CHARACTERISTICS OF SUSPENDED SEDIMENT IN THE SAN JUAN RIVER NEAR BLUFF, UTAH

By Kendall R. Thompson

With a section on general source areas of runoff and sediment discharge by J. C. Mundorff

---

U.S. GEOLOGICAL SURVEY

Water-Resources Investigations 82-4104

Salt Lake City, Utah

1982

UNITED STATES DEPARTMENT OF THE INTERIOR

JAMES G. WATT, Secretary

GEOLOGICAL SURVEY

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

Copies of this report can
be purchased from:

Open-File Services Section
Western Distribution Branch
U.S. Geological Survey
Box 25425, Federal Center
Denver, Colorado 80225
[Telephone: (303) 234-5888]

CONTENTS

ILLUSTRATIONS

TABLES

CONVERSION FACTORS

Most values in this report are given in inch-pound units. For those readers who may prefer to use metric units rather than inch-pound units, the conversion factors for the terms used in this report are listed below.

Multiply	By	To obtain
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)
foot (ft)	0.3048	meter (m)
inch (in.)	25.40	millimeter (mm)
	2.540	centimeter (cm)
mile (mi)	1.609	kilometer (km)
square mile (mi^2)	2.590	square kilometer(km^2)
ton	0.9072	metric ton (t)

CHARACTERISTICS OF SUSPENDED SEDIMENT IN THE SAN JUAN RIVER NEAR BLUFF, UTAH

By Kendall R. Thompson

ABSTRACT

The San Juan River above the station near Bluff drains about 23,000 square miles in the Four Corners region of Arizona, Colorado, New Mexico, and Utah. Average annual precipitation in the river basin ranges from less than 6 to more than 60 inches. Sedimentary rocks consisting mostly of sandstone, siltstone, and shale underlie most of the basin.

Fluvial sediment records were collected in the San Juan River near Bluff, Utah, during the period 1914-80. Mean annual suspended-sediment discharge during this period was about 25,410,000 tons with annual loads ranging from 3,240,000 tons in 1978 to 112,400,000 tons in 1941.

Double-mass curve analysis indicates that the relationship between annual suspended-sediment load and annual stream discharge changed between water years 1941-44 and 1972-73. Possible causes for this change are changes in sampling equipment and in laboratory procedures, and unusually large runoff that occurred in 1941 and 1972. Unidentified or unknown factors also are probably involved; the actual reasons for the change may never be fully understood. Navajo Dam apparently has had no significant effect on fluvial sediment at the sampling site.

The use of annual stream discharge to predict annual suspended-sediment load in the San Juan River near Bluff probably will produce inaccurate results because of the size and diversity of the basin, the within-year variation of discharge, and the quality of records available. A positive correlation exists between sand concentration and stream discharge at this site; however, considerable variability is evident. A relationship between sand concentration and stream discharge is not apparent when stream discharge exceeds 6,000 cubic feet per second.

INTRODUCTION

Purpose and Scope

The U.S. Geological Survey has operated a streamflow-gaging station since 1914 on the San Juan River near Bluff, San Juan County, Utah. This station is identified as station 09379500, San Juan River near Bluff, Utah (see U.S. Geological Survey, 1980, p. 21 and 376). Fluvial-sediment records also have been collected by the Geological Survey at the gaging station since 1914. The records collected through 1965 were compiled by Mundorff (1968, p. 198-251); those collected from 1966 to 1980 were compiled in U.S. Geological Survey report series Water-resources data for Utah (U.S. Geological Survey, 1980).

In 1980, collection of suspended-sediment records was terminated at station 09379500. The purpose of this report is to evaluate the records that were collected and to describe suspended-sediment characteristics in the San Juan River near Bluff based on those records. Because the data collected prior to 1930 were discontinuous and in order to perform systematic analysis, only those collected during water years 1930-80 were used in the compilations and statistical analyses for this report.

Some records of bedload discharge also were collected at the San Juan River near Bluff gage; however, it is beyond the scope of this investigation to evaluate and analyze these records. Accordingly, no calculations of total fluvial-sediment discharge from the San Juan River basin are included in this report.

General Description of the San Juan River Basin

The San Juan River basin above the station near Bluff includes about 23,000 square miles in the Four Corners region of Arizona, Colorado, New Mexico, and Utah (fig. 1). The San Juan River, second largest tributary to the Colorado River, originates in the San Juan Mountains of Colorado and empties into Lake Powell (a reservoir on the Colorado River in Utah and Arizona). Principal tributaries to the San Juan River are the Navajo, Los Pinos, Animas, Piedra, and La Plata Rivers in Colorado and New Mexico. The only major impoundment on the San Juan River is Navajo Reservoir, which began filling in June 1962. The reservoir has a usable storage capacity of 1,696,000 acre-feet.

Altitudes in the San Juan River basin range from about 3,700 feet (National Geodetic Vertical Datum of 1929) at Lake Powell to more than 14,000 feet in the San Juan Mountains of Colorado. The climate ranges from arid in the lower altitudes in the basin to alpine in the San Juan and other mountain ranges. Average annual precipitation ranges from less than 6 inches near Lake Powell to more than 60 inches in the San Juan Mountains (Iorns and others, 1965, pl. 1). Precipitation comes from both winter frontal storms that move in from the west and summer convection-type storms that move in from the south. The convection storms produce local but intense rainfall that generates rapid runoff and sediment transport.

Rocks ranging in age from Precambrian to Holocene are exposed in the San Juan River basin. Those in the headwaters of the San Juan Mountains are chiefly crystalline, igneous, and metamorphic rocks. Those that underlie most of the basin, however, are sedimentary rock of both marine and continental origin. They consist chiefly of sandstone, siltstone, and shale (Iorns and others, 1965, pl. 1). The siltstone and shale generally are easily eroded and undoubtedly contribute significantly to the sediment load of the San Juan River.

General Source Areas of Runoff and Sediment Discharge

by J. C. Mundorff

Data from upstream sites can be useful in describing and interpreting the suspended-sediment characteristics on the San Juan River near Bluff, Utah. Table 1 shows the percentages of water and sediment discharges of the San Juan River near Bluff that originate upstream from Shiprock, New Mexico; the percentages of the water and sediment discharges of the San Juan River at Shiprock that originate upstream from the Animas River at Farmington, New Mexico; and the percentages of water and sediment discharges near Bluff that

Table 1.—Relative contributions of stream discharge and suspended-sediment discharge in the San Juan River from various parts of the drainage basin

Water year	Animas River at Farmington, N. Mex. (station 09364500) Percentage of discharge of San Juan River at Shiprock		San Juan River at Shiprock, N. Mex. (station 09368000) Percentage of discharge of San Juan River near Bluff		Cottonwood Wash near Blanding, Utah (station 09378700) Percentage of discharge of San Juan River near Bluff	
	Streamflow	Suspended sediment	Streamflow	Suspended sediment	Streamflow	Suspended sediment
1952	38	8	98	40	—	—
1953	43	17	92	18	—	—
1954	40	3	96	74	—	—
1955	43	3	97	62	—	—
1956	42	7	100	59	—	—
1957	39	4	96	63	—	—
1958	38	9	94	59	—	—
1959	45	10	101	46	—	—
1960	36	8	100	84	—	—
1961	41	7	99	64	—	—
1962	40	15	95	44	—	—
1963	74	7	81	34	—	—
1964	44	5	88	58	—	—
1965	44	13	95	24	—	—
1966	31	10	89	30	—	—
1967	39	3	88	87	—	—
1968	61	8	88	31	[1] 1	[1] 10
1969	40	4	93	42	.5	1
1970	45	9	89	37	.2	1
1971	40	6	91	31	.1	.5
1972	38	6	104	28	—	—
1973	47	18	82	18	—	—
1974	30	20	96	41	—	—
1975	50	17	91	64	—	—
1976	40	15	91	58	—	—
1977	35	7	81	156	—	—
1978	68	8	92	183	—	—
1979	39	10	88	45	—	—
1980	45	13	88	40	—	—

[1] March-September 1968.

