ANNUAL REPLENISHMENT OF BED MATERIAL BY SEDIMENT TRANSPORT IN THE WIND RIVER NEAR RIVERTON, WYOMING

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CONVERSION FACTORS AND VERTICAL DATUM

Multiply	By	To obtain
inch	2.54	centimeter
foot	0.3048	meter
yard	0.914	meter
mile	1.609	kilometer
square foot	0.0929	square meter
square mile	2.590	square kilometer
cubic foot	0.02832	cubic meter
cubic yard	0.765	cubic meter
foot per second	0.3048	meter per second
cubic foot per second	0.02832	cubic meter per second
ton	908	kilogram

Sea level: In this report, "sea level" refers to the National Geodetic Vertical Datum of 1929--a geodetic datum derived from an adjustment of the first-order level nets of the United States and Canada, formerly called *Sea Level Datum of 1929.*

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By Myron L. Smalley[1], William W. Emmett[2], and A. Mainard Wacker[3]

Abstract

The U.S. Geological Survey, in cooperation with the Wyoming Department of Transportation, conducted a study during 1985-87 to determine the annual replenishment of sand and gravel along a point bar in the Wind River near Riverton, Wyoming. Hydraulic-geometry relations determined from streamflow measurements; streamflow characteristics determined from 45 years of record at the study site; and analyses of suspended-sediment, bedload, and bed-material samples were used to describe river transport characteristics and to estimate the annual replenishment of sand and gravel.

The Wind River is a perennial, snowmelt-fed stream. Average daily discharge at the study site is about 734 cubic feet per second, and bankfull discharge (recurrence interval about 1.5 years) is about 5,000 cubic feet per second. At bankfull discharge, the river is about 136 feet wide and has an average depth of about 5.5 feet and average velocity of about 6.7 feet per second. Stream slope is about 0.0010 foot per foot. Bed material sampled on the point bar before the 1986 high flows ranged from sand to cobbles, with a median diameter of about 22 millimeters.

Data for sediment samples collected during water year 1986 were used to develop regression equations between suspended-sediment load and water discharge and between bedload and water discharge. Average annual suspended-sediment load was computed to be about 561,000 tons per year using the regression equation in combination with flow-duration data. The regression equation for estimating bedload was not used; instead, average annual bedload was computed as 1.5 percent of average annual suspended load—about 8,410 tons per year. This amount of bedload material is estimated to be in temporary storage along a reach containing seven riffles—a length of approximately 1 river mile.

On the basis of bedload material sampled during the 1986 high flows, about 75 percent (by weight) is sand (2 millimeters in diameter or finer); median particle size is about 0.5 millimeter. About 20 percent (by weight) is medium gravel to small cobbles—12.7 millimeters (0.5 inch) or coarser. The bedload moves slowly (about 0.03 percent of the water speed) and briefly (about 10 percent of the time). The average travel distance of a median-sized particle is about 1 river mile per year.

The study results indicate that the average replenishment rate of bedload material coarser than 12.7 millimeters is about 1,500 to 2,000 tons (less than 1,500 cubic yards) per year. Finer material (0.075 to 6.4 millimeters in diameter) is replenished at about 4,500 to 5,000 cubic yards per year. The total volume of potentially usable material would average about 6,000 cubic yards per year.

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INTRODUCTION

The sediment load of a river commonly is considered to be a pollutant that is aesthetically displeasing and environmentally degrading. Conversely, part of the sediment load (sand and gravel) may represent a natural resource for use by society. The potential usefulness of the sediment load is enhanced when it is composed of particle sizes found in deposits on the riverbed that would be replenished by newly transported sediment after mining. As such, river deposits become renewable resources, periodically replaced by sediment transport in the river.

Acceptable gravel resources for highway construction and maintenance are becoming increasingly scarce or costly. Regulatory environmental constraints, ongoing mining of sand and gravel sources that are within economical travel distances of highways, increased public awareness of the value of such resources, and stringent engineering-quality standards for gravel are primary factors. Where available, renewable river deposits might provide local supplies of gravel.

The Wyoming Department of Transportation obtained a large tract of land in 1985 for use as a gravel source. The tract is on a large point bar formed by the Wind River near Riverton, Wyoming. Preliminary inspection showed that the active part of the point bar contained excellent quality construction gravel and finer maintenance material. This material was considered to be a potentially renewable resource available for annual removal. In order to evaluate that possibility, the U.S. Geological Survey, in cooperation with the Wyoming Department of Transportation, conducted an investigation of the quantity, size, and annual transport rates of bedload at the site. The investigation was done during 1985-87.

Selected sediment terms used in this report are defined as follows:

Bedload—Material in the water moving on or near the immobile streambed by rolling, sliding, and saltation within a few particle diameters above the streambed. In this report, bedload is expressed in tons.

Bedload discharge—A measure of the quantity (weight) of bedload per unit time, also referred to as bedload-transport rate. In this report, bedload discharge is expressed in tons per day.

Bed material—The mixture of sediment that composes a streambed. Bed material is stationary, but particle size is important to sediment transport because as energy level of a stream increases, some bed-material particles are mobilized and become part of the bedload or suspended load. In this report, composition of bed material is defined by particle-size distribution.

Suspended sediment—Material, usually small particles, suspended by turbulence of the flow or existing as colloids, and transported at about the same downstream velocity as the flowing water. Suspended sediment is distributed at all depths in flowing water. In this report, suspended sediment is expressed as concentration in milligrams per liter.

Suspended-sediment load—A general term referring to the quantity (weight) of suspended sediment in transport. In this report, annual suspended-sediment load is expressed in tons.

Suspended-sediment discharge—A computed value of the quantity (weight) of suspended sediment per unit time, also referred to as suspended-sediment transport rate. In this report, suspended-sediment discharge is expressed in tons per day.

Total sediment load—The sum of bedload and suspended-sediment load. In this report, total sediment load is expressed in tons.

Total sediment discharge—The sum of bedload discharge and suspended-sediment discharge. In this report, total sediment discharge is expressed in tons per day.

Purpose and Scope

This report quantifies the annual replenishment of bed material in the Wind River during periods of sediment transport at high flows. It also provides estimates of the amounts of gravel 12.7 millimeters (0.5 inch) or larger, which is suitable for construction, and smaller sizes suitable for other uses, such as winter abrasives.

Sediment transport was measured and analyzed in the study reach, with emphasis on bedload-transport rates and particle-size distributions. Suspended-sediment and bedload samples collected at a streamflow-gaging station cableway were used in combination with streamflow data and hydraulic geometry from discharge measurements to develop relations of suspended-sediment and bedload discharge to water discharge and to compute average annual total sediment load. Particle-size analyses of bedload samples were used to define the size composition of the material in transit. Suspended-sediment discharge data were needed for calculations of average annual total sediment load, and to develop an alternative relation for estimating bedload discharge.

Location and Description of Study Reach

The Wind River heads in northwestern Wyoming and flows southeastward to Riverton, in central Wyoming, where the study reach is located (fig. 1). Farther downstream, the name changes to the Bighorn River, which is tributary to the Yellowstone, Missouri, and Mississippi Rivers.

Most of the data for this study were collected at U.S. Geological Survey streamflow-gaging station 06228000, Wind River at Riverton, Wyoming. The station is on the left bank, 265 feet downstream from the bridge on State Highway 789, about 1 mile southeast of Riverton (fig. 1). Gage heights and bed elevations in this report are reported in feet above gage datum, which is 4,901.56 feet above sea level. The drainage area upstream from the station is about 2,309 square miles. The study reach extends from the station through a point bar that begins about 1 mile downstream.

Hydrologic measurements have been made at or near the station since 1906, and continuous hydrograph records date from 1912. Low-water measurements may be made by wading near the station, and high-water measurements are made from the cableway about 300 feet downstream (fig. 1). Hydraulic-geometry values determined from wading measurements made between the station and the cableway are consistent with values from measurements using the cableway. However, hydraulic-geometry values determined from wading measurements made upstream from the station, where the river generally is wider, may be different from those made downstream.

The flow of the Wind River at Riverton is affected considerably by upstream diversions for irrigation of about 150 square miles and by some flow regulation at several upstream reservoirs. No additional regulations or diversions of the flow have occurred since 1942, so the 45 years of streamflow record (1942-86) used herein are compatible for purposes of analysis. Years of record refers to water years, and by convention, a water year represents the period October 1 through September 30.

The Wind River is typical of snowmelt-fed streams, with high flows during late spring and early summer. Most of the water and almost all sediment is transported during May and June. Storm runoff is of short duration and does not contribute substantially to annual sediment load. The channel bottom consists mainly of sand, gravel, and cobbles; detailed size-distribution data for bed material are presented later in this report. Channel slope surveyed near the gage is 0.0010 foot per foot.

Method of Study

Streamflow is monitored at the gaging station by a continuous-stage (gage-height) recorder. Periodic discharge measurements are used to relate gage height to discharge; therefore, the continuous gage-height record enables determination of instantaneous and mean (for various time periods) discharge.

