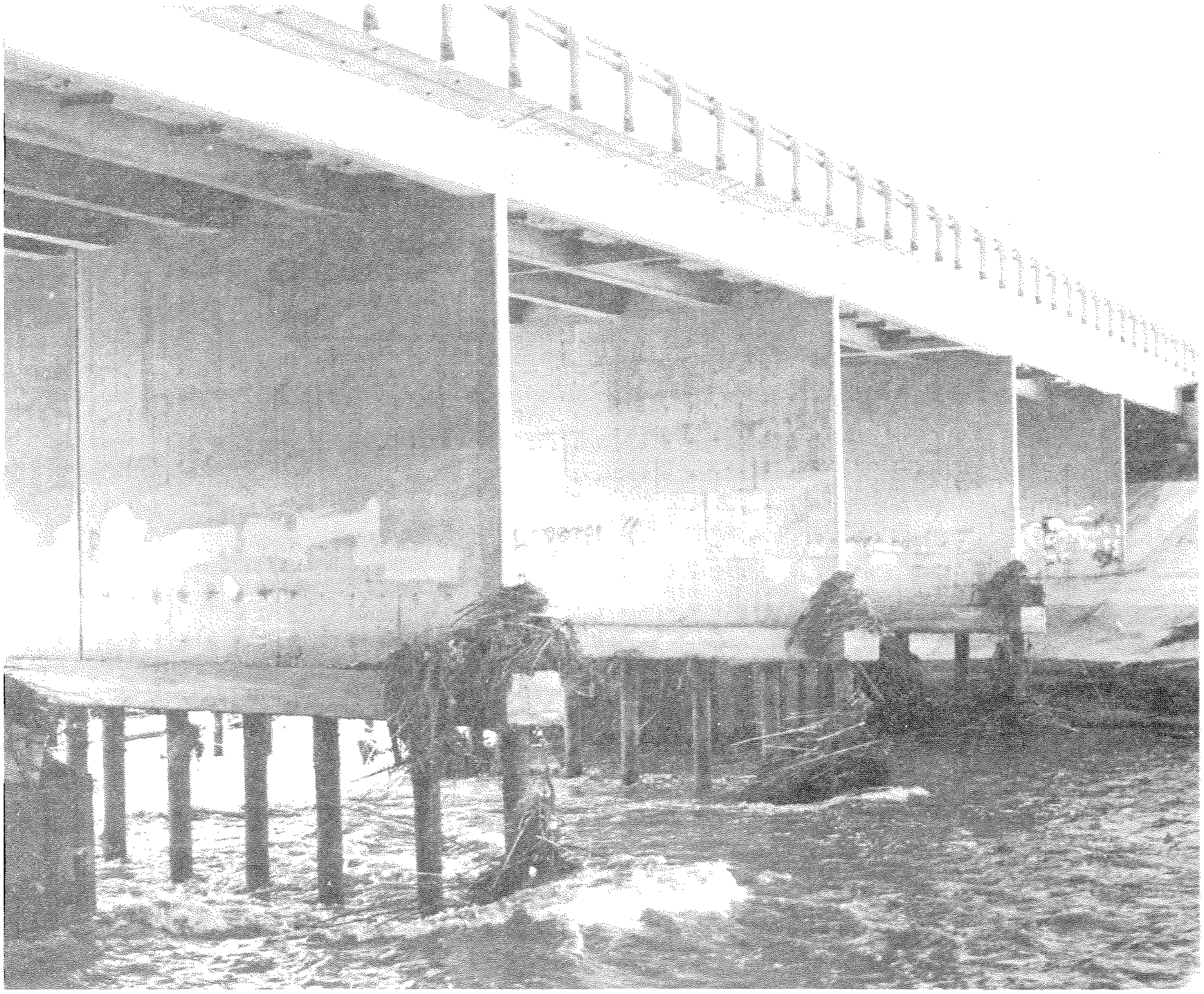


FIGURE A13 Scour of the bed of the Santa Ana River under the Fifth Street bridge in Santa Ana exposed the foundation pilings, as a result of the prolonged discharge of moderate flows from Prado Dam following the floods of February 1980. (Figure 8, Carl Nelson, Section 3.)

