SEDIMENT DISCHARGE IN MUDDY CREEK AND THE EFFECT OF SEDIMENTATION RATE ON THE PROPOSED WOLFORD MOUNTAIN RESERVOIR NEAR KREMMLING, COLORADO

By Barbara C. Ruddy

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CONVERSION FACTORS

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

Multiply	*By*	*To obtain*
acre-foot (acre-ft)	1,233	cubic meter
cubic foot	0.02832	cubic meter
cubic foot per second (ft^3/s)	.02832	cubic meter per second
foot (ft)	.3048	meter
foot per second (ft/s)	.3048	meter per second
inch	25.40	millimeter (mm)
mile (mi)	1.609	kilometer
pound	.4536	kilogram
pound per cubic foot (lb/ft^3)	16.02	kilogram per cubic meter
square foot	.9290	square meter
square mile (mi^2)	2.589	square kilometer
ton	.9074	metric ton
ton per day (ton/d)	.9074	metric ton or megagram per day
ton per year (ton/yr)	.9074	metric ton or megagram per year

Temperature in degree Celsius (°C) may be converted to degree Fahrenheit (°F) by use of the following formula:

$$°F = 9/5\ °C+32.$$

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

Stream-discharge data collected from May 1982 through October 1985 and sediment data collected from March 1985 through October 1985 at streamflow-gaging station 09041500 Muddy Creek at Kremmling, Colorado, were used to determine total-sediment discharge into the proposed Wolford Mountain Reservoir. The data were divided on a seasonal basis, and statistical relations between suspended-sediment discharge and stream discharge were determined for the rising stage, falling stage, and base-flow period. One statistical relation between bedload discharge and stream discharge was determined from all collected data. These relations were used with 3 years of daily stream-discharge data to estimate total-sediment discharge. Total-sediment discharge was largest prior to the annual peak stream discharge and decreased thereafter. At least 97 percent of the total-sediment discharge was suspended sediment.

Mean annual total-sediment discharge in Muddy Creek near Kremmling was estimated to be 83,000 tons per year for 1983 through 1985 water years. At this rate of mean annual total-sediment discharge, water-storage capacity of the proposed Wolford Mountain Reservoir at site C would decrease 10 percent after 100 years.

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.

The proposed Wolford Mountain Reservoir on Muddy Creek is being investigated for its potential as a water-storage reservoir by the U.S. Geological Survey in cooperation with the Colorado River Water Conservation District as a result of a settlement reached with the Northern Colorado Water Conservancy District on compensatory storage for the Windy Gap Diversion. The proposed reservoir also is being investigated for its potential as a joint use or exchange reservoir in a separate study by the Colorado Water and Power Development Authority that is jointly sponsored by the Colorado River Water Conservation District and the Denver Water Department (D.H. Merritt, Colorado River Water Conservation District, written commun., 1986). The Middle Park Water Conservancy District and Grand County have the water storage rights for the proposed Wolford Mountain Reservoir on Muddy Creek, a tributary of the Colorado River. The reservoir would be located 1 to 5 mi north of Kremmling (fig. 1), dependent upon final site selection. The proposed reservoir would be used for streamflow regulation, water-supply storage, and recreation.

Purpose and Scope

The purpose of this report is to present data on total-sediment discharge of Muddy Creek at Kremmling, and to estimate the effect of sedimentation rate on the water-storage capacity of the proposed Wolford Mountain Reservoir at site C. Four sites--A, B, C, and D--were originally considered for the proposed reservoir, but presently (1986), sites B and D are not being considered. Site A has the largest water-storage capacity of 119,600 acre-ft and site C has the smallest water-storage capacity of 60,500 acre-ft. Site C also is the subject of a feasibility study and environmental impact statement being prepared for the Colorado River Water Conservation District under the direction of the Routt National Forest and the Kremmling Office of the U.S. Bureau of Land Mangagement (D.H. Merritt, Colorado River Water Conservation District, written commun., 1986). Therefore, the effects of sediment deposition will be discussed for site C. Stream-discharge data collected from May 1982 through October 1985 and sediment data collected from March 1985 through October 1985 at streamflow-gaging station 09041500 Muddy Creek at Kremmling, were used to estimate total-sediment discharge at the proposed reservoir site (site C).

Description of Study Area

The Muddy Creek basin is located in north-central Colorado, 100 mi northwest of Denver (fig. 1). Muddy Creek at Kremmling drains an area of 290 mi^2; the streamflow-gaging station 09041500 Muddy Creek at Kremmling, hereinafter referred to as the Muddy Creek gage, is at an elevation of 7,340 ft and is 2.8 mi upstream from the mouth. Muddy Creek originates near Rabbit Ears Peak at an elevation of 10,600 ft, and flows generally south. Near Kremmling, Muddy Creek flows in a more westerly direction; then it flows south into the Colorado River, 35 mi downstream from the headwaters of Muddy Creek. The Gore Range lies west of Muddy Creek, the Rabbit Ears Range lies to the northeast, and Wolford Mountain lies to the east, just north of Kremmling. Most tributaries of Muddy Creek flow from the east or west to join the main stem. Muddy Ditch diverts water at a site about 2,000 ft upstream from the Muddy Creek gage and continues for more than 1 mi before flowing back into Muddy Creek.

The proposed Wolford Mountain Reservoir and most of the length of Muddy Creek are located on Upper Cretaceous marine shale and fine-grained sandstone of the Pierre Shale. The reservoir will be built upon the impermeable shale of the Muddy Buttes basin, which is just north of Kremmling. Wolford Mountain has been designated as a potential National Natural Landmark by the National Park Service. It is part of a fault block in which Precambrian igneous rocks were thrust over younger Cretaceous shale and sandstone.

The primary land uses within the Muddy Creek basin are agricultural, either livestock grazing or irrigated hay meadows. Upstream parts of the basin also are used for recreation. Kremmling, located near the mouth of Muddy Creek, is the only town within the basin.

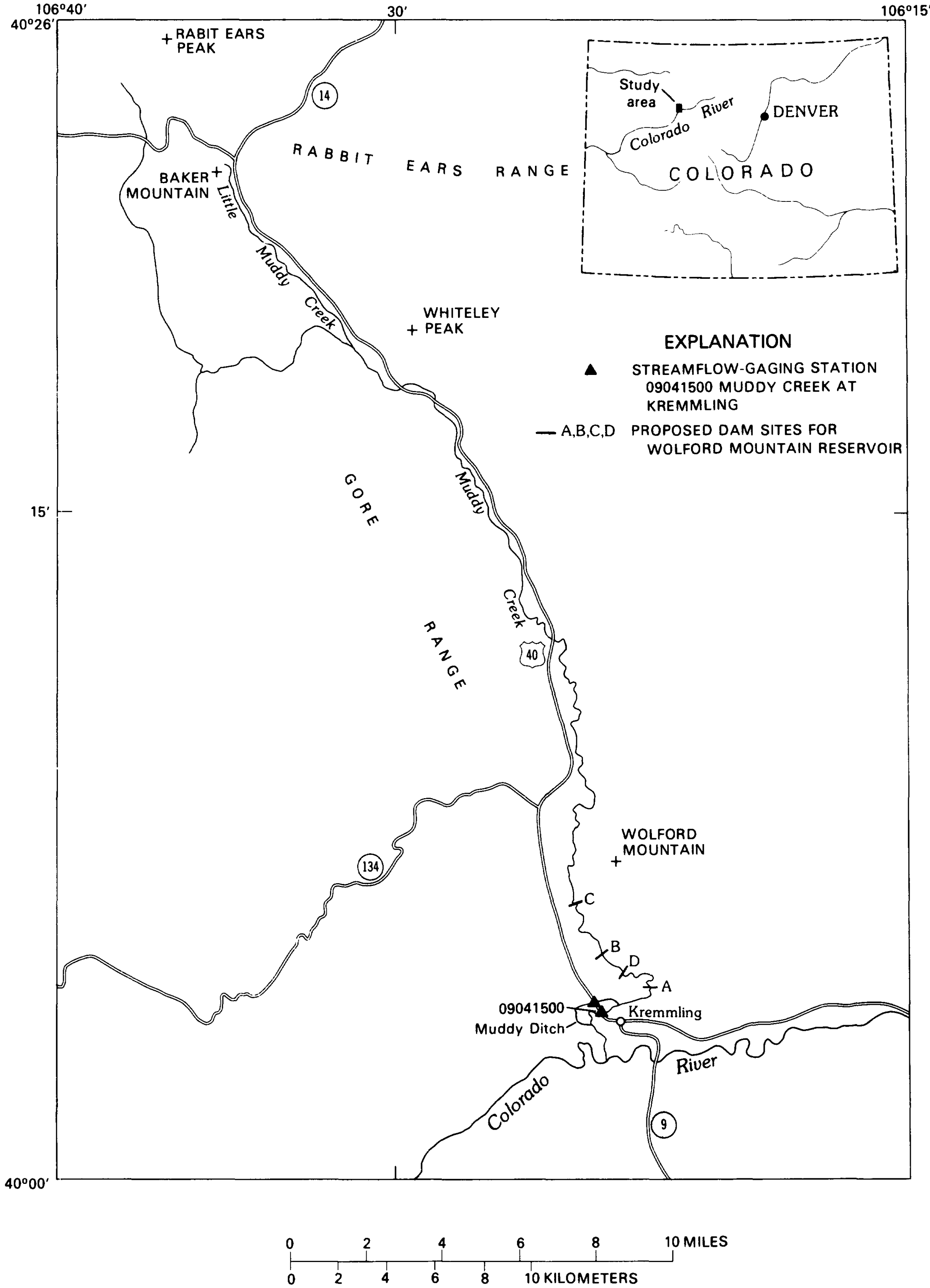

Figure 1.--Location of Muddy Creek basin and study area.

