# ANNUAL SUSPENDED-SEDIMENT LOADS IN THE GREEN RIVER AT GREEN RIVER, UTAH, 1930-82

By Kendall R. Thompson

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WILLIAM P. CLARK, Secretary

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Dallas L. Peck, Director

For additional information
write to:
District Chief
U.S. Geological Survey
Water Resources Division
Room 1016 Administration Building
1745 West 1700 South
Salt Lake City, Utah 84104

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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 kilometer |

# ANNUAL SUSPENDED-SEDIMENT LOADS IN THE GREEN RIVER AT GREEN RIVER, UTAH, 1930-82

By Kendall R. Thompson


## ABSTRACT

The Green River above the gaging station (09315000) at Green River, Utah, drains about 44,850 square miles in Utah, Colorado, and Wyoming. The average annual precipitation near the station was 6.11 inches.

During 1930-82, the U.S. Geological Survey collected records of fluvial sediment at station 09315000. Based on these records the mean annual suspended-sediment load was about 15,630,000 tons, ranging from 1,780,000 tons during 1934 to 43,400,000 tons during 1937. The minimum daily load of 54 tons was on September 27, 1956, and the maximum daily load of 2,230,000 tons was on July 11, 1936.

Analysis of the suspended-sediment records collected from 1930-82 at station 09315000 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 approximately between water years 1944-46 and coincides with a change in sampling equipment. The U.S. D-43 suspended-sediment sampler was first used at station 09315000 during October 1945 (1946 water year). The second change, which occurred approximately between water years 1963-65, coincides with the completion of Flaming Gorge Dam during November 1962 (1963 water year) upstream from the station. The mean annual suspended-sediment loads were reduced by about 35 percent at station 09315000 after the completion of the dam. 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 1965 provided a basis for a predictive model. If, for example, an annual stream discharge of 4,000,000 acre-feet were used, the annual suspended-sediment discharge is predicted to be 7,860.000 tons; and it could range from 3,400,000 to 12,100,000 tons at a 90-percent confidence level. It is possible, therefore, that any estimate using this model could have about a 50-percent error at a 90-percent confidence level.

The variability of the annual suspended-sediment loads at station 09315000 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 operated a streamflow-gaging station from 1894-99 and 1904-82 on the Green River at Green River, Emery County, Utah (fig. 1). The station is identified as station 09315000, Green River at Green River, Utah, in reports of the U.S. Geological Survey (1966-82). Fluvial-sediment records were collected at the station from 1930-82. The records collected from 1930-65 were compiled by Mundorff (1968, p. 129-152), and particle-size data also 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 09315000 and to describe suspended-sediment loads in the Green River at Green River, Utah. 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 requires bedload data, or to do a detailed analysis of the records.

### General Description of the Green River Basin

The Green River basin upstream from gaging station 09315000 includes about 44,850 square miles in Utah, Colorado, and Wyoming, of which about 4,260 square miles are noncontributing. About 3,960 square miles of the noncontributing drainage basin are located in the Great Divide Basin in southern Wyoming. The station is 1.1 miles southeast of the town of Green River, Utah, and 117.4 river miles upstream from the mouth of the Green River.

The Green River, which is the largest tributary to the Colorado River, heads in the Bridger National Forest area of the Wind River Range, Wyoming (fig. 1). Principal tributaries of the Green River upstream from station 09315000 are the Big Sandy River, Blacks Fork, and the Yampa, Duchesne, White, and Price Rivers. Flaming Gorge Reservoir is the largest impoundment on the Green River. Flaming Gorge Dam is 407.5 river miles upstream from the river mouth, and 290.1 river miles upstream from station 09315000. The reservoir has a capacity of 3,789,000 acre-feet, of which 39,700 acre-feet is dead storage. The drainage above the reservoir is 19,350 square miles, which is about 43 percent of the drainage upstream from station 09315000 at Green River, Utah. Storage in Flaming Gorge Reservoir began November 1, 1962. Fontenelle Reservoir is about 160 river miles upstream from Flaming Gorge Reservoir. Storage in Fontenelle Reservoir began April 1964, after the completion of Flaming Gorge Dam; consequently, Fontenelle Reservoir has had no direct effect on sediment transport at the Green River station 09315000.

Altitudes in the drainage basin range from about 13,800 feet at Gannett Peak near the headwaters of the Green River to 4,040.18 feet at station 09315000. The climate ranges from humid in the headwaters to arid near the station. The average annual precipitation for 1906-81 near the station was