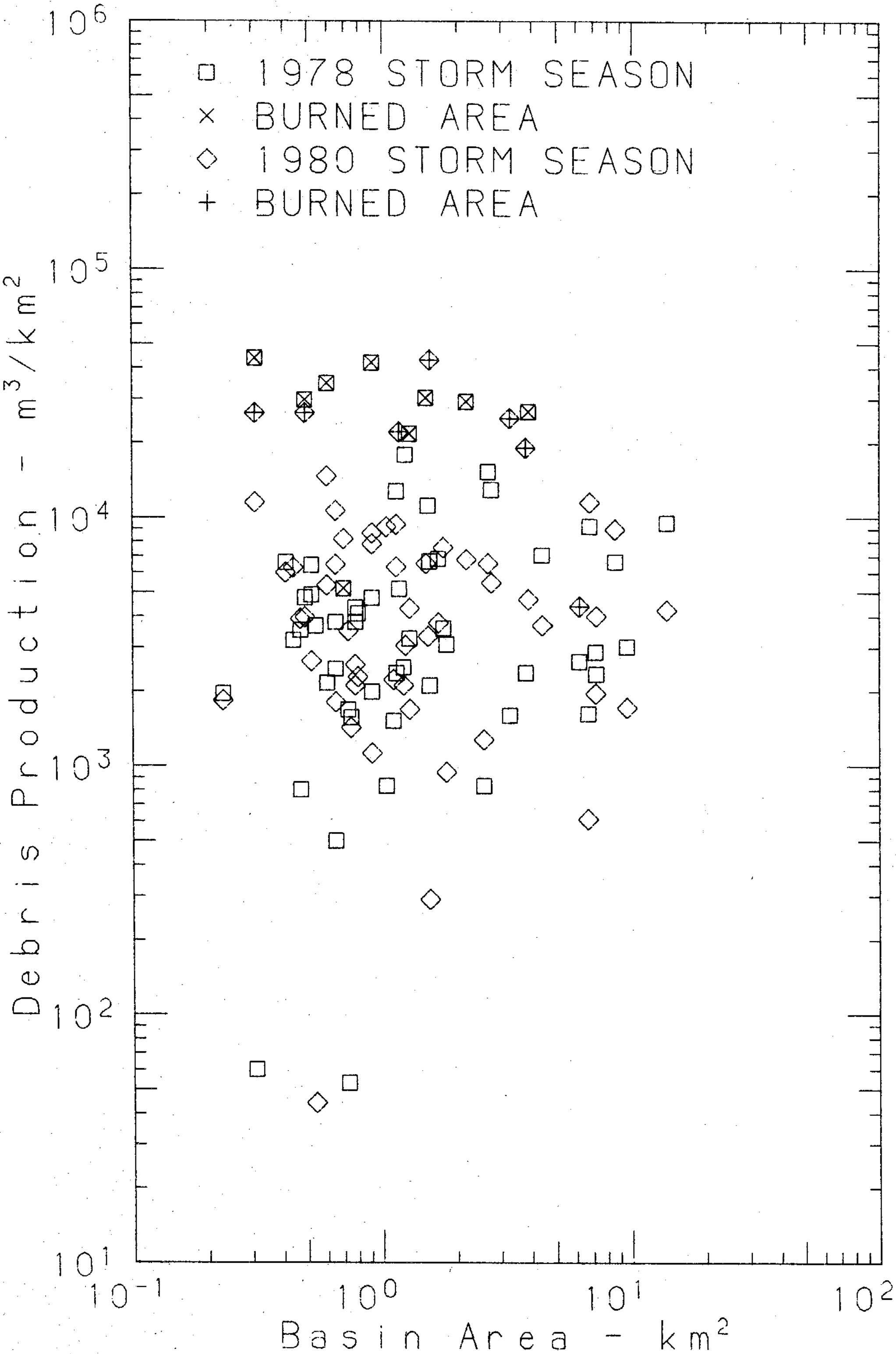


FIGURE A14 Debris production rates on small mountain watersheds during 1978 and 1980. For the watersheds that had been recently burned, the production was increased about 5 to 10 times above that of similar unburned watersheds. (Figure 3, Daniel Davis, Section 4.)

