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Evidence For High Magnitude Floods Along the Waimakariri River, South Island, New Zealand

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Abstract

The largest accurately gauged flood in the Waimakariri River was the 100-year flood of December 1957. Erosion scarps along margins of tributary alluvial fans, large gravel sheets exposed in floodplain banks, and trees buried under fluvial gravel suggest that two floods of greater magnitude than the 1957 event have occurred in the last ca. 300 years.

Introduction

A catastrophic flood of the Waimakariri River could inundate almost the whole of metropolitan Christchurch, affect 255,000 people and cause damage estimated at $5,000 million (Griffiths, 1991). Numerous large floods have inundated parts of Christchurch since 1848 (S.C.R.C.C., 1957; N.C.C.B., 1986; Logan, 1987), but the magnitudes of these historical floods have not been investigated in detail. One of the most accurate methods of estimating ungauged historical or palaeo-flood magnitudes involves correlating flood stages between multiple slackwater sites in a stable bedrock gorge (Baker, 1987). Although the Waimakariri River flows through a bedrock gorge for approximately 30 km, the gorge is generally inaccessible, and the bed is mantled by thick alluvial deposits which probably scour substantially during large floods, thereby creating difficulty in accurately estimating peak flood discharges. Alternative palaeohydrological methods were therefore chosen to investigate high magnitude floods along the upper Waimakariri River.

Erosion scarps along the margins of tributary fans (Costa, 1978), floodplain vegetation (Helley and Lamarche, 1968, 1973; Yanosky, 1982; Hupp, 1988; Martens, 1992) and deposits of coarse-grained sediment over fine-grained floodplains (McKee et al., 1967; Costa, 1974; Ritter, 1975, 1988; Patton, 1988) are seldom used to determine the absolute magnitude of historical or palaeo-floods. However, these features can be used to determine the number of floods exceeding a threshold magnitude, usually the largest known historical flood (Helley and Lamarche, 1973; Patton, 1988). 'Threshold exceedence' data can significantly improve flood magnitude/frequency estimates, even if flood magnitudes are unknown (Stedinger and Cohn, 1986, 1987). The 'threshold exceedence' approach was adopted in this study, which compares the geomorphic effects of the largest historically gauged flood, the 100-year flood of December 27th 1957, to field evidence for past high magnitude floods along the upper Waimakariri River.

Catchment Description

The Waimakariri is one of several large rivers that flow eastwards from the Southern Alps. It is 150 km in length, and drains a catchment of 3560 km^2 which can be divided into two distinct geographical regions, the upper and lower catchments (Fig. 1). The 2490 km^2 upper catchment has a maximum elevation of 2400 m, is mountainous, glaciated and extends from the headwaters of the Waimakariri and Poulter Rivers to the confluence of the Kowai River (Gage, 1958). Between the Esk and Kowai river confluences, the Waimakariri is confined within a bedrock gorge incised to a depth of 300 metres. Downstream of the Kowai River, it enters the Canterbury Plains, which consist of a series of coalesced glacial outwash fans. Here the Waimakariri again braids and flows eastward in a broad but progressively shallowing trench. A hinge point, 18 km from the sea, separates current fan building from river entrenchment into the outwash fans (Griffiths, 1979).

The bedrock of the Waimakariri River catchment consists almost entirely of indurated sandstone (greywacke) and argillite with localised limestone, volcanics, conglomerate and coal measures (N.C.C.B., 1986). Alluvial fans, moraine and glacial outwash deposits occur throughout the catchment. Floodplains are common in sheltered areas downstream of tributary alluvial fans and outcropping bedrock spurs (Reinfelds and Nanson, 1993).

Average annual rainfall decreases along a very steep west-east gradient, from about 8000 mm along the main divide, to less than 700 mm at the coast (N.C.C.B., 1986). Most floods result from heavy rainfall on the main divide during northwesterly conditions associated with frontal disturbances within low pressure systems over the Tasman Sea (Griffiths and McSaveney, 1983). The mean annual flood for Waimakariri River (gauged 5 km from the sea) is 1520 m^{3}s^{-1}, the probable maximum flood is 8000±1000 m^{3}s^{-1}, and the mean annual flow is 121 m^{3}s^{-1} (Griffiths, 1979; Griffiths et al., 1989; N.C.C.B., 1986).

