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16. Abstracts

Long-term total-sediment discharge of the Trinity River and selected tributaries is estimated. Water-discharge data for the period 1912-70 and sediment data collected between 1955 and 1970 were used to evaluate trends and relations between sediment discharge (suspended and bedload) and water discharge.

The hydraulic and sediment-transport characteristics of many of the streams in the basin were significantly altered by the December 1964 flood. Data indicate that the depth and velocity of streams changed drastically; and that for equal magnitudes of streamflow, suspended-sediment discharges after the 1964 flood were several times larger than before the flood.

The long-term average annual sediment discharge of the Trinity River near Hoopa is estimated to be 3,120,000 tons (2,830,000 metric tons). The percentage of clay, silt, and sand or coarser material at this station is estimated to be 20, 32, and 48 percent. Bedload discharge is estimated to be 19 percent of the total-sediment discharge.

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SEDIMENT DISCHARGE IN THE TRINITY RIVER BASIN

CALIFORNIA

By J. M. Knott

U.S. GEOLOGICAL SURVEY

Water-Resources Investigations 49-73

Prepared in cooperation with the

California Department of Water Resources

April 1974

UNITED STATES DEPARTMENT OF THE INTERIOR

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GEOLOGICAL SURVEY

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CONVERSION FACTORS

Factors for converting English units to the International System of Units (SI) are given below to four significant figures. However, in the text the metric equivalents are shown only to the number of significant figures consistent with the values for the English units.

English	*Multiply by*	*Metric (SI)*
acre-ft (acre-foot)	1.234×10^{-3}	hm^3 (cubic hectometer)
ft (foot)	3.048×10^{-1}	m (meter)
ft/mi (foot per mile)	1.894×10^{-1}	m/km (meter per kilometer)
ft/s (foot per second)	3.048×10^{-1}	m/s (meter per second)
ft^3/s (cubic foot per second)	2.832×10^{-2}	m^3/s (cubic meter per second)
$(ft^3/s)/mi^2$ (cubic foot per second per square mile)	1.093×10^{-2}	$(m^3/s)/km^2$ (cubic meter per second per square kilometer)
in (inch)	2.54	cm (centimeter)
lb/ft^3 (pound per cubic foot)	1.601×10^{-2}	g/cm^3 (gram per cubic centimeter)
mi (statute mile)	1.609	km (kilometer)
mi^2 (square mile)	2.590	km^2 (square kilometer)
ton (short ton)	9.072×10^{-1}	metric ton
ton/mi^2 (short ton per square mile)	3.502×10^{-1}	metric ton/km^2 (metric ton per square kilometer)
yd^3 (cubic yard)	7.646×10^{-1}	m^3 (cubic meter)
yd^3/mi^2 (cubic yard per square mile)	2.952×10^{-1}	m^3/km^2 (cubic meter per square kilometer)

SEDIMENT DISCHARGE IN THE TRINITY RIVER BASIN, CALIFORNIA

By J. M. Knott

ABSTRACT

The Trinity River basin has a drainage area of 2,969 mi^2 (7,690 km^2) and is in a mountainous area of the Klamath Mountains in northern California. Elevations in the basin range from about 170 ft (52m) above mean sea level at the confluence with the Klamath River to more than 9,000 ft (2,740 m) at Mount Eddy.

The basin is underlain by a complex assemblage of rocks that include pre-Cenozoic metamorphic rocks of unknown age; Paleozoic and Mesozoic sedimentary and volcanic rocks that in places are strongly metamorphosed; intrusive, ultramafic, and granitic rocks of Mesozoic age; and unconsolidated deposits of Cenozoic age.

During the study period a historic storm and flood event occurred (December 1964) that significantly altered the hydraulic and sediment-transport characteristics of many streams in the basin. Data compiled for sediment stations on the Trinity River and several of the larger tributaries indicated that suspended-sediment discharges for equal magnitudes of streamflow were several times larger after than before the 1964 event. The quantity of suspended sediment transported by a given water discharge has progressively decreased since 1966 but, through 1970, was still larger than the quantity transported prior to the 1964 flood. Also, bedload discharges at most measurement stations increased after the 1964 flood. The deposition of large quantities of coarse material in stream channels after the flood has provided a ready supply of sediment for transport. Increases in stream velocity suggest that the streams have increased their ability to transport sediment.

The long-term average annual sediment discharge of the Trinity River near Hoopa is estimated at 3,120,000 tons (2,830,000 metric tons), or 1,450 tons/mi^2 (508 metric tons/km^2), excluding the area upstream from Lewiston Dam. The percentage of clay, silt, and sand or coarser material at this station is estimated at 20, 32, and 48 percent. Bedload discharge, which consists of sediment ranging in size from sand to cobbles, is estimated at 19 percent of the total sediment discharge. Long-term total discharge in the basin probably ranges from about 200 tons/mi^2 (70 metric tons/km^2) for the upper reaches of the Trinity River to 3,000 tons/mi^2 (1,050 metric tons/km^2) for the lower reaches.

INTRODUCTION AND ACKNOWLEDGMENTS

In 1969 the U.S. Geological Survey, in cooperation with the California State Department of Water Resources, began a study to define the sediment budget of the Trinity River basin. The purposes of this study were to (1) determine the total-sediment discharge at existing sediment stations; and to (2) predict long-term sediment discharge. A 59-year period (1912-70) was used to define long-term streamflow conditions. This period included several cycles of wet and dry years.

Sediment-transport data used in the study were obtained during the 1955-70 period. The bulk of these data consisted of records of daily suspended-sediment discharge and periodic suspended-sediment samples from hydrologic stations established on several of the larger tributaries of the Trinity River. Special measurements were made during the 1970 storm season to measure bedload discharge, using the Helley-Smith sampler, and to determine parameters required for the indirect computation of bedload discharge, using the Meyer-Peter and Muller equation.

The author appreciates the contributions of H. C. Aubrey, M. M. Crumrine, G. W. LaRue, J. E. Lee, and J. R. Palmer who participated in the collection of field data; and W. R. Dupre and George Porterfield who provided beneficial suggestions and ideas for data interpretation and report preparation. The report received valuable review and criticism from J. R. Ritter, E. F. Serr, and C. E. Stearns.

PREVIOUS INVESTIGATIONS

Several investigations of sedimentation in the Trinity River basin have been made prior to and concurrent with this study. The U. S. Geological Survey water-supply paper series titled "Quality of Surface Waters of the United States, Parts 9-14," and the open-file report series titled "Water-Resources Data for California--Part 2, Water-Quality Records" provide much of the basic data used in interpretive studies of the Trinity River basin. Stewart and LaMarche (1967) studied the effects of the December 1964 flood on Coffee Creek. Anderson (1968, 1970), from studies of the effects of major floods on suspended-sediment discharge, discussed the large increase in sediment discharge that occurred after two major floods in the Trinity and other basins in northern California. Ritter (1968) studied changes in channel morphology of the Trinity River and eight tributaries downstream from Trinity Dam. Hickey (1969) documented the variations in streambed elevation that occurred at U.S. Geological Survey gaging stations in northwestern California before and after the December 1964 flood. Hawley and Jones (1969) summarized some of the suspended-sediment characteristics of the basin prior to the 1965 water year. The California Resources Agency (1970) investigated sediment problems in the Trinity River near Lewiston. The U.S. Department of Agriculture (1972) prepared a comprehensive report on sediment yield and land treatment of the basin for the period 1940-65.

DESCRIPTION OF AREA

General Features and Land Use

The Trinity River basin (fig. 1) lies within Humboldt and Trinity Counties in the Klamath Mountains in California. The basin, with a drainage area of 2,969 mi^2 (7,690 km^2) is dominated by steep, rugged mountains rising above swift-flowing streams and narrow valleys. Elevations range from about 170 ft (52 m) at Weitchpec (confluence with the Klamath River) to 9,025 ft (2,751 m) at Mt. Eddy.

The principal tributaries of the Trinity River include the South Fork (932 mi^2 or 2,410 km^2), New River (233 mi^2 or 603 km^2), North Fork (152 mi^2 or 394 km^2), Coffee Creek (117 mi^2 or 303 km^2), and East Fork (109 mi^2 or 282 km^2). Stream gradients on the Trinity River range from 10 ft/mi (2 m/km) near its mouth to more than 400 ft/mi (76 m/km) in the headwaters. Longitudinal profiles of the Trinity River and its principal tributaries are shown in figure 2.

Streamflow of the Trinity River, from Lewiston to the headwaters in the northeastern part of the basin, has been subject to regulation since November 1960 when water was stored behind Trinity Dam. In April 1963, Lewiston dam was completed and water was diverted to the Sacramento River basin by way of the Clear Creek tunnel (fig. 1). Some small dams or diversion structures, for mining or agriculture, probably have been built in the basin, but their effect on runoff is negligible.

The major industry in the Trinity River basin was gold mining until late 1942 (O'Brien, 1965) when nonstrategic metal mining was restricted nationwide. After the decline of mining, lumbering became the major industry. In recent years tourism has become significant. Few areas are suitable for agriculture because of the rugged terrain.

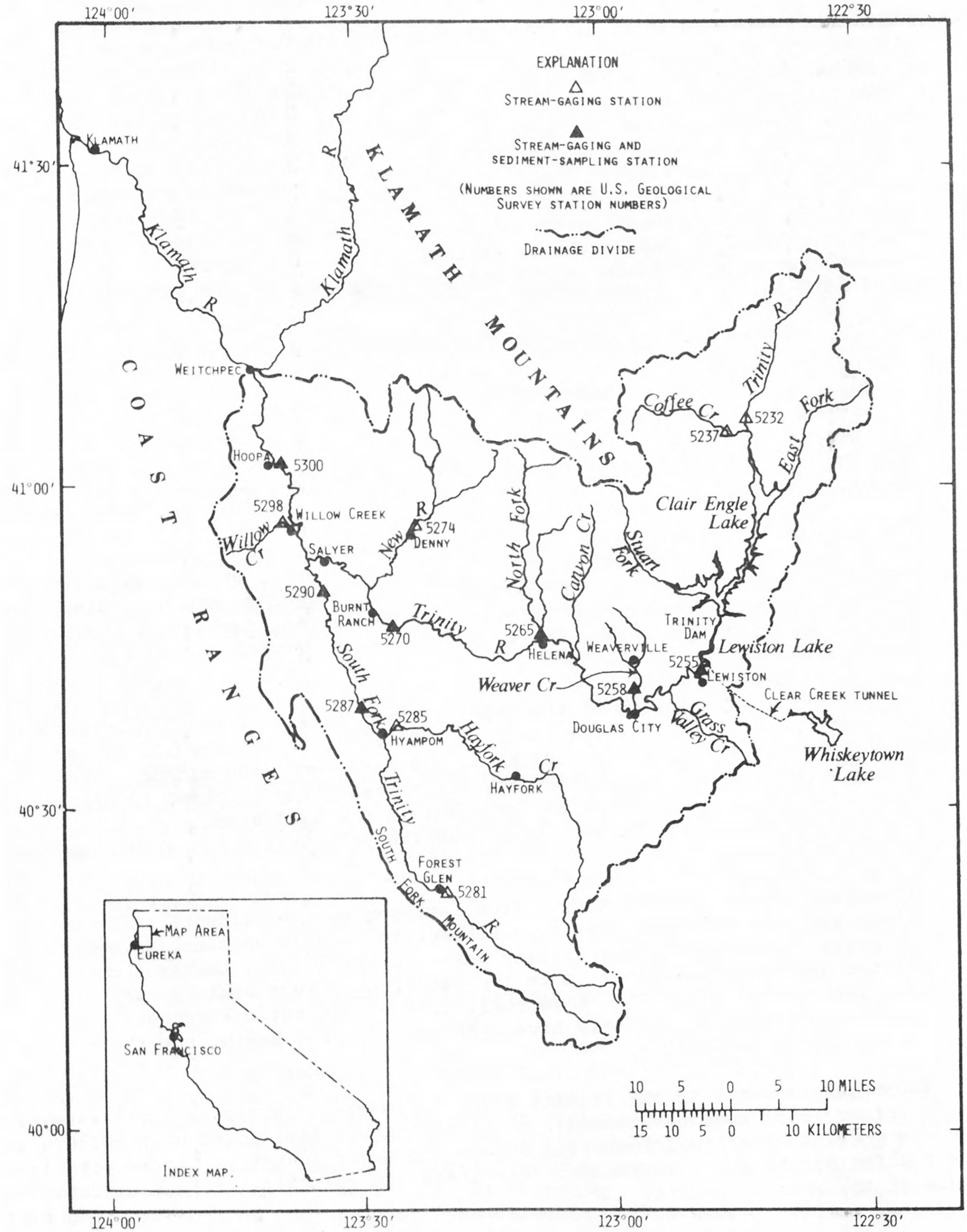


FIGURE 1.--Selected stream-gaging and sediment-sampling stations in the Trinity River basin.

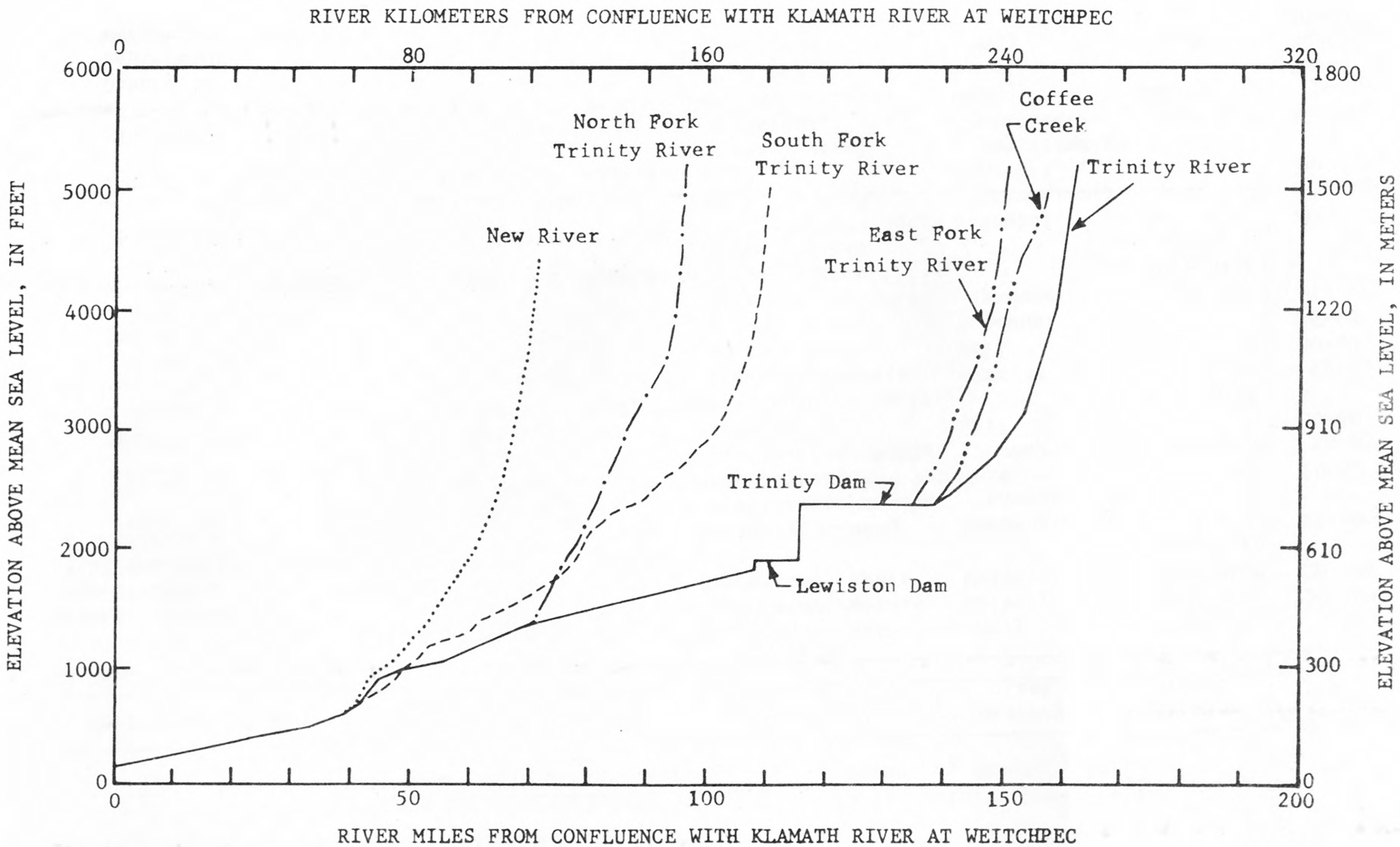


FIGURE 2.--Longitudinal profiles of principal streams in the Trinity River basin.

Table 1.--Characteristics of soil associations in the Trinity River basin
[From U.S. Department of Agriculture, Soil Conservation Service, 1972]

Soil association	Percent of total area	Slope (percent)	Parent material	Drainage class	Erosion hazard	Effective depth (inches)
Hugo-Josephine	3.2	30-50	Sandstone	Well	High	30-60+
Hugo-Josephine	.2	50-75	Sandstone	Well	Very high	30-60+
Sheetiron-Masterson-Hugo	12.5	30-75			Very high	
Sheetiron			Metamorphosed sedimentary rocks	Somewhat excessively		20-40
Masterson			Metamorphosed sedimentary rocks	Well		20-40
Hugo			Sandstone	Well		30-60
Boomer-Nuens	37.7	30-75	Metamorphosed basic igneous rocks		Very high	
Boomer				Well		30-60
Nuens				Somewhat excessively		24-48
Chawanakee-Corbett-Siskiyou	9.3	15-75	Weathered granitic rock		Very high	
Chawanakee				Somewhat excessively		20-40
Corbett				Somewhat excessively		24-48
Siskiyou				Excessively		15-30
Dubakella-Ishi Pishi-Weitchpec	5.9	9-50	Serpentine	Well	High	
Dubakella						20-40
Ishi-Pishi						30-60
Weitchpec						20-40

Josephine-Sites-Maymen	13.1	9-50				
Josephine			Sandstone, shale, or schist	Well	High	30-60+
Sites			Schist or shale	Well	High	30-60+
Maymen			Sandstone (graywacke)	Somewhat excessively	Very high	5-20
Yollabolly-Rock land	2.9	30-75				
Yollabolly			Metamorphosed sedimentary rocks	Excessively	Very high	5-20
Rock land			Rock outcrops	--	--	--
Chiquito-Rock land-Corbett	4.2	30-75				
Chiquito			Slightly weathered granite rock	Excessively	Very high	12-36
Rock land			Rock outcrops	--	--	--
Corbett			Weathered granite rock	Excessively	Very high	24-48
Windy-Rock land	9.1	15-75				
Windy			Volcanic material	Somewhat excessively	Very high	20-40
Rock land			Rock outcrops	--	--	--
Ferndale	.2	0-9	Loamy fine sand	Well	Low	60+
Kilarc-Plumas	.8	0-30				
Kilarc			Sandstone, shale, or conglomerate	Moderately well	Moderate	24-48
Plumas			Stratified sand and gravel	Well	Low	20-60

Geology

The Trinity River basin is underlain by a complex assemblage of rocks that include pre-Cenozoic metamorphic rocks of unknown age; Paleozoic and Mesozoic sedimentary and volcanic rocks that in places are strongly metamorphosed; intrusive ultramafic and granitic rocks of Mesozoic age; and unconsolidated deposits of Cenozoic age (Strand, 1962, 1964).

Vegetation and Soils

A major part of the Trinity River basin is covered by forests. Forested areas are predominantly mixed conifer types, such as fir and pine, which have been extensively developed for marketable timber. The remainder of the basin is covered by woodland (oaks and other hardwoods) and brushland.

According to the U. S. Department of Agriculture (1972) there are 12 general soil associations in the Trinity River basin. Table 1 lists the soil associations and outlines some of their more important features. The Boomer-Nuens soil association covers the largest area (37.7 percent). These soils generally lie on steep land slopes (30-75 percent) and are highly erodible when surface vegetation is removed. Most of the other soils in the basin are similar to the Boomer-Nuens association in that they lie on steep slopes and present a high erosion hazard. Less than 20 percent of the basin consists of rock lands or soils lying on gentle slopes that can be classified as having a low to moderate erosion hazard.

