ANNUAL SUSPENDED-SEDIMENT LOADS IN
THE COLORADO RIVER NEAR CISCO,
UTAH, 1930-82

By Kendall R. Thompson

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CONVERSION FACTORS

Values in this report are given in inch-pound units. Conversion factors to metric units are listed below:

Multiply inch-pound units	By	To obtain metric units
acre	0.4047	square hectometer
	0.004047	square kilometer
acre-foot	0.001233	cubic hectometer
	1233	cubic meter
cubic foot per second	0.02832	cubic meter per second
foot	0.3048	meter
gallon	3.785	liter
inch	25.40	millimeter
	2.540	centimeter
mile	1.609	kilometer
square mile	2.590	square kilometer
ton (short)	0.9072	metric ton
ton per square mile	0.350	metric ton per square mile

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ABSTRACT

The Colorado River upstream of gaging station 09180500 near Cisco, Utah, drains about 24,100 square miles in Utah and Colorado. Altitudes in the basin range from 12,480 feet near the headwaters to 4,090 feet at station 09180500. The average annual precipitation for 1894-1982 near the station was 7.94 inches. The annual precipitation near the headwaters often exceeds 50 inches.

Rocks ranging in age from Precambrian to Holocene are exposed in the drainage basin upstream from station 09180500. Shale, limestone, siltstone, mudstone, and sandstone probably are the most easily eroded rocks in the basin, and they contribute large quantities of sediment to the Colorado River.

During 1930-82, the U.S. Geological Survey collected records of fluvial sediment at station 09180500. Based on these records, the mean annual suspended-sediment load was 11,390,000 tons, ranging from 2,038,000 tons in water year 1981 to 35,700,000 tons in water year 1938. The minimum daily load of 14 tons was on August 22, 1960, and the maximum daily load of 2,790,000 tons was on October 14, 1941.

Analysis of the suspended-sediment records collected from 1930-82 at station 09180500 indicated that the accuracy of the records is fair prior to 1945 and good for the remaining period of record. The records after 1945 reflect the use of improved sampling equipment.

A double-mass curve showed changes in relationship between annual suspended-sediment load and annual stream discharge. The first change occurred in the early 1940's, and it coincides approximately with a change in sampling equipment. The U.S. D-43 suspended-sediment sampler was first used at station 09180500 during October 1945. The second change, which occurred approximately between water years 1967-68, coincides with the closure of the dam at Blue Mesa Reservoir (allowing 1-2 years for the reservoir to fill). Blue Mesa Reservoir impounds water of the Gunnison River (the largest tributary to the Colorado River upstream from station 09180500), and it has regulated flow in the river system since November 27, 1965. The mean annual loads at station 09180500 were reduced by about 22 percent after the closure of Blue Mesa Dam, and the mean annual suspended-sediment yield was reduced from 402 to 315 tons per square mile. Other factors may have been involved or responsible for these changes, but their identification is beyond the scope of this report.

The data collected after 1968 were used in a regression equation, but the equation proved to be a poor predictor of annual suspended-sediment load

using annual stream discharge as the independent variable. If, for example, an annual stream discharge of 4,000,000 acre-feet is used, the equation predicts annual suspended sediment to be about 6,462,000 tons; but it could range from 717,000 to 12,207,000 tons at a 90-percent confidence interval.

The variability of the annual suspended-sediment loads at station 09180500 is obvious. The localized nature of precipitation in the basin and the variation in geology upstream from the gaging station contribute to this variability.

INTRODUCTION

The U.S. Geological Survey has operated a streamflow-gaging station since 1895 on the Colorado River near Cisco, Grand County, Utah (fig 1). This station is identified as station 09180500, Colorado River near Cisco, Utah, in reports of the U.S. Geological Survey (1966-82). Prior to 1918, this river was called the Grand River. Fluvial-sediment records were collected at station 09180500 from 1914-15 and 1930-82. The records collected from 1914-65 were compiled by Mundorff (1968, p. 17-41), and particle-size data were included in that report. Records collected after 1965 were reported annually by the U.S. Geological Survey (1966-82), including particle-size data, daily concentrations, and daily loads.

Purpose and Scope

The purpose of this report is to evaluate the sediment data that were collected at station 09180500 and to describe annual suspended-sediment loads in the Colorado River near Cisco based on those data. A predictive regression model was constructed for estimating annual suspended-sediment loads using annual stream discharge as the independent variable. It is beyond the scope of this report to calculate total fluvial-sediment loads, which require bedload data, or to do detailed analysis of the records.

General Description of the Colorado River Basin

The Colorado River basin upstream from station 09180500 includes about 24,100 square miles in Utah and Colorado. The gaging station is 11 miles south of Cisco, 36 miles downstream from the Colorado-Utah State line, 1 mile downstream from the mouth of the Dolores River, and 97 miles upstream from the confluence with the Green River. The Colorado River originates in the Rocky Mountains near the continental divide in Colorado (fig. 1). Principal tributaries of the Colorado River upstream from station 09180500 are the Dolores, Gunnison, Roaring Fork, Eagle, Blue, and Fraser Rivers. Lake Granby, near the headwaters of the Colorado River, is the only major reservoir on the main stem of the river upstream from station 09180500. Several large reservoirs in the Colorado River basin upstream from station 09180500 are described below:

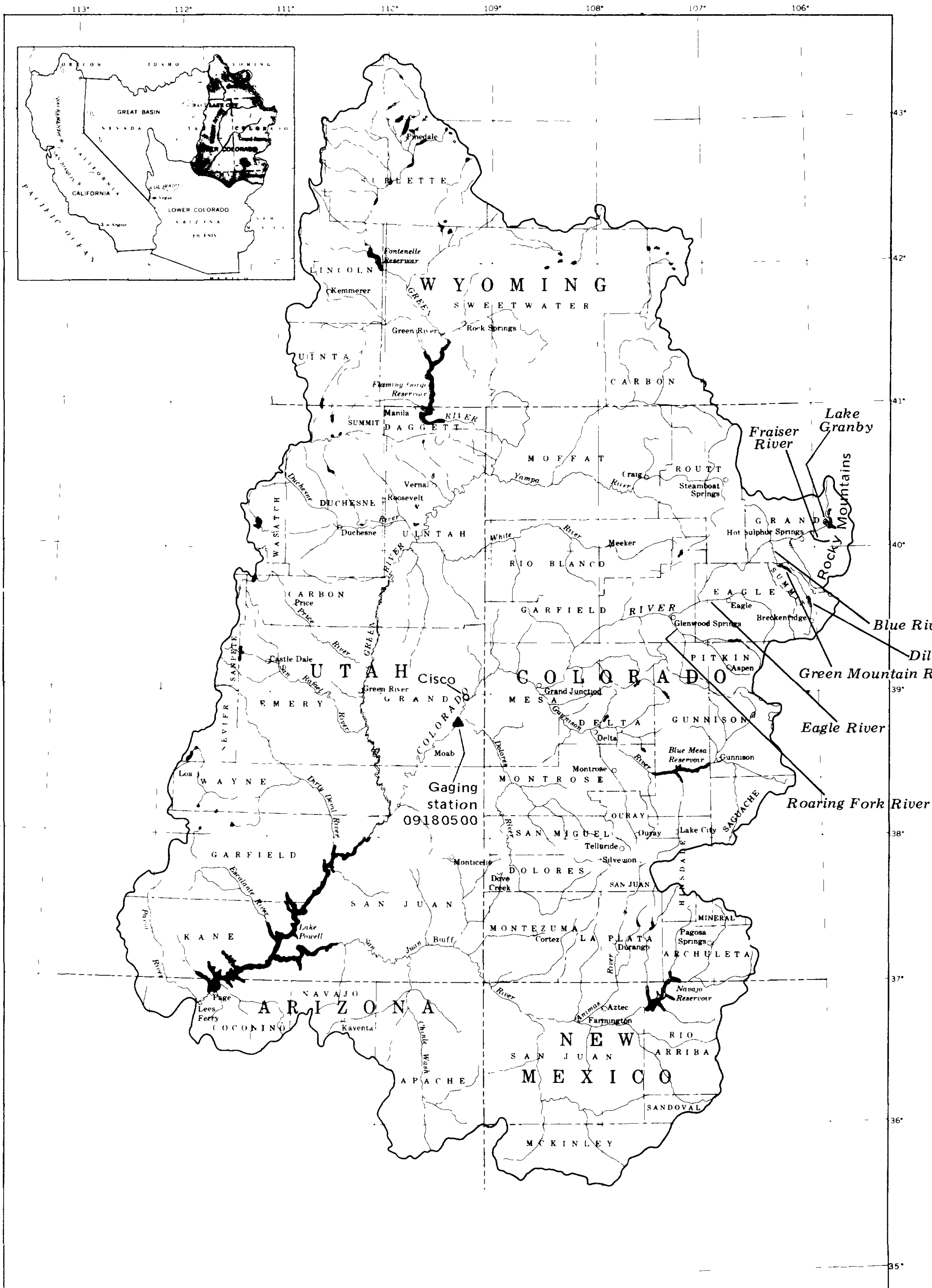

Figure 1.—Location of gaging station 09180500 on the Colorado River near Cisco, Utah.

Reservoir	Capacity (acre-feet)	Drainage area (square miles)	Storage began	Drainage
Blue Mesa	829,600	3,426	Oct. 26, 1965	Gunnison River
Lake Granby	465,000	312	June 14, 1950	Colorado River
Dillon	254,000	335	Sept. 3, 1950	Blue River
Green Mountain	146,900	598	Nov. 1942	Blue River

Altitudes in the Colorado River basin range from 12,480 feet near the headwaters of the river to 4,090 feet at station 09180500. The climate varies from humid-subhumid in the headwaters to arid near the station. The average annual precipitation for 1894-1982 near the station was 7.94 inches (National Oceanic and Atmospheric Administration, 1982, p. 9), but the annual precipitation near the headwaters of the river often exceeds 50 inches. Precipitation results from winter frontal storms that generally come from the west and summer convection storms that generally come from the south. The convection storms produce local but intense rainfall which generates rapid runoff and sediment transport. Precipitation during late October through mid-April is mostly snow, particularly at higher altitudes in the basin. The annual snowfall ranges from 200-300 inches in the higher altitudes to about 5 inches in the lower areas (Hedlund and others, 1971, p. 10).

Rocks ranging in age from Precambrian to Holocene are exposed in the Colorado River basin above Cisco. They consist mostly of consolidated and semiconsolidated continental and marine sedimentary rocks, with lesser exposures of igneous rocks, metamorphic rocks, alluvium, and lacustrine deposits (Hedlund and others, 1971, p. 10). Rocks orginating in marine and brackish-water environments, such as shale and some limestone, siltstone, mudstone, and sandstone, probably are the most easily eroded rocks in the basin, and they contribute large quantities of sediment to the Colorado River.

Collection and Evaluation of Records

Sampling to determine suspended-sediment concentrations at station 09180500 began in August 1914 and ended in 1915. Sampling was restarted in 1930 and was continuous through 1982. Sampling to determine suspended-sediment particle size began in 1951 and was continuous through 1982. Most of the suspended-sediment sampling was done from a cableway at the station.

Prior to 1945, sampling for suspended sediment was by simple, inexact methods. Many samples were collected by dipping bottles and other containers in the river. Various methods were used to weight the containers in an attempt to collect depth-integrated samples. Some sampling devices permitted the container to be opened below the surface of the water, and this type of sampler collected samples at specific points in the sampling vertical. It was virtually impossible, however, to obtain accurate depth-integrated samples with this type of equipment. The U.S. D-43 suspended-sediment sampler was developed in 1943, and it was the first standard sampler designed to collect accurate, depth-integrated, suspended-sediment samples. With this and subsequent samplers, accurate depth-integrated samples could be collected over a wide range of flow conditions, thus providing a more representative suspended-sediment record. The U.S. D-43 suspended-sediment sampler was first used at station 09180500 during October 1945. The development and use of suspended-sediment sampling equipment is described in a series of reports released by the U.S. Interagency Committee on Water Resources (1941a, 1941b, 1948, 1952, 1961, and 1963).