Suspended-sediment and bedload-sediment samples were collected at the cableway during May and June 1986. Suspended-sediment samples were collected using the equal-width increment (EWI) method described by Guy and Norman (1970). Bedload-sediment samples were collected with a Helley-Smith bedload sampler (Helley and Smith, 1973), generally using the procedures described by Emmett (1980). Particle-size distributions of bedload and bed material were determined by dry sieving and weighing of each sample. Each bedload sample was a composite sample from about 20 equally spaced cross-channel sampling locations at the cableway.

Multiple bed-material samples were collected at each of nine sites along a left-bank point bar about 1 mile downstream from the cableway (see fig. 1), prior to the high (bedload-transporting) flows of 1986. Bed-material sampling was repeated at two of the sites during 1987 (after the 1986 high flows, but before the 1987 high flows). The bed-material samples before and after the 1986 high flows were used to determine the approximate size composition of material under consideration for mining. Since flows did not permit pebble-count techniques, simple grab-samples of about 1 cubic foot were collected at each of several left-bank points on cross sections marked with letters in fig. 1. The point bar is the potential gravel source mentioned previously in the Introduction. Material composing the point bar is similar in size to bed material at the cableway.

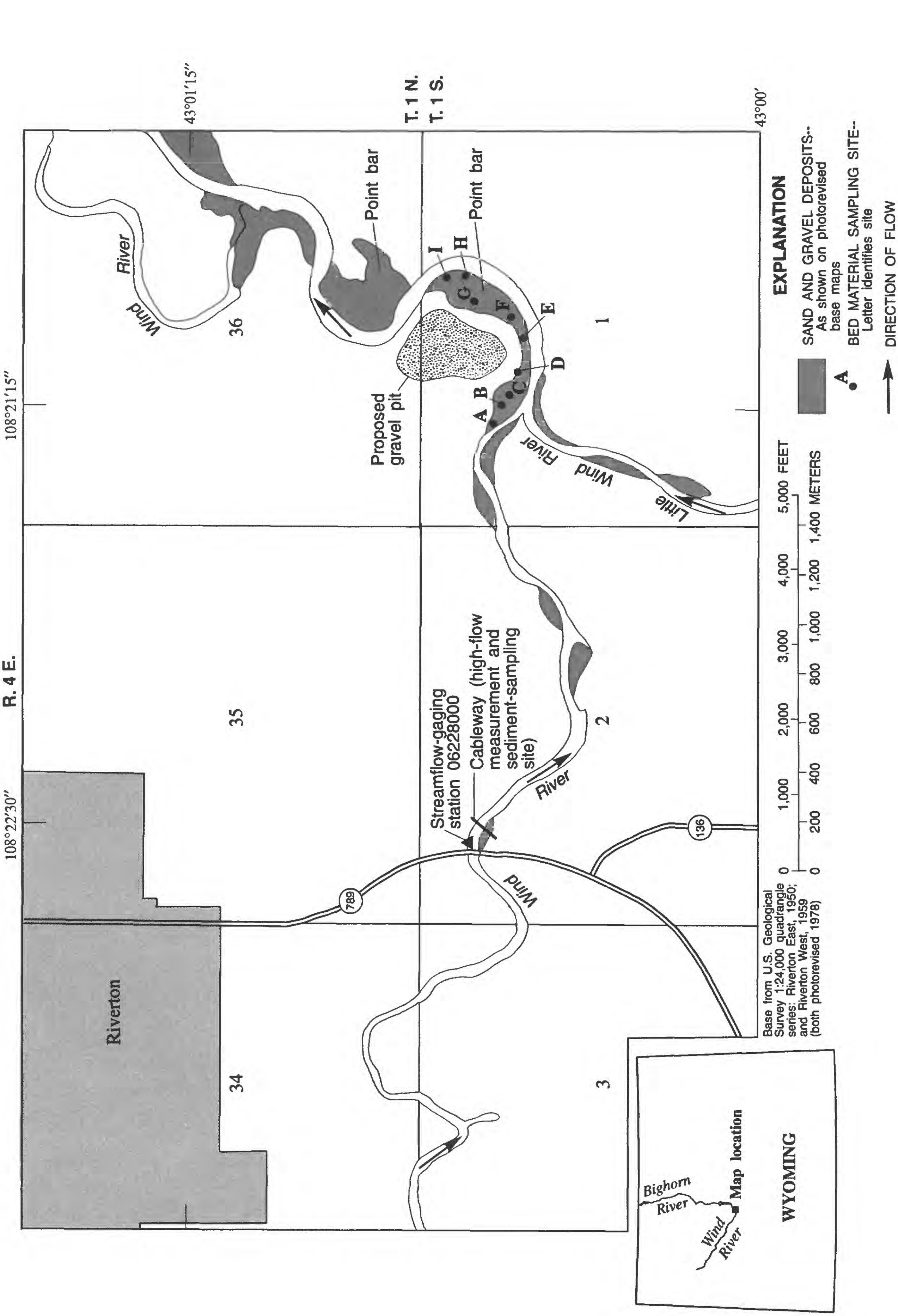

Figure 1.--The study reach along the Wind River near Riverton, Wyoming. The reach extends from streamflow-gaging station 06228000 to sampling site I.

For purposes of this study, principal data were collected during water year 1986. Streamflow during spring 1986 was larger than normal, both in magnitude and duration. Details of the streamflow and sediment transport are presented in later sections of this report.

STREAM CHARACTERISTICS

Site-specific stream characteristics (hydraulic geometry and streamflow), based on discharge measurements and statistical values determined from published discharge records, are used later in this report for calculations of total sediment load. Hydraulic-geometry characteristics include cross-section area, mean width, depth, and velocity of flow, and streambed elevation. Streamflow characteristics include annual instantaneous peak discharges, mean, maximum, and minimum daily discharges, and flow duration.

Hydraulic Geometry

The relations between selected channel features and water discharge generally are termed hydraulic-geometry relations (Leopold and Maddock, 1953). Hydraulic-geometry relations have been shown to provide a generalized description of river behavior (for example, Emmett, 1975). For a given streamflow-gaging station, the hydraulic-geometry relations are for a specific cross section, which is referred to as at-a-station hydraulic geometry. Data used to develop such relations are obtained from discharge-measurement notes.

A partial summary of discharge measurements for streamflow-gaging station 06228000, Wind River at Riverton, Wyoming, is given in table 1. The measurements are listed for water years 1985 through 1987, a period centered around the principal measurements made during water year 1986. Measurements made under ice cover, which commonly have different hydraulic-geometry relations than for open-channel flow, were discarded from the tabulation, as were measurements made upstream from the station, which may not be compatible with those made in the reach between station and cableway. The remaining 18 discharge measurements represent flows ranging from high to low discharge. Measurements of discharges larger than 1,000 cubic feet per second were made from the cableway; smaller discharges were measured by wading between the gage structure and cableway.

Hydraulic-geometry relations for Wind River at Riverton are shown in figure 2. Data from table 1 are plotted in relation to water discharge. As discussed below, a regression relation was determined for each data set by the method of least squares for log-transformed data. The mathematical relations are a power function of discharge, and both the graphical plot and mathematical relation are shown for each data set in figure 2.

For all regressions, r^2 denotes the coefficient of determination; although r^2 commonly is used to indicate a goodness of fit of the regressed line to the numerical data, more accurately it is a measure of the variation in the dependent variable that can be accounted for by the regression equation.

The graphs and relations of figure 2 enable estimations throughout the range of measured discharge for surface width, mean depth, mean velocity, flow area, gage height, and mean streambed elevation. The simple power functions are

$$W = aQ^b;$$

$$D = cQ^f; \text{ and}$$

$$V = kQ^m;$$

where W is stream surface width, in feet;
D is mean depth, in feet;
V is mean velocity, in feet per second;
Q is water discharge, in cubic feet per second;
a, c, and k are coefficients; and
$b, f,$ and m are exponents, which are the slopes of the regression lines in figure 2.