Climate

The climate of the Trinity River basin corresponds to the warm temperate classification of Köppen, as given in Strahler (1969, p. 224-225). Summers are generally warm 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. Snowfalls occur during winter months at elevations above 2,000 ft (610 m) and commonly accumulate to significant depths at elevations above 4,000 ft (1,220m). Annual precipitation varies from less than 40 in (102 cm) at lower elevations to more than 80 in (203 cm) at higher elevations (fig. 3). Precipitation for the entire basin averages about 55 in (140 cm) per year (Rantz, 1964, p.8).

Long-term temperature data for Weaverville (National Climatic Center, Pub. Ann.) suggest that temperatures in the river valleys generally are mild. The mean monthly temperature at Weaverville ranges from about 3° Celsius (37°F) in January to 22 Celsuis (72°F) in July. Daily extremes are more variable with temperatures as low as -22° Celsius (-8°F) and as high as 47° Celsius (117°F).

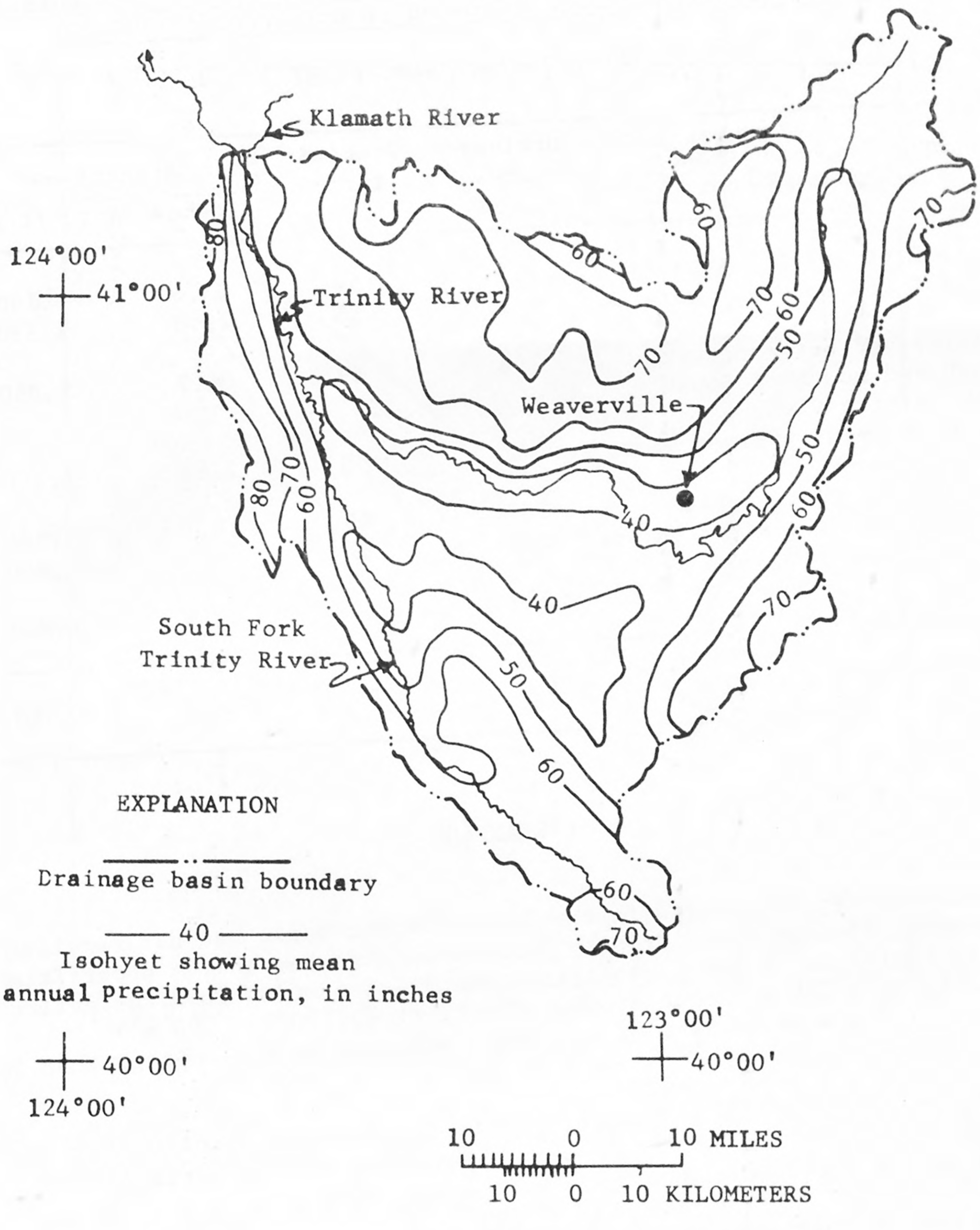


FIGURE 3.--Isohyetal map of Trinity River basin (from Rantz, 1969).

Table 2.--Average annual precipitation and streamflow prior to regulation of the Trinity River basin (adjusted to base period 1900-59)

(From Rantz, 1964, p. 8)

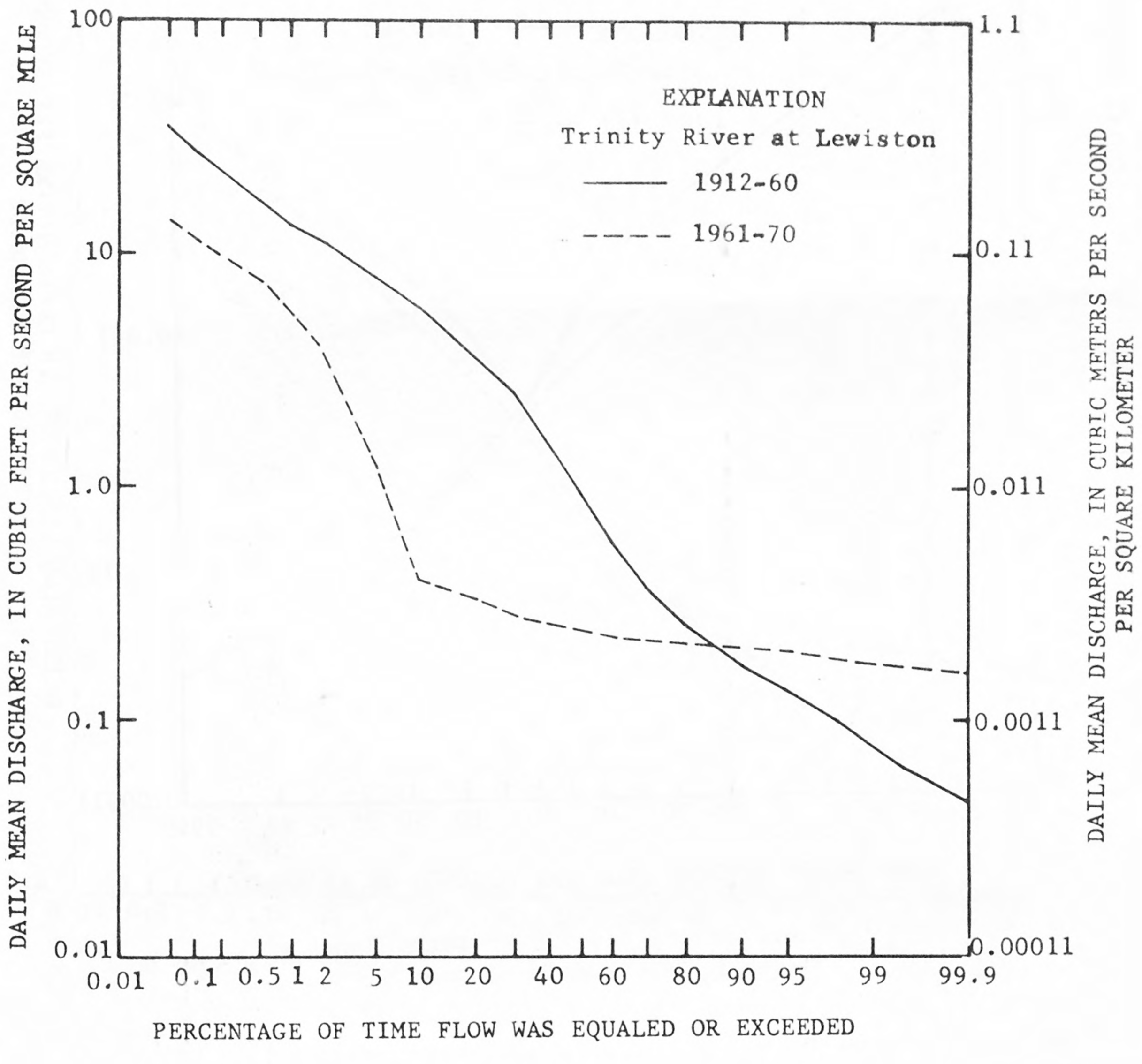
Hydrologic unit and location in basin	Drainage area (sq mi)	Precipi-tation (inches)	Streamflow	
			Inches	Acre-ft/sq mi
Trinity River at Lewiston	727	59	33.6	1,790
Trinity River Between Lewiston and Burnt Ranch	711	55	25.3	1,350
Trinity River between Burnt Ranch and mouth of South Fork Trinity River	296	59	34.7	1,850
South Fork Trinity River above Hayfork Creek	342	53	27.8	1,480
Hayfork Creek above mouth	387	43	18.1	964
South Fork Trinity River between Hayfork Creek and mouth	180	57	34.5	1,840
Trinity River between South Fork Trinity River and mouth	326	61	34.5	1,840
Total Trinity River	2,969	55	29.2	1,560

STREAMFLOW

Historically, streamflow in the Trinity River basin was not regulated until November 1960 when the Trinity Dam was constructed on the upper Trinity River near Lewiston. Prior to this time annual streamflow from the entire basin (table 2) averaged about 4,600,000 acre-ft (5,700,000,000 m^3). Streamflow in the western part of the basin was considerably higher than in the eastern part.

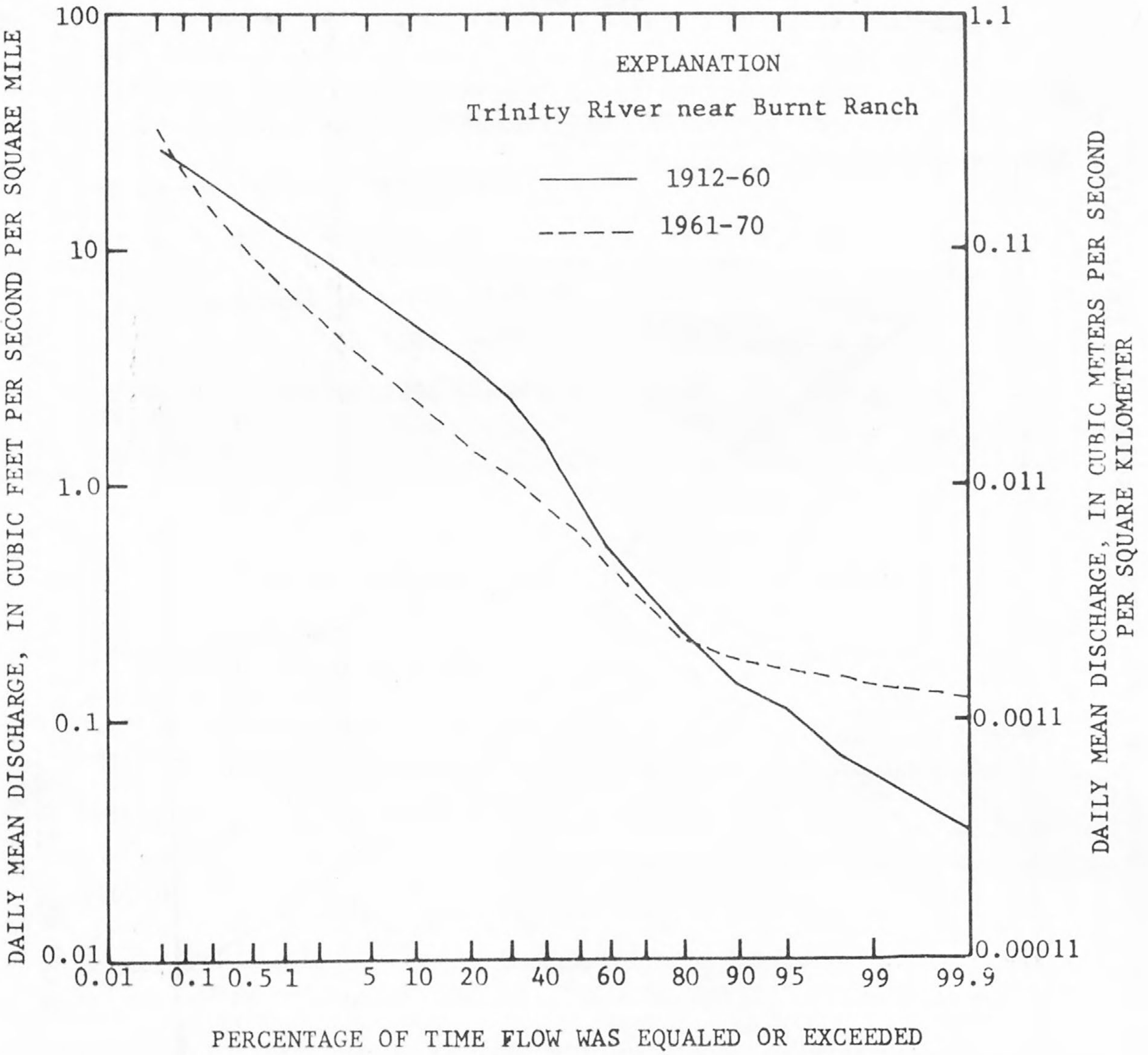
After regulation (1961-70), the streamflow from the Trinity River was reduced by storage behind Trinity Dam from November 1960 to April 1963 and by diversion to the Sacramento River drainage after 1963.

The largest reduction in streamflow occurred at the gaging station at Lewiston, downstream from Lewiston dam (fig. 1). Regulation resulted in smaller medium flows and larger low flows (fig. 4a). High flows, characteristic of the period 1912-60, were generally eliminated. Streamflow for the period 1961-70 averaged 242,000 acre ft (299 hm^3) per year compared to 1,190,000 acre-ft (1470 hm^3) per year for the period 1912-60.



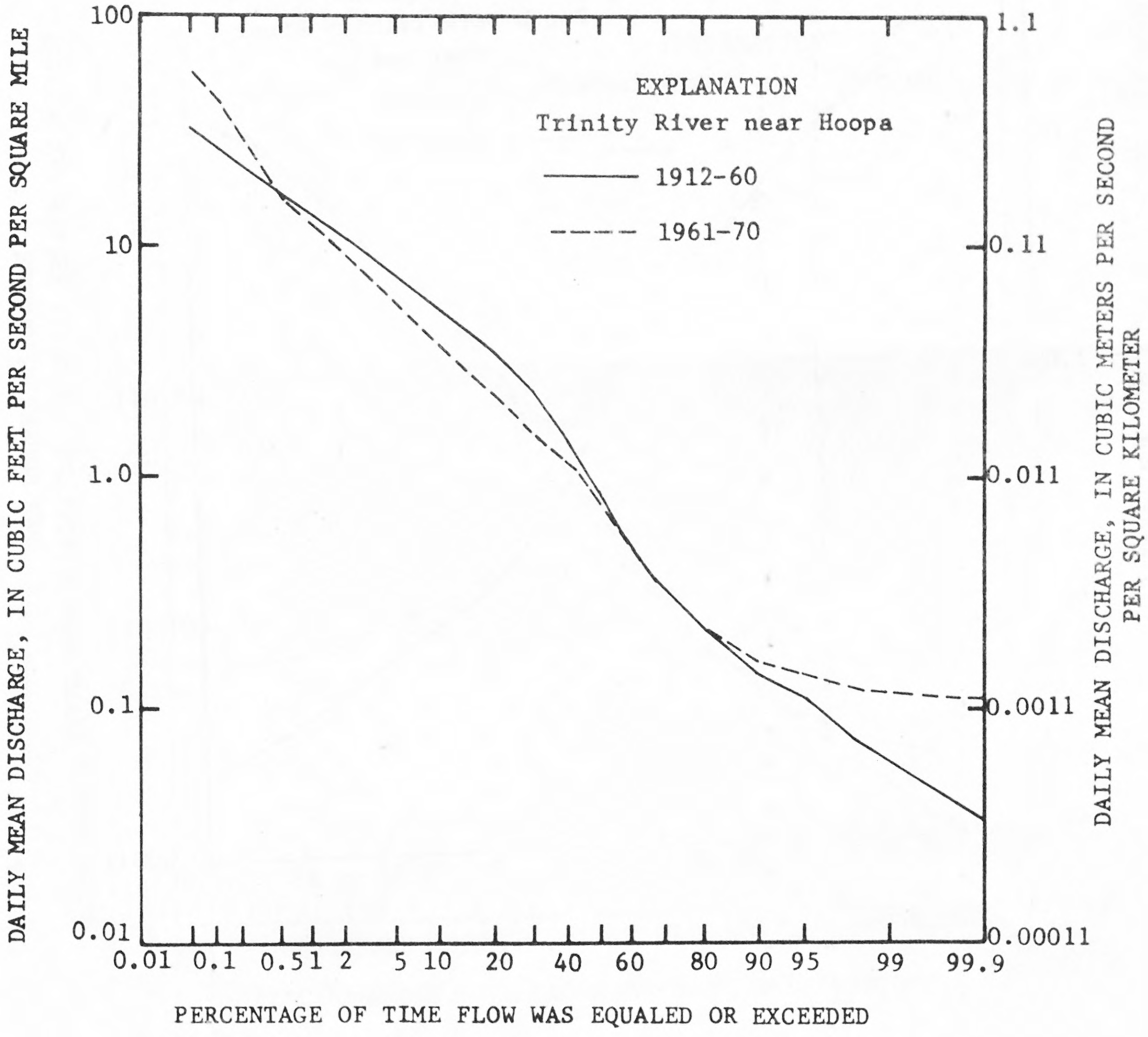
a. Trinity River at Lewiston.

FIGURE 4.--Flow-duration curves.

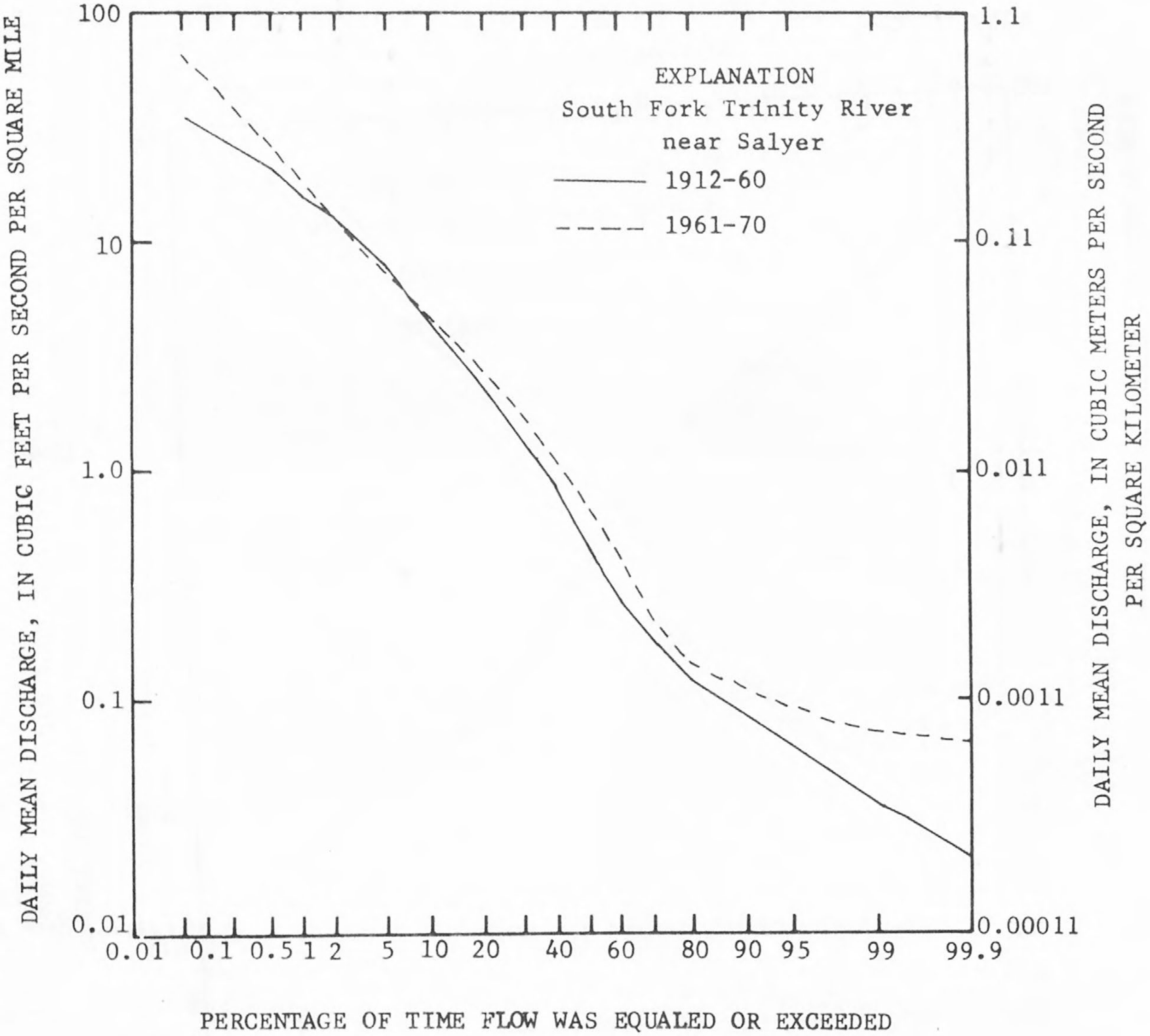


b. Trinity River near Burnt Ranch.
FIGURE 4.--Continued.