STREAM DISCHARGE

The U.S. Geological Survey has collected stream-discharge data at the Muddy Creek gage since April 1982. Some data also were collected during 1904 and 1905. The sites (A-D) for the proposed Wolford Mountain Reservoir are located 1 to 5 mi north of Kremmling and upstream from the Muddy Creek gage. A streamflow-gaging station is also maintained on Muddy Ditch. Combined stream discharges of Muddy Creek and Muddy Ditch are reported at the Muddy Creek gage, because the ditch diversion is only 2,000 ft upstream from the Muddy Creek gage and would be part of the stream discharge into the reservoir, if it were constructed. The mean daily combined stream discharge for Muddy Creek and Muddy Ditch from May 1982 through September 1985 was 146 ft^3/s. The maximum combined stream discharge was 1,670 ft^3/s on May 16, 1984. The minimum recorded daily discharge was 1.0 ft^3/s on September 24-25, 1905. A hydrograph of the combined monthly mean stream discharge for May 1982 through September 1985 is shown in figure 2. Stream discharge during the 1984 water year was larger than during the 1983 or 1985 water years. The plot of the mean monthly stream discharge for the period of record shows the monthly distribution of the streamflow during the period (fig. 3). Over 70 percent of the annual stream discharge of Muddy Creek occurs during April, May, and June as a result of snowmelt runoff.

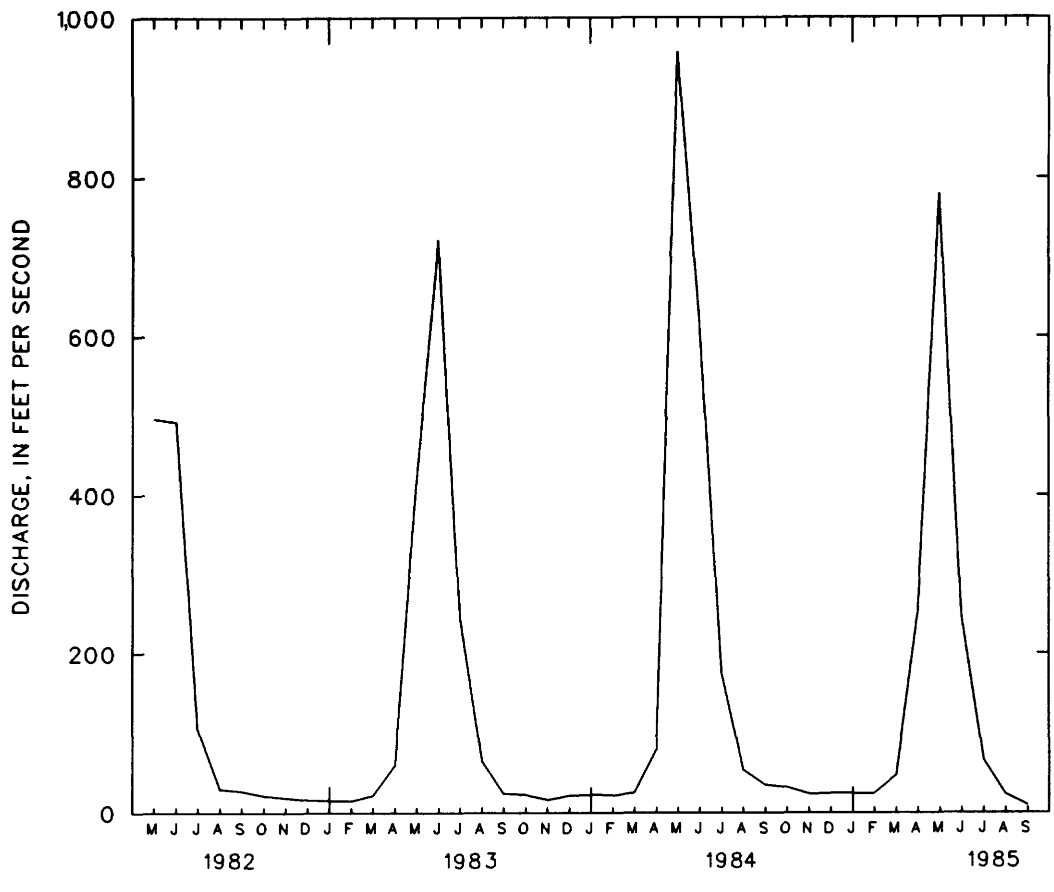

Figure 2.--Monthly mean stream discharge at streamflow-gaging station 09041500 Muddy Creek at Kremmling, May 1982 through September 1985.

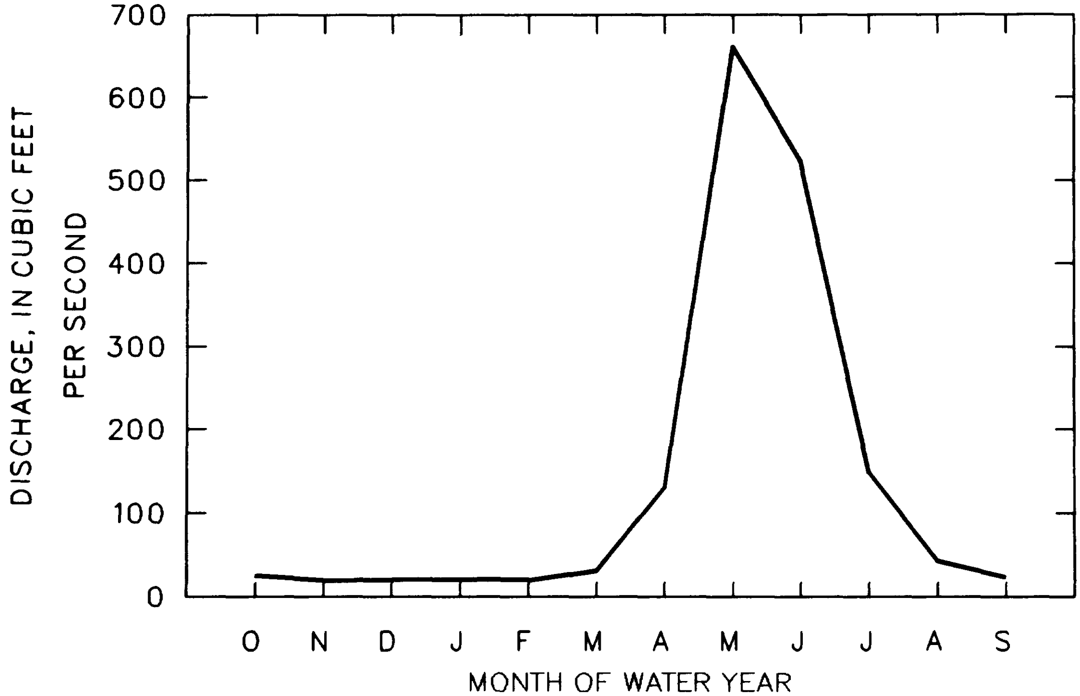

Figure 3.--Mean monthly stream discharge at streamflow-gaging station 09041500 Muddy Creek at Kremmling, May 1982 through September 1985.

SEDIMENT DISCHARGE

Suspended-sediment and bedload data were collected at the Muddy Creek gage during 1985. These sediment data were used with daily stream-discharge data to estimate the total-sediment discharge near the proposed Wolford Mountain Reservoir. The sediment data were collected from March through October 1985. More samples were collected during high stream discharge than during low stream discharge. Additional sediment samples were collected during peak stream discharge because this also is the time of maximum sediment discharge.

Suspended-Sediment Discharge

Suspended sediment, the sediment particles suspended by turbulence of the flow or existing as colloids, is the major part of the total-sediment discharge. Sediment is material mobilized by overland flow in upstream areas of the watershed, from sloughing of streambanks, or from streambed erosion, and includes organic matter and precipitates. The nature of the material in suspension is dependent on the soil, land use, precipitation, slope of the watershed, and other factors.