FIGURE A15 Damage from flood resulting from rain on a recently burned watershed. (Figure 10, James Stubchaer, Section 4.)

FIGURE A16 Home near Lake Elsinore under water. Photograph courtesy of U.S. Army Corps of Engineers. (Figure 6, Charles White, Section 6.)

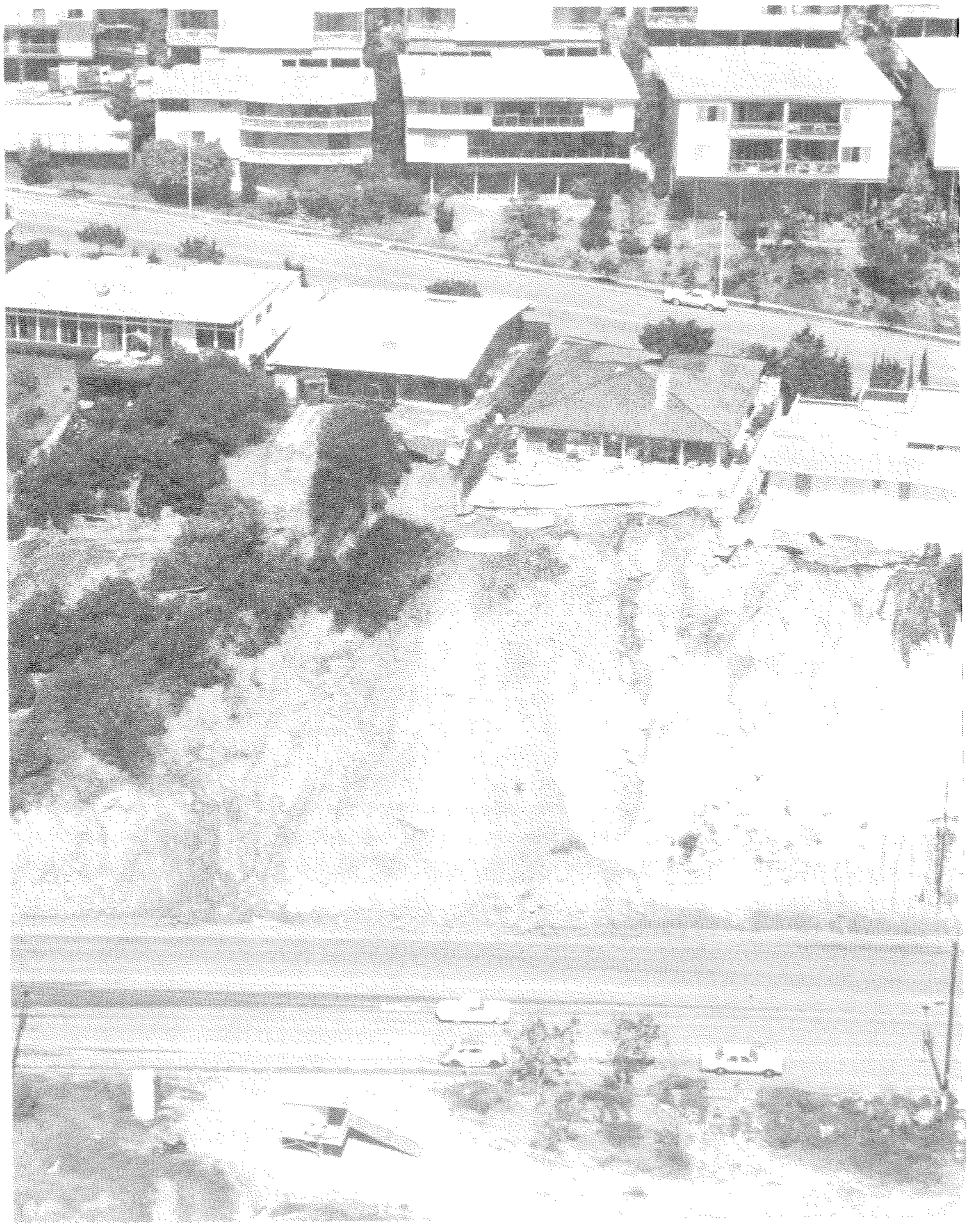


FIGURE A17 Aerial view north across Pacific Coast Highway in Malibu, Los Angeles County, shows sloughing and sliding that has damaged residential properties built too close to the edge of the ancient sea cliff. Rocks along the coast here are commonly highly fractured and deeply weathered and, hence, very susceptible to slope failure. Photograph courtesy of A. L. Parmer, California Department of Transportation. (Figure 3, Harold Weber, Section 5.)