Note: The drainage area of the Animas River at Farmington is 1,360 square miles or about 11 percent of the drainage area upstream from San Juan River at Shiprock.
The drainage area of the San Juan River at Shiprock is 12,600 square miles or about 55 percent of the drainage area upstream from San Juan River near Bluff, which has a drainage area of 23,000 square miles.
The drainage area of Cottonwood Wash near Blanding is 205 square miles or about 1 percent of the drainage area upstream from San Juan River near Bluff.

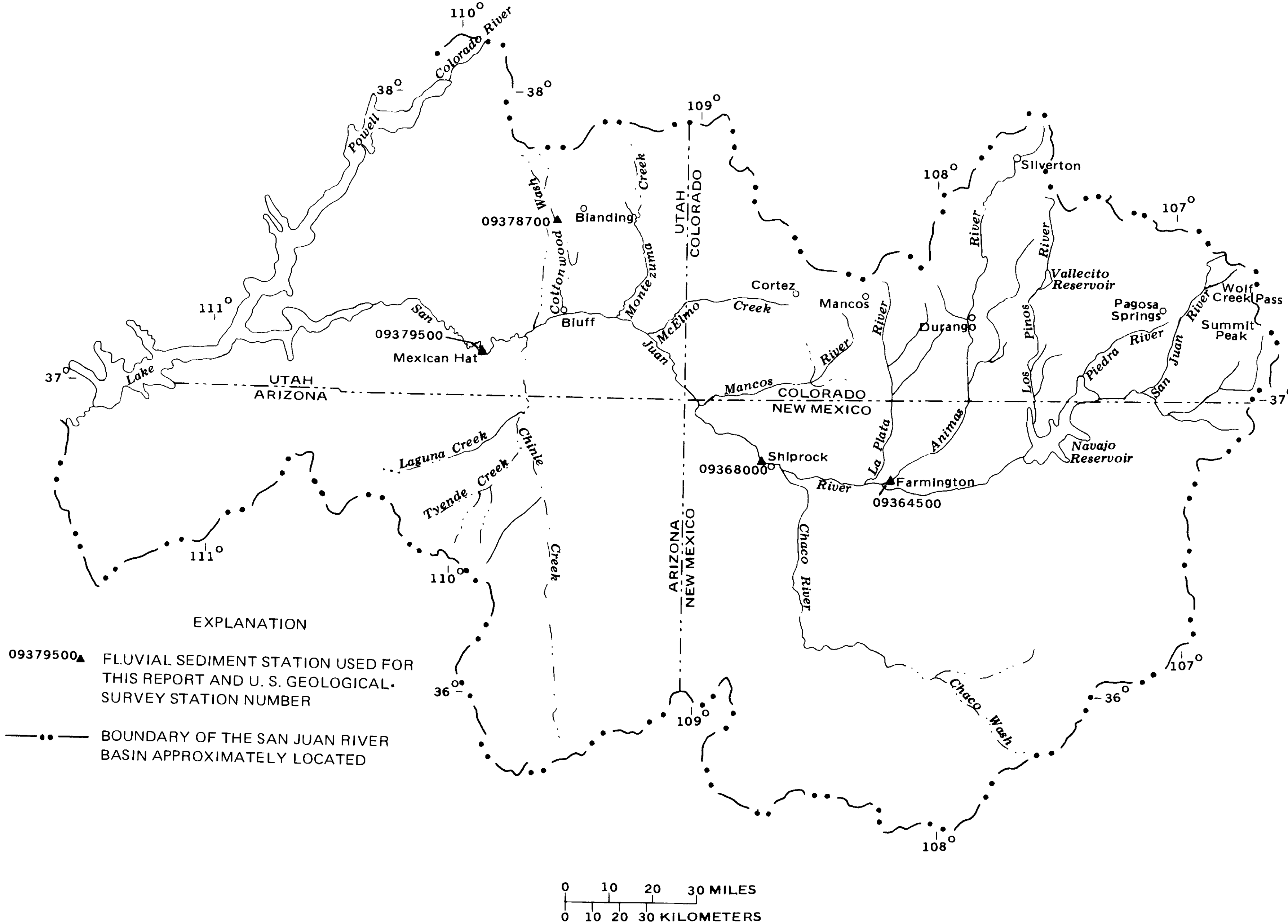

Figure 1.—Location of selected fluvial-sediment stations in the San Juan River basin.

originate in the very small drainage area of Cottonwood Wash near Blanding, Utah. Locations of the respective data sites are shown in figure 1.

On the average, about 43 percent of the water discharge but only about 9 percent of the sediment discharge of the San Juan River at Shiprock (fig. 1) originated from the Animas River near Farmington drainage. The Animas River near Farmington represents 11 percent of the drainage area of the San Juan River at Shiprock, and the combined drainage areas of the Animas River near Farmington and the San Juan River upstream from Navajo Dam represent 36 percent of the drainage area of the San Juan River at Shiprock. The trap efficiency for reservoirs, such as Navajo Reservoir, commonly exceeds 95 percent. Thus, the sediment contribution from about one-third of the drainage area upstream from Shiprock is a very minor part of the sediment discharge at Shiprock and is a negligible part of the sediment discharge of the San Juan River near Bluff. Available data suggest that the annual suspended-sediment load of the San Juan River near Bluff includes practically no sediment from 4,600 square miles (20 percent) of the 23,000-square-mile drainage area and a somewhat disproportionately large amount of sediment from 8,400 square miles of drainage area that is downstream from the Animas River and Navajo Reservoir and upstream from Shiprock.

Data for Cottonwood Wash near Blanding demonstrate the very large sediment discharges that can be contributed by a very small part of the drainage area of the San Juan River near Bluff. During a 6-month period (March-September) in 1968, the suspended-sediment load at the Blanding site was 1 percent of the annual sediment load of the San Juan River near Bluff, although the drainage area upstream from the Blanding site is less than 1 percent of the San Juan River drainage area.

Suspended-sediment yield, in tons per square mile per year, for the drainage area of the San Juan River near Bluff and for selected parts of that area are given in the following table:

San Juan River near Bluff (station 09379500)			San Juan River at Shiprock (station 09368000)		
Water years	Drainage area (square miles)	Tons per square mile per year	Water years	Drainage area (square miles)	Tons per square mile per year
1930-80	23,000	1,100	--	--	--
1952-80	23,000	795	1952-80	12,900	651
1963-80	23,000	821	1963-80	12,900	575
1963-80	[1]19,800	956	1963-80	[2]9,670	767
1963-80	[3]10,100	[3]1,130	--	--	--

[1]Drainage area of the San Juan River near Bluff (23,000 mi^2) minus drainage areas upstream from Navajo Reservoir (3,230 mi^2).
[2]Drainage area of the San Juan River at Shiprock (12,900 mi^2) minus drainage area upstream from Navajo Reservoir (3,230 mi^2).
[3]Drainage area and suspended-sediment yield of the intervening area between the San Juan River near Bluff and the San Juan River at Shiprock.

The suspended-sediment load for the San Juan River near Bluff for the 10-year period 1930-39 was about 395 million tons and for the 10-year period 1940-49 about 360 million tons. The suspended-sediment load for each of these 10-year periods was approximately double the load for each of the following 10-year periods (1950-59, 161 million tons; 1960-69, 184 million tons; and 1970-79, 182 million tons). These variations should be considered in evaluating the data in the preceding table. Comparison of the data for the period 1963-80 is especially significant because storage in Navajo Reservoir began in June 1962. Thus, the effective area of sediment contribution was reduced by about 25 percent for San Juan River at Shiprock and by about 14 percent for San Juan River at Bluff. The data show that, for the 10,100 square miles of drainage area downstream from the Shiprock station, the suspended-sediment yield was significantly greater than for the drainage area upstream from Shiprock.

