EQL Report No. 17-B

SEDIMENT MANAGEMENT FOR SOUTHERN CALIFORNIA MOUNTAINS, COASTAL PLAINS AND SHORELINE

PART B
INLAND SEDIMENT MOVEMENTS BY NATURAL PROCESSES

by

BRENT D. TAYLOR

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PREFACE

In southern California the natural environmental system involves the continual relocation of sedimentary materials. Particles are eroded from inland areas where there is sufficient relief and precipitation. Then, with reductions in hydraulic gradient along the stream course and at the shoreline, the velocity of surface runoff is reduced and there is deposition. Generally, coarse sand, gravel and larger particles are deposited near the base of the eroding surfaces (mountains and hills) and the finer sediments are deposited on floodplains, in bays or lagoons, and at the shoreline as delta deposits. Very fine silt and clay particles, which make up a significant part of the eroded material, are carried offshore where they eventually deposit in deeper areas. Sand deposited at the shoreline is gradually moved along the coast by waves and currents, and provides nourishment for local beaches. However, eventually much of this littoral material is also lost to offshore areas.

Human developments in the coastal region have substantially altered the natural sedimentary processes, through changes in land use, the harvesting of natural resources (logging, grazing, and sand and gravel mining); the construction and operation of water conservation facilities and flood control structures; and coastal developments.

In almost all cases these developments have grown out of recognized needs and have well served their primary purpose. At the time possible deleterious effects on the local or regional sediment balance were generally unforeseen or were felt to be of secondary importance.

In 1975 a large-scale study of inland and coastal sedimentation processes in southern California was initiated by the Environmental Quality Laboratory at the California Institute of Technology and the Center for Coastal Studies at Scripps Institution of Oceanography.

This volume is one of a series of reports from this study. Using existing data bases, this series attempts to define quantitatively inland and coastal sedimentation processes and identify the effects man has had on these processes. To resolve some issues related to long-term sediment management, additional research and data will be needed.

In the series there are four Caltech reports that provide supporting studies for the summary report (EQL Report No. 17). These reports include:

EQL Report 17-A -- Regional Geological History

EQL Report 17-B -- Inland Sediment Movements by Natural Processes

EQL Report 17-C -- Coastal Sediment Delivery by Major Rivers in Southern California

EQL Report 17-D -- Special Inland Studies

Additional supporting reports on coastal studies (shoreline sedimentation processes, control structures, dredging, etc.) are being published by the Center for Coastal Studies at Scripps Institution of Oceanography, La Jolla, California.

CONTENTS

INLAND SEDIMENT MOVEMENTS BY NATURAL PROCESSES

B1. Introduction and Summary

Surface sediment movements on coastal drainages in southern California cover the range from very small to very large, e.g., from the dry down-slope sliding of individual sediment particles induced by the nearby movement of an animal or summer breeze, to the fluvial transport of hundreds of tonnes per minute by rivers in flood. Between these two extremes, there are many other types of movement, involving complex processes. Deterministic models that might be used to predict the occurrence of events in the field, even for a given set of meteorological conditions, are not yet available because of the many variables involved. However, using statistical methods, sediment transport events can be studied as time-series, or correlated with geological, meteorological, and in some cases, biological variables to estimate spatial and temporal probabilities of occurrence.

In southern California, natural conditions (including forest fires) produce extreme variations, temporal and spatial, in the occurrence of inland sedimentation events. This variation complicates even a statistical description of sediment movements by requiring a large body of field data. Available data useful in studying sediment movements are substantial, but they are very limited from the standpoint of quantitatively defining conditions throughout the study area, even for a few decades.

This report and EQL Report No. 17-C attempt, within the limits of available data, to quantify regional sediment movements through two natural boundaries: (1) the interface between erosional and depositional areas, and (2) the shoreline. Geologically, inland surface areas can be characterized as being either "erosional or depositional." In southern California, areas with steep slopes and moderate to high rainfall -- mountains and hills -- are erosional, whereas flatter areas of lower rainfall -- inland valleys and coastal plains -- serve primarily as depositional areas for sediments yielded from erosional areas. Within the study area, 4/5 of the coastal drainage is erosional and 1/5 depositional (see Plate B-2). This interface between erosional and depositional areas is one of the two boundaries considered in defining regional sediment movements.

The second interface of special importance is the boundary between terrestrial and marine processes -- the shoreline. With the exception of some lagoonal and marsh areas along the coast, the shoreline in southern California is distinct and easily defined.

EQL Report No. 17-C treats sediment deliveries to the shoreline by major rivers and streams that flow over larger depositional areas before reaching the coast. On most of these rivers and streams, sediment discharge measurements have been made for a number of years by the U.S. Geological Survey. This report, on the other hand, quantifies sediment flux from erosional upland areas.

In coastal southern California more than 94 percent of the erosional inland areas are catchments that debouch water and sediment onto intermediate depositional areas with possible losses of both sediment (deposition) and water (percolation) prior to entering the ocean. However, there are many smaller catchments in key areas that drain directly to the shoreline without any significant intermediate deposition. Sediment yields from erosional areas in both types of catchments are considered in this report.

Average annual denudation rates on 36 gaged catchments distributed throughout the region vary from 0.01 mm/yr on plains areas to more than 4 mm/yr in small, steep mountainous catchments. The denudation rates for mountain or hill catchments are remarkedly uniform throughout the study area despite significant variations in parent rock types, geological history, and size distributions of eroded material. Estimated effects of human developments and artificial control structures on erosion suggest that overall regional erosion has been altered very little during the past 50 years, but in a few areas, human effects may have been significant.

Study results indicate that in this coastal drainage region, under natural conditions, an average of 12 million m^3 of sedimentary debris are yielded from upland catchments each year. This material (6.1 million m^3 fines, 5.1 million m^3 sand, and 0.8 million m^3 of gravel and boulders) is delivered primarily to large inland valleys and coastal plains areas, but an average annual volume of some 0.7 million m^3 (0.5 million m^3 fines, and 0.1 million m^3 sand) is delivered directly to the coast. Locally, yearly catchment sediment yields have varied more than four orders of magnitude during the past five decades.

Comparisons of aggregate upland sediment yields and coastal sediment deliveries on major river systems suggest that under recent natural conditions alluvial rivers in the southern part of the study area are depositional along their flood plains, with only a fraction of the aggregate sediment yields being delivered to the shoreline. But on three northern rivers, this comparison suggests net flood plain <u>erosion</u> under recent natural conditions.

In the following sections, the first two, B2 and B3, identify the natural and human factors that govern sedimentation processes in southern California. The purpose of these sections is to provide a background for the quantitative discussion to follow in section B4. It should be noted that while this discussion identifies key factors in regional sedimentation, it does not provide a rigorous model that may be used to quantify natural sedimentation processes.

Section B4 develops regionwide estimates of catchment sediment yields, using an equation based on field data relating denudation rate (sediment yield per unit area) to catchment area and geographic land type -- mountains, hills, or plains. These estimates are aggregated by larger hydrographic drainage units, and compared with estimates of coastal sediment delivery for eight major river basins (EQL Report No. 17-C).

B2. Natural Conditions

B2.1 General Factors Affecting Catchment Erosion

In attempting to quantify the active processes in a natural drainage basin one encounters not only a complex set of physical, chemical, and biological processes, but also strong nonlinear interactions and constantly changing conditions.

For example, if a physiographic unit (e.g., mountain range) is being uplifted more rapidly than it is lowered by erosional processes, hillslopes and drainage channels will steepen. As catchment slopes steepen, erosion rates will increase until there is an eventual equilibrium with the local rate of uplift. Conversely, as the rate of uplift of an erosional unit is reduced below the rate of down-cutting, there will be a general reduction in slopes over geological time. Consequently, the average erosion rate will eventually be reduced and approach the local rate of uplift, which may be zero.

At present, there are areas of significant recent tectonic uplift in coastal southern California, and other areas where rates of uplift appear to be small compared to erosion rates. For example, in the San Gabriel Mountains current uplift rates have been estimated (Scott and Williams, 1974) at 5 to 7 m per 1,000 years, with denudation rates around 1 to 2 m per 1,000 years, suggesting a "youthful" mountain range where down-cutting has not yet reached equilibrium with uplift rate.

In other areas such as the San Joaquin Hills, near the coast, between Newport Bay and San Juan Capistrano, the landforms are well-rounded and of moderate slope, suggesting that in this area surface erosion may be the dominant geomorphic process and that the natural rate of down-cutting (1/2 meter per 1,000 years) is significantly greater than the rate of recent tectonic uplift.

With tectonic processes, internal stress can lead to the fracturing of parent rock. This endogenic disintegration enhances chemical and biological weathering of surface materials and renders them more susceptible to erosional processes; but on the other hand infiltration capacity is increased, and consequently, surface runoff is reduced. In the San Gabriel Mountains, intense stress fracturing has been reducing parent granitic and metamorphic bedrock to a broad gradation of fragment sizes near the surface and at depth.

For simplification, in developing a model that might be used to characterize sediment yield over a few decades, it can be assumed that except for the occurrence of fire, a catchment does not change appreciably over the short term. Then, recent catchment behavior can be extrapolated to estimate annual sediment yields over a future period of interest.

Two general techniques are available with this simplification. First, sediment yield may be measured as the sediment discharge from the catchment for a period of time sufficient to identify the catchment's characteristic behavior.

Second, a predictive model can be used to estimate catchment sediment yield. This model would be based on specific physical characteristics of the catchment, including climatic inputs. Catchment sediment yield then is estimated by measuring the required input variables and applying the model. Such a model, in its development, usually requires sediment yield data on a number of test catchments for calibration.

Each technique has advantages and disadvantages. The first is accurate and detailed, but may require data collected over a period of 20 or more years. The second technique requires lengthy time series data on some but not all catchments of interest. Estimates of sediment yield using this technique are, in general, less accurate than with the first technique because of the reduced number of input variables in the model compared with the complex physical processes that are important.

Due to the very limited sediment discharge data currently available for upland catchments in southern California, and the need to estimate sediment yields on ungaged catchments, the second technique has been adopted in this report. In EQL Report 17-C a modification of the first technique is used to estimate shoreline sediment deliveries by flood-plain rivers and streams whereon sufficient time series of sediment discharge and streamflow data are available.

Natural factors that primarily determine short-term catchment sediment yields in southern California include: surface geology, precipitation, topography, vegetation, and fire. These factors will be discussed with some key references, although it is not possible to use this information quantitatively in developing estimates of sediment yields.

Surface Geology

In coastal southern California, inland geological surfaces are composed primarily of sedimentary, granitic, and metamorphic materials of varying age and structural condition. Regional geological history is discussed in detail in EQL Report No. 17-A, with Plate A-2 identifying compositional surface geology.

Surface geology affects catchment sediment yield in several ways. First, surface material constitutes the primary source materials that are picked-up and transported. Thus, except for particle-size alterations that take place during transport, physical and chemical characteristics of this material define the size distribution as well as mineral composition of the sediment yield. For example, weathered granite produces coarse feldspathic sand usually of uniform size; metamorphic crystalline rocks generally produce sediments with a broad range of sizes including boulders, cobbles, sand, and silt; and siltstones and shales yield silt and clay particles.

Local regolith composition strongly influences the mechanics and relative importance of different hillslope erosion processes, and the depth and constitution of the regolith affect infiltration rates, and thus surface runoff.

Materials in the surface layer influence local vegetation by providing materials in which the plant root structure develops, as well as a matrix for retaining moisture for plant use. Chemically, the regolith also provides some of the materials needed for plant growth.

Surface materials in hydraulic transit further affect catchment sedimentation by influencing stream mechanics and channel development processes.

Precipitation

The climatic factor primarily responsible for the physical dislocation and transport of sediment in southern California is rainfall. There are primarily two large-scale weather patterns responsible for precipitation in coastal southern California. During winter, cool, moist, unstable polar air masses originating near the Aleutian Islands enter the region from the west; and in the fall tropical storms may approach from the south. These patterns bring in seasonal precipitation, including episodic rains of several days which have produced short-period rainfall intensities among the most severe recorded anywhere on earth.

Plate B-1 identifies variations in mean annual precipitation throughout the coastal region and also illustrates the close relationship between rainfall and elevation in this area.

Rainfall data are collected at several hundred stations in the study area. Most of these stations are located in accessible urban areas, with a large percentage in the populous Los Angeles basin. Each of the seven counties -- Santa Barbara, Ventura, Los Angeles, San Bernardino, Riverside, Orange and San Diego -- publishes periodic hydrologic reports that identify available rainfall data within their respective areas. There have also been limited analytical studies.

The California Department of Water Resources (1976, 1981) has published precipitation statistics (frequency-duration, etc.) for a number of individual stations in the study area.

In 1954, the Geological Survey published a comprehensive Hydrologic Atlas (Troxell et al., 1954) on the San Bernardino and eastern San Gabriel mountains area. This report includes a brief but lucid description of local rainfall characteristics.

Southern California's climate has been described as Mediterranean in type, with seasonal precipitation generally occurring between November and March. Figure B2-1 illustrates this monthly variation in rainfall, and Fig. B2-2 identifies annual variations in rainfall over 130 years at San Diego.* While mean annual rainfall varies considerably (three to five times greater in local mountains than in adjoining valleys and coastal plain areas) as shown in Plate B-1, the monthly distribution of rainfall and relative variations from one year to another shown in Figs. B2-1 and B2-2, respectively, are typical throughout the region.

Local rainfall also varies with coastal location, becoming drier as one moves downcoast toward Mexico. During the 100-year period, 1881-1980, mean annual rainfall at Santa Barbara was 45.7 cm, at Los Angeles 37.8 cm, and at San Diego 25.5 cm, indicating nearly a factor of two difference in rainfall from one coastal extreme to the other.

As shown in Fig. B2-1, during a given month local rainfall can vary from zero to four or five times normal during winter (wet) months and 30-40 times normal during the dry season.

*Location of longest continuous rainfall record in southern California.

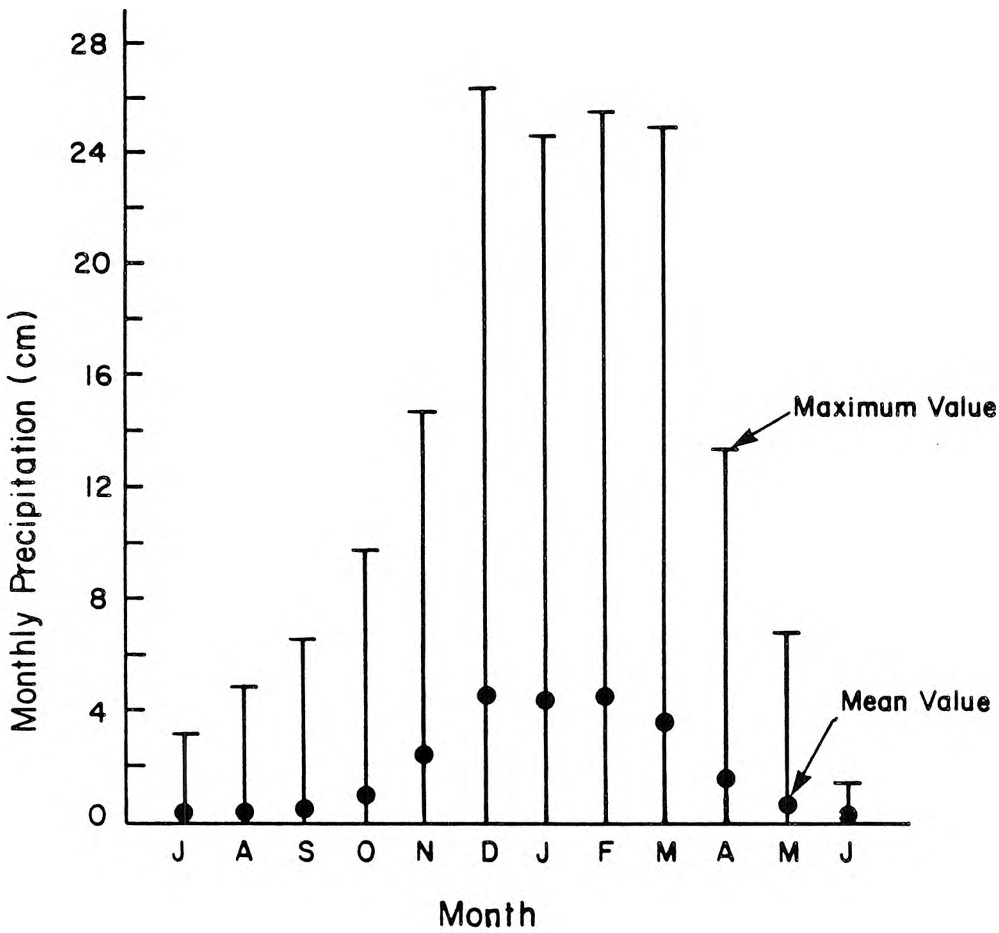

Figure B2-1: Monthly precipitation at San Diego: 130-year means, and maximum values recorded for period 1851-1980 (minimum value for all months 0.0).

