Within-event spatially distributed bedload: linking fluvial sediment transport to morphological change

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ABSTRACT

Maps of apparent bedload velocity are presented along with maps of associated channel change. Apparent bedload velocity is the bias in acoustic Doppler current profiler (aDcp) bottom track (Doppler sonar) due to near-bed particle motion (Rennie et al. 2002). The apparent bedload velocity is correlated to bedload transport (Rennie and Villard 2004), and thus serves as an indicator of local bedload transport. Spatially distributed aDcp surveys in a river reach can be used to generate maps of channel bathymetry, water velocity, bed shear stress, and apparent bedload velocity (Rennie and Church 2010). It is possible to relate the observed spatial patterns of bedload and forcing flow. In this paper, the technique is used to measure bedload flux pathways during two sequential aDcp spatial surveys conducted in a Rees River, New Zealand braid bar diffluence-confluence before and after a major flood event that inundated the entire braid plain. The aDcp surveys were complemented with terrestrial laser scans (TLS) of the bar topography. Linking aDcp bathymetry and TLS topography allowed for generation of complete digitial elevation models (DEMs) of the reach, from which morphological change between surveys were determined. Most intriguingly, the primary bedload pathway observed during the first survey resulted in sufficient deposition during the major flood event to fill and choke off an anabranch. This is perhaps the first direct field measurement of spatially distributed bedload and corresponding morphological change.

INTRODUCTION

Braided rivers are common throughout the piedmont regions of the world. Braiding is associated with large sediment supply and relatively steep channel gradients, and is characterized by multiple flow channels (anabranches) between mid-channel bars (cf Church 1992). Sand and gravel in braid bars represent a large and readily accessed supply of aggregate, and braided rivers throughout the world are under intense development pressure due to their rich water and sediment resources.

Braid bars are subject to rapid erosion and deposition during individual flood events (Lane 1995), thus braided river anabranches are fundamentally unstable. Primary anabranches near the edge of the braid plain can also direct flow towards and destabilize main channel banks. Understanding bed material transport in braided rivers is thus essential for river management. However, characterization of bed material transport in braided rivers is a challenge owing to the large spatial and temporal variability of transport (Hoey et al. 2001). The location of primary anabranches and principal transport pathways can change during an individual flood event. Consequently, few studies of spatially distributed bedload in a braided river have been attempted. Other than morphological approaches based on differences between subsequent digital elevation models (Lane et al. 1995, Lane et al. 2003, Brasington et al. 2003, Bertoldi et al. 2010), we are aware of only one previous attempt to map spatial distributions of bed material transport in a braided river based on direct physical sampling (Ferguson et al. 1992).

In this paper we use an acoustic Doppler current profiler (aDcp) to measure the spatial distribution bedload transport in braid bar diffluence-confluence unit of the braided gravel-bed Rees River, New Zealand. Apparent bedload velocity (v_a) is the bias in aDcp bottom tracking (Doppler sonar) due to near-bed particle motion, and serves as a metric of relative bed-load transport. Rennie et al. (2002) first demonstrated that apparent bedload velocity can be correlated with bed material transport rate. The bias is determined by comparing boat velocity measured independently by bottom tracking and by a global positioning system (GPS). A major advantage of v_a compared to physical bedload sampling is that it can be measured from a moving boat to map spatial variability in bedload activity throughout a reach (Rennie and Millar 2004). Rennie and Church (2010) presented the first maps of spatially distributed depth (H), depth-averaged water velocity (U), shear velocity (u_*), and apparent bed-load velocity measured by aDcp in a large gravel-bed river reach. Using such maps it is possible to identify sediment transport pathways between areas of erosion and deposition in the reach. A preliminary attempt to conduct such a spatial survey was completed in a single Rees River braid anabranch channel in 2010 (Brasington et al. 2011, Rennie 2012). In this paper we describe a comprehensive field survey of a braid bar diffluence-confluence unit. A total of five aDcp spatial surveys of the channel unit were completed in January-February 2011. In this paper we present two surveys completed before and after a large discharge event (Figure 1). The aDcp surveys were complemented with terrestrial laser scans (TLS) of the channel unit surface, which permitted characterization of channel erosion and deposition during the flood event.

