# SEDIMENTATION in the MIDDLE FORK EEL RIVER BASIN CALIFORNIA

OPEN—FILE REPORT



U.S. DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY
Water Resources Division
Menlo Park, California, 1971
PREPARED IN COOPERATION WITH THE CALIFORNIA DEPARTMENT OF WATER RESOURCES

UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY
Water Resources Division

---

# SEDIMENTATION IN THE MIDDLE FORK EEL RIVER BASIN

# CALIFORNIA

By

J. M. Knott, 1937-

---

Prepared in cooperation with the
California Department of Water Resources



OPEN-FILE REPORT



Menlo Park, California
June 11, 1971

CONTENTS

## ILLUSTRATIONS

## TABLES

# SEDIMENTATION IN THE MIDDLE FORK EEL RIVER BASIN, CALIFORNIA

---

By J. M. Knott

---

## ABSTRACT

The Middle Fork Eel River basin has a drainage area of 753 square miles and is in a mountainous area on the western flank of the coast ranges in northern California. Elevations in the basin range from about 860 feet above mean sea level at the confluence with the Eel River to more than 7,500 feet at several peaks along the eastern divide.

The basin is underlain by the Franciscan Formation which here includes complexly faulted sandstones, shales, conglomerates, and metasedimentary rocks of Jurassic or Late Cretaceous age. Active landslides and slumps are extensive and most surface features are directly related to faulting. Major movement of slide debris occurs during winter months when heavy rains saturate the thick mountain soils and lubricate the underlying parent material.

During the study period an historic storm and flood event occurred (December 1964) which significantly altered the hydraulic and sediment-transport characteristics of several of the larger streams in the basin. Data compiled for sediment stations on the Black Butte and Middle Fork Eel Rivers indicated that suspended-sediment discharges for equal magnitudes of streamflow, were several times larger after the event than before. Suspended-sediment discharges have progressively decreased since the event but, through 1968, were still larger than preflood levels. Bedload discharges were also increased after the flood. Massive deposits of coarse material, added to upper basin stream channels after the flood, are apparently responsible for an increased capacity of such streams to transport sediment.

Long-term total-sediment discharge for sampling sites in the basin ranged from 625 tons per square mile per year for Short Creek to 3,760 tons per square mile per year for Elk Creek. Long-term sediment yield for Middle Fork Eel River near Dos Rios (proposed Dos Rios damsite) will be about 2,140,000 tons or 1,570 acre-feet per year.

If a high dam were built on the Middle Fork Eel River near Dos Rios, most of the sediment deposited in the large Dos Rios Reservoir during the first 100 years of operation would be distributed in the upper elevations of the reservoir above the 1,350-foot level. Sediment deposits would occupy less than 10 percent of the original reservoir capacity above the 1,200-foot level and would reduce the capacity of the entire reservoir approximately 2 percent. Sediment would accumulate to a depth of about 15 feet behind the dam and sedimentation characteristics of the reservoir at the end of this period would be relatively unchanged from those of the original reservoir.

If a low dam were built at the same site, sediment deposited in the reservoir would be distributed uniformly between the 1,100 and 1,290-foot levels. Sediment deposits near the dam would approach a thickness of about 180 feet after 100 years of operation and would occupy 100 percent of the original reservoir capacity below the 1,092-foot level. Original capacity of the reservoir would be reduced about 29 percent. Original sedimentation characteristics of the reservoir would be significantly altered at the end of this period.

## INTRODUCTION

The Middle Fork Eel River basin is one of several areas in northern California that are under consideration as sources of water to augment water supplies in the Sacramento-San Joaquin Delta. Most of the proposals for development of the basin include the construction of a dam and reservoir on the Middle Fork Eel River near Dos Rios. Original capacities of alternative reservoirs proposed for this site range from 536,000 acre-feet (small Dos Rios) to 7,600,000 acre-feet (large Dos Rios).

This report includes an estimate of long-term sediment yields from several of the larger tributaries in the Middle Fork Eel River basin and probable distribution characteristics of sediment within the largest and smallest of the proposed reservoirs. Sedimentation data used in the study were obtained during 1956-68. The bulk of these data consisted of records of daily suspended-sediment discharge and analyses of periodic sediment samples from hydrologic stations established on several of the larger tributaries. Special measurements were made during the 1968 storm season to determine parameters required for the indirect computation of bedload discharge using the Meyer-Peter and Muller equation.

Estimates of total sediment yield were made by extending short-term sediment- and water-discharge data on the basis of long-term flow records. A 55-year period (1911-14, 1917-67) was used to define long-term conditions. This period includes several cycles of wet and dry years and coincides with the longest record of streamflow in the Eel River basin--that of Eel River at Scotia.

Sediment distribution within several of the alternative reservoirs was predicted by considering reservoir shape and sediment inflow using methods described by Borland and Miller (1958). Sedimentation characteristics were evaluated for the "large" and "small" Dos Rios Reservoir alternatives assuming a 100-year period of deposition.

This report was prepared by the U.S. Geological Survey, in cooperation with the California Department of Water Resources. The work was done under the general supervision of R. Stanley Lord, chief of the California District, Water Resources Division, and under the direct supervision of L. E. Young, chief of the Menlo Park subdistrict office. The author appreciates the beneficial suggestions and ideas for data interpretation and report preparation provided by George Porterfield J. P. Akers, D. M. Culbertson, J. R. Ritter, P. R. Wood, W. M. Brown, J. Polos, and J. C. Wallace.

The author also wishes to express gratitude to Walter Delamore and Joseph Thompson, residents of the Dos Rios-Covelo area, who collected many sediment samples from the Black Butte and Middle Fork Eel Rivers for virtually the entire period of record.

The report received valuable review and criticism from Thomas Maddock, Jr., R. F. Clawson, and E. F. Serr.

Investigations of sedimentation in the basin were initiated in 1956 when a suspended-sediment station was established on the Middle Fork Eel River near Dos Rios. The data collected at this and other sites have been published annually in the U.S. Geological Survey water-supply paper series titled "Quality of Surface Waters of the United States, Parts 9-14" and in the open-file report series, "Water-Resources Data for California." Hawley and Jones (1969), in a study of coastal basins in northern California, summarized some of the suspended-sediment characteristics of the basin prior to the 1965 water year. A more comprehensive report on the Eel River basin (Brown and Ritter, 1971) described turbidity-concentration relations, basin characteristics, and significant changes in suspended-sediment yield that occurred after the December 1964 flood. Sedimentation studies by the U.S. Department of Agriculture (1970) contain information pertaining to sediment yield, recommendations for reducing erosion, and watershed management.

## DESCRIPTION OF AREA

### General Features and Land Use

The Middle Fork Eel River basin (fig. 1) lies within Mendocino and Trinity Counties on the western flank of the coast ranges of northern California. The basin, with a drainage area of 753 square miles, is a contrast of steep, rugged mountains rising above infrequent valley flats (fig. 2). Elevations range from about 860 feet above mean sea level at the mouth to more than 7,500 feet at several peaks along the eastern divide. The location of valleys and drainage channels are controlled largely by past tectonic activity. Tributaries to the Middle Fork Eel River combine to form a trellis network. Stream gradients range from 18 feet per mile near the mouth to more than 1,800 feet per mile in the headwaters. Longitudinal profiles of selected streams where hydrologic data are available are shown in figure 3.

Because of the remoteness of the area, rugged landscape, and lack of developed mineral resources, industrial development has been slow. Population density is very low with less than three persons per square mile. Principal occupations include ranching and lumbering. The many forests and streams are extremely popular with recreationists, who enjoy the good hunting, fishing, and scenic beauty of the upland area.

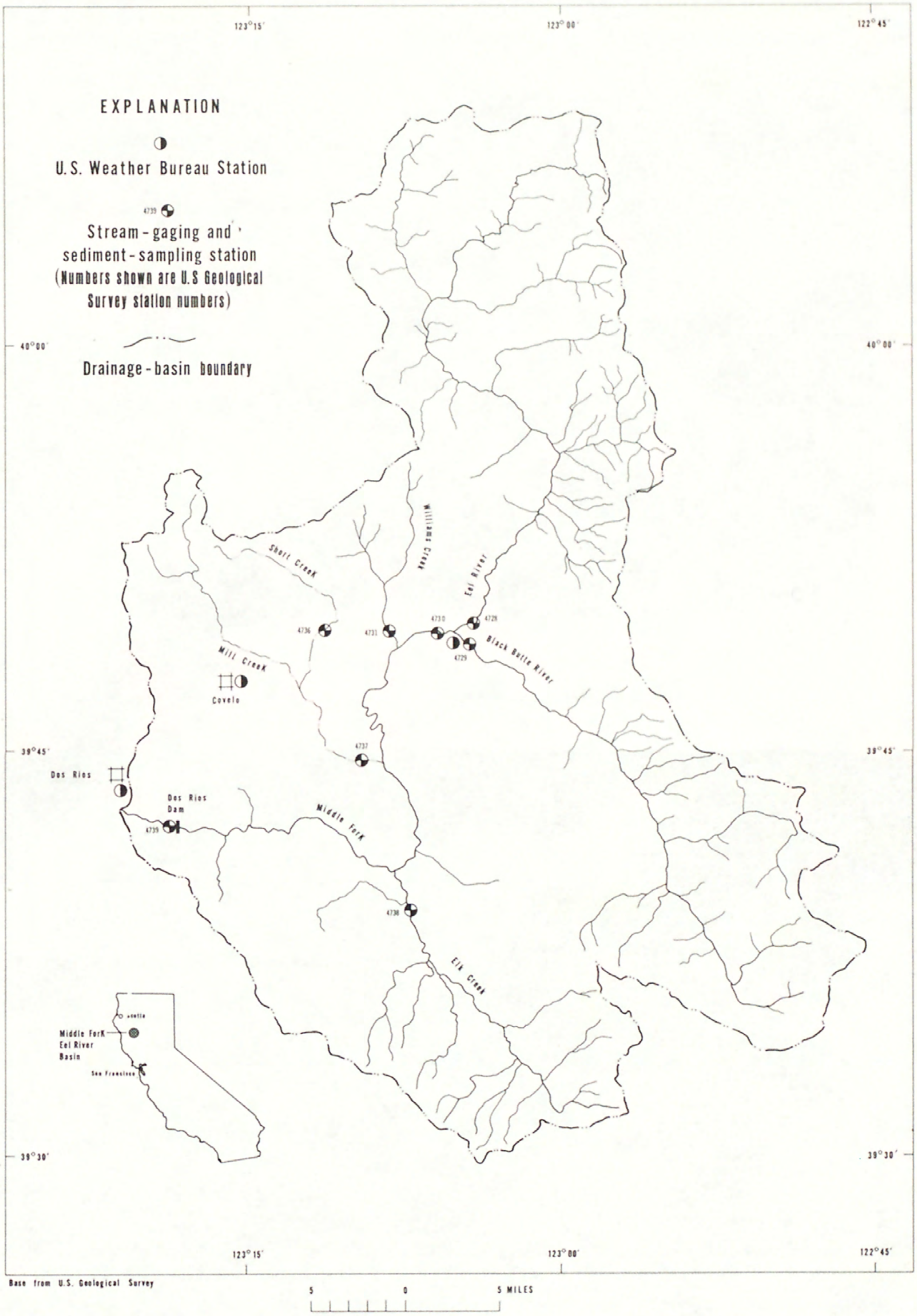


FIGURE 1.--Location of stream-gaging and sediment-sampling stations.

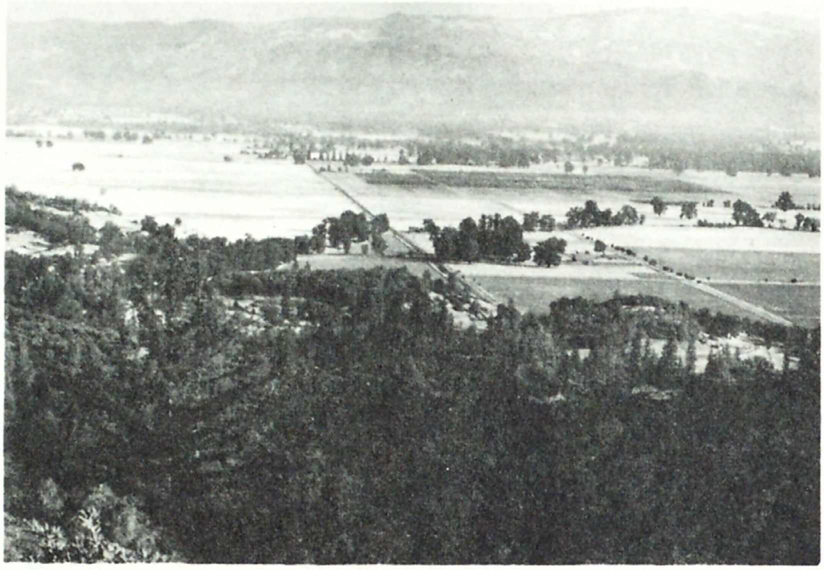

FIGURE 2.--Round Valley, a fault-formed valley in the western part of the Middle Fork Eel River basin.

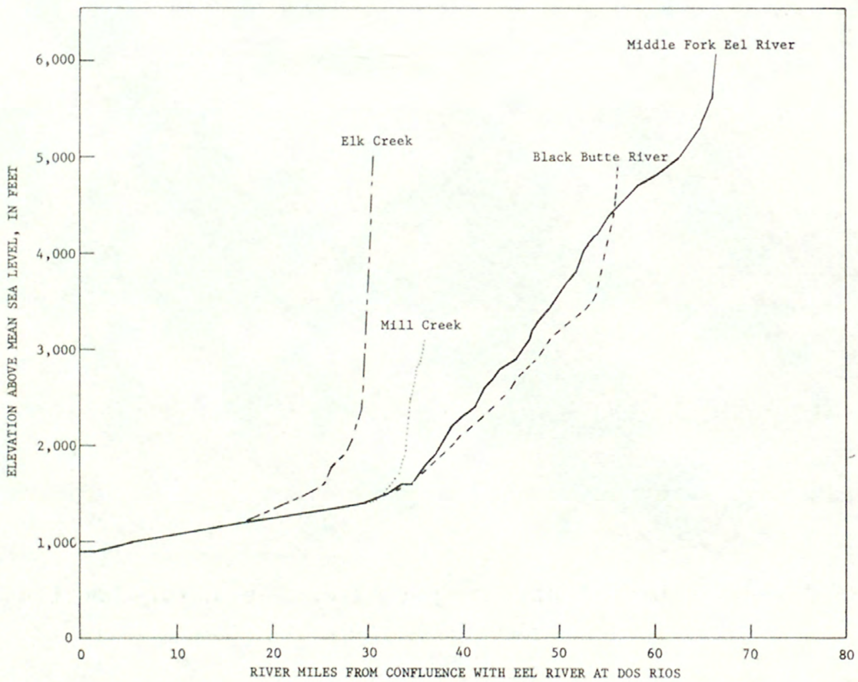


FIGURE 3.--Longitudinal profiles of selected streams in the Middle Fork Eel River basin.

## Vegetation and Soils

Distribution of vegetal cover throughout the basin is typical of upland areas in the coast ranges of northern California. Forested areas of marketable timber abound at higher elevations and are predominately mixed conifer-types such as fir and pine. Vegetation in the intermediate and lower elevations consists of woodland (oak and other hardwood species) and grasses. Chaparral commonly grows in drier areas.

Most of the soils are formed upon well-fractured parent rock and attain moderate-depth profiles ranging from 20 to 60 inches (C. E. Stearns, written commun., 1968). The soils have good infiltration and retention properties and are stable where land slopes are less than 30 percent. However, on steeper slopes the soils and underlying strata are highly susceptable to erosion during major storms. Figure 4, which shows the distribution of soil types based on land slope and erodibility, was compiled from soil-characteristic maps supplied by the U.S. Department of Agriculture (C. E. Stearns, written commun., 1968).

## Geology

The Franciscan Formation, a widespread unit in northern California, underlies most of the Middle Fork Eel River basin. Principal constituents of this unit are complexly faulted sandstones, shales, conglomerates, and metasedimentary rocks. Franciscan rocks are of Late Jurassic to Late Cretaceous age (Bailey and others, 1964, p. 142).

Landslides or slumps are common in areas where rock units are severely fractured and where land slopes exceed 30 percent. Major movement of slide debris occurs during winter months when heavy rains saturate the thick mountain soils and lubricate the underlying parent material. Streams contribute to ground instability by effectively removing debris from the lower end of slides (fig. 5).

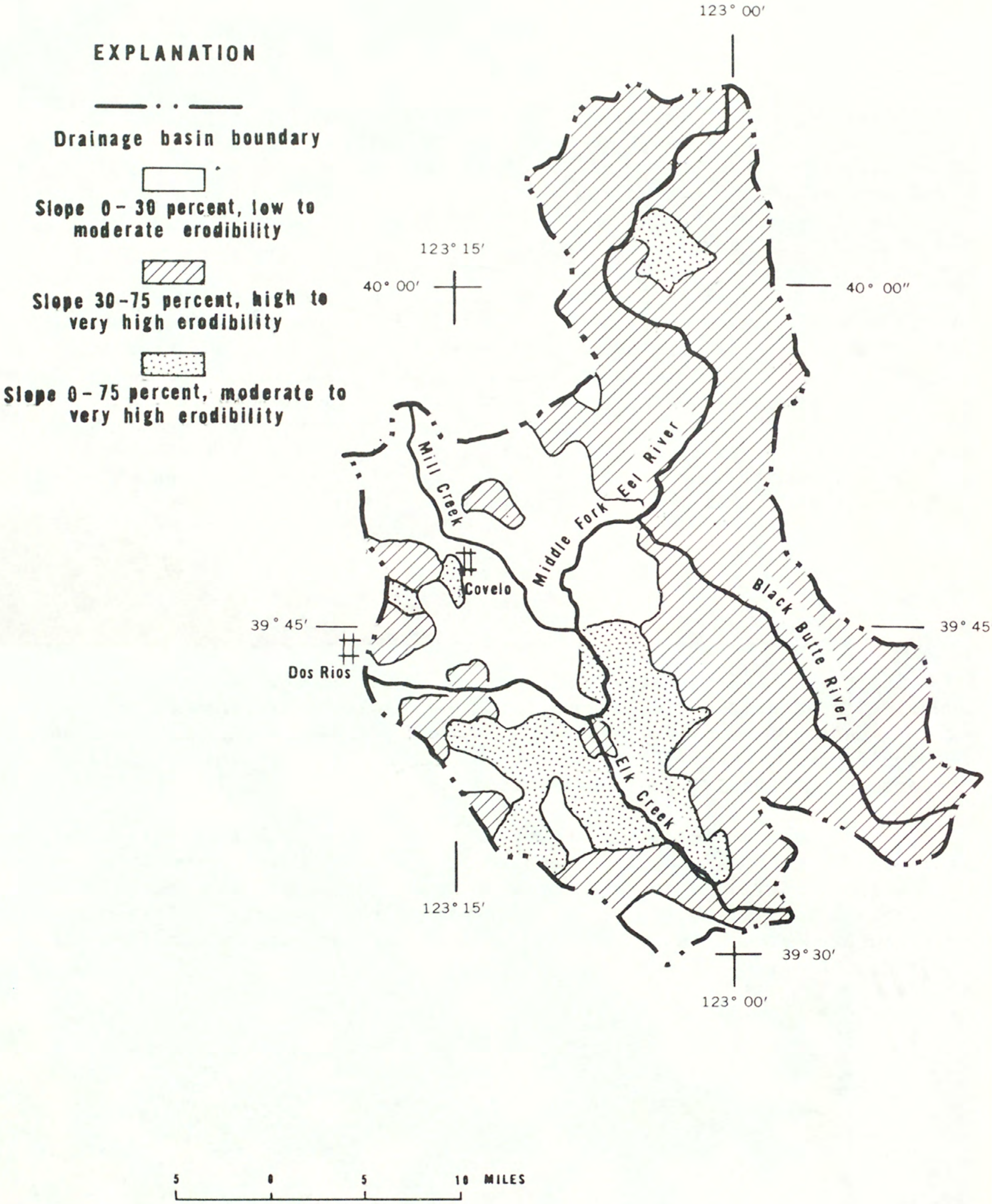


FIGURE 4.--Distribution of soils in relation to erodibility and land slope.

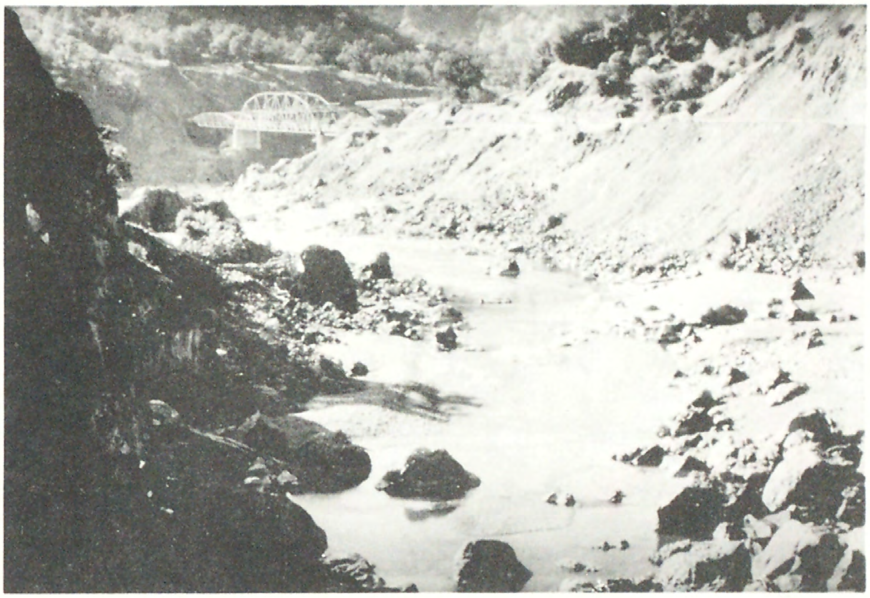

FIGURE 5.--Slump areas adjacent to the Middle Fork Eel River. Active slumping generally extends into stream channels where debris is effectively removed by the streams.

### Climate

The Middle Fork Eel River basin has a Mediterranean-type climate. Summers are characterized by long periods of hot, dry weather with infrequent precipitation and winters are cool and humid. About 80 percent of the annual precipitation, most of which is rainfall, occurs between November and March (fig. 6). Snowfalls occur during winter months but seldom accumulate to significant depths except at higher altitudes near the eastern divide.

Three climatological stations are maintained in the basin by the U.S. Weather Bureau (table 1 and fig. 1). All of these stations are located at lower elevations and probably represent less-than-average basin precipitation. Rantz (1964, p. 6) estimated that the long-term basinwide precipitation averaged 54 inches per year. Mean monthly temperatures at the Covelo station range from about 4°Celsius in January to 23°Celsius in July. Daily extremes are more variable, with temperatures as low as -14°Celsius and as high as 46°Celsius.

## STREANFLOW

Throughout the Middle Fork Eel River basin streamflow is unregulated and, except for snowmelt, is primarily influenced by rainstorms. Stream levels fluctuate extensively during winter months when storm events are frequent and decrease steadily through the summer and early fall. More than 50 percent of the total precipitation is discharged as runoff (Rantz, 1964, p. 6).

Gaging stations are maintained on all the principal tributaries, and streamflow records have been compiled for various periods (table 2). Annual streamflow is extremely variable. Runoff during wet years may be four to five times greater than runóff during dry years. The sequential distribution of wet and dry years is also quite variable, with periods of each type often lasting for several years.

Table 1.--Summary of climatological data for the Middle Fork Eel River basin
[Records from annual summaries of the U.S. Weather Bureau]

| U.S. Weather Bureau station location | Period of record (yr) | Elevation above mean sea level (ft) | Average annual precipitation (in.) | Range in annual precipitation (in.) | Range in monthly precipitation[1] (in.) | Average annual temperature (°Celsius) | Minimum and maximum temperature recorded[1] (°Celsius) |
|---|---|---|---|---|---|---|---|
| Dos Rios | 1931-66 | 927 | 47.15 | 21.47-69.97 | 0.00-31.37 | - | - |
| Covelo | 1935-68 | 1385 | 41.16 | 25.38-63.17 | .00-22.50 | 13.1 | -14, 46 |
| Covelo, Eel River Ranger Station | 1951-68 | 1514 | 41.15 | 22.67-[2]54.7 | .00-[2]28.3 | - | - |

[1]Temperatures converted from °Fahrenheit to °Celsius.
[2]Estimated from Covelo and Dos Rios weather stations.