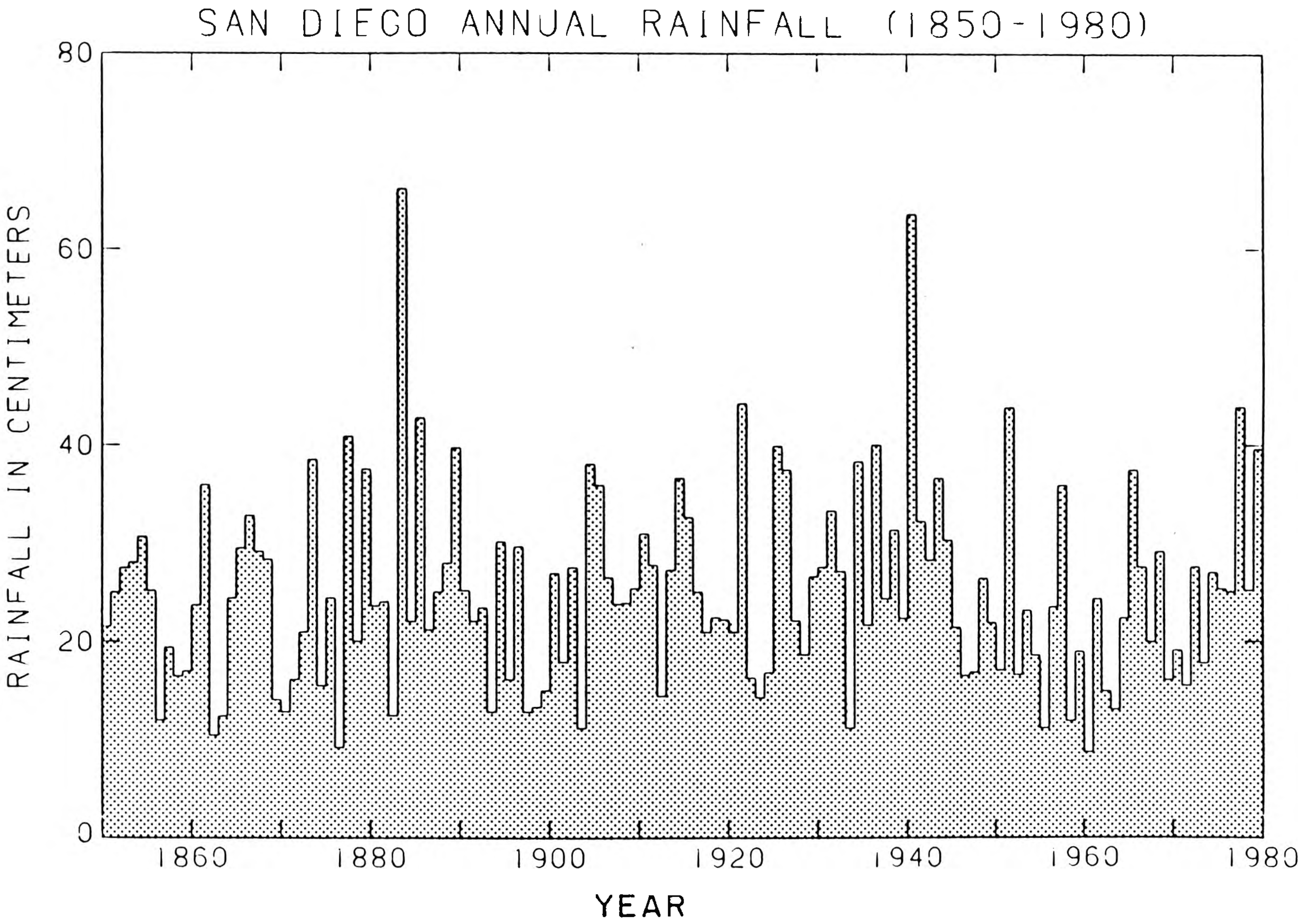

Figure B2-2: Annual Precipitation at San Diego for 130-year period 1850-1980.

Figure B2-3 identifies longer-term wet and dry periods during the past 130 years, which lasted in some cases for several decades. The 130-year record is not long enough to identify climatic changes that may be taking place in the region. Attempts were made during the study to correlate available tree-ring data with annual rainfall data in order to synthetically extend local rainfall records. These attempts, however, were unsuccessful due to the low correlation between tree growth and annual precipitation.

Figure B2-4 is a plot of the cumulative departures from the mean annual rainfall at Santa Barbara, Los Angeles, and San Diego. The plot illustrates both temporal and regional variations in rainfall. The periods 1883 through 1904 and 1934 through 1977 are characterized by an interval of unusually wet years followed by an interval of dry years, for all three stations. A similar cycle for the period 1904 through 1934 is evident for Santa Barbara and Los Angeles, but not for San Diego.

Precipitation is not only primarily responsible for the dominant physical processes that dislodge and transport sediments in this region. It also is an important factor in physical and chemical weathering processes, and in part determines local vegetation species and density. In spite of these important roles it is difficult to relate rainfall parameters to sedimentation processes in a quantitative way. The basic difficulties are two-fold: first, an absence of adequate, detailed field data for analyses, and second, the general complexity of field processes and variations in field conditions.

Langbein and Schumm (1958) have shown in general studies that variations in rainfall can affect catchment sediment yield in different ways. An increase in mean annual precipitation in arid climates leads to an increase in mean annual sediment yield. In humid climates an increase in mean precipitation reduces sediment yield. These results suggest that in arid climates, the probable increase in

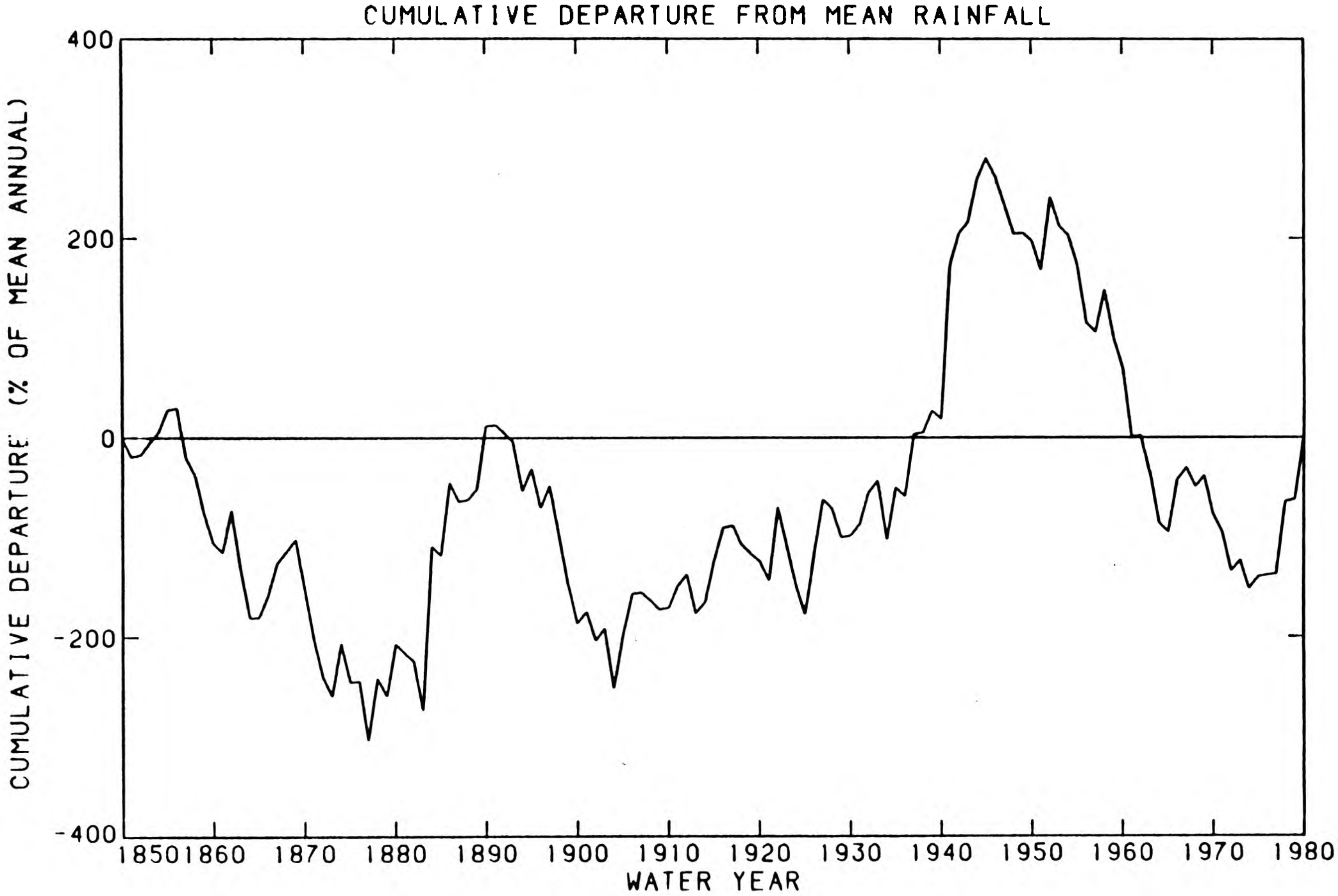

Figure B2-3: Cumulative annual departures from mean precipitation as percent of mean, at San Diego for 130-year period 1851-1980.

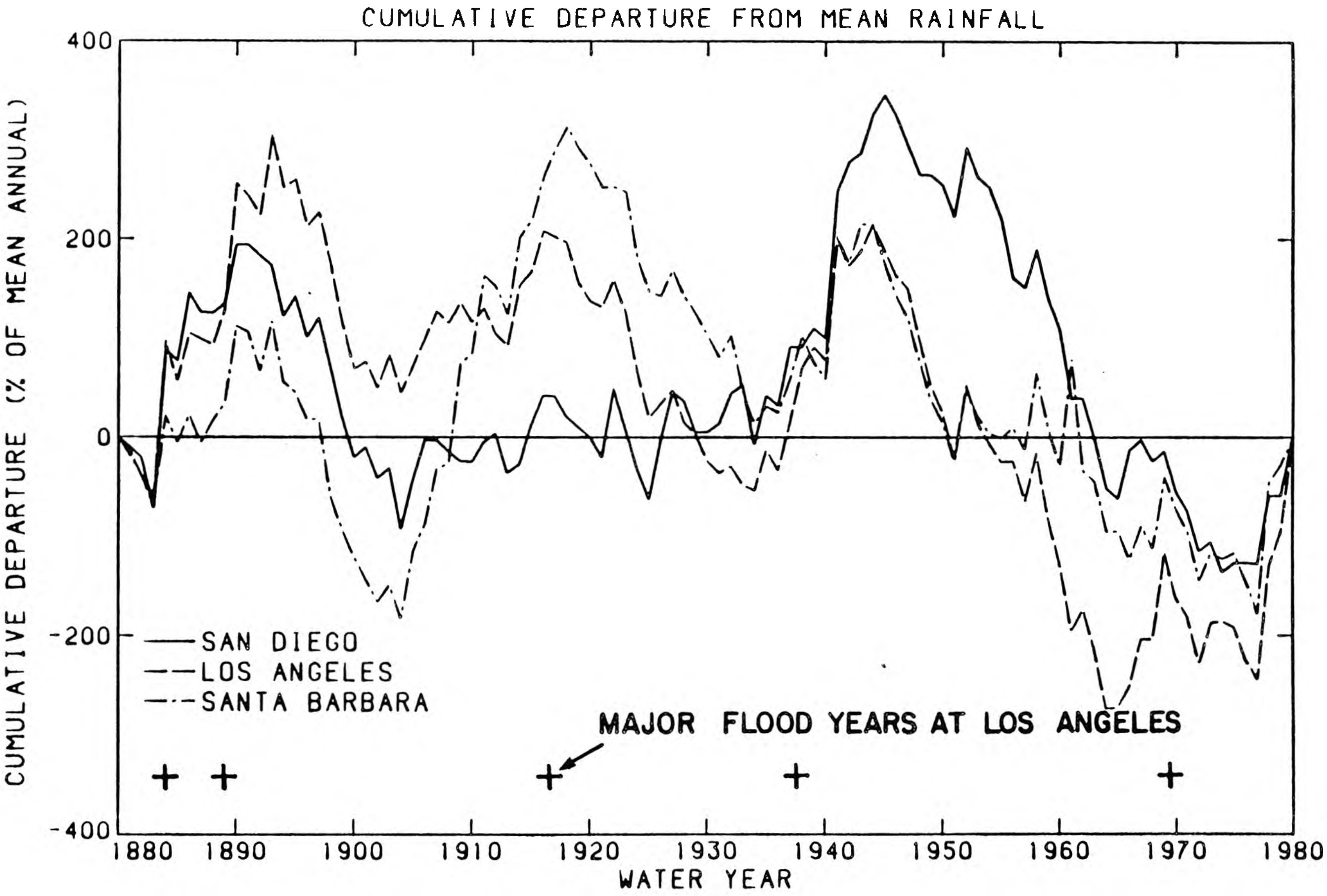

Figure B2-4: Cumulative departure from mean annual precipitation as percent of mean, at Santa Barbara, Los Angeles and San Diego for 100-year period 1881-1980.

stabilizing vegetative cover with increase in mean rainfall does not offset the increased erosion potential produced by increased mean runoff (and infiltration). In humid climates, apparently the converse is true. In coastal southern California the climate is semi-arid, and thus the relation between mean annual precipitation and catchment sediment yield may be complex. At present, however, there is not enough field data available to clarify local relations.

Topography

As shown in Plate A-1 of EQL Report 17-A, in the coastal drainages of southern California, local topography ranges from gently-sloping valley and plain areas through mature well rounded hills with vertical reliefs of hundreds of meters to high rugged mountainous areas with peak elevations over 3,000 m.

Topography affects sediment yield in a number of ways. The macro-topography of an area defines surface drainage units and general land type -- mountains, hills, etc., while micro-topographic features define hillslopes and drainage channels. Topography also influences catchment precipitation and vegetation.

Local slope determines the gravitational component acting to dislodge and transport particles and larger mass units. Slope also strongly affects velocity and depth of surface runoff, and thus the erosive power of these flows. In addition, hillslope length and shape are important factors in slope stability.

Hillslope sedimentation processes are determined by local conditions and are essentially independent of conditions (and events) at other locations in the catchment. The notable exception to this is the influence of vertical and lateral channel undermining along the toe of a hillslope (Anderson et al., 1959). On the other hand topographic influences on channel sedimentation processes are more complex. Local channel conditions are in some measure the consequence of all upstream hillslope and channel processes in the catchment, and therefore all upstream topographic factors. If the channel system served only to transport hillslope material delivered to it during a storm, channel processes could be neglected in quantifying catchment sediment yield. But lateral channel movements alter hillslope stability, and channels may aggrade or degrade. Thus channel activity can reduce or amplify sediment yield and is an active part of the catchment sedimentation system.

Vegetation

Section D3 (including Plates D3-1,2) in EQL Report 17-D identifies native vegetation throughout coastal southern California, and probable changes in vegetation that have taken place with the advent of man. In coastal southern California, vegetation varies from sparse alkali grasses in dry inland valleys to chaparral (a variable mixture of several semi-arid vegetation types) so thick a man can't walk through it, to strong stands of deciduous/coniferous forests at higher elevations.

Vegetation affects sediment yield processes by altering above-surface, surface, and sub-surface conditions. The vegetation rising above the surface intercepts falling rain, thereby reducing surface impact, and altering drop sizes. Part of the intercepted rain is retained; some of this water evaporates from the above-surface plant material, and the remainder is delivered to the ground by stem flow.

Above-surface vegetation alters hydraulic erosion processes at the surface by offering protruding elements that retard the movement of surface runoff. Also, matted surface vegetation such as grasses protect sediment particles from direct attack by rain drop impact and surface flows.

The root systems of vegetation help break up parent rocks near the surface and enhance infiltration and the movement of sub-surface water. Both of these factors contribute to physical and chemical weathering. At the same time, sub-surface vegetation serves to stabilize the regolith against mass movements due to the tensile and shear strength of root systems and their network-like attachment to otherwise loose materials. In a field study by Corbett and Rice (1966) in the San Gabriel Mountains it was found that when deep-rooted vegetation types were replaced by shallow-rooted species, mass movements on hillslopes increased dramatically.

On the average, for a given watershed and climate, the more vegetative cover there is, the smaller will be the sediment yield.

Fire

A detailed discussion of the effects of fire on erosion processes and regional fire history (including an historical fire frequency map, Plate D4-1) over the past few decades is included in section D4 of EQL Report 17-D.

Fire destroys most above-surface vegetation and thus lays bare surface materials. Furthermore, the wettability and infiltration capacity of many mountain soils is greatly reduced by the heat and ash from the fire. With this, the effectiveness of rainfall in producing erosion is enhanced until vegetation is re-established. Therefore, a storm that occurs shortly after a burn generally causes significantly more sediment yield and much larger flood flows than it would have without the burn.

The periodic occurrence of fires may or may not increase long-term erosion rates. If catchment sediment yield is limited by the physical and chemical weathering rates of near-surface materials rather than transport processes, fire will increase long-term sediment yield only insofar as it enhances the net weathering process. If surface materials are generally decomposed, however, and their susceptibility to erosion and transport is limited by available precipitation and vegetative cover, the occurrence of fire should increase average erosion rates by periodically increasing the vulnerability of the loose surface materials.

Field reconnaissance suggests that upland catchments in southern California are primarily of the second type -- there appears to be a constant abundance of loose surficial material. Thus, with fires, one might expect catchment sediment yield rates to increase by the amount of increased erosion taking place during the regrowth period. In an analysis of fire and sediment yield data collected over a 32-year period on 21 catchments, Fall* identified variable net increases due to fire, with a mean increase of about 10 percent in average annual sediment yield for the 21 catchments. The included catchments varied in size from less than 1 km^2 to more than 400 km^2, and were located along the south frontage of the San Gabriel Mountains where the native vegetation is predominantly chapparal.

Fires in southern California usually occur in the fall after several months without significant rainfall, and often during Santa Ana winds, which blow occasionally from the northeast and are dry and warm. Driven by ambient and self-induced winds, the fires burn rapidly through brush, sometimes only scorching vegetation types with thick stems or significant plant moisture. Fire destroys essentially all small brush and grass foliage above the ground. With some plant types it also destroys the regenerative parts of root systems located near the surface. In other cases, fire not only leaves vital regrowth elements intact, but induces the sprouting of seeds that otherwise would remain dormant. For deep-rooted vegetation whose regenerative capacity is destroyed, several years are required in the semi-arid climate for decay and substantial loss of structural strength, and local regrowth has usually taken place before this occurs.

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*Edward W. Fall, California Institute of Technology, personal communication, May 1978.

By destroying above-surface foliage and shallow root systems (surface temperatures during a fire can reach several hundred degrees Centigrade), a burn significantly alters fluvial sedimentation by altering vegetation effects outlined in the previous section. Also, a fire can significantly change the chemical and physical properties of sediment materials near the surface where, with large temperature gradients, combustion gases diffuse, coalesce and react. Among other possible effects, this can produce a non-wettable layer near the surface that repels water and thus enhances runoff. With time, several years perhaps, this condition apparently reverses itself or the layer is removed by surface erosion, and a pre-fire condition again occurs.

In coastal southern California, severe natural disasters known as "fire-flood sequences" are not uncommon. In addition to causing many millions of dollars in damages, these events have taken a number of human lives during the past few decades, even though in many cases the contributory catchments are only a few square kilometers in drainage area. Following a fire, if, during subsequent storm periods, the right combination of antecedent soil moisture conditions and short-period, high-intensity rainfall are realized, relatively large abrupt flood waves can develop sometimes transporting more sediment by volume than water. These high-momentum flood waves can easily pick up and transport automobiles and bury houses.

B2.2 Mechanisms of Sediment Erosion and Transport on Upland Catchments

Sediment erosion and transport refer in this report to the near-surface detachment and movement of solid particles by gravitational processes. Table B2-1 differentiates the six types of sediment erosion and transport events most common in southern California. In each case, there are notable differences in the time and mass scales, and the mechanics of movement. A practical description of what takes place with each of the six processes might include:

Table B2-1

Sediment Erosion and Transport Processes in Southern California

	Particle Movements	Mass Movements
Dry	a) Ravel*	d) Landslides
		e) Creep
Wet	b) Rainsplash	d) Landslides
	c) Rill and channel transport	f) Sediment ("mud") flows

*Individual particle movement down slopes.