FLUVIAL SEDIMENT IN THE SAN JUAN RIVER NEAR BLUFF

Collection of Records

Most of the suspended-sediment sampling at station 09379500 was done from a cableway several hundred feet downstream from the stream-gaging station. Sampling to determine suspended-sediment concentrations was started in 1914; the sampling was discontinuous from 1914 to 1929 and continuous from 1930 to 1980. Determinations of particle-size distribution of the suspended sediment were started in 1935 and were continuous through 1980 except for periodic interruptions between 1937 and 1940.

Prior to 1944, sampling for suspended-sediment determinations was done by crude 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 a depth-integrated sample. Some sampling devices permitted the container to be opened below the surface of the water. This type of sampler collected samples at specific points in the sampling vertical. It was virtually impossible to obtain good depth-integrated samples with this type of equipment. The U.S. D-43 suspended-sediment sampler was developed in 1943 and was first used at station 09379500 in May 1944. (A series of reports titled "A study of methods used in the measurement and analysis of sediment loads in streams" give details concerning the development and use of suspended-sediment sampling equipment. See "References cited" for individual reports.) 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. Nevertheless, the reliability of the records collected at station 09379500 is influenced by a number of other factors, including conditions at the site, changes of personnel, and so forth.

Samples were analyzed by the Geological Survey to determine suspended-sediment concentrations and, beginning in 1935, particle-size distribution of the sediment. Methods of analysis also used varied considerably during the 51 years of continuous record; this too has an effect on the reliability of the records.

A few records of particle-size distribution of bedload material were collected for the San Juan River at station 09379500. Such records are needed to calculate total sediment discharge. As previously stated, it was beyond the scope of this report to make those calculations.

Evaluation of Records

It is important to consider the reliability of the available data at this site before any analysis of the data is attempted. Data for station 09379500 have been collected continuously for 51 years. Numerous changes have occurred during these 51 years. Sampling equipment and technique, laboratory equipment and technique, streamflow measuring and recording equipment, and personnel have all changed over this period of time. When determining the reliability of data, the sampling site also must be considered. After reviewing the data and the factors that may have influenced the reliability of the data, several conclusions can be drawn.

1. The sediment data collected prior to May 1944 are not as representative of actual conditions as the data collected after that date. The data collected since May 1944 reflect the more reliable and accurate sampling using the U.S. D-43 and subsequent depth-integrating samplers.

2. The records for 1962-80 are of poorer quality than those for 1944-61. This is because much of the sampling during 1962-80 was done by local observers. In the remote area of the sampling site, it is difficult to find and train dependable local observers.

3. Frequently, insufficient sampling was done, especially during periods of high runoff, thus providing an inadequate record of actual suspended-sediment discharge. This is especially true for 1962-80 when sampling was done by local observers.

4. The sampling site at 09379500 is located in a stream reach with a streambed that is predominantly sand. Sand boils are common in this stream reach. A sand boil is a condition arising from turbulence that causes sand to be transported to the surface of the water and then settle again to the streambed with little or no downstream displacement. Accurate suspended-sediment samples can be collected at this site using proper equipment when the sand boil problem is mild; however, when the sand boil problem is severe, accurate suspended-sediment samples cannot be collected.

5. Changes in laboratory personnel and techniques in suspended-sediment analyses have introduced some inconsistency in the fluvial-sediment record. The record since the early 1940's reflects improved laboratory techniques (R. E. Cabell, formerly U.S. Geological Survey, oral commun., 1981).

6. Some of the peak stream discharge records that greatly exceeded the rating for station 09379500 add to the uncertainties of the suspended-sediment discharge data during these times.

Based on the foregoing conclusions, the suspended-sediment records for gaging station 09379500 are considered to be poor prior to 1944 and fair to poor for the remaining period of record. Results of analyses of those records should be viewed with discretion.

Suspended-Sediment Characteristics

The following discussions of the discharge and particle-size distribution of suspended sediment are based on suspended-sediment records collected during 1930-80 and 1935-80, respectively.

Sediment load

Annual suspended-sediment loads for the period of continuous record at station 09379500 are shown in figure 2. As shown, the suspended-sediment load varied considerably. The maximum suspended-sediment load of 112,400,000 tons occurred in 1941 and the minimum of 3,234,000 tons occurred in 1978. The mean annual suspended-sediment discharge for 51 years of continuous record is 25,410,000 tons with a standard deviation of 21,646,000 tons.

A change in both the volume and variability of annual suspended-sediment load is apparent in figure 2. The annual volume and variability of suspended-sediment load was greater during 1930-42 than during 1943-80. The mean suspended-sediment discharge for 1930-42 was 46,342,000 tons per year with a standard deviation of 27,801,000 tons per year. The mean suspended-sediment discharge for 1943-80 was 18,250,000 tons per year with a standard deviation of 13,264,000 tons per year. Less variability in stream discharge occurred between the two periods (fig. 3), indicating that stream discharge alone did not cause the variability of suspended-sediment discharge.

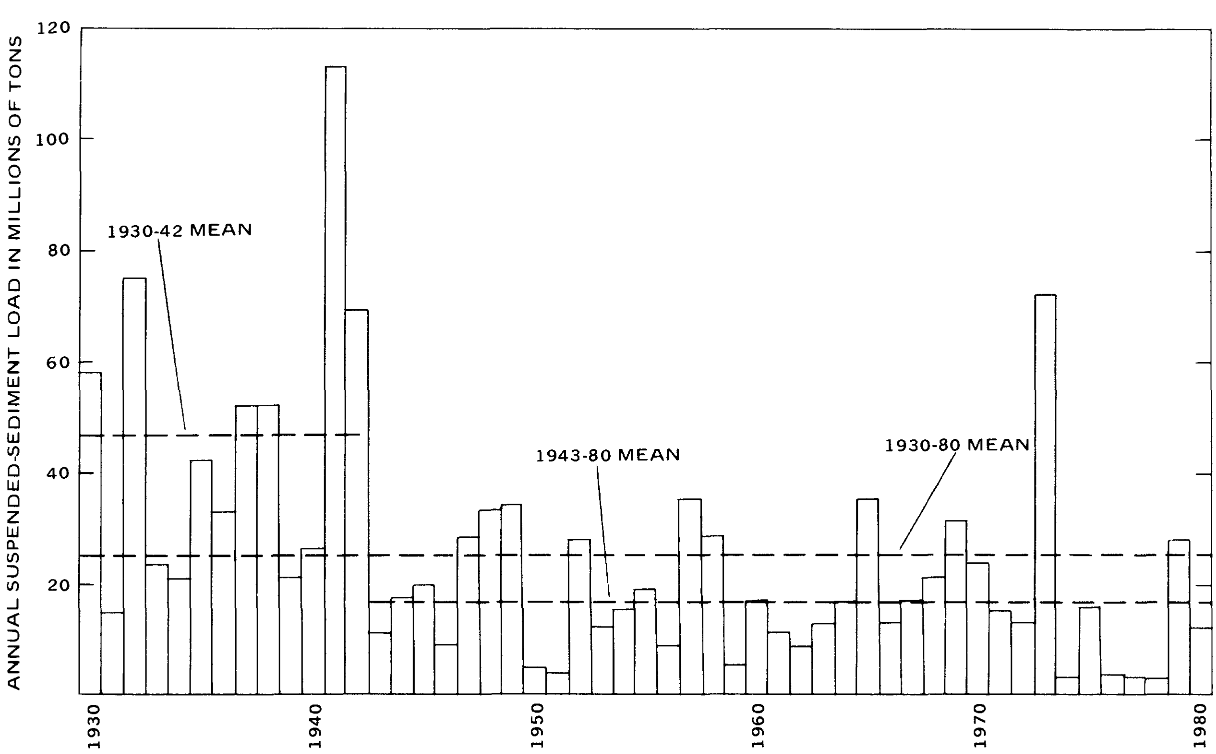

Figure 2.—Annual suspended-sediment load, San Juan River near Bluff, Utah, water years 1930-80.

