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Sampler size and sampling time affect bed load transport rates and particle sizes measured with bed load traps in gravel-bed streams

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Abstract A bed load trap was designed for collecting gravel and cobble bed load and tested in four mountain gravel-bed streams. The traps permit a long sampling duration of about 1 h and have a large 0.3 × 0.2 m opening as well as a large sampler bag. Samples collected with the bed load traps have well-defined power-function bed load rating curves with exponents of 8–16. Compared to a Helley-Smith sampler with a 7.6 × 7.6 cm opening, bed load transport measured with the traps is smaller during low flows and larger during high flows. Bed load particle-size distributions obtained with the traps coarsen more pronouncedly with flow than those obtained with a Helley-Smith sampler. These differences in sampled bed load transport rates and size distributions have implications for computations such as critical discharge, annual load, and effective discharge.

Key words bed load sampling; bed load traps; flow competence; gravel bed load transport; initial motion; rating curve; Rocky Mountain gravel-bed rivers; sampling time

INTRODUCTION

The relationship between gravel bed load transport rates and discharge (or any other measure of flow) varies widely between streams. This is particularly true in mountain streams and may be attributed to the stream-specific arrangements of bed-material particles in gravel- and cobble beds as well as site-specific conditions of sediment supply. Similarly, critical discharge (or any other measure of critical flow) for incipient motion of a given particle-size class varies among streams and is poorly predictable. Therefore, if site-specific information is needed for a given mountain stream, measurements of bed load transport seem to have the best potential for accurate results. The sampler employed for measuring bed load in a given mountain stream should not only be portable but also specifically designed for sampling gravel and cobble particles. Automatically recording portable hydrophones and similar devices (e.g. Bogen & Møen, 2003; Downing *et al.*, 2003; Froehlich, 2003; Gottesfeld & Tunnicliff, 2003; Habersack, 2003; Laronne *et al.*, 2003; Mizuyama *et al.*, 2003; Sear, 2003; Sear *et al.*, 2003) provide useful temporal records of the onset and cessation of motion and relative transport rates. However, the exact particle-size distribution in motion or the exact transport rate is usually unknown. To obtain this information, one still needs a sampler that, for given flows, provides bed load samples that can be weighed and sieved.

The transport frequency of gravel and cobble particles of the size class that is just beginning to move is very low; exactly how low is a matter of observer definition (or patience), e.g. one particle per metre width per hour. For accurate samples of gravel and cobble transport rates at the threshold of motion, the sampling duration must be equal to or larger than the presumed transport frequency of the largest mobile particle size to be collected. Other prerequisites for accurate sampling of gravel and cobble bed load are a sampler opening large enough for cobbles to enter, while the sampler bag must have a sufficiently fine mesh to retain small gravel particles. The bag size must be large enough to hold the large quantity of smaller bed load particles that accompany cobble transport at the onset of motion. Bed load samplers with those criteria were not available. We therefore developed a bed load trap that has these attributes (Fig. 1).

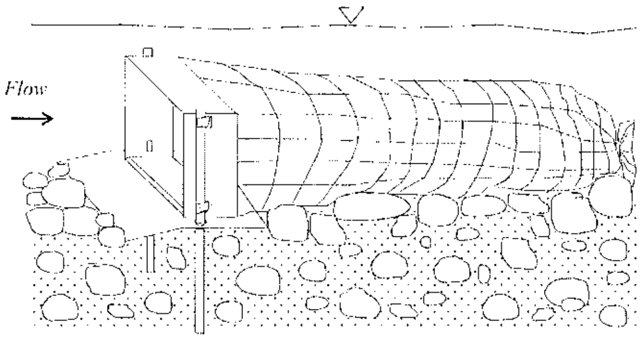

Fig. 1 Bed load trap for collecting gravel and cobble bed load.

