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Constraints on duration of sediment storage in a wide, gravel-bed river, New Zealand

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ABSTRACT The area of inactive zones in a braided gravel bed river shrinks as the magnitude and duration of competent flow events increase. In a narrower and aggrading reach the entire bed is activated by events that recur twice annually and bed material is stored by actual fill exceeding actual scour. In the wide, braided and stable reach, bed material is stored in bars and its residence time increases as bar height and bar width increase. The depth of bed activity also increases as event flow increases. Armouring of branch channel bed and banks is particularly noticeable in the wide reach; it is the main sedimentologic constraint on the residence time of bed material.

BACKGROUND

The extent to which bed material is stored in wide gravel bed rivers has been addressed by comparing conventional resurveys and by augmenting them with aerial photograps (Ferguson & Weritty, 1983). Bed material storage cannot, however, be determined accurately by these means because they can only be used to evaluate net vertical and plan form changes. This was shown in studies dealing with narrower rivers, where scour chains and gauged surveys were used to evaluate the actual vertical activity of the bed (Madej, 1984; Carling, 1987; Kelsey et al., 1987). The dissection and formation of gravel bars may be viewed as a mechanism whereby stored sediment is periodically activated or mobilised (Ashmore, 1985). This paper describes the extent of this activity and its variation with event magnitude and sediment characteristics in a wide gravel bed river.

THE NORTH BRANCH ASHBURTON RIVER

The watershed of this tributary includes mainly greywacke with some volcanics of the Palmer, Taylor, Mt. Hutt, Pudding Hill, Old Man and Alford Ranges, forming part of the New Zealand Southern Alps. Altitudes exceed 2,100 m within the basin area (300 km^2) extending above the gorge, below which the river flows across the Canterbury Plains (80 km^2). The mean annual precipitation for the entire basin is 1400 mm and the mean and 50 year flood peaks at the gorge Old Weir site are 180 and 570 m^3 s^{-1}. The river is steep (1.15%), wide (200 m) and braided below the gorge, where an upper reach was chosen for detailed study (Fig. 1). At low flow this reach often has two braids with well developed longitudinal bars, some of which are covered with dense, perrenial vegetation. The bars are comprised of finer textured gravel compared to that of braid channels; the channels are armoured (Table 1). The lower reach is flatter (0.73%), narrower (84 m), finer textured and has alternate bars, with two braids at most. Both reaches have been confined, but the upper is stable while the lower has aggraded at an average rate of 6 cm yr^{-1} during 1937-57 and 3.8 cm yr^{-1} thereafter; the latter rate excludes gravel extracted from the bed, with which the rate would have totalled 8.4 cm yr^{-1}.

