Sedimentation in the Piru Creek Watershed Southern California

GEOLOGICAL SURVEY WATER-SUPPLY PAPER 1798-E

Prepared in cooperation with the California Department of Water Resources

Sedimentation in the Piru Creek Watershed Southern California

By KEVIN M. SCOTT, JOHN R. RITTER, *and* JAMES M. KNOTT

SEDIMENTATION IN SMALL BASINS

GEOLOGICAL SURVEY WATER-SUPPLY PAPER 1798–E

Prepared in cooperation with the California Department of Water Resources

UNITED STATES GOVERNMENT PRINTING OFFICE, WASHINGTON : 1968

UNITED STATES DEPARTMENT OF THE INTERIOR

STEWART L. UDALL, *Secretary*

GEOLOGICAL SURVEY

William T. Pecora, *Director*

For sale by the Superintendent of Documents, U.S. Government Printing Office
Washington, D.C. 20402 - Price 35 cents (paper cover)

CONTENTS

ILLUSTRATIONS

TABLES

SYMBOLS

A	Drainage area.
A'	Area of reservoir quadrilateral.
A''	Area of lake segment.
A_{ch}	Area of main channel of a watershed.
A_p	Planimetric area of a watershed.
aP	Precipitation during 21 days antecedent to day of maximum precipitation.
C	Cover density.
D	Diameter.
DR	Dispersion ratio.
E	Cross-sectional area of sediment at a range.
EP	Effective precipitation.
Fire	Percentage of watershed burned by fire.
I	Probable maximum 24-hour precipitation.
L	Stream length.
M	Mean diameter.
MAQ	Mean annual runoff per unit area.
MAP	Mean annual precipitation.
N_1,N_2	Number of streams of order designated by subscript.
P	Maximum daily precipitation of storm.
P_1,P_2	Physiographic parameters.
q	Maximum yearly peak discharge.
r	Linear correlation coefficient.
R_b	Stream bifurcation ratio.
R_c	Ratio of stream-channel slopes.
RD	Relative discharge.
RE	Relative erodibility.
RRA	Relative rain area modified for California latitudes.
S_A	Sediment-area factor.
SA	Surface-aggregation ratio.
S/C	Suspended silt and clay divided by colloids.
S_M	Sediment-movement factor.
S_y	Sediment yield.
S_y',S_y''	Sediment yield per unit area.
T_1, T_2, T_3	Transport-efficiency factors.
$TMAQ$	Total mean annual runoff for a basin.
V	Volume.
W	Width of sediment range.
α	Skewness.
θ_g	Ground-slope angle.
σ_ϕ	Sorting.
ϕ	$-\log_2 D$.

SEDIMENTATION IN SMALL BASINS

SEDIMENTATION IN THE PIRU CREEK WATERSHED SOUTHERN CALIFORNIA

By KEVIN M. SCOTT, JOHN R. RITTER, and JAMES M. KNOTT

ABSTRACT

Piru Creek is a southerly drainage of the Transverse Ranges in southern California. Geologically recent tectonic activity has created a terrain in which many different kinds of rocks are exposed and in which landscapes of different maturity are adjacent. Estimates of the sediment yield of the watershed, obtained by a variety of techniques, are consequently variable and range from 165 to 303 acre-feet per year. The Piru Creek watershed has undergone a period of extensive aggradation that may be ending, possibly in response to changes in land use.

Santa Felicia Reservoir, which impounds Piru Creek near its mouth, was surveyed to determine the sediment yield of the watershed. The 10 years of reservoir record (1955–65) was a period of subnormal precipitation. Consequently, streamflow data were used to extend the sediment record through a major wet-dry fluctuation and to obtain an estimate of the probable long-term sediment yield.

The probable sediment yield of the basin above Pyramid Rock, site of a proposed reservoir on Piru Creek upstream from Santa Felicia Reservoir, is 225 acre-feet per year, or 0.79 acre-foot of sediment per square mile per year. The yield was determined by applying a basin-size correction to the sediment yield of the entire basin. Measurements of suspended sediment indicate that 570,000 tons, a volume of 504 acre-feet, were transported past the Pyramid damsite during calendar year 1965. November and December 1965 constituted one of the most intense storm periods in southern California history, and the quantity of sediment transported during 1965 can be considered to represent the expectable maximum. The yield for 1965 confirms the long-term estimate of sediment yield as being substantially and unexpectedly less than that of surrounding watersheds.

Comparable figures for sediment yield were obtained from other analyses of sedimentation in basins of the Transverse Ranges and by correlation of sediment yields in other basins. Multiple-regression equations were calculated using sedimentation records of seven nearby reservoirs.

Regional climatic parameters, effective precipitation and precipitation intensity, were used in the analysis because of the general paucity of climatic data for the Piru Creek basin. Soil erodibility was assessed by determining dispersion and surface-aggregation ratios for each of the seven major lithologic types in the watersheds.

Sediment yields based on correlations using drainage-area and physiographic factors were substantially higher than those based on water-discharge, climatic, land-use, and soil-erodibility factors. The differences in computed yields are due to marked heterogeneity in climate, lithology, and landscape maturity throughout the Transverse Ranges, factors which combine to cause an abnormally low sediment yield in the Piru Creek basin. The sediment yield of Piru Creek has the capacity to increase by approximately 50 percent if subjected to the wildfire prevalence typical of nearby watersheds. However, the premise of interpreting future conditions in light of those of the past probably is the best approach in forecasting sediment yields, unless trends are clearly evident.

INTRODUCTION AND ACKNOWLEDGMENTS

A primary concern in the design of a reservoir is the rate of depletion of reservoir capacity by the accumulation of sediment. This factor assumes added significance in a region of high, yet variable, sediment yield. Such a region is the Transverse Range province of southern California, in which the Piru Creek basin is located. Sediment yield here is generally greater than in most other parts of California where sedimentation in reservoirs has been measured, and the region is one of marked variability in factors affecting erosion and transport of sediment.

A reasonably correct prediction of the long-term sediment yield for the drainage basin above a reservoir is essential. Overly large estimates of sediment yield will result in needless expense of design tolerance for large quantities of sediment. Low estimates may decrease the useful life of a reservoir through reduction of its capacity by the unexpectedly high rate of sediment accumulation and may cause economic loss as well as disruption of water-use planning.

This report applies and compares a variety of methods of estimating sediment yield in the Piru Creek basin above the site of a planned terminal-storage reservoir that is part of the California Water Plan. The methods are applicable to most parts of the Transverse Ranges and to similar regions which are tectonically active and physiographically diverse. The report discusses the techniques and problems of estimating sediment yields where direct measurements have not been made.

The primary method of determining sediment yield is measurement of suspended sediment and streamflow and, thus, the suspended-sediment discharge. The low-frequency and flashy character of runoff in the Piru Creek basin has made the establishment of a sediment-sampling program impractical to date (1966). However, installation of automatic sediment-sampling devices to collect samples at a series of predetermined stages is possible. Such devices were installed at three streamflow gaging stations at the following locations near the damsite: Piru Creek below Buck Creek, Cañada de Los Alamos below Apple Canyon, and Piru Creek above Frenchman's Flat (fig. 1).

The sediment collected by the automatic sampler does not include bedload—sediment which rolls and bounces along the stream bottom.

Reservoir surveys, which consist of measurements of accumulated sediment along preestablished cross sections, are an additional source of direct sediment-volume determination. Such measurements include bedload but exclude suspended sediment passed through the reservoir, the quantity of which depends on the trap efficiency of the catchment. Sediment trapped by Santa Felicia Reservoir, near the mouth of Piru Creek, was measured to establish the overall sediment yield for the drainage basin and was used as a basis for comparison of other methods of computing sediment yield.

Another technique which frequently has been used to estimate sediment yields in the Transverse Range province is the correlation of direct sediment measurements for different basins according to the degree of similarity in the factors that affect sediment yield. The primary factors controlling erosion and sediment yields are watershed area, climate, land use, and soil erodibility. Soil erodibility is of particular importance in areas of young soils where parent material is a significant soil-forming factor generally unrelated to the other factors. Equations incorporating the primary factors were derived to estimate the sediment yield. Sediment yield from the drainage areas above Matilija, Pacoima, Big Tujunga, Big Santa Anita, Sawpit, Big Dalton, and San Dimas Reservoirs, all near the Piru Creek watershed, (fig. 1) had already been measured. By correlation of the yields from the areas above the reservoirs with different parameters of basin characteristics, regression lines were drawn, and the yield for Piru Creek above Pyramid Rock was calculated.

The writers wish to express their gratitude to the following individuals: H. W. Anderson and J. R. Wallis, for consultation and the supply of unpublished data collected by the Pacific Southwest Forest and Range Experiment Station; M. F. Burke, of the Los Angeles County Flood Control District, who provided long-term rainfall records for Los Angeles County; G. M. Kennedy, of the Soil Conservation Service, for aid in obtaining soil information; W. P. Price and Frank Beckwith, of the United Water Conservation District, who provided data and collected sediment samples at Lake Piru; and W. H. Hansen and W. T. Dresser supervisors of Los Padres and the Angeles National Forests, respectively, who provided fire histories for the Piru and adjacent watersheds. The project was conducted cooperatively with the State of California and was completed under the general supervision of W. W. Dean and George Porterfield, of the Water Resources Division, U.S. Geological Survey. The manuscript benefited substantially from the criticism of H. W. Anderson, D. M. Culbertson, and C. H. Hembree.

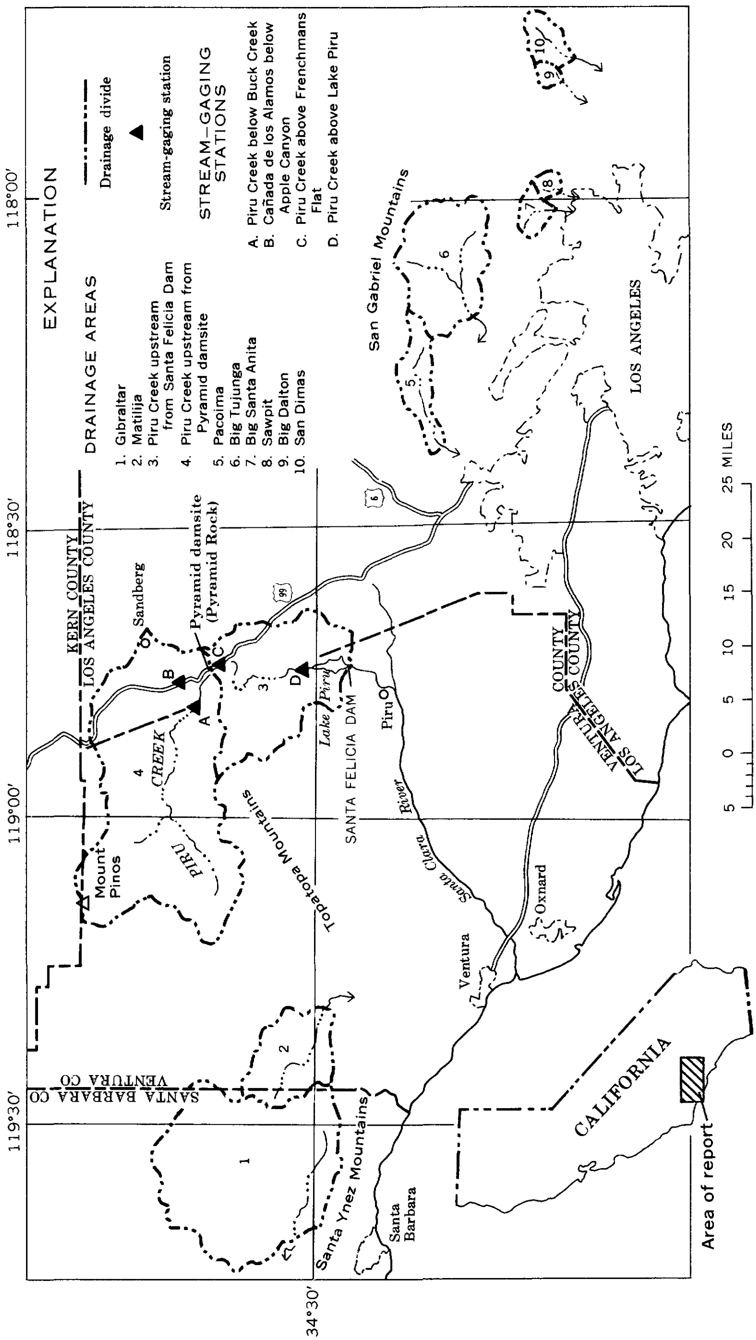

FIGURE 1.—Index map of the Piru Creek watershed and the drainage areas of all reservoirs noted in the text.

LOCATION AND PHYSICAL FEATURES

Piru Creek drains south from the center of the Transverse Ranges, a group of mountains which trend east-west and include the San Gabriel Mountains; the Transverse Ranges are athwart the general northwest trend of the Coast Ranges. Piru Creek joins the Santa Clara River near Piru, about 30 miles northwest of Los Angeles (fig. 1). The drainage basin is mainly in Ventura County but is partly in Los Angeles and Kern Counties. The headwaters of Piru Creek are in the southwest corner of the upper basin, from which the stream descends rapidly and meanders across an area of gentle relief; in general the flow is parallel to structural trends. The upper basin is a broad expanse of terrain ranging in altitude from about 3,000 to 6,000 feet above mean sea level and is bounded on the south by part of the Topatopa Mountains and on the north by Mount Pinos (alt 8,831 ft), the highest point in the basin. About the same proportion of slopes face north as face south in the area above the proposed damsite (fig. 2), near Pyramid Rock (alt 2,250 ft).

FIGURE 2.—View of Piru Creek gorge at the Pyramid damsite looking north. The highway will be rerouted around the reservoir site. The phyllitic shale cropping out at this locality is fairly resistant.

Santa Felicia Dam, about 5 miles upstream from the confluence of Piru Creek and the Santa Clara River, impounds runoff from 425 square miles of the basin. The proposed reservoir at Pyramid Rock will act as catchment area for 284 square miles of the basin. The physiography of the area above Pyramid Rock is distinctly different from that below. The general flow of streams in the upstream area is to the east, as opposed to the southward flowing streams in the downstream area, and the topography is more subdued. Recent tectonic activity has created the present southward drainage of the upper basin, which formerly drained northeastward into the Mojave Desert.

The part of the basin between Santa Felicia Reservoir and the Pyramid damsite is distinctly more mountainous and contains fewer valley flats than the area upstream. The area in the immediate vicinity of Santa Felicia Dam is marked by steep—some precipitous—slopes formed on rather easily erodible rocks. As a result, the area near the dam probably contributes substantially more sediment per unit area than more remote areas. There is no way, unfortunately, to measure quantitatively the relative contributions of areas according to their position within a watershed.

CLIMATE

Piru Creek basin has a Mediterranean-type climate. Summers are dry and warm, and the winters are wet and cool. The mean annual temperature at Sandberg (fig. 1) is 55.5°F, and the mean monthly temperature ranges from 39.9°F in January to 74.4°F in July (fig. 3). The Sandberg weather station is in the northeastern part of the basin

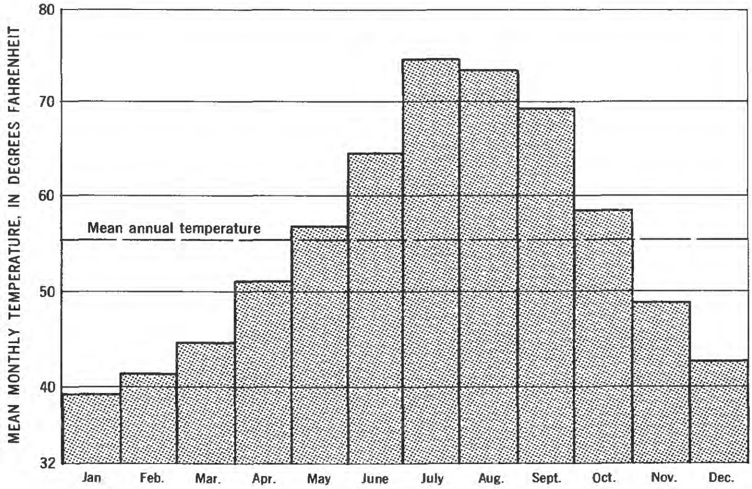

FIGURE 3.—Mean monthly temperatures at the Sandberg weather station.

at an altitude of 4,517 feet, or about 400 feet higher than the mean altitude of the basin.

