Bedload measurements, East Fork River, Wyoming

(fluvial geomorphology/sediment transport/bedload)

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Geology

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ABSTRACT A bedload trap in the riverbed provided direct quantitative measurement of debris-transport rate in the East Fork River, Wyoming, a basin of 466 km^2 drainage area. Traction load moves only during the spring snow melt season. Data collected in three spring runoff seasons during which a peak flow of 45 m^3/s occurred showed that transport rate is correlated with power expenditure of the flowing water and at high flows becomes directly proportional to power as suggested by Bagnold.

General statement

Bedload is that debris carried by a river in rolling and saltation near the bed. Though bedload may best be defined as that part of the sediment load supported by frequent solid contact with the unmoving bed, in practice it is the debris moving on or near the streambed rather than in the main bulk of the flowing water.

Direct measurement of the total bedload in a natural river has been attempted only a few times previously. Other measurements of bedload have been made with bucket or basket samplers. Bedload data from rivers are exceedingly sparse. In view of this history, the data here reported are unique and are more valuable than any analysis or interpretation possible at present; therefore, the comparisons presented at the end of this report are considered tentative.

Measurement technique

Across the East Fork River near Boulder, Wyo., we constructed a concrete trough in the bed, orthogonal to the flow direction, that would constitute an open slot into which would fall any sediment debris moving near or on the streambed. The river averages about 18 m wide and at bankfull stage has an average depth of about 1.2 m. In the vicinity of the measurement reach, the bed is gravel on the riffles and bars, but coarse sand constitutes the bulk of the bedload.

The trough is 0.4 m wide and 0.6 m deep; the level of the lip or top surface corresponds to the natural bed, lower in elevation at the thalweg than near the banks. On the bottom of the concrete trough lies an endless belt of rubber, 0.3 m wide, that is threaded around some drive and guidance cylinders, returning overhead, where it is supported by a suspension bridge across the river. Thus, sediment falling into the open slot drops on the moving belt and is carried laterally to a sump constructed in the riverbank where it is scraped off the belt. From the sump, the sediment is excavated by a series of perforated buckets on an endless belt. The buckets lift the sediment to an elevation 3 m above the riverbank and dump the load into a weighing hopper. When the hopper is periodically evacuated by opening a bottom door, the accumulated sediment falls on a horizontal endless belt that carries it in a downstream direction 12 m and dumps the load on a transverse endless belt which, in turn, carries the debris toward the river and dumps it into the flowing water to be carried downstream in a normal manner. In this way, the trapped sediment is collected, weighed continuously, and returned to the river.

The concrete slot across the riverbed may be closed by a series of eight gates, each 1.83 m in length. The gated length of the slot is thus 14.6 m, constituting the full width of the bed active in bedload transport. The gates are actuated hydraulically and may be opened or closed individually. When the gates are open, the open slot or trap is 0.15 m wide.

The hopper collecting the debris stands on a large scale that may be read visually. The belt-and-bucket-transport system can accommodate a load received at a rate as great as 150 kg/min.

River description

The project site is at latitude 42°40′23″ N and longitude 109°34′16″ W. The drainage area of East Fork River at the project site is 466 km^2. About half of this basin area lies within the Wind River Mountains that rise to an elevation of 4300 m. The other half of the basin area is provided by a major tributary, Muddy Creek, that enters the East Fork about 3 km upstream of the project and drains an upland of rolling hills underlain by lower Tertiary sandstone and shale of the Wasatch Formation. The mountain part of the basin is underlain by granite and metamorphic rocks, mostly of Precambrian age. We believe that much of the sand portion of the debris load comes from the Muddy Creek basin, but most of the water during high flow comes from melting snow of the mountain area. The high-flow season is generally late May to mid June and little bedload movement occurs at other times in the year.

In the vicinity of the project, the East Fork meanders in a flood plain averaging 120 m in width which, in turn, is confined within a glacial outwash terrace of sand and gravel, the tread or surface of which is some 5.5 m above the water surface. This terrace and outcrops of Wasatch are sources of fresh sand and gravel debris wherever the river impinges laterally against them.

The level of the flood plain corresponds with the bankfull stage of the river at which the water has an average depth of about 1.2 m. The bankfull discharge is about 20 m^3/s which, in the annual flood series, has a recurrence interval of about 1.5 years.