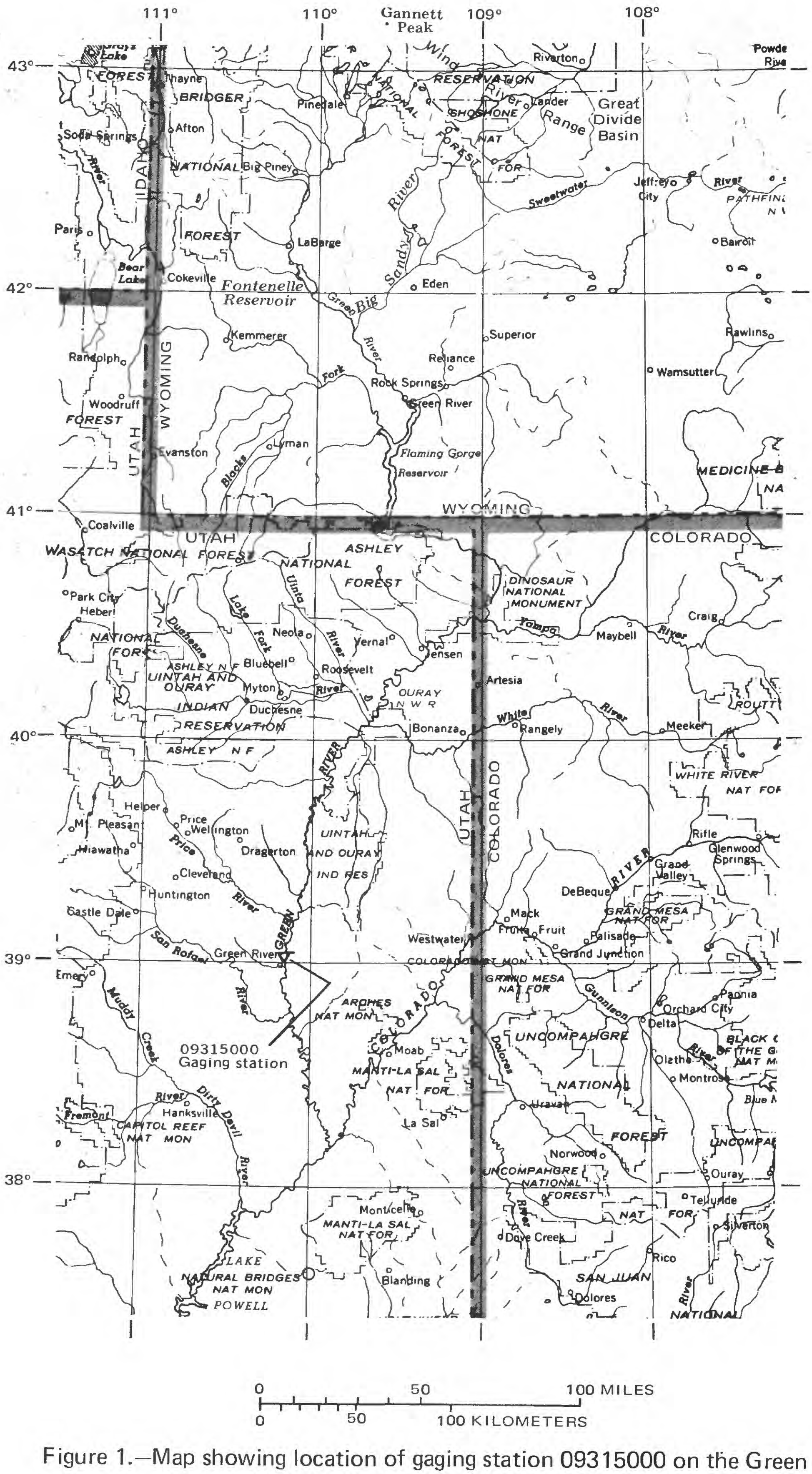


Figure 1.—Map showing location of gaging station 09315000 on the Green River at Green River, Utah.

6.11 inches (National Oceanic and Atmospheric Administration, 1981, p. 6). Precipitation results from winter frontal storms, which generally come from the west, and summer convection storms, which generally come from the south. The convection storms produce local but intense rainfall which generates rapid runoff and sediment transport.

Rocks ranging in age from Precambrian to Holocene are exposed in the Green River drainage basin above Green River, Utah. Most of these rocks are shale, siltstone, mudstone, sandstone, and limestone of Tertiary age (Stokes, 1964). The shale, siltstone, and mudstone probably are the most easily eroded rocks in the basin, and they contribute a large part of the sediment load in the Green River.

## COLLECTION AND EVALUATION OF RECORDS

Sampling to determine suspended-sediment concentrations began in May 1930, and sampling to determine particle size began in April 1951. Most of the sampling for suspended sediment at station 09315000 was from a cableway about 0.25 mile downstream from the stream gage or from a highway bridge about 500 feet upstream from the gage. The sampling was continuous through September 1982.

Prior to 1945, the sampling for suspended sediment was by simple, inexact methods. Many samples were collected by dipping bottles or 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 09315000 in 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, 1961a, and 1961b).

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 52 years in which data were collected at station 09315000. During that time there were numerous changes in sampling, laboratory, streamflow-measuring and recording equipment, all involved techniques, and 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 was a good site for the collection of suspended-sediment data.

2. Sampling at the highway bridge (mostly by daily observers) was affected by the bridge structure. The data obtained at the highway bridge, however, were correlated with data collected at the cableway during record computation.

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

4. Not enough samples were collected during a storm to define suspended-sediment loads without extrapolation. A large part of the suspended-sediment loads commonly is transported during storms.

Based on the foregoing conclusions, the suspended-sediment records for station 09315000 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

Annual suspended-sediment loads for 1930-82 at station 09315000 are shown in figure 2. The annual suspended-sediment load varied considerably. The minimum and maximum annual loads occurred within 3 years of each other--the minimum of 1,780,000 tons--during 1934 and the maximum of 43,400,000 tons during 1937. The mean annual suspended-sediment load for 52 years was 15,630,000 tons, with a standard deviation of 10,800,000 tons. The minimum daily suspended-sediment load of 54 tons was on September 27, 1956, and the maximum daily load of 2,230,000 tons was on July 11, 1936.