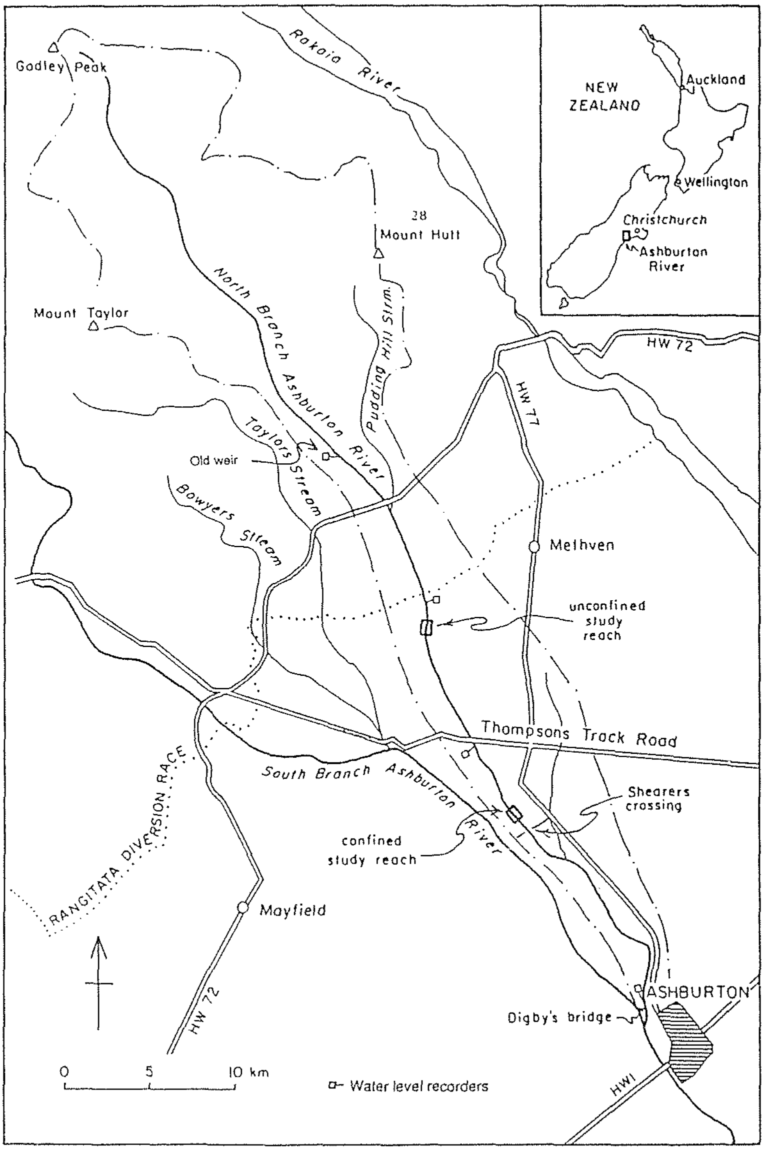

Fig. 1. Map of the North Ashburton River showing location of the study reaches.

Table 1. Texture of the North Branch Ashburton River bed at the study sites including sand, without which all the moments (in mm) are about 20% larger

textural moment	Upper reach		Lower reach	
D_{50} subsurface	21		21	
D_{84} subsurface	64		64	
D_{95} subsurface	147		112	
	bar	branch channel	bar	branch channel
D_{50} surface	28	65	21	65
D_{84} surface	74	119	39	74
D_{95} surface	137	181	74	99

TECHNIQUES

To determine the extent to which bed material was mobilised, networks of 17 and 24 cross sections respectively were surveyed in the upper and lower reaches before and after flow events during 1985-86. These were augmented by measurements of scour and fill using a total of 200 scour chains inserted along six cross sections in each reach. The North Branch below the gorge was photographed with a 35 mm camera before the first and after each flow event. Based on the photos, maps were drawn to determine active bed areas.

Flow velocity and depth were measured at the reaches and at Thompson's Track Bridge (Fig. 1). The second flow event (30 $m^3 s^{-1}$) included a constant discharge of18 $m^3 s^{-1}$ from the Rangitata Diversion Race (see Fig. 1). More than 1000 magnetic gravel tracers (Hassan et al., 1984) were placed on and in the river bed at both sites.

EXTENT OF BED ACTIVITY

Most of the river bed in the upper reach remained immobilised during the first three small events, while the entire bed of the lower reach, except for embayments protected by the live training works (willows), was activated during the second and subsequent events. For brevity we present only conventional cross sectional resurvey and chain scour/fill measurements.

Width of bed activity

Fig. 2 shows the extent to which the river bed was mobilised. A best fit line was fitted by eye. The widths of activity are based on aerial photos, scour chains and tracer particle measurements as well as conventional resurveys because the latter do not register activity when scour equals fill. Accordingly, the widths of activity plotted in Fig. 2 are larger than those derived solely from conventional resurveys. Peak discharge and duration of bed load were obtained from hydrographs at Old Weir (Fig.1).

Fig. 2a demonstrates perhaps more accurately than previous studies

(Hein & Walker. 1977: Ferguson and Weritty, 1983) that larger portions of the river bed become activated as the magnitude of flow events increases. This occurs because additional braids and bars are activated as discharge increases (Mosley, 1982). In other words, Fig. 2a shows the extent to which progressively smaller portions of the bed store immobilised bed material as the magnitude of an event increases.