STUDY AREA

The Rees River drains a 405 km^2 basin in the schist terrain of Central Otago Province, to the east of the Southern Alps, New Zealand. The ReesScan Project (Brasington 2010, Brasington et al. 2010) is a study of a 2.5 km long x 0.7 km wide slowly aggrading braided piedmont reach. This reach connects the main Rees valley with the Rees-Dart delta at the head of Lake Wakatipu. Mean surface D_{50} in the study reach ranges from 18-45 mm. The braid bar diffluence-confluence unit studied in the present paper was located at the downstream end of the ReesScan study reach.

METHODS

The two aDcp surveys were conducted January 27-29 2011 (Survey A) and February 9 2011 (Survey B). For Survey A we used a SonTek S5 River Surveyor aDcp integrated with a Leica 1200 Real Time Kinematic GPS mounted on a small tethered Hydroboard. For Survey B we used a SonTek M9 River Surveyor aDcp integrated with a Novatel Real Time Kinematic GPS mounted on a OceanSciences tethered boat. At shallow flow depths the two River Surveyors are essentially the same, as both use 3 MHz transducers. In both cases live-streamed data were viewed on a hand-held computer via a Bluetooth radio connection. The River Surveyors returned water velocities throughout the vertical profile in 10 cm bins and bottom track boat velocities biased by sediment transport. The first water velocity bin was at 40 cm below the water surface. The concurrently-measured RTK-GPS position enables time-series data on apparent bedload velocity (v_a) to be resolved from the difference between the biased bottom-track and GPS estimated boat velocities, along with georeferenced water surface elevation, water depth, bed elevation, and flow velocity data. The aDcps were guided manually across the river in dense transects (nominally 1 m spacing, see Figures 2a and 3a), moving at speeds less than the mean water velocity. Transect spacing in Survey B was somewhat greater than in Survey A due to greater difficulty manipulating the tethered boat during the higher flow event. Measurements of depth-avearged water velocity and apparent bedload velocity were interpolated using linear kriging at a grid resolution of 2 m.

A Leica 6100 TLS was used to survey the exposed channel unit bar surface during low flow immediately following Survey A (January 30 2011) and for Survey B at the end of the receding limb of the large flood (February 12 2011). The TLS data were fused with aDcp bathymetric bed elevation data in ArcGIS using Delaunay triangulation, with breaklines along channel edges, followed by gridding of data at 0.25 m spatial resolution. A level of detection of ±0.10 m elevation difference between the two DEMs was used to identify channel morphological change between Surveys A and B.

RESULTS AND DISCUSSION

Survey A was conducted at relatively low flow on the falling limb of a minor flood event (Figure 1). Flow was concentrated in the main anabranch of the channel unit at the upstream end, where the anabranch thalweg was on the channel left (Figures 2b and 2c). Some of this flow diverged into a minor anabranch at the diffluence in the lower portion of the study reach (Figures 2b and 2c). The minor anabranch included a confluence with another minor anabranch, where a relatively deep scour hole was observed. The highest water velocities observed during this survey were approximately 1.9 m/s, and were associated with deeper channel locations.

The observed spatial distribution of apparent bedload velocity during Survey A (Figure 2d) suggests that a bedload pathway occurred, even during this relatively moderate flow, along the left bank thalweg in the upper portion of the main anabranch. Interestingly, the pathway of the majority of high apparent bedload velocity did not continue along the main anabranch, but shifted into the left bank minor anabranch. This suggests that sediment being transported along the main anabranch was being diverted into the minor anabranch during Survey A.

Survey B was conducted at a higher flow on the receding limb of a large flood event (Figure 1). The flood event was the largest observed in the two years of the ReesScan project (2009/10 and 2010/11), and inundated the entire braid plain. During Survey B the flow was fully concentrated in the main anabranch. The greatest depths were again observed on the channel left, but the locus in the upper portion of the reach shifted downstream compared to Survey A (Figure 3b). Other locations of greater depth included the channel right near the trees at the upstream end of the reach, and on the channel left at the lower end of the reach. Highest velocities (up to 2.4 m/s) were again associated with these deeper locations (Figure 3c).

The most notable feature of Survey B is the lack of flow in the left bank minor anabranch. In fact, this anabranch completely filled with sediment during the large flood event. The DEMs for both surveys are shown in Figure 4, and the difference between these two DEMs is shown in Figure 4c. It is evident that the minor anabranch filled with approximately 1 m of sediment, which corresponds to the initial depth of the anabranch (Figure 2b). Sediment transport during the major flow event continued to follow the sediment transport pathway observed during Survey A, consequently filling and effectively choking off this anabranch. We believe this is the first direct field observation of sediment transport leading to an observed major morphological change. Apparent bedload velocity vectors during Survey B (Figure 3d) are also large on the channel left heading into the deposition zone that blocked the minor anabranch. It appears that the transport and deposition processes that blocked the minor anabranch during the major flood were continuing during Survey B.