Table B2-2

Characteristics of Sediment
Erosion and Transport Processes
in Southern California

	General Time Scale of Sediment Movement	General Mass Scales	General Distance of Movement
a) Ravel	seconds $0(10^{0}s)$*	milligrams $0(10^{-6}kg)$	meters $0(10^{0}m)$
b) Rain Splash	tenths of a second $0(10^{-1}s)$	milligrams $0(10^{-6}kg)$	centimeters $0(10^{-2}m)$
c) Rill and Channel Transport	minutes $0(10^{2}s)$	milligrams to tonnes $0(10^{-6}-10^{3}kg)$	kilometers $0(10^{3}m)$
d) Creep	years	hundreds of tonnes to tens of thousands of tonnes $0(10^{5}-10^{7}kg)$	centimeters per year $0(10^{-2}m/yr)$
e) Landslides	seconds $0(10^{0}s)$	kilograms to tens of thousands of tonnes $0(10^{0}-10^{7}kg)$	tens of meters $0(10^{1}m)$
f) Sediment Flows	minutes $0(10^{2}s)$	kilograms to tens of thousands of tonnes $0(10^{0}-10^{7}kg)$	hundreds of meters $0(10^{2}m)$

*0( ) means "on the order of. . .," i.e., approximate value within plus or minus a half power of ten of the indicated number.

1. Time scale of process
2. Mass scale of process
3. Temporal and spatial frequency of occurrence
4. Distance of movement

A more complete description would also include:

5. Conditions for occurrence
6. Mechanics of movement

Table B2-2 gives general estimates based on limited field data and observations regarding items 1, 2, and 4 for the six different process types. It is not possible, however, with available data, to accurately estimate item 3 and thus estimate the general importance of individual processes throughout the region, or for specific upland areas.

B2.3 Inland Deposition on Alluvial Fans, Valleys and Coastal Plains

Once eroded from the surface, particles are fed into natural drainage channels, which combine, eventually forming a main channel that delivers debris and water to the mouth of the catchment. Most of the upland catchments in coastal southern California (94 percent by area) drain to intermediate valley and plains areas rather than directly to the coast. At the mouth of these catchments, with the changes in land-form, there are significant reductions in channel gradient. These reductions result in reduced stream velocity and sediment transport capacity, and thus partial deposition. This deposition provides an alluvial fan just downstream from the mouth of the catchment. Channel gradients on fans are steeper than those common in valleys and on plains areas but generally lower than channel slopes upstream in the catchment. Most of the coarse sediments yielded from the catchment are deposited near the top of the alluvial fan, and as the stream leaves the toe of the fan it generally carries only finer material (sand, silt, and clay). Thus an active fan may be thought of as a sediment sink, selectively removing primarily coarser particles from catchment sediment yield. Fan deposition is thickest near the mouth of the catchment and spreads outward onto the valley or plain with a downward slope from the mouth to the outer edges. The fan-like deposition is the result of continual changes in channel location over the fan surface which result from the unstable nature of a depositional stream.

Throughout the study area, alluvial fans in one form or another provide transitions from upland catchments to depositional areas. With small drainages from mature hills, the "fan" may consist only of a smooth concave feature composed of finer material. Such transitions are not formally classified as alluvial fans because of their size, shape, and composition. But they serve the same basic purpose in fluvial process as the large majestic fans that spread out below mountain catchments like those along the south frontage of the San Gabriel Mountains.

Alluvial fans and the processes involved in their development have been studied in some detail (Schumm, 1977; Hooke, 1967). But there are still important unanswered questions, such as: rates of fan deposition compared with upstream catchment sediment yields, and size distributions of fan sediments compared with sizes of materials delivered from the catchment. Thus in southern California this part of the inland/coastal sediment system is still not well defined.

After crossing a fan, an alluvial stream flows out onto the floor of an inland valley like the San Gabriel Valley, or a coastal floodplain. Here, upland streams coalesce, becoming tributary to larger streams and rivers. Since fluvial materials primarily form the valley floors and coastal plains it might be expected that streams and rivers flowing over these areas continue in a generally depositional mode. However, river basin conditions can change (over the short term, streamflow; over the longer term, uplift and climate), effecting stream erosion in otherwise depositional areas. Also with quasi-static conditions, the stream may eventually form, through deposition, an "equilibrium" profile across depositional areas, and thereafter flow in the mean without either net deposition or erosion. The characteristic natural regimes of flood plain rivers in southern California have not yet been well-defined in this regard.

B3. Human Perturbations

With the advent of modern man in southern California, human activities have significantly changed natural erosion and deposition processes. In the strictest sense, human activities and developments have modified each of the five primary factors (topography, precipitation, vegetation, fire, and surface geology) governing hillslope and channel sedimentation processes.

B3.1 Alterations in Primary Factors

Topography

Through urban development, road and highway construction, and sand and gravel mining activities, man has altered the natural topography, creating both steeper and more gentle slopes than were present naturally. These artificial changes are usually coupled with changes in vegetation and surface geologic constitution. Urban and highway developments can increase local erosion severely during construction. But, after this initial period denudation rates on urban developments in erosional areas are usually reduced through paving and stabilization to a fraction of their natural values.

More than 90 percent of the urban development in southern California has taken place on low-lying depositional areas, where natural denudation rates are essentially zero, and therefore the only significant effect of these developments on sedimentation has been to increase runoff to local stream channels.

Sand and gravel mining activities have included the extraction of materials both along and away from active stream channels. The effects on sedimentation processes for the two cases can be quite different. Sites away from an active channel are usually located in areas of Recent fluvial deposition where sedimentary materials are close to the surface. The excavations in such areas obviously do not influencing upland erosion, and being unconnected with active stream channels they do not change deposition processes in any significant way.

However, sand and gravel pits in stream beds cause major local changes in stream morphology, as explained in a case study for San Juan Creek by Vanoni, Born and Nouri (1982), when an alluvial fan forms within the pit. If the flood is large enough, the sediment transport may be enough to completely refill the pit. The net effect of any pit in or connected to a stream is to increase deposition locally, and reduce downstream sediment delivery. It is difficult, though, to make quantitative long-term estimates of the reduction in coastal sediment due to the sand and gravel mining operations along and in the main channels of rivers in the coastal zone.

Precipitation

Human activities have altered natural precipitation through limited efforts, mostly in Los Angeles County, to artificially induce precipitation by cloud seeding (introducing silver bromide crystals into incoming water-vapor-laden air masses). In an evaluation study of cloud seeding in Los Angeles County (Thompson and Strange, 1975), it was concluded that from 1961 to 1975 artificial seeding increased annual precipitation by about 20 percent over a 500 km^2 target area in the San Gabriel Mountains. Available data suggest that average denudation rates in this area vary with mean annual catchment precipitation raised to approximately the 3/2 power. With a 20 percent increase in mean annual precipitation and an average catchment denudation rate of 1 mm/yr, this relation would suggest an increased sediment yield on 500 km^2 of 150,000 m^3/yr. However, cloud seeding operations are only conducted during storm conditions having a low flood (erosion) potential. Thus the actual increase in erosion due to cloud seeding in the San Gabriel Mountains in probably only a fraction of this amount.

Vegetation

Significant changes in vegetation have come about in low-lying areas with urbanization and agricultural development. There have also been notable changes on some hillslope areas with open range grazing of livestock and timber harvesting. The widespread agricultural use (including irrigation) of low-lying plains areas may have transformed some naturally stable depositional areas into erosional areas by creating irrigation drainage channels and bare ground conditions. These possible effects, however, have not been documented. On the other hand, irrigated urban areas with lawns, shrubbery, and trees are much more protected from erosion than they were in their original natural states.

The specific effects of upland grazing and timber harvesting also are not known. Both have the potential for accelerating local erosion processes. On the Morena Reservoir drainage, a study by the City of San Diego et al. (1953) attributed severe gullying in what appear to be stable fluvial deposits to overgrazing in the area around the turn of the last century. Residual effects from overgrazing and timber harvesting activities can persist for some time, especially in a semi-arid environment. Due to limitations in available information and data as to the extent and period of these activities as well as their effects on sedimentation processes, it is not possible to estimate their net effect on sediment yield.

Surface Geology

The activities of man have altered surface geology, with resulting impacts on sediment transport, by: construction activities where surface materials are covered with asphalt or concrete; changes in land surface morphology; changes in stream networks and diversion of water from one river to another; and the more subtle effects on rates of surface weathering caused by alterations in vegetation. The quantitative effects of these changes are in most cases very difficult to determine. This is true for the concrete lining of river channels where erosion and percolation are prevented, but transport capacities are greater due to increased water velocity compared to natural channels. Although channelization has a primary effect on stream mechanics and sedimentation, little research has been done in this area; thus, it is an important area for future work. On some rivers it appears that channelization may have substantially increased the shoreline delivery of sand-sized sediments.*

Fire

Plate D4-1 in EQL Report 17-D identifies fire histories throughout the study area back to around 1910. This map indicates that during the period 1910-1975, (1) fires occurred in upland (erosional) areas predominantly, and (2) there have been significant variations in fire frequency from one location to another. Similar data are not available to define conditions prior to the advent of recent human development. Therefore, it is not possible to identify anthropogenic changes in fire frequencies and burn areas. One characteristic that probably has changed is the scale of individual events. Before modern man, fires caused by native elements must have burned large areas, being limited only by significant changes in meteorological conditions or critical reductions in fuel (dry vegetation) density. With large-scale human development came artificial fire control and new sources of ignition. Thus more fires were started, but, with more rigorous controls, individual fires were generally not allowed to burn as large an area as they would have under wholly natural conditions. One consequence of this probable reduction in burn area could be an increase in partial versus total burns on catchments. Such a change could alter long-term average sediment yields. This, however, has not been substantiated.

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*Alfanso Robles, Los Angeles District, Corps of Engineers, July 1979; and Carl Nelson, Orange County Environmental Management Agency, January 1981, personal communication.

In summary, the effects of man's activities on the five general factors governing upland erosion are both positive and negative. With existing data it is not possible to accurately estimate their local or overall consequence on upland erosion. But the positive/negative nature of the human disturbances suggests that the overall effect may be small, although locally or temporarily the increase in erosion can be severe.

B3.2 Man's Activities Affecting Inland Deposition

As explained earlier, the natural stream paths from upland catchments to the ocean generally provide for partial deposition of sediments along the way. This partial deposition, along with the generally unstable behavior of alluvial streams and rivers, as well as local water conservation needs, has led to the construction of many sediment entrapment structures and extensive artificial channels (see section D1, and Plate D1-1, EQL Report 17-D).

Entrapment structures force streamborne sediments to deposit artificially at specific locations. Thus debris basins and reservoirs near the mouths of upland catchments trap sediments and reduce natural building processes on downstream alluvial fans, flood plains, and along the shoreline.

Artificial channels in southern California are generally located on flood plain areas (including alluvial fans) below entrapment structures. They provide stream bank stabilization and in some cases, a concrete bed also. Channelization fixes a stream's course, preventing changes in local cross section, progressive channel migration, and stream avulsion. In all cases, it is intended that the artificial channel convey whatever sedimentary material is delivered to it so that there is not significant erosion or deposition along the channelized reach, and in this regard the channels generally operate as intended. However, unwanted deposition sometimes occurs along lower reaches in times of flood. For example, the severe storms of 1969 left several hundred thousand cubic meters of sediments in the lower reaches of Calleguas Creek and the Santa Ana River channels. As noted earlier, channelization can increase coastal sediment delivery by providing a more efficient hydraulic channel for flood waters. Whereas the natural channel regime often involves flood plain spreading and consequently significant deposition of streamborne sediments before they reach the coast.

The large water conservation and flood control dams in this region are located primarily along the major streams and rivers, treated in EQL Report 17-C where their respective effects on coastal sediment delivery are discussed.

B4. Annual Sediment Yields

The boundary between erosional and depositional areas can generally be defined topographically by delineating mountain and hill areas from valley floors and plains. A more precise definition, however, is possible by identifying surface areas whereon there has been recent deposition of fluvial sediments. Using California geological maps (Jennings et al., 1977), a composite map was prepared identifying these depositional areas (see Plate B-2). All other inland areas in the region were treated as being geologically erosional.

A statistical model based on catchment characteristics was used to estimate sediment yield from upland erosional areas. There are several such models available at present. The widely recognized Universal Soil Loss Equation, which applies primarily to erosion on uniform low-slope agricultural areas, has been used to estimate sediment yields on smaller natural catchments. A second, more pertinent model, developed by Flaxman (1972), is based primarily on data from natural catchments located in the American southwest. Anderson (1949) and Scott and Williams (1974) have proposed models for estimating sediment yields in the western Transverse Ranges. Data for these two models were obtained primarily from drainages in the San Gabriel Mountains. In all four of the models, the predictive equations were developed through statistical regression.

The notion of using statistical regression to predict watershed behavior derives from the complex nature of hydraulic and sedimentation processes operative in a natural catchment -- complexity that has thus far defied the development of rigorous deterministic models for all but the simplest cases. Statistical regression offers a useful way to identify general catchment interrelationships and approximate the functional nature of these relations. By identifying general parametric relationships for catchments, regression analyses can also help improve understanding of catchment mechanics and lead to more rigorous modeling.

With each of the models described, as well as others currentlv available, input data requirements exceed the data base now available on most catchments in the study area, and conversely, it was felt that none of these models make use of all pertinent available data. For each of these reasons, a new model was developed for use in this study. It was thought that by using all available data in coastal southern California and pertinent catchment parameters that are easily obtainable throughout the study area, the most accurate regional definition of sediment yield would be obtained.

In the semi-arid, Mediterranean-type climate of southern California large sediment movement events can occur in a matter of hours or days. The scale of individual events and their frequency of occurrence are important, but in quantifying the regional sediment budget the time scale of primary importance is the year. This is the natural unit of time over which general meteorological patterns, including coastal wave conditions, are repeated; and it is variations in these annual patterns that produce the more important perturbations in the regional sediment budget. For this reason and the fact that currently available data do not allow for a more detailed prediction, the objective in this report is to estimate average annual sediment yields.

B4.1 Measured Denudation Rates and Regression Analysis

Longer-term sediment delivery data for upland drainages were compiled to develop the catchment sediment yield model. The data include debris accumulation measurements in 36 water conservation reservoirs, flood control reservoirs, and smaller debris basins. These 36 structures were chosen primarily based on their (1) extended periods of record, and (2) high sediment trap efficiencies (estimated to be near 100%*). Some consideration was also given to obtaining uniform geographic distribution of the data. The drainages are listed in Table B4-1, and their general locations are shown in Fig. B4-1. They are distributed throughout the region with a somewhat disproportionate concentration in the San Gabriel Mountains area. Three of the drainages are located just outside the study area, but are considered similar to neighboring drainages within the study area. The drainages range in total area from 1 km^2 to more than 1100 km^2 with periods ranging from 11 to 54 years long (within the period 1892-1977). Drainage area (A) is considered to be an important variable in the regression analysis below.

Average annual catchment denudation rate ($\overline{DR}$) was computed for each of the 36 drainages based on the total sediment accumulation (volumetric) in the control structure during the period of measurement. Thus, the measured value of $\overline{DR}$ is equal to the volume of accumulated sediment divided by total erosional area in the drainage and the number of years over which the accumulation took place.** The control structure sediment trap efficiency was in each case assumed to be 100 percent. Values of $\overline{DR}$ for the 36 drainage areas are given in Table B4-1.

Another important variable is topography which can be characterized by L, the dominant land type: mountains (M), hills (H), or plains (P). Mountainous areas are defined as those having rugged topographic features with vertical reliefs on the order of thousands of meters. Hill areas have more mature features and reliefs on the order of

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*For some of the smaller structures (the debris basins), the trap efficiency for the fine sand, silt and clay can be considerably less than one, but there is insufficient data to make an adjustment.

**While there is uncertainty as to the sediment deposition volume in the entrapment facility versus the original volume <u>in situ</u>, this way of expressing catchment sediment yield is easily understood since it suggests a simple average reduction in surface elevation.

