Experiences and results from using a big-frame bed load sampler for coarse material bed load

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ABSTRACT In a mountain river coarse material bed load was sampled with a 1.6 m x 0.3 m opening net sampler. Consecutive samples varied in transport rates and grain-size composition. The results of a grain-size analysis suggest that the mode of bed load transport at Squaw Creek switches between selective and equilibrium transport.

INTRODUCTION

The predictive value of bed load formulas for coarse material is still not satisfactory. The processes occurring during coarse material bed load transport have not yet been clarified. Particle interaction and its impact on initial motion have been investigated by various researchers but their findings seem to be contradictory.

One of the main problems regarding transport modes is that during a transport event under natural conditions processes on the river bottom would have to be observed and measured which still cannot be achieved. Even measuring coarse material bed load transport in mountain rivers is still a difficult task. Ordinary hand held samplers do not provide representative samples of the typically very widespread grain-size distribution of mountain river sediments and measuring efforts are hampered by the extreme force of flow during floods with coarse material bed load transport. A practicable and cheap method of measuring not only the quantity but also the grain-size distribution of coarse particles in transport has to be employed.

METHOD OF SAMPLING

Sampling conditions at Squaw Creek

At Squaw Creek, Gallatin Range, Montana (USA) a bed load sampler had to be used that was suitable for the prevalent conditions (ERGENZINGER & CUSTER 1982, 1983; BUNTE et al. 1987; CUSTER et al. 1987; BUGOSH & CUSTER 1989). Grain-size distributions of the gravel bar and the river bottom range from sand to cobbles with a D50 of the gravel bar of 20 mm and 120 mm at the river bed (before truncation). Sampling was carried out during bankfull discharge of a snow-melt high flow ranging between 4 - 6 m³/s with its typical diurnal fluctuations of flow. With flow velocities approaching 2 m/s and water depths of about 0.7 m it is nearly impossible to use a 3 by 3 inch or 6 by 6 inch hand held Helley-Smith sampler. Needless to say, those samples would not have represented the coarser fraction of the river sediments.
The big-frame net sampler

The big-frame net sampler used at Squaw Creek has a wooden frame 0.3 m by 1.6 m with a fisherman's net attached. The length of the net is 3 m and the mesh width was chosen to be 10 mm to reduce the pressure of flow on the sampler. At the measuring site the river is 8 m wide and spanned by a bridge under which a catwalk crosses the river at a distance of about 1 m above the river bottom, exactly above a small artificial waterfall made by three logs to protect the bridge. Two vertical bars are wedged into these logs and fastened on the catwalk on their upper end to provide support for the sampler. Once lowered onto the river bottom the frame is pressed onto the bars by the flow. After sampling, the frame is vertically winched up. When the frame is just out of the flow one of the vertical bars is removed. The frame floats downstream on the water surface dragging the net behind. Held by a thick rope the sampler is maneuvered to the next shallow bank where it can be emptied. One measuring cycle (the actual sampling time not included) takes about half an hour and three persons to handle it.

Sample sizes and time resolution

This sampling device provides bed load samples representing a fairly wide part of the active cross-section. The grain-size distributions sampled range from 10 - 180 mm, thus covering the coarser part of mountain river sediments. Time resolution is such that one five-minute sample can be taken every half hour. Sample weights reached 90 kg, thus providing (nearly) enough coarse bed load material for a grain-size analysis. Owing to unpredictable transport rates the sampling durations were kept rather short so that sample weights did not reach the standards set by IBBEKEN (1974) and CHURCH et al. (1987).

Time and location of samples taken

The bar sediments were taken as a bulk sample from a gravel bar that begins to be flooded at Q1.8. The river bed was analyzed by an areal sample. At spring high flow 24 samples of bed load were taken with the big frame net sampler. In order to investigate temporal variations of bed load the grain-size properties of serial samples were analysed. During one nocturnal flow five consecutive samples of bed load were taken within a seven-hour interval. During the other night another series of seven samples was gained over a twelve-hour period.