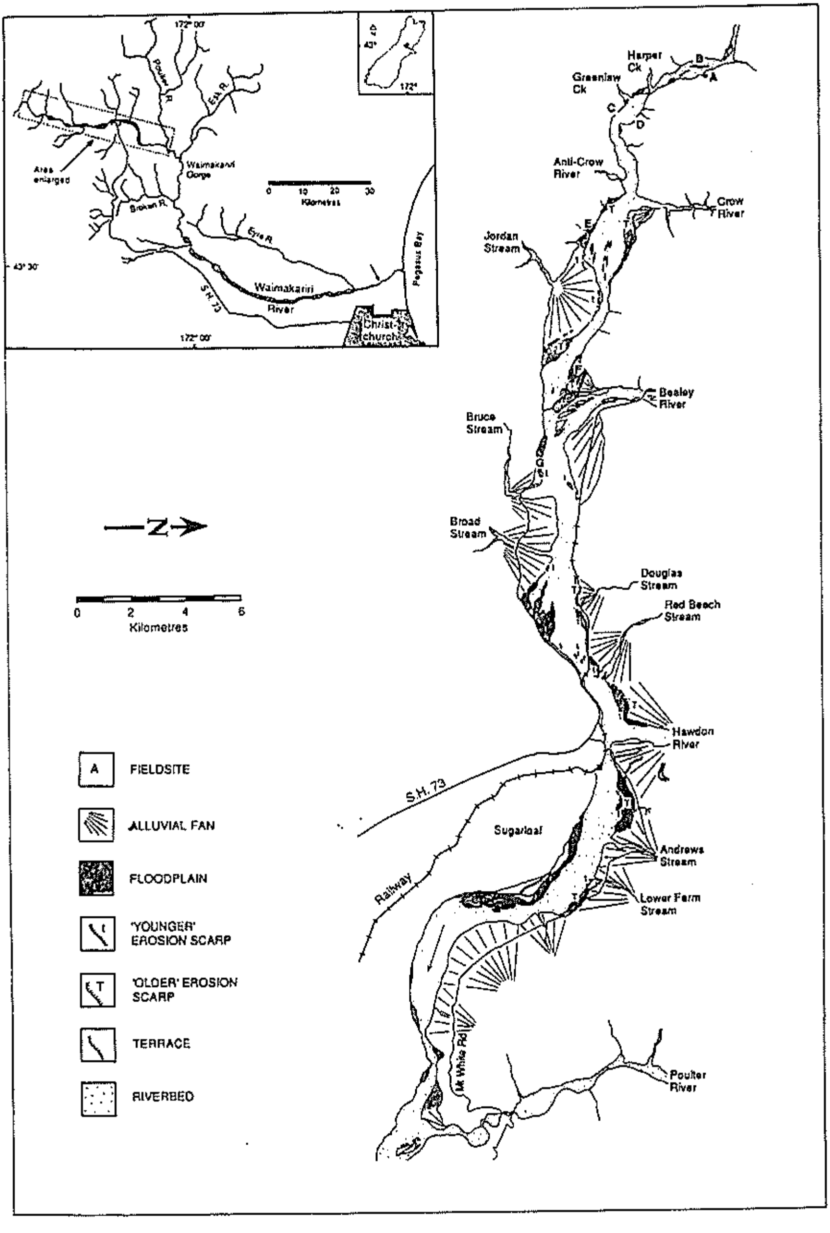

FIG 1 — Map of the upper Waimakariri River showing field sites and the location of tributary fan erosion scarps.