After regulation, streamflow was reduced to a lesser extent at gaging stations downstream from Lewiston (figs. 1 and 4b, 4c). The frequency of occurrence of flow events during the periods 1961-70 and 1912-60 more nearly agree for the Hoopa station than for those at the Burnt Ranch station. This indicates that the effect of regulation on streamflow decreases with distance downstream from Trinity Dam. Regulation probably reduced the average annual streamflow at each downstream station by about 900,000 acre-ft (1,100 hm^3).

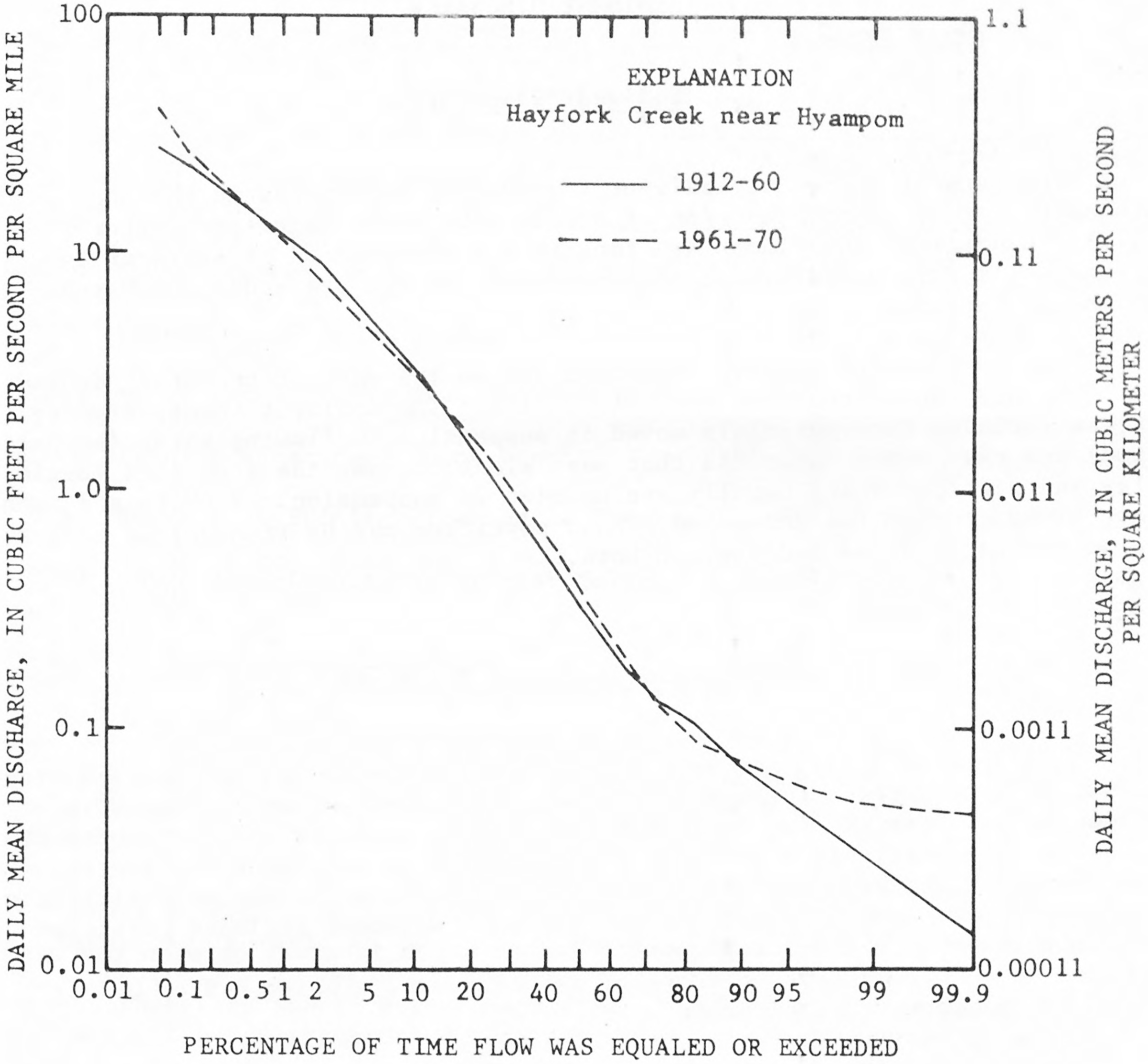


c. Trinity River near Hoopa.
FIGURE 4.--Continued.



a. South Fork Trinity River near Salyer.
FIGURE 5.--Flow-duration curves.

Flow-duration curves for gaging stations on Hayfork Creek near Hyampom and South Fork Trinity River near Salyer (fig. 5a, 5b) are representative of unregulated streamflow conditions. These curves suggest that streamflow magnitudes generally were larger during the 1961-70 period than during the 1912-1960 period when flow was unregulated.



b. Hayfork Creek near Hyampom.
FIGURE 5.--Continued.

SEDIMENT DISCHARGE

Sediment Transport

The largest source of sediment transported by streams in the basin probably originates from erosion of streambanks (U.S. Dept. Agriculture, 1972). Landslides and slumps are important local sources of sediment in places where rock units are highly fractured, slopes are steep, or barren soils are exposed.

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

Suspended-Sediment Discharge

During this study, sediment transported in suspension was sampled with standard depth-integrating samplers (U.S. Inter-Agency Committee on Water Resources, Subcommittee on Sedimentation, 1963). 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 included 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 ft (9 or 15 cm) above the streambed.

Suspended-sediment data were obtained at seven sampling sites in the Trinity River basin (fig. 1) subsequent to 1955 when samples were first taken near Hoopa. These data include daily sediment records, for sites where a sampling program was sufficient to construct a chronological record of sediment discharge, and periodic sediment records where samples were obtained during selected storms or at monthly intervals. Stations for which sediment data are available are listed in table 3.

Table 3.--Sediment stations in the Trinity River basin

(From Porterfield, 1972)

Station number	Sediment Discharge	Drainage area (sq mi)	Period of Record	Type of Record
11-5255	Trinity River at Lewiston	[1]728	9/55-9/61	Periodic
5258	Weaver Creek near Douglas City	48.4	10/62-9/69	Periodic
5265	North Fork Trinity River at Helena	151	10/62-9/70	Periodic
5270	Trinity River near Burnt Ranch	[1,2]1439	10/67-9/68	Periodic
5287	South Fork Trinity River below Hyampom	764	10/66-9/70	Daily
5290	South Fork Trinity River near Salyer	898	9/55-4/56 10/56-9/67	Periodic Daily
5300	Trinity River near Hoopa	[1,2]2865	9/55-5/56 10/56-9/70	Periodic Daily

[1]Includes 692-square-mile area upstream from Trinity Dam (11/60-4/63).
[2]Includes 719-square-mile area upstream from Lewiston dam since April 1963.

Annual suspended-sediment and water discharges for daily-record stations are summarized in table 4. The variation in sediment discharge from year to year is commonly very large and is generally dependent on the size of individual storms rather than annual water discharge. A few large storms may result in more sediment being transported than may normally result from many smaller storms.

Sediment discharge of the Trinity River at Lewiston and near Hoopa has decreased since the construction of Trinity and Lewiston dams. Regulation by these dams has resulted in a reduction in effective drainage area and an attenuation of high flows which transport most of the sediment.

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

Station number	Sediment station	Water year Oct. 1-Sept. 30	Water discharge (acre-ft)	Suspended-sediment discharge	
				Tons	Tons per sq mi
11-5287	South Fork Trinity River below Hyampom	1967	1,027,000	1,343,000	1,760
		1968	853,500	1,102,000	1,440
		1969	1,557,000	1,935,000	2,530
		1970	1,373,000	2,689,000	3,520
11-5290	South Fork Trinity River near Salyer	1957	802,600	425,000	473
		1958	2,413,000	2,501,000	2,790
		1959	938,300	349,600	389
		1960	837,900	408,900	455
		1961	967,600	198,600	221
		1962	751,900	113,800	127
		1963	1,468,000	757,900	844
		1964	862,400	289,500	322
		1965	1,805,000	10,340,000	11,500
		1966	1,129,000	1,676,000	1,870
		1967	1,331,000	1,838,000	2,050
11-5300	Trinity River near Hoopa	1957	3,386,000	1,688,000	[a]589
		1958	8,886,000	7,423,000	[a]2,590
		1959	3,441,000	2,193,000	[a]765
		1960	3,133,000	1,682,000	[a]587
		1961	2,768,000	368,600	[b]170
		1962	2,214,000	336,000	[b]155
		1963	4,454,000	1,684,000	[b]775
		1964	2,440,000	672,600	[c]313
		1965	4,267,000	33,740,000	[c]15,700
		1966	2,874,000	7,240,000	[c]3,370
		1967	3,286,000	6,539,000	[c]3,050
		1968	2,201,000	3,386,000	[c]1,580
		1969	4,511,000	7,608,000	[c]3,550
		1970	4,197,000	7,658,000	[c]3,570

[a]Based on a drainage area of 2,865 sq mi.
[b]Based on a drainage area of 2,173 sq mi.
[c]Based on a drainage area of 2,146 sq mi.

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 generally is 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 Trinity River near Hoopa and South Fork Trinity River near Salyer are shown in figures 6 and 7. The curves for both stations show a large increase in sediment discharge at given 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 progressive decrease in sediment discharge and appear to be approaching rates that existed prior to the 1964 flood. Annual sediment-transport curves for the South Fork Trinity River below Hyampom (fig. 8) show similar decreases in sediment discharge even though data prior to or during the December 1964 flood are not available for comparison.

The curves shown in figures 6 through 8 indicate major changes in the relation between sediment discharge and water discharge after the 1964 water year. These changes are similar to those that occurred on many streams in northern California following the historic December 1964 flood. These changes have been discussed in studies by Anderson (1968, 1970), Brown and Ritter (1971), and Knott (1971).

At the Hoopa Station the difference between sediment-transport curves for the periods 1957-60 and 1961-64 (fig. 6) is attributed to the effect of regulation of water releases at Trinity Dam which impounded high flows from an area of low sediment yield. Figure 6 indicates that, for higher flows, sediment-transport rates during 1961-64 were significantly larger than those during 1957-60. This increase, after Lewiston dam became operational, would be expected, because streamflow originating from the Trinity River basin above Lewiston contains a much smaller relative sediment concentration than streamflow of an equivalent frequency originating between Lewiston and Hoopa (Hawley and Jones, 1969, p. 13). The total quantity of sediment transported at Hoopa during 1961-64, however, was less than it would have been, had the dam not been operational, because peak flows were reduced and thus the competence of the Trinity River to erode streambanks and to transport sediment discharged by tributaries was reduced.

Available suspended-sediment data for other sediment stations suggest that the 1964 flood did not change sediment discharge uniformly at all locations. At the North Fork Trinity River near Helena station (fig. 9) sediment discharge in 1965 was significantly larger than during 1963-64. A different sediment-transport curve for each year during postflood period (1965-70) was used to describe adequately the changing rate of sediment discharge. At Weaver Creek near Douglas City (fig. 10) there was no apparent difference between sediment discharge that occurred before and after the flood. At this station one sediment-transport curve was used for the period 1963-69.

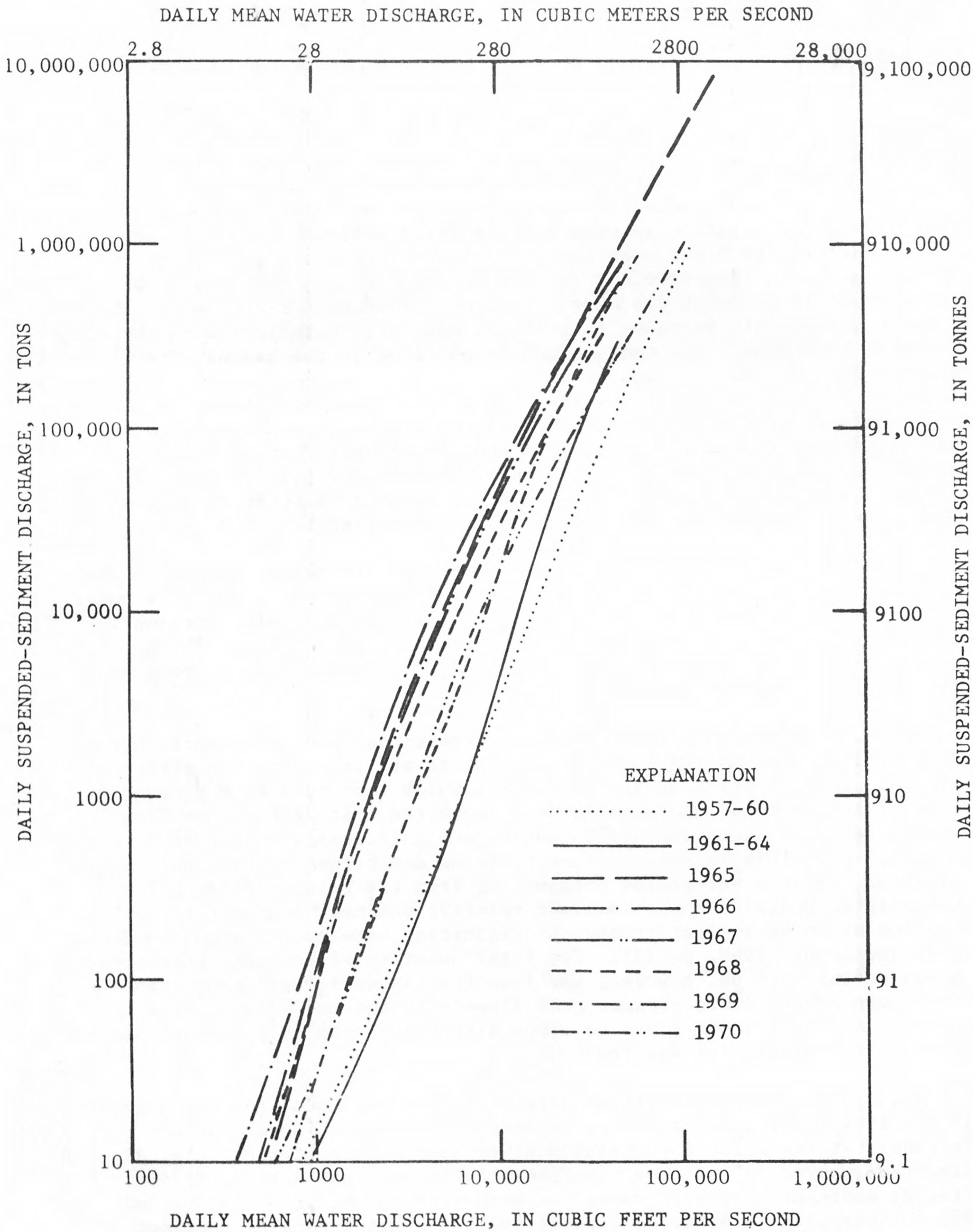


FIGURE 6.--Relation of suspended-sediment discharge to water discharge at Trinity River near Hoopa, water years 1957-70.

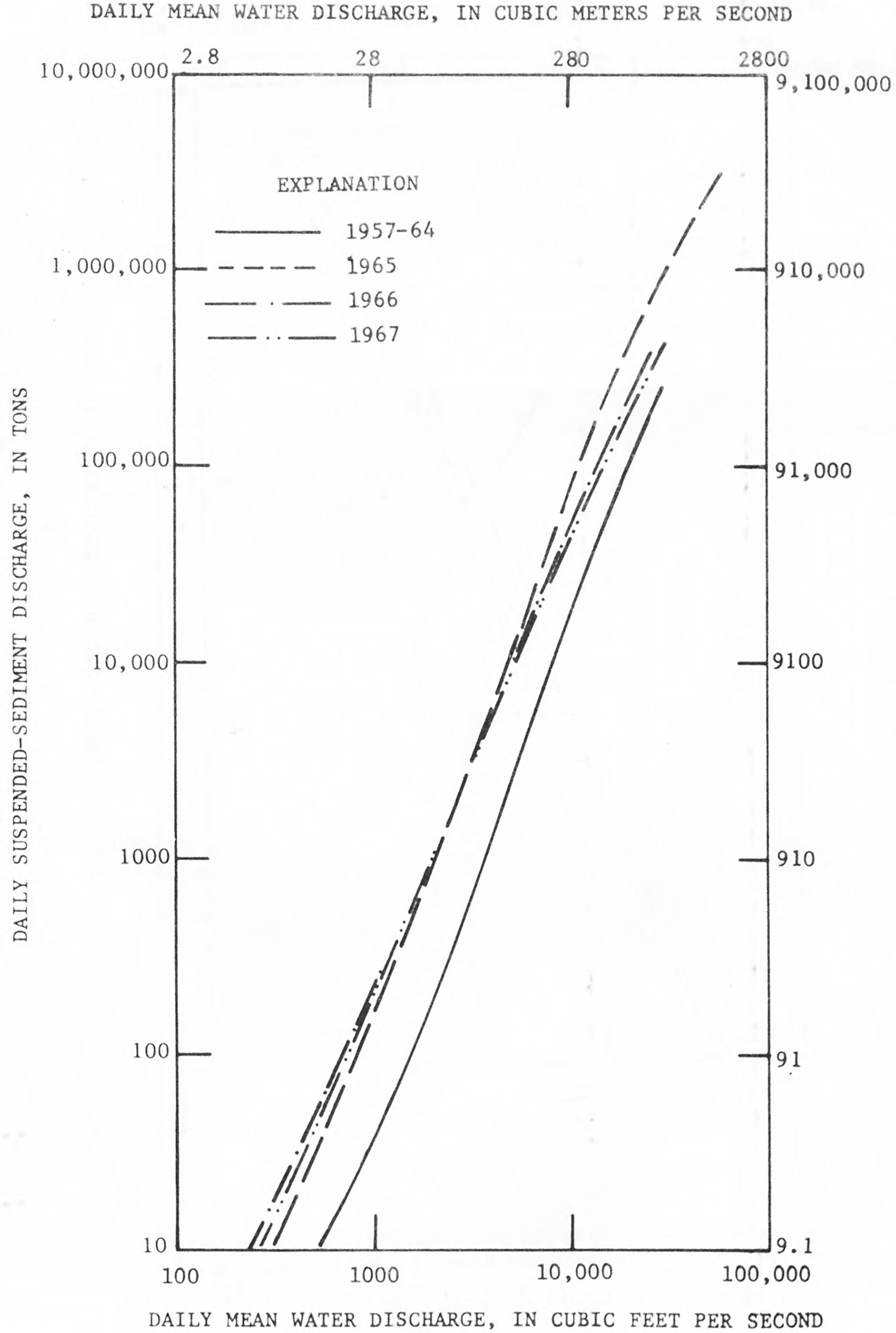


FIGURE 7.--Relation of suspended-sediment discharge to water discharge at South Fork Trinity River near Salyer, water years 1957-67.