DATA ANALYSIS

Sieving and grain-size distribution

All samples (bed load, gravel bar and bed surface) were sieved at half phi intervals. In order to compare grain-size properties of the river bed and the bar with actually transported bed load all samples were commonly truncated at 11.2 mm (-3.5 phi) because particles smaller than 10 mm passed through the mesh width of the net. The grain-size frequency distribution of the three sediment units are shown in fig.1.
The bed surface layer
The grain-size distribution of the surface layer of the river bed is typically skewed towards the coarser grain-sizes as indicated by SUTHERLAND (1987), while all the other grain-sizes are about equally well represented by weight. Some of the big particles are blocky and wedged into the surface layer, improving its stability. Nevertheless, according to the definition by ANDREWS & PARKER (1987) the surface layer of Squaw Creek should be called rather pavement than armour, as the bed, though seemingly stable, changed its form during "normal" high flows with a recurrence interval of less than two years and developed a pronounced pool-riffle situation within the measuring reach.

The gravel bar
The grain-size distribution of the gravel bar as a depositional structure of a former (large?) transport event shows that all the particles present in the pavement can be transported, but favourably, the transport concentrates on pebbles. The grain-size composition of the gravel bar is symmetrical and Gaussian distributed. Most of the gravel bar's coarse material is in the pebble range between 32 and 45 mm.

Bed load material
The average grain-size distribution of the seven consecutive samples of current coarse bed load material taken during typical high flow in the night of May 24 - 25 basically has the same grain-size composition as the gravel bar. The concentration of pebbles is more pronounced showing their high and preferential mobility. These pebbles seemingly have the least chance of settling in a "hiding place" between two cobbles. Thus, given a sufficient competence of flow, it is pebbles that are transported most frequently.

Comparison of consecutive bed load samples
The temporal variation of bed load transport rates and the grain-size composition of consecutive samples is plotted on the hydrograph (fig. 2). Transport rates and grain-size distributions fluctuate most
strongly during the falling limb of a daily high flow (see the morning of May 25, 1988). Though discharge was not stationary its variation between 5.5 and 6 m³/s cannot be made responsible for such strong variations of transport rates, especially as high transport rates do not necessarily coincide with high discharges but show the typically wide scatter (1 order of magnitude) on a plot bed load transport rate versus discharge (fig. 3). The fluctuation of transport
Using a big-frame bed load sampler for coarse material bed load transport rate.

**FIG. 4** The variability of grain-size parameters with bed load transport rate and discharge.
rates has been described by numerous authors representing several theories for bed load waves (GOMEZ et al. 1989). In order to gain an insight into processes causing oscillating transport rates at Squaw Creek the grain-size distribution of bed load samples was analyzed.

The grain-size frequency distributions revealed that the spectra of consecutive samples varied strongly. While some spectra seemed to be evenly Gaussian distributed, others gave the impression of being cut off at their coarse part. To quantify these variations in grain-size distribution a grain-size analysis was carried out for all bed load samples. The "moment" method as used by SCHLEYER (1987) proved to be better suited to the problems associated with truncated grain-size distributions than the method proposed by FOLK & WARD (1957). All calculations were based on 1/4 phi units.

Variation of grain-sizes and grain-size parameters

Grain-size parameters examined are the $D_{\text{max}}$ size class and the four moments which correspond to mean diameter, sorting, skewness and kurtosis, respectively. The variation of grain-size parameters with transport rates and discharge is plotted in fig. 4. $D_{\text{max}}$ size class, mean, sorting and symmetry generally increase with bed load transport rate, though the data scatter widely. The grain-size parameters basically show the same tendency with discharge. However, the variability of grain-size parameters is especially obvious for large flows.

In order to clarify the scatter between grain-size parameters and transport rates or flow respectively and to try to identify the processes involved, the data are separated into four groups according to flow conditions and transport rates:

1. five consecutive samples taken during the night of 23-24 May 1988 at discharges between 5.0 and 5.26 m³/s.
2. samples taken during the night of 24 - 25 May 1988 with discharges between 5.58 - 5.73 m³/s
   (a) and large transport rates between 41 - 72 g/m-s.
   (b) and small transport rates ranging from 3 - 12 g/m-s.
3. the rest of the samples from the beginning and the end of the high-flow period with discharges ranging between 3.9 and 5.8 m³/s.