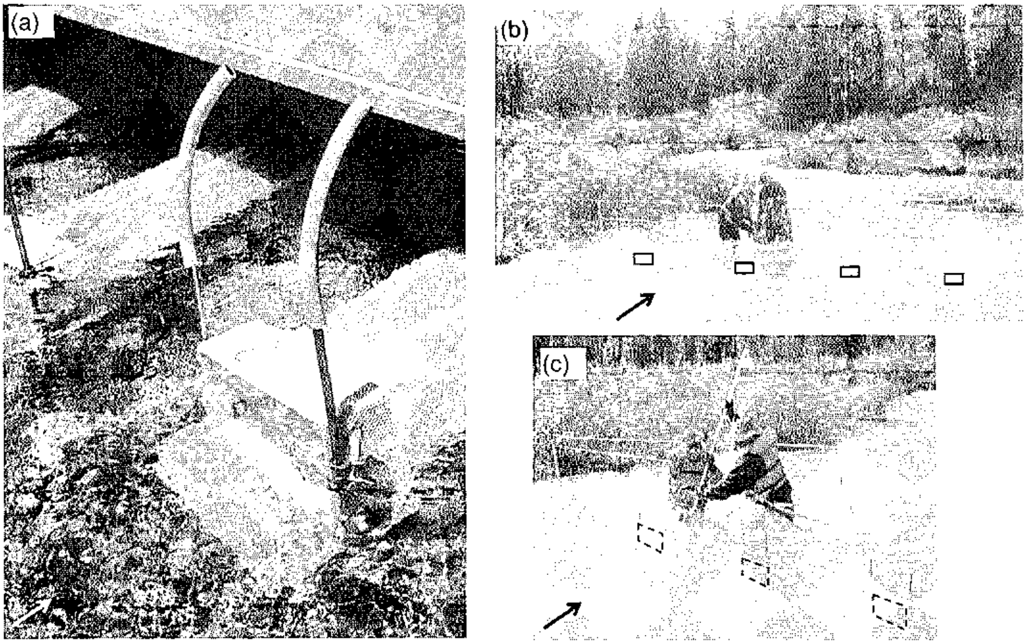

Fig. 2 (a) Bed load traps with ground plates at East St. Louis Creek in low flow. (b)Emptying bed load traps at Little Granite Creek in bankfull flow. The open squares indicate the positions of 4 of the 6 bed load traps which are completely submerged by flow. (c) Using a 7.6 × 7.6 cm opening Helley-Smith sampler at Little Granite Creek near bankfull flow.

METHODS

The bed load traps (Fig. 1) consist of a 0.3 × 0.2 m aluminium frame onto which a 0.9 m long net with a 3.9 mm mesh width is attached. For the usual 1-h duration of each sample, the frame is fastened onto a ground plate anchored on the stream bottom (Fig. 2(a)). This arrangement frees the operator from holding the traps and avoids unwanted particle pick-up during trap placement or retrieval from the bed surface. Several bed load traps are deployed across the stream in 1–2 m increments (Fig. 2(b)). Bed load was sampled with these traps in four mountain gravel-bed streams with plane-bed or step-pool morphology at wadable flows (Bunte *et al.*, 2001, 2003; Table 1).

Although not designed for coarse gravel and cobble bed load, a Helley-Smith sampler (7.6 × 7.6 cm opening) (Helley & Smith 1971) is often used in mountain streams, because this portable and readily available sampler is easy to use. In order to compare the sampling results of the bed load traps with those of the Helley-Smith sampler, bed load was also collected with a Helley-Smith sampler at each of the four streams (Fig. 2(c)), using a standard sampling scheme (e.g. 2 minutes per location spaced at 0.3–1 m increments across the stream). These data were pooled with extensive Helley-Smith data sets collected by others (Ryan & Emmett 2002; Water Resources Team of the Winema National Forest, Oregon; Ryan *et al.*, 2002).