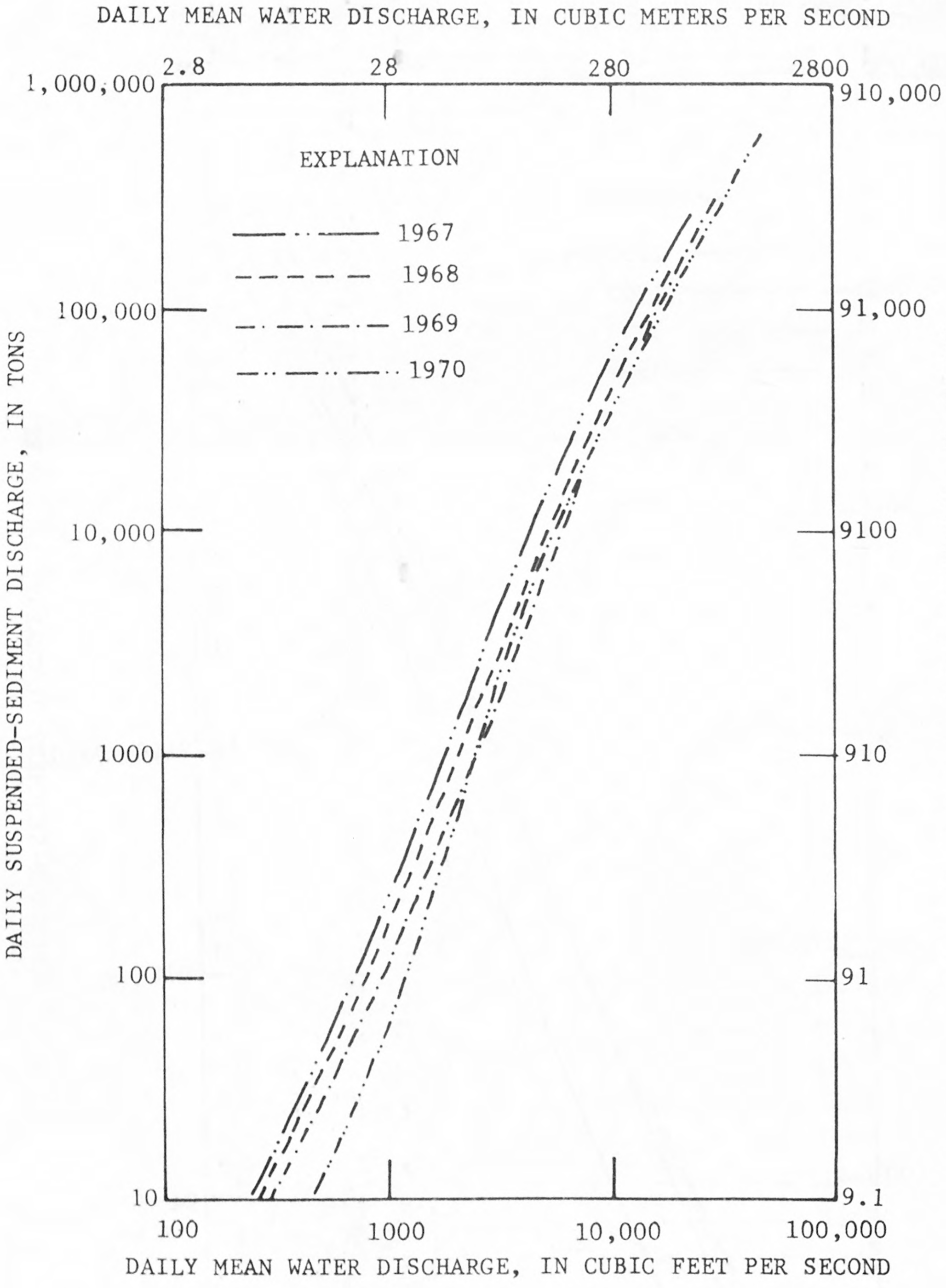


FIGURE 8.--Relation of suspended-sediment discharge to water discharge at South Fork Trinity River below Hyampom, water years 1967-70.

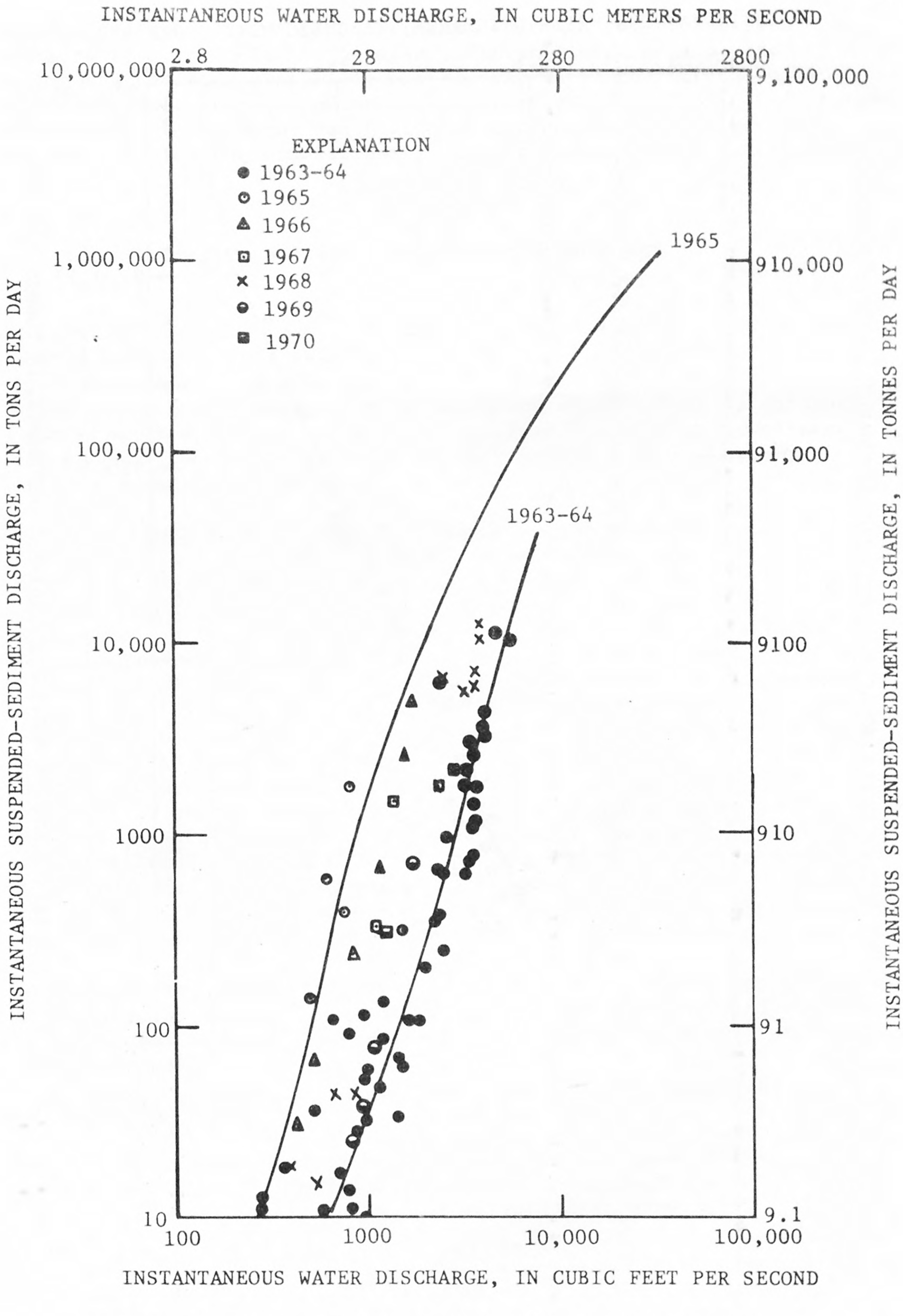


FIGURE 9.--Relation of suspended-sediment discharge to water discharge at North Fork Trinity River at Helena, water years 1963-70.

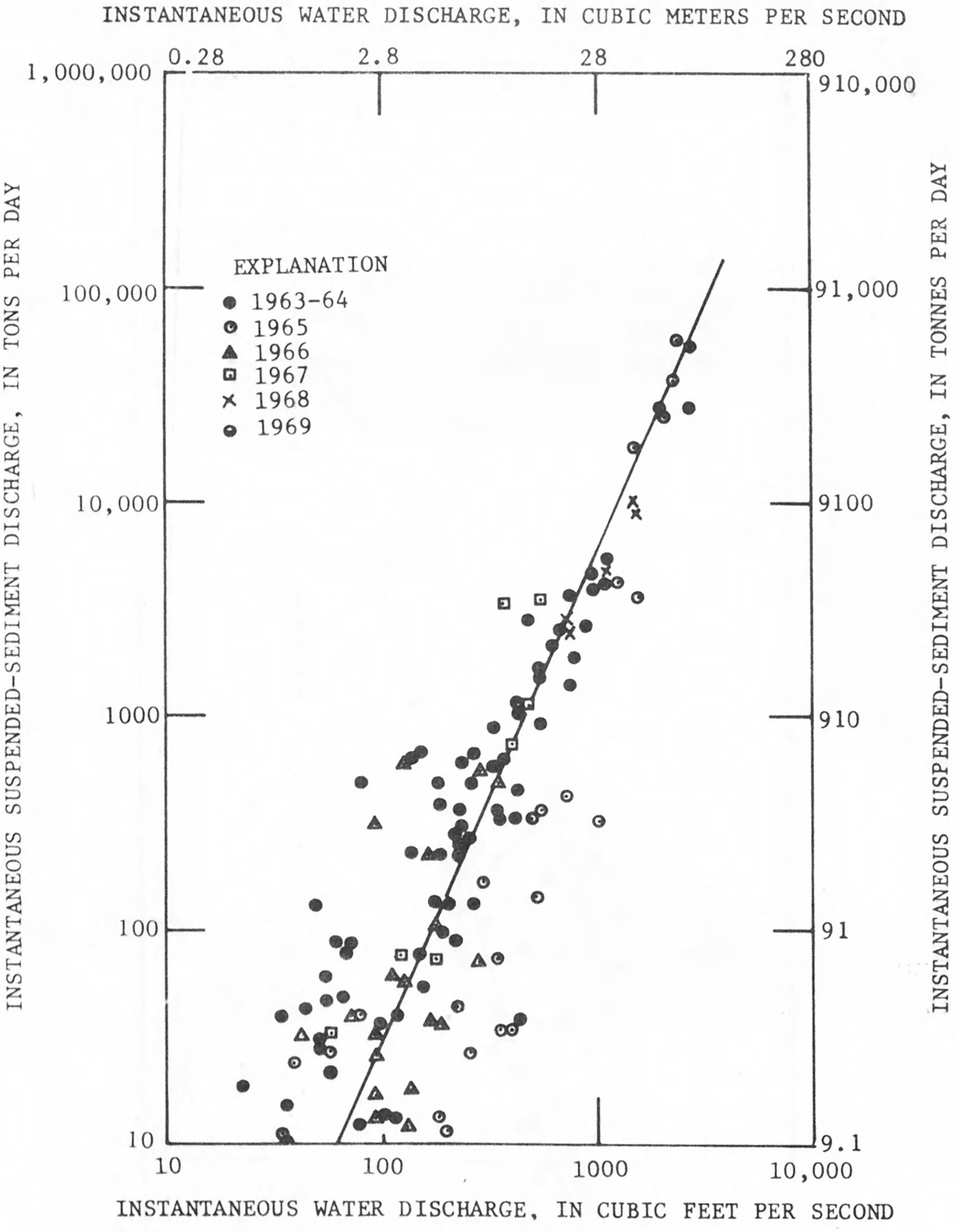


FIGURE 10.--Relation of suspended-sediment discharge to water discharge at Weaver Creek near Douglas City, water years 1963-69.

Suspended-sediment data for the Trinity River station at Lewiston are shown in figure 11. The relation between sediment discharge and water discharge for the Lewiston station is representative of the period prior to construction of Trinity Dam and prior to the December 1964 flood. Only meager data were obtained at the Burnt Ranch station during the 1968 water year. These data were considered insufficient to construct a sediment-transport curve.

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 1912-70. 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. Flow-duration data for Trinity River near Hoopa prior to construction of Trinity Dam were adjusted to represent regulation of streamflow by the dam.

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. Because annual sediment discharges for the postflood period were abnormally high, they were weighted by the recurrence interval of the December 1964 flood (about 100 years) and by the number of years required for sediment discharges to return to preflood levels. For example, examination of sediment-transport curves for the Trinity River near Hoopa (fig. 6) indicates that, subsequent to the 1964 flood, the annual curves progressively shift toward the preflood curve and suggests that sediment-transport rates will not be comparable to preflood rates for several years after 1970. Therefore, assuming that sediment discharge in the 10 years following the flood was increased by an event with a recurrence of 100 years, the weight assigned to each postflood year was 1/100 for a 100-year series. The remainder of the 100-year series, representative of preflood conditions (1961-64), was assigned a weight of 90/100. A similar adjustment was applied to the South Fork and North Fork Trinity River stations because the postflood trend of the sediment-transport curves was similar.

No weighting was applied to annual sediment discharges for Weaver Creek near Douglas City, because significant differences in sediment- and water-discharge relations were not observed for Weaver Creek. Data for Trinity River at Lewiston were not collected after 1961.

Long-term suspended-sediment discharges were computed for each of the sampling sites and are listed in table 5. Annual discharges range from 165 tons/mi^2 (58 metric tons/km^2) for Trinity River at Lewiston to 1,170 tons/mi^2 (410 metric tons/km^2) for Trinity River near Hoopa.

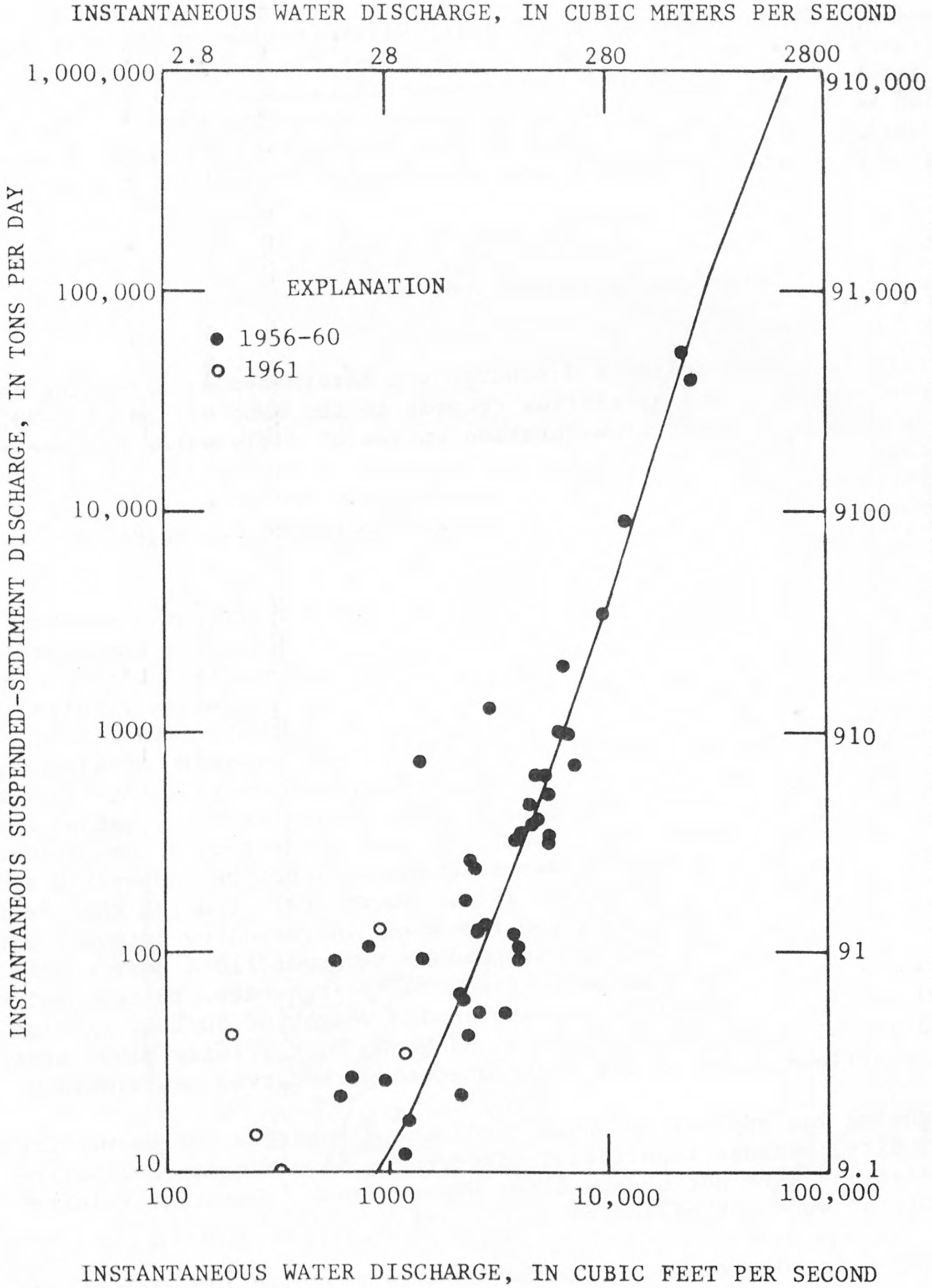


FIGURE 11.--Relation of suspended-sediment discharge to water discharge at Trinity River at Lewiston, water years 1956-61. Flow regulated at Trinity Dam during 1961 water year.

Table 5.--Adjusted suspended-sediment discharge for selected sites in the Trinity River basin, 1912-70

Station number	Sediment station	Sediment-contributing drainage area (sq mi)	Annual discharge	
			Tons	Tons/sq mi
11-5255	Trinity River at Lewiston	728	[a]120,000	[a]165
-5258	Weaver Creek near Douglas City	48.4	34,600	715
-5265	North Fork Trinity River at Helena	151	54,700	362
-5270	Trinity River near Burnt Ranch	720	--	--
-5287	South Fork Trinity River below Hyampom	764	672,000	880
-5290	South Fork Trinity River near Salyer	898	860,000	958
-5300	Trinity River near Hoopa	2,146	[b]2,520,000	[b]1,170

[a]Representative of 1912-60 period, prior to construction of Trinity Dam.
[b]Assuming regulation by Trinity and Lewiston dams during 1912-70.

Bedload Discharge

Bedload discharge, which is the quantity of sediment transported on or near the streambed, was investigated at three sediment stations in the Trinity River basin. Data collected at two of these stations, North Fork Trinity River at Helena and South Fork Trinity River below Hyampom, consisted of the direct measurement of bedload discharge and the measurement of stream characteristics required for the indirect determination of bedload discharge by the Meyer-Peter and Muller equation. Bedload discharge for the third station, Trinity River near Hoopa, was computed using only the Meyer-Peter and Muller equation because high stream velocities and excessive water depths precluded direct measurement of bedload discharge.

Bedload discharge was measured using a bedload sampler devised for use in streams carrying coarse sediments (Helley and Smith, 1971, p. 1-18). This sampler was convenient to use and was stable in stream velocities as large as 8.8 ft/s (2.7 m/s). Because the sampler had not been calibrated for gravel-size material, a trap efficiency coefficient of 1.0 was assumed.

Bedload discharge was also computed using the Meyer-Peter and Muller bedload formula. This formula was developed from flume studies in Switzerland and converted to English units by the U.S. Bureau of Reclamation (1960). 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 during the 1970 water year. These data were collected at water discharges ranging from low flow at all stations to a maximum of 64,000 ft^3/s (1,810 m^3/s) at Trinity River near Hoopa. The bedload discharge at values of water discharge larger than those measured was estimated from streamflow measurements, analysis of bed material, and channel cross sections determined from high-water marks. Field data included measurements of water discharge, water-surface slope, channel geometry, and particle-size distribution of bed material. Changes in streambed characteristics upstream and downstream from sampling sections were documented from photographs.

Water discharge was determined from velocity, depth, and width measurements using standard equipment and methods. Where possible, special low-flow measurements were made at high-flow sampling sections to determine velocity and depth of flow required to initiate bed movement.

