SEDIMENT DISCHARGE IN THE COLORADO RIVER NEAR DE BEQUE, COLORADO

By David L. Butler

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DONALD PAUL HODEL, Secretary

GEOLOGICAL SURVEY

Dallas L. Peck, Director

For additional information
write to:

District Chief
U.S. Geological Survey
Box 25046, Mail Stop 415
Denver Federal Center
Lakewood, CO 80225

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CONVERSION FACTORS

Inch-pound units used in this report may be converted to SI (International System) units by using the following conversion factors:

Multiply	*By*	*To obtain*
acre	0.4047	hectare
acre-foot (acre-ft)	1233.6	cubic meter
cubic foot per second (ft^3/s)	0.02832	cubic meter per second
foot (ft)	0.3048	meter
gallon (gal)	3.785	liter
inch (in.)	25.40	millimeter (mm)
mile (mi)	1.609	kilometer
pound (lb)	0.4536	kilogram
pound per cubic foot (lb/ft^3)	16.017	kilogram per cubic meter
square foot (ft^2)	0.0929	square meter
square mile (mi^2)	2.589	square kilometer
ton	0.9074	metric ton or megagram

Temperature in degree Celsius (°C) can be converted to degree Fahrenheit (°F), by use of the following formula: $°F = 1.8°C+32$

The following term and abbreviation also is used in this report: milligram per liter (mg/L).

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ABSTRACT

A study was conducted to determine annual-sediment discharge at the site of a proposed reservoir on the Colorado River at Una, located 3 miles upstream from De Beque, Colorado. Eleven suspended-sediment samples were collected during 1984 at the De Beque bridge. These data were combined with suspended-sediment data collected for the Colorado River at two nearby streamflow-gaging stations to define relations between suspended-sediment discharge and stream discharge. Best results were obtained when the data were separated into two periods, March through October and November through February. The data for March through October were separated into two periods: (1) Rising stream-stage period, which includes data collected prior to the date of the annual peak-stream discharge, and (2) falling stream-stage period, which includes data collected after the date of the annual peak-stream discharge.

Nine bedload samples were collected during 1984 to determine the contribution of bedload-sediment discharge to total-sediment discharge. Bedload accounted for less than two percent of total-sediment discharge. The best relations describing bedload-sediment discharge were obtained when the bedload data were separated into two periods: (1) Data collected prior to the date of the annual peak-stream discharge, and (2) data collected after the date of the annual peak-stream discharge.

Mean annual-sediment discharge in the Colorado River at the proposed Una reservoir site was estimated to be 1,065,000 tons per year for the period October 1966 through September 1984. Water storage capacity of the proposed reservoir would decrease about 30 percent after 100 years at this sediment-discharge rate.

INTRODUCTION

Sediment deposition in a reservoir affects dam design and reservoir operation because the sedimentation rate is the primary factor affecting the water-storage capacity of a reservoir. In order to estimate reservoir sedimentation rate, the following information is required: (1) Stream discharge, (2) total-sediment discharge, (3) particle-size distribution of the sediment, and (4) trap efficiency of the reservoir. The U.S. Geological Survey has collected this type of information in the Colorado River Basin since 1972 as part of a statewide program of sediment-data collection that has one of its objectives to provide sediment-yield data at potential reservoir sites.

Purpose and Scope

This report demonstrates how the data collected in the sediment-data network can be used in conjunction with site-specific data to calculate potential sediment deposition in a proposed reservoir in the Colorado River Basin. The Colorado River Water Conservation District has obtained water rights for the proposed Una Reservoir on the Colorado River. The reservoir would be located about 35 mi northeast of Grand Junction near the town of De Beque (fig. 1). The Una Reservoir would have a capacity of 196,000 acre-ft and would be used for industrial and domestic water supplies and power generation.

Approach

Suspended-sediment and bedload-sediment data were collected during 1984 for the Colorado River near the Una Reservoir site. These data were combined with periodic suspended-sediment data collected for the Colorado River at nearby streamflow-gaging stations to develop regression relations between sediment discharge and stream discharge. Using these relations with historical stream-discharge data, the mean annual-sediment discharge at the Una site was estimated. Using this information with particle-size data and the computed trap efficiency of the Una Reservoir, the sedimentation rate in the Una Reservoir was estimated.

Description of Study area

Physiography

The Colorado River upstream from De Beque drains an area of 7,370 mi^2. The river flows in a general southwest direction from Rocky Mountain National Park toward Grand Junction. Elevation within the basin ranges from 4,900 ft at the Una damsite to over 14,000 ft at several high mountain peaks. Elevation generally decreases east to west within the basin.

The eastern and southeastern parts of the drainage basin are dominated by high mountainous terrain incised by several major tributaries of the Colorado River. Canyons and mesas are prevalent in the western part of the basin.

The Una Reservoir site is located in a deep valley where local relief of 3,000 to 4,000 ft is common within a few miles of the river. The river valley is about 1 mi wide in the De Beque area, and it is bounded by high cliffs north of the river and by terrace deposits and hills south of the river. At the proposed damsite, the river valley is incised into older slopewash and terrace deposits and is about 0.5 mi wide.

Geology

The Una Reservoir site is located within the Piceance structural basin. The dam and reservoir would be underlain by recent river deposits and older terrace gravels that are underlain by the Wasatch Formation of Eocene age. Cliffs along the Colorado River valley in the De Beque area are formed in the Green River Formation of Eocene age, which is known for its large deposits of oil shale.

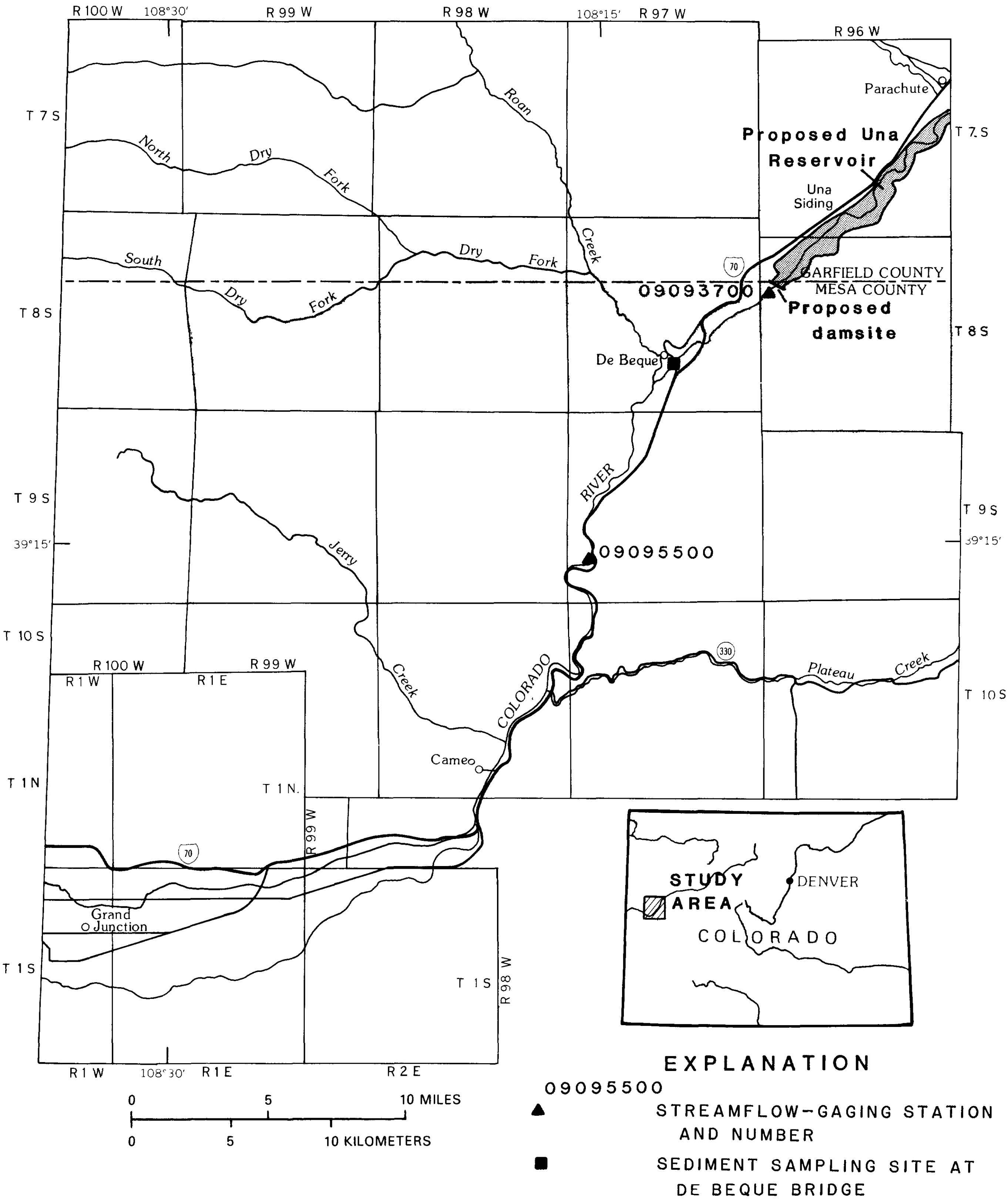


Figure 1.--Location of study site.

Land Use

Present-day land use in the Upper Colorado River Basin primarily is related to agriculture and recreation. Little urbanization has occurred within the Basin except for small areas near larger towns or near major recreation areas. The primary use of agricultural land is for rangeland. There are approximately 158,000 acres of irrigated land in the Upper Colorado River Basin upstream from De Beque (U.S. Geological Survey, 1985). Since the late 19th century, metal and coal mining were very active in parts of the Basin, but present-day mining activity is limited. Several large water-development projects have been constructed upstream of the damsite in the Upper Colorado River Basin since the 1930's.