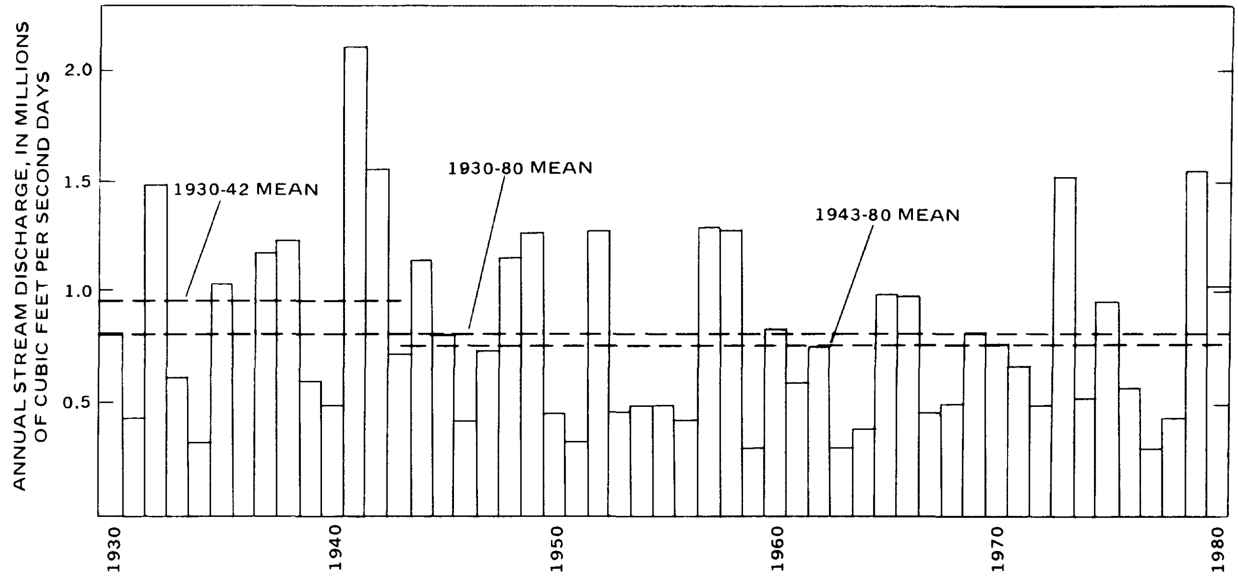

Figure 3.—Annual stream discharge, San Juan River near Bluff, Utah, water years 1930-80.

The double-mass curve shown in figure 4 provides further evidence that a change occurred in the early 1940's. This double-mass curve was constructed by plotting cumulative annual stream discharge against cumulative annual suspended-sediment load. "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." (See Searcy and Hardison, 1960, p. 33.) A break in the slope of the double-mass curve occurred approximately between water years 1941-44 and also between water years 1972-73 as shown in figure 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 stream discharge trend were evident. Cumulative annual suspended-sediment loads versus time was plotted (not presented) to help identify changes in suspended-sediment trends that might have occurred. A change in slope similar to the changes in the double-mass curve (fig. 4) was apparent.

Some factor other than stream discharge influenced the change in trend of suspended sediment. One or a combination of the following may explain the change that occurred in the early 1940's:

1. In May 1941 (1941 water year), an unusually high spring runoff occurred. As a result of the high spring runoff, the second largest monthly suspended-sediment load and the highest annual suspended-sediment load for the period of record were recorded (table 2). In addition, a very large rainstorm occurred in October 1941 (1942 water year) just 5 months after the large spring runoff in May of the same year. As a result of this rainstorm the third largest monthly suspended-sediment load and the third largest annual suspended-sediment load for the period of record were recorded.

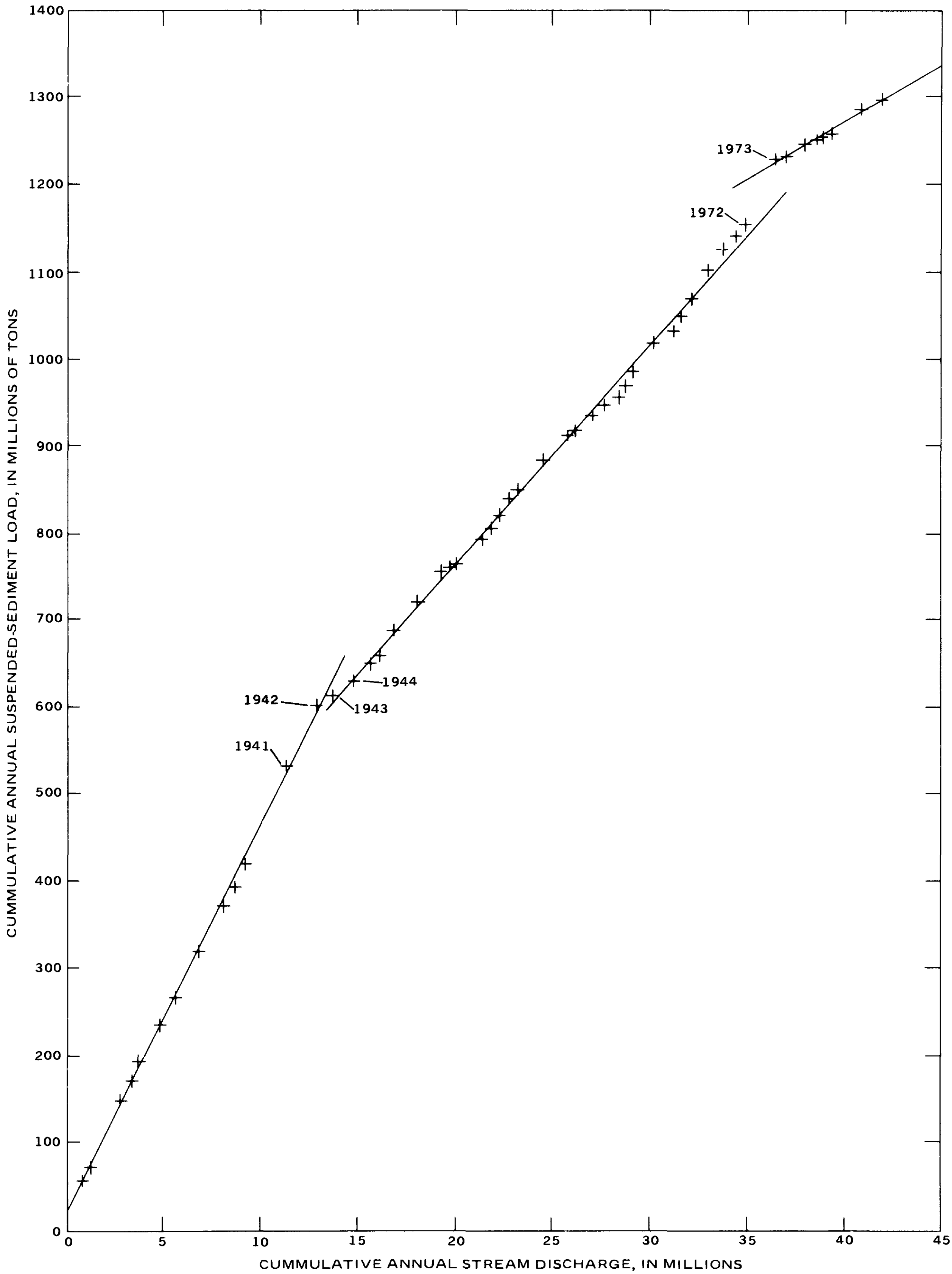

Figure 4.—Double-mass curve showing relationship between annual suspended-sediment load and annual stream discharge, San Juan River near Bluff, Utah, water years 1930-80.