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

Channel geometry was determined on several occasions during the 1970 water year to monitor depth, width, and streambed elevations for a range of streamflow. The data were obtained by level surveys during low-flow periods between storms, and from soundings or streamflow measurements during storms.

Manning n values of stream roughness were estimated by comparing channel geometry and roughness at sampling sites with photographs and descriptions of natural stream channels where Manning n values had been defined (Barnes, 1967).

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 generally were too deep or too swift for direct access to streambeds. Several methods were employed to determine the probable particle-size distribution of the bed material at high streamflows.

At higher stages, bed material was collected from stream channels with a clamshell-type sampler (U.S. BM-54). This sampler, which collects samples from the top 2 in (5 cm) of the streambed (U.S. Inter-Agency Committee on Water Resources, Subcommittee on Sedimentation, 1958), generally was used when large stream velocities and excessive depths were 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 elevations verified that coarser material was being transported. At locations where BM-54 samples contained few particles finer than 32 mm it was assumed that the particle-size distribution of the streambed was relatively coarse and was similar to that observed during low flow.

During low stages, the particle-size distribution of material in streambeds was determined by sieving bed material, optical examination of photographs, and by particle counts (Wolman, 1954).

Relation Between Bedload Discharge and Water Discharge

Bedload parameters were measured periodically at several sites in the Trinity River basin. The stream channels at these sites changed considerably during major storms. Bed material near the surface usually was scoured away during rising stages and was replaced with similar size material during falling stages. The particle size of the streambed material generally changed significantly during storm events. The percentage of sand present in the streambed generally increased during high flows.

A relation between bedload discharge and water discharge was established by constructing sediment-transport curves similar to those used for suspended-sediment data. Although few comparable data points are available, bedload discharge computed from low-flow samples using the Meyer-Peter and Muller equation agree reasonably well with bedload discharge measured with the Helley-Smith sampler (table 6 and figs. 12-13).

Bedload discharge computed from low-flow and from storm-flow bed samples at Trinity River near Hoopa (fig. 14) indicate a relatively large difference (percentage wise) for medium and low flows and a smaller difference for high flows.

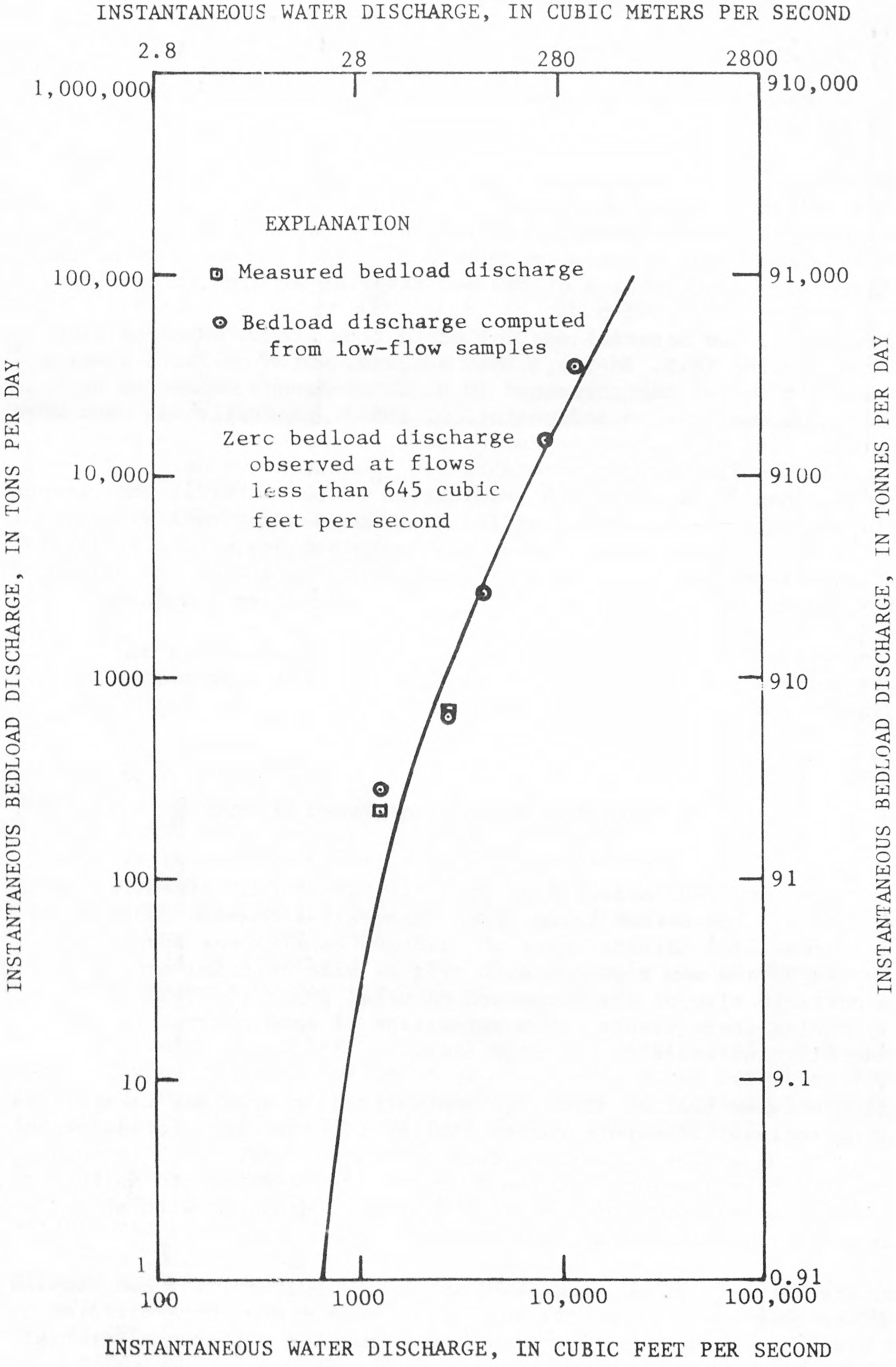


FIGURE 12.--Relation of bedload discharge to water discharge at North Fork Trinity River at Helena, 1970 water year.

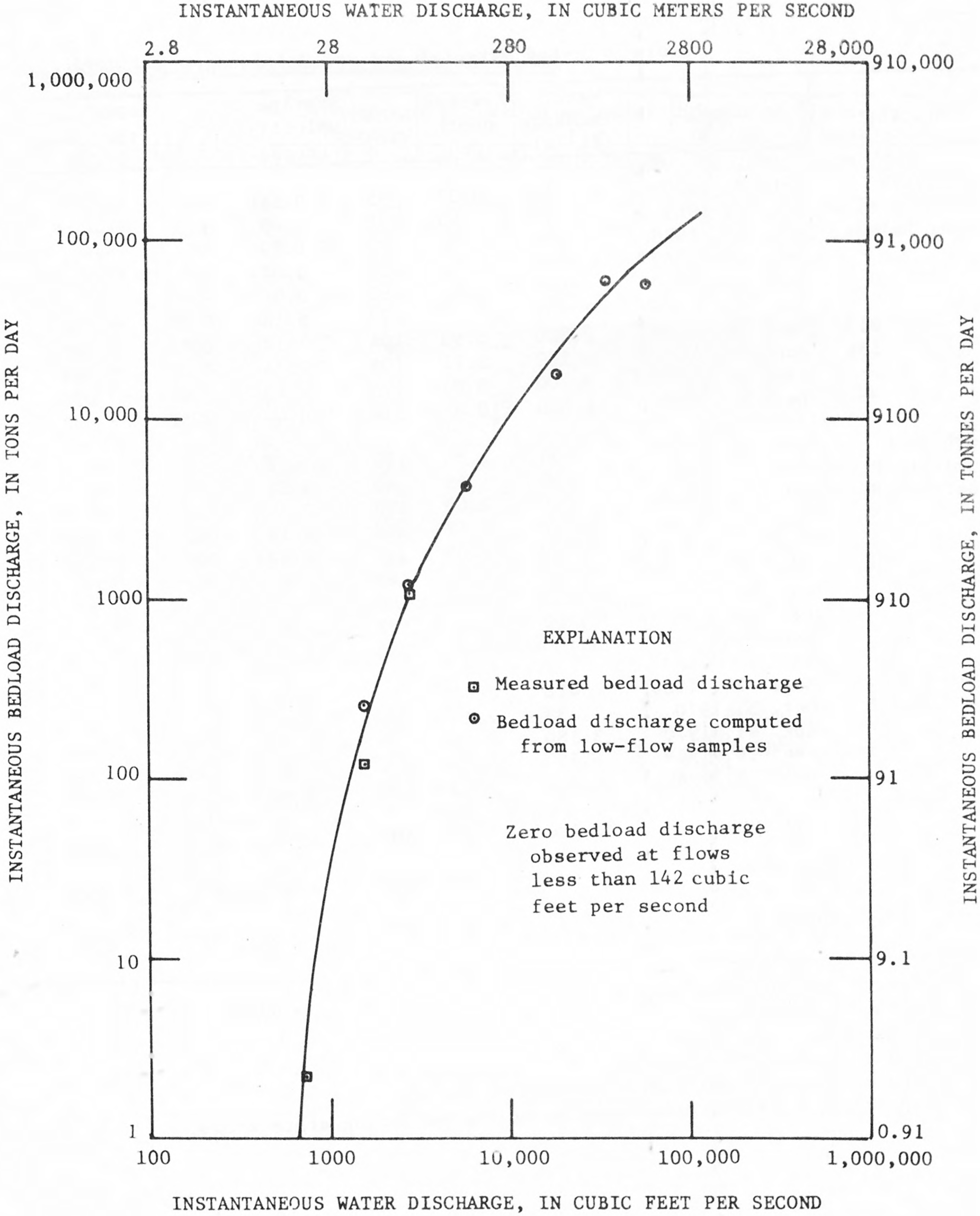


FIGURE 13.--Relation of bedload discharge to water discharge at South Fork Trinity River below Hyampom, 1970 water year.

Table 6.--Bed material and streamflow data for selected

Station	Date	Water discharge (ft^3/s)	Average depth (ft)	Width (ft)	Average velocity (ft/s)	Slope (ft/ft)	Stream roughness (n)
North Fork Trinity River near Helena	Oct. 7, 1970	19	0.37	95	0.54	--	--
	Oct. 1, 1969	30	.43	88	.80	--	--
	Apr. 24, 1970	174	.97	93	1.93	--	--
	Dec. 17, 1969	475	1.52	94	3.32	--	--
	Feb. 19, 1970	645	2.05	95	3.31	--	--
	Dec. 19, 1969	1,400	2.78	99	5.13	.0030	[b].034
	Jan. 18, 1970	2,920	3.93	104	7.14	.0028	[b].033
	Jan. 25, 1970	4,160	5.11	105	7.74	.0035	[b].032
	Jan. 22, 1970	8,700	8.03	115	9.43	.0045	[b].032
	Dec. 21, 1969	12,800	[c]10.8	114	[c]10.4	.0052	[b].032
South Fork Trinity River below Hyampom	Oct. 9, 1970	54	1.55	123	.28	--	--
	Oct. 2, 1969	142	.65	66	3.32	--	--
	Apr. 23, 1970	710	2.00	103	3.45	--	--
	Dec. 18, 1969	1,550	2.17	172	4.16	.0029	[b].035
	Feb. 21, 1970	2,900	3.66	177	4.48	.0026	[b].035
	Dec. 19, 1969	5,960	[c]5.9	183	[c]5.5	[d].0023	[b].033
	Jan. 21, 1970	19,200	[c]11.6	190	[c]8.7	[d].0020	[b].030
	Dec. 21, 1969	33,700	[c]15.3	192	[c]11.5	[d].0028	[b].030
	Jan. 24, 1970	59,100	[c]19.2	196	[c]15.7	[d].0023	[b].030
Trinity River at Hoopa	Sept. 29, 1969	418	1.79	81	2.88	--	--
	Oct. 5, 1970	433	2.11	70	2.93	--	--
	Apr. 21, 1970	3,180	2.63	212	5.70	.0043	[b].040
	Dec. 16, 1969	6,450	2.86	331	6.80	.0039	[b].040
	Dec. 15, 1969	10,100	4.03	380	6.60	.0040	[b].039
	Jan. 20, 1970	31,300	8.29	502	7.52	.0028	[b].030
	Jan. 17, 1970	64,100	13.70	522	8.97	.0031	[b].030
	Jan. 24, 1970	115,000	[c]20.1	552	[c]10.4	.0029	[b].030

1/ Computed from bed-material samples collected during low flow.
[a] Zero bedload observed.
[b] Estimated.
[c] Computed from hydraulic geometry of stream channel.
[d] Computed from channel characteristics.
[e] Computed from bed-material samples collected during storm flows.

sampling sites in the Trinity River basin

Particle-size distribution of streambed material (percent)					[1/]Computed bedload	Measured bedload
<0.062 mm	0.062-2.0 mm	2.0-64 mm	64-256 mm	>256 mm	(tons/day)	(tons/day)
--	15	64	21	--	--	[a]0
--	9	83	8	--	--	[a]0
--	--	--	--	--	--	[a]0
--	--	--	--	--	--	[a]0
--	--	--	--	--	--	[a]0
--	34	64	--	--	290	216
--	37	63	--	--	640	661
--	--	--	--	--	2,600	--
--	--	--	--	--	15,000	--
--	--	--	--	--	35,000	--
--	17	75	8	--	--	[a]0
1	22	75	2	--	--	[a]0
--	77	23	--	--	--	2.1
--	45	55	--	--	260	125
--	35	65	--	--	1,200	1,060
--	--	--	--	--	4,200	--
--	--	--	--	--	17,000	--
--	--	--	--	--	58,000	--
--	--	--	--	--	56,000	--
--	43	28	26	3	--	[a]0
--	41	23	25	11	--	[a]0
--	11	52	32	5	50-80[e]	--
--	32	28	36	4	220-550[e]	--
--	38	52	10	--	3,700-6,000[e]	--
--	70	30	--	--	22,000-37,000[e]	--
--	57	43	--	--	89,000-92,000[e]	--
--	--	--	--	--	[e]130,000-150,000	--

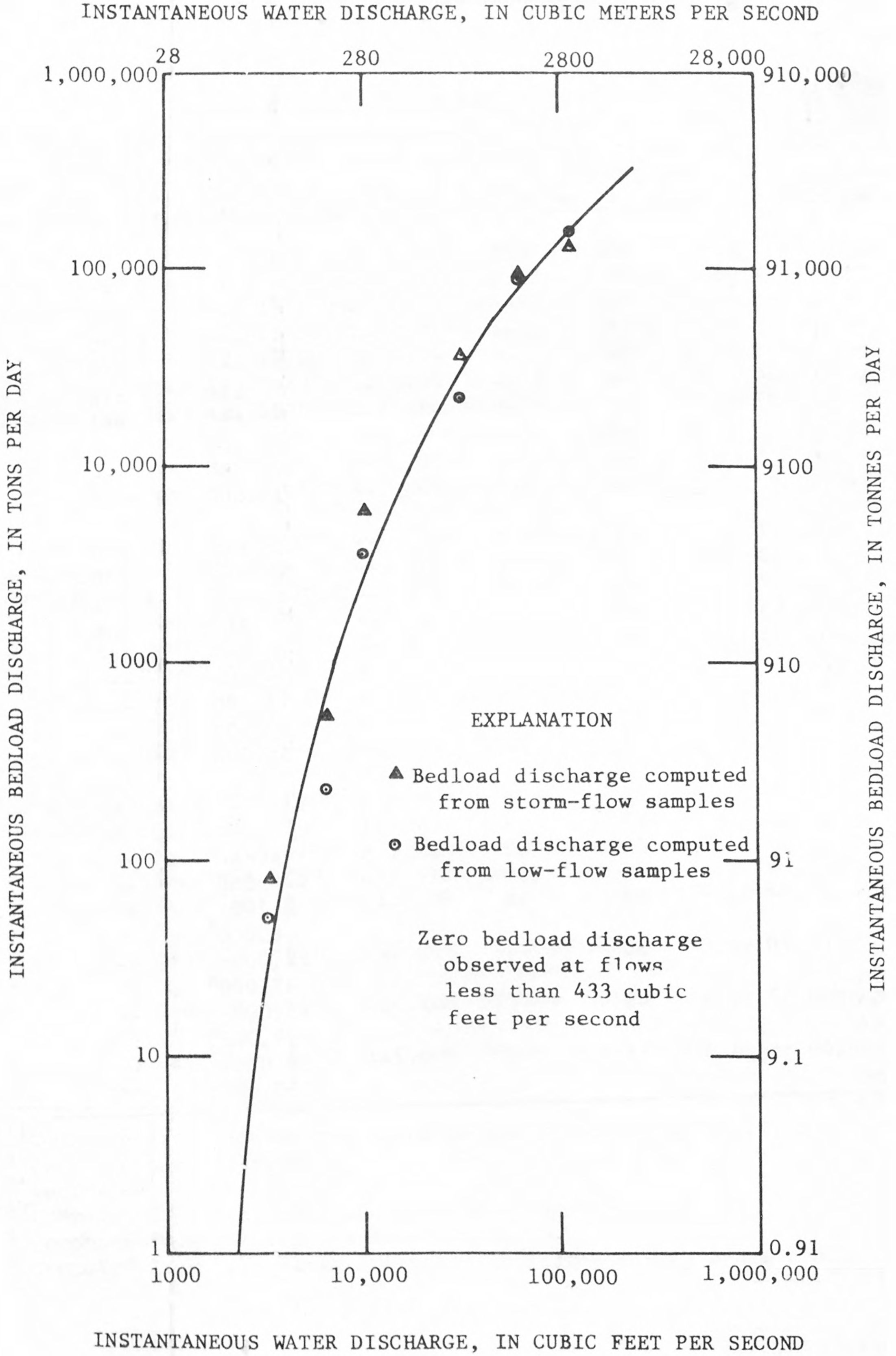


FIGURE 14.--Relation of bedload discharge to water discharge at Trinity River near Hoopa, 1970 water year.

Table 7.--Present bedload discharge for selected sites in the Trinity River basin

Station number	Sediment station	Sediment-contributing drainage area (sq mi)	Annual bedload discharge	
			Tons	Tons/sq mi
11-5258	Weaver Creek near Douglas City	48.4	[a]4,000	[a]80
-5265	North Fork Trinity River at Helena	151	17,000	110
-5287	South Fork Trinity River below Hyampom	764	240,000	310
-5290	South Fork Trinity River near Salyer	898	[a]320,000	[a]360
-5300	Trinity River near Hoopa	[b]2,146	600,000	[b]280

[a]Estimated.
[b]Excluding 719 square-mile area upstream from Lewiston dam.

Present Rate of Bedload Discharge

Present bedload discharge at various sites in the Trinity River basin considered representative of postflood hydrologic conditions was computed for North Fork Trinity River at Helena, South Fork Trinity River below Hyampom, and Trinity River near Hoopa by applying bedload discharges determined from the sediment-transport curves to daily-flow data for the base period 1912-70. The resultant discharges are given in table 7. Annual bedload discharge at South Fork Trinity River near Salyer was estimated using the sediment-transport curve for Hyampom because stream-channel characteristics were comparable at both sites. Bedload discharge at Weaver Creek near Douglas City was estimated on the basis of a field reconnaissance of channel characteristics and suspended-sediment data using a classification system suggested by Maddock (Lane and Borland, 1951, p. 123).

Total Sediment Discharge

Evaluation of total sediment discharge in the Trinity River basin was particularly complex, because sediment-transport rates at several sites do not seem to be in equilibrium. During the postflood period (1965-70) relative rates of sediment transported in suspension were definitely decreasing toward preflood levels, but it was not apparent whether bedload discharges representative of the postflood period (1965-70) 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 elevations prior to 1971 (fig. 15) were determined from hydrologic data collected during low-water streamflow measurements (Hickey, 1969, p. 8-9). These data show that, at some gaging stations in the Trinity River basin, the streambed elevation was raised several feet following the December 1964 flood (South Fork Trinity River near Salyer and Willow Creek near Willow Creek). Changes in streambed elevations were much smaller at some stations (North Fork Trinity River at Helena, New River at Denny, South Fork Trinity River at Forest Glen, and Trinity River near Hoopa) and were insignificant at others (Weaver Creek near Douglas City, Trinity River near Burnt Ranch, and Hayfork Creek near Hyampom).