STREAM DISCHARGE

Stream-discharge data for the Colorado River has been collected by the U.S. Geological Survey since October 1966 at a streamflow-gaging station located three miles upstream from De Beque (fig. 1). The gage (station 09093700, Colorado River near De Beque, hereinafter referred to as the De Beque gage) is located at the proposed damsite for the Una Reservoir. Mean daily discharge for the period October 1966 through September 1984 was 3,860 ft^3/s. Maximum discharge for the period of record was 38,200 ft^3/s on May 26, 1984. Minimum daily mean discharge at this station was 914 ft^3/s. A hydrograph of the monthly mean stream discharge for the period of record for the De Beque gage is shown in figure 2. Four very distinct years are shown in figure 2: the low-flow years of 1977 and 1981 and the high-flow years of 1983 and 1984. A plot of average monthly mean stream discharge for the 18-year period of record shows the seasonal distribution of streamflow for the Colorado River at the De Beque gage (fig. 3). Nearly 60 percent of the annual stream discharge occurs during May, June, and July.

An estimate of runoff from the Upper Colorado River Basin may be obtained by use of long-term stream-discharge records. Daily stream-discharge data have been collected for the Colorado River since October 1933 at streamflow-gaging station 09095500 (Colorado River near Cameo, hereinafter referred to as the Cameo gage) located about seven miles downstream from De Beque (fig. 1). The stream-discharge record for the De Beque gage could be extended 33 years by using the Cameo gaging station stream-discharge record. The De Beque gage stream-discharge record was considered suitable to use for future projections of stream discharge for the Colorado River because most of the water-storage and transmountain diversion projects in the Basin upstream from Be Beque were constructed prior to placement of the gage at De Beque. Therefore, the De Beque gage stream-discharge record should more accurately reflect changes in discharge caused by the diversions than the Cameo gage stream-discharge record, which contains data collected prior to construction of many of the diversions. During the 1983 water year, about 419,000 acre-ft of water were diverted out of the Upper Colorado River Basin, which is about 10 percent of the measured annual-stream discharge for 1983 at the De Beque gage.

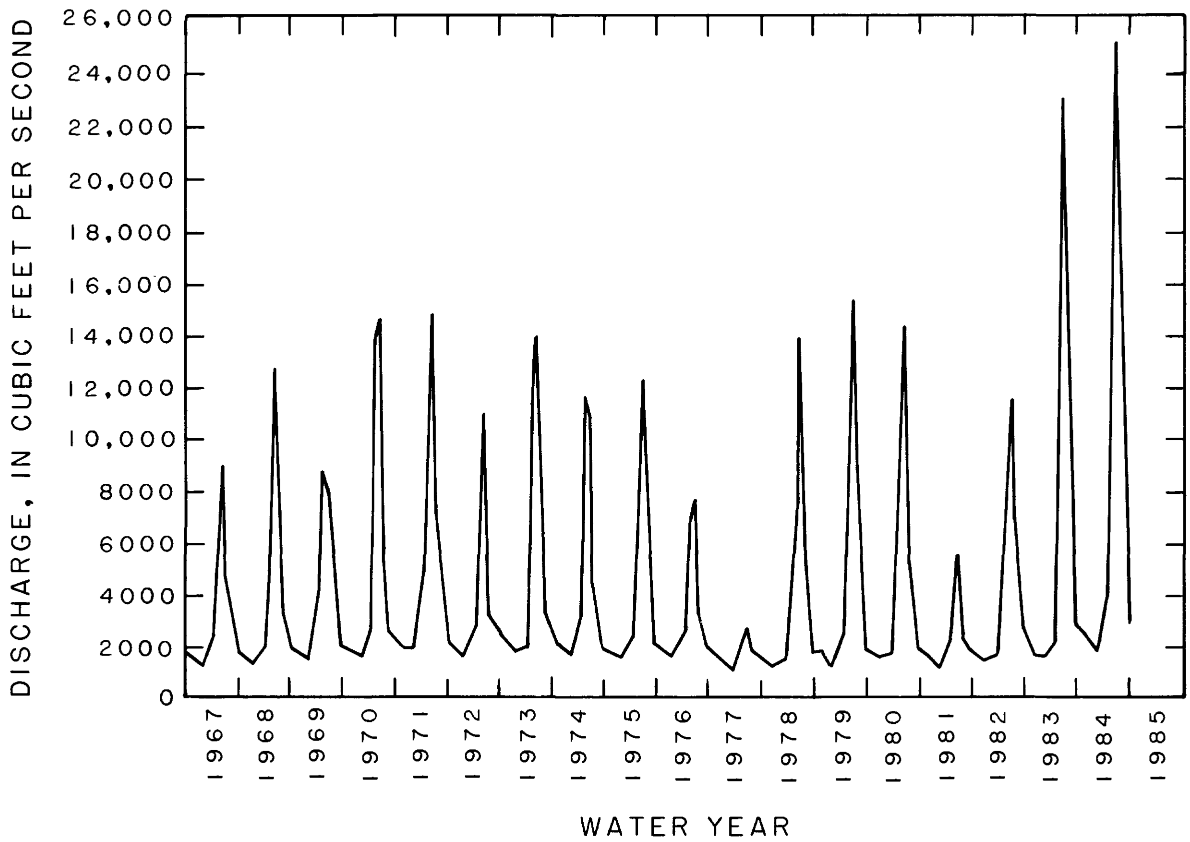


Figure 2.--Monthly mean discharge for streamflow-gaging station 09093700, Colorado River near De Beque, 1967-84 water years.

SEDIMENT DISCHARGE

Sediment particles transported in suspension in water by the turbulence of a stream comprise the suspended-sediment part of the total-sediment load. Suspended sediment is primarily fine material derived from streambanks and upstream areas of the watershed.

Bedload sediment consists of sediment particles transported on or near the streambed by rolling, sliding, or saltation. The primary distinction between bedload sediment and suspended sediment is that the weight of the bedload particles primarily is supported by the streambed, whereas the weight of the suspended-sediment particles primarily is supported by the water.

Suspended-Sediment Discharge

Eleven suspended-sediment samples were collected during 1984 for this study. Sediment sampling during 1984 was done from the county bridge at De Beque (fig. 1), hereinafter referred to as the De Beque bridge, located about 3 mi downstream from the De Beque gage. Sediment sampling was done at the De Beque bridge instead of the De Beque gage because the bedload-sampling

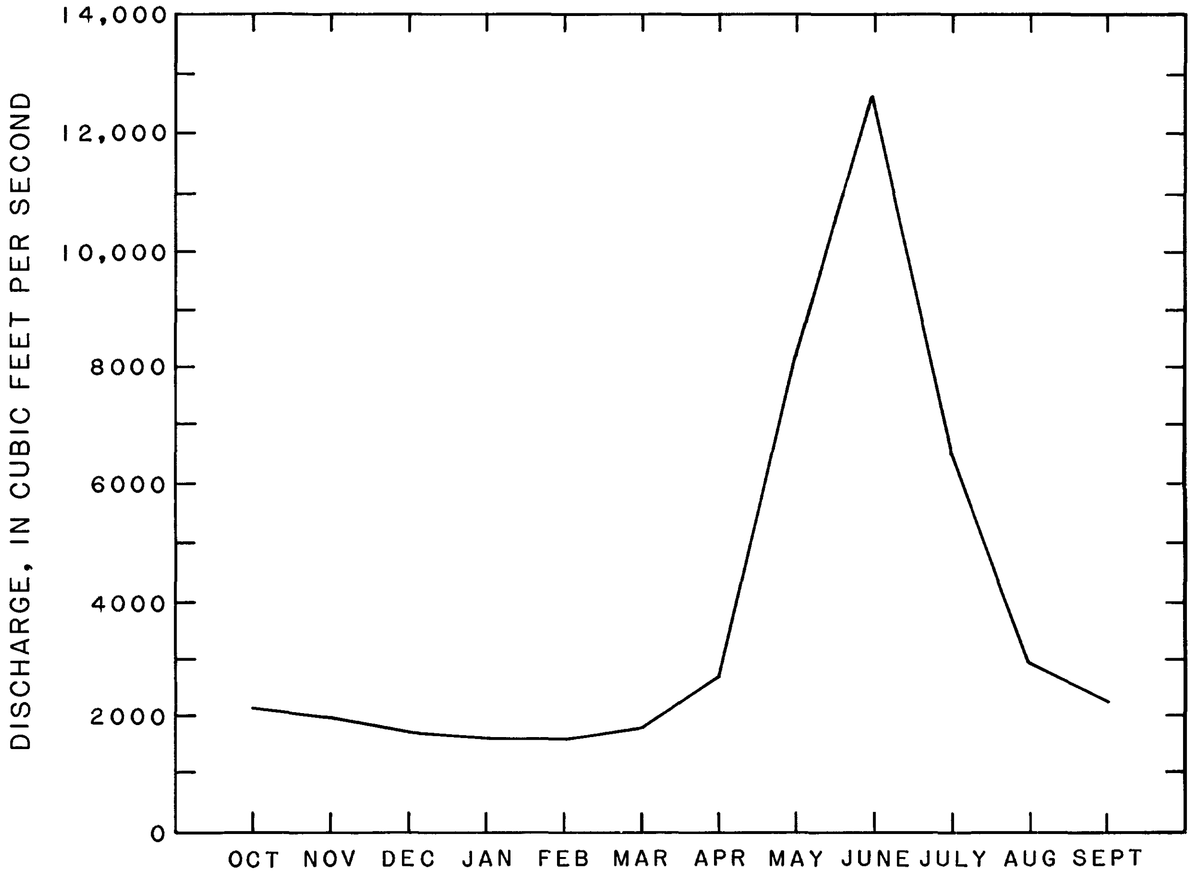


Figure 3.--Average monthly mean discharge for streamflow-gaging station 09093700, Colorado River near De Beque, 1967-84 water years.

equipment was too large and heavy to be used on the cable car at the gage. No tributary inflow into the Colorado River occurs between the De Beque gage and the De Beque bridge. Therefore, the sediment discharge at the bridge was assumed to be equal to the sediment discharge at the De Beque gage. Samples for suspended sediment were collected at 10-ft intervals across the river. Standard depth-integrating sampling techniques described by Guy and Norman (1970) were used at each sampling interval. The samples collected during each visit were composited at the sediment laboratory for determination of average concentration and particle-size distribution of the sediment. Stream-discharge measurements were made at the De Beque bridge in conjunction with sediment sampling. Standard stream-discharge measuring techniques described by Rantz and others (1982) were used.