Table B4-1

Gaged Drainage Areas Used in Multiple Regression Computations of α, β, and γ in Eq. B4-2

Catchment Area Identified by Control Structure	Map Identification Number	Period of Sediment Yield Measurement (Total Years of Measurement)	Dominant Land Type[a]	Erosional Area, A, in Catchment (Total Area in Catchment) km^2	Measured Average Denudation Rate, $\overline{DR}$, for Erosional Areas in Catchment mm/yr	Computed Value of α, for $\beta = 3.1$ $\gamma = -0.14$	Sub-Regional Value[b] of α_R (Sub-region)[c]	Ratio of Computed Value of $\overline{DR}$ to Measured Value
Gibraltar Reservoir	1	1919-69 (49.8)	M	523. (524.)	0.66	0.073		1.27
Cachuma Reservoir	2	1953-69 (16.6)	M	478. (508.)	1.41	0.15		0.60
Matillija Reservoir	3	1948-70 (22)	M	111. (141.)	0.79	0.070	0.093 (WT)	1.32
Lake Piru	4	1955-75 (20)	M	1029. (1101.)	0.64	0.078		1.19
Dry Canyon Reservoir	5	1935-77 (42)	H	11.5 (11.5)	0.75	0.12		0.76
Fairmont Reservoir	6	1913-39 (26)	H	6.14 (6.14)	0.73	0.11		0.85
Rindge Reservoir	7	1926-45 (19)	H	97.9 (97.9)	0.26	0.058		1.13
Stone Canyon Reservoir	8	1921-39 (18.1)	H	3.0 (3.0)	1.11	0.15	0.065 (SM)	0.43
Chatsworth Reservoir	9	1918-39 (21)	H	8.1 (11.5)	0.34	0.053		1.23
Encino Reservoir	10	1921-39 (18)	H	3.37 (3.37)	0.39	0.054		1.21

Table B4-1 (Continued)

Catchment Area Identified by Control Structure	Map Identification Number	Period of Sediment Yield Measurement (Total Years of Measurement)	Dominant Land Type[a]	Erosional Area, A, in Catchment (Total Area in Catchment)	Measured Average Denudation Rate, $\overline{DR}$, for Erosional Areas in Catchment mm/yr	Computed Value of α, for $\beta = 3.1$ $\gamma = -0.14$	Sub-Regional Value[b] of α_R (Sub-region)[c]	Ratio of Computed Value of $\overline{DR}$ to Measured Value
Pacoima Reservoir	11	1929-73 (44)	M	73.0 (73.0)	1.07	0.089	0.095 (SG)	1.06
Tujunga Reservoir	12	1931-71 (40)	M	213. (213.)	0.70	0.068		1.40
Hansen Reservoir	13	1940-69 (29)	M	361. (378.)	0.73	0.076		1.24
Brand Debris Basin	14	1935-75 (40)	M	2.67 (2.67)	1.10	0.058		1.65
Las Flores Debris Basin	15	1935-75 (40)	M	1.17 (1.17)	3.04	0.14		0.67
Dunsmore Debris Basin	16	1935-75 (40)	M	2.18 (2.18)	2.25	0.11		0.83
Haines Debris Basin	17	1935-75 (40)	M	3.96 (3.96)	1.04	0.058		1.65
West Ravine Debris Basin	18	1935-75 (40)	M	0.65 (0.65)	4.09	0.18		0.54
Devil's Gate Reservoir	19	1920-74 (54)	M	80.8 (82.6)	1.63	0.14		0.69
Santa Anita Reservoir	20	1927-73 (46)	M	28.0 (28.0)	1.97	0.14		0.66

Table B4-1 (Continued)

Catchment Area Identified by Control Structure	Map Identification Number	Period of Sediment Yield Measurement (Total Years of Measurement)	Dominant Land Type[a]	Erosional Area, A, in Catchment (Total Area in Catchment) km^2	Measured Average Denudation Rate, $\overline{DR}$, for Erosional Areas in Catchment mm/yr	Computed Value of α, for β = 3.1 γ = -0.1	Sub-Regional Value[b] of α_R (Sub-region)[c]	Ratio of Computed Value of $\overline{DR}$ to Measured Value
Sawpit Reservoir Reservoir	21	1927-70 (43)	M	8.65 (8.65)	1.93	0.12		0.80
Cogswell Reservoir	22	1934-69 (35)	M	102. (102.)	1.23	0.11		0.88
San Gabriel Reservoir	23	1939-79 (35)	M	424. (424.)	1.46	0.16		0.61
Big Dalton Reservoir	24	1929-72 (43)	M	11.6 (11.6)	1.31	0.084		1.13
San Dimas Reservoir	25	1922-71 (49)	M	42.0 (42.0)	0.87	0.067		1.41
Live Oak Reservoir	26	1922-71 (49)	H	6.48 (6.48)	0.60	0.090		1.05
Thompson Creek	27	1928-69 (41)	H	6.77 (7.77)	0.87	0.13		0.72
Fullerton Debris Basin	28	1941-62 (20.4)	H	12.4 (13.0)	0.23	0.038		1.98
Mockingbird Canyon Reservoir	29	1914-40 (26)	P	29.8 (29.8)	0.06	0.097		0.78
Lake Hemet	30	1892-40 (48)	M	144. (169.)	0.41	0.038		2.00

Table B4-1 (Continued)

Catchment Area Identified by Control Structure	Map Identification Number	Period of Sediment Yield Measurement (Total Years of Measurement)	Dominant Land Type[a]	Erosional Area, A, in Catchment (Total Area in Catchment) km^2	Measured Average Denudation Rate, $\overline{DR}$, for Erosional Areas in Catchment mm/yr	Computed Value of α, for $\beta = 3.1$ $\gamma = -0.14$	Sub-Regional Value[b] of α_R (Sub-region)[c]	Ratio of Computed Value of $\overline{DR}$ to Measured Value
Lake Henshaw	31	1922-51 (29)	H	494. (534.)	0.50	0.14	0.075 (PR)	0.54
Dehr Creek Reservoir	32	1918-51 (33)	P	4.1 (4.1)	0.07	0.085		0.88
Lake Hodges	33	1919-48 (29.5)	H	699. (780.)	0.19	0.055		1.36
El Capitan Reservoir	34	1935-56 (21)	H	461. (461.)	0.46	0.13		0.59
Morena Reservoir	35	1910-48 (38.3)	H	265. (283.)	0.93	0.24		0.32
Barrett Reservoir	36	1921-55 (34)	H	345. (350.)	0.51	0.13		0.56

a - Land type abbreviations: M = mountains, H = hills, P = plains

b - Subregional values of α_R were determined by adjusting the fitted value of α to produce a mean value of 1 for the ratio of computed to measured $\overline{DR}$.

c - Sub-region abbreviation: WT = western Transverse Ranges, SM = Santa Monica Mountains, SG = San Gabriel Mountains, PR = Peninsular Ranges

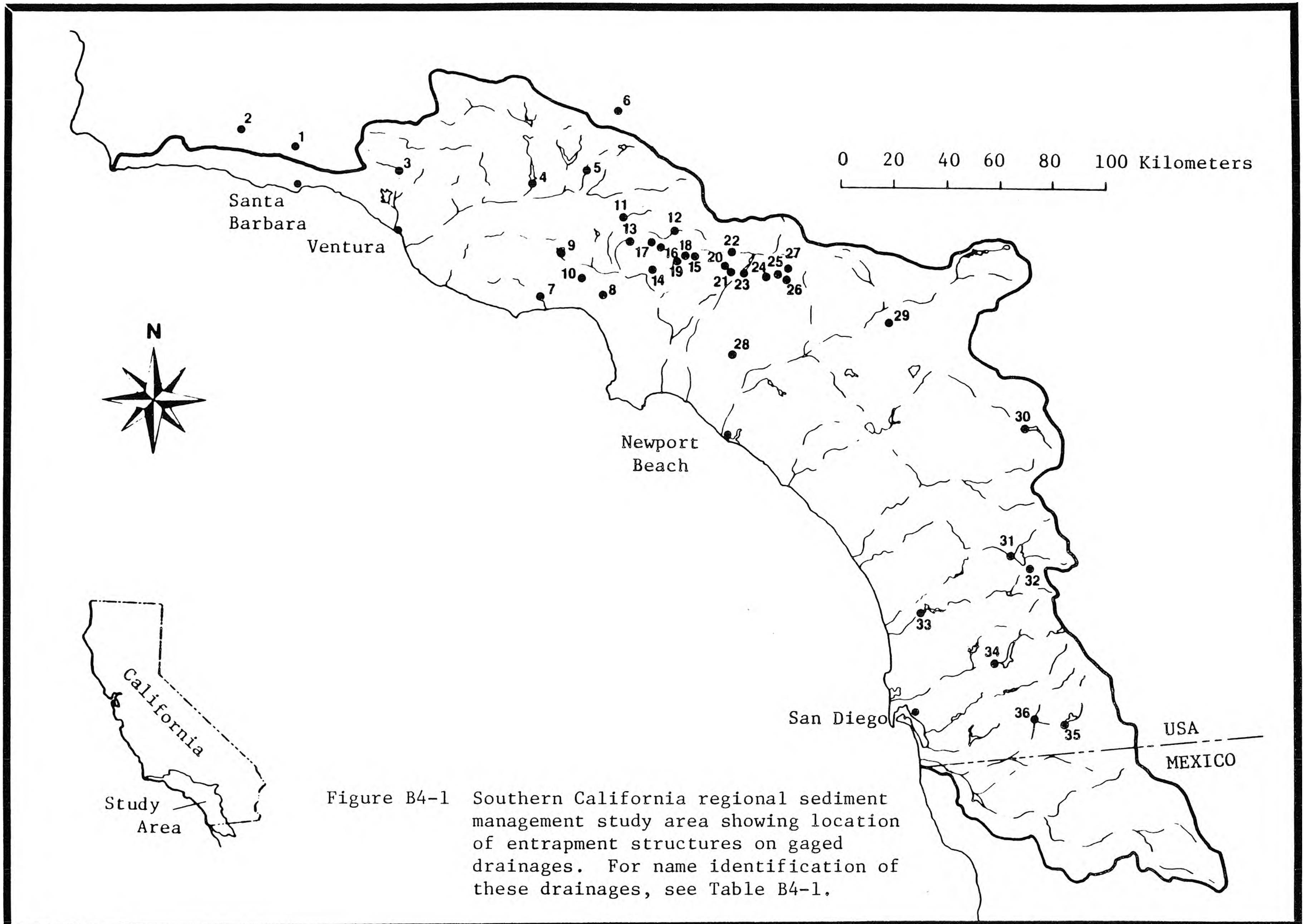

Figure B4-1 Southern California regional sediment management study area showing location of entrapment structures on gaged drainages. For name identification of these drainages, see Table B4-1.

hundreds of meters, and plains are essentially smooth with characteristic reliefs on the order of meters per kilometer. While this land type designation is not rigorous, as will be seen later, it clearly segregates the data, which suggests that this simple classification parameter might be used to partially characterize catchment erosion potential. Designated mountainous drainages have the highest average denudation rates; hill areas have lower denudation rates, and on plains areas measured values of $\overline{DR}$ are very small. The non-zero denudation rates measured for plains areas are believed to be primarily the results of sediment yield and runoff from secondary hill-type features on these catchments, rather than from the plains areas themselves which are depositional features.

A third parameter related to sediment yield, which is readily available and might be included with land type and area to predict sediment yield, is mean annual catchment precipitation ($\overline{P}_A$). Using these three parameters (L, A, and $\overline{P}_A$), a regression relation of the form

$$\overline{DR} = \alpha L^{\beta} A^{\gamma} \overline{P}_A^{\ \delta} \qquad \text{(B4-1)}$$

was tested using data from drainages listed in Table B4-1.

Preliminary analyses indicated that Eq. B4-1 fit the available data as well or better than alternate functional forms, and also that $\overline{P}_A$ did not improve the regression correlation, probably due to the strong correlation between land type and mean annual rainfall. Therefore, $\overline{P}_A$ was dropped from the regression model to give:

$$\overline{DR} = \alpha L^{\beta} A^{\gamma} \qquad \text{(B4-2)}$$

A multiple regression analysis using the logarithms of $\overline{DR}$, L, and A yielded:

$$\alpha = 0.0936$$
$$\beta = 3.11$$
$$\gamma = -0.141$$

with the Land-type parameter defined by:

Land type*	L	L^{β}
Plains (P)	1.0	1.00
Hills (H)	2.0	8.63
Mountains (M)	2.7	22.0

The multiple correlation coefficient for the logarithms is $R = 0.86$. Equation B4-2 and the supporting data are plotted in Fig. B4-2.

The value $\gamma = -0.141$ in Eq. B4-2 suggests that for each land type there is a slight reduction in $\overline{DR}$ with increase in erosional area (A). A similar trend has been reported by others (Brune, 1948; Langbein and Schumm, 1958; and Vanoni, 1975). Langbein and Schumm suggested two probable causes of this trend: 1) larger basins have lower mean surface gradients than smaller ones, and 2) the probability that a given storm condition will cover the entire basin is lower for larger basins than for smaller basins.

On each gaged catchment included in the analysis, area (A) was defined as "erosional" area within the drainage. Thus it was assumed that all debris removed from erosional areas within the drainage was delivered to the artificial trap structure, with no loss on intermediate depositional areas. On some of the catchments deposition areas occupy part of the drainage -- along the main channel and elsewhere. On these drainages a significant portion of

*Land types were quantified by arbitrarily assigning plains areas a value of 1.0, hill areas 2.0, and then by computer iteration determining a value for mountains that yielded a statistical best-fit (i.e., minimum unexplained variance) of the data. This value is 2.7. Note that two values of L can be chosen arbitrarily because of the two fitted coefficients α and β.

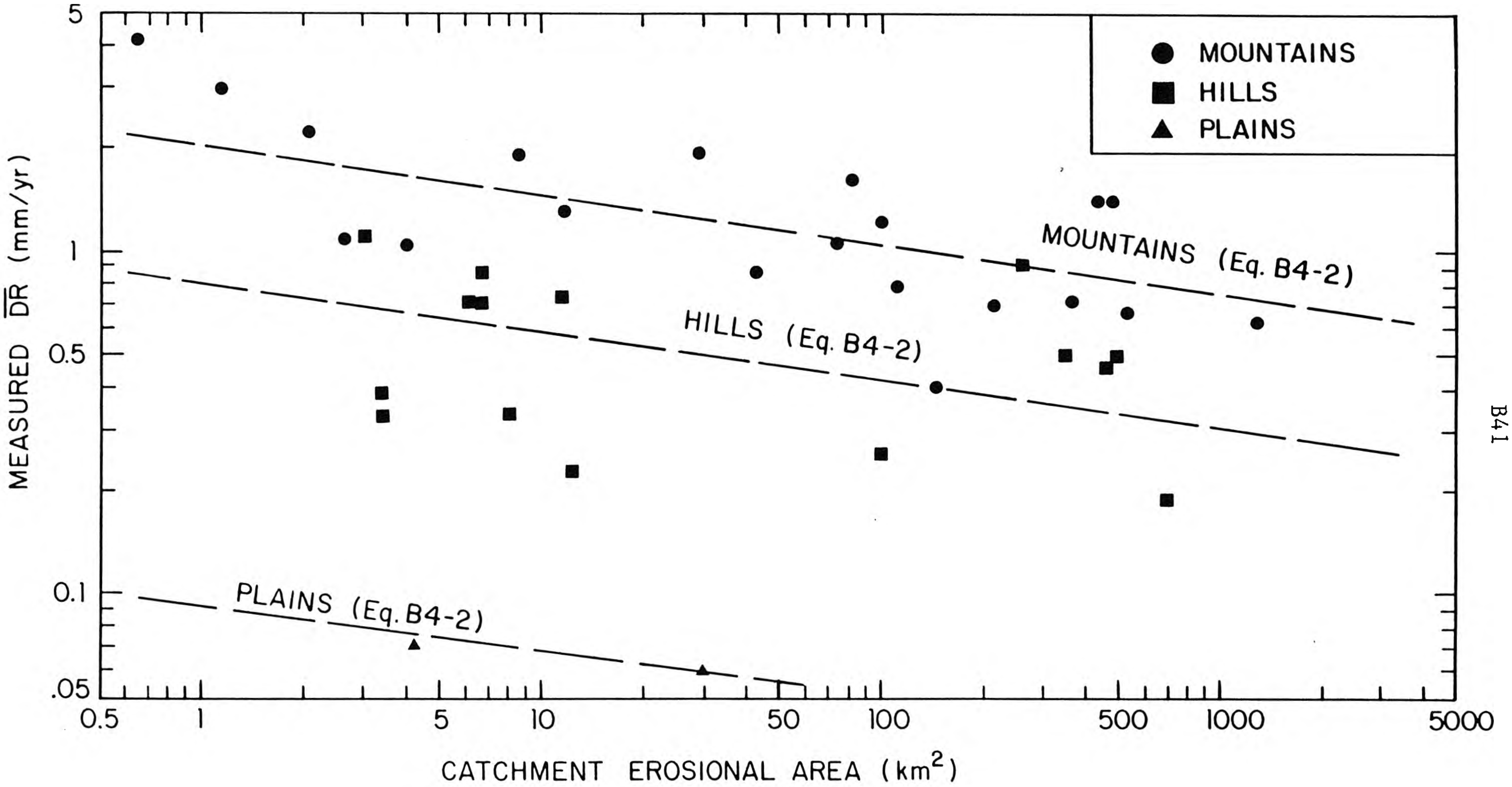

Figure B4-2 Average annual denudation rate as a function of erosional area and dominant land type for 36 catchments identified in Table B4-1.

the eroded sedimentary debris from erosional areas may have been temporarily or permanently deposited before reaching the reservoir. If this is true, measured values of $\overline{DR}$, based on the erosional areas in these drainages, are lower by some undetermined amount than the true values. Two examples of this are Lake Hodges and Lake Hemet. In each case, the measured denudation rates (based on reservoir sedimentation) are lower than might be expected, and a sizeable part of each total drainage area is depositional.

Reasons for the scatter in Fig. B4-2 include:

1. Nonuniformity of catchment variables within the study area. Catchment variables such as soil type and vegetation vary over the study area.

2. Fire and precipitation histories. Local patterns of fire and rainfall can cause large fluctuations in the data which tend to be averaged out, over the long term.

3. Variations in periods of record for the 36 gaged catchments. Since the various debris records have different durations and starting points, the scatter due to fire history is increased further.

4. Measurement errors in debris accumulation data. This error probably varies with individual drainage. On catchments where multiple measurements have been made, significant errors are less likely than on catchments where only a single measurement was made.

5. Variations in structural trap efficiency. Entrapment data were chosen with one criterion being that the control structure provide for essentially total entrapment of sediment inflow. However, based on variations in operating procedures, and reservoir size relative to drainage area and runoff, trap efficiency probably varies between 90 and 100 percent for drainages listed in Table B4-1 (excluding debris basins).

To partially compensate for the nonuniformity of catchment variables, the coefficient α has been adjusted on a subregional basis, as explained in the next section.

Predicted Denudation Rates

In order to obtain estimates of upland sediment yield throughout the study area, the map locating recent depositional areas (Plate B-2) was augmented by subdividing erosional areas into individual catchment or in some cases multiple catchment (multiple-stream) areas. Estimates of $\overline{DR}$ and sediment yield for each catchment area were then obtained as follows:

1. Erosional catchment area (A) was measured.
2. Dominant catchment area land type (L) was determined by superimposing plate B-2 (original 1:250,000 scale) on a map whereon mountain, hill, and plain areas had been delineated based on USGS topographic maps.
3. With these data, values of β and γ previously determined by regression, and a subregional value of the coefficient α (see Table B4-1), $\overline{DR}$ was computed for the designated catchments using Eq. B4-2.

On the smaller catchment areas wherein there are multiple independent streams, in order to compute $\overline{DR}$ using Eq. B4-2, the erosional area, A, was divided by the number of independent contributory streams. Thus for simplification it was assumed that the included independent drainages were of equal size.

Subregional values of α were used rather than the overrall value (0.0936) for the following reason: Variations in individual values of α computed for each drainage area in Table B4-1 using Eq. B4-2 (β = 3.11, γ = -0.141) reflect, in part, differences in the five primary sediment yield factors (topography, precipitation, surface geology, vegetation, and fire) not included in the two independent variables: L and A. They also help compensate for local inaccuracies in the general statistical relationship between dependent and independent variables in Eq. B4-2. Therefore, values of α for nearby drainages of generally similar geology and hydrology should give a more accurate estimate in computing $\overline{DR}$ for an ungaged catchment area than would a regionwide value.

The subregional values of α_R were determined by adjusting the overall value of α to produce an average value of 1 for the ratios of computed to measured denudation rate within a subregion. The following subregional values of α_R were obtained:

Mountain Range(s)	Abbreviation	α_R
Western Transverse	WT	0.093
Santa Monica	SM	0.065
San Gabriel	SG	0.095
Peninsular	PR	0.075

These values suggest that the western Transverse Ranges and the San Gabriel Mountains have notably higher denudation rates than the Santa Monica Mountains and the Peninsular Ranges.