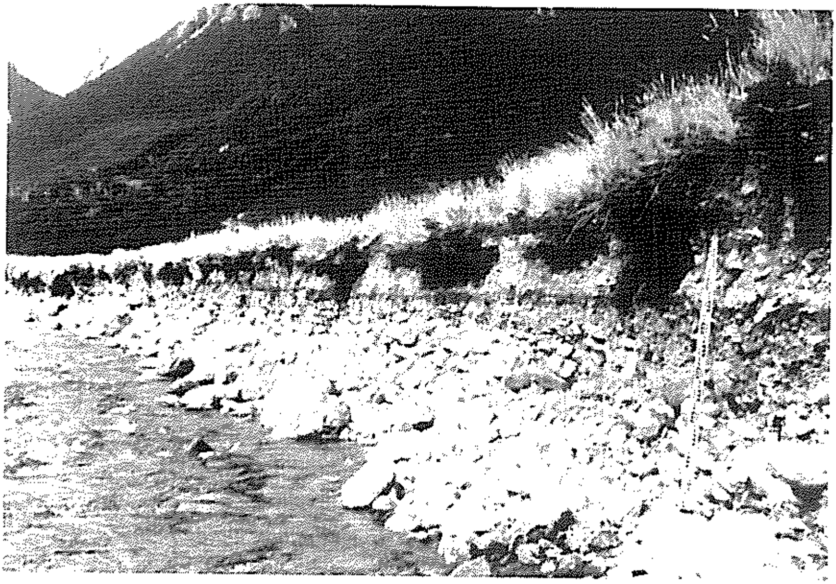

FIG 2 — Downstream end of the 'older' gravel sheet deposited over alluvial fines at site B. The sheet is up to 50 cm deep, resembles a large bedform, and can be traced along the cut-bank exposure for over 50 metres. Similar gravel sheets occur at sites C to G. River flow is away from the viewer.

Data Sources and Research Methods

The method adopted in this study was to investigate geomorphic effects of the 100-year December 1957 flood with regard to changes in position of tributary alluvial fan margins and sediment deposition over floodplains. Aerial photography for the upper catchment dates from 1948, 1959/60 and 1986.

The 1948 series covers the Waimakariri River from just upstream of Jordan Stream fan to the confluence of the Poulter River, while the 1959/60 and 1986 series cover from the confluence of the White River to the entrance of Waimakariri Gorge (Fig. 1). Areas of sediment deposition, bank erosion and erosion scarps along tributary fans resulting from the 1957 flood are clearly visible on the 1959/60 aerial photographs. These sites were accurately located in the field for comparison with the position of palaeo-tributary fan erosion scarps and palaeo-gravel sheets exposed in floodplain cut-banks.

Effects of the 1957 Flood

The largest flood on record since accurate gauging began in 1930 occurred on December 27th, 1957 when 324 mm of rain fell at Arthurs Pass between 26-27 December. Rainfall intensities at Arthurs Pass reached a maximum of 36 mm/h with maximum six and twelve hour intensities of 26.2 mm/h and 22 mm/h respectively (Canterbury Regional Council, unpublished data). A peak discharge of 3990 m^3s^{-1} was recorded at the Old Highway Bridge gauge (Fig. 1) corresponding to a recurrence interval of approximately 100 years (N.C.C.B., 1986).

Although most changes visible on the 1948 and 1959/60 aerial photos have been attributed to this single event, significant floods also occurred in 1950, 1955 and 1956 with recurrence intervals of approximately 12, 8 and 6 years respectively. Without additional evidence it is difficult to determine whether the effect of the 1957 flood was greater than the cumulative effect of the preceding events. The short time interval between these floods, however, would have been conducive to the 1957 flood effecting a maximum of geomorphic change, particularly through floodplain bank erosion and formation of erosion scarps along tributary fans. The 1959/60 aerial photos from which these changes are interpreted were taken 14 or 26 months after the 1957 flood; no significant floods occurred in the intervening period. A small (30 m^2) sand splay deposited over a floodplain observed in February 1991 was still unvegetated by February 1993, supporting the assumption that the time period between the 1957 flood and the 1959/60 aerial photos was insufficient to mask the flood's effects.

Comparison of 1948 and 1959/60 aerial photos revealed that downstream from the White River confluence, most of the Waimakariri riverbed (including lichen, moss and Raoulia sp. covered boulder bars) was activated by the 1957 flood. Along the length of the river in the upper catchment, bank retreat and tributary fan erosion was generally minor, while overbank deposition of substantial amounts of sand or gravel onto vegetated floodplain surfaces was limited to a single area, the floodplain immediately downstream of Broad Stream fan (Fig. 1). Two lobes of angular medium gravel, probably originating from Broad Stream fan, were deposited over the floodplain surface, and numerous abandoned channels within the floodplain were re-activated. The floodplain was eroded to 51% of its 1948 aerial extent between 1948 and 1960, but since re-vegetated to 93% of its 1948 area by 1986 (Reinfelds, 1991).

