Sediment Yield of the Castaic Watershed, Western Los Angeles County California—A Quantitative Geomorphic Approach

GEOLOGICAL SURVEY PROFESSIONAL PAPER 422-F

Prepared in cooperation with State of California Department of Water Resources

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By LAWRENCE K. LUSTIG

PHYSIOGRAPHIC AND HYDRAULIC STUDIES OF RIVERS

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[Plates are in pocket]

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SYMBOLS

u	Order of a stream, where unbranched tributaries are designated as first order and the confluence of two streams of a given order is designated by the next higher order number
A_u	Area of a basin of order u, where u is the highest order number of the streams contained
L_u	Length of stream or stream channel of order u
ΣL	Total stream length
N_u	Number of streams of order u
ΣN	Total number of streams
θ_u	Gradient of stream channel of order u
θ_g	Ground slope, measured orthogonal to contours
$\overline{E}$	Mean basin elevation
D	Drainage density, where $D=\Sigma L/A_u$
F	Stream frequency, where $F=N_u/A_u$
R_b	Bifurcation ratio, where $R_b=N_u/N_{u+1}$
R_a	Basin-area ratio, where $R_a=A_u/A_{u-1}$
R_L	Stream-length ratio, where $R_L=\overline{L}_u/\overline{L}_{u-1}$
R_c	Stream-channel-slope ratio, where $R_c=\bar{\theta}_u/\bar{\theta}_{u+1}$
R_i	Ruggedness index, where $R_i=D\times\overline{E}$
R_h	Relief ratio; $R_h=H/L_b$, where H is basin relief and L_b is basin length
Q	Water discharge
S_y	Sediment yield
S_A	Sediment-area factor, where $S_A=A_p/\cos\bar{\theta}_g$ and A_p is planimetric area
S_M	Sediment-movement factor, where $S_M=S_A\times\overline{\sin\theta_g}$
T_e	Transport-efficiency factors, where $T_e=T_1, T_2, T_3, \Sigma L$
T_1	Transport-efficiency factor, where $T_1=\overline{R}_b\times\Sigma L$
T_2	Transport-efficiency factor, where $T_2=\Sigma N\times\overline{R}_c$
T_3	Transport-efficiency factor, where $T_3=(N_1+N_2)(R_{c_{1/2}})+(N_2+N_3)(R_{c_{2/3}})+\ldots+(N_{n-1}+N_n)(R_{c_{(n-1)/n}})$
I_C	Intercept value giving the sediment yield of Castaic drainage basin
r	Simple-correlation coefficient
r_r	Rank-correlation coefficient
H_o	Null hypothesis for one-sided tests
α	Confidence interval
λ	Linear-scale ratio
σ_λ	Standard deviation of linear-scale ratios

SEDIMENT YIELD OF THE CASTAIC WATERSHED, WESTERN LOS ANGELES COUNTY, CALIFORNIA—A QUANTITATIVE GEOMORPHIC APPROACH

By Lawrence K. Lustig

ABSTRACT

This report treats the problem of estimating, within a short period of time, the long-term sediment yield of the Castaic watershed in the general absence of hydrologic data. The estimate provided is based on a comparison of geomorphic parameters for watersheds in the San Gabriel Mountains, for which long-term sediment-yield data are available, and for the Castaic watershed.

The geomorphic parameters that best correlate with sediment yield are (1) a sediment-area factor, defined as $S_A = A_p/\cos \bar{\theta}_g$, where A_p is the planimetric area of a watershed and $\bar{\theta}_g$ is the mean ground-slope angle, (2) a sediment-movement factor, defined as $S_M = S_A \times \overline{\sin \theta_g}$, where S_A is the sediment-area factor, as defined above, and $\overline{\sin \theta_g}$ is the mean of the sines of the ground-slope angles, (3) total stream length, (4) a transport-efficiency factor, $T_1 = \bar{R}_b \times \Sigma L$, where $\bar{R}_b$ is the mean bifurcation ratio and ΣL is total stream length, (5) a transport-efficiency factor, $T_2 = \Sigma N \times \bar{R}_c$, where ΣN is the total number of streams and $\bar{R}_c$ is the mean stream-channel-slope ratio, and (6) a transport-efficiency factor, $T_3 = (N_1 + N_2)(R_{c_{1/2}}) + (N_2 + N_3)(R_{c_{2/3}}) + \ldots + (N_{n-1} + N_n)(R_{c_{n-1/n}})$, where the subscripts designate stream order.

These parameters are plotted against the known long-term sediment yield as simple regressions for six watersheds in the San Gabriel Mountains. Both parametric and nonparametric tests of the computed correlation coefficients show that the relationships are significant at the 95-percent confidence level. For these watersheds, relief ratio correlates poorly with sediment yield and cannot be used. Variation in basin shape is thought to be the primary cause of this failure.

The value of each parameter computed for the Castaic watershed is substituted into the appropriate regression-line equation obtained for watersheds in the San Gabriel Mountains; thus, a series of sediment-yield values is provided. The data suggest that an estimate of 250 acre-feet per year will approximate the long-term sediment yield of the Castaic watershed. This estimate depends, to some extent, on an assumption of balance between the dynamic factors and the geometric properties of the Castaic watershed and the watersheds in the San Gabriel Mountains.

Additional support for the estimated annual sediment yield is provided by an assessment of the yield that would be expected (1) from consideration of the contrast in effective precipitation between the Castaic and San Gabriel watersheds, and (2) from consideration of the difference in drainage area between the Castaic watershed and the neighboring Piru watershed. These methods provide sediment-yield values of about 280 and 220 acre-feet per year, respectively, which suggest the possible range in average annual sediment yield and lend added credence to the previous estimate of 250 acre-feet per year.

Data on the size distribution of the granule-to-clay size fraction of sediments in the Castaic watershed are presented. It is shown that the sedimentary rocks and the metamorphic-igneous complex that occur in the watershed contribute approximately equal quantities of sediment in the silt-clay size range of about 8 percent, whereas the granitic rocks contribute one-half of this amount. The contribution of the granitic rocks is less because these rocks crop out over a smaller area. Sediment in the sand-sized range is abundant everywhere in the watershed, and certain suggestions for future debris-dam locations based upon the yield of sand from subbasins, are given.

The net long-term channel erosion in the Castaic watershed is discussed on the basis of data on the cores of trees whose roots have been exposed by channel erosion. The data suggest that the channels do not contribute a large percentage of the total sediment yield and, hence, that sheet erosion of hillslopes is responsible for most of the sediment production.

INTRODUCTION

The life expectancy of reservoirs has been of practical importance to man since he first began his interference with the natural location of water supplies. The ancient civilizations often rose or fell in accord with the success or failure of their aqueduct and storage systems in arid regions (Glueck, 1959), as attested to by the many abandoned cities discovered by the modern archaeologist. Because we can no longer afford such disruption, considerable study is devoted to the several problems pertinent to the location of any proposed reservoir site.

A segment of the California State Water Project requires the construction of three terminal reservoirs for water storage in southern California. One of these reservoirs is to be created by the construction of a dam below the junction of Castaic and Elizabeth Lake Canyons in the Castaic watershed in southern California. One factor that will influence the life expectancy of this proposed reservoir is the anticipated long-term sediment yield, which is discussed in this report.

STATEMENT OF THE PROBLEM AND THE APPROACH EMPLOYED

That the magnitude of the problem of sediment yield above reservoir sites is a function of the planned storage capacity and of the operation of such reservoirs rather than of the absolute yield should be recognized at the outset. A sedimentation rate of 200 acre-feet per year in a given watershed, for example, will result in a life expectancy of 50 years if the planned capacity is but 10,000 acre-feet and of 500 years if the capacity is to be ten times as great. This comparison is, of course, axiomatic but it is the reason why equal sedimentation rates in different watersheds may be described as either of critical or negligible import. This report, however, is concerned solely with the absolute long-term sediment yield of the Castaic watershed; the problem treated is how best to determine this yield.

There are three possible methods for determining the sediment yield of a given watershed. As outlined by Gottschalk (1957) these methods are (1) obtaining sediment-load data directly, (2) estimating rates of erosion within the watershed, and (3) comparing the watershed with neighboring basins for which sediment-yield data are available. Because most of the streams in the Castaic watershed are intermittent and few data on water and sediment discharge are extant, the first of these methods is not applicable to the problem. The second method would require that pins be driven into valley walls and that careful surveys of stream channels be conducted over a period of years. When combined with some data on dendrochronology, such an approach might provide an estimate of the rate of erosion within the watershed and the long-term yield to be expected. Because of one of the boundary conditions of the problem, namely that an estimate of the sediment yield be provided within a year, this approach could not be employed either. The last method (3) was therefore chosen by process of elimination. Although the time limitation just mentioned did not allow as complete an exploration of this method as might be deemed desirable, particularly in regard to comparison by field studies, it did not hinder comparison by morphometric analysis. This tool of quantitative geomorphology provides the main basis for the estimate of sediment yield given in this report. Supported by field observations, sediment analyses, and other data, this approach offered the sole possibility of success under the given conditions.

The neighboring watersheds that provide the basis for comparison are in the San Gabriel Mountains. Sediment-yield data on the basins selected for study encompass a period ranging from approximately 30 to 40 years, and the basins meet the requirements for a comparative approach.

ACKNOWLEDGMENTS AND PERSONNEL

The study reported on here was conducted under the supervision of George Porterfield, who accompanied the writer in the field on several occasions, aided in selection of locations for the installation of single-stage sampling devices, and lent much encouragement during various phases of the investigation. Mr. H. V. Peterson accompanied the writer during an initial reconnaissance of the Castaic watershed and neighboring watersheds in the San Gabriel Mountains and provided several useful suggestions regarding the conduct of the study, as well as stimulating discussions of the problems involved. The writer received the benefit of critical review from S. A. Schumm, L. B. Leopold, and H. V. Peterson and gratefully acknowledges their several suggestions, which did much to improve this report. Sediment samples from the canyons of the Castaic watershed were collected with the assistance of A. D. Lovelace whose capable service in the field is appreciated. The size distribution of these samples was determined by V. L. Gamble by means of the visual-analysis method. Single-stage sampling devices were planned and assembled by J. M. Knott and were installed in the Castaic watershed by Mr. Knott, in company with the writer. Sediment-yield data on the watersheds in the San Gabriel Mountains were kindly provided by M. F. Burke, Division Engineer, Los Angeles County Flood Control District. This project was conducted in cooperation with the California Department of Water Resources.

THE CASTAIC WATERSHED

PHYSICAL DESCRIPTION OF THE AREA

LOCATION AND EXTENT

The Castaic watershed is in western Los Angeles County, to the northwest of the San Gabriel Mountains (pl. 1). Its areal extent of approximately 137 square miles is bounded by Antelope Valley in the Mohave Desert to the north, San Francisquito Canyon to the east, U.S. 99 to the south and southwest, and by the Piru watershed to the west.

The area of approximately 18 square miles that is contiguous with the Castaic watershed and that borders it on the northeast is not considered in this report. Although this small area contains lakes, it is topographically separated from the Castaic watershed, and surface flow between the two areas does not normally occur.

TOPOGRAPHY AND DRAINAGE

Elevations within the Castaic watershed range from about 1,200 to 5,700 feet; the mean basin elevation, computed by methods to be later described, is 3,240 feet. Canyons are both deep and steep sided. The mean ground-slope angle is about 40°, indicating that level ground is not prevalent save along stream courses. Many of the steepest slopes occur within that part of the basin in which sedimentary rocks crop out (pl. 2). Erosion along joint planes and the tendency toward block fracturing of nearly horizontal strata have produced many canyons whose lower walls approach the vertical.

The drainage is moderate to good, its density being 2.23 miles per square mile. Most streams within this fifth-order watershed are intermittent, but the flow persists during all but the hottest months of the year. Surface flow in Castaic Canyon normally does not reach the gaging station (pl. 2) because of seepage into the permeable alluvium of the stream-channel floor and because of water use from wells near and below the junction of Castaic and Elizabeth Lake Canyons. Surface flow ceases near the junction of Castaic and Fish Canyons (pl. 2), except when storm runoff occurs. Surface flow in Elizabeth Lake Canyon generally continues to a point slightly nearer the basin mouth but then becomes subsurface flow for the same reasons. Personal observation of surface flow in nearly all canyons tributary to Castaic and Elizabeth Lake Canyons and of the presence of water snakes in a few of the streams indicates that the general impression of aridity conveyed by the lower reach of the basin (fig. 1) is not representative of the entire watershed.