2. A major change in sampling equipment occurred on May 1, 1944 when the Colorado River sampler, which had been used, was replaced with the U.S. D-43 sampler (Miller, 1951). Miller reports that originally he thought the break in the curve was caused by the change in sampler. However, a study done by Nelson and Benedict (1950) showed the average ratio of concentrations collected with the Colorado River sampler to values obtained with the U.S. D-43 sampler was 0.82 and ranged from 0.59 to 1.00 (Nelson and Benedict, 1950). If this correction was applied to the double-mass curve it would increase the angle of the break. Miller came to the same conclusion and suggests the reasons for the break are climatic rather observational.

3. A change in methodology for suspended-sediment analysis occurred at this time. (See p. 7.)

A second change in the slope of the double-mass curve occurred between water years 1972 and 1973. This change in slope of the double-mass curve occurred in the same direction as the first change. In addition, the ratio of the slope before the change to the slope after the change shows similar values of 0.513 and 0.568.

A second double-mass curve (not presented) was constructed by plotting 1964-80 values of cumulative annual suspended-sediment load for the San Juan River at Shiprock against those for the San Juan River near Bluff. A change in slope occurred in this double-mass curve approximately between water years 1972 and 1973. This provides further evidence that a change did occur between the 1972 and 1973 water years and that it occurred downstream of Shiprock.

A third double-mass curve (not presented) was constructed by plotting cumulative annual suspended-sediment load against cumulative annual stream discharge in the San Juan River at Shiprock. No break in the double-mass curve was evident between the 1972-73 water years. This also indicates the cause for the change in relationship between suspended-sediment load and streamflow at the San Juan River near Bluff site occurred downstream from the San Juan River at Shiprock site for this period.

A possible cause for the change in the stream discharge-suspended sediment load relation that occurred between 1972-73 water years is a large rainstorm that occurred in October 1972 (1973 water year). As a result of this storm the largest daily suspended-sediment load for the period of record was recorded on October 20, 1972. The San Juan River transported 15,700,000 tons of suspended sediment on that day (table 2). This contributed to the largest suspended-sediment load ever recorded at the station. The load for October was more than 48,300,000 tons or 67 percent of the total sediment load for the entire 1973 water year.

It is significant to note that rainstorms occurred at both times represented by a change in slope on the double-mass curve. These two rainstorms were very large and both occurred during October.

It is beyond the scope of this report to determine how the large rainstorms of October 1941 and October 1942, or the high spring runoff of May 1941 may have changed or influenced the relationship between stream discharge

Table 2.--Suspended-sediment loads and stream discharge for indicated period in water years 1941, 1942, and 1973

	Load (tons)	Streamflow (cfs-days)
Time period included		
May 1941 (1941 water year)	42,830,000	667,000
October 1941 (1942 water year)	38,890,000	330,000
October 1972 (1973 water year)	[1]48,325,000	171,000
October 20, 1972 (1973 water year)	15,700,000	26,400
Water-year totals		
1941	[1]112,400,000	2,139,000
1942	69,080,000	1,552,000
1973	72,081,000	1,525,000

[1]Maximum recorded for period of record

and suspended sediment at gaging station 09379500. Some processes that may have been involved are (1) a massive flushing caused by the extremely large runoff, (2) erosion and changes in channel geometry and gradients of the San Juan River and tributaries, and (3) changes in aggradation-degradation in the drainage basin.

The factors identified above as possible causes for the changes in relationship between stream discharge and suspended-sediment load do not preclude the possibility of some unknown factor being involved. This unknown or unidentified factor may have influenced or caused the change in relationship identified by the double-mass curve in the early 1940's and between the 1972 and 1973 water years. The evidence presented does not support any one specific factor or combination of factors. The actual reason for the changes in relationship shown by the double-mass curve may never be fully understood.

Navajo Dam, completed in 1962, apparently has had no significant effect on the relationship between stream discharge and suspended-sediment load at station 09379500. This probably is because the dam impounds runoff from less than 14 percent of the drainage areas upstream from station 09379500. Furthermore, much of the area that drains to Navajo Reservoir is underlain by crystalline rock and is well vegetated, yielding much less sediment per unit area than the remaining part of the San Juan River basin. Therefore, it should not have an easily detectable effect on the fluvial-sediment load at gaging station 09379500 about 180 river miles downstream.

The long-term relationship between stream discharge and suspended-sediment load is commonly used to estimate suspended-sediment load at sites for which any stream-discharge records are available; however, this relationship at station 09379500 produces poor results. Regression analyses of the stream discharge-suspended sediment load relationship (fig. 5) produced a significant correlation (correlation coefficient r = 0.801) however, analysis of the plot and the 95-percent confidence level (fig. 6) suggest that the annual stream discharge from records collected at station 09379500 would produce a poor estimate of annual suspended-sediment load at that station. For example, if an annual stream discharge of 1 million cubic feet per second-days were used, annual suspended sediment could range anywhere from 6,580,000 to 59,340,000 tons at a 95-percent level of confidence. The above analysis used the entire period of record, but this study has identified three periods where the relations between water discharge and discharge were different. Given the high variability in the data, the periods 1930-41 and 1973-80 were too short to define transport curves. However, if a separate transport curve could be developed for each period, the conclusion would remain the same; estimates based on those curves would be very poor.