TABLE A1 Slope Failures in the City of Los Angeles, 1978 Storms (Table 3, James Slosson and James Krohn, Section 5.)

Description	Number of Sites	Number of Failures	Percent Failure	Dollar Value (millions)
Pre-1963 (before modern code)	37,000	2,790	7.5	40-49
Post-1963 (modern code)	30,000	210	0.7	1-2

Note: The categories of failure are (1) soil slippage and erosion (28 percent); (2) mudflow and debris flow (30 percent); (3) slump/arcuate landslides, pre-1963 and natural slopes (22 percent); (4) reactivation of old failures, pre-1963 (8 percent); (5) new bedrock landslides, pre-1963 (5 percent); (6) shallow fill slope and some natural slope failure, post-1963 (7 percent, with the modern code promulgated in April 1963).

Source: Slosson and Krohn (1979).

FIGURE A18 Rear yard and house of a pre-1963 subdivision inundated by mudflow off a natural slope during a 1980 storm in Tarzana, California. (Figure 4, James Slosson and James Krohn, Section 5.)

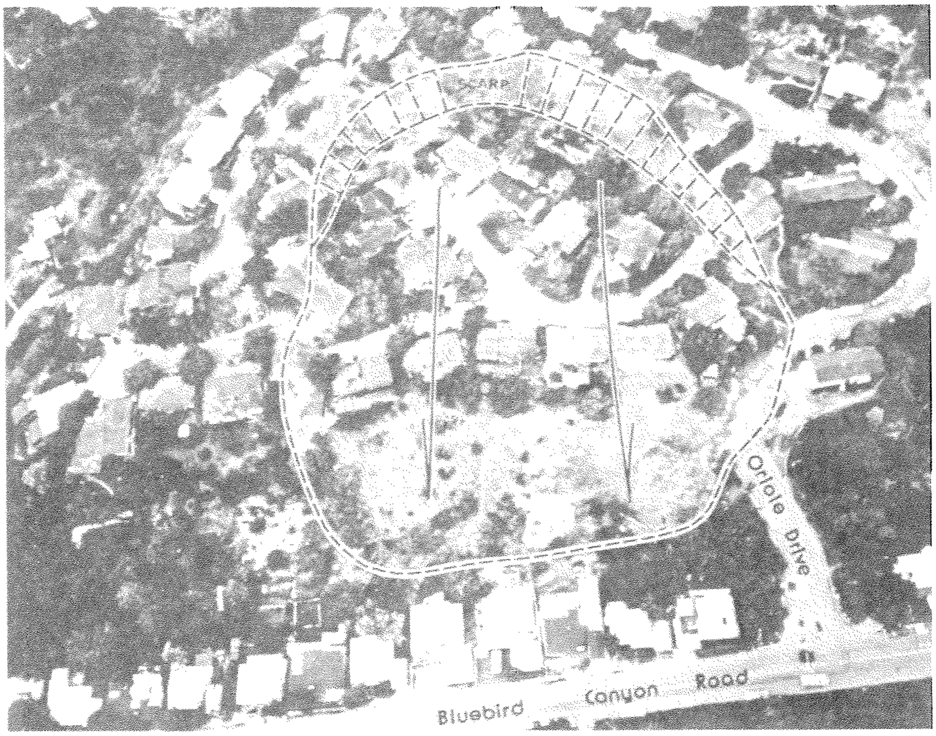


FIGURE A19 Aerial view of Bluebird Canyon landslide immediately following the October 2, 1978, event. (Figure 1A, Beach Leighton, Section 5.)