Seventeen suspended-sediment samples were collected during 1985 for this study. The samples were collected using the equal-width-increment method (U.S. Office of Water Data Coordination, 1977; Guy and Norman, 1970). The suspended-sediment samples were collected at two locations. During high flow, the samples were collected from the highway bridge 450 ft downstream from the Muddy Creek gage. During low flow, the creek was waded and samples were collected in a riffle section about 400 ft upstream from the Muddy Creek gage. There were no irrigation diversions or inflows between these two sampling locations. Suspended-sediment samples were not collected in Muddy Ditch because the suspended-sediment concentrations in the ditch were assumed to be similar to the suspended-sediment concentrations in Muddy Creek. The suspended-sediment discharge in Muddy Ditch was included in the suspended-sediment discharge calculated for Muddy Creek by adding the ditch discharge to the stream discharge. Suspended-sediment samples were collected across Muddy Creek at approximately 15 equally spaced verticals; two traverses were made during the high-flow season. Depth-integrated suspended-sediment samples from each traverse were combined at the laboratory and analyzed to determine average concentration and particle-size distribution of the sediment. The duplicate sample from the second traverse was used to verify the concentrations or it was analyzed for complete particle-size distribution. Stream discharge also was measured at this time using standard techniques described by Rantz and others (1982). Stage was continuously recorded at the Muddy Creek gage.

Instantaneous measurements of water temperature and stream discharge at the Muddy Creek gage are summarized in table 1. Stream-discharge, suspended-sediment-concentration, suspended-sediment discharge, bedload-discharge, and total-sediment discharge data are summarized in table 2. Particle-size distribution of suspended sediment is summarized in table 3.

Table 1.--*Summary of water-temperature and stream-discharge data at streamflow-gaging station 09041500 Muddy Creek at Kremmling, March through October 1985*

[--, no data]

Date of sample	Time of sample	Temperature (degrees Celsius)	Stream discharge (cubic feet per second)	Width (feet)	Mean depth (feet)	Mean velocity (feet per second)	Area (square feet)
03-20-85	1100	0.0	72	33.0	0.70	3.14	23.0
03-29-85	1100	.0	36	38.0	.59	.38	22.5
04-17-85	1515	--	456	53.0	3.75	2.29	199
04-26-85	1105	4.0	286	45.0	2.16	2.95	97.1
05-01-85	1215	8.0	568	58.0	4.36	2.24	253
05-03-85	1030	8.5	702	64.0	4.83	2.27	309
05-06-85	1140	8.5	1,120	111	4.92	2.05	546
05-07-85	1010	6.5	1,140	112	4.91	2.08	550
05-09-85	1110	8.5	981	73.0	5.88	2.29	429
05-15-85	1050	8.0	621	60.0	4.37	2.37	262
05-22-85	1030	8.0	666	60.0	4.62	2.40	277
06-06-85	1040	13.0	368	52.0	3.33	2.13	173
06-27-85	1045	12.5	87	37.0	.88	2.68	32.5
07-25-85	0935	15.5	65	36.0	.66	2.70	24.0
09-03-85	0930	16.0	13	32.0	.44	.92	14.0
10-01-85	1030	4.5	12	31.0	.47	.84	14.7
10-29-85	1000	5.5	27	32.5	.54	1.58	17.4

Table 2.--*Stream-discharge, suspended-sediment-concentration, and sediment-discharge data at streamflow-gaging station 09041500 Muddy Creek at Kremmling, March through October 1985*

[--, no data]

Date of sample	Stream discharge (cubic feet per second)	Suspended-sediment concentration (milligrams per liter)	Suspended-sediment discharge (tons per day)	Bedload discharge (tons per day)	Total-sediment discharge (tons per day)
03-20-85	72	180	35	--	--
03-29-85	36	61	5.9	--	--
04-17-85	456	2,610	3,210	--	--
04-26-85	286	308	238	--	--
05-01-85	568	2,640	4,050	28	4,080
05-03-85	702	3,120	5,910	24	5,930
05-06-85	1,120	734	2,220	19	2,240
05-07-85	1,140	440	1,350	24	1,370
05-09-85	981	404	1,070	17	1,090
05-15-85	621	175	293	27	320
05-22-85	666	311	559	35	594
06-06-85	368	256	254	5.4	259
06-27-85	87	67	16	.15	16
07-25-85	65	631	111	--	--
09-03-85	13	59	2.1	--	--
10-01-85	12	56	1.8	--	--
10-29-85	27	54	3.9	--	--

Table 3.--*Particle-size distribution of suspended sediment in samples collected at streamflow-gaging station 09041500 Muddy Creek at Kremmling, March through October 1985*

[--, no data]

Date of sample	Percent finer than indicated size, in millimeters							
	1.0	0.500	0.250	0.125	0.062	0.016	0.004	0.002
03-29-85	--	--	--	--	95	--	--	--
04-17-85	--	--	--	--	93	--	--	--
04-26-85	--	--	--	--	86	--	--	--
05-01-85	--	--	--	--	88	--	--	--
05-03-85	--	--	100	99	93	68	49	42
05-03-85	--	--	--	--	89	--	--	--
05-06-85	--	100	99	97	95	91	76	59
05-06-85	--	--	--	--	96	--	--	--
05-07-85	100	99	97	96	95	88	70	58
05-07-85	--	--	--	--	96	--	--	--
05-09-85	100	99	98	94	89	80	63	52
05-15-85	--	--	--	--	34	--	--	--
05-22-85	--	--	--	--	80	--	--	--
06-06-85	--	--	--	--	79	--	--	--
06-27-85	--	--	--	--	56	--	--	--
07-25-85	--	--	--	--	99	--	--	--
09-03-85	--	--	--	--	91	--	--	--
10-01-85	--	--	--	--	77	--	--	--
10-29-85	--	--	--	--	89	--	--	--

Analysis of the 1985 suspended-sediment data (table 2) indicated that the suspended-sediment concentrations were related to stream discharge and time of year. Increases in stream discharge generally were associated with increases in suspended-sediment concentration. During the first part of the snowmelt runoff or rising stage period (March through early May), suspended-sediment concentrations were initially large and were caused by the flushing of easily mobilized sediment and by sloughing of streambanks. Because of this initial flushing, suspended-sediment concentrations increased before the annual peak stream discharge. In mid-April, stream discharge increased slightly, with a large increase in suspended-sediment concentration. The stream discharge then decreased until late April, and then increased until it peaked on May 6, at 1,260 ft^3/s (no sediment sample was collected at this stream discharge). Smaller suspended-sediment concentrations were measured after the peak stream discharge. The suspended-sediment concentration was large in July (table 2) because of a rainstorm and the resultant overland flow that mobilized a large quantity of fine-grained sediment. During low stream-discharge conditions, the suspended-sediment concentrations generally were less than 100 mg/L.

Particle-size distribution of suspended sediment also exhibited some changes during the year (fig. 4). Prior to the peak stream discharge in May, more than 90 percent of the suspended sediment was finer than 0.062 mm. After the peak stream discharge, an average of 80 percent of the suspended sediment was finer than 0.062 mm, indicating a relative decrease in fine-sized particles. Results of the three samples collected during the low stream-discharge period indicate that the percentage of suspended sediment finer than 0.062 mm may increase; however, insufficient data exist to substantiate this increase.

Suspended-sediment samples were collected during a range of flow conditions to define the sediment-discharge stream-discharge relation. A large proportion of suspended-sediment samples was collected during the peak stream discharge, when most of the sediment was being transported. No samples were collected during the winter (November through March), but samples collected during other periods of low stream discharge had very small suspended-sediment concentrations.

The graph showing the relation between suspended-sediment concentration and stream discharge (fig. 5) indicates a large scatter in the concentration data. A large part of the scatter is due to differences in sediment availability at different times of the year. Given similar discharges, suspended-sediment concentrations may vary widely, depending on whether the sample was collected during the rising stage of the annual hydrograph, when larger quantities of fine-sized sediment are available for transport, or during the falling stage of the annual hydrograph, after sediment sources have been somewhat depleted (fig. 6).

Suspended-sediment discharge was calculated from the suspended-sediment concentration and stream discharge by the equation:

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

where Q_s = 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.