CLIMATE

The climate of the Castaic watershed is similar to that existing elsewhere in southern California. Summers are hot and dry and temperatures often reach or exceed 100°F.; winters are generally mild and wet. Temperatures are below freezing during the winters at higher elevations, but the number of freeze-thaw cycles per year is not known. Cyclonic storms that move eastward and northeastward from the Pacific Ocean

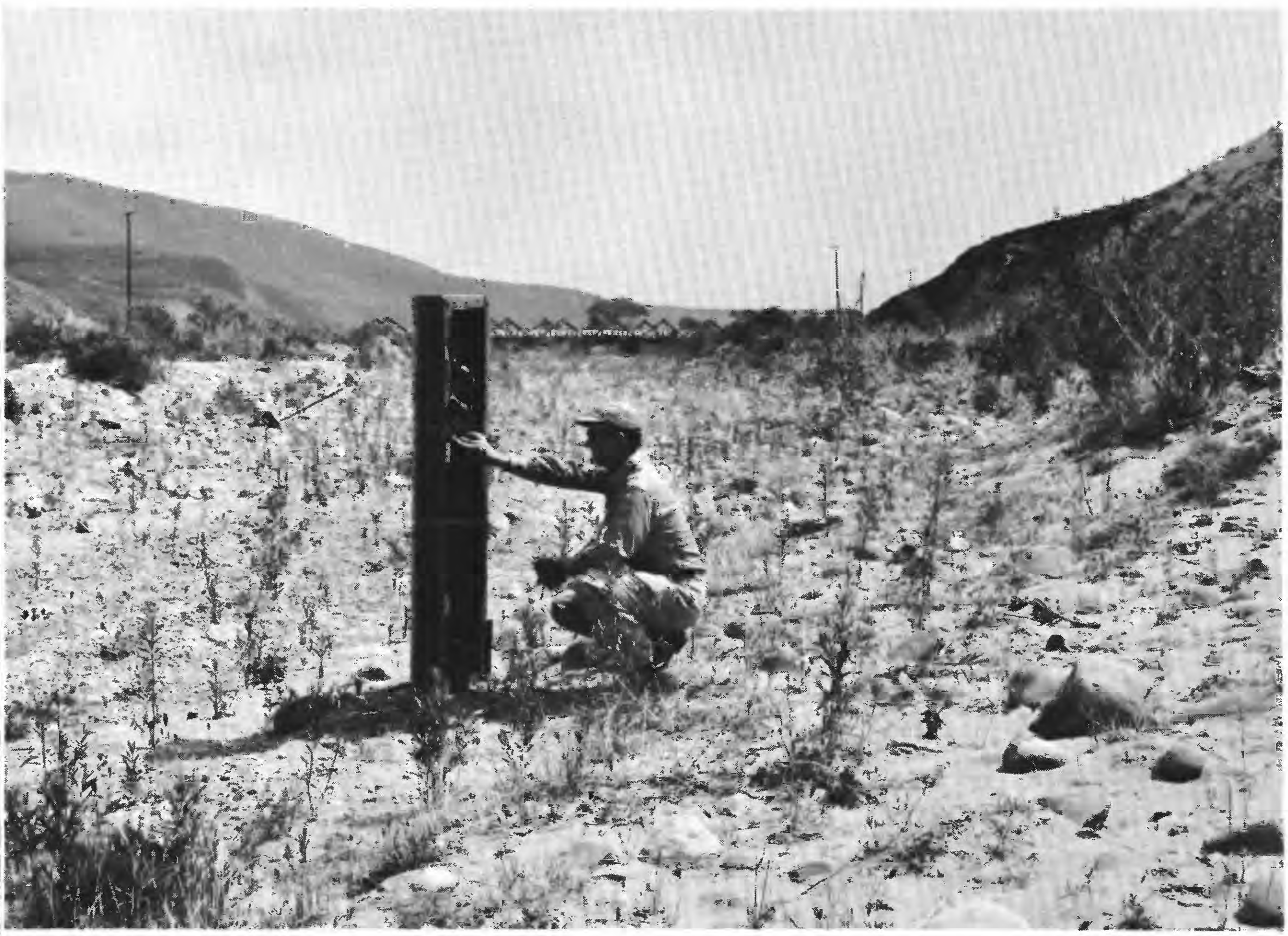

FIGURE 1.—View downstream at the single-stage sampling site in the lower reach of Castaic Creek. Note the sparseness of vegetation in this area which characterizes the lower part of the watershed. The boulders and cobbles visible in the right foreground are abundant throughout the area to be occupied by the proposed reservoir. The single-stage sampler is 5 feet high. It is bolted to reinforcing rods that are set in concrete.

during the winter months provide most of the annual precipitation.

Precipitation data have been obtained at only one station within the watershed; this station is in Elizabeth Lake Canyon (pl. 2) at an elevation of 2,075 feet. Total annual precipitation may fluctuate considerably from year to year, and periods of drouth recur intermittently. The total precipitation recorded in 1961, for example, was 8.26 inches, whereas the following year it was 24.72 inches at this station. Even a long-term mean value at a single station cannot accurately reflect the orographic and areal variations in precipitation that would be expected within the watershed, however, and more data are sorely needed. A regional isohyetal map (California Water Resources Board, 1953), based on the data of the Elizabeth Lake station and on long-term records elsewhere, shows that annual precipitation in the watershed ranges from about 14 to 22 inches per year. This is the best estimate that can be made at present. Maximum precipitation occurs, of course, at the higher elevations; the percentage attributable to snowfall is not known.

VEGETATION AND SOILS

The lower reach of the Castaic watershed appears to be semiarid, as previously mentioned. The vegetation in this area consists of scattered sage and some phreatophytes, but riparian species of trees and shrubs and grasses grow along most of the stream channels elsewhere in the watershed. An assemblage of chaparral and sage provides moderate to good cover on the slopes and ridges of most of the watershed and is more characteristic of the basin than is the assemblage of the lower reach. Woodland communities are prevalent only at higher elevations and along the basin divide; oaks are common in these areas.

Immature alluvial soils border the stream-channel flats; these soils generally lack profiles and range from

FIGURE 2.—View of the Liebre Mountain area from the south. The granitic rocks of Liebre Mountain are separated from the sedimentary rocks in the foreground by a valley that coincides with a fault zone at the mountain front. (See dashed line.) Valley-wall slopes are moderate to steep in the area and vegetative cover is more abundant than in the lower part of the watershed.

a few inches to about 2 feet in depth. Residual rock fragments mixed with finer material mantles the steep slopes and the parts of the watershed at higher elevations; neither soil profiles nor zonation was noted. Soils tend to be thickest in the northeastern part of the watershed, where foliation planes of the metamorphic rocks are exposed to weathering.

SUMMARY OF GEOLOGY

The geology of the area has not been mapped in detail; and because of the time limitations of this study, only the more general aspects could be recorded. Lithologies are therefore grouped into three major types in the following discussion: igneous, metamorphic, and sedimentary. The lithologic boundaries as well as the surface trace of major faults shown on plate 2 should be regarded as both approximate in location and inferred over much of their extent.

The Castaic watershed is bounded by two strike-slip fault zones, which are the San Andreas to the north and the San Gabriel to the south. The watershed proper contains several major and many minor faults. In the absence of stratigraphic and other data, the nature of these faults cannot be determined but the Liebre Mountain and Clearwater faults (pl. 2) that trend approximately east to west may, in part, also represent strike-slip movement. The general aspect of the Liebre Mountain area as viewed from the south is shown in figure 2.

The Liebre Mountain area consists wholly of granitic rocks that contain intermediate to mafic inclusions. This granitic mass is bordered on the southeast and east by a metamorphic complex that consists predominantly of gneiss, schist, and metasedimentary rocks, all of which are intruded in many areas by granite and by aplitic dikes. A typical exposure of this complex is shown in figure 3.

Sedimentary rocks of Tertiary age crop out elsewhere in the watershed (pl. 2). South of the Liebre Mountain and Ruby Canyon faults, these Tertiary strata dip

FIGURE 3.—View of the metamorphic-igneous complex in Elizabeth Lake Canyon. A dike has intruded the metasedimentary rocks that are visible in the right foreground. Note the steep slope of this valley wall, which bounds the channel in Elizabeth Lake Canyon.

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steeply toward the south and in some places approach the vertical. Beyond these zones of deformation, to the south, dips become more gentle; and in large areas the strata are nearly horizontal (fig. 4). The entire sedimentary sequence in the basin forms the east limb of a syncline that plunges northwest (Eaton, 1939).

The sedimentary rocks comprise a coarse facies, consisting predominantly of alternating conglomerate and sandstone. The conglomerate ranges from pebble to boulder size; individual clasts consist of a wide variety of igneous and volcanic rock types. The sandstone ranges from fine to very coarse grained and from well indurated to highly friable. This wide range in both grain size and in degree of cementation combines with alternating thicknesses of beds to produce outcrops that resemble shale-sandstone sequences (fig. 5). True shales are extremely scarce, however, and the sediment yield from the sedimentary rocks of the watershed is derived from only a few siltstones and silty sandstones, in addition to the rock types already cited. Jointing and fracturing of the sedimentary beds are widespread and are a major factor in the production of sediment in the watershed.

SOURCES OF SEDIMENT

To ascertain whether a large percentage of the total sediment yield of the Castaic watershed might be attributable to a single lithologic source or to an individual subbasin, 61 samples were collected within the basin. These samples were obtained from talus slopes below outcrops as well as from the beds and banks of stream channels. All are composite samples; in stream channels, for example, as many as 18 individual samples were taken at a given cross section to provide the data shown for a given location on plate 2. The average weight percentages of granules, sand, and silt-clay particles in samples are grouped by lithologic source and by subbasin in table 1. These data provide the basis for much of the following discussion.

FIGURE 4.—View of the relatively undeformed Tertiary sedimentary rocks in the southern part of the Castaic watershed. The strata crop out as a series of ledges in the canyon and are visible in the center of the photograph. The ledges probably reflect differential resistance to weathering of the sedimentary strata.

TABLE 1.—*Weight percentage of granules, sand, and silt-clay in the granule-to-clay size fraction of samples from the Castaic watershed*

Source	Number of samples	Granules (2-4 mm)	Sand (0.062-2 mm)	Silt-clay (<0.062 mm)
Sedimentary rocks	33	8.6	82.6	8.8
Metamorphic-igneous complex	21	14.3	77.7	8.0
Granitic rocks	7	20.6	75.5	3.9
Castaic Creek drainage basin	47	10.8	81.7	7.5
Elizabeth Lake Canyon drainage basin	14	15.1	75.3	9.6
Subbasin 2	19	9.7	82.9	7.4
Subbasin 3	13	13.8	80.1	6.1
Subbasin 5	3	13.0	76.5	10.5

Consideration of the data listed in table 1 shows that the silt-clay contribution from the area in which sedimentary rocks crop out (pl. 2) is slightly greater than, but nearly equal to, the silt-clay fraction that is contributed by the metamorphic-igneous complex. The difference in the silt-clay yield from these two lithologic groups may result from inadequacies of sampling; if so, then the difference is apparent rather than real. The granitic rocks of the Liebre Mountain area contribute only one-half the silt-clay yield of either the sedimentary or metamorphic-igneous source areas.