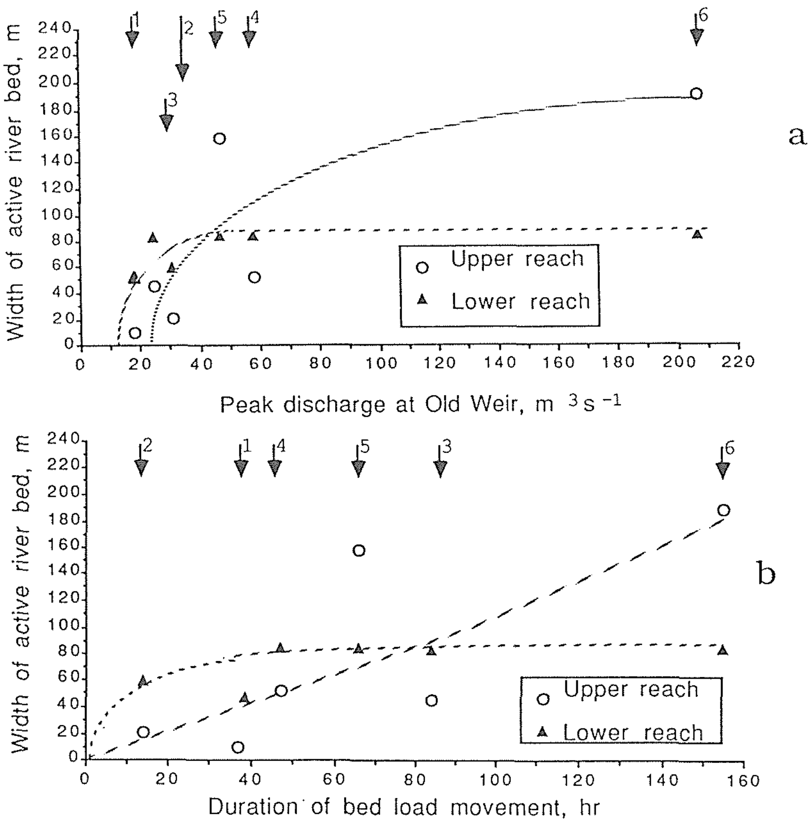

Fig. 2. Width of bed activity vs. peak discharge (a) and vs. duration of bedload movement (b). The numbers denote the six successive flow events monitored during December 1985 - March 1986.

The duration of flood hydrographs varies primarily with antecedent soil moisture, storm duration and snow melt in a complex manner, so it is not surprising that the extent of river bed activity also increases with an increase in the duration of bedload transport (Fig. 2b). Pertinently, the width of the active river bed increased due to continuous bank failure in the upper reach also during the second flow event, even though water discharge remained essentially constant. Event 3 was double peaked with a very wide time base, which serves to explain why the width of bed activity was considerably larger during this event than during event 2 (compare Fig. 2a and 2b). These observations demonstrate that bed material is progressively mobilised and flushed from storage areas even when discharge remains constant or decreases, as long as competent conditions prevail for bed movement or bank failure.

Depth of bed activity

The frequency distributions of net resurvey scour and net fill in the upper (Fig. 3a) and lower (Fig 3b) reaches were derived from sampling resurvey cross section drawings every 5 and 3 m, respectively. They differ in three manners:

1) The distributions differ in their kurtosis or peakedness (see K values in Fig. 3). The upper reach exhibited only minor scour or fill during the first small events, whereas the bed in the lower reach was disturbed in excess of 1.4 m (|scour| + fill) by these events.

2) The braided river bed was activated to considerable depths only during large events (with exceptions of bank erosion during event 3). In contrast, the range in depths of activity did not vary significantly in the narrow reach; it may have increased slightly with increase in peak discharge and duration of bed load movement.

3) The distributions are symmetrical at both reaches for the large events, but prefential scour or fill occurred in the wide, braided reach during small events (see the skewness values denoted by Sk in Fig. 3) due to bank erosion and avulsion.

The term 'scour layer' most appropriately refers to the depth of scour. The extent of vertical bed activity is also dependent on the magnitude of deposition. Therefore, we refer not only to chain scour and fill values separately, but also to the sum of their absolute values as a measure of bed activity (Laronne et al., 1986; Potter et al., 1987). This measure of bed activity was significantly larger than that surmised from the conventional resurveys (Fig. 3). The scour chain measurements (Table 2) demonstrate that although some bed areas either scoured or filled, many (and particularly in the lower reach) scoured and filled during every flow event.

