

Bedload transport rates and the stream hydrograph: results from a new type of load cell bedload trap

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Introduction

Bedload transport is known to be highly unpredictable. At the fundamental level, bedload transport is a function of the entrainment and the movement of individual grains on a stream bed (Hassan & Church, 1992). To date, most studies have attempted to derive physically-based or empirical models of entrainment, and where transport rate is to be calculated, between transport rates and section averaged or even local estimates of driving force. One of the main stumbling blocks to the modelling of bedload transport arises from the fluctuations in rate caused by time varying passage of sediment from upstream. The supply of sediment available to be transported is known to be a function of both temporal and spatial variations in entrainment characteristics (cluster, armouring and patches) of the river bed (Larrone et al 2000). Stream beds dilate, or become more packed under marginal transport conditions, affording higher resistance to transport. In supply limited rivers, the sudden availability of new sources of bedload from armour break-up, bar mobilisation or bank collapse, may become locally important. Such variability is reflected in the high degree of scatter recorded in bedload transport datasets, although it seems particularly pronounced in supply limited humid-temperate streams (Reid & Frostick, 1986).

An important element in the process of bedload transport is the extent to which local vs. remote sources of supply interact with the sequence of flows to create temporal and spatial variability in transport at a section. We can hypothesise that sediment will be available at different times (flows) and in different places during an event. As flows rise, new sources are accessed, the significance of which will depend on the geomorphology of the channel; for example, channels with relatively high bar amplitude will only access sediment on the bar tops relatively infrequently. Similarly, wide shallow channels, may access most of the channel bed relatively rapidly. An additional factor influencing the temporal patterns of bedload at a section, will be the distance over which bedload can travel to supply material to the point of measurement. Most tracer studies of particle movement indicate an average event travel distance of < 4 channel widths, with maximum average values of < 17 channel widths for high magnitude floods. An important factor affecting the connectivity of the measurement point with upstream sediment supply must therefore be the duration of flow over the critical threshold for transport, together with some consideration of where the sources of sediment are within the upstream reach. Set alongside this aspect of the flood hydrograph (the event duration) is the event magnitude, as this conditions the proximity to thresholds of entrainment, armour break up, and access to vertical change in sediment source area. Long term, high resolution bedload data is rare, since most trapping studies tend to be project specific, or are undertaken in environments where the number of transport events is limited (Powell et al. 1992). However, if we are to better understand the processes of bedload transport it will be important to extend the data sets over longer periods of time.

This paper takes a holistic look at the influence of the flood hydrograph on bedload transport yield measured at a downstream station using a dataset of 60 individual bedload events collected over the period 1998 – 2002.

Study Site and Methods

Four bedload samplers were installed across a section in a straight reach of the Highland Water, a small gravel-bed channel located in a 12.5km² semi-natural wooded catchment in southern England (Booker et al 2001). The Highland Water Bedload Sampler (HWBS) is a load-cell based continuous recording pit-trap (Sear et al. 2000). Annual re-calibration has proven the system to be stable, with some drift accounted for by accumulation of sediment around the load cell cradle. The traps have functioned without the need for maintenance for over 75 bedload events. Flows have varied up to floods of 1:50 year Recurrence Interval.

Results

Bedload transport is dominated by material in the coarse sand – medium gravel ranges (D_{16} 1.3mm, D_{50} 3 – 7mm, D_{84} 7-22 mm), typically the same composition as upstream bar material,

