Managing flow for geomorphic form: erosion and accretion of river benches

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Abstract

In the last decade there has been an increasing awareness of the importance of channel morphology in the healthy functioning of Australian rivers. However, the relationship between channel morphology and the flow and sediment regime of a river is often poorly understood. As a result, within-channel features such as bars, banks and benches are often considered static. Benches are an actively accreting fine-grained bank-attached feature within the river channel which contribute a significant store of suspended-grained sediment and have been identified as ecologically important. As managers design and release environmental flows, they need to know how much these flows will modify benches. Benches are a characteristic feature of Australian rivers, and this paper describes initial findings of a field study of the relationship between flow, sediment transport, and bench morphology in the mostly unregulated Ovens River, and highly regulated River Murray, southeastern Australia. We discuss the impact of regulation and importance of flow regime variability in the formation and destruction of benches.

Keywords

Hydromorphology, environmental flows, Ovens River, Murray

Introduction

In-channel benches are an important morphological and ecological component in the meandering rivers of southeast Australia, yet benches are often destroyed and not reformed in a regulated river (Walker & Thoms, 1993). Benches are defined here as "a *bank-attached, planar and narrow, fine-grained sediment deposit occurring at elevations between the river bed and the floodplain*" and five key types exist: concave, point, linear, tributary confluence and feature benches (Vietz *et al.,* 2004). Flow regulation usually alters the frequency and duration of flows that inundate benches, and as a result, environmental flow projects often target benches as important components of an environmental flow strategy (EarthTech, 2006). Numerous authors have noted the lack of understanding of the hydrologic factors responsible for bench formation (e.g. Page & Nanson, 1982; Thoms & Sheldon, 1996; Changxing *et al.,* 1999; Steiger *et al.,* 2001). What flows are responsible for most of the vertical growth of benches? Which flows erode the bench surface or edge? Without answers to these questions we have little basis for environmental flow releases aimed at benches. This paper reports some initial results from a study of the relationship between flow, sediment transport, and bench morphology in the highly regulated River Murray and the mostly unregulated Ovens River, southeastern Australia. We concentrate here on concave benches and ask the question: what flows accrete and erode concave benches? It is commonly thought that benches are formed by 'drapes' at lower flows and destroyed by near-bankfull flows (Cohen, 2003) (Figure 1).

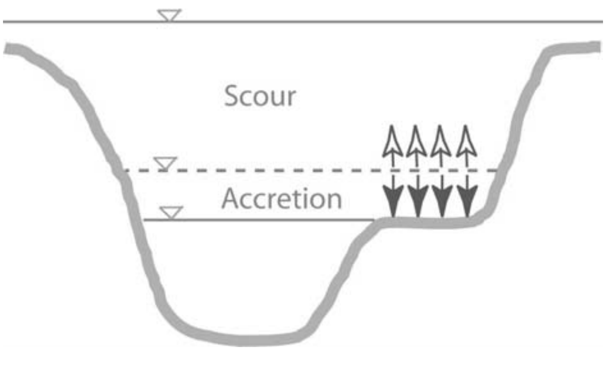

Figure 1. Conceptual model of current understanding of bench accretion and scour. The dashed line represents the water level at the threshold between accretion and scour.

Methods

The findings reported in this paper are mainly based on field investigations of hydraulics and sedimentology associated with two concave benches on the lower Ovens River, and two on the River Murray, near Corowa (Figure 2).