Computed values of $\overline{DR}$ and average annual sediment yield for catchment areas defined in Plate B-2 are given in Table B4-2.

Table B4-1 lists the relative variations in computed versus measured values of $\overline{DR}$ for the 36 gaged drainage areas. All but three of these values differ by less than a factor of 2, with variations among neighboring drainage areas almost as severe as the range of variation throughout the region. Variations in the ratio of computed to measured denudation rate are highest in the Peninsular Ranges subregion.

B4.2 Variations in Catchment Sediment Yields

The above analysis does not treat the question of variations in catchment sediment yields. Of particular interest is the

Table B4-2

Estimated Denudation $\overline{DR}$ for Catchment

Erosional Areas Defined in Plate B-2

Catchment Area Identification Number Plate B-2	Hydrographic Drainage Unit	Drainage Area – A km^2	Dominant Land Type[b]	Sub-Region[c]	Independant Streams in Catchment Area	Computed[d] Value of $\overline{DR}$ mm/yr	Estimated Natural Annual Sediment Yield m^3/yr	Human Changes in Land Use[e]	Estimated Change in Sediment Yield with Present Land Use m^3/yr
1[a]	A	90.9	H	WT	19	0.64	58,300		
2[a]	A	92.1	H	WT	1	0.42	38,900		
3[a]	A	9.2	M	WT	4	1.81	16,600		
4[a]	A	36.7	M	WT	4	1.49	54,600		
5	A	19.4	H	WT	1	0.53	10,200		
6[a]	A	45.2	M	WT	4	1.44	65,300		
7	A	42.8	M	WT	4	1.46	62,300		
8	A	71.1	H	WT	3	0.51	36,400		
9	A	29.9	H	WT	2	0.55	16,300		
10	A	23.1	M	WT	2	1.44	33,300		
11	A	29.2	M	WT	1	1.26	36,900		
12	A	26.2	H	WT	2	0.56	14,600	1/3 U	-2,400
13	A	34.0	H	WT	1	0.49	16,500	1/2 U	-4,100
14	A	22.4	H	WT	1	0.52	11,600	1/2 U	-2,900
15	A	13.6	M	WT	1	1.41	19,100		
16	A	11.6	H	WT	1	0.57	6,600		
17	A	20.7	H	WT	2	0.58	11,900		
18	A	10.9	H	WT	1	0.57	6,200		
19	A	38.1	H	WT	2	0.53	20,100		
20	A	33.3	M	WT	1	1.24	41,300		
21[a]	A	67.0	M	WT	5	1.41	94,500		
22	B	122.6	M	WT	1	1.03	126,500		
23	B	11.2	M	WT	1	1.45	16,200		
24	B	62.9	M	WT	1	1.13	71,300		
25	B	30.3	M	WT	1	1.26	38,100		
26	B	83.0	M	WT	1	1.09	90,500		
27	B	12.6	M	WT	1	1.42	17,900		
28	B	23.1	P	WT	1	0.06	1,400	1/2 U	- 700

Table B4-2 (Continued)

Catchment Area Identification Number Plate B-2	Hydrographic Drainage Unit	Drainage Area — A km^2	Dominant Land Type[b]	Sub-Region[c]	Independant Streams in Catchment Area	Computed[d] Value of DR mm/yr	Estimated Natural Annual Sediment Yield m^3/yr	Human Changes in Land Use[e]	Estimated Change in Sediment Yield with Present Land Use m^3/yr
29	B	130.5	H	WT	1	0.40	52,500	1/5 A	
30	B	76.9	H	WT	1	0.43	33,300		
31	C	26.5	H	WT	2	0.56	14,700	1/4 A	
32	D	35.7	H	WT	2	0.53	19,000	1/5 A	
33	D	44.9	H	WT	2	0.52	23,100		
34	D	33.3	H	WT	3	0.57	19,000		
35	D	92.8	M	WT	1	1.07	99,700		
36	D	14.6	H	WT	1	0.55	8,000		
37	D	13.6	H	WT	1	0.55	7,500		
38	D	26.2	H	WT	3	0.59	15,400		
39	D	638.7	M	WT	1	0.82	522,300		
40	D	39.1	M	WT	1	1.21	47,400		
41	D	62.8	M	WT	1	1.13	71,200		
42	D	20.4	M	WT	1	1.33	27,100	1/5 A	
43	D	24.1	M	WT	1	1.30	31,300		
44	D	909.5	M	WT	1	0.78	707,600		
45	D	63.4	M	WT	1	1.13	71,800		
46	D	21.8	M	WT	1	1.32	28,700		
47	D	115.3	M	WT	4	1.27	145,900		
48	D	22.1	H	WT	2	0.57	12,600		
49	D	15.3	H	WT	1	0.54	8,300		
50	D	60.2	M	WT	1	1.14	68,700		
51	D	63.4	M	WT	1	1.13	71,800		
52	D	34.7	M	WT	2	1.36	47,200		
53	D	167.8	M	WT	1	0.99	165,700		
54	D	48.6	H	WT	2	0.51	24,800		
55	D	140.9	M	WT	1	1.01	142,600		
56	D	22.1	H	WT	1	0.52	11,400		
57	D	33.7	H	WT	1	0.49	16,400		

Catchment Area Identification Number Plate B-2	Hydrographic Drainage Unit	Drainage Area — A km^2	Dominant Land Type[b]	Sub Region[c]	Independant Streams in Catchment Area	Computed[d] Value of $\overline{DR}$ mm/yr	Estimated Natural Annual Sediment Yield m^3/yr	Human Changes in Land Use[e]	Estimated Change in Sediment Yield with Present Land Use m^3/yr
58	D	119.0	M	WT	3	1.21	144,000		
59	D	20.4	H	WT	1	0.52	10,700		
60	D	64.0	H	WT	1	0.44	28,500		
61	D	70.7	H	WT	1	0.44	31,000		
62	D	75.0	H	WT	3	0.51	38,100		
63	D	24.8	H	WT	1	0.51	12,600		
64	D	14.6	H	WT	1	0.55	8,000	1/4 A	
65	D	20.4	H	WT	1	0.52	10,700		
66	D	31.6	H	SG	1	0.50	15,900		
67	D	100.0	H	SG	2	0.47	47,200		
68	D	34.3	H	SG	1	0.50	17,100		
69	D	19.0	M	SG	2	1.52	28,800		
70	D	29.6	M	SG	2	1.42	42,200		
71	D	21.4	H	SG	2	0.59	12,600		
72	D	20.7	M	SG	1	1.36	28,100		
73	D	34.3	H	SG	1	0.50	17,100		
74	D	19.0	H	WT	1	0.53	10,000	1/5 U	-1,000
75	D	66.3	H	SM	4	0.38	25,000		
76	D	14.6	M	SM	1	0.98	14,300		
77	D	26.5	H	SM	1	0.35	9,400	1/4 U	-1,200
78	D	62.7	H	SM	1	0.31	19,600	1/5 A	
79	D	16.3	M	SM	1	0.96	15,700		
80	D	15.3	M	SM	1	0.97	14,800		
81	D	15.0	M	SM	1	0.97	14,600		
82	D	18.0	H	SM	1	0.37	6,700	1/5 A	
83	D	86.5	H	SM	1	0.30	25,800	1/5 A, 1/5 U	-2,600
84	E	13.6	P	SM	1	0.04	600	1/5 A, A	
85	F	40.5	H	SM	1	0.33	13,500	2/5 A, 2/5 U	-2,700
86	F	27.5	H	SM	2	0.39	10,600	3/5 A	

Table B4-2 (Continued)

Catchment Area Identification Number Plate B-2	Hydrographic Drainage Unit	Drainage Area — A km^2	Dominant Land Type[b]	Sub-Region[c]	Independant Streams in Catchment Area	Computed[d] Value of $\overline{DR}$ mm/yr	Estimated Natural Annual Sediment Yield m^3/yr	Human Changes in Land Use[e]	Estimated Change in Sediment Yield with Present Land Use m^3/yr
87	F	14.3	H	SM	2	0.42	6,100	1/2 A	
88	F	37.4	H	SM	3	0.39	14,700	4/5 A	
89	F	29.9	H	SM	1	0.35	10,400	1/4 A	
90	F	49.3	H	SM	3	0.38	18,600	1/4 A	
91	F	41.1	H	SM	2	0.37	15,000	1/5 A	
92	F	28.6	H	SM	2	0.39	11,000		
93	F	9.5	H	SM	1	0.41	3,900		
94	F	24.1	H	SM	1	0.36	8,600		
95	F	12.6	H	SM	1	0.39	4,900	1/5 A	
96	F	19.7	H	SM	1	0.37	7,300	1/2 A	
97	F	37.4	H	SM	1	0.34	12,600	1/4 A	
98	F	26.5	H	SM	1	0.35	9,400	4/5 A	
99	F	34.3	H	SM	1	0.34	11,700	4/5 A	
100	F	2.0	P	SM	1	0.06	100	U	- 100
101	F	18.4	H	SM	1	0.37	6,800		
102	F	21.4	H	SM	4	0.44	9,500		
103	F	19.4	H	SM	2	0.41	7,900		
104	F	23.5	H	SM	3	0.42	9,900		
105[a]	G	66.3	H	SM	1	0.31	20,600		
106[a]	G	64.4	H	SM	4	0.38	24,400		
107[a]	G	9.8	H	SM	1	0.41	4,000	1/5 A	
108[a]	G	50.3	H	SM	2	0.36	17,900		
109[a]	G	51.0	M	SM	4	1.00	50,800		
110[a]	G	123.0	H	SM	1	0.28	35,000		
111	G	8.2	H	SM	1	0.42	3,400	1/5 A	
112	G	28.6	H	SM	3	0.41	11,700	2/5 A	
113	G	36.4	H	SM	1	0.34	12,300		
114[a]	G	23.1	M	SM	1	0.92	21,100		
115[a]	G	47.6	H	SM	1	0.33	15,500		

Table B4-2 (Continued)

Catchment Area Identification Number Plate B-2	Hydrographic Drainage Unit	Drainage Area — A km^2	Dominant Land Type[b]	Sub-Region[c]	Independant Streams in Catchment Area	Computed[d] Value of DR mm/yr	Estimated Natural Annual Sediment Yield m^3/yr	Human Changes in Land Use[e]	Estimated Change in Sediment Yield with Present Land Use m^3/yr
116[a]	G	36.0	H	SM	2	0.37	13,400	1/5 U	-1,300
117	G	42.2	H	SM	3	0.39	16,300	3/5 U	-4,900
118	G	63.2	H	SM	7	0.41	26,000	4/5 U	-10,400
119	G	18.7	H	SM	2	0.41	7,600	4/5 U	-3,100
120	G	69.4	P	SM	1	0.04	2,500	U	-2,500
121	G	7.3	P	SM	1	0.05	400	U	- 400
122	G	224.1	P	SM	1	0.03	6,800	U	-6,800
123[a]	G	83.4	H	SM	5	0.38	31,400	4/5 U	-12,600
124	H	18.7	H	SM	2	0.41	7,600	1/2 U	-1,900
125	H	16.0	H	SM	2	0.42	6,700	4/5 U	-2,700
126	H	25.2	H	SM	3	0.42	10,500	3/5 U	-3,100
127	H	24.8	H	SM	5	0.45	11,100	3/5 U	-3,300
128	H	19.0	H	SM	4	0.45	8,500	1/4 U	-1,100
129	H	22.8	H	SM	2	0.40	9,100		
130	H	10.9	H	SM	1	0.40	4,400	1/2 A	
131	H	35.7	H	SM	2	0.37	13,300		
132	H	21.8	H	SM	2	0.40	8,700	2/5 U	-1,700
133	H	13.3	P	SM	2	0.05	300	3/5 U	- 200
134	H	12.6	M	SG	2	1.61	20,300		
135	H	88.3	M	SG	1	1.11	97,800		
136	H	54.8	M	SG	1	1.18	64,900		
137	H	269.1	M	SG	1	0.95	254,700		
138	H	34.3	M	SG	1	1.27	43,400	1/4 U	-5,400
139	H	133.3	H	SG	1	0.41	54,800	3/5 U	-16,400
140	H	20.1	H	PR	1	0.42	8,500	4/5 U	-3,400
141	H	58.4	M	SG	1	1.17	68,600	1/5 U	-6,900
142	H	80.4	P	PR	1	0.04	3,300	U	-3,300
143	H	143.1	P	PR	1	0.04	5,300	U	-5,300
144	H	34.3	M	SG	2	1.40	47,900	1/4 U	-6,000

Table B4-2 (Continued)

Catchment Area Identification Number Plate B-2	Hydrographic Drainage Unit	Drainage Area — A km^2	Dominant Land Type[b]	Sub-Region[c]	Independant Streams in Catchment Area	Computed Value of $\overline{DR}$ mm/yr[d]	Estimated Natural Annual Sediment Yield m^3/yr	Human Changes in Land Use[e]	Estimated Change in Sediment Yield with Present Land Use m^3/yr
145	H	46.9	M	SG	2	1.34	62,600	1/5 U	-6,300
146	H	31.6	M	SG	1	1.28	40,500		
147[a]	I	47.6	P	PR	1	0.04	2,100	U	-2,100
148	J	24.1	M	SG	1	1.33	32,100		
149	J	13.6	M	SG	1	1.44	19,600		
150	J	533.4	M	SG	1	0.86	458,500		
151	J	37.1	M	SG	2	1.38	51,200	1/5 U	-5,100
152	J	68.8	M	SG	3	1.34	92,200		
153	J	14.3	H	SG	1	0.56	8,100		
154	J	110.2	H	PR	1	0.33	36,800	3/5 U	-11,000
155	J	36.5	H	PR	1	0.39	14,300	1/5 U	-1,400
156	J	52.4	H	PR	6	0.48	25,000	1/2 U	-6,200
157	J	10.5	P	PR	1	0.05	600	U	- 600
158	J	12.9	P	PR	1	0.05	700	U	- 900
159	J	39.0	P	PR	1	0.04	1,700	U	-1,700
160	J	83.4	H	PR	2	0.38	32,000	1/2 U	-8,000
161	J	16.7	P	PR	1	0.05	800	U	- 800
162	J	8.8	H	PR	1	0.48	4,200	1/2 U	-1,100
163[a]	K	3.7	P	PR	1	0.06	200	U	- 200
164	K	4.1	P	PR	1	0.06	300	U	- 300
165[a]	K	17.7	P	PR	1	0.05	900	U	- 900
166	L	53.6	H	PR	2	0.41	21,900		
167	L	50.5	H	PR	14	0.54	27,300	1/5 A	
168	L	69.4	M	SG	1	1.15	79,500		
169	L	51.8	M	SG	1	1.19	61,900	1/4 U	-7,700
170	L	21.1	H	PR	1	0.42	8,900	2/5 A, 2/5 U	-1,800
171	L	23.1	M	SG	1	1.34	30,900		
172	L	20.7	M	SG	1	1.36	28,100		
173	L	72.5	M	SG	1	1.14	82,600		

Table B4-2 (Continued)

Catchment Area Identification Number Plate B-2	Hydrographic Drainage Unit	Drainage Area — A km^2	Dominant Land Type[b]	Sub-Region[c]	Independant Streams in Catchment Area	Computed[d] Value of DR mm/yr	Estimated Natural Annual Sediment Yield m^3/yr	Human Changes in Land Use[e]	Estimated Change in Sediment Yield with Present Land Use m^3/yr
174	L	12.6	M	SG	2	1.61	20,300		
175	L	12.6	M	SG	1	1.46	18,400		
176	L	20.4	M	SG	2	1.50	30,600		
177	L	160.1	H	PR	1	0.32	50,700		
178	L	11.9	H	PR	1	0.46	5,400		
179	L	18.7	H	PR	1	0.43	8,000		
180	L	27.5	M	PR	1	1.03	28,400		
181	L	33.7	M	PR	2	1.11	37,300		
182	L	17.3	M	PR	1	1.10	19,100		
183	L	53.7	M	PR	1	0.94	50,500		
184	L	11.2	H	PR	1	0.46	5,200	1/2 A	
185	L	50.0	M	PR	2	1.05	52,400		
186	L	130.9	M	PR	1	0.83	108,600		
187	L	20.1	H	PR	1	0.42	8,500		
188	L	174.1	H	PR	1	0.31	54,500		
189	L	19.7	H	PR	2	0.47	9,300		
190	L	5.8	M	PR	2	1.42	8,200		
191	L	10.9	M	PR	1	1.18	12,800		
192	L	14.3	H	PR	1	0.45	6,400		
193	L	23.8	H	PR	1	0.41	9,900		
194	L	34.0	M	PR	2	1.11	37,600		
195	L	24.1	M	PR	1	1.05	25,400		
196	L	24.5	H	PR	1	0.41	10,100		
197	L	21.4	M	PR	1	1.07	22,900		
198	L	34.0	M	PR	2	1.11	18,800		
199	L	10.9	M	PR	1	1.18	12,800		
200	L	12.9	M	PR	2	1.27	16,400		
201	L	15.0	M	PR	1	1.13	16,900		

Table B4-2 (Continued)

Catchment Area Identification Number Plate B-2	Hydrographic Drainage Unit	Drainage Area — A km^2	Dominant Land Type[b]	Sub-Region[c]	Independant Streams in Catchment Area	Computed[d] Value of $\overline{DR}$ mm/yr	Estimated Natural Annual Sediment Yield m^3/yr	Human Changes in Land Use[e]	Estimated Change in Sediment Yield with Present Land Use m^3/yr
202	L	9.5	M	PR	3	1.40	13,300		
203	L	10.9	M	PR	4	1.43	15,600		
204	L	7.1	M	PR	1	1.25	8,900		
205	L	10.5	M	PR	2	1.31	13,700	1/5 A, 1/5 U	-1,400
206	L	46.2	H	PR	1	0.38	17,400	1/5 A, 2/5 U	-3,500
207	L	15.3	H	PR	1	0.44	6,800	1/4 U	- 800
208	L	49.9	H	PR	2	0.41	20,600	1/5 A, 1/5 U	-2,100
209	L	40.8	H	PR	1	0.38	15,700		
210	L	17.3	H	PR	1	0.43	7,500		
211	L	7.5	H	PR	1	0.49	3,700		
212	L	13.9	P	PR	1	0.05	700	3/5 A	
213	L	70.6	H	PR	2	0.39	27,700	1/5 A	
214	L	43.9	H	PR	4	0.46	20,300		
215	L	46.9	H	PR	4	0.46	21,500		
216	L	19.7	P	PR	1	0.05	1,000	U	
217	L	10.9	P	PR	1	0.05	600	4/5 A, 1/5 U	- 100
218	L	1.3	P	PR	1	0.07	100	1/2 A, 1/2 U	- 100
219	L	2.7	P	PR	1	0.07	200	2/5 U	- 100
220	L	0.4	P	PR	1	0.09	-	U	
221	L	1.9	P	PR	1	0.07	100	2/5 A, 2/5 U	
222	L	79.2	H	PR	1	0.35	27,700	1/5 A, 2/5 U	-5,500
223	L	1.1	P	PR	1	0.07	100	4/5 A, 1/5 U	
224	L	29.6	P	PR	1	0.05	1,400	A	
225	L	74.3	P	PR	1	0.04	3,000	1/5 A, 3/5 U	-1,800
226	L	267.9	P	PR	1	0.03	9,100	2/5 A, 1/5 U	-1,800
227	L	134.0	H	PR	1	0.33	43,600		
228	L	50.5	H	PR	2	0.41	20,800		
229	L	13.6	H	PR	3	0.52	7,100		