The samples of group # 1 with relatively small rates of bed load transport were taken consecutively during the rising limb of the hydrograph with rather low rates of discharge. These samples do not show much variation in sorting (2nd moment), but all the other grain-size parameters, their $D_{\text{max}}$, mean diameter (1st moment), symmetry (3rd moment) and kurtosis (4th moment) increase regularly with the amount of bed load being transported and even with the amount of flow.

During heavier flow (group # 2) bed load transport is highly unpredictable. Not only the amount but also the composition of bed load material varies extremely with flow. Though the upper limit of the amount and grain-size transported is fixed by the river's capacity and competence, everything else is highly variable. With their large temporal variations bed load transport rates are strongly fluctuating.

Samples of group # 2a comprising large amounts of bed load have a large $D_{\text{max}}$ and mean, moderate sorting but good symmetry. These samples resemble an equilibrium transport (ANDREWS & PARKER, 1987). By contrast, samples of group # 2b with small bed load transport rates have a dearth of coarse material and a low mean particle diameter.
They are better sorted and more strongly skewed in either direction than the bigger samples of the previous group 2a. As the bedload of group 2b was moved within the same range of discharges as the large bed load samples, these small samples indicate a selective transport of finer material (GOMEZ, 1983). Those abrupt changes in bed load quantity and quality that are not matched by discharge variations were observed in consecutive samples of bed load spaced in 1-2 hour intervals. At Squaw Creek they correspond with wavelike transport measured continuously by the magnetic tracer technique. Bed load waves are especially conspicuous on the falling limbs of the daily high flows (ERGENZINGER et al. 1983; CUSTER et al. 1987; BUNTE et al. 1987).

CONCLUSION

During rising discharge of moderate flows the quantity and the grain-size distribution of bed load increases regularly according to the river's growing competence and capacity. The force of the flow is the main factor controlling the amount and quality of bed load.

After the discharge has exceeded a threshold value of about 5.5 m$^3$/s at Squaw Creek the river's capacity is high enough to transport most of the bed material present. But though the strength of flow is sufficient cobbles and bulks of gravel are only transported temporarily because interactions between grain-sizes (hiding, exposure) hamper the direct conversion of stream flow energy into motion of bed load.

According to the findings described above the fluctuating transport at Squaw Creek can be interpreted as the result of switching between selective transport and equilibrium transport. The reason for this alternation may be partly explained with reference to ANDREW'S & PARKER'S (1987) theory.

During the rising stage the pavement is coarsened by selectively transporting the finer material (small skewed samples of group 2b). This roughening of the surface is a prerequisite for the onset of equilibrium transport. When the fines are winnowed out the cobbles become fully exposed to flow and are transported, leaving smaller material below them unprotected and thus exposed to flow and transported as well (large symmetrical samples of group 2a). In contrast to ANDREWS & PARKER (1987) equilibrium transport at Squaw Creek is not a self-supporting continuously sustained process but an intermittent process uneven in space and time.

For rivers like Squaw Creek the process of coarse material bed load transport may be explained as follows: when the local scour is deep enough erosion will cease owing to a decrease in shear stress or even owing to a smoothing of the surface by a depletion of cobbles. Having reached an area of reduced shear stress somewhere downstream, the big particles will settle and locally provide a rougher surface in which the smaller material can come to rest as well. Owing to this deposition the river bottom locally aggradates decreasing the flow depth and increasing shear stress. A cyclic process of local deposition and erosion is produced which in the case of a slightly supply-limited river like Squaw Creek might be responsible for wave-like bed load transport phenomena. To test this hypothesis more serial representative samples of coarse bed load material have to be analysed. Future work needs to concentrate on dimensions and speed of bed load waves as well as on classifications of rivers regarding their bed load availability.

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