Specifically, the principal relations presented in figure 2A-C are:

$$W = 89.1\ Q^{0.05}, \quad (r^2 = 0.336); \qquad (1)$$

$$D = 0.129\ Q^{0.44}, \quad (r^2 = 0.978); \text{ and} \qquad (2)$$

$$V = 0.087\ Q^{0.51}, \quad (r^2 = 0.969). \qquad (3)$$

Table 1. *Selected water-discharge measurements at streamflow-gaging station 06228000, Wind River at Riverton, Wyoming, water years 1985-87*

[Excluding measurements made upstream from station or under ice. Gage height and mean streambed elevation are above gage datum]

Measurement number	Date	Gage height (feet)	Water discharge (cubic feet per second)	Surface width (feet)	Mean depth (feet)	Mean velocity (feet per second)	Flow cross-sectional area (square feet)	Mean streambed elevation (feet)
685	10/01/87	3.01	219	117	1.47	1.27	172	1.54
684	09/08/87	2.74	148	116	1.23	1.03	143	1.51
683	08/11/87	3.01	209	119	1.40	1.25	167	1.61
682	07/29/87	3.88	542	121	2.18	2.05	264	1.70
681	06/10/87	5.02	1,360	118	3.42	3.37	404	1.60
679	04/01/87	3.59	378	125	1.66	1.82	208	1.93
674	10/03/86	4.26	667	133	2.38	2.10	317	1.88
672	07/25/86	3.62	345	125	1.90	1.45	238	1.72
671	07/02/86	6.40	2,610	130	4.33	4.64	563	2.07
670	06/18/86	8.20	4,980	142	5.47	6.41	777	2.73
669	05/29/86	6.49	2,650	126	4.21	4.99	531	2.28
667	04/23/86	4.37	601	125	2.27	2.12	284	2.10
666	03/14/86	3.76	379	125	1.54	1.96	193	2.22
665	03/10/86	3.98	446	121	1.72	2.14	208	2.26
662	11/12/85	3.76	341	125	1.62	1.69	202	2.14
661	10/10/85	3.78	451	105	1.82	2.36	191	1.96
660	08/12/85	3.33	252	96	1.57	1.67	151	1.76
657	04/02/85	2.93	167	114	1.25	1.18	142	1.68

Further, from the continuity equation, $W \times D \times V = Q$, it can easily be shown that the product of the coefficients $a \times c \times k = 1$, and that the sum of the exponents $b + f + m = 1$.

Also,

$$A = W \times D = (a \times c)\ Q^{(b+f)}, \text{ or}$$
$$A = 11.49\ Q^{0.49},\quad (r^2 = 0.968), \tag{4}$$

where A is flow cross-sectional area, in square feet (fig. 2D).

The relations shown in figure 2A-C indicate that log-transformed depth and velocity increase linearly with log-transformed discharge at the Wind River at Riverton gage; in the range of plotted data, width changes little with increasing discharge.

The relation between gage height and discharge is usually called the stage-discharge relation. The regression equation is

$$GH = 0.63\ Q^{0.30},\ (r^2 = 0.987), \tag{5}$$

where GH is gage height, in feet above gage datum (fig. 2E).

Equation (5) was developed using only data from table 1; the generally used stage-discharge relation for that gaging station is a non-linear curve used with shifting control methods for a longer period of time. This rating (shown here for comparison, but otherwise not used in this report), with shifts for the period of the study, is approximated by the relation

$$GH = 0.36\ Q^{0.37},\ (r^2 = 0.997).$$

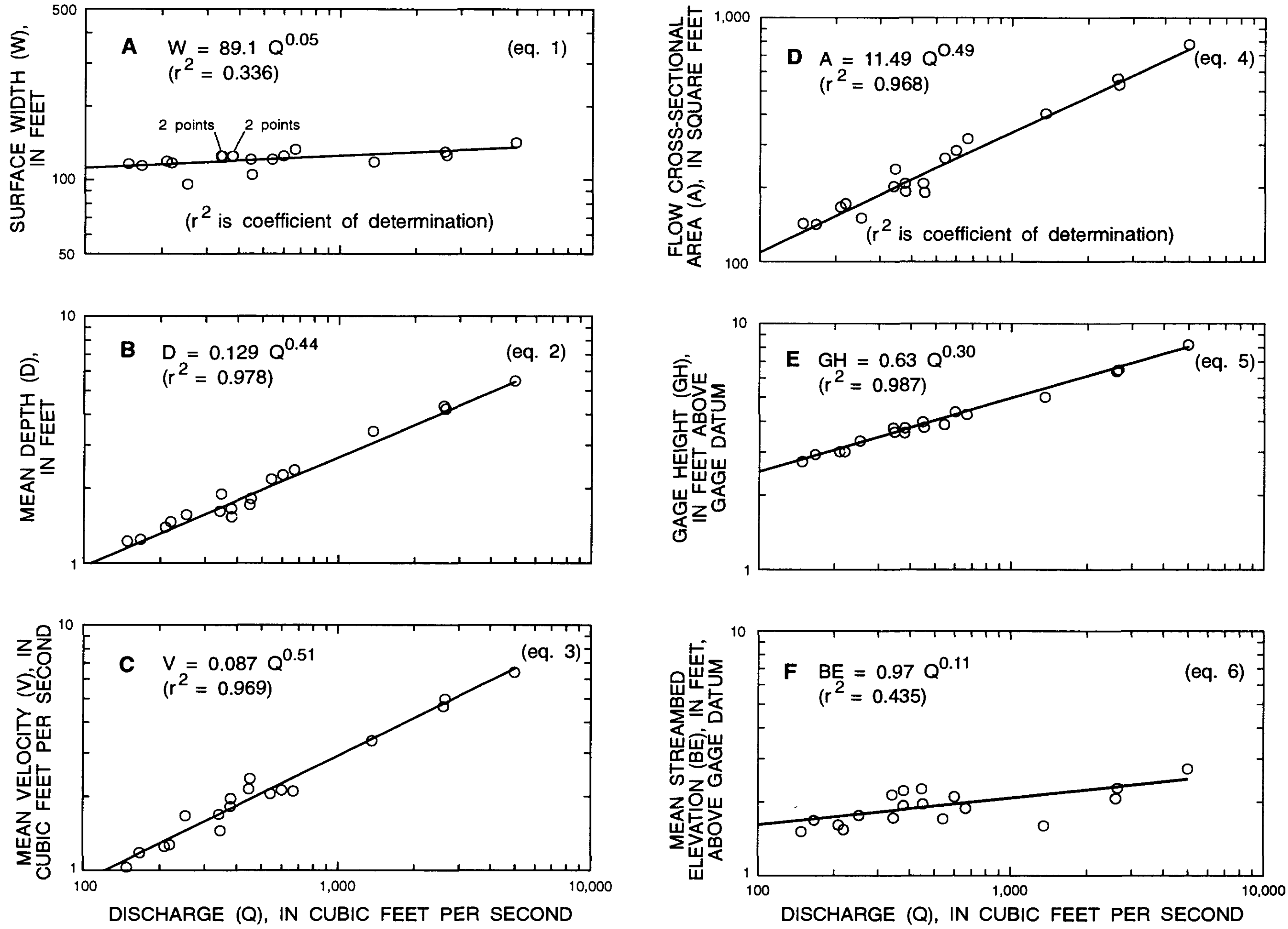

Figure 2.--Hydraulic-geometry relations at streamflow-gaging station, Wind River at Riverton, Wyoming.

Mean streambed elevation (in feet above gage datum) is simply gage height minus mean depth. The regression equation using data from table 1 is

$$BE = 0.97\ Q^{0.11},\ (r^2 = 0.435), \qquad (6)$$

where *BE* is mean streambed elevation, in feet above gage datum (fig. 2F).

The relation in figure 2F indicates that streambed elevations tend to increase slightly with increases in discharge. This tendency is compatible with observed aggradation at riffle reaches in other rivers (for example, Emmett and others, 1983) and the measurement reach is a riffle.

The streambed elevation shown in figure 2F indicates that the bed elevation may be about 0.5 foot higher during high flow than low flow. In the absence of repetitive longitudinal profiles by level survey or sonar, estimates of the volume of material in storage along the riffle during high flow are only speculation. However, assuming riffle spacings of about six channel widths (Leopold and others, 1964, p. 194), that the riffle length is about half the riffle spacing, and a stream width of about 125 feet (fig. 2A), the volume of material temporarily in storage at each riffle is about 24,000 cubic feet, and its weight is about 1,200 tons. This estimated quantity is subsequently used in this report to demonstrate possible downstream distances of annual movement of sediment particles composing the temporary fill.

Streamflow

Water discharges of the Wind River at Riverton (streamflow-gaging station 06228000) for water years 1942-86 are listed in table 2; discharges tabulated include instantaneous peak discharge, and the mean, maximum, and minimum daily discharges. The average daily discharge of the Wind River at Riverton for water years 1942-86 is 734 cubic feet per second. This discharge is computed by averaging the daily mean discharges for this period.