Mean annual precipitation ranges from about 12 inches near Sandberg to about 24 inches in the southwestern part of the basin. Mean annual rainfall for the entire basin is 17.1 inches and is 15.9 inches for the basin upstream from Pyramid Rock. Mean monthly precipitation at Sandberg ranges from about 0.02 inch in July to 2.58 inches in February (fig. 4).

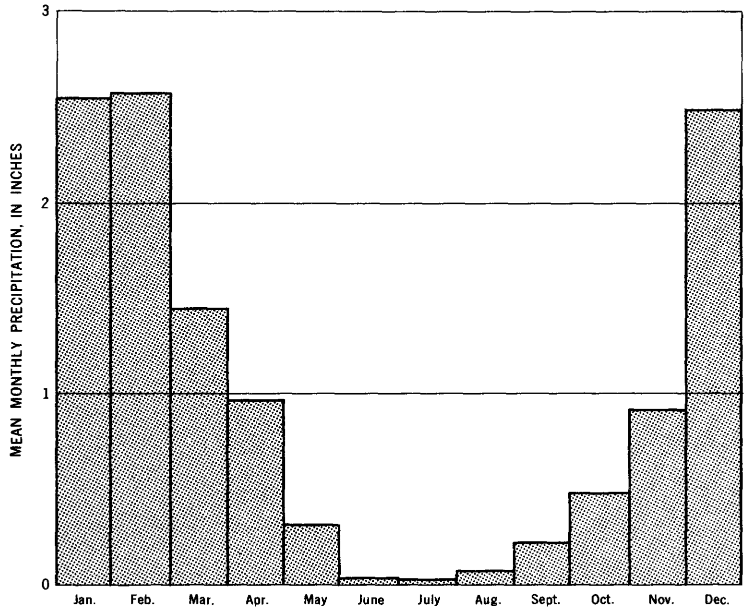

FIGURE 4.—Mean monthly precipitation at the Sandberg weather station.

The only long-term precipitation record in the Piru watershed is that for Sandberg. However, 11 precipitation stations are distributed around the drainage area within 10 miles of the drainage divide. Consequently, the area is included in long-term, extended-record compilations and isohyetal maps. The record at Sandberg emphasizes the climatic variation over a long period of time (fig. 5). The mean annual precipitation at Sandberg is 12.1 inches, but during the 10 years since Santa Felicia Reservoir was constructed and sediment began accumulating, precipitation has averaged 11.0 inches. During the first 10 years of record (1933–42), precipitation averaged 14.7 inches, nearly double the low 10-year average (1947–56) of 7.5 inches.

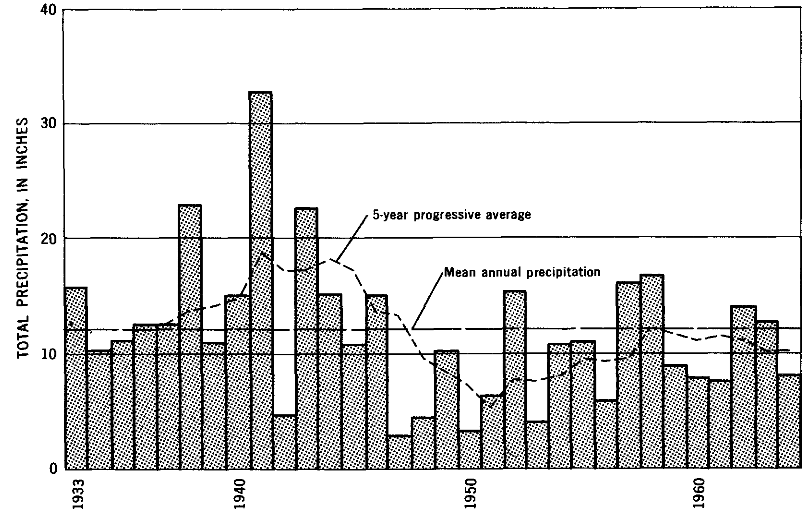

FIGURE 5.—Annual precipitation at the Sandberg weather station from 1933 to 1964.

LITHOLOGY AND STRUCTURE

The Transverse Ranges are a complex structural and stratigraphic province. Piru Creek basin includes part of the eastern end of the Ventura stratigraphic basin, the site of dominantly marine deposition throughout most of the Tertiary Period. The part of the Piru watershed between the Pyramid damsite and Santa Felicia Dam is formed in this thick sedimentary sequence (fig. 6) composed of moderately well consolidated sandstone and conglomerate with interbedded shale. Basement rock for the sedimentary series is an assemblage of pre-Cretaceous igneous and metamorphic rocks which underlies much of the high country in the upper part of the basin.

The area is bisected by the northwest-trending San Gabriel fault, a major rift with a large well-defined lateral separation. The northeastern part of the basin above Pyramid Rock, between the San Gabriel fault and the San Andreas rift (the major structural lineament of California), is in the Ridge stratigraphic basin. The Ridge stratigraphic basin is the site of one of the thickest recorded nonmarine sedimentary sections of Miocene and Pliocene age. The generally soft, readily erodible sequence is exposed in the northeastern part of Piru Creek basin which receives the quantity of precipitation near the optimum for erosion (Langbein and Schumm, 1958, p. 1077), and consequently, badland topography has resulted locally. A comparison of relative sedimentation rates in California and the extent to which they reflect rock type suggests that a much higher than average sediment yield per unit area is attributable to this terrain.

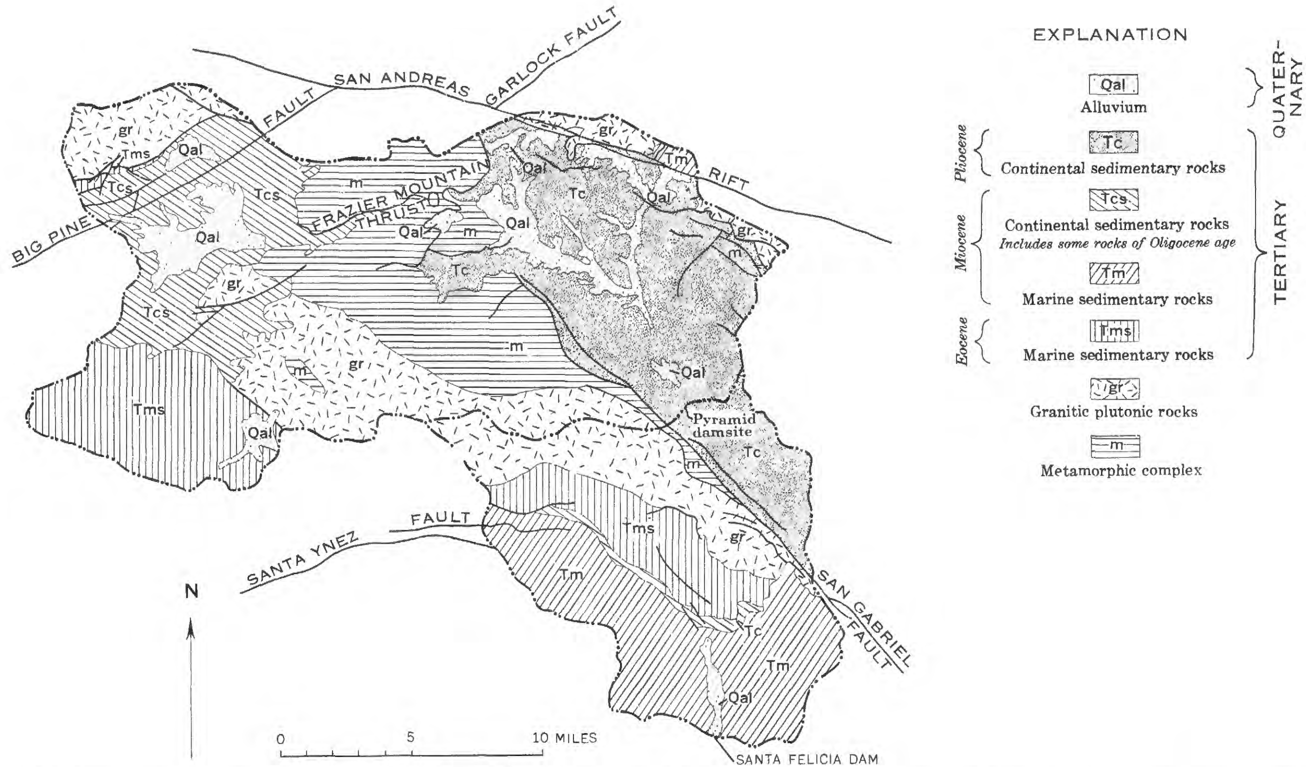

FIGURE 6.—Major rock types in the drainage area of Santa Felicia Reservoir. •• — indicates drainage divide. Geology from Crowell (1952), Kundert (1955), and Carman (1964).

The diverse types of rocks in the Piru Creek basin (fig. 6, table 1) must be considered in determining sediment supply at any particular point. Determinations are further complicated by the intensity of tectonic activity, which must have radically influenced landform evolution within the basin in comparatively recent geologic time. The Pleistocene orogeny of the Coast Ranges is the latest in several mountain-building episodes that are sufficiently recent to be reflected in the present topography.

Piru Creek basin may approximate the ultimate in tectonic effects on sedimentation rates. The drainage basin is immediately south of the juncture of the San Andreas, San Gabriel, Big Pine, and Frazier Mountain faults, each of which transects the area and has large demonstrable displacement. The recently active San Cayetano thrust fault underlies part of the lower Piru Creek basin. A dip-slip component of displacement of 3,500 feet (Shepard, 1960) on the Bayley fault, a major branch of the San Gabriel fault, has occurred within the basin since middle Pleistocene time. About 3.5 miles of horizontal displacement is apparent along the same shear zone of the Bayley fault, which forms the channel of Piru Creek for 3 miles upstream from Pyramid Rock.

TABLE 1.—*Proportions of lithologic types exposed in the Piru Creek watershed*

Lithologic types	Percentage of area	
	Upstream from Santa Felicia Reservoir	Upstream from Pyramid damsite
Alluvium of Quaternary age	7.3	9.9
Continental sedimentary rocks of Pliocene age	20.1	22.8
Continental sedimentary rocks of Miocene age (includes some rocks of Oligocene age)	13.5	.5
Marine sedimentary rocks of Miocene age	9.9	13.3
Marine sedimentary rocks of Eocene age	13.4	12.1
Granitic plutonic rocks	20.5	19.9
Metamorphic complex	15.3	21.5

GEOMORPHOLOGY

Tectonism probably will not change the sediment yield throughout the lifetime of any reservoir as much as will climatic and land-use factors. Tectonic events have brought about the present distribution of rock types, and differential erosion has produced the present topography. However, differential movement in the recent past between drainage basins and parts of basins may influence sediment yields. Differences in maturity of landscapes between and within basins introduces uncertainty in correlations of rates of sediment yield; this interaction of the effects of lithology and of erosion stage thus provides additional uncertainty in the assessment of sediment yields. The relation between lithology and a slope parameter, the first-order stream gradient, calculated from U.S. Geological Survey topographic maps at a scale of 1: 24,000 illustrates the dependence of physiography on rock type (table 2).

TABLE 2.—*Relation of lithology to first-order stream gradient in the Piru Creek watershed*

Lithology	*First-order stream gradient (ft per ft)*
Alluvium of Quaternary age	0. 083
Continental sedimentary rocks of Pliocene age	. 130
Continental sedimentary rocks of Miocene age (includes some rocks of Oligocene age)	. 118
Marine sedimentary rocks of Miocene age	. 246
Marine sedimentary rocks of Eocene age	. 213
Granitic plutonic rocks	. 305
Metamorphic complex	. 263

One unusual feature of the area is the alternation of highly erodible and highly resistant rocks, particularly along the course of Piru Creek. This variation in rock type results in broad alluviated subbasins alternating with gorges incised in bedrock. In addition to the primary control of stream gradients by regional tilting of bedrock and by contrasts in erodibility of different rock types, many resistant layers in the sedimentary sequences form local base levels and slope inflections and create local segments of alluviation—numerous valley flats (fig. 7) alternate with bedrock channels.

FIGURE 7.—View of Piru Creek looking upstream from a point 4 miles upstream from Santa Felicia Dam. A typical valley flat is visible in the foreground. Peak at left is Blue Point.

309-538 O—68——3

The headwaters of Piru Creek are in readily erodible sediments. The stream passes abruptly into highly resistant gneiss, then into extremely erodible rocks of Pliocene age in the eastern part of the upper basin, and then again into the gneiss for a short distance. The anomalous course of Piru Creek, which flows southeast across many structural trends and against the predominant northwest dip of the rocks, was first noticed by Hershey (1902).

Alluviation of much of the upper basin seems to be abnormal (fig. 8) compared with alluviation of surrounding areas and thus suggests a previous period of aggradation. Active channel erosion and local gullying suggest that the period of alluviation may be ending, possibly in response to grazing. A large potential source of sediment exists upstream from Pyramid damsite, and a substantial increase in sediment yield could be triggered by only moderate changes in climate or land use.

FIGURE 8.—Lockwood Valley, a broad alluviated area in the western part of the Piru Creek basin. Frazier Mountain forms the skyline. Snow remaining more than a few days is rare except on the highest elevations.

Several erosion surfaces, some representing stripped nonconformities at the base of thick sediment accumulations of Pleistocene age, are conspicuous in the upper basin at altitudes of approximately 4,000 and 7,000 feet above mean sea level and are locally affected by faulting (Crowell, 1952). At least two terraces, one 30 to 50 feet and one 15 to 20 feet above the bottom of the stream, occur along lower reaches of Piru Creek. The lower course of the stream has aggraded appreciably, 90 feet of sediment having been reported near Blue Point (Shepard, 1960, fig. 7) and 80 feet at the Santa Felicia damsite (Cordova, 1956).

Landslides are a significant mechanism of sediment movement in the area. Ten unpublished theses on the geology of approximately one-third of the total basin record many mappable landslides and additional landslide deposits. The slides are most common on slopes formed in sedimentary rocks adjacent to fault lines and are sediment-supply mechanisms with probable strong periodicity related to climatic variations. Additional fault zone or "rift" topography in the area includes offset alluvial remnants and terraces, sagponds, and faceted spurs.

SOILS AND VEGETATION

Most of the area is covered by shallow, irregular stony soils formed in place by residual weathering. Typical of such soils is the Altamont Loam in the southernmost part of the basin, the only part covered by a soil survey (Nelson and others, 1920). The Altamont Loam is 8 to 15 inches deep, contains shale fragments and caliche concentrations, and occurs locally on upland areas. Soils along stream channels are young, sporadically located alluvial soils, such as the Yolo Sandy Loam, 12 to 30 inches in thickness, and vary to lighter textured varieties.

Chaparral is the commonest form of vegetative cover, particularly on slopes underlain by sandstone and conglomerate. Seasonal grasses dominate in soil formed on finer grained sedimentary rocks and alluvium. Groves of oak, cottonwood, and willow occur in stream channels and near springs. Oak, transitional to pine, and some fir and juniper occur at altitudes above 5,000 feet. The pattern is modified by topography; higher altitude forms of vegetation occur on northern slopes and in canyon bottoms as a result of shading and the downhill flow of cold air.

LAND USE AND FIRE HISTORY

Most of the area is culturally undeveloped. The main human factor affecting sediment yield is road construction. U.S. Highway 99, the new ridge route, was built in the late 1930's but has been widened and straightened subsequently. The necessary rerouting of the highway around the new reservoir will be the most immediate cultural factor increasing sediment yield at the proposed damsite.

Some cattle ranching is practiced in the upper basin along with some dry farming on lowland flats.

In southern California, brush-covered watersheds with seasonal rain are susceptible to fires, some of which cause high but temporary sediment yields during the following years. This is particularly true of the basins used for sediment-yield correlation with the Piru Creek basin; however, less than 10 percent of the Piru Creek watershed has been burned since 1940 (less than 0.4-percent burn per yr).