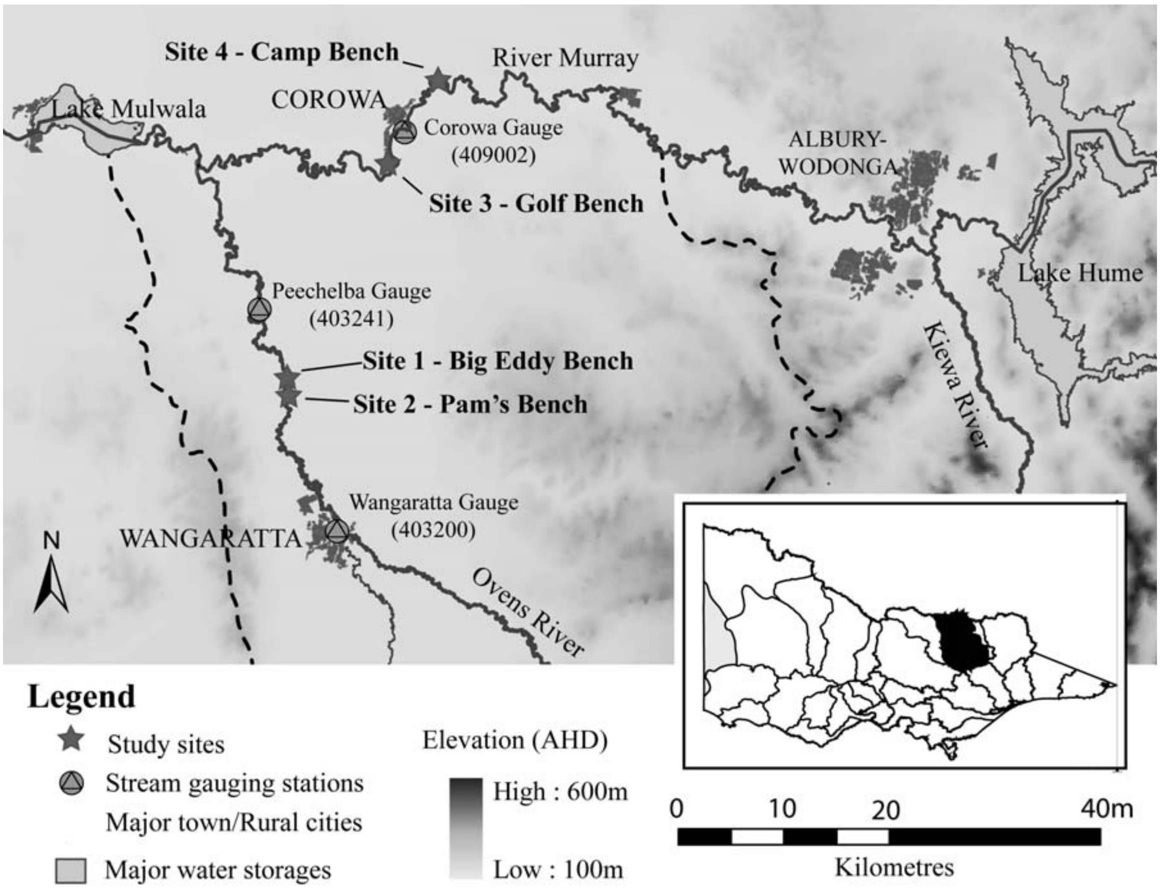

Figure 2. Study reaches of the Ovens River and River Murray, northeast Victoria, the four detailed field sites are identified with stars (inset: Ovens River catchment within Victoria).

The Ovens River Catchment in northeast Victoria is one of the last largely unregulated rivers (extractions exist) in the Murray-Darling Basin, it provides a unique opportunity to investigate the natural channel morphology and the relationship to the flow and sediment regime. The Ovens River exhibits higher flow variability, greater than that experienced by the River Murray naturally, and considerably greater than the variability under regulated conditions (Table 1).

Table 1. Mean Annual Flow (MAF) and flow variability for the Ovens River and the River Murray under regulated ('natural') and unregulated ('current') conditions (raw data from various sources)

	Ovens River	River Murray ('natural')	River Murray ('current')
MAF (GL/a)	1,710	4,910	5,300
Variability	6.84	3.71	1.59

Note: Variability = Range (10-90th percentile)/median

The two main approaches for investigating the hydromorphology of benches involved:

1. Use of the two-dimensional computational hydraulic model River2D (Steffler & Blackburn, 2002) to investigate the hydraulic environment over the two Ovens River benches for the full range of in-channel flows. River2D has commonly been applied to the replication of hydraulic conditions within natural channels and has a proven ability to model eddy flow responsible for benches. Topographic surveys provide the channel form (Figure 3) and model calibration was based on measured water slopes and field velocities.