Effects of the 100-year flood of 1957 were limited in both impact and extent; if not for erosion downstream of Broad Stream fan, there would be little remaining trace of this flood along the upper Waimakariri River. The area of maximum intensity for the storm was centred over the upper Poulter River which received a storm rainfall of 450 mm, while the headwaters of Waimakariri River received 400 mm (G. Horrell, 1993 pers. com.). Although effects of the 1957 flood in Poulter River have not been investigated, it seems unlikely that a 10% difference in basin rainfall can account for the lack of widespread geomorphic effect of the 1957 flood in Waimakariri River. The limiting extent of significant geomorphic change to a single site (the floodplain downstream of Broad Stream fan) suggests that floods of the magnitude of the 1957 event cause only localised erosion and deposition.

Evidence for Palaeofloods: Gravel Sheets Over Floodplain Surfaces

Seven sites were found where large gravel sheets overlie floodplains previously accreting only fine-grained sediment, or where gravel sheets have buried trees at a substantial distance from the presently active riverbed (Fig. 1).

Distribution and Characteristics of Gravel Sheets

Floodplain cut-bank exposures revealed large gravel sheets deposited over surfaces previously accreting only fine-grained sediment (field texture generally silty clay loam) at sites A to C, E and G (Fig. 1). At sites C, D and F, the gravel sheets have buried mature *Nothofagus solandri* trees. At Sites B, C, E and G, the exposed gravel sheets are substantially larger and generally coarser than any recent gravel splays deposited on nearby floodplain surfaces (eg. Fig. 3). The uniform nature of the deposits, imbrication of clasts and the bar-like morphology of these units suggest deposition by substantial floods.

The longest stratigraphic records are preserved at site B and E, where two large gravel sheets are exposed in the stratigraphy. The lowermost, and hence oldest, gravel sheets are coarser than the younger gravel sheets and are more extensive, being traceable through the stratigraphy for approximately 50 m at both sites (Fig. 3). Small iron nodules and hardpan-like features have developed in the underlying alluvial fines at site B. At sites A, C and G single, extensive gravel sheets close to the floodplain surface were found. The unweathered nature of these 'younger' gravel sheets and underlying alluvial fines suggest that they are fairly recent.

Large *N. solandri* trees buried to depths of up to 1 m (Site D) by flood-transported gravel occur at sites C, D and F. The buried trees generally have maximum diameters of 50 cm with many being killed by burial. At all three sites, young *N. solandri* 22-30 cm in diameter have grown on the surface of the flood gravels, providing a means of dating the events responsible. At site F at Klondyke corner most of the large trees are buried under approximately 50 cm of gravel, with a maximum b-axis grain size of 5 cm, at a perpendicular distance of 150 m from a bankline formed by the 1957 flood.