FIGURE A20 The Bluebird Canyon landslide (in October 1978) damaged or affected more than 50 homes in a hillside development in Laguna Beach. (Figure 1, James Slosson and James Krohn, Section 5.)

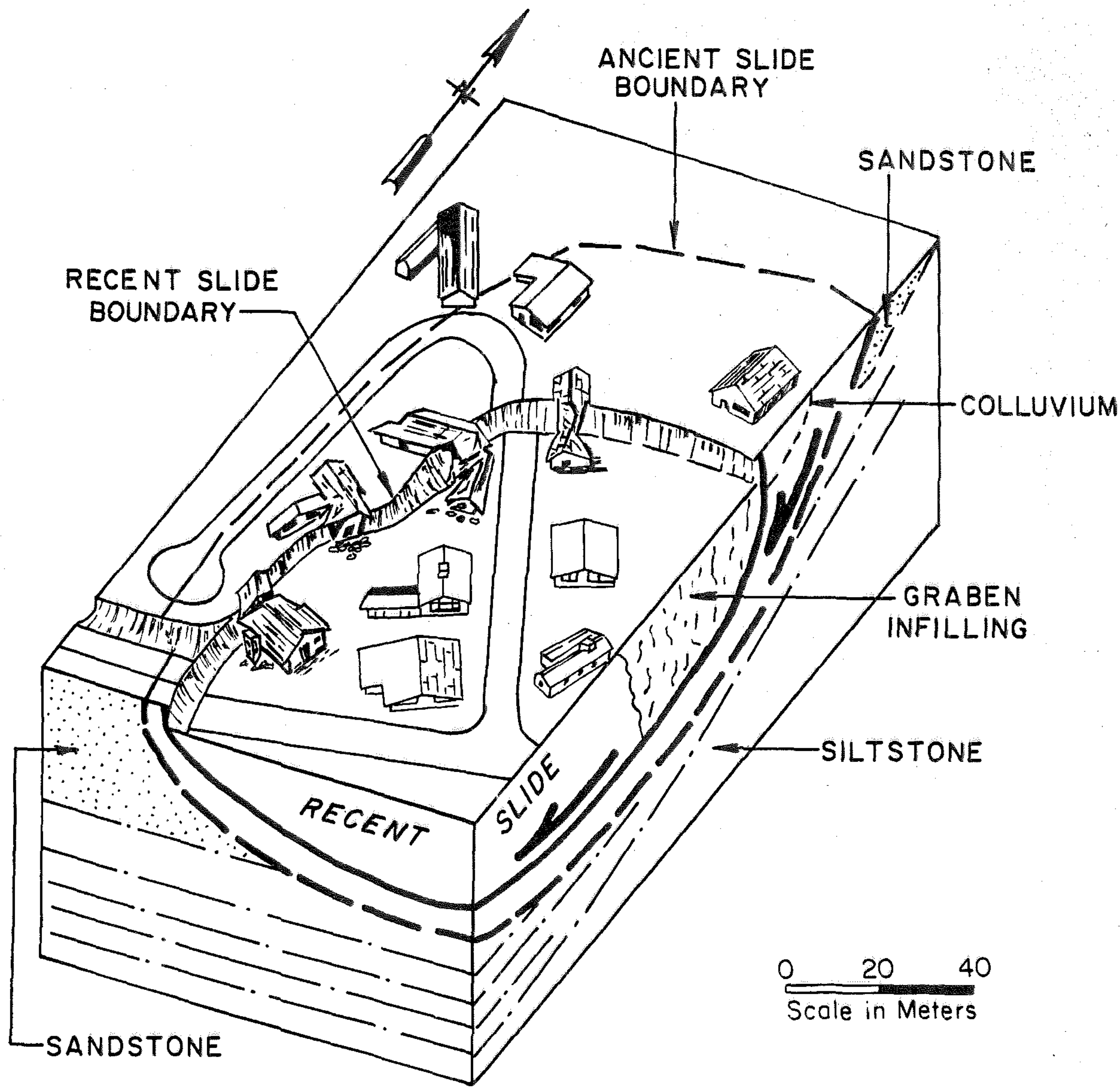


FIGURE A21 Block diagram showing Bluebird Canyon landslide. (Figure 3, Beach Leighton, Section 5.)