Peak-flow frequency calculations were performed by standard methods suggested in Interagency Advisory Committee on Water Data (1981). For the annual instantaneous peak-discharge data (table 2), frequency information is listed in table 3. These calculations indicate, for example, that in any given year there is an equal chance (exceedance probability of 0.50) of the annual peak discharge being larger or smaller than 5,920 cubic feet per second, and there is a 1-percent chance (exceedance probability of 0.01), that the annual peak will be 10,500 cubic feet per second or

Table 2. *Summary of instantaneous peak- and daily-discharge data at streamflow-gaging station 06228000, Wind River at Riverton, Wyoming, water years 1942-86*

[Average daily discharge for water years 1942-86 is 734 cubic feet per second]

Water year	Discharge (cubic feet per second)				Water year	Discharge (cubic feet per second)			
	Instantaneous peak	Daily				Instantaneous peak	Daily		
		Mean	Maximum	Minimum			Mean	Maximum	Minimum
1986	7,320	772	6,930	53	1963	9,050	741	7,050	38
1985	2,130	328	1,800	28	1962	6,660	787	6,210	58
1984	4,020	590	3,290	79	1961	4,380	402	3,430	34
1983	7,010	929	6,340	40	1960	1,980	254	1,130	16
1982	5,800	666	5,190	50	1959	4,120	313	2,930	54
1981	7,780	377	6,650	31	1958	6,740	702	5,600	50
1980	5,570	602	4,820	68	1957	9,550	1,080	8,770	180
1979	4,500	461	3,870	45	1956	8,200	966	7,600	127
1978	5,500	712	4,880	47	1955	2,720	316	1,930	10
1977	1,790	250	1,110	9.8	1954	5,510	634	4,590	37
1976	4,310	683	3,710	67	1953	7,700	529	6,570	34
1975	7,500	754	6,960	103	1952	5,740	812	4,770	61
1974	7,880	834	7,430	21	1951	7,680	1,240	6,950	270
1973	5,320	561	4,390	42	1950	4,760	978	4,450	221
1972	7,680	973	7,310	198	1949	4,860	775	4,160	135
1971	9,380	1,120	8,990	114	1948	6,030	917	5,510	18
1970	4,700	411	3,620	24	1947	8,400	1,260	8,250	170
1969	3,980	582	3,280	84	1946	3,940	737	2,830	190
1968	4,500	594	3,490	88	1945	6,070	917	5,340	140
1967	9,550	1,060	9,090	63	1944	7,290	1,010	6,630	168
1966	2,620	420	2,080	39	1943	6,600	1,280	6,220	330
1965	7,490	1,060	7,010	93	1942	6,620	985	5,820	292
1964	5,800	657	4,890	38					

larger. The reciprocal of annual exceedance probability is the recurrence interval, in years. Accordingly, an exceedance probability of 0.04 is equivalent to a recurrence interval of 25 years. For example, the 50-year flood (exceedance probability of 0.02) is estimated as about 10,100 cubic feet per second. Generally, flow frequency may be extrapolated to a recurrence interval about twice the length of record, which is about 100 years for water years 1942-86 used in table 3.

Table 3. *Peak-flow frequency at streamflow gaging station 06228000, Wind River at Riverton, Wyoming, water years 1942-86*

[Log Pearson Type-III frequency; bankfull discharge corresponds approximately to the discharge with a 1.5-year recurrence interval--about 5,000 cubic feet per second]

Annual exceedance probability	Recurrence interval (years)	Instantaneous peak discharge (cubic feet per second)
0.99	1.01	1,540
.90	1.11	3,170
.50	2.0	5,920
.20	5	7,800
.10	10	8,730
.04	25	9,600
.02	50	10,100
.01	100	10,500

Bankfull discharge commonly is assumed to have physical significance as a channel-forming discharge. Bankfull discharge of stream channels similar to Wind River has a recurrence interval of about 1.5 years (Emmett, 1975, p. 39). Assuming a recurrence interval of 1.5 years for bankfull discharge in the Wind River, interpolation of data in table 3 indicates a corresponding discharge of about 5,000 cubic feet per second. From hydraulic-geometry relations, it was determined that at bankfull discharge, the river is about 136 feet wide (eq. 1), has an average depth of about 5.5 feet (eq. 2), and has a mean flow velocity of about 6.7 feet per second (eq. 3).

Streamflow during water year 1986 was larger than normal. The Wind River peaked at a discharge of 7,320 cubic feet per second on June 7; from table 3, this peak discharge has about a 4-year recurrence interval.

Flow-duration determinations were made by standard methods. The values of daily mean discharge were arranged in decreasing order, and the number of days of occurrence for each magnitude of flow determined the percentage of time, or duration, of each flow (Searcy, 1959).

The cumulative percentage of time each discharge value was equaled or exceeded is the flow-duration array. Such an array for the Wind River (presented later in table 8) was used in computation of annual sediment loads. Although the flow-duration tabulation was prepared using daily mean discharge data, a comparison of maximum daily-flow and instantaneous-peak data (table 2) throughout the 45-year record used indicates the flow-duration array based on daily means is not substantially different from an array based on instantaneous values. This is an important consideration in computing sediment loads (for example, Ferguson, 1987). Minimum daily flows listed in table 2 were not used in the analysis, but are included to indicate the range of flows in the Wind River near Riverton.

SEDIMENT TRANSPORT AND PARTICLE SIZE

Measurements of suspended-sediment and bedload discharges were a principal emphasis of this study; sediment-discharge measurements are summarized in table 4. Total sediment discharge is the sum of suspended-sediment discharge and bedload discharge. Sediment- and water-discharge data from table 4 are plotted in figure 3 to provide ratings for instantaneous sediment discharge; least-squares linear regressions were fit to log-transformed data, and these relations are shown as solid lines on the figure. Numerically, the regression relations are:

$$G_s = 1.64 \times 10^{-4} Q^{2.25}, \quad (r^2 = 0.478); \tag{7}$$

$$G_b = 1054 \times 10^{-4} Q^{0.92}, \quad (r^2 = 0.216); \text{ and} \tag{8}$$

$$G_t = 2.14 \times 10^{-4} Q^{2.22}, \quad (r^2 = 0.481), \tag{9}$$

where G_s is the suspended-sediment discharge, in tons per day;
G_b is the bedload discharge, in tons per day;
G_t is the total sediment discharge, in tons per day; and
Q is the instantaneous water discharge, in cubic feet per second.

Table 4. *Summary of sediment-discharge measurements at streamflow-gaging station 06228000, Wind River at Riverton, Wyoming, water year 1986*

[Instantaneous water discharges are consistent with equation 5; median particle diameter, size for which one-half the sample, by weight, is finer and one-half is coarser. Data listed were used to derive equations 7-9 and are plotted in figure 3]

				Suspended sediment		Bedload		
Sample number	Date (1986)	Time (hour)	Water discharge, Q (cubic feet per second)	Concentration (milligrams per liter)	Discharge, G_s (tons per day)	Discharge, G_b (tons per day)	Median particle diameter (millimeters)	Total sediment discharge,[1] G_t (tons per day)
1	5/28	1755	3,010	5,530	44,900	332	0.5	45,300
2	5/28	2110	3,160	4,850	41,400	668	.6	42,000
3	5/29	0945	2,220	1,900	11,400	66	.5	11,500
4	5/29	1130	2,430	1,920	12,600	84	.5	12,700
5	5/30	1855	4,160	4,010	45,000	314	.4	45,400
6	5/30	1950	4,190	4,010	45,400	174	.4	45,500
7	5/30	2200	4,270	4,950	57,100	206	1.0	57,300
8	5/30	2200	4,270	4,950	57,100	296	18	57,400
9	5/31	0800	3,210	1,910	16,600	85	.4	16,600
10	5/31	0800	3,210	1,810	15,700	109	.5	15,800
11	6/02	1520	4,940	3,050	40,700	405	.5	41,100
12	6/02	2040	5,560	3,990	59,900	222	.5	60,100
13	6/03	0750	5,570	2,630	39,600	111	.5	39,700
14	6/04	2150	6,680	2,720	49,100	98	.5	49,200
15	6/05	0540	7,230	2,080	40,600	531	15	41,100
16	6/05	0935	6,910	1,720	32,100	531	.6	32,600
17	6/12	1540	4,360	1,890	22,200	394	.4	22,600
18	6/12	2030	4,570	1,760	21,700	288	.4	22,000
19	6/13	0700	3,600	963	9,360	254	.4	9,610
20	6/24	1640	3,090	842	7,020	171	.4	7,200
21	6/24	1935	3,190	773	6,660	158	.5	6,820
22	6/25	0820	2,550	483	3,330	80	.5	3,410
23	6/26	1550	2,830	593	4,530	315	.4	4,850
24	6/26	2120	2,890	274	2,140	94	.5	2,230
25	6/27	1010	2,380	203	1,300	153	.5	1,460

[1] The total sediment discharge may be different from the sum of suspended-sediment and bedload discharges because of rounding differences.