It is evident in Figure 4c that deposition also occurred in the main anabranch during the large flood event, with the greatest deposition in the centre of the upper portion of the anabranch. This deposition resulted in a nascent mid-channel bar. Scour occurred along both banks of the anabranch adjacent to the new mid-channel bar, presumably due to high shear stresses imposed by flow convergence as a result of flow acceleration around the new deposit. This scour caused the downstream shift in the deepest part of the anabranch noted above. The overall pattern of channel change is of anabranch widening to accommodate greater discharge. The majority of the flow observed during Survey B diverted around the central deposition zone, with some shallow flow traversing across the new bar (Figure 3c). The apparent bedload velocity vectors during Survey B (Figure 3d) mirrored these patterns, with large values occurring over the central deposit, presumably due to continued deposition and possibly downstream translation of the bar.

CONCLUSIONS

Sequential spatial surveys of a braided river diffluence-confluence unit using an aDcp and a TLS yielded the first direction field observations of within-event spatially distributed bedload that could be directly linked to morphological channel change.

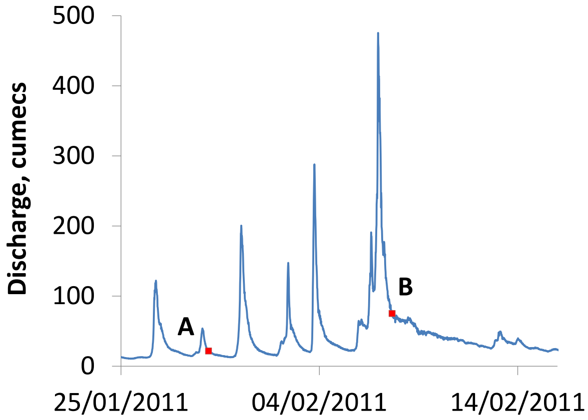

Figure 1. Rees River hydrograph showing times of the surveys.