The granitic rocks may contribute more fine sediment than would be suspected, however. They are generally weathered to a depth of 1 or more feet in the Liebre Mountain area, and the weathering of ferromagnesian minerals, that precedes the breakup of granites, must produce some clay. Moreover, the high average percentage of granules (20.6) in the granitic sediment and the decrease in abundance of this size class to the south (pl. 2) is significant. Granules consist of polymineralic aggregates of sand-sized particles that are rapidly reduced to these particles through weathering, regardless of the frequency and duration of transport (Lustig, 1963). The breakup of granules produces a change in the size distribution of sediments mainly because sand will be added, but some silt and clay will also be produced. Because the streams that drain the Liebre

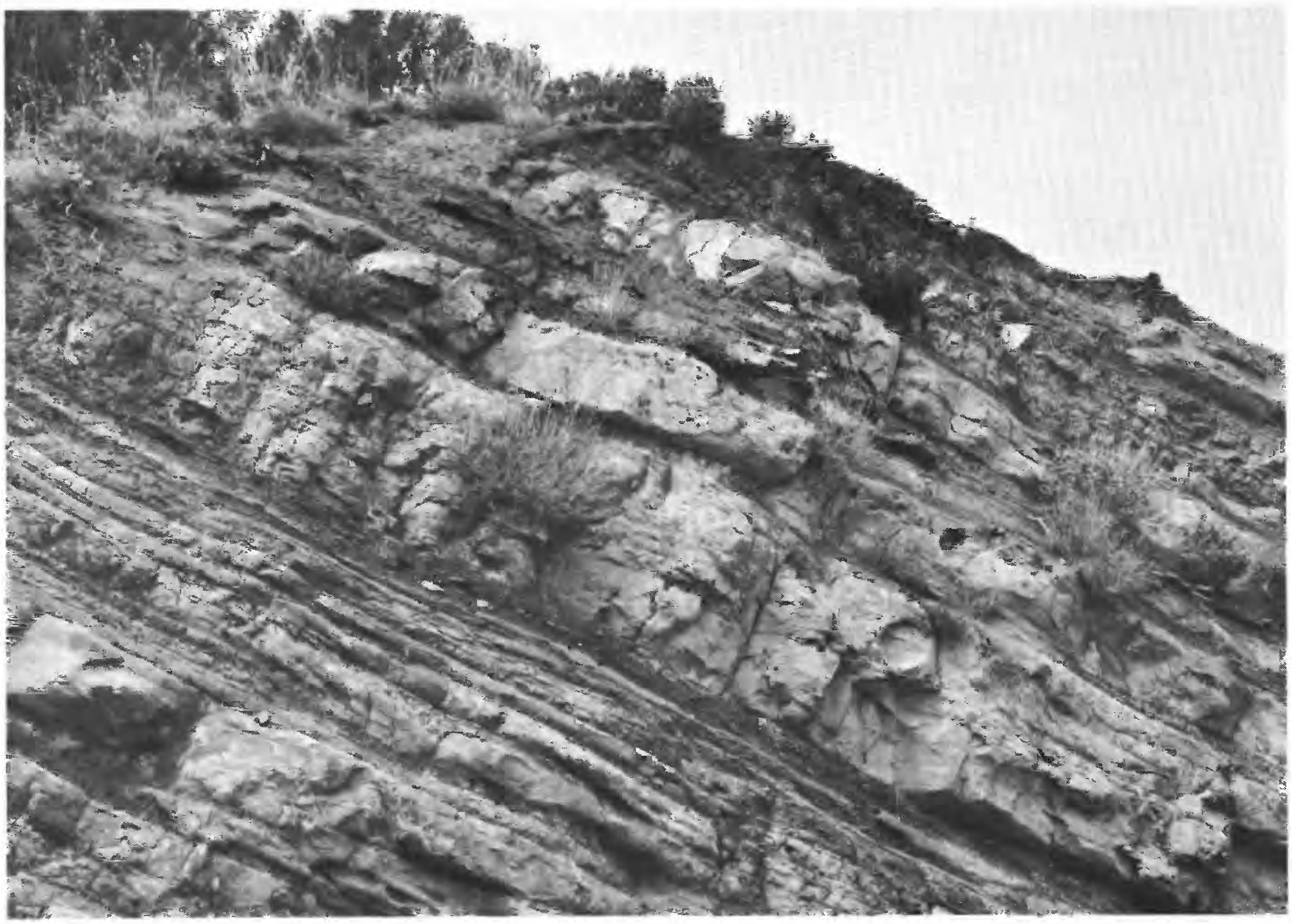

FIGURE 5.—View of a typical outcrop of the Tertiary sedimentary rocks in the Castaic watershed. The alternation of thick to massive beds and thinner strata is typical of many sequences in the watershed. The rocks in this section are all highly friable. The thin beds consist of siltstone and silty sandstone. Note the jointing and tendency toward block-fracturing in this exposure. The massive unit visible in the center is approximately 4 feet thick.

Mountain granitic area (pl. 2) flow through the sedimentary outcrop area of the sedimentary rocks to the south, this secondary contribution of fine sediment from the granitic rocks is somewhat masked.

The lithology of the source area does not appear to exert a pronounced influence upon the production of fine sediment within the watershed. Most of the sediments are sands and coarser clastics; the rather low percentages of silt-clay listed in table 1 would be still smaller if total sediment had been considered rather than the granule-to-clay size fraction.

The sediment that occurs in the proposed reservoir site today reflects this dominance of coarse clastics throughout the watershed. Composite samples from cross sections in Castaic Creek and the Elizabeth Lake Canyon channels contain approximately 85 percent sand in the granule-to-clay size fraction, and no marked skewness toward the smaller sizes occurs. Numerous boulders are, in fact, present at the proposed damsite. Because many of these large particles seem to have been transported fairly recently, their occurrence in these wide, shallow channels of gentle slope must result from either high velocity or density flows. Therefore, the production of sediment in the area in which sedimentary rocks crop out may be greater than is suggested by their silt-clay content.

As previously mentioned, jointing and fracturing of the sedimentary rocks are widespread in the watershed. Slopes are unstable and rock fragments are frequently heard tumbling down canyon walls to the channels below. Much of the sandstone is so friable that it disintegrates to its constituent particles when it falls to the ground from a height of about 4 feet. Sediments so produced occur mainly within the Castaic Creek drainage basin and they may compose much of the total sediment yield because the water discharge from this basin may be greater than the discharge from the Elizabeth Lake Canyon drainage basin.

The conglomeratic facies, however, is well cemented, and jointing and fracturing of these rocks produce large blocks that also fall to canyon bottoms. One such rockfall is shown in figure 6. It forms a natural debris dam above the single-stage-sampler location in subbasin 2 (pl. 2). The author suggests that the present effectiveness of this natural barrier be increased in order to further reduce the sediment yield from the contributing drainage systems in that area.

The Fish Canyon drainage basin (subbasin 3, pl. 2) may also yield much sediment that is transported by Castaic Creek because it is relatively large in area and because the major tributaries head near the basin divide where precipitation is greatest. For these reasons, a sediment sampling station was located near the mouth of this subbasin but data have not yet been obtained.

Subbasin 5 (pl. 2) is thought to be a source of much sediment in the Elizabeth Lake Canyon drainage basin. The small number of samples taken in this area (table 1) may in part account for the greater silt-clay abundance listed; however, field observation shows that fracturing and shearing of the rocks has occurred along a major fault zone that coincides with Ruby and Tule Canyons. If the precipitation and discharge in these canyons is sufficient, the sediment yields will be high. For these reasons a single-stage sampler was also installed at the mouth of Ruby Canyon.

In summary, the entire watershed provides an excellent sediment source despite the fact that silt and clay are not abundant. The sediment yield of the Castaic Creek drainage system may prove to be greater than the yield of the remainder of the watershed owing to the occurrence of friable sedimentary rocks and to a probable higher water discharge. Subbasins 2, 3, and 5 (pl. 2) are worthy of consideration as good locations for construction of debris dams.

LONG-TERM CHANNEL EROSION

A discussion of the sources of sediment is incomplete unless the possible sediment yield from channel erosion is considered. The roots of many of the riparian species of trees that grow along stream channels in the Castaic watershed have been exposed by channel erosion. In one such exposure (fig. 7) approximately 4 feet of net channel erosion has apparently occurred along the stream reach within the lifespan of the tree. If a sufficient number of such exposures are present in a watershed, determination of the net channel erosion is possible; and, hence, some estimate of the sediment yield from this source can be obtained simply by coring and dating the trees. Although an extensive investigation of the inherent possibilities of the method was not undertaken for this study, some pertinent data were obtained.

The total stream length of the Castaic watershed is approximately 307 miles. If an average bankfull channel width of 20 feet (which appears reasonable from field observations) is assumed, the total channel area is 32,420,000 square feet. The examples of root exposure that were noted in the field suggest that approximately 3 feet of net channel erosion has occurred within the lifespan of the trees in many parts of the watershed. If a rectangular channel cross section is assumed, the volume of sediment that has been removed is 97,260,000 cubic feet. The trees that were cored proved to be less than 100 years in age, and none observed in the field are thought to be much older. If the channel erosion has occurred within the last

FIGURE 6.—Rockfall of conglomerate blocks in subbasin 2 that has produced a natural debris dam. The block in the right foregound is 5 feet high, measured from the channel floor; but much larger conglomerate blocks also occur. Note the coarse nature of the well-indurated conglomeratic facies and the trace of joint planes that are visible on the nearly vertical canyon wall in the background. The effectiveness of this natural dam could be easily increased by blasting out additional material from the canyon walls above the site.

100 years, then an average of approximately 22 acre-feet of sediment per year can be attributed to this process in the watershed.

Two major qualifications of the foregoing calculation must be considered. First, the calculation is based upon the arbitrary assumption that channel erosion occurs everywhere within the watershed. There is little doubt that aggradation occurs today along certain parts of the drainage system; reaches that are aggrading cannot be detected, however, unless detailed surveys are made over a period of years. If this assumption alone is considered, the calculation provides too great an estimate.

A second qualification that is perhaps more significant is the fluctuation between aggradation and degradation during the 100-year period considered. This fluctuation

FIGURE 7.—Exposure of the roots of a tree in Ruby Canyon by channel erosion. Approximately 4 feet of net channel erosion is indicated at this point. Note the cobbles and boulders that are visible within the root system, suggesting that much coarse material has been removed in this reach of the stream.

depends upon the kinds and sequence of runoff events. More sediment is probably attributable to channel erosion during any long time interval than is suggested by the method of calculation that is outlined here.

Despite these qualifications, the estimated long-term channel erosion of 22 acre-feet per year is useful. It will be shown in this report that a reasonable estimate of the total long-term sediment yield of the Castaic watershed is 250 acre-feet per year. If the estimated yield from channel erosion had proved to be a large percentage of this total yield, then the validity of the total yield would be subject to considerable question. The results of many studies indicate that in most watersheds the sediment contribution by sheet erosion of valley slopes far outweighs the contribution by channel erosion. The estimate of channel erosion provided here suggests, therefore, that the Castaic watershed does not differ in behavior from most watersheds in regard to sources of sediment. The data suggest that perhaps 20 percent of the total sediment yield is derived from channel erosion.

THE SAN GABRIEL WATERSHEDS

The watersheds in the San Gabriel Mountains that provided a basis for the comparative approach to the problem of sediment yield will be described as a group rather than individually. Emphasis will be placed upon differences or similarities in physical characteristics among the watersheds studied.

PHYSICAL DESCRIPTION OF THE AREA

LOCATION AND EXTENT

The watersheds are in the San Gabriel Mountains, a range approximately 70 miles long and 25 miles wide that trends in an east-west direction (pl. 1). As shown on plate 1, the San Dimas, Big Dalton, Sawpit, and Big Santa Anita watersheds are in the central and eastern parts of the range, along its southern front. The Big Tujunga watershed occupies a more central position with respect to the interior of the range, and the Pacoima watershed lies along the west margin of the mountains. These watersheds range in area from about 3 to 82 square miles; all are therefore smaller in drainage area than the Castaic watershed (137 sq mi).

TOPOGRAPHY AND DRAINAGE

Although elevations in the San Gabriel Mountains exceed 10,000 feet at the east end of the range, elevations in the watersheds studied are somewhat comparable to those in the Castaic drainage basin (1,200 to 5,700 feet). Elevations in the Sawpit, Big Santa Anita, and San Dimas watersheds range from about 1,300 to 5,700 feet and are therefore nearly identical with the range of elevations in the Castaic watershed. Elevations are lower in the Big Dalton watershed, ranging from 1,600 to 3,500 feet, and are higher in the Pacoima and Big Tujunga watersheds, ranging from 1,700 to 6,500 feet and from 2,300 to 7,100 feet, respectively. Thus, only the Pacoima and Big Tujunga watersheds exhibit greater maximum elevations than the Castaic watershed.

Canyons are narrow, deeply dissected, and steep walled throughout the San Gabriel watersheds. Valley-wall slopes in the San Gabriel Mountains seem to be much steeper than those in the Castaic watershed when viewed in the field, owing in part to a greater difference in the relief of the canyons. Valley-wall slopes are in fact steeper in many watersheds in the San Gabriel Mountains, but the mean ground-slope angle in these watersheds, computed as later described, is generally about 5° less than in the Castaic watershed.

Streamflow tends to be intermittent near the mountain front and perennial in interior parts of the range. Except for Sawpit watershed (pl. 1), drainage densities are comparable to that of the Castaic watershed (D=2.23 miles per sq. mi.). The drainage density of the Sawpit watershed is 3.64 miles per square mile; this value is 1.33 to 1.77 miles per square mile greater than the value for the drainage densities of the other basins studied.

CLIMATE

The climate in the watersheds of the San Gabriel Mountains is similar to that in the Castaic watershed: summers are hot and dry, and winters are mild and wet. Most of the total precipitation is produced by the same cyclonic storms that move eastward and northeastward during the winter months. Because the large mass of the San Gabriel Mountains intercepts and forces upward the incoming moist air, more rainfall is induced along the south half of the mountains than in the Castaic watershed. Total annual precipitation ranges from about 20 to 40 inches along an east-west belt between the foothills and the summit of the range. In the watersheds of the San Gabriel Mountains that were studied, precipitation is probably 5 to 10 inches greater than that in the Castaic watershed; it also occurs more frequently.