The water-surface slope, averaged over 1.5 km of river length, is 0.0007. There are no data presently available to indicate any appreciable change of slope with stage.

Collection and presentation of data

The data in Table 1 include the hydraulic information most useful for interpretation of the transport rates recorded. Data on grain-size distribution of the trapped load are presented in Table 2. Accumulated weights of the trapped load are recorded approximately each minute for periods of 20 min to several hours.

Table 1. Summary data of river hydraulics and bedload transport

Date[a]	River discharge Total[b] Q (m³/s)	Effective[c] Q' (m³/s)	Flow area[d] A (m²)	Mean depth[e] d (m)	Hydraulic radius[f] R (m)	Mean velocity[g] $\bar{u}$ (m/s)	Bedload transport rate[h] I_b (kg/s)	Bedload size[i] D_{50} (mm)
5-26-73	17.0	16.1	15.2	1.04	0.91	1.06	0.179	1.35
5-28-73	6.66	6.50	8.02	0.55	0.51	0.81	0.008	—
5-29-73	7.50	7.30	8.70	0.59	0.55	0.84	0.010	—
6-01-73	17.0	16.1	15.2	1.04	0.91	1.06	0.173	0.45
6-02-73	18.8	17.8	16.3	1.11	0.96	1.09	0.214	0.74
6-03-73	17.5	16.6	15.5	1.06	0.93	1.07	0.219	0.71
6-06-73	11.8	11.3	11.8	0.81	0.73	0.96	0.121	0.56
6-07-73	16.7	15.9	15.0	1.03	0.90	1.06	0.237	0.60
6-08-73	20.3	19.2	17.1	1.17	1.01	1.19	0.199	0.98
5-25-74	5.44	5.34	6.99	0.48	0.45	0.76	0.051	0.54
5-26-74	10.3	9.92	10.8	0.74	0.67	0.92	0.749	0.59
5-27-74	22.9	21.5	18.6	1.27	1.08	1.15	1.60	1.03
5-28-74	32.0	29.8	23.4	1.60	1.31	1.28	2.05	1.40
5-29-74	45.0	41.5	29.5	2.01	1.58	1.41	2.65	1.52
5-30-74	34.6	32.2	24.6	1.68	1.37	1.31	0.716	1.51
5-31-74	24.4	22.9	19.4	1.33	1.12	1.18	0.589	1.40
6-01-74	25.9	24.3	20.2	1.38	1.16	1.20	0.188	0.94
6-02-74	27.2	25.5	20.9	1.43	1.20	1.22	0.118	0.99
6-03-74	31.9	29.7	23.3	1.59	1.31	1.27	0.157	0.88
6-04-74	29.9	27.9	22.3	1.52	1.26	1.25	0.261	0.92
6-05-74	28.3	26.5	21.5	1.47	1.22	1.23	0.278	0.81
5-27-75	2.44	2.44	4.03	0.28	0.27	0.61	0.019	0.70
5-30-75	2.04	2.04	3.56	0.24	0.24	0.57	0.015	—
6-02-75	5.98	5.82	7.42	0.51	0.47	0.78	0.441	0.74
6-03-75	9.52	9.13	10.2	0.70	0.64	0.90	0.720	0.78
6-04-75	10.5	10.0	10.9	0.74	0.67	0.92	0.740	1.16
6-05-75	11.2	10.7	11.4	0.78	0.70	0.94	0.885	1.26
6-06-75	21.3	20.0	17.7	1.21	1.04	1.13	2.84	1.36
6-07-75	26.6	24.8	20.5	1.40	1.18	1.21	1.89	1.28
6-08-75	27.5	25.6	21.0	1.44	1.20	1.22	1.58	1.41
6-09-75	26.2	24.3	20.2	1.38	1.16	1.20	0.763	1.35
6-10-75	15.3	14.4	14.0	0.96	0.85	1.03	0.317	1.11
6-11-75	10.6	10.1	10.9	0.75	0.68	0.92	0.100	1.02
6-13-75	16.7	15.8	15.0	1.02	0.90	1.06	0.252	0.50
6-14-75	27.6	25.7	21.1	1.44	1.20	1.22	0.843	1.27
6-15-75	31.4	29.0	22.9	1.57	1.29	1.27	1.08	1.05
6-16-75	32.8	30.3	23.6	1.62	1.32	1.28	1.08	1.19
6-17-75	23.8	22.2	19.0	1.30	1.10	1.17	0.725	1.36
6-18-75	13.5	12.8	12.9	0.88	0.79	0.99	0.097	0.59
6-19-75	10.5	10.1	10.9	0.75	0.68	0.92	0.088	0.73
6-21-75	7.48	7.23	8.64	0.59	0.55	0.84	0.029	0.70
6-22-75	7.25	7.01	8.45	0.58	0.54	0.83	0.043	0.64
6-23-75	8.55	8.24	9.47	0.65	0.60	0.87	0.056	0.77
6-24-75	11.3	10.8	11.5	0.78	0.71	0.94	0.177	0.98
6-25-75	23.2	21.7	18.7	1.28	1.09	1.16	0.763	1.10
6-26-75	13.8	13.1	13.1	0.90	0.80	1.00	0.361	0.99
7-01-75	24.8	23.1	19.5	1.34	1.13	1.18	1.97	1.63
7-08-75	23.0	21.5	18.6	1.27	1.08	1.16	0.289	0.91