Analysis of suspended-sediment data collected during 1984 at the De Beque bridge indicates that suspended-sediment concentration was not solely a function of stream discharge. A rapid increase in stream discharge occurred from May 8 to May 16 (U.S. Geological Survey, 1985). It was during that period that the maximum suspended-sediment concentration was measured--3,780 mg/L on May 15 (table 1). Concentrations of suspended sediment were smaller in three subsequent samples but remained greater than 1,000 mg/L until after the flood peak, which occurred on May 26 (U.S. Geological Survey, 1985). Concentrations of suspended sediment from samples collected after May 26 were less than 500 mg/L and were less than 200 mg/L by August.

Table 1.--*Suspended-sediment concentrations and sediment discharge data collected during 1984, Colorado River at De Beque bridge*

[--, dashes indicate no data]

Date	Stream discharge (cubic feet per second)	Suspended-sediment concentration (milligrams per liter)	Suspended-sediment discharge (tons per day)	Average bedload discharge (tons per day)	Total sediment discharge (tons per day)
4-24-84	4,490	204	2,470	46	2,520
5-15-84	22,800	3,780	233,000	501	234,000
5-18-84	26,100	1,310	92,300	1,300	93,600
5-23-84	28,900	1,040	81,200	1,240	82,400
5-25-84	34,400	1,380	128,000	1,170	129,000
5-31-84	31,500	449	38,200	432	38,600
6-12-84	20,400	415	24,500	28	24,500
6-22-84	25,400	293	20,100	--	--
7-11-84	20,000	290	15,700	--	--
7-24-84	9,470	153	3,910	1	3,910
8-28-84	6,290	98	1,660	27	1,690

The large suspended-sediment concentration measured on May 15 could have been caused by flushing of easily mobilized sediment and by stream-bank sloughing during the rapid increase in stream discharge during the second week of May. Decreasing concentrations after the flood peak probably were related to a gradual shift of snowmelt sources to the higher-elevation parts of the watershed during June. Although a secondary increase in stream discharge occurred during mid-June, suspended-sediment concentrations continued to decrease. Much of the higher-elevation areas within the Upper Colorado River Basin are composed of igneous and metamorphic rocks (Tweto, 1979), which generally are less erodible than the sedimentary rocks comprising the lower elevation areas. Therefore, snowmelt runoff from higher-elevation areas usually contains less suspended sediment.

Particle-size distribution of suspended sediment (table 2) also exhibited changes during the sampling period. Because sediment-particle size is often discussed in terms of the sand-silt-clay size fractions, the particle-size distributions in table 2 were converted to sand-silt-clay percentages, as shown in table 3. The shift in particle-size distribution shown in figure 4 is a plot of the silt plus clay-size fraction (percent of suspended sediment finer than 0.0625 mm) analyzed in samples collected at the De Beque bridge (table 3) and the Cameo gage (see table 6 in the "Supplemental Sediment Data" section at the end of this report) from late April through August. Samples collected prior to the flood peak (May 26) had more than 75 percent suspended sediment finer than 0.0625 mm; after the flood peak, this fraction decreased to 50 or 60 percent during June and July. During August, the percent suspended sediment finer than 0.0625 mm in the samples had increased to more than 70 percent.

Table 2.--*Particle-size distribution of suspended-sediment samples collected at De Beque bridge during 1984*

[--, dashes indicate no data]

Date	Percentage finer than indicated size (millimeters)							
	1.0	0.500	0.250	0.125	0.0625	0.016	0.004	0.002
4-24-84	100	100	95	92	86	58	31	28
5-15-84	100	100	97	92	82	55	31	22
5-18-84	100	100	94	88	79	53	30	24
5-23-84	100	100	96	88	75	45	23	18
5-25-84	100	100	95	88	78	51	29	24
5-31-84	100	100	93	84	71	42	21	14
6-12-84	100	100	93	81	62	37	21	13
6-22-84	100	99	88	75	59	36	20	13
7-11-84	100	100	92	75	59	33	21	14
[1]7-24-84	100	100	99	90	71	--	--	--
[1]8-28-84	100	99	96	88	78	--	--	--

[1]Insufficient amount of fine material in sample for analysis of sediment finer than 0.0625 millimeters.

Table 3.--*Particle-size distribution of suspended-sediment samples collected at De Beque bridge during 1984 grouped into sand-silt-clay percentages*

[Sand, particles 0.0625 millimeters (mm) or greater in diameter; silt, particles less than 0.0625 mm but greater than or equal to 0.004 mm in diameter; clay, particles less than 0.004 mm in diameter; --, dashes indicate no data; total percent may not equal 100 because of rounding]

Date	Percent sand	Percent silt	Percent clay
4-24-84	14	55	31
5-15-84	18	51	31
5-18-84	21	48	30
5-23-84	25	52	23
5-25-84	22	49	29
5-31-84	29	50	21
6-12-84	39	41	21
6-22-84	41	39	20
7-11-84	41	38	21
[1]7-24-84	29	--	--
[1]8-28-84	22	--	--

[1]Insufficient amount of fine material in sample for analyses of silt and clay particle sizes.

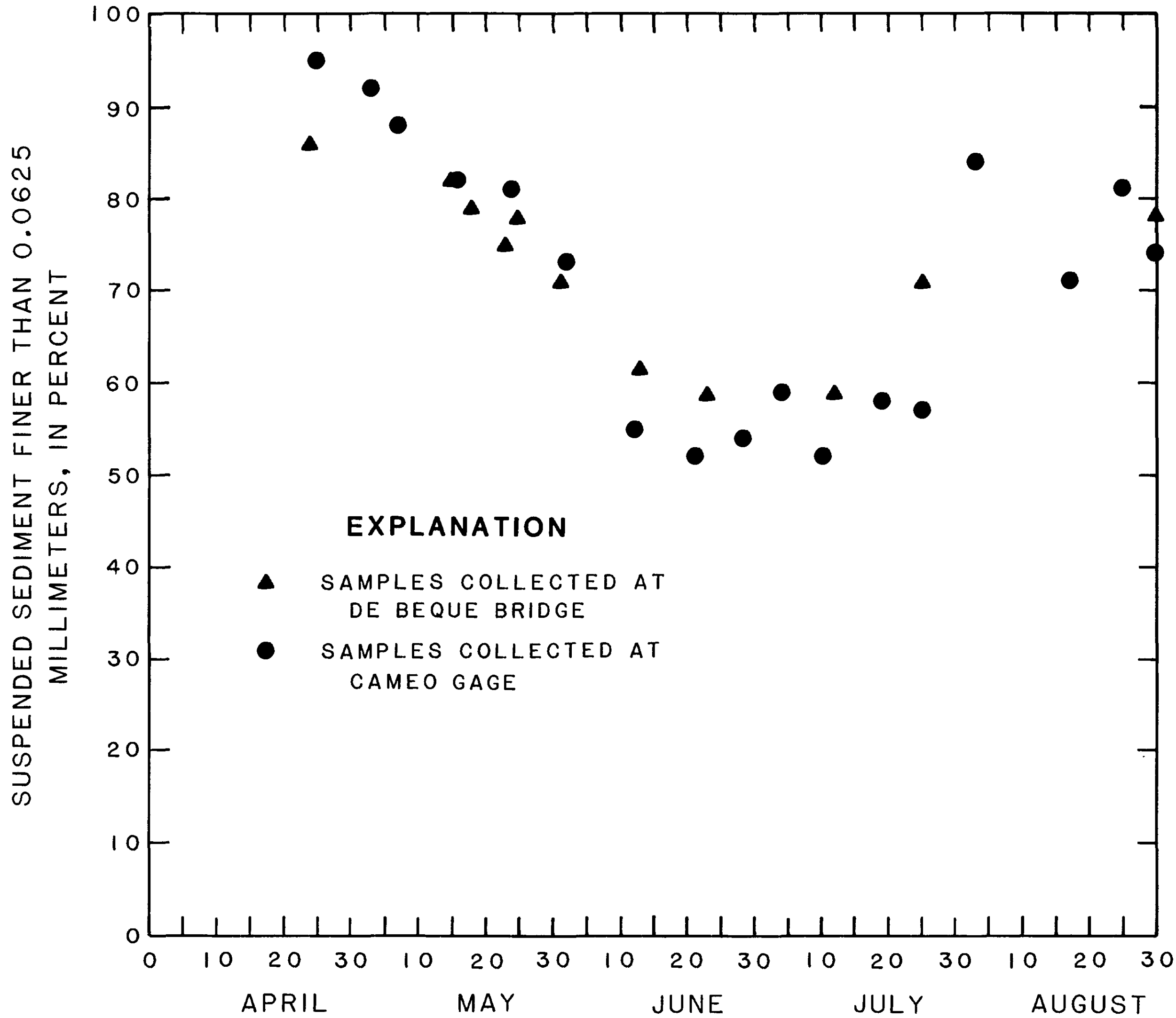


Figure 4.--Percentage of suspended-sediment material finer than 0.0625 millimeters in diameter in samples collected from Colorado River at De Beque bridge and at streamflow-gaging station 09095500, Colorado River near Cameo, April through August 1984.

Suspended-sediment samples were collected over a range of stream discharges to define the relation between sediment discharge and stream discharge. The suspended-sediment data base was expanded for the Una Reservoir site by including 53 periodic suspended-sediment samples collected at the De Beque gage from 1973 to 1982 (see table 7 in the "Supplemental Sediment Data" section located at the end of this report) with the data collected during 1984. These additional data helped define suspended-sediment stream-discharge relations and helped adjust the relation to account for the occasional large suspended-sediment concentrations in the Colorado River that result from summer and fall rainstorms.

A single suspended-sediment concentration stream-discharge relation may be difficult to define for a river draining a large, complex watershed such as the Colorado River. The plot of suspended-sediment concentration and stream discharge for all samples collected at the De Beque bridge and at the De Beque gage is shown in figure 5. The scattered nature of the plot shows a poor relation between suspended-sediment concentration and stream discharge.