VEGETATION AND SOILS

The greater precipitation in the watersheds of the San Gabriel Mountains generally supports more vegetation; hence, the ground-cover density is greater than that of the Castaic watershed. Vegetation, like rainfall, is also orographically controlled; and, in addition to a greater ground-cover density, a greater abundance of woodland communities that include spruce, pine, and oak distinguishes these watersheds from the Castaic drainage basin.

Soils of the watersheds in the San Gabriel Mountains are similar in occurrence to those in the Castaic drainage basin but generally possess a higher clay and organic content and tend to be thicker. Anderson and Trobitz (1949) have described the soils as rocky, sandy loams that are generally less than 3 feet thick and lack profiles. Soils are as thick as 6 feet (Maxwell, 1960) in a few places, however.

SUMMARY OF GEOLOGY

The San Gabriel Mountains are a structurally complex range that contains many major and minor faults. Although the geology of the area is much better known than is that of the Castaic watershed, for purposes of this report and for reasons of consistency, only the lithologic contrast between the two areas need be noted here. The watersheds studied occur within areas that consist of several igneous and metamorphic rock types, the metamorphic types including schist, gneiss, and metasedimentary rocks. Clastic sedimentary rocks are generally lacking in the watersheds of the San Gabriel Mountains whereas such rocks crop out over approximately one-third of the Castaic drainage area; therein lies the chief geologic difference between the two areas.

Joints and fractures are very common in the rocks of the San Gabriel Mountains. It has not been possible to quantitatively assess the abundance of these features relative to similar zones in the Castaic watershed, however.

SEDIMENT-YIELD DATA

Because any comparative study must depend upon the reliability of the information that is used for standard or known values, some discussion of the sediment-yield data from the watersheds of the San Gabriel Mountains is warranted.

These data (table 2) are derived from repeated surveys of the respective reservoirs during the past 30 to 40 years. Although surveys of each of the reservoirs have not generally been made during the same year, if the number of years of sediment accumulation (table 2) is divided by the total number of surveys, the average number of years between surveys is seen to range from about 2 to 5.

These data probably are internally consistent and reliable for the following reasons: (1) All data are derived from reservoirs, (2) the period of record is sufficient to include the years of major storms as well as relatively dry years, and (3) the methods used to compute the sediment accumulation in each reservoir is identical. In summary, the sediment yield of these watersheds, expressed in acre-feet per year, is probably satisfactory for the purposes of this report.

Sediment yield is also expressed in acre-feet per year per square mile, and the yield from the major storm of 1938 is shown in the same units (table 2). These data will be cited elsewhere in this report, where appropriate.

TABLE 2.—*Data on reservoirs and sediment yield of watersheds in the San Gabriel Mountains, California*

Reservoir	Dam completion date	Initial capacity (acre-feet)	Latest survey date	Loss of storage capacity (percent)	Number of years of sediment accumulation	Total number of surveys	Sediment yield (acre-ft per yr)	Sediment yield (acre-ft per yr per sq mi)	Sedmient yield of the flood of 1938 [1] (acre-ft per sq mi)
Sawpit	June 1927	476	May 1962	42.9	[2] 35.58	9	8.43	2.52	20.65
Big Dalton	August 1929	[3] 1053	January 1962	17.5	32.25	6	5.71	1.27	18.70
Big Santa Anita	March 1927	1376	April 1962	54.2	[2] 35.50	16	43.18	4.00	30.19
San Dimas	September 1922	1496	April 1962	51.3	40.50	9	21.70	1.34	13.46
Pacoima	February 1929	6060	May 1962	24.4	[2] 35.75	8	52.62	1.87	20.85
Big Tujunga	July 1931	6240	July 1962	34.9	31.75	11	113.23	1.38	18.29

[1] Surveys made prior to 1938 do not have a common date. All reservoirs were surveyed between 1934 and 1936, except for Big Tujunga which was not surveyed between the initial debris year of 1930–31 and 1938. The data given are therefore based upon the assumption that the total sediment yield between 1938 and the previous survey date accrued solely during the flood of 1938.

[2] Dam construction was sufficiently advanced to trap debris from a storm in February 1927, and the first debris-year is assumed to be 1926–27.

[3] The initial topographic survey was made in November 1934. The capacity determined at that time is given as the initial capacity; observation suggested that little sediment accumulated prior to 1935.

QUANTITATIVE GEOMORPHOLOGY

GENERAL DISCUSSION

The methods of quantitative geomorphology are widely applicable to problems involving erosion and sedimentation. The major impetus for studies in this field was provided by Horton (1945), who set forth many of the principles and parameters that are today applied to drainage-basin studies. Subsequent investigators, notably Strahler (1950, 1952, 1954, 1957, 1958) and several of his students (Miller, 1953; Schumm, 1956; Melton, 1957; Coates, 1958; Broscoe, 1959; Morisawa, 1959; Maxwell, 1960), have enlarged these concepts, introduced new parameters, and extended the data to include a wide variety of geographic regions. In addition to providing a sound basis for quantitative landform description and comparison, these and other studies have led to a better understanding of geologic processes and of the interrelationship between geomorphic characteristics and the hydrology of drainage basins.

Sherman (1932) initially demonstrated that the unit hydrograph varied with basin shape and slope, but Langbein and others (1947) provided one of the first mathematical treatments, relating discharge and drainage area. Anderson (1949; Anderson and Trobitz, 1949) was among the first to apply multiple-regression methods to hydrologic problems in watersheds, and to relate forest-cover density to discharge and sedimentation. Potter (1953) showed that peak flow was correlative with the length and slope of the principal channel, and Morisawa (1959) extended Anderson's multiple regression approach to relate peak intensity of runoff with several additional geomorphic variables. In a highly sophisticated statistical treatment, Maxwell (1960) computed the correlations among peak discharge and storm rainfall, cover density, antecedent rainfall, and nine geomorphic parameters taken five at a time. In similar fashion, Benson (1962) related the *T*-year annual peak discharge to climatic and geomorphic factors by multiple-regression analysis.

From the foregoing abbreviated survey of the literature, it can be concluded that many geomorphic parameters can exert an effect upon the discharge from a given watershed. This conclusion is true if, as shown for example by Hack (1957),

$$Q=f(A_u), \quad (1)$$

because

$$A_u=f(N_u, L_u, \Sigma L, \Theta, \dots) \quad (2)$$

and discharge is therefore a function of these same variables. It is reasonable to suppose then that certain geomorphic parameters will also affect sediment yield if

$$S_y=f(Q), \quad (3)$$

that is, if sediment yield is some function of water discharge, and the methods of quantitative geomorphology should, therefore, be applicable to the problem of determination of the anticipated sediment yield of a given watershed.

In addition to stream discharge, however, sediment yield is undoubtedly a complex function of a veritable host of climatic, geologic, edaphic, and other characteristics of a watershed. If sufficient data on these characteristics are available, then the methods of multiple regression will enable one to derive an equation expressing sediment yield in terms of all the variables. The applicability of such an equation, however, will still depend upon qualitative factors such as the arbitrary assignation of numerical values for the erodibility of rocks of various lithologic character.

Such procedure is, in any event, precluded in the problem considered in this report because available hydrologic data for the Castaic drainage basin (pl. 2) are scarce. Knowledge of the long-term sediment yield from watersheds in the San Gabriel Mountains, however, is equivalent to knowledge of the cumulative effect of all the variables operative in that area. Determining the role of geomorphic factors in the production of sediment from the watersheds of the San Gabriel Mountains should therefore be possible by simple linear regression of each parameter with the known sediment yield. Determination of the same geomorphic parameters for the Castaic watershed should then provide a means by which some reasonable estimate of anticipated sediment yield can be made. With this approach in mind, the methods of quantitative geomorphology were applied; a morphometric study of the Castaic and San Gabriel Mountains watersheds was undertaken in a search for significant parameters.

BASIC-DATA COLLECTION

The morphometric data listed in table 3 were obtained from U.S. Geological Survey topographic maps having a scale of 1:24,000. These maps depict the mountainous terrain of the areas studied in considerable detail. Some errors, both of location and of omission of first-order stream channels, do occur, however. Several examples of such errors have been cited by Coates (1958) and Maxwell (1960), among others. Maxwell proved their occurrence in the San Dimas watershed of the San Gabriel Mountains by a careful field check and revised the maps involved accordingly. Time limitations prevented a similar correction of the maps employed in the present study, and for this reason the effect of typical map discrepancies upon the data should be noted.

The morphometric properties most readily altered by omission of first-order streams are: stream-channel order, number of streams, stream-channel length, basin order, and drainage density and other derived parameters. Such parameters are a function of map scale (Giusti and Schneider, 1963, for example), and any first-order stream channel can generally be shown to be of much higher order number if detailed mapping on a larger scale is undertaken (Leopold and Miller, 1956), however. The values obtained for drainage density (table 3), for example, may be less than the true values because drainage density is proportional to total stream-channel length. Basin-order designations are also less, for similar reasons. The values obtained can still be used for comparative purposes, however, because they have been affected to the same degree; the fact that the maps including the basins studied are of equal scale obviates the difficulties imposed by the discrepancies of these maps.

Stream order and basin order were designated in accord with Strahler's (1952) modification of the usage of Gravelius (1914) and Horton (1945). Stream-channel lengths were measured with dividers set at 0.01 mile. The use of dividers provided more consistent replicate results than could be obtained with a map measurer. This was particularly true for measurement of the lengths of highly sinuous streams. The mean stream-channel length of streams of each order ($\overline{L}_u$) and the cumulated lengths of streams of each order (ΣL_u) were computed for each watershed; the values are listed in table 3.

Drainage areas were measured with a compensating polar planimeter, and the mean values of replicate sets of measurements were recorded. Areas of sub-basins of each order (A_u) within a given watershed were cumulated in order to verify total drainage area. The results accorded to the nearest 0.05 square mile. The mean area of each basin order ($\overline{A}_u$) and the cumulated area of each basin order (ΣA_u) were computed for each of the seven watersheds (table 3).

Random-number overlays, of a size sufficient to cover the area of each watershed, were prepared to determine the mean ground-slope angle of each basin. The procedure, as described by Strahler (1954) is simple. At each of 100 random locations within each basin, the slope was measured over a 200-foot reach orthogonal to contour lines. The mean ground-slope angle ($\bar{\theta}_g$) was calculated from these sets of 100 measurements to the nearest one-half of a degree. Replicate measurements of slope at alternative sets of 100 random locations were made within the largest of the watersheds that were studied to test sufficiency of sample size. The expected reduction of the standard deviation of the means of these replicate sets, compared to that of the original set of values, occurred, and the variance from the mean of the means was within the limits of error of the measurements. It was concluded, therefore, that a random sample of 100 ground-slope angles was sufficiently large to be representative of the population of ground-slope angles of each watershed.

The value of the sine of each of the 100 ground-slope angles within each watershed was recorded, and the mean value $\overline{(\sin\ \theta_g)}$ was computed. The reasons for computing the sine rather than the tangent of the angles will be discussed later. The cosine of the mean ground-slope angle was also computed to calculate S_A, sediment area ($S_A = A_p/\cos\ \bar{\theta}_g$). These data are listed in table 3.

Elevations at each random location in a basin were read from the maps, and the means of each set of 100 values ($\overline{E}$) were computed (table 3). These values are thought to be representative of the mean basin elevations. Proportional dividers were used to interpolate between adjacent contours to the nearest 5 feet. This same procedure was followed in measuring elevation differences along stream channels. These values were used to compute the mean stream-channel gradients of streams of each order ($\bar{\theta}_u$) within each basin (table 3).

The number of streams of each order (N_u) within a basin was determined by inspection, and relief ratio ($R_h = H/L_b$) was computed in accord with Schumm's (1956) procedure. All other parameters that are listed in table 3 are derived properties that require stream length, basin area, stream-channel gradient, or the number of streams of a given order for their computation. These derived parameters are: drainage density ($D = \Sigma L/A_u$), stream frequency ($F = N_u/A_u$), bifurcation ratio ($R_b = N_u/N_{u+1}$), stream-length ratio ($R_L = \overline{L}_u/\overline{L}_{u-1}$), basin-area ratio ($R_a = A_u/A_{u-1}$), stream-channel-slope ratio ($R_c = \bar{\theta}_u/\bar{\theta}_{u+1}$), and the ruggedness index ($R_i = D \times \overline{E}$).