It is important to consider the reliability of available records before an analysis of the records is attempted. The sampling site also must be considered. Numerous changes have occurred during the 53 years that data were collected continuously at station 09180500. During that time there were numerous changes in sampling, laboratory, streamflow-measuring and recording equipment, and all involved different techniques and different personnel.

After reviewing the records and other factors that may have influenced the reliability of the records, the following conclusions have been made:

1. The cableway at station 09180500 is a good site for the collection of suspended-sediment data if proper sampling techniques are used. The proximity of the sampling site to the mouth of the Dolores River may adversely influence suspended-sediment data collection at times (due to incomplete mixing of the two distinctly different waters) if improper sampling techniques are used.

2. The data collected prior to October 1945 are not as representative of actual conditions as the data collected later. Data collected after October 1945 reflect the more reliable and accurate sampling with the U.S. D-43 and subsequent depth-integrating samplers.

3. Infrequent sampling during storms often resulted in storm loads that could not be calculated without extrapolation, thus resulting in less accurate storm-load data. Large suspended-sediment loads commonly are transported during storms, and the extrapolated storm-load data undoubtably resulted in less accurate load calculations. Based on the foregoing conclusions, the suspended-sediment records for gaging station 09180500 are considered to be fair prior to 1945 and good for the remaining period of record.

SUSPENDED-SEDIMENT LOADS

Annual Suspended-Sediment Loads, 1930-82

The annual suspended-sediment loads at station 09180500, which are shown in figure 2, have varied considerably. The minimum annual load of 2,038,000 tons occurred during the 1981 water year, and the maximum annual load of 35,700,000 tons occurred during the 1938 water year. The mean annual suspended-sediment load for 53 years of continuous record was 11,390,000 tons, with a standard deviation of 7,895,000 tons. The minimum daily suspended-sediment load of 14 tons was on August 22, 1960, and the maximum daily load of

2,790,000 tons was on October 14, 1941. It is interesting to note that the suspended-sediment load transported on October 14, 1941 (2,790,000 tons), exceeded the suspended-sediment load transported during the entire 1981 water year (2,038,000 tons).

A change in the volume and variability of annual suspended-sediment loads is apparent from figure 2. The annual volume and variability was greater during 1930-45 than during 1946-82, but less variability in annual stream discharge occurred between the two periods (fig. 3). The mean annual suspended load for the two periods was 17,642,000 tons between 1930-45 and 8,687,000 tons between 1946-82, whereas the mean annual stream discharge was 5,219,000 acre-feet during 1930-45 and 4,664,000 acre-feet during 1946-82. The variation in annual stream discharge alone would not appear to be sufficient to cause the variability evident in the annual suspended-sediment loads.

The double-mass curve shown in figure 4 provides further evidence of a change based on the concept that "A break in the slope of the double-mass curve means that a change in the constant of proportionality between the two variables has occurred * * * and * * * indicates the time at which a change occurs in the relationship between the two quantities." (Searcy and Hardison, 1960, p. 33.) A break in the slope of the double-mass curve occurred in the early 1940's and also approximately between water years 1967-68 (fig. 4). Cumulative annual stream discharge versus time was plotted (not presented) to help identify changes in trends of stream discharge that might have occurred; however, no long-term changes were evident in annual stream discharge similar to those indicated by the double-mass curve in figure 4. Cumulative annual suspended-sediment load versus time was plotted (fig. 5) to help identify changes in suspended-sediment trends which might have occurred, and changes in slope similar to the changes in the double-mass curve (fig. 4) are apparent. Thus, some factor(s) other than annual stream discharge also influenced the change in trend of suspended sediment.

The change that occurred in the early 1940's coincides approximately with a major change in sampling equipment. The U.S. D-43 suspended-sediment sampler was first used at station 09180500 during October 1945 (1946 water year). The change that occurred approximately between water years 1967-68 coincides with the closure of the dam at Blue Mesa Reservoir during November 1965 (1966 water year), allowing 1 to 2 years for the reservoir to fill.

A comparison of annual suspended-sediment loads for the three time periods indicated in figure 4 is presented in table 1. A decreasing trend is apparent, but it may be somewhat misleading if the factors involved in the changes are not considered. The change that occurred approximately between water years 1943-46 was apparently caused by an improvement in sampling equipment and technique; thus it does not represent a real change in suspended-sediment loads. The annual suspended-sediment loads for 1930-45 probably were smaller than the published records indicate whereas the annual suspended-sediment loads reported after 1945 are representative of actual suspended-sediment transport at station 09180500. The reduction in annual suspended-sediment loads after water years 1967-68 can be attributed to the completion of Blue Mesa Reservoir.