SAMPLING INTENSITY

Because bed load traps and Helley-Smith samplers collect over different time spans and different fractions of the total width, we defined a relative sampling intensity I_r in order to quantify these differences:

$$I_r = \frac{w_s \cdot n_s \cdot \Delta t}{w_{act} \cdot t_{tot}} \tag{1}$$

where w_s and n_s are the width and number of traps (or sampling locations for the Helley-Smith sampler) per cross section, Δt is the sampling time, w_{act} is the active stream width, and t_{tot} is the total time increment allotted to one sample. We typically used a sampling time of 1 h for the bed load traps in order to provide a (sufficiently) long duration for the collection of infrequently moving (large) particle sizes near the threshold of motion. A 1-h sampling time also matches the typical time required to

Table 1 Characteristics of the four streams sampled.

Stream	Drainage Area (km^2)	Q_{bkf} (m^3 s^{-1})	w_{bkf} (m)	Surface D_{50} (mm)	D_{84}	Stream gradient (-)	Stream type*, morphology †	Range of measmts (% Q_{bkf})
Little Granite Cr.	55	5.7	14.3	69	141	0.017	B4, plane-bed	65–135
Cherry Cr.	41	3.1	9.5	49	152	0.025	B4, plane-bed	49- 145
St. Louis Cr.	34	4.0	6.5	53	120	0.017	B4, plane-bed	28–65
East St. Louis Cr.	8	0.76	3.7	108	258	0.093	A3, step-pool	26–71

* Rosgen (1994).

† Montgomery & Buffington (1997).

collect a bed load sample with a Helley-Smith sampler. Sampling times longer than 1 h may fail to have near-constant discharge during snowmelt highflows and thus prohibit allocation of a bed load sample to a discharge value. We typically deployed 4 to 6 bed load traps across streams 4–12 m wide, resulting in sampling intensities of 15–30% (equation 1). Sampling the entire stream width continuously over the entire time period allotted to one sample equals 100%. By contrast, sampling intensities for the Helley-Smith sampler only attained 0.4–0.5%; a difference of a factor of about 50.

RESULTS

Steep and well-defined rating curves

The long sampling duration facilitated by temporarily mounting the bed load traps onto ground plates permits collecting very small samples when transport rates are low. The smallest possible sample that is obtained by collecting one 4-mm particle per hour per trap equals a unit transport rate of 0.0002 g m^{-1} s^{-1}. However, the large opening size of the bed load traps and the large bag size also permit the collection of very large samples during high transport rates. For example, the largest sample obtained (at Little Granite Cr.) comprised 20 kg of gravel and cobbles collected over 6 min and had a unit transport rate of 185 g m^{-1} s^{-1}. This range spans 6 orders of magnitude between the lowest and the highest measured flows. Transport rates measured with the bed load traps generally increased steeply with discharge and the data scatter was comparatively low. Power function rating curves fitted to the bed load trap data were well-defined ($0.76 < r^2 < 0.91$) for all four streams and had high exponents between 8 and 16 (Table 2 and Fig. 3). These values are similar to rating curve exponents of 5–20 observed by other researchers who measured gravel bed load transport using devices with long sampling times and large sampler openings (e.g. Hassan & Church, 2001; Wilcock, 2001; Bunte, 1996). By contrast, power function rating curves fitted to the Helley-Smith data were less well defined ($0.35 < r^2 < 0.59$) and had exponents ranging between 1.7 and 3.6.

Comparison with Helley-Smith sampler

Detailed gravel transport rates obtained by the bed load traps and the Helley-Smith sampler are shown for comparison in Fig. 4. Results obtained at East St. Louis Creek

Table 2 Exponents ($Q_b = a \cdot Q^{b}$) and coefficients of determination (r^2) for bed load rating- and flow competence curves from the bed load traps and the Helley-Smith sampler (HS).

