# New views of the morphodynamics of large braided rivers from high-resolution topographic surveys and time-lapse video

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Abstract Four new technologies were combined to investigate morphological change along a 4 km reach of the 1-km-wide, braided, gravel-bed Waimakariri River on New Zealand's South Island. River-bed topography was surveyed four times over 15 months, capturing the change caused by near-bankfull flood events. Dry areas of river bed were surveyed either with digital photogrammetry or airborne laser scanning. A combination of remote-sensing and ground-based bathymetry was used to survey the beds of wetted braids. Two video cameras, mounted 35 m above the river bed, provide hourly daytime imagery of the central area of the study reach and an invaluable record of the coherence of morphologic features. This data set provides a view of form and process in a large braided river that has hitherto only been possible in laboratory channels, and identifies features such as low relief drainage basins that appear to be unique to field-scale braided channels.

Key words Waimakariri River; braided rivers; digital photogrammetry; airborne laser scanning; time-lapse video

## **INTRODUCTION**

Current understanding of the morphology and behaviour of braided channels stems largely from laboratory studies (e.g. Ashmore, 1991; Hoey & Sutherland, 1991; Ashmore, 2001), analysis of braided channel planform statistics and scaling properties (e.g. Sapozhnikov & Foufoula-Georgiou, 1996), or cellular-type computer models that greatly simplify the processes and physics (e.g. Murray & Paola, 1994). Study of field-scale braided channels (which range in width from  $10^2$  to  $10^4$  m) at a detail consistent with laboratory studies has been logistically difficult if not impossible, and recourse has typically been made to "sampling" topography along cross-sections (e.g. Ferguson & Ashworth, 1992). In the last few years, however, new remote sensing technologies have become available that permit the acquisition of high-spatial-density topographic data, which in turn promises a rich harvest of quantitative measurements of braided

channel morphology and processes—if they can be successfully applied to the braided river environment at field scales. In this paper we report on a study of a reach of the braided gravel-bed Waimakariri River, New Zealand, that combines aerial-sensing platforms with ground-based real time kinematic (RTK) GPS technology. While the primary aim of the study was to investigate the feasibility of a fully three-dimensional application of the "morphological" method for measuring bed-load transport due to floods (e.g. Lane *et al.*, 1995; Stojic *et al.*, 1998), an important by-product, which we focus on here, has been simply capturing the static and evolving morphology of a large braided river.

#### **STUDY AREA**

The approximately 4-km-long study reach on the Waimakariri River (Fig. 1) is located at Crossbank, 7 km north of Christchurch on New Zealand's South Island. The overall bed slope is 0.0048, while the  $d_{50}$  of the gravelly bed material is 28 mm (Carson & Griffiths, 1989). Mean flow is 120 m<sup>3</sup> s<sup>-1</sup>, the mean annual flood is 1520 m<sup>3</sup> s<sup>-1</sup>, the suspended sediment load is 3.1 Mt year<sup>-1</sup>, and the bed load (determined from analysis of historical cross-sections and gravel-extraction data) is approximately 210 000–250 000 m<sup>3</sup> year<sup>-1</sup> (Carson & Griffiths, 1987).

Along the study reach, the river is confined to a straight, 1500-m-wide fairway by flood-banks. This width has been further reduced by belts of willows so that the width of active, un-vegetated river-bed averages 1000 m. Bed-load transport during floods was studied immediately upstream of the study reach by Carson & Griffiths (1989); Nicholas (2000) used cross-section data from Crossbank to theoretically estimate long-term average bed load; while the sedimentation history of the lower Waimakariri channel has been reported by Griffiths (1979) and Blakely & Mosley (1987).



**Fig. 1** The Waimakariri at Crossbank study reach, photographed February 2000. Flow  $(65 \text{ m}^3 \text{ s}^{-1})$  is from left to right. White lines show fields-of-view of up- and downstream-facing video cameras.

# **METHODS**

The principle aim of the data collection was to survey the river-bed topography at high spatial density before and after floods, so as to be able to map areas of erosion and deposition and to quantify the volumes of gravel mobilized. We conducted four surveys between February 1999 and May 2000, capturing the changes caused by an  $800 \text{ m}^3 \text{ s}^{-1}$  flood in March 1999 and an 840 m<sup>3</sup> s<sup>-1</sup> flood in April 2000.

The first three surveys used digital photogrammetry to map the elevation of the dry areas of river bed. The topography of the beds of the wetted channels was mapped with the aid of image-analysis techniques. This first involved fitting digital elevation models (DEMs) to the water surface topography using waters-edge elevations extracted from the photogrammetric analysis. Then, water depth was classified from colour aerial photographs using empirically calibrated relationships between water depth and water colour (a separate calibration was established for each survey). The wetted bed elevation was then obtained by subtracting the water depth map from the water surface map. This approach is detailed by Westaway *et al.* (2000, in press). The water depth calibration data sets were collected with a small dinghy equipped with an echo-sounder integrated with an RTK GPS unit.

The fourth survey employed an Optech airborne laser scanner (ALS) to survey the dry river-bed topography. Some two million points were scanned at an average horizontal spacing of 1.6 m. The standard error for ground elevation points interpolated from the ALS was 0.16 m. Proprietary software was used to filter out laser returns from riparian vegetation. The wetted channel water depths were mapped as described above, with waters-edge laser shots used to create DEMs of the water surface.