2. Collection of accreted material on the bench surface using artificial turf mats at all four sites. Analysis of this sediment involved both sieve and laser particle size analysis (Coulter Counter) in a manner similar to that described by Steiger *et al.* (2003).

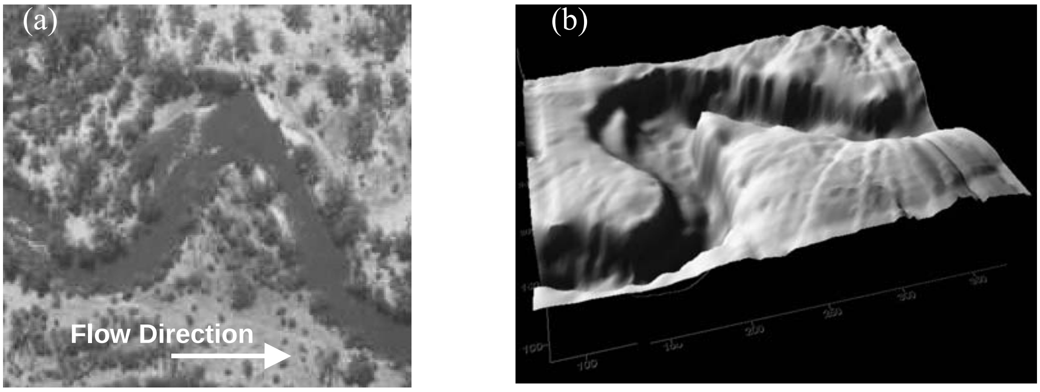

Figure 3. (a) Site 'Big Eddy' bench (top left of bend), Ovens River from 1989 aerial photograph, and (b) three-dimensional representation of this site from survey (plotted in Surfer®), flow left to right

Results

The Ovens River benches were inundated seven times during the study period (2005), and accretion mats were collected 5 times (Figure 4). Benches on the regulated River Murray were inundated twice over a 1.5 year period (shallow but long duration events) and the mats were collected once. The mass of sediment deposited on the Ovens benches during the study period is between three to thirteen times greater than that for the Murray (Table 2), even though all bench surfaces are at a similar elevation relative to bankfull. In one near-bankfull event at the site Big Eddy bench up to 13 kg/m² of fine sediment was deposited in 8 days, equating to 1.2 tonnes of fine sediment stored on the one bench. Sediment accreted on these surfaces equates to between 30 and 300 mm per year, a rate that is supported by evidence from stratigraphic analysis (Geoff Vietz, unpublished data). The sediment deposited on the Ovens benches is clearly dominated by the silt fraction, and preliminary results for the Murray indicate a similar composition albeit with higher sand proportion (≈ 50% fine sand fraction).