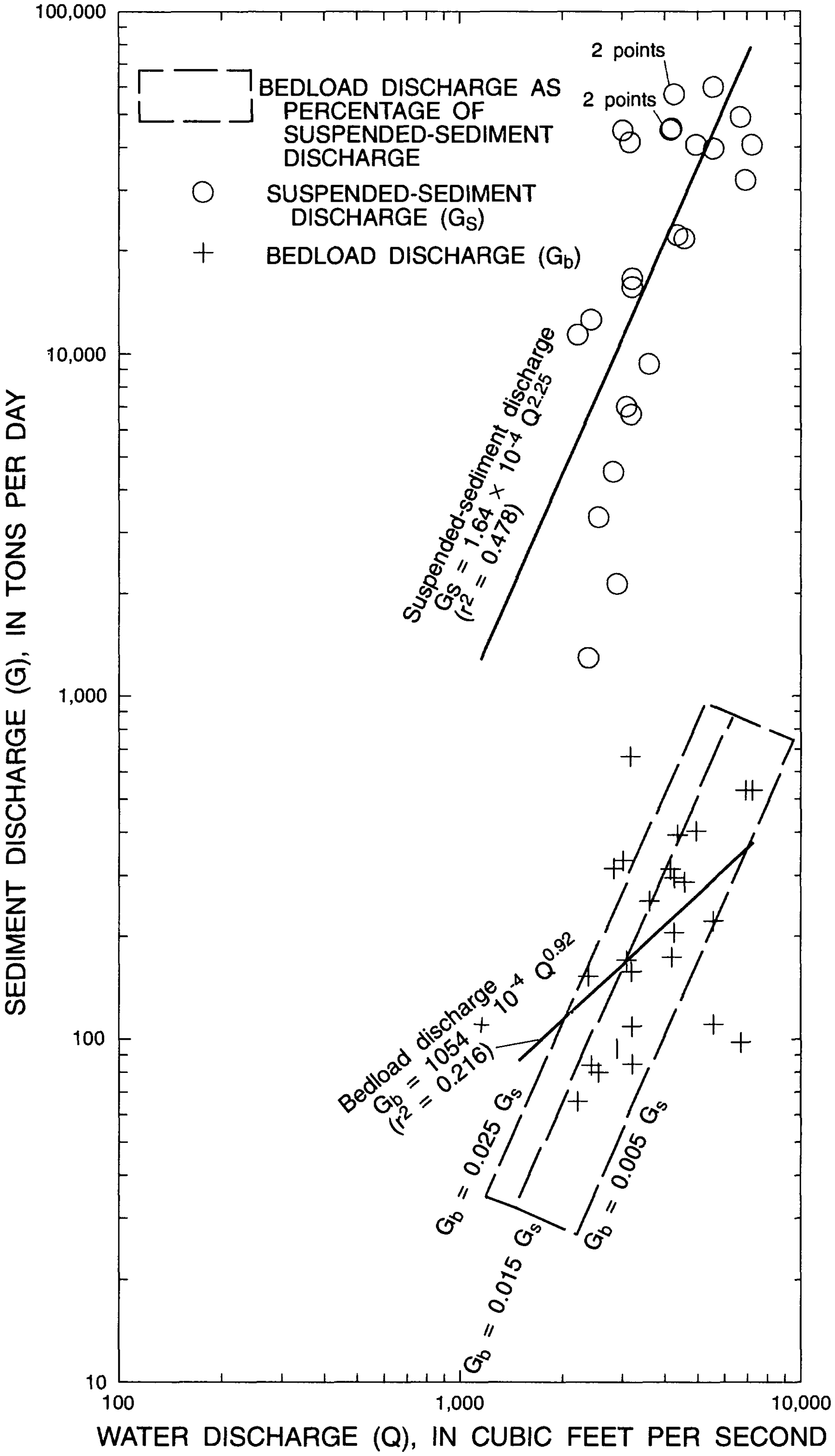

Figure 3.--Relation of suspended-sediment discharge and bedload discharge to water discharge at streamflow-gaging station Wind River at Riverton, Wyoming, May 28-June 27, 1986.

The regression equation for bedload discharge (eq. 8) is not totally consistent with past experience and is an example where a least-squares regression of sediment data may not be satisfactory. Primarily, the slope of the least-squares regression is sufficiently flat that bedload discharge at large flows is underestimated, and bedload discharge at small flows is overestimated. It also is likely that near the lower limit of measured bedload, bedload discharges decrease and approach zero at smaller water discharges.

As an alternative to the least-squares regression line (eq. 8), a visual fit was used. Empirically derived regressions of measured bedload discharge as a function of water discharge for several other rivers indicate exponents (slopes) between 1.5 and 2.0 (for example, Emmett and others, 1989). For the study site, bedload discharges ranging between about 0.5 and 2.5 percent of the measured suspended-sediment discharges are indicated by the area outlined by the dashed box in figure 3. The dashed box is plotted parallel to the curve for suspended-sediment discharge and is characteristic of bedload-discharge relations in other gravel-bed rivers (Emmett, 1984).

The range in slopes within the boxed area is intermediate to the regressed value of 0.92 (eq. 8) and the boxed value (2.25 from eq. 7) in figure 3. The dashed line representing bedload discharge (G_b) equal to 1.5 percent (the midpoint of the range, 0.5-2.5) of suspended-sediment discharge (G_s),

$$G_b = 0.015\ G_s, \qquad (10)$$

provides an approximate visual fit to bedload data. This percentage relation between bedload and suspended-sediment discharge is similar to the observed trend of data for the Tanana River, Alaska (Burrows and others, 1979). For the Wind River bedload data, a visual fit within the boxed area probably is more physically representative than the least-squares statistical fit.

No particle-size analysis was run on suspended-sediment samples, but qualitatively, particles were extremely fine sand to very fine sand. All bedload samples were sieved for size; results are listed in table 5. At the end of table 5, the values labeled as "average" are unweighted, or simple arithmetic means of the individual percentages. The values labeled as "weighted average" are the arithmetic means of the individual percentages weighted by the bedload discharge at the time of sampling. Assuming that the 25 measurements listed in table 5 represent the range in actual bedload conditions, then the particle-size distribution of the total annual bedload in the Wind River at Riverton is represented by the weighted-average distribution.

Bed-material samples were obtained at each of nine downstream sites (sites A-I, fig. 1) on March 31, 1986 to define the composition of the bed prior to the 1986 period of sediment transport (high streamflows). Additional bed-material samples were collected at sites D and H on May 26, 1987 to define new deposition attributed to the 1986 flows. Particle-size determinations from those samplings were used to compare size composition of the mobile bed material with that of bedload samples collected during May and June, 1986.

The distribution of particle sizes of bed-material samples is listed in table 6. All sampling sites are on a point bar along the left bank and are about 1 mile downstream from the streamflow-gaging station (fig. 1). Sampling sites A and B are upstream of a major right-bank tributary (Little Wind River, fig. 1), and other sampling sites are opposite the tributary or slightly downstream. Averages of values for individual bed-material samples are listed by sample grouping at the end of table 6. The sample grouping A1-B3 consists of six samples of bed material collected upstream from the confluence of the Wind and Little Wind Rivers and includes only material deposited by the Wind River. The sample grouping A1-B3 is considered to be representative of bed material in this reach of the Wind River. Photographs of the river and bed material near sampling site E are shown in figure 4.

The two sets of averaged bedload particle-size data (end of table 5) and the A1-B3 set of bed material particle-size data (end of table 6) are part of the information plotted in figure 5. Bed material contains about 20 percent (by weight) sand-size and smaller material (2.0 millimeters in diameter or finer), about 70 percent (by weight) gravel (2.0-64 millimeters in diameter), and about 10 percent (by weight) cobble-size material (greater than 64 millimeters in diameter). Most of the gravel is about 10 to 50 millimeters in diameter (about 0.5 to 2 inches), and the median particle diameter is about 22 millimeters (about 1 inch).

Table 5. *Particle-size distribution of bedload samples at streamflow-gaging station 06228000, Wind River at Riverton, Wyoming, water year 1986*

[Nozzle diameter for collection of bedload samples is 76.2 millimeters; bedload discharge, see table 4 for date and time]

Sample number	Bedload discharge (tons per day)	Percentage (by weight) finer than indicated sieve size, in millimeters									
		0.25	0.5	1	2	4	8	16	32	64	128
1	332	20	50	75	78	79	81	84	86	100	
2	668	13	44	59	61	62	64	72	86	100	
3	66	14	54	94	97	97	98	98	100		
4	84	10	52	93	96	96	96	97	99	100	
5	314	23	66	83	85	86	87	89	95	100	
6	174	24	70	91	93	94	95	97	99	100	
7	206	12	39	50	51	51	52	54	75	92	100
8	296	12	35	46	46	46	47	49	64	90	100
9	85	21	57	72	73	73	74	79	94	100	
10	109	11	51	85	89	89	90	94	100		
11	405	13	54	74	80	81	85	90	95	100	
12	222	13	50	79	84	86	88	92	99	100	
13	111	16	50	70	76	81	86	93	100		
14	98	14	50	76	84	87	90	95	100		
15	531	6	33	43	45	46	47	51	66	91	100
16	531	7	38	61	64	65	67	72	83	95	100
17	394	16	66	87	90	90	91	93	97	100	
18	288	18	67	86	87	88	88	90	95	100	
19	254	15	70	96	98	99	99	100			
20	171	27	58	88	91	92	93	95	100		
21	158	8	51	79	83	83	84	86	90	100	
22	80	9	55	94	99	99	99	100			
23	315	13	75	98	99	99	99	100			
24	94	11	52	96	98	99	100				
25	153	7	58	97	100						
Average		14	54	79	82	82	83	86	91	97	100
Weighted average[1]		14	52	73	76	76	78	81	84	84	100

[1] Weighted averages are the arithmetic means of the individual percentages weighted by the bedload discharge at the time of sampling.

