14

Sediment Size that Determines Channel Morphology

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ABSTRACT

Studies of 12 gravel-bar streams in the mountains of Colorado and Wyoming show that the bulk or largest volume of bedload is in the sand size, much smaller than the size seen in the bed materials and on the bars. The coarse fraction, though small in volume of annual transport, determines and comprises the major features of the channel morphology. High discharges carry bedload only slightly more coarse than do low discharges, though the transport rate of high discharge is very much larger than that at low flow. In gravel-bed streams the bed material is much coarser than the sediment that is largest in amount over a period of time. The coarsest small percentage of the total volume make up the bars, the riffles, and the surface material on the bed. The largest clasts, as well as the largest volume of the annual bedload, are carried at discharges near the bankfull stage.

14.1 INTRODUCTION

A growing interest in gravel-bed streams has led to an expanded database involving bedload transport rates determined by Helley–Smith sampler and associated sediment size distribution. There are also a few data sets in which the total bedload was caught in a settling basin or trap. The latter data include a measure of the large mobile clasts that exceed the size of the mouth of a sampler.

In the snow runoff seasons of 1988 and 1989 detailed measurements were made in several gravel streams in the mountains of Colorado, USA. This unusually complete set of data on bedload and sediment size distribution allows several questions of interest to be discussed. Some characteristics of the streams studied are listed in Table 14.1.

14.2 SIZE DISTRIBUTION OF BED MATERIAL AND TRAPPED SEDIMENT

The East Fork River near Boulder, Wyoming in the vicinity of the bedload trap is a few miles downstream from the place where the river leaves the mountains, flows through moraines, and thence meanders in a valley between terraces of glacial outwash. But soon after entering this valley zone it is joined by a tributary,

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Table 14.1 Channel characteristics at locations where sediment samples were taken

Stream	Elevation (m)	Drainage area (km^2)	Bankfull discharge (m^3/s)	Channel width (m)	Slope	D_{84} of bed material (mm)
East Fork near Boulder, WY	2200	466	20	15	0.0007	20
Poudre Pass Creek near Chambers Lake, CO	3050		9.6	20	0.0062	150
Lower Trap Creek, near Chambers Lake	3000	12.2	4.5	5	0.018	70
Upper Trap Creek, CO near Chambers Lake	3050	9.8	4.5	9	0.060	152
SFK Cache La Poudre near Nederland, CO	2340	228	11.3	14	0.008	147
Little Beaver Creek near Pingree Park	2426	32	1.8	7	0.026	158
Left Hand Creek near Lyons, CO	2288	134	5.9	9	0.035	120
Middle Boulder Creek near Nederland, CO	2560	76	11	14	0.015	90
Goose Creek no. 1 near Cheesman, CO	2304	209	3.8	7	0.015	120
East Fork Encampment Creek, WY	2921	9.1		3.3	0.027	170
Coon Creek, WY	2906	16.8		5.1	0.023	220

Muddy Creek, that is contributing sand washed out of glacial material. The sediment load from Muddy Creek is enhanced in recent times by irrigation return flow. The description of the bedload trap and studies of the data have been published previously (Leopold & Emmett, 1976, 1977; Emmett, 1980).

The sediment derived from the basin upstream of Muddy Creek is primarily gravel, which is prominently displayed in the riffles. The streambed in pools is generally covered with sand, derived for the most part from Muddy Creek. The bedload, then, consists principally of sand, but the gravel of the riffles also is moved. Painted rocks of gravel size placed on gravel riffles were carried away.

The major morphological features: riffles, central bars, and point bars, are composed of and formed by the coarse part of the total bedload. The bulk of the bedload is of finer material, principally sand.

The bedload trap on the East Fork River consisted of an open slot across the full width of the channel, 14.6 m, which caught all of the bedload. The size distribution of the trapped bedload is shown in Figure 14.1. Data for Figure 14.1 are from Emmett's Table 2 (1980). The data represent a composite of samples taken during 31 days in 1976. A single sample representing a given discharge is a composite of about 40 scoops taken during a period of five to eight hours, and comprising 80 kg of sediment.

The 31 days of sampling in 1976 extended through a whole snow-melt season beginning on 18 May, when the discharge was 9.87 m^3/s, and ending 21 June, when the discharge was 9.53 m^3/s. The peak discharge in this season occurred on 5 June, when the discharge was 22.4 m^3/s. The bankfull discharge is about 20 m^3/s, which in the annual flood series has a recurrence interval of 1.5 years. This snow-melt period of measurement in 1976 included discharges from 0.47 to 1.12 times the bankfull, a typical range in normal runoff years. This period includes the bulk of the sediment transport that occurs during a year.

Note in Figure 14.1 that the D_{50} caught in the conveyor-belt was 1.13 mm, and that 60% of the total weight caught in the trap was a size between 0.5 and 2.5 mm.

The bed material of the East Fork River is described by a composite of 232 individual samples collected at 29 cross-sections in a 200 m reach near the bedload trap. The median particle size of each cross-section varied from 0.6 to 25.4 mm. The largest median values occurred at the two riffles included in the sampled reach. A map showing the cross sections and the bed-material size in each is shown in Figure 5 of Emmett (1980).

The size distribution of the bed material is plotted in Figure 14.1 so that the bed material may be compared with the sediment caught in the conveyor-belt trap. The D_{50} of the bed material is 1.25 mm. Sixty per cent of the total weight is made up of sizes between 0.5 and 12 mm.