The graphs in figure 15 indicate that streambed elevations changed somewhat during other large floods, such as the one which occurred in December 1955. Prior to December 1964, however, changes in streambed elevations were relatively small or of short duration.

Where data were available, the hydraulic geometry of streams was investigated to determine if significant changes had occurred as a result of the December 1964 flood. Logarithmic graphs that show the relation of width, depth, and velocity to water discharge (fig. 16) were prepared from streamflow measurements obtained during 1958-70. The graphs indicate that large changes in velocity and depth occurred at stations where streambed elevations had been raised more than a few feet after the December 1964 flood. The largest changes occurred at low to median flows where velocities increased from 35 to 200 percent (fig. 17). Depths at median flow decreased from 35 to 70 percent. The difference between preflood and postflood velocities and depths generally decrease with increased flow. Observed changes in stream width generally are less, percentage wise, than changes in velocity or depth, probably because streambanks are generally steep and are composed of bedrock.

The effect of changes in hydraulic geometry, relative to bedload discharge, can be approximated by rearranging the Meyer-Peter and Muller equation into parameters of depth, width, and velocity and making various assumptions. If it is assumed that the hydraulic radius (r) of a stream can be approximated by the average depth (d), substitution of the slope component of the Manning flow equation

$$S = \frac{v^2}{r^{4/3}}\left(\frac{n}{1.49}\right)^2$$

into the Meyer-Peter and Muller equation results in

$$G_s = 1.606B\left[3.306\left(\frac{Q_s}{Q}\right)\left(\frac{n}{1.49}\right)^2\left(\frac{D_{90}{}^{1/6}}{n_s}\right)^{3/2}\left(\frac{dv^2}{d^{4/3}}\right) - 0.627D_m\right]^{3/2}$$

rearranging terms and combining constants

$$G_s = 2.918Bn^3\left(\frac{Q_s}{Q}\right)^{3/2}\left(\frac{D_{90}{}^{1/6}}{n_s}\right)^{9/4}\left[\frac{v^2}{d^{1/3}} - \frac{0.627D_m}{3.306\left(\frac{Q_s}{Q}\right)\left(\frac{n}{1.49}\right)^2\left(\frac{D_{90}{}^{1/6}}{n_s}\right)^{3/2}}\right]^{3/2}$$

If depth, width, and velocity are variables and Q_s/Q, bed material particle size, and roughness are invariant, then a change in the hydraulic characteristics of a stream would be expected to change the bedload discharge according to the equation

$$\frac{Gs_2}{Gs_1} = \frac{B_2}{B_1}\left[\frac{\dfrac{v_2{}^2}{d_2{}^{1/3}} - \dfrac{0.627D_m}{3.306\left(\frac{Q_s}{Q}\right)\left(\frac{n}{1.49}\right)^2\left(\frac{D_{90}{}^{1/6}}{n_s}\right)^{3/2}}}{\dfrac{v_1{}^2}{d_1{}^{1/3}} - \dfrac{0.627D_m}{3.306\left(\frac{Q_s}{Q}\right)\left(\frac{n}{1.49}\right)^2\left(\frac{D_{90}{}^{1/6}}{n_s}\right)^{3/2}}}\right]^{3/2}$$

For large bedload discharges the negative component on the right side of the equation (Q_s/Q, bed material particle size, and roughness) becomes small relative to the positive component (velocity and depth) and the equation can be approximated as

$$\frac{G_{s_2}}{G_{s_1}} = \left(\frac{B_2}{B_1}\right)\left(\frac{v_2}{v_1}\right)^3\left(\frac{d_1}{d_2}\right)^{1/2}$$

for a given flow.

The modified bedload equation thus indicates that bedload discharge after the 1964 flood was most sensitive to changes in stream velocity and least sensitive to changes in stream depth. Bedload discharges after the 1964 flood are assumed to be larger than bedload discharges before the flood at sites where stream velocities and widths increased and stream depths decreased. Temporarily at least, the postflood addition of thick sediment deposits in stream channels and increased velocities have increased the quantity of coarse material available for transport and the competence of the streams to transport coarse material. Present bedload discharges probably will remain larger than preflood bedload discharges for many years because postflood deposits, through 1970, have not been substantially reduced. The quantity of coarse sediment supplied from source areas is apparently about equal to the increased quantity of coarse sediment transported by streams in the basin.

Postflood bedload discharge is probably equal to the preflood bedload discharge at sites where small changes in hydraulic geometry occurred during the flood. Postflood bedload discharge at the Trinity River station near Hoopa may also fall in this category, because an insignificant change in hydraulic geometry is indicated for high flows (fig. 17) that transport most bedload discharge.

Smaller postflood velocities and larger stream depths at Trinity River near Burnt Ranch suggest that the competence of the stream to move coarse bed material is less after the flood than before. Also, because the change in hydraulic geometry is small and because no appreciable quantities of sediment were deposited at the site following the 1964 flood, it seems reasonable to assume that significant quantities of coarse sediment, transported by upstream tributaries, are being deposited along the Trinity River upstream from the Burnt Ranch site. This assumption is supported by reports of substantial deposition of streambed sediments in 1964 at various sites between Lewiston Dam and the North Fork Trinity River (Ritter, 1968).

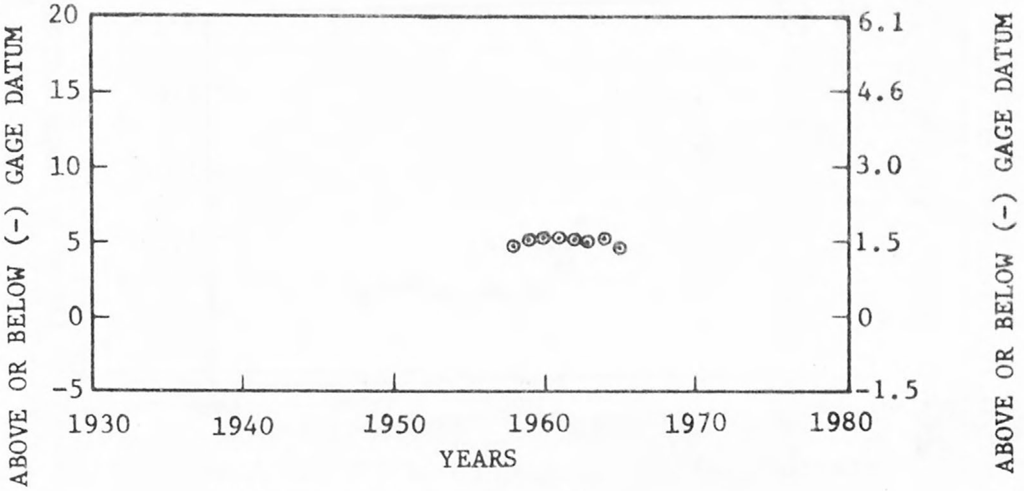
At sites where long-term sediment data were available, total sediment discharge was computed as the sum of long-term suspended-sediment and present bedload discharge (table 8). Where possible, the total sediment discharge was divided into clay, silt, sand, and bedload fractions according to particle-size distribution. The particle-size distribution of the bedload fraction was not determined but probably ranges between fine sand (0.062 mm) and coarse gravel (512 mm).

Table 8.--Total-sediment discharge for selected sediment stations in the Trinity River basin

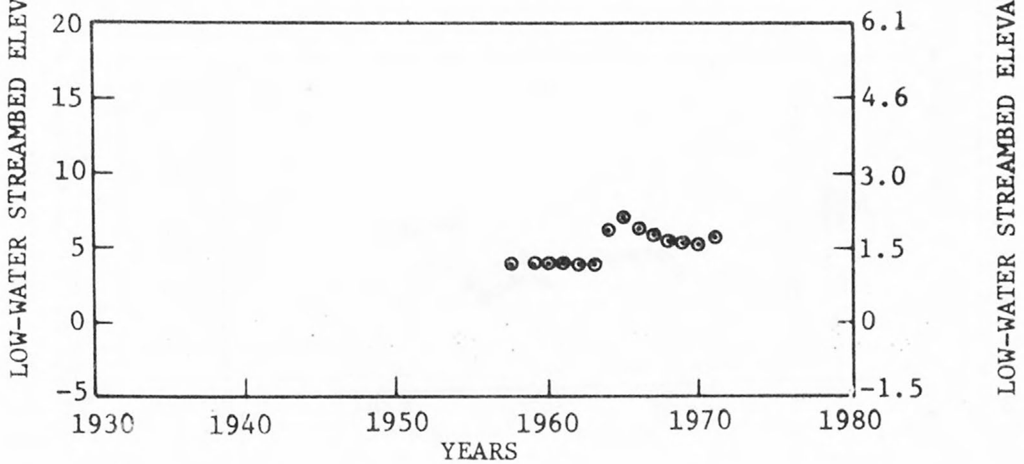
Station number	Sediment station	Sediment-contributing drainage area (sq mi)	Annual sediment discharge (Tons): Suspended sediment: Clay	Suspended sediment: Silt	Suspended sediment: Sand	Suspended sediment: Total	Bedload	Total
11-5255	Trinity River at Lewiston	728	[a]31,000	[a]45,000	[a]44,000	120,000	--	--
-5258	Weaver Creek near Douglas City	48.4	10,000	14,600	10,000	34,600	4,000	38,600
-5265	North Fork Trinity River at Helena	151	5,400	23,700	25,600	54,700	17,000	71,700
-5287	South Fork Trinity River below Hyampom	764	142,000	209,000	321,000	672,000	240,000	912,000
-5290	South Fork Trinity River near Salyer	898	188,000	290,000	382,000	860,000	320,000	1,180,000
-5300	Trinity River near Hoopa	[b]2,146	609,000	1,000,000	911,000	2,520,000	600,000	3,120,000

[a]Representative of period prior to construction of Trinity Dam (1912-60).
[b]Excluding 719-square-mile area upstream from Lewiston Dam.

Total sediment discharges estimated for existing sediment stations probably do not represent the extremes in total sediment discharges that occur in the Trinity River basin. Suspended-sediment data collected at the Lewiston station prior to the December 1964 flood (table 5) suggest that minimum sediment discharges in the basin may be about 200 tons/mi^2 (70 metric tons/km^2). Maximum sediment discharges probably occur downstream from the confluence of New River and Trinity River and along reaches of the South Fork Trinity River downstream from Salyer. These areas probably yield on the order of 2,000 to 3,000 tons/mi^2 (700 to 1,000 metric tons/km^2). Some large sediment discharges have been reported for small areas affected by logging. The California Resources Agency (1970), in their investigation of sediment problems in an 8-mile reach of the Trinity River downstream from Lewiston dam, reported a maximum sediment yield of 3,560 yd^3/mi^2 (1,050 m^3/km^2) per year for Grass Valley Creek. If a specific weight of 73 lb/ft^3 (1.17 g/cm^3) is used to convert volume of sediment to weight units (U.S. Dept. of Agriculture, 1972, p. 134), then the sediment discharge of Grass Valley Creek would be about 3,500 tons/mi^2 (1,200 metric tons/km^2) per year.

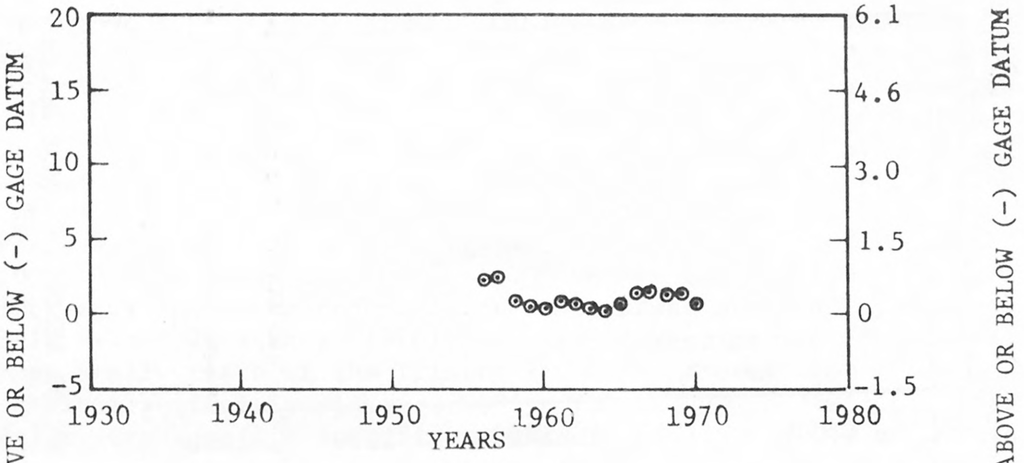


Station number: 11-5258
Weaver Creek near Douglas City
Station datum, in feet above msl: 1,680
Notable unit flood peaks: 60 $ft^3/s/mi^2$ Jan. 31, 1963; 82 $ft^3/s/mi^2$ Dec. 22, 1964.
Station discontinued September 1969

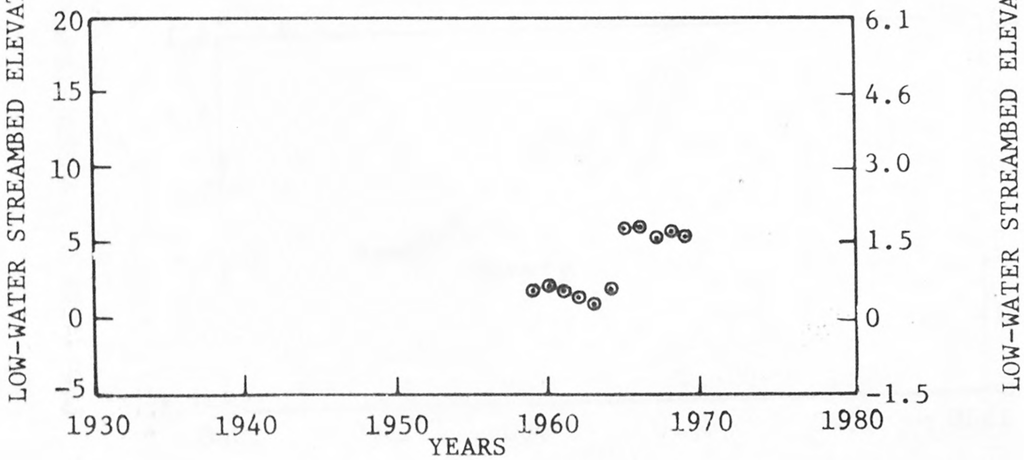


Station number: 11-5265
North Fork Trinity River at Helena
Station datum, in feet above msl: 1,380
Notable unit flood peaks: 89 $ft^3/s/mi^2$ Jan. 12, 1959; 237 $ft^3/s/mi^2$ Dec. 22, 1964.

FIGURE 15.--Graphs showing variations in low-water streambed elevations at selected gaging stations in the Trinity River basin, 1931-71 (from Hickey, 1969, and subsequent streamflow data available in U.S. Geological Survey files).

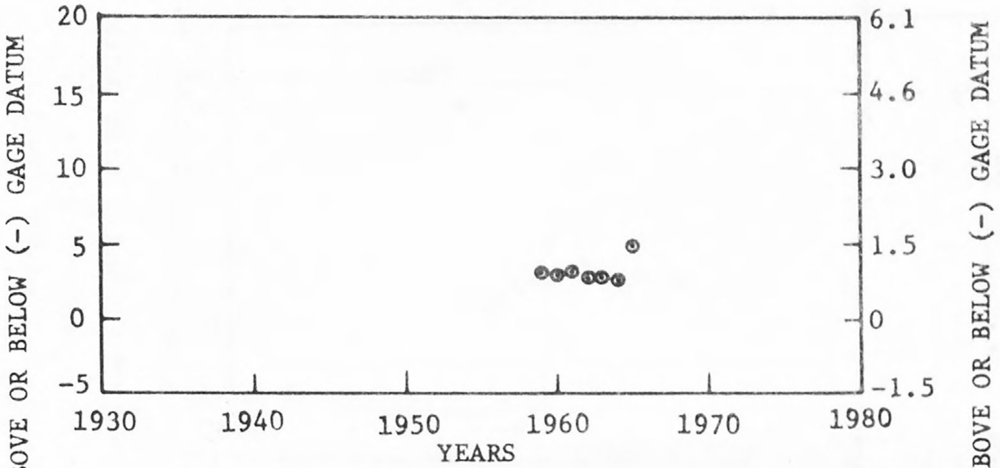


Station number: 11-5270
Trinity River near Burnt Ranch
Station datum, in feet above msl: 944.05
Notable unit flood peaks: 120 $ft^3/s/mi^2$ Dec. 22, 1955; 57 $ft^3/s/mi^2$ Feb. 25, 1958; 110 $ft^3/s/mi^2$ Dec. 22, 1964.

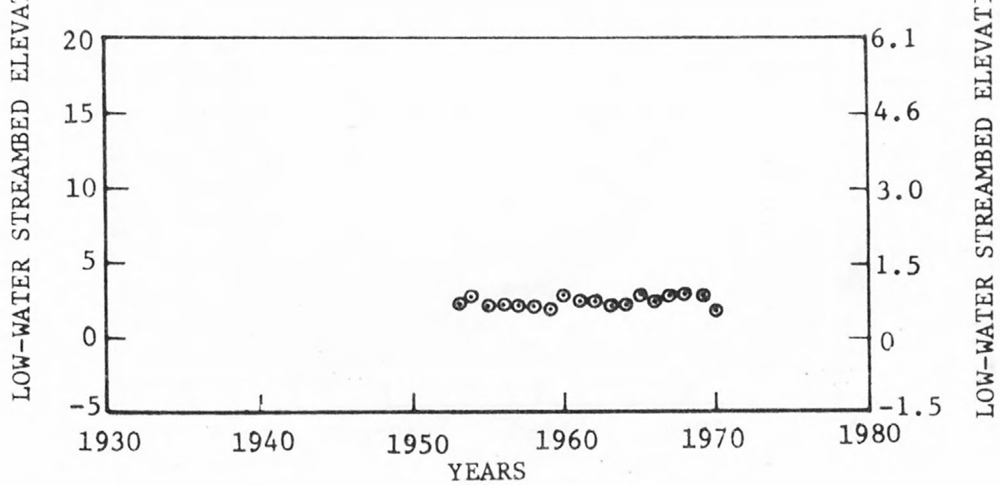


Station number: 11-5274
New River at Denny
Station datum, in feet above msl: 1,349.34
Notable unit flood peaks: 55 $ft^3/s/mi^2$ Dec. 2, 1962; 347 $ft^3/s/mi^2$ Dec. 22, 1964.
Station discontinued September 1969.

FIGURE 15.--Continued.

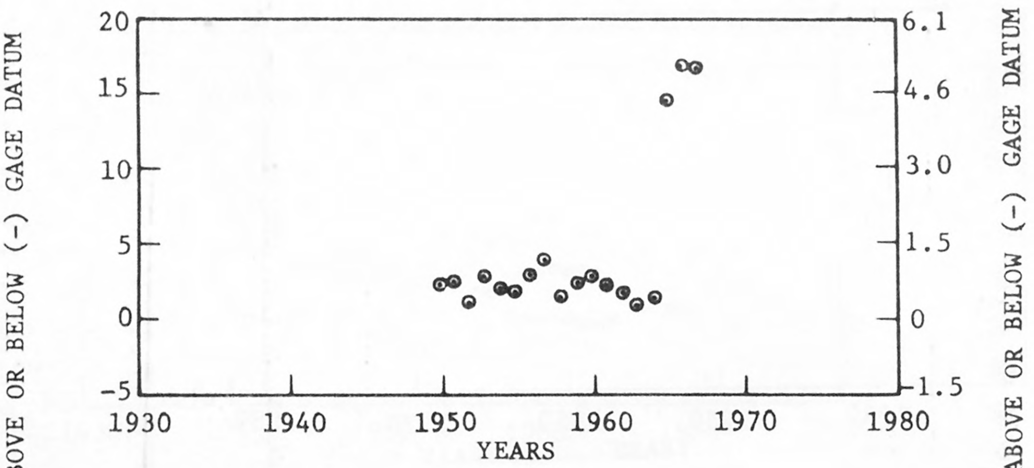


Station number: 11-5281
South Fork Trinity River at Forest Glen
Station datum, in feet above msl: 2,253.49
Notable unit flood peaks: 163 $ft^3/s/mi^2$ Dec. 22, 1955. 198 $ft^3/s/mi^2$ Dec. 22, 1964.
Station discontinued September 1965.