Stream	Bed load transport rating curves				Flow competence curves			
	Exponent		r^2		Exponent		r^2	
	Traps	HS	Traps	HS	Traps	HS	Traps	HS
Little Granite Cr	16.2	3.1	0.76	0.44	3.5	0.88	0.67	0.46
Cherry Cr.	11.5	1.7	0.90	0.35	2.7	0.67	0.90	0.57
St. Louis Cr.	10.8	3.2	0.49	0.59	2.4	1.03	0.43	0.46
East St. L. Cr.	8.4	3.6	0.78	0.54	1.5	1.01	0.40	0.27

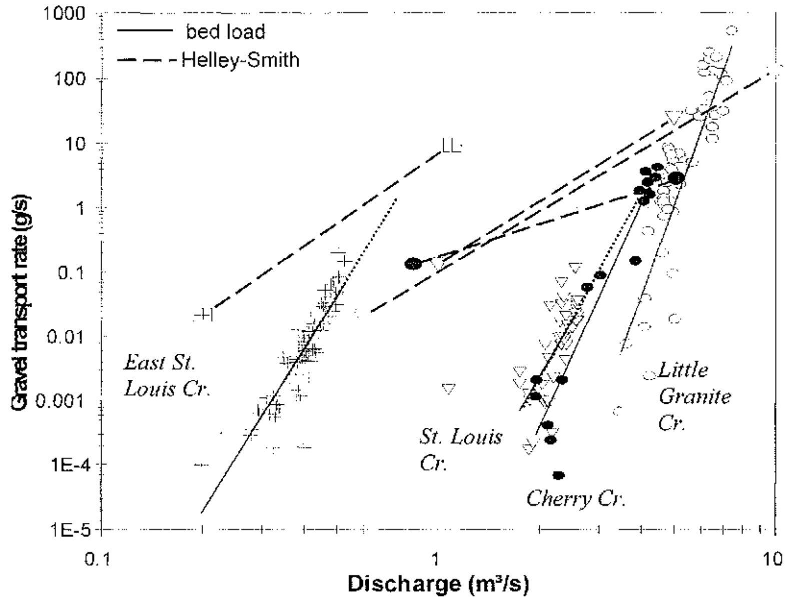

Fig. 3 Bed load rating curves obtained from the bed load traps for all four streams sampled. The respective rating curves for the Helley-Smith sampler are shown for comparison as dashed lines keyed to the symbol for each site. Dotted lines extend bed load trap rating curves to bankfull flow.

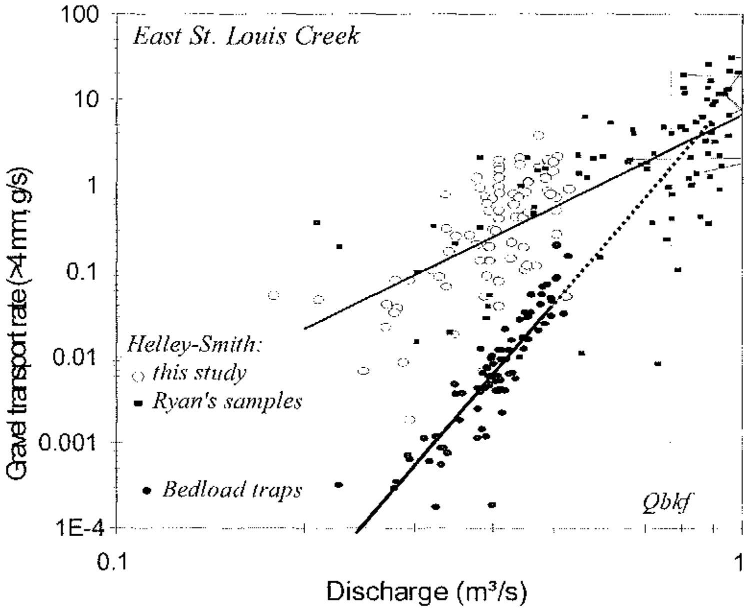

Fig. 4 Bed load transport rates and rating curves obtained from samples collected with bed load traps and a 3-inch Helley-Smith sampler at East St. Louis Creek. The grey-shaded area represents the envelope of bed load transport rates computed from Helley-Smith samples. Dotted line extends bed load trap rating curve to bankfull flow.