DIRECT MEASUREMENT OF SEDIMENT DEPOSITED IN LAKE PIRU

A reservoir survey of Lake Piru (Santa Felicia Reservoir), which stores runoff from nearly the entire Piru Creek basin, was made in October and November 1965 to measure the sediment stored in the reservoir. Lake Piru was formed in 1955 by the construction of Santa Felicia Dam by the United Water Conservation District and is 4.4 miles northeast of Piru in Ventura County (fig. 1). The dam is an earthfill structure 85 feet high and 1,275 feet long and forms a reservoir in a narrow gorge that extends about 4.3 miles upstream (figs. 9, 10).

FIGURE 9.—View of Lake Piru looking from the east shore upstream from Santa Felicia Dam.

RESERVOIR USE AND OPERATION

Water released from Lake Piru is used for ground-water recharge and irrigation on the Oxnard Plain. Water-discharge records for Piru Creek downstream from Santa Felicia Dam indicate an average annual outflow of 24,900 acre-feet for the period October 1955–October 1965. Complete records of streamflow into and out of the reservoir are published by the U.S. Geological Survey in the water-supply paper series, "Surface Water Supply of the United States—Part 11, Pacific Slope Basins in California," and the annual series,

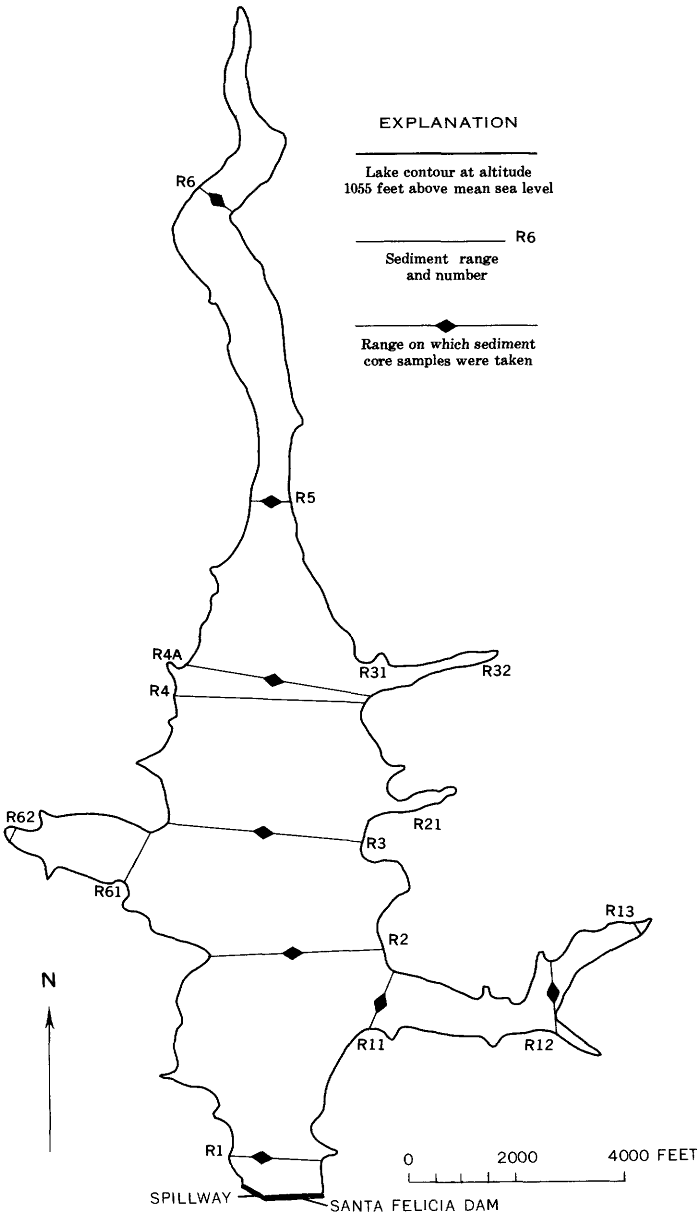

FIGURE 10.—Locations of sediment ranges on Lake Piru.

"Water Resources Data for California—Part 1, Surface Water Records of California, Volume 1, Colorado River basin, Southern Great Basin, and Pacific Slope basins excluding Central Valley."

Operations at Lake Piru, like those at many reservoirs in southern California, are oriented toward water conservation. Water that is not used during wet years is held for the inevitable dry years. The storage of water in Lake Piru has ranged from zero for a few weeks in 1961 to 78,500 acre-feet in 1958. The reservoir has never filled to maximum capacity, 101,225 acre-feet.

Water releases for ground-water recharge are generally uniform and average about 10 to 20 acre-feet per day throughout much of the year. Water required for irrigation is generally released during March and April and sometimes exceeds 200 acre-feet per day. The quantity of water released for irrigation is variable, depending on the availability and the demand, and is less than 10 percent of the total outflow. This mode of operation of the reservoir minimizes seasonal fluctuations of reservoir levels and redistribution of sediment within the reservoir.

METHOD OF SURVEY

A series of sediment ranges (fig. 10) was established by the United Water Conservation District before completion of Santa Felicia Dam, and a resurvey of these established ranges was selected as the best method of measuring sedimentation in Lake Piru. The amount of sediment was calculated by the prismoidal method (Eakin and Brown, 1939, p. 158–159) from the difference between the 1955 and 1965 cross sections. The elevation of the sediment surface was determined by transit-stadia traverse where the lakebed was exposed and by lead-line sounding where the lakebed was submerged.

A reconnaissance of the reservoir when the lake was low indicated that much sediment was deposited as a delta between ranges 4 and 5 (fig. 10). Range 4 is established along a bedrock ridge extending about a third of the way across the reservoir from the right bank. All sediment originally deposited along the ridge has been removed be subaerial erosion. The resistant bedrock layer forming the constriction impounds a moderate amount of sediment that is unmeasured along range 4. Therefore, a new cross section, 4A, was established upstream from the constriction formed by the ridge. The original bottom of the reservoir along range 4A was determined by core holes, and the measured depth of sediment was used in calculating the volume of the deposited sediment.

SEDIMENT SAMPLING

Samples of lakebed sediment were collected at several points along each survey range. Veihmeyer tubes were used at ranges where the lakebed was exposed to obtain samples which represent an accurate vertical distribution of the sediment layer. A split-core sampler suspended by standard streamflow-measuring equipment was used at ranges where the lakebed was submerged. The split-core sampler penetrated the sediment layer by the force of its own weight, the depth of penetration being restricted by various properties of the deposited sediment such as cohesiveness, grain size, and compaction.

SEDIMENT PROPERTIES

Specific weight was determined for most of the sediment samples (table 3). Samples were reconstructed in the laboratory to obtain values of specific weight that would represent conditions of initial deposition. Water was added to the samples, which were stirred and allowed to settle. The reconstructed specific weight was computed by dividing the dry weight by the volume of the settled sediment.

Specific weight of the sediment deposited in Lake Piru ranges from 33 to 96 pounds per cubic foot (fig. 11) and generally increases with distance upstream from the dam. Pronounced variation from range to range may be due to such factors as compaction, grain size of sediment, turbidity currents, erratic inflow characteristics, and reservoir shape. Mean specific weight of lake-bottom sediment is 52 pounds per cubic foot. The value was computed by adjusting the average specific weight of each reservoir segment to the volume of sediment deposited therein. Specific gravity of the sediment samples, determined by the flask method (U.S. Bureau of Reclamation, 1960, p. 443), ranged from 2.63 to 2.70 (table 3).

TABLE 3.—*Specific gravity and specific weight of sediment samples from Lake Piru*

Range	Specific gravity	Specific weight (lb per cu ft)	Range	Specific gravity	Specific weight (lb per cu ft)
1	2.66	43.0	5	2.66	96.5
2	2.70	36.4	6	2.63	88.9
3	2.70	33.0	11	2.65	66.0
4A	2.68	74.6	12	2.66	96.0

Particle-size distribution was determined for all samples of lake sediment (table 4). Samples in the sand and gravel range (>0.062 mm, Wentworth scale) were analyzed by sieving, and samples in the silt and clay range (<0.062 mm) were analyzed by the pipet method. Particle size of lake sediment from range 3 downstream to the dam is quite uniform, and the sand content is small (fig. 11). Lack of sand in this area is due to the settling of coarse-grained material in the upper reaches of the lake. Most of the sediment in the lower reaches of the reservoir is transported to the site of deposition by turbidity flows, a mechanism only rarely capable of transporting sand. The median grain size in this area ranges from 0.0024 to 0.0091 mm.

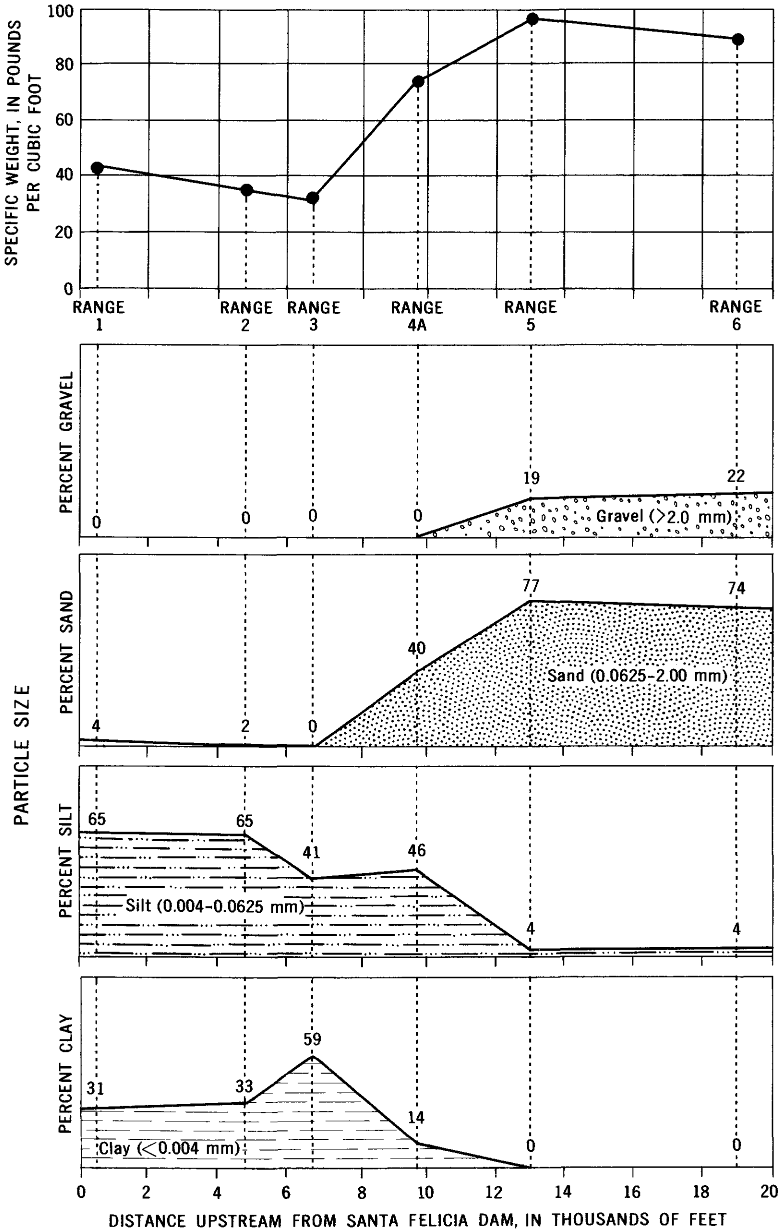

FIGURE 11.—Specific weight and particle size of sediment deposited in main stem of Lake Piru.

Sediment deposited in the reservoir above range 3 increases in coarseness with distance upstream from the dam. Median grain size increases from 0.0024 mm at range 3 to 0.88 mm at range 6. Most of the

TABLE 4.—*Particle-size distribution of sediment samples from Lake Piru*

[All samples analyzed by sieve, by pipet, in distilled water, and by chemical dispersion]

Range	Percent finer than indicated size, in millimeters														Median particle size (millimeter)
	0.002	0.004	0.008	0.016	0.031	0.062	0.125	0.250	0.500	1	2	4	8	16	
1	26	31	47	64	88	96	100								0.0088
2	26	33	48	64	82	98	100								.0091
3	47	59	68	87	98	100									.0024
4A	12	14	17	26	32	60	88	99	100						.048
5				1	2	4	11	22	39	64	81	91	98	100	.68
6	1	1	1	2	3	4	6	10	24	56	78	89	95	100	.88
11	9	10	12	18	27	38	58	74	78	87	92	92	94	100	.095
12				1	1	2	8	20	34	51	69	94	100	100	.96

sediment is in the main stem of the reservoir; that deposited in tributary arms is only about 2.2 percent of the total volume.

The mean particle size, sorting, and skewness of the samples at each range are shown in figure 12. Parameters were calculated by the methods of Inman (1952, p. 130) using phi units where $\phi=-\log_2 D$, D being the particle diameter in millimeters (Krumbein, 1936, p. 37). In general, the sediment becomes finer grained, more poorly sorted, and more positively skewed from the head of the reservoir toward the dam. Most of the sand entering the reservoir is deposited in the

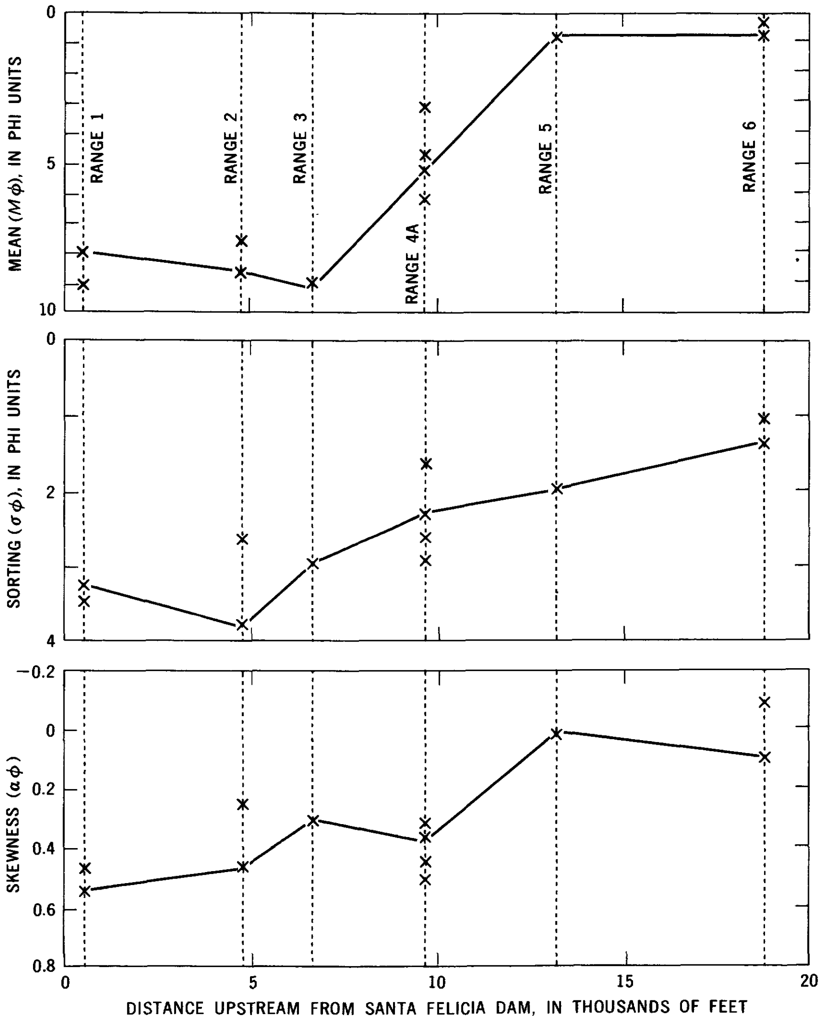

FIGURE 12.—Mean particle size, sorting, and skewness of sediment in Lake Piru.

delta and is bypassed by the silt and clay fractions, which are transported and deposited farther down the reservoir.