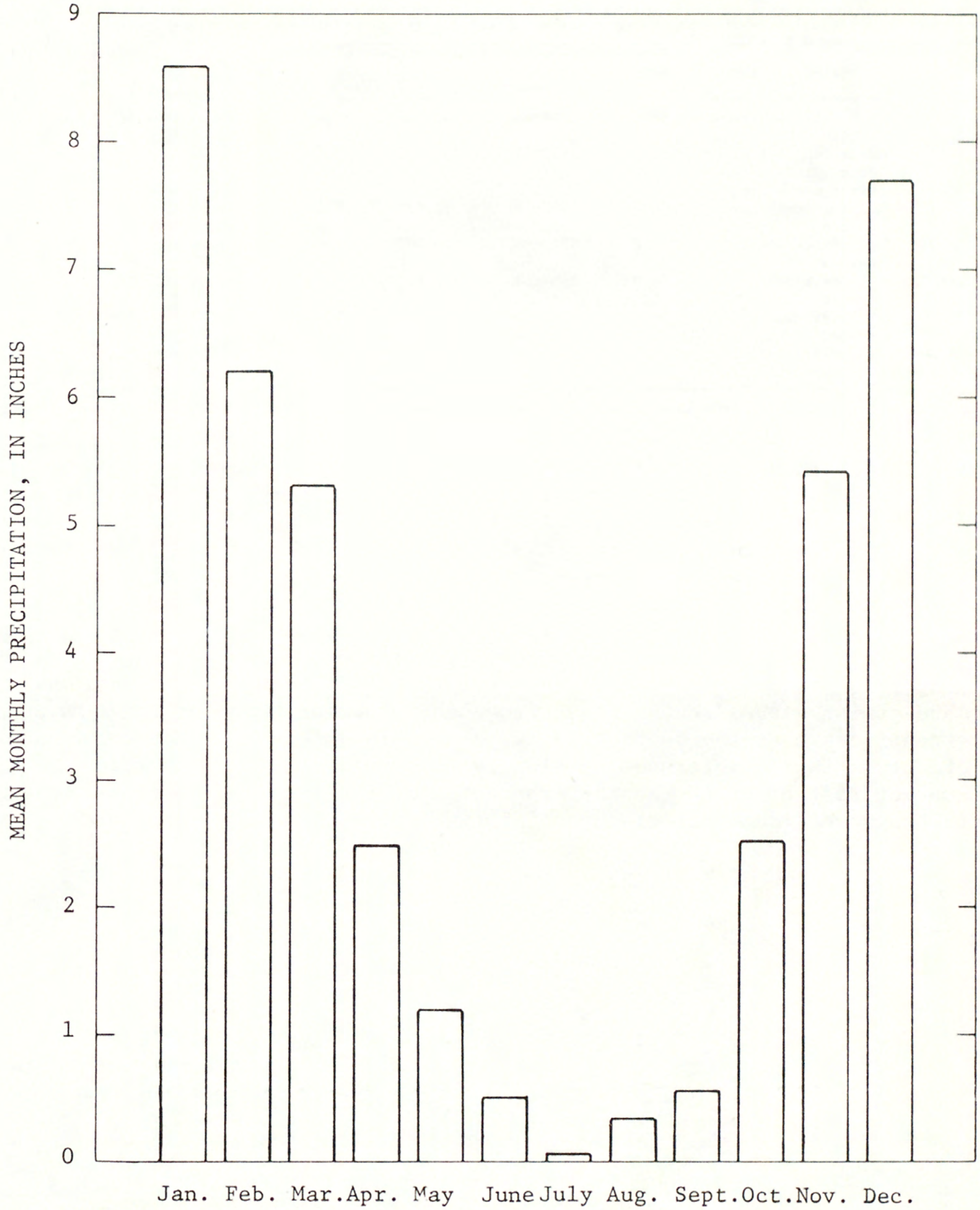


FIGURE 6.--Mean monthly precipitation at the Covelo weather station (1935-68).

Table 2.--Water discharge of selected streams in the Middle Fork Eel River basin

| Station number | Gaging station | Drainage area (sq mi) | Period of record (water years) | Average annual water discharge (acre-ft) | Average annual water discharge (acre-ft/sq mi) | Range of annual water discharge (acre-ft) | Range of annual water discharge (acre-ft/sq mi) |
|---|---|---|---|---|---|---|---|
| 4729 | Black Butte River near Covelo | 162 | 1959-68 | 203,400 | 1,260 | 89,950-452,000 | 555-2,790 |
| 4730 | Middle Fork Eel River below Black Butte River near Covelo | 367 | 1952-67 | 758,700 | 2,070 | 334,900-1,411,000 | 913-3,840 |
| 4731 | Williams Creek near Covelo | 30.4 | 1962-68 | 59,290 | 1,950 | 34,720-89,090 | 1,140-2,930 |
| 4736 | Short Creek near Covelo | 15.2 | 1959-68 | 16,360 | 1,080 | 8,860-28,300 | 583-1,860 |
| 4737 | Mill Creek near Covelo | 96.9 | 1957-68 | 108,600 | 1,120 | 53,970-237,700 | 557-2,450 |
| 4738 | Elk Creek near Hearst | 84.1 | 1965-68 | 126,800 | 1,510 | 85,390-220,700 | 1,020-2,620 |
| 4739 | Middle Fork Eel River near Dos Rios | 745 | 1958-68 | 1,324,000 | 1,780 | [1]647,200-2,767,000 | [1]869-3,710 |

[1] Computed from difference of Eel River below Dos Rios and Eel River above Dos Rios streamflow record.

The periods for which flow records are available are not representative of long-term conditions. Annual streamflow data compiled for the Eel River at Scotia, a long-term records station located downstream from the study area, indicate that the period 1952-68 constituted a prolonged wet cycle. Short-term flow data for streams in the Middle Fork Eel River basin were extended on the basis of long-term data for Eel River at Scotia using the base period 1911-14, 1917-67. The longer record includes two wet cycles and two dry cycles. Duration curves of daily mean flow for short- and long-term periods are shown in figures 7 through 10. In each instance the base-period curves show a lower frequency of occurrence for large magnitude streamflows than the short-term curves. This factor, and the convergence of curves in the intermediate flow ranges, suggest that streamflow characteristics of the short-term record differ from the base period only in the more frequent incidence of large flows

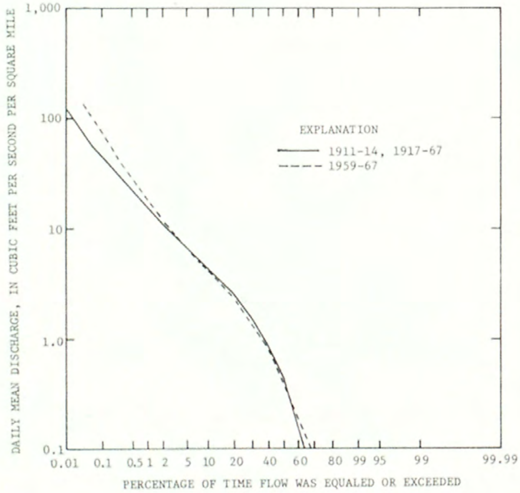


FIGURE 7.--Flow-duration curve for Black Butte River near Covelo.

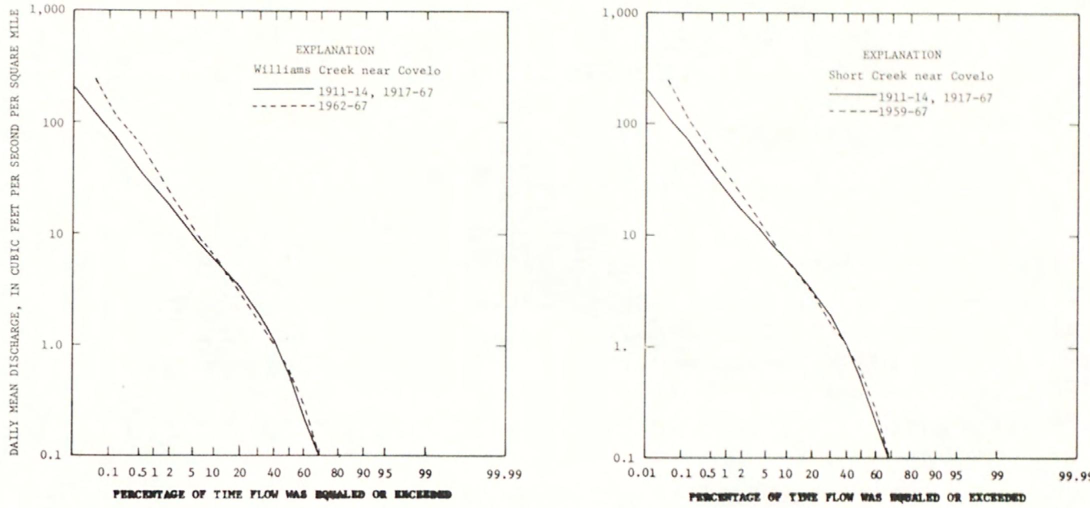


FIGURE 8.--Flow-duration curves for Williams Creek and Short Creek near Covelo.

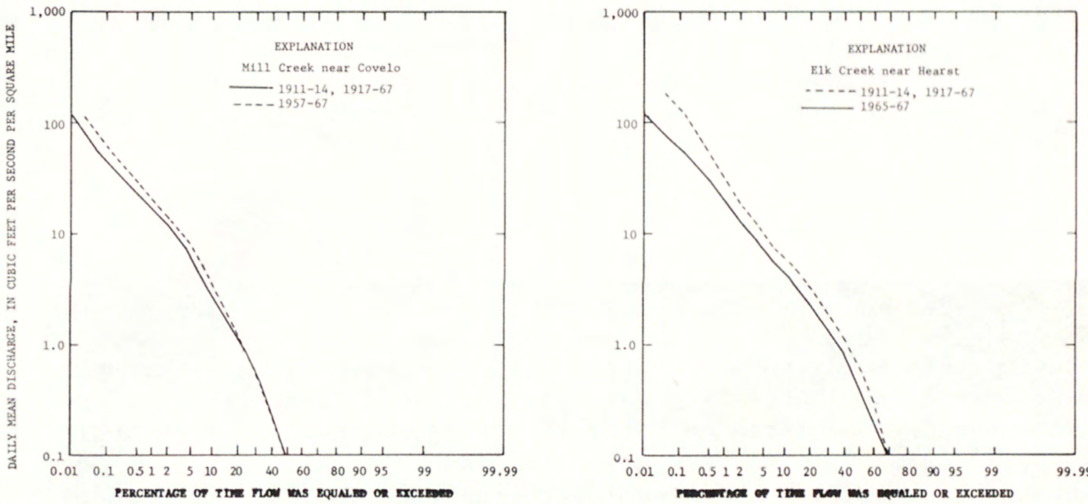


FIGURE 9.--Flow-duration curves for Mill Creek near Covelo and Elk Creek near Hearst.

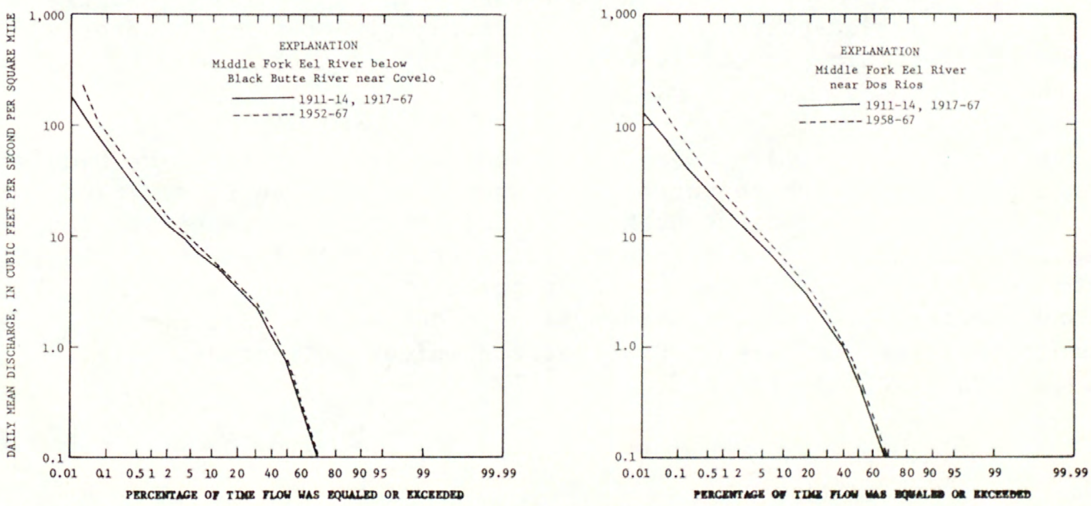


FIGURE 10.--Flow-duration curves for Middle Fork Eel River below Black Butte River near Covelo and Middle Fork Eel River near Dos Rios.

# SEDIMENT DISCHARGE

## Sediment Transport

Most of the sediment transported by streams in the basin is derived from thick mountain soils and highly fractured rocks. Because of their generally fine texture and fractured condition the rocks are easily eroded and, when saturated with water during storms, the eroded material moves readily downslope and thus contributes large quantities of debris to streams through sheet erosion and landslides.

Once the eroded material enters a stream system its rate of transport depends on particle size and streamflow characteristics. The sediment discharge includes the fine material that is moved in suspension in flowing water (suspended load) and the coarse sediment that moves along or near the streambed (bedload). Clay and silt particles usually are carried in suspension and gravel particles move along or near the streambed. Sand particles may be transported either as suspended load or as bedload, or both.

## Suspended-Sediment Discharge

During this study, sediment transported in suspension was sampled with standard depth-integrating samplers described in Report 14 of the U.S. Inter-Agency Committee on Water Resources, Subcommittee on Sedimentation (1963, p. 36-60). Samples were collected at one to six verticals in the stream cross section to determine the average concentration and particle-size distribution of the water-sediment mixture at the time of measurement. Samples of suspended sediment include particles (usually finer than 2 mm) transported in the depth interval between the water surface and, depending on the type of sampler used, a point 0.3 or 0.5 foot above the streambed.

Suspended-sediment data were collected at eight sites in the Middle Fork Eel River basin subsequent to 1956 when samples were first taken near Dos Rios. These data include both daily and periodic sediment-station records. Daily stations require a sampling program sufficient to construct a chronological record of sediment transport, whereas periodic stations require only sufficient sampling to define a relation between sediment and water discharge. Stations for which sediment data are available are listed in table 3.

Table 3.--Sediment stations in the Middle Fork Eel River basin

| Station no. | Sediment station | Drainage area (sq mi) | Period of record (water year) | Type of record |
|---|---|---|---|---|
| 4728 | Middle Fork Eel River above Black Butte River near Covelo | 204 | 1968 | Daily |
| 4729 | Black Butte River near Covelo | 162 | 1966-68 | Daily[1] |
| 4730 | Middle Fork Eel River below Black Butte River near Covelo | 367 | 1963-67 | Daily |
| 4731 | Williams Creek near Covelo | 30.4 | 1961-64, 1967-68 | Periodic |
| 4736 | Short Creek near Covelo | 15.2 | 1961-64 | Periodic |
| 4737 | Mill Creek near Covelo | 96.9 | 1967-68 | Periodic |
| 4738 | Elk Creek near Hearst | 84.1 | 1966-68 | Periodic |
| 4739 | Middle Fork Eel River near Dos Rios | 745 | 1956-57<br>1958-68 | Periodic<br>Daily |

[1] Periodic record during May to November 1966.

Stations located on the Middle Fork Eel River near Dos Rios (proposed Dos Rios damsite) and near the Eel River Ranger Station downstream from the mouth of Black Butte River provided the most comprehensive data. Continuous records of sediment discharge at these stations were particularly valuable, because they provided a means for documenting sedimentation rates that occurred before, during, and after the disastrous flood of December 1964. Most of the data for other stations were collected either before or after the flood and at less frequent intervals.

Annual suspended-sediment and water discharge for the daily-record stations are summarized in table 4. It is evident that the variation in annual sediment yield at individual stations is large, especially between the 1964 and 1965 water years; the discharge increased almost one hundredfold at the Middle Fork Eel River site near Covelo. Comparison between stations for concurrent years, however, shows a much lower variation in regional sediment discharge and suggests that erosional processes may be somewhat uniform throughout the basin.

Table 4.--Annual suspended-sediment and water discharge for daily-record stations in the Middle Fork Eel River basin

| Station no. | Sediment station | Water year Oct. 1-Sept. 30 | Water discharge (acre-ft) | Suspended-sediment discharge | |
|---|---|---|---|---|---|
| | | | | Tons | Tons per sq mi |
| 4728 | Middle Fork Eel River above Black Butte River near Covelo | 1968 | 410,300 | 884,000 | 4,330 |
| 4729 | Black Butte River near Covelo | a1966 | 167,100 | 474,300 | 2,930 |
| | | b1967 | 280,900 | 930,800 | 5,750 |
| | | 1968 | 185,100 | 319,900 | 1,970 |
| 4730 | Middle Fork Eel River below Black Butte River near Covelo | 1963 | 829,000 | 1,618,000 | 4,410 |
| | | 1964 | 334,900 | 105,300 | 287 |
| | | 1965 | 1,339,000 | 10,100,000 | 27,500 |
| | | 1966 | 559,000 | 1,116,000 | 3,040 |
| | | 1967 | 798,700 | 1,974,000 | 5,380 |
| | | c1968 | 595,400 | 1,204,000 | 3,280 |
| 4739 | Middle Fork Eel River near Dos Rios | 1958 | 2,498,000 | 4,157,000 | 5,580 |
| | | 1959 | 746,900 | 841,900 | 1,130 |
| | | 1960 | 886,000 | 2,649,000 | 3,550 |
| | | 1961 | 1,110,000 | 848,000 | 1,140 |
| | | 1962 | 857,600 | 579,000 | 777 |
| | | 1963 | 1,614,000 | 4,710,000 | 6,320 |
| | | 1964 | 647,300 | 759,400 | 1,020 |
| | | 1965 | 2,768,000 | 18,710,000 | 25,100 |
| | | 1966 | 1,066,000 | 4,330,000 | 5,810 |
| | | 1967 | 1,434,000 | 4,880,000 | 6,550 |
| | | 1968 | 934,700 | 2,568,000 | 3,450 |

a. For period Nov. 17, 1965 to Apr. 30, 1966.
b. For period Dec. 1, 1966 to Sept. 30, 1967.
c. Sum of data at Middle Fork Eel River above Black Butte River and Black Butte River near Covelo.

## Relation Between Suspended-Sediment Discharge and Water Discharge

A common method for studying sediment-transport characteristics at individual sites is to construct a graph of sediment discharge versus water discharge. This relation is generally expressed as a plot on logarithmic paper and is referred to as a sediment-transport curve. Sediment-transport curves showing the relation between average daily sediment discharge and water discharge for the Middle Fork Eel River near Covelo and Dos Rios are shown in figures 11 and 12. The curves for both Middle Fork Eel River stations show a large increase in sediment discharge at equal values of streamflow for the 1965 water year. This increase in sediment discharge coincides with the flood of December 1964, which was the maximum known flood in the basin. The recurrence interval for a flood of such magnitude (Young and Cruff, 1967, p. 6) is at least 113 years. Since the 1965 water year the annual sediment-transport curves show a definite progressive decrease in sediment discharge and appear to be approaching rates that existed prior to the flood. Annual sediment-transport curves for the Black Butte River (fig. 13) show similar decreases in sediment discharge even though data prior to or during the December 1964 flood were not available for comparison.

The curves shown in figures 11 through 13 indicate that the December 1964 flood induced major changes in sediment discharge versus water discharge relations in upstream parts of the Middle Fork Eel River basin. Others who have attributed changes in sediment discharge of the Eel River to the December 1964 flood include Anderson (1968, p. 175), Brown and Ritter (1971) and many personnel of the U.S. Geological Survey responsible for collecting and tabulating sedimentation data in the north coastal area of California.

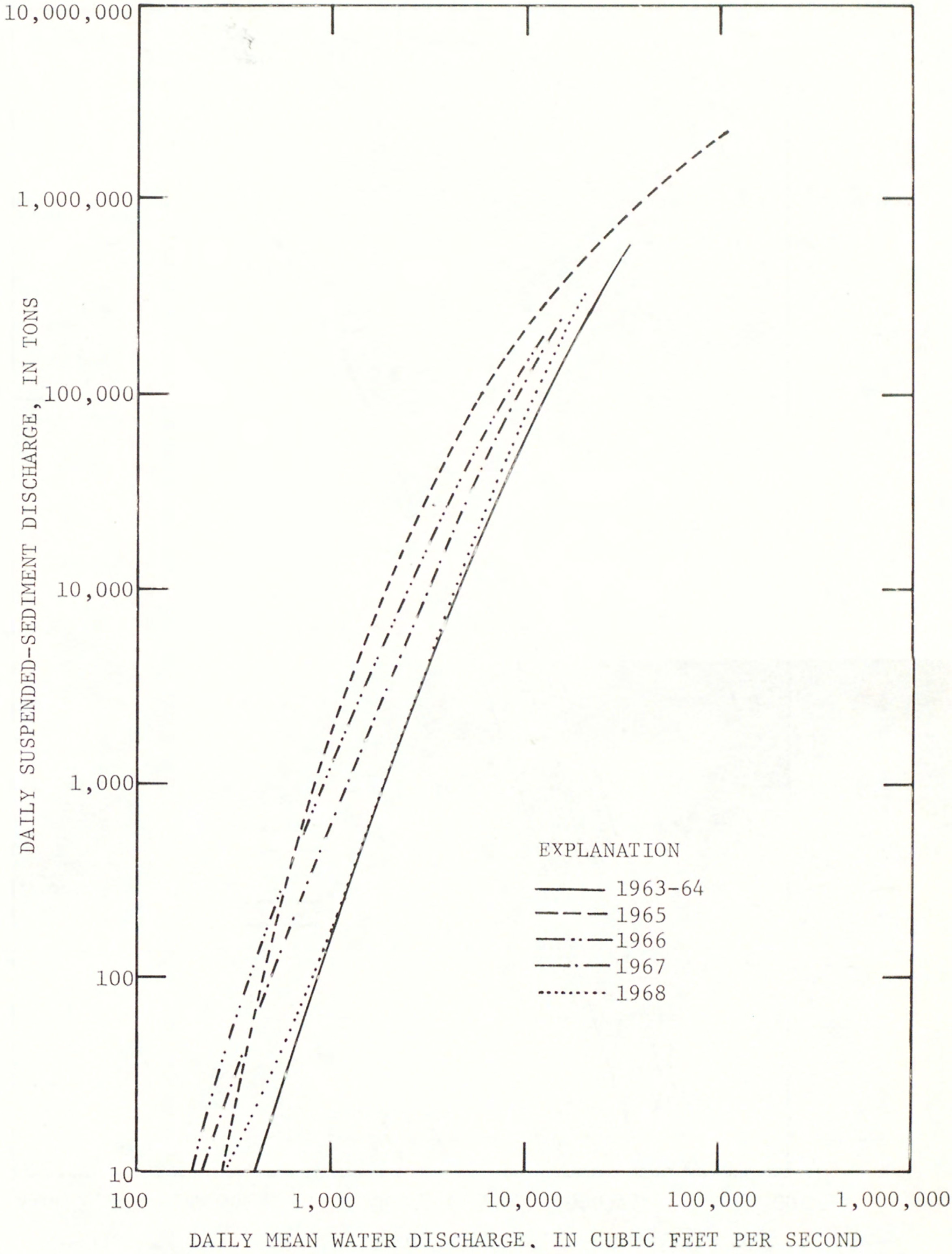


FIGURE 11.--Relation of suspended-sediment discharge to water discharge at Middle Fork Eel River below Black Butte River near Covelo for water years 1963-68.