A change in the volume and variability of annual suspended sediment is apparent from figure 2. The annual volume and variability of suspended-sediment load was greater during 1930-63 than during 1964-82. The mean load for 1930-63 was 19,500,000 tons per year, with a standard deviation of 11,490,000 tons per year, whereas the mean load for 1964-82 was 8,700,000 tons per year, with a standard deviation of 4,000,000 tons per year. Little change in mean annual stream discharge occurred between the same two periods (fig. 3), with a mean of 3,930,000 acre-feet for 1930-63 and 4,080,000 acre-feet for 1964-82. However, variability is greatly reduced in the latter period. This indicates that changes in the mean annual stream discharge alone did not cause the apparent change in annual suspended-sediment load.

The double-mass curve 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 approximately between

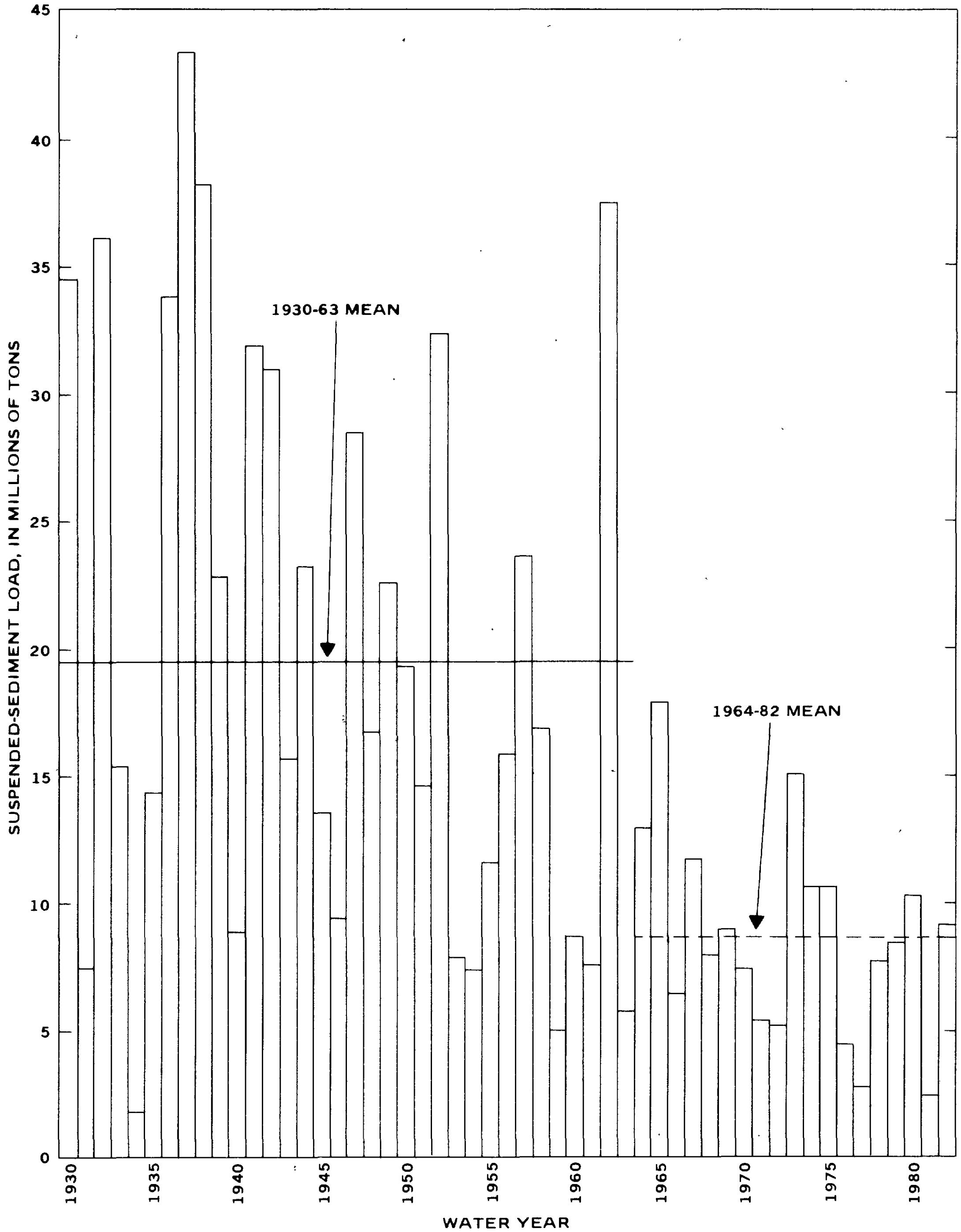

Figure 2.—Annual suspended-sediment load at station 09315000, water years 1930-82.

