SEDIMENT DISCHARGE IN ROCK CREEK AND THE EFFECT OF SEDIMENTATION RATE ON THE PROPOSED ROCK CREEK RESERVOIR, NORTHWESTERN COLORADO

By David L. Butler

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Multiply	*By*	*To obtain*
acre-foot (acre-ft)	1234	cubic meter
acre-foot per year (acre-ft/yr)	1234	cubic meter per year
cubic foot per second (ft^3/s)	0.02832	cubic meter per second
cubic foot per second per square mile [$(ft^3/s)/mi^2$]	0.01093	cubic meter per second per square kilometer
foot (ft)	0.3048	meter
inch (in.)	25.40	millimeter (mm)
mile (mi)	1.609	kilometer
pound per cubic foot (lb/ft^3)	16.02	kilogram per cubic meter
square mile (mi^2)	2.590	square kilometer
ton	0.9074	metric ton
ton per day per square mile ($ton/day/mi^2$)	0.3504	metric ton per day per square kilometer
ton per year (ton/yr)	0.9074	metric ton per year

The following term and abbreviation also is used in this report:

milligram per liter (mg/L).

Sea level: In this report "sea level" refers to the 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 of 1929."

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ABSTRACT

Sediment data collected from 1976 to 1985 and stream-discharge data collected from 1952 to 1980 at gaging station 09060500, Rock Creek near Toponas, Colorado, were used to determine total-sediment discharge into the proposed Rock Creek Reservoir. Suspended-sediment discharge and bedload discharge were related to stream discharge by using logarithmic regression relations. Mean annual suspended-sediment discharge was estimated to be 309 tons per year, and mean annual bedload discharge was estimated to be 428 tons per year in Rock Creek at the Toponas gaging station for the 1953 through 1980 water years. The mean annual total-sediment discharge into the proposed reservoir was estimated to be 768 tons per year, which includes 10-percent addition to the suspended-sediment discharge calculated for the Toponas gaging station to account for suspended-sediment discharge from Horse Creek. This rate of mean annual total-sediment discharge would decrease the long-term water-storage capacity of the proposed reservoir by less than 1 percent after 100 years.

Suspended-sediment discharge per unit-drainage-basin area at gaging station 09060550, Rock Creek at Crater, located about 5 miles downstream from the proposed reservoir site, was equivalent to suspended-sediment discharge per unit-drainage-basin area at the Toponas gaging station during 1985. Long-term sediment data collection at the Crater gaging station could be used for detecting changes in suspended-sediment discharge in Rock Creek at the proposed reservoir site.

INTRODUCTION

Sedimentation rate in a reservoir affects dam and reservoir design and operation because sedimentation is a primary factor affecting water-storage capacity of the reservoir. Sedimentation rate at a proposed reservoir site can be determined if the following information is known: (1) Stream discharge, (2) total-sediment discharge, (3) particle-size distribution of sediment, and (4) operation plans, dimensions, and trap efficiency of the proposed reservoir.

A site on Rock Creek, located about 8 mi east of Toponas in southern Routt County (fig. 1), was investigated by the U.S. Geological Survey in cooperation with the Colorado River Water Conservation District to determine total-sediment discharge in Rock Creek. The proposed Rock Creek Reservoir would have a capacity of 54,000 acre-ft (Western Engineers, Inc., 1984); it would be built for the Colorado River Water Conservation District for water users in western Colorado. Preliminary water-supply studies for the proposed reservoir have been completed; however, the effect of sedimentation rate on the long-term water-storage capacity of the proposed reservoir had not been determined.

Purpose and Scope

The primary purpose of this report is to present data on total-sediment discharge in Rock Creek at the proposed damsite of the Rock Creek Reservoir and to estimate the effect of sedimentation rate on water-storage capacity of the proposed reservoir. Sediment data collected at inactive gaging station 09060500, Rock Creek near Toponas, hereinafter referred to as the Toponas gage, and at the mouth of Horse Creek were used to determine total-sediment discharge at the proposed reservoir site. The Toponas gage is located about 0.7 mi upstream from the damsite; Horse Creek discharges into Rock Creek about 400 ft downstream from the Toponas gage (fig. 1). Suspended-sediment data were collected from May 1976 to August 1985 at the Toponas gage and during 1985 at Horse Creek. Bedload sediment was collected during 1985 and stream discharge was recorded from October 1952 through September 1980 at the Toponas gage.

A secondary purpose of this report is to compare sediment discharges measured during 1985 at the Toponas gage with sediment discharges at gaging station 09060550, Rock Creek at Crater, hereinafter referred to as the Crater gage. The Crater gage is located about 5 mi downstream from the Toponas gage (fig. 1). Sediment data are collected at the Crater gage as part of a sediment-data program, which is designed to provide sediment-discharge data for streams in Colorado. If sediment discharge at the Crater gage can be related to sediment discharge at the Toponas gage, then sediment sampling at the Crater gage could be useful for monitoring sediment discharge in Rock Creek at the proposed reservoir site.

Acknowledgment

Gary Decker and others from the U.S. Forest Service office in Steamboat Springs, Colo., assisted in sediment-sample collection from Rock Creek at the Toponas gage during 1985.

PHYSICAL SETTING

Rock Creek drains 192 mi^2 of the western slope of the Gore Range in northwestern Colorado. The drainage area upstream from the proposed Rock Creek Reservoir (fig. 1) is 53 mi^2. Elevation in Rock Creek basin ranges from 6,600 ft at the confluence of Rock Creek and the Colorado River at McCoy, to about 11,000 ft near the headwaters of Rock Creek and its primary tributary, Egeria Creek. The elevation of Rock Creek at the proposed damsite is 8,540 ft.