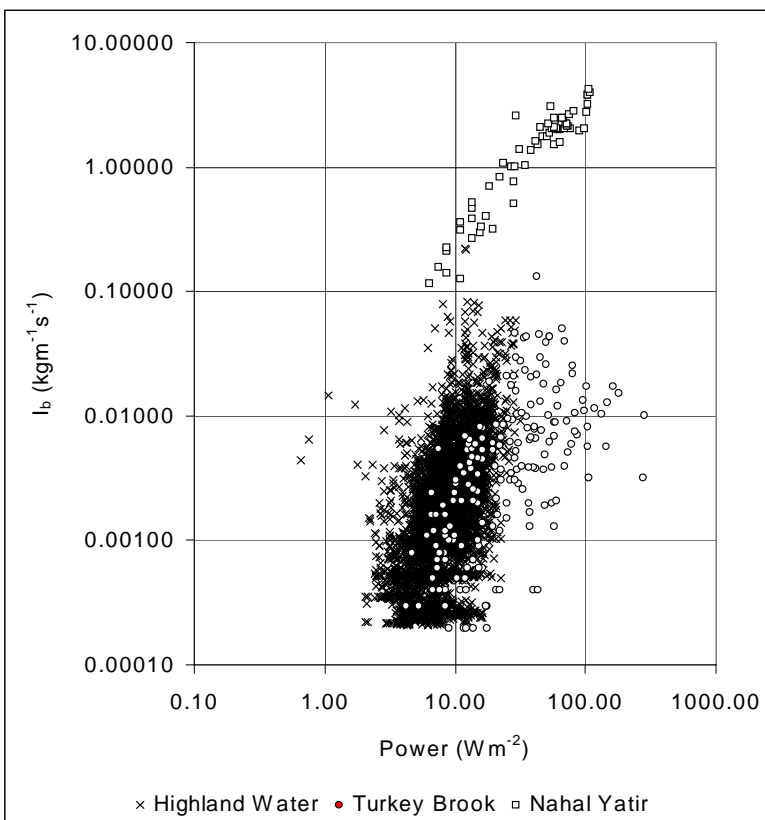


Figure 1: Scatter in the relationship between specific stream power and bedload transport rate for Highland Water and selected streams.

and somewhat finer than surface armour found on riffles and in pools. Considerable scatter is shown in the relationship between specific stream power and transport rate (Figure 1). Transport rates are low compared to Desert Flash floods, but are of similar magnitude to those observed in the Turkey Brook, a stream with similar geology and sedimentological properties (Reid & Larrone, 1995). In accounting for the scatter observed in their transport rates, Reid et al. (1985) suggested that the thresholds of initiation of transport and cessation were often different, with lower thresholds for final motion. A similar result is found in the Highland water, but is interpreted not as representing the difference in static vs. dynamic resistance to movement, but rather a due to the temporal variability in the supply of material from upstream sources. Similarly, Reid et al (1985) observed a temporal variation

in entrainment thresholds associated with prolonged periods of bed stability. This was not observed in the Highland Water, rather as the period between bedload events increased subsequent entrainment thresholds tended to reduce. This is interpreted as representing the difference in dominant sediment sources; the Highland Water largely deriving bedload from upstream patches of fine material stored in bars and pools.

One of the main goals of sediment transport research is to be able to predict the volume or mass of material transported by floods. The dominance of discrete upstream sources of bedload, suggests that much of the variability in observed transport rates, relate to the ability of upstream sediment to make it to the traps on an individual event. This is more closely associated with the duration of bedload above the threshold for transport than event magnitude. However, the magnitude of the event is still significant because it determines not only the power available to initiate transport, but also conditions event duration, and the access to vertically segregated sediment sources. A measure of the total event power above the threshold for sediment transport can be derived with units in Mjm^{-1} . The relationship between total event power and

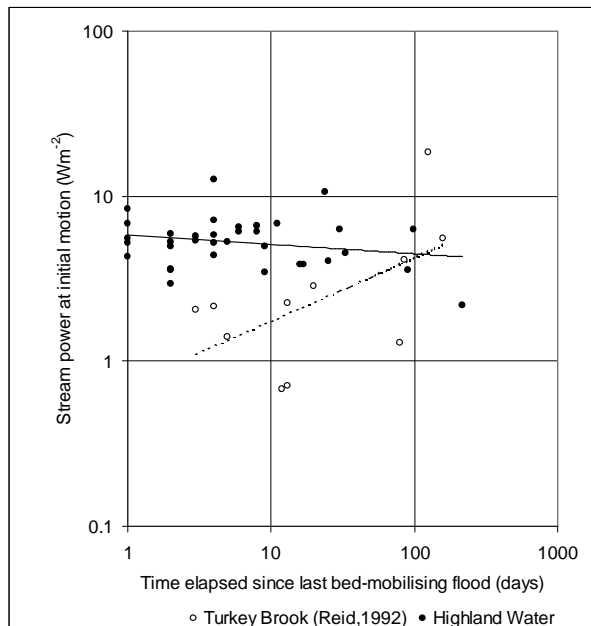


Figure 2: Variation in the threshold of transport with time between bedload events for Highland Water and Turkey Brook (after Reid & Frostick 1986)