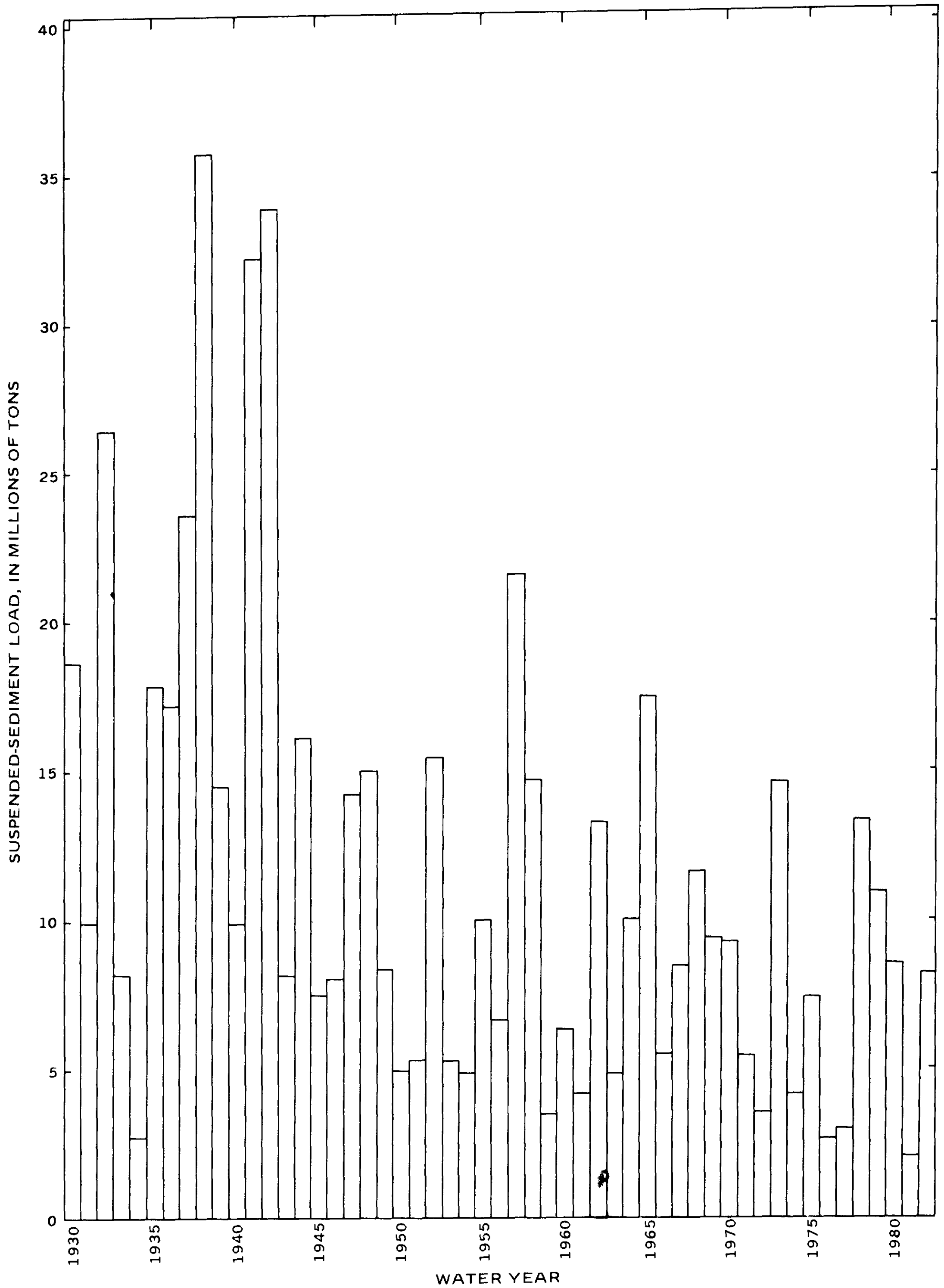

Figure 2.—Annual suspended-sediment load at station 09180500, water years 1930-82.

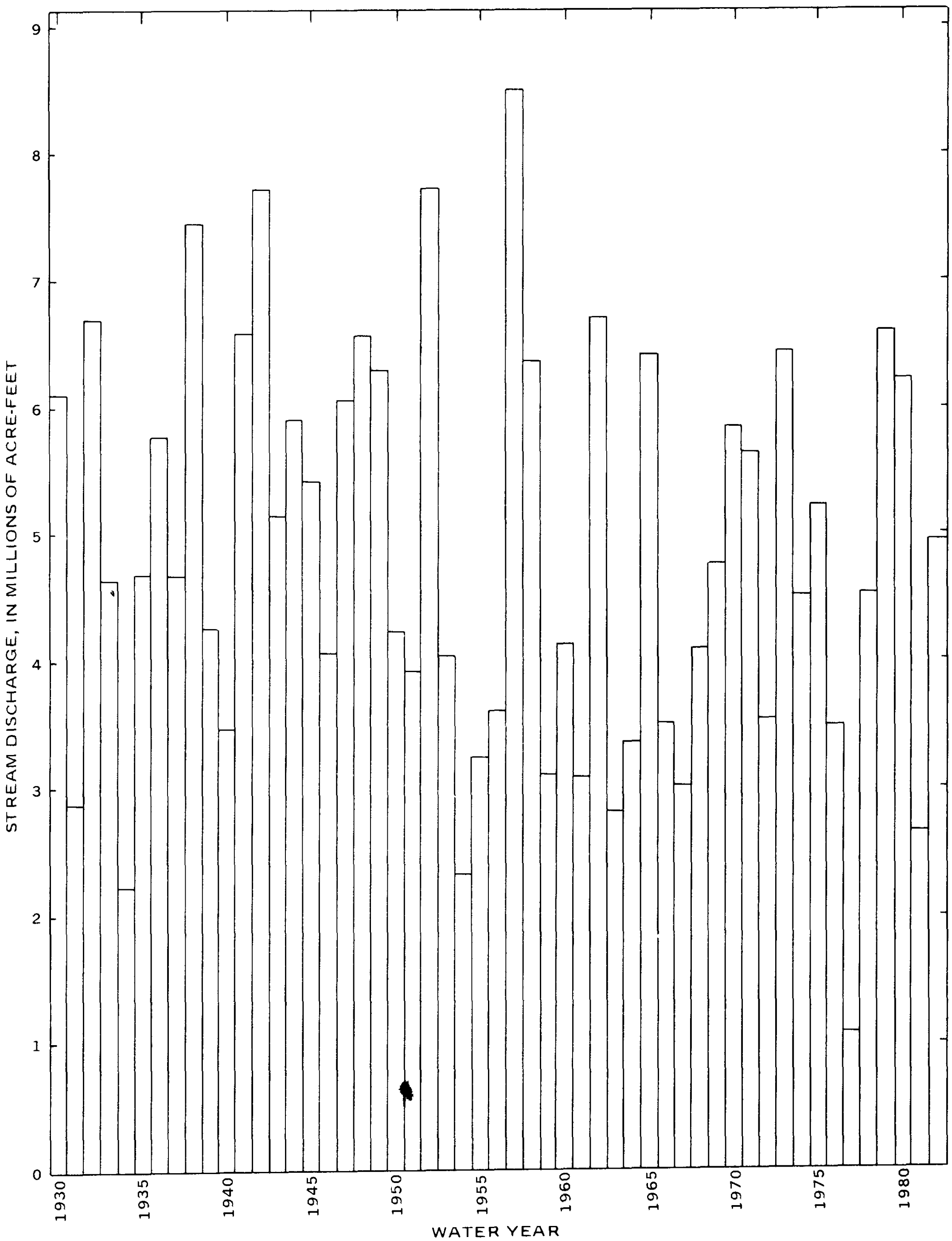

Figure 3.—Annual stream discharge at station 09180500, water years 1930-82.