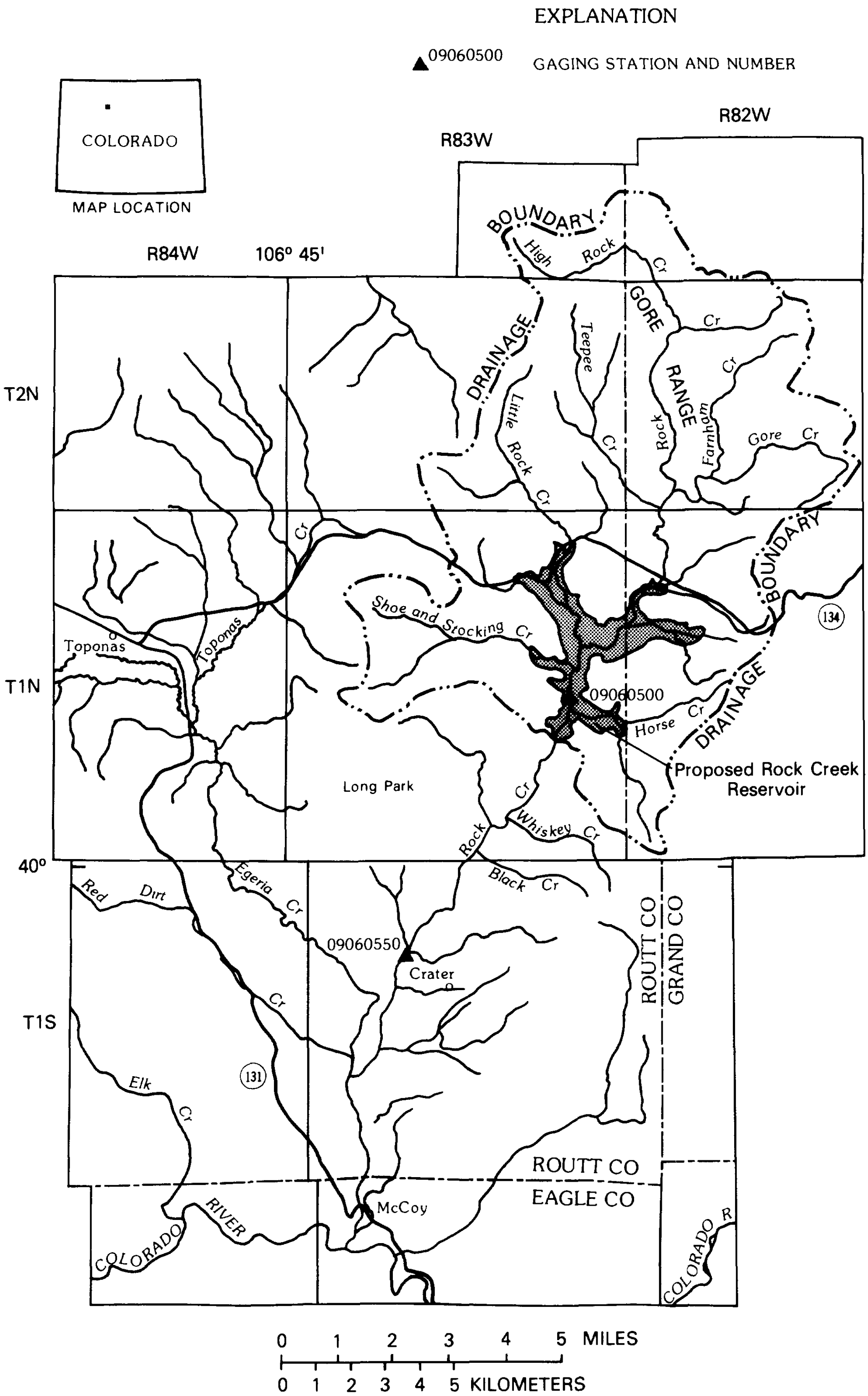

Figure 1.--Location of Rock Creek basin, proposed Rock Creek Reservoir, and sediment-sampling stations.

Physiography, Geology, and Climate

The Rock Creek basin is within the Middle Rocky Mountain physiographic province (Hunt, 1974). The basin upstream from the proposed reservoir site is characterized by foothills and upland meadows. The mean elevation of the drainage basin upstream from the Toponas gage is 9,400 ft (Richter and others, 1984).

Between the Toponas gage and the Crater gage, Rock Creek flows through a canyon incised 500 to 1,000 ft below adjacent mesas and upland plateaus. The drainage basin downstream from the Crater gage consists primarily of small canyons, mesas, and gullies.

Outcrops in the Rock Creek basin upstream from the confluence with Egeria Creek are predominantly granitic rock of Precambrian age (Tweto, 1979). Small areas of sedimentary rocks of the Morrison Formation of Jurassic age occur in the Horse Creek basin, and sedimentary rocks of the Minturn Formation of Pennsylvanian age occur in the Long Park area. There is a basalt flow of Holocene age at Crater. Downstream from the confluence with Egeria Creek, outcrops in the Rock Creek basin are predominantly sedimentary deposits of the Dakota Sandstone of Cretaceous age, the Minturn Formation of Pennsylvanian age, and the Maroon Formation of Pennsylvanian and Permian age.

Climate in the Rock Creek basin is continental and is controlled locally by mountains. Summers are cool and winters are cold, with moderately heavy winter snowfall, in the drainage basin upstream from the Toponas gage. Annual precipitation in the basin upstream from the Toponas gage is 25 in. (Richter and others, 1984). Annual precipitation decreases to about 15 in. at McCoy.

Vegetation and Land Use

Fir, pine, and aspen forests, interspersed with open meadows of grass and brush, compose the basin upstream from the proposed reservoir site. Downstream from the reservoir site, the forests and meadows grade into scrub oak, mountain mahogany, and sagebrush with decreasing elevation. The lowest elevation zones in the basin contain pinyon pine, juniper, and sagebrush.

Population is sparse in the Rock Creek basin; the only inhabited towns are Toponas and McCoy. The drainage basin upstream from the reservoir site is located in the Routt National Forest administered by the U.S. Forest Service. This area is used primarily for recreational purposes, livestock grazing, and small-scale logging. Ranching is the primary activity in the lower Rock Creek basin. Water for irrigation is diverted from Rock Creek between the proposed reservoir site and the Crater gage for use along lower Rock Creek and on the benches south of Crater. A small cinder-pit operation is at Crater.

STREAM DISCHARGE

Daily stream discharge was recorded for 28 years from October 1952 through September 1980 (1953 through 1980 water years) at the Toponas gage. The mean daily stream discharge determined for this period was 32.9 ft^3/s (23,820 acre-ft/yr). The maximum recorded stream discharge was 494 ft^3/s in May 1976. The minimum daily mean stream discharge was 2.2 ft^3/s in August and September 1954. There are no significant water diversions in the drainage basin upstream from the Toponas gage; therefore, the stream-discharge record for the Toponas gage should reflect natural runoff in the upper Rock Creek basin.

The variation of mean annual stream discharge for Rock Creek at the Toponas gage is shown in figure 2. Mean annual stream discharge ranged from 11.8 ft^3/s for the 1954 water year to 59.4 ft^3/s for the 1962 water year. The variation of mean monthly stream discharge for Rock Creek is shown in figure 3. Seventy-eight percent of the annual stream discharge for the 1953 through 1980 water years occurred during April, May, and June, which is the snowmelt-runoff period in the Rock Creek basin.

Stream discharge at the proposed damsite is approximately equal to the stream discharge at the Toponas gage plus the stream discharge of Horse Creek. Horse Creek drains 4.5 mi^2 and was not gaged. Assuming that stream discharge per unit area from the Horse Creek basin was equivalent to stream discharge per unit area from Rock Creek basin upstream from the Toponas gage, then the mean annual stream discharge for Horse Creek can be estimated. Mean annual stream discharge per unit area for Rock Creek upstream from the Toponas gage for 1953 through 1980 water years was 0.69 $(ft^3/s)/mi^2$. Applying this value to Horse Creek gives a mean annual stream discharge for Horse Creek of about 3.1 ft^3/s.

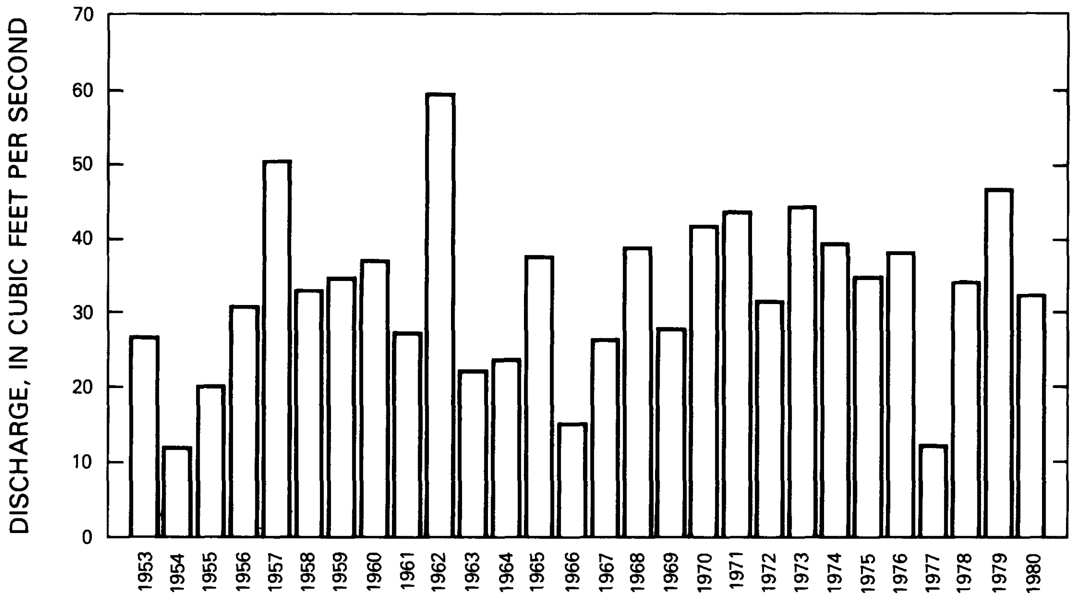

Figure 2.--Mean annual stream discharge for gaging station 09060500, Rock Creek near Toponas, 1953 through 1980 water years.