The difference between the trapped sediment and the

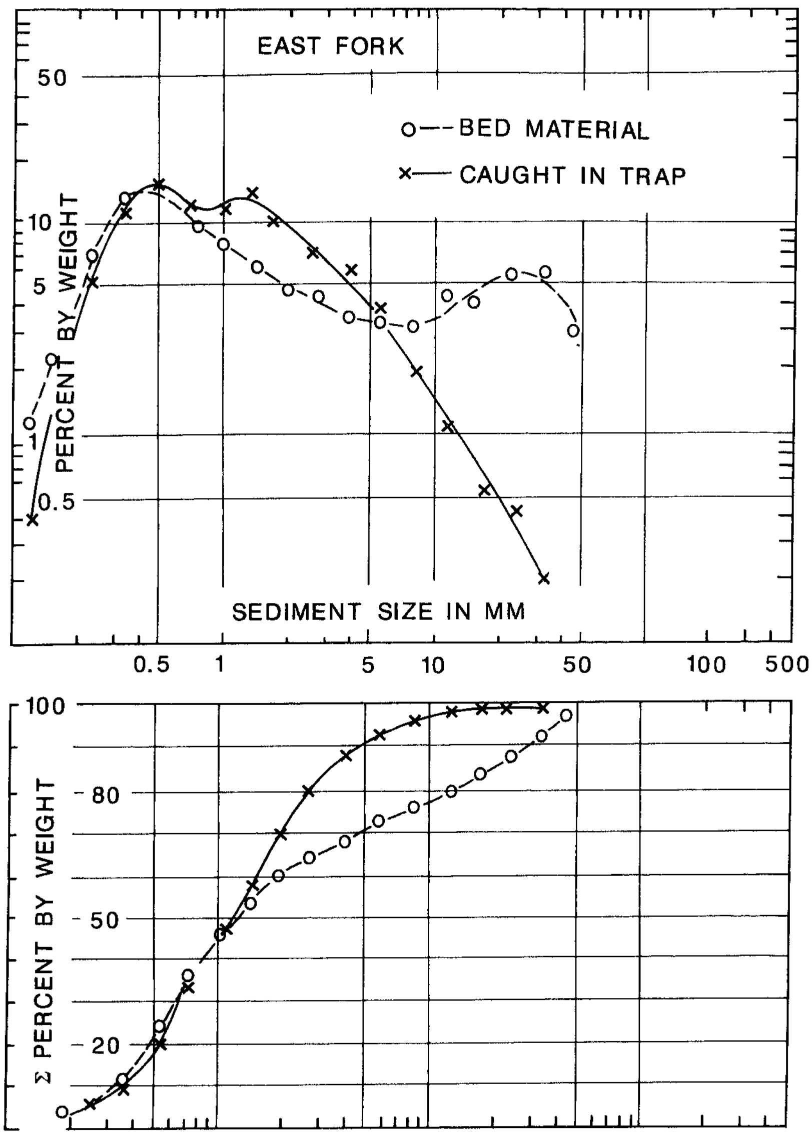

Figure 14.1 Size distribution of bed material and of sediment caught in the bedload trap, East Fork River, Wyoming. The bed material data are the average of 232 samples. Sediment caught in the conveyor-belt trap, transport weighted, is an average of 52 samples caught in 31 days during 1976 (Emmett, 1980, Table 2). Upper diagram, percentage by weight of sediment of different size classes, not cumulated. Lower diagram, same as upper diagram, but cumulated; the ordinate is percentage by weight equal to or less than each size class

bed material is in the size classes larger than the median. The distribution of the finer than 50% by weight portion is nearly the same for the trapped sediment and the bed material, as can be seen in the near coincidence of the two curves of Figure 14.1 in the range 0–50% by weight.

Other installations where the total bedload was trapped are constructed on two gravel-bed streams in the Medicine Bow area of Wyoming, and are operated by the US Forest Service (Wilcox, 1989).

On both Coon Creek and East Fork Encampment Creek (see Table 14.1), a large wooden box or enclosure was constructed to trap all incoming bedload. Each year the sediment was excavated by machine, and the volume and size distribution measured. The transport rate of bedload was also measured during storm periods with a Helley–Smith sampler.

In the years 1986–1988 the sediment removed was 5.5, 9.2, and 12.8 tonnes, respectively, at Encampment Creek. In the years 1983–1986 and 1988 the totals were 220, 75, 60, 150, and 50 tonnes, respectively, at Coon Creek. This amounted to an annual yield of 0.92 tonnes/km^2 per year from Encampment Creek and 6.0 tonnes/km^2 per year from Coon Creek.

These unique data are summarised in Figures 14.2 and 14.3. In these graphs the size distributions of four materials are plotted: (1) the bulk of the sediment excavated from the box trap labelled "pond"; (2) bedload samples taken during storm events with a Helley–Smith sampler; (3) bulk sample of bed material; and (4) bed material measured by pebble count sampling.

Encampment Creek and Coon Creek data are similar in certain respects despite the difference in annual sediment yield. The size distributions of the bulk materials collected in the box traps were nearly identical to those obtained from the Helley–Smith sampler.

In the largest particle size class, above 64 mm the sampler under-represented the actual load. In the box trap the sediment caught included a small percentage by weight of sizes of 128, 256, and 512 mm that clearly could not fit into the 10 cm nozzle of the sampler.

In all three of these installations where the total bedload was trapped, the bulk of the load was of sand size, despite the fact that the bed material was of much larger size. In the East Fork the riffles are gravel, not sand. The D_{84} of the bed material, 20 mm, is typical of what one sees on the riffles and bars.

In Coon Creek and Encampment Creek the bed material is gravel having D_{84} sizes of 220 and 120 mm, respectively. Yet 70% of the material caught in the box trap was less than 6 mm. The D_{50} of the trapped material was between 1.5 and 2 mm. Thus, the bulk of bedload in these gravel streams is sand, yet the streambed is obviously gravel and cobbles.

This conclusion applies not only to the three streams where a trap caught all of the bedload, but also to the other gravel rivers discussed. Table 14.2 shows the sediment size category comparing the largest percentage by weight of the bedload sampled in the eight mountain streams studied. Note that in all these gravel streams, the size category of either 1 or 2 mm comprised from 15% to 33% of the weight of bedload caught during the runoff season. The Colorado streams are gravel-bed, with the D_{84} of bed material between 150 and 200 mm.

All the streams listed in Table 14.2 can be classified as gravel-bed channels in that the bars, the riffles, and the point bars are predominantly composed of gravel. In all of these streams the bed material or surface layer of clasts is somewhat coarser than clasts immediately below the surface. The ubiquitous condition of gravel-bed channels has, unfortunately, been called armouring or paving, implying the presence of a pavement. Such terms suggest that the surface layer or bed material does not move. Measurements show that even the D_{84} of the bed material moves in discharges below, or at, bankfull, but in small quantities. Thus, the occurrence of clasts larger than 100 mm in the material caught in the box traps or ponds confirms the mobility of coarse bed material.

14.3 SIZE DISTRIBUTION OF THE BED MATERIAL

In both the Encampment and Coon Creeks bed material was measured in two ways: by a volume taken to the laboratory for drying, sieving and weighing; and by pebble counting.

In both these streams there is a marked difference in sorting of the bulk of the load, mostly sand, and the gravel material. Note in Figures 14.2 and 14.3 that the box trap material labelled "pond" is poorly sorted in that there are equal percentages by weight in categories of size from 0.5 to 10 mm. In contrast, gravel bed material has a sharp maximum of about 100 mm, with smaller percentages by weight in both smaller and larger sizes.