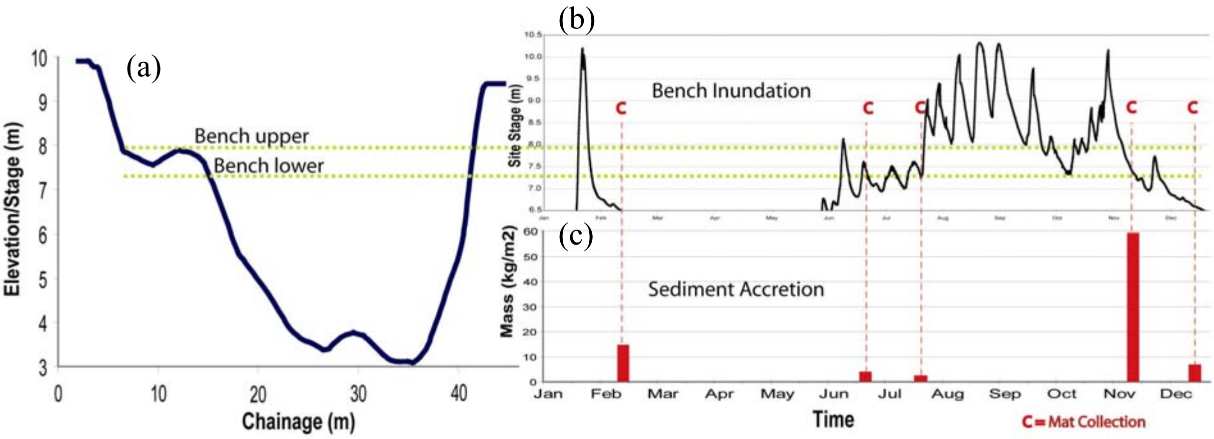

Figure 4. (a) Cross section of the site 'Big Eddy' bench on the Ovens River (note vertical exaggeration), (b) the site hydrograph for the study period of 2005 (relative to bench elevation) and (c) sediment mass deposited from each intervening period

Table 2. Sediment mass and fractions collected on benches during study period

	Mass (kg/m²)	Sand%	Silt%	Clay%
Big Eddy bench, Ovens River	78.9	26	67	7
Pam's bench, Ovens River	34.5	18	75	7
Camp bench, River Murray	11.4	39	56	5
Golf bench, River Murray	6.2	na	na	na

Note: Ovens River results are based on an average of 6 mats on each bench over five events. River Murray results are based on 4 to 7 mats on each bench, with less than half so far analysed for fractions.

The hydrodynamic model was run through a range of discharges - from incipient inundation of the bench up to bankfull – in order to investigate the velocity environment over the bench. It is evident that even at near-bankfull discharges, often associated with scour of the channel, the bench environment experiences reverse flows of low velocity (Figure 5). At near-bankfull flows, with depth averaged velocities in the thalweg greater than 1.5 m/s, velocities over the bench do not exceed 0.5 m/s or bed shear stresses of 0.4 N/m² (see Vietz *et al.* (2006) for a detailed description of modeling).

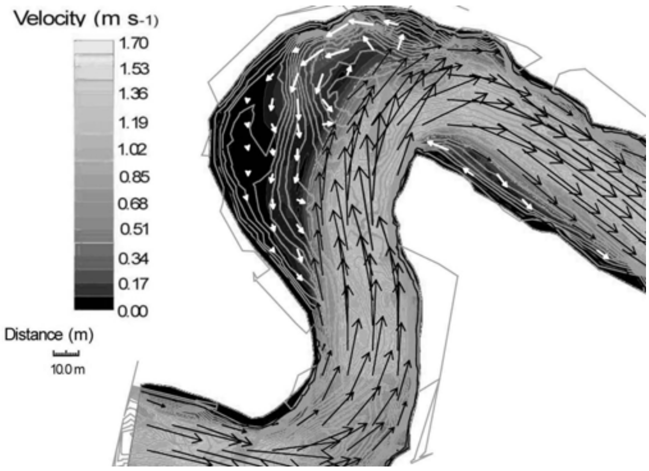

Figure 5 . Velocity magnitude (shading) and vectors over the site 'Big Eddy' bench (located in the expansion zone top left of channel) at a near-bankfull flow of 157 m³/s

Discussion

The dynamic nature of cross-sectional morphology

While considerable emphasis has been placed on the dynamic nature of planform change, particularly in regard to actively eroding rivers, the cross-sectional morphology of river channels is often considered as static. This is a common belief over management timescales (ca. 3-20 years). With the current focus in Victoria on setting environmental flow allocations based on channel morphology, the active nature of channel form is an important consideration. The benches in the Ovens River display the potential for vertical adjustment of tens of centimeters per year and flow targets may need to be altered within several years time. This is not the case for the River Murray which the benches are starved of sediment.

