Geomorphology 244 (2015) 169–179

Contents lists available at ScienceDirect

Geomorphology

journal homepage: www.elsevier.com/locate/geomorph

Real time measurements of sediment transport and bed morphology during channel altering flow and sediment transport events

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ARTICLE INFO

Article history:
Received 12 July 2014
Received in revised form 6 March 2015
Accepted 9 March 2015
Available online 14 March 2015

Keywords:
Sediment transport
Techniques
Channel morphology
Bedload monitoring

ABSTRACT

Real-time measurements of bed changes over a reach are a missing piece needed to link bed morphology with sediment transport processes during unsteady flows when the bed adjusts quickly to changing transport rates or visual observation of the bed is precluded by fine sediment in the water column. A new technique is presented that provides continuous measurement of sediment movement over the length of a flume. A bedload monitoring system (BLMS) was developed that makes use of pressure pillows under a false flume bottom to measure sediment and water weights over discrete flume channel sections throughout a flow event. This paper details the construction of the BLMS and provides examples of its use in a laboratory setting to reconstruct bed slopes during unsteady flows and to create a real-time record of sediment transport rates across the flume channel bed during a sediment transporting flow.

Data gathered from the BLMS compared well against techniques commonly in use in flume studies. When the BLMS was analyzed in conjunction with bed surface DEMs and differenced DEMs, a complete transport and bed adjustment picture was constructed. The difference DEMs provided information on the spatial extent of bed morphology changes. The BLMS supplied the data record necessary to reconstruct sediment transport records through the downstream channel, including locations and time periods of temporary sediment storage and supply. The BLMS makes it possible to construct a continuous record of the spatial distribution of sediment movement through the flume, including areas of temporary aggradation and degradation. Exciting implications of future research that incorporates a BLMS include a more informed management of river systems as a result of improved temporal predictions of sediment movement and the associated changes in channel slope and bed morphology.

1. Introduction

An alluvial channel bed alters its topography in response to changes in flow rates and sediment supply through measureable changes in sediment transport rates and channel bed slope. Thus, alluvial channels are often characterized by spatially variable patterns of erosion and deposition, bed slope, and bedform morphology. During a single flood, the same bed areas may scour and fill, the surface layer may break and reform, and erosion and deposition volumes may be significant but spatially variable. The result can be a bed surface similar in appearance and volume to that prior to the flow event, masking much of the adjustment in bed morphology and sediment flux that occurred during the flood. These flood-induced adjustments may reduce total aquatic habitat (Wood and Armitage, 1997) or be beneficial if there is exchange between sediment in transport and the active layer of the bed (Brussock et al., 1985; Salant et al., 2006). Real-time measurements of changes in bed topography are needed to link bed morphology with sediment transport processes during flow events.

Sediment transport and bed morphology measurement techniques have evolved over time toward increased spatial and temporal resolution. Sediment transport rates have been determined using direct and indirect as well as active and passive measurement techniques (Gray et al., 2010). Direct measurements focus on individual cross sections from which bedload flux data are extrapolated across a reach, necessarily limiting the spatial area that is measured. Manual sampling has been through the use of either a suspended sampler like a Helley-Smith (Kleinhans and Brinke, 2001) or through the placement of nets on the channel bed (Bunte et al., 2004). Bedload sediment is captured at multiple but discrete locations across the channel width and summed for a total transport rate. Continuous direct measurements of sediment transport have been accomplished most effectively using pit traps in river beds (Garcia et al., 2000; Sear et al., 2000). The amount of sediment moved over distinct time frames and the grain size distribution of the transported sediment can be determined through repeat visits to the pit traps (Leopold, 1992; Hassan and Church, 2001). The bedload trap

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http://dx.doi.org/10.1016/j.geomorph.2015.03.009

design has been modified through the addition of load cells and data recorders to refine the temporal measure of bedload sediment transport (Reid et al., 1980; Sear et al., 2000; Bergman et al., 2007) and to increase trap efficiency to near 100% (McMahon, 2013). Impact plates and geophones have been installed in mountain streams (Rickenmann and McArdell, 2007; Rickenmann et al., 2012) and bedrock channels (Richardson et al., 2003) where sediment movement can be episodic and significant. The width of the channel bed is overlain with a plate to which either a piezoelectric or geophone sensor is attached. Signals recorded as sediment passes over the plate create a continuous measure of bedload movement. Magnetic detector strips have been similarly installed across channel widths where they record the movement and magnetic content of bedload (Gottesfeld and Tunnicliffe, 2003; Hassan et al., 2009). The use of impact and magnetic sensors can be combined with large sediment traps or bed surveys for additional information about the grain size distributions and spatial patterns of transport events. These methods provide a robust record of bedload sediment flux but are limited to a single location in the channel.