COMPUTATION OF SEDIMENT VOLUME

The 1965 reservoir survey indicated that 2,470 acre-feet of sediment (an average sedimentation rate of 247 acre-ft per yr or 0.58 acre-ft per sq mi per yr) had accumulated in Lake Piru since 1955. The sediment volume was computed from the prismoidal formula (Eakin and Brown, 1939, p. 158–159)

$$V=\frac{A'}{3}\left(\frac{E_1+E_2}{W_1+W_2}\right)+\frac{A''}{3}\left(\frac{E_1}{W_1}+\frac{E_2}{W_2}\right), \qquad (1)$$

where V=Volume of sediment, in acre-feet,
A'=Area, in acres, of the quadrilateral formed by connecting the points of range intersection with maximum lake level,
A''=Area of lake segment, in acres,
E=Cross-sectional area of sediment at the range, in square feet,
and W=Width of range at maximum lake level, in feet.

The volume of sediment deposited in reservoirs is usually representative of the total sediment discharge to the reservoir. A small percentage of sediment may pass through the reservoir in suspension. The percentage of the total sediment inflow retained in the reservoir is known as the trap efficiency and, in general, is affected by such factors as slope of the reservoir, ratio of inflow to capacity, sediment properties, water salinity, turbidity currents, and reservoir operation. The principal factors affecting trap efficiency of Lake Piru have been the mode of operation and the inflow to the reservoir. The water level has never reached the spillway elevation and, consequently, the only way sediment could leave the lake is via gate valves in the dam. Normal procedure has been to release only minimum flows during and immediately after storm periods. The trap efficiency of Lake Piru probably is nearly 100 percent, and the sediment volume measured by the 1965 reservoir survey represents nearly the total sediment inflow.

Any reduction in trap efficiency that may result from sediment passed through Santa Felicia Dam is probably compensated for by the addition of sediment derived from within the reservoir. Throughout the history of Lake Piru, lateral slopes and tributary stream channels in the upper part of the reservoir have actively been degraded. The sediment removed from these areas is deposited with sediment eroded from the watershed and is included in the total measured sediment volume. However, the quantity of sediment added in this manner is probably small in relation to the total inflow.

MEASUREMENT OF SUSPENDED SEDIMENT TRANSPORTED BY FLOODS

The quantity of suspended sediment transported by Piru Creek was measured at two stream-gaging stations—one immediately downstream from the proposed Pyramid damsite and the other upstream from Lake Piru (fig. 1). Samples of the water-sediment mixture were obtained at low flow with hand-operated depth-integrating samplers. Higher flows were sampled at the gaging station on Piru Creek below the Pyramid damsite by an automatic sampler which obtained samples at a series of fixed elevations on the rising stage of each runoff event. Data were obtained from automatic samplers installed at two additional gages—Piru Creek below Buck Creek and Cañada de Los Alamos below Apple Canyon (fig. 1)—but lack of water-discharge data for high flows prevented calculation of the quantity of suspended sediment transported at those localities.

The concentration of suspended sediment in each of the flow samples was determined so that the relation between water discharge and sediment concentration could be established. Sediment concentration ranged from 2 to 268,000 parts per million. Such extreme variability is typical of semiarid and arid regions with flash floods and ephemeral runoff. Particle size, specific gravity, and specific weight were determined for selected samples.

The installation of the automatic samplers in January 1965 preceded one of the most intense storm periods in the history of southern California, November and December 1965. The Sandberg weather station received 9.80 inches of precipitation in November, a month in which the mean precipitation is 0.92 inch. An additional 3.90 inches fell in December, which previously had averaged 2.49 inches. The rain gage at Lake Piru collected 15.76 inches in November and 6.08 inches in December months in which an average of only 1.67 and 1.87 inches of precipitation had fallen previously. The November rainfall was the second greatest monthly precipitation in the 33-year record at Sandberg and the greatest recorded monthly total in 14 years of data collection at the Lake Piru station. The runoff during calendar year 1965 can be considered as being in the uppermost range of reasonably expected flows to pass the damsite and to have transported a near-maximum sediment load under present watershed conditions. The short period of flow measurement at the Pyramid damsite prevents a more specific discussion of the frequency of the 1965 floods.

The total amount of suspended sediment to pass the damsite during this wet year was 570,000 tons. This is the sum of all daily sediment discharges during calendar year 1965, but virtually the entire amount was transported by the flows of November and December. Sediment loads for periods during which suspended-sediment concentrations or water discharge changed rapidly were obtained by subdividing each day and computing a mean concentration and load for each day. The quantity of suspended sediment that was transported during unsampled periods was estimated by comparing recorded water discharges with similar flows which were sampled. Conversion of the amount of 570,000 tons to volume, using a specific weight of 52 pounds per cubic foot based on sediment deposited in Lake Piru, gives a sediment yield at the damsite of 504 acre-feet, or 1.77 acre-feet per square mile of drainage area. These values represent only suspended sediment to which, for strict comparison with the other estimates of total sediment yield presented here, must be added values for bedload and an inestimable, but relatively small, quantity of unmeasured load.

Because the sediment-yield rate determined from the 1965 reservoir survey of Santa Felicia Reservoir is used in the following sections as a basis for comparing the validity of yields derived by other techniques, a comparison of the rate of suspended-sediment movement past the damsite with that into the reservoir is significant. Collection of samples upstream from the head of the reservoir allows us to make such a comparison for one of the November 1965 flood peaks. The results (table 5) indicate a considerably greater sediment yield per unit area at Piru Creek upstream from Lake Piru (494 tons per sq mi) than at the Pyramid damsite (374 tons per sq mi). The higher yield at the downstream station is attributable to a much higher rainfall in November at Lake Piru (15.76 in.) than at Sandberg (9.80 in) and to a greater proportion of erodible rocks in the drainage area downstream from the damsite.

TABLE 5.—*Comparison of the quantity of suspended sediment transported past the damsite with that supplied to the head of Lake Piru for a storm in November 1965*

[Results are estimated, except where value is preceded by *]

Date	Piru Creek above Frenchmans Flat (Pyramid damsite)				Piru Creek above Lake Piru (Santa Felicia Reservoir)			
	Mean discharge (cfs)	Suspended sediment			Mean discharge (cfs)	Suspended sediment		
		Concentration (ppm)	Tons per day	Tons per sq mi		Concentration (ppm)	Tons per day	Tons per sq mi
Nov. 15	44	300	170		64	1,680	*969	
16	798	14,100	*57,600		862	20,100	*73,700	
17	1,120	11,000	47,000		2,170	14,000	*96,400	
18	325	840	790		837	4,000	9,700	
19	250	580	430		406	2,000	2,300	
20	114	210	*65		188	1,100	560	
21	56	160	24		109	750	*221	
Total	2,707		106,079	374	4,636		183,850	[1] 494

[1] Based on a drainage area of 372 sq mi.

FORMULAS DEVELOPED FOR ESTIMATING SEDIMENT YIELD IN SOUTHERN CALIFORNIA

Two formulas that have been derived to estimate sediment yields in southern California were applied to the Piru Creek watershed above Santa Felicia Dam. The first of these, based on surveys of sediment accumulation in Gibraltar Reservoir (U.S. Department of Agriculture, 1953, app. 2, table 3) is

$$\log S_{y'} = \log \frac{RE}{100} + \log \frac{RD}{100} + 0.689 + 0.866 \log q - 1.236 \log C + 0.370 \log A_{ch}, \quad (2)$$

where

RE = Relative erodibility, antilog $(1.678+0.0183\ S/C)$, with Gibraltar being taken as 100,
S/C = Suspended silt and clay divided by colloids, in percent,
RD = Relative discharge, 0.370 power of ratio of annual flow to peak flow of year to 0.866 power (Gibraltar being taken as 100),
q = Maximum yearly peak discharge, in cubic feet per second per square mile,
C = Cover density on the watershed, in percent,
A_{ch} = Area of main channel of the watershed, in acres per square mile.

The U.S. Department of Agriculture (1953, app. 2, table 3) determined the relative erodibility, RE, of Piru Creek basin as 399; the average relative discharge, RD, as 105; and the area of main channel, A_{ch}, as 4.9 acres per square mile. A value of 77.4 percent was used for the cover density, C. Substitution of these constants reduced equation 2 to

$$\log S_{y'} = 0.866 \log q - 0.769. \quad (3)$$

Maximum yearly peak discharges from 1956 to 1965 were substituted for q, and the yearly sedimentation in Lake Piru was computed (table 6). The total sediment yield for the 10 years, 4,255 acre-feet, is considerably higher than the 2,470 acre-feet measured in the 1965 survey of Lake Piru.

The second formula was derived by Anderson (1949, p. 579) from sedimentation records of many reservoirs in the San Gabriel and the San Bernardino Mountains. This formula, with the same symbols as equation 2, is

$$\log S_{y'} = 1.041 + 0.866 \log q + 0.370 \log A_{ch} - 1.236 \log C \quad (4)$$

The values for A_{ch} and C are the same as those used in equation 1, and the equation is reduced to

$$\log S_{y'} = 0.866 \log q - 1.041. \quad (5)$$

Table 6 shows that for the years 1956–65 the total sedimentation, calculated by use of equation 5, was 2,285 acre-feet.

TABLE 6.—*Calculations of yearly sedimentation in Lake Piru*

Water year (Oct. 1-Sept. 30)	Peak discharge (cfs)	Equation (3)		Equation (5)	
		$S_{y'}$ (acre-ft/per sq mi)	S_y (acre-ft)	$S_{y'}$ (acre-ft/per sq mi)	S_y (acre-ft)
1956	1,230	0.480	204	0.258	109
1957	3,600	1.216	517	.653	278
1958	8,600	2.582	1,097	1.387	589
1959	3,820	1.279	544	.687	292
1960	292	.137	58	.074	31
1961	528	.231	98	.124	53
1962	12,200	3.499	1,487	1.879	799
1963	512	.225	96	.121	51
1964	318	.148	63	.079	34
1965	484	.214	91	.115	49
Total			4,255		2,285

Anderson's formula (eq. 5) for annual sediment yeild in southern California provides a remarkably close approximation to the measured sedimentation rate in the resevoir survey. The formula was used, therefore, to calculate annual sediment yields from the area above Lake Piru from 1932 to 1965 (table 7). The measured sediment yield was 1.08 times that calculated by Anderson's formula, and all yields computed from the formula were adjusted by this factor to correspond with measured rates. Cover density (C) and channel area (A_{ch}) were assumed to be constant throughout this period. The expansion of the

TABLE 7.—*Calculated annual sedimentation rates at Lake Piru*

Year	Peak discharge (cfs)	S_y, sedimentation rate (acre-ft per yr)	Cumulative acre-ft	Year	Peak discharge (cfs)	S_y, sedimentation rate (acre-ft per yr)	Cumulative acre-ft
1932	15,800	934	934	1949	165	18	7,659
1933	1,200	101	1,035	1950	472	45	7,704
1934	12,000	736	1,771	1951	30	1	7,705
1935	3,660	264	2,035	1952	7,010	464	8,169
1936	1,040	89	2,124	1953	618	56	8,225
1937	5,000	346	2,470	1954	1,150	96	8,321
1938	35,600	1,890	4,360	1955	330	32	8,353
1939	2,600	196	4,556	1956	1,230	118	8,471
1940	1,470	120	4,676	1957	3,600	301	8,772
1941	7,500	491	5,167	1958	8,600	637	9,409
1942	948	82	5,249	1959	3,820	316	9,725
1943	16,000	1,148	6,397	1960	292	34	9,759
1944	8,500	547	6,944	1961	528	57	9,816
1945	3,350	245	7,189	1962	12,200	864	10,680
1946	3,000	222	7,411	1963	512	55	10,735
1947	2,500	190	7,601	1964	318	37	10,772
1948	420	40	7,641	1965	484	53	10,825

data to 1932, the time of first flow measurement, gave an approximation of sediment yield during the wet years of the 1930's and early 1940's. The overall average annual sediment yield covers at least one wet period and one dry period. The average sediment yield for the area above Lake Piru for the 34-year period was 318 acre-feet per year. This yield will be compared with sediment yields of neighboring basins which have longer records of reservoir sedimentation.

ESTIMATES OF SEDIMENT YIELD BY CORRELATION WITH AND REGRESSION ANALYSIS OF DATA IN ADJACENT BASINS

COMPARISON OF SEDIMENTATION RATES

DETECTION OF CHANGES IN WATERSHED CONDITIONS

In making long-term comparisons of sediment yields, the assumption is that all environmental factors within the different basins have remained approximately constant. Because of fires, road construction, or other changes in the watershed environment, the sediment yield may change. For example, Anderson (1955, p. 121) has shown that sediment yield in Gibraltar watershed (fig. 1) increased markedly following forest and brush fires and decreased as the watershed recovered from the fire damage. Thus, the history of the basins should be evaluated wherever possible. Basins in the same general area do not necessarily have similar sedimentation histories and may not be correlative in terms of sediment yield.

Anderson (1955, p. 125) suggests double-mass plotting of peak discharges against precipitation effectiveness as a method of detecting the effects of changes in watershed characteristics. Precipitation effectiveness is defined as

$$P^{1.87} \times aP^{0.47}, \qquad (6)$$

where P is the maximum daily precipitation of the storm producing the peak discharge, and aP is the precipitation occurring 21 days antecedent to the maximum day. Any major deflection of the double-mass curve indicates a change in characteristics.

Such analysis by double-mass plots can be made for only three of the studied basins for which sediment yields are compared—Piru, Matilija, and Big Santa Anita (fig. 1)—because there are no records of peak discharges available for other basins (figs. 13, 14, 15). The Piru Creek watershed has been virtually untouched by fire, relative to some surrounding areas. The only fire of consequence occurred in 1960 and burned less than 5 percent of the drainage area. Matilija and Big Santa Anita watersheds have been completely burned, Matilija in 1948 and Big Santa Anita in 1953. Figures 13 and 14 show

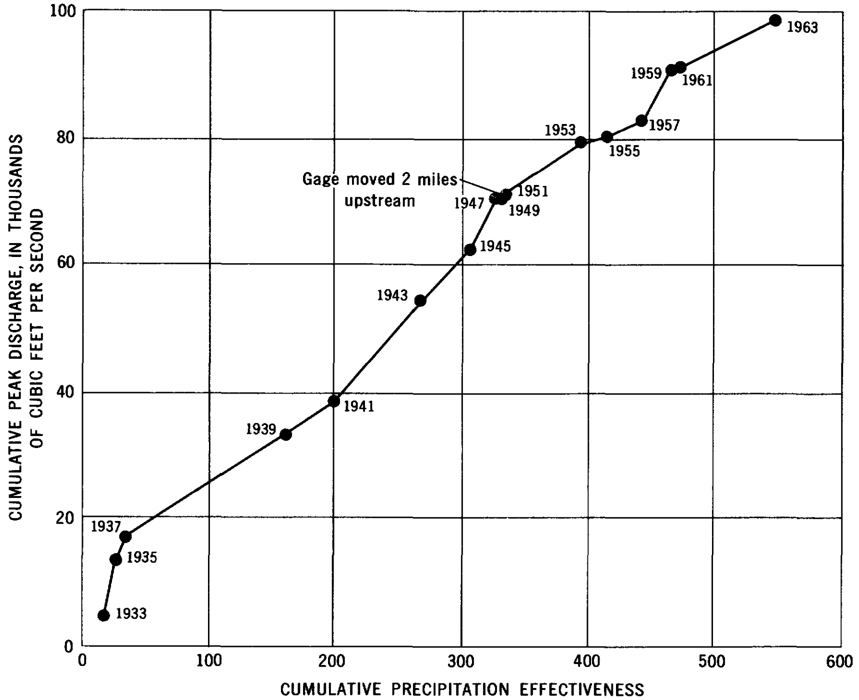

FIGURE 13.—Double-mass plot of peak discharge against precipitation effectiveness for the Matilija Creek drainage basin.

that these burns are not detectable in the double-mass plots. In general, trends for the three watersheds are similar from 1947 on.