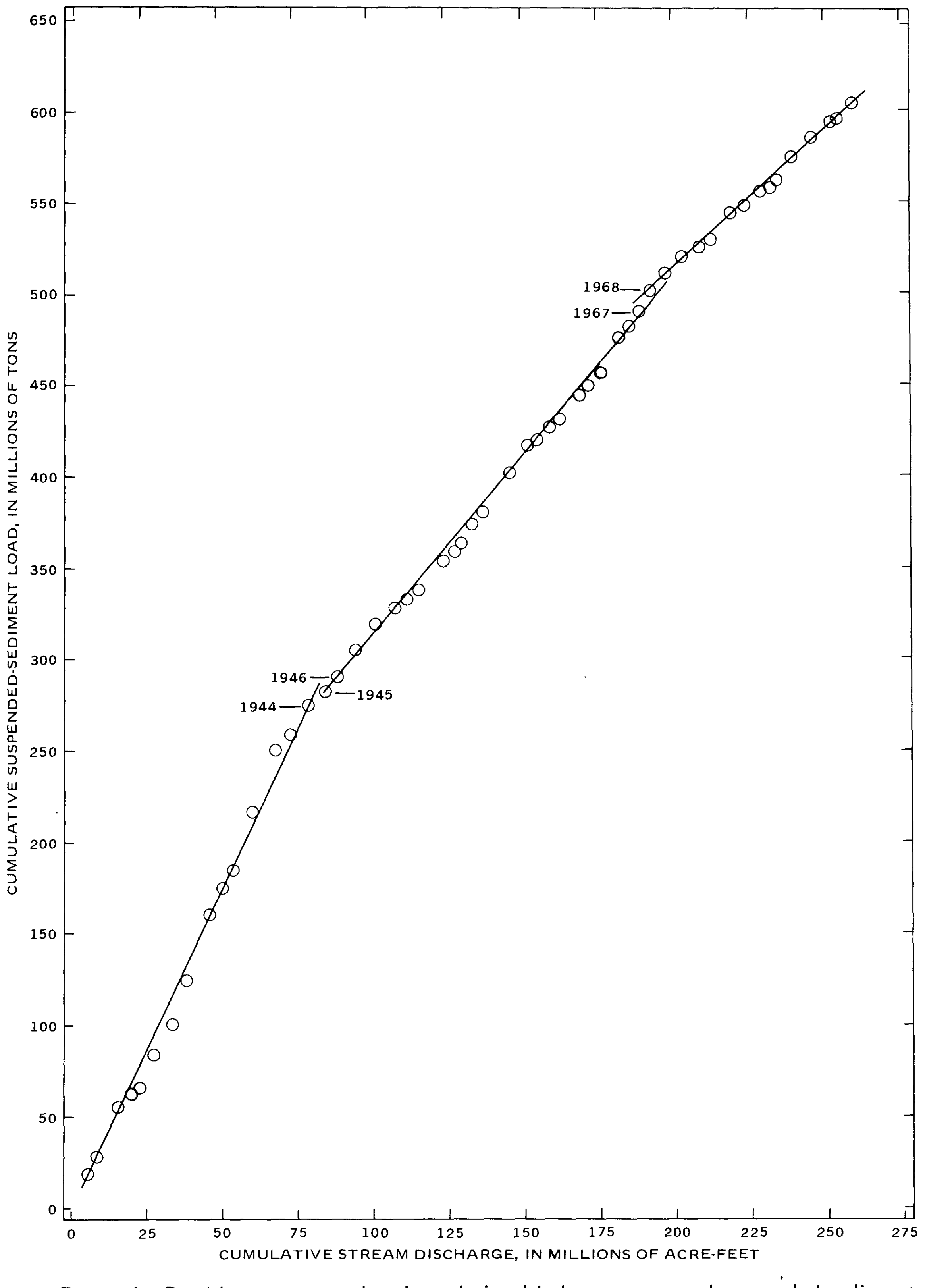

Figure 4.—Double mass curve showing relationship between annual suspended-sediment load and annual stream discharge at station 09180500, water years 1930-82.