There is an intrinsic high variability about mean scour/fill values. The chain data also show that scour and subsequent deposition occur in the stable upper reach and also in the lower aggrading one. This clarifies the mechanism of sediment storage in channels: sediment layers are not necessarily deposited conformably upon each other but, instead, most of the bed material deposited by a given event is subsequently mobilised (and thereby scour occurs) before additional incoming bed material is deposited. Thus, the bed is subject to both scour and fill during an event. The situation may be more complex than this as fill could precede scour, or there may be several cycles of scour and fill during a single event.

BED MATERIAL STORAGE AREAS

Although bed material was mobilised in the lower, narrow reach by small events, storage occurred by vertical accretion, with sand and suspended load deposited on the vegetated training banks. While the branch channels in both reaches are armoured (Table 1), the armour in the braided reach is

Table 2. Average chain scour/fill magnitudes (cm) for all bed areas that were mobilised during events 1-6. The number of relocated chains is added parenthetically beside the respective standard deviations

	Upper reach		Lower reach	
	average	s.d.	average	s.d.
scour only	10.5	9.5(28)	27.1	22.9(10)
fill only	15.3	13.4(7)	12.5	11.3(11)
net scour with later fill	19.9	19.8(24)	44.0	26.0(64)
net fill with former scour	21.4	24.4(24)	38.1	28.2(64)