Table 6. *Particle-size distribution of bed-material samples collected from point bar along left bank of Wind River downstream of streamflow-gaging station 06228000, Wind River at Riverton, Wyoming*

[Sample number: Letters A-I refer to sampling sites in figure 1; numbers refer to multiple samples collected at each site]

Sample number	Date	Percentage (by weight) finer than indicated sieve size, in millimeters 0.25	0.5	1	2	4	8	16	32	64	128
		Values for individual samples									
A1	03/31/86	7	11	13	15	18	22	35	58	85	100
A2	03/31/86	7	13	15	18	22	28	42	67	94	100
A3	03/31/86	7	13	15	18	22	29	44	65	86	100
B1	03/31/86	10	16	18	21	25	30	44	70	96	100
B2	03/31/86	8	15	17	18	20	26	30	57	81	100
B3	03/31/86	11	17	19	20	23	27	36	70	87	100
C2	03/31/86	8	17	20	24	27	31	47	74	97	100
D1	03/31/86	10	20	24	28	33	43	64	87	100	
D2	03/31/86	7	13	16	18	21	27	43	71	97	100
D3	03/31/86	7	14	17	20	22	26	40	72	94	100
D4	05/26/87	44	78	79	80	80	81	84	91	100	
D5	05/26/87	8	19	22	25	27	31	47	69	88	100
D6	05/26/87	10	20	23	26	29	35	50	67	91	100
E1	03/31/86	8	13	15	16	17	18	23	52	85	100
E2	03/31/86	8	16	19	22	24	26	39	68	96	100
F2	03/31/86	16	24	26	29	32	35	46	70	95	100
F3	03/31/86	7	18	22	25	29	35	53	78	98	100
G1	03/31/86	3	7	12	19	24	28	40	59	78	100
G2	03/31/86	4	9	15	23	29	35	48	73	96	100
G3	03/31/86	6	14	18	24	29	35	47	66	83	100
H1	03/31/86	9	21	27	34	39	44	55	75	97	100
H2	03/31/86	8	16	20	26	31	39	58	86	99	100
H3	03/31/86	4	9	11	15	18	23	33	49	72	([1])
H4	05/26/87	22	40	54	69	78	84	91	98	100	
H5	05/26/87	5	13	18	24	29	35	48	69	95	100
I1	03/31/86	7	13	16	20	23	26	35	50	75	100
I2	03/31/86	7	20	33	49	58	63	70	83	99	100
		Averages of values for sample groupings									
A1, A2, A3, B1, B2, B3		8	14	16	18	22	27	38	64	88	100
D1, D2, D3, H1, H2, H3		8	16	19	24	27	34	49	73	93	100
D4, D5, D6, H4, H5		18	34	39	45	49	53	64	79	95	100

[1] Size distribution of particles larger than 64 millimeters not determined for this sample.

A

B

Figure 4.--Point bar at sampling site E along the Wind River near Riverton, Wyoming, March 31, 1986. **A**, Looking cross-stream from point bar; sampling site E is in foreground. **B**, Closeup of point-bar surface (bed material) at sampling site E.

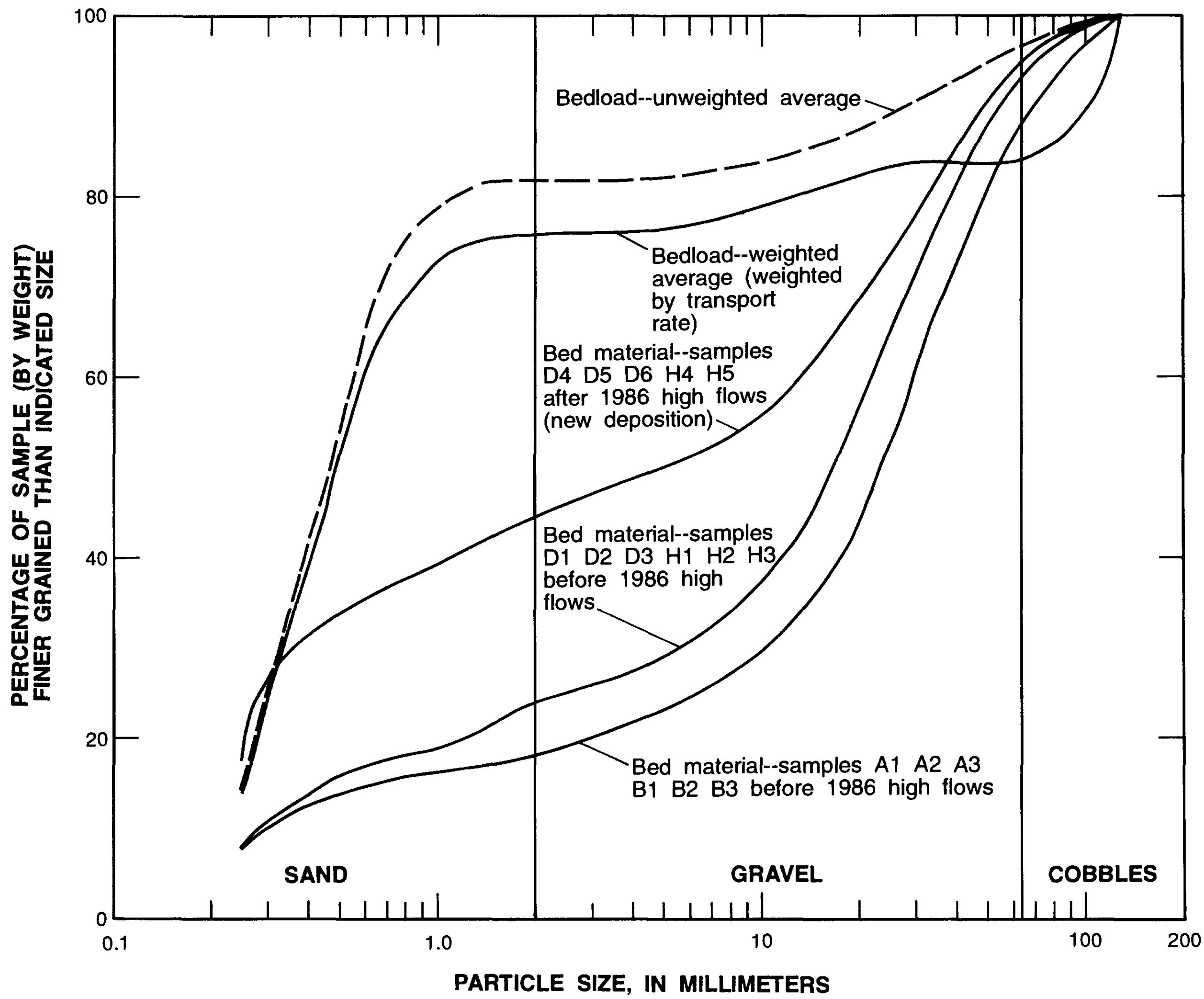

Figure 5.--Averaged particle-size distributions of bedload samples during the 1986 high flows and of bed-material samples before and after the 1986 high flows, Wind River at or near streamflow-gaging station 06228000.

Sampling sites D and H (fig. 1) represent areas sampled before and after the high (bedload-transporting) flows of 1986. The sites are along the left bank just downstream from the mouth of the Little Wind River. The particle-size distribution in bed-material samples collected at sites D and H before high flows is not greatly different from that at sites A and B (fig. 5). New deposition during the 1986 high flows resulted in particle sizes at sites D and H that were intermediate to the sizes of bed material sampled before the high flows and bedload sampled during the high flows (fig. 5).

In summary, bedload in the study reach (table 5 and fig. 5) contains proportionally by weight more sand-sized material (0.062-2 millimeters in diameter) than does the bed material (table 6 and fig. 5). Weighted-average data (table 5 and fig. 5) indicate that about 75 percent (by weight) of bedload is sand-sized and smaller—2 millimeters (0.08 inch) or finer; median diameter is about 0.5 millimeter (0.02 inch). Only about 20 percent (by weight) is medium gravel to small cobbles—12.7 millimeters (0.5 inch) or larger. About 15 percent (by weight) of bedload is cobbles, but this represents few particles. Median particle sizes interpolated from table 5 are listed adjacent to respective bedload discharges in table 4. For general computational purposes, about 20 percent (by weight) of bed-load is medium gravel to small cobbles, a particle-size range that is important for many construction activities. Much of the 80 percent transported that is smaller than 12.7 millimeters might be suitable for highway uses such as abrasives for winter sanding.

Hydraulic-geometry characteristics of the river that correspond to the sediment measurements listed in table 4 were calculated using equations 1-6 and the water discharges listed in table 4. These characteristics are listed in table 7.