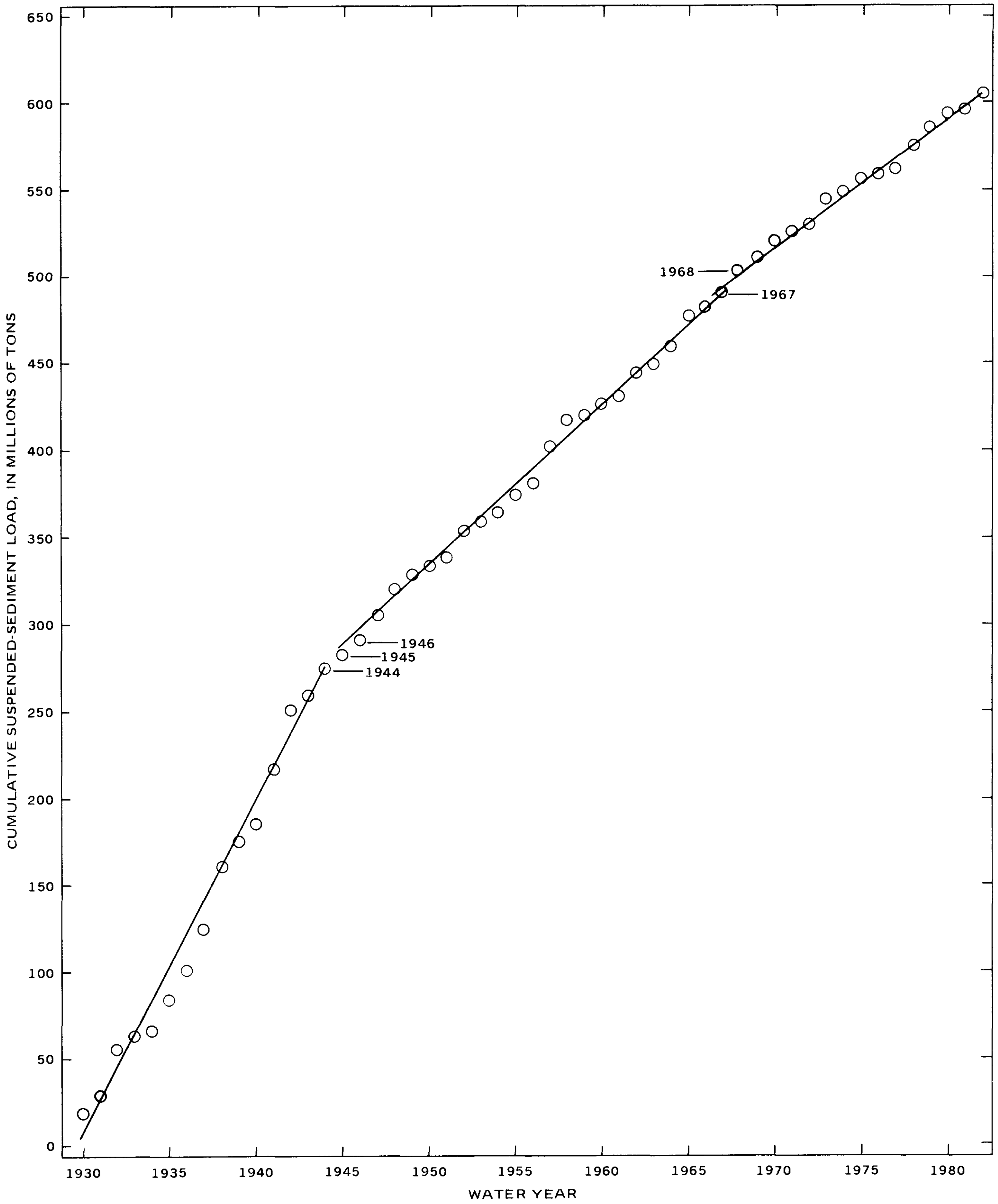

Figure 5.—Cumulative annual suspended-sediment load at station 09180500, water years 1930-82.

Table 1.--Comparison of annual suspended-sediment loads at station 09180500

Statistics	Annual suspended-sediment load, in millions of tons		
	1930-45	1946-67	1968-82
Mean	17.642	9.439	7.585
Minimum	2.720	3.462	2.038
Maximum	35.700	21.540	14.553
Standard deviation	10.166	5.067	4.010
Coefficient of variation[1]	57.6	53.7	52.9
Percentile[2]			
5	2.720	3.568	2.038
25	8.618	5.201	3.540
50	16.625	8.192	8.170
75	25.690	14.318	10.902
95	35.700	20.921	14.553

[1] The coefficient of variation is a dimensionless measure of variability, and it is the ratio of the standard deviation to the mean expressed as a percent.

[2] Percentiles are measures of position and are used to describe the location of a specific piece of data in relation to the rest of the data. For example, the 25th percentile indicates that about 25 percent of the annual suspended-sediment loads are less than the indicated value and about 75 percent are more.

Blue Mesa Reservoir acts as a sediment trap and essentially removes most of the suspended sediment in the Gunnison River (the largest tributary to the Colorado River upstream from station 09180500) that originates from sources upstream from the dam. This reservoir impounds water contributed from about 14 percent of the drainage upstream from the gaging station, and it has regulated flow in the Colorado River since November 27, 1965 (U.S. Geological Survey, 1982, p. 47). Although little change in annual streamflow occurred after the reservoir was essentially full, the distribution of streamflow did change. A comparison of flow duration curves (fig. 6) for 1930-66 and 1969-82 (1967-68 were not used because the reservoir was filling) shows that the reservoir apparently reduced peak flows and increased minimum flows. This change in the distribution of streamflow undoubtably affected suspended-sediment loads at station 09180500.

The mean annual suspended-sediment loads were reduced by about 22 percent in the Colorado River at station 09180500 after the closure of Blue Mesa Dam (table 2). The mean annual suspended-sediment yield was reduced from 402 tons per square mile (1946-65) to 315 tons per square mile (1968-82). Other factors may have been involved or responsible for the changes that occurred between water years 1944-46 and 1967-68, but their identification is beyond the scope of this report. It is probable, however, that the change in sampling equipment during October 1945 and the completion of Blue Mesa Reservoir during November 1965 were responsible for the changes that occurred at station 09180500.

Estimating Annual Suspended-Sediment Loads

The long-term relationship between annual stream discharge and annual suspended-sediment load could be used to obtain gross estimates of annual suspended-sediment loads only if annual stream discharge is available. It is important to note, however, that this relation is not accurate if the relationship between annual streamflow and annual suspended-sediment load changes, or if there is great variability between these two factors.

The relationship between annual streamflow and annual suspended-sediment load has changed at station 09180500. The annual data after 1968 were suitable for use in a regression equation (coefficient of correlation $r = 0.66$), but the data prior to 1968 were not suitable for use in the equation. The regression equation and the 90-percent confidence limits for the regression line are shown in figure 7. The regression equation is

$$Y = 1.757X - 566{,}000$$

where

Y is annual suspended-sediment load in millions of tons; and
X is annual streamflow in millions of acre-feet.

This equation should not be extrapolated; that is, it should not be used outside the range of data used to define the relation.

Using the regression equation and an annual stream discharge of 4,000,000 acre-feet as an example, the annual suspended-sediment load is predicted to be about 6,462,000 tons; but it could range from 717,000 to 12,207,000 tons at a