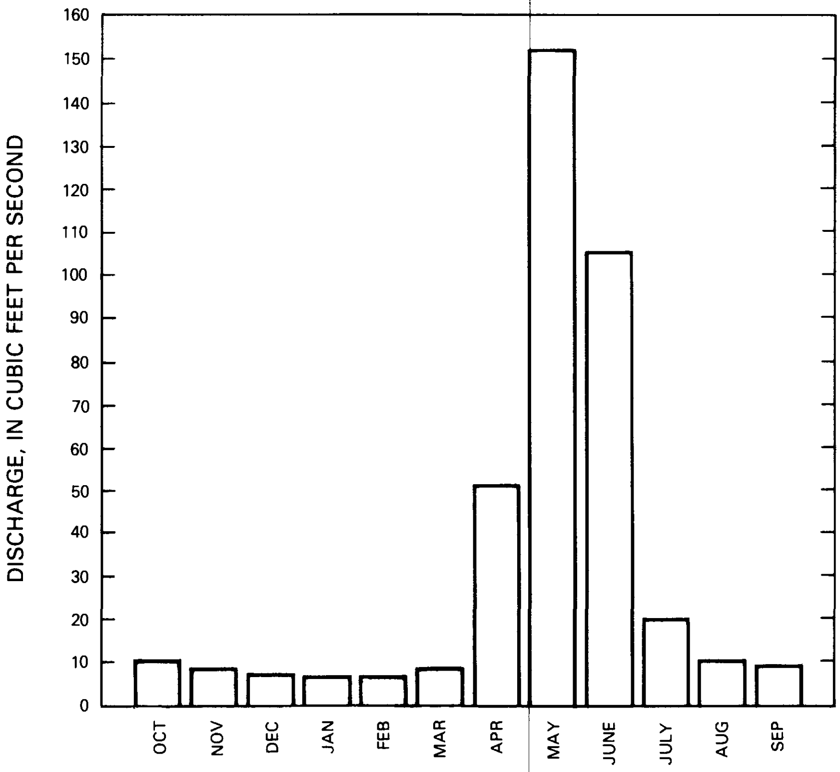

Figure 3.--Mean monthly stream discharge for gaging station 09060500, Rock Creek near Toponas, 1953 through 1980 water years.

During 1985, the only stream-discharge measurements at the Toponas gage were made in conjunction with sediment sampling. The Toponas gage was not reactivated for this study. The largest instantaneous stream discharge measured at the Toponas gage during 1985 was 327 ft^3/s on May 2. Based on the stream-discharge record for Rock Creek at the Crater gage, the maximum stream discharge during 1985 occurred on May 6 at the Toponas gage.

SEDIMENT DISCHARGE AT TOPONAS GAGE

The total-sediment discharge has two components, suspended sediment and bedload sediment. The suspended-sediment part of the total-sediment discharge is comprised of sediment particles transported in suspension in water by the turbulence of a stream. The bedload sediment part of the total-sediment discharge is comprised of sediment particles transported on or near the streambed by rolling, sliding, or saltation. The distinction between bedload sediment and suspended sediment is that the weight of bedload particles primarily is supported by the streambed, whereas the weight of suspended-sediment particles primarily is supported by the water.

Suspended-Sediment Discharge

Sediment data collected at the Toponas gage from May 18, 1976, to July 31, 1985, were used to evaluate suspended-sediment discharge into the proposed Rock Creek Reservoir. Fifty-eight suspended-sediment samples were collected at the Toponas gage from May 18, 1976, to August 15, 1984, by the U.S. Forest Service (table 7 in the "Supplemental Sediment Data" section at the back of this report) and 14 samples were collected during 1985 for this study (table 1). Suspended-sediment samples were collected using the equal-width method (Guy and Norman, 1970). Stream discharge was measured in conjunction with sediment sampling, using methods described by Rantz and others (1982).

The maximum concentration of suspended sediment sampled at the Toponas gage was 90 mg/L (June 27, 1979); no other sample had a concentration larger than 32 mg/L. The concentration of 90 mg/L may be in error because the sample was collected at a stream discharge of 55 ft^3/s during a period of decreasing stream stage. However, this single measurement does not affect the validity of subsequent analysis and interpretation. The small suspended-sediment concentrations for the Toponas gage are the result of limited sediment sources within the drainage basin. The granitic rocks in the basin upstream from the Toponas gage are not easily eroded, and only small areas of soil are exposed because of extensive vegetative cover. Because of the small concentrations of suspended sediment collected at the Toponas gage, quantities of sediment in the samples were insufficient to do complete particle-size analysis. The only particle-size data obtained were the percentage finer than 0.0625 mm listed in table 1, which is the silt plus clay fraction of the sediment sample.

Suspended-sediment concentration is converted to suspended-sediment discharge by:

$$Qs = 0.0027QC \qquad (1)$$

where

Qs = suspended-sediment discharge, in tons per day;
0.0027 = conversion factor;
Q = stream discharge, in cubic feet per second; and
C = suspended-sediment concentration, in milligrams per liter.

The stream discharge at the cross section sampled is used in equation 1. However, sediment samplers used for this study do not sample the bottom 0.3 ft of the vertical; therefore, all the stream discharge at the cross section is not actually sampled when using suspended-sediment samplers. A correction factor can be applied to equation 1 to approximate the part of stream discharge sampled. This method is described in Colby and Hembree (1955). The suspended-sediment discharges listed in table 1 have the correction factors applied. The original sediment data provided by the U.S. Forest Service are listed in table 7 of the "Supplemental Sediment Data" section at the back of this report; however, correction factors were estimated for these samples prior to further analysis.

Horse Creek discharges into Rock Creek between the Toponas gage and the proposed damsite. Three samples for suspended sediment were collected at the mouth of Horse Creek during 1985 (table 2); however, these samples were not considered to be sufficient for determining the contribution from Horse Creek to the estimated suspended-sediment discharge into the proposed reservoir. Because geology and physiography are similar between the Horse Creek basin and the Rock Creek basin upstream from the Toponas gage, suspended-sediment discharge per unit drainage area was assumed to be equal for the two basins.