LENGTH OF RESERVOIR-SEDIMENTATION RECORDS

A summary of the reservoir-sedimentation data (table 8) indicates that sediment records for the six reservoirs in the San Gabriel Mountains (fig. 1) are of comparable length, 31 to 40 years. There have been marked fluctuations of precipitation in the region since 1932, and, consequently, the relatively short records at Santa Felicia and Matilija Reservoirs, 10 to 15 years, must be extended to a comparable length before comparisons of sediment yields can be made. The record at Matilija Reservoir has been extended back to 1927 by use of flow data (Boyle Engineering, written commun., 1964). The formula developed by Anderson (1949, p. 579) from watersheds in the San Gabriel Mountains also utilizes flow data and was used to extend the Piru Creek record to 1932. These extended sedimentation rates are used in the following correlations:

TABLE 8.—*Data on reservoirs and sediment yield of watersheds in southern California*

Reservoir	Year of dam completion	Year of last survey	Total number of surveys	Sediment yield (acre-ft per yr)	Sediment yield (acre-ft per sq mi)
Sawpit	1927	1962	9	8.4	2.52
Big Dalton	1929	do	6	5.7	1.27
Big Santa Anita	1927	do	16	43.2	4.00
San Dimas	1922	do	9	21.7	1.34
Pacoima	1929	do	8	52.6	1.87
Big Tujunga	1931	do	11	113.2	1.38
Matilija	1948	1963	2	35.6	.70
				[1] 52.0	[1] 1.03
Santa Felicia (Lake Piru)	1955	1965	1	246.9	.58
				[2] 318.0	[2] .75

[1] Calculated average from 1927 to 1963.
[2] Calculated average from 1932 to 1965.

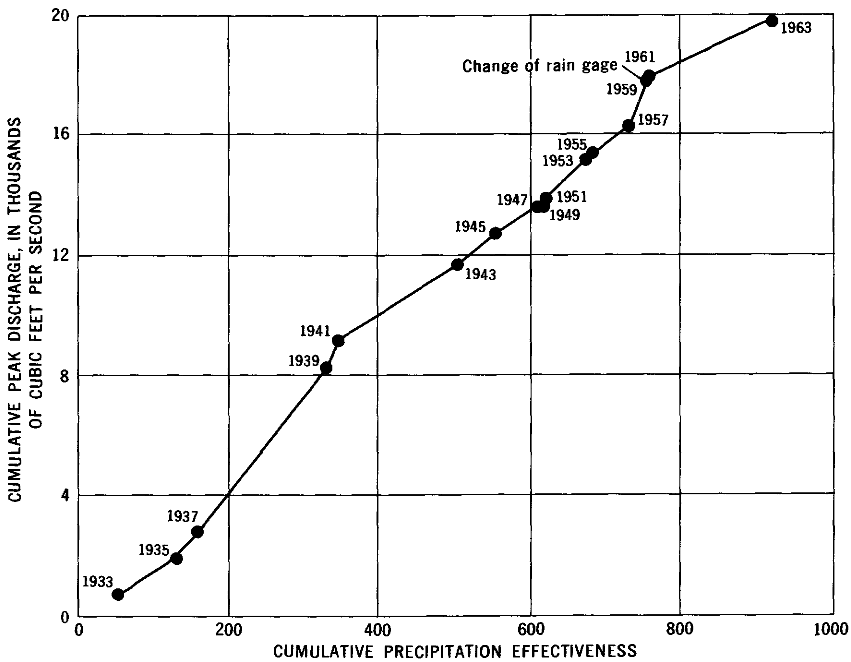

FIGURE 14.—Double-mass plot of peak discharge against precipitation effectiveness for the Santa Anita Creek drainage basin.

CORRECTION OF SEDIMENT YIELDS FOR BASIN SIZE

Comparison of sediment yields from basins of different size is complicated by the fact that yield per unit area depends on the size of the basin. Several factors—such as longer flow paths and consequent greater opportunity for intrabasin deposition, lower stream gradients, and the lesser probability of intense storms covering all the drainage in larger areas—combine to create this effect.

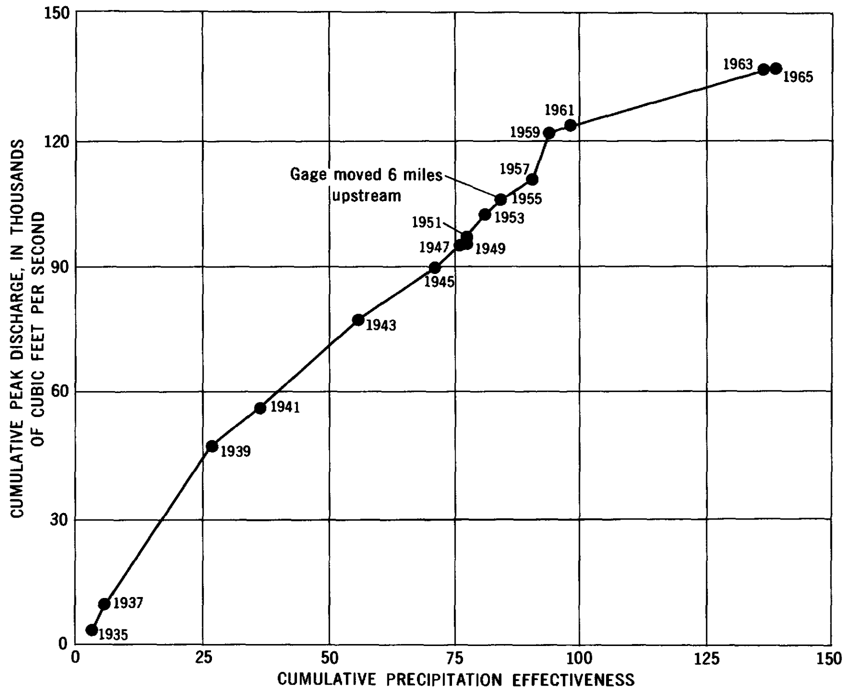

FIGURE 15.—Double-mass plot of peak discharge against precipitation effectiveness for the Piru Creek drainage basin.

Brune (1948) has shown that sediment yield is inversely proportional to the 0.15 power of the basin area. Calculation of the exponent for all the basins in this study results in an exponent of 0.22. In spite of the fact that the Brune exponent was developed in the midwestern United States, it is probably the more valid of the two figures because of the relatively small number of reservoirs used in this study. The Brune coefficient is used to adjust the sediment yield per square mile for each watershed to that for a watershed of 78.0 square miles, which is the mean area of all the basins. Two of the watersheds have areas of less than 5 square miles, a size for which Brown (1950, p. 381–383) has shown variation in sediment yield to be extremely dependent on land-use and terrain factors.

CORRECTION FOR TRAP EFFICIENCY

Prior to correlation of the reservoir sediment yields the trap efficiency of each impoundment was also considered. A method of approximating trap efficiency from the relation of reservoir capacity to inflow (Brune, 1953, p. 414) was applied to each reservoir. Trap efficiencies estimated on this basis ranged from 94 to nearly 100 percent. Correction of the sediment yields for this small range of trap efficiencies was not justified because of the unmeasurable effects of sluicing, reservoir operation, and limitations of survey accuracy.

CORRELATION OF SEDIMENT YIELD WITH BASIN SIZE

The fundamental factor in correlating sediment yields within a region is the size of the contributing basin. Sediment yields of eight of the basins shown in figure 1 can be plotted against basin area to establish the yield-area relation (fig. 16). The linear correlation coefficient, *r*, is 0.949. On this basis, by substituting the area of the basin above Pyramid Rock in the regression equation, a value of 260 acre-feet per year is obtained. However, by assuming a constant yield per unit area for the entire Piru Creek basin, a value of 212 acre-feet per year is obtained for the drainage area above Pyramid Rock.

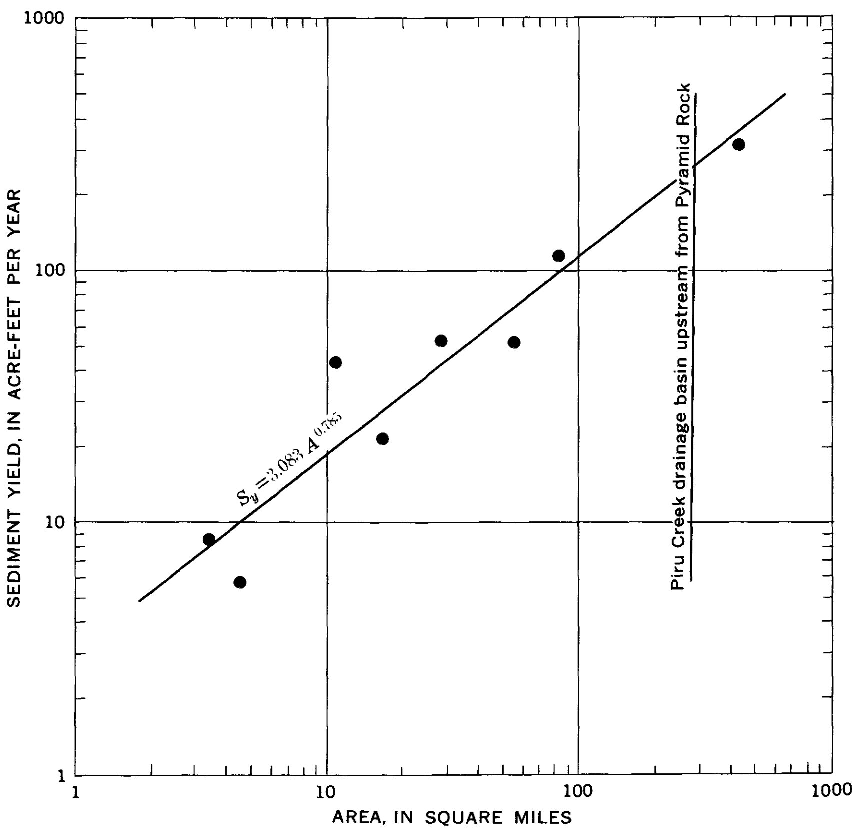

FIGURE 16.—Relation of sediment yield to basin area for basins listed in text. The vertical line represents the area of the Piru Creek drainage basin upstream from Pyramid Rock. The corresponding sediment yield is 260 acre-feet per year.

CORRELATION OF SEDIMENT YIELD WITH PHYSIOGRAPHIC PARAMETERS

Many physiographic variables have been proposed in an attempt to improve on the use of basin size as a geometric factor influencing sediment yield. Several such physiographic parameters have been applied by Lustig (1965) to the Castaic watershed, which is adjacent to and east of the Piru Creek basin, and the same factors are applicable to Piru Creek. Lustig used data from six reservoirs included in this study—Pacoima, Big Tujunga, Big Santa Anita, Sawpit, Big Dalton, and San Dimas (fig. 1).

The physiographic parameters defined by Lustig are as follows: A sediment-area factor (S_A), a sediment-movement factor (S_M), total stream length (ΣL), and three transport-efficiency factors (T_1, T_2, and T_3) (table 9). Linear regression lines (figs. 17–22) relating each of these parameters to sediment yield were drawn using the least-squares method.

SEDIMENT-AREA FACTOR

The sediment-area factor is defined as

$$S_A = A_p / \cos \overline{\theta_g}, \qquad (7)$$

where A_p is the planimetric area of a watershed, in square miles, and $\overline{\theta_g}$ is the mean ground-slope angle for values obtained at 100 random locations as described by Lustig (1965). The intercept value, using this sediment-area factor for the Piru Creek watershed upstream from Pyramid Rock, is 251 acre-feet per year (fig. 17). The linear correlation coefficient, r, is 0.957.

SEDIMENT-MOVEMENT FACTOR

The sediment-movement factor is defined as

$$S_M = S_A \times \overline{\sin \theta_g}, \qquad (8)$$

where S_A is the previously defined sediment-area factor, and $\overline{\sin \theta_g}$ is the mean of the sines of the ground-slope angles at 100 random locations. An intercept value of 200 acre-feet per year is obtained for the sediment yield upstream from Pyramid Rock (fig. 18) by using this correlation factor ($r=0.964$).

TOTAL STREAM LENGTH

Total stream length (ΣL) is the sum of the lengths of all streams within a watershed. Figure 19 indicates that by using this correlation factor ($r=0.946$) a sediment yield of 303 acre-feet per year is obtained for the basin upstream from Pyramid Rock.

TABLE 9.—*Morphometric data and physiographic parameters of the Piru Creek drainage basin and watersheds near Los Angeles*

[Data for Sawpit, Big Dalton, Big Santa Anita, San Dimas, Pacoima, and Big Tujunga Reservoirs are from Lustig (1965)]

Watershed	Basin order	Area of basin (sq mi)	Number of streams of order u	Total length of streams of order u (miles)	Mean length of streams of order u (miles)	Mean channel slope of streams of order u (ft per ft)	Mean basin altitude (ft above sea level)	Mean ground-slope angle (degrees)	Bifurcation ratio	Stream-channel slope ratio	Sediment-area factor	Sediment-movement factor	Transport-efficiency factors T_1	T_2	T_3
Sawpit	3	3.34	$N_1=$ 13	$\Sigma L_1=$ 8.13	$\bar{L}_1=$ 0.63	$\bar{\theta}_1=0.292$	3,010	33.5	$N_1/N_2=2.60$	$\bar{\theta}_1/\bar{\theta}_2=1.45$	4.01	2.18	46.25	36.86	40.62
			$N_2=$ 5	$\Sigma L_2=$ 9.89	$\bar{L}_2=$ 1.98	$\bar{\theta}_2=$ .201			$N_2/N_3=5.00$	$\bar{\theta}_2/\bar{\theta}_3=2.42$					
			$N_3=$ 1	$\Sigma L_3=$ 12.17	$\bar{L}_3=$ 12.17	$\bar{\theta}_3=$ .083			$\overline{R}_b$ =3.80	$\overline{R}_c$ =1.94					
Big Dalton	3	4.50	$N_1=$ 6	$\Sigma L_1=$ 6.31	$\bar{L}_1=$ 1.05	$\bar{\theta}_1=$ .207	2,620	30.5	$N_1/N_2=3.00$	$\bar{\theta}_1/\bar{\theta}_2=3.45$	5.23	2.59	22.00	22.68	32.34
			$N_2=$ 2	$\Sigma L_2=$ 8.60	$\bar{L}_2=$ 4.30	$\bar{\theta}_2=$ .060			$N_2/N_3=2.00$	$\bar{\theta}_2/\bar{\theta}_3=1.58$					
			$N_3=$ 1	$\Sigma L_3=$ 8.80	$\bar{L}_3=$ 8.80	$\bar{\theta}_3=$ .038			$\overline{R}_b$ =2.50	$\overline{R}_c$ =2.52					
Big Santa Anita	3	10.79	$N_1=$ 17	$\Sigma L_1=$ 15.50	$\bar{L}_1=$ .91	$\bar{\theta}_1=$ .279	3,485	34.0	$N_1/N_2=3.67$	$\bar{\theta}_1/\bar{\theta}_2=1.96$	13.01	7.18	102.95	47.67	49.52
			$N_2=$ 3	$\Sigma L_2=$ 21.47	$\bar{L}_2=$ 7.16	$\bar{\theta}_2=$ .142			$N_2/N_3=3.00$	$\bar{\theta}_2/\bar{\theta}_3=2.58$					
			$N_3=$ 1	$\Sigma L_3=$ 23.72	$\bar{L}_3=$ 23.72	$\bar{\theta}_3=$ .055			$\overline{R}_b$ =3.34	$\overline{R}_c$ =2.27					
San Dimas	4	16.17	$N_1=$ 12	$\Sigma L_1=$ 19.02	$\bar{L}_1=$ 1.59	$\bar{\theta}_1=$ .155	3,305	33.0	$N_1/N_2=3.00$	$\bar{\theta}_1/\bar{\theta}_2=1.42$	19.23	10.34	70.53	39.33	42.67
			$N_2=$ 4	$\Sigma L_2=$ 23.50	$\bar{L}_2=$ 5.88	$\bar{\theta}_2=$ .109			$N_2/N_3=2.00$	$\bar{\theta}_2/\bar{\theta}_3=1.85$					
			$N_3=$ 2	$\Sigma L_3=$ 27.21	$\bar{L}_3=$ 13.61	$\bar{\theta}_3=$ .059			$N_3/N_4=2.00$	$\bar{\theta}_3/\bar{\theta}_4=2.95$					
			$N_4=$ 1	$\Sigma L_4=$ 30.27	$\bar{L}_4=$ 30.27	$\bar{\theta}_4=$ .020			$\overline{R}_b$ =2.33	$\overline{R}_c$ =2.07					
Pacoima	3	28.10	$N_1=$ 49	$\Sigma L_1=$ 46.26	$\bar{L}_1=$ .94	$\bar{\theta}_1=$ .228	4,050	33.5	$N_1/N_2=7.00$	$\bar{\theta}_1/\bar{\theta}_2=2.09$	33.70	18.34	428.68	102.03	128.96
			$N_2=$ 7	$\Sigma L_2=$ 55.66	$\bar{L}_2=$ 7.95	$\bar{\theta}_2=$ .109			$N_2/N_3=7.00$	$\bar{\theta}_2/\bar{\theta}_3=1.49$					
			$N_3=$ 1	$\Sigma L_3=$ 61.24	$\bar{L}_3=$ 61.24	$\bar{\theta}_3=$ .073			$\overline{R}_b$ =7.00	$\overline{R}_c$ =1.79					
Big Tujunga	5	82.00	$N_1=$ 136	$\Sigma L_1=$ 116.01	$\bar{L}_1=$ .85	$\bar{\theta}_1=$ .216	4,540	30.5	$N_1/N_2=4.39$	$\bar{\theta}_1/\bar{\theta}_2=2.37$	95.17	47.40	674.98	345.32	479.21
			$N_2=$ 31	$\Sigma L_2=$ 156.98	$\bar{L}_2=$ 5.06	$\bar{\theta}_2=$ .091			$N_2/N_3=3.88$	$\bar{\theta}_2/\bar{\theta}_3=1.62$					
			$N_3=$ 8	$\Sigma L_3=$ 176.32	$\bar{L}_3=$ 22.04	$\bar{\theta}_3=$ .056			$N_3/N_4=4.00$	$\bar{\theta}_3\bar{\theta}/_4=1.22$					
			$N_4=$ 2	$\Sigma L_4=$ 185.11	$\bar{L}_4=$ 92.56	$\bar{\theta}_4=$ .046			$N_4/N_5=2.00$	$\bar{\theta}_4/\bar{\theta}_5=2.56$					
			$N_5=$ 1	$\Sigma L_5=$ 189.07	$\bar{L}_5=$ 189.07	$\bar{\theta}_5=$ .018			$\overline{R}_b$ =3.57	$\overline{R}_c$ =1.94					