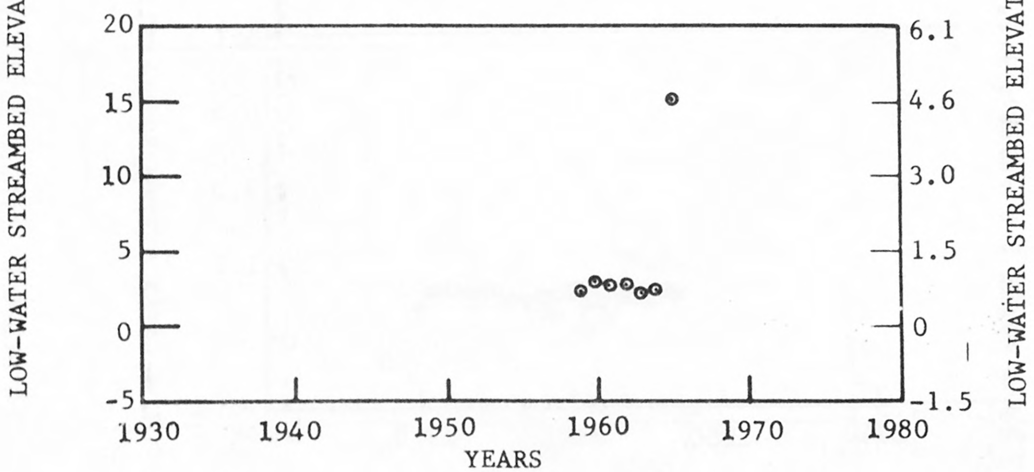


Station number: 11-5285
Hayfork Creek near Hyampom
Station datum, in feet above msl: 1,270.67
Notable unit flood peaks: 67 $ft^3/s/mi^2$ Dec. 22, 1955. 76 $ft^3/s/mi^2$ Dec. 22, 1964.

FIGURE 15.--Continued.

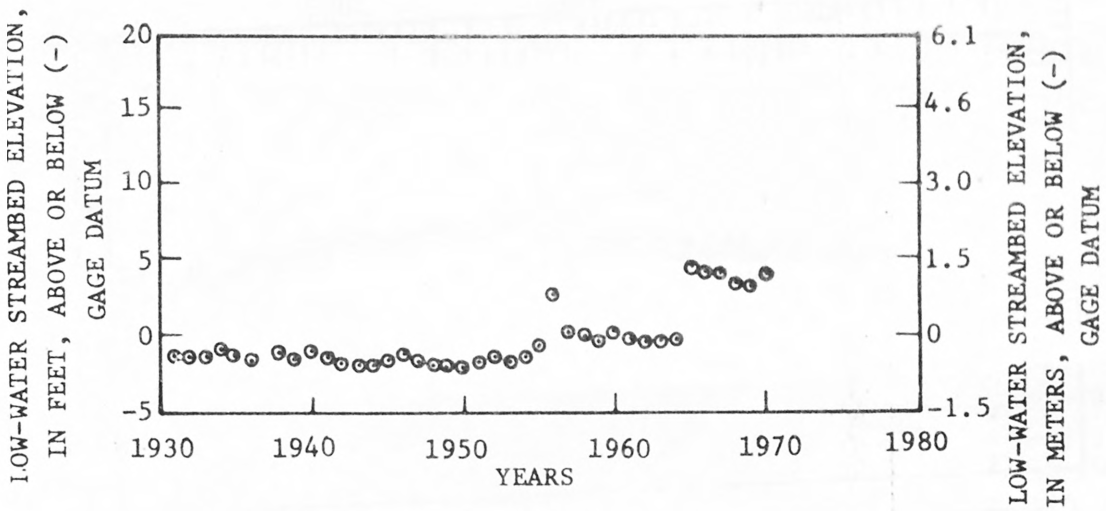


Station number: 11-5290
South Fork Trinity River near Salyer
Station datum, in feet above msl; 549.99
Notable unit flood peaks: 72 $ft^3/s/mi^2$ Dec. 22, 1955; 106 $ft^3/s/mi^2$ Dec. 22, 1964.
Station discontinued September 1967.



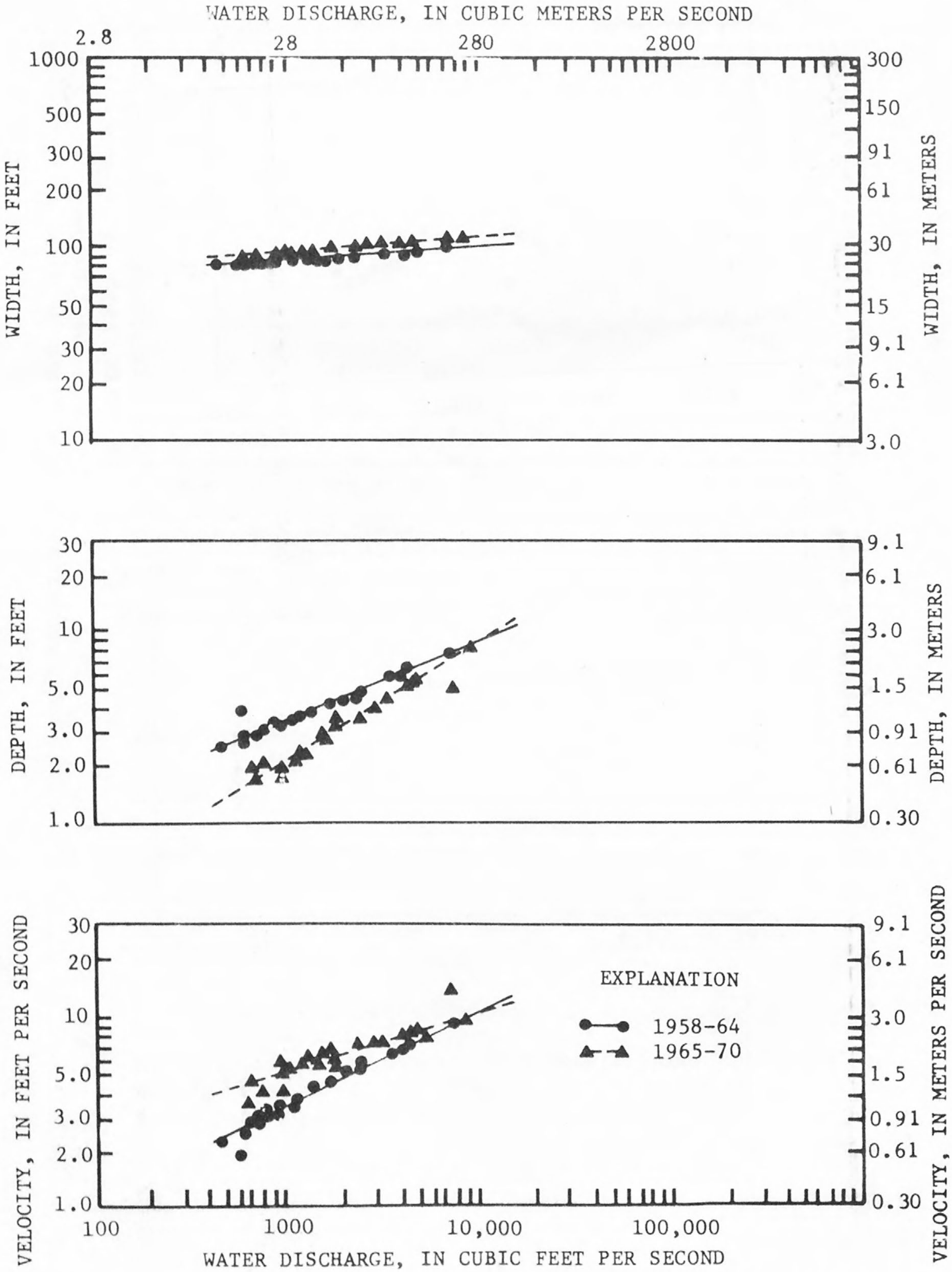
Station number: 11-5298
Willow Creek near Willow Creek
Notable unit flood peaks: 121 $ft^3/s/mi^2$ Jan. 20, 1964; 415 $ft^3/s/mi^2$ Dec. 22, 1964.
Station moved to new location July 1965.

FIGURE 15.--Continued.



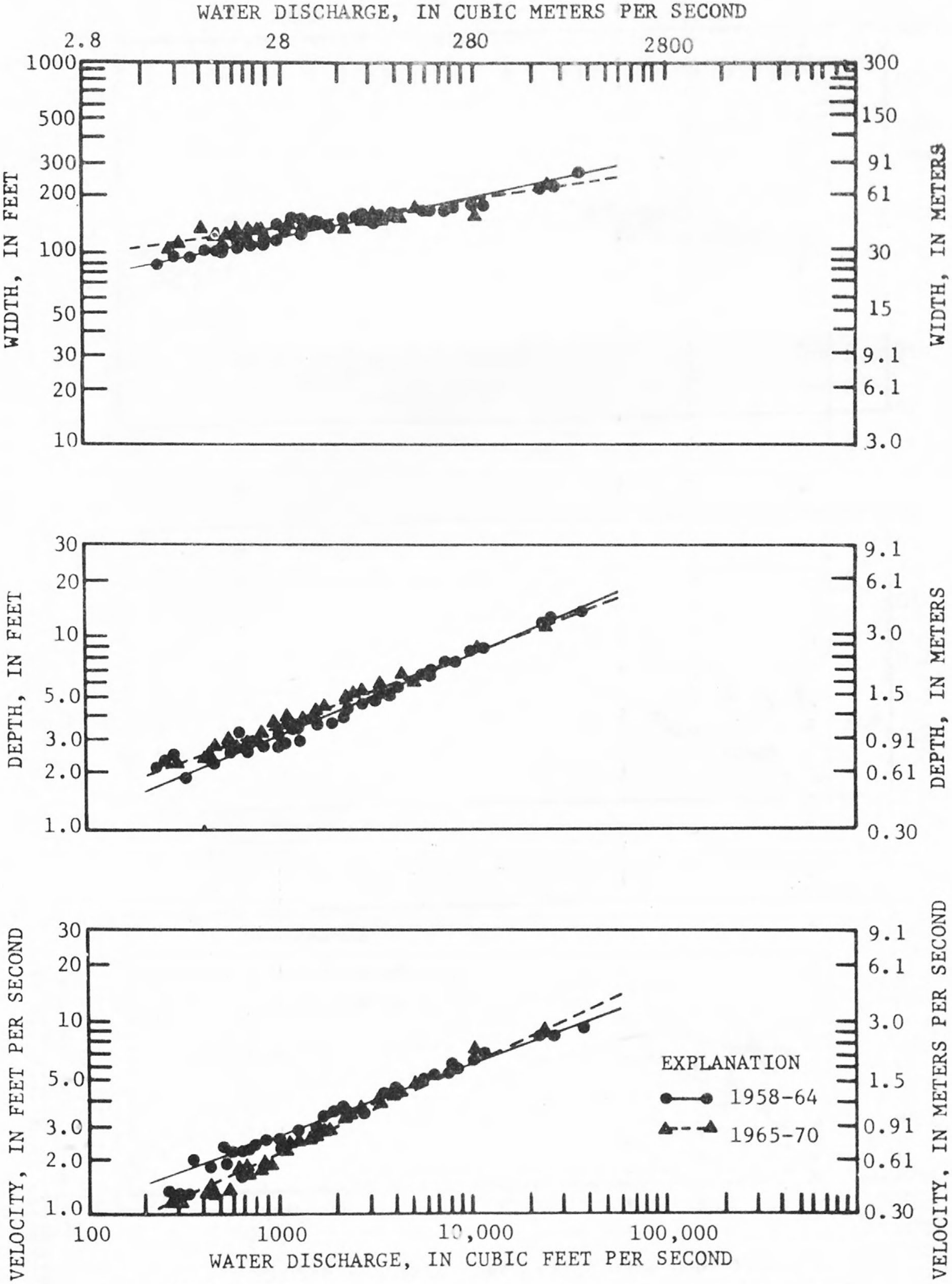
Station number: 11-5300
Trinity River near Hoopa
Notable unit flood peaks: 67 $ft^3/s/mi^2$ Dec. 22, 1955; 44 $ft^3/s/mi^2$ Feb. 19, 1958; 108 $ft^3/s/mi^2$ Dec. 22, 1964. Station moved to new location February 1965. Streambed elevations for period 1965-71 adjusted to gage datum for period 1931-64.

FIGURE 15.--Continued.



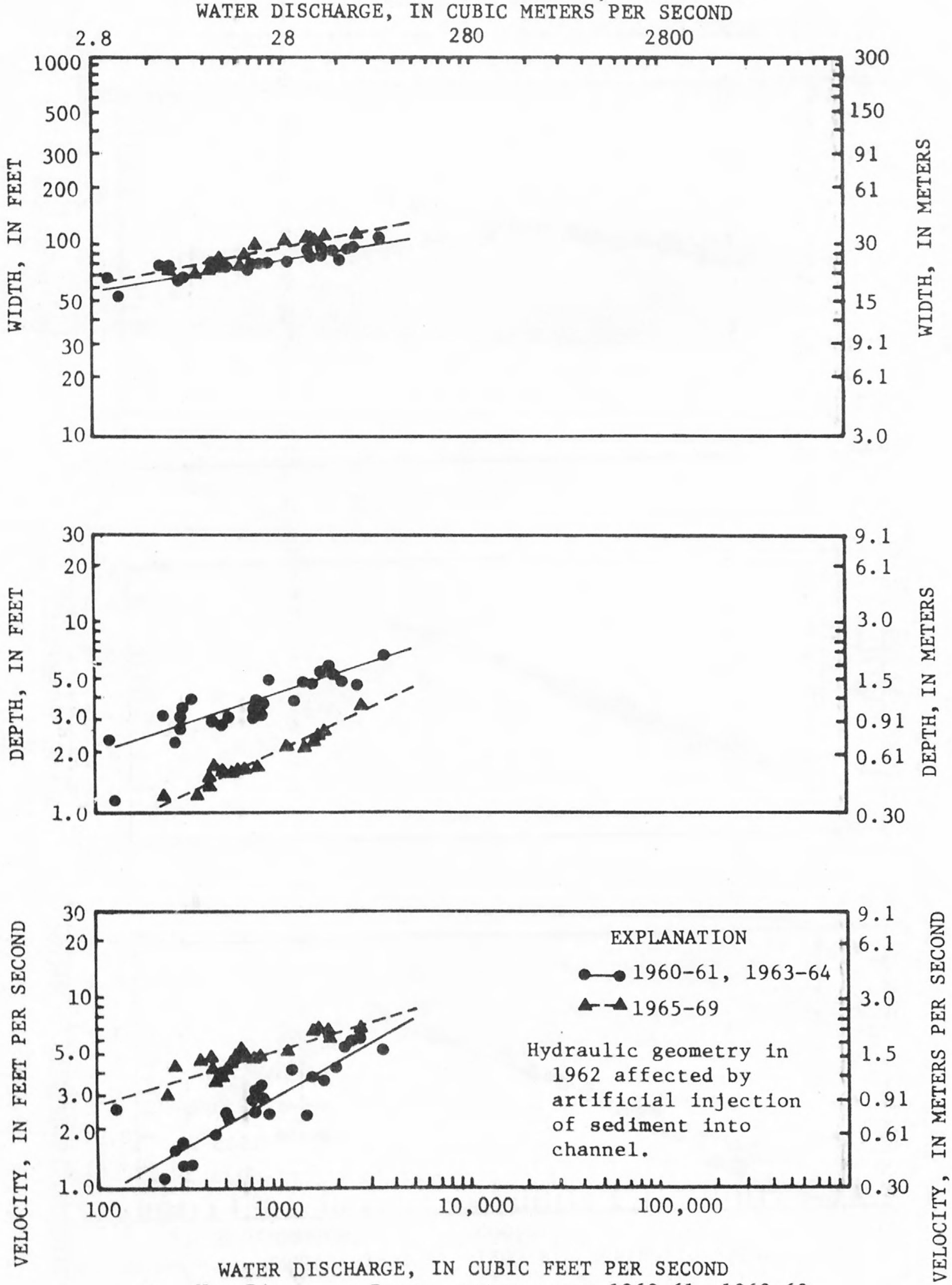
a. North Fork Trinity River at Helena, water years 1958-70

FIGURE 16.--Relation of width, depth, and velocity to water discharge.



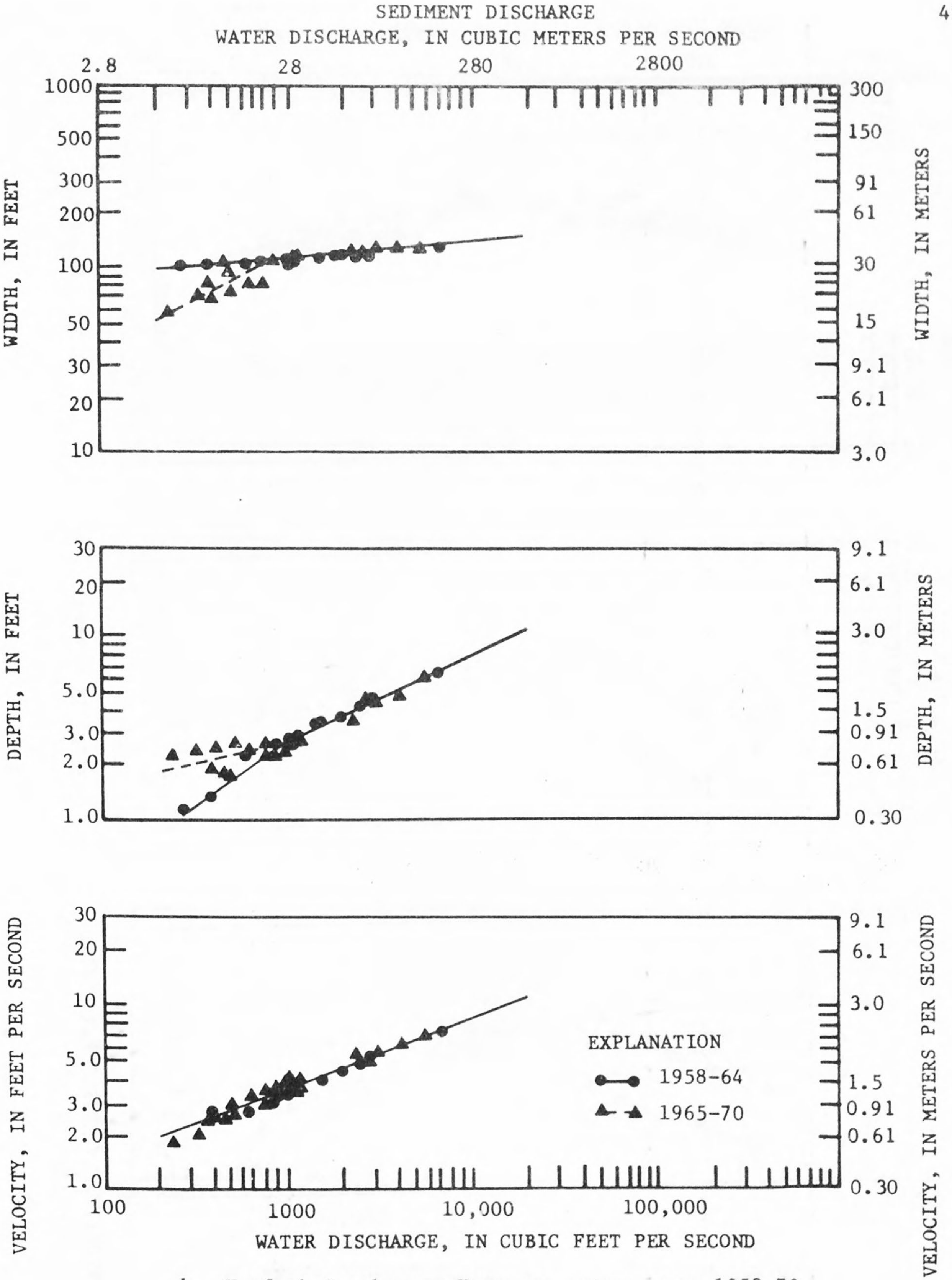
b. Trinity River near Burnt Ranch, water years 1958-70.