GEOMORPHIC PARAMETERS

Each of the parameters listed in table 3, obtained as described in the preceding section, was considered both individually and in various combinations for possible correlation with the sediment yield of the watersheds of the San Gabriel Mountains. Although a trial-and-error approach will suffice in seeking the correlation of individual parameters with sediment yield, the choice of combinations of these parameters must be governed by consideration of both the relationship between two parameters of a paired set and the expected influence of the paired set upon sediment yield. One would not, for example, expect a product of mean stream length of a given stream order and mean basin elevation ($\overline{L}_u \times \overline{E}$) to produce an explicable correlation with

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TABLE 3.—*Morphometric data and geomorphic parameters of the Castaic*

Watershed	Basin order	Area of basin of order u (sq mi)	Mean area of basin of order u (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 (feet per foot)	Mean basin elevation (ft)	Mean ground-slope angle (degrees)	Stream frequency (number per sq mi)
Castaic	5	A_1=83.28	$\bar{A}_1$=0.45	N_1=187	ΣL_1=200.21	$\bar{L}_1$=1.07	$\bar{\theta}_1$=0.189	3240	40.5	F_1=2.25
		A_2=79.60	$\bar{A}_2$=1.85	N_2=43	ΣL_2=245.54	$\bar{L}_2$=5.71	$\bar{\theta}_2$=.078			F_2=.54
		A_3=82.12	$\bar{A}_3$=6.32	N_3=13	ΣL_3=269.42	$\bar{L}_3$=20.72	$\bar{\theta}_3$=.043			F_3=.16
		A_4=111.72	$\bar{A}_4$=27.93	N_4=4	ΣL_4=294.62	$\bar{L}_4$=73.66	$\bar{\theta}_4$=.027			F_4=.04
		A_5=137.63	$\bar{A}_5$=137.63	N_5=1	ΣL_5=307.49	$\bar{L}_5$=307.49	$\bar{\theta}_5$=.014			F_5=.01
Sawpit	3	A_1=2.29	$\bar{A}_1$=.18	N_1=13	ΣL_1=8.13	$\bar{L}_1$=.63	$\bar{\theta}_1$=.292	3010	33.5	F_1=5.68
		A_2=1.94	$\bar{A}_2$=.39	N_2=5	ΣL_2=9.89	$\bar{L}_2$=1.98	$\bar{\theta}_2$=.201			F_2=2.58
		A_3=3.34	$\bar{A}_3$=3.34	N_3=1	ΣL_3=12.17	$\bar{L}_3$=12.17	$\bar{\theta}_3$=.083			F_3=.30
Big Dalton	3	A_1=4.30	$\bar{A}_1$=.72	N_1=6	ΣL_1=6.31	$\bar{L}_1$=1.05	$\bar{\theta}_1$=.207	2620	30.5	F_1=1.40
		A_2=4.41	$\bar{A}_2$=2.21	N_2=2	ΣL_2=8.60	$\bar{L}_2$=4.30	$\bar{\theta}_2$=.060			F_2=.45
		A_3=4.50	$\bar{A}_3$=4.50	N_3=1	ΣL_3=8.80	$\bar{L}_3$=8.80	$\bar{\theta}_3$=.038			F_3=.22
Big Santa Anita	3	A_1=6.69	$\bar{A}_1$=.39	N_1=17	ΣL_1=15.50	$\bar{L}_1$=.91	$\bar{\theta}_1$=.279	3485	34.0	F_1=2.54
		A_2=8.06	$\bar{A}_2$=2.69	N_2=3	ΣL_2=21.47	$\bar{L}_2$=7.16	$\bar{\theta}_2$=.142			F_2=.37
		A_3=10.79	$\bar{A}_3$=10.79	N_3=1	ΣL_3=23.72	$\bar{L}_3$=23.72	$\bar{\theta}_3$=.055			F_3=.09
San Dimas	4	A_1=10.54	$\bar{A}_1$=.88	N_1=12	ΣL_1=19.02	$\bar{L}_1$=1.59	$\bar{\theta}_1$=.155	3305	33.0	F_1=1.14
		A_2=7.54	$\bar{A}_2$=1.89	N_2=4	ΣL_2=23.50	$\bar{L}_2$=5.88	$\bar{\theta}_2$=.109			F_2=.53
		A_3=9.95	$\bar{A}_3$=4.98	N_3=2	ΣL_3=27.21	$\bar{L}_3$=13.61	$\bar{\theta}_3$=.059			F_3=.20
		A_4=16.17	$\bar{A}_4$=16.17	N_4=1	ΣL_4=30.27	$\bar{L}_4$=30.27	$\bar{\theta}_4$=.020			F_4=.06
Pacoima	3	A_1=16.81	$\bar{A}_1$=.34	N_1=49	ΣL_1=46.26	$\bar{L}_1$=.94	$\bar{\theta}_1$=.228	4050	33.5	F_1=2.91
		A_2=12.43	$\bar{A}_2$=1.78	N_2=7	ΣL_2=55.66	$\bar{L}_2$=7.95	$\bar{\theta}_2$=.109			F_2=.56
		A_3=28.10	$\bar{A}_3$=28.10	N_3=1	ΣL_3=61.24	$\bar{L}_3$=61.24	$\bar{\theta}_3$=.073			F_3=.04
Big Tujunga	5	A_1=43.52	$\bar{A}_1$=.32	N_1=136	ΣL_1=116.01	$\bar{L}_1$=.85	$\bar{\theta}_1$=.216	4540	30.5	F_1=3.13
		A_2=53.61	$\bar{A}_2$=1.73	N_2=31	ΣL_2=156.98	$\bar{L}_2$=5.06	$\bar{\theta}_2$=.091			F_2=.58
		A_3=54.71	$\bar{A}_3$=6.84	N_3=8	ΣL_3=176.32	$\bar{L}_3$=22.04	$\bar{\theta}_3$=.056			F_3=.15
		A_4=64.35	$\bar{A}_4$=32.18	N_4=2	ΣL_4=185.11	$\bar{L}_4$=92.56	$\bar{\theta}_4$=.046			F_4=.03
		A_5=82.00	$\bar{A}_5$=82.00	N_5=1	ΣL_5=189.07	$\bar{L}_5$=189.07	$\bar{\theta}_5$=.018			F_5=.01

sediment yield. Although each of the variables in this example may indeed bear some relation to sediment yield, their relation to each other is not obvious, and the results of a correlation between the pair and sediment yield would defy explanation. In this sense, all possible combinations of parameters have not been tested for correlation with sediment yield.

The parameters discussed below are, except for relief ratio, those which are interpreted as meaningful and which correlated well with sediment yield. Certain of the parameters to be described appear in this report for the first time, and comparison with previous results is therefore not possible. Among the more common parameters, such as drainage density or ruggedness index, only total drainage area provided a good correlation with sediment yield. As previously indicated (equations 1, 2, 3), if this were not true, then the relationship between sediment yield and various parameters that are a function of drainage area could not be investigated. The relationship between sediment yield and drainage area will, however, be held in abeyance for discussion in a subsequent section of this report.

The linear-regression lines that relate sediment yield with each of the following geomorphic parameters were fitted by the least-squares method. Correlation coefficients computed for each pair of variates are cited below where appropriate; the statistical significance of these coefficients will be explained in a subsequent subsection entitled "Discussion of results."

RELIEF RATIO

The relief ratio of a watershed (Schumm, 1956) is defined as $R_h = H/L_b$, where H is the difference in elevation between the basin divide and mouth and L_b is the maximum basin length measured along a line as nearly parallel to the principal channel as possible. The relief ratio is therefore a dimensionless number that approximates overall watershed slope. Because of lack of adequate maps, or for ease of computation, relief ratio has often been correlated with sediment yield in preference to treating hypsometric data as suggested by Langbein and others (1947) and Strahler (1952). In addition, it is logical to assume that the energy input of such hydrologic factors as runoff and discharge should be, in part, a function of this parameter. Morisawa (1959) found that relief ratios of watersheds in the Appalachian Mountains correlated well with peaks of discharge and rainfall-runoff intensities, and Hadley and Schumm (1961) obtained a good correlation with sediment yield in the Cheyenne River drainage basin. Accordingly, relief ratio for each of the watersheds in the San Gabriel Mountains was among the first parameters determined during the morphometric study for this report. The linear regression of sediment yield with relief ratio for the basins studied is shown in figure 8. The rather poor correlation (r=0.658) between these variates is apparent, and the data are included here for illustrative purposes only.

drainage basin and of watersheds in the San Gabriel Mountains, California

Drainage density (mile per sq mi)	Ruggedness index	Bifurcation ratio	Stream-length ratio	Basin-area ratio	Stream-channel-slope ratio	Relief ratio	Sediment-area factor	Sediment-movement factor	Transport efficiency factors		
									T_1	T_2	T_3
2.23	7,225	$N_1/N_2=4.35$ $N_2/N_3=3.31$ $N_3/N_4=3.25$ $N_4/N_5=4.00$ $\overline{R}_b=3.73$	$\overline{L}_5/\overline{L}_4=4.17$ $\overline{L}_4/\overline{L}_3=3.56$ $\overline{L}_3/\overline{L}_2=2.63$ $\overline{L}_2/\overline{L}_1=5.34$ $\overline{R}_L=4.18$	$A_5/A_4=1.23$ $A_4/A_3=1.36$ $A_3/A_2=1.03$ $A_2/A_1=.96$ $\overline{R}_a=1.15$	$\bar{\theta}_1/\bar{\theta}_2=2.42$ $\bar{\theta}_2/\bar{\theta}_3=1.81$ $\bar{\theta}_3/\bar{\theta}_4=1.59$ $\bar{\theta}_4/\bar{\theta}_5=1.93$ $\overline{R}_e=1.94$	0.058	180.97	116.16	1146.94	481.12	694.64
3.64	10,956	$N_1/N_2=2.60$ $N_2/N_3=5.00$ $\overline{R}_b=3.80$	$\overline{L}_3/\overline{L}_2=6.15$ $\overline{L}_2/\overline{L}_1=3.17$ $\overline{R}_L=4.66$	$A_3/A_2=1.72$ $A_2/A_1=.85$ $\overline{R}_a=1.29$	$\bar{\theta}_1/\bar{\theta}_2=1.45$ $\bar{\theta}_2/\bar{\theta}_3=2.42$ $\overline{R}_c=1.94$	.340	4.01	2.18	46.25	36.86	40.62
1.95	5,109	$N_1/N_2=3.00$ $N_2/N_3=2.00$ $\overline{R}_b=2.50$	$\overline{L}_3/\overline{L}_2=2.05$ $\overline{L}_2\overline{L}_1=4.09$ $\overline{R}_L=3.07$	$A_3/A_2=1.02$ $A_2A_1=1.03$ $\overline{R}_a=1.03$	$\bar{\theta}_1/\bar{\theta}_2=3.45$ $\bar{\theta}_2/\bar{\theta}_3=1.58$ $\overline{R}_c=2.52$	.061	5.23	2.59	22.00	22.68	32.34
2.20	7,667	$N_1/N_2=5.67$ $N_2/N_3=3.00$ $\overline{R}_b=4.34$	$\overline{L}_3/\overline{L}_2=3.31$ $\overline{L}_2/\overline{L}_1=7.86$ $\overline{R}_L=5.59$	$A_3/A_2=1.34$ $A_2/A_1=1.20$ $\overline{R}_a=1.27$	$\bar{\theta}_1/\bar{\theta}_2=1.96$ $\bar{\theta}_2/\bar{\theta}_3=2.58$ $\overline{R}_c=2.27$	.230	13.01	7.18	102.95	47.67	49.52
1.87	6,180	$N_1/N_2=3.00$ $N_2/N_3=2.00$ $N_3/N_4=2.00$ $\overline{R}_b=2.33$	$\overline{L}_4/\overline{L}_3=2.22$ $\overline{L}_3/\overline{L}_2=2.31$ $\overline{L}_2/\overline{L}_1=3.70$ $\overline{R}_L=2.74$	$A_4/A_3=1.63$ $4_3/A_2=1.32$ $A_2/A_1=.72$ $\overline{R}_a=1.22$	$\bar{\theta}_1/\bar{\theta}_2=1.42$ $\bar{\theta}_2/\bar{\theta}_3=1.85$ $\bar{\theta}_3/\bar{\theta}_4=2.95$ $\overline{R}_c=2.07$	.139	19.28	10.34	70.53	39.33	42.67
2.18	8,829	$N_1/N_2=7.00$ $N_2/N_3=7,00$ $\overline{R}_b=7.00$	$\overline{L}_3/\overline{L}_2=7.70$ $\overline{L}_2/\overline{L}_1=8.46$ $\overline{R}_L=8.08$	$A_3/A_2=2.26$ $A_2/A_1=.74$ $\overline{R}_a=1.50$	$\bar{\theta}_1/\bar{\theta}_2=2.09$ $\bar{\theta}_2/\bar{\theta}_3=1.49$ $\overline{R}_c=1.79$	.070	33.70	18.34	428.68	102.03	128.96
2.31	10,487	$N_1/N_2=4.39$ $N_2/N_3=3.88$ $N_3/N_4=4.00$ $N_4/N_5=2.00$ $\overline{R}_b=3.57$	$\overline{L}_5/\overline{L}_4=2.04$ $\overline{L}_4/\overline{L}_3=4.20$ $\overline{L}_3/\overline{L}_2=4.36$ $\overline{L}_2/\overline{L}_1=5.95$ $\overline{R}_L=4.14$	$A_5/A_4=1.27$ $A_4/A_3=1.18$ $A_3/A_2=1.02$ $A_2/A_1=1.23$ $\overline{R}_a=1.18$	$\bar{\theta}_1/\bar{\theta}_2=2.37$ $\bar{\theta}_2/\bar{\theta}_3=1.62$ $\bar{\theta}_3/\bar{\theta}_4=1.22$ $\bar{\theta}_4/\bar{\theta}_5=2.56$ $\overline{R}_c=1.94$	.078	95.17	47.40	674.98	345.32	479.21

Good correlation between relief ratio and sediment yield is absent probably for two reasons, aside from the obvious difficulties and ambiguities involved in determining the maximum basin length (L_b) as defined. First, several of the watersheds in question (pl. 1) possess nearly identical basin relief but differ drastically in maximum length. This difference is an obvious consequence of variation in basin shape. Because relief ratio is an indirect function of basin shape, this parameter cannot provide consistent correlation with sediment yield in the absence of similarity of shape.