This difference in sorting appears to be general. Figure 14.4 presents the size distribution of bed material and that caught in the Helley–Smith sampler for three of the mountain, gravel-bed streams in Colorado. In these data the same finding is seen for a rather straight cumulative curve describing the

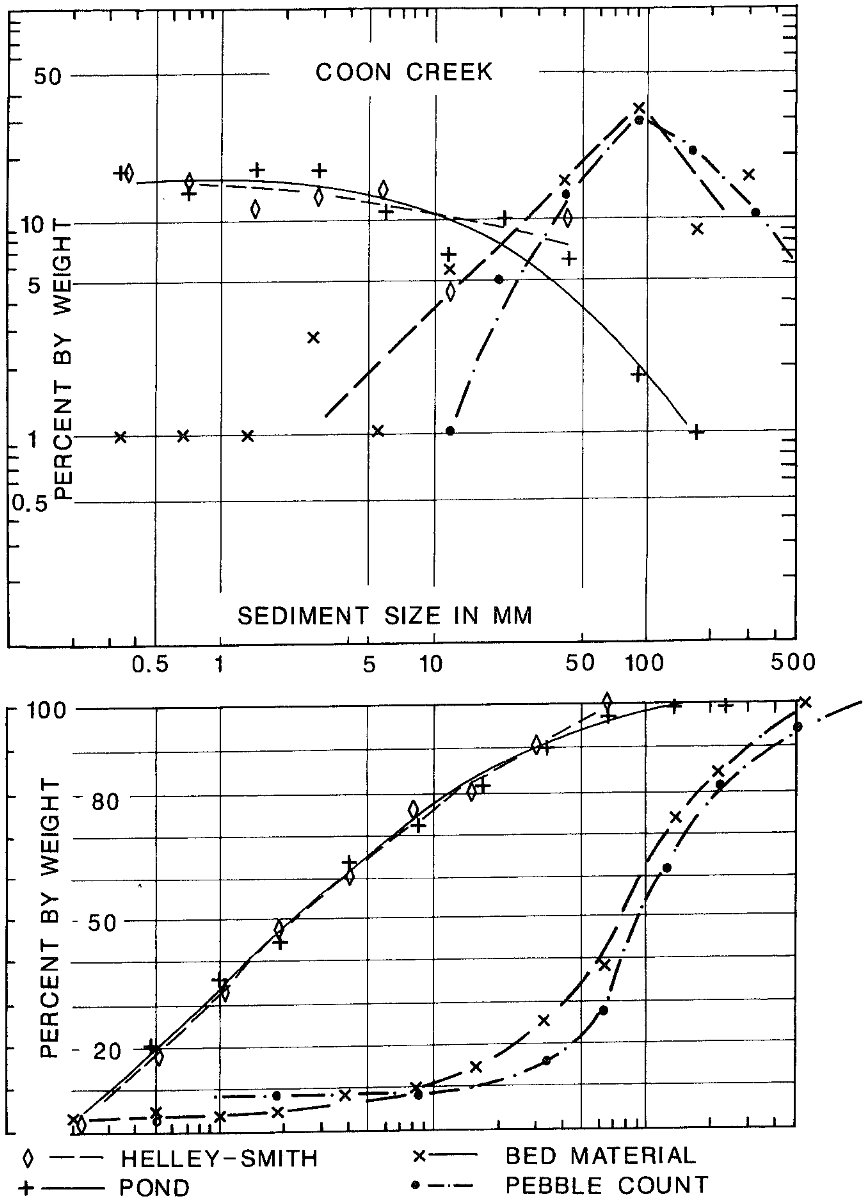

Figure 14.2 Size distribution of bedload in Coon Creek, Medicine Bow National Forest, Wyoming, showing four types of measurements. Bedload in box-pond is nearly identical to that caught in Helley–Smith sampler, but the latter did not catch the clasts greater than 64 mm. Bed material in bulk sample is nearly the same as size determined by pebble count

bedload caught and the markedly S-shaped curve for bed material. Such curves are available for most of the streams listed in Table 14.1, and they show similar tendencies.

For many of these streams, the size distributions of gravel on channel bars and in the subarmour or sub-pavement are available. The subarmour nearly always has a curve that lies between the bed material and the bedload caught in the sampler: that is, finer than bed material but coarser than the caught bedload.

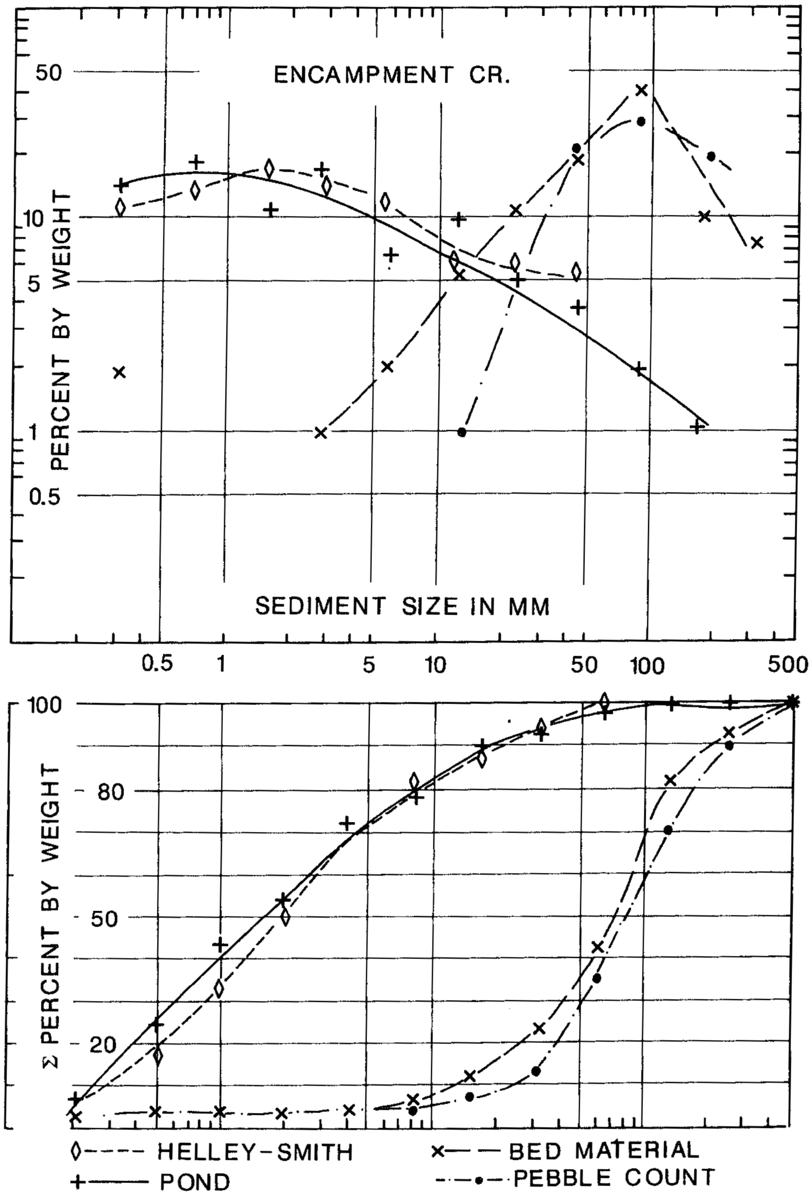

Figure 14.3 Size distribution of bedload in East Fork Encampment Creek, Medicine Bow National Forest, Wyoming, showing four types of measurements. As in Coon Creek, sediment caught in box-pond is nearly the same as that in Helley–Smith sampler except for large clasts. Bed material and pebble count data are nearly the same