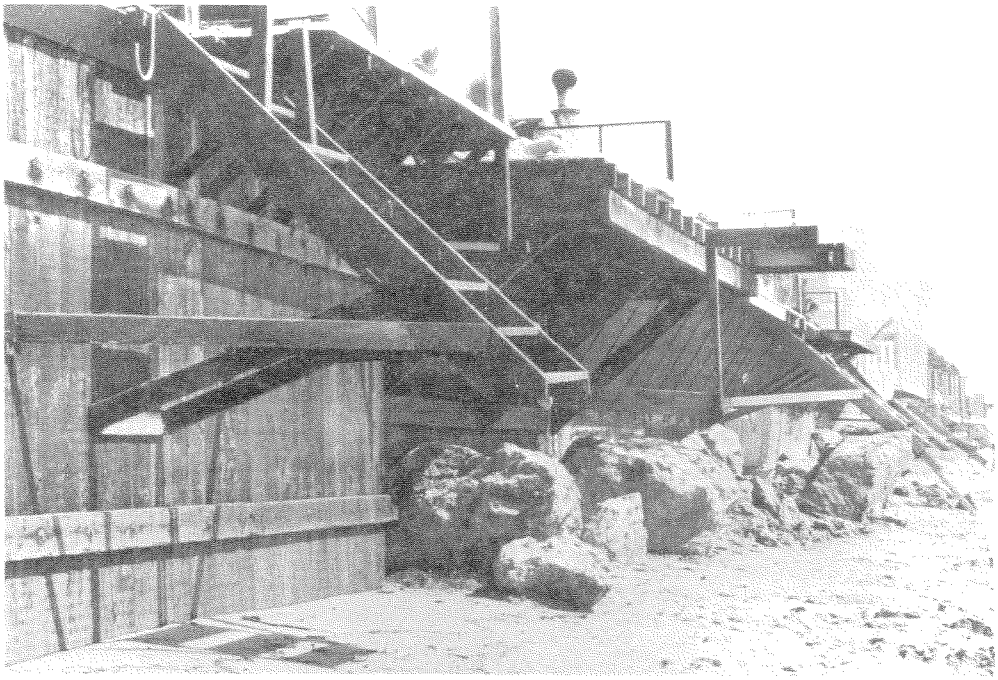


FIGURE A22 View down coast near lot 60 of Malibu Colony. Note depth of beach erosion below the top of the bulkhead and the emergency placement of rock rubble at the toe of the seawall. (Figure 5, George Armstrong, Section 7.)

FIGURE A23 View up coast of damaged patio and destroyed bulkhead at lot 42 of Malibu Colony, March 7, 1978. (Figure 6, George Armstrong, Section 7.)

FIGURE A24 View of damage to Leadbetter Beach, Santa Barbara, February 23, 1980. Shore Processes Laboratory photograph. (Figure 11, Martha Shaw, Section 7.)

APPENDIX B:

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(1980)

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APPENDIX C:

NATIONAL RESEARCH COUNCIL REPORTS OF POSTDISASTER INVESTIGATIONS, 1964-82

Copies available from sources given in footnotes a, b, and c.

EARTHQUAKES

[a]The Great Alaska Earthquake of 1964:

Biology, 0-309-01604-5/1971, 287 pp.
Engineering, 0-309-01606-1/1973, 1198 pp.
Geology, 0-309-01601-0/1971, 834 pp.
Human Ecology, 0-309-01607-X/1970, 510 pp.
Hydrology, 0-309-01603-7/1968, 446 pp.
Oceanography and Coastal Engineering, 0-309-01605-3/1972, 556 pp.
Seismology and Geodesy, 0-309-01602-9/1972, 598 pp.
Summary and Recommendations, 0-309-01608-8/1973, 291 pp.

[c]Engineering Report on the Caracas Earthquake of 29 July 1967 (1968) by M. A. Sozen, P. C. Jennings, R. B. Matthiesen, G. W. Housner, and N. M. Newmark, 233 pp.