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[a] Dates correspond to dates listed in Table 2.

[b] Complete river discharge including overbank flow.

[c] Discharge over 14.6 m width of bedload trap; includes all flow over the active width of the streambed.

[d] Flow area of effective width w; $A = Q'/\bar{u} = wd = 14.6d$.

[e] Mean depth over effective width; $d = A/w = A/14.6$.

[f] Hydraulic radius of effective area; $R = (A/w + 2d) = A/(14.6 + 2d)$.

[g] Mean velocity of effective discharge; $\bar{u} = Q'/A = Q'/wd = Q'/14.6d$.

[h] Transport rate of solids, in immersed weight per second, over 14.6 m width of bedload trap; immersed weight is $[(\sigma - \rho)/\sigma]$ times dry weight. $\sigma = 2650$ kg/m³, density of solids; $\rho = 1{,}000$ kg/m³, density of fluid; dry weight = 0.85 measured wet weight; therefore, $I_b = 0.53$ measured wet weight.

[i] D_{50} is median diameter of grains; complete grain-size data are given in Table 2.

Table 2. Grain-size distribution of bedload sediment

Date[a]	Percent by weight finer than sieve size (mm) indicated												
	0.25	0.35	0.50	0.71	1.00	1.41	2.00	2.83	4.00	5.66	8.00	11.3	16.0
5-26-73	1.3	3.7	9.9	22.1	36.8	52.0	67.6	80.0	88.8	95.7	98.2	99.4	99.9
5-28-73	—	—	—	—	—	—	—	—	—	—	—	—	—
5-29-73	—	—	—	—	—	—	—	—	—	—	—	—	—
6-01-73[b]	9.6	30.7	57.7	71.6	77.9	83.0	87.9	92.2	95.9	98.2	99.4	99.4	100.0
6-02-73	2.6	7.4	22.1	48.2	62.6	73.0	83.3	90.9	96.2	98.4	99.7	100.0	—
6-03-73[b]	3.2	10.3	26.7	50.1	65.4	77.3	86.9	93.2	97.4	99.1	99.8	99.9	100.0
6-06-73[b]	7.5	26.3	44.4	62.0	70.6	77.7	84.1	89.0	92.7	95.2	97.6	99.5	100.0
6-06-73[b]	4.7	16.4	40.1	58.3	67.4	76.6	86.5	94.1	97.9	99.3	99.8	100.0	—
6-08-73	1.9	4.8	13.8	34.0	51.2	65.6	77.9	87.9	94.9	98.1	99.5	99.9	100.0
5-25-74	8.9	27.0	46.2	63.8	75.9	85.1	92.3	96.1	98.2	99.2	99.7	99.9	100.0
5-26-74	4.3	13.0	38.3	62.6	75.3	83.5	90.8	95.8	98.7	99.5	99.8	100.0	—
5-27-74	1.4	4.6	15.6	32.4	48.8	62.3	75.7	85.5	92.2	95.1	96.5	97.2	97.7
5-28-74	0.5	1.9	6.9	18.8	34.1	50.4	66.8	78.8	88.2	93.2	96.1	96.1	98.5
5-29-74	0.5	1.4	5.6	17.3	33.5	47.4	59.4	69.0	76.5	81.0	83.5	85.7	86.5
5-30-74	1.2	2.6	7.6	18.2	32.3	47.1	63.0	76.3	86.4	92.6	96.5	98.3	99.7
5-31-74	1.1	4.0	10.0	22.3	36.4	49.6	64.2	77.3	88.0	93.5	97.0	98.7	99.4