14.4 IMPLICATIONS FOR CHANNEL MORPHOLOGY

The largest portion of the bedload in these gravel-bed channels is not in the gravel size, but in the sand size. Yet the visual impression of the channels is formed by the coarser fraction that makes up not only the bed, but also the point bars and the pool–riffle sequence. Thus, the principal morphological features of the channel are made of material representing only a small

Table 14.2 Season totals of bedload samples caught in Helley–Smith sampler, 1989

Stream	Number of days	Total weight caught (g)	Total weight per day of sampling (g)	Largest rock caught (mm)	Size category* with largest percentage of weight: mm	Percentage of total weight in category
Goose Creek no. 1	17	40 319	2371	30	1.0	31
Goose Creek no. 2	10	3 348	334	64	1.0	23
Goose Creek no. 4	16	8 578	536	41	1.0	23
Left Hand	56	211 297	3773	113	1.0	33
Middle Boulder	20	32 792	1639	98	2.0	15
SFK Cache La Poudre	40	11 196	279	43	1.0	27
Little Beaver	40	10 389	259	45	1.0	30
Upper Trap	22	13 841	629	136	2.0	19

*Sizes listed are passing through, not held on. Sieve sizes were 0.5, 1, 2, 4, 5, 6, 8, 11.2, 16, 22, 32, and 45 mm. Size category of 1 mm is from 0.5 to 1 mm.

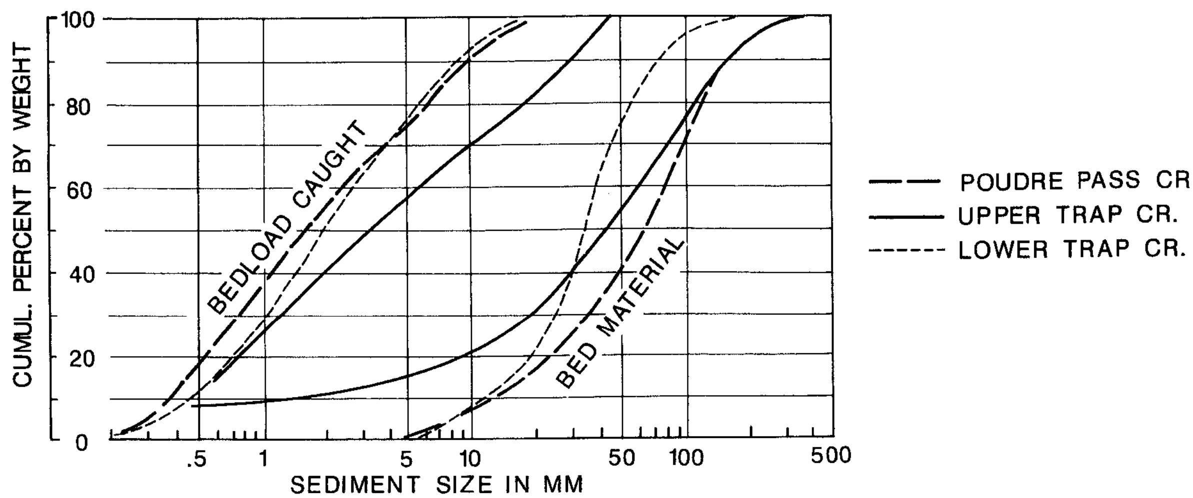

Figure 14.4 Size distribution of bedload in three mountain streams in Colorado. Bedload caught in Helley–Smith sampler is compared with bed material of the channel

percentage of the total annual bedload. The median size of the bed material in these data is equalled or exceeded in only about 3% of the total bedload moved.

14.5 DISCHARGES THAT MOVE THE BULK OF THE BEDLOAD

The measurement points of streams in Table 14.1 are all located in close proximity to a gauging station for which a flow duration curve was plotted. A bedload rating curve constructed from Helley–Smith sampling is also available. Applying the percentage of time various discharges were experienced to the associated bedload transport rate, the total bedload carried by each discharge category was computed. The computation was carried out for each bedload sampling point.

A typical relation obtained is shown in Figure 14.5 for Left Hand Creek. This creek has a drainage area 134 km^2 and a D_{84} of bed material 120 mm. The