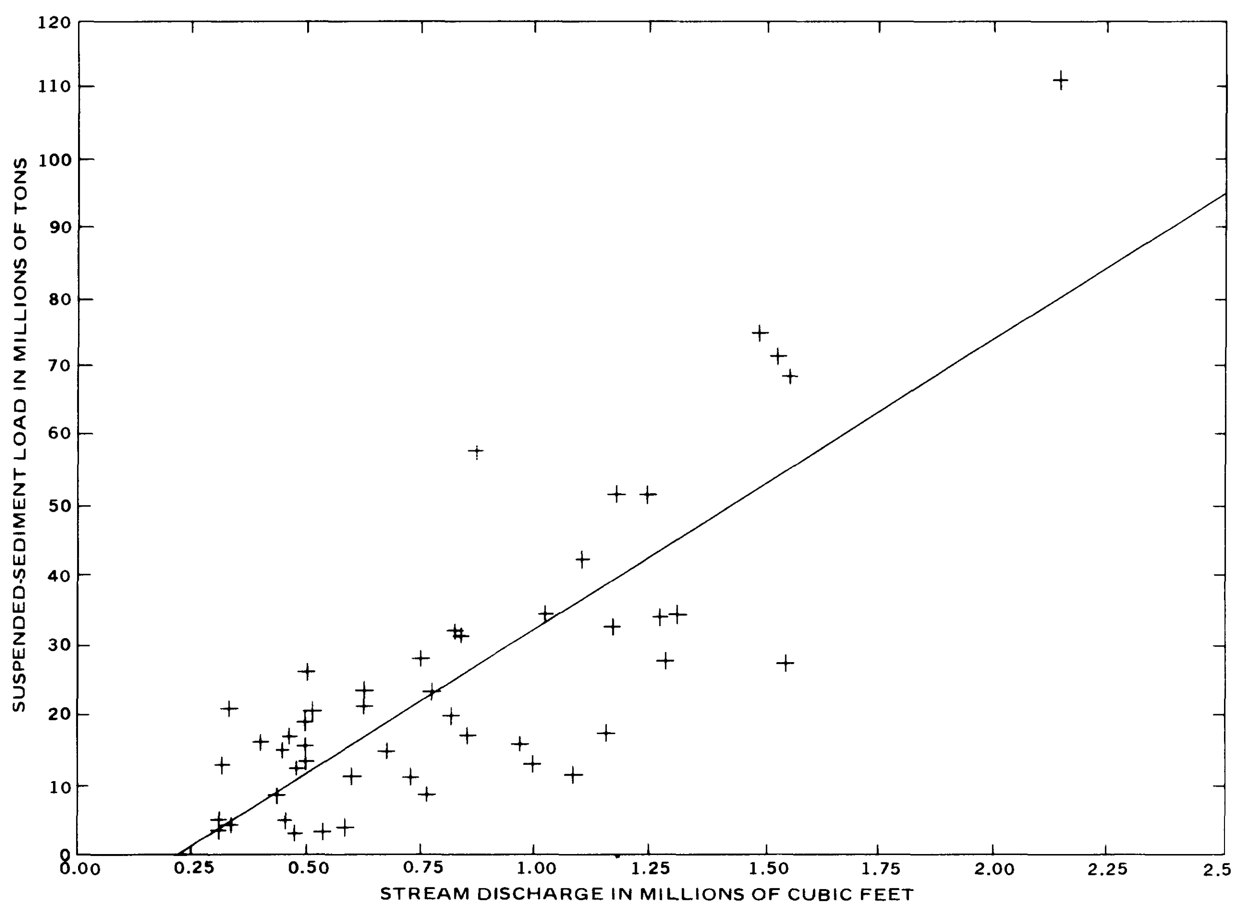

Figure 5.—Relationship between annual suspended-sediment load and annual stream discharge, San Juan River near Bluff, Utah, water years 1930-80.

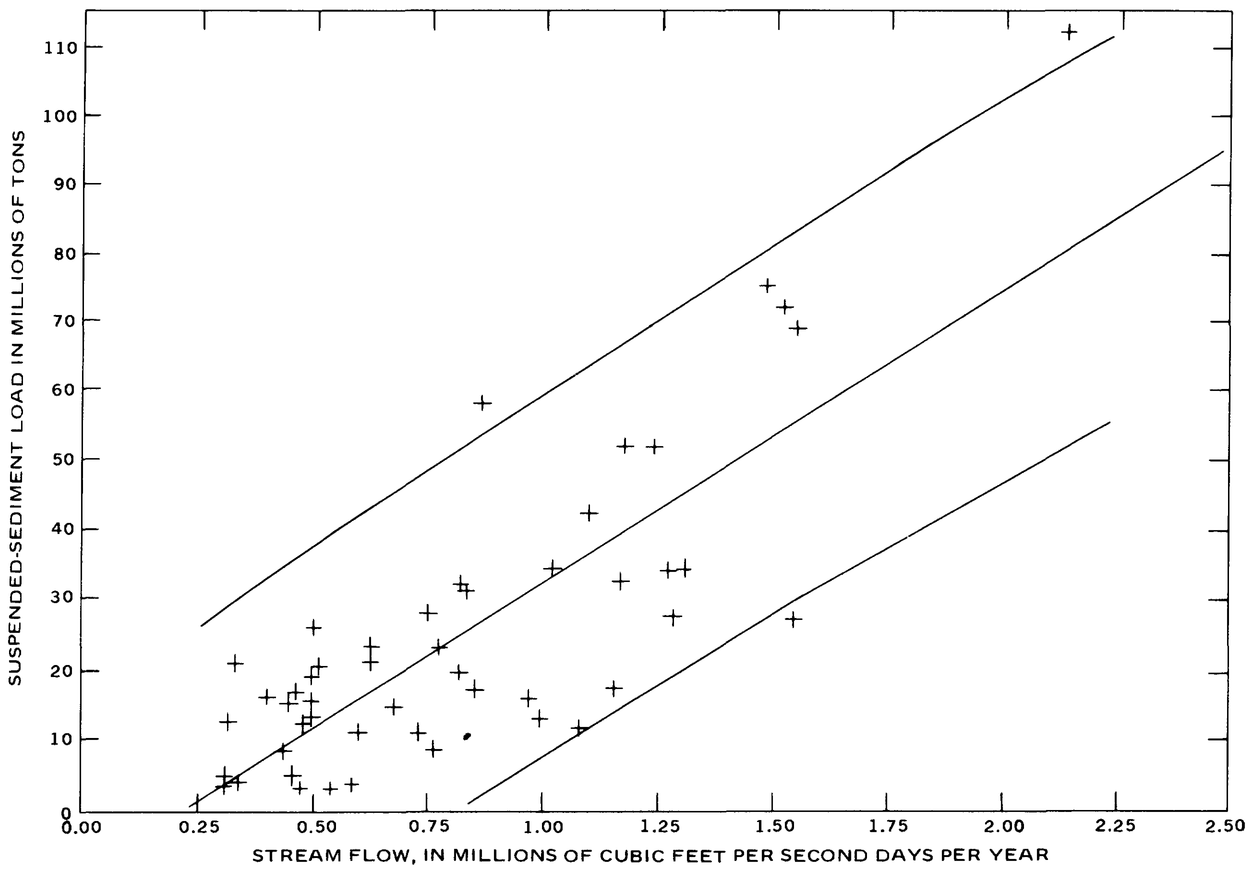

Figure 6.—Relationship between annual suspended-sediment load and annual stream discharge showing 95-percent confidence interval for estimating unknown annual suspended-sediment load, San Juan River near Bluff, Utah, water years 1930-80.

There are several reasons why the streamflow records collected at gaging station 09379500 would produce poor estimates of sediment discharge at the station. They include the localized nature of precipitation in the basin upstream from the station and the questionable nature of the suspended-sediment records available. Numerous tributaries enter the San Juan River upstream from station 09379500. The majority of these tributaries carry large amounts of sediment during high runoff, especially rainstorm runoff. Runoff from these tributaries may substantially increase the suspended-sediment concentration of the San Juan River but have only a small effect on the annual stream load.

Particle-size distribution

The size of sediment particles carried by a stream may vary from very fine clay to boulders. A scale of sizes used by the Geological Survey is shown in table 3. Fine sediment particles are easily carried in suspension in natural streams. Coarse sediment particles may be suspended in the stream discharge for relatively short distances and frequently roll or bounce along the streambed. Sand suspended in a stream may be supported by vertical

Table 3.--Classes of sediment-particle size
(Guy, 1969)

Class	Size (millimeters)	Class	Size (millimeters)
Boulders	> 256	Medium sand	0.50-0.25
Large cobbles	256-128	Fine sand	.25-.062
Small cobbles	128-64	Very fine sand	.125-.062
Very coarse gravel	64-32	Coarse silt	.062-.031
Coarse gravel	32-16	Medium silt	.031-.016
Medium gravel	16-8.0	Fine silt	.016-.008
Fine gravel	8.0-4.0	Very fine silt	.008-.004
Very fine gravel	4.0-2.0	Coarse clay	.004-.0020
Very coarse sand	2.0-1.0	Medium clay	.0020-.0010
Coarse sand	1.0-0.50	Fine clay	.0010-.0005
		Very fine clay	.0005-.00024

currents in turbulent flow. The magnitude of these currents is largely a function of stream velocity, streambed roughness, and distance above the streambed. The suspended load of sand within a stream cross section can be considered to be a function of the mean velocity of the stream.

Concentrations of fine sand were plotted versus stream discharge for the San Juan River at station 09379500 (fig. 7) to determine if a relationship exists between sand concentration coarser than 0.062 millimeter and stream discharge. Because of the large amount of data collected, the results of only 116 analyses were used. They were chosen randomly using a random-number table from the available data. Errors, if any, introduced by differing methods of sample analyses over the long period of record were considered negligible.