6-01-74	2.5	9.8	23.3	37.2	52.6	65.3	77.3	86.1	92.5	96.5	98.3	99.4	100.0
6-02-74	3.5	11.5	26.1	38.5	50.4	60.7	71.1	80.4	88.0	92.8	95.4	97.6	98.5
6-03-74	3.2	14.0	31.0	43.3	54.2	63.7	73.3	81.9	90.1	95.0	98.5	100.0	—
6-04-74	1.9	8.5	23.3	38.8	53.4	65.8	77.4	85.7	91.9	95.7	97.9	99.6	100.0
6-05-74	2.2	10.0	30.1	45.0	58.3	69.3	80.0	87.9	93.7	96.9	99.0	100.0	—
5-27-75[b]	3.8	11.4	27.7	50.5	72.8	91.8	98.9	99.5	100.0	—	—	—	—
5-30-75	—	—	—	—	—	—	—	—	—	—	—	—	—
6-02-75	4.3	14.2	30.8	48.1	60.8	73.7	85.7	92.2	96.5	99.0	99.8	100.0	—
6-03-75[b]	6.4	16.5	32.6	46.6	58.8	70.6	82.4	91.7	97.3	98.5	99.5	99.5	100.0
6-04-75	1.6	4.8	14.4	29.1	43.1	59.0	76.7	89.4	96.5	98.6	99.7	99.8	100.0
6-05-75	1.0	3.2	10.4	24.2	38.6	55.5	73.5	86.9	95.4	98.6	99.5	99.8	100.0
6-06-75	0.8	2.3	8.2	21.9	36.1	51.7	69.3	82.6	91.6	95.8	97.9	98.8	99.6
6-07-75	0.9	2.3	8.1	22.9	38.8	54.8	70.8	82.3	90.4	94.5	97.1	98.6	99.6
6-08-75	1.8	4.0	8.4	19.5	32.9	50.0	68.0	81.6	91.0	95.4	98.0	99.2	99.7
6-09-75	1.5	4.7	9.8	21.5	36.0	52.1	68.2	80.8	89.6	94.2	97.3	98.9	99.8
6-10-75[b]	2.5	7.7	15.0	27.2	44.1	63.1	80.1	91.5	97.2	99.1	99.8	100.0	—
6-11-75[b]	5.1	15.9	25.0	35.6	49.0	64.0	79.2	90.2	96.8	98.8	99.7	99.8	100.0
6-13-75	5.9	28.7	50.2	68.2	77.7	84.6	90.8	95.5	98.6	99.6	99.9	100.0	—
6-14-75	2.0	5.7	14.4	27.8	40.8	54.3	68.0	79.6	88.9	93.6	96.8	99.1	99.7
6-15-75	1.3	5.5	13.8	30.4	47.8	62.0	74.7	84.4	91.8	94.9	97.3	98.6	99.5
6-16-75	1.4	5.1	14.0	28.2	43.9	56.2	69.3	80.5	89.7	94.2	97.1	98.5	99.3
6-17-75	0.9	4.5	11.8	24.0	36.9	51.8	68.4	81.2	90.7	95.8	98.2	99.4	99.9
6-18-75[b]	4.9	24.4	42.3	58.8	74.3	86.1	93.5	97.1	99.0	99.5	99.9	100.0	—
6-19-75	3.5	16.6	30.0	48.9	63.1	76.4	87.4	93.8	97.3	98.9	99.6	99.9	100.0
6-21-75	7.0	20.6	35.0	50.2	63.8	74.7	83.7	90.5	95.4	97.3	99.0	100.0	—
6-22-75	7.0	22.9	39.0	54.9	68.6	78.7	86.7	92.2	96.2	98.1	99.0	99.5	100.0
6-23-75	4.1	15.5	29.8	45.7	61.9	75.0	85.1	92.1	96.6	98.5	99.3	99.8	100.0
6-24-75	3.2	12.7	24.2	36.4	50.7	64.1	77.6	88.1	94.9	98.2	99.8	100.0	—
6-25-75	1.5	5.9	17.8	33.5	46.5	58.7	70.6	80.7	89.0	93.5	96.9	98.7	99.8
6-26-75	1.8	5.5	15.6	32.1	49.4	66.9	82.5	92.4	97.6	99.1	99.7	99.9	100.0
7-01-75	1.7	6.2	11.7	20.3	30.7	43.6	59.1	73.2	85.4	92.3	96.5	98.3	99.0
7-08-75	2.2	10.3	24.1	40.2	53.5	66.6	76.7	84.6	91.0	94.2	96.5	97.9	98.6