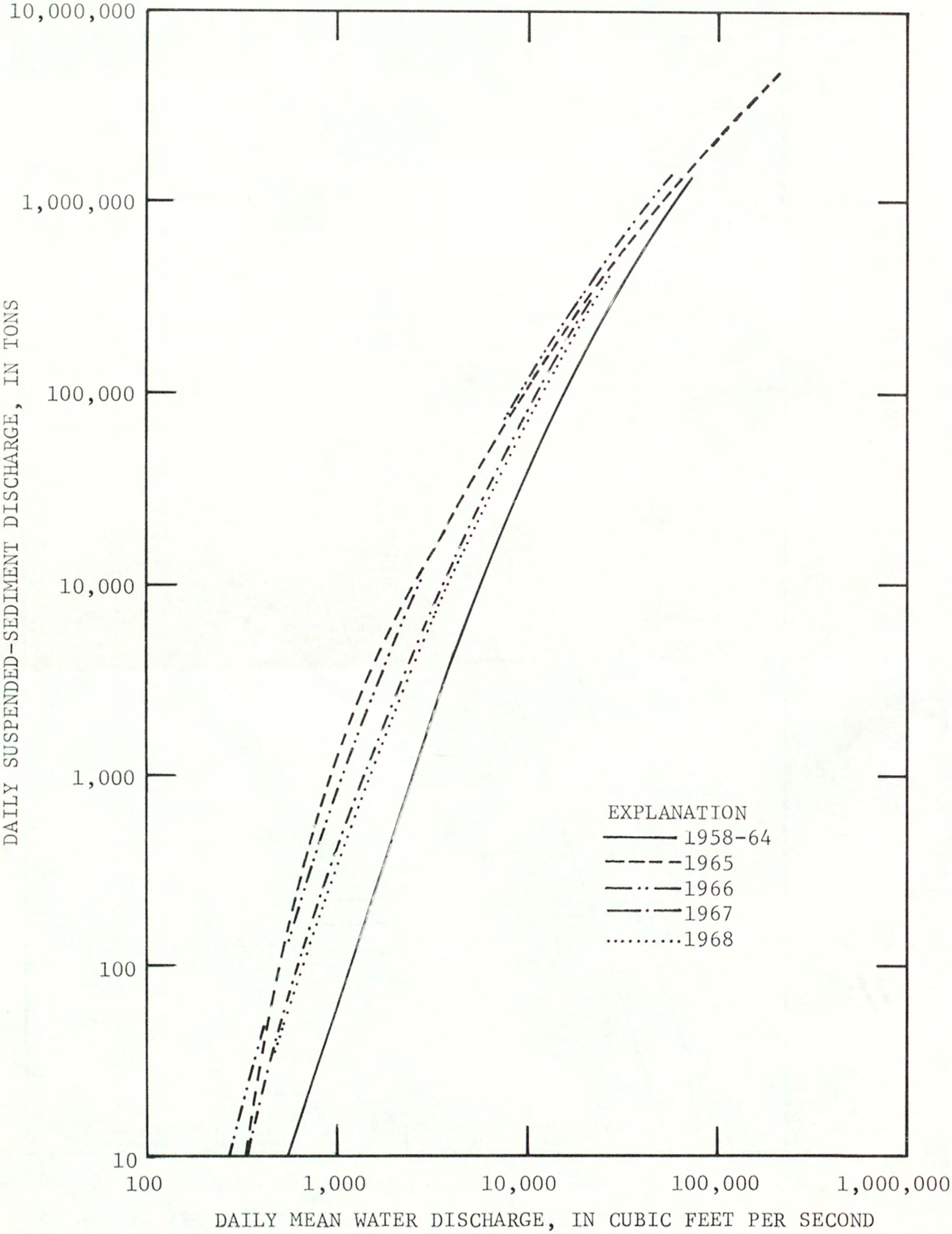


FIGURE 12.--Relation of suspended-sediment discharge to water discharge at Middle Fork Eel River near Dos Rios for water years 1958-68.

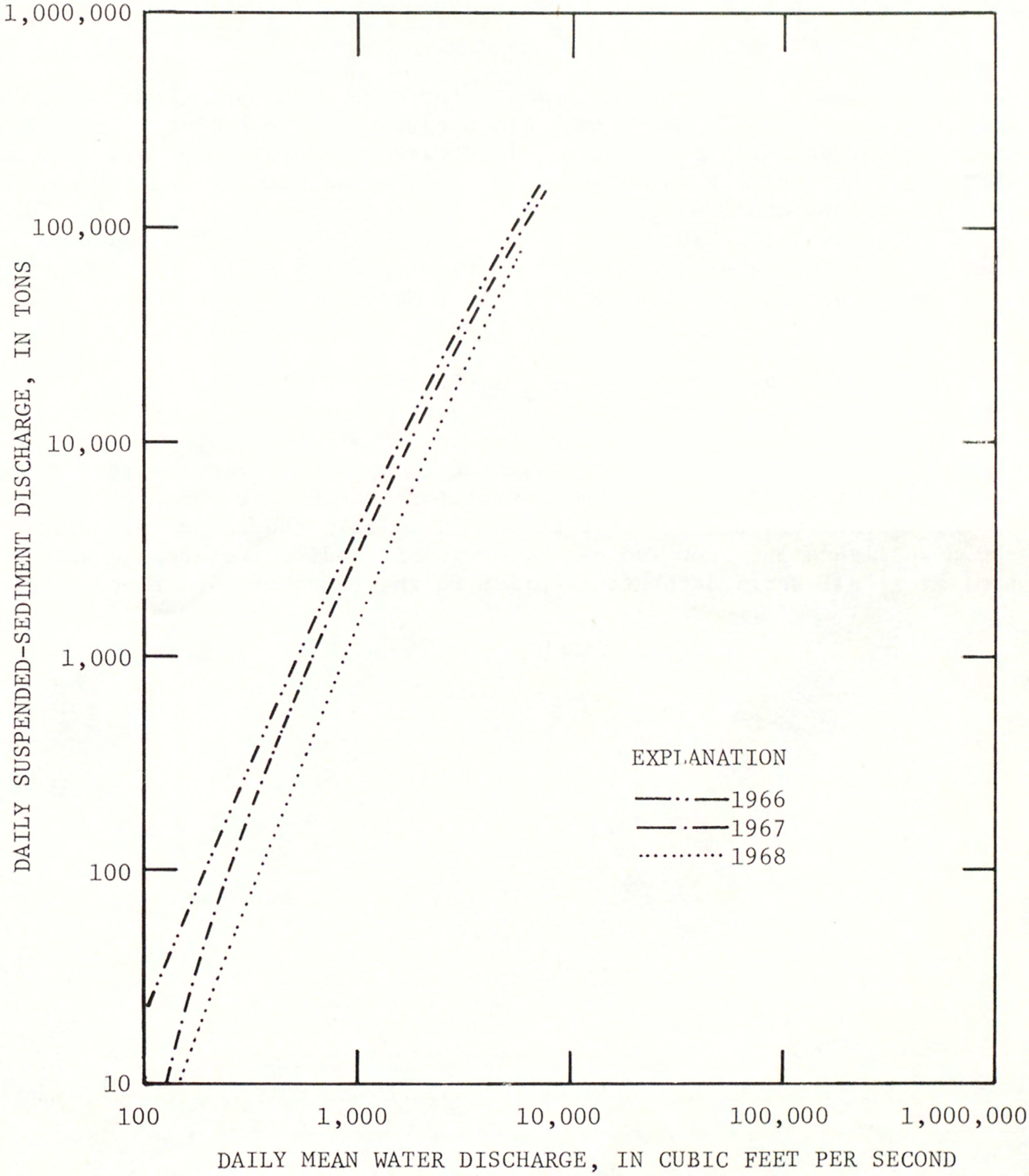


FIGURE 13.--Relation of suspended-sediment discharge to water discharge at Black Butte River near Covelo for water years 1966-68.

Only one other sediment station was in operation both before and after the December 1964 flood. This station, Williams Creek near Covelo, was operated during 1961-64 and 1967-68. Sediment samples were collected at the Williams Creek station at a frequency of about 12 to 15 samples per year. The sediment-transport curve for Williams Creek (fig. 14) does not show any significant variation between preflood or postflood relations. Short-term effects may have occurred, however, but they are indeterminate because sediment data were not collected during the period immediately following the December 1964 flood.

Field observations indicate that, for some stations, channel changes associated with the December 1964 flood were relatively minor. Hickey (1969) reported that large changes in streambed elevation occurred at many stream-gaging stations in northwestern California between the low-water periods of 1964 and 1965 and that these changes were related to the flood of December 1964. Graphs prepared by Hickey (1969, p. 8-9) showed that increases in low-water streambed elevation in the Middle Fork Eel River basin were large at stations on the Black Butte and Middle Fork Eel Rivers and were small at stations on Short Creek and Mill Creek.

Sediment-transport curves for Elk Creek, Mill Creek, Short Creek, and Williams Creek (where small channel changes were observed) are shown in figure 15. These curves, adjusted for unit drainage area, suggest that suspended-sediment discharge for such streams was similar before and after the December 1964 flood. Sediment-transport curves for the preflood period of the Middle Fork Eel River (fig. 16) lie within the series of curves shown in figure 15, thus indicating that unit sediment discharge was similar at all sediment stations prior to the December 1964 flood.

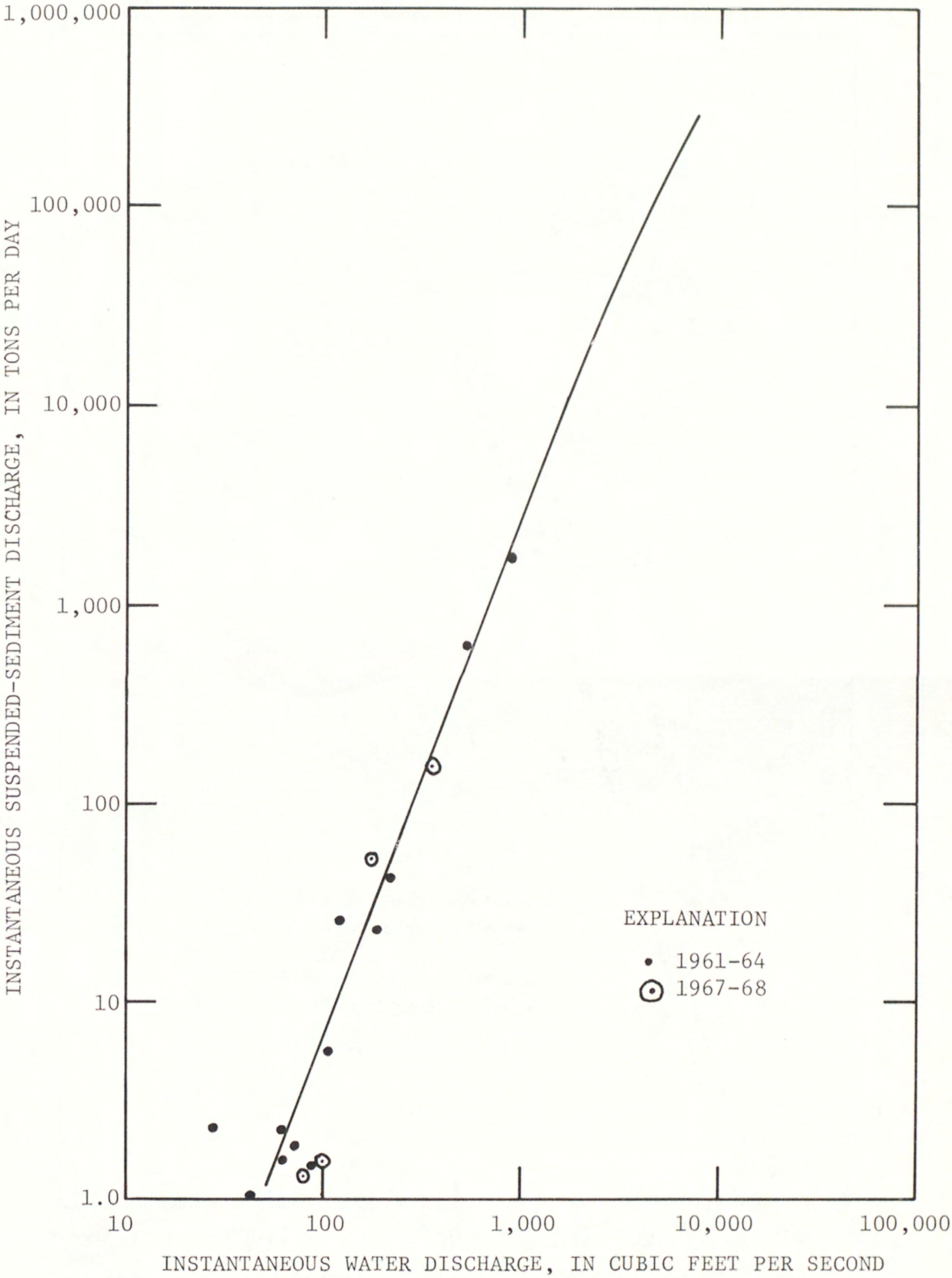


FIGURE 14.--Relation of suspended-sediment discharge to water discharge at Williams Creek near Covelo for water years 1961-64, 1967-68.

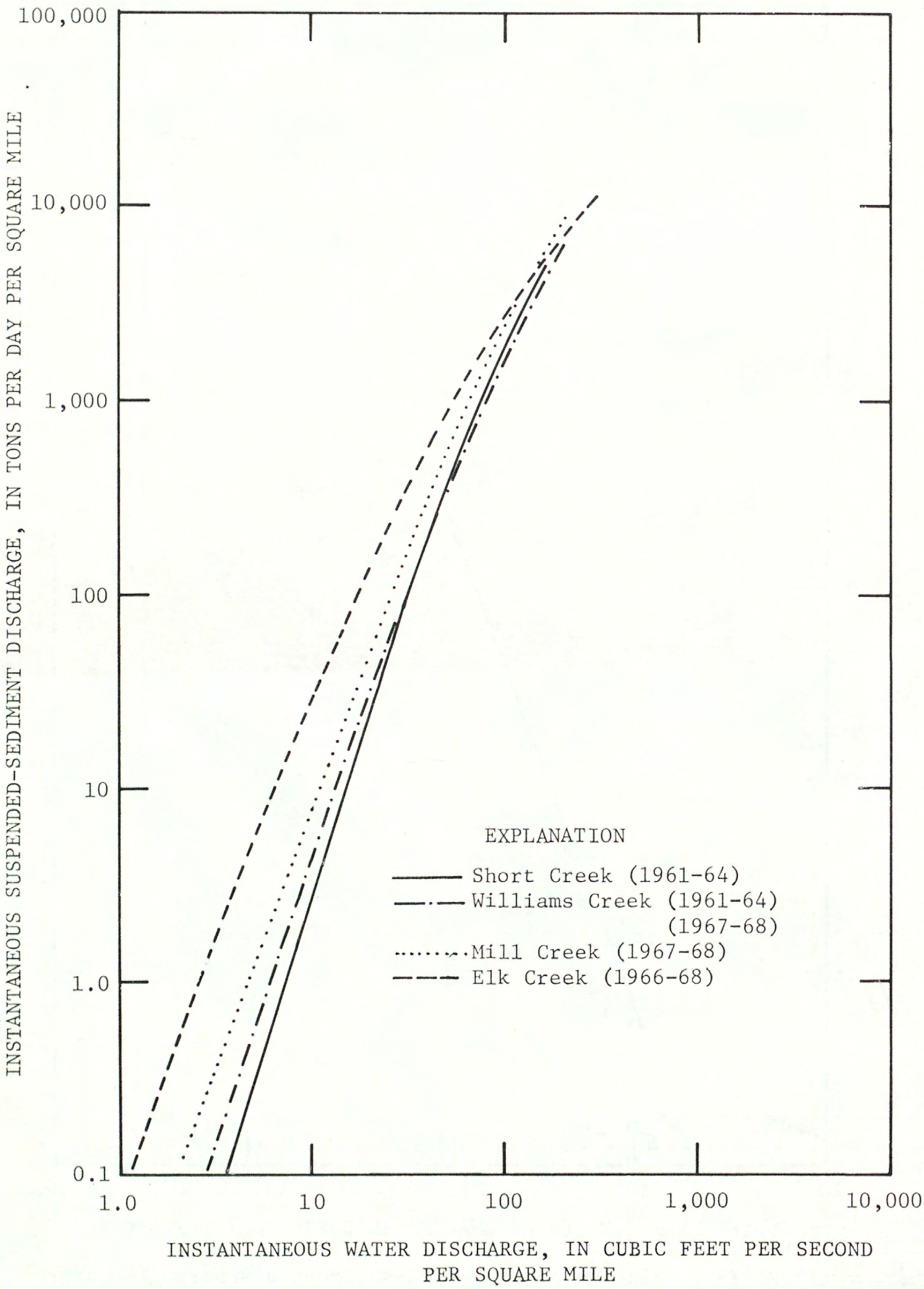


FIGURE 15.--Relation of suspended-sediment discharge to water discharge at periodic stations in the Middle Fork Eel River basin.

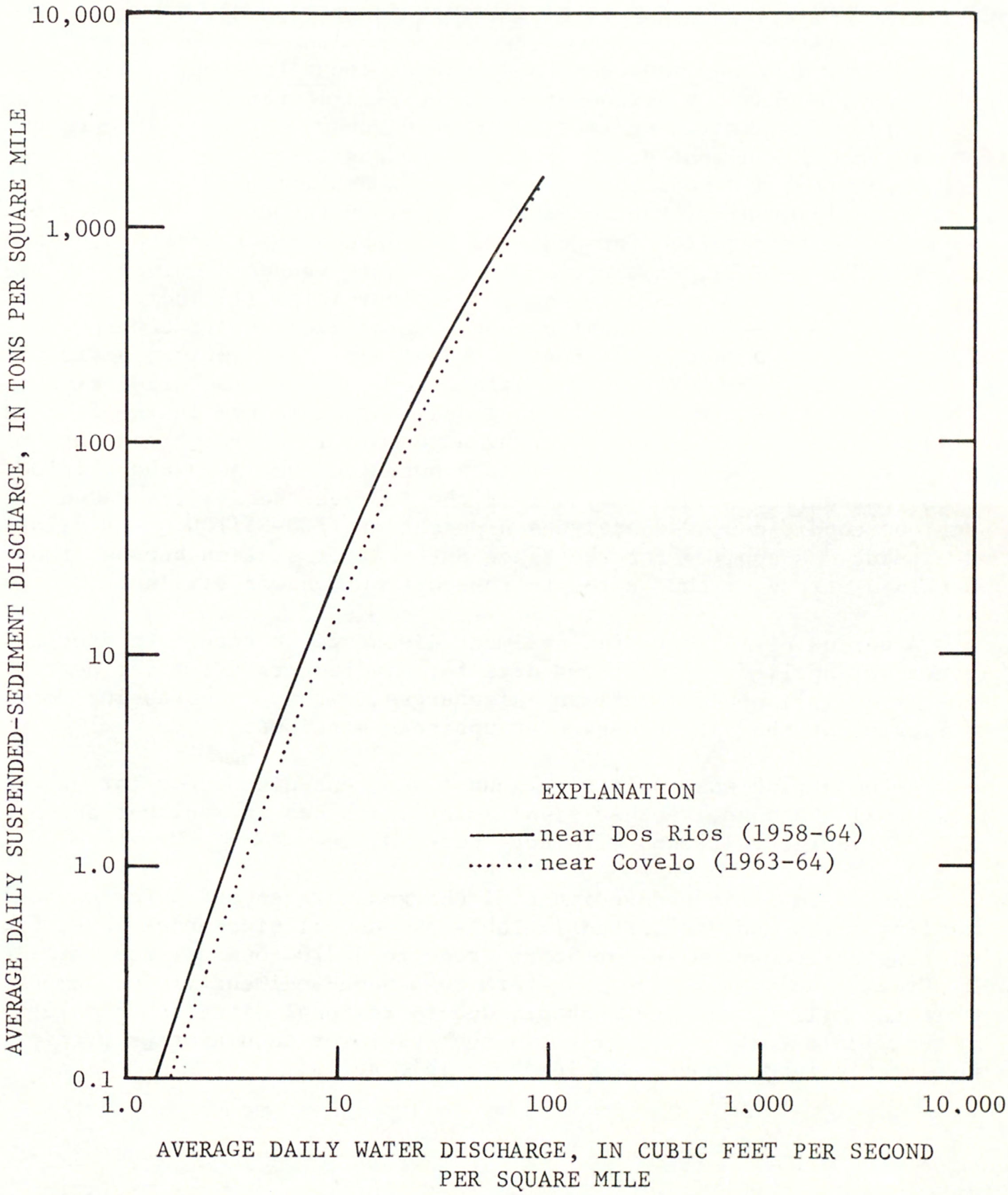


FIGURE 16.--Relation of suspended-sediment discharge to water discharge at Middle Fork Eel River stations prior to December 1964 flood.

## Long-Term Suspended-Sediment Discharge

Long-term suspended-sediment discharge was determined by extending short-term suspended-sediment and streamflow records to the base period 1911-14, 1917-67. Correlations were made using flow-duration curves of daily water discharge and an average relation between water and sediment discharge as established from sediment-transport curves.

At some stations, however, a single sediment-transport curve could not be applied for the period of sediment record because of large, but temporary, increases in sediment discharge subsequent to the December 1964 flood. Annual sediment discharges for the postflood period were computed from streamflow and sediment-transport data and weighted according to the recurrence interval of the December 1964 flood (about 100 years) and the number of years required for sediment discharges to return to preflood levels. For example, examination of sediment-transport curves for the Middle Fork Eel River below Black Butte River (fig. 11) indicates that, subsequent to 1964, the annual curves progressively shift toward the preflood curve and suggests that, for equivalent streamflow, sediment discharge after 1969 will be equivalent to sediment discharge prior to the flood. Therefore, assuming that sediment discharge in the 5 years following the flood was increased by an event with a recurrence of 100 years, the weight assigned to each postflood year was about 1/100 for a 100-year series. The remainder of the 100-year series, representative of preflood conditions, was assigned a weight of (100-5)/100. A similar adjustment was applied for the Black Butte River station because the postflood trend of the sediment-transport curves was similar.

A period of 10 years for sediment discharge to return to preflood levels was applied to postflood data for Middle Fork Eel River near Dos Rios (fig. 12), because sediment discharges, although decreasing were not decreasing at the rate observed at upstream stations.

No weighting was applied to annual sediment discharges for other individual stations, because significant variances in sediment and water-discharge relations were not observed.

Long-term suspended-sediment discharges were computed for each of the sampling sites and are listed in table 5. Annual discharges range from 565 tons per square mile for Short Creek to 3,270 tons per square mile for Elk Creek. Abnormally low long-term suspended-sediment yields computed for Short and Mill Creeks are probably due to regional differences relative to the Middle Fork Eel River basin such as lower than average precipitation, more gentle land slopes, and less erosible soils.