Matilija	5	54.40	$N_1=$ 160 $N_2=$ 37 $N_3=$ 7 $N_4=$ 2 $N_5=$ 1	$\Sigma L_1=$ 105.11 $\Sigma L_2=$ 132.49 $\Sigma L_3=$ 146.79 $\Sigma L_4=$ 155.03 $\Sigma L_5=$ 159.05	$\bar{L}_1=$ .65 $\bar{L}_2=$ 3.51 $\bar{L}_3=$ 18.52 $\bar{L}_4=$ 78.22 $\bar{L}_5=$ 159.05	$\bar{\theta}_1=$ .313 $\bar{\theta}_2=$ .162 $\bar{\theta}_3=$ .083 $\bar{\theta}_4=$ .057 $\bar{\theta}_5=$ .022	3,600	29.0	$N_1/N_2=4.32$ $N_2/N_3=5.29$ $N_3/N_4=3.50$ $N_4/N_5=2.00$ $\bar{R}_b=3.78$	$\bar{\theta}_1/\bar{\theta}_2=1.93$ $\bar{\theta}_2/\bar{\theta}_3=1.95$ $\bar{\theta}_3/\bar{\theta}_4=1.46$ $\bar{\theta}_4/\bar{\theta}_5=2.59$ $\bar{R}_c=1.98$	62.17	29.47	601.21	409.86	486.92
Piru Creek above Pyramid damsite	6	284.00	$N_1=$ 1,093 $N_2=$ 236 $N_3=$ 48 $N_4=$ 10 $N_5=$ 3 $N_6=$ 1	$\Sigma L_1=$ 576.85 $\Sigma L_2=$ 747.38 $\Sigma L_3=$ 858.18 $\Sigma L_4=$ 893.59 $\Sigma L_5=$ 916.10 $\Sigma L_6=$ 936.55	$\bar{L}_1=$ .53 $\bar{L}_2=$ 3.17 $\bar{L}_3=$ 17.88 $\bar{L}_4=$ 89.36 $\bar{L}_5=$ 305.37 $\bar{L}_6=$ 936.55	$\bar{\theta}_1=$ .181 $\bar{\theta}_2=$ .099 $\bar{\theta}_3=$ .057 $\bar{\theta}_4=$ .028 $\bar{\theta}_5=$ .016 $\bar{\theta}_6=$ .018	4,915	19.5	$N_1/N_2=4.63$ $N_2/N_3=4.92$ $N_4/N_5=4.80$ $N_4/N_5=3.33$ $N_5/N_6=3.00$ $\bar{R}_b=4.14$	$\bar{\theta}_1/\bar{\theta}_2=1.83$ $\bar{\theta}_2/\bar{\theta}_3=1.74$ $\bar{\theta}_3/\bar{\theta}_4=2.04$ $\bar{\theta}_4/\bar{\theta}_5=1.75$ $\bar{\theta}_5/\bar{\theta}_6=.89$ $\bar{R}_c=1.65$	301.17	98.48	3,877.32	2,295.15	3,070.86
Piru Creek above Santa Felicia Dam	6	425.00	$N_1=$ 1,439 $N_2=$ 318 $N_3=$ 67 $N_4=$ 14 $N_5=$ 4 $N_6=$ 1	$\Sigma L_1=$ 791.63 $\Sigma L_2=$ 1,021.69 $\Sigma L_3=$ 1,167.35 $\Sigma L_4=$ 1,213.44 $\Sigma L_5=$ 1,240.55 $\Sigma L_6=$ 1,282.55	$\bar{L}_1=$ .55 $\bar{L}_2=$ 3.21 $\bar{L}_3=$ 17.42 $\bar{L}_4=$ 86.67 $\bar{L}_5=$ 310.13 $\bar{L}_6=$ 1,282.55	$\bar{\theta}_1=$ .215 $\bar{\theta}_2=$ .121 $\bar{\theta}_3=$ .074 $\bar{\theta}_4=$ .037 $\bar{\theta}_5=$ .018 $\bar{\theta}_6=$ .015	4,125	22.0	$N_1/N_2=4.53$ $N_2/N_3=4.75$ $N_3/N_4=4.79$ $N_4/N_5=3.50$ $N_5/N_6=4.00$ $\bar{R}_b=4.31$	$\bar{\theta}_1/\bar{\theta}_2=1.78$ $\bar{\theta}_2/\bar{\theta}_3=1.64$ $\bar{\theta}_3/\bar{\theta}_4=2.00$ $\bar{\theta}_4/\bar{\theta}_5=2.06$ $\bar{\theta}_5/\bar{\theta}_6=1.20$ $\bar{R}_c=1.74$	458.47	169.63	5,527.79	3,206.82	3,965.72

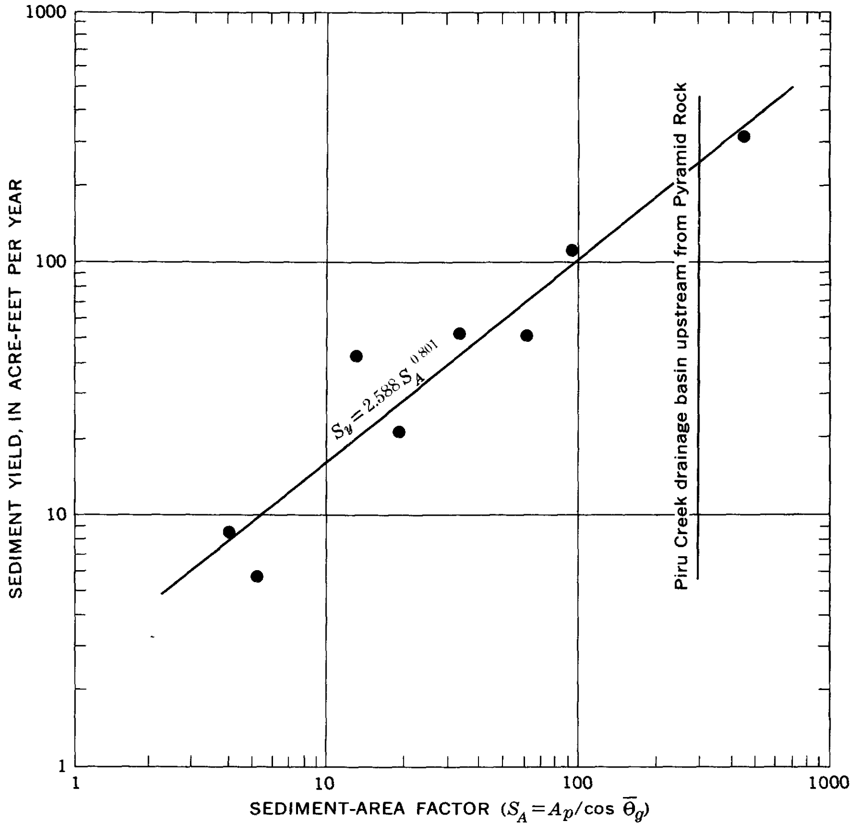

FIGURE 17.—Relation of sediment yield to the sediment-area factor (S_A) for basins listed in text. The vertical line represents the sediment-area factor of the Piru Creek drainage basin upstream from Pyramid Rock. The corresponding sediment yield is 251 acre-feet per year.

TRANSPORT-EFFICIENCY FACTORS

The first of the three transport-efficiency factors is defined as

$$T_1 = \bar{R}_b \times \Sigma L, \qquad (9)$$

where $\bar{R}_b$ is the mean bifurcation ratio, and ΣL is the total stream length. Sediment yield upstream from Pyramid Rock, determined by this correlation factor ($r=0.957$), is 280 acre-feet per year (fig. 20).

The second transport-efficiency factor is defined as

$$T_2 = \Sigma N \times \bar{R}_c, \qquad (10)$$

where ΣN is the total number of streams of all orders, and $\bar{R}_c$ is the mean channel-slope ratio for a watershed. The intercept value, determined by use of this correlation factor ($r=0.902$), is 296 acre-feet per year (fig. 21).

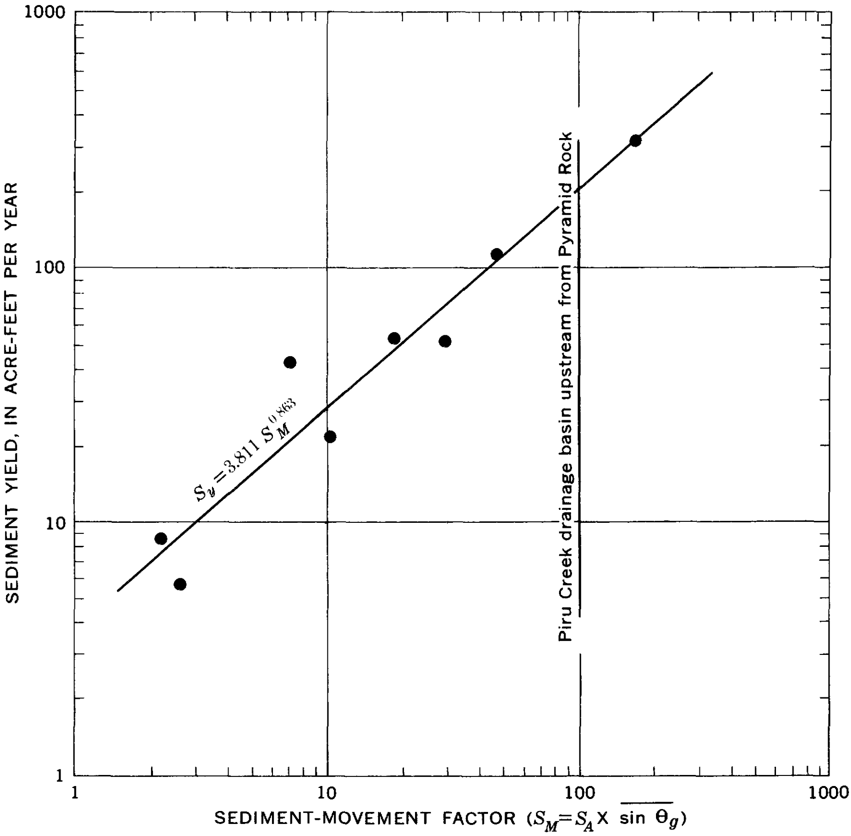

FIGURE 18.—Relation of sediment yield to the sediment-movement factor (S_M) for basins listed in text. The vertical line represents the sediment-movement factor of the Piru Creek drainage basin upstream from Pyramid Rock. The corresponding sediment yield is 200 acre-feet per year.

The third transport-efficiency factor is defined as

$$T_3=(N_1+N_2)(R_{c_{1/2}})+(N_2+N_3)(R_{c_{2/3}})+\ldots+(N_{n-1}+N_n)(R_{c_{\frac{n-1}{n}}}), \quad (11)$$

where N is the number of streams of the order designated by the subscript, and R_c is the ratio of the stream-channel slope of each stream order to that of the next highest stream order. The value of the intercept of the regression line (r=0.931) is 281 acre-feet per year (fig. 22).

Sediment yield was also calculated by the ratio method

$$S_y=318\frac{P_1}{P_2}, \quad (12)$$

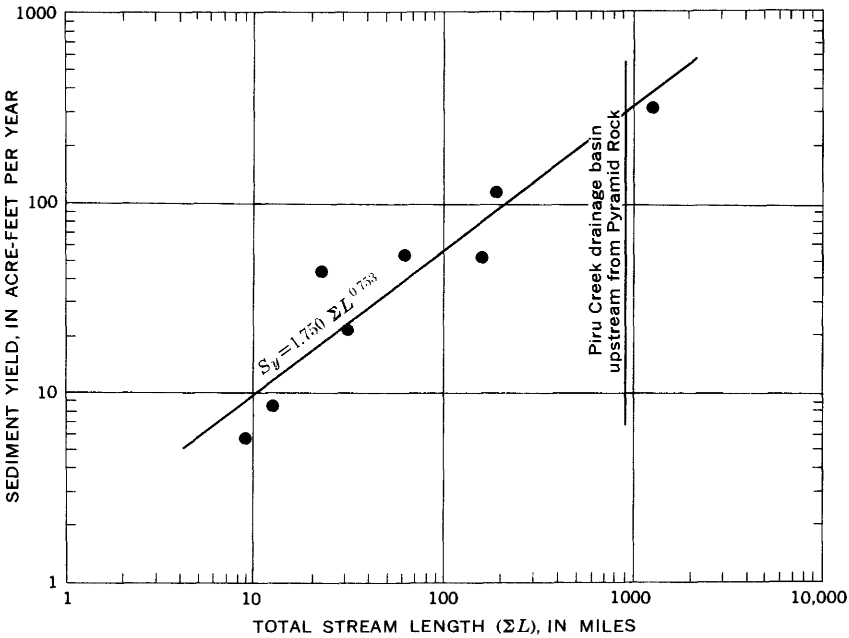

FIGURE 19.—Relation of sediment yield to the total stream length (ΣL) for basins listed in text. The vertical line represents the total stream length of the Piru Creek drainage basin upstream from Pyramid Rock. The corresponding sediment yield is 303 acre-feet per year.

where S_y is the sediment yield upstream from Pyramid Rock, in acre-feet per year, 318 is the sediment yield upstream from Santa Felicia Dam, in acre-feet per year, and $\frac{P_1}{P_2}$ is the ratio of the geomorphic parameters of the two areas. Table 10 shows that sediment yield determined by this method is considerably lower than the yield obtained by using the regression method.