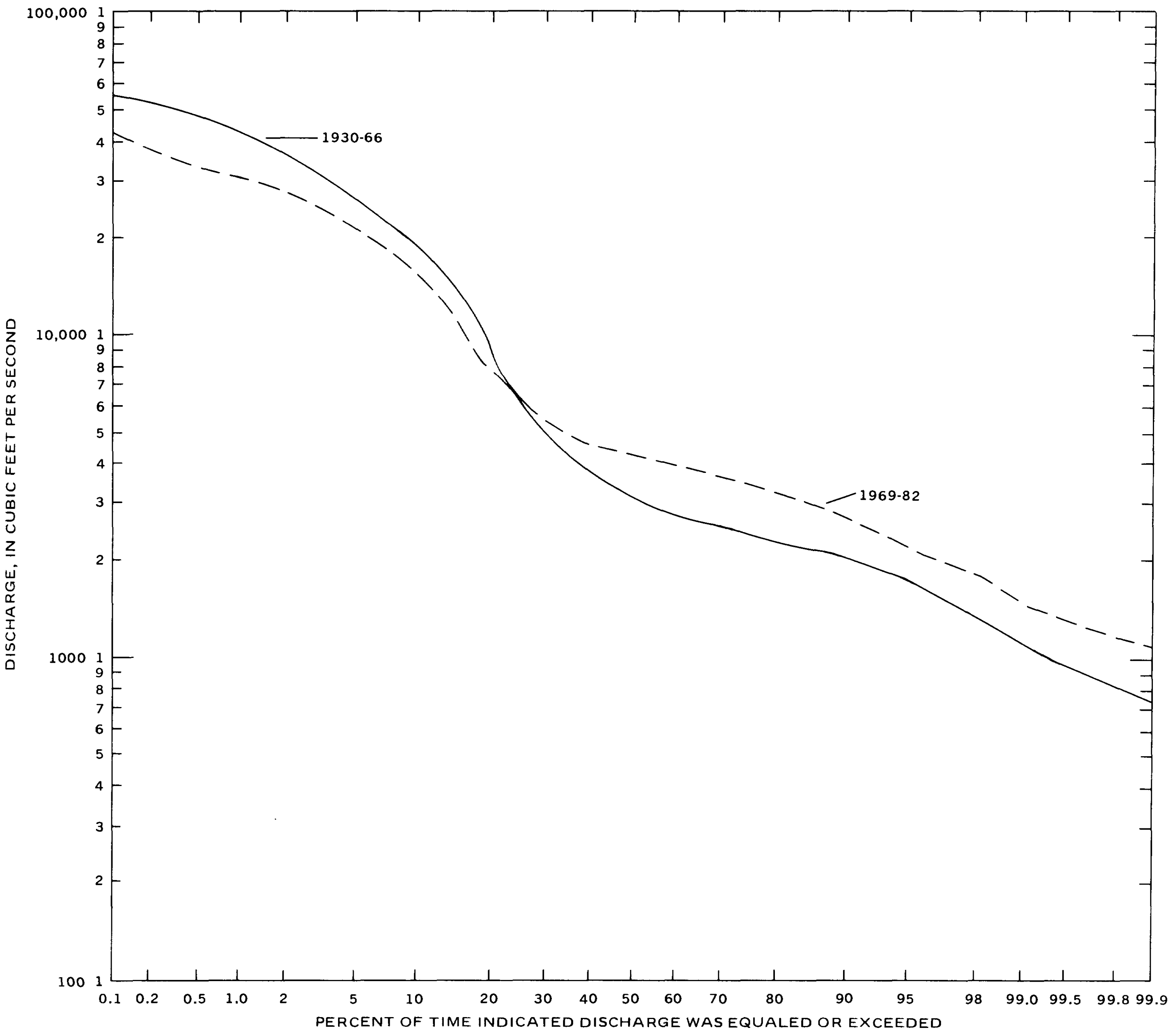

Figure 6.—Flow-duration curves for station 09180500.

Table 2.--Suspended-sediment loads at station 09180500 before and after the closure of Blue Mesa Dam

	Mean annual load (tons)	Mean annual yield (tons per square mile)	Mean annual reduction in sediment load (tons)	Decrease in annual-sediment load (percent)
1946-65 [1] (before dam)	9,685,000	402	--	--
1968-82 [2] (after dam)	7,585,000	315	2,100,000	22

[1] 1930-45 were not used because of the change in sampling equipment after 1945.

[2] 1966-67 were not used because the reservoir was filling.