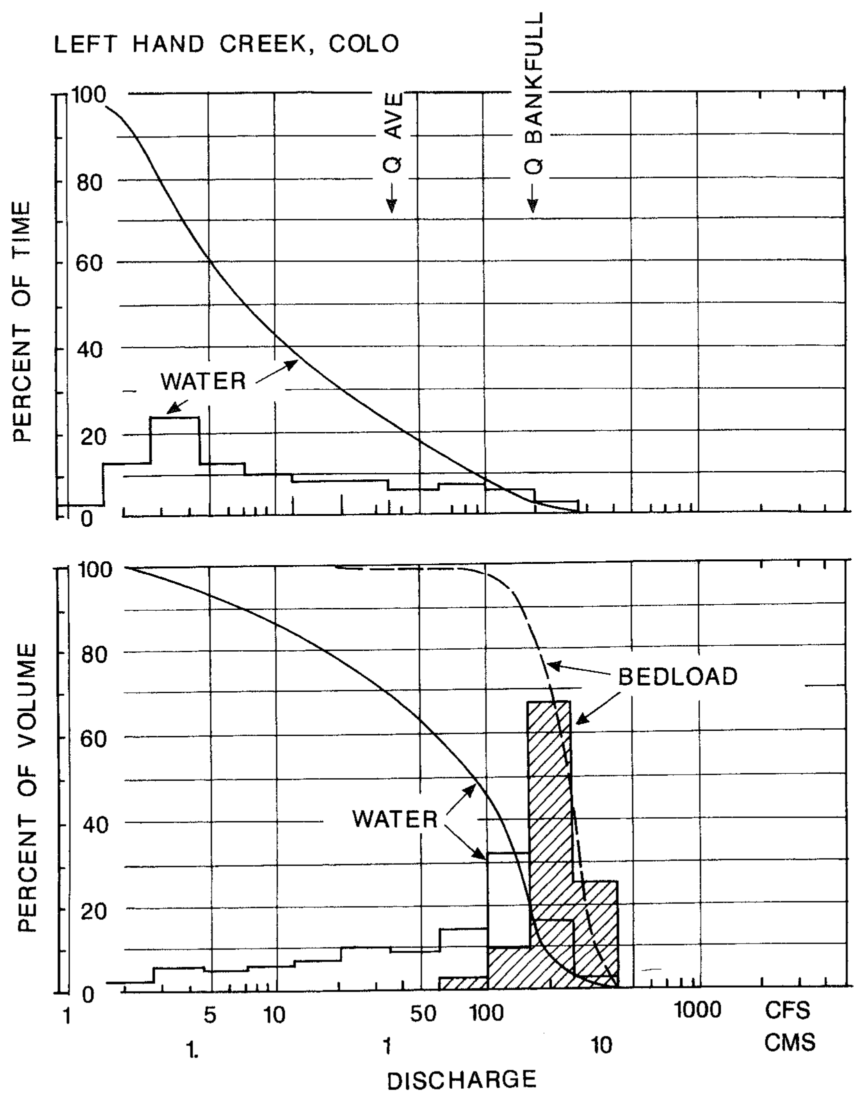

Figure 14.5 Relation of discharge to the percentage of time and percentage of volume of water in a Colorado mountain stream. The relation of discharge to volume of sediment is shown for bedload. For both relations, data are expressed as a histogram, and the same data are expressed as cumulated values, equal to or greater than

upper graph shows the percentage of time various discharges occur. The data are shown in the form of a cumulative curve typically used for a flow duration curve, but also as a histogram of non-cumulated percentages. The most common category was about 0.1 m^3/s that occurred 24% of the time. The average discharge was equalled or exceeded 20% of the time, a common characteristic for many rivers.

The bottom graph in Figure 14.5 shows the percentage of the annual or long-term volume of both water and bedload carried by various categories of discharge. The largest volume of water is carried in the category of discharge 2.8–4.5 m^3/s, or 0.47–0.76 times bankfull discharge.

The maximum bedload is carried in the discharge category 4.5–7.3 m^3/s or 0.76–1.2 times bankfull. At discharges both smaller and larger, less bedload is transported. The discharge carrying the maximum sediment load has been called the effective discharge. In a study of some gravel-bed streams in Colorado,

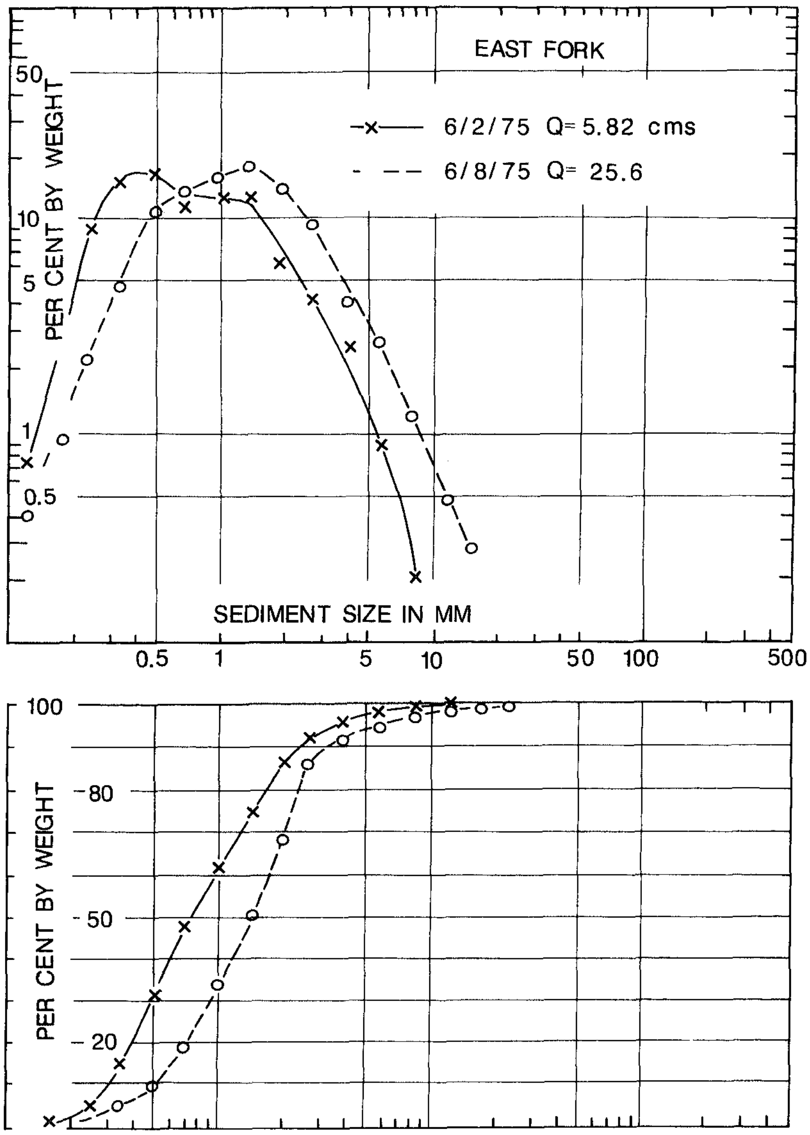

Figure 14.6 Bedload size distribution during the day of lowest and highest discharge in the year 1975 at the bedload trap, East Fork, Wyoming

Andrews (1984) found that the effective discharge was approximately equal to the bankfull discharge. The example above is in agreement with Andrews' findings.

14.6 SEDIMENT SIZE DISTRIBUTION AS DISCHARGE CHANGES

One might expect the size of bedload moved to increase proportionally with an increase in discharge. The data show that such increase does occur, but its magnitude is rather small. Two examples are given in Figures 14.6 and 14.7. In these figures the size distribution of bedload caught in a Helley–Smith sampler is shown for a large and a small discharge. In Figure 14.6, at the East Fork River in Wyoming, the five-fold increase in discharge resulted in a change of D_{50} from 0.7 to 1.4 mm, or a two-fold increase. In Figure 14.7, at Goose Creek no. 1, a change in discharge from 0.76