Table 5.--Long-term suspended-sediment discharge in the Middle Fork Eel River basin, 1911-14, 1917-67

| Station number | Sediment station | Drainage area (sq mi) | Annual yield | |
|---|---|---|---|---|
| | | | Tons | Tons/sq mi |
| 4728 | Middle Fork Eel River above Black Butte River, near Covelo | 204 | 505,000 | 2,480 |
| 4729 | Black Butte River near Covelo | 162 | 273,000 | 1,690 |
| 4730 | Middle Fork Eel River below Black Butte River, near Covelo | 367 | 778,000 | 2,120 |
| 4731 | Williams Creek near Covelo | 30.4 | 60,500 | 1,990 |
| 4736 | Short Creek near Covelo | 15.2 | 8,580 | 565 |
| 4737 | Mill Creek near Covelo | 96.9 | 109,000 | 1,120 |
| 4738 | Elk Creek near Hearst | 84.1 | 275,000 | 3,270 |
| 4739 | Middle Fork Eel River near Dos Rios | 745 | 1,980,000 | 2,660 |

## Bedload Discharge

Bedload discharge for sediment stations in the Middle Fork Eel River basin was computed using the Meyer-Peter and Muller bedload formula. This formula, converted to English units by the U.S. Bureau of Reclamation (1960a), was developed from flume studies in Switzerland. The converted equation is

$$G_s = 1.606B\left[3.306\left(\frac{Q_s}{Q}\right)\left(\frac{D_{90}{}^{1/6}}{n_s}\right)^{3/2} dS - 0.627\ D_m\right]^{3/2}$$

where

$G_s$ = total bedload discharge, in tons per day,

$B$ = bottom width of the stream channel, in feet,

$Q_s$ = the water discharge that transports a specific bedload, in cubic feet per second,

$Q$ = total water discharge, in cubic feet per second,

$D_{90}$ = particle size at which 90 percent of the bed material is finer, in millimeters,

$n_s$ = Manning $n$ value for the streambed,

$d$ = depth of flow, in feet,

$S$ = slope of the energy gradeline, in feet per foot,

$D_m$ = effective size of the bed material, in millimeters,

[$D_m$ = $\Sigma D\Delta p/100$ where $D$ is the geometric mean diameter of particles in a given size fraction and $p$ is the percent by weight in that size fraction.]

## Field Measurements

Most of the data required for the computation of bedload discharge were obtained from measurements made in the basin during the 1968 water year. Primary emphasis was given to existing daily sediment stations and the Elk Creek station, which was near a site proposed for a major diversion structure. Measurements were made at water discharges ranging from low flow at all stations to a maximum of 15,800 cfs (cubic feet per second) at Middle Fork Eel River near Dos Rios. The bedload discharge at values of water discharge larger than those measured in 1968 was estimated from streamflow measurements and channel cross sections determined in previous years. Field data included measurements of water discharge, slope, channel geometry, and particle-size distribution of bed material. Changes in streambed characteristics upstream and downstream from sampling sections were documented from photographs of the various reaches.

Water discharge was determined from velocity, depth, and width measurements using standard U.S. Geological Survey equipment and methods. Where possible, special low-flow measurements were made along high-flow sampling sections to obtain data for conditions of zero bedload.

Water-surface slopes were determined from reference points or water-level recorders established within the sampling reach. Water-surface slopes were adjusted for velocity head differences where sufficient data were available.

Channel geometry was determined on many occasions throughout the storm season to monitor depth, width, and streambed elevations for a range of streamflow. The data were obtained by level survey during low-flow periods between storms, and from soundings or streamflow measurements during storms. Datum to gage height or mean sea level (m.s.l.) was established at each sampling site.

## Particle-Size Distribution of Bed Material

Bed-material samples, representative of the sediment occurring in the submerged parts of the stream channels, were difficult to obtain at most stages of flow because the streams were generally too deep or too swift for direct access to the streambed. In addition, fluctuations in the size of particles transported as bedload at various stages were extreme. Particles that constituted a major fraction of bed material at high stages (0.062-8.0 mm) were commonly absent or present in minor amounts at low stages. Coarser material (32-512 mm) was abundant in the streambed at low stages and unmeasurable at higher stages. Several methods were employed to determine the probable particle-size distribution for historical magnitudes of streamflow.

Bed material, at higher stages, was collected from the channel with a clamshell-type sampler (U.S. BM-54). This sampler, weighing about 100 pounds, was designed to obtain a sample from the top 2 inches of the streambed (U.S. Inter-Agency Committee on Water Resources, Subcommittee on Sedimentation, 1958) and is generally used when large stream velocities and depths are encountered. Design limitations of this equipment precluded obtaining quantitative data for particles coarser than 32 mm, although examination of bed material photographs and changes in streambed elevation verified that coarser material was being transported.

Particle-size distribution of coarse material in the streambed was determined by optical examination of photographs and by particle counts taken during low-flow periods between storms. Particles as small as 1.0 mm were analyzed using these methods.

Techniques for determining the particle-size distribution of coarse bed material using an optical counter and photographs are discussed by Ritter and Helley (1968). Individual particles are measured by adjusting the diameter of a spot of light to equal the intermediate diameter of the particle as shown in the photograph. Particles are mechanically counted and recorded according to relative diameter. The true sizes are determined by multiplying the relative diameter by the scale factor of the photograph. Particle-size distribution is determined by weighting the particles on the basis of volume as suggested by Pashinsky (1964). An example of the format used by Ritter and Helley is given in table 6. Values of shape coefficients range from 0.4 for flattened particles to 0.6 for prismatic or angular particles. Photographs (fig. 17) used for this type of analysis were generally taken from a point 4.0 feet above the streambed at points where BM-54 samples were taken during high flows.

Table 6.--Example of volumetric method of calculating particle-size distribution of bed material from Black Butte River near Covelo, California.

(Format from Ritter and Helley, 1968)

Date: April 23, 1968

| (1) Size interval (mm) | (2) Number of particles | | | Total | (3) Mean diameter of interval (mm) | (4) Cube of mean diameter ($cm^3$) $(3)^2$ | (5) Shape coeffi-cient | (6) Volume of mean particle ($cm^3$) (4)x(5) | (7) Volume of all particles ($cm^3$) (2)x(6) | (8) Cumulative volume ($cm^3$) Σ(7) | (9) Cumulative percent |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Photo 1 | Photo 2 | Photo 3 | | | | | | | | |
| 2.83 | 0 | 3,900 | 0 | 3900 | 1.41 | 0.0028 | 0.50 | 0.0014 | 5.46 | 5.46 | 0.2 |
| 2.83-4.00 | 54 | 2 | 53 | 109 | 3.42 | .040 | .52 | .021 | 2.29 | 7.75 | .3 |
| 4.00-5.66 | 139 | 34 | 173 | 346 | 4.83 | .113 | .53 | .060 | 20.8 | 28.6 | 1.0 |
| 5.66-8.00 | 224 | 36 | 156 | 416 | 6.83 | .319 | .54 | .172 | 71.6 | 100 | 3.4 |
| 8.00-11.3 | 154 | 34 | 111 | 299 | 9.7 | .913 | .53 | .484 | 145 | 245 | 8.4 |
| 11.3-16.0 | 92 | 30 | 74 | 196 | 13.7 | 2.57 | .53 | 1.36 | 267 | 512 | 17.7 |
| 16.0-22.6 | 56 | 19 | 49 | 124 | 19.3 | 7.19 | .51 | 3.67 | 455 | 967 | 33.3 |
| 22.6-32.0 | 20 | 15 | 35 | 70 | 27.3 | 20.3 | .51 | 10.4 | 728 | 1,700 | 58.6 |
| 32.0-45.2 | 3 | 9 | 16 | 28 | 38.6 | 57.5 | .50 | 28.8 | 806 | 2,500 | 86.2 |
| 45.2-64.0 | | 1 | 2 | 3 | 54.6 | 163 | .50 | 81.5 | 244 | 2,750 | 94.8 |
| 64.0-70.9 | | 1 | | 1 | 67.5 | 308 | .50 | 154 | 154 | 2,900 | 100.0 |


FIGURE 17.--Bed material at Black Butte River near Covelo, April 23, 1968 (photograph number 3 of table 6). Scale numbers shown in tenths of a foot.

A grid method (Wolman, 1954) was also used for counting and analyzing coarse material. Particles, ranging in intermediate diameter from 1.0 to 512 mm, were measured at rectangular grid points 5 or 10 feet apart. In most cases 150 to 200 particles were counted at each site. Particle-size distribution, using the Wolman method, is determined by dividing the number of particles in a specific size interval by the total number of particles in the sample.

The volume-grid area method combines techniques used in both the optical and Wolman methods. Particles are counted in the field according to the Wolman method, and particle-size distribution is computed using techniques similar to those used by Ritter and Helley (1968, p. 11-12) for estimating the number of particles too small for optical counting. An example of particle-size distribution computed by the volume-grid area (VGA) method is given in table 7. Bed material data listed in tables 6 and 7 were collected at the same locations and times. Comparisons were made of the optical, VGA, and Wolman methods to determine whether any of the methods were compatible (fig. 18). Figure 18 seems to indicate a close agreement between VGA and optical methods in the lower and intermediate parts of the distribution curves. The presence of coarser material for the upper end of the VGA curve than for the optical curve is probably due to differences in sampling methods. There may be a greater statistical chance of observing the largest particle in the channel by measuring single grains at a large number of points throughout the reach than by measuring a large number of grains at a small number of sampling points. Size distributions computed by the Wolman method generally indicate larger percentages of smaller particles than do the other two methods. Differences among the methods were consistent for comparative data collected at other sites in the basin.

Table 7.--Example of volume-grid area method of calculating particle-size distribution of bed material from Black Butte River near Covelo

Date: April 23, 1968 Grid dimensions: 5.0 x 5.0 feet

| 1<br>Size interval (mm) | 2<br>Geometric mean diameter of interval (mm) | 3<br>Cube of geometric mean diameter ($cm^3$) $(2)^3$ | 4<br>Shape coefficient | 5<br>Volume of geometric mean diameter ($cm^3$) (3)x(4) | 6<br>Number of particles counted | 7<br>Grid area surrounding one particle ($cm^2$) | 8<br>Square of geometric mean diameter ($cm^2$) $(2)^2$ | 9<br>Number of particles in one grid unit (7)/(8) | 10<br>Number of particles in channel (6)x(9) | 11<br>Volume of all particles of interval ($cm^3$) (5)x(10) | 12<br>Culumative volume ($cm^3$) $\Sigma(11)$ | 13<br>Cumulative percent |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0.5-1.0 | 0.707 | 0.00035 | 0.5 | 0.00018 | 7 | 23,200 | 0.00500 | $4.64x10^6$ | $3.25x10^7$ | 5,850 | 5,850 | 0.1 |
| 1.0-2.0 | 1.41 | .00280 | .5 | .00140 | 2 | 23,200 | .0199 | $1.17x10^6$ | $2.34x10^6$ | 3,280 | 9,130 | .2 |
| 2.0-4.0 | 2.83 | .0227 | .5 | .0114 | 5 | 23,200 | .0800 | $2.90x10^5$ | $1.45x10^6$ | 16,500 | 25,600 | .6 |
| 4.0-8.0 | 5.66 | .181 | .5 | .0905 | 23 | 23,200 | .320 | $7.25x10^4$ | $1.67x10^6$ | 151,000 | 177,000 | 4.3 |
| 8.0-16 | 11.32 | 1.45 | .5 | .725 | 32 | 23,200 | 1.28 | $1.81x10^4$ | $5.79x10^5$ | 420,000 | 597,000 | 14.5 |
| 16-32 | 22.63 | 11.6 | .5 | 5.80 | 46 | 23,200 | 5.12 | $4.53x10^3$ | $2.08x10^5$ | 1,210,000 | 1,810,000 | 44.0 |
| 32-64 | 45.26 | 92.7 | .5 | 46.4 | 38 | 23,200 | 20.5 | $1.13x10^3$ | $4.29x10^4$ | 1,990,000 | 3,800,000 | 92.5 |
| 64-128 | 90.52 | 742 | .5 | 371 | 3 | 23,200 | 81.9 | $2.83x10^2$ | $8.49x10^2$ | 315,000 | 4,110,000 | 100.0 |

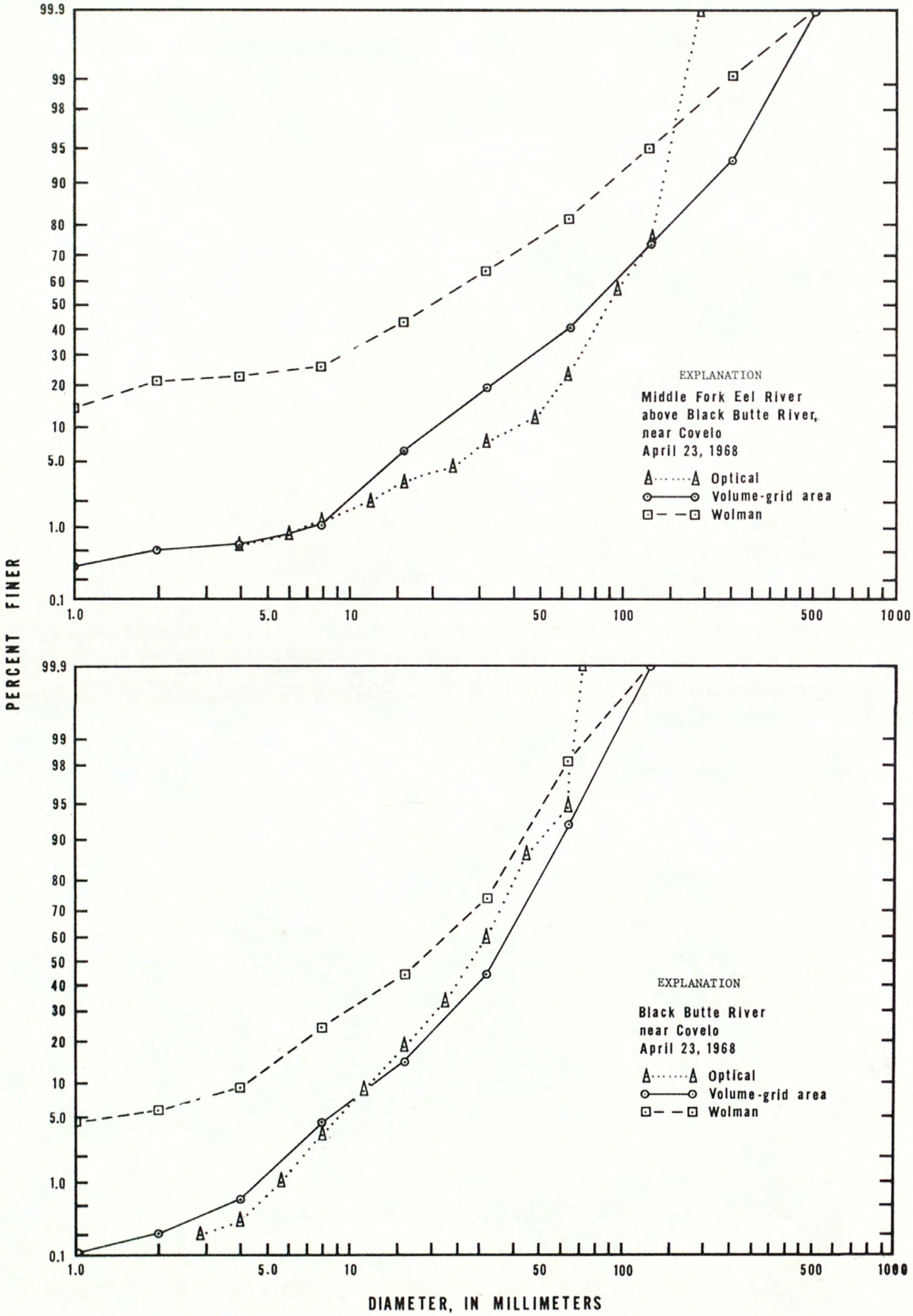


FIGURE 18.--Particle-size distribution determined by optical, volume-grid area, and Wolman methods.

## Streambed Roughness

Manning $n$ values of streambed roughness were computed from an empirical relation derived from streams with stable boundaries and coarse bed material. This relation (fig. 19), one of several described by Limerinos (1969), was obtained by plotting a roughness parameter

$$\frac{n_s}{R^{1/6}} \text{ against relative smoothness } \frac{R}{D_\omega}$$

where $n_s$ = Manning $n$ value for the streambed,

$R$ = hydraulic radius of the stream channel,

$D_\omega$ = weighted particle size = $0.6D_{84}+0.3D_{50}+0.1D_{16}$,

where $D_{84}$ = 84-percent particle size.

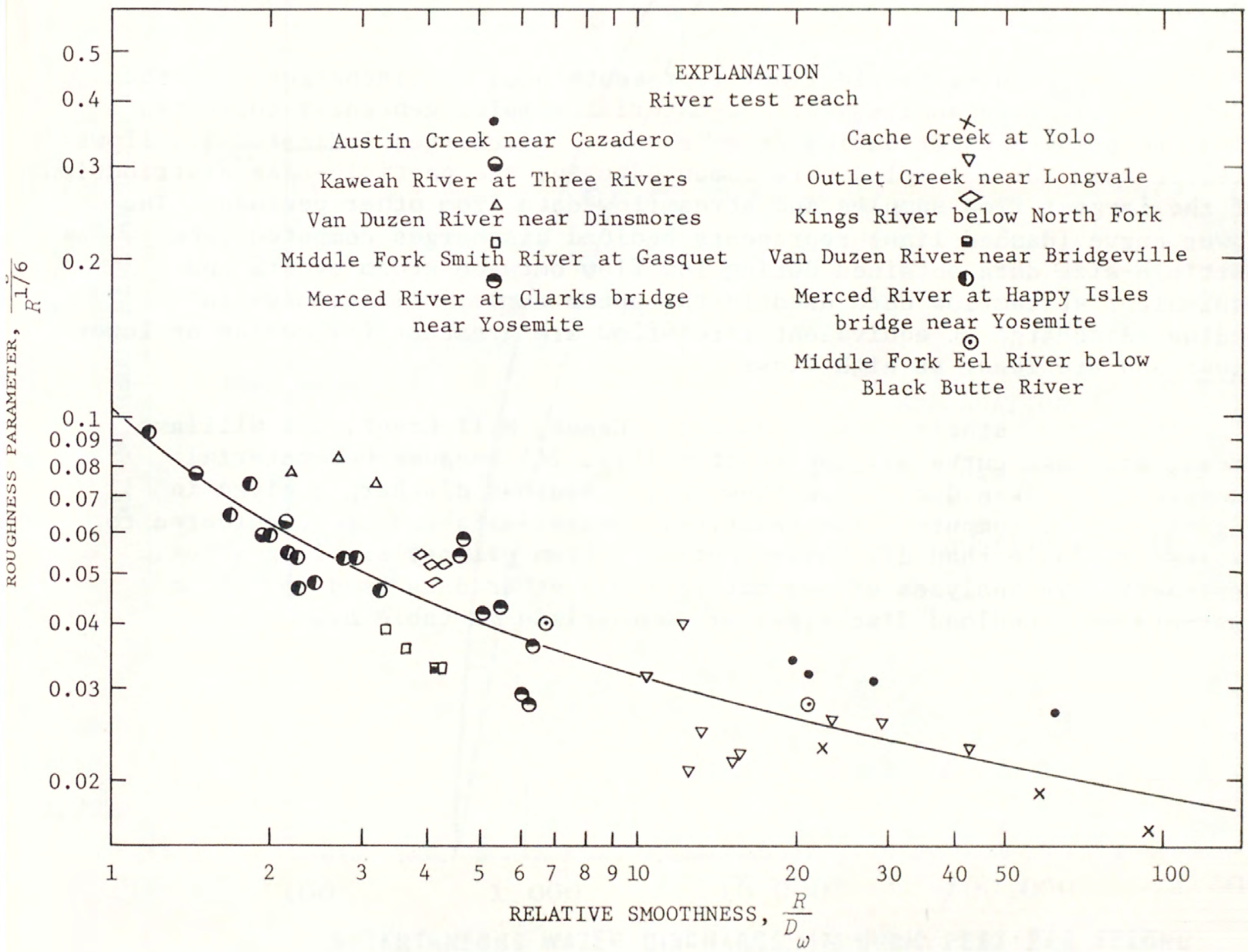


FIGURE 19.--Relation of roughness parameter to relative smoothness based on weighted size of intermediate diameter of streambed particles (from Limerinos, 1969).

## Relation Between Bedload Discharge and Water Discharge

Bedload parameters were measured periodically at several sites in the Middle Fork Eel River basin. The stream channels at these sites were very active during major storms. Bed material near the surface usually was scoured away during rising stages and was replaced with similar material during falling stages. The grain size of the streambed material changed continually throughout the storm event and ranged from pebble-cobble mixtures at low flows to sand-pebble mixtures at higher flows.

A relation between bedload discharge and water discharge was established by constructing sediment-transport curves similar to those used for suspended-sediment data. However, because of the extreme variability in streambed composition observed during the 1968 storm season, two curves (figs. 20-23) were used to compensate for probable variations in bedload discharge resulting from significant changes in grain size. Bedload discharge for these stations was computed by averaging the two curves.

The upper curve (solid line) represents bedload discharges computed from particle-size analyses of bed-material samples generally collected with the BM-54 sampler during storm events. Discharges indicated for flows greater than those sampled were computed using the particle-size distribution of the largest flow samples and streamflow data from other periods. The lower curve (dashed line) represents bedload discharges computed from particle-size data obtained during low flow between storm events and equivalent streamflow data used in the upper curve. Differences in bedload discharge at equivalent streamflow are greatest for median or lower flows and are least at high flows.

At several stations, such as Short Creek, Mill Creek, and Williams Creek, only one curve was constructed (fig. 24) because bed-material samples were taken during low flow only. Bedload discharges given in figure 24 were computed from relatively meager data and are considered to be less reliable than discharges obtained from primary sampling sites. Representative analyses of bed material and other data used to define instantaneous bedload discharges are summarized in table 8.

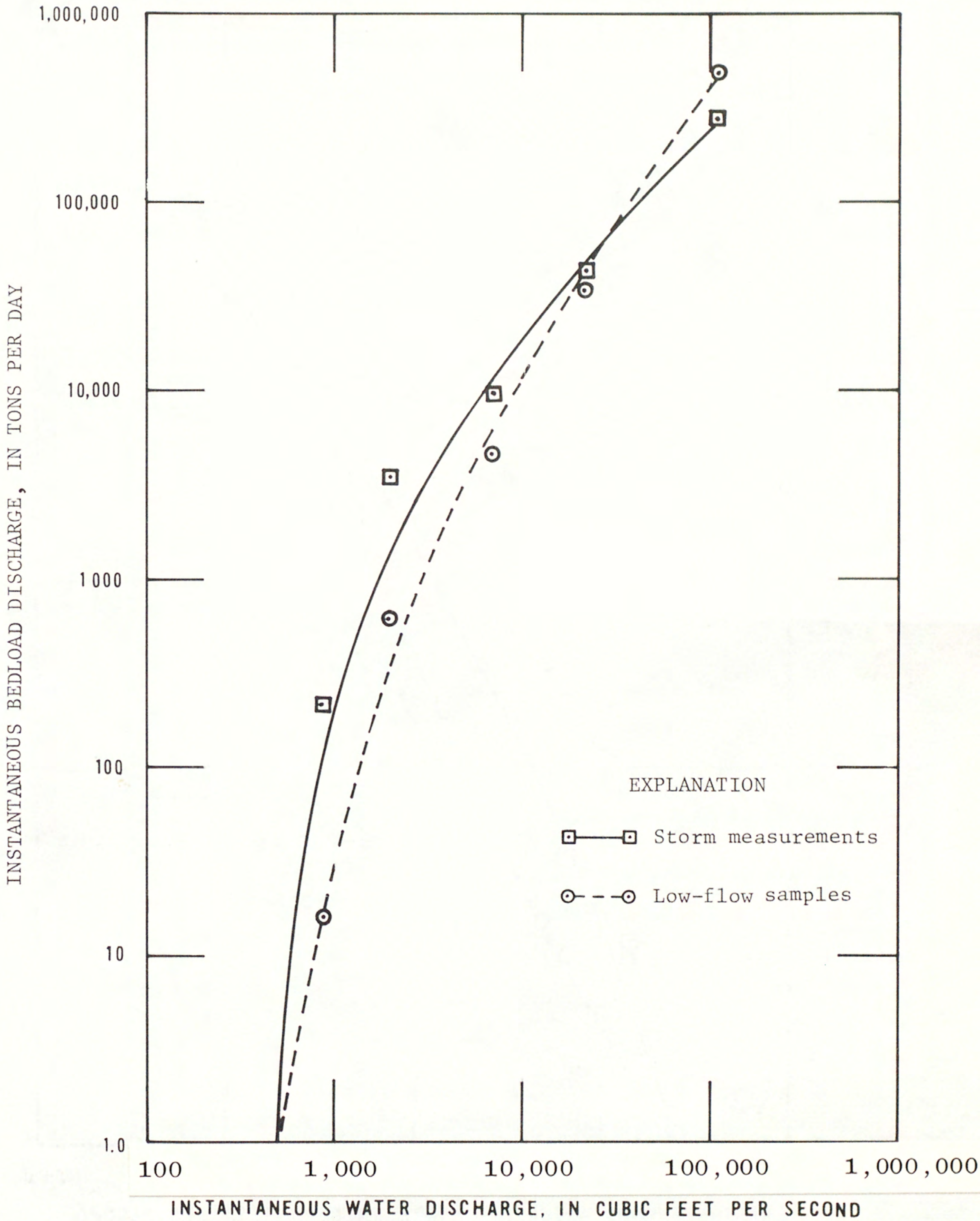


FIGURE 20.--Relation of bedload discharge to water discharge at Middle Fork Eel River above Black Butte River near Covelo.

