Using riverbed Digital Elevation Models to inform river management

Les modèles altimétriques numériques des lits de rivière au service de la gestion fluviale

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RÉSUMÉ

La gestion fluviale doit s'appuyer sur la compréhension des processus opérant au sein de la voie d'eau gérée et tenir compte du fait que le comportement de la voie d'eau est influencé par une connectivité longitudinale : ce qui va vers l'amont (contre-courant) doit aller vers l'aval (courant). La gestion des rivières caillouteuses à activité latérale en Nouvelle-Zélande a permis le développement des plaines inondables et la protection des ressources et infrastructures agricoles. La gestion de ces systèmes dynamiques a été considérée un succès en raison d'approches qui ont redressé et circonscrit le cours de la rivière grâce à l'utilisation d'un système de stabilisation des rives et contrôlé le niveau des lits grâce à l'extraction du gravier. Cependant, en remplaçant les larges corridors riverains par des voies plus étroites, et en réduisant la connectivité latérale avec les pentes et plaines inondables avoisinantes, cette activité a également un impact sur la diversité morphologique et sur l'habitat de la rivière ainsi que sur les ressources potentielles de gravier. Cet article emploie les modèles altimétriques numériques (MANs) des lits de rivière fournis par des relevés annuels d'environ 1km de long effectués sur la rivière Motueka, à Nelson, Nouvelle-Zélande, dans une approche tenant compte des interrelations nécessaires à la gestion efficace de la rivière entre processus, flux sédimentaire et morphologie fluviale. L'article démontre que dans le cas des rivières à lit de gravier les MANs des lits de rivière peuvent s'avérer un outil utile pour établir la nature et le comportement de la rivière à l'échelle longitudinale, et constitue de la sorte un apport important à la gestion fluviale de ces systèmes.

ABSTRACT

River management should be informed by an understanding of processes operating within the managed channel and recognition that channel behaviour is conditioned by reach-to-reach connectivity: what is up(stream) must come down(stream). River management in New Zealand's laterally active gravelly rivers has permitted floodplain development and protection of agricultural resources and infrastructure. Management of these dynamic systems has been hailed as a success for approaches that have straightened and confined the river using bank protection and managed riverbed levels by gravel extraction. However, this activity also impacts river morphological / habitat diversity and potential gravel resource, by replacing broad riparian corridors with narrower channels, and reducing lateral connectivity with the adjacent floodplain and slopes. This paper uses riverbed digital elevation models (DEMs) derived from annual surveys of ~1 km long reaches in the Motueka River, Nelson, New Zealand, in an approach which brings together an understanding of the interrelationships between process, sediment flux and channel morphology, which are required for effective river management. The paper demonstrates the utility of riverbed DEMs as a potential tool to frame river character and behaviour at the reach scale in gravel-bed rivers, thereby providing an important contribution to river management in these systems.

KEYWORDS

Bedload, channel degradation, deposition, erosion, gravel-bed river, morphological budgeting, sediment transfer.

1 INTRODUCTION

1.1 Background and rationale

River management is most likely to be effective, efficient and sustainable where strategies take into account the natural character of a system (Brierley and Fryirs, 2009). Sediment transfer and its interaction with channel morphology must be understood and predicted if upland rivers in particular are to be managed effectively (Raven *et al*., 2010). This is because channel morphology conditions flood capacity and conveyance (Raven *et al*., 2010) and there is a strong link between sediment supply, sediment storage and flood risk. Accordingly, effective channel management, which has traditionally been the realm of engineers, must be more rigorously informed by geomorphic processes.

This paper uses relatively high resolution annual ground surveys from sites in the upper Motueka River, Nelson, New Zealand to derive riverbed DEMs from which to demonstrate reach-scale dynamics operating in a laterally constrained upland gravel-bed river, which in turn ought to inform better river management. It is important to note that discrete reach behaviour is, however, just one part of the jigsaw of river management, which, if it is to be holistic, must be understood within the wider catchment context (Raven *et al*., 2010). Nevertheless, Brierley and Fryirs (2009) argue that reach characteristics and behaviour must be understood to provide a framework for effective management.

1.2 River Management

The Motueka catchment drains 2076 km^2 of the northern South Island of New Zealand (Fig. 1). Management of the river for flood control as part of the Motueka Catchment Control Scheme has included: siting stopbanks at strategic locations; establishing clear uniform-width channels by river training, fairway clearance, bank protection, and groynes; vegetation screens to contain spread of water and sediment during floods. Acute river bends have been cut. This has narrowed and straightened the main channel. Mean bed levels (MBL) have progressively reduced over time (Figure 1c), partly associated with gravel extraction (Figure 1d). The degradational trends identified in Figure 1c are probably long-term, since coasts in the region are also eroding, thus the behaviour of the discrete reaches being assessed here must be understood in this wider catchment context.