Table 1.--*Stream-discharge and sediment data at gaging station 09060500, Rock Creek near Toponas, during 1985*

[Correction factor is the fraction of the stream discharge actually sampled by the suspended-sediment sampler; corrected suspended-sediment discharge is 0.0027 × stream discharge × suspended-sediment concentration × correction factor; -- indicates no data]

Date of sample	Stream discharge (cubic feet per second)	Suspended-sediment concentration (milligrams per liter)	Correction factor	Corrected suspended-sediment discharge (tons per day)	Suspended sediment finer than 0.0625 millimeters (percent)	Bedload discharge (tons per day)	Total-sediment discharge (tons per day)
05-02-85	179	32	0.90	14	--	5.4	19
05-08-85	327	17	.93	14	--	8.2	22
05-14-85	227	18	.91	10	--	6.8	17
05-16-85	205	11	.91	5.5	--	15	21
05-20-85	252	11	.92	6.9	--	16	23
05-22-85	226	13	.91	7.2	47	10	17
05-29-85	270	12	.93	8.1	56	6.8	15
06-04-85	173	3	.87	1.2	--	1.4	2.6
06-10-85	141	6	.86	2.0	--	1.7	3.7
06-18-85	72	4	.81	.63	--	.03	.66
06-26-85	56	4	.73	.44	--	.05	.49
07-10-85	17	1	.58	.03	95	.00	.03
07-22-85	23	9	.59	.33	23	.15	.48
07-31-85	15	1	.50	.02	81	--	--

Table 2.--*Stream-discharge and suspended-sediment data for Horse Creek at mouth during 1985*

[Correction factor is the fraction of the stream discharge actually sampled by the suspended-sediment sampler; corrected suspended-sediment discharge is 0.0027 × stream discharge × suspended-sediment concentration × correction factor]

Date of sample	Stream discharge (cubic feet per second)	Suspended-sediment concentration (milligrams per liter)	Correction factor	Corrected suspended-sediment discharge (tons per day)
05-08-85	33	21	0.82	1.5
05-20-85	22	6	.76	.27
06-10-85	4.7	1	.42	.01

Horse Creek drains 4.5 mi^2 and Rock Creek upstream from the Toponas gage drains 47.6 mi^2; therefore, suspended-sediment discharge in Horse Creek was assumed to equal about 10 percent of the suspended-sediment discharge in Rock Creek at the Toponas gage.

The relation of suspended-sediment discharge to stream discharge is approximately linear for logarithm-transformed data, and results in a regression equation of the form:

$$\log(Qs) = a + b[\log(Q)], \qquad (2)$$

where

log = base 10 logarithm;
Qs = suspended-sediment discharge, in tons per day;
a = regression intercept;
b = regression slope; and
Q = stream discharge, in cubic feet per second.

If a relation such as equation 2 can be determined for Rock Creek, then the annual suspended-sediment discharge can be determined from historical stream-discharge data for the period of record. This determination assumes that the sediment relation has not changed significantly throughout the period of discharge record.

A regression relation of suspended-sediment discharge to stream discharge was developed for Rock Creek at the Toponas gage using sediment data collected during 1985 (table 1) and the data collected from May 1976 to August 1984 by the U.S. Forest Service (table 7, in the "Supplemental Sediment Data" section at the back of this report). This relation is given in table 3 and plotted in figure 4. Separating the data into seasons of the year did not improve the regression relations; therefore, a single relation is given for suspended-sediment discharge.

Table 3.--*Regression relations of sediment discharge and stream discharge*

[*n* is number of data pairs; r^2 is coefficient of determination; *se* is standard error of estimate, in logarithmic units; log is base 10 logarithm; *Qs* is suspended-sediment discharge, in tons per day; *Q* is stream discharge, in cubic feet per second; and *Qb* is bedload discharge, in tons per day]

Dependent variable	Statistical values for regression of dependent variable versus stream discharge			
	n	r^2	Regression equation	*se*
Suspended-sediment discharge, gaging station 09060500, Rock Creek near Toponas	72	0.84	$\log(Qs) = -2.56 + 1.40[\log(Q)]$	0.37
Bedload discharge, gaging station 09060500, Rock Creek near Toponas	13	.83	$\log(Qb) = -5.94 + 2.85[\log(Q)]$	.56
Suspended-sediment discharge, gaging station 09060550, Rock Creek at Crater	12	.83	$\log(Qs) = -3.50 + 1.91[\log(Q)]$	.37

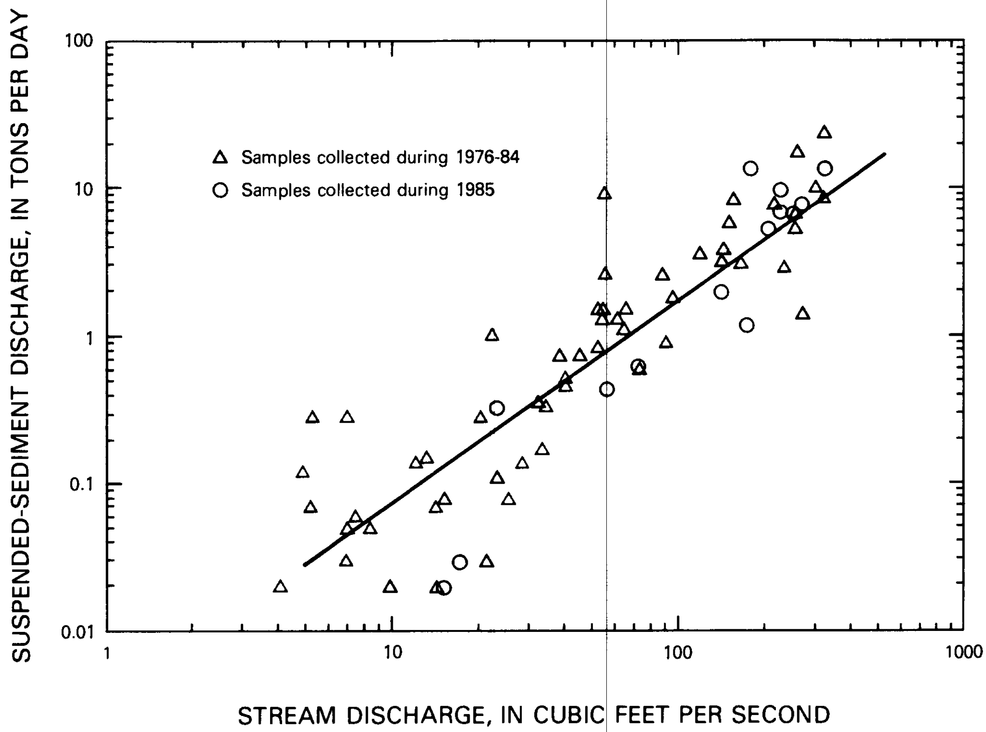

Figure 4.--Relation of suspended-sediment discharge to stream discharge at gaging station 09060500, Rock Creek near Toponas, using data collected from 1976 to 1985.

Bedload Discharge

Bedload discharge was a significant part of total-sediment discharge in Rock Creek at the Toponas gage based on the data collected during 1985 (table 1). Bedload samples were collected using Helley-Smith samplers described by Emmett (1980). The bedload discharges listed in table 1 were calculated using the dry weight of sediment collected in two traverses of the channel. The percentage of bedload discharge to the total-sediment discharge increased during the first 3 weeks of May, followed by decreasing percentages thereafter. Bedload discharge accounted for more than 50 percent of the total-sediment discharge in samples collected May 16, 20, and 22. The large percentage of bedload sediment in those samples is a function of decreased suspended-sediment discharge and increased bedload discharge. The maximum bedload discharge occurred on May 20, 2 weeks after the peak stream discharge on May 6 (based on record from Crater gage). The particle-size data given in table 4 indicate that most bedload sediment sampled in Rock Creek was coarse sand and fine gravel (0.5 to 4.0 mm).