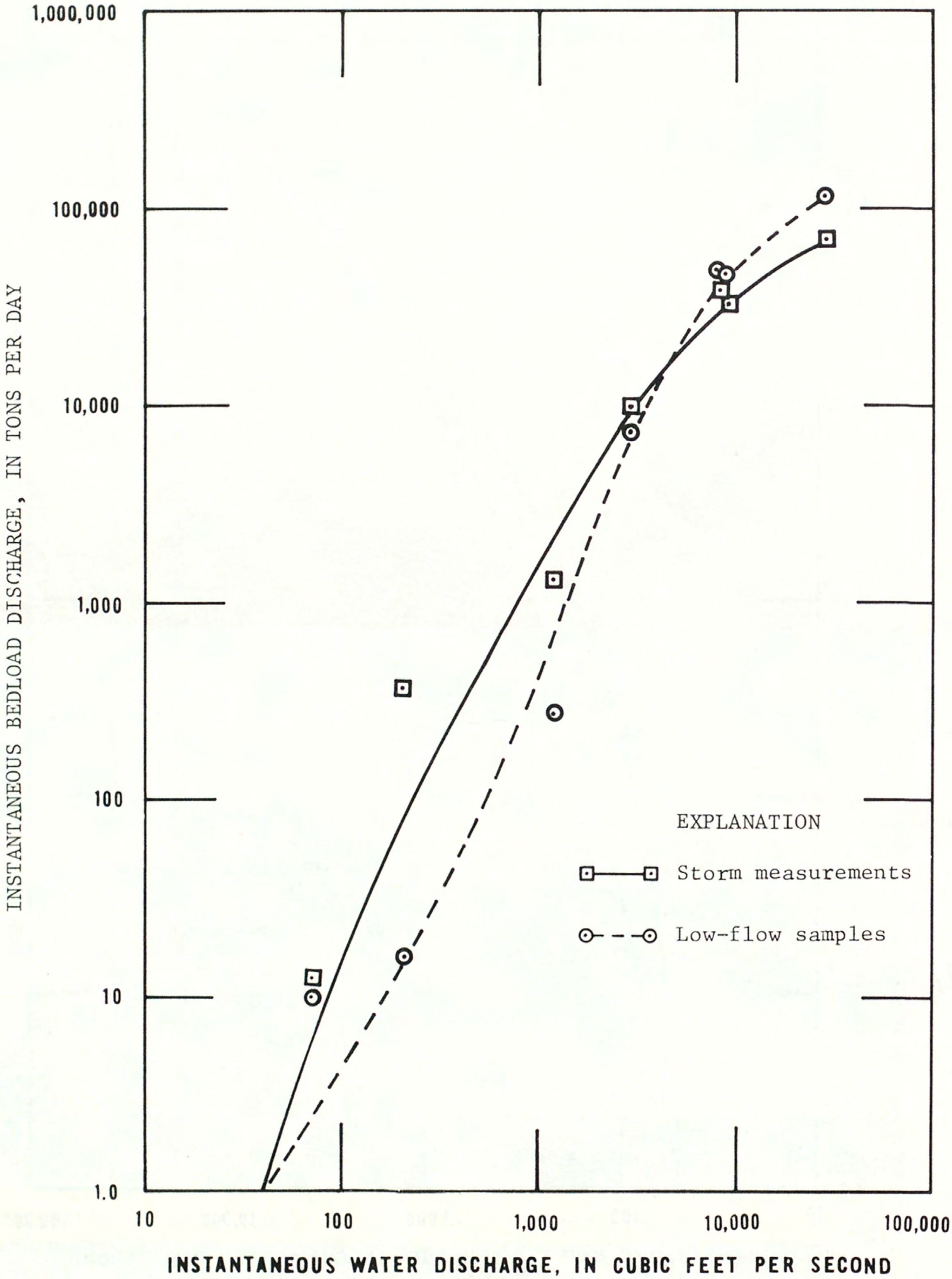


FIGURE 21.--Relation of bedload discharge to water discharge at Black Butte River near Covelo.

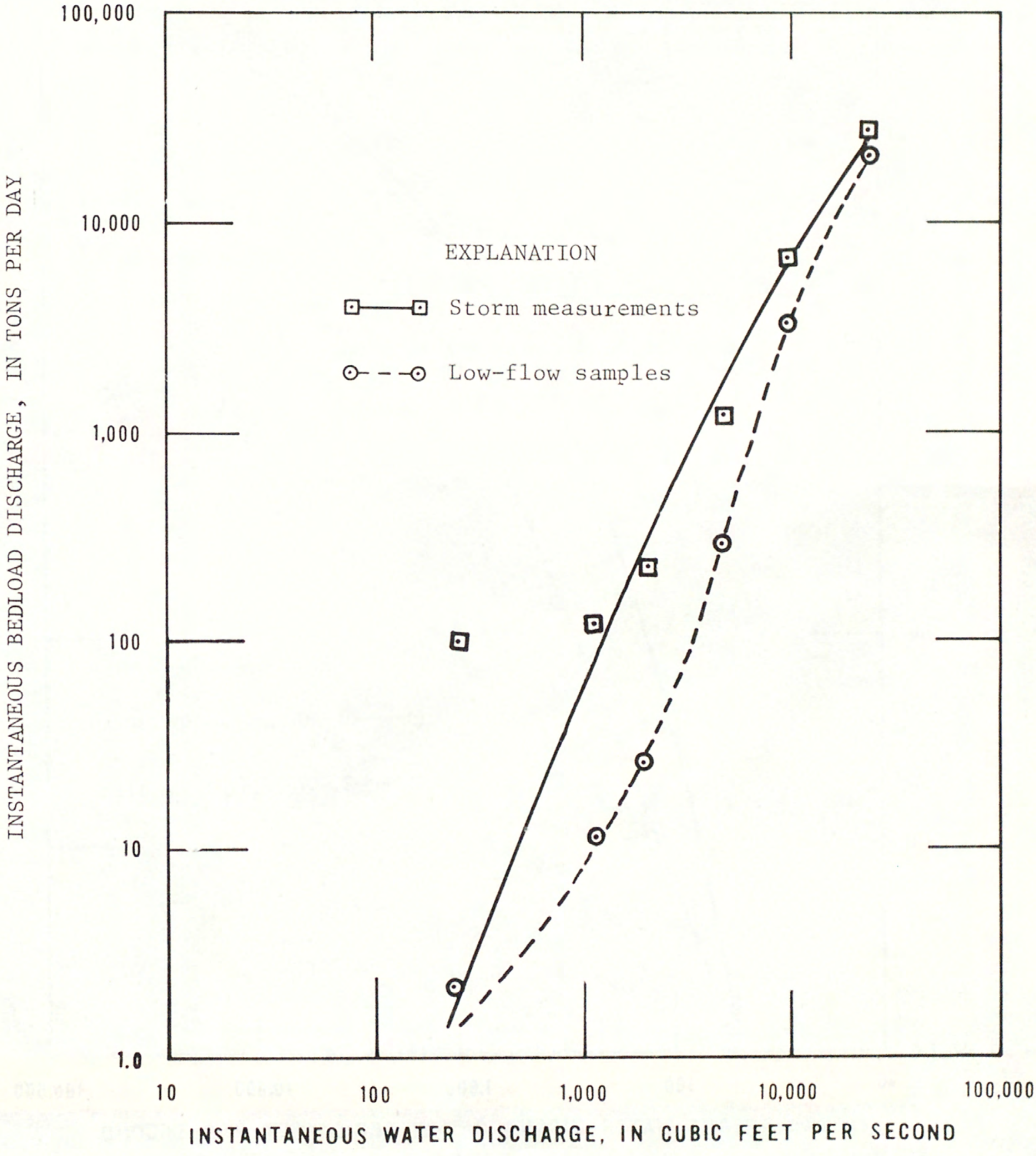


FIGURE 22.--Relation of bedload discharge to water discharge at Elk Creek near Hearst.

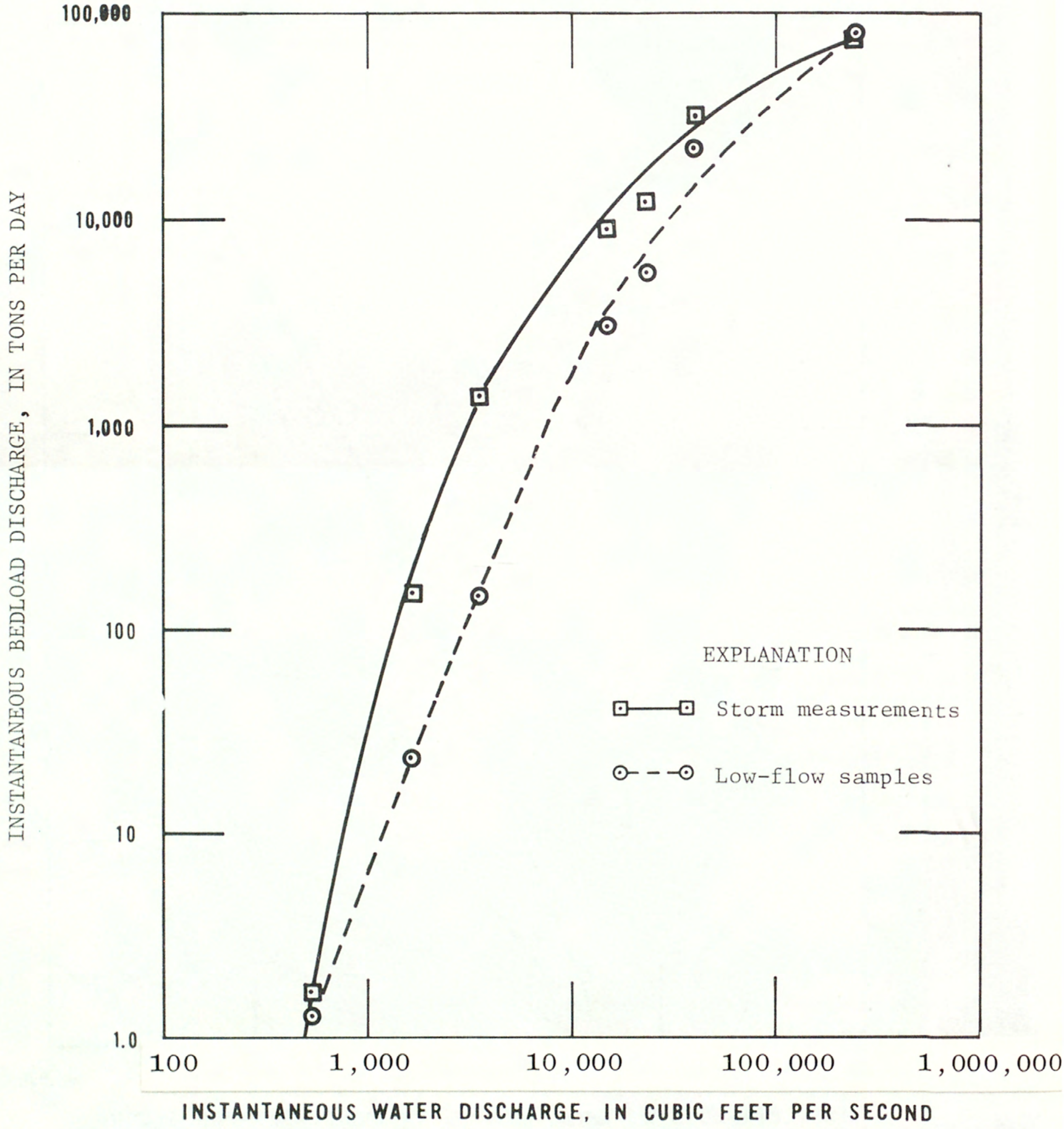


FIGURE 23.--Relation of bedload discharge to water discharge at Middle Fork Eel River near Dos Rios.

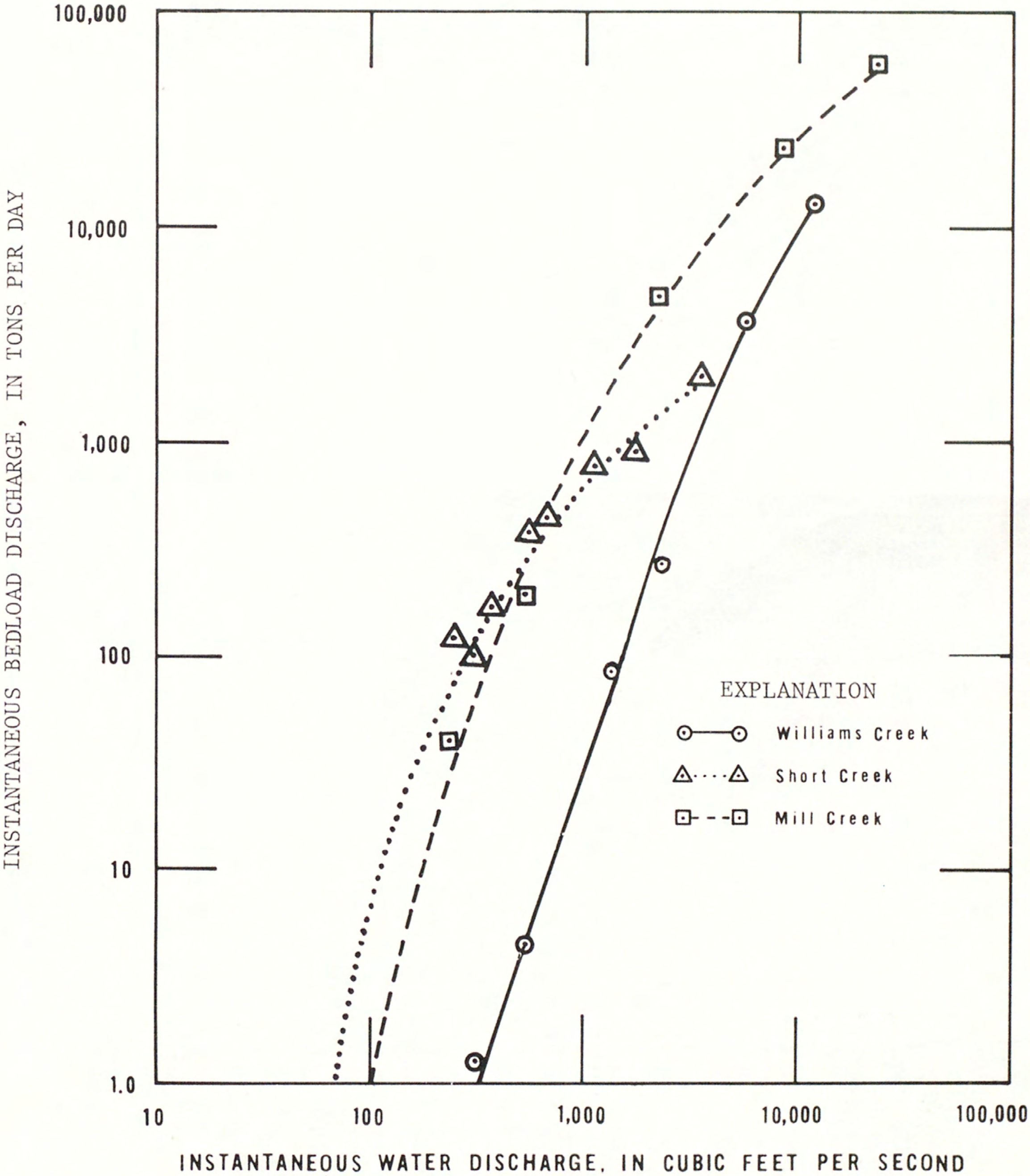


FIGURE 24.--Relation of bedload discharge to water discharge at Short Creek, Mill Creek, and Williams Creek near Covelo.

Table 8.--Bed material and streamflow data for selected sampling sites in the Middle Fork Eel River basin

| Station | Date | Water discharge (cfs) | Average depth (ft) | Width (ft) | Average velocity (ft/sec) | Slope (ft/ft) | Streambed roughness (fig. 19) | Composition of streambed (percent) | | | | Range of compute bedload (tons per day) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | Sand (0.062-2.0 mm) | Granule-pebble (2.0-64 mm) | Cobble (64-256 mm) | Boulder (>256 mm) | |
| Middle Fork | aNov. 1,1967 | 15 | - | - | | 0.0054 | - | 1 | 25 | 74 | | b0 |
| Eel River | aApr.23,1968 | 299 | - | - | | .0047 | - | 1 | 41 | 52 | 6 | b0 |
| above | Jan.23,1968 | 916 | 1.48 | 142 | 4.36 | .0068 | 0.045 | c7 | c93 | - | - | 16-204 |
| Black | Jan.17,1968 | 2,030 | 2.40 | 138 | 6.15 | .0070 | .040 | 7 | 93 | - | - | 593-3,320 |
| Butte | Feb.22,1968 | 7,080 | 4.12 | 178 | 9.66 | .0070 | .040 | 32 | 68 | - | - | 4,490-9,150 |
| River | Feb.19,1968 | 21,000 | d6.13 | 238 | d14.4 | .0075 | .036 | c40 | c60 | - | - | 33,000-42,000 |
| near | Dec.22,1964 | e104,000 | d15.7 | 261 | d25.4 | e.0075 | .033 | - | - | - | - | 270,000-490,000 |
| Covelo | | | | | | | | | | | | |
| Black | Oct.31,1967 | 7.4 | .39 | 24 | .80 | .0059 | - | 23 | 77 | - | - | b0 |
| Butte | aDec.14,1967 | 39 | - | - | - | - | - | 1 | 72 | 27 | - | b0 |
| River | Dec.14,1967 | 39 | .48 | 93 | .88 | - | - | 16 | 84 | - | - | b0 |
| near | Dec.12,1967 | 73 | .55 | 58 | 2.28 | e.004 | .033 | 87 | 13 | - | - | 9.8-12 |
| Covelo | aApr.23,1968 | 118 | - | - | - | - | - | <1 | 92 | 8 | - | - |
| | Nov.14,1967 | 202 | 1.48 | 93 | 1.46 | e.004 | .033 | 30 | 70 | - | - | 16-368 |
| | Jan.16,1968 | 1,210 | 2.78 | 93 | 4.68 | .0039 | .032 | 35 | 65 | - | - | 270-1,380 |
| | Feb.20,1968 | 2,960 | 5.16 | 101 | 5.67 | .0042 | .030 | 46 | 54 | - | - | 7,340-9,540 |
| | Jan.14,1968 | 8,300 | d8.15 | 136 | d7.49 | .0053 | .029 | c28 | c67 | c5 | - | 38,700-47,700 |
| | Feb.19,1968 | 9,000 | d8.16 | 135 | d8.17 | .0055 | .030 | c46 | c53 | c1 | - | 32,500-44,900 |
| | Dec.22,1964 | 29,000 | d12.8 | 177 | d12.9 | .0052 | .029 | | | | - | 67,400-114,00 |
| Williams | Nov.16,1967 | 4.3 | - | - | - | - | - | - | 65 | 35 | - | b0 |
| Creek | Feb. 1,1967 | 343 | 1.16 | 58 | 5.10 | e.003 | .043 | - | - | - | - | 1.2 |
| near | Mar.16,1967 | 583 | 1.40 | 70 | 5.96 | e.0035 | .041 | - | - | - | - | 4.2 |
| Covelo | Jan. 5,1965 | 1,440 | 2.91 | 74 | 6.68 | e.005 | .037 | - | - | - | - | 82 |
| | Jan.14,1968 | 2,320 | 3.70 | 79 | 7.95 | e.005 | .036 | - | - | - | - | 280 |
| | Jan.31,1963 | 5,880 | d5.48 | 81 | d13.2 | e.0065 | .034 | - | - | - | - | 3,600 |
| | Dec.22,1964 | 11,300 | d9.41 | 101 | d11.9 | .0065 | .033 | - | - | - | - | 13,200 |
| Short Creek | Dec.18,1962 | 40 | - | - | - | - | - | 62 | 38 | - | - | - |
| near | Jan. 5,1959 | 266 | 1.97 | 32 | 4.22 | e.003 | .029 | - | - | - | - | 116 |
| Covelo | Dec. 1,1960 | 321 | 1.75 | 33 | 5.55 | e.003 | .029 | - | - | - | - | 95 |
| | Feb.11,1961 | 390 | 2.08 | 34 | 5.52 | e.003 | .029 | - | - | - | - | 160 |
| | Feb. 1,1960 | 582 | 2.89 | 37 | 5.44 | e.0035 | .029 | - | - | - | - | 353 |
| | Jan.31,1961 | 684 | 3.24 | 37 | 5.70 | e.0035 | .029 | - | - | - | - | 409 |
| | Dec. 4,1966 | 1,100 | 4.05 | 40 | 6.79 | e.004 | .029 | - | - | - | - | 711 |
| | Jan. 4,1966 | 1,850 | 4.64 | 42 | 9.49 | e.004 | .029 | - | - | - | - | 840 |
| | Dec.22,1964 | 3,600 | d7.1 | 49 | d10.3 | e.005 | .029 | - | - | - | - | 1,950 |
| Mill Creek | aNov.15,1967 | 0 | - | - | - | - | - | 38 | 62 | - | - | b0 |
| near | Dec. 8,1966 | 247 | d0.97 | 102 | d2.49 | e0.0025 | 0.029 | - | - | - | - | 38 |
| Covelo | Jan.31,1968 | 382 | - | - | - | - | - | 39 | 61 | - | - | - |
| | Feb. 2,1967 | 518 | 1.63 | 105 | 3.03 | e.0027 | .029 | - | - | - | - | 191 |
| | Mar.16,1967 | 2,290 | 4.67 | 118 | 4.16 | e.003 | .029 | - | - | - | - | 4,510 |
| | Jan.31,1963 | 8,950 | d9.3 | 118 | d8.15 | e.0032 | .029 | - | - | - | - | 21,100 |
| | Dec.22,1964 | 24,000 | d16.1 | 118 | d12.6 | e.0032 | .029 | - | - | - | - | 54,400 |
| Elk Creek | aNov. 2,1967 | 3.8 | - | - | - | - | - | <1 | 70 | 30 | - | b0 |
| near | aApr.24,1968 | 45 | - | - | - | - | - | 1 | 54 | 37 | 8 | b0 |
| Hearst | Jan.25,1968 | 118 | - | - | - | - | - | 27 | 73 | - | - | - |
| | Mar.12,1968 | 252 | .85 | 77 | 3.84 | .0060 | .044 | 47 | 53 | - | - | 2.2-99 |
| | Jan.31,1968 | 260 | - | - | - | - | - | 27 | 73 | - | - | - |
| | Jan. 7,1966 | 1,170 | 1.29 | 186 | 4.88 | e.0045 | .042 | - | - | - | - | 11-118 |
| | Dec. 5,1966 | 1,980 | 1.73 | 198 | 5.77 | e.0045 | .042 | - | - | - | - | 26-241 |
| | Dec. 4,1966 | 4,670 | 2.75 | 210 | 8.08 | e.0045 | .038 | - | - | - | - | 284-1,280 |
| | Dec.21,1964 | 9,800 | 4.59 | 231 | 9.23 | e.0046 | .035 | - | - | - | - | 3,220-6,710 |
| | Dec.22,1964 | 24,000 | d5.35 | 432 | d10.4 | .0041 | .034 | - | - | - | - | 20,500-27,100 |
| Middle | aNov. 3,1967 | 38 | - | - | - | .0022 | - | 1 | 49 | 50 | - | b0 |
| Fork Eel | Nov.30,1967 | 270 | 2.44 | 48 | 2.31 | .0004 | - | - | - | - | - | b0 |
| River | aDec.13,1967 | 556 | - | - | - | - | - | 1 | 67 | 32 | - | - |
| near | Dec.13,1967 | 556 | 3.02 | 64 | 2.88 | e.0018 | .036 | 1 | 64 | 35 | - | 1.3-1.7 |
| Dos Rios | Jan.22,1968 | 1,740 | 4.25 | 79 | 3.30 | .0018 | .031 | 7 | 93 | - | - | 24-166 |
| | Jan.18,1968 | 3,610 | 5.45 | 126 | 5.25 | .0021 | .032 | 24 | 76 | - | - | 150-1,530 |
| | Feb.21,1968 | 15,800 | 13.15 | 132 | 9.10 | .0025 | .032 | 16 | 84 | - | - | 3,030-9,360 |
| | Jan.15,1968 | 22,500 | d16.0 | 135 | d10.4 | .0027 | .032 | - | - | - | - | 5,740-14,200 |
| | Jan.14,1968 | 40,000 | d21.6 | 145 | d12.7 | .0036 | .032 | - | - | - | - | 22,300-33,400 |
| | Dec.22,1964 | e266,000 | 40.0 | 300 | d22.2 | e.0034 | .032 | - | - | - | - | 74,000-75,000 |

a. Bed-material composition determined for high-water section.
b. Zero bedload movement observed.
c. Bed-material composition determined from subsequent samples.
d. Computed from hydraulic geometry of stream channels (Leopold and Maddock, 1953).
e. Estimated.