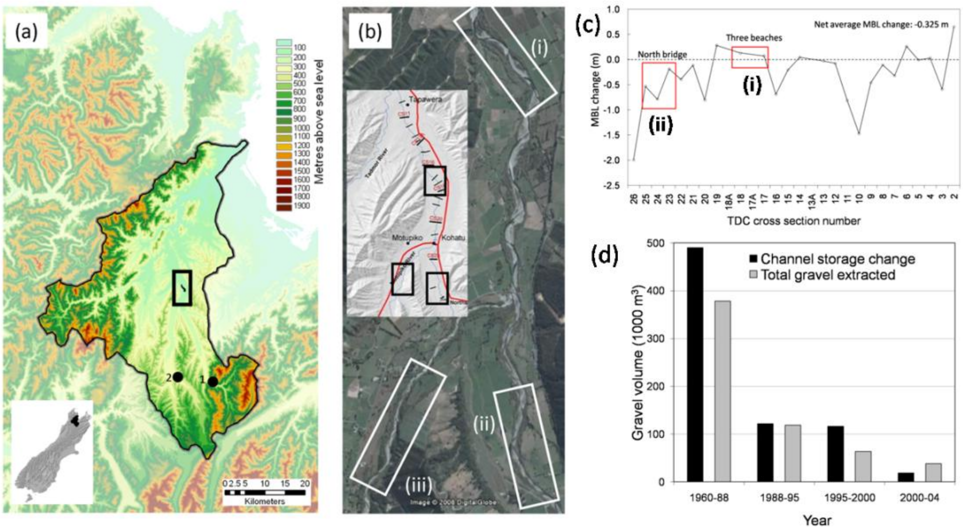


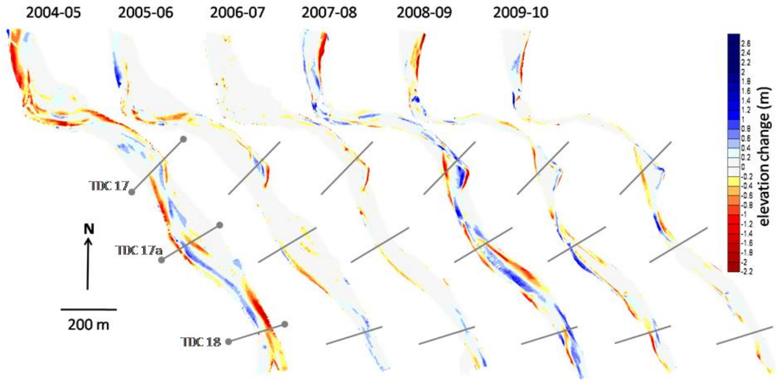
Figure 1. Motueka catchment: (a) catchment topography with flow gauges (circles), (b) study reaches (i) Three Beaches, Motueka (ii) Norths Bridge, Motueka and (iii) Quinney's Bush, Motupiko, with Tasman District Council (TDC) cross section locations; (c) Upper Motueka mean bed-level change between 1960 and 2004 based on quintennial cross section surveys; (d) Upper Motueka gravel volume loss between 1960 and 2000.

2 METHOD

Reaches in the upper Motueka River (Fig. 1) were mapped annually between 2004-2010 using Real Time Kinematic-differential Global Positioning Survey (RTK-dGPS) and Total Station ground survey equipment to generate channel topography data for DEM construction. DEMs were generated in Surfer® spatial analysis software using Triangulation with Linear Interpolation (TLI). Successive DEMs were subtracted from one another to create a DEM of difference, producing a surface representing the distribution of change between surveys from which volumetric change was derived.

3 RESULTS & DISCUSSION

An example suite of results from the Three Beaches reach is shown in Fig. 2. Space does not permit display of results from the upstream sites (see Fuller & Basher 2012).



Date	Ern. (m^3)	Depn. (m^3)
2004 2005	27765	16418
2005 2006	9832	9043
2006 2007	7063	5573
2007 2008	14331	21945
2008 2009	10940	7721
2009 2010	7640	6800

Figure 2. DEMs of difference and sediment flux (erosion and deposition), Three Beaches, 2004-2010.

3.1 Morphological change and sediment transfers

Complex patterns of erosion and deposition and variable magnitudes of morphological change between dates were evident (Fig. 2). Erosion typically occurred within the wetted channel and outside of bends with hard banks (rip rap); while deposition occurred within the channel when accommodation space was provided by lateral channel migration or bedload sheets stalled across low bar platforms within the active channel. Extent of activity and change was related to magnitude and frequency of flood events between successive surveys. The largest flood during the survey period at Three Beaches (March 2005) mobilised the greatest amount of sediment and was the only event to result in morphological modification (deposition) on the higher bar platforms within the active channel (Fig. 3, 2004-05). The river at Three Beaches is predominantly degrading its bed.

3.2 Implications for management

These results demonstrate that within straightened, narrowed reaches of a wandering gravel-bed river, the system remains dynamic and challenges concepts based on stable channel design. Such rivers must be recognised as highly dynamic and managed in this context. Since the channel is laterally constrained, excess stream power is used to scour its bed, deepening the channel and generating the degradation evident. The result is self perpetuating, since as the channel deepens, higher flows become confined within-channel and given armoured banks, further scour ensues. Channel incision decouples channel and floodplain processes and disconnects large areas of catchment from the sediment cascade. Incised channels potentially generate higher transport capacities, mobilizing large bedload volumes and contributing to further bed degradation. The limited deposition on higher bar platforms may have serious implications on the availability of the gravel resource in this catchment, since TDC has previously extracted gravel by bar-top skimming, which is not being replenished.

4 CONCLUSIONS

DEMs of riverbeds, which quantify morphological adjustment and associated sediment flux, and here demonstrate the high degree of dynamism inherent in laterally constrained, engineered gravel-bed channels, provide important information to better understand reach behaviour than may be feasible using cross section data alone. Use of DEMs provides a valuable tool for effective river management. We entirely agree with Brierley and Fryirs (2009, 1213), that it is “imperative to frame management actions in relation to the character and behaviour of any given reach”, in which we suggest analysis of riverbed DEMs should play a major role to better understand that reach character and behaviour.

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