ANNUAL SEDIMENT LOADS AND REPLENISHMENT

Measurements of suspended-sediment and bed-load discharge (table 4 and fig. 3) were sufficient to allow computation of the approximate average annual loads using a technique described by Miller (1951). Ratings of instantaneous suspended-sediment and bed-load discharge (fig. 3) and flow-duration data were combined to estimate the discharge of sediment for each water-discharge interval. These values were multiplied by the duration of each interval and totaled to obtain average annual discharge (total load) of sediment.

The computation of the average annual suspended-sediment load and bedload for water years 1942-86 in the Wind River at the streamflow-gaging station is shown in table 8. In this table, the flow-duration data for daily mean water discharges during the period 1942-86 are listed in columns 1-3. The percentages of time that water discharges in column 1 were equaled or exceeded are listed in column 2, and the interval percentages of time used to compute sediment loads are listed in column 3. Columns 4 and 9 list the suspended-sediment and bedload discharges calculated from equations 7 and 8 (the equations also are given in fig. 3). Columns 5 and 10 list the interval values of the annual suspended-sediment load and bed-load during each interval of time (column 3). Columns 6 and 11 are the cumulative summations of columns 5 and 10; the final summation in column 6 represents the average annual suspended load, and the final summation in column 11, the average annual bedload. Columns 7 and 8 list interval and cumulative percentages of average annual suspended load, and columns 12 and 13 list the interval and cumulative percentages of average annual bedload.

From the computations shown in table 8, average annual suspended-sediment load during water years 1942-86 is estimated to be about 561,000 tons (col. 6) and average annual bedload, about 13,900 tons (col. 11). The computations also indicate that about 90 percent of the suspended-sediment load (col. 8) was transported during the 10 percent of time of highest flows (col. 2), and only about 40 percent of bedload (col. 13) was transported during that time.

As previously discussed, bedload discharge may be better estimated as a function of suspended-sediment discharge (eq. 10) than by the least-squares regression of the measured data (eq. 8). Alternative computations for bedload discharge using equation 10 are listed in table 9. The last two columns in table 9 are replacements for columns 10 and 11 in table 8, and percentage data for bedload are the same as percentage data for suspended load. With bedload discharge estimated from suspended-sediment discharge, average annual bedload was computed to be about 8,410 tons (table 9) for the period of water years 1942-86; about 90 percent of bedload is transported during only 10 percent of the time.

Table 7. *Summary of calculated hydraulic-geometry characteristics corresponding to sediment measurements at streamflow-gaging station 06228000, Wind River at Riverton, Wyoming*

[Water discharges from table 4. Characteristics calculated from equations 1-6. Channel slope at measurement reach = 0.0010 foot per foot]

		Calculated characteristic					
Sample number	Water discharge, *Q* (cubic feet per second)	Surface width, *W* (feet)	Mean depth, *D* (feet)	Mean velocity, *V* (feet per second)	Flow cross-sectional area, *A* (square feet)	Gage height, *GH* (feet)	Mean streambed elevation, *BE* (feet)
1	3,010	133	4.38	5.17	582	6.96	2.34
2	3,160	133	4.47	5.30	596	7.07	2.35
3	2,220	131	3.83	4.43	501	6.36	2.26
4	2,430	132	3.98	4.64	524	6.53	2.29
5	4,160	135	5.05	6.10	682	7.67	2.43
6	4,190	135	5.06	6.12	684	7.69	2.43
7	4,270	135	5.10	6.18	691	7.74	2.43
8	4,270	135	5.10	6.18	691	7.74	2.43
9	3,210	133	4.50	5.34	600	7.10	2.36
10	3,210	133	4.50	5.34	600	7.10	2.36
11	4,940	136	5.44	6.66	742	8.08	2.47
12	5,560	137	5.73	7.07	786	8.37	2.50
13	5,570	137	5.74	7.08	787	8.38	2.51
14	6,680	138	6.22	7.77	860	8.85	2.56
15	7,230	139	6.44	8.08	894	9.06	2.58
16	6,910	139	6.31	7.90	874	8.94	2.57
17	4,360	135	5.15	6.25	698	7.78	2.44
18	4,570	136	5.26	6.40	714	7.89	2.45
19	3,600	134	4.74	5.67	635	7.35	2.39
20	3,090	133	4.43	5.24	589	7.02	2.35
21	3,190	133	4.49	5.33	599	7.09	2.36
22	2,550	132	4.07	4.75	536	6.63	2.30
23	2,830	133	4.26	5.01	565	6.84	2.33
24	2,890	133	4.30	5.06	570	6.88	2.33
25	2,380	131	3.95	4.59	519	6.49	2.28

Table 8. *Computation of average annual sediment loads for water years 1942-86 at streamflow-gaging station 06228000, Wind River at Riverton, Wyoming*

[Numbers in parentheses are column numbers discussed in text]

Water			Suspended sediment					Bedload				
				Annual load					Annual bedload			
Discharge (cubic feet per second) (1)	Percentage of time discharge equaled or exceeded (2)	Interval percentage of time (3)	Discharge (tons per day) (4)	Interval (tons) (5)	Cumulative (tons) (6)	Interval (percentage) (7)	Cumulative (percentage) (8)	Discharge (tons per day) (9)	Interval (tons) (10)	Cumulative (tons) (11)	Interval (percentage) (12)	Cumulative (percentage) (13)
9,000	0.01	0.01	125,000	4,580	4,580	0.82	0.82	438	16	16	0.11	0.11
7,300	.20	.19	78,400	54,400	59,000	9.70	10.52	362	251	267	1.80	1.92
5,900	.63	.43	48,600	76,300	135,000	13.61	24.12	298	468	735	3.35	5.27
4,800	1.51	.88	30,600	98,200	233,000	17.52	41.64	247	792	1,530	5.68	10.95
3,900	2.82	1.31	19,200	91,700	325,000	16.36	58.00	204	975	2,500	6.99	17.94
3,200	4.22	1.40	12,300	62,800	388,000	11.21	69.20	170	870	3,370	6.24	24.18
2,600	6.10	1.88	7,710	52,900	441,000	9.44	78.64	141	966	4,340	6.92	31.10
2,100	8.07	1.97	4,770	34,300	475,000	6.12	84.76	116	832	5,170	5.97	37.07
1,700	9.99	1.92	2,970	20,800	496,000	3.71	88.48	95	669	5,840	4.79	41.86
1,400	12.27	2.28	1,920	16,000	512,000	2.85	91.33	80	665	6,500	4.77	46.63
1,100	14.82	2.25	1,120	10,400	522,000	1.85	93.18	64	596	7,100	4.27	50.90
930	16.87	2.05	766	5,730	528,000	1.02	94.20	55	411	7,510	2.95	53.85
750	20.62	3.75	472	6,460	534,000	1.15	95.35	45	617	8,130	4.43	58.28
610	25.96	5.34	297	5,790	540,000	1.03	96.39	37	728	8,860	5.22	63.49
500	35.86	9.90	190	6,860	547,000	1.22	97.61	31	1,120	9,980	8.06	71.56
400	53.47	17.61	115	7,390	555,000	1.32	98.93	25	1,630	11,600	11.70	83.25
330	68.30	14.83	75	4,040	559,000	.72	99.65	21	1,150	12,800	8.26	91.51
220	84.43	16.13	30	1,770	560,000	.32	99.97	15	864	13,600	6.20	97.71
95	95.46	11.03	5	183	561,000	.03	100	7	274	13,900	1.97	99.68
51	98.24	2.78	1	11	561,000	.00	100	4	39	13,900	.28	99.96
9.8	100	1.76	0	0	561,000	.00	100	1	5	13,900	.04	100

Table 9. *Computation of average annual bedload for water years 1942-86, using an empirical factor, at streamflow-gaging station 06228000, Wind River at Riverton*

[Average annual bedload is computed as 1.5 percent of average annual suspended-sediment load (eq. 10); water discharges (listed) and flow-duration percentages (not listed) are identical to those for suspended sediment in columns 7 and 8, table 8. Cumulative totals are rounded after adding unrounded figures in interval column]

Water discharge (cubic feet per second)	Annual bedload (tons)	
	Interval	Cumulative
9,000	69	69
7,300	816	885
5,900	1,140	2,030
4,800	1,470	3,500
3,900	1,380	4,880
3,200	942	5,820
2,600	794	6,610
2,100	515	7,130
1,700	312	7,440
1,400	240	7,680
1,100	156	7,830
930	86	7,920
750	97	8,020
610	87	8,100
500	103	8,210
400	111	8,320
330	61	8,380
220	27	8,410
95	3	8,410
51	0	8,410
9.8	0	8,410

The line visually fitted to the bedload-discharge data in figure 3 supports the rationale for bedload being 1.5 percent of suspended-sediment load (table 9). Therefore, average annual bedload during 1942-86 is more likely to approximate 8, 410 tons (table 9) than 13,900 tons (table 8).