Concerns about the spatial limitation of direct bed sampling has led to a number of indirect measurement methods. The Acoustic Doppler Current Profiler (ADCP) applies the Doppler principle to measure the movement of small particles in the water column. The method of application of an ADCP can be adjusted so that the signal records suspended sediment transport (Gaeuman and Jacobson, 2006) or the migration of sand waves over a channel bed (Rennie et al., 2002; Gaeuman and Jacobson, 2007). Application of the ADCP to measure changing bedload and bedform transport has been particularly useful in flood situations. When large flood waves pass through a channel quickly, the ADCP can provide a measure of sand and gravel transport that would otherwise not be possible because of the speed of the flood wave and the amount of sediment in transport (Rennie and Millar, 2007; Curran and Ables, 2009). High resolution bathymetry measurements, whether from ADCPs, sonar, or high density surveying, are used in photogrammetry analysis to create digital elevation models (DEMs) of channel beds. Where these measurements have been repeated over time, the sequential DEMs can be differenced to provide time-integrated estimates of net changes in the channel bed surface and to infer the amount of sediment movement (Zunic et al., 2009; Ashmore and Church, 1998; Rumsby et al., 2008; Tsubaki et al., 2012). When used in a laboratory setting, repeated scanning can be performed to a high degree of accuracy and used to identify small movements of individual grains (Ockelford and Haynes, 2013). In a field situation, repeated bathymetry imaging provides bulk sediment mass transport information over a large spatial area. Bedform migration and changes in channel bed topography have been used to estimate bulk transport rates occurring through a channel reach and to extend the area of channel over which bed changes are measured (e.g. Ashmore and Church, 1998; Chandler et al., 2002; Lane et al., 2003; Wheaton et al., 2010). These indirect methodologies have the advantage of covering large river reaches in a nonintrusive manner, but none provides a real-time measure of bed sediment movement through a channel reach. It is the high resolution temporal and spatial measurements of sediment flux that are necessary to relate the sediment movement to changes in bed morphology.

In this paper we present a new bedload monitoring system (BLMS) that provides continuous measurement of sediment movement over a flume-defined reach in a laboratory setting. The laboratory provides the advantage over the field case because a measurement system can be installed under the length of the flume making possible the collection of high resolution data. The BLMS directly measures sediment weights over the length of the flume, monitoring changes in mass that reflect spatial and temporal patterns of erosion and deposition. From the BLMS, sediment transport rates, changes in the channel bed slope, and intermediate fluctuations in bed morphology can be reconstructed for a flow event. We present the BLMS in detail with examples of how the BLMS has been used in laboratory experiments to further the interpretation of channel processes occurring during large flows. We evaluate the new method for use during sediment feed and sediment recirculation experiments where DEM differencing was also applied.

2. Bedload monitoring system

2.1. Background and setup

The BLMS design was inspired by sediment bedload transport monitoring methods that have been successful in field application. The most notable of these was the Reid sampler system by which a portion of the stream bedload is diverted into a concrete box buried in the river bed with top flush with the bed surface (Reid et al., 1980; Harris and Richards, 1995; Garcia et al., 2000; Sear et al., 2000; Laronne et al., 2003). A second box inside the concrete box rests on top of a water-filled rubber pressure pillow. Sediment in transport through the channel falls into and collects in the inner box. A pressure transducer attached to the pillow enables continuous measurement of the overlying weight of inner box, sediment, and water (Reid et al., 1980; Harris and Richards, 1995). Pressure changes associated with the changing water levels in the stream are accounted for using either a synchronous record of stream water stage or a pressure transducer (Garcia et al., 2000). The BLMS design presented here is a modification and expansion of the use of pressure pillows in a laboratory setting.

The BLMS consisted of measuring sections that extended over the 9-m channel bed length of a flume 11 m in total length, 0.6 m wide, and 0.5 m deep. The flume was divided into individual measurement sections, each 1.0 m long and 0.60 m wide. Each section consisted of a Plexiglas board 1.0 m long, 0.60 m wide, and 0.02 m thick resting on a circular tube that was connected to a pressure transducer recording in range 0–1 bar (Omegadyne, Inc., model no. PXM409-001BGV). With this design, each section was isolated and supported solely by the pressure tube (Fig. 1). The tubes were neoprene and filled with water to prevent compression and to provide a larger dynamic measurement range than was possible from air-filled tubes. Once in place, the boards created a false bottom in the flume. To ensure that each Plexiglas board was supported solely by the pressure tube, it was essential that water and sediment be prevented from filling the space between the Plexiglas boards and the flume bottom. An abrasion-resistant latex rubber sheet with 0.152 mm thickness was laid over the boards and secured to the flume walls with clear tape. Flow discharge was controlled by a variable frequency motor capable of flows up to 0.12 m^3/s. Honeycomb meshes at the inlet dampened turbulence to facilitate flow adjustment. In all tests water was

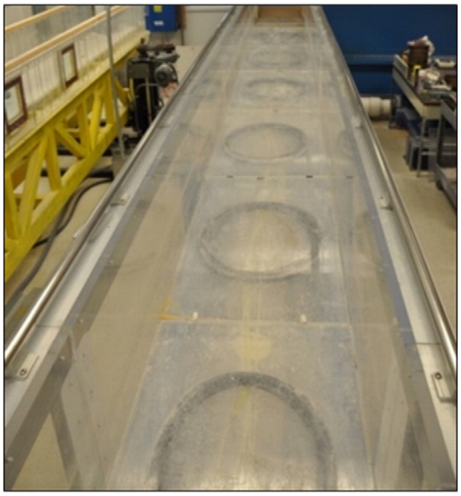

Fig. 1. Bedload monitoring system without sediment. View is looking down the flume. The Plexiglas plates and pressure tubes underneath are visible. The latex sheet and sediment have not yet been added.