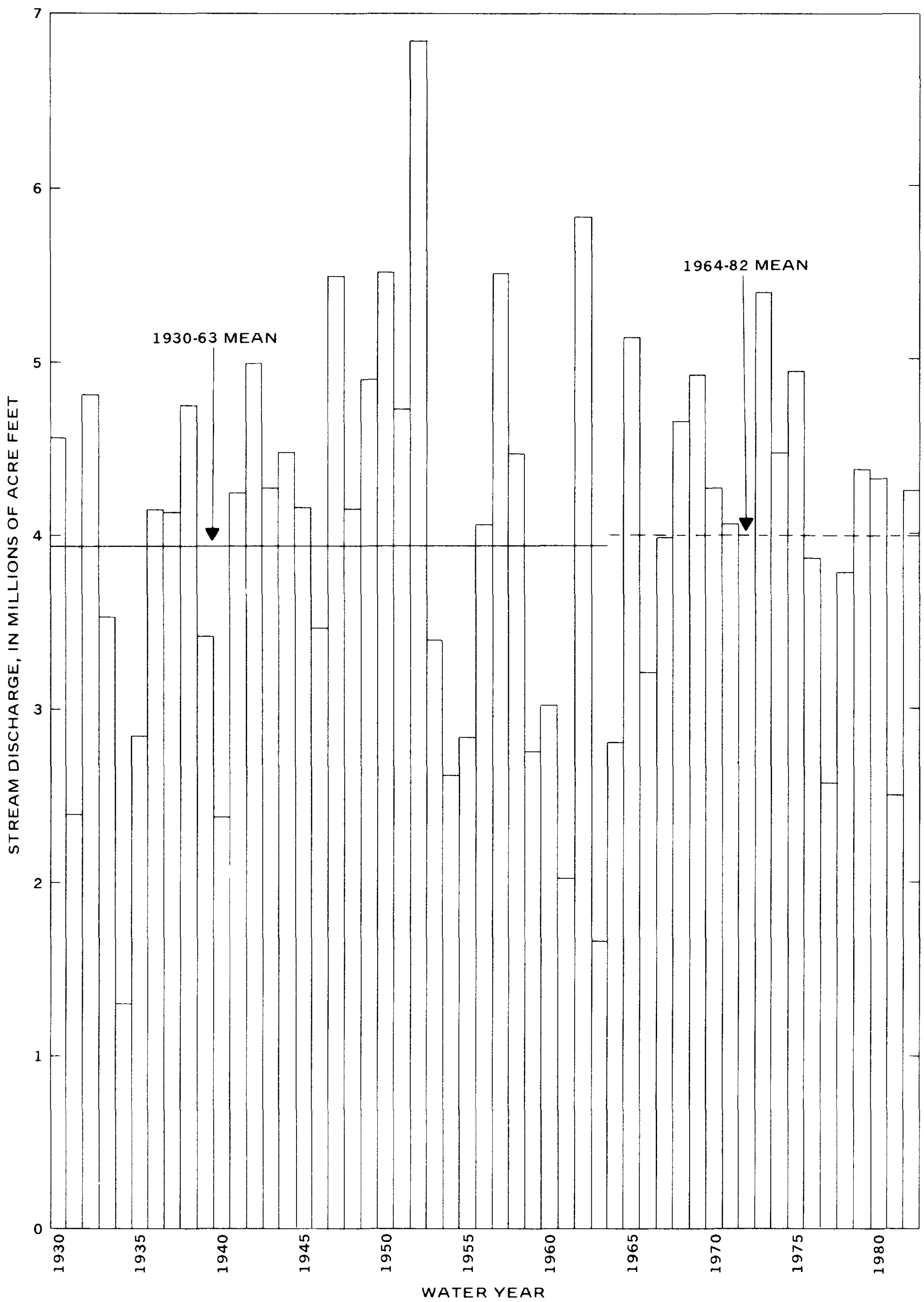


Figure 3.—Annual stream discharge at station 09315000, water years 1930-82.