Second, relief ratio is a measure of the slope of a surface, the horizontal projection of which is taken as the drainage area of a watershed. Sediment yield, however, is a function of sediment availability and might be expected to be more closely related to total surface area than to planimetric drainage area in certain drainage basins. Clearly, two basins can be equal in planimetric area and yet differ in total surface area because of topographic variation. One could not expect equal sediment yields from 100 square miles of horizontal mesa and from 100 square miles of rugged mountains, to cite an extreme example. For these reasons, a substitute for the relief-ratio parameter was devised as described in the following discussion.

SEDIMENT-AREA FACTOR

To approximate watershed surface area with a minimum of computational difficulty and yet avoid elimination of drainage area, with which stream discharge and many geomorphic parameters are indeed interrelated, a parameter, herein termed the "sediment-area factor," was computed. Sediment area is defined as $S_A=A_p/\cos \bar{\theta}_g$, where A_p is the planimetric area of a watershed and $\bar{\theta}_g$ is the mean ground-slope angle for values obtained at 100 random locations, as previously described.

Consideration of the simple relationships shown in figure 9 provides the rationale for the sediment-area expression. Figure 9 is a diagrammatic longitudinal section of a watershed that contains three main groups of hills, the steepest of which occurs in the divide area. If we wish to find the total length of slopes that are exposed to erosion in this two-dimensional portrayal, then, assuming symmetry of the hills, we would compute

$$L_1/\cos \theta_1+2L_2/\cos\theta_2+2L_3/\cos \theta_3, \quad (4)$$

which gives the desired result, namely

$$S_1+2S_2+2S_3. \quad (5)$$

If we add the interhill lengths, which are also on the surface exposed to erosion, then the total length in any two-dimensional portrayal clearly will be much greater than L_b. L_b is basin length, as used in the relief ratio expression, and it is measured in the horizontal plane. Figure 9 suggests that one approximation to total surface length in two dimensions can be derived from the relief ratio, H/L_b; the length BC is such an approximation and it can easily be obtained.

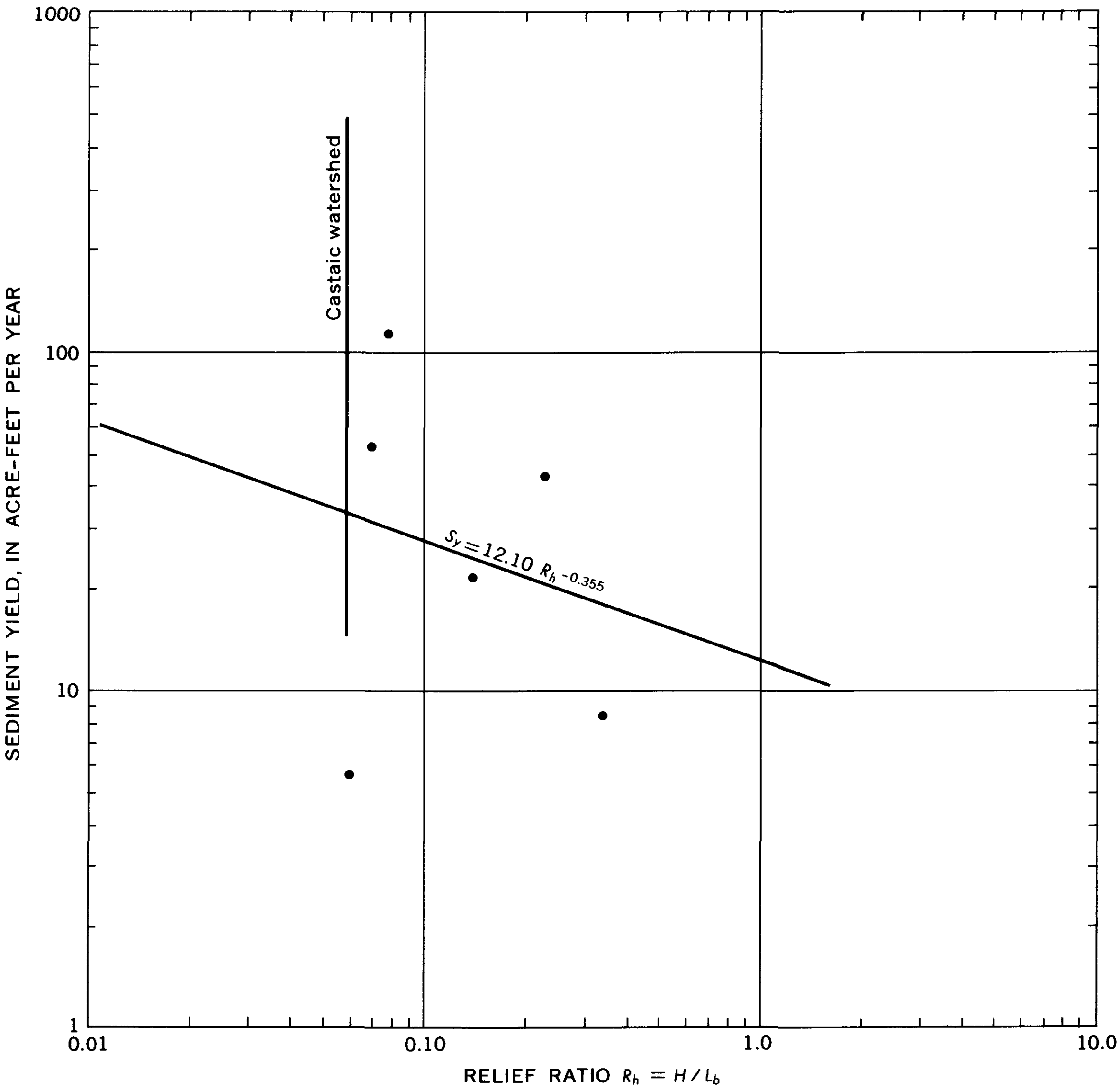

FIGURE 8.—Relation of sediment yield and relief ratio for watersheds in the San Gabriel Mountains. The vertical line represents the relief ratio of the Castaic watershed; its intercept (I_C) with the curve gives the sediment-yield estimate provided by this parameter. r=0.685, I_C=33.17.

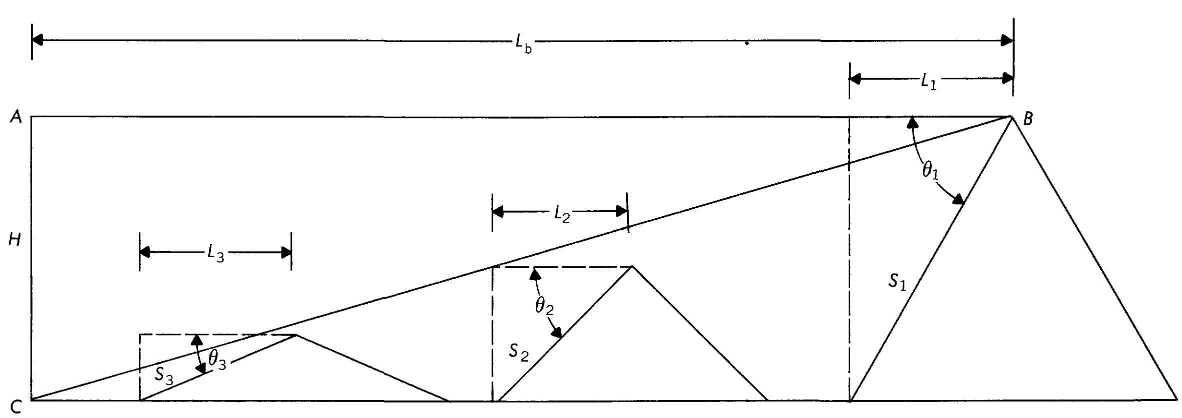

FIGURE 9.—Diagrammatic longitudinal section of a watershed that contains three main groups of hills, showing the geometry of the relief ratio and sediment-area factor. L_b is basin length; AC is basin relief or H; S_1, S_2, S_3 are lengths of hillslopes; L_1, L_2, L_3 are horizontal projections of S_1, S_2, and S_3, respectively; θ_1, θ_2, θ_3 are angles of hillslopes.

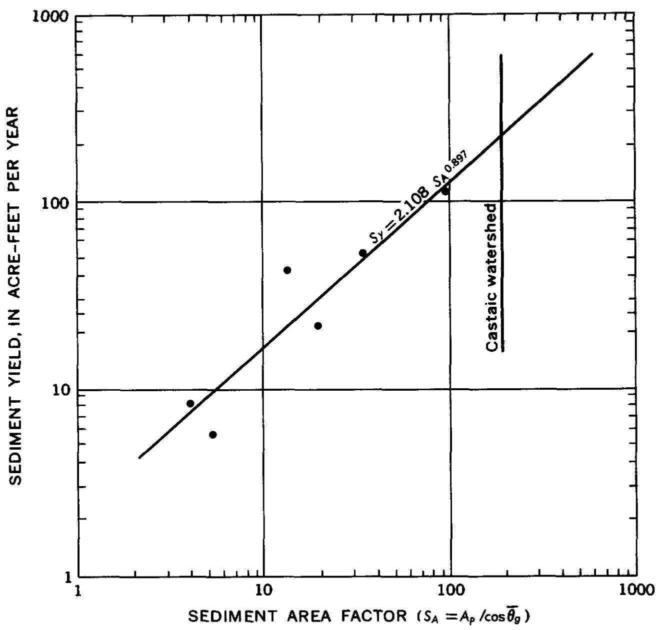

FIGURE 10.—Relation of sediment yield and the sediment-area factor for watersheds in the San Gabriel Mountains. The vertical line represents the value of the sediment-area factor in the Castaic watershed; its intercept (I_C) with the curve gives the sediment-yield estimate provided by this parameter. $r=0.929$, $I_C=223.41$.

Difficulties will arise, however, when one attempts to extend the approximation just cited to the three-dimensional problem. Symmetry of hills will not necessarily prevail and, moreover, relief ratio will vary with basin shape as previously mentioned. For these reasons the sediment-area factor, namely $S_A=A_p/\cos\bar{\theta}_g$, was used in this report. The expression is, in effect, an approximate integration of the general expression $L_i/\cos\theta_i$ within the watershed. Because the mean ground-slope angle was obtained from a random sample of slope values in a given watershed, it represents the mean of all slopes in that watershed, and A_p, of course, is equivalent to ΣL_i.

The sediment-area factor is thought to represent the true surface area of a given watershed and, therefore, the availability of sediment within that watershed, to a first approximation. The regression of sediment yield with S_A is shown in figure 10. The correlation coefficient is 0.929, clearly suggesting that this parameter is superior to relief ratio for the areas studied.

SEDIMENT-MOVEMENT FACTOR

The valley-side slopes in a watershed have a direct bearing on problems of sediment-yield estimation. Other factors being equal, one can state qualitatively that an increase in steepness of slope will result in both an increase in the rapidity of runoff and a greater supply of sediment provided to the drainage system for transport. The downslope movement of sediment, upon which the supply of sediment depends, is a function of both gravitational and shearing stresses and the nature of the material available. Because the sine of the angle of slope is the ratio of the gravitational stresses to the shearing stresses that act upon either bedrock or its sediment cover, the sine of this angle is a geomorphic parameter of significance and is more meaningful than other trigonometric functions of slope.