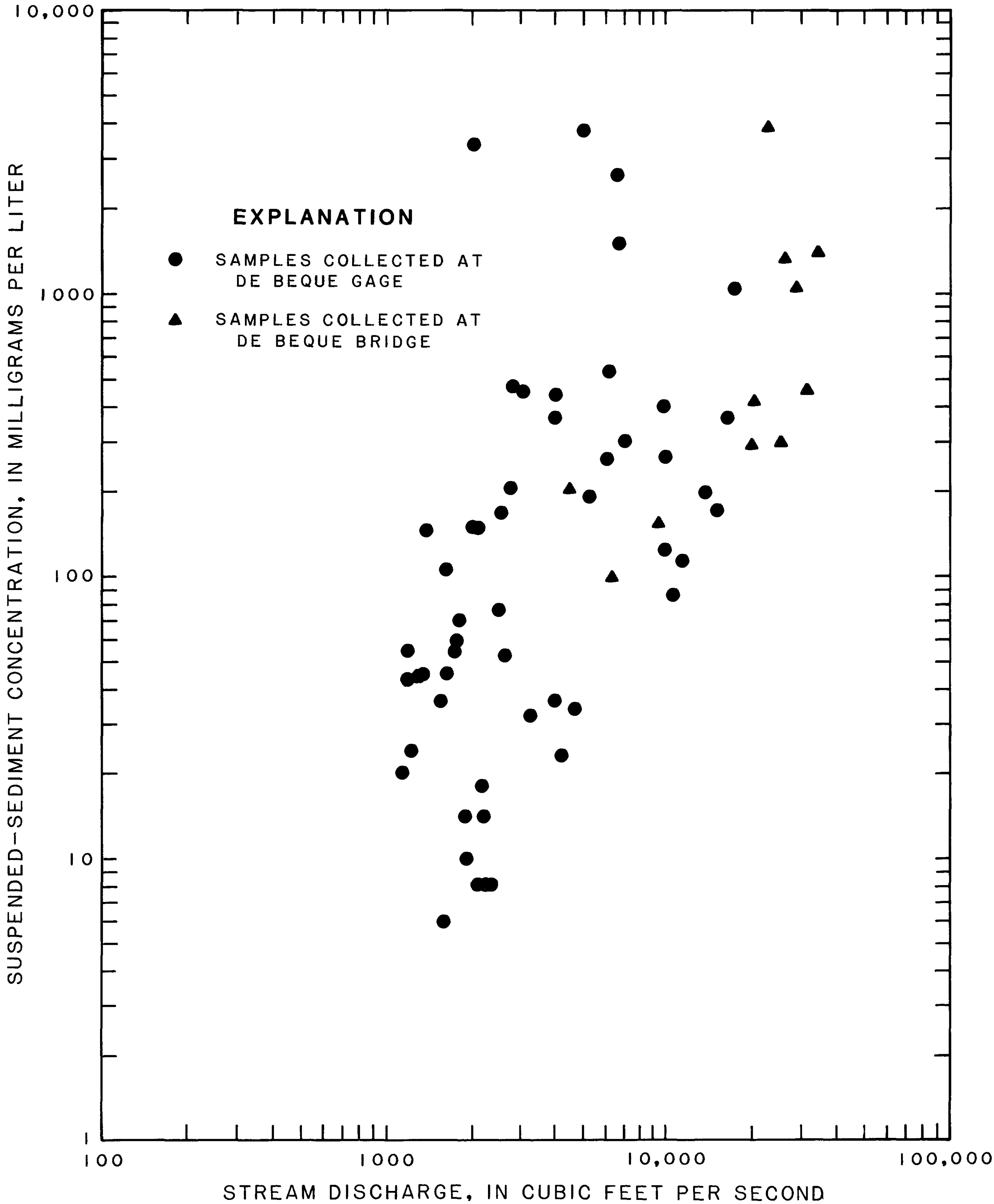


Figure 5.--Suspended-sediment concentration versus stream discharge for samples collected at De Beque bridge and at streamflow-gaging station 09093700, Colorado River near De Beque.

Suspended-sediment concentration is converted to sediment discharge by:

$$Q_s = 0.0027QC, \quad (1)$$

where

Q_s = suspended-sediment discharge, in tons per day;
0.0027 = conversion factor;
Q = stream discharge, in ft^3/s; and
C = suspended-sediment concentration, in mg/L.

A plot of the suspended-sediment discharge versus stream discharge is shown in figure 6. A comparison of figures 5 and 6 shows less scatter of data points in figure 6, which was expected because stream discharge is contained in both of the variables plotted. The relation of suspended-sediment discharge to stream discharge was used as a matter of convenience, because suspended-sediment discharge was the variable to be estimated. This relation often is approximately linear for the logarithm-transformed data, and results in an equation of the form:

$$\ln(Q_s) = a + b\,(\ln(Q)), \quad (2)$$

where

ln = natural logarithm;
a = regression intercept; and
b = regression slope.

A number of regression equations were examined to find the best relation or set of relations to define the suspended-sediment stream-discharge relation for the data. The best results were obtained when the data set was divided into two periods: March through October and November through February. The best statistical relations for the suspended-sediment data for the March through October period were obtained when the data were divided into two groups. All samples collected in the period prior to the date of the annual peak-stream discharge were grouped into the rising-stream-stage period; all samples collected in the period after the date of the annual peak-stream discharge were grouped into the falling-stream-stage period.

Because there was a paucity of suspended-sediment data available for the November through February period, the suspended-sediment stream-discharge relation for that period was determined using suspended-sediment data collected at the Cameo gage during the 1983-84 water years (see table 6 in the "Supplemental Sediment Data" section at the end of this report) and data collected at the De Beque gage from 1973 to 1982 (table 7, "Supplemental Sediment Data" section at the end of this report). Suspended-sediment concentrations in the Colorado River at the Cameo gage were considered equivalent to suspended-sediment concentrations at the De Beque gage only for the November through February period, because Roan Creek discharges into the Colorado River between the De Beque and Cameo gages. During November through February, Roan Creek usually has little affect on suspended-sediment discharge in the Colorado River; however, during spring runoff and during large rainstorms, Roan Creek can transport significant amounts of suspended sediment into the Colorado River. The best approximation of suspended-sediment discharge for the November through February period was developed from the mean

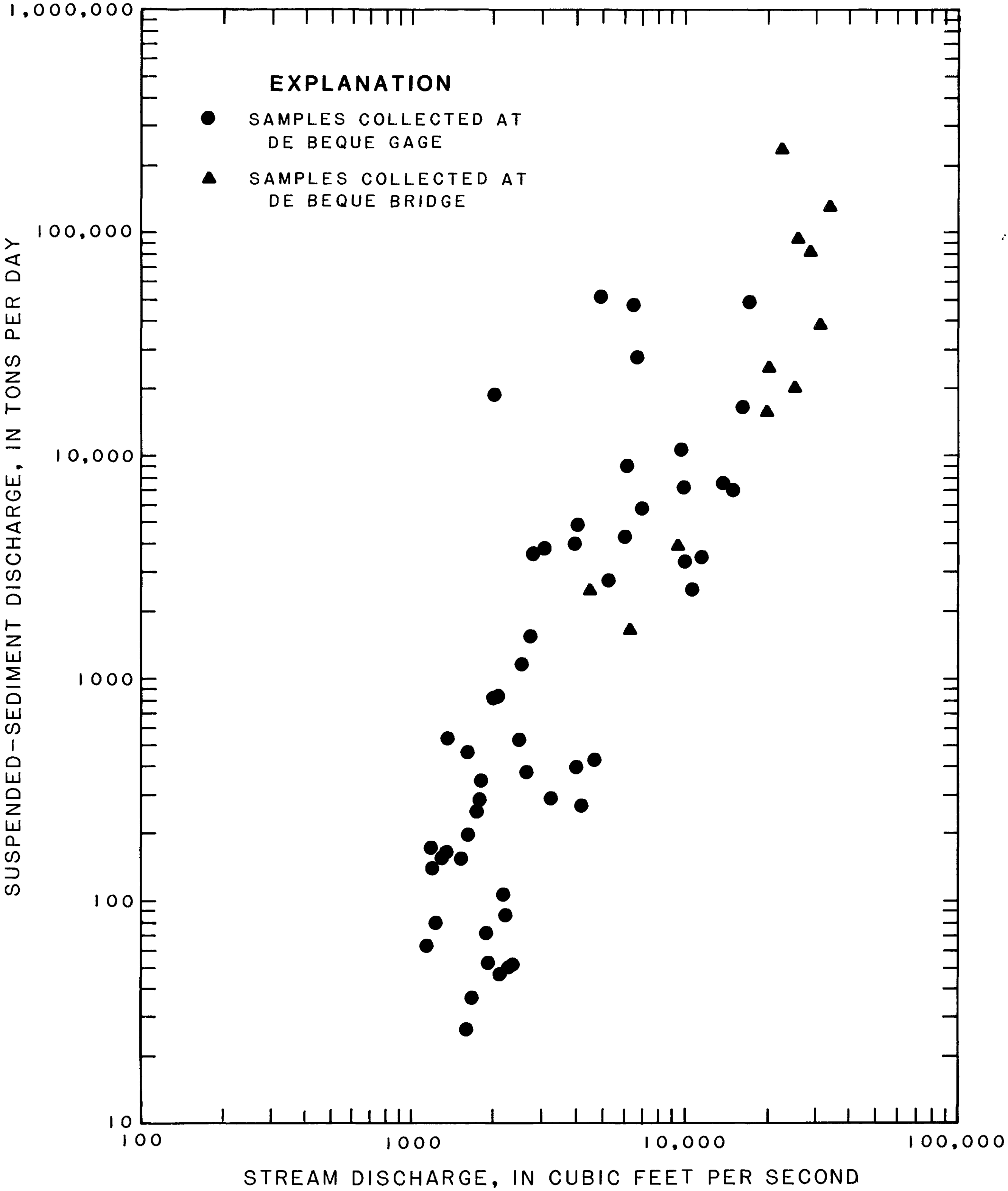


Figure 6.--Suspended-sediment discharge versus stream discharge for samples collected at De Beque bridge and at streamflow-gaging station 09093700, Colorado River near De Beque.

suspended-sediment concentration of all samples collected during that period at the two gages. The regression equation was computed from the suspended-sediment discharge values calculated using the mean suspended-sediment concentration and the instantaneous stream discharges at which the samples were collected. A summary of the suspended-sediment discharge regression equations is given in table 4; a plot of these equations is shown in figure 7.