Table 4.--*Particle-size distribution of sediment in bedload samples for gaging station 09060500, Rock Creek near Toponas*

[--, insufficient material for size analysis]

	Percentage finer than indicated size, in millimeters								
Date	0.125	0.250	0.500	1.0	2.0	4.0	8.0	16.0	32.0
05-02-85	1	2	12	49	87	96	99	100	100
05-08-85	1	2	7	24	61	85	95	99	100
05-14-85	0	1	7	24	65	87	94	96	100
05-16-85	0	0	3	16	48	73	87	96	100
05-20-85	0	1	4	22	59	79	91	98	100
05-22-85	0	1	5	25	63	81	90	96	100
05-29-85	0	1	8	31	59	76	88	99	100
06-04-85	1	1	10	34	65	84	93	100	100
06-10-85	0	1	9	40	80	96	100	100	100
06-18-85	1	5	20	62	96	100	100	100	100
06-26-85	1	4	19	42	58	71	100	100	100
07-10-85	--	--	--	--	100	100	100	100	100
07-22-85	0	2	16	62	94	99	100	100	100

Some bedload samples had rather large differences in the quantity of material collected for the two traverses, although the second traverse was taken immediately after the first traverse was completed. Some variability of bedload may have been caused by the sampler not lying flat on the streambed because of rocks and cobbles, allowing sediment particles to pass underneath the sampler mouth. Also, temporal variability in the movement of bedload sediment can cause large differences in the quantity of sediment collected by the sampler.

Bedload discharge at the Toponas gage was related to stream discharge by a relation similar to equation 2. The regression relation is given in table 3 and plotted in figure 5. Data were insufficient to relate bedload discharge to season of the year.

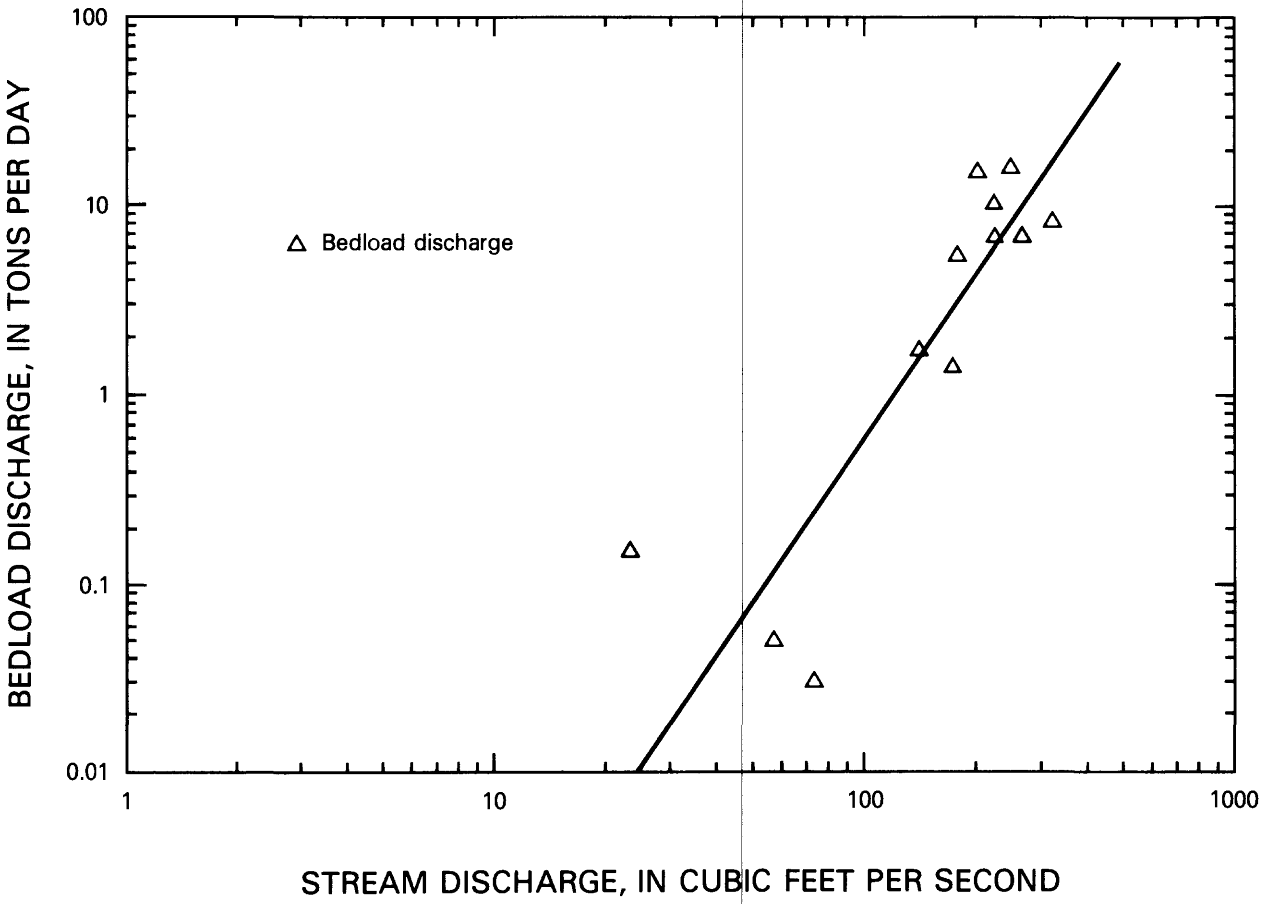

Figure 5.--Relation of bedload discharge to stream discharge at gaging station 09060500, Rock Creek near Toponas.

Because bedload discharge is a significant part of the total-sediment discharge in Rock Creek at the Toponas gage, it is desirable to know if relations other than the regression relation listed in table 3 might be used to estimate bedload discharge in Rock Creek. However, theoretical methods described in the literature (Simons and Sentürk, 1977) for estimating bedload discharge were developed for stream channels having characteristics different from those at Rock Creek. An important assumption for use of many of these methods is that the availability and mobility of sediment in the stream are unlimited. The particle-size data given in table 4 indicate that Rock Creek at the Toponas gage can transport particle sizes of bed material no larger than about 8 mm (fine gravel or smaller), based on bedload samples collected during 1985. However, much of the streambed in Rock Creek consists of larger gravel and cobble-size materials, which are too large to be transported at the expected range of discharge in Rock Creek. Therefore, the assumption for using the theoretical methods may not be valid, and computed bedload discharges may not be meaningful.

Haddock (1978) modeled bedload discharge in high mountain streams in the Front Range in Colorado. These streams had limited sediment sources as does Rock Creek. The first model from Haddock estimates bedload discharge from stream discharge and drainage density (the ratio of total stream length to drainage area). The second model estimates bedload discharge from stream discharge, stream power, drainage density, and maximum basin relief. Stream discharge and drainage area for the Rock Creek basin upstream from the Toponas gage are similar to the streams used in Haddock's models. Estimated bedload discharge using these models was compared to the measured bedload data collected during 1985 and to the estimated bedload discharge using the regression relation given in table 3. The first model with stream discharge and drainage density as independent variables underestimated the measured bedload discharge by factors of 5 to 20; the relation given in table 3 gave better results. The second model by Haddock gave reasonable estimates of bedload discharge for samples collected at larger stream discharges, but overestimated bedload discharge for the samples collected during June and July. This model offered no improvement in estimating bedload discharge compared to the relation listed in table 3.

The drainage density for Rock Creek basin upstream from the Toponas gage is 2.27, which is smaller than the drainage densities of the basins used in Haddock's models. New regression coefficients for the two models were developed by adding the Rock Creek bedload data to Haddock's data base and rerunning the regressions. The resultant models did not significantly improve the estimated bedload discharge in Rock Creek when compared to original models; therefore, the relation listed in table 3 was used for estimating annual bedload discharge in Rock Creek at the Toponas gage.