## Present Rate of Bedload Discharge

The present bedload discharge, considered representative of hydrologic conditions during the water years 1965 through 1968, was computed for each of the sediment stations by averaging extreme values of bedload discharge from the sediment-transport curves (figs. 20-24) and daily-flow data for the base period 1911-14, 1917-67. The resultant discharges are given in table 9. Annual bedload discharges range from 26 tons per square mile at the Williams Creek site to 630 tons per square mile at the Black Butte River site.

Comparison of data given in table 9 indicates that the sum of bedload transported by several of the larger tributaries greatly exceeds the amount of bedload discharged from the basin near Dos Rios. The measuring section near Dos Rios is relatively narrow compared with other sites in the basin and represents a natural turbulence flume. Because of the increased turbulence, a significant fraction of material transported as bedload at upstream sites probably is lifted into suspension and measured as part of the suspended load at the Dos Rios site. Other factors contributing to the small amount of bedload discharge for the Dos Rios site may include downstream reduction in particle size by attrition, disintegration by atmospheric weathering, and decomposition by chemical reaction.

Table 9.--Present bedload discharge in the Middle Fork Eel River basin

| Station no. | Sediment station | Drainage area (sq mi) | Annual yield | |
|---|---|---|---|---|
| | | | Tons | Tons/sq mi |
| 4728 | Middle Fork Eel River above Black Butte River, near Covelo | 204 | 123,000 | 603 |
| 4729 | Black Butte River near Covelo | 162 | 102,000 | 630 |
| 4730 | Middle Fork Eel River below Black Butte River, near Covelo | 367 | 226,000 | [1]616 |
| 4731 | Williams Creek near Covelo | 30.4 | 780 | 26 |
| 4736 | Short Creek near Covelo | 15.2 | 920 | 60 |
| 4737 | Mill Creek near Covelo | 96.9 | 44,400 | 457 |
| 4738 | Elk Creek near Hearst | 84.1 | 40,700 | 484 |
| 4739 | Middle Fork Eel River near Dos Rios | 745 | 160,000 | 215 |

[1]Average bedload of Black Butte River and Middle Fork Eel River above Black Butte River stations.

## Total Sediment Discharge

Evaluation of total sediment discharge in the Middle Fork Eel River basin was particularly complex, because several of the larger tributaries in upstream areas did not appear to be in equilibrium. During this investigation relative rates of sediment transported in suspension were definitely decreasing toward pre-1964 levels, but it was not apparent whether bedload discharges representative of the postflood period (1965-68) would remain constant or would change significantly. An attempt to determine possible future trends in bedload discharge was made by considering the effect of the December 1964 flood on low-water streambed elevations and on the hydraulic geometry (Leopold and Maddock, 1953) of selected tributaries.

Changes in streambed elevation during 1925-69 (fig. 25) were determined from early plan-profile maps of the Middle Fork Eel River published by the U.S. Geological Survey in 1926 and hydrologic data from low-water streamflow measurements (Hickey, 1969, p. 8-9). These data show that, at gaging stations on the upper Middle Fork Eel River and on the Black Butte River, streambed elevations increased more than 20 feet between 1925 and 1967. Measurements made at the Black Butte River site indicated that most of the increase in elevation occurred in the period immediately following the December 1964 flood. On the Middle Fork Eel River and its tributaries, differences between streambed elevations in 1925 and 1969 generally decreased in a downstream direction resulting in a minimum aggradation of 3 feet near Dos Rios.

Where data were available, the hydraulic geometry of streams in the basin was investigated to determine if significant changes had occurred as a result of the December 1964 flood. Logarithmic graphs of width, depth, and velocity versus water discharge (figs. 26 and 27) were prepared from streamflow-measurement data obtained during 1959-69. Figures 26 and 27 generally show that after the flood event, widths and velocities of the streams were considerably larger and average depths of the streams became shallower at equivalent values of water discharge. Thus, major changes in the hydraulic geometry of the streams have been induced by the December 1964 flood.

Temporarily at least, the postflood addition of thick sediment deposits in upper basin stream channels and increased velocities have increased the capacity of the streams to transport sediment. Present bedload discharges, although higher than preflood rates, will probably decrease in the near future because streambed elevations in 1968 and 1969 (fig. 25) are decreasing from maximum levels in 1967. Bedload discharges, however, should remain high, relative to preflood rates until the postflood deposits have been dissipated or become sufficiently armored. Annual bedload discharge was not weighted according to the frequency of the 1964 flood because the number of years required for the streams to return to preflood conditions was not defined.

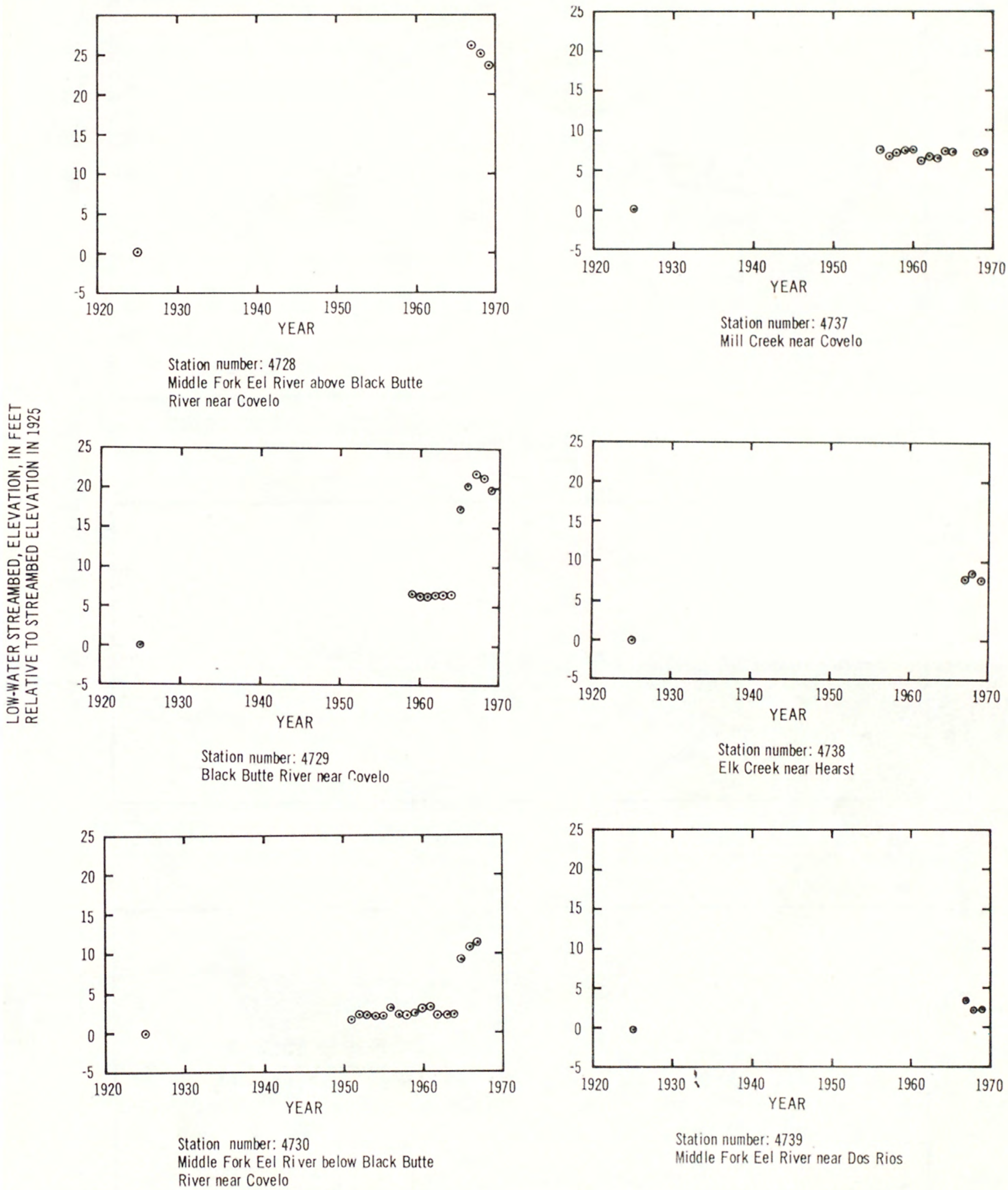


FIGURE 25.--Graphs showing variations in low-water streambed elevation at selected gaging stations in the Middle Fork Eel River basin, 1925-69 (from plan-profile maps of the Middle Fork Eel River published by the U.S. Geological Survey in 1926 (Hickey, 1969) and subsequent streamflow data available in U.S. Geological Survey files).

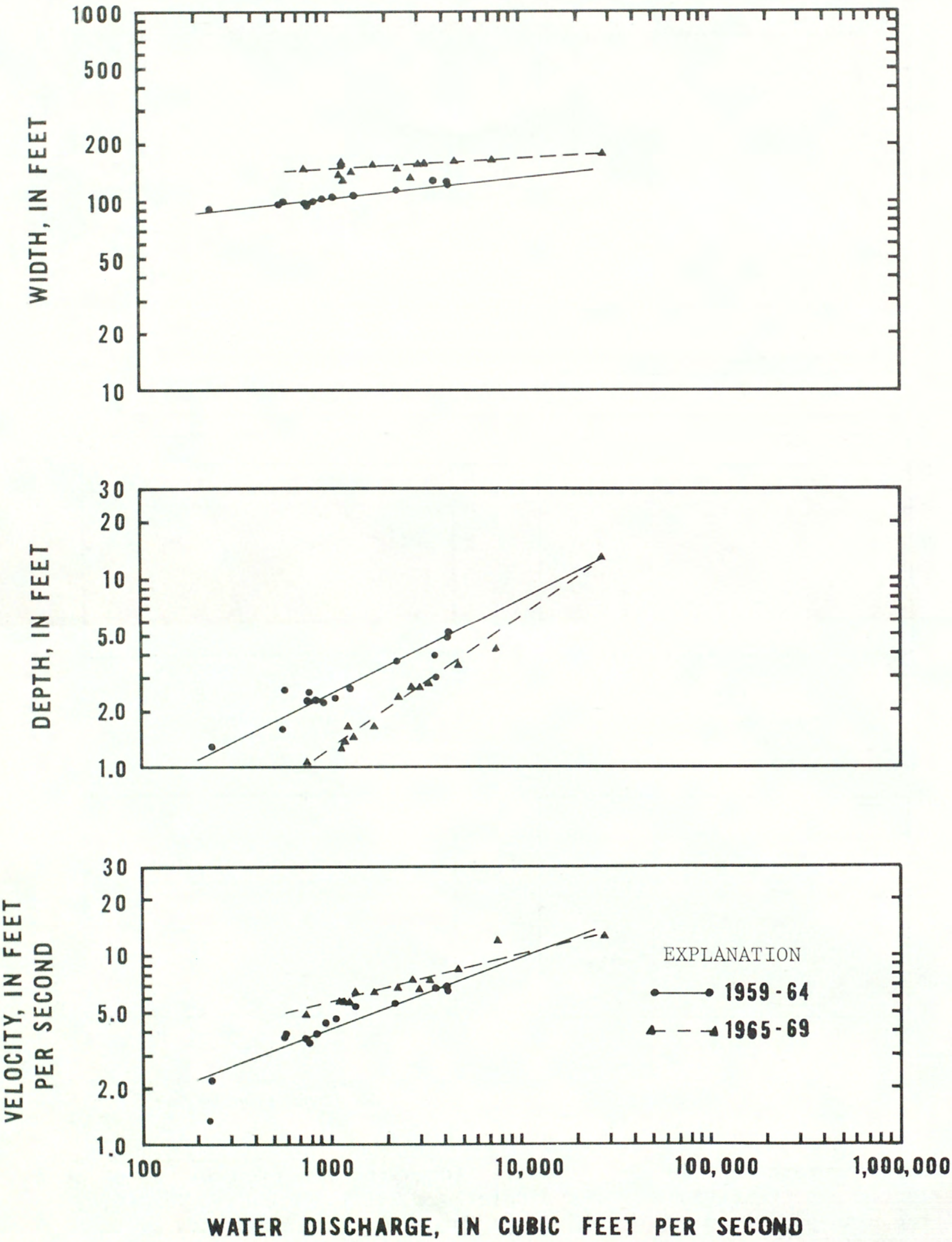


FIGURE 26.--Relation of width, depth, and velocity to water discharge at Black Butte River near Covelo for water years 1959-69.

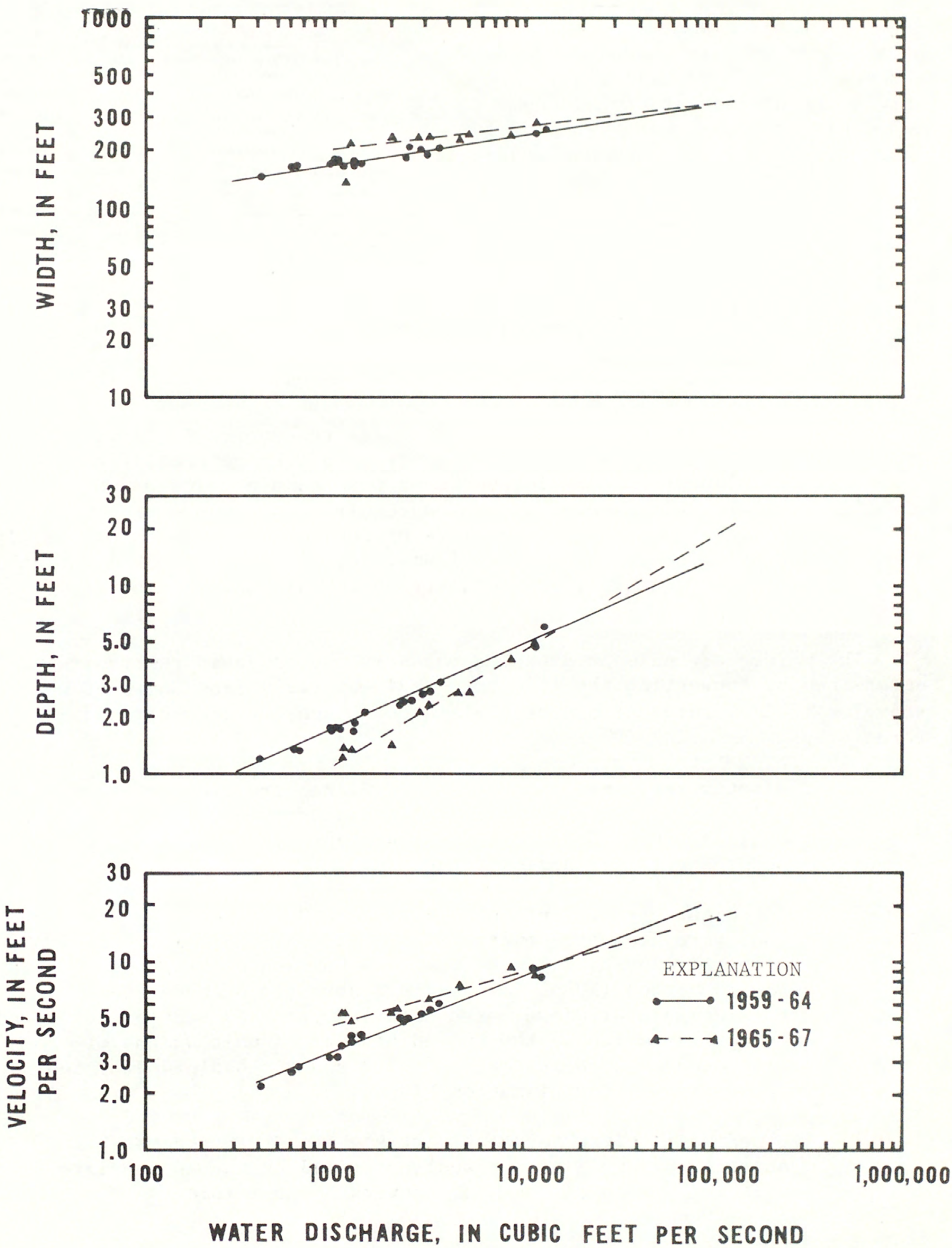


FIGURE 27.--Relation of width, depth, and velocity to water discharge at Middle Fork Eel River below Black Butte River near Covelo for water years 1959-67.

Total sediment discharge (table 10) was computed as the sum of the long-term suspended-sediment and present bedload discharge. Long-term total discharges ranged from 625 tons per square mile per year for Short Creek to 3,760 tons per square mile per year for Elk Creek.

Table 10.--Total sediment discharge in the Middle Fork Eel River basin

| Station number | Sediment station | Drainage area (sq mi) | Annual yield | |
|---|---|---|---|---|
| | | | Tons | Tons/sq mi |
| 4728 | Middle Fork Eel River above Black Butte River, near Covelo | 204 | 628,000 | 3,080 |
| 4729 | Black Butte River near Covelo | 162 | 375,000 | 2,310 |
| 4730 | Middle Fork Eel River below Black Butte River, near Covelo | 367 | 1,000,000 | 2,720 |
| 4731 | Williams Creek near Covelo | 30.4 | 61,300 | 2,020 |
| 4736 | Short Creek near Covelo | 15.2 | 9,500 | 625 |
| 4737 | Mill Creek near Covelo | 96.9 | 153,000 | 1,580 |
| 4738 | Elk Creek near Hearst | 84.1 | 316,000 | 3,760 |
| 4739 | Middle Fork Eel River near Dos Rios | 745 | 2,140,000 | 2,870 |

## RESERVOIR SEDIMENTATION

Accumulation of sediment in water-storage reservoirs is inevitable and is an important factor in the design of such storage facilities. A design, which allocates space for sediment to accumulate and which considers the effect of sedimentation on required water-diversion structures, will prolong the useful life of the facility and should result in lower operating costs. The most significant factors of sedimentation usually include the quantity of and distribution of sediment in the reservoir.

The volume of sediment expected to enter the proposed reservoirs was determined by converting the long-term sediment yield from units of weight to volume. Conversion of sediment yield to volume was accomplished in three steps.

1. The total sediment yield was divided into fractions of clay, silt, sand, and bedload on the basis of numerous particle-size analyses (U.S. Geol. Survey, ann. repts.), which were weighted according to streamflow frequency.

2. Unit weight coefficients of 35, 71, and 97 pounds per cubic foot were used to convert clay, silt, and sand yields, respectively, to volume. These coefficients, proposed by Lara and Pemberton (1965) for use in reservoirs of moderate to considerable drawdown, were compiled from 462 samples collected in 21 reservoirs in the United States. A unit weight of 119 pounds per cubic foot was used for the bedload fraction (U.S. Bureau of Reclamation, 1960b, p. 97).

3. The sediment volume for each particle-size fraction was obtained by dividing the sediment yield by the appropriate unit weight and dimensional conversion coefficients.

Predictions of sediment distribution in the proposed reservoirs were based on the area-reduction method described by Borland and Miller (1958). This method, developed from observed sediment accumulation in 30 reservoirs, assumes that sedimentation is related to reservoir shape and that many reservoirs can be classified into standard types (fig. 28). Standard classifications include gorge (type IV), hill (type III), flood plain-foothill (type II), and lake (type I) reservoirs. Gorge reservoirs are characterized by small increases in capacity with depth; in contrast, lake reservoirs exhibit large increases in capacity with depth. Sediment distribution within a reservoir is predicted by prorating the amount of sediment inflow for a specified period, usually 100 years, according to a representative distribution curve (fig. 29).

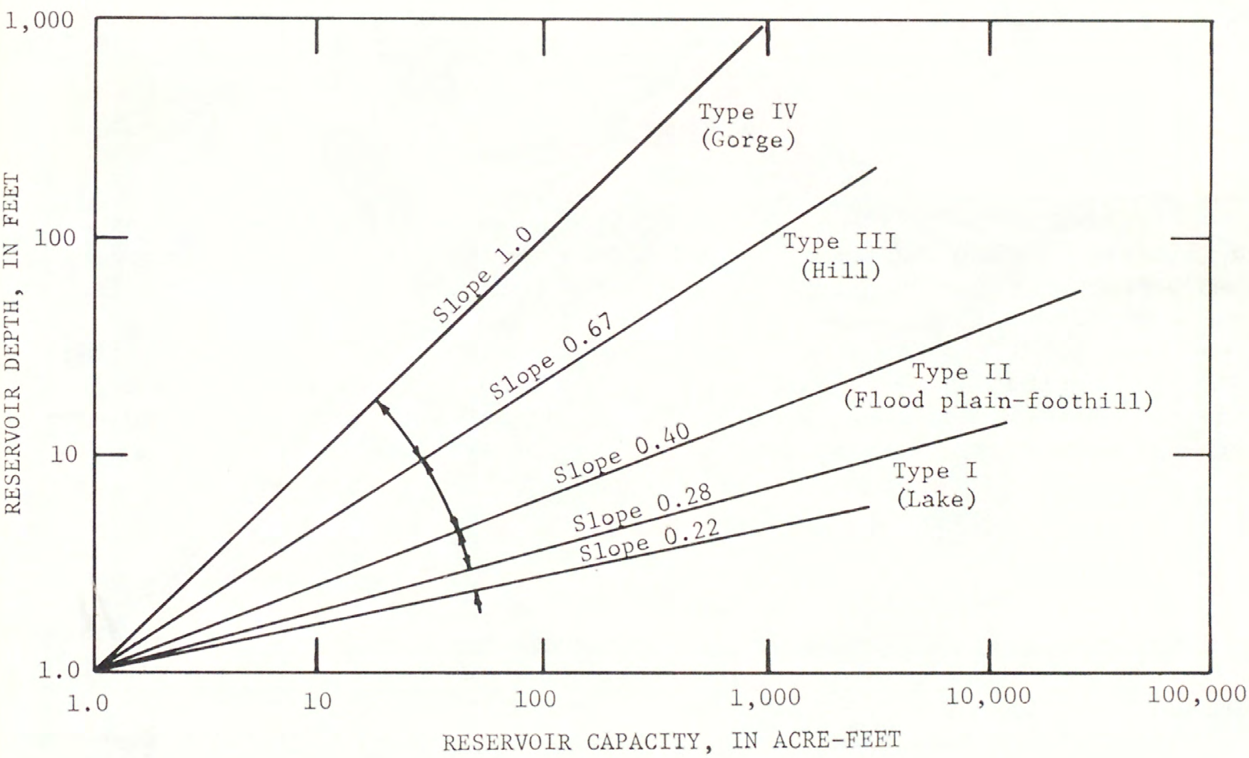


FIGURE 28.--Relation of depth to capacity for standard reservoir types (Borland and Miller, 1958).