To determine whether a relationship existed between sediment yield and the movement of sediment toward the drainage net, a parameter, herein termed the "sediment-movement factor," was defined as $S_M=S_A\times\overline{\sin\theta_g}$, where S_A is sediment area, as previously defined, and $\overline{\sin\theta_g}$ is the mean of the sines of the ground-slope angles at each of 100 random locations in a given watershed. Sediment area is included in this expression for sediment movement because it is logical to consider the product of the forces acting upon the sediment and the availability of that sediment. The regression of sediment yield with S_M is shown in figure 11. The correlation coefficient is 0.940, suggesting that, like S_A, the defined sediment-movement factor is a significant geomorphic parameter.

TOTAL STREAM LENGTH

Total stream length also correlated well with sediment yield ($r=0.935$); the linear regression is shown in figure 12. Although greater length of an individual stream implies that more sediment deposition can occur along its course, greater total stream length within a watershed implies both greater precipitation and runoff and greater sediment-availability and sediment-movement

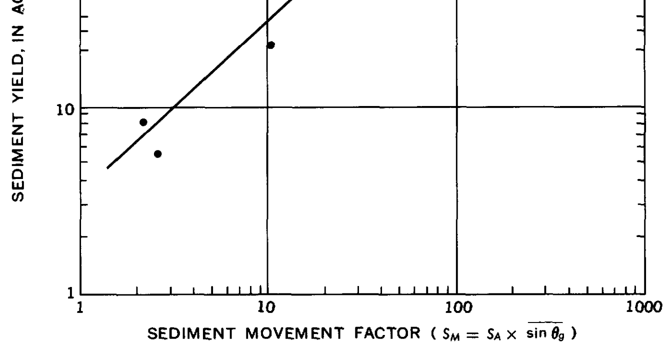

FIGURE 11.—Relation of sediment yield and the sediment-movement factor for watersheds in the San Gabriel Mountains. The vertical line represents the value of the sediment-movement factor in the Castaic watershed; its intercept (I_C) with the curve gives the sediment-yield estimate provided by this parameter. $r=0.940$, $I_C=279.40$.

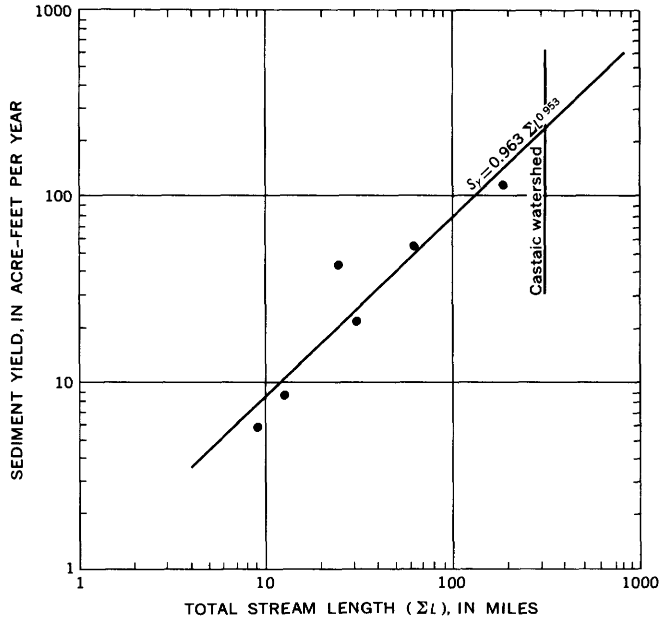

FIGURE 12.—Relation of sediment yield and total stream length for watersheds in the San Gabriel Mountains. The vertical line represents the total stream length of the Castaic watershed; its intercept (I_C) with the curve gives the sediment-yield estimate provided by this parameter. $r=0.935$, $I_C=226.26$.

possibilities. Thus, it would be expected that total stream length be related to sediment yield.

TRANSPORT-EFFICIENCY FACTORS

Although total stream length (ΣL) might be considered a measure of transport efficiency, it is apparent upon reflection that both the unit hydrograph and the sediment yield of two watersheds may vary considerably, despite equal values of ΣL. Both the number of individual stream channels that compose ΣL and the gradients of these channels, among other factors, can cause such variation. For this reason three additional geomorphic parameters were defined and computed in an attempt to more closely reflect transport efficiency T_e; these parameters are herein designated as T_1, T_2, and T_3.

The first of these factors is defined as $T_1=\overline{R}_b\times\Sigma L$, where $\overline{R}_b$ is the mean bifurcation ratio and ΣL is, again, total stream length. T_1 may be regarded as an adjustment of total stream length to more closely reflect the nature of the drainage net, the individual segments of which compose ΣL. The regression of sediment yield with T_1 is shown in figure 13; the correlation coefficient is 0.944, which is slightly higher than that for ΣL alone.

The second transport-efficiency factor is defined as $T_2=\Sigma N\times\overline{R}_c$, where ΣN is the total number of streams of all orders and $\overline{R}_c$ is the mean stream-channel-slope ratio for a given watershed. The total number of streams is, again, a factor that reflects the vagaries of drainage nets, and the gradients of these streams are obviously related to transport efficiency. The regression of sediment yield with T_2 is shown in figure 14; the correlation coefficient is 0.886.

The third and last of the transport-efficiency factors is defined as $T_3=(N_1+N_2)(R_{c_{1/2}})+(N_2+N_3)(R_{c2/3})+\ldots+(N_{n-1}+N_n)(R_{c_{(n-1)/n}})$, where N is the number of streams of each order, designated by the appropriate subscript, and R_c is the ratio of the stream-channel slope of each stream order to the next higher order, as designated by a subscript. This expression for T_3 can be seen by inspection to be an adjustment of that for T_2. It weights the streams of lower order and their respective gradients more heavily to accord with the greater abundance of these streams and is therefore

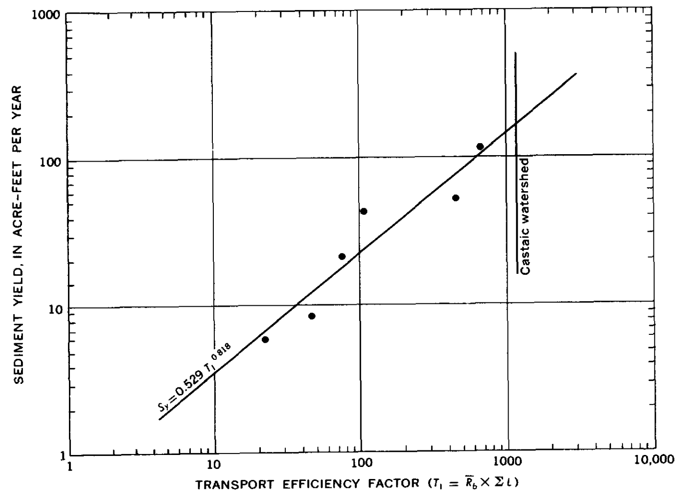

FIGURE 13.—Relation of sediment yield and the transport-efficiency factor T_1 for watersheds in the San Gabriel Mountains. The vertical line represents the value of T_1 in the Castaic watershed; its intercept (I_C) with the curve gives the sediment-yield estimate provided by this parameter. $r=0.944$, $I_C=168.50$.

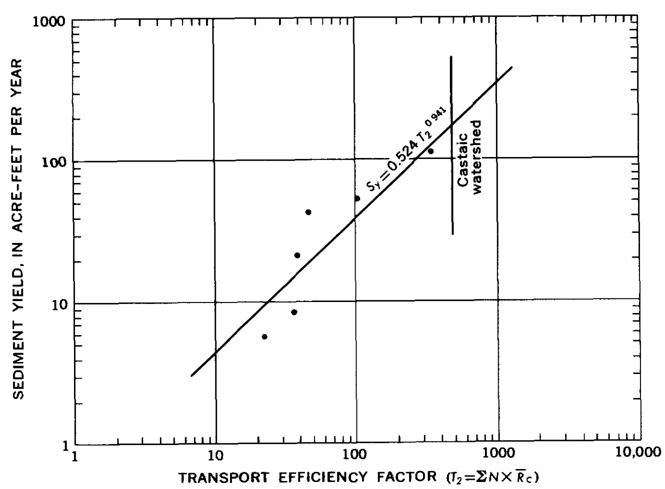

FIGURE 14.—Relation of sediment yield and the transport-efficiency factor T_2 for watersheds in the San Gabriel Mountains. The vertical line represents the value of T_2 in the Castaic watershed; its intercept (I_C) with the curve gives the sediment-yield estimate provided by this parameter. $r=0.886$, $I=175.15$.

more satisfactory from a mathematical viewpoint. If basin hydrology and sediment yield are considered, however, T_2 may be the superior geomorphic parameter of the two because of the importance of the principal channel of a drainage net and water discharge, as indicated by Langbein and others (1947), Potter (1953), and others cited in this report. One should not, however, conclude that the tributary streams of lower order are necessarily of little consequence; they are the connecting links between the available sediment and its ultimate transport by streamflow in the principal channel. Sediment yield at a basin mouth may depend upon the transport efficiency of the principal channel, but the sediment supply to this channel depends, in turn, upon the efficiency of the tributary streams of lower order. Accordingly, the parameter defined here, namely T_3, and to a lesser extent T_2 as well, is thought to reflect the transport efficiency within a watershed. The regression of sediment yield with T_3 is shown in figure 15; the correlation coefficient for this pair of variates is 0.842.

DISCUSSION OF RESULTS

As previously stated, sediment yield represents the cumulative interaction of a large number of climatic, geologic, edaphic, and other watershed characteristics. The results of this study indicate, however, that sediment yield is also a function of the geomorphic parameters given in the following equation:

$$S_y=f(S_A,S_M,T_e), \qquad (6)$$

where S_A is sediment area or an availability factor, S_M is a sediment-movement factor, and T_e is a transport-efficiency factor, here used in substitution for ΣL,

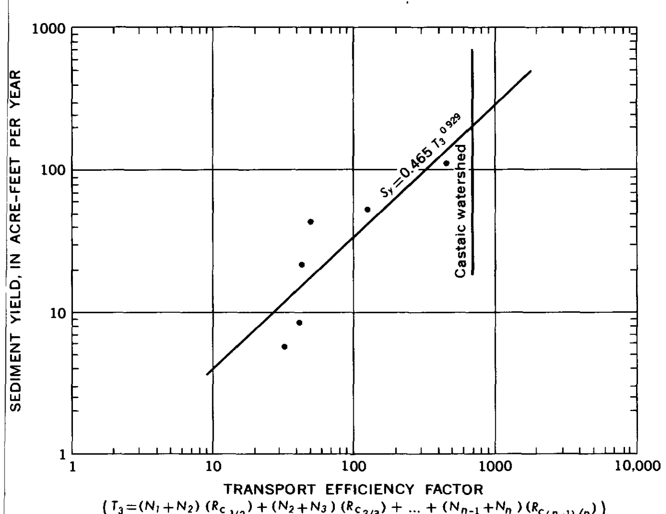

FIGURE 15.—Relation of sediment yield and the transport-efficiency factor T_3 for watersheds in the San Gabriel Mountains. The vertical line represents the value of T_3 in the Castaic watershed; its intercept (I_C) with the curve gives the sediment-yield estimate provided by this parameter. $r=0.842$, $I_C=202.75$.

T_1, T_2, and T_3. Establishing such a relationship is incidental to this report, however. More pertinent to the problem under consideration, that of estimating the sediment yield of the Castaic drainage basin, are the results of the relationship, namely the intercept values I_C that are shown on the regression plots of sediment yield with each of the geomorphic parameters (figs. 8, 10–15).

The vertical line shown on each of these regression plots represents the value of each of the respective geomorphic parameters computed from morphometric analysis of the Castaic drainage basin. The intercept values (I_C) given are obtained by the intersection of each regression line with these vertical lines. Each value of I_C was computed by substituting the value of a parameter in the Castaic drainage basin into the appropriate regression-line equation, obtained for the watersheds of the San Gabriel Mountains. The value of any I_C can, of course, also be obtained graphically but with less accuracy. The reliability of the series of sediment-yield values obtained by this procedure depends upon (1) the degree of significance of the correlation between sediment yield and each of the geomorphic parameters for the watersheds of the San Gabriel Mountains, and (2) the degree of similarity between the Castaic drainage basin and those in the San Gabriel Mountains. Discussion of these two points follows.