Table B4-2 (Continued)

Catchment Area Identification Number Plate B-2	Hydrographic Drainage Unit	Drainage Area — A km^2	Dominant Land Type[b]	Sub-Region[c]	Independant Streams in Catchment Area	Computed[d] Value of $\overline{DR}$ mm/yr	Estimated Natural Annual Sediment Yield m^3/yr	Human Changes in Land Use[e]	Estimated Change in Sediment Yield with Present Land Use m^3/yr
230	L	29.2	H	PR	2	0.44	13,000		
231	L	33.5	H	PR	1	0.40	13,200		
232	L	6.4	H	PR	1	0.50	3,200	2/5 A	
233	L	28.6	M	PR	2	1.13	32,400		
234	L	8.5	H	PR	1	0.48	4,100	2/5 A	
235	L	1.8	P	PR	1	0.07	100	2/5 A	
236	L	42.6	M	PR	5	1.22	51,900		
237	L	36.5	M	PR	2	1.09	40,000	1/5 A	
238	L	30.4	H	PR	1	0.40	12,200	3/5 A	
239	L	53.6	H	PR	1	0.37	19,800	1/5 A, 1/5 U	-1,900
240	L	33.0	H	PR	1	0.40	13,100		
241	L	23.5	H	PR	3	0.49	11,400		
242	L	22.4	P	PR	1	0.05	1,100	U	-1,100
243	L	1.8	P	PR	1	0.07	100	U	- 100
244	L	49.9	H	PR	3	0.44	21,800		
245	L	13.3	H	PR	1	0.45	6,000	2/5 U	-1,200
246	L	49.3	M	PR	2	1.05	51,700		
247	L	33.3	M	PR	2	1.11	36,900		
248	L	54.8	M	PR	2	1.03	56,700		
249	L	43.2	M	PR	1	0.97	41,900		
250	L	30.4	H	PR	2	0.44	13,400	1/5 A	
251	L	45.7	H	PR	7	0.50	22,700	1/5 A, 1/5 U	-2,300
252	N	55.4	H	PR	6	0.47	26,300	1/5 A, 1/5 U	-2,600
253	N	41.4	P	PR	1	0.04	1,800	U	-1,800
254	N	65.2	H	PR	4	0.44	28,500	2/5 A, 1/5 U	-2,800
255[a]	N	43.5	H	PR	5	0.48	20,800	1/5 U	-2,100
256[a]	N	23.8	H	PR	1	0.41	9,900	1/5 A, 1/5 U	-1,000
257	N	19.7	H	PR	1	0.43	8,400	1/5 U	- 800
258	N	49.3	H	PR	1	0.37	18,500	2/5 A, 2/5 U	-3,700

Table B4-2 (Continued)

Catchment Area Identification Number Plate B-2	Hydrographic Drainage Unit	Drainage Area — A km^2	Dominant Land Type[b]	Sub-Region[c]	Independant Streams in Catchment Area	Computed[d] Value of $\overline{DR}$ mm/yr	Estimated Natural Annual Sediment Yield m^3/yr	Human Changes in Land Use[e]	Estimated Change in Sediment Yield with Present Land Use m^3/yr
259	N	8.5	H	PR	1	0.48	4,100	2/5 U	- 800
260	N	8.2	H	PR	1	0.48	4,000	1/5 U	- 400
261[a]	N	22.4	H	PR	1	0.42	9,400	2/5 A	
262	N	59.7	H	PR	1	0.36	21,700	1/5 A, 1/4 U	-2,700
263	N	85.2	H	PR	1	0.35	29,500		
264	N	12.9	H	PR	1	0.45	5,800	4/5 A	
265	N	48.7	H	PR	2	0.41	20,100	2/5 A	
266	N	45.7	H	PR	1	0.38	17,300		
267	N	124.2	M	PR	1	0.84	103,800		
268	N	33.5	H	PR	2	0.44	14,600		
269	N	22.8	H	PR	3	0.49	11,100		
270[a]	N	21.4	H	PR	1	0.42	9,000	1/5 U	- 900
271[a]	N	29.2	H	PR	1	0.40	11,800	1/4 U	-1,500
272	N	10.2	H	PR	1	0.47	4,800	1/5 A	
273	N	8.2	H	PR	1	0.48	4,000		
274	N	23.5	H	PR	1	0.42	9,800		
275	N	39.0	H	PR	1	0.39	15,100		
276	N	244.2	H	PR	1	0.30	72,900		
277	N	109.0	H	PR	3	0.39	42,600		
278[a]	N	35.0	H	PR	5	0.49	17,200		
279[a]	N	70.0	H	PR	1	0.36	24,900		
280[a]	N	48.1	H	PR	1	0.38	18,100		
281	O	32.3	H	PR	2	0.44	14,100		
282	O	127.2	H	PR	1	0.33	41,600	1/5 A	
283	O	18.7	H	PR	1	0.43	8,000		
284	O	22.4	H	PR	1	0.42	9,400		
285	O	6.8	H	PR	1	0.49	3,400	1/5 A	
286	O	11.9	P	PR	1	0.05	600	1/2 A	
287	O	11.2	P	PR	1	0.05	600	1/2 A	

Table B4-2 (Continued)

Catchment Area Identification Number Plate B-2	Hydrographic Drainage Unit	Drainage Area – A km^2	Dominant Land Type[b]	Sub-Region[c]	Independant Streams in Catchment Area	Computed Value of DK[d] mm/yr	Estimated Natural Annual Sediment Yield m^3/yr	Human Changes in Land Use[e]	Estimated Change in Sediment Yield with Present Land Use m^3/yr
288	O	11.2	H	PR	1	0.46	5,200	1/4 A	
289	O	13.9	P	PR	1	0.05	700	4/5 A	
290	O	13.6	P	PR	1	0.05	700	4/5 A	
291	O	124.2	H	PR	1	0.33	40,800	1/2 A	
292	O	174.8	H	PR	4	0.38	66,500	1/4 A	
293	O	88.9	P	PR	1	0.04	'3,500	1/5 A	
294	O	16.0	P	PR	1	0.05	800	1/5 A	
295	O	22.1	H	PR	2	0.46	10,200		
296	O	43.2	H	PR	2	0.42	18,200	1/5 A	
297	O	23.5	P	PR	1	0.05	1,100		
298	O	268.5	H	PR	5	0.37	99,300		
299	O	46.9	H	PR	2	0.42	19,500		
300	O	27.5	H	PR	1	0.41	11,200		
301	O	109.6	H	PR	1	0.33	36,600		
302	O	19.0	H	PR	1	0.43	8,100		
303	O	63.9	M	PR	1	0.92	58,600		
304	O	30.9	H	PR	1	0.40	12,400		
305	O	85.9	H	PR	2	0.38	32,800		
306	O	66.4	H	PR	1	0.36	23,800		
307	O	68.2	H	PR	2	0.39	13,400		
308	O	26.5	H	PR	1	0.41	10,800		
309	O	169.3	H	PR	1	0.31	53,200		
310	O	44.9	P	PR	1	0.04	2,000		
311	P	12.9	H	PR	1	0.45	5,800		
312	P	12.2	H	PR	1	0.46	5,600		
313	P	45.1	H	PR	1	0.38	17,100		
314	P	37.1	P	PR	1	0.05	1,700		
315	P	27.5	H	PR	1	0.41	11,200		
316	P	42.0	H	PR	2	0.42	17,700		

Table B4-2: Estimated Denudation Rates $\overline{DR}$ Obtained Using Eq. B4-2, for Catchment Areas Defined in B-2.

Catchment Area Identification Number Plate B-2	Hydrographic Drainage Unit	Drainage Area – A km^2	Dominant Land Type[b]	Sub-Region[c]	Independant Streams in Catchment Area	Computed Value of $\overline{DR}$ mm/yr[d]	Estimated Natural Annual Sediment Yield m^3/yr	Human Changes in Land Use[e]	Estimated Change in Sediment Yield with Present Land Use m^3/yr
317	P	62.1	H	PR	2	0.40	24,800		
318	P	23.8	M	PR	1	1.05	25,100		
319	P	26.2	M	PR	2	1.15	30,100		
320	P	54.2	M	PR	2	1.04	56,100		
321	P	30.3	M	PR	2	1.12	34,100		
322	P	43.2	H	PR	1	0.38	16,500		
323	P	33.5	H	PR	6	0.51	17,000		
324	P	37.1	H	PR	1	0.39	14,500		
325	P	15.6	H	PR	1	0.44	6,900		
326	P	39.0	H	PR	1	0.39	15,100		
327	P	10.9	M	PR	1	1.18	12,800		
328	P	27.3	M	PR	1	1.03	28,200		
329	P	42.0	H	PR	1	0.38	16,100		
330	P	52.4	H	PR	1	0.37	19,400		
331	P	14.6	H	PR	1	0.44	6,500		
332	P	27.9	H	PR	1	0.41	11,300		
333	P	27.9	H	PR	2	0.45	12,500		
334	P	54.8	P	PR	1	0.04	2,300		
335	P	18.4	H	PR	1	0.43	7,900		
336	P	111.4	M	PR	1	0.85	94,500		
337	P	19.7	H	PR	1	0.43	8,400	1/5 A	
338	P	38.1	H	PR	3	0.45	17,300	2/5 A	
339	P	48.1	H	PR	2	0.41	19,900	2/5 A	
340	P	95.6	H	PR	1	0.34	32,600	3/5 A	
341	P	83.4	H	PR	2	0.38	32,000	2/5 A	
342	P	27.4	H	PR	1	0.41	11,100	1/5 A	
343	P	36.7	H	PR	1	0.39	14,300	1/5 A	
344	P	30.6	P	PR	1	0.05	1,400	2/5 A, 1/5 U	- 300

Table B4-2 (Continued)

Catchment Area Identification Number Plate B-2	Hydrographic Drainage Unit	Drainage Area – A km^2	Dominant Land Type[b]	Sub-Region[c]	Independant Streams in Catchment Area	Computed[d] Value of DR mm/yr	Estimated Natural Annual Sediment Yield m^3/yr	Human Changes in Land Use[e]	Estimated Change in Sediment Yield with Present Land Use m^3/yr
345	Q	37.0	H	PR	2	0.43	15,900	1/5 A, 1/2 U	-4,000
346	Q	21.4	P	PR	1	0.05	1,000	4/5 U	- 800
347	Q	15.6	P	PR	1	0.05	800	1/5 A, 1/2 U	400
348	Q	37.1	H	PR	2	0.43	15,900	2/5 A, 1/5 U	-1,600
349	Q	31.6	P	PR	1	0.05	1,500	2/5 A	
350	Q	76.7	H	PR	1	0.35	27,000	2/5 A	
351	Q	48.1	H	PR	3	0.44	21,100	1/5 A, 1/5 U	-2,100
352	Q	174.1	H	PR	2	0.35	60,100	1/5 A, 1/5 U	-6,000
353	Q	19.4	P	PR	1	0.05	1,000	1/3 A, 1/3 U	- 300
354	R	17.3	P	PR	1	0.05	900	1/5 A, 3/5 U	- 500
355	R	13.3	H	PR	1	0.45	6,000	1/5 A, 1/5 U	- 600
356	R	24.8	P	PR	1	0.05	1,200	2/5 A, 2/5 U	- 500
357	R	46.9	H	PR	2	0.42	19,500	1/5 A	
358	R	7.1	H	PR	1	0.49	3,500		
359	R	71.2	H	PR	1	0.36	25,300		
360	R	62.1	H	PR	3	0.42	26,300		
361	R	188.8	H	PR	1	0.31	58,500	1/5 A	
362	R	233.8	H	PR	2	0.33	77,500	1/5 A	
363	R	9.5	H	PR	3	0.55	5,200	1/5 A	
364	R	11.9	H	PR	1	0.46	5,400	1/5 A, 1/4 U	- 700
365	R	10.2	H	PR	2	0.52	5,300	1/5 A	
366	R	7.1	H	PR	2	0.54	3,900	1/5 A	
367	S	7.5	P	PR	1	0.06	400	1/5 A	
368	S	4.1	P	PR	1	0.06	300		
369	S	2.4	H	PR	1	0.57	1,400	1/5 A	
370	S	105.9	H	PR	1	0.34	35,600		
371	S	67.0	P	PR	1	0.04	2,800	1/4 A	
372[a]	S	149.8	P	PR	1	0.04	5,600	3/5 U	-3,400

Table B4-2 (Continued)

Catchment Area Identification Number Plate B-2	Hydrographic Drainage Unit	Drainage Area — A km^2	Dominant Land Type[b]	Sub-Region[c]	Independant Streams in Catchment Area	Computed Value of $\overline{DR}$[d] mm/yr	Estimated Natural Annual Sediment Yield m^3/yr	Human Changes in Land Use[e]	Estimated Change in Sediment Yield with Present Land Use m^3/yr
373	T	24.1	P	PR	3	0.06	1,300	4/5 U	-1,400
374	T	27.9	H	PR	1	0.41	11,300	1/5 U	-1,100
375	T	38.4	H	PR	2	0.43	16,400	1/5 U	-1,600
376	T	19.0	H	PR	2	0.47	9,000		
377	T	39.4	H	PR	1	0.39	15,200		
378	T	23.1	H	PR	1	0.42	9,600	1/4 U	-1,200
379	T	152.2	H	PR	1	0.32	48,600		
380	T	3.1	H	PR	1	0.55	1,700		
381	T	6.1	H	PR	1	0.50	3,100		
382	T	4.1	H	PR	1	0.53	2,200		
383	T	28.9	H	PR	3	0.47	13,600		
384	T	454.8	H	PR	1	0.27	124,400		
385	T	52.7	H	PR	2	0.41	21,500	1/5 U	-2,200
386	T	28.6	H	PR	1	0.40	11,600	3/5 U	-3,500
387	T	46.9	P	PR	1	0.04	2,000	U	-2,000
388	T	11.2	P	PR	1	0.05	600	U	- 600
389[a]	U	14.7	P	PR	1	0.05	800	4/5 U	- 600
390	U	27.9	P	PR	1	0.05	1,300	U	-1,300
391	U	41.8	P	PR	1	0.04	1,900	U	-1,900
392	U	23.1	P	PR	1	0.05	1,100	U	-1,100
393	U	20.7	P	PR	1	0.05	1,000	4/5 U	- 800
394	V,W	218.6	H	PR	4	0.37	80,600	1/4 U	-10,100
395	V,W	22.5	H	PR	1	0.42	9,400		
396	V,W	298.4	H	PR	1	0.29	86,600		
397	V,W	15.8	H	PR	1	0.44	6,900		
398	V,W	42.0	P	PR	1	0.04	1,900		
399	V,W	26.2	H	PR	1	0.41	10,700		
400	V,W	17.1	H	PR	1	0.43	7,400		
401	V,W	244.6	H	PR	1	0.30	73,000		

Table B4-2 (Continued)

Catchment Area Identification Number Plate B-2	Hydrographic Drainage Unit	Drainage Area — A km^2	Dominant Land Type[b]	Sub-Region[c]	Independant Streams in Catchment Area	Computed Value of DR[d] mm/yr	Estimated Natural Annual Sediment Yield m^3/yr	Human Changes in Land Use[e]	Estimated Change in Sediment Yield with Present Land Use m^3/yr
402	V,W	33.5	H	PR	2	0.44	14,600		
403	V,W	19.5	P	PR	1	0.05	1,000		
404	X	44.9	P	PR	1	0.04	2,000		
405	X	26.5	H	PR	1	0.41	10,800		
406	X	60.4	H	PR	1	0.36	22,000		
407	X	450.3	H	PR	1	0.27	123,400		
408	X	54.9	H	PR	1	0.37	20,200		
409	X	67.7	H	PR	1	0.36	24,200		
410	X	101.3	H	PR	1	0.34	34,300		
411	X	189.7	H	PR	1	0.31	58,700		
412	X	137.9	H	PR	4	0.39	54,300		
413	X	86.0	H	PR	1	0.35	29,800		
414	X	16.7	H	PR	1	0.44	7,300		
415	X	142.7	H	PR	5	0.40	57,700		
416	X	41.1	H	PR	1	0.38	15,800		
417	X	64.9	H	PR	1	0.36	23,400		
418	X	202.5	H	PR	2	0.34	68,500		
419	X	36.7	H	PR	1	0.39	14,300		
420	X	67.3	H	PR	1	0.36	24,100		
421	X	245.2	H	PR	1	0.30	73,200		
422	X	225.7	P	PR	1	0.03	7,900		
423	X	18.0	H	PR	1	0.43	7,800		
424	X	315.4	H	PR	5	0.36	114,000		
425	X	207.4	H	PR	1	0.31	63,400		
426	X	84.2	H	PR	1	0.35	29,200		
427	X	126.3	H	PR	1	0.33	41,400		
428	X	161.6	H	PR	1	0.32	51,200		
429	X	550.8	H	PR	1	0.27	146,700		
430	X	38.8	H	PR	1	0.39	15,000		

Table B4-2 (Continued)

Catchment Area Identification Number Plate B-2	Hydrographic Drainage Unit	Drainage Area — A km^2	Dominant Land Type[b] LT	Sub-Region[c]	Independant Streams in Catchment Area	Computed[d] Value of $\overline{DR}$ mm/yr	Estimated Natural Annual Sediment Yield m^3/yr	Human Changes in Land Use[e]	Estimated Change in Sediment Yield with Present Land Use m^3/yr
431	X	100.6	H	PR	3	0.40	39,800		
432	X	216.6	H	PR	4	0.37	80,000		
433	X	101.3	H	PR	2	0.37	37,800		

a - Direct coastal drainage, no intermediate depositional area.

b - Land type abbreviations: M = Mountains, H = Hills, P = Plains

c - Sub-region abbreviations: WT = Western Transverse, SM = Santa Monica, SG = San Gabriel, PR = Peninsular Ranges.

d - $\overline{DR}$ based on average per independent stream, i.e. total area divided by the number of independent streams in the catchment.

e - Land use abbreviations: U = Urban, A = Agricultural.