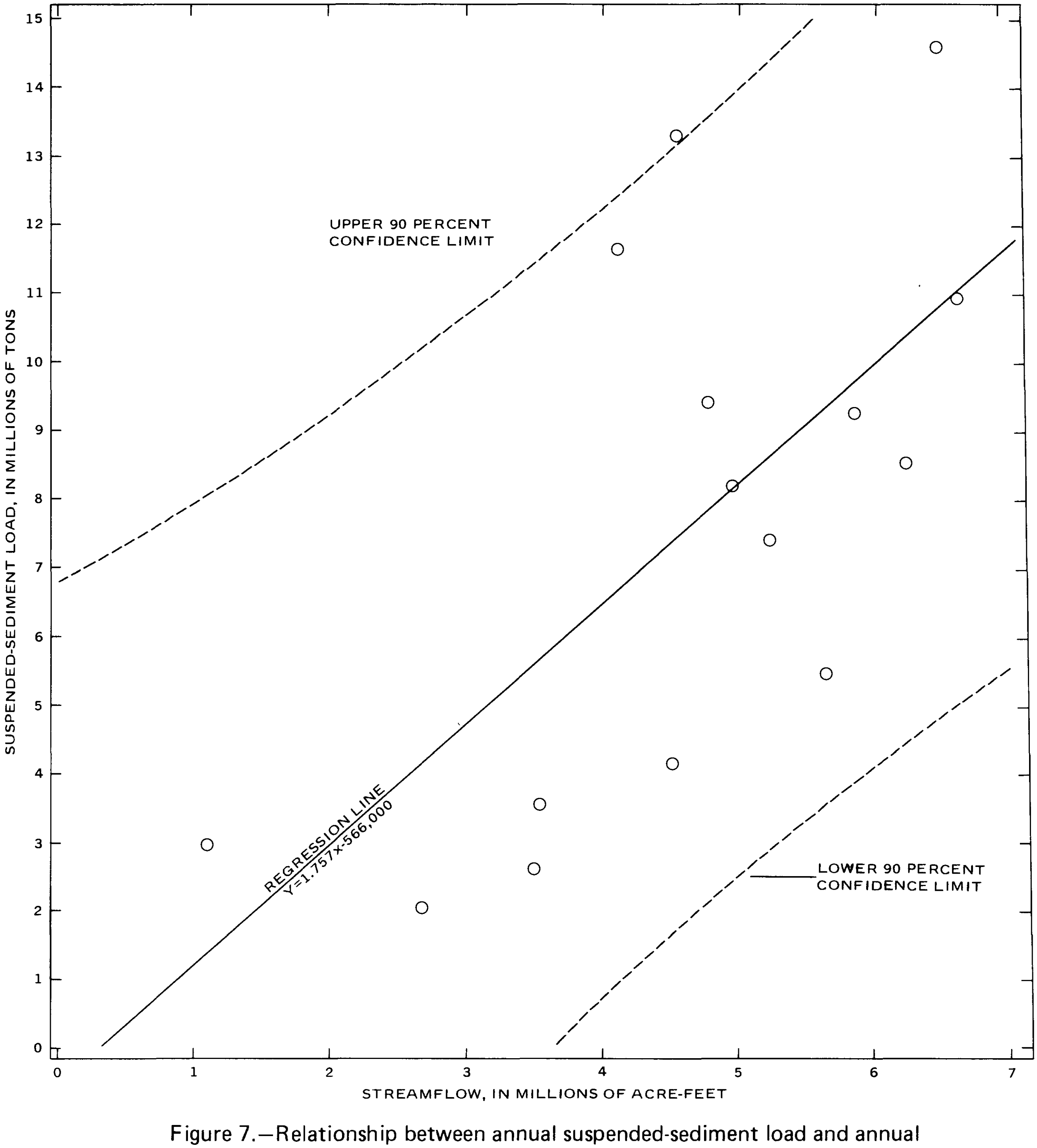

Figure 7.—Relationship between annual suspended-sediment load and annual stream discharge showing 90 percent confidence interval, at station 09180500, water years 1968-82.

90-percent confidence level. It is possible, therefore, that any estimate using this equation could have a large error.

The variability of the annual suspended-sediment loads at station 09180500 is large. Because of this large variability and because of poor correlation between annual suspended-sediment loads and annual stream discharge, the regression equation is a poor predictor of annual suspended-sediment loads. The localized nature of precipitation and the variations in geology in the basin upstream from the gaging station contribute to this variability. Numerous tributaries enter the Colorado River upstream from the gaging station, and many of these tributaries carry large amounts of sediment during periods of high runoff, especially runoff from rainfall. Runoff from many of these tributaries may substantially change the suspended-sediment load of the Colorado River while having a much smaller effect on streamflow. Neff (1967, p. 236) reports that in arid regions, more than 60 percent of the long-term sediment yield is associated with runoff that has recurrence intervals of more than 10 years.

SUMMARY

During 1930-82, the mean annual suspended-sediment load at gaging station 09180500, Colorado River near Cisco, Utah, was 11,390,000 tons, ranging from 2,038,000 tons in water year 1981 to 35,700,000 tons in water year 1938. The daily load ranged from 14 tons on August 22, 1960, to 2,790,000 on October 14, 1941.

Analysis of the suspended-sediment records indicates the accuracy of the records is fair prior to 1945 and good for the remaining period of record. The records after 1945 reflect the use of improved sampling equipment.

A double-mass curve showed changes in relationship between annual suspended-sediment load and annual stream discharge. The first change occurred during the early 1940's and coincides approximately with a change in sampling equipment. The U.S. D-43 suspended-sediment sampler was first used at this site during October 1945. The second change, which occurred approximately between water years 1967-68, coincides with the closure of the dam at Blue Mesa Reservoir (allowing 1-2 years for the reservoir to fill). Blue Mesa Reservoir impounds water of the Gunnison River (largest tributary to the Colorado River upstream from station 09180500), and it has regulated flow in the river system since November 27, 1965. The mean annual suspended-sediment loads were reduced about 22 percent, and the mean annual suspended-sediment yield was reduced from 402 to 315 tons per square mile after the closure of the dam.

The annual data collected after 1968 were used to define a regression equation. The localized nature of precipitation and the variations in geology plus the importance of sediment contributions from tributary streams cause this equation to be a poor predictor of annual suspended-sediment loads using annual streamflow as the independent variable. For example, using an annual stream flow of 4,000,000 acre-feet, the regression equation predicts the annual suspended-sediment load to be about 6,462,000 tons; but it could range from 717,000 to 12,207,000 tons at a 90-percent confidence level.

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DEFINITION OF TERMS

Acre-foot.--The quantity of water required to cover 1 acre to a depth of 1 foot. It is equivalent to 43,560 cubic feet, about 326,000 gallons, or 1,233 cubic meters.

Bedload.--Material moving on or near the streambed by rolling or sliding. It sometimes makes brief excursions into the flow a few diameters above the bed.

Cubic foot per second.--The rate of discharge representing a volume of 1 cubic foot passing a given point during 1 second. It is equivalent to approximately 7.48 gallons per second, or 448.8 gallons per minute, or 0.02832 cubic meter per second.

Depth-integrated sample.--A suspended-sediment sample that is accumulated continuously in a sampler, which is moved vertically at a constant transit rate and which admits the water-sediment mixture at a velocity equal to the stream velocity at every point of transit.

Double-mass curve.--As used in this report, a double-mass curve is constructed by plotting cumulative annual stream discharge against cumulative annual suspended-sediment load.

Flow-duration curve.--A cumulative frequency curve that shows the precentage of time that specified discharges are equaled or exceeded.

Fluvial.--Pertaining to a river or stream.

Gaging station.--A site on a stream, canal, lake, or reservoir where systematic observations of hydrologic data are obtained.

Stream discharge.--As used in this report, the discharge that occurs in a natural channel.

Suspended-sediment.--The sediment that at any given time is maintained in suspension by the upward components of turbulent currents or that exists in suspension as a colloid.

Suspended-sediment discharge.--The rate at which the dry weight of suspended sediment passes a section of a stream; or the quantity of suspended sediment, as measured by dry weight, that passes a section in a given time.

Suspended-sediment load.--The quantity of suspended sediment that passes a section in a specified period, usually measured in tons.

Total sediment discharge.--The sum of (1) measured suspended-sediment discharge, (2) unmeasured suspended-sediment discharge, and (3) bedload discharge. It is the rate at which the total quantity of sediment, by dry weight, passes a section.

Water year.--A 12-month period from October 1 through September 30 that is designated by the calendar year in which it ends. Thus, the year ending September 30, 1982, is the "1982 water year."