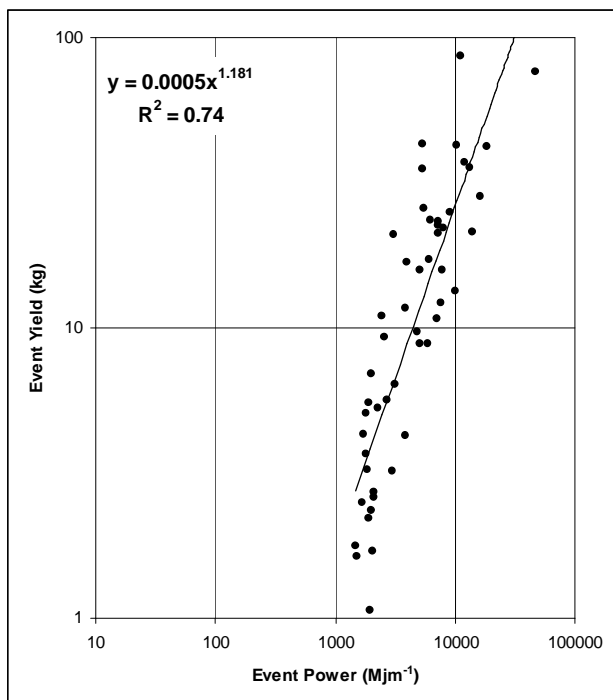


Figure 3: Relationship between total event power and event yield, for 60 floods in the Highland Water.

total event yield is given in Figure x. Over 70% of the variation in event yields is explained by this term, compared to 52% and 54% for maximum stream power or event duration respectively. Factors contributing to the unexplained variation include the presence of stochastic supply from bank collapse, the exhaustion of upstream sources and the suspected influence of turbulence in conditioning sediment transport rates particularly at lower flows.

The influence of event duration and magnitude on sediment transport rates has been previously suggested as a means of classifying the effectiveness of extreme floods (Costa & O'Connor, 1995). Three types of flood were discerned; A) those that have high magnitudes, but short duration, B) those that have long duration but are below or at the threshold of motion and C) those that are of high magnitude

and duration. The latter were considered to be the most geomorphologically effective since these had the largest total available energy for sediment transport. Using the database of 60 floods covering events up to 1:50 year RI, it is possible for the first time to test this conceptual model (Figure x). In Figure x, the circles scale in proportion with total event yield (a measure of geomorphological effectiveness). Geomorphological effectiveness is maximised for events of high magnitude and long duration (B), but also for those of long duration and moderate magnitude (C). Short duration high magnitude events (A) owe much of their effectiveness to the