SIGNIFICANCE OF CORRELATIONS

Although several of the parameters involved can be considered as either populations or samples for each watershed, the watersheds will herein be treated as samples for statistical purposes. This treatment will allow demonstration that the six watersheds of the San Gabriel Mountains comprise a sample of sufficient size to be representative of a population of watersheds. The significance of the correlations obtained from this sample of six basins can be determined by application of Fisher's t test for small samples (Ezekial, 1941, p. 318). The statistic t is defined as

$$t=\frac{r\sqrt{n-2}}{\sqrt{1-r^2}}, \qquad (7)$$

where n is one less than the size of the sample, and r is the correlation coefficient to be tested for significance. To test the null hypothesis that the correlation coefficients discussed in this report are equal to zero, namely

$$H_o: r_{S_A}=r_{S_M}=r_{T_e}=r_{R_h}=0, \qquad (8)$$

at the 95-percent level of significance ($\alpha=0.05$), values of t were computed for each of the geomorphic parameters and t-distribution tables were consulted. The probabilities for S_A, S_M, ΣL, and T_1 are approximately 0.01, and those for T_2, T_3, and R_h are 0.03, 0.055, and 0.185, respectively. It can be concluded, therefore, that the correlations obtained are significant at the chosen level of confidence, except for relief ratio and perhaps T_3, which may or may not be significant, and that S_A, S_M, ΣL, and T_1 would be significantly correlated with sediment yield at the 99-percent confidence level, had $\alpha=0.01$ been chosen for the test.

The assumption of Fisher's t test, however, includes the requirement that the variates, or, in the strict sense, the errors, be normally distributed. Because uncertainty exists whether this condition is fulfilled by the data, Spearman's rank-correlation coefficient (Miller and Kahn, 1962, p. 335) was also computed and tested. The rank-correlation coefficient can be expressed as

$$r_r=1-\frac{6\Sigma(x_i-y_i)^2}{n(n^2-1)}, \qquad (9)$$

where x_i, y_i are the variates expressed as ranks, and n is the sample size or the number of pairs of variates. Because this statistic is nonparametric, it does not require the restrictive assumptions of the t test for application. A test of the null hypothesis of equation 8 for the rank-correlation coefficients of each geomorphic parameter and sediment yield leads to conclusions similar to those previously obtained. The coefficients for ΣL, S_A, S_M, and R_h are 0.943, 0.886, 0.886, and -0.029, respectively, and are 1.000 for T_1, T_2, and T_3. For a one-sided test such as this, a rank-correlation coefficient of 0.829 or more is significant at the 95-percent confidence level. The null hypothesis (eq. 8) can again be rejected; only relief ratio, among the geomorphic parameters investigated, fails to exhibit significant correlation with sediment yield.

SIMILARITY BETWEEN THE CASTAIC AND THE SAN GABRIEL MOUNTAINS WATERSHEDS

The second factor upon which the reliability of the results depends, namely the degree of similarity between the Castaic and the San Gabriel Mountains watersheds, cannot be quantitatively assessed in an equally convincing manner. The degree of similarity between two systems, such as watersheds, is complete only when accord can be demonstrated between both the geometric and dynamic properties of those systems (Murphy, 1949). Because the dynamic properties, such as the frequency of precipitation, are nearly unknown for the Castaic drainage basin, any demonstration of similarity can at best be only partial. In addition, the balance between geometric and dynamic properties is obviously a factor of importance in problems of sediment yield from a given watershed. A decrease in the frequency of precipitation can, when combined with an increase in the intensity of precipitation and a reduction of vegetative cover, result in sediment yields of greater magnitude than might otherwise occur, other factors being equal. Given disparate basin geometries—including relief, slopes, drainage density, and other factors—equivalent dynamic changes are unlikely to produce identical results. Because the dynamic properties of the Castaic drainage basin are unknown, the differences in balance that relate to the expected sediment yield cannot be evaluated in a comparison with the watersheds in the San Gabriel Mountains.

Simple tests of geometric similarity between watersheds (Strahler, 1958) can be applied to the Castaic and San Gabriel Mountains watersheds, however, in order to compare the geometric properties alone. The ratio between such linear-scale factors as the mean length of first-order streams or the mean area of second-order drainage basins in two watersheds, for example, can be computed and designated as $\lambda_{\bar{L}_1}$ and $\lambda_{\bar{A}_2}$, respectively. If geometric similarity between the two watersheds exists, then such λ's or linear-scale ratios should closely correspond. Such ratios were computed for each of the watersheds studied, and the Castaic watershed was compared with each of the San Gabriel Mountains drainage basins in turn. Although the individual values of λ did not exhibit close correspondence, mean values of the linear-scale ratios ranged from 0.96 for the comparison of Castaic with the Big Santa Anita drainage basin to 1.14 for that of Castaic with San Dimas drainage basin, except for the comparison of Castaic with Sawpit, which gave a mean value of 1.98. The computed value of σ_λ, however, ranged from 0.48 to 0.92, again except for the Castaic-Sawpit comparison ($\sigma_\lambda=2.34$). These large standard deviations, relative to values of λ in the neighborhood of 1.00, suggest that the geometric similarity is only poor to fair, even if the Sawpit drainage basin is omitted. In addition, a comparison of the values of such dimensionless numbers as R_b, R_c, R_L, R_a, and others (table 3) reveals considerable variance.

In the absence of demonstrated geometric similarity of the watersheds, the reliability of the results of this study must depend, to some extent, upon an assumption of balance between the dynamic and geometric properties of these watersheds. The estimated sediment yield of the Castaic watershed, discussed in the following subsection, is subject to this limitation, and the fact should not be glossed over.

ESTIMATED SEDIMENT YIELD OF THE CASTAIC WATERSHED

Despite the foregoing qualification, the data presented in this report can be used to estimate the long-term sediment yield of the Castaic watershed. The intercept values (I_C), obtained as previously described, range from 168 to 279 acre-feet per year (fig. 10–15), if one omits relief ratio, for which I_C is 33 acre-feet per year (fig. 8). The I_C values obtained from regressions of the parameters S_A and S_M with sediment yield suggest an average of 250 acre-feet per year, whereas the average I_C value for ΣL, T_1, T_2 and T_3 is 193 acre-feet per year. This difference could mean that the Castaic watershed contains a quantity of sediment that is available for transport in excess of the transport efficiency. H. V. Peterson (oral commun.) agrees with the writer that such a condition is probable. Aside from this implication, the data indicate the range of values within which the true long-term sediment yield of the watershed should occur. A value of about 250 acre-feet per year probably approximates this true value. Consideration of several reasons for this conclusion follows.

First, correlation of drainage area with sediment yield also provides a comparable value by use of the I_C method and, thus lends support to the estimate of 250 acre-feet previously given. This should not be construed, however, as precluding the need for a search for significant parameters as outlined in this report. Any estimate based on consideration of but a single parameter would be highly suspect, regardless of the known relation of that parameter and sediment yield.

Because several of the parameters used in this report are themselves correlative with drainage area, as expressed by equation 2, and are therefore not independent, additional support for the estimate of sediment yield is necessary. Langbein and Schumm (1958) have shown that the sediment yield of watersheds in various climatic regions reaches a peak when effective precipitation ranges from about 10 to 14 inches per year. Sediment yield decreases rapidly to either side of this peak; lesser amounts of precipitation produce much less runoff, whereas greater annual precipitation results in an increase in vegetation which tends to decrease erosion.

As noted previously, precipitation data in the Castaic watershed are few; although long-term records are available from neighboring locations, extrapolation of these records is somewhat hazardous. Moreover, effective precipitation is the precipitation required to produce a given amount of runoff in a basin and this value is uncertain for the Castaic watershed. The available evidence suggests, however, that the probable effective precipitation in the Castaic watershed and in those watersheds studied in the San Gabriel Mountains is approximately 18 and 25 inches per year, respectively.

The data of Langbein and Schumm (1958) showed that the sediment yield of the Castaic watershed will be approximately 23 percent greater than the yields of the watersheds in the San Gabriel Mountains if the cited contrast in effective precipitation is correct. The sediment yields of the San Gabriel Mountains watersheds that were studied for this report range from 1.27 acre-feet per square mile for the Big Dalton drainage basin to 4.00 acre-feet per square mile for the Big Santa Anita drainage basin (table 2). The average sediment yield of the six watersheds is 2.60 acre-feet per square mile. Rowe (1962) stated that measurements in "typical" watersheds in the San Gabriel Mountains indicate a long-term erosion rate of 1.67 acre-feet per square mile. If the Big Santa Anita watershed, which has the highest yield of those studied, is omitted, then the average sediment yield of the remaining watersheds is precisely that given by Rowe. If this average value is increased by 23 percent, as suggested by the precipitation-sediment yield relationship just discussed, then the yield of the Castaic watershed becomes 2.05 acre-feet per square mile, or about 280 acre-feet per year.

Sediment-yield data of the Piru watershed (California Water Resources Board, 1953) are also pertinent to the results of this report. This basin more closely resembles the Castaic watershed in terms of both lithology and climate than do those watersheds in the San Gabriel Mountains discussed thus far. Piru watershed was not included in the morphometric study because the period of record is far shorter than that for watersheds in the San Gabriel Mountains, hence the sediment-yield data are not comparable. The similarity between the Piru and the Castaic watersheds, in addition to the fact that the Piru watershed is larger (422 sq mi) than any of the basins previously discussed, is deemed sufficient reason for inclusion of the data in this discussion, however. The sediment yield of the Piru watershed was originally estimated to be 675.2 acre-feet per year, or 1.6 acre-feet per square mile; this estimate was later revised downward to 480 acre-feet per year, or approximately 1.1 acre-feet per square mile (California Water Resources Board, 1953).

Because the results of many studies indicate that sediment yield per square mile decreases as drainage area increases, Langbein and Schumm (1958) proposed a power adjustment of 0.15. If this adjustment is applied to correct for the smaller drainage area of the Castaic watershed, the results show that the sediment yield per square mile of the Castaic watershed should be about 20 percent greater than that of the Piru watershed. On this basis, the sediment yield of the Castaic watershed would be either 1.92 or 1.32 acre-feet per square mile, depending upon the sediment-yield value that is used for the Piru watershed.

RANGE OF THE SEDIMENT-YIELD VALUES FOR THE CASTAIC WATERSHED

Because the anticipated annual sediment yield of a watershed is of great use in treating problems of reservoir design, an estimate of the minimum and maximum yield, or range of values, is also required. The data discussed in the foregoing section of this report suggest that the range of sediment-yield values that should be used is 200 to 300 acre-feet per year.

These sediment-yield values are, of course, long-term averages. The actual minimum value for any watershed is zero, or approximately so, in certain years. The maximum sediment yield for a given year is much more difficult to determine. Guyman and others (1963) synthesized flood hydrographs of various recurrence intervals for the Castaic watershed. He suggested that a 1000-year flood will produce a peak discharge of approximately 120,000 cubic feet per second at the damsite, given an effective storm precipitation of about 19 inches. Obviously, there is no sound method for determining the sediment yield of the watershed for such a storm in the absence of knowledge of the water-discharge-sediment-discharge relations. Some insight into the possible sediment yield during major storms can be obtained, however. The storm of 1938 was one of the most severe on record in southern California; it produced a 50- or 100-year flood in many watersheds. The average sediment yield of watersheds in the San Gabriel Mountains in acre-feet per year per square mile is listed in table 2, and the sediment yield of these watersheds that resulted from the 1938 storm is listed in an adjacent column. These data show that the greatest increase in sediment yield per square mile occurred, in general, in watersheds that exhibit the lowest average sediment-yield values. For example, the Big Dalton watershed (table 2) produced 14.72 times its average sediment yield per square mile, whereas the Big Santa Anita watershed produced only 7.55 times its annual yield per square mile during the 1938 storm.

If this general relationship is applied to the Castaic watershed, a storm akin to that of 1938 would produce about 11 times the average sediment yield of 1.82 acre-feet per square mile that is suggested in this report.

CONCLUSIONS

The simple-correlation methods used in this report indicate that the long-term sediment yield of the Castaic watershed is about 250 acre-feet per year. Comparison with the watersheds in the San Gabriel Mountains on the basis of the effective-precipitation contrast suggests that the sediment yield may be greater (280 acre-feet per year). Comparison with the Piru watershed on the basis of an inverse relationship between drainage area and sediment yield, however, suggests a lesser value of about 220 acre-feet per year. This range of values is thought to lend added credence to the estimate of 250 acre-feet per year that is offered in this report.

For purposes of reservoir design, the range of sediment-yield values should be expanded slightly; 200 to 300 acre-feet per year is a range that should compensate for the uncertainties and approximations that have been indicated in this report. Although the sediment yield produced by storms of given recurrence intervals cannot be computed, a storm equivalent to that of 1938 in southern California would probably produce approximately 20 acre-feet of sediment per square mile from the Castaic watershed.

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