Additional notes - Hydrographic drainage units are identified in Fig. B4-3.

- Drainage Areas in column 3 are for erosional surfaces only.

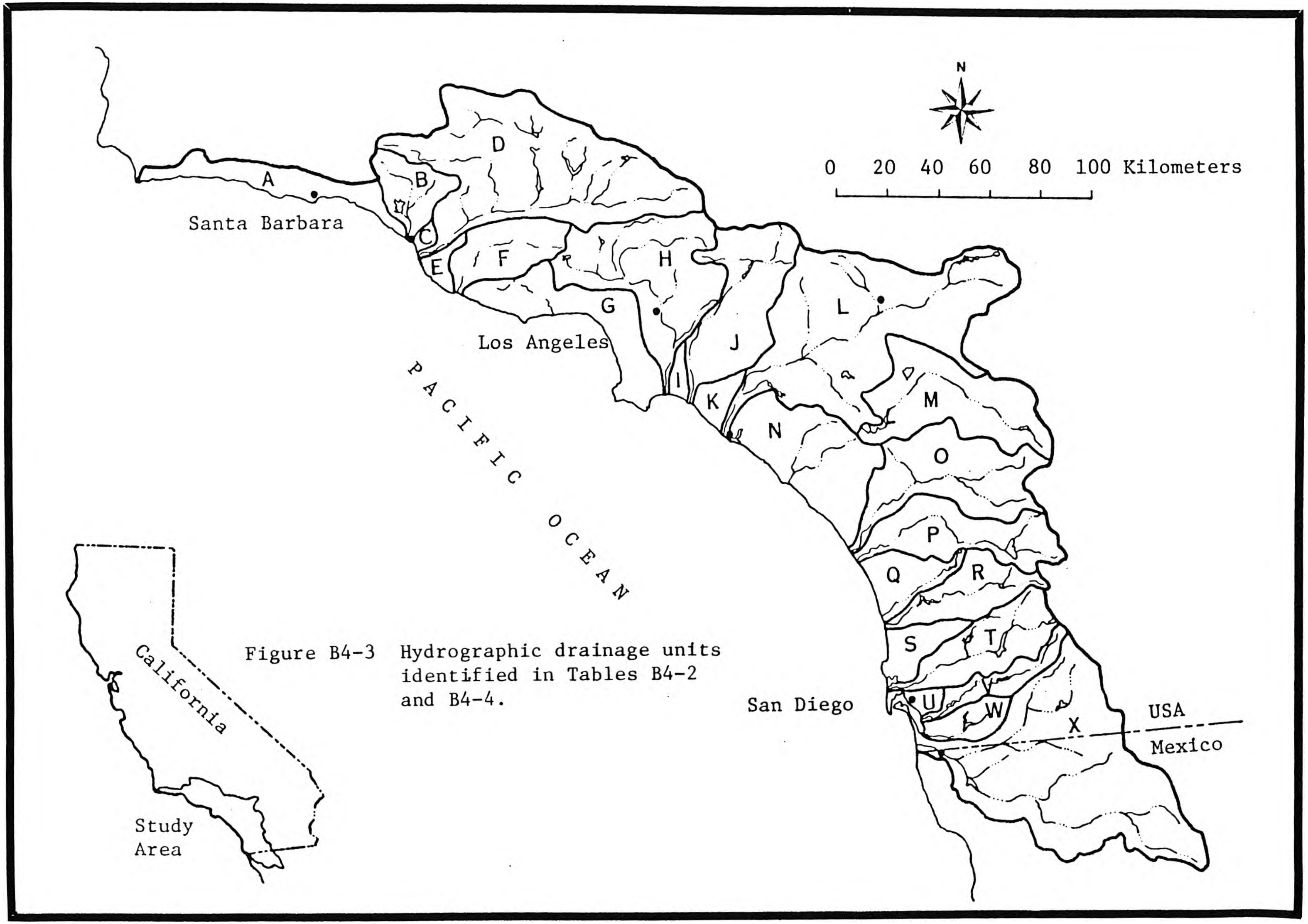

Figure B4-3 Hydrographic drainage units identified in Tables B4-2 and B4-4.

expected range of annual variations in local sediment yield, and also the larger-scale spatial correlations in annual events.

On Sespe Creek, a major upland catchment in the Santa Clara River drainage, streamflow measurements have been made since 1931, and during nine recent years there have been concurrent measurements of suspended sediment discharge. With these data and the general technique used on the Santa Clara and other rivers in EQL Report 17-C, estimates have been obtained for annual suspended sediment discharge from 1928 to 1975. These annual values range over more than four orders of magnitude, with severe storm-year values approximately one order of magnitude above the mean value. Similar variations in annual suspended sediment yield were indicated for 1929-71 on San Juan Creek -- an upland catchment with tributary areas in the Santa Ana Mountains and San Joaquin Hills in Orange County. On both streams annual values approximate a log-normal frequency distribution. Since total sediment yield is usually closely related to suspended sediment yield, the former should also show similar annual variations on these streams, and for streams throughout the study area.

Precipitation in southern California is extremely seasonal, with almost all of the rainfall coming between the first of November and the end of March. Infrequently there are thunderstorms and tropical disturbances that enter the study area from the south during summer months. The scales and movements of winter and summer storms are such that most areas in the region are affected by a given storm. However, if a storm enters the study area from the northwest, the northern part of the area usually receives the most rainfall. Whereas if the storm comes from a southerly direction, the southern part of the study area will usually be hardest hit, with reduced precipitation in the north. The year 1969 provides a good example of this. Two severe storms, one in January and another during February, hit the northern part of the study area. The storm came in from the northwest, and there was severe rainfall in Santa Barbara, Ventura, Los Angeles, San Bernardino, Riverside and Orange counties but not in San Diego County. In fact, in San Diego County, 1969 was not considered a "flood year." Conversely, in August and September of 1975 and 1976, tropical storms hit the southern part of the study area, causing flood damage in San Diego County, but only moderate, unseasonal precipitation in Los Angeles and other northern counties.

B4.3 General Size Distributions of Eroded Sediments

On erosional surfaces throughout the study area there are significant variations in surface geology, from fine-grained shales, siltstones and sandstones in the western Transverse Ranges to weathered granites of the southern California batholith in the Peninsular Ranges, and tectonically fragmented granites and metamorphics in the San Gabriel and San Bernardino mountains.

This variety in surface materials suggests that the particle size distributions of materials delivered from these areas may differ significantly. Existing agency data which may be used to accurately identify such differences are limited. They include a one-time survey of sediments accumulated in Piru Reservoir in the Transverse Ranges; spot sampling of debris size distributions in Sierra Madre Reservoir, Kinneloa West, Kinneloa, Little Dalton, Big Dalton, and Bradbury debris basins in the San Gabriel Mountains; Sunset Canyon debris basin in the Verdugo Hills (just west of the San Gabriel Mountains) and a one-time survey of accumulated sediments in Morena Reservoir in the Peninsular Ranges. In addition, measurements of the specific weight (dry) of entrapped sediments have been made in San Gabriel and Devil's Gate reservoirs in the San Gabriel Mountains, and Piru and Morena reservoirs; and reconnaissance estimates are available for 8 of the other reservoirs. These data are compiled in Table B4-3.

This data set is obviously not extensive enough to define local conditions throughout the study area. The data can, however, be

Table B4-3

Size Distribution and Specific Weight Data for
Upland Sediment Yield Accumulations in Reservoirs

Control Structure	Total Drainage Area (km^2)	Mean Specific Wt. (Measured) (gm/cm^3)	Mean Specific Wt. (Estimated) (gm/cm^3)	Measured Mean Size - Distributions: Fines (< 0.06 mm)	Sand	Coarse (> 2 mm)	Rock Types on Erosional Surfaces in Drainage above Control Structure
Lake Piru	1029.0	0.85	---	78%	19%	3%	Sedimentary rocks primarily fine-grained; Moderately faulted
Bouquet Reservoir	30.0	---	0.64	---	---	---	Granitic - metamorphic rocks; moderately faulted
Stone Canyon Reservoir	3.0	---	0.96	---	---	---	Sedimentary rocks
Encino Reservoir	3.4	---	0.64	---	---	---	Sedimentary rocks
Chatsworth Reservoir	11.5	---	0.64	---	---	---	Sedimentary rocks; primarily fine-grained
Sierra Madre Reservoir	6.2	---	---	5-10%	55-65%	30-35%	
Kinueloa West Debris Basin	0.4	---	---	20-25%	50-60%	20-25%	
Kinueloa Debris Basin	0.5	---	---	10%	55-60%	20-25%	
Bradburry Debris Basin	1.8	---	---	20-25%	45-55%	25-30%	Granitic-metamorphic (gneiss and schist) rocks; severly faulted (Sierra Madre Reservoir through Big Dalton Reservoir)
Lower Sunset Canyon Debris Basin	1.7	---	---	20-30%	30-45%	35-40%	
Devils Gate Reservoir	82.6	1.30	---	---	---	---	
San Gabriel Reservoir	424.0	1.57	---	---	---	---	
Little Dalton Debris Basin	8.6	---	---	15-20%	45-55%	30-35%	
Big Dalton Reservoir	6.8	---	---	15-20%	50-60%	25-30%	
Laguna Reservoir	1.9	---	0.64	---	---	---	Sedimentary rocks
Mockingbird Canyon Reservoir	29.8	---	0.96	---	---	---	Granitic rocks
Hemet Reservoir	169.0	---	1.20	---	---	---	Primarily granitic, some loosely - consolidated fine-grained sedimentary
Lake Hodges	780.0	---	1.04	---	---	---	Granitic rocks
Morena Reservoir	283.0	1.12	0.96	30%	70%	0%	Granitic rocks

extrapolated to estimate general size characteristics of sediment yields for larger areas. Size distribution data for Piru Reservoir indicate that sediments delivered from western Transverse Range catchments are composed primarily of fine-grained material with only a small amount of sand and very little material coarser than 2 mm. Corresponding data from the San Gabriel Mountains (and Verdugo Hills, which are similar geologically) suggest that erosion from this geomorphic unit yields some fine sediment and coarse material, but approximately half of the debris is sand. Data for Morena Reservoir indicate that sediments yielded from the Peninsular Range are primarily sand-size particles with a small amount of finer material and essentially no gravel.

Available data and the above extrapolations agree with the correlative geological estimates of debris sizes based on expected responses of the different rock types to natural physical and chemical "weathering" processes. Fine-grained sedimentary rocks like those of the western Transverse Ranges generally decompose to produce fine-grained debris essentially devoid of coarser particles. Whereas severe fracturing and faulting of granite and metamorphic rocks through a long and active tectonic history, as in the San Gabriel Mountains, produce coarse fragments with extreme variations in particle sizes, from boulders to sand and fine sediments. In the Peninsular Ranges, the surface is composed largely of chemically weathered granitic materials, which produce sand-sized debris and minor amounts of finer material.

Unfortunately, these three larger geomorphic units do not include all upland catchments in the study area. Notable exceptions are the Santa Monica Mountains, uplifted coastal marine terraces in Santa Barbara, Orange, and San Diego counties, and miscellaneous hill areas throughout the study area.

B4.4 Aggregate Catchment Sediment Yields

In this section estimated sediment yields for the 433 catchments are aggregated by drainage unit. The individual catchments in a drainage unit were defined from a map of Quaternary alluvium, material which has been deposited in Recent geologic time. The area within each catchment is primarily erosional and the sediment yield is that which is delivered to the depositional area of the drainage unit, i.e. the area of Quaternary alluvium. In this sense, the aggregate sediment yields should be roughly equivalent to the amount of erosion taking place within a drainage unit. Under natural conditions, some of this material would be deposited in alluvial fans or valley deposits (in those areas defined as depositional) while the rest would find its way to a coastal lagoon or the ocean.

The technique of estimating erosion within a drainage unit by aggregating the sediment yields of individual erosional catchments is complicated by the catchment area factor in Eq. B4-2. Since sediment yield is a function of catchment area, to some extent the estimated amount of erosion within a drainage unit will be a function of the resolution of the map used to define depositional and erosional areas. If a high resolution map is used such that very small depositional areas are defined, then the unit can be divided into a large number of small catchments. On the other hand, if a low resolution map is used, small depositional features may be missed, and the unit can be divided into fewer, but larger, basins. Therefore, the use of a high resolution map is expected to give a larger aggregate sediment yield, and therefore a larger estimate of erosion, in a drainage unit than the use of a low resolution map. In the study area, some difficulties were encountered in defining erosional basins, as will be discussed for some specific cases later.

In Table B4-2, individual catchment areas are identified as to which larger hydrographic drainage unit they are part of. The twenty-six hydrographic drainage units are located in Fig. B4-3, and Table B4-4 identifies these units and lists aggregate estimates of total average annual sediment yield from erosional areas in each. Also included in this table are estimates of the mean size distributions of eroded sediments for all but three minor units. The basis for the estimated size distributions is as follows.

Upland catchments in the Santa Ynez Mountains group, Ventura River basin, and Ventura group are cut into sedimentary formations of sandstones, shales, siltstones, and conglomerates. These are the same general formations that contribute much of the eroded sediment in the Piru drainage. Therefore, it is estimated that the size distributions of sediments yielded from these areas are approximately the same as that in Piru, or 80 percent fines, 20 percent sand, and essentially no coarser material.

In the Santa Clara River basin eroded sediments derive from granitic rocks and the San Gabriel Mountains (granitic and metamorphic) in headwater areas. Thus there are probably significant variations in the size distributions of catchment debris, but reasonable estimates of mean basin values based on areal weighting by rock type, would be 70 percent fines, 25 percent sand, and 5 percent coarser materials.

Calleguas Creek basin and the Santa Monica Mountains group are composed largely of sedimentary formations and volcanic rock; also the specific weights of accumulated sediments in Encino and Chatsworth reservoirs suggest primarily fine-grained sediments from this area. Thus it is estimated that sediments from erosional areas in these hydrographic units have a mean size distribution of 80 percent fines and 20 percent sand.

Table B4-4

Estimated Annual Upland Erosion Rates
by Hydrographic Drainage Unit
for Natural and Actual Conditions

Hydrographic Drainage Units		Total Drainage Area (Total Erosional Area) km^2	Natural Upland Erosion Rate				Assumed Size Fractions[a] % Fines-Sand-Coarse	Actual Upland Erosion Rate Total m^3/yr
				By Size Fraction				
Name	Code Fig. B4-3		Total m^3/yr	Fines < 0.06 mm m^3/yr	Sand m^3/yr	Coarse > 2 mm m^3/yr		
Santa Ynez Mountains Group	A	901 (767)	671,500	537,200	134,300	-	80-20-0	662,100
Ventura River Basin	B	585 (553)	447,700	358,200	89,500	-	80-20-0	447,000
Ventura Group	C	52 (27)	14,700	11,800	3,000	-	80-20-0	14,700
Santa Clara River Basin	D	4,172 (3,743)	3,063,000	2,144,100	612,600	153,200	80-20-0	3,058,000
Oxnard Group	E	159 (14)	600	-	-	-	NE	600
Calleguas Creek Basin	F	837 (481)	192,500	154,000	38,500	-	80-20-0	189,700
Santa Monica Mountains Group	G	1,493 (1,046)	321,100	256,900	64,200	-	80-20-0	279,100

Table B4-4 (Continued)

Hydrographic Drainage Units: Name	Code Fig. B4-3	Total Drainage Area (Erosional Area) km²	Natural Upland Erosion Rate: Total m³/yr	By Size Fraction: < 0.06 mm m³/yr	Sand m³/yr	Coarse > 2 mm m³/yr	Assumed Size Fractions[a] % Fines-Sand-Coarse	Actual Upland Erosion Rate Total m³/yr
Los Angeles River Basin	H	2,155 (1,215)	852,800	170,600	426,400	255,800	20-50-30	785,800
Long Beach Group	I	120 (48)	2,100	-	-	-	NE	48
San Gabriel River Basin	J	1,663 (1,062)	777,800	155,600	388,900	233,300	20-50-30	741,000
Huntington Beach Group	K	234 (26)	1,400	-	-	-	NE	0
Santa Ana River Basin	L	4,406 (3,055)	1,821,400	637,500	1,001,800	182,100	35-55-10	1,788,100
Lake Esinore Basin	M	(Closed Interior Basin, Not Treated)						
Laguna Hills Group	N	1,737 (1,454)	585,800	410,100	175,700	-	70-30-0	564,700
Santa Margarita River Basin	O	1,927 (1,790)	607,100	212,500	394,600	-	35-65-0	607,100

Table B4-4 (Continued)

Hydrographic Drainage Units		Total Drainage Area (Erosional Area) km^2	Natural Upland Erosion Rate				Assumed Size Fractions[a] Fines-Sand-Coarse	Actual Upland Erosion Rate Total m^3/yr
				By Size Fraction				
Name	Code Fig. B4-3		Total m^3/yr	Fines < 0.06 mm m^3/yr	Sand m^3/yr	Coarse > 2 mm m^3/yr		
San Luis Rey River Basin	P	1,450 (1,309)	647,800	226,700	421,100	-	35-65-0	647,500
Escondido Creek Group	Q	568 (242)	144,300	72,200	72,200	-	50-50-0	129,100
San Diegito River Basin	R	896 (704)	238,500	95,400	143,100	-	40-60-0	236,200
San Clemente Canyon Group	S	437 (336)	46,100	36,900	9,200	-	80-20-0	42,700
San Diego River Basin	T	1,119 (961)	292,100	116,800	175,300	-	40-60-0	278,500
San Diego Group	U	157 (114)	6,100	-	-	-	NE	400
Sweetwater and Otay River Basins	V,W	937 (937)	292,100	146,000	146,000	-	50-50-0	282,000

Table B4-4 (Continued)

Hydrographic Drainage Units		Total Drainage Area (Erosional Area) km^2	Natural Upland Erosion Rate				Assumed Size Fraction % Fines-Sand-Coarse	Actual Upland Erosion Rate Total m^3/yr
Name	Code Fig. B4-3		Total m^3/yr	By Size Fraction: Fines < 0.06 mm m^3/yr	Sand m^3/yr	Coarse > 2 mm m^3/yr		
Tijuana River Basin	X	4,390 (4,184)	1,298,200	454,400	843,800	-	35-65-0	1,298,200
TOTALS		30,395 (24,068)	12,324,700	6,196,900	5,140,200	824,400		12,052,700

a NE: No estimate, data insufficient.