Table 4.--*Summary of suspended-sediment and bedload-discharge regression equation results*

[n is number of data points; r^2 is coefficient of determination; se is standard error of estimate in logarithmic units; ln is natural logarithm; Q_s is suspended-sediment discharge, in tons per day; Q is stream discharge, in cubic feet per second; Q_B is bedload discharge, in tons per day; * denotes the relation is not significant at 0.01 probability]

Dependent variable	Statistical values for regression of dependent variable versus stream discharge			
	n	r^2	Regression equation	se
Suspended-sediment discharge, March through October, rising stage	28	0.85	$\ln(Q_s) = -8.50 + 1.96 \ln(Q)$	0.87
Suspended-sediment discharge, March through October, falling stage	26	0.71	$\ln(Q_s) = -10.05 + 2.00 \ln(Q)$	1.21
Suspended-sediment discharge, November through February	32	1.0	$\ln(Q_s) = -1.74 + \ln(Q)$	0.00
Bedload discharge, rising stage	5	0.96	$\ln(Q_B) = -10.36 + 1.69 \ln(Q)$	0.33
Bedload discharge, falling stage	3	0.51	$\ln(Q_B) = -8.99 + 1.37 \ln(Q)$*	1.57

Bedload Discharge

Bedload samples were collected in conjunction with suspended-sediment samples using Helley-Smith samplers and sampling techniques described by Emmett (1980). Bedload sampling was done at the same verticals as the suspended-sediment sampling. Bedload samples were collected to determine average bedload discharge (table 1) and particle-size distribution of bedload sediment (table 5). Two samples were not collected because of lost equipment.

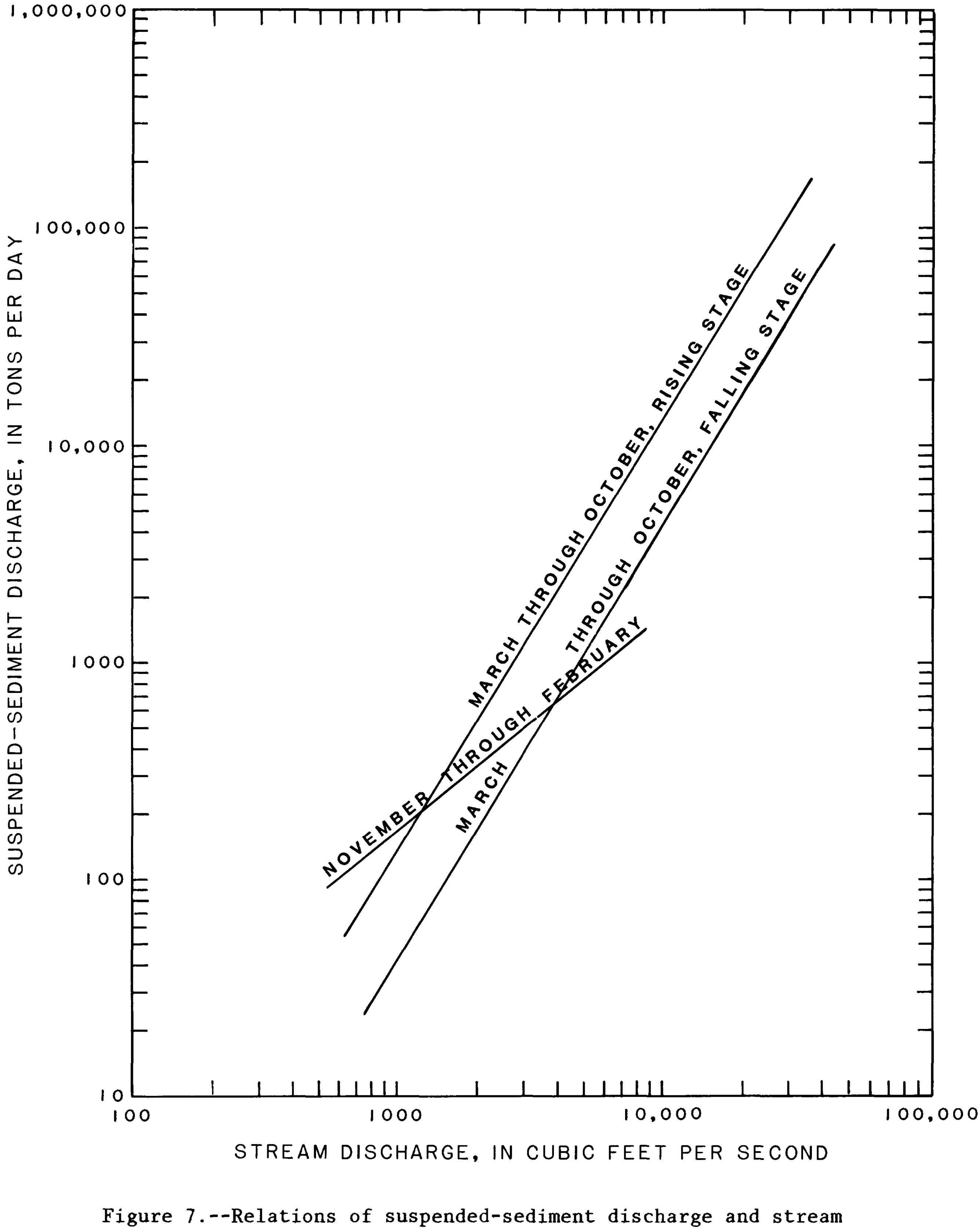


Figure 7.--Relations of suspended-sediment discharge and stream discharge, Colorado River at proposed site of Una Reservoir.

Table 5.--*Particle-size distribution of bedload samples collected during 1984, Colorado River at De Beque bridge*

[Composite of two traverses except where noted by *, indicating samples where one traverse was taken]

Date	Percentage finer than indicated size (millimeters)										
	64.0	32.0	16.0	8.0	4.0	2.0	1.0	0.500	0.250	0.125	0.0625
4-24-84*	100	87	86	77	66	56	46	26	2	0	0
5-15-84	100	94	91	89	86	83	77	54	9	3	1
5-18-84	100	86	71	62	55	48	40	24	2	1	0
5-23-84	100	76	62	54	49	45	38	22	2	1	0
5-25-84*	97	79	64	57	51	46	41	25	2	0	0
5-31-84	44	30	24	21	19	18	17	14	4	1	0
6-12-84	100	95	93	81	75	70	66	58	23	4	1
6-22-84	NO SAMPLE COLLECTED										
7-11-84	NO SAMPLE COLLECTED										
7-24-84*	100	100	100	90	81	76	69	56	2	0	0
8-28-84*	100	100	99	88	80	75	68	44	3	1	0

During the 1984 sampling period, samples containing the largest amount of bedload sediment were collected during May, prior to the peak discharge on May 26. Maximum measured bedload discharge was 1,300 tons per day on May 18. Apparently, bedload discharge decreased rapidly after the peak stream discharge on May 26. Bedload discharge was two-thirds less on May 31, 5 days after the peak discharge, than on May 25, the day before the peak discharge. Stream discharge was only 8 percent less on May 31 than on May 25. The best relations between bedload discharge and stream discharge were obtained when the samples were separated into two periods relative to the peak discharge on May 26: (1) The rising-stream-stage period, and (2) the falling-stream-stage period. Regression equation results are given in table 4 and are plotted in figure 8.

Bedload movement was variable in the stream cross section at the De Beque bridge. Much of the bedload sample collected during the period of greatest bedload discharge in May came from a few sections in mid-channel downstream from an island. Size distribution of bedload also was quite variable (table 5). Much of the bedload sampled was composed of sediment particles less than 16 mm in diameter. Larger size classes (16 mm and greater) were collected during the larger stream discharge period in late May. Material greater than 16 mm accounted for about 75 percent of the bedload sample collected on May 31. Emmett (1980) found that the Helley-Smith bedload sampler has decreased efficiencies for particles greater than 16 mm in size because of the paucity of large particles moving as bedload.