are typical of results obtained at all four streams. Gravel transport rates from the bed load traps were lower and had less data scatter during moderate high flows than gravel transport rates measured with a Helley-Smith sampler. The gap between bed load rating curves of the traps and the Helley-Smith sampler reached 1–4 orders of magnitude at 50% of bankfull flow. When high flows exceeded approximately bankfull, gravel transport rates collected with the bed load traps were higher than those from the Helley-Smith sampler. Thus, bed load rating curves were generally steeper for the bed load traps than for the Helley-Smith sampler and crossed near bankfull flow (Table 2 and Fig. 3). These differences are attributed to the long, 1-h sampling period which, during infrequent particle motion, facilitates sampling much smaller transport rates for the largest mobile size classes than the 1–2 min sampling time typical of the Helley-Smith. The large opening of the trap allows large gravel and cobble particles to easily enter the sampler, whereas these particles sizes may not contribute to the sample when using a sampler with a 7.6 × 7.6 cm opening. In addition, the large bag of the traps also allows sampling for a relatively long duration at high transport rates when cobbles start to become mobile.

The differences in sampler dimensions and sampling time produce not only different transport rates, but also different bed load particle-size distributions. Particle-size percentiles of samples collected with the bed load trap coarsened pronouncedly with increasing discharge (Fig. 5). By contrast, the Helley-Smith samples contain more coarse particles at very low flows, while at high flows, Helley-Smith samples remain finer. The bed load D_{max} particle sizes from the trap samples likewise increase steeply with flow. The flow competence curves fitted to data from all four streams have larger exponents for the traps than for the Helley-Smith (Fig. 6 and Table 2).

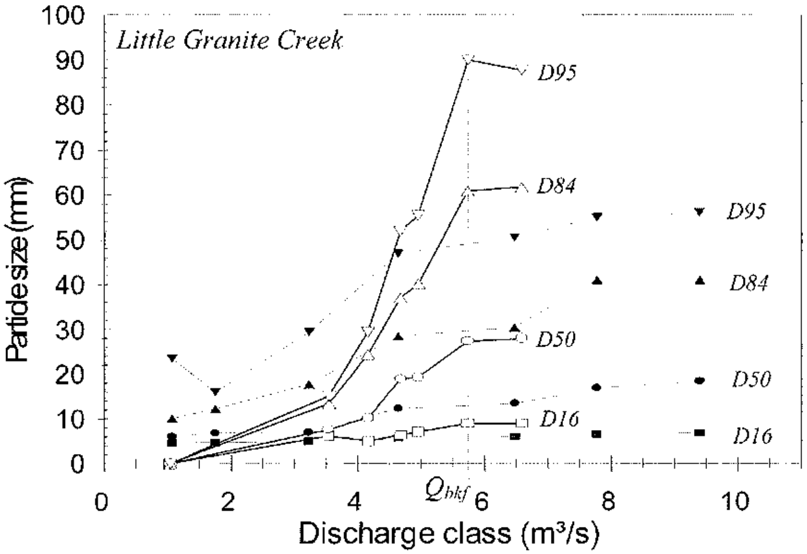

Fig. 5 Increase of bed load particle-size percentiles with grouped values of discharge for samples obtained from the bed load traps (thick lines) and the Helley-Smith sampler (thin lines).