It is assumed that an increase in stream discharge would result in an increase in sand concentration; therefore, as stream discharge increased, the sand concentration in the water column also would increase. Although the data plotted in figure 7 show considerable scatter, statistical analysis of the data disclosed a positive correlation (correlation coefficient $r = 0.401$).

The variability (scatter) shown in figure 7 probably is due to the diversity of geology and runoff in the San Juan River basin. The numerous diverse tributaries of the San Juan River contribute various quantities and sizes of sediments to the river. In arid regions, such as the lower San Juan River basin (downstream from Navajo Dam), the greatest amount of sediment transport usually occurs during intense rainstorms. Factors such as geology of individual tributary drainages or location and intensity of rainstorms greatly influence the volume and characteristics of sediment transported to the San Juan River. For example, a rainstorm occurring in a tributary draining an area that produces large amounts of fine sediments can rapidly change the particle-size distribution and sediment load in the San Juan River. This large inflow of fine sediment into the river may significantly change the sediment load and particle-size distribution of the sediments in the river but may produce only minor changes in stream discharge. Other

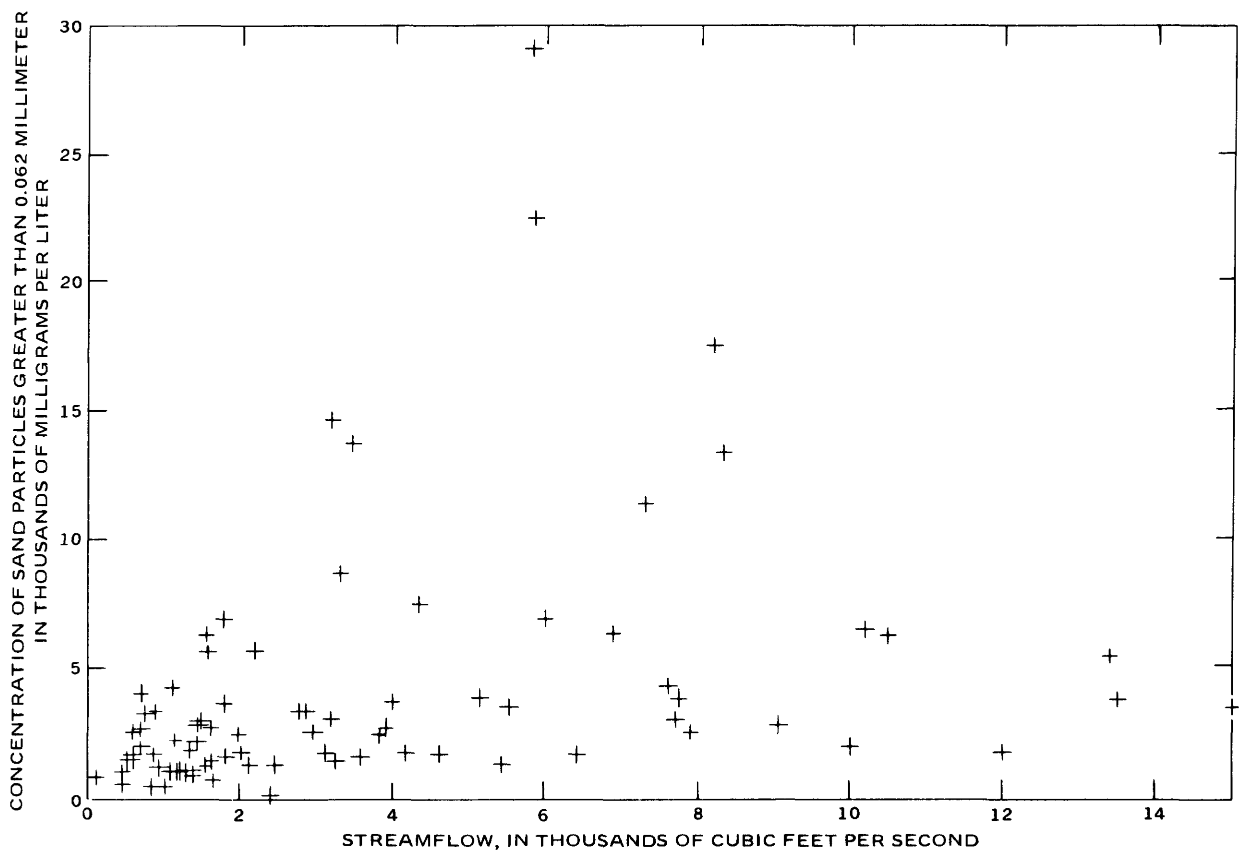

Figure 7.—Relationship between streamflow and concentration of sand particles greater than 0.062 millimeter in diameter.

tributaries or the same tributaries under different conditions may contribute large amounts of coarser sediments to the river. If the stream discharge of the river is not adequate to keep these particles in suspension, they are deposited in the river channel until there is sufficient stream discharge to transport them downstream. Any combination of factors in a drainage basin as large as that of the San Juan River may alter the sediment characteristics of the river in a variety of ways. Another reason for the variability of particle-size distribution may be the poor sampling site and the reliability of samples collected by local observers.

Much of the variability shown in figure 7 may occur predominantly during low to moderate stream discharge. To investigate whether a better relationship existed during high stream discharges, the sand concentrations (particles coarser than 0.062 millimeter) were plotted against stream discharges that exceeded 6,000 cubic feet per second (fig. 8). The correlation (correlation coefficient r=0.079) between stream discharge and sand concentration is not significant at a 95-percent level of confidence.