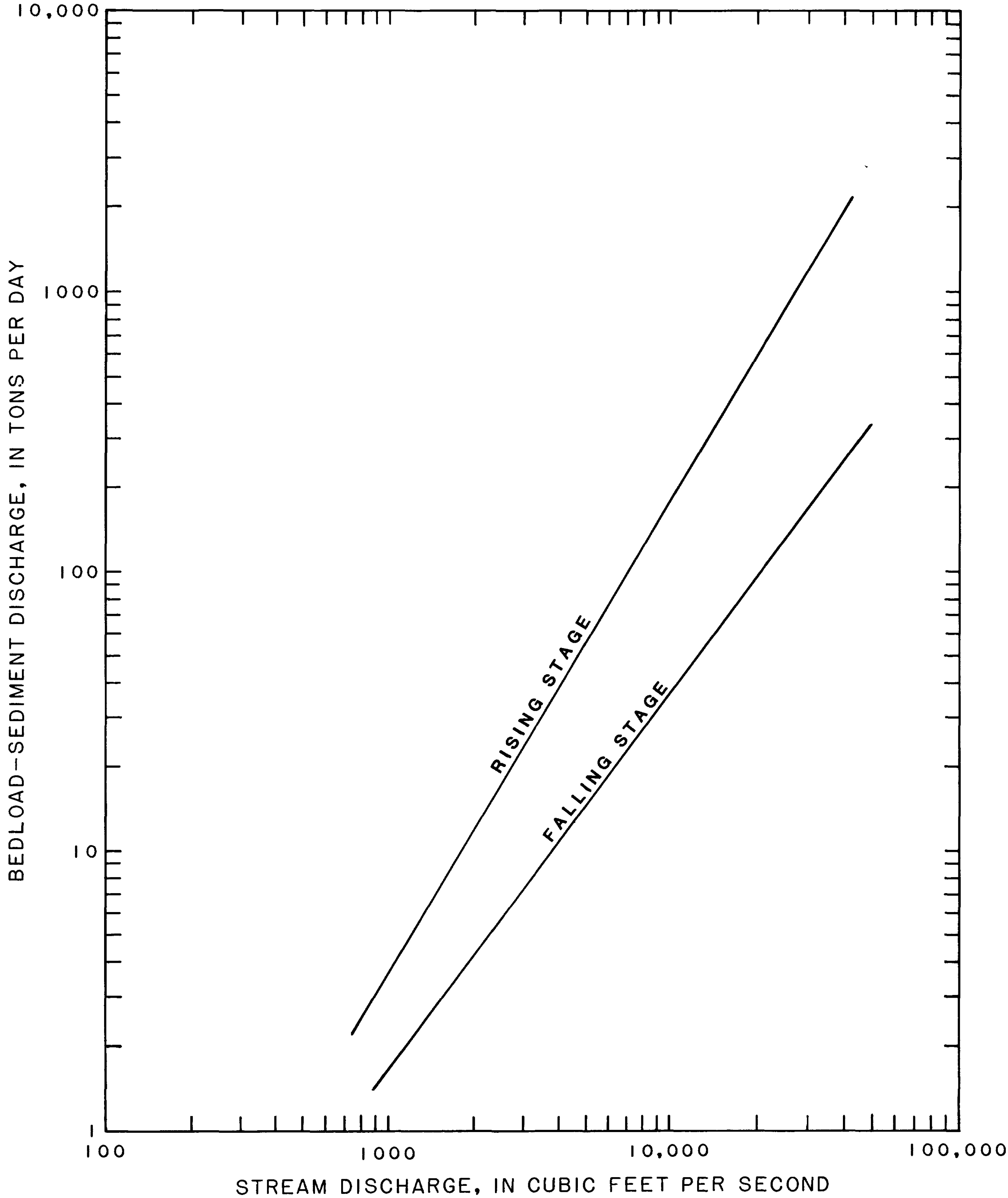


Figure 8.--Relations of bedload-sediment discharge and stream discharge, Colorado River at proposed site of Una Reservoir.

Total-Sediment Discharge

Total-sediment discharge was estimated by adding measured suspended-sediment discharge to bedload discharge (table 2). Suspended sediment accounted for more than 98 percent of the total-sediment discharge for the nine complete sediment samples collected at the De Beque bridge during 1984 (fig. 9).

Adding measured suspended-sediment discharge and bedload discharge obtained with a Helley-Smith bedload sampler may produce an erroneous estimate of total-sediment discharge. Equipment used to collect suspended-sediment samples does not sample the bottom 0.3 ft of the stream. The suspended-sediment discharge is calculated by multiplying the entire stream discharge by the suspended-sediment concentration; therefore, the part of suspended sediment in the bottom 0.3 ft of flow is included in measured suspended-sediment discharge. The Helley-Smith bedload sampler will trap suspended material coarser than 0.25 mm in the bottom 0.3 ft. Hence, part of the suspended-sediment discharge is accounted for in both suspended-sediment discharge and bedload discharge. However, the amount of suspended sediment trapped by the Helley-Smith sampler in the bottom 0.3 ft was an insignificant part of the total-sediment discharge because the trapped suspended sediment probably was a small part of the bedload discharge, which in turn accounted for only 2 percent of the total sediment discharge. Corrections can be made in suspended-sediment discharge calculations to remove the bottom 0.3 ft of flow from suspended-sediment discharge. For most samples, the correction factor would be greater than 0.95. Therefore, the errors produced by direct addition of suspended-sediment discharge and bedload discharge would not significantly affect estimates of total-sediment discharge.

Annual-Sediment Discharge

Mean annual-sediment discharge for the Una Reservoir site was calculated from the stream-discharge record for the De Beque gage and the sediment-discharge relations developed for this study. A computer program was developed (J.E. Kircher, U.S. Geological Survey, written commun., 1984) to calculate daily-sediment discharge from the appropriate regression equation, using the mean daily-discharge values from the stream-discharge record. The program used regression equations based on periods of the year and also used separate equations for rising and falling stream stages for the runoff period. To apply the correct equation to each day in the runoff period, the program determined the date of the annual-peak discharge for each water year. The sum of daily sediment-discharge values was the annual-sediment discharge for each water year. When all annual totals were calculated, a mean annual-sediment discharge was calculated for the period of stream-discharge record.

Using the relations for suspended-sediment discharge in table 5, a mean annual suspended-sediment discharge of 1,044,000 tons per year was calculated for the Una Reservoir site for the 1967-84 water years. Based on the data collected in 1984, the suspended sediment was assumed to account for 98 percent of the total-sediment discharge. Hence, total-sediment discharge equalled suspended-sediment discharge divided by 0.98, or multiplied by 1.02. Multiplying the calculated mean annual suspended-sediment discharge by 1.02

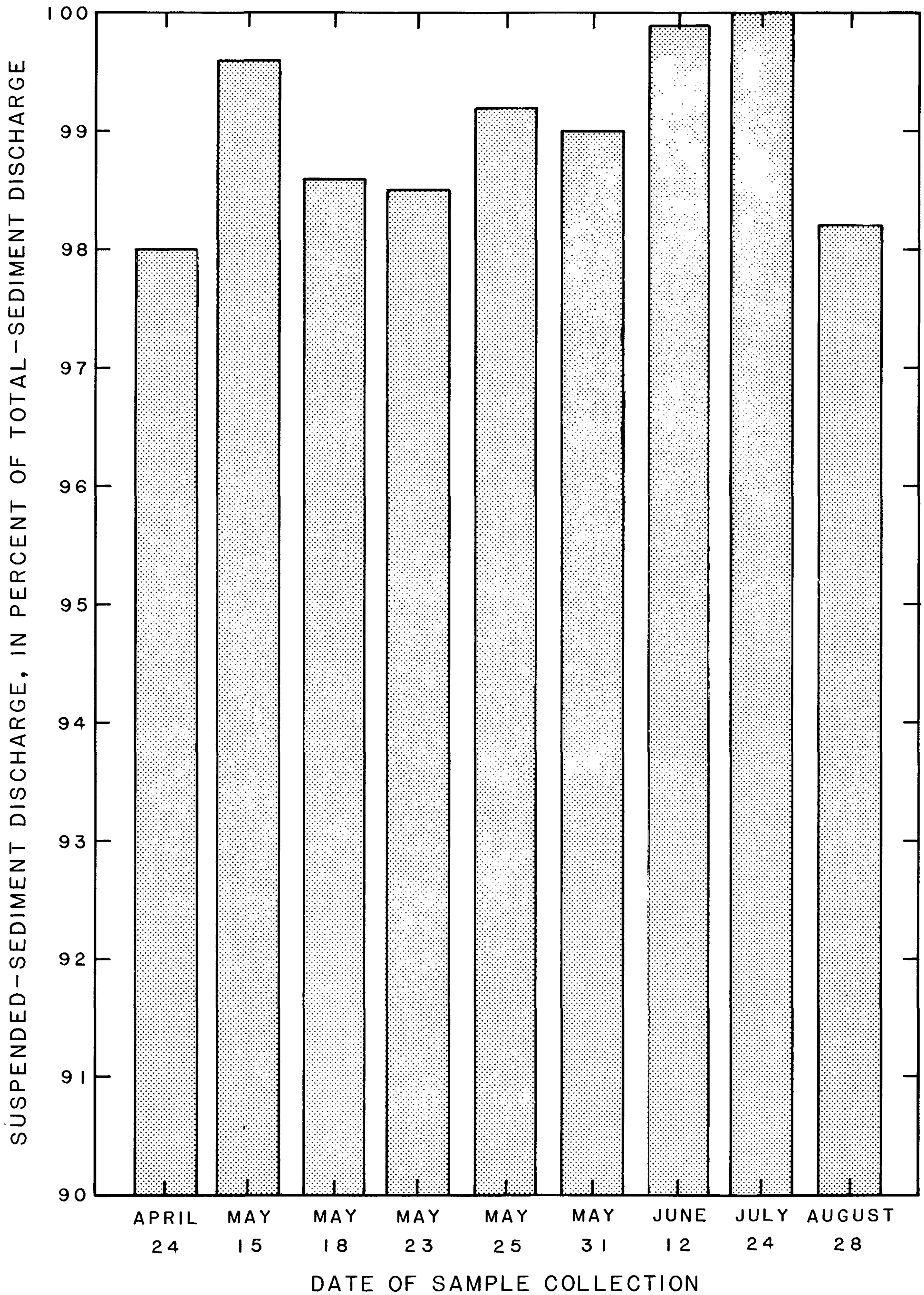


Figure 9.--Relative proportion of suspended sediment in sediment samples collected at the De Beque bridge during 1984.

resulted in a mean annual-sediment discharge of 1,065,000 tons per year. The 95-percent confidence interval for mean annual-sediment discharge was 575,000 to 1,470,000 tons per year.

SEDIMENTATION EFFECTS AT UNA RESERVOIR SITE

Factors that affect sediment deposition in a reservoir include sediment-inflow rate, particle size of incoming sediments, trap efficiency of the reservoir, specific weight of deposited sediments, and distribution of sediment in the reservoir. If operational plans and dimensions of the proposed reservoir are known, and if information on sediment discharge and particle-size distribution can be obtained, then changes in reservoir capacity caused by sediment deposition can be estimated.

Trap efficiency, the percentage of incoming sediments that remain in the reservoir, depends on reservoir size and stream discharge into the reservoir. An initial trap efficency of 95 percent was calculated using the Churchill method (Vanoni, 1975) for the Una Reservoir. Reservoir dimensions of 196,000 acre-ft capacity and 9.7 mi length (Beck and Associates, 1982) were used for the computations. A trap efficiency of 100 percent is often assumed for reservoirs the size of the proposed Una Reservoir (Vanoni, 1975).