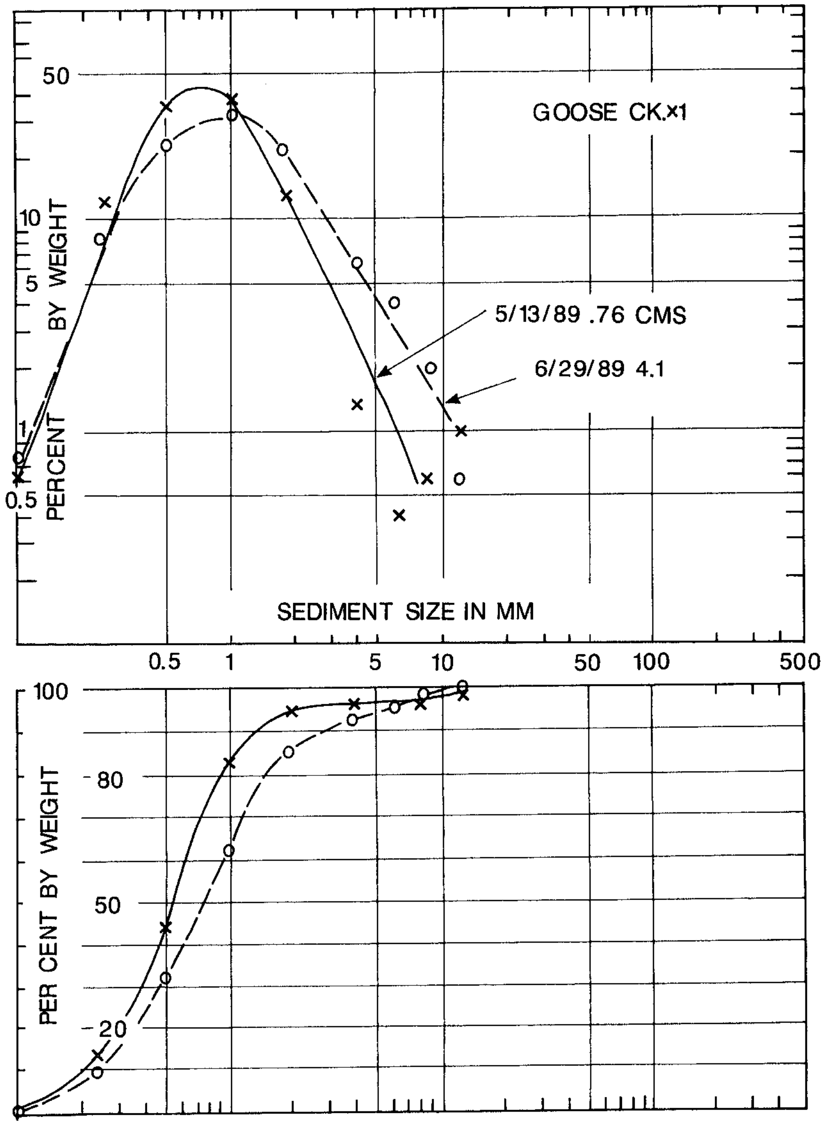

Figure 14.7 Bedload size distribution determined by Helley–Smith sampler at the time of lowest and highest discharge in 1989, Goose Creek no. 1, Pike National Forest, Colorado

to 4.1 m^3/s resulted in a change of D_{50} from 0.55 to 0.75 mm. In all the cases studied, low and high discharges both had a wide distribution of bedload size from sand to small gravel, but the increase in size with discharge was not very large.

14.7 CONCLUDING DISCUSSION

Gravel-bed streams have a bedload smaller in grain size than material seen on the channel bed. Sand is the size of the major volume of bedload in gravel-bed streams. However, the major morphological features of gravel-bed streams are composed of gravel, not the sand that makes up the bulk of bedload. Channel bed material, point bars, and riffles in the pool–riffle sequence are all made up of gravel that moves at a low transport rate, the clasts of which move only occasionally, and for short distances when they do move.

Size distributions are characterised by better sorting in the coarse bed material than in the sandy bulk of the bedload. Size in any category is only slightly larger under high than under low discharges. Thus, it appears that the gravel-bed channels, the coarse fraction, moved only occasionally and moved only short distances in any one season, makes up the principal morphological features of the channel.

14.8 REFERENCES

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14.9 DISCUSSION

14.9.1 Discussion by P. D. Komar

Leopold has documented that the bedload in a number of gravel-bed streams consists mainly of sand rather than gravel. This is also true in Oak Creek, Oregon, but only at lower-flow stages. While collecting bedload samples with a vortex trap, Milhous (1973) noted that at a discharge of about $1\ m^3/s$ the bed pavement begins to break up so that increasing quantities of gravel appear in the trap samples at higher flow stages. This transition is presented graphically in Figures 14.8 and 14.9, based on the data of Milhous. Figure 14.8 shows the respective percentages of sand and gravel found in the bedload samples at various discharges. The division has been placed at -1.25ϕ (2.35 mm), the closest sieve size employed in the analyses to the sand–granule division (2 mm) in the Wentworth scale. This size is meaningful in that, as seen in Figure 14.9, it roughly corresponds to the change in the bedload median grain size (D_{50}) at $Q=1\ m^3/s$. Above that flow stage there is a regular increase in D_{50} with increasing discharge, while there is considerable scatter in the data at lower flow stages, apparent in both Figures 14.8 and 14.9. In contrast to these changes in the degree of data scatter for D_{50} and the percentage gravel, the measured bedload transport rates form a continuous trend over the full range of flow discharges and bed stresses (Shih & Komar, 1990b). The two X data points in the graphs represent strongly bimodal distributions, and this accounts for their deviations from the established trends. The 2.35 mm division between sand and gravel also represents the saddle within those bimodal distributions (Shih & Komar, 1990a). It is noteworthy that the bed material itself does not have a bimodal distribution; the pavement contains only 3% sand while the subpavement is 15% sand.

Therefore, at a flow stage of about $1\ m^3/s$, when the bed-material pavement begins to break up, there is an overall change in the character of Oak Creek. At lower flow stages the stream is similar to those described by the author where the bedload consists predominantly of sand while the stream's geometry is governed by the bed gravel. However, Oak Creek differs in that it converts to a gravel-transport system at higher discharges.

14.9.2 Discussion by P. C. Klingeman

The author makes provocative observations about bedload transport and its relation to the bed material source. He clearly documents some transport features that contrast the smaller sizes (in the sand range) of the predominant bedload compared to the coarser bed material (in the gravel size range). While such differences might be argued for on the basis of the frequencies of different flow magnitudes that move sediment during a given year, (he explores this), other features of channel morphology also merit mention.

In particular, I suggest that it may be necessary for us to re-examine our ideas about "representative" bed material. Several related questions illustrate this concern; What do we mean by "representative" bed material size distributions? What are their relations to bed material transport in gravel-bed rivers? How representative are our bed material samples? What constitutes a "representative" bed material sample? Is a bulk sample, whether composited from several areas