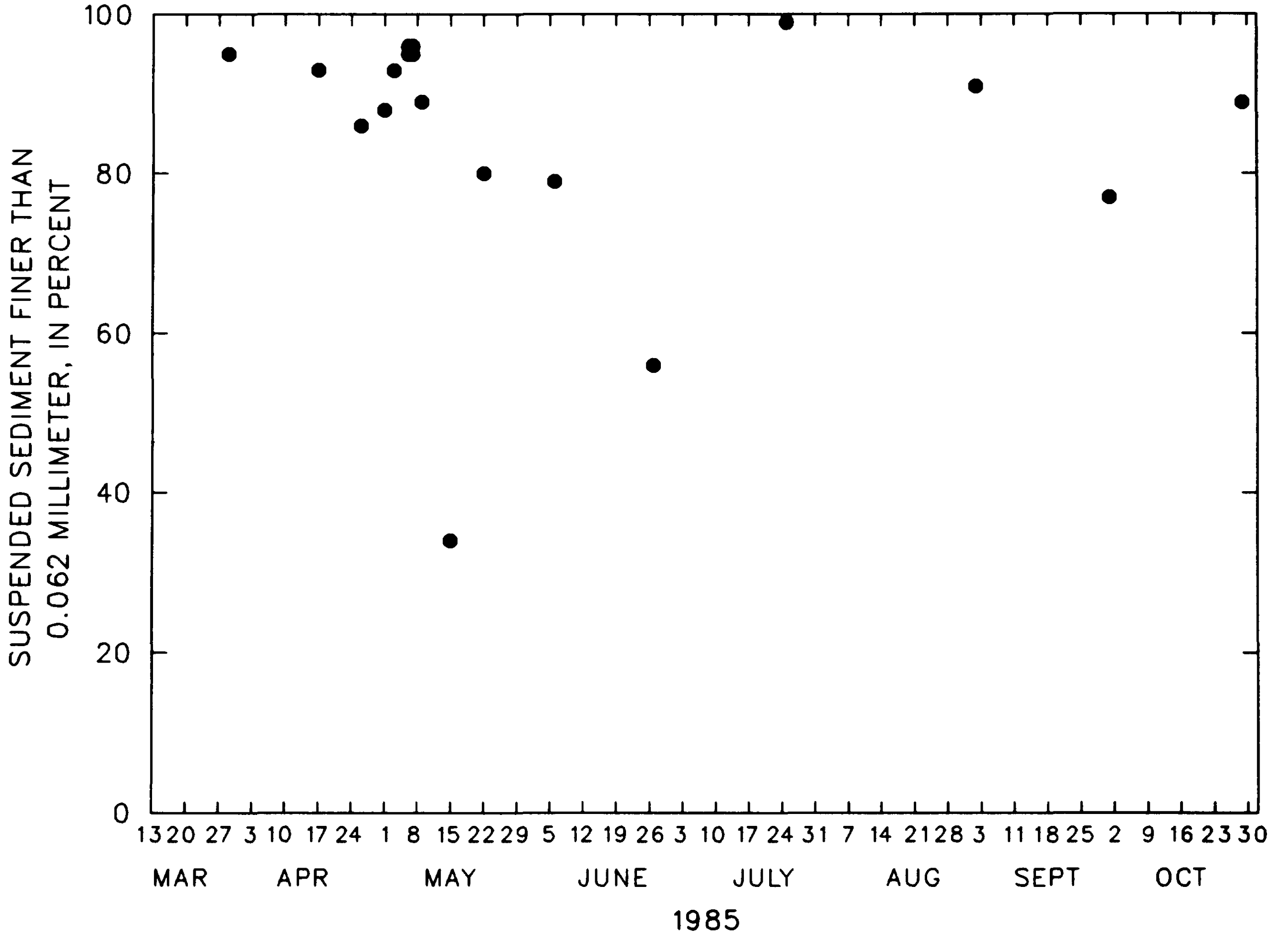

Figure 4.--Percentage of suspended sediment finer than 0.062 millimeter in size collected at streamflow-gaging station 09041500 Muddy Creek at Kremmling, March through October 1985.

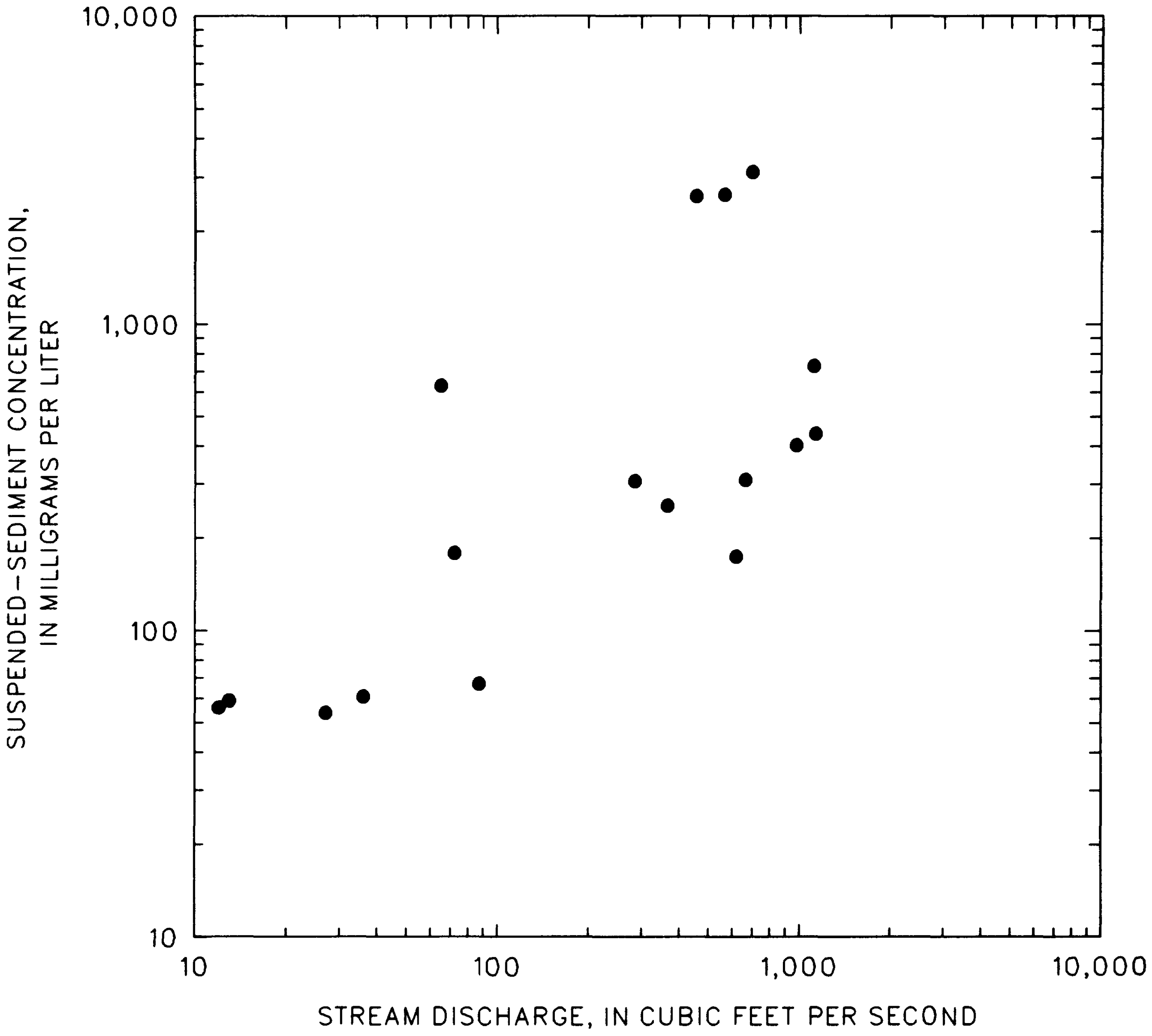

Figure 5.--Relation between suspended-sediment concentration and stream discharge at streamflow-gaging station 09041500 Muddy Creek at Kremmling.