[a] Dates correspond to dates listed in Table 1.

[b] Size distribution determined from bedload samples concurrently collected with the Helley-Smith bedload sampler.

At low and moderate discharges, all gates are open so the load accumulated in the weighing hopper represents the total for the river. At high discharges, gates are opened individually and the transport rate for the whole river is computed by adding the rates recorded in the eight gates individually opened.

At low flow, all discharge, Q, is within the 14.6-m width of the gated slot; at bankfull ($Q \approx 20$ m^3/s), the water spreads over the full 18-m width of channel, but only 5% of this discharge is in the near-bank zones beyond the 14.6-m wide bedload trap; at maximum discharge (45 m^3/s), about 8% of the discharge is beyond the ends of the bedload trap. The total river discharge and that portion flowing within the 14.6-m width of the trap are tabulated in Table 1. Essentially, all bedload is accounted for and all the flow passes through the 18 m width of channel at the measuring section. Though overbank flow onto the flood plain occurs in other reaches of the river, at the project site a high natural bank

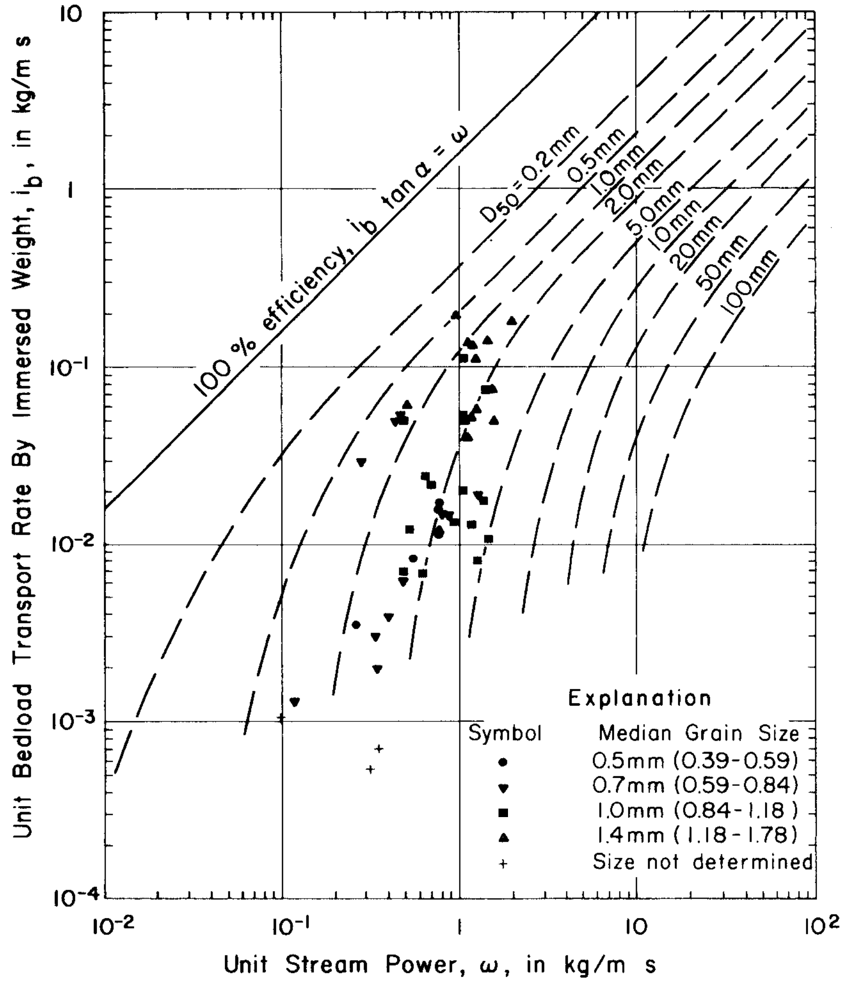

FIG. 1. Bedload-transport rate as a function of stream power.

on the right side and a short embankment on the left prevent any overbank flow.