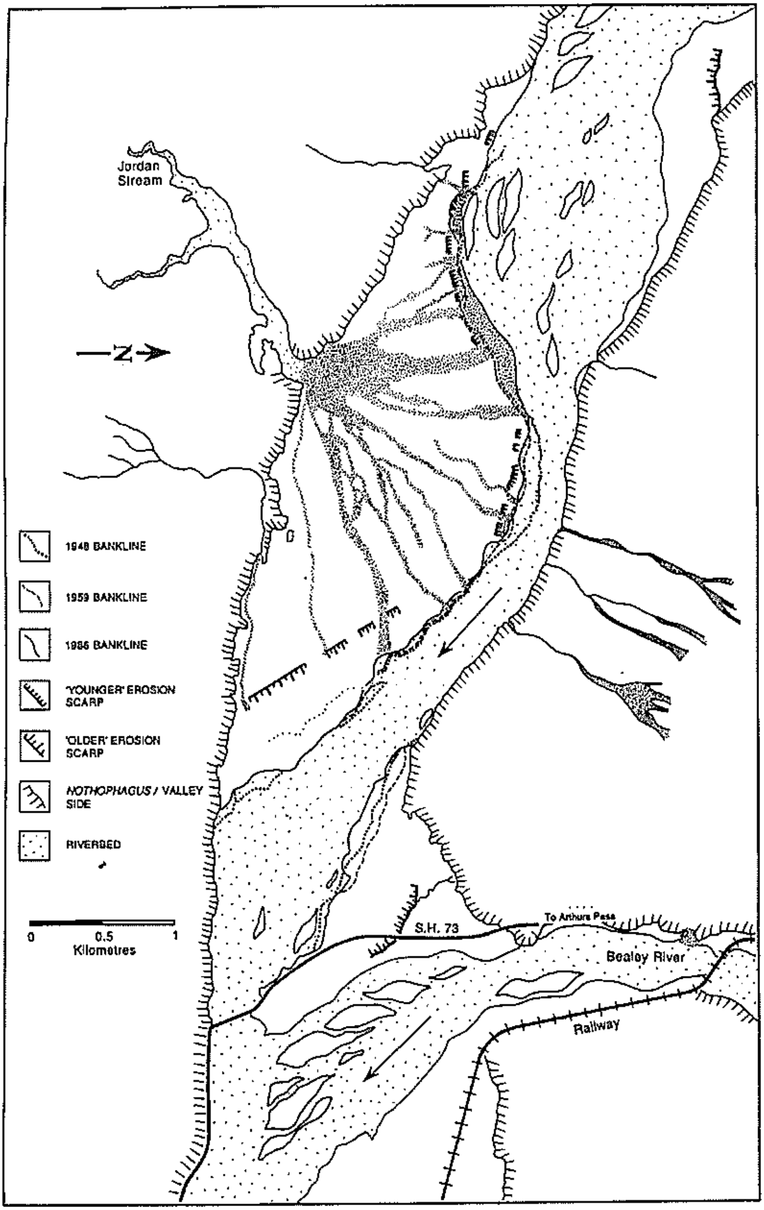

FIG 3 — Map of the Waimakariri River in the vicinity of Jordan Stream fan. The positions of the 'older' and 'younger' erosion scarps on Crow River, Jordan Stream and Bealey River fans are illustrated, as well as bankline positions in 1948, 1959 (post 1957 flood) and 1986. Note the straightness of the 'older' Jordan Stream fan erosion scarp.

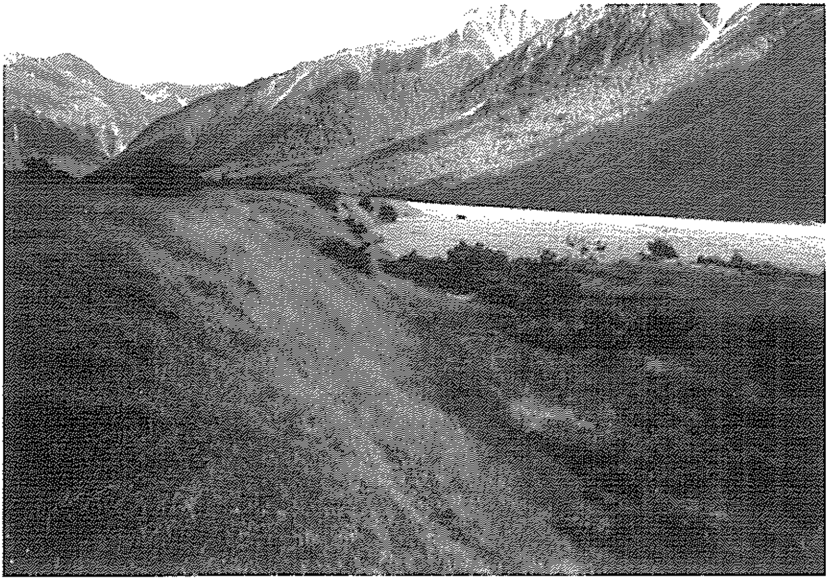

FIG 4 — View of the 'older' erosion scarp along the downstream margin of Jordan Stream fan. Recent 'fan-in-fan' sediments can be seen in the right middle ground, floodplain on the right foreground, and fan surface on the left. Note the absence of matagouri from the scarp face and fan surface except where gullies have eroded.

Origin of the Gravel Sheets

Field observations, in conjunction with 1959/60 aerial photos, reveal that the 100-year 1957 flood did not deposit a significant amount of sediment at any of the seven sites where gravel sheets were found. Either the riverbed morphology in the vicinity of all of these sites was not conducive to overbank deposition at the time of the 1957 flood, or the 1957 flood was not of sufficient magnitude to deposit coarse-grained sediment at these sites. Although floods of the magnitude of the 1957 event can produce substantial localised deposition and erosion, they do not seem to produce widespread changes. While good age controls are lacking the similarity in diameter between *N. solandri* at Sites C, D and F suggests that the same event may have been responsible for deposition of the substantial gravel sheets at these sites.