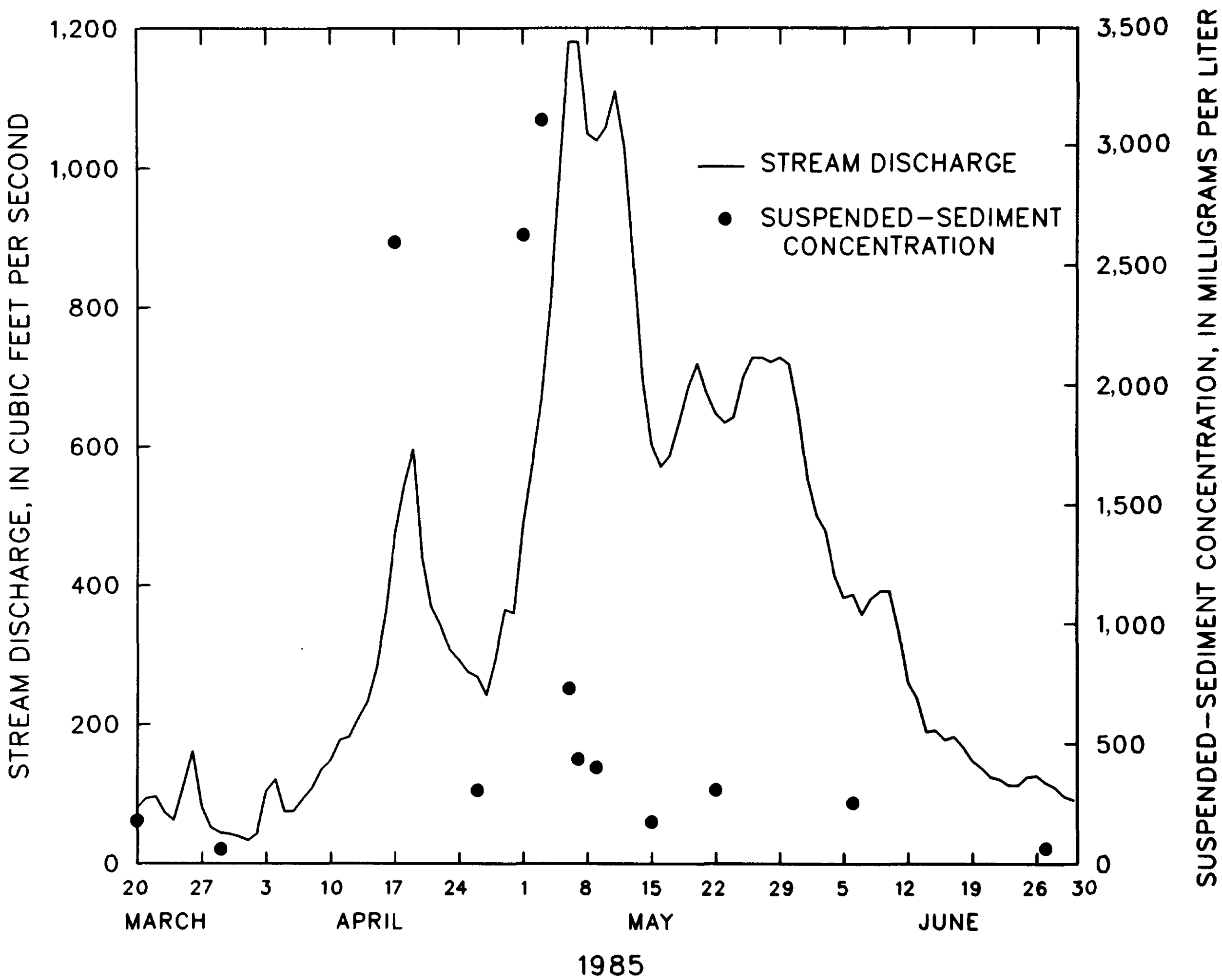

Figure 6.--Stream discharge and suspended-sediment concentration at streamflow-gaging station 09041500 Muddy Creek at Kremmling, March through June 1985.

Suspended-sediment discharge was plotted as a function of stream discharge (fig. 7). The relation between suspended-sediment discharge and stream discharge is better than the relation between suspended-sediment concentration and stream discharge, because the stream discharge is used in the calculation of suspended-sediment discharge. The relation between suspended-sediment discharge and stream discharge approximates a linear relation on logarithm-transformed data. Regression equations then were developed to predict suspended-sediment discharge when only stream discharge would be available. The natural logarithms of the suspended-sediment discharge were regressed on the natural logarithms of the stream discharge. Several equations were tested to define the best relations between suspended-sediment discharge and stream discharge. Scatter in the relation between suspended-sediment discharge and stream discharge was least, when the relations were developed on a seasonal basis (fig. 8). The data were divided into three seasonal periods: March through early May, the annual rising-stage period; mid-May through August, the annual falling-stage period; and September through February, the annual base-flow period. The division between the rising and falling stage was based on the actual suspended-sediment discharge peak, which occurred prior to the stream-discharge peak. The sample collected in July was not used in the analysis, because the large suspended-sediment concentration was not typical of the falling-stage period, but probably was due to a storm that increased stream discharge and suspended-sediment concentrations. The data also were divided using the actual suspended-sediment peak, which occurred before the stream-discharge peak, rather than the stream-discharge peak. A regression equation was not developed for the low stream-discharge period because of insufficient data. The average suspended-sediment concentration from the period was used in equation 1 to estimate suspended-sediment discharge. A summary of the suspended-sediment discharge relations is listed in table 4. Note that the relations are based on 1 year of data collection and may not represent long-term averages. The equations are presented in their natural logarithmic form, but the equations are used in the exponentiated forms in calculations in this report. Note that the simple exponentiation of the regression equations yields an estimate of the median value of the suspended-sediment discharge and not the mean value of the suspended-sediment discharge.

Bedload Discharge

Bedload discharge consists of material moving on or near the streambed by rolling and sliding and sometimes suspended in the flow, a few particle diameters above the bed. When flow velocities decrease, the particles that move as bedload will stop and become part of the bed material. Several hydraulic and supply related factors affect bedload transport in a steady flow, and as a result, the bedload discharge fluctuates temporally and spatially (Hubbell and others, 1985).

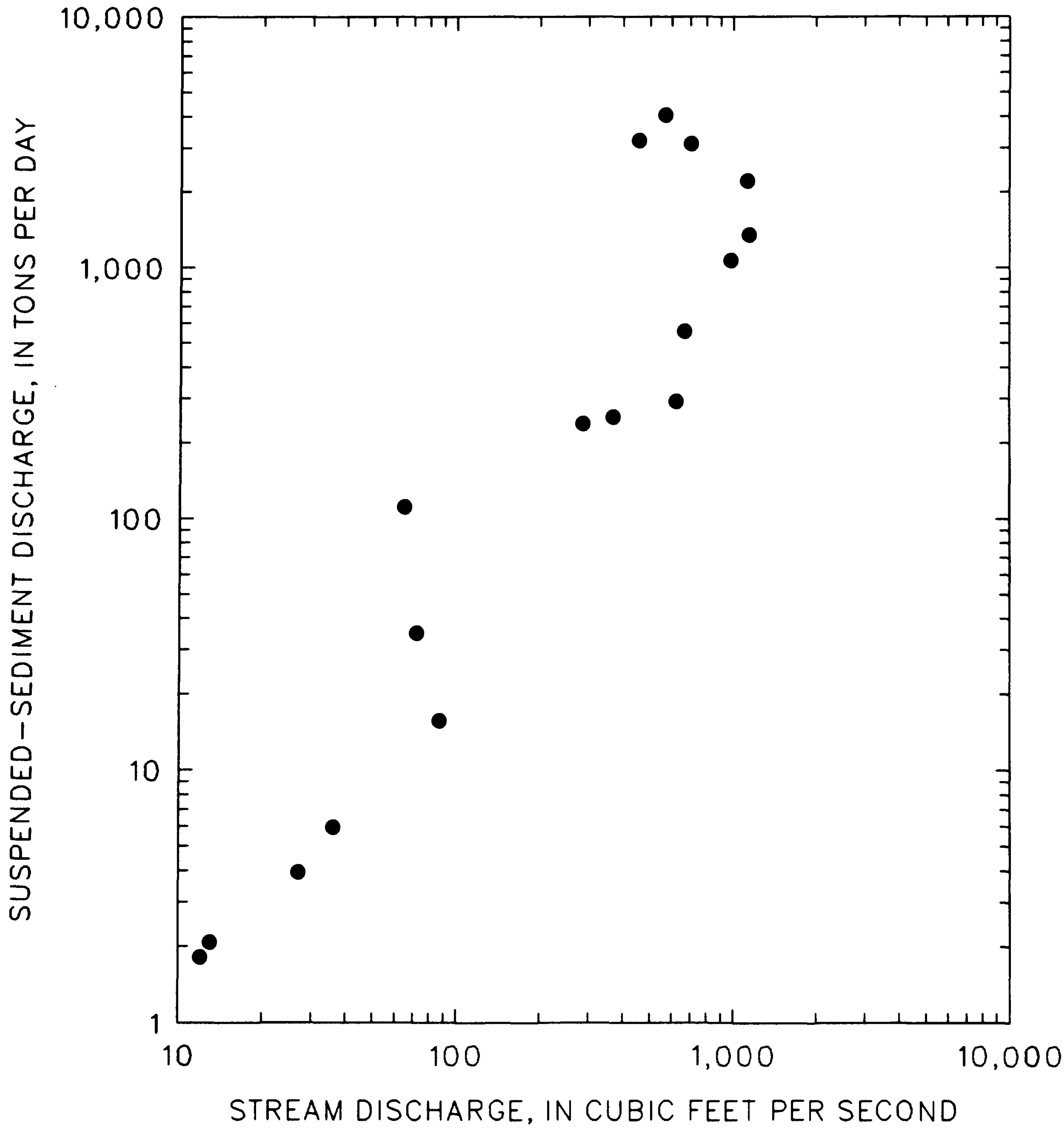

Figure 7.--Relation between suspended-sediment discharge and stream discharge at streamflow-gaging station 09041500 Muddy Creek at Kremmling.