Flows that form

A model of bench construction by inundation flows and destruction by bankfull flows is not supported by this study. A placid reverse flow environment is responsible for the deposition of fine-grained sediment on benches. Benches are not necessarily maintained by flows that just inundate the bench surface, but seemingly by most flows greater than bench inundation, with both magnitude and particularly duration important. In the concave benches investigated, the reverse flow environment was present throughout the full range of flows from bench inundation up to bankfull. In particular, as flow depth over the bench increases there appears to be a level where the velocity environment is most conducive to deposition, prior to velocities increasing again as the flow level nears bankfull.

There was no scour of the bench surfaces during the detailed monitoring period of more than one year. Even at bankfull flows large low-velocity reverse-flow environments were evident and were associated with deposition rather than erosion. The main cause of bench destruction is erosion of the streamside edge of the bench by both the turbulence at the flow separation envelope, and specifically for the Murray benches, from wave action at regulated flow levels maintained just below the bench over long periods of time. Hickin (1986) alluded to the preservation of concave benches being dependent on the dominance of the constructional annual flood over the destructive lower flows.

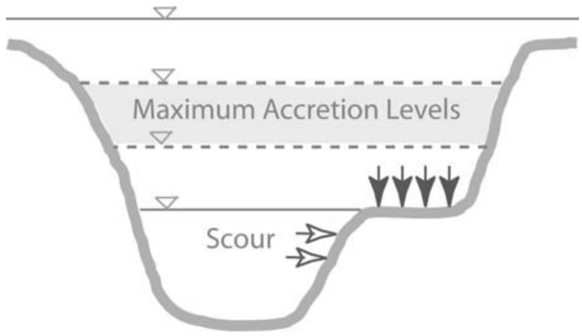

Figure 6. Conceptual model proposed whereby benches are maintained by flows between benchfull elevation and bankfull, particularly in the range considerably greater than benchfull. Scour can occur due to constant flows lower than benchfull

In addition to adequate flows, bench construction and maintenance requires adequate suspended sediment load. In the Ovens River the suspended sediment load has experienced little historic change, whereas for the Murray much of the sediment has been trapped behind Hume Dam and other tributary dams (Erskine *et al.*, 1993). The largest Murray sediment loads are now delivered during irrigation flows (Thoms *et al.*, 2000). It appears that the lack of sediment in the regulated Murray is starving the benches of sediment and so halting their natural development.

Channels as a fine-grained sediment storage
With the knowledge that many benches are not temporary but may eventually form a component of the floodplain, their role in the storage of fine-grained sediment becomes more important to the estimation of sediment budgets commonly focused on floodplain storage. Initial estimates from bench distribution throughout the Ovens River (see Vietz *et al.*, 2004) and deposition measured at the two sites indicates that more than 4 kt/y of fine-grained material is stored in benches. This equates to more than 5% of the estimated 80 kt/y of suspended sediment transported from the Ovens River to the River Murray each year (DeRose *et al.*, 2005). This small contribution could be pertinent to rivers disconnected from their floodplain, and may be an important inclusion in estimating catchment sediment budgets.

Conclusion

Benches are an important component of an ecologically healthy river. They are dynamic, related to the sediment and flow regime and contribute a significant store of suspended sediment. This study has found that:

- Concave benches in the Ovens River build vertically at a rate of 50 – 300 mm/year;
- Most deposition occurs at flows considerably greater than benchfull, up to bankfull;
- Deposition on River Murray benches is dramatically reduced due to the reduction in sediment supply and flow variability;
- Concave bench surfaces do not erode even at flows greater than bankfull;
- Erosion of benches is restricted to the streamside and downstream edge; and
- In mostly unregulated systems (solely extractions) benches need to be considered as a dynamic morphology and in regulated rivers targeted flow and sediment supplies are required for bench maintenance.

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