Specific weight of sediment was used to convert sediment inflow to the volume that deposits will occupy in the reservoir. An initial specific weight of sediment was calculated using a method based on size distribution of incoming sediment and on a reservoir classification scheme (Strand, 1974). Combining sediment-size data collected during 1984 (table 3) with additional sand-silt-clay-size analyses for samples collected at the De Beque and Cameo gages, a size distribution of 25 percent clay, 47 percent silt, and 28 percent sand was determined and used to calculate an initial specific weight of 67 lb/ft^3.

Because the specific weight of the deposits will increase as compaction occurs, an average specific weight was estimated over various periods in time. The approximation of the integral to estimate average specific weight is (Strand, 1974):

$$W_t = W_i + .4343K \left(\frac{T}{T-1} \ln(T) - 1 \right), \qquad (3)$$

where

W_T = average specific weight of sediment deposits after T years, in lb/ft^3;

W_i = initial specific weight of sediment deposits, in lb/ft^3;

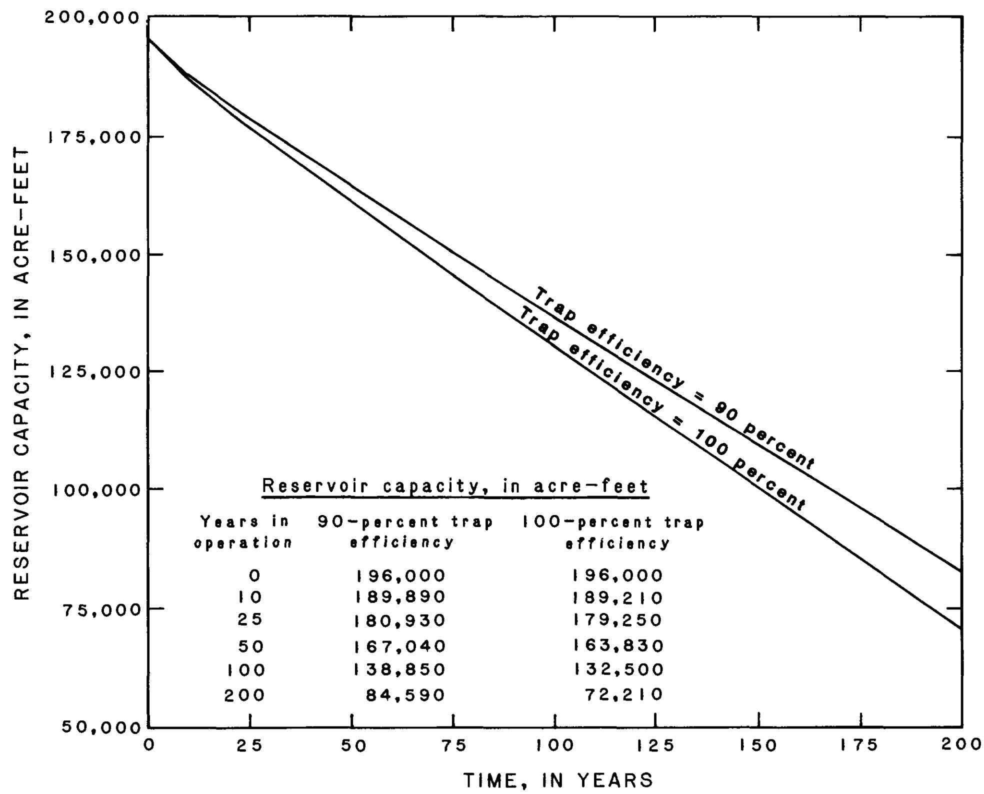
K = coefficient calculated from size distribution of incoming sediments and the reservoir type; and

ln = natural logarithm.

The average specific weight of the deposits would increase to 73 lb/ft^3 after 25 years and to 77 lb/ft^3 after 100 years.

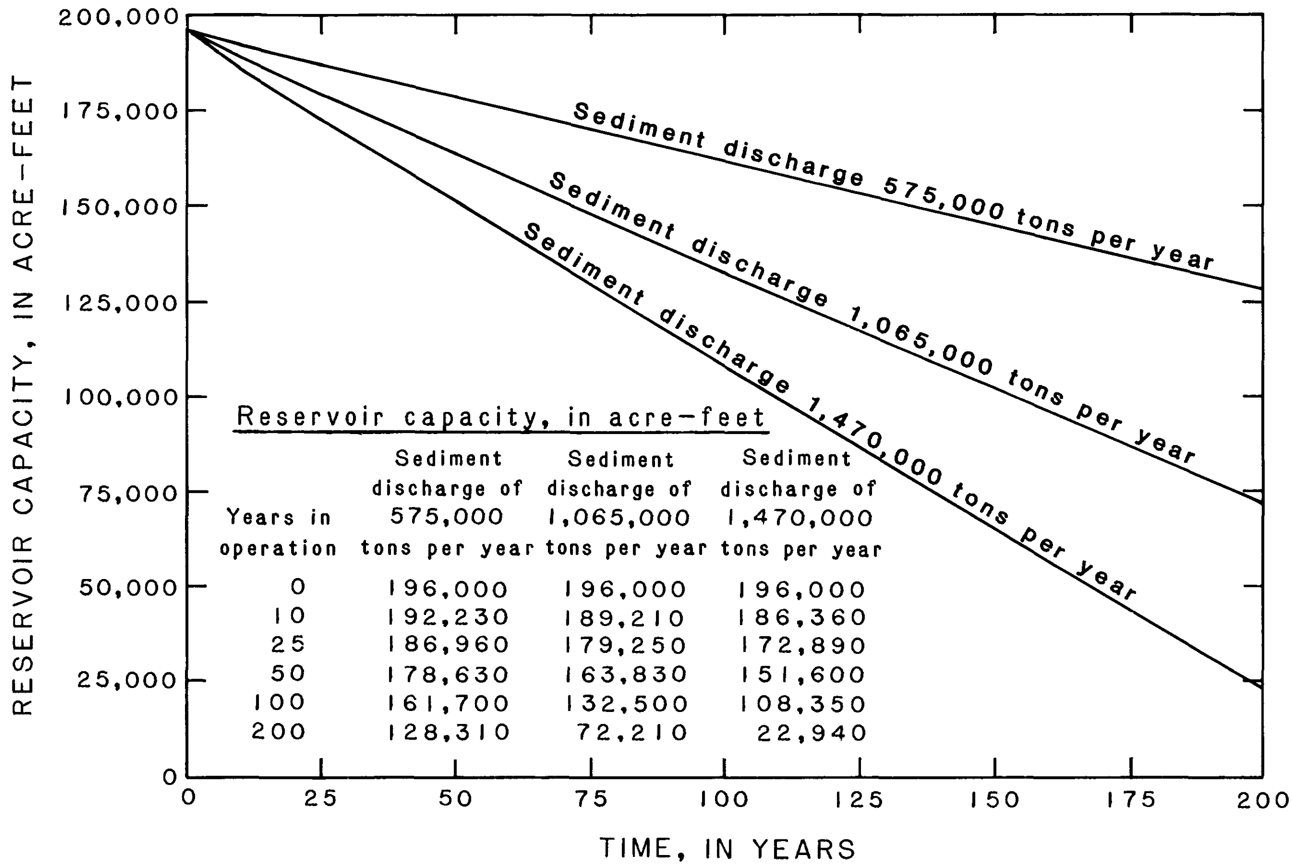
Weight of sediment deposits (in tons) was estimated for a period of interest by multiplying mean annual-sediment discharge (1,065,000 tons per year) times the number of years and the trap efficiency. Converting that value to pounds and dividing by the average specific weight of deposits results in the volume the deposits will occupy, in cubic feet. After converting the volume to acre-feet, the capacity of the reservoir after a certain period of sediment deposition was calculated.

Estimated capacities of the Una Reservoir for several time periods are given in figure 10. Trap efficiencies of 90 percent and 100 percent were used, because computation of future trap efficiency at reduced reservoir capacities showed that the trap efficiency of the reservoir would remain greater than 90 percent for at least 100 years. Sediment deposition would cause about a 30-percent reduction in capacity of the Una Reservoir after 100 years. Using the 95-percent confidence interval of the mean annual-sediment discharge (575,000 to 1,470,000 tons per year), error estimates were computed for the reservoir capacities shown in figure 10. For example, the change in reservoir capacity assuming 100-percent trap efficiency based on the 95-percent confidence interval of sediment discharge is compared to the change in reservoir capacity using the mean annual-sediment discharge (1,065,000 tons per year) in figure 11. After 100 years, sediment discharge of 575,000 tons per year would cause about a 17-percent decrease in capacity of the Una Reservoir; sediment discharge of 1,470,000 tons per year would cause about a 45-percent decrease in capacity of the reservoir.



Years in operation	90-percent trap efficiency	100-percent trap efficiency
0	196,000	196,000
10	189,890	189,210
25	180,930	179,250
50	167,040	163,830
100	138,850	132,500
200	84,590	72,210

Figure 10.--Capacity of proposed Una Reservoir based on projected sediment discharge of the Colorado River.



Years in operation	Sediment discharge of 575,000 tons per year	Sediment discharge of 1,065,000 tons per year	Sediment discharge of 1,470,000 tons per year
0	196,000	196,000	196,000
10	192,230	189,210	186,360
25	186,960	179,250	172,890
50	178,630	163,830	151,600
100	161,700	132,500	108,350
200	128,310	72,210	22,940

Figure 11.--Capacity of the proposed Una Reservoir for 100-percent trap efficiency based on the 95-percent confidence interval of the projected sediment discharge of the Colorado River.

The sedimentation rate in the proposed Una Reservoir determined for this study was dependent on several assumptions and factors affecting sediment discharge. One assumption was that 18 years of stream-discharge data for the De Beque gage were reasonably adequate for predicting future stream discharge at the Una Reservoir. However, man-induced or climatic changes in stream discharge could change the amount of sediment transported by the Colorado River. Another assumption was that the sediment-discharge stream-discharge relations, which were developed from periodic-sediment samples collected at three locations during an 11-year period, gave reasonable estimates of sediment discharge at the proposed reservoir site. Temporal shifts in the sediment-discharge relations were not determined. Significant changes in sediment discharge in the Colorado River upstream from the proposed Una Reservoir could cause large changes in sedimentation rate in the reservoir. Construction of upstream reservoirs, particularly on the mainstem of the Colorado River, could reduce sediment discharge at the proposed site of the Una Reservoir by trapping sediment in the upper reservoirs. Changes in land-use practices or the operation of new industrial or construction projects could affect sediment yield in parts of the upstream watershed and correspondingly affect sediment discharge at the Una Reservoir site.

