# A new instrument to record sediment movement in bedrock channels.

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## *Introduction*

Measurements of initial motion and bedload transport are difficult in alluvial streams but pose a particular problem in high-energy bedrock rivers. Not only is expensive instrumentation at risk of being destroyed, but suspension cables and support frames are usually inadequate to allow successful deployment. In addition there is a considerable risk to the safety of researchers in such environments. These problems may be addressed by the development of instrumentation which is robust during high-flows but which is deployed safely during low-flows. A long sampling period, with a high-frequency sampling interval, is required as sediment transport will not occur immediately after deployment, but only when a floodwave passes through the system. Finally the system needs to be cheap to allow for replication and for inevitable instrument losses in such hostile environments.

## *Instrument Details and Limitations*

An instrument has been developed to detect the acceleration of a steel plate fixed to a rock riverbed upon being struck by a clast. A counting data logger is attached to the underside of this plate within a recess chiselled into the bedrock. Small commercially available rock-fixings are used to anchor the steel plate to the bedrock. The acceleration sensor itself is placed within the water-tight datalogger and it uses the same battery supply. The device is limited by the need to install it in low-water conditions and by its insensitivity to clast size. We have yet to properly calibrate the detection threshold of the device, but clasts as small as a few mm are detected. Importantly, it has shown to be reliable and rugged in the extreme environment presented by bedrock channels in flood. The device is relatively small; the dimensions of the logger being 8 x 6 x 3.5cm, whilst the impact plate is 15 x 13 cm and is 6mm thick (Fig. 1).

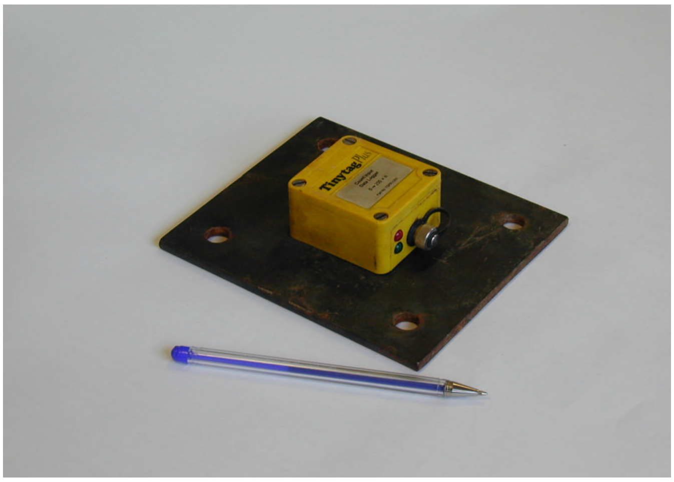

Figure 1. Impact sensor and impact plate shown in inverted position.

The internal battery is replacable and can power the unit for over six months. A version with a small external sensor is also under development for laboratory-flume experiments with sand size particles. At the time of writing the cost of the field unit is around £400.

There are some limitations to the sensors currently in use which need to be considered when interpreting data-charts. The sensors can record a maximum of 3 counts per second, and impacts which occur less than 1/3 second after the previous one are not recorded. This works out at 1800 counts in a

10 minute interval. The highest recorded count in the results presented below is 1850. This recording, and others of similar magnitude, therefore are probably saturated. In addition, the response of the sensors is not linear, as the likelihood of two impacts occurring less than one third of a second apart increases with transport rate.

### *Preliminary Results*

To date, the main uses of the device has been (a) the detection of the thresholds of sediment motion and cessation, (b) relative intensities of transport through time and (c) comparison of simultaneous differences in transport intensities in different regions of a channel. Some recent results from the field (in Birk Beck, Cumbria, UK) are presented below for an 'extreme' flood during which flow velocities of 3.5m/s were measured directly and in which velocities commonly reach 4m/s. During this event, coarse gravel including large cobbles and rounded boulders up to 1m in diameter were moved through the test section. The largest tabular block known to have moved measured 1.5m x 1.0m x 0.5m. An uncalibrated pressure sensor, deployed in the same manner as the inpact sensors, initially produced useful results but was later destroyed. However all three impact sensors which were deployed, survived and gave excellent results (Fig. 2). In Figure 2 the main bedload transport occurred along the left side of the channel (left track) with a additional contribution along a central track. A further minor bedload track occurred near the right bank but transport intensities were too low to be visible in this figure. In view of the failure of the single pressure sensor, additional water depth data are reported, which were obtained from two non-invasive ultrasonic water level sensors mounted above the river. Depth was then determined from knowledge of the distance from each sensor to the bedrock surface.