To monitor morphologic change at a greater frequency than afforded by the synoptic photogrammetric or ALS surveys, we installed two video cameras 35 m above the river bed on electricity pylons. These, solar powered and video-linked to a computer located 4 km away, allowed us to capture images of the river bed at 20-min intervals during daylight hours. This raw oblique imagery was converted to georeferenced orthoimagery using photogrammetric methods (e.g. Chandler & Ashmore, 2001).

# **RIVER-BED MORPHOLOGY**

## **Broad-scale morphology**

The remote-sensing approach provides striking detail of the river-bed morphological features, as illustrated by the detrended DEM for the February 2000 survey (Fig. 2(a)). At a broad scale, as featured in the smoothed DEM (Fig. 2(b), based on a 100-m wide smoothing window), there is a central "semi-braided" channel that at times appears to meander across the braid plain between low-relief alternate bars and at other times bifurcates through broad central islands. The relative relief of the alternate bars is less than 2 m.

At a finer detail (Fig. 2(a)), active braiding tends to be focused in the "channel within a channel", while dendritic drainage networks appear to be developed on the



**Fig. 2** Detrended relief maps of the study reach, as surveyed February 2000: (a) based on 1-m pixels; (b) after smoothing over a 100-m-square window.

higher-lying areas. These networks are clearly fractal in pattern, and some develop to fourth order. Some first-order channels may have been formed from older braids by isolation from the main channel due to marginal deposition along the main channel, however, other first-order channels are clearly the result of incision by convergent flows. In fact, a close inspection of the topographic divides around the margins of the areas showing dendritic patterns reveals that the study reach appears to comprise at least three large flow-convergence areas that drain into the lower-lying actively-braiding belt. The impression gained is that during floods, flows converge into each "catchment" from over a broad area of river bed. The dendritic pattern will tend to be encouraged at discharges when water without bed material spills over the divides. Similar dendritic networks have been described from the nearby braided Rakaia River by Rundle (1985).

## Morphological change

The four surveys showed that whereas the detailed topography on the higher-lying alternate bars tends to be stable (i.e. the drainage networks tend to persist), the lower-



**Fig. 3** Detrended relief maps of the study reach in February and May 2000. An avulsion route is marked by the white arrow.

lying braid belt underwent continual change (Fig. 3). Indeed, time-lapse observations from the video cameras show that the classical braiding processes (such as described by Ashmore, 1991) continue, albeit at a slow rate, even at the lowest baseflows.

At the broad scale, large avulsion events occur when the main braid belt diverts into an adjacent convergence zone. Such an avulsion occurred during an 840 m<sup>3</sup> s<sup>-1</sup> flood in April 2000, and was captured on the video cameras and between the February and May 2000 surveys (Fig. 3).

## Gravel lobes and sheets

Within the actively braiding belt, gravel transport during floods occurred in association with migrating gravel lobes and sheets. At lower flows, particularly on flood recessions, channel-confined migrating lobes were observed with the video cameras (Fig. 4). These, with heights of the order of 0.3–1 m and widths of 3–10 m, migrated at speeds up to 10 m  $h^{-1}$ . The time-lapse videos showed that the lobe translation process involved flow convergence and bed scour on the back-slope of the lobes—that is, they



**Fig. 4** Oblique video frames of a channel-confined assemblage of gravel lobes (arrowed) on a flood recession. Frame (b) was taken 200 min after frame (a); water level changed little over this interval. Flow is from top to bottom.

"ate their tails". The lobes eventually stalled and became exposed as the floods receded. When this occurred, the waning flows, where draped over the steep lobe fronts, sometimes carved smaller-scale chutes and built smaller lobes at the chute toes.

During near bankfull flows, when much of the 1000 m wide braid plain was inundated, the gravel transport along the braid belt was characterized by translating gravel sheets. While still lobate in planform and also of the order of 0.3–1 m high, these were much wider and "sheet-like" (up to 200 m wide). They stalled quickly when flood flows receded, and as the waning flows converged into channels, the original sheet morphology was modified by smaller-scale incised channels, chutes, and secondary lobes—often to the point where the original sheet form became unrecognizable. While the existence of gravel sheets in the study reach was noted previously by Griffiths (1993), we believe that this is the first instance where they have been recorded during floods.

## Importance of floods to river-bed morphology

Our topographic surveys and time-lapse videos of the Waimakariri highlight the effects of changing water discharges (i.e. floods) on the river-bed morphology. During the peak of large, bankfull or near bankfull, floods, the bedforms and channel shifts tend to scale with the braid plain width. When the flows recede, this large-scale morphology is reworked as the flows become channelized, and a suite of smaller morphological features develop that scale with the width of individual braids. At baseflows, where the channels are often (but not always) stable, the water may simply be draped over relict morphology.

#### CONCLUSIONS

Remote sensing technologies have been successfully used to acquire synoptic topographic data over a large braided river bed at high spatial detail. The resulting topographical data sets reveal a richness of morphological features that are easily missed by two-dimensional imagery or ground inspection. Along the Waimakariri study reach, braiding processes are focused along a lower-lying belt that meanders around large alternate bars or mid-channel islands. These slightly higher areas typically show well-developed dendritic drainage networks and tend to be more stable over time. Timelapse video has been able to capture the transitory existence of large gravel sheets during bankfull floods and their subsequent reworking by smaller floods. During smaller floods and on flood recessions, the video shows that gravel transport occurs as channel-confined migrating lobes. In combination, the remotely-sensed synoptic surveys and time-lapse video permit large-scale braided rivers to be observed and measured at a detail previously only possible in laboratory channels or at small field sites.

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