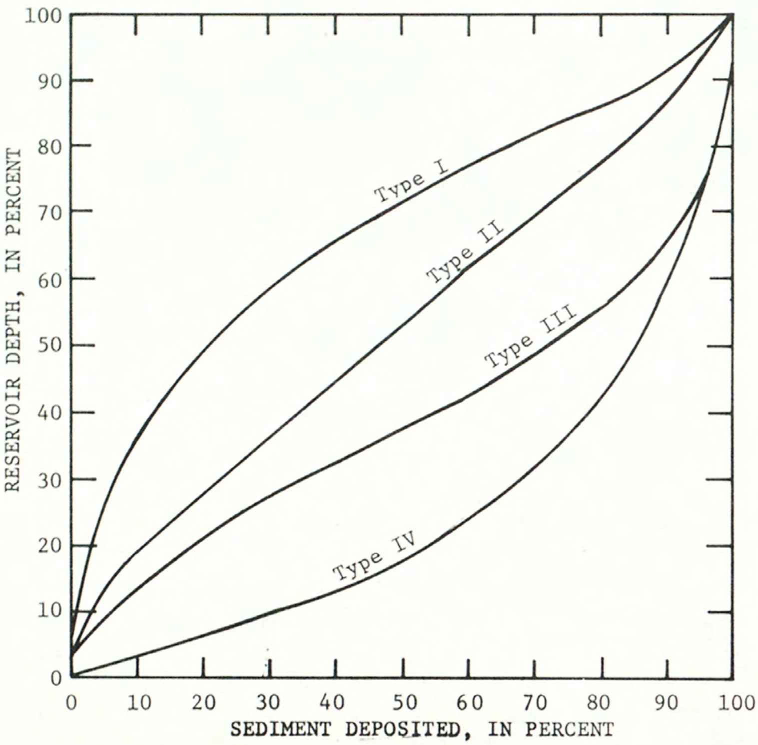


FIGURE 29.--Relation of depth to sediment distribution for standard reservoir types (Borland and Miller, 1958).

Sedimentation in specific arms of the large Dos Rios Reservoir was determined by dividing the reservoir into segments (fig. 30) and computing sediment volume for each segment. Sediment distribution in the segments was computed from area-capacity data (California Department of Water Resources files) for various sites within the Middle Fork Eel River basin. Sediment-inflow data were extrapolated from existing sediment stations. Sedimentation in the small Dos Rios Reservoir was not divided into segments because sufficient area-capacity data were not available.

## Large Dos Rios Reservoir

### Description of Reservoir

The large Dos Rios Reservoir (fig. 30) would impound 7,600,000 acre-feet of water and inundate about 40,000 acres (California Department of Water Resources, 1969) below an elevation of 1,602 feet above m.s.l. This reservoir would inundate the present boundaries of Covelo and the adjacent valley (fig. 1). The reservoir would be narrow along the Middle Fork Eel River and relatively wide in the Mill Creek arm. Reservoir levels would fluctuate between elevations of 1,425 and 1,602 feet above m.s.l. (California Department of Water Resources, 1970), with the latter elevation representing average conditions during winter months.

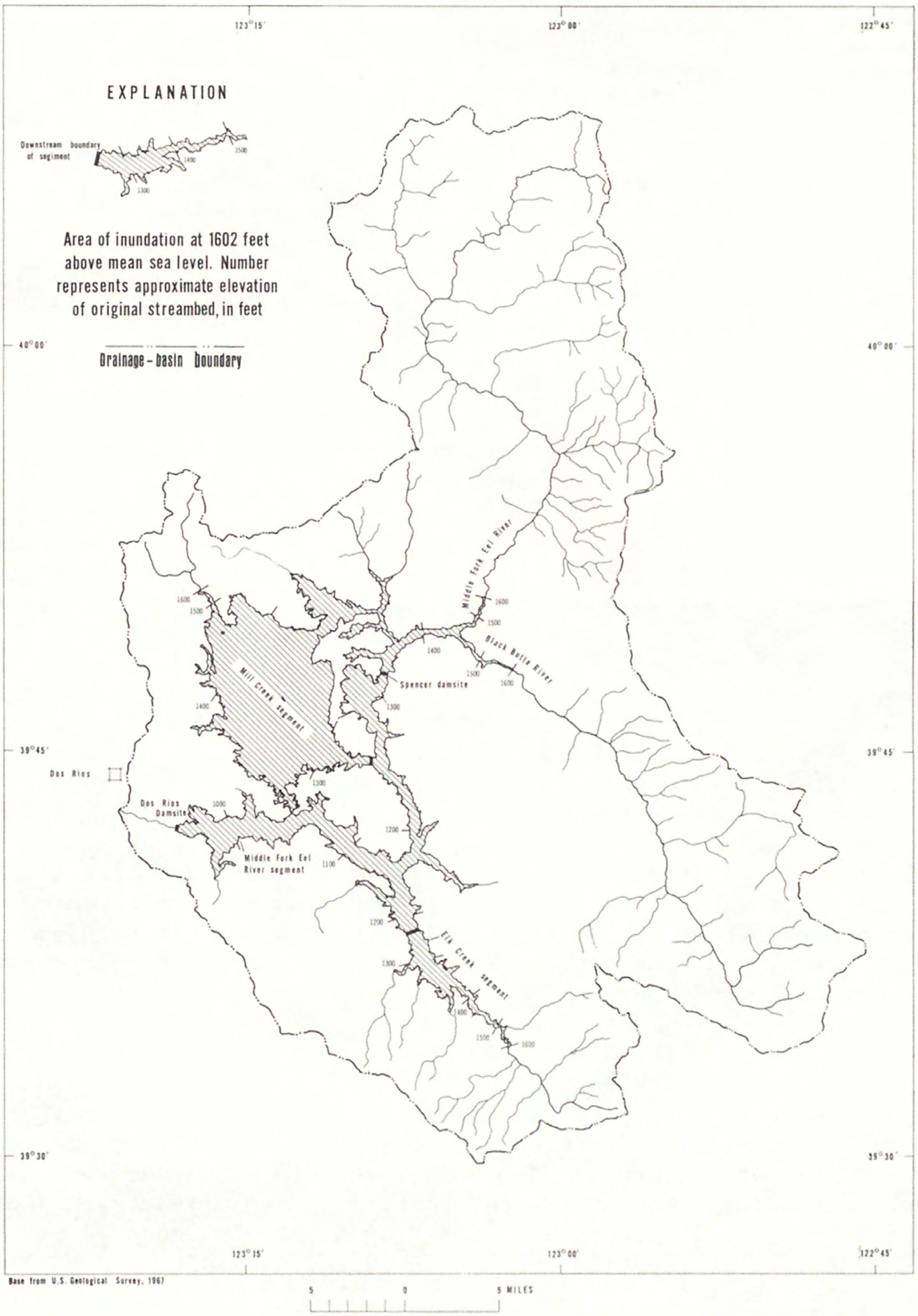


FIGURE 30.--Large Dos Rios Reservoir, Mendocino County.

## Sediment Inflow

Most of the sediment contributed to the proposed reservoir site is derived from areas where long-term sediment-transport data are available (table 10). Sediment yield from the remaining areas (about 20 percent) was estimated from unit rates determined for adjacent gaging stations. Sediment-transport rates for the entire drainage (table 11) were divided into clay, silt, sand, and bedload fractions according to particle size. Representative particle sizes of the bedload fractions were not determined but probably range between fine sand (0.062 mm) and coarse gravel (512 mm). A comparison of basinwide sediment yield computed from upstream stations, with long-term sediment yields for the Dos Rios station, indicates less material in the clay through sand sizes (<2.0 mm) and more coarse material at upstream stations than at Dos Rios. Although an apparent imbalance between fine and coarse material may be the result of normal errors inherrent in sampling or in extension of short-term data, an imbalance is assumed to exist because of the extensive changes observed in the basin since the December 1964 flood. Finer material transported as bedload at upstream stations probably is suspended by increased turbulence occurring at the Dos Rios sediment station and is included in the sand fraction of the suspended load at the downstream station. Another factor that may contribute to an imbalance in the basin is the high rate of disintegration of coarse sediment deposits observed in some tributaries. Significant amounts of bed material occurring in the streambed near the Elk Creek gaging station are extremely susceptible to disintegration when exposed to the atmosphere (fig. 31). Such an accelerated reduction of coarse material to sand sizes may be responsible for an increase in suspended load downstream at the expense of bedload. This phenomena has been observed throughout North Coastal basins in California and similar occurrences in Washington have been described by Glancy (1971).

Volumetric data for the Middle Fork Eel River near Dos Rios (table 11) indicate that sediment inflow to the large Dos Rios Reservoir would consist of 43 percent clay, 34 percent silt, and 23 percent sand and gravel. The weighted average unit weight of sediment deposits in the reservoir would be about 62 pounds per cubic foot.

Sediment inflow to the large Dos Rios Reservoir, computed from sediment discharges for the entire Middle Fork Eel River basin, would total about 157,000 acre-feet for a 100-year period. This inflow is representative of the maximum amount of sediment contributed to the reservoir because some areas within the reservoir will be permanently submerged and will not be exposed to erosion. No correction, however, was applied to the sediment inflow for either the large or small Dos Rios Reservoirs because operational data were tentative at the time of this study and many alternative proposals were under consideration.

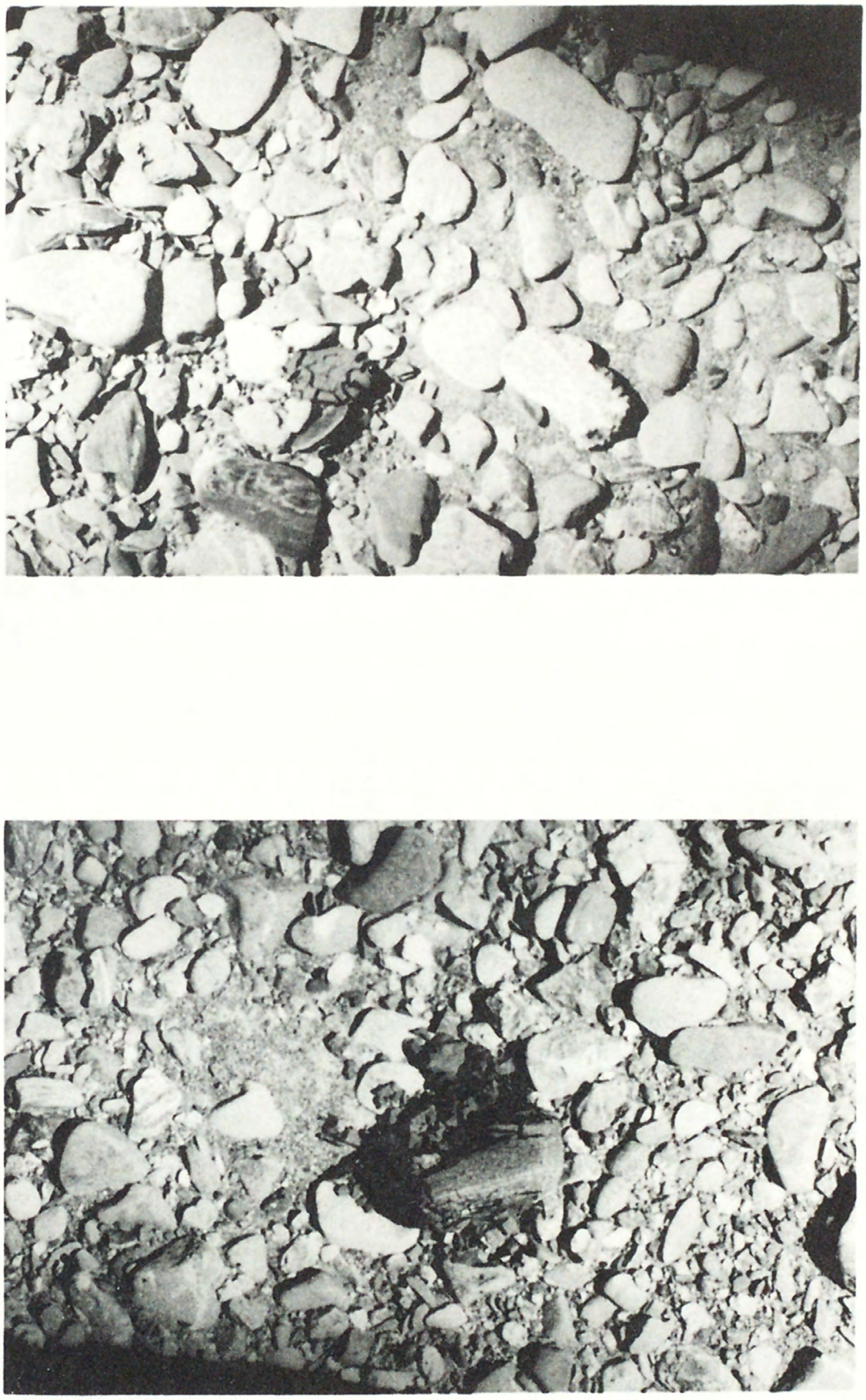

FIGURE 31.--Disintegrated fragments of bed material in the streambed of Elk Creek.

## Distribution of Sediment

Examination of data in table 11 indicates that nearly half of the sediment would enter the proposed reservoir near the confluence of the Black Butte and Middle Fork Eel Rivers. Elk Creek and tributaries downstream from the mouth of Mill Creek would contribute a large part of the remainder. Mill Creek, on the other hand, should supply a relatively small quantity of sediment to the reservoir.

Table 11.--Basinwide sediment inflow to proposed Dos Rios Reservoir

| Basin | Drainage area (sq mi) | Annual sediment inflow | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Clay | Silt | Sand | Bedload | Total | Clay | Silt | Sand | Bedload | Total |
| | | (Tons) | | | | | (Acre-feet) | | | | |
| Middle Fork Eel River below Black Butte River gaging station | 367 | 231,000 | 292,000 | 255,000 | 225,000 | 1,003,000 | 303 | 189 | 121 | 87 | 700 |
| Drainage between gaging station and Williams Creek | 7 | 4,400 | 5,600 | 4,800 | 4,300 | 19,100 | 5.8 | 3.6 | 2.3 | 1.9 | 13.6 |
| Williams Creek at mouth | 31 | 17,000 | 20,300 | 24,400 | 800 | 62,500 | 22 | 13 | 12 | .3 | 47.3 |
| Drainage between Williams Creek and Mill Creek | 21 | 13,200 | 16,700 | 14,400 | 12,800 | 57,100 | 17 | 11 | 6.8 | 5.0 | 39.8 |
| Mill Creek at mouth | 100 | 34,200 | 43,800 | 34,500 | 45,700 | 158,200 | 45 | 28 | 16 | 18 | 107 |
| Drainage between Mill Creek and Elk Creek | 57 | 51,000 | 74,700 | 60,400 | 27,400 | 213,500 | 67 | 48 | 29 | 10 | 154 |
| Elk Creek at mouth | 115 | 103,000 | 151,000 | 122,000 | 55,700 | 431,700 | 135 | 98 | 58 | 21 | 312 |
| Drainage between Elk Creek and Dos Rios gaging station | 47 | 42,100 | 61,600 | 49,800 | 22,600 | 176,100 | 55 | 40 | 24 | 8.5 | 127.5 |
| Total | 745 | 495,900 | 665,700 | 565,300 | 394,300 | 2,121,200 | 649.8 | 430.6 | 269.1 | 151.7 | 1,501.2 |
| Middle Fork Eel River gaging station near Dos Rios | 745 | 513,000 | 830,000 | 636,000 | 160,000 | 2,139,000 | 672 | 536 | 301 | 62 | 1,573 |

The probable distribution of sediment within the reservoir was investigated by dividing the reservoir into three segments represented by parts of the Elk Creek, Mill Creek, and Middle Fork Eel River arms. Each segment was classified by standard type (figs. 28 and 32) and sediment inflow was prorated according to standard distribution curves. The time interval considered for sediment deposition corresponds to the first 100 years of operation with a normal water surface at 1,602 feet above m.s.l.

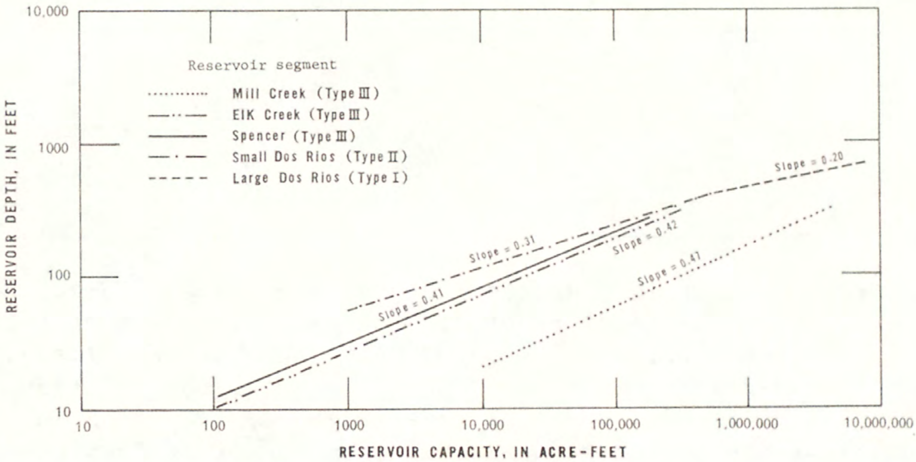


FIGURE 32.--Relation of depth to original capacity for Dos Rios Reservoir segments.

The Elk Creek segment (fig. 30) receives inflow from 70 percent of the Elk Creek drainage and constitutes about 4.4 percent of the storage capacity of the proposed reservoir. Depth-capacity data for this segment indicate a standard shape similar to a type III (hill) reservoir (fig. 32). Sediment inflow, for the first 100 years, would approximate 22,000 acre-feet or 14 percent of the total inflow to the reservoir. Distribution curves (fig. 33) indicate that most of the sediment would be deposited in the lower levels below 1,400 feet above m.s.l. Sediment deposits in this segment would occupy less than 10 percent of the original capacity above the 1,500-foot level and would be about 17 feet thick at the downstream boundary (table 12).

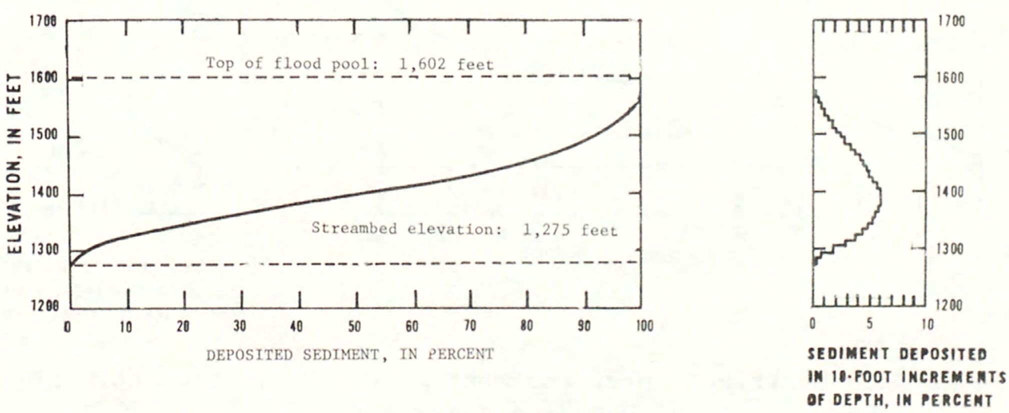


FIGURE 33.--Distribution of sediment in the Elk Creek segment of Dos Rios Reservoir.

Table 12.--Original capacity and projected volume of sediment deposited in the Elk Creek segment in the first 100 years of operation

| Elevation (feet) | Original capacity (acre-feet) | Volume of sediment in interval (acre-feet) | Loss of capacity in interval (percent) |
|---|---|---|---|
| 1,602 | 335,000 | 0 | 0 |
| 1,600 | 330,000 | 220 | .2 |
| 1,550 | 230,000 | 1,500 | 1.7 |
| 1,500 | 140,000 | 3,600 | 6.2 |
| 1,450 | 82,000 | 5,500 | 14 |
| 1,400 | 42,000 | 6,200 | 22 |
| 1,350 | 14,000 | 3,100 | 28 |
| 1,320 | 3,000 | 1,400 | 61 |
| 1,300 | 700 | 360 | 88 |
| 1,292 | 290 | 290 | 100 |
| 1,275 | 0 | | |

Table 13.--Original capacity and projected volume of sediment deposited in the Mill Creek arm of large Dos Rios Reservoir in the first 100 years of operation

| Elevation (feet) | Original capacity (acre-feet) | Volume of sediment in interval (acre-feet) | Loss of capacity in interval (percent) |
|---|---|---|---|
| 1,602 | 4,120,000 | 0 | 0 |
| 1,600 | 4,100,000 | 110 | .0 |
| 1,550 | 3,000,000 | 750 | .1 |
| 1,500 | 2,000,000 | 1,800 | .2 |
| 1,450 | 1,200,000 | 2,700 | .4 |
| 1,400 | 500,000 | 3,000 | .8 |
| 1,350 | 100,000 | 1,500 | 1.8 |
| 1,320 | 18,000 | 620 | 3.5 |
| 1,300 | 400 | 160 | 53 |
| 1,290 | 100 | 51 | 52 |
| 1,281 | 1 | 1 | 100 |
| 1,280 | 0 | | |

The Mill Creek segment is characterized by an extremely large storage capacity (54 percent of the total reservoir) and a small sediment inflow, amounting to 11,000 acre-feet in 100 years. Although surface dimensions of the Mill Creek and Elk Creek segment seem unrelated, the relation between depth and capacity is about the same (fig. 32) resulting in a type III shape classification for both. Distribution of sediment would be identical in terms of sediment inflow percentage but thickness of sediment deposits would be much less in the Mill Creek segment (fig. 34). Data in table 13 indicate that loss of capacity through sedimentation would be insignificant and that very little of the sediment inflow would be transported beyond the downstream boundary of the segment in 100 years.

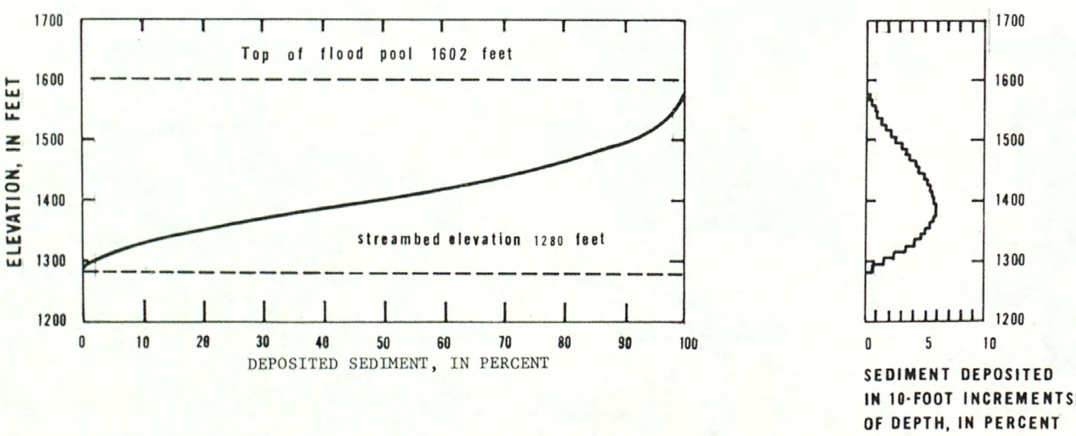


FIGURE 34.--Distribution of sediment in the Mill Creek segment of Dos Rios Reservoir.

The Middle Fork Eel River segment includes storage along the Black Butte and Middle Fork Eel Rivers and the lower part of Elk Creek. This segment would received about 124,000 acre-feet of sediment in the first 100 years or 80 percent of the total sediment inflow to the reservoir. Most of the sediment would enter at the upstream end near the present confluence of the Black Butte and Middle Fork Eel Rivers. Sedimentation upstream from the proposed Spencer damsite (fig. 30) was evaluated from depth-capacity data for Spencer Reservoir (fig. 32). Distribution of sediment in the remainder of the segment was determined from total distribution data for the entire reservoir minus sediment accumulation in each of the upper segments.