Evidence for Palaeofloods: Erosion Scarps on Tributary Fans

Eroded margins of prograding tributary fans have been used as indicators for floods of exceptional magnitude. On the basis of erosion scarps along two tributary fans, Costa (1978) suggested that the 1976 Big Thompson flood, Colorado, was the largest flood on Big Thompson River since the formation of these fans (ca. 10,000 years) because no evidence of prior fan cutting and filling was revealed in the fan stratigraphy. Erosion scarps along tributary fans may be abandoned at a considerable distance from currently active riverbed as channels migrate in conjunction with riverbed aggradation and as sediment delivery changes across the tributary fan. The first mechanism is of particular importance to braided rivers because of their accentuated lateral migration in areas of bedload sediment accumulation (Church, 1983; Davies, 1987), and their ability to undergo considerable changes in width (thereby eroding tributary fan margins) in response to storm-induced sediment slugs whose effects can persist long after the passing of the flood (Beschta, 1983).

Causes of Erosion Scarps Along Tributary Fans

Numerous tributary fans along the Waimakariri River have erosion scarps inset behind younger fan sediments, which can be distinguished on aerial photos and in the field (Figs. 1 and 3). Along these fans, 'fan-in-fan' or floodplain development results in erosion scarps being abandoned at a considerable distance from the active riverbed. At least three processes form abandoned erosion scarps along tributary fans:

i) river or channel migration unrelated to high magnitude floods;
ii) a switch in fan activity and position of sediment delivery; and
iii) high magnitude floods.

River or individual braid-channel migration toward a tributary fan can form an erosional scarp closer to the fan apex. Re-establishment of the previous river course and subsequent 'fan-in-fan' or floodplain development can leave the eroded scarp at a considerable distance from the normal position of the fan margin.

The large tributary fans entering the Waimakariri River valley do not deliver sediment evenly across the fan; approximately one third of the fan margin receives sediment at any time. Aerial photos, for example, show that prior to the 1950s floods, the Jordan Stream fan delivered more sediment to its central sector (see 1948, 1959 and 1986 fan margin positions; Fig. 3) with consequent erosion of the upstream (western) fan margin. Between 1959 and 1986, sediment delivery switched to the upstream (western) margin with almost 200 m of fan margin progradation since 1959. Since the switch in sediment delivery, the central fan sector eroded further back than the 1957 flood trim-line (see 1959 fan margin; Fig. 3).

High magnitude floods are capable of eroding scarps deep into tributary fans (Costa, 1978). However, if abandoned trim-lines are to be used as evidence for high magnitude floods, the other processes forming erosional scarps must be discounted. The morphology of an erosion scarp can be indicative of its origin. For example, gradual erosion of tributary fans by river or braid-channel migration usually forms a distinctively scalloped margin, while erosion scarps formed during high magnitude floods may not be so distinctly scalloped. The extent of abandoned erosion scarps along individual fans, their position relative to recent trim-lines caused by historical floods and inter-relationships with other evidence for high magnitude floods should be considered before conclusions are reached as to their origins.

Distribution and Characteristics of Erosion Scarps Along Waimakariri River

Prominent erosion scarps abandoned at considerable distances from current fan margins occur on almost all tributary fans downstream of Crow River. Vegetation and morphological differences distinguish these abandoned erosion scarps, suggesting 'older' and 'younger' types (Fig. 1). 'Older' erosion scarps generally lack matagouri (*Discaria toumatou*) which suggests that the site has not been disturbed for 200-300 years (Burrows, 1977; Dobson and Burrows, 1977). In addition, two 'older' fan scarps have large *Nothofagus* in front, providing a minimum age of formation. 'Younger' fan scarps are characterised by matagouri 1 m to 2 m in height and generally occur closer to the currently active riverbed than the 'older' scarps. In some cases, such as Hawdon River, a continuous erosion scarp features both 'older' and 'younger' sections.