SUMMARY

Sediment and stream-discharge data collected at streamflow gaging stations on the Colorado River near De Beque and Cameo, and at a bridge at De Beque, were used to determine total-sediment discharge in the Colorado River. Mean annual-sediment discharge developed from these data aided in determining the sedimentation rate in a proposed reservoir on the Colorado River at Una, which is 3 mi upstream from De Beque.

Eleven suspended-sediment samples were collected at the De Beque bridge during 1984. These data were combined with sediment data collected at the gaging stations to establish regression equations defining suspended-sediment discharge. Best results were obtained when the data were separated into two periods, March through October and November through February. The data for March through October were further divided into two periods: (1) Rising stream-stage period, which includes data collected prior to the date of the annual peak-stream discharge, and (2) falling stream-stage period, which includes data collected after the date of the annual peak-stream discharge. Nine bedload samples also were collected; results indicate that bedload accounts for a very small part of the total-sediment discharge at the proposed site of the Una Reservoir.

Using suspended-sediment relations and 18 years of stream-discharge data, mean annual suspended-sediment discharge was computed at 1,044,000 tons per year for the Colorado River at the proposed site of the Una Reservoir for 1967-84 water years. Because suspended sediment comprised at least 98 percent of the total-sediment load, mean annual total-sediment discharge was set equal to the suspended-sediment discharge times 1.02, which resulted in a total-sediment discharge of 1,065,000 tons per year.

Sedimentation effects on the proposed Una Reservoir were computed using total-sediment discharge, particle-size, and trap-efficiency data of the reservoir. The capacity of the Una Reservoir would decrease approximately 30 percent after 100 years because of sediment deposition. Sediment discharge into the reservoir could be affected by changes in: (1) Stream discharge at the Una site, (2) the sediment-discharge stream-discharge relation, and(or) (3) sediment yield in the watershed upstream from the Una site.

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SUPPLEMENTAL SEDIMENT DATA

Table 6.--*Suspended-sediment data collected from October 1982 through September 1984 at streamflow-gaging station 09095500, Colorado River near Cameo*

[--, dashes indicate no data]

Date of sample	Stream discharge (cubic feet per second)	Suspended-sediment concentration (milligrams per liter)	Suspended-sediment discharge (tons per day)	Suspended sediment (percent finer than 0.0625 millimeters)
10-04-82	3,000	50	405	60
10-11-82	2,600	81	569	--
10-13-82	2,740	19	141	--
10-18-82	2,760	15	112	--
10-28-82	2,910	356	2,800	76
11-04-82	2,310	29	181	--
11-17-82	2,440	16	105	--
11-24-82	2,110	26	148	--
12-03-82	2,040	22	121	--
12-10-82	1,990	13	70	--
12-17-82	2,010	24	130	--
12-20-82	1,700	32	147	--
01-24-83	1,600	68	294	--
02-03-83	1,570	71	301	--
02-11-83	1,700	138	633	--
02-18-83	1,670	78	352	--
02-25-83	1,800	226	1,100	--
03-02-83	1,880	462	2,350	--
03-09-83	1,630	109	480	--
03-18-83	2,030	217	1,190	--
03-23-83	1,700	82	376	--
04-01-83	1,910	164	846	--
04-06-83	1,640	62	275	--
04-15-83	1,680	40	181	--

Table 6.--*Suspended-sediment data collected from October 1982 through September 1984 at streamflow-gaging station 09095500, Colorado River near Cameo*--Continued

Date of sample	Stream discharge (cubic feet per second)	Suspended-sediment concentration (milligrams per liter)	Suspended-sediment discharge (tons per day)	Suspended sediment (percent finer than 0.0625 millimeters)
04-22-83	2,370	348	2,230	--
04-28-83	3,810	839	8,630	76
05-06-83	4,260	1,190	13,700	80
05-13-83	7,740	2,240	46,800	80
05-20-83	5,990	1,840	29,800	86
05-27-83	16,700	5,670	256,000	79
06-03-83	20,200	1,700	92,700	73
06-10-83	19,700	835	44,400	65
06-13-83	23,900	753	48,600	--
06-21-83	27,600	743	55,400	--
07-01-83	25,000	442	29,800	--
07-08-83	20,400	337	18,600	--
07-15-83	16,400	304	13,500	--
07-21-83	10,900	268	7,890	--
07-29-83	8,990	227	5,510	--
08-04-83	8,760	290	6,860	--
08-12-83	6,010	1,020	16,600	81
08-19-83	5,810	675	10,600	--
08-26-83	4,440	101	1,210	--
09-02-83	3,660	33	326	--
09-09-83	3,110	32	269	--
09-14-83	2,740	24	178	--
09-22-83	2,200	14	83	--
09-28-83	2,290	29	179	--

Table 6.--*Suspended-sediment data collected from October 1982 through September 1984 at streamflow-gaging station 09095500, Colorado River near Cameo*--Continued

Date of sample	Stream discharge (cubic feet per second)	Suspended-sediment concentration (milligrams per liter)	Suspended-sediment discharge (tons per day)	Suspended sediment (percent finer than 0.0625 millimeters)
10-04-83	2,440	102	671	--
10-14-83	2,620	3,880	27,500	--
10-21-83	2,680	47	340	--
10-26-83	2,590	36	252	--
11-04-83	2,590	26	182	--
11-10-83	2,520	101	687	--
11-17-83	2,580	64	446	--
11-23-83	2,370	31	198	--
12-01-83	2,420	22	144	--
12-09-83	2,560	31	214	--
12-15-83	2,130	29	167	--
12-20-83	2,480	28	194	--
01-06-84	2,580	182	1,270	--
02-15-84	2,400	490	3,170	--
02-24-84	2,130	30	173	--
03-08-84	2,420	104	680	--
04-06-84	3,730	243	2,450	--
04-11-84	4,010	408	4,420	--
04-20-84	5,200	903	12,700	--
04-25-84	5,580	1,030	15,500	95
05-03-84	4,990	1,540	20,700	92
05-07-84	5,460	980	14,500	88
05-16-84	27,300	4,210	310,000	82
05-24-84	32,000	1,320	114,000	81

Table 6.--*Suspended-sediment data collected from October 1982 through September 1984 at streamflow-gaging station 09095500, Colorado River near Cameo*--Continued

Date of sample	Stream discharge (cubic feet per second)	Suspended-sediment concentration (milligrams per liter)	Suspended-sediment discharge (tons per day)	Suspended sediment (percent finer than 0.0625 millimeters)
06-01-84	30,600	574	47,400	73
06-06-84	26,400	486	34,600	--
06-11-84	20,000	859	46,400	55
06-20-84	25,800	471	32,800	52
06-27-84	23,900	317	20,500	54
07-03-84	23,600	282	18,000	59
07-09-84	17,300	331	15,500	52
07-18-84	12,800	243	8,400	58
07-24-84	9,740	205	5,390	57
08-01-84	9,490	498	12,800	84
08-09-84	6,560	175	3,100	78
08-15-84	5,690	168	2,580	71
08-23-84	6,300	206	3,500	81
08-28-84	6,160	132	2,200	74
09-06-84	4,860	69	905	84
09-12-84	4,200	37	420	81
09-19-84	3,800	55	564	83
09-26-84	3,360	124	1,120	89

Table 7.--*Suspended-sediment data collected from 1973-82 at streamflow-gaging station 09093700, Colorado River near De Beque*
[--, dashes indicate no data]

Date of sample	Stream discharge (cubic feet per second)	Suspended-sediment concentration (milligrams per liter)	Suspended-sediment discharge (tons per day)
02-10-73	2,270	8	49
11-21-73	2,110	8	46
03-21-74	2,540	166	1,140
05-03-74	7,040	298	5,660
05-24-74	10,000	121	3,270
06-07-74	10,700	85	2,460
07-09-74	4,020	36	391
07-25-74	4,990	3,710	50,000
08-22-74	2,180	18	106
03-31-75	1,550	36	151
05-16-75	6,750	1,480	27,000
07-03-75	13,900	196	7,360
12-22-76	1,300	44	154
03-17-77	1,140	20	62
04-13-77	2,000	148	799
12-06-77	1,350	45	164
01-23-78	1,190	43	138
03-17-78	1,370	143	529
04-18-78	2,820	468	3,560
05-30-78	9,830	394	10,500
06-12-78	17,400	1,020	47,900
07-26-78	3,290	32	284
08-28-78	1,760	59	280
10-10-78	1,590	6	26
11-20-78	1,600	6	26
04-26-79	4,000	363	3,920
07-26-79	5,290	190	2,710
08-21-79	3,090	448	3,740
11-13-79	1,910	10	52
12-11-79	1,880	14	71

Table 7.--*Suspended-sediment data collected from 1973-82 at streamflow-gaging station 09093700, Colorado River near De Beque*--Continued

Date of sample	Stream discharge (cubic feet per second)	Suspended-sediment concentration (milligrams per liter)	Suspended-sediment discharge (tons per day)
03-21-80	1,810	70	342
05-02-80	6,200	528	8,840
06-06-80	16,500	361	16,100
06-20-80	15,200	167	6,850
07-18-80	4,250	23	264
09-15-80	2,350	8	51
10-21-80	2,220	14	84
02-18-81	1,220	24	79
04-06-81	1,180	54	172
05-06-81	4,060	435	4,770
05-21-81	2,750	204	1,510
05-29-81	6,060	258	4,220
06-08-81	9,950	262	7,040
07-08-81	2,510	76	515
08-06-81	1,730	54	252
09-08-81	2,030	3,350	18,400
10-19-81	2,090	146	824
12-07-81	1,610	105	456
03-08-82	1,620	45	197
05-03-82	6,570	2,600	46,100
06-15-82	11,500	111	3,450
07-22-82	4,720	33	421
09-08-82	2,640	52	371