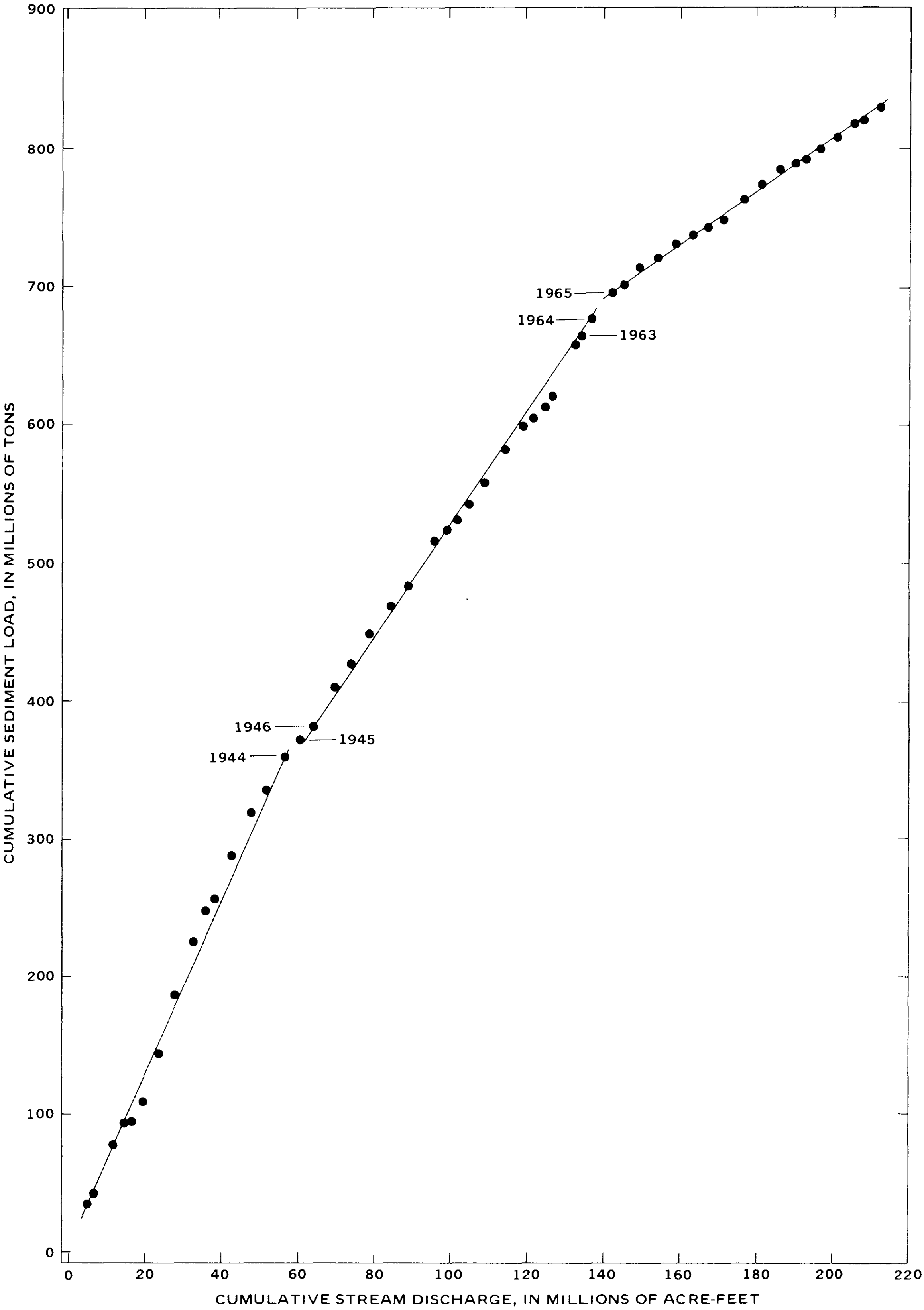


Figure 4.—Double-mass curve showing relationship between annual suspended-sediment load and annual stream discharge at station 09315000, water years 1930-82.

water years 1944-46 and also approximately between water years 1963-65 (fig. 4). Cumulative annual stream discharge versus time was plotted (not presented) to help identify changes in stream-discharge trends that might have occurred; however, no long-term changes in annual stream discharge were evident, but variability of annual mean discharges is significantly smaller during 1964-82 than during 1930-63. Cumulative annual suspended-sediment load versus time was plotted in figure 5 to help identify changes in suspended-sediment trends that 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 between water years 1944-46 coincides with a change in sampling equipment. The U.S. D-43 suspended-sediment sampler was first used at station 09315000 during October 1945 (1946 water year).

The change that occurred approximately between water years 1963-65 coincides with the completion of Flaming Gorge Dam during November 1962 (1963 water year), which impounds water contributed from about 43 percent of the drainage basin upstream from station 09315000. Flaming Gorge Reservoir acts as a sediment trap, and it removes most of the suspended sediment in the Green River from all sources upstream from the dam. 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 1930-62 and 1965-82 (1963-64 was not used because the reservoir was filling) shows that the reservoir reduced peak flows and increased minimum flows. This change in the distribution of streamflow undoubtedly affected suspended-sediment loads.

A double-mass curve (similiar to figure 4) also was constructed (not presented) for station 09261000, the Green River near Jensen, which is 202.5 river miles upstream from station 09315000 and 87 river miles downstream from Flaming Gorge Dam. Continuous annual data for water years 1949-79 were plotted. A change in slope was noted approximately between water years 1963-65, similar to the change in figure 4. This second plot helps confirm that Flaming Gorge Reservoir influenced the change in the relationship between annual suspended-sediment loads and annual streamflow in the Green River at station 09315000.

Mean annual loads were reduced by about 50 percent at station 09261000 and by about 35 percent at station 09315000 after the closure of Flaming Gorge Dam (table 1). The reduction in annual suspended-sediment yield of the Green River downstream from Flaming Gorge Dam is about 110 tons per square mile. Other factors may have been involved or responsible for the changes that occurred between water years 1944-46 and 1963-65, but their identification is beyond the scope of this report. It is most probable, however, that the changes in relationship that occurred at station 09315000 were caused by changes in sampling equipment in October 1945 and the completion of Flaming Gorge Dam in November 1962.