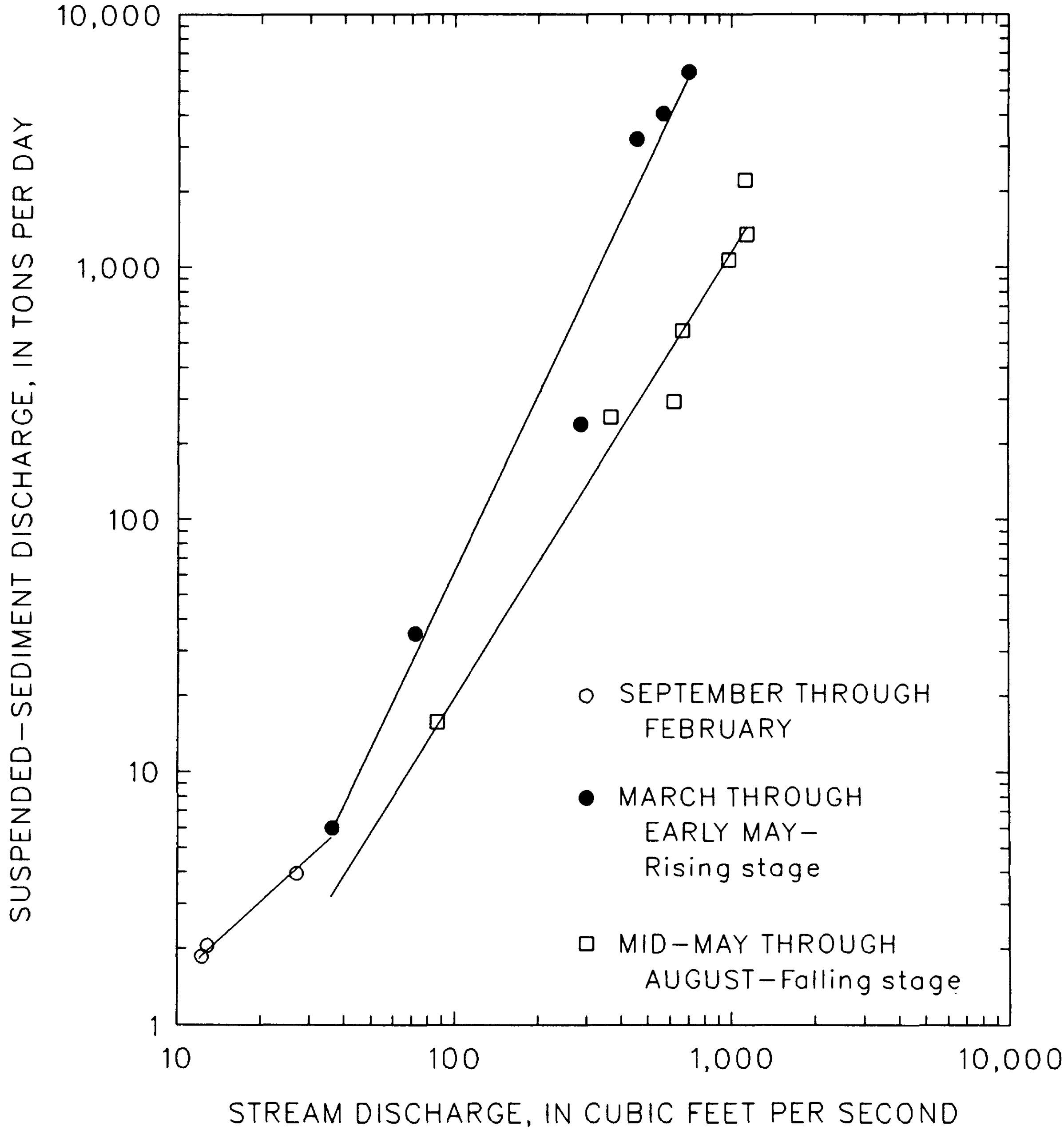

Figure 8.--Relations of suspended-sediment discharge and stream discharge at streamflow-gaging station 09041500 Muddy Creek at Kremmling.

Table 4.--*Regression relations of sediment discharge as a function of stream discharge*

[n, the number of data points; r, correlation coefficient; se, standard error of estimate, in percent; ln, natural logarithm units; Q_s, suspended-sediment discharge, in tons per day; Q, stream discharge, in cubic feet per second; Q_b, bedload discharge, in tons per day; --, insufficient data to develop regression equation]

	Statistical values for regression of dependent variables as a function of stream discharge			
Dependent variable	n	r	se	Regression equation
Suspended-sediment discharge, March through early May, rising stage.	6	0.98	65	$\ln Q_s = -6.57+2.32 \ln Q$
Suspended-sediment discharge, mid-May through August, falling stage.	7	.98	34	$\ln Q_s = -5.18+1.77 \ln Q$
Suspended-sediment discharge, September through February, base-flow conditions.	3	--	--	$\ln Q_s = -1.88+ \ln Q$
Bedload discharge.	9	.90	89	$\ln Q_b = -10.12+1.97 \ln Q$

The bedload samples from Muddy Creek were collected using Helley-Smith bedload samplers and the techniques described by Emmett (1980). Bedload samples were collected in conjunction with the suspended-sediment samples and at the same verticals during May and June. Bedload samples were not collected after June because the stream discharge had decreased sufficiently so that no measurable bedload was collected in the sampler. The bedload samples were collected: (1) to determine the part of total load moving as bedload; (2) to calculate an average bedload discharge (table 2); and (3) to determine the particle-size distribution of the bedload (table 5).

There was considerable variation in the quantity of bedload sampled and in bedload discharges. The bedload discharge was larger before and after the peak stream discharge than during the peak. The maximum measured bedload discharge, 35.2 ton/d on May 22, occurred after the peaks of suspended-sediment discharge and stream discharge. This variation seems to be incongruous, but it correlated with the stream velocity measured in the channel (table 1). At very large discharges, Muddy Creek flowed out of its banks, and, although the volume of stream discharge was larger, the stream velocities measured within the channel were less than at some smaller discharges. The bedload data were not separated on a seasonal basis as were the suspended-sediment data. The best relation between stream discharge and bedload discharge was obtained when all the bedload data were analyzed together. The regression equation is listed in table 4 and plotted with the bedload data in figure 9.

Table 5.--*Particle-size distribution of bedload in samples collected at streamflow-gaging station 09041500 Muddy Creek at Kremmling, May and June 1985*

[Composite of two traverses]

Date	Percent finer than indicated size, in millimeters									
	32.0	16.0	8.0	4.0	2.0	1.0	0.500	0.250	0.125	0.062
05-01-85	100	100	100	100	97	80	25	2	1	0
05-03-85	100	100	100	99	92	78	42	3	2	1
05-06-85	100	100	100	98	94	78	38	2	1	0
05-07-85	100	100	100	99	93	67	24	2	0	0
05-09-85	100	100	100	98	91	59	18	1	0	0
05-15-85	100	100	99	95	80	55	20	2	1	0
05-22-85	100	100	99	93	79	49	16	1	1	0
06-06-85	100	100	98	96	94	84	42	3	1	1
06-27-85	97	70	70	62	53	33	14	3	1	0

The bedload discharge was variable within the cross section. Most of the bedload sample was collected at midchannel, where the stream velocities were largest. A composite sample from two traverses was made for each bedload sample because there could be a considerable variation in the quantity of bedload collected during each traverse. The average bedload discharge then was used in the analysis.

Particle-size distribution of bedload was less than 16 mm, except on June 27, when 97 percent or more of the particles were finer than 32 mm in size. Larger sized particles could have been moving because the mean velocity was 2.68 ft/s and several verticals had velocities larger than 4.00 ft/s at a discharge of 87 ft^3/s. The bedload sample was collected in a riffle section, where the bed slope and also the water-surface slope probably were steeper, enabling larger sized particles to be transported.

Total-Sediment Discharge

Measured instantaneous suspended-sediment discharge and instantaneous bedload discharge were added together to determine total-sediment discharge (table 2). On the average, suspended sediment accounted for more than 97 percent of the total-sediment discharge on the 9 days that both suspended sediment and bedload were measured (fig. 10). On May 15 and 22, days following the peak suspended-sediment concentration and stream discharge (fig. 6), this percentage decreased. The midchannel velocities at a smaller stream discharge also were larger than the midchannel velocities at a larger stream discharge.