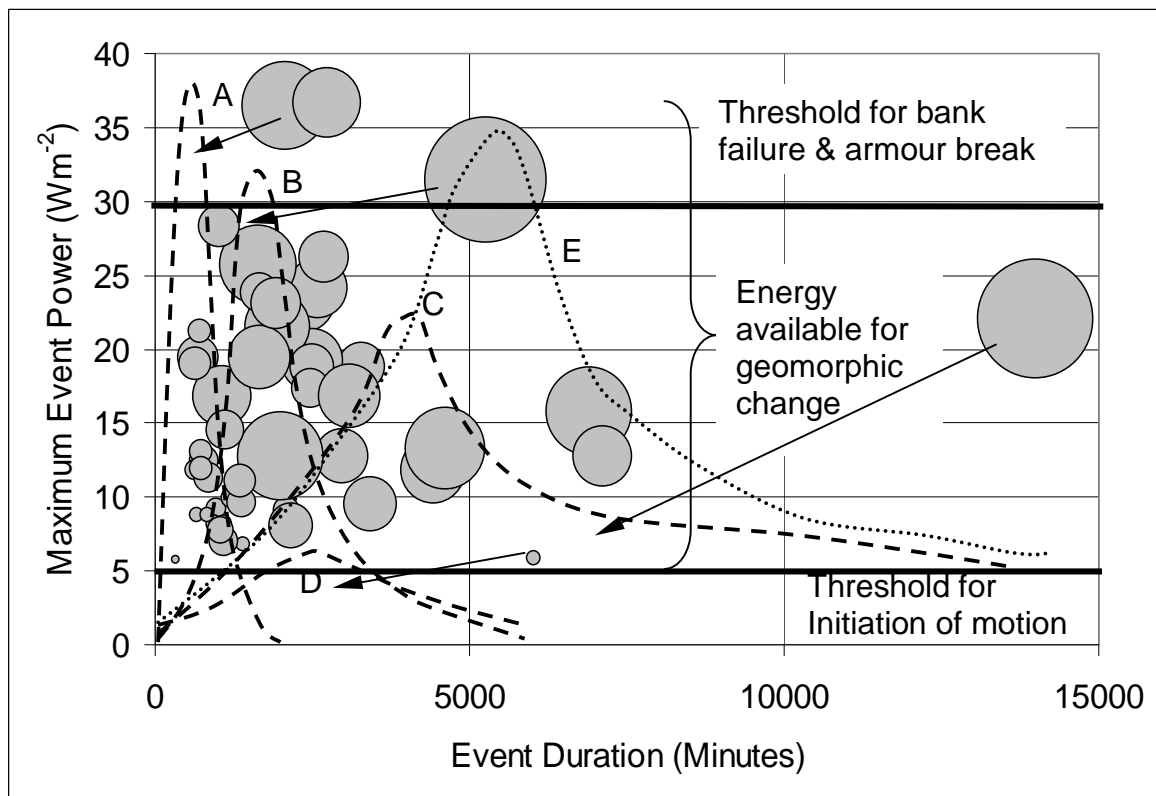


Figure 3: Classification of floods in terms of geomorphological effectiveness after Costa & O'Connor (1995). Circles are scaled according to event yield for 60 floods on the Highland Water.

collapse of the river banks, and break up of the Armour layer, creating new local sources of bedload. Conversely, events that fail or are close to the threshold of transport of whatever duration (D), generate only limited movement. The reason for the effectiveness of Type (B) is that they not only access new sources through armour break-up and bank erosion, but they also establish connectivity between sediment sources over much longer reaches of channel. The identification of the significance of the form of the flood hydrograph on bedload transport has implications for interpreting the impacts of land management activity and climate change on channel morphology. Conditions that increase flood magnitude but reduce flood duration may be associated with sedimentation since transfer of material will occur over relatively short distances. Conversely, longer duration events of higher or similar magnitude to present, may result in much more significant channel activity as longer reaches of the river network become connected.

Conclusions

A new portable and cheap load-cell based continuous recording bedload trap has been successfully deployed and run for four years, over which time 75 bedload events have been recorded for flows up to 1:50 year RI. Sediment transport rates are of comparable magnitude to those reported in similar streams, but there are significant differences. Thresholds for initiation of bedload transport do not increase with time between events, rather these remain stable or reduce. Similarly, events are characterised by negative hysteresis. Both these factors point to the importance of upstream sources in controlling temporal variations in event yield. It is demonstrated that for predictive purposes, total event power, a variable that includes duration as well as magnitude, explains over 70% of the variability in event yield. A model of the effectiveness of different flood types is tested. Four types of event are identified in the highland water. Those of high magnitude and long duration are associated with maximum effectiveness because they not only access new sources through armour break-up and bank erosion, but they also establish connectivity between sediment sources over much longer reaches of channel.

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