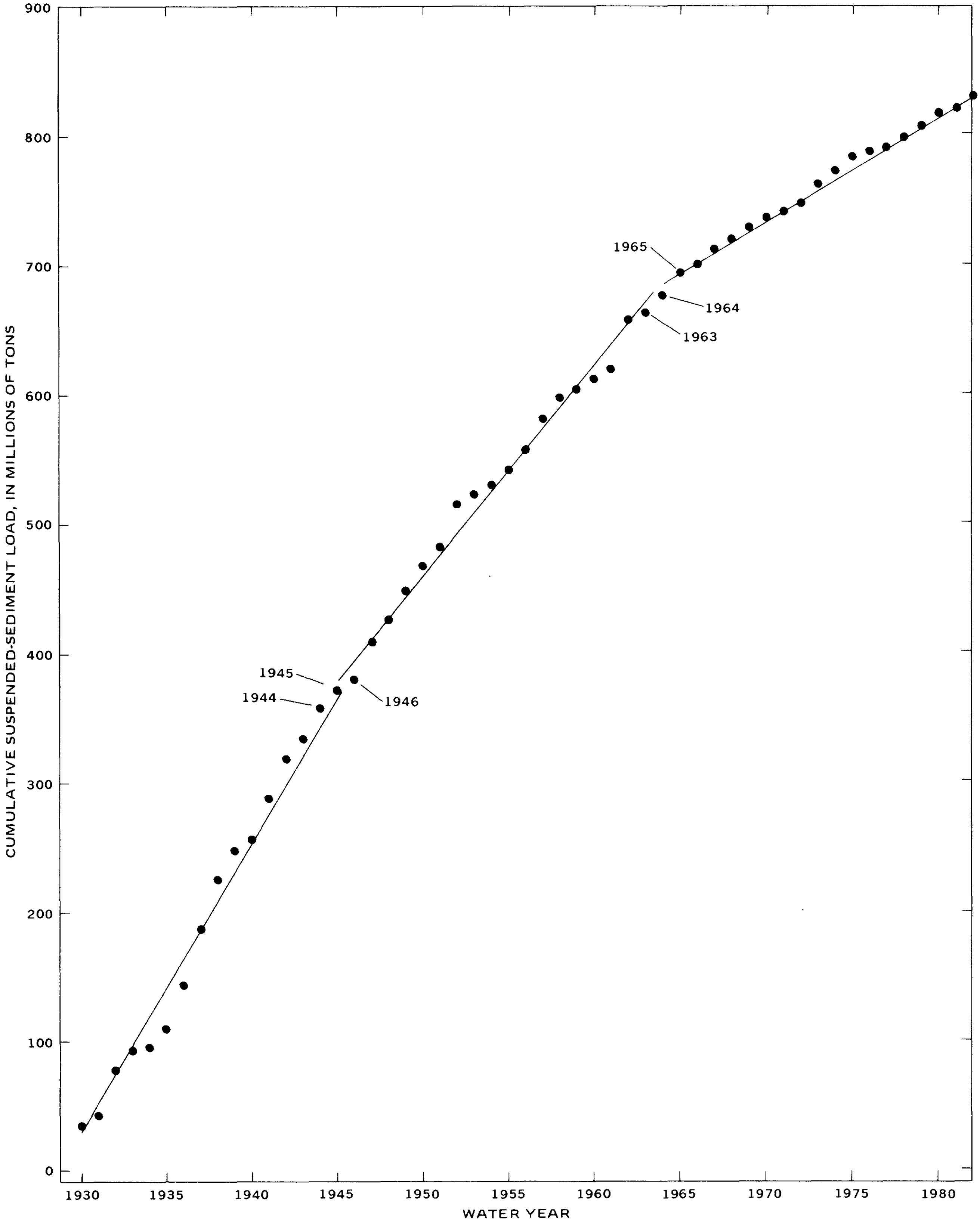


Figure 5.—Cumulative annual suspended-sediment load at station 09315000, water years 1930-82.