Combining the suspended-sediment discharge and the bedload discharge measured with the Helley-Smith sampler may overestimate the total-sediment discharge. The bottom 0.3 ft of the stream is not sampled by the equipment used to sample suspended sediment, but the suspended-sediment discharge is

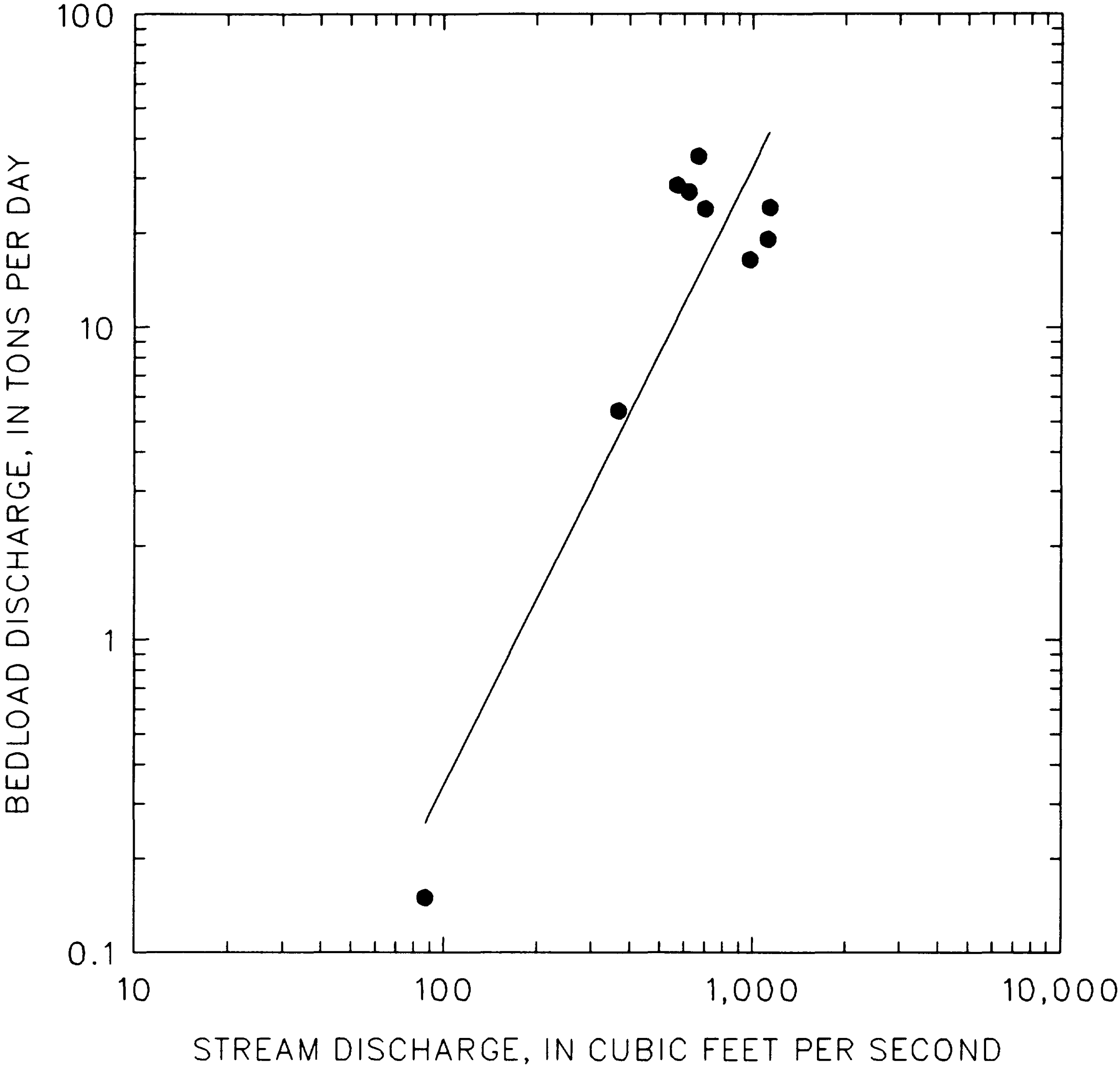

Figure 9.--Relation of bedload discharge and stream discharge at streamflow-gaging station 09041500 Muddy Creek at Kremmling.

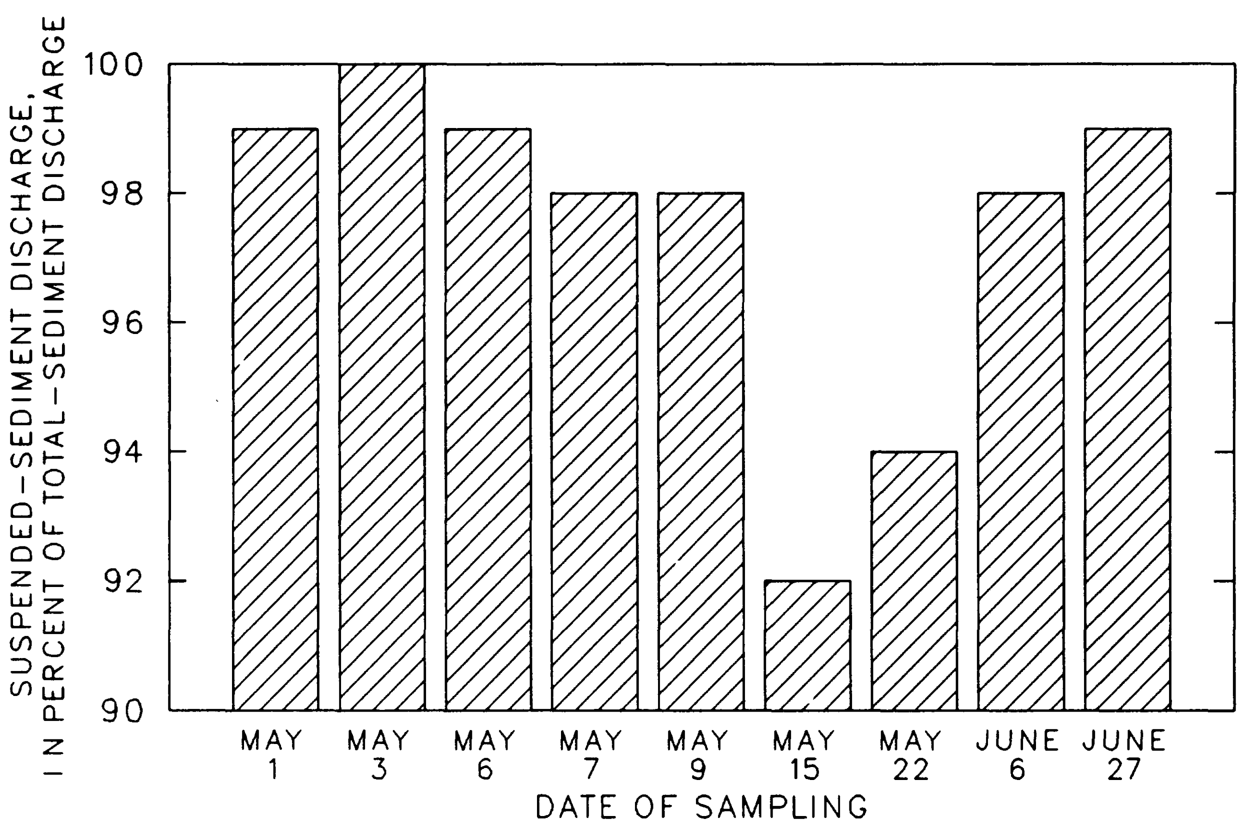

Figure 10.--Relative percentage of suspended sediment in samples collected at streamflow-gaging station 09041500 Muddy Creek at Kremmling, May and June 1985.

calculated by multiplying the depth-integrated suspended-sediment concentration by the total-stream discharge. Therefore, an extrapolation of suspended sediment in the bottom 0.3 ft of flow is included in the computation of suspended-sediment discharge even though it is not sampled. The Helley-Smith bedload sampler will collect sediment coarser than 0.25 mm in the bottom 0.3 ft of flow. As a result, some of the suspended sediment coarser than 0.25 mm may be accounted for in both the suspended-sediment discharge and the bedload discharge, leading to a potential overestimation of total-sediment discharge. In Muddy Creek, 97 percent or more of the measured suspended sediment is finer than 0.25 mm (table 3), and it is probable that little, if any, of this material was collected in the Helley-Smith sampler; therefore, corrections were not needed to the computation of total-sediment discharge.

Annual Sediment Discharge

Daily suspended-sediment discharge was estimated for the Muddy Creek gage by using 3 complete years of daily stream-discharge records and the suspended-sediment-discharge relations developed during this study. The estimated daily suspended-sediment discharges were summed to obtain annual suspended-sediment discharges for 3 water years. A computer program (J.E. Kircher, U.S. Geological Survey, oral commun., 1985) was used to calculate the mean daily suspended-sediment discharge by using the mean daily stream discharge and the appropriate regression equation. The program uses regressions of suspended-sediment discharge and stream discharge for various seasons of the year. The program identifies the date of the maximum mean stream discharge for each water year; the user estimates the date of the peak suspended-sediment concentration; the appropriate equation is applied. The three different periods of the year then are based on the suspended-sediment concentration rather than the stream discharge. During 1985, the peak suspended-sediment concentration occurred before the peak stream discharge, so the peak suspended-sediment concentration was assumed to have occurred several days before the peak stream discharge in the 2 previous years. Mean annual suspended-sediment discharge then was calculated for Muddy Creek for the 1983 through 1985 water years.

A mean annual suspended-sediment discharge of 80,700 tons/yr was calculated for the proposed Wolford Mountain Reservoir for the 1983 through 1985 water years. On the basis of the data collected in 1985, suspended sediment was assumed to account for 97 percent of the total-sediment discharge. Therefore, the total-sediment discharge was approximated by the suspended-sediment discharge multiplied by 1.03. This resulted in a calculated mean annual total-sediment discharge of about 83,000 tons/yr for the 3 years of data. Actual annual total-sediment discharges ranged from 64,800 tons/yr in 1985 to 110,000 tons/yr in 1984. Note that annual total-sediment discharge estimates were based on 3 years of stream discharge data. However, relations between sediment and stream discharge were based on several measurements made during only 1 year and these 3 years of stream-discharge data were from water years having larger than average stream discharges. These relations may change with the incorporation of additional data.