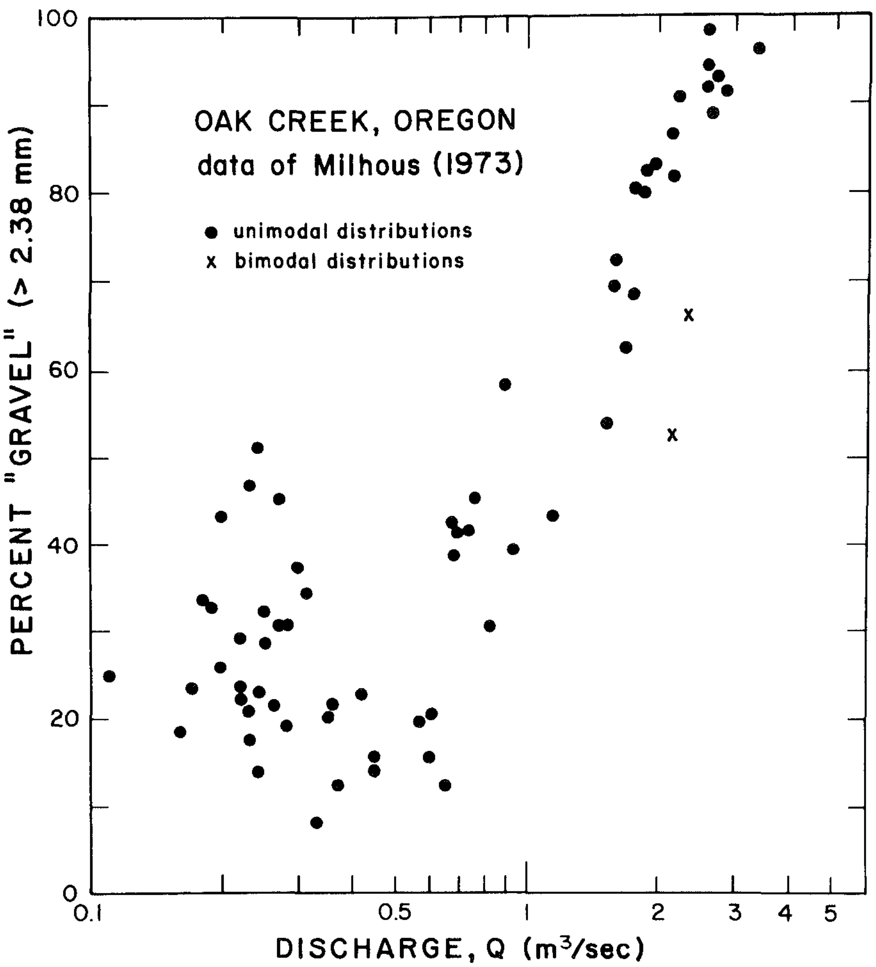

Figure 14.8 Increase in the gravel contents of bedload samples from Oak Creek as the discharge increases, demonstrating the progressive shift from a sand-dominated stream at low flow stages to one where the bedload is predominantly gravel at high flow discharges

or representing a single point in the channel, meaningful for explaining relations between bedload and bed material? Is a pebble count over some extent (still a composite) indicative of bed material and its relation to bedload?

Bed material sampling in a gravel-bed river is a major task. This is because of the spatial variability of the bed material itself and the large sample sizes required to obtain statistically useful information. Depending on how the bed is sampled, results may significantly differ. Therefore, it is extremely important to define the objectives of the sampling programme clearly before doing the sampling.

Several techniques for sampling the bed are available, and are reported in the literature. These allow spatially characterisation of the bed for its overall hydraulic roughness, sediment size distribution, or participation in general sediment transport at large discharges that essentially mobilise all of the bed surface.

But at low discharges, particularly those near the threshold of particle transport, these sampling tech-

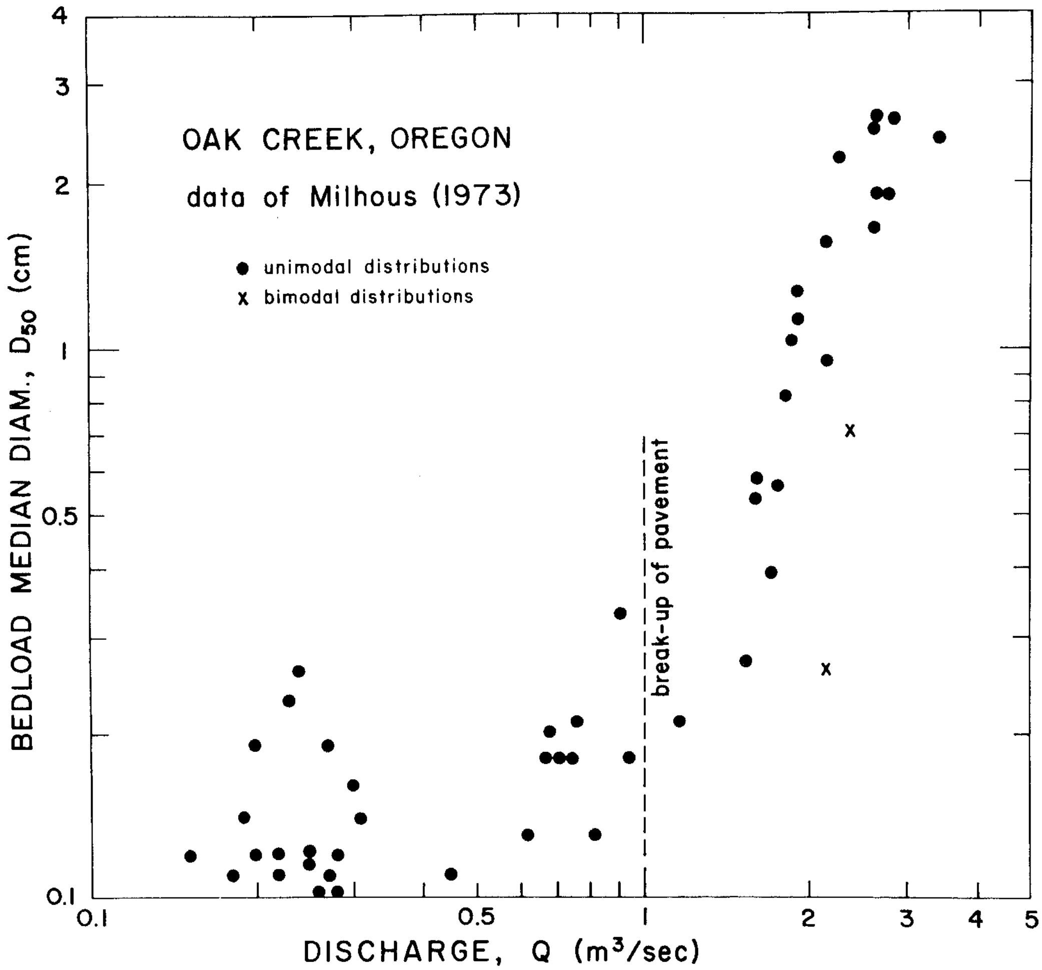

Figure 14.9 The progressive increase in the median diameters of the bedload samples from Oak Creek as the discharge increases

niques may be inadequate to explain the contrasting size gradation curves of bedload and bed material that the author has shown. By attempting to sample the bed "representatively", we may have discounted (and therefore not sampled) local storage pockets of smaller-size sediment.

Local storage pockets for small sediment may have a transitory relation to hydrograph fluctuations. There are many instances on recession limbs of hydrographs when the majority of the coarse bed has stopped moving and become stabilised, yet a significant transport of sand and small gravel is still occurring. Such transport may continue until later, when discharges have diminished and/or the sand has reached a quieter local zone where it is deposited. On the rising limbs of hydrographs such zones may be the main source areas for renewed sediment transport. (For example, these zones have been identified for Redwood Creek in Chapter 13 of this volume.)