Total-Sediment Discharge

Total-sediment discharge at the Toponas gage for samples collected during 1985 (table 1) are the sum of the corrected suspended-sediment discharge and the bedload discharge. Corrected suspended-sediment discharges are adjusted to account for the unsampled part of stream discharge (bottom 0.3 ft), as discussed previously in this report. The bedload sampler collects sediment particles coarser than 0.25 mm in the bottom 0.25 ft (3-in. sampler size) of the stream. Therefore, the bedload sampler will collect suspended sediment and bedload coarser than 0.25 mm in the zone not sampled by the suspended-sediment sampler. Thus, the only part of the total-sediment discharge not sampled is the suspended-sediment particles finer than 0.25 mm in the zone not sampled by the suspended-sediment sampler. Much of the streambed of Rock Creek is composed of material larger than 0.25 mm; therefore, the quantity of sediment finer than 0.25 mm that would be available for transport is probably limited. The magnitude of the unsampled suspended-sediment discharge was assumed to be not significant with respect to estimates of sedimentation rate and the long-term water-storage capacity of the proposed reservoir.

Annual Sediment Discharge

Annual total-sediment discharge was computed using regression relations for sediment discharges listed in table 3 and the 28 years of historical stream-discharge data for the Toponas gage. Because land use has not changed significantly in the basin upstream from the Toponas gage, the regression relations were assumed to be applicable to the 28-year period. Mean daily total-sediment discharge was computed using the regression relations and mean daily stream discharge; sums of the daily values give the annual total-sediment discharge for each year. Then the mean annual total-sediment discharge was computed for the 28-year period. Separate estimates of annual suspended-sediment discharge and annual bedload discharge were computed. The mean annual suspended-sediment discharge was 215 tons/yr and the mean annual bedload discharge was 186 tons/yr using the regression relations for the Toponas gage. The flow duration, sediment-rating-curve method can also be used to compute annual total-sediment discharge (Miller, 1951). The mean annual suspended-sediment and bedload discharges computed by that method gave the same results compared to the method described, which was expected.

Ferguson (1986) has shown that an error is introduced in estimating sediment concentrations or sediment discharges from log-log regression relations. The estimated values, which are obtained from the antilog of the regression value, will always be underestimated by a factor that is dependent upon the degree of error or the variance about the regression line. For log-log regression relations expressed in base 10 logarithm units, this correction factor is equal to $\exp[(2.65)(s^2)]$, where exp is the base e antilog and s^2 is the mean error sum of squares (the square of the "se" term given in table 3). These correction factors are 1.44 for the suspended-sediment-discharge relation and 2.30 for the bedload-discharge relation. Applying these correction factors to the sediment discharges listed in the previous paragraph results in a mean annual discharge of 309 tons/yr for suspended sediment and 428 tons/yr for bedload sediment at the Toponas gage. Adding 10 percent to the suspended-sediment discharge to account for sediment discharge from Horse Creek results in an estimated mean annual suspended-sediment discharge of 340 tons/yr at the proposed reservoir site. Bedload discharge from Horse Creek was not considered a significant part of the total-sediment discharge at the damsite. Thus, the mean annual total-sediment discharge at the proposed damsite is estimated as 768 tons/yr, which is the sum of the mean annual suspended-sediment discharge and the mean annual bedload discharge.

EFFECT OF SEDIMENTATION RATE ON THE PROPOSED ROCK CREEK RESERVOIR

Factors affecting the sedimentation rate of a reservoir include: (1) Quantity of sediment and water discharge into the reservoir; (2) trap efficiency of the reservoir; (3) reservoir size and operation; (4) particle size of the sediment; and (5) specific weight of the deposits (Vanoni, 1975). Using estimates of total-sediment discharge with historical stream-discharge data and information about reservoir dimensions and operational plans, the sedimentation rate, and thus changes in water-storage capacity of the reservoir, were calculated.

Trap efficiency, the percentage of incoming sediment that remains in the reservoir, depends on reservoir size and water discharge into the reservoir. An initial trap efficiency of about 100 percent was calculated for the proposed Rock Creek Reservoir using the Churchill method (Vanoni, 1975).

Sediment discharge into a reservoir can be converted to the volume the deposits would occupy in the reservoir using specific weight of the deposits. An initial specific weight of the sediment was calculated using a method based on size distribution of incoming sediment and on a reservoir classification that depends on the operational plans of the reservoir (Strand, 1974). Using a particle-size distribution of 25 percent clay, 30 percent silt, and 45 percent sand, an initial specific weight of 71 lb/ft^3 was calculated for sediment in the proposed Rock Creek Reservoir. The specific weight of sediment deposits could vary by at least 10 percent depending on the size distribution used in the calculation. However, errors in determining specific weight will not change the conclusions regarding sedimentation rate and long-term water-storage capacity of the reservoir.

Compaction increases the specific weight of the sediment deposits with time. Average specific weight of sediment deposits for various time periods was calculated using a method described by Strand (1974). The specific weight of sediment deposits would increase to 79 lb/ft^3 after 50 years and to 80 lb/ft^3 after 100 years.

Using the mean annual total-sediment discharge into the proposed reservoir (768 tons/yr), trap efficiency (100 percent), and specific weight of sediment deposits, the volume that the sediment deposits would occupy after various time periods was determined. The calculated volume that the sediment occupies was subtracted from the initial reservoir water-storage capacity (54,000 acre-ft) to determine possible changes in reservoir water-storage capacity. The water-storage capacity of the proposed Rock Creek Reservoir would decrease from 54,000 acre-ft to 53,956 acre-ft after 100 years, which is less than 1-percent decrease in water-storage capacity. If the mean annual total-sediment discharge was underestimated by 100 percent, the mean annual total-sediment discharge would be 1,536 tons/yr. That rate of mean annual total-sediment discharge would decrease the water-storage capacity of the Rock Creek Reservoir to 53,912 acre-ft after 100 years, which also is less than 1-percent decrease in water-storage capacity. These estimates indicate that total-sediment discharge from Rock Creek would have a very small effect on the water-storage capacity of the proposed reservoir.

Errors in the estimated total-sediment discharge for Rock Creek could produce errors in the sedimentation rates estimated for the reservoir. The bedload discharge was determined from data collected for only one runoff season. Temporal variation of bedload discharge may not be adequately defined. Bedload discharge apparently is a significant part of the total-sediment discharge at the proposed reservoir site, and large errors in the bedload discharge would change the estimated total-sediment discharge used to calculate the sedimentation rate in the reservoir. However, if the bedload discharge was underestimated by one order of magnitude, conclusions regarding the water-storage capacity of the reservoir would not be changed.

Changes in stream discharge (natural or human caused) or changes in sediment yield in the basin upstream from the proposed reservoir could change total-sediment discharge into the reservoir. Factors that affect sediment yield include: geology, vegetation cover, land use, rainfall frequency and intensity, and such basin characteristics as drainage area, stream length, slope, and drainage density. Because the estimated total-sediment discharge at the proposed reservoir site was small, based on the data collected for this study, an increase in sediment yield in the basin upstream from the reservoir site could increase total-sediment discharge in Rock Creek and consequently the sedimentation rate of the Rock Creek Reservoir. The magnitude of such an increase would have to be very large before the sedimentation rate of the reservoir became significant; for example, a tenfold increase in total-sediment discharge would decrease water-storage capacity of the reservoir by only 1 percent after 100 years.