Data collected in the San Gabriel Mountains at several different sites indicate that this mountain range produces approximately 20 percent fines, 50 percent sand, and 30 percent coarser material. For both the Los Angeles and San Gabriel river basins the San Gabriel Mountains are the dominant source of erosional debris and thus this general size distribution offers reasonable estimates for both of these basins.

Erosional surfaces in the Santa Ana River basin include significant areas in the San Gabriel, San Bernardino, and Santa Ana mountains, and the Puente Hills. Considering the relative size of each of the different erosional areas within the basin, and estimated size distributions for the San Gabriel and San Bernardino mountains, and the sedimentary formations of the Santa Ana Mountains and Puente Hills, a mean estimate of 30 percent fines, 55 percent sand, and 15 percent coarse material is assumed for this basin.

The Laguna Hills group is primarily sedimentary formations with some granitic areas. Thus it is estimated that erosional debris form this group is 70 percent fines and 30 percent sand.

The Santa Margarita and San Luis Rey river basins drain southern California batholith formations like those in the Morena drainage, but they also contain some hilly, sedimentary catchments near the coast. Mean size distributions for these two basins are estimated to be 35 percent fines and 65 percent sand.

About one-half of the erosional area in the Escondido Creek group is sedimentary, with the other half granitic materials of the southern California batholith. Therefore, a composite estimate of 50 percent fines and 50 percent sand-size material has been assumed for this group.

The San Dieguito and San Diego river basins are of similar shape, draining granitic formations of the southern California batholith, with contributions from sedimentary formations near the coast. The estimated size distribution for each is 40 percent fines and 60 percent sand. The San Clemente Canyon group is located between the San Dieguito and San Diego basins. This group drains coastal sedimentary areas, and the estimated mean size distribution is 80 percent fines and 20 percent sand.

Erosional areas in the composite Sweetwater and Otay river basins are approximately half sedimentary and half southern California batholith, again suggesting general estimates of 50 percent fines and 50 percent sand.

Finally, the Tijuana River basin, which contains Morena Reservoir, drains southern California batholith formations and some coastal sedimentary rock areas. Mean estimates for this basin are 35 percent fines and 65 percent sand.

Sediment yields by general size distribution are included in Table B4-4. They provide regional estimates of 6 million m^3 of fine material, 5 million m^3 of sand, and approximately 1 million m^3 of coarse sediments, for a total of 12 million m^3 of material yielded annually (average) from erosional areas.

B4.5 Man's Effects on Upland Sediment Yields

In Table B4-2, based on recently compiled USGS land use maps, estimates have been made of the effects of general changes in land use on catchment sediment yield. There is much uncertainty about the effects of urbanization and agriculture on denudation rates. These effects undoubtedly vary both during the initial development period and after equilibrium is re-established, depending on local conditions and specific development.

However, to obtain some estimate of the probable effects of these changes inasmuch as urbanization generally stabilizes surface materials, it was roughly estimated that in hill and mountain catchment areas urbanization has reduced the local value of denudation rate $\overline{DR}$ by 50%, and on erosional plain areas urbanization has reduced $\overline{DR}$ to zero. It was further assumed that in general agricultural land use does not materially alter denudation rates on naturally erosional areas. Based on these assumptions and the relative changes in land use indicated in Table B4-2, estimates were made of reductions in upland sediment yield. These estimates have been aggregated by hydrographic drainage unit in Table B4-4. The estimated overall reduction in erosional sediment yield for the study areas is less than 3 percent, and while individual reductions on most of the major hydrographic drainage units are negligible, for a few they are on the order of 5 to 10 percent and in the Santa Monica Mountains 14 percent.

B4.6 Comparison of Upland Erosion and Coastal Sediment Delivery

In Table B4-5 the estimates of upland erosion are compared with the results of the analysis in EQL Report 17-C for 8 drainage units which have been defined as major river basins with moderate development. As indicated in Table B4-5, each value of coastal sediment delivery refers to a specific period of record, which represents the available data base. For both the estimates of erosion and coastal sediment delivery, the values given are for natural, undisturbed conditions and not actual conditions. For most cases, the actual shoreline deliveries are much less than the natural deliveries, because of dams along the river courses.

On the three northernmost rivers -- the Ventura River, Santa Clara River, and Calleguas Creek -- the ratios of coastal sediment yield to upland erosion are 2.0, 1.2, and 1.3, respectively. However, on the five southernmost rivers -- the Santa Margarita, San Luis Rey, San Dieguito, San Diego, and Tijuana rivers -- these ratios range from 0.1 to 0.6. If the numbers are taken to be correct, then the implication is that the deposits of Quaternary alluvium in the northernmost rivers must

Table B4-5

Comparison of Shoreline Sediment Delivery Estimates from EQL Report 17-C and Estimates of Upland Erosion Rates

Hydrographic Drainage Unit (Code, Fig. B4-3)	Period of Record at Shoreline	Shoreline Sediment Delivery $10^3 m^3/yr$	Long Term Upland Erosion Rate $10^3 m^3/yr$	Ratio
Ventura River Basin (B)	1933-75			
Total		893	448	2.0
Fines		618	358	1.7
Sand		275	89.5	3.1
Santa Clara River Basin (D)	1928-75			
Total		3580	3060	1.2
Fines		2550	2140	1.2
Sand		1030	613	1.7
Calleguas Creek Basin (F)	1928-76			
Total		250	193	1.3
Fines		173	154	1.1
Sand		77.3	38.5	2.0
Santa Margarita River Basin (F)	1931-75			
Total		50.5	607	0.1
Fines		16.1	212	0.08
Sand		34.1	395	0.09
San Luis Rey River Basin (P)	1930-75			
Total		202	648	0.3
Fines		138	227	0.6
Sand		64.3	421	0.08
San Dieguito River Basin (R)	1919-78			
Total		75.5	239	0.3
Fines		51.4	95.4	0.5
Sand		24.0	143	0.2
San Diego River Basin (T)	1913-75			
Total		35.3-177	292	0.1-0.6
Fines		24.0-121	117	0.2-1.0
Sand		11.2-56.1	175	0.06-0.3
Tijuana River Basin (X)	1937-75			
Total		310	1300	0.2
Fines		211	454	0.5
Sand		99.1	844	0.1

be currently eroding, while those in the southernmost rivers are currently undergoing deposition. Before accepting this conclusion the accuracy of the numbers in Table B4-5 must be verified, and other evidence bearing upon this conclusion must be analyzed.

Some physiographic and hydraulic data support the notion that the southern rivers are more likely to be depositional than the northern rivers, as can be seen from a comparison of the Ventura and Tijuana rivers. Even though drainage area of the Tijuana River is about 8 times larger than the Ventura River, the natural flow of the river is estimated to be lower than the Ventura River. Percolation losses along the Tijuana River are high (EQL Report 17-C, pp. C219 - C222). The bed profile of the Ventura River is much steeper than that of the Tijuana River (EQL Report 17-C, pp. C32, C194). Finally, material eroded in the Tijuana River basin has been shown to be coarser than in the Ventura River basin, and coarser material is more likely to be deposited within a basin.

On the other hand the accuracy of the results must be considered. The problem of resolution of individual catchments has been discussed, as well as the general problems (section B4.1) with the method of estimating erosion. In particular, if some of the large individual catchments in the Santa Clara River basin and elsewhere in the northern part of the study area had been subdivided into smaller basins, the estimates of erosion in the northern area would have been larger. Also if some precipitation parameters had been included in the analysis, erosion estimates on the generally drier southern basins probably would have been lower. There are also problems with the technique used to estimate coastal sediment yield from the major rivers, and these problems are more acute for the southern rivers (EQL Report 17-C, p. C211). Another specific problem is that each basin has a different period of record. All things considered, the accuracy of the ratio of upland erosion to coastal sediment yield is probably on the order of a factor of two.

In summary, for the three northern rivers, the upland erosion may be on the same order or somewhat less than the coastal sediment yield, implying that the alluvial fans, flood plains or channels may be undergoing some erosion (particularly on the Ventura River). In the southern river basins, deposition is most likely taking place in these areas.

B5. Conclusions

In characterizing inland sediment movements in southern California, the sediment deliveries through two natural boundaries are of critical importance to sediment management. The first boundary is the interface between upland areas, which are geologically erosional, and valley/plain areas, the surfaces of which are largely depositional in origin. In southern California this interface is generally distinct in most areas, and can be identified topographically or with the aid of surface geology maps.

The second boundary is the terrestrial/marine interface or shoreline. This boundary is also easily identified in southern California, except near lagoonal and marsh areas.

It is estimated that an average of 12 million m^3 of sedimentary debris is eroded each year from erosional areas in southern California coastal drainage systems, distributed as follows according to grain size:

Average Annual Upland Erosion

Silt and Clay:	6 million m^3/yr
Sand:	5 million m^3/yr
Gravel and Boulders:	1 million m^3/yr
Total:	12 million m^3/yr

There are large differences in the size distributions of upland sediment yields throughout the study area. Available data suggest that sediments eroded from the western Transverse Ranges are approximately 4/5 silt and clay-sized material and 1/5 sand; whereas the San Gabriel and San Bernardino mountains produce 1/4 fines, 1/2 sand, and 1/4 coarse material; and the Peninsular Ranges yield 1/3 fines and 2/3 sand-sized material.

Data collected on two upland catchments indicate that annual denudation rates over the past five decades have varied about four orders of magnitude, from a few thousandths of a millimeter to more than 10 mm with individual annual values approximating a log-normal frequency distribution. Based upon generally similar climatic conditions, these relative variations are probably typical for catchments throughout the region.

Comparing upland erosion with corresponding shoreline sediment deliveries under natural conditions (no dams or other manmade structures), study results indicate that with the Ventura, Santa Clara, and Calleguas basins shoreline sediment deliveries are on the order of, or exceed, upland erosion. This would indicate that these streams may be "erosional" along their flood plains, channels, or alluvial fan areas under natural conditions. For five southern rivers in the study area the opposite appears to be true. Here estimated coastal sediment deliveries are considerably smaller than the estimated amounts of upland erosion, suggesting that under natural conditions these rivers are depositional in flood plains, channels, or alluvial fans. However, this conclusion must be considered somewhat tentative because of possible unavoidable errors and biases in the analyses, as discussed in Section B4-6.

Also many streams and rivers in the southern sector have lagoons or estuaries at their mouths. These natural trap areas further reduce the volume of sediment delivery to the shoreline from inland drainages. These factors have not been considered quantitatively in the analysis above.

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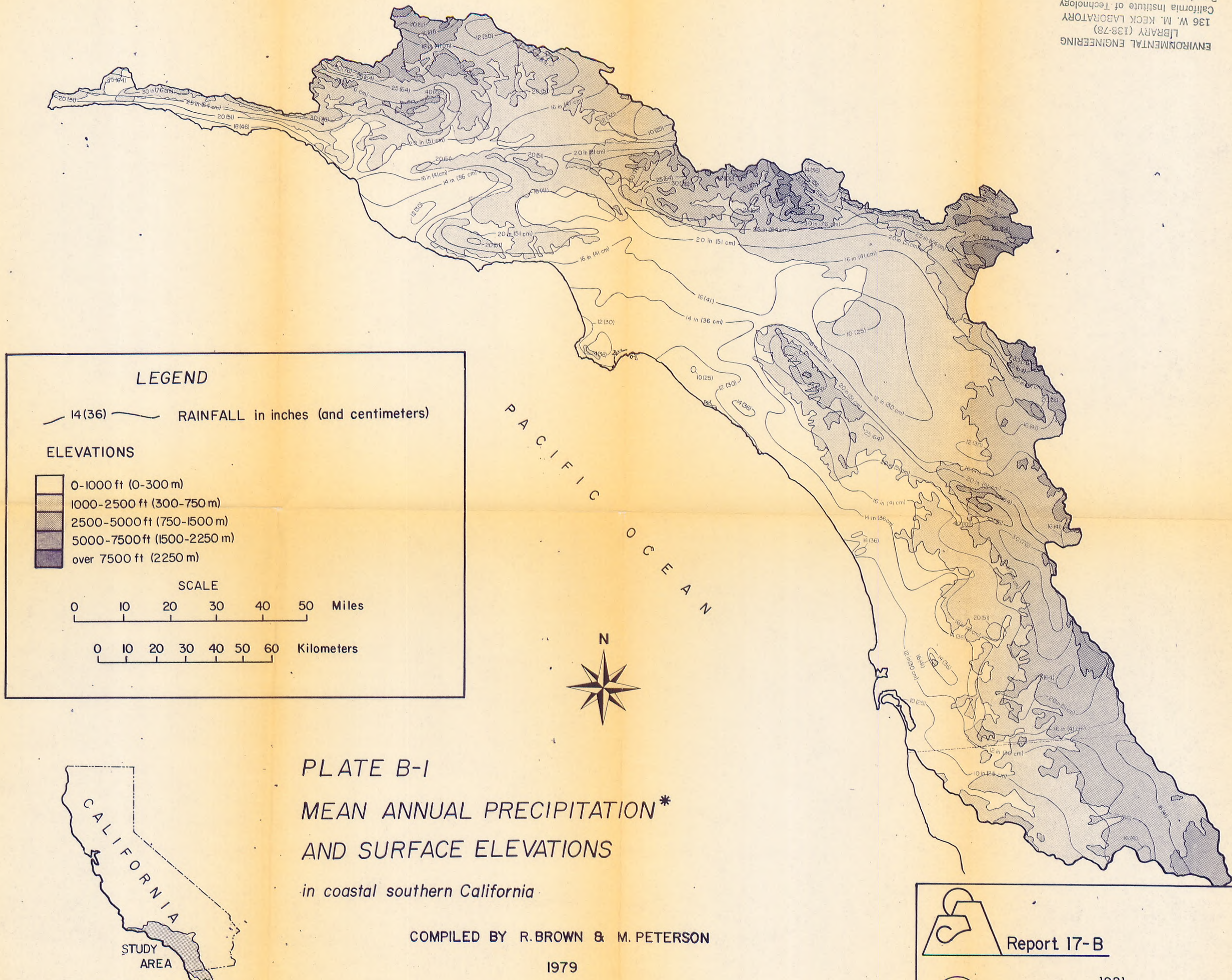

INDEX MAP

PLATE B-1
MEAN ANNUAL PRECIPITATION* AND SURFACE ELEVATIONS

in coastal southern California

COMPILED BY R. BROWN & M. PETERSON

1979

*(90 year rainfall after Rantz, 1969)

Report 17-B

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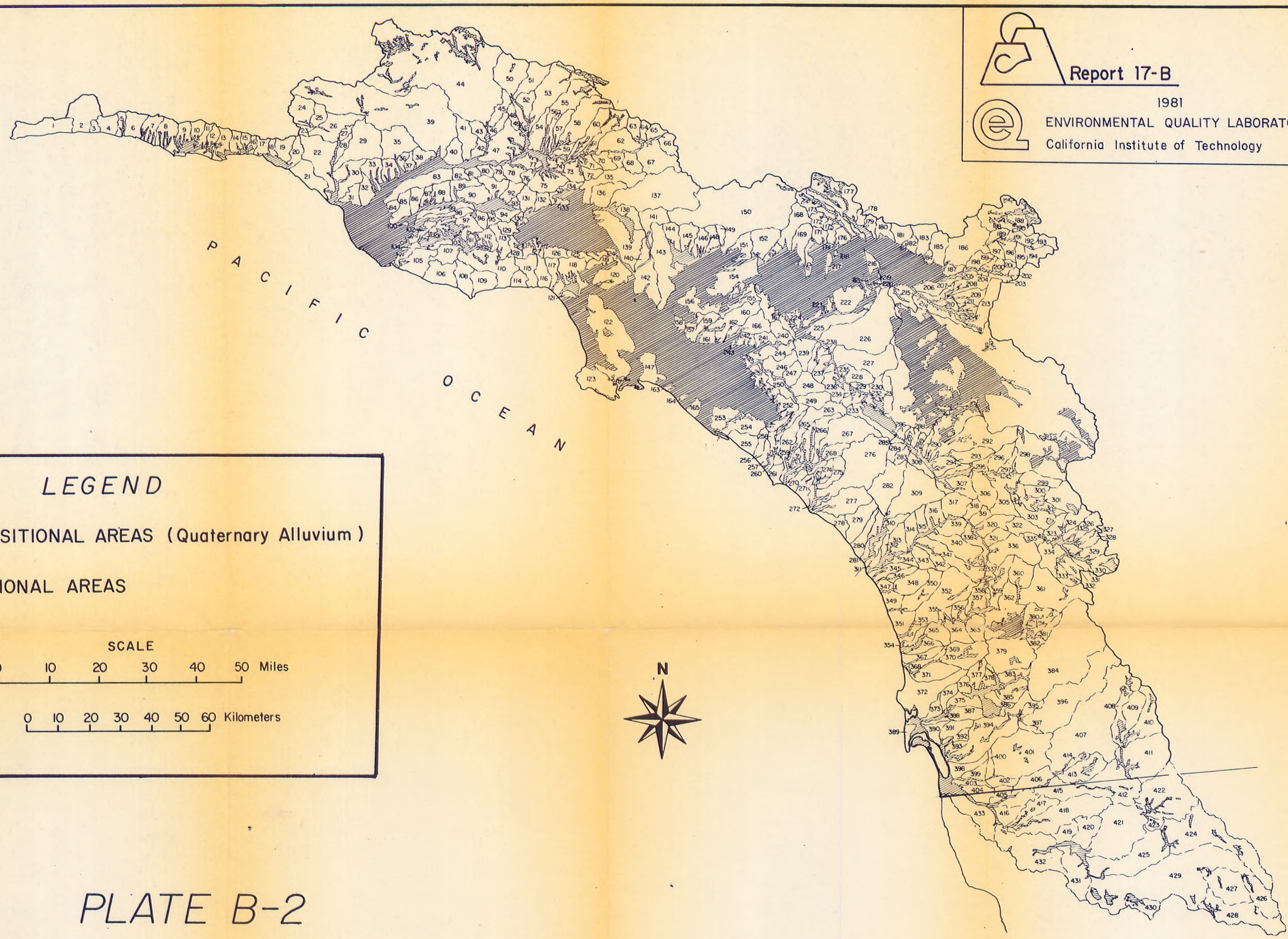

LEGEND

DEPOSITIONAL AREAS (Quaternary Alluvium)

EROSIONAL AREAS

SCALE

0 10 20 30 40 50 Miles

0 10 20 30 40 50 60 Kilometers

PLATE B-2
RECENT EROSIONAL AND DEPOSITIONAL AREAS

on coastal drainages in southern California, with delineation of individual (erosional) catchment areas

COMPILED BY J. MANIATIS, P. MARBLE & B. TAYLOR

1979

INDEX MAP