For comparison with the computed average annual sediment loads for 1942-86, loads were computed for water year 1986—the year during which the sediment samples for this investigation were collected (table 4). The results are listed in table 10. Daily loads were computed for all days in which daily mean discharge exceeded 1,000 cubic feet per second—a total of 46 days, or 12.6 percent of the year. Daily suspended-sediment loads for 1986 were computed using equation 7; the total for the year is about 904,000 tons. Bedload for 1986 was computed to be about 13,600 tons (1.5 percent of suspended-sediment load; eq. 10). These larger-than-average loads, compared with 561,000 tons for average annual suspended load (table 8) and 8,410 tons for average annual bedload (table 9), reflect the higher-than-average streamflow of 1986; however, average annual conditions normally are used for sediment-load computations in design considerations.

Particle-size data for bedload (weighted-average curve, fig. 5) indicate that about 20 percent (by weight) of bedload is medium-size gravel (12.7 millimeters, or 0.5 inch) or larger. This replenishment amounts to 1,500 to 2,000 tons annually, or 30,000 to 40,000 cubic feet (less than 1,500 cubic yards) for average annual flow conditions. Smaller material, with particle diameters between 0.075 and 6.4 millimeters (0.003-0.25 inch), makes up most of the remaining bedload. Allowing for about 2 to 3 percent in the 6.4-millimeter to 12.7-millimeter range and negligible quantities smaller than 0.075 millimeters, about 6,500 tons (4,500 to 5,000 cubic yards) of material with diameters between 0.075 and 6.4 millimeters is transported for average annual flow conditions.

As discussed in the section on Hydraulic geometry, it is estimated that about 1,200 tons of bedload material is in temporary storage along a riffle. Bedload along the length of seven riffles would be about 8,400 tons—approximately equivalent to the average annual bedload, estimated to be 8,410 tons (table 9). If riffle spacings are roughly equal to six channel widths, and average width is approximately 125 feet (fig. 2A), then there are seven riffles in about 1 river mile. On the basis of this reasoning and the estimate of storage along the riffle, the annual travel distance of bedload would be about 1 river mile. This travel distance was used to estimate average annual bedload velocity, for comparison with velocities in other rivers.

Assuming bedload moves about 1 river mile annually, but moves only during about 10 percent of the time, then the average velocity of bedload, when moving, is about 145 feet per day or 0.0017 foot per second. Further, if average water velocity during bedload transport is about 5.5 feet per second (fig. 2C), then the average velocity of the bedload is about 0.03 percent of the average water velocity. This average bedload velocity (relative to water velocity) is about the same value reported by Emmett and others (1983) for East Fork River in western Wyoming.

Table 10. *Computation of total sediment load for water year 1986, using regression equation and empirical factor, at streamflow-gaging station 06228000, Wind River at Riverton, Wyoming*

[Sediment loads are for daily mean discharges greater than 1,000 cubic feet per second; summation approximates load for water year 1986. Daily suspended-sediment load computed from equation 7. Daily bedload computed as 0.015 X daily suspended-sediment load. The sum of values listed for suspended load and bedload may not equal the value listed for total load because of rounding]

Daily mean discharge (cubic feet per second)	Daily sediment load (tons)			Daily mean discharge (cubic feet per second)	Daily sediment load (tons)		
	Suspended	Bedload	Total		Suspended	Bedload	Total
6,930	69,800	1,050	70,800	3,280	13,000	195	13,200
6,820	67,300	1,010	68,300	2,970	10,400	156	10,600
6,750	65,800	986	66,700	2,930	10,100	151	10,200
6,270	55,700	836	56,500	2,890	9,780	147	9,920
6,040	51,200	768	52,000	2,880	9,700	146	9,850
5,770	46,200	693	46,900	2,850	9,480	142	9,620
5,390	39,700	595	40,300	2,830	9,330	140	9,470
4,960	32,900	494	33,400	2,790	9,030	136	9,170
4,700	29,200	437	29,600	2,770	8,890	133	9,020
4,600	27,800	417	28,200	2,770	8,890	133	9,020
4,480	26,200	393	26,600	2,620	7,840	118	7,960
4,200	22,600	340	23,000	2,590	7,640	115	7,760
4,150	22,000	331	22,400	2,390	6,380	96	6,480
4,530	26,800	403	27,200	2,330	6,030	90	6,120
4,150	22,000	331	22,400	2,330	6,030	90	6,120
4,070	21,100	317	21,400	2,150	5,030	75	5,110
3,970	20,000	299	20,300	2,150	5,030	75	5,110
3,850	18,600	279	18,900	1,800	3,380	51	3,430
3,840	18,500	278	18,800	1,640	2,740	41	2,780
3,770	17,800	267	18,000	1,630	2,700	41	2,740
3,730	17,300	260	17,600	1,330	1,710	26	1,740
3,530	15,300	230	15,600	1,260	1,510	23	1,540
3,480	14,800	223	15,100	1,060	1,030	15	1,040
			Total loads (1986)		904,250	13,572	918,000

Bedload velocities reported for the Toklat River in Alaska (Burrows and others, 1988) also generally are similar to the low velocities indicated for the Wind River. Burrows and others measured bedload velocity by tracking radio transmitters implanted in gravel- and cobble-sized particles. During active bedload movement particles moved in brief intervals followed by long at-rest periods. Even longer periods of inactivity were recorded when instrumented particles were buried or abandoned due to recession or channel migration.

The similarity of estimated bedload velocities in the study reach to velocities in the East Fork and Toklat Rivers suggests similarity of the patterns of bedload-particle movement and temporary storage. It also supports the estimation that bedload in the study reach moves about 1 mile per year.

The replenishment of bedload material in the study reach, therefore, would average about 6,000 cubic yards each year, distributed along a reach about 1 mile long. The material would consist of nearly 1,500 cubic yards of material suitable for construction (coarser than 12.7 millimeters) and about 4,500 cubic yards of finer-grained material suitable for other uses, such as winter abrasives (0.075 - 6.4 millimeters).

SUMMARY AND CONCLUSIONS

The annual replenishment of bed material in the Wind River near Riverton, Wyoming by sediment transport during periods of higher flows was quantified. Also, the average annual amounts of bedload 12.7 millimeters or larger (medium gravel to small cobbles) suitable for construction, and smaller sizes (sand and fine gravel) suitable for other uses (such as winter abrasives), were estimated.

Streamflow information determined from the 45-year record (1942-86) at the streamflow-gaging station, Wind River at Riverton, Wyoming, were used to describe stream characteristics. Average daily discharge was about 734 cubic feet per second. Bankfull discharge, from log-Pearson type III frequency analysis (1.5-year recurrence interval), was estimated to be about 5,000 cubic feet per second, and the 50-year flood was estimated as about 10,100 cubic feet per second. Hydraulic-geometry relations indicate that at bankfull discharge, the river is about 136 feet wide, has an average depth of about 5.5 feet, and has a mean flow velocity of about 6.7 feet per second. Stream slope is about 0.0010 foot per foot. The streambed is mainly gravel; median particle diameter of bed material sampled on the point bar before the 1986 high flow is about 22 millimeters.

Measurements of water discharge, suspended-sediment load, and bedload during water year 1986 were used to compute regression equations for suspended-sediment discharge and bedload discharge. However, bedload discharge calculated using an empirical factor of 1.5 percent of suspended-sediment discharge (eq. 10) was selected as more physically representative than the bedload discharge calculated from the regression equation (eq. 8). The regression equation for suspended-sediment discharge (eq. 7) and the empirical factor for bedload discharge, combined with flow-duration data for 1942-86, were used to compute annual averages of about 561,000 tons of suspended sediment and about 8,410 tons of bedload transported by the river. About 1,200 tons of bedload material is estimated to be in temporary storage along one riffle; therefore, the amount of bedload material temporarily stored along seven riffles—a length of approximately 1 river mile—is approximately equivalent to the average annual bedload transported by the river.

On the basis of data collected for this study, it appears that bedload moves slowly (about 0.03 percent of the water velocity) and briefly (about 10 percent of the time). Bedload was estimated to travel about 1 river mile per year. Average bedload velocity in the study reach is similar to bedload velocities reported for some other rivers. Particle-size analyses of bedload material sampled during the 1986 high flows indicate that (1) about 75 percent (by weight) is sand—2 millimeters (0.08 inch) or finer; (2) median diameter is about 0.5 millimeter (0.02 inch); and (3) about 20 percent (by weight) is medium gravel to small cobbles—12.7 millimeters (0.5 inch) or coarser.

The average replenishment rate of large sediment (gravel and cobbles) temporarily stored on the streambed and potentially available for use is about 1,500 to 2,000 tons per year, or somewhat less than 1,500 cubic yards per year. An average of about 4,500 to 5,000 cubic yards per year of finer-grained bedload material, ranging from 0.075 to 6.4 millimeters in diameter, also would be available, as well as a very small volume of material ranging from 6.4 to 12.7 millimeters in diameter. The total volume of potentially usable material would average about 6,000 cubic yards per year.

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