TOTAL-SEDIMENT DISCHARGE AT CRATER GAGE

Gaging station 09060550, Rock Creek at Crater (fig. 1), was established in December 1984 for collection of stream-discharge, water-quality, and sediment data as part of the hydrologic-data program in Colorado. Sediment data collected during 1985 at the Crater and Toponas gages were compared to determine if sediment data collected at the Crater gage are transferable to the Toponas gage and subsequently to the proposed site of the Rock Creek Reservoir. Sediment data might be collected at the Crater gage for several years, and these data could be useful to monitor variation of total-sediment discharge in Rock Creek and perhaps to detect a significant change in total-sediment discharge if it should occur.

Suspended-sediment concentrations were less than 100 mg/L in the 12 samples collected at the Crater gage during 1985 (table 5). The relation of suspended-sediment discharge to stream discharge for these samples is given in table 3 and shown in figure 6. This relation is compared to the suspended-sediment discharge versus stream discharge relation (table 6) developed from the sediment data collected during 1985 at the Toponas gage (fig. 6). As is evident in table 6, if drainage-basin area upstream from each gage (72.0 mi^2 for Crater gage; 47.6 mi^2 for Toponas gage) is considered, the suspended-sediment discharge relations are equivalent for the two sites. The suspended-sediment discharge at the Toponas gage could be approximated from samples collected at the Crater gage by multiplying suspended-sediment discharge at the Crater gage by 0.66 (47.6 divided by 72.0).

Bedload data were insufficient to adequately define bedload discharge in Rock Creek at the Crater gage. In five of the six samples collected at the Crater gage to determine total-sediment discharge (table 5), suspended-sediment discharge accounted for more than 75 percent of the total-sediment discharge. Bedload discharge may constitute a smaller fraction of the total-sediment discharge at the Crater gage than at the Toponas gage because of increased stream power and turbulence of Rock Creek at the Crater gage, which could suspend a larger fraction of the sediment particles in the stream. The stream gradient is steeper at the Crater gage (about 0.03) than at the Toponas gage (about 0.006), which increases stream power, and the streambed at the Crater gage contains larger bed material, which increases turbulence in the stream. More bedload-sediment data would be needed at both sites before bedload discharge in Rock Creek could be compared in detail.

Table 5.--*Stream-discharge and sediment data at gaging station 09060550, Rock Creek at Crater, during 1985*

[Correction factor is the fraction of the stream discharge actually sampled by the suspended-sediment sampler; corrected suspended-sediment discharge is 0.0027 × stream discharge × suspended-sediment concentration × correction factor; -- indicates no data]

Date of sample	Stream discharge (cubic feet per second)	Suspended-sediment concentration (milligrams per liter)	Correction factor	Corrected suspended-sediment discharge (tons per day)	Suspended sediment finer than 0.0625 millimeter (percent)	Bedload discharge (tons per day)	Total-sediment discharge (tons per day)
04-16-85	142	73	0.83	23	--	--	--
05-07-85	332	32	.87	25	48	3.2	28
05-09-85	365	38	.88	33	46	10	43
05-14-85	204	34	.87	16	--	2.0	18
05-16-85	209	11	.87	5.4	--	.52	5.9
05-21-85	262	7	.86	4.3	71	2.9	7.2
05-23-85	232	9	.85	4.8	--	--	--
05-30-85	286	16	.86	11	61	.82	12
06-06-85	160	23	.80	8.0	66	--	--
06-12-85	96	11	.74	2.1	78	--	--
06-26-85	45	14	.66	1.1	86	--	--
07-16-85	13	1	.51	.02	--	--	--

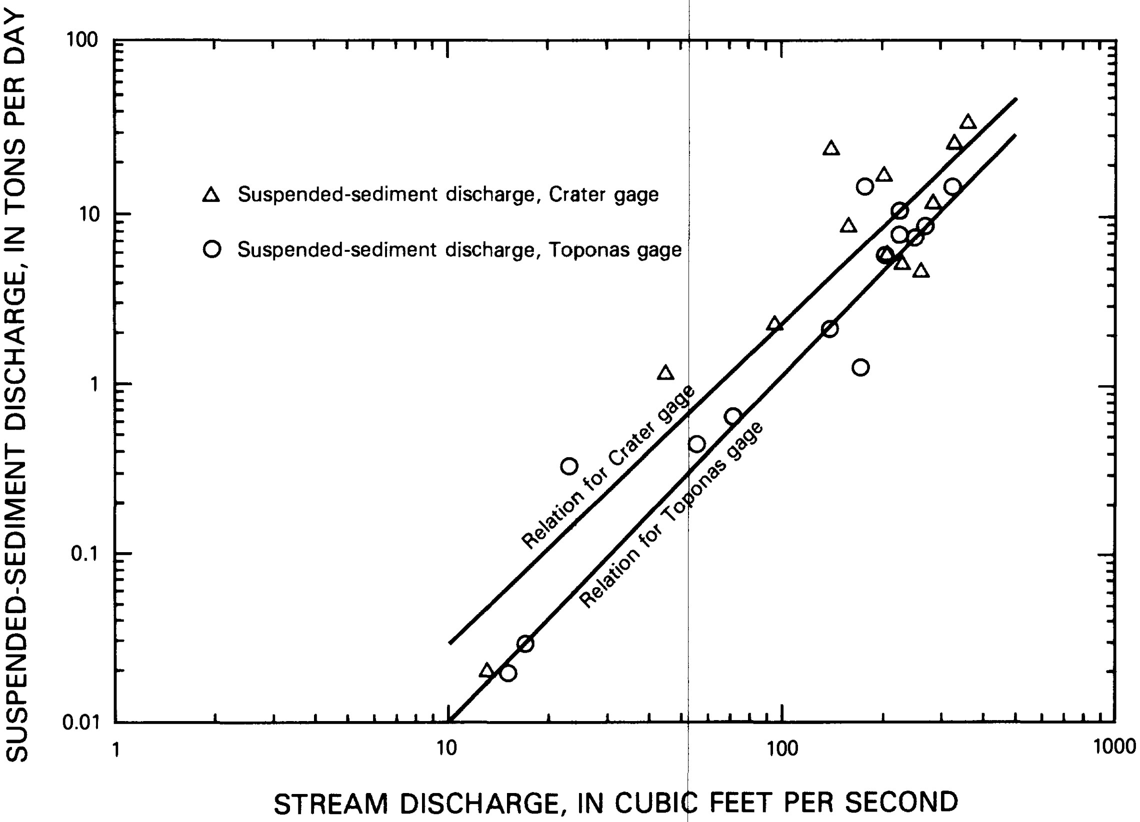

Figure 6.--Relations of suspended-sediment discharge to stream discharge at gaging stations 09060500, Rock Creek near Toponas, and 09060550, Rock Creek at Crater, for data collected during 1985.

Table 6.--*Comparison of suspended-sediment discharge at various stream discharges between gaging station 09060500, Rock Creek near Toponas, and gaging station 09060550, Rock Creek at Crater, using sediment data collected during 1985*

[Relation for station 09060500, the Toponas gage, is $\log Q_s=-3.78+1.94(\log Q)$; relation for station 09060550, the Crater gage, is $\log Q_s=-3.50+1.91(\log Q)$; Q_s is suspended-sediment discharge, in tons per day, and Q is stream discharge, in cubic feet per second]

Q	Predicted Q_s, in tons per day		Predicted Q_s, in tons per day per square mile of drainage basin area	
	Toponas gage	Crater gage	Toponas gage	Crater gage
10	0.01	0.03	0.00	0.00
50	.33	.56	.01	.01
100	1.3	2.1	.03	.03
150	2.8	4.5	.06	.06
200	4.8	7.9	.10	.11
300	11	17	.22	.24
400	19	30	.39	.41

SUMMARY AND CONCLUSIONS

Suspended-sediment data collected from 1976 to 1985 and bedload-sediment data collected during 1985 at inactive gaging station 09060500, Rock Creek near Toponas, were used to calculate total-sediment discharge in Rock Creek into the proposed Rock Creek Reservoir. After adjusting the suspended-sediment discharge determined for Rock Creek at the Toponas gage to account for total-sediment discharge from Horse Creek, which discharges into Rock Creek between the gage and the proposed damsite, the sedimentation rate of the reservoir was estimated.