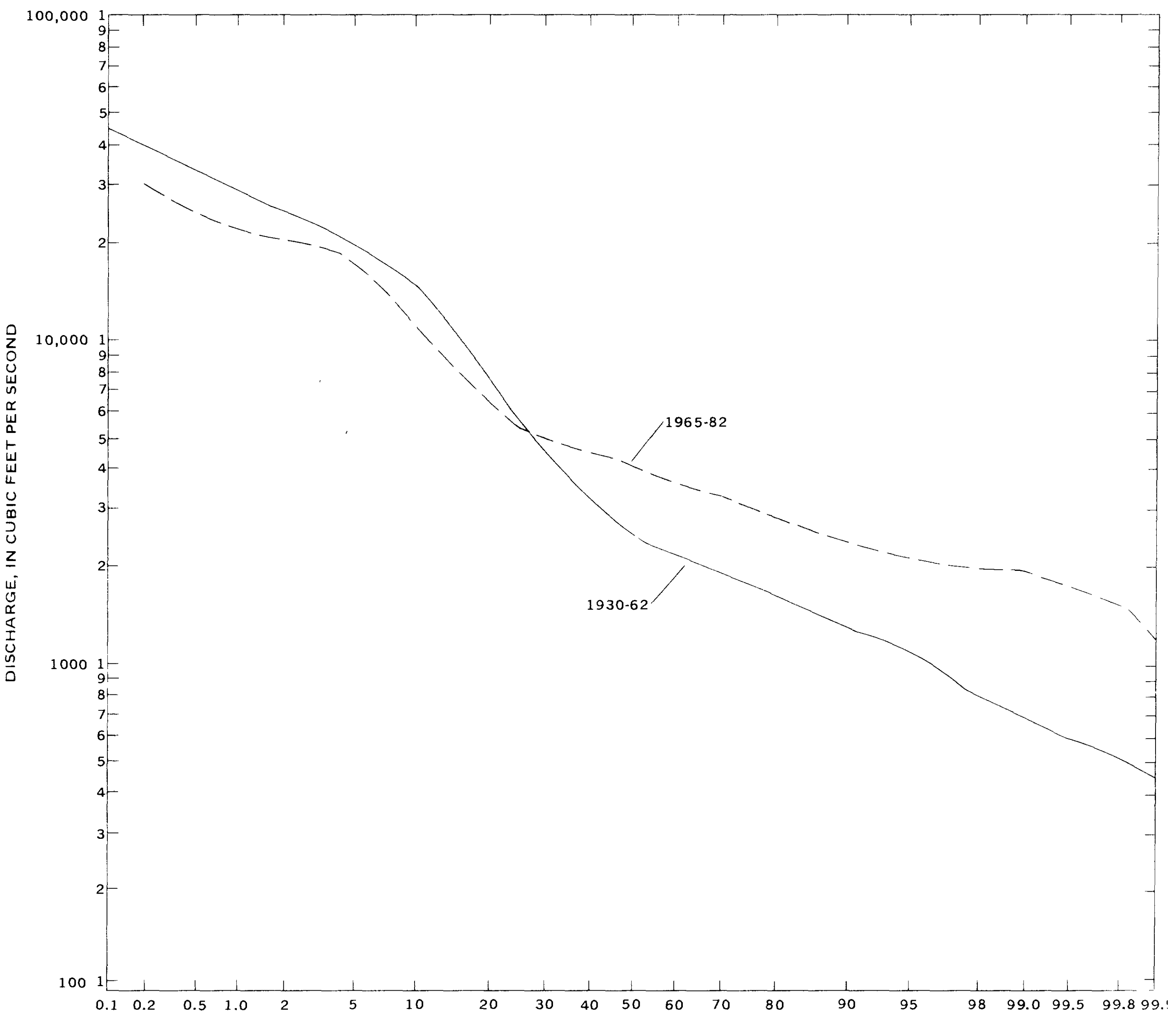


Figure 6.—Flow-duration curves for the Green River at station 09315000.

Table 1.--Suspended-sediment loads before and after the closure of Flaming Gorge 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) |
|---|---|---|---|---|
| | Green River at Jensen, station 09261000 | | | |
| 1949-61[1] (before dam) | 6,566,000 | 221 | -- | -- |
| 1964-79 (after dam) | 3,299,000 | 111 | 3,267,000 | 50 |
| | Green River at Green River, station 09315000 | | | |
| 1949-61[1] (before dam) | 13,765,000 | 307 | -- | -- |
| 1964-79 (after dam) | 8,968,000 | 200 | 4,797,000 | 35 |

[1] 1962-63 were not used because the reservoir was filling.

## 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 if only annual stream discharge is available. It is important to note, however, that this correlation is not accurate if the relationship between annual streamflow and annual suspended-sediment load changes or if there is major variability between the two factors.

The relationship between annual streamflow and annual suspended-sediment load has changed at station 09315000. Because of the changes, the data prior to 1964 could not be used in a regression model. The annual data after 1965, however, were suitable for use in a predictive regression model (coefficient of determination, $r^2=0.65$). The regression model and the 90-percent confidence limits for the regression line are shown in figure 7. The equation for this regression model is

$$Y= 4.07X - 8,426,000,$$

where Y is annual suspended-sediment load in millions of tons, and X is annual streamflow in millions of acre-feet. Regression equations such as this should not be extrapolated beyond the range of data used to define the relation. The above equation, for example, should not be used for annual water discharge that is less than about 2.5 million acre-feet. At discharges of less than 2.1 million acre-feet, the relation obviously does not apply because it yields negative loads.