Coarse sediment entering from the upstream end of the reservoir would settle in the Middle Fork Eel River channel upstream from Spencer damsite (fig. 30). A large delta would probably form between the 1,480 to 1,580-foot levels (fig. 35). The silt and clay fraction of the sediment inflow would be uniformly distributed downstream with only the finest clays reaching the dam. The slight increase of sediment shown in figure 35, from the 1,350 to 1,280-foot levels, probably indicates a slight damming of sediment at the intersection of Elk Creek with the main stem. Sediment deposits in this segment would occupy less than 10 percent of the original capacity above the 1,200-foot level and would fill the channel at the dam to the 931-foot level (table 14).

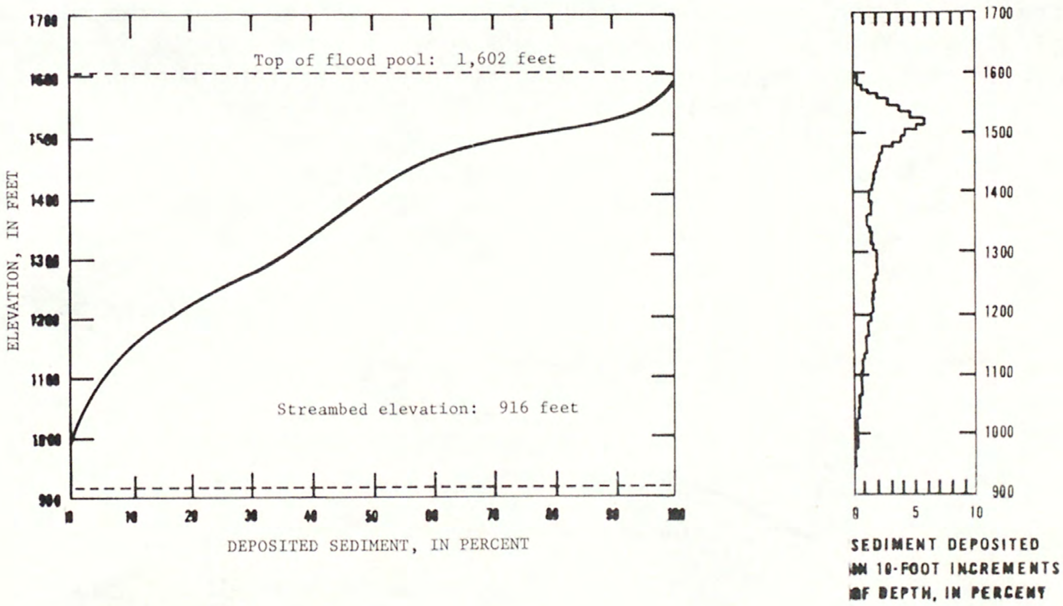


FIGURE 35.--Distribution of sediment in the Middle Fork Eel River segment of Dos Rios Reservoir.

Table 14.--Original capacity and projected volume of sediment deposited in the Middle Fork Eel River arm of large Dos Rios Reservoir in the first 100 years of operation

| Elevation (feet) | Original capacity (acre-feet) | Volume of sediment in interval (acre-feet) | Loss of capacity in interval (percent) |
|---|---|---|---|
| 1,602 | 3,140,000 | 0 | 0 |
| 1,600 | 3,100,000 | 4,800 | .7 |
| 1,550 | 2,400,000 | 27,900 | 4.6 |
| 1,500 | 1,800,000 | 19,900 | 4.0 |
| 1,450 | 1,300,000 | 10,900 | 3.2 |
| 1,400 | 960,000 | 8,000 | 2.5 |
| 1,350 | 640,000 | 4,700 | 3.6 |
| 1,320 | 510,000 | 3,700 | 6.2 |
| 1,300 | 450,000 | 4,600 | 6.6 |
| 1,280 | 380,000 | 7,400 | 7.4 |
| 1,250 | 280,000 | [1]10,500 | [1]9.5 |
| 1,200 | 170,000 | [1]8,300 | [1]10 |
| 1,150 | 88,000 | 6,100 | 13 |
| 1,100 | 40,000 | 4,200 | 17 |
| 1,050 | 15,000 | 2,400 | 22 |
| 1,000 | 4,200 | 990 | 28 |
| 950 | 610 | 68 | 17 |
| 940 | 200 | 34 | 19 |
| 931 | 18 | 18 | 100 |
| 916 | 0 | | |

[1]Data reported for intervals between 1,150 and 1,280 feet elevation include sediment deposited in lower Mill and Elk Creek arms.

Table 15.--Original capacity and projected volume of sediment deposited in the large Dos Rios Reservoir in the first 100 years of operation

| Elevation (feet) | Original capacity (acre-feet) | Volume of sediment in interval (acre-feet) | Loss of capacity in interval (percent) |
|---|---|---|---|
| 1,602 | 7,600,000 | 0 | 0 |
| 1,600 | 7,500,000 | 5,100 | .3 |
| 1,550 | 5,600,000 | 30,100 | 1.8 |
| 1,500 | 3,900,000 | 25,200 | 1.9 |
| 1,450 | 2,600,000 | 19,100 | 1.7 |
| 1,400 | 1,500,000 | 17,200 | 2.3 |
| 1,350 | 750,000 | 15,100 | 5.0 |
| 1,300 | 450,000 | 5,400 | 7.7 |
| 1,280 | 380,000 | 7,400 | 7.4 |
| 1,250 | 280,000 | 10,500 | 9.5 |
| 1,200 | 170,000 | 8,300 | 10 |
| 1,150 | 88,000 | 6,100 | 16 |
| 1,100 | 49,200 | 4,200 | 12 |
| 1,050 | 15,000 | 2,400 | 22 |
| 1,000 | 4,200 | 990 | 28 |
| 950 | 610 | 68 | 17 |
| 940 | 200 | 34 | 19 |
| 931 | 18 | 18 | 100 |
| 916 | 0 | | |

Composited depth-capacity data for the entire reservoir (fig. 32) indicate that sediment inflow would be primarily deposited in upper elevations as in a type I standard reservoir. Distribution curves of deposited sediment (fig. 36) closely resemble those of the Middle Fork Eel River segment, which receives nearly 80 percent of the total sediment inflow. Sediment deposited in the Elk and Mill Creek segments would be concentrated at lower elevations than sediment deposited along the Middle Fork Eel River. Only minor amounts of sediment, however, would be transported beyond the boundaries of the Elk and Mill Creek segments. Sediment deposits would occupy less than 10 percent of the original capacity above the 1,200-foot level and less than 25 percent above the 940-foot level (table 15). The original capacity of the entire reservoir would be reduced about 2.1 percent after the first 100 years of operation. Reservoir shape and sediment distribution patterns would not appreciably change during this period (fig. 36).

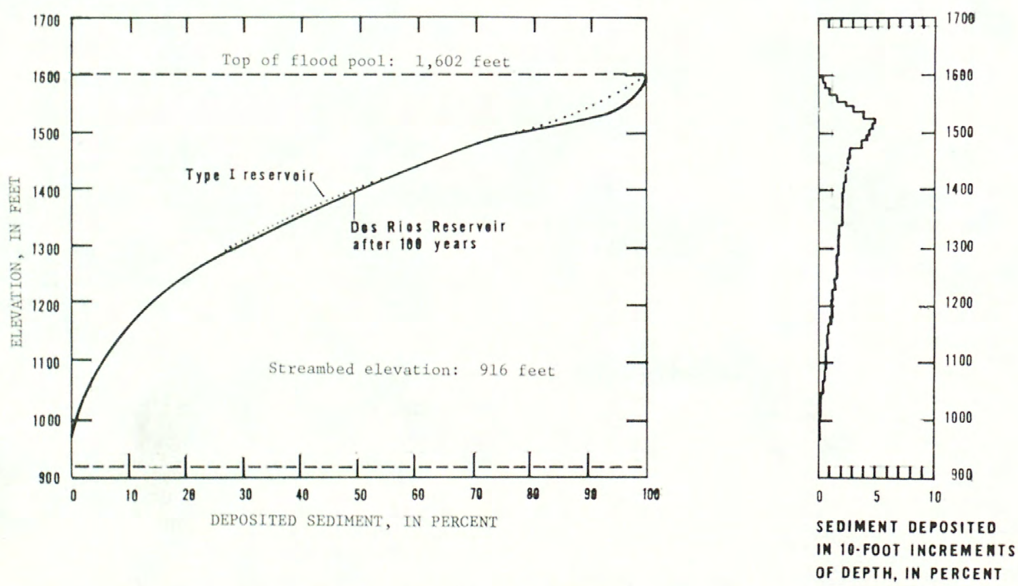


FIGURE 36.--Distribution of sediment in the large Dos Rios Reservoir.

### Trap Efficiency

The characteristic of a reservoir to retain sediment, expressed as a percentage of the sediment inflow, is referred to as its trap efficiency. The trap efficiency is affected by many factors, such as the ratio of reservoir storage capacity to inflow, channel slope, sediment properties, water chemistry, turbidity currents, and reservoir operation. A trap efficiency of 98 percent was estimated for the large Dos Rios Reservoir by comparing its capacity-inflow ratio with those of other reservoirs in the United States. Trap efficiencies of these reservoirs, compiled by Brune (1953, p. 407-418), were obtained by direct measurement of sediment inflow and outflow. An adjustment of the quantity and distribution of deposited sediment inflow was not made because the estimate of trap efficiency was nearly 100 percent.

The volume of sediment remaining within the physical boundaries of the reservoir would also be affected by the mode of reservoir operation and additional adjustments of the sediment inflow should be made for the final reservoir design. Sediment inflow to the large Dos Rios Reservoir should be reduced about 5 percent for such factors as the quantity of sediment deposited in tributary arms above the maximum lake level and reduction in erosion from areas that are submerged during storm periods. It is also possible that a large adjustment will be required for increases in sediment yield from landslide and slump areas adjacent to the shoreline of the reservoir.

## Small Dos Rios Reservoir

### Description of Reservoir

The small Dos Rios Reservoir (fig. 37) would impound 536,000 acre-feet of water and would inundate 4,300 acres of canyon lands (California Department of Water Resources, 1969) below an elevation of 1,320 feet above m.s.l. This reservoir would submerge about 700 acres in low valley areas near the town of Covelo. The reservoir would be relatively narrow and sinuous in the upper reaches and would extend about 25 miles upstream from the dam. Water levels are expected to fluctuate between elevations of 1,270 and 1,320 feet above m.s.l. (California Department of Water Resources, 1970), with the latter elevation representing average conditions during winter months.

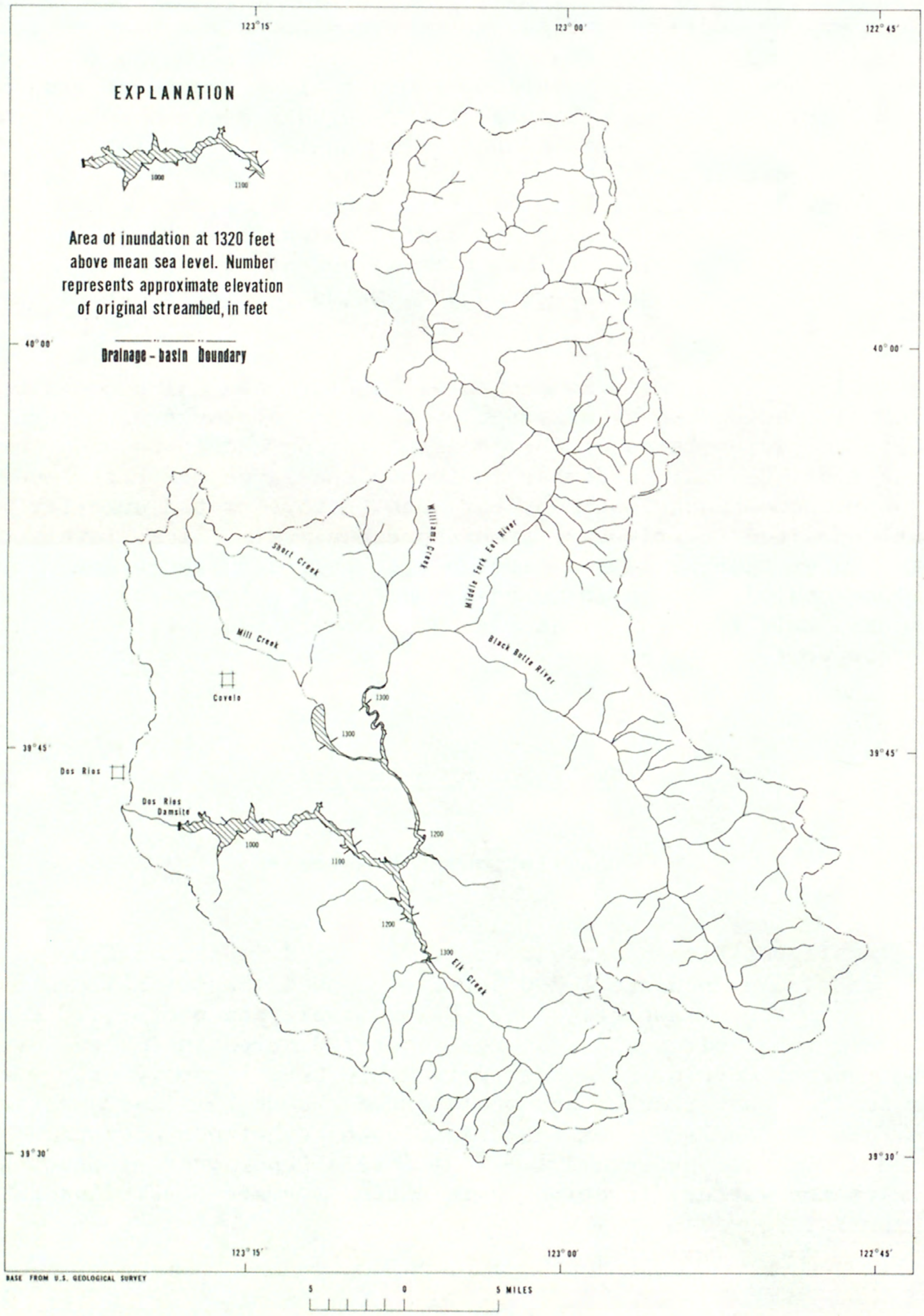


FIGURE 37.--Small Dos Rios Reservoir, Mendocino County.

## Distribution of Sediment

Original depth-capacity data for the small Dos Rios Reservoir (fig. 32) indicate that most sediment inflow would be distributed in intermediate elevations similar to a type II standard reservoir. Sediment-distribution curves (fig. 38), indicate that sediment would be uniformly deposited from the 1,100 to 1,290-foot levels. The volume of sediment deposited below 1,092 feet, although low in percentage (fig. 38), is equivalent to the original capacity of the reservoir at that elevation and indicates a complete loss of storage (table 16). Sediment would occupy about 29 percent of the total original reservoir capacity at the end of the first 100 years of operation. Reservoir shape and sedimentation characteristics would be significantly changed and would be comparable to that of a type I reservoir.

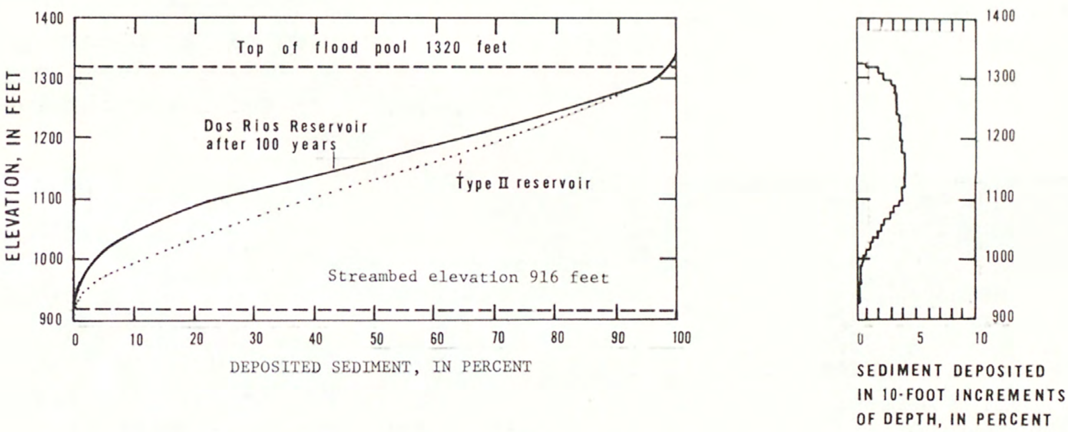


FIGURE 38.--Distribution of sediment in the small Dos Rios Reservoir.

Table 16.--Original capacity and projected volume of sediment deposited in the small Dos Rios Reservoir in the first 100 years of operation

| Elevation (feet) | Original capacity (acre-feet) | Volume of sediment in interval (acre-feet) | Loss of capacity in interval (percent) |
|---|---|---|---|
| 1,320 | 536,000 | | |
| | | 4,300 | 5.0 |
| 1,300 | 450,000 | | |
| | | 22,400 | 13 |
| 1,250 | 280,000 | | |
| | | 28,400 | 26 |
| 1,200 | 170,000 | | |
| | | 30,900 | 38 |
| 1,150 | 88,000 | | |
| | | 31,200 | 65 |
| 1,100 | 40,200 | | |
| | | 4,900 | 96 |
| 1,092 | 35,100 | | |
| | | 35,100 | 100 |
| 916 | 0 | | |

### Trap Efficiency

Trap efficiency of the small Dos Rios Reservoir, estimated by comparing capacity-inflow data with that of other reservoirs (Brune, 1953, p. 407-418) would be 96 percent. Predicted changes in reservoir shape and sedimentation characteristics during the first 100 years of operation would lower the trap efficiency to about 95 percent. Sediment inflow was not adjusted to compensate for the quantity of sediment discharged from the reservoir.

Sediment inflow to the small Dos Rios Reservoir should be reduced about 2 percent for such factors as the quantity of sediment deposited in tributary arms above the maximum lake level and reduction in erosion from areas that are submerged during storm periods. A major adjustment would probably be required for increases in sediment yield to the small Dos Rios Reservoir from landslides and slumps adjacent to the shoreline. Recent studies by the California Department of Water Resources (R. F. Clawson, written commun., 1970) suggest that slow-moving landslides or slumps could contribute as much as 115,000 acre-feet of sediment to the reservoir in the first 100 years of operation.

## SUMMARY

Suspended-sediment data collected from 1956 to 1968 indicate that the quantity of sediment transported by streams in the Middle Fork Eel River basin is extremely variable. Annual suspended-sediment discharge for the Middle Fork Eel River near Dos Rios (proposed Dos Rios damsite) ranged from 777 to 25,100 tons per square mile during the period of record.

The historic storm and the resulting flood of December 1964 was responsible for subsequent sediment-transport rates several times larger than prevailed before the flood. Suspended-sediment records for sites established prior to the flood indicate that present suspended-sediment discharges are progressively decreasing and that preflood conditions may be reached within 5 to 10 years after the flood. Postflood bedload discharges are presently at high levels relative to preflood rates. Massive deposits of coarse material, added to stream channels in the upper basin since the 1964 flood, have altered greatly the hydraulic characteristics of major tributaries and have resulted in an increased capacity of the streams to transport sediment. Large bedload discharges will persist until the coarse sediment deposits are dissipated or until the channel becomes sufficiently armored to resist erosion.

Long-term total-sediment discharge for sampling sites in the basin ranged from 625 tons per square mile per year for Short Creek to 3,760 tons per square mile per year for Elk Creek . Long-term sediment discharge for the entire basin averaged 2,870 tons per square mile per year as determined from data for Middle Fork Eel River near Dos Rios.

Sediment inflow to the proposed Dos Rios Reservoir would be about 2,140,000 tons or 1,570 acre-feet per year using an average unit weight of 62 pounds per cubic foot. Average composition of deposited sediment would be about 43 percent clay, 34 percent silt, and 23 percent sand and gravel.

Most of the sediment deposited in the large Dos Rios Reservoir during the first 100 years of operation would be distributed in elevations of the reservoir above the 1,350-foot level. Sediment would occupy less than 10 percent of the original reservoir capacity above the 1,200-foot level and would reduce the capacity of the entire reservoir 2.1 percent. Sediment would accumulate to a depth of about 15 feet behind the dam and characteristics of sediment distribution within the reservoir would be relatively unchanged from those of the original reservoir.

Sediment deposited in the small Dos Rios Reservoir would be distributed uniformly between the 1,100 and 1,290-foot levels. Sediment deposits near the dam would approach a thickness of about 180 feet after 100 years of operation and would occupy 100 percent of the original reservoir capacity below the 1,092-foot level. The original capacity of the reservoir would be reduced about 29 percent resulting in significant changes in sediment distribution.

## SELECTED REFERENCES

Anderson, H. W., 1968, Major flood effect on subsequent suspended sediment discharge (abs.): Am. Geophys. Union Trans., v. 49, no. 1, p. 175.

Bailey, E. H., Irwin, W. P., and Jones, D. L., 1964, Franciscan and related rocks and their significance in the geology of western California: Calif. Div. of Mines and Geology, Bull. 183, 165 p.

Borland, W. M., and Miller, C. R., 1958, Distribution of sediment in large reservoirs: Am. Soc. of Civil Engineers Proc., Paper 1587, 18 p.

Brown, W. M., III, and Ritter, J. R., 1971, Sediment transport and turbidity in the Eel River basin, California: U.S. Geol. Survey Water-Supply Paper 1986 (in press).

Brune, G. M., 1953, Trap efficiency of reservoirs: Am. Geophys. Union Trans., v. 34, p. 407-418.

California Department of Water Resources, 1969, Eel River development alternatives: Bull. 172, 36 p.

______1970, Eel River development alternatives; supporting studies: Bull. 172, 120 p.

Glancy, P. A., 1971, Sediment transport by streams in the Chehalis River basin, Washington: U.S. Geol. Survey Water-Supply Paper 1798H (in press).

Hawley, N. L., and Jones, B. L., 1969, Sediment yield of coastal basins in northern California, 1958-64: U.S. Geol. Survey open-file rept., 19 p.

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

Lara, J. M., and Pemberton, E. L., 1965, Initial unit weight of deposited sediments: Federal Inter-Agency Sedimentation Conference Proc., 1963, Paper 82, p. 818-845.

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

Limerinos, J. T., 1969, Determination of the Manning coefficient from measured bed roughness in natural channels: U.S. Geol. Survey open-file rept., 87 p.

Pashinskiy, A. F., 1964, Experience of the study of alluvial deposits of the Prezuapse River: Soviet Hydrology; Selected Papers no. 3, (Trudy GGI), no. 111, 1964, p. 156-173.

Rantz, S. E., 1964, Surface-water hydrology of coastal basins of northern California: U.S. Geol. Survey Water-Supply Paper 1758, 77 p.

Ritter, J. R., and Helley, E. J., 1968, An optical method for determining particle sizes for coarse sediment: U.S. Geol. Survey open-file rept., 43 p.

U.S. Bureau of Reclamation, 1960a, Investigation of Meyer-Peter and Muller bedload formulas: 22 p.

______1960b, Design of small dams: p. 71-155.

U.S. Department of Agriculture, 1970, Sediment yield and land treatment: U.S. Dept. Agriculture, water, land and related resources, app. no. 1, 143 p.

U.S. Geological Survey, published annually, Quality of surface waters of the United States, parts 9-14, Colorado River basin to Pacific slope basins in Oregon and lower Columbia River basin: U.S. Geol. Survey, water-supply paper.

______published annually, Water Resources data for California, part 2, water quality records: Menlo Park, Calif., Water Resources Division.

U.S. Inter-Agency Committee on Water Resources, Subcommittee on Sedimentation, 1958, Operation and maintenance of U.S. BM-54 bed-material sampler: Rept. M, 14 p.

______1963, Determination of fluvial sediment discharge: Rept. 14, p. 36-60.

Wolman, M. G., 1954, A method of sampling coarse river-bed material: Am. Geophys. Union Trans., v. 35, no. 6, p. 951-956.

Young, L. E., and Cruff, R. W., 1967, Magnitude and frequency of floods in the United States: U.S. Geol. Survey Water-Supply Paper 1686, 308 p.