The average of the values obtained from the correlations with geomorphic parameters, 269 acre-feet, is about the same as that obtained from the relation with basin size, 260 acre-feet. The geomorphic parameters are highly area dependent when applied to this set of data. The parameters do not correlate significantly with sediment yield in acre-feet per square mile, a correlation which would be more valid than those employing total sediment yield. The sediment-area and sediment-movement factors are based on drainage area; the total stream length and the total number of streams are also directly related to drainage area (figs. 23, 24). Thus, use of most of the geomorphic parameters does not improve on the use of basin size to compute sediment yield. However, use of the sediment-movement factor (S_M) does produce a value for sediment yield that

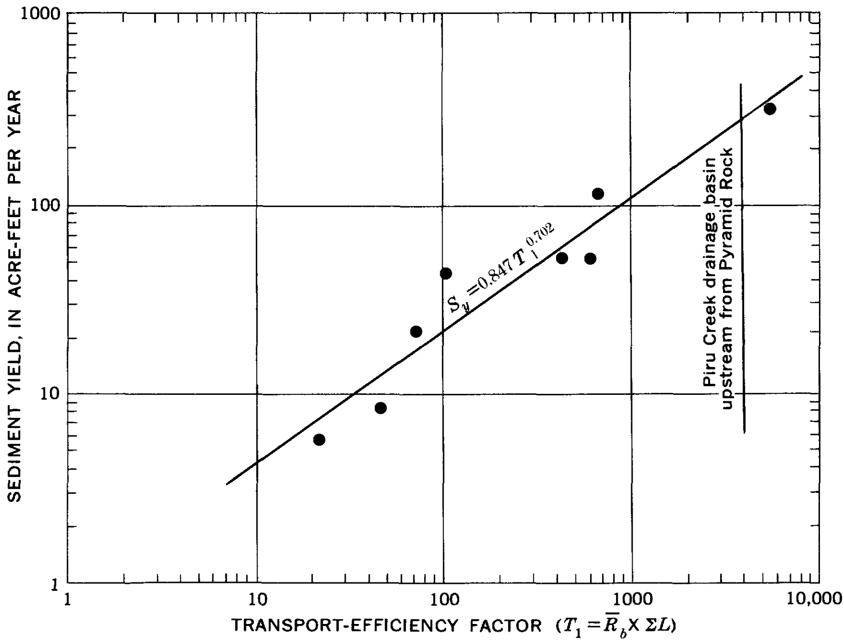

FIGURE 20.—Relation of sediment yield to a transport-efficiency factor (T_1) for basins listed in text. The vertical line represents the transport-efficiency factor of the Piru Creek drainage basin upstream from Pyramid Rock. The corresponding sediment yield is 280 acre-feet per year.

approximates those obtained from the reservoir-sediment survey and by use of the Anderson method (1949, p. 579). Validation or invalidation of the physiographic-factor approach must await further evaluation.

TABLE 10.—*Sediment yield for Piru Creek basin upstream from Pyramid Rock calculated from physiographic parameters*

Physiographic parameter	Sediment yield above Pyramid Rock (acre-ft per yr)	
	Regression method	Ratio method
Sediment area	251	208
Sediment movement	200	184
Total stream length	303	232
Transport-efficiency factors:		
T_1	280	223
T_2	296	228
T_3	281	246

ADDITIONAL FACTORS AFFECTING SEDIMENT YIELD

CLIMATIC FACTORS

Second in probable importance to basin size in influence on sediment yield are climatic factors. Annual precipitation and rainfall intensity

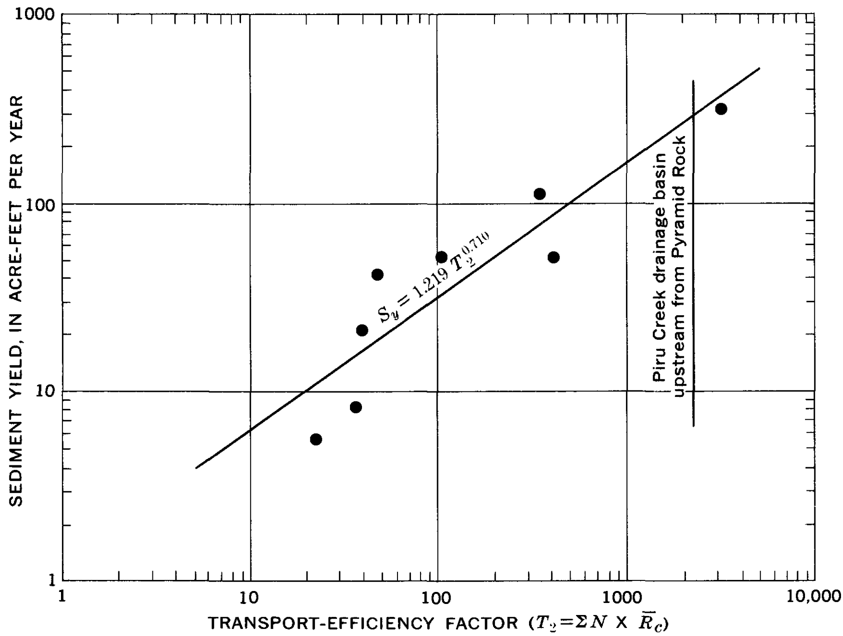

FIGURE 21.—Relation of sediment yield to a transport-efficiency factor (T_2) for basins listed in text. The vertical line represents the transport-efficiency factor of the Piru Creek drainage basin upstream from Pyramid Rock. The corresponding sediment yield is 296 acre-feet per year.

are the climatic parameters most commonly used. In addition, Leopold (1951, p. 351–352) has shown that variations in storm frequency can produce changes in erosion rates even without any changes in annual precipitation.

Langbein and Schumm (1958) have considered the effects of low runoff in dry areas and dense vegetative cover in wet areas and have shown that maximum sediment yield occurs when effective precipitation is about 10 to 14 inches. Effective precipitation was plotted against sediment yield by Langbein and Schumm and is calculated by use of the relation of runoff to precipitation and temperature (Langbein and others, 1949, fig. 2). Data for each basin discussed here are adjusted to a mean annual temperature of 50° F.

A positive correlation between sediment yield per square mile and effective precipitation, an r of 0.61, was determined for the basins studied. This positive correlation was in range of effective precipitation for which Langbein and Schumm found a negative relation. A rank-correlation coefficient of 0.5 is significant at the 80-percent level. Lack of agreement with the Langbein and Schumm relation can be attributed to masking of the precipitation effect on sediment yield by other factors, to the general variability of small watersheds, or to

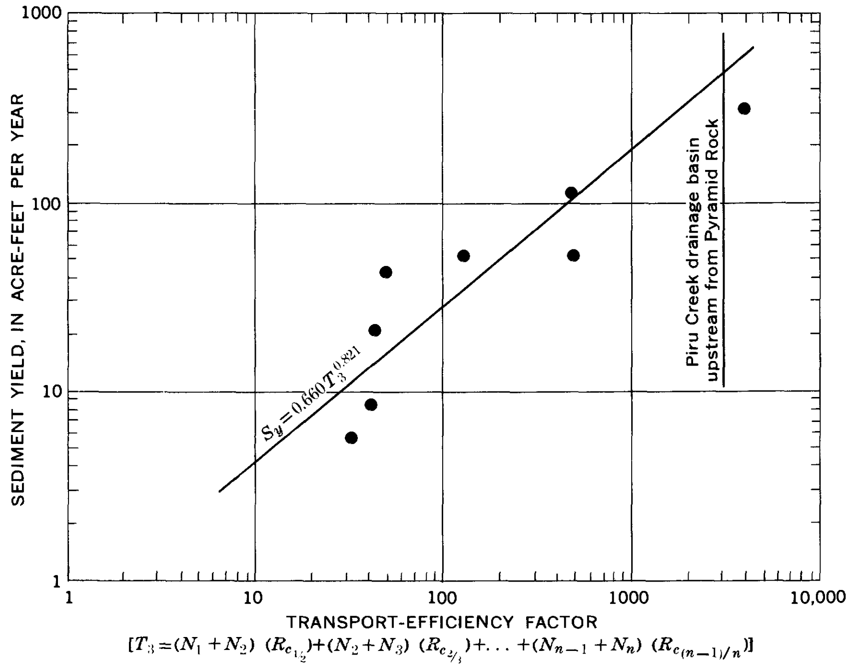

FIGURE 22.—Relation of sediment yield to a transport-efficiency factor (T_3) for basins listed in text. The vertical line represents the transport-efficiency factor of the Piru Creek drainage basin upstream from Pyramid Rock. The corresponding sediment yield is 281 acre-feet per year.

the fact the sediment-yield data for areas such as the Transverse Ranges were unavailable to Langbein and Schumm.

SOIL-ERODIBILITY FACTORS

Anderson (1954, p. 278) has shown that sediment yield is significantly related to differences in the erodibility of soils within a watershed. In a study of variation of soil erodibility as related to soil-forming factors, André and Anderson (1961, p. 3354) have shown that parent material is more important than topography or vegetation. The mountain soils of the Piru Creek basin are more youthful than those studied in northern California by André and Anderson and should be even more closely related to rock type.

Soil samples in the Piru Creek watershed were collected on westerly slopes of 20°–30° to conform with previous studies of soil erodibility. The samples were cored from a 0- to 6-inch depth by several penetrations with a Viehmeyer sampler.

In previous studies a variety of erodibility indexes has been used, and most of them are measures of the degree of aggregation of the finer particle sizes into larger, more stable aggregates. Two indices were computed for soils of the Piru Creek basin—the dispersion ratio

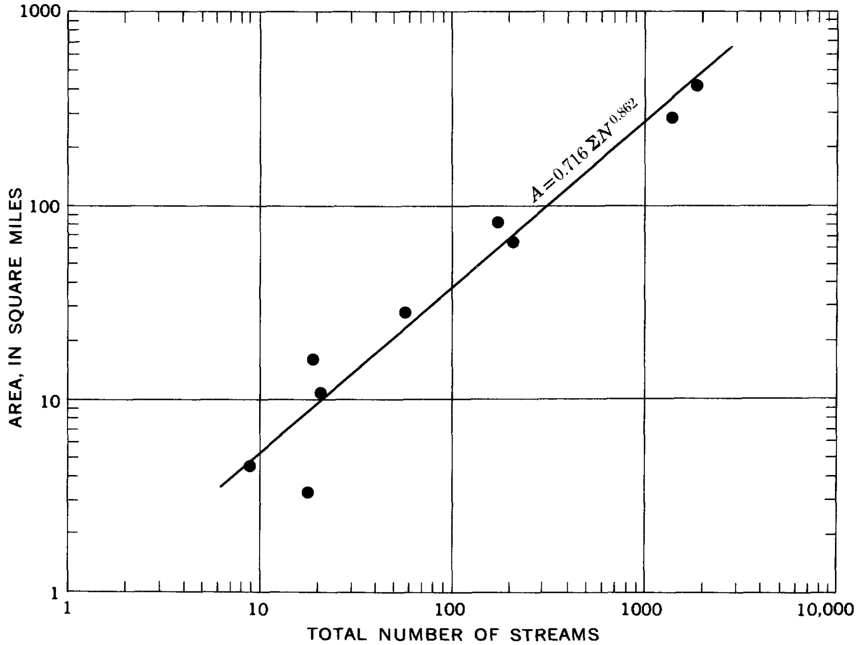

FIGURE 23.—Relation of basin size to total number of streams for basins listed in text.

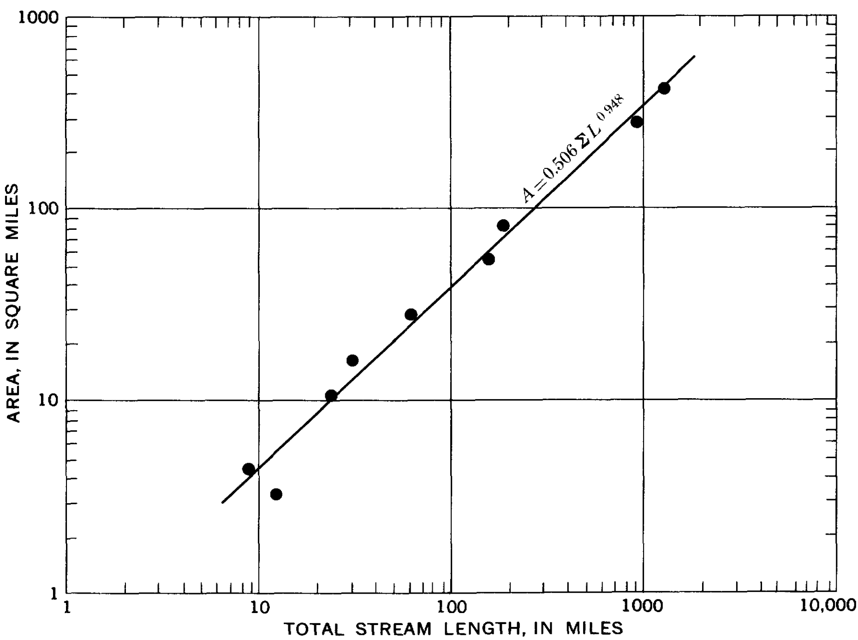

FIGURE 24.—Relation of basin size to total stream length (ΣL) for basins listed in text.

of Middleton (1930, p. 3), which Anderson (1951, p. 131) indicates quantitatively relates to sediment yield, and the surface-aggregation ratio (Anderson, 1954, p. 272). The indices are defined as follows:

Dispersion ratio (*DR*): Total percentage of measured silt- and clay-size particles in an undispersed soil divided by the percentage of these sizes when the soil is dispersed.

Surface-aggregation ratio (*SA*): Surface area of particles coarser than silt divided by the aggregated silt plus clay. Surface area, in square centimeters per gram, is obtained by treating the particles as spheres with a specific gravity of 2.65 and by assigning mean diameters to the sand, granule, and pebble subdivisions. Aggregated silt plus clay is the percentage of dispersed silt and clay minus the percentage measured before dispersion.

Size distribution of the silt and clay was determined by hydrometer (Bouyoucos, 1936) before and after dispersion with sodium hexametaphosphate. Samples were then wet sieved to determine the distribution within the sand, granule, and pebble ranges.

Three samples were taken from soils developed on each of the major rock types in the basin (table 11). The dispersion ratios correlate well with determinations on soil lithosequences in other areas, but surface-aggregation ratios tend toward higher yet relatively similar values (Anderson and Wallis, 1965, p. 27). An average soil erodibility for the basin was calculated from the average erodibility values and the proportional area of exposure of each rock type and was used in the correlations and analyses discussed below.

The seven correlative basins, excluding the Santa Felicia drainage area, are each dominated by a single lithologic assemblage; Matilija basin, by marine sediments of early Tertiary age; and those basins in the San Gabriel Mountains, by plutonic and metamorphic assemblages. Soil erodibilities corresponding to rock types in the Piru Creek area were applied to the other basins.

TABLE 11.—*Dispersion and surface-aggregation ratios as related to lithologic type*

Lithologic type	Dispersion ratios			Surface-aggregation ratios		
	Ratios	Mean	Confidence limits at 0.95 probability	Ratios	Mean	Confidence limits at 0.95 probability
Alluvium of Quaternary age	50, 59, 67	59	±22	146, 152, 216	171	±90
Continental sedimentary rocks of Pliocene age	52, 55, 59	55	9	95, 103, 110	103	19
Continental sedimentary rocks of Miocene age (includes some Oligocene)	35, 37, 37	36	3	64, 68, 68	67	9
Marine sedimentary rocks of Miocene age	43, 45, 45	44	3	61, 68, 68	66	9
Marine sedimentary rocks of Eocene age	33			71		
Granitic plutonic rocks	40, 43, 46	43	8	118, 120, 143	127	32
Metamorphic complex	46, 55, 45	49	13	130, 178, 190	166	77

OTHER FACTORS AFFECTING SEDIMENT YIELD

The previous discussions establish a good correlation between sediment yield and basin area. However, the values of sediment yield upstream from Pyramid Rock that were obtained by using area and physiographic parameters are consistently higher than the sediment yield determined by the reservoir survey and the formula of Anderson (1949). These values of sediment yield suggest that climatic, land-use, and soil-erodibility factors cause the sediment yield in the Piru Creek basin to be substantially less than that in the other basins. The small quantity of data available, however, preclude any elaborate statistical analysis to assess these factors.