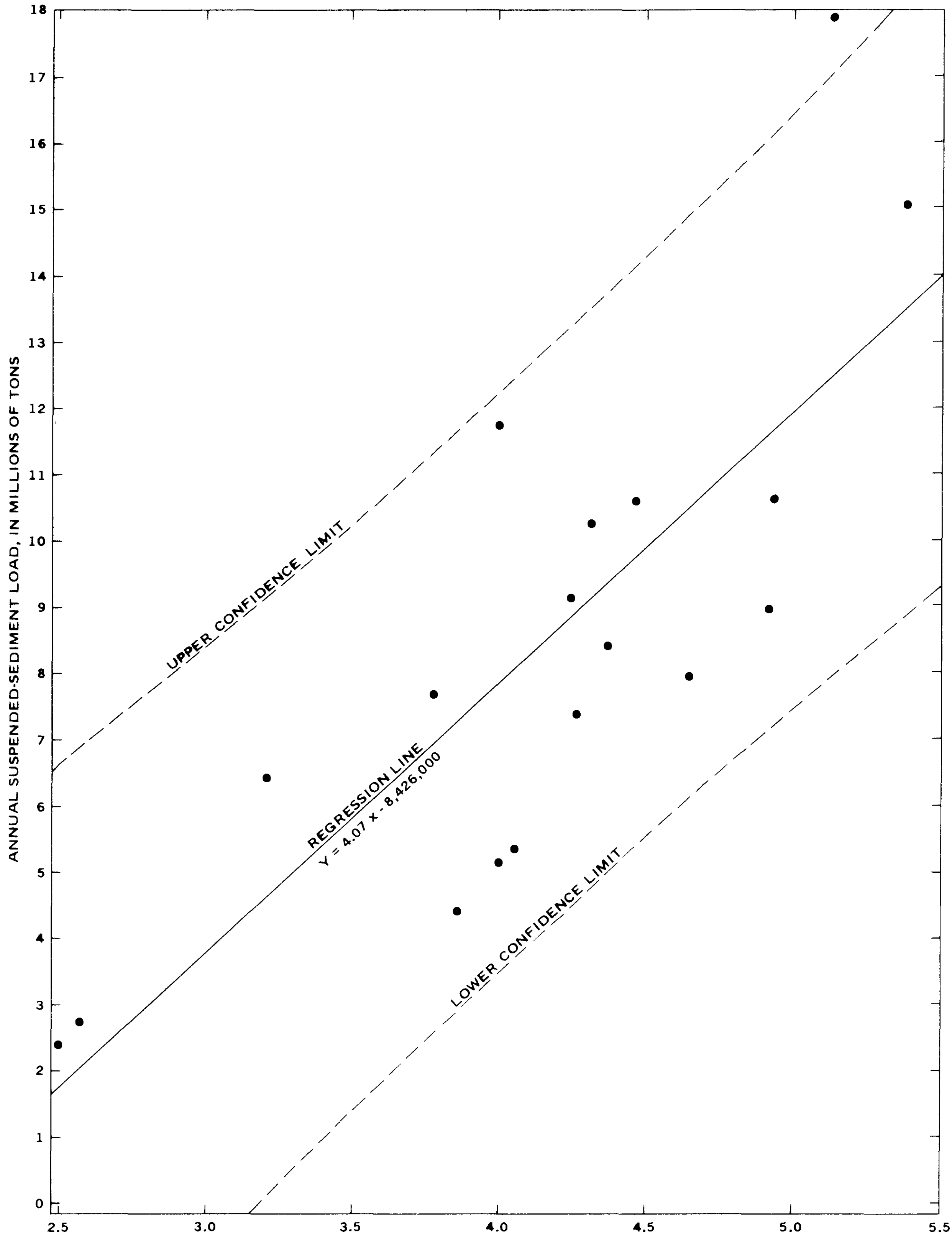


Figure 7.—Relationship between annual suspended-sediment load and annual stream discharge showing 90 percent confidence limits at station 09315000, water years 1965-82.

Using the regression model and an annual stream discharge of 4,000,000 acre-feet, annual suspended-sediment load is predicted to be about 7,860,000 tons and could range from 3,400,000 tons to 12,100,000 tons at a 90-percent confidence level. It is possible, therefore, that any estimate using this model could have about a 50-percent error at a 90-percent confidence level.

The variability of the annual suspended-sediment loads at station 09315000 is obvious. 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 Green River upstream from the station, and many of these tributaries carry large amounts of sediment during periods of high runoff, especially rainstorm runoff. In general, runoff from these tributaries may substantially increase the annual suspended-sediment load of the Green River but may have only a small effect on the annual streamflow. For example, the 1975-79 mean annual suspended-sediment load for the White River at its mouth was 1,759,000 tons (Seiler and Tooley, 1982, p. 1), and the mean annual streamflow was 466,420 acre-feet. For the same period, the mean annual suspended-sediment load at station 09315000 was 6,784,000 tons, and the mean annual streamflow was 3,905,000 acre-feet. The White River contributed about 26 percent of the annual suspended load but only about 12 percent of the annual streamflow of the Green River during this period. Neff (1967, p. 236) reports that in arid regions more than 60 percent of the long-term sediment yield is associated with runoff having recurrence intervals exceeding 10 years.

## SUMMARY

During 1930-82, the mean annual suspended-sediment load at gaging station 09315000, Green River at Green River, Utah, was about 15,630,000 tons, ranging from 1,780,000 tons during 1934 to 43,400,000 tons during 1937. The daily load ranged from 54 to 2,230,000 tons.

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 approximately between water years 1944-46 and coincides with a change in sampling equipment. The U.S. D-43 suspended-sediment sampler was first used at this site during October 1945 (1946 water year). The second change, which occurred approximately between water years 1963-65, coincides with the completion of Flaming Gorge Dam during November 1962 (1963 water year) upstream from the gaging station. The mean annual suspended-sediment loads were reduced by about 35 percent at station 09315000 after the completion of the dam.

The data collected after 1965 provided a basis for a predictive model. If, for example, an annual stream discharge of 4,000,000 acre-feet were used, the annual suspended-sediment discharge is predicted to be 7,860,000 tons; and could range from 3,400,000 to 12,100,000 tons at a 90-percent confidence level. It is possible, therefore, that any estimate using this model could have about a 50-percent error 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.

Bed material.--The material of which a streambed is composed.

Cubic foot per second.--The rate of discharge representing a volume of 1 cubic foot passing a given point during 1 second and 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 percentage of time that specified discharges are equaled or exceeded.

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."