Linear-regression relations of logarithm-transformed data were developed to relate suspended-sediment and bedload discharge to stream discharge. Using these relations with 28 years of stream-discharge data collected at the Toponas gage, the mean annual discharges for suspended sediment and bedload sediment were computed for Rock Creek at the Toponas gage. The mean annual suspended-sediment and bedload discharges were adjusted to correct for the error introduced in predicting sediment discharge from regression relations of logarithm-transformed data. The corrected mean annual discharge was an estimated 309 tons/yr for suspended sediment and an estimated 428 tons/yr for bedload sediment. The mean annual suspended-sediment discharge was adjusted by 10 percent to account for suspended-sediment discharge of Horse Creek, resulting in a suspended-sediment discharge at the proposed site of the Rock Creek Reservoir of 340 tons/yr. Thus, the mean annual total-sediment discharge at the proposed reservoir site is estimated as 768 tons/yr; this rate of total-sediment discharge into the reservoir would have minimal effects on long-term water-storage capacity of the reservoir, decreasing capacity by less than 1 percent after 100 years. This estimate assumes that no significant changes in stream discharge or total-sediment discharge in the upstream drainage basin occur. If total-sediment discharge was underestimated by 100 percent, the effect of total-sediment discharge on the water-storage capacity of the reservoir would remain negligible.

Sediment data were collected during 1985 at gaging station 09060550, Rock Creek at Crater, which is located about 5 mi downstream from the proposed Rock Creek Reservoir. Suspended-sediment data collected at the Crater gage could be used for long-term monitoring of suspended-sediment discharge in Rock Creek prior to construction of the dam. The suspended-sediment discharge relations for the Toponas and Crater gages estimate the same suspended-sediment discharge per unit drainage basin area. Bedload discharge was not compared between the two gages on Rock Creek because of insufficient data.

REFERENCES CITED

Colby, B.R., and Hembree, C.H., 1955, Computations of total sediment discharge, Niobrara River near Cody, Nebraska: U.S. Geological Survey Water-Supply Paper 1357, 187 p.

Emmett, W.W., 1980, A field calibration of the sediment-trapping characteristics of the Helley-Smith bedload sampler: U.S. Geological Survey Professional Paper 1139, 44 p.

Ferguson, R.I., 1986, River loads underestimated by rating curves: Water Resources Research, v. 22, no. 1, p. 74-76.

Guy, H.P., and Norman, V.W., 1970, Field methods for measurement of fluvial sediment: U.S. Geological Survey Techniques of Water-Resources Investigations, bk. 3, chap. C2, 59 p.

Haddock, D.R., 1978, Modeling bedload transport in mountain streams of the Colorado Front Range: Fort Collins, Colorado State University, Earth Resources Department, M.S. thesis, 74 p.

Hunt, C.B., 1974, Natural regions of the United States and Canada: San Francisco, W.H. Freeman and Company, 725 p.

Miller, C.R., 1951, Analysis of flow-duration, sediment rating curve method of computing sediment yield: U.S. Bureau of Reclamation, Sediment Section, Hydrology Branch, 15 p.

Rantz, S.E., and others, 1982, Measurement and computation of streamflow--Volume 1. Measurement of stage and discharge: U.S. Geological Survey Water-Supply Paper 2175, 284 p.

Richter, B.D., Kircher, J.E., Remmers, M.A., and Forst, B.A., 1984, Summary of basin and streamflow characteristics for selected basins in western Colorado and adjacent states: U.S. Geological Survey Open-File Report 84-137, 266 p.

Simons, D.B., and Sentürk, Fuat, 1977, Sediment transport technology: Fort Collins, Colorado, Water Resources Publications, 807 p.

Strand, R.I., 1974, Sedimentation, appendix H, in Design of small dams: U.S. Bureau of Reclamation, p. 767-796.

Tweto, Ogden, 1979, Geologic map of Colorado: U.S. Geological Survey, scale 1:500,000, 2 sheets.

Vanoni, V.A., ed., 1975, Sedimentation engineering: New York, American Society of Civil Engineers, Manuals and Reports on Engineering Practices, no. 54, 745 p.

Western Engineers, Inc., 1984, Rock Creek water supply study: Grand Junction, Colo., 17 p.

SUPPLEMENTAL SEDIMENT DATA

Table 7.--*Suspended-sediment data collected at gaging station 09060500, Rock Creek near Toponas, from 1976 to 1984*

[Data furnished by Gary Decker, U.S. Forest Service, Steamboat Springs, Colorado]

Date of sample	Stream discharge (cubic feet per second)	Suspended-sediment concentration (milligrams per liter)	Suspended-sediment discharge (tons per day)
05-18-76	141	9.9	3.8
06-25-76	22.5	3.3	.20
07-07-76	8.3	4.0	.09
07-14-76	6.9	5.0	.09
09-08-76	4.0	2.8	.03
05-11-77	40	6.8	.73
05-16-77	54	14	2.0
05-24-77	33	3.1	.28
05-31-77	28	3.1	.23
06-21-77	4.8	16	.21
07-05-77	6.9	27	.50
07-18-77	5.2	10	.14
08-15-77	7.4	5.4	.11
08-29-77	12	7.6	.25
09-12-77	9.7	1.3	.03
06-08-78	272	2.0	1.5
06-13-78	256	8.9	6.2
06-19-78	143	12	4.6
06-27-78	64	7.7	1.3
07-06-78	73	3.8	.75
07-20-78	20	8.6	.46
08-02-78	14	1.0	.04
08-16-78	6.8	2.7	.05
05-23-79	324	11	9.6
05-30-79	326	28	25
06-06-79	260	28	20
06-21-79	90	4.9	1.2
06-27-79	55	90	13
07-06-79	40	7.2	.78
07-17-79	22	28	1.7

Table 7.--*Suspended-sediment data collected at gaging station 09060500, Rock Creek near Toponas from 1976 to 1984*--Continued

Date of sample	Stream discharge (cubic feet per second)	Suspended-sediment concentration (milligrams per liter)	Suspended-sediment discharge (tons per day)
07-31-79	13	7.7	.27
06-16-80	119	14	4.5
07-08-80	38	11	1.1
07-29-80	1.5	5.7	.02
08-25-80	1.5	6.0	.02
04-30-81	65	12	2.1
05-26-81	55	13	1.9
06-22-81	14	3.2	.12
07-23-81	5.1	8.1	.11
05-12-82	156	24	10
06-09-82	217	15	8.8
07-09-82	52	15	2.1
06-14-83	260	11	7.7
06-23-83	233	5.2	3.3
07-01-83	95	9.5	2.4
07-07-83	61	11	1.8
07-12-83	52	8.4	1.2
07-19-83	32	6.3	.54
06-07-84	304	13	11
06-20-84	165	8.1	3.6
06-21-84	150	17	6.9
06-26-84	87	15	3.5
07-06-84	45	8.6	1.0
07-10-84	54	15	2.2
07-25-84	34	5.5	.50
08-02-84	25	2.0	.14
08-08-84	21	1.0	.06
08-15-84	15	4.0	.16