Discharge measurements by current meter are made nearly every day during the sampling season from the suspension bridge at the project site.

The weight of the trapped load is recorded each minute as it accumulates in the hopper so the weights represent a wet sample. Numerous comparisons of the weight of samples when wet and after drying give a consistent ratio of dry/wet weight of 0.85.

Samples of the trapped sediment for size analysis are scooped from the endless belt as the weighing hopper is periodically emptied. These samples are taken to the laboratory where they are dried, sieved, and weighed by size fractions.

Discussion

The most important general characteristic of bedload derived from this investigation is its variability.

Bedload-transport rates are extremely variable in both space and time at a given river cross section. This is due in part to the fact that, at low to intermediate stages, bedload in the East Fork River is moving in the form of sand dunes that extend diagonally over part of the channel width. With the progressive down-channel passage of dunes, the trapped bedload weights show an irregular cyclic variation, as would be expected. The dunes can be observed visually at low stage, but increased depth and turbidity at middle and high stages obscure the bed. But when the bed is visible, it is also observed that bedload is transported in sheets or tongues not associated with any obvious dunes. This is especially true at the downstream point of a permanent gravel bar in the left third of the channel and just upstream of the bedload trap. Such a sheet or tongue appears to migrate laterally in a random manner and is also irregular in intensity from minute to minute. Characterization of bedload movement in a two-dimensional diagram implying a steady transport equal at all positions across the channel is, at best, a very approximate and somewhat misleading picture.

Available data from laboratory flumes confirm the postulated rapid increase of transport rate with stream power, but none have had the capacity to test Bagnold's (1, 2) assertion that, at high flows, transport rate is directly proportional to power. The data presented here include discharge rates high enough to confirm tentatively that hypothesis, at least in this river.

The data in Table 1 have been plotted in Fig. 1 in the form of bedload-transport rate per meter of width (i_b) as a function of unit stream power (ω), both quantities in the same units of kg/m s. Unit stream power is defined as the unit weight of water (1,000 kg/m^3) times the discharge of water per meter of width over the 14.7 m width of the bedload trap (m^3/m s) times the gradient of the river (m/m). The median size of bedload material is indicated by the various symbols in the figure.

During the first several days of initial spring rise of river stage each year the transport rate for a particular value of power is larger than later in the season. This apparently is the result of changing availability of bed material. Also, the median size of debris is of smaller size at the beginning than at the end of the runoff season, when it reaches a maximum of about 1.5 mm.

From experience and a few other data, we have suggested by the curved broken lines in Fig. 1 what we think represents the relation of bedload transport to stream power for most rivers. The family of curves is labeled for values of median size of transported sediment, D_{50}, in mm. The curves apply only when the moving load is of nearly uniform grain size or when there is sufficient stream power to move sediment of all size fractions of which D_{50} is the median size. Though it is recognized that the ratio of flow depth to grain size is important in the dynamics relating transport rate to power (2), a satisfactory way of incorporating this ratio into plots of river data has not yet been found.

The plotted data in Fig. 1 show the tendency for transport rate to become proportional to stream power at high discharge. In the East Fork River for a given hydrograph rise, the direct proportionality holds through about a 4-fold increase of stream power and a concurrent fourfold increase of bedload-transport rate.

A measure of bedload transport efficiency is the proportion of stream power utilized for bedload transport (2). To the extent that the family of curves sketched in Fig. 1 represent river conditions, the curves also provide a range of efficiencies, the efficiency being largest for the transport of fine sand (about 25%) and decreasing as the bedload size gets larger. The efficiency in transport of 30 to 50 mm debris is estimated as about 1%. These figures alter somewhat the conventional wisdom that the efficiency of rivers in using energy to transport sediment is always small.

The bedload trap on East Fork is part of the sediment-investigation program of the U.S. Geological Survey, and was constructed by Robert M. Myrick, Project Engineer, who also assisted in the data collection. Some of the principal ideas used in the design were contributed by Brig. R. A. Bagnold.

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