FIGURE 16.--Continued.



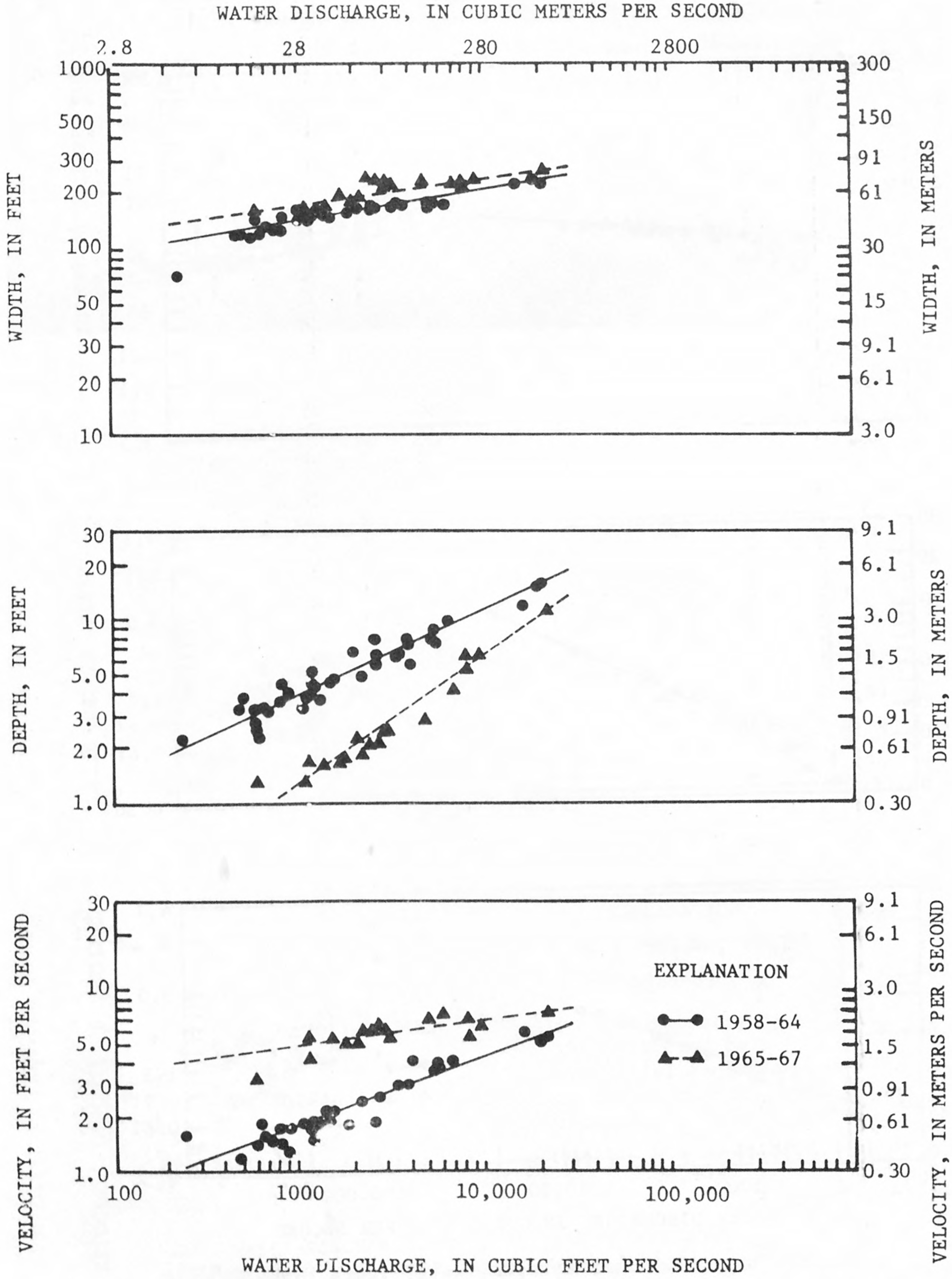
c. New River at Denny, water years 1960-61, 1963-69

FIGURE 16.--Continued.



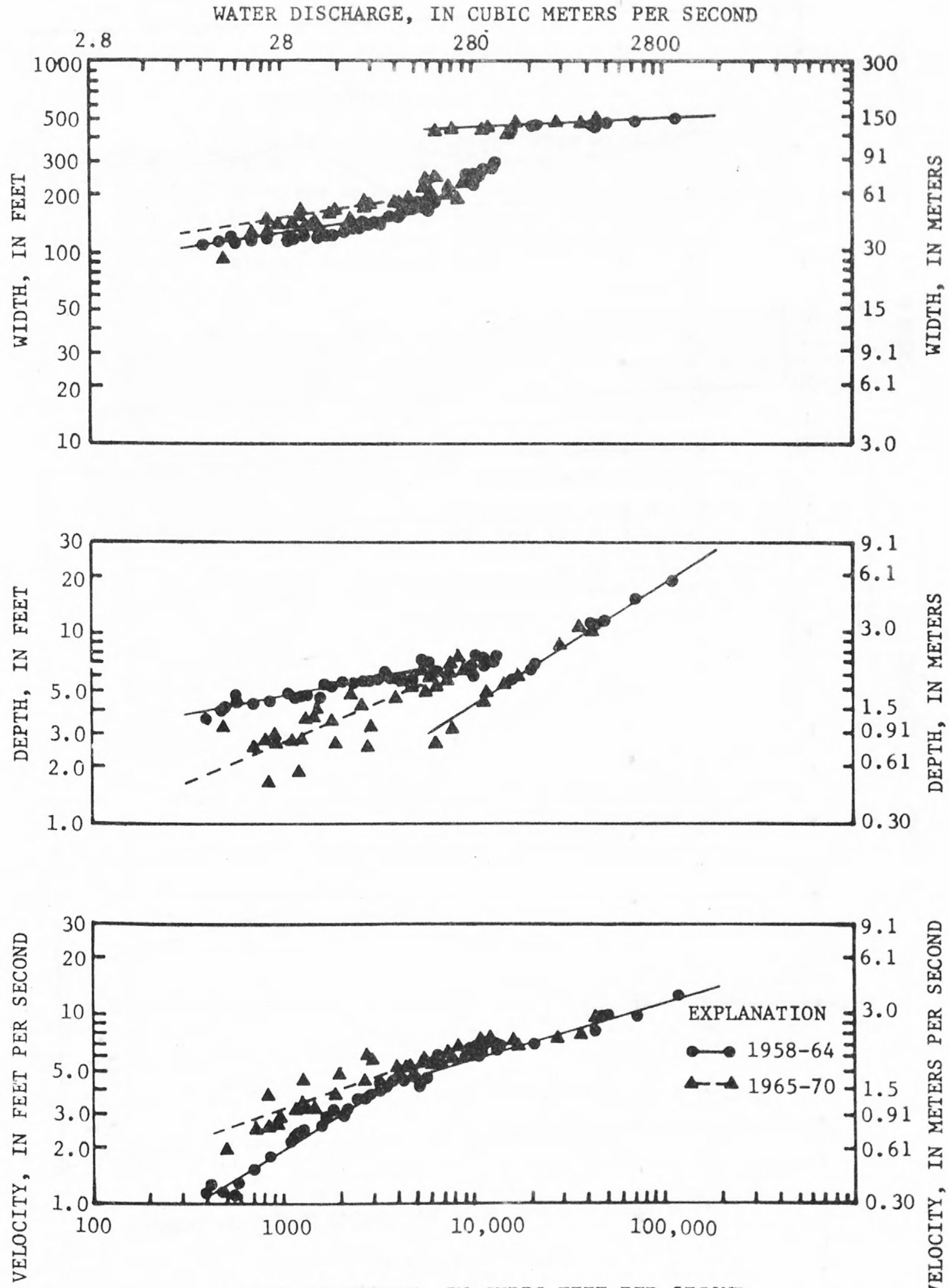
d. Hayfork Creek near Hyampom, water years 1958-70.

FIGURE 16.--Continued.



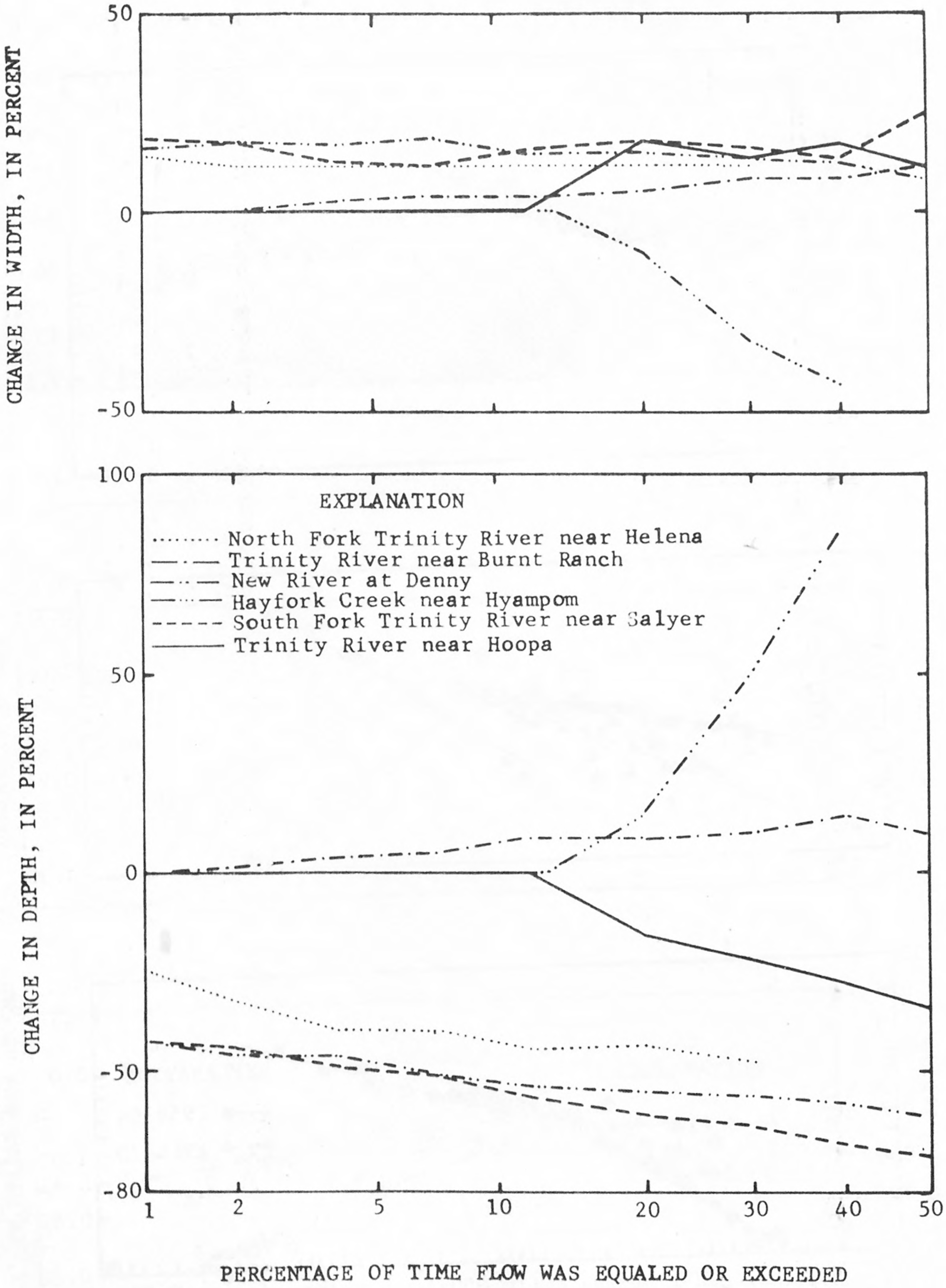
e. South Fork Trinity River near Salyer, water years 1958-67.

FIGURE 16.--Continued.



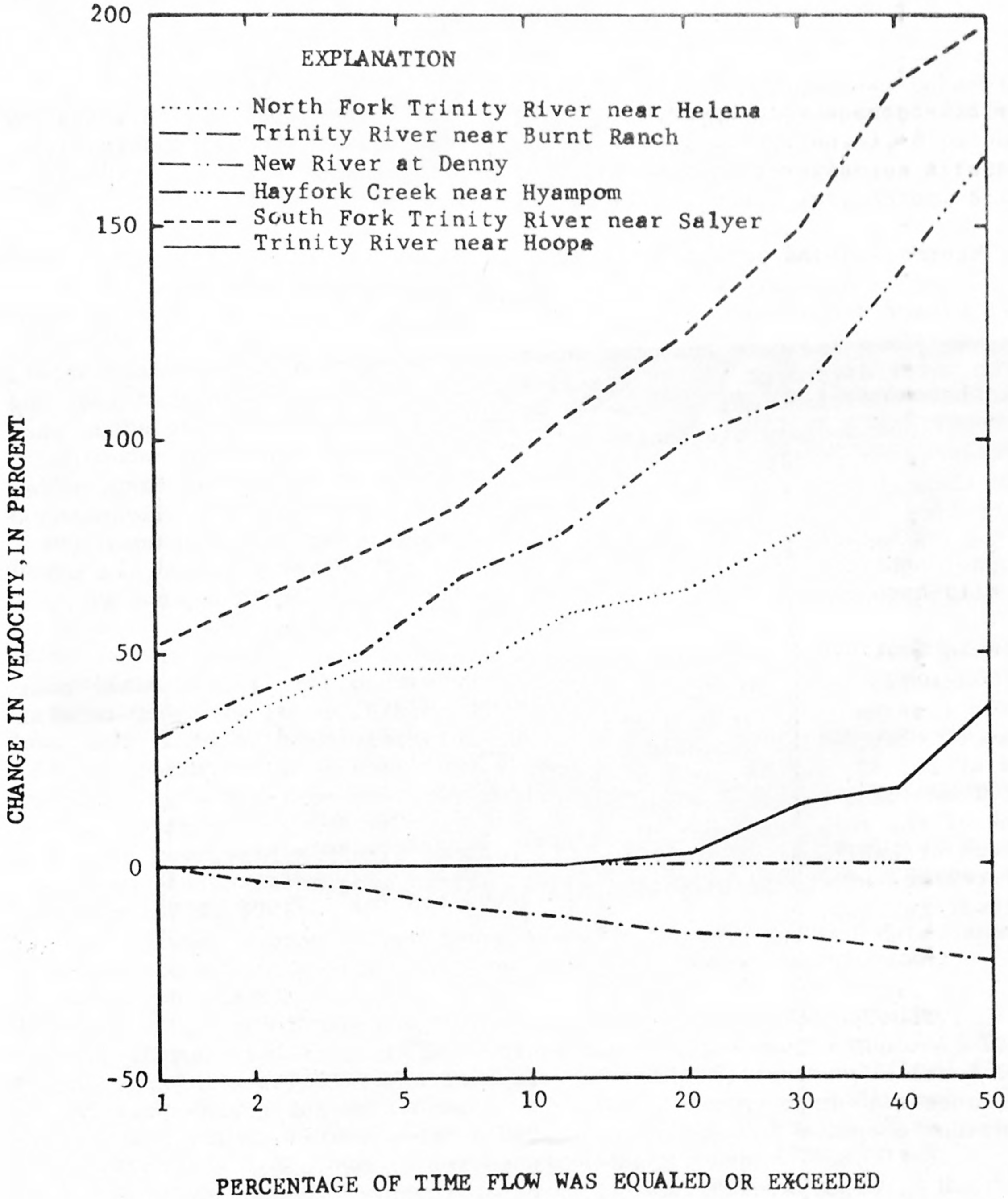
f. Trinity River near Hoopa, water years 1958-70.

FIGURE 16.--Continued.



a. Depth and width.

FIGURE 17.--Observed changes that occurred after the December 1964 flood at selected stations in the Trinity River basin.



b. Velocity.

FIGURE 17.--Continued.

SUMMARY

Suspended-sediment data collected from 1955 to 1970 indicate that the quantity of sediment transported from year to year by streams in the Trinity River basin is extremely variable. Annual suspended-sediment discharge for the Trinity River near Hoopa ranged from 155 to 15,700 tons/mi^2 (54 to 5,500 metric tons/km^2) during the period 1957-70.

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 the quantity of suspended sediment transported by a given water discharge has progressively decreased since December 1964 and that preflood conditions may be reached within a period of 10 years after the flood. Postflood bedload discharges at several sites are presently at high levels relative to preflood rates. Massive deposits of coarse material, added to stream channels since the 1964 flood, have greatly changed the hydraulic characteristics of major tributaries. These changes generally increased the capacity of the streams to transport sediment. Large bedload discharges will persist until the coarse sediment deposited by the flood is dissipated or until stream channels become sufficiently armored to resist erosion.

The long-term average annual sediment discharge of the Trinity River near Hoopa is estimated at 3,120,000 tons (2,830,000 metric tons), or 1,450 tons/mi^2 (508 metric tons/km^2) excluding the area upstream from Lewiston Dam. The percentage of clay, silt, and sand or coarser material at this station is estimated at 20, 32, and 48 percent, respectively. Bedload discharge, which consists of sediment ranging in size from sand to cobbles, is estimated at 19 percent of the total sediment discharge. Long-term total sediment discharge in the basin probably ranges from about 200 tons/mi^2 (70 metric tons/km^2) for the upper reaches of the Trinity River to 3,000 tons/mi^2 (1,000 metric tons/km^2) for the lower reaches.

SELECTED REFERENCES

Anderson, H. W., 1968, Major flood effect on subsequent suspended-sediment discharge (abs): Am. Geophys. Union Trans., v. 49, no. 1, 8 p.

______1970, Principal components analysis of watershed variables affecting suspended-sediment discharge after a major flood: Int. Assoc. Sci. Hydrol., Pub. 96, p. 404-416.

Barnes, H. H., Jr., 1967, Roughness characteristics of natural channels: U.S. Geol. Survey Water-Supply Paper 1849, 213 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, 70 p.

California Resources Agency, 1970, Task force findings and recommendations on sediment problems in the Trinity River near Lewiston and a summary of the watershed investigation: Task Force rept. to the Secretary for Resources.

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.

Helley, E. J., and Smith, Winchell, 1971, Development and calibration of a pressure-difference bedload sampler: U.S. Geol. Survey open-file rept., 18 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.

Knott, J. M., 1971, Sedimentation in the Middle Fork Eel River basin, California: U.S. Geol. Survey open-file rept., 60 p.

Lane, E. W., and Borland, W. M., 1951, Estimating bed load: Am. Geophys. Union Trans., v. 32, no. 1, 3 p.

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.

National Climatic Center, published annually, Climatological data, annual summaries for California: Asheville, N.C., Natl. Oceanic and Atmospheric Adm.

O'Brien, J. C., 1965 Mines and mineral resources of Trinity County, California: California Div. Mines and Geology County Rept. 4, 125 p.

Porterfield, George, 1972, An inventory of published and unpublished fluvial-sediment data for California: U.S. Geol. Survey open-file rept., 26 p.

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

______1969, Mean annual precipitation in the California region: U.S. Geol. Survey open-file rept., 5 p.

Ritter, J. R., 1968, Changes in the channel morphology of Trinity River and eight tributaries, California, 1961-65: U.S. Geol. Survey open-file rept., 60 p.

Stewart, J. H., and La Marche, V. C., 1967, Erosion and deposition produced by the flood of December 1964 on Coffee Creek, Trinity County, California: U.S. Geol. Survey Prof. Paper 422-K, 22 p.

Strahler, A. N., 1969, Physical geography, 3d edition: New York, John Wiley and Sons, 733 p.

Strand, R. G., 1962, Geologic map of California, Olaf P. Jenkins edition, Redding sheet: California Div. Mines and Geol., scale 1:250,000.

______1964, Geologic map of California, Olaf P. Jenkins edition, Weed sheet: California Div. Mines and Geol., scale 1:250,000.

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

U.S. Department of Agriculture, 1972, Water, land, and related resources, north coastal area of California and portions of southern Oregon; appendix no. 2, Sediment yield and land treatment: Berkeley, Calif., River Planning Staff, 133 p.

U.S. Geological Survey, published annually 1947-72, 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 papers.

______published annually, 1961-72, Water resources data for California--part 2, water-quality records: U.S. Geol. Survey open-file repts.

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.