Obtaining a significant result from multiple-regression analysis with more than three independent variables is virtually impossible with only eight watersheds for comparison. The number of variables used (table 12) was therefore reduced; this was accomplished by a logical rather than an empirical approach because of the small sample size. A preliminary step in assessing the data was to correlate each of the factors with sediment yield adjusted to remove the effect of area by expressing the yields in acre-feet per square mile and by basing all data on a mean basin size using the power adjustment of Brune (1948). However, multiple correlation based only on variables with the highest gross or net correlation is generally too high. Removal of the dominant factor, area, does not appreciably reduce this possibility. This procedure may result in discarding factors which would show a truly important relation to sediment yield through a more sophisticated analysis impossible to use in this study.

Instead, parameters for multiple-regression analysis were selected on the basis of having been shown to significantly affect sediment yield in previous studies and on the basis of the logical effect of each variable on sediment yield. Runoff, effective precipitation, mean annual precipitation, precipitation intensity, and surface-aggregation ratio were chosen as factors for correlation. Inclusion of two factors, such as area and runoff, for the same effect results in multicollinearity and erroneous correlations.

A regression of sediment yield ($S_{y''}$) corrected with the power adjustment for basin size against several factors is

$$\log S_{y''} = -0.64 + 2.25 \log MAP - 1.80 \log I + 0.11 \log SA, \quad (13)$$

where

MAP = mean annual precipitation, in inches,

I = probable maximum 24-hour precipitation, in inches (U.S. Weather Bureau, 1960),

and SA = surface-aggregation ratio.

TABLE 12.—*Summary of watershed parameters*

Basin	S_y (acre-ft per yr)	S_y' (acre-ft per sq mi per yr)	S_y'' (acre-ft per sq mi per yr)	A (sq mi)	MAP (inches)	EP (inches)	RRA percent	I (inches)	$Fire$ (percent)	A_{ch} (acres per sq mi)	DR	SA	$TMAQ$ (acre-ft per yr)	MAQ (acre-ft per sq mi per yr)	MAQ (inches)
Matilija	52.0	0.956	0.902	54.40	28.7	25.8	95	38.0	100	7.0	33.0	71.0	14,413	264.9	5.0
Piru (at Santa Felicia Dam)	318.0	.748	.959	425.00	17.1	16.0	91	24.5	5.1	4.9	45.6	103.1	[1] 27,900	65.6	1.2
Piru (above Pyramid damsite)				284.00	15.9		83	21.5	2.3	7.0	46.5	119.2			
Pacoima	52.62	1.87	1.61	28.10	25.6	24.5	92	25.0	6.1	9.7	43.0	127.0	6,660	237.0	4.4
Big Tujunga	113.23	1.38	1.39	82.00	25.5	22.5	88	27.5	4.2	4.6	43.0	127.0	15,740	192.0	3.6
Big Santa Anita	43.18	4.00	2.96	10.79	35.1	30.2	97	37.5	99.1	1.7	43.0	127.0	4,370	405.0	7.6
Sawpit	8.43	2.52	1.58	3.34	34.0	22.3	98	37.5	97.0	3.0	43.0	127.0	617	184.7	3.5
Big Dalton	5.71	1.27	.830	4.50	27.0	21.4	100	33.0	100	3.4	43.0	127.0	695	154.4	2.9
San Dimas	21.70	1.34	1.06	16.17	28.0	19.5	98	33.0	100	4.1	43.0	127.0	2,010	124.3	2.3

[1] Estimated.

The adjusted standard error of estimate is ±0.165 log unit.

A regression with sediment yield per square mile ($S_{y'}$) gives

$$\log S_{y'} = -6.48 + 1.70 \log EP + 0.70 \log I + 1.61 \log SA, \quad (14)$$

where EP=effective precipitation, in inches (Langbein and others, 1949, fig. 2). The adjusted standard error of estimate is +0.111 log unit.

The following relation is obtained, regressing with sediment yield (S_y):

$$\log S_y = -4.13 + 0.95 \log MAQ - 0.22 \log I + 1.25 \log SA, \quad (15)$$

where MAQ=mean annual runoff, in acre-feet per square mile. The adjusted standard error of estimate is ±0.156 log unit. The negative coefficient for log I in equations 13 and 15 is contrary to experience; sediment yield should increase as precipitation intensity increases. Therefore, equation 14 with a positive correlation with precipitation intensity is probably the most valid.

Only observed coefficients of multiple correlation greater than 0.885 will shown any true correlation—based on eight samples and three independent variables at the 0.95-probability level (Fisher, 1928; Ezekiel and Fox, 1959). Although the most significant regression correlation is that which includes the effect of basin area in the form of mean annual discharge, the other factors included in the regressions probably explain some of the variation not due to area. Coefficients of multiple correlation of the three equations are 0.730, 0.930, and 0.979. Equations 14 and 15 show true minimum correlations of 0.53 and 0.87 at the 0.95-probability level. The multiple-correlation coefficient deteriorates as area is progressively removed from the analysis, and this emphasizes the strong dependence of sediment yields on that factor.

The three above equations produce estimates of sediment yield at Santa Felicia Reservoir of 238, 257, and 201 acre-feet per year, all of which are below the value of 318 acre-ft per yr used in the regression. Applying the equations for $S_{y''}$ and $S_{y'}$ to the data for that part of the Piru Creek basin upstream from Pyramid Rock provides values of 184 and 175 acre-feet per year.

PROBABLE ACCURACY OF SEDIMENT-YIELD PREDICTIONS IN THE PIRU CREEK WATERSHED

The difficulty of precisely predicting sediment yield in watersheds as diverse as that of Piru Creek is evident from the results of this multivariate approach. The range of sediment yield given by the methods used (table 13) plainly indicates that only a reasonable estimate can be obtained. This estimate must be further qualified because the assumption is made that future conditions will be similar to past conditions. Changes in either dynamic or geometric factors will affect sediment yield, particularly in an area as unstable and varied from the standpoint of land use and intensity of geomorphic processes as the Piru Creek watershed has been and is likely to be. Study of the area indicates that marked periods of aggradation and degradation have taken place during development of the present landscape and that pronounced changes in factors controlling sediment movement and yield have occurred.

TABLE 13.—*Sediment yields calculated for Piru Creek basin upstream from Pyramid Rock*

Method	*Sediment yield (acre-ft per yr)*
1. Rate based on yield per unit area obtained from 10-year accumulation in Santa Felicia Reservoir (ratio method, using areas)	167
2. Method 1 extended back to 1932, using the Anderson (1949) formula	212
3. Method 2 modified for effect of basin area	225
4. Regression, using area	260
5. Regressions, using physiographic parameters (table 10)	200
	251
	280
	281
	296
	303
6. Method 2 subdivided by ratio method, using physiographic parameters (table 10)	184
	208
	223
	228
	232
	246
7. Multiple regressions, using climatic, soil-erodibility, and flow parameters	175
	184

A period of high sediment yield could result from changes in either land use or tectonic activity. Burned areas in the San Gabriel Mountains have shown 10 times the preburn rate of erosion, much of which occurred as dry creep during the dry season (Krammes, 1960, p. 4). The U.S. Forest Service in 1950 estimated an average expectable burn percentage in the Piru Creek watershed of 1.4 percent of the area each year. The actual burn rate for the 26-year period 1940–66 has been only 0.4 percent. The change in average cover density associated with a burn rate of 1.4 percent as opposed to 0.4 percent would increase sediment yield by a factor of 1.46 (H. W. Anderson, oral commun, 1966). Greater fire protection and increasing effectiveness of fire-fighting techniques probably reduce the future burn probability in the watershed and may have accounted in part for the less-than-expected burn since 1940.

Slope rejuvenation resulting from recent uplift in the San Gabriel Mountains increased local sediment yield as much as five times (Anderson and others, 1959, p. 6). The same effects could occur in the Piru Creek area. In fact, the area above Pyramid Rock may be more sensitive than most owing to the recent period of pronounced alluviation. The potential exists for a sediment yield substantially higher than estimated values. If future conditions are relatively similar to those of the past, however, the estimate will be confirmed.

CONCLUSIONS AND PROBABLE LONG-TERM SEDIMENT YIELD AT THE PYRAMID DAMSITE

The largest values for projected sediment yield above Pyramid Rock were obtained from the regression analysis involving area, 260 acre-feet per year, and the physiographic variables, 200 to 303 acre-feet per year with a mean value of 269 (table 13). The value obtained by dividing the sediment yield measured at Santa Felicia Reservoir by area is 212 acre-feet per year.

The use of physiographic parameters does not give a more accurate result than the use of area. Wallis (1965, p. 11) notes that physiographic variables other than area are generally of secondary importance compared to area, climate, and land use as factors affecting sediment yield. Such an apparent impasse, reinforced by the results of this study, is by no means an indictment of the use of physiographic factors. The attempts to segregate meaningful physiographic variables from the large number proposed in the literature should be continued. The sediment-movement factor, for example, gives the value (200 acre-feet per year) most in line with the measured rate of 212 acre-feet per year upstream from Pyramid Rock.

Consideration of climatic, land-use, and soil-erodibility factors apparently improves somewhat on correlation with area, and results in calculated sediment yields of 175 and 184 acre-feet per year. These moderately low yields, compared with the yield of 212 acre-feet per year, are probably due to the effects of the basin variability on the correlations. The Piru Creek watershed, in particular the area upstream from Pyramid Rock, is markedly more arid than the surrounding basins for which data are available. Were there no direct measurement of the sediment yield at any point in the basin, however, the correlations including climatic, land-use, and soil-erodibility factors would have to be favored on the basis of the results of previous sediment-yield studies and are seen, in this study, to provide a result closer to the measured yield. Generalized and regional trends in climatic, land-use, and soil factors may be a useful addition to areal sediment-yield correlations in diverse areas, such as the Transverse Ranges.

In light of the extreme variability and the small number of basins available for correlation of reservoir sediment accumulations, the most acceptable estimate of the sediment yield upstream from Pyramid Rock is that which is based on the amount of sediment measured in Santa Felicia Reservoir. The yield obtained from the reservoir survey, extended back over a range of climatic conditions by the Anderson technique (1949) and increased to correspond to a smaller area by use of the Brune power adjustment (1948), is 225 acre-feet per year. An estimated range in rates is ± 50 acre-feet per year. Confidence limits applied to the mean of the values in table 13 (231 acre-feet per year) are ± 19 at the 0.95 probability level.

REFERENCES

Anderson, H. W., 1949, Flood frequencies and sedimentation from forest watersheds: Am. Geophys. Union Trans., v. 30, p. 576–584.

——— 1951, Physical characteristics of soils related to erosion: Jour. Soil and and Water Conserv., v. 6, p. 129–133.

——— 1954, Suspended sediment discharge as related to streamflow, topography, soil, and land use: Am. Geophys. Union Trans., v. 35, p. 268–281.

——— 1955, Detecting hydrologic effects of changes in watershed conditions by double-mass analysis: Am. Geophys. Union Trans., v. 36, p. 119–125.

Anderson, H.W., Coleman, G. B., and Zinke, P. J., 1959, Summer slides and winter scour—dry-wet erosion in southern California mountains: Pacific Southwest Forest and Range Expt. Sta. Tech. Paper 36, 12 p.

Anderson, H. W., and Wallis, J. R., 1965, Some interpretations of sediment sources and causes, Pacific Coast basins in Oregon and California: Federal Inter-Agency Sedimentation Conf., Proc., U.S. Dept. Agriculture Misc. Pub. 970, p. 22–30.

André, J. E., and Anderson, H. W., 1961, Variation of soil erodibility with geology, geographic zone, elevation, and vegetation type in northern California wildlands: Jour. Geophys. Research, v. 66, no. 10, p. 3351–3358.

Bouyoucos, C. J., 1936, Directions for making mechanical analyses of soils by the hydrometer method: Soil Sci., v. 42, p. 225–229.

Brown, C. B., 1950, Effects of soil conservation, *in* Trask, P. D., ed., Applied sedimentation: New York, John Wiley & Sons, Inc., p. 380–406.

Brune, G. M., 1948, Rates of sediment production in Midwestern United States: U.S. Dept. Agriculture Soil Conserv. Service SCB–TP–65, 40 p.

——— 1953, Trap efficiency of reservoirs: Am. Geophys. Union Trans., v. 34, p. 407–418.

Carman, M. F., Jr., 1964, Geology of the Lockwood Valley area, Kern and Ventura Counties: California Div. Mines and Geology Spec. Rept. 81, 62 p.

Cordova, Simon, 1956, Geology of the Piru Area, Ventura County, California: California Univ., unpub. Master's thesis in geology.

Crowell, J. C., 1952, Geology of the Lebec quadrangle, California: California Div. Mines and Geology Spec. Rept. 24, 24 p.

Eakin, H. M., and Brown, C. B., 1939, Silting of reservoirs: U.S. Dept. Agriculture Soil Conserv. Service Tech. Bull. 524, p. 153–167.

Ezekial, Mordecai, and Fox, K. A., 1959, Methods of correlation and regression analysis [3d ed.]: New York, John Wiley & Sons, Inc., 548 p.

Fisher, R. A., 1928, The general sampling distribution of the multiple correlation coefficient: Royal Soc. [London] Proc., v. 121, ser. A, p. 654–672.

Hershey, O. H., 1902, The Quaternary of southern California: California Univ. Dept. Geol. Sci. Bull., v. 3, p. 1–29.

Inman, D. L., 1952, Measures for describing the size distribution of sediments: Jour. Sed. Petrology, v. 22, no. 3, p. 125–145.

Krammes, J. S., 1960, Erosion from mountain side slopes after fire in southern California: Pacific Southwest Forest and Range Expt. Sta. Research Note 171, 7 p.

Krumbein, W. C., 1936, Application of logarithmic moments to size frequency distribution of sediments: Jour. Sed. Petrology, v. 6, p. 35–47.

Kundert, C. J., 1955, Los Angeles sheet *of* Geologic map of California: California Div. Mines and Geology Map Sheet.

Langbein, W. B., and Schumm, S. A., 1958, Yield of sediment in relation to mean annual precipitation: Am. Geophys. Union Trans., v. 39, p. 1076–1084.

Langbein, W. B., and others, 1949, Annual runoff in the United States: U.S. Geol. Survey Circ. 52, 14 p.

Leopold, L. B., 1951, Rainfall frequency—An aspect of climatic variation: Am. Geophys. Union Trans., v. 32, p. 347–357.

Lustig, L. K., 1965, Sediment yield of the Castaic watershed, western Los Angeles County, California—A quantitative geomorphic approach: U.S. Geol. Survey Prof. Paper 422–F, 23 p.

Middleton, H. E., 1930, Properties of soils which influence soil erosion: U.S. Dept. Agriculture Tech. Bull. 178, 16 p.

Nelson, J. W., Dean, W. C., Kocher, A. E., Watson, E. B., and Carpenter, E. J., 1920, Soil survey of the Ventura area, California—Advance sheet: U.S. Dept. Agriculture Bur. Soils field operations, 87 p.

Shepard, G. L., 1960, Geology of the Whitaker Peak–Canton Canyon area, southern California: Los Angeles, California Univ. unpub. master's thesis in geology.

U.S. Bureau of Reclamation, 1960, Earth manual: Denver, 751 p.

U.S. Department of Agriculture, 1953, Report of survey—Santa Clara–Ventura Rivers and Calleguas Creek watersheds, California: 34 p., 5 apps.

U.S. Geological Survey, published annually, Water resources data for California—Part 1, Surface water records, Volume 1, Colorado River basin, southern Great Basin, and Pacific Slope basins excluding Central Valley: U.S. Geol. Survey.

——— Surface water supply of the United States—Part 11, Pacific slope basins in California: U.S. Geol. Survey water-supply papers (published annually through 1960; published periodically, 1961 to present).

U.S. Weather Bureau, 1960, Probable maximum precipitation for the United States west of the 105th meridian: U.S. Weather Bur. Tech. Paper 38, 66 p.

Wallis, J. R., 1965, A factor analysis of soil erosion and stream sedimentation in northern California: California Univ. unpub. Ph.D. dissertation in soil science, 141 p.

U.S. GOVERNMENT PRINTING OFFICE : 1968—O-309-538