EFFECT OF SEDIMENTATION RATE ON THE PROPOSED WOLFORD MOUNTAIN RESERVOIR

Several major factors affect sediment deposition in a reservoir: (1) Sediment-inflow rate, (2) particle size of the sediments, (3) specific weight of the deposited sediment, (4) trap efficiency of the reservoir, and (5) reservoir size and operation. The sedimentation rate of a reservoir and the resultant decrease in water-storage capacity can be estimated using sediment-discharge data, particle-size distribution of the sediment, specific weight of the deposited sediment, and the operational plans and dimensions of the proposed reservoir.

Reservoir trap efficiency is defined as the percentage of incoming sediment that remains in the reservoir; it is dependent on the reservoir size and stream discharge into the reservoir. A trap efficiency of 100 percent, which usually is assumed for reservoirs the size of the proposed Wolford Mountain Reservoir, was calculated using the Churchill method (Vanoni, 1975). The reservoir dimensions for Wolford Mountain Reservoir at site C were used in the calculations because this proposed site most likely would be constructed if the reservoir were to be built. Site C is the smallest proposed reservoir and would be the most affected by sedimentation. A water-storage capacity of 60,500 acre-ft and a length of 5.5 mi (Western Engineers, Inc., 1983) were used.

Specific weight of sediment is used to convert sediment discharge in units of dry weight into units of volume it would occupy in the reservoir. The initial specific weight of sediment was calculated using a method based on particle-size distribution of the incoming sediment and reservoir operation classification (Strand, 1974). Suspended sediment in samples collected at the Muddy Creek gage had a mean particle-size distribution of 53 percent clay, 41 percent silt, and 6 percent sand. The particle-size distribution of the suspended sediment was used in the calculation because it accounted for more than 97 percent of the sediment discharging into the proposed reservoir. The initial specific weight was estimated to be 48.3 lb/ft^3.

The average specific weight of the sediment deposits would increase with time as compaction occurs and the void space diminishes. Average specific weights were calculated for several time periods (Strand, 1974) during the expected operation of the reservoir. The average specific weight of the deposits is expected to increase to 59.4 lb/ft^3 after 25 years and to 65.4 lb/ft^3 after 100 years.

The weight of the sediment deposits in the reservoir can be estimated for a period of interest by multiplying the mean annual total-sediment discharge of Muddy Creek (83,000 tons/yr) times the number of years times the trap efficiency. That value then is converted to pounds, and divided by the average specific weight of the sediment deposits to obtain the volume, in cubic feet. Volume, in cubic feet, is converted to acre-feet, and the point in expected operation of the reservoir can be calculated after a certain period of sediment depostion.

The estimated water-storage capacity at site C of the proposed Wolford Mountain Reservoir is shown in figure 11. The present rate of mean annual total-sediment discharge would cause a 10-percent decrease in water-storage capacity after 100 years.

The sedimentation rate of the proposed Wolford Mountain Reservoir, determined for this study, was dependent on several assumptions and factors affecting sediment discharge. One assumption was that the 3 years of stream-discharge data were adequate for predicting future stream discharge. The quantity of data is very limited and the data may not be representative of actual long-term averages. The 3 years of stream-discharge data were collected during water years that had larger than average stream discharges. A second assumption is that sediment data from 1 year accurately describe the relations between stream discharge and sediment discharge. Sediment data from 1 year may not describe long-term trends. This 1 year of sediment data also was collected during a water year having larger than average stream discharges. Man-induced or climatic changes could change the stream discharge, sediment availabilty, or the relation between the stream discharge and sediment discharge.

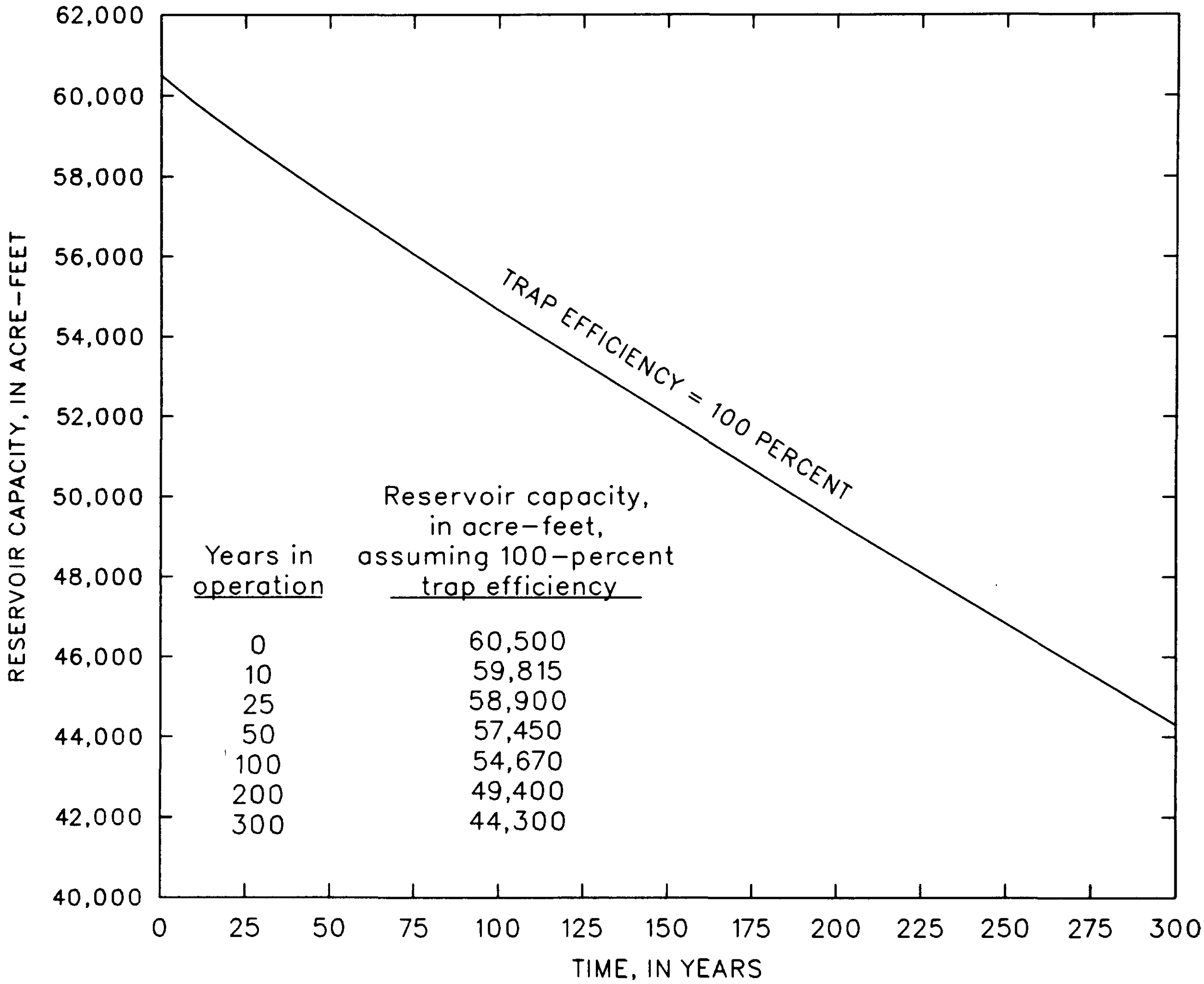

Figure 11.--Water-storage capacity of the proposed Wolford Mountain Reservoir at site C, based on projected sediment discharge of Muddy Creek.

SUMMARY

Suspended- and bedload-sediment data were collected at streamflow-gaging station 09041500 Muddy Creek at Kremmling, to determine total-sediment discharge at this station. Statistical relations between suspended-sediment discharge and stream discharge were determined for data sets that were divided on a seasonal basis: rising stage, falling stage, and base-flow period. The statistical relation between bedload discharge and stream discharge was determined from a single data set which consisted of all collected data. Total-sediment discharge, the sum of suspended-sediment discharge and bedload discharge, was largest prior to the annual peak stream discharge and decreased thereafter. At least 97 percent of the total-sediment discharge was in the suspended phase.

Mean annual total-sediment discharge in Muddy Creek near Kremmling was estimated to be 83,000 tons/yr for the 1983 through 1985 water years. The total-sediment discharge ranged from 64,800 tons/yr in 1985 to 110,000 tons/yr in 1984. At this rate of mean annual total-sediment discharge, the proposed Wolford Mountain Reservoir at site C, with a water-storage capacity of 60,500 acre-ft, would decrease 10 percent in capacity after 100 years.

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