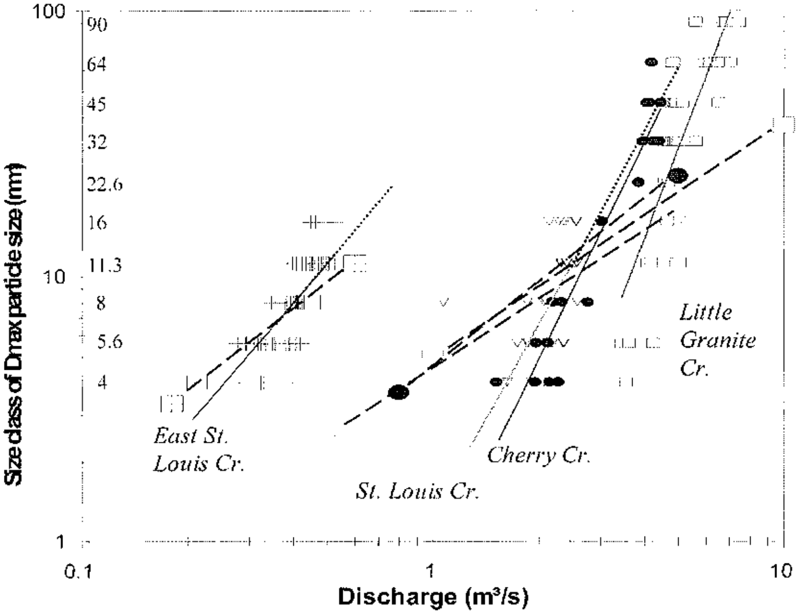

Fig. 6 Flow competence curves determined from samples collected with the bed load traps for all four streams sampled. The respective flow competence curves for the Helley-Smith sampler are shown for comparison as dashed lines keyed to the symbol for each site. Dotted lines extend flow competence curves up to bankfull flow.

IMPLICATIONS

The sampler-dependent differences in sampled transport rates and particle-size distributions have implications for all computations that are based on measured bed load transport rates. Critical discharge for gravel mobility is higher when computed based on bed load trap samples compared to computations based on Helley-Smith samples. Annual bed load discharge computed from bed load trap samples is smaller for years of low flow and higher for years with high flows than annual bed load discharge computed from Helley-Smith samples. Effective discharge, which in a magnitude–frequency analysis determines the flow that transports the majority of bed load in a given stream over the long run, is strongly affected by the rating curve steepness. In streams with snowmelt regimes, effective discharge seems to be in the neighbourhood of bankfull flow when computed from bed load rating curves with exponents around 3 but shifts to progressively higher flows as exponents of the bed load rating curves increase. This study has shown that sampling duration and sampler dimensions greatly affect sampled transport rates and bed load particle-size distributions. Consequently, other computations, such as incipient motion, annual load, and effective discharge will also be influenced by these factors of equipment and technique. The implications of this alternative way of looking at bed load data raise fundamental questions that challenge our basic understanding of fluvial systems.

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REFERENCES

Bogen, J. & Møen, K. (2003) Bedload measurements with a new passive acoustic sensor. In: *Erosion and Sediment Transport Measurement in Rivers: Technological and Methodological Advances* (ed. by J. Bogen, T. Fergus & D. E. Walling) (Proc. Workshop, Oslo, Norway, June 2002). IAHS Publ. 283 (*this issue*).

Bunte, K. (1996) Analyses of the temporal variation of coarse bed load transport and its grain size distribution (Squaw Creek, Montana, USA). English translation of PhD dissertation, Freie University Berlin, Germany. USDA Forest Service, Rocky Mountain Forest and Range Experiment Station, Gen. Tech. Report RM-GTR-288.

Bunte, K., Abt, S. R. & Potyondy, J. P. (2001) Portable bed load traps with high sampling intensity for representative sampling of gravel transport in wadable mountain streams. In: *Interagency Sedimentation* (Proc. Seventh Conf., Reno, Nevada, USA), vol. 2, III.24–III.31.

Bunte, K., Abt, S. R., Potyondy, J. P. & Ryan, S. E. (2003) Measurement of coarse gravel and cobble transport using a portable bed load trap. *J. Hydraul. Engineer* (submitted)

Downing, J., Farley, P. J., Bunte, K. *et al.* (2003) Acoustic gravel-transport sensor. In: *Erosion and Sediment Transport Measurement in Rivers: Technological and Methodological Advances* (ed. by J. Bogen, T. Fergus & D. E. Walling) (Proc. Workshop, Oslo, Norway, June 2002). IAHS Publ. 283 (*this issue*).