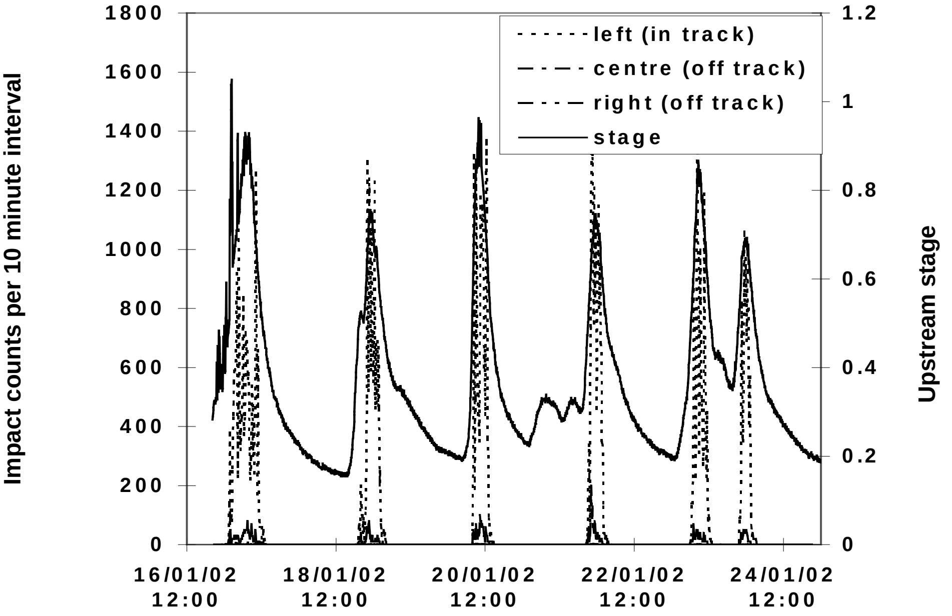

Figure 2. Variation in number of bedload impacts during the passage of six flood peaks.

### *Discussion*

Bedload is routed along well-defined and narrow pathways within the channel, as shown by the distinctly different records of the three sensors. This conclusion is supported by qualitative observations. Specifically, during the prolonged summer low-flows, the bedrock surface becomes covered by algae. The first autumn floods scours the algae completely from distinct bedload tracks, leaving several visually distinct 'clean' ribbons of bedrock separated by algal-covered areas. There is a well-defined critical shear stress for bedload transport that is detectable by the sensors of 40 - 50 $Nm^{-2}$. Using a Shields' parameter of $\theta = 0.045$ within the well-known Shields' threshold entrainment equation a minimum detectable grain size of 55 - 70mm is indicated. Nevertheless, the critical shear stress for initiation of transport (as detected by the sensors) is variable between events, and occurs between 40 and 100 $Nm^{-2}$. In contrast, the critical shear stress for the cessation of transport is more constant at 40 – 50 $Nm^{-2}$. Consequently, during any single event, the graph of recorded bedload impacts versus shear stress shows a hysteresis of bedload transport, in which transport persists at lower shear stresses than those required to initiate it (Fig. 3).

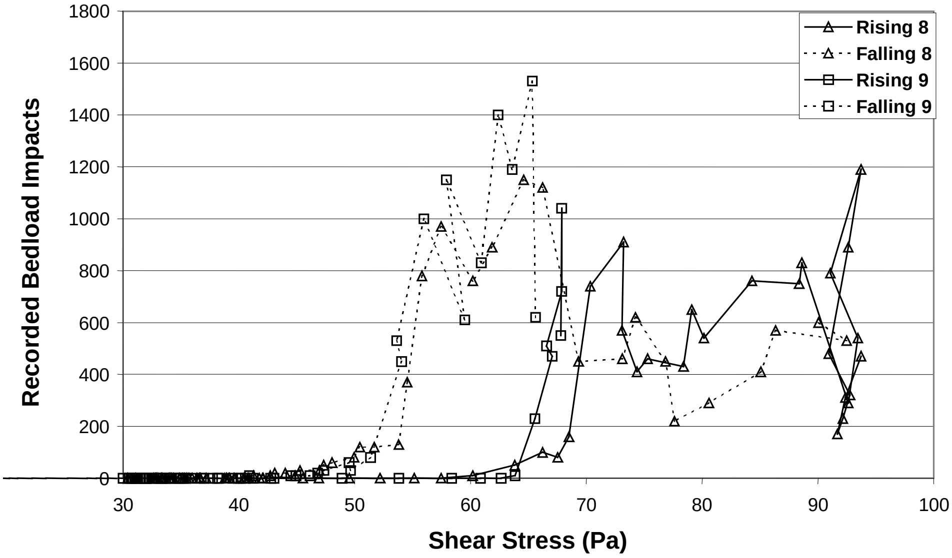

Figure 3. Hysteretic behaviour of bedload transport intensity for flood events 8 and 9.

Although the curves are variable in shape, they generally indicate increasing bedload transport with increasing shear stress above the threshold. During falling stage, transport rates show a gradual decrease at first, followed by a more rapid decrease as the threshold is approached from above. The peak transport rate may even occur during falling stage. In fact, although the curves during rising stage are variable, the falling stage curves often overlie each other. Some few events, for example 8 and 9 (Fig. 3) are very similar in behaviour. Although transport rates show an increasing trend with stage above the threshold, transport rates are highly stochastic and illustrate the pulsing nature of bedload. No clear trends over the period of the record can be identified, nor do the very large events appear to have an effect on the subsequent events. However these latter two observations may reflect the length of the period of monitoring. A longer study period might indicate seasonal or event-by-event exhaustion effects (see Carling and Hurley, 1987).

## *Conclusion*

I new robust bedload sensor has been developed for deployment in high-energy bedrock channels. The instrument has provided high-quality data on initiation and cessation of motion of bedload. In addition, the variation of relative transport intensity during individual flood events has been recorded at a fine time-resolution enabling the detection of pulsing in bedload motion and distinct hysteretic behaviour when comparing the waxing and waning limbs of hydrographs.

## *References*

Carling, P.A. & Hurley, M.A. (1987) A time-varying stochastic model of the frequency of bedload events in two small trout streams. pp 897-916 In: Thorne, C. & Bathurst, J. (Eds) '*Sediment Transport in Gravel-bed Rivers*', John Wiley & Sons, Chichester, England.