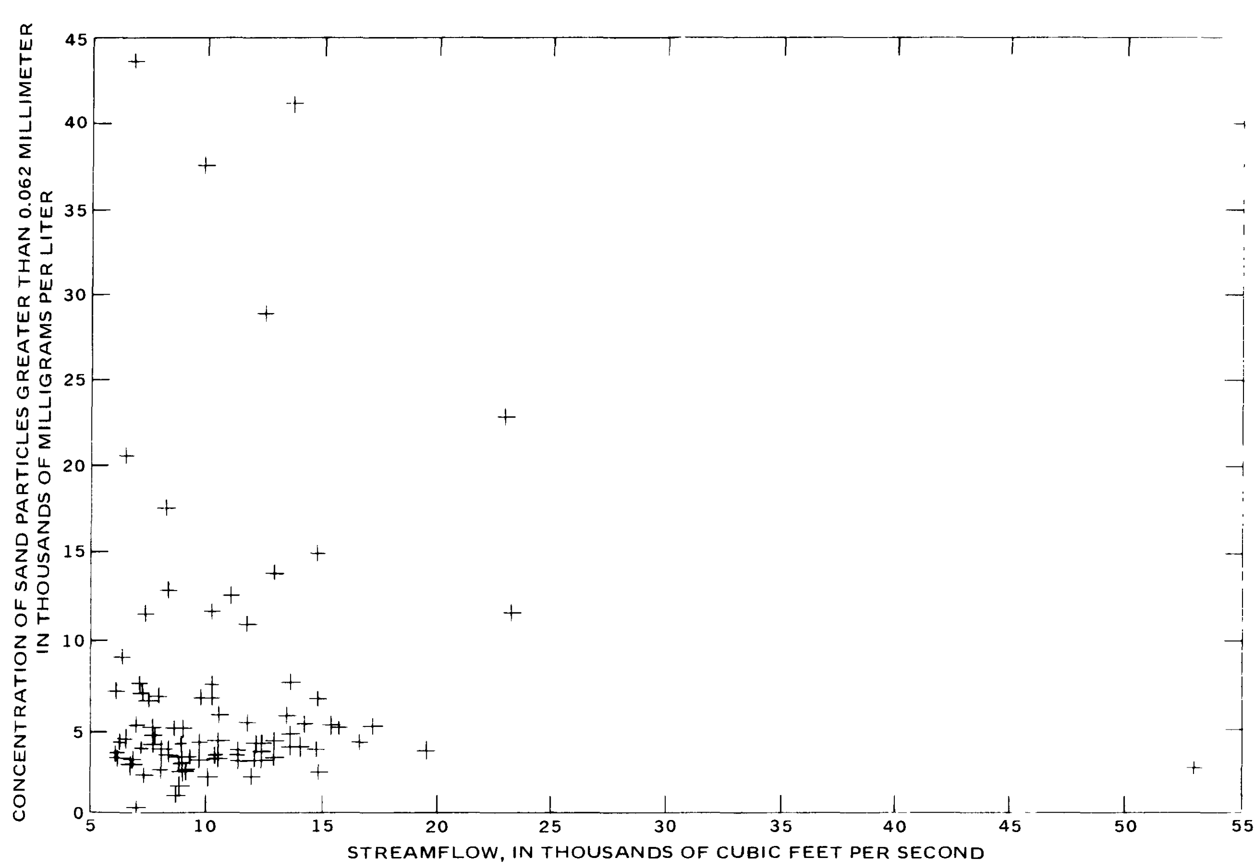

Figure 8.—Relationship between streamflow greater than 6,000 cubic feet per second and concentration of sand particles greater than 0.062 millimeter in diameter.

SUMMARY AND CONCLUSIONS

The San Juan River above the station at Bluff drains about 23,000 square miles in the Four Corners region of Arizona, Colorado, New Mexico, and Utah. Average annual precipitation in the river basin ranges from less than 6 to more than 60 inches. Sedimentary rocks consisting mostly of sandstone, siltsone, and shale underlie most of the basin.

During the period 1914-80, the Geological Survey collected records of fluvial sediment in the San Juan River near Bluff, Utah (U.S. Geological Survey streamflow-gaging station 09379500). Collection of these records was discontinued in 1981. Based on the records of suspended sediment collected from 1930 to 1980, mean suspended-sediment discharge in the San Juan River near Bluff was about 25,410,000 tons per year ranging from an annual load of 3,234,000 tons in 1978 to 112,400,000 tons in 1941. Total fluvial-sediment discharge was not computed.

Analyses of the suspended-sediment records collected from 1930 to 1980 indicate that the records generally are only fair to poor chiefly because of the following factors: (1) Infrequent sampling during high runoff, (2) changes in personnel, sampling equipment, and analytical techniques during the long period of record, and (3) a somewhat less than ideal sampling site. These same factors also apparently affected the quality of the records of particle-size distribution of the suspended sediment.

Even though the records of fluvial sediment in the San Juan River near Bluff are of generally fair to poor quality, they are adequate for obtaining gross estimates of sediment transport in the river and the general character of the sediment. A double-mass curve showed a change in relationships between annual suspended sediment load and annual stream discharge that occurred between the water years 1941-44 and 1972-73. Possible causes for these changes are a change in laboratory procedures, and unusually high runoff that occurred in 1941 and 1972. An unknown or unidentified factor may also be involved in this change in relationship as shown by the double-mass curve. The actual reason for these changes may never be fully understood.

The use of annual stream discharge to predict annual suspended-sediment load will produce poor results. The large size and the diversity of geology and precipitation patterns in the San Juan River basin present too many variables to form a constant relationship between suspended-sediment load and stream discharge. A positive correlation exists between sand concentration and stream discharge at this site; however, the correlation is weak. There is no significant correlation when stream discharges are restricted to those in excess of 6,000 cubic feet per second.

If collection of such records are resumed in this reach of the river, careful consideration should be given to selection of a different sampling site--a site at which a more representative sampling of the suspended and bedload sediment can be obtained. Automatic pumping samples also should be considered because of the remoteness of the area.

REFERENCES CITED

Guy, H. P., 1969, Laboratory theory and methods for sediment analysis: Techniques of Water-Resources Investigations of the U. S. Geological Survey, Chapter C1, Book 5, Laboratory Analysis, 58 p.

Iorns, W. V., Hembree, C. H., and Oakland, G. L., 1965, Water resources of the Upper Colorado River Basin--Technical report: U.S. Geological Survey Professional Paper 441, 370 p.

Miller C. R., 1951, Analysis of flow-duration, sediment, rating curve method of computing sediment yield: U.S. Bureau of Reclamation, Project Planning Division, p. 12.

Mundorff, J. C., 1968, Fluvial sediment in Utah, 1905-65, a data compilation: Utah Department of Natural Resources Information Bulletin 20, 400 p.

Nelson, M. E., and Benedict, P. E., 1950, Measurement and Analysis of Suspended Sediment Loads in Streams, _in_ Proceedings of the American Socety of Civil Engineers, September 1950, v. 76, p. 22.

Searcy, J. K., and Hardison, C. H., 1960, Double-mass curves: U.S. Geological Survey Water-Supply Paper 1541-B, 66 p.

U.S. Geological Survey, 1966-80, Water resources data for Utah: U.S. Geological Survey Data Report UT-80-1. A series.

U.S. Interagency Committee on Water Resources, A study of methods used in measurement and analysis of sediment loads in streams:

Report No. 3, Analytical study of methods of sampling suspended sediment, University of Iowa, Iowa City, Iowa, November 1941, 82 p.

Report No. 5, Laboratory investigation of suspended-sediment samples, University of Iowa, Iowa City, Iowa, December 1941, 99 p.

Report No. 6, The design of improved types of suspended-sediment samplers, U.S. Army, Corps of Engineers, St. Paul, Minnesota, May 1952, 103 p.

Report No. 8, Measurement of the sediment discharge of streams, University of Iowa, Iowa City, Iowa, March 1948, 92 p.

Report No. 13, The single-stage sampler for suspended sediment, St. Anthony Falls Hydrologic Laboratory, Minneapolis, Minnesota, 1961, 105 p.

Report No. 14, Determination of fluvial sediment discharge, St. Anthony Falls Hydrologic Laboratory, Minneapolis, Minnesota, 1963, 151 p.

DEFINITION OF TERMS

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

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

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

Cfs-day--The volume of water represented by flow of 1 cubic foot per second for 24 hours. It is equivalent to 86,400 cubic feet, approximately 1.9835 acre-feet, about 646,000 gallons or 2,447 cubic meters.

Cubic foot per second (ft^3/s)--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 meters per second.

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

Double-mass curve--In this report a double-mass curve was constructed by plotting cumulative annual stream discharge against cumlative annual suspended-sediment load.

Fluvial sediment--Sediment that is transported by, suspended in, or deposited by water.

Mean concentration--The time-weighted concentration of suspended sediment passing a stream section during 24-hour day.

Milligrams per liter (mg/L)--The concentration of suspended sediment is currently expressed in milligrams per liter, and is based on the ratio of the dry weight of sediment to the volume of water-sediment mixture.

National Geodetic Vertical Datum of 1929 (NGVD of 1929)--A geodetic datum derived from a general adjustment of the first-order level nets of both the United States and Canada, formerly called mean sea level.

Parts per million (ppm)--For suspended sediment, it is computed as 1 million times the ratio of the dry weight of sediment to the weight of the mixture of water and sediment.

Sediment yield--The sediment outflow from a drainage basin for a specific period of time usually expressed in terms of mass or volume per unit of time.

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

Stream discharge--In this report, stream discharge is 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 passing a section in a specified period and is 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--The 12-month period, October 1 through September 30, as used by the U.S. Geological Survey. The water year is designated by the calendar year in which it ends. Thus, the year ending September 30, 1980 is called the "1980 water year."