Froehlich, W. (2004) Monitoring of bed load transport in streams by use. In: *Erosion and Sediment Transport Measurement in Rivers: Technological and Methodological Advances* (ed. by J. Bogen, T. Fergus & D. E. Walling) (Proc. Workshop, Oslo, Norway, June 2002). IAHS Publ. 283 (*this issue*).

Gottesfeld, A. S. & Tunnicliff, J. (2003) Bed load measurements with a passive magnetic induction device. In: *Erosion and Sediment Transport Measurement in Rivers: Technological and Methodological Advances* (ed. by J. Bogen, T. Fergus & D. E. Walling) (Proc. Workshop, Oslo, Norway, June 2002). IAHS Publ. 283 (*this issue*).

Habersack, H. M. (2003) Use of radio-tracking techniques in bedload transport investigations. In: *Erosion and Sediment Transport Measurement in Rivers: Technological and Methodological Advances* (ed. by J. Bogen, T. Fergus & D. E. Walling) (Proc. Workshop, Oslo, Norway, June 2002). IAHS Publ. 283 (*this issue*).

Hassan, M. A. & Church, M. (2001) Sensitivity of bed load transport in Harris Creek: Seasonal and spatial variation over a cobble-gravel bar. *Water Resour. Res.* **37**(3), 813–825.

Helley, E. J. & Smith, W. (1971) Development and calibration of a pressure-difference bed load sampler. US Geol. Survey Water Resource Division, Open-File Report, Menlo Park, California, USA.

Laronne, J. B., Alexandrov, Y., Bergman, N. *et al.* (2003) The continuous monitoring of bedload flux in various fluvial environments. In: *Erosion and Sediment Transport Measurement in Rivers: Technological and Methodological Advances* (ed. by J. Bogen, T. Fergus & D. E. Walling) (Proc. Workshop, Oslo, Norway, June 2002). IAHS Publ. 283 (*this issue*).

Mizuyama, T., Fujita, M. & Nonaka, M. (2003) Measurement of bedload with the use of hydrophone in mountain torrents. In: *Erosion and Sediment Transport Measurement in Rivers: Technological and Methodological Advances* (ed. by J. Bogen, T. Fergus & D. E. Walling) (Proc. Workshop, Oslo, Norway, June 2002). IAHS Publ. 283 (*this issue*).

Montgomery, D. R. & Buffington, J. M. (1997) Channel-reach morphology in mountain drainage basins. *Geol. Soc. Am. Bull.* **109**(5), 596–611.

Ryan, S. E. & Emmett, W. W. (2002) The nature of flow and sediment movement in Little Granite Creek near Bondurant, WY. USDA Forest Service, Rocky Mountain Research Station. Gen. Tech. Report RMRS-GTR-90.

Ryan, S. E., Porth, L. S. & Troendle, C. A. (2002) Defining phases of bed load transport using piecewise regression. *Earth Surf. Processes Landf.* **27**(9), 971–990.

Rosgen, D. L. (1994) A classification of natural rivers. *Catena* **21**, 169–199.

Sear, D. A. (2003) Event bedload yield measured with load cell bedload traps and prediction of bedload yield from hydrograph shape. In: *Erosion and Sediment Transport Measurement in Rivers: Technological and Methodological Advances* (ed. by J. Bogen, T. Fergus & D. E. Walling) (Proc. Workshop, Oslo, Norway, June 2002). IAHS Publ. 283 (*this issue*).

Sear, D. A., Lee, M. W. E., Carling, R. J. *et al.* (2003) An assessment of the accuracy of the Spatial Integration Method (SIM) for estimating coarse bedload transport in gravel-bedded streams using tracers. In: *Erosion and Sediment Transport Measurement in Rivers: Technological and Methodological Advances* (ed. by J. Bogen, T. Fergus & D. E. Walling) (Proc. Workshop, Oslo, Norway, June 2002). IAHS Publ. 283 (*this issue*).

Wilcock, P. R. (2001) Toward a practical method for estimating sediment transport rates in gravel-bed rivers. *Earth Surf. Processes Landf.* **26**, 1395–1408.