[c]The Western Sicily Earthquake of 1968 (1969) by J. Eugene Haas and Robert S. Ayre, 70 pp.

[b]The Gediz, Turkey, Earthquake of 1970 (1970) by Joseph Penzien and Robert D. Hanson, 88 pp.

[b]Destructive Earthquakes in Burdur and Bingol Turkey, May 1971 (1975) by W. O. Keightley, 89 pp.

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[a]Available from National Academy Press, 2101 Constitution Avenue, N.W., Washington, D.C. 20418.

[b]Available from Committee on Natural Disasters, National Academy of Sciences, 2101 Constitution Avenue, N.W., Washington, D.C. 20418.

[c]Available from National Technical Information Service, 5285 Port Royal Road, Springfield, Virginia 22161.

[c]The San Fernando Earthquake of February 9, 1971 (March 22, 1971) by a Joint Panel on San Fernando Earthquake, Clarence Allen, Chairman, 31 pp.

[c]The Engineering Aspects of the QIR Earthquake of April 10, 1972, in Southern Iran (1973) by R. Razani and K. L. Lee, 160 pp.

[c]Engineering Report on the Managua Earthquake of 23 December 1972 (1975) by M. A. Sozen and R. B. Matthiesen, 122 pp.

[c]The Honomu, Hawaii, Earthquake (1977) by N. Nielson, A. Furumoto, W. Lum, and B. Morril, 95 pp.

[b]Engineering Report on the Muradiye-Caldiran, Turkey, Earthquake of 24 November 1976 (1978) by P. Gulkan, A. Gurpinar, M. Celebi, E. Arpat, and S. Gencoglu, 67 pp.

[b,c]Earthquake in Romania March 4, 1977, An Engineering Report, National Research Council and Earthquake Engineering Research Institute (1980) by Glen V. Berg, Bruce A. Bolt, Mete A. Sozen, and Christopher Rojahn, 39 pp.

[b,c]Earthquake in Campania-Basilicata, Italy, November 23, 1980, A Reconnaissance Report, National Research Council and Earthquake Engineering Research Institute (1981) by James L. Stratta, Luis E. Escalante, Ellis L. Krinitzsky, and Ugo Morelli, 100 pp.

FLOODS

[b]Flood of July 1976 in Big Thompson Canyon, Colorado (1978) by D. Simons, J. Nelson, E. Reiter, and R. Barkau, 96 pp.

[b]Storms, Floods, and Debris Flows in Southern California and Arizona--1978 and 1980, Proceedings of a Symposium, September 17-18, 1980, National Research Council and California Institute of Technology (1982) by Norman H. Brooks et al., 487 pp.

DAM FAILURES

[b]Failure of Dam No. 3 on the Middle Fork of Buffalo Creek Near Saunders, West Virginia, on February 26, 1972 (1972) by R. Seals, W. Marr, Jr., and T. W. Lambe, 33 pp.

[b]Reconnaissance Report on the Failure of Kelly Barnes Lake Dam, Toccoa Falls, Georgia (1978) by G. Sowers, 22pp.

LANDSLIDES

[b]Landslide of April 25, 1974, on the Mantaro River, Peru (1975) by L. Lee and J. Duncan, 79 pp.

[b]The Landslide at Tuve, Near Goteborg, Sweden on November 30, 1977 (1980) by J. M. Duncan, G. Lefebvre, and P. Lade, 25 pp.

WINDSTORMS

[c]Lubbock Storm of May 11, 1970 (1970) by J. Neils Thompson, Ernest W. Kiesling, Joseph L. Goldman, Kishor C. Mehta, John Wittman, Jr., and Franklin B. Johnson, 81 pp.

[c]Engineering Aspects of the Tornadoes of April 3-4, 1974 (1975) by K. Mehta, J. Minor, J. McDonald, B. Manning, J. Abernathy, and U. Koehler, 124 pp.

[b,c]The Kalamazoo Tornado of May 13, 1980 (1981) by Kishor C. Mehta, James R. McDonald, Richard C. Marshall, James J. Abernathy, and Deryl Boggs, 54 pp.