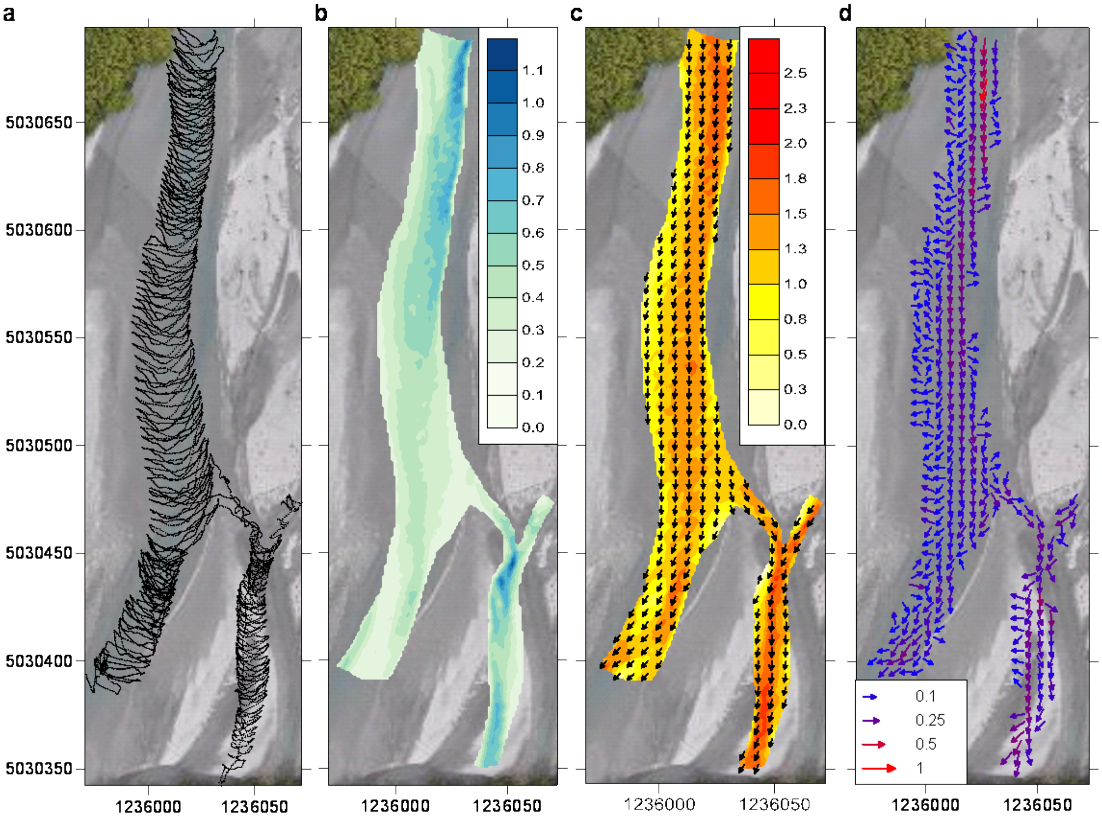

Figure 2. Survey A: (a) aDcp transects surveyed on 27 January 2011, (b) interpolated flow depths (m), (c) interpolated flow velocities (m s^{-1}) and (d) interpolated apparent bed velocity (m s^{-1}). The aerial photograph was taken on 27 February 2011 following storm events that caused morphological change subsequent to that discussed in this paper. Map units are in NZTM in m.

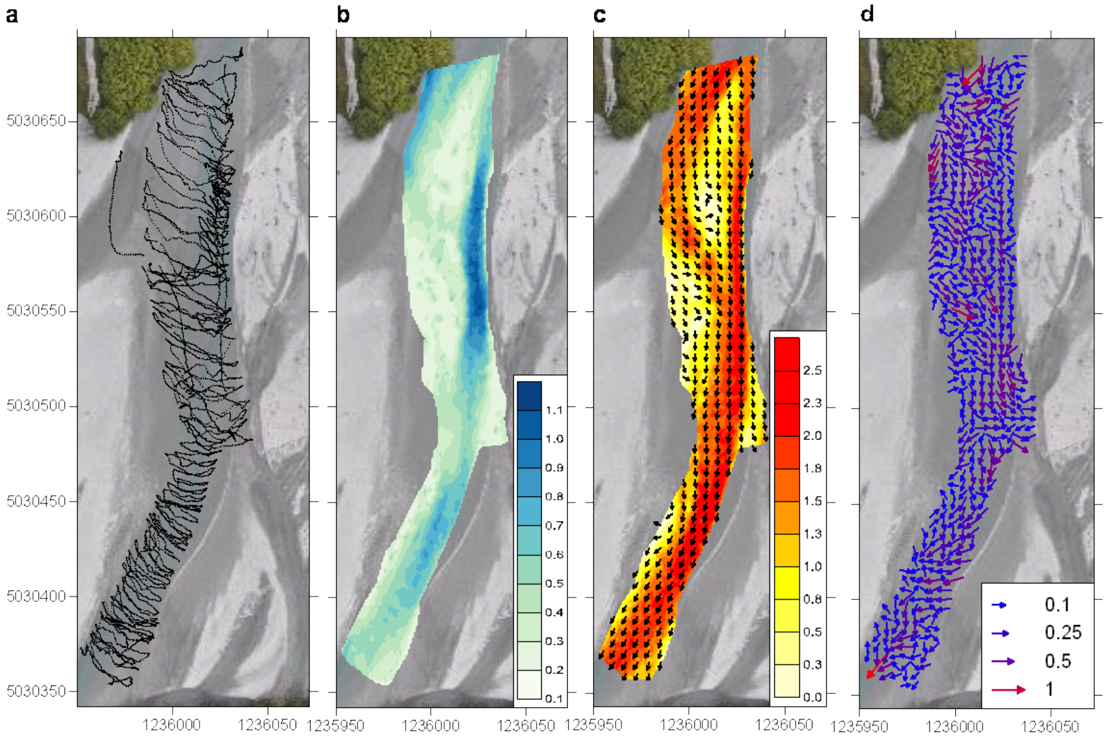

Figure 3. Survey B: (a) aDcp transects surveyed on 8 February 2011, (b) interpolated flow depths (m), (c) interpolated flow velocities (m s^{-1}) and (d) interpolated apparent bed velocity (m s^{-1}).

Figure 4.Topography and morphological change: (a) Survey A DEM, (b) Survey B DEM and (c) morphological change between surveys A and B.