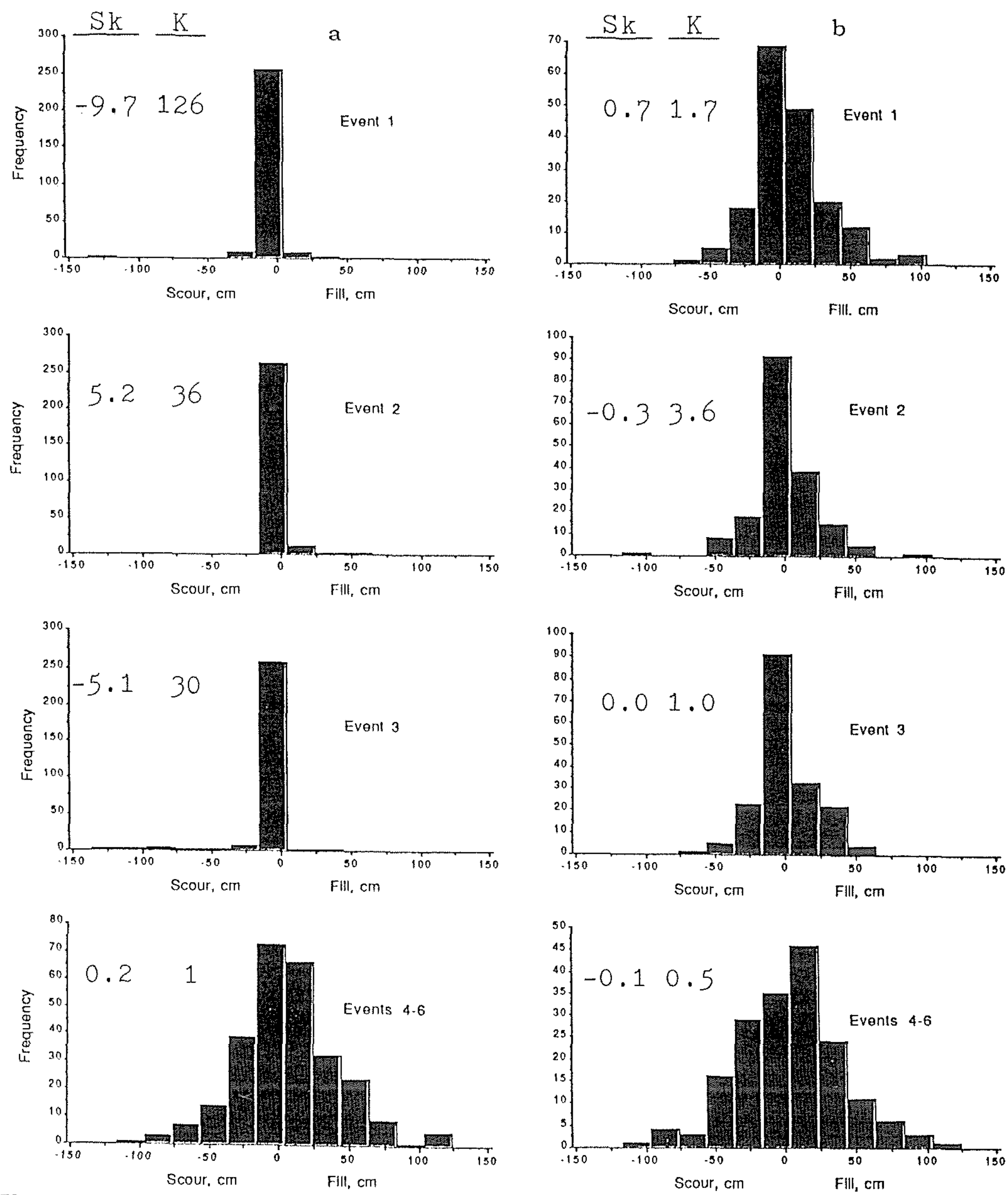

Fig. 3. Frequency distributions of net resurvey scour and fill in the upper (a) and lower (b) study reaches, North Branch Ashburton River.

considerably coarser than further downstream. This explains the reduced bed activity in the braided reach at lower flows. In this reach bed material was stored in bars and bar remnants. These are bars or, more often than not, bar remnants that vary in width and height. Bars which were considerably elevated above the braids were insignificantly affected by events 1-4 and only moderately by the largest and sixth event, which recurs once in three years. These bars were also covered by a perennial or a dense shrub mat indicating stability. Lower bars and bar areas in contact with main branch channels were progressively eroded, but those which were sufficiently wide and high remained almost intact as braids were deflected elsewhere. The bed of the lower reach is devoid of vegetation, indicating that most of it is frequently mobilised to a considerable depth as demonstrated in Fig. 2 and 3b. Thus, the storage duration of the entire scour layer is short, merely a few months, even though this reach is undergoing massive aggradation. The relationships between bar height, river width and duration of sediment storage are depicted in Fig. 4.

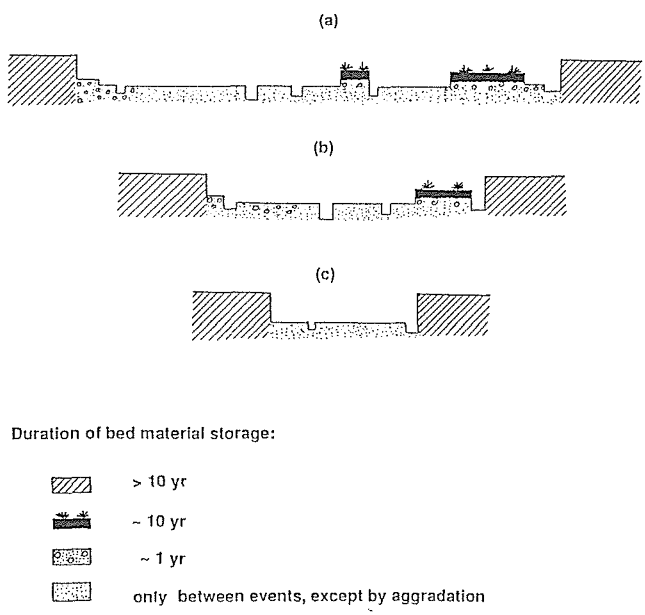

Fig. 4. Schematic cross sections depicting storage potential of a braided (a), slightly confined (b) and considerably confined reach (c).

It is interesting that only the narrow stretches above and below the upper study reach were completely activated, whereas the wider ones contained stable bar remnants. Differing from the Bella Coola River (Church, 1983), this suggests that the narrow stretches are mobile, sediment-transporting conduits where residence time of sediment is short if the reach is stable, and even in an aggrading reach it is short for the bed material within the scour layer. The wider reaches provide for a more efficient storage simply because they contain a larger number of bars and a larger cross sectional area of stored sediment.

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