Therefore, when our analysis covers bed material transport over the full range of likely discharges, some changes in our sampling methods should be considered. We should separately sample the local storage zones of finer-sized material and estimate their spatial distribution, in addition to the general "representative" sampling that is usually undertaken. This additional information about the streambed could help explain the transport conditions documented by the author, where the bulk of bedload is often in the sand size and is much smaller than the size seen in the bed material and on the bars.

14.9.3 Discussion by T. E. Lisle

Parker & Klingeman (1982) use observed similarities between bedload and bed material size distributions as a basis for a hypothesis of the bed pavement as a regulator of fractional transport rates of grain sizes. Bed material is assumed to furnish the supply of bedload *en masse* without size-selective transport over the long term. The author provides clear examples from the Rocky Mountains that this assumption is not always valid. The writer provides two other comparisons of grain size which, with the author's examples, show an association between relative supply of coarse sediment and degree of correspondence between bedload and bed material size distributions.

Gravel bedload in the East Fork River originates from reworking of Pleistocene glacial outwash that underlies the modern meandering channel, and very little is contributed along with the primary source of sandy bedload, which is streambank erosion of a terrace along a tributary (Andrews, 1979). Although gravel is present in bedload and the gravel bed is moulded under modern equilibrium conditions, gravel was put into the streambed under a sediment transport regime much different from the present one. As shown, gravel in the bed is greatly underrepresented in bedload.

The basin of Jacoby Creek in north coastal California is unglaciated and gravel is contributed directly to the channel by a variety of ongoing processes of mass movement and surface erosion. Mean channel-bed elevation has not changed significantly in the past two decades. Bedload is also finer than bed material, but the difference is not as great as in the author's examples (Figure 14.10). Bedload material was collected with a Helley–Smith sampler with a 76 mm orifice (Lisle, 1989) and bed material was sampled as described by Lisle & Madej in Chapter 13 of this volume. Because the trapping efficiency of the bedload sampler for particles of sieve size greater than 32 mm was uncertain, bedload and bed material size distributions were truncated at 32 mm. As a result the coarsest 30% of the bed material size distribution was disregarded. Truncation limits confidence in the conclusion that the distributions of the full spectrum of bedload and bed material sizes in the channel are different. Including the coarsest sizes in the comparison would most likely make the contrast even greater, however, as the coarsest sizes were most underrepresented in bedload in the Rocky Mountain streams.

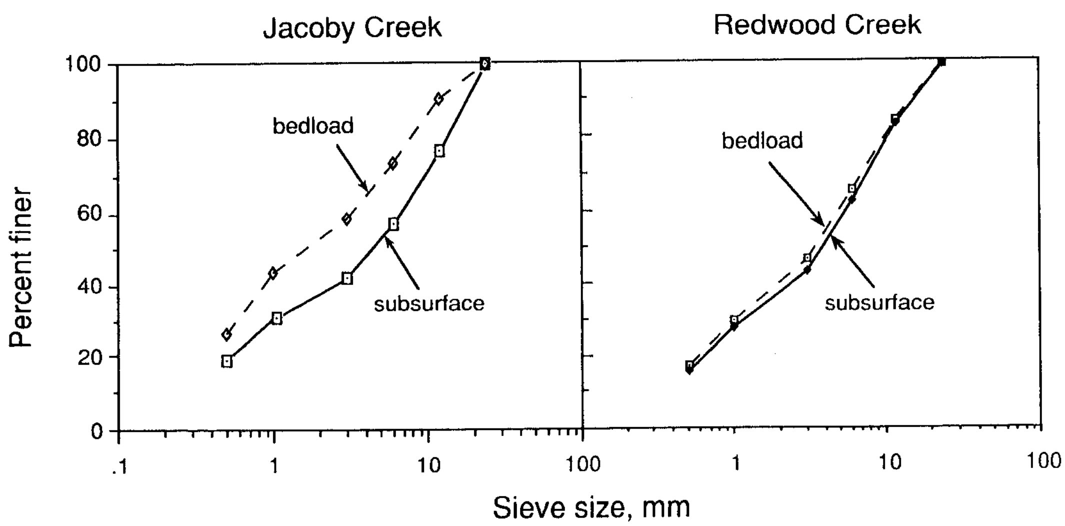

Figure 14.10 Bedload and bed material size distributions for Jacoby Creek and Redwood Creek, north coastal California, USA

Size distributions for Redwood Creek were taken from a reach that has remained aggraded since the early 1970s (Lisle & Madej, Chapter 13 of this volume). The channel undergoes deep scour and fill each year, and its bed has been the primary source of large yields of bedload. Size distributions for bedload (USGS, 1970–1988) and bed material (Lisle & Madej, Chapter 13 of this volume) show close correspondence. Distributions were also truncated at 32 mm, but in this case only the coarsest 10 per cent of the bed material distribution was eliminated.

These examples suggest that bed material and bedload size distributions are equivalent only in gravel-bed channels where the full range of bed material particle sizes are contributed to the channel by modern erosional processes. Data from Jacoby Creek suggest, however, that even under these conditions sediment sorting can lead to disparity in size distributions. The author's results reveal a problem of channel adjustments leading to different relations between bedload and bed material sizes. The problem deserves further study.

14.9.4 Reply by L. B. Leopold

The contributions of Komar, Klingeman, and Lisle expand the material in my chapter and are much appreciated.

As Komar points out, most of the streams in the examples I presented did not reach bankfull in the periods under discussion.

The East Fork in Wyoming exceeded bankfull yet the trapped bedload was much finer than the average of the surface material of the channel bed. But the East Fork is somewhat unique because the sand that dominates presently trapped bedload has a different geographical source from the gravel that makes up the bars. This was pointed out by Lisle. So in these respects my data are not the best test for the hypothesis I advanced.

The hypothesis is also in queestion because of our usual procedure for sampling the bed material as explained by Klingeman. He states that our procedure may de-emphasise pockets of sand that are often found in pool zones at low flow. However, the US Forest Service's large traps, built by making a deep pool to collect all the bedload, are of special significance (1989). The total bedload in 1987 to 1989 was caught in two streams, East Fork Encampment Creek and in Coon Creek, both gravel streams. Both showed that bedload size distribution caught in a Helley–Smith sampler was closely coincident with that of the large volume deposited in the trap, the D_{50} of which was about 2 mm. In both streams the D_{50} of the bed material was about 45 mm.

The discussion shows that we need more examples of total bedload trapped, not merely sampled. We also need greater attention to choice of sampling methodology depending on the question under investigation.

14.10 DISCUSSION REFERENCES

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