'Older' Erosion Scarps

'Older' erosion scarps are clearly visible on Crow River fan, Jordan Stream fan and Bealey River fan (Fig. 1). Prominent scarps on Crow River and the un-named small tributary directly opposite (just upstream from Anti-Crow hut) are vegetated solely with grasses and have a *Nothofagus* tree or stump with diameters of 52-54 cm in front of the scarp, providing a limiting minimum age for the erosion of these fans. In addition, very coarse boulder bars occur in front of the Crow River scarp at its downstream end. The 'older' scarp on the downstream side of Jordan Stream appears as a straight cut on the aerial photos (Fig. 3), and matagouri is absent from the scarp face and adjacent fan surface (Fig. 4). The Bealey River fan is also prominently scarped and similarly lacks matagouri. Additional 'older' erosion scarps without matagouri can be recognised on Bruce and Broad Stream, Hawdon River, Andrews Stream and Lower Farm stream fans (Fig. 1) At all of these sites, the 1957 flood did not to erode into 'older' erosion scarps.

'Younger' Erosion Scarps

'Younger' erosion scarps characterised by matagouri from 1 to 2 m high growing on the scarp face occur on Jordan Stream fan, Broad Stream fan, Douglas Stream fan, Red Beech Stream fan and a section of Hawdon River fan (Fig. 1). The 'younger' scarps on Jordan Stream fan are not continuous along the circumference of the fan. For a large sector along the upstream (western) fan margin, the 'younger' scarp was being actively eroded prior to 1948 (Fig. 3). Along the remainder of the fan, however, the 1957 flood was unable to reach the 'younger' erosion scarps (Fig. 3). The 1957 flood did not effectively erode the central sector of Jordan Stream fan (Fig. 3), yet at this point, the Waimakariri River is constricted to approximately one quarter its normal width which would presumably maximise its erosive potential. Along Broad and Bruce Stream fans, only very small remnants of the 'younger' scarps remain (Fig. 1). Erosion by numerous low magnitude events along Broad and Bruce Stream fan margins since 1959/60 has re-activated the erosion scarps which were previously inactive in 1948, and formed distinctively scalloped fan margins.

Origin of the Waimakariri Tributary Fan Erosion Scarps

The widespread occurrence of 'younger' erosion scarps beyond the reach of the 1957 flood on most of the tributary fans in the upper Waimakariri Valley and the coincidence of large gravel sheets deposited over floodplains in close proximity to these sites, suggests that a likely cause of their formation is a flood of greater magnitude than the 1957 event. The simplest explanation for the 'older' erosion scarps on Crow River, Jordan Stream and Bealey River fans is that these features were formed by a single high magnitude flood. No terraces occur adjacent to the scarps, hence their formation by lateral migration in conjunction with a higher base level is unlikely. Nor are they related to levels of glacial Lake Speight (Gage, 1958) because these scarps are at least 80 m above the highest discernible lake shorelines. The straight cut of the 'older' erosion scarp on the downstream sector of Jordan Stream fan also suggests that it was formed in a single event, because erosion by multiple events usually forms distinctively scalloped margins.

Discussion

Geomorphic evidence sugests that two floods greater than the 1957 event occurred over the last ca. 300 years. The 'younger' gravel sheet at Site B, the gravel sheets at Sites A-H and the 'younger' erosion scarps on the tributary fans downstream from Crow River were probably formed by the same flood, as dendrochronological estimates of their age are crudely similar. Assuming an annual growth rate of 1-2 mm (Norton, 1991 pers. com.), *N. solandri* 22-

30 cm in diameter as found at sites C, D and F are in the order of 60 to 150 years old, while matagouri 1-2 m high (as found on 'younger' erosion scarps) are also within this range (Reinfelds, 1991). This flood was larger than the 1957 flood in the upper Waimakariri River and occurred sometime between 1840 and 1930. Some scarps activated by the 1957 flood on Jordan Stream fan are currently being eroded; erosion scarps formed by 'moderate' size floods are more likely to be eroded by subsequent, lesser events than scarps formed by 'exceptional' floods. Variation in age, even on the same fan, between Waimakariri 'younger' or 'moderate flood' erosion scarps along other rivers, can therefore be expected.

Numerous ungauged large floods occurred in Waimakariri River from 1840 to 1930 (S.C.R.C.C., 1957; Logan, 1987), of which the largest are listed in Table 1. From the available data, the most likely event responsible for the 'younger' fan scarps and recent gravel sheets is either the 1874 or 1926 floods. Additional information from newspaper reports and other historical sources is required to determine with confidence the relative magnitude of other large floods, particularly the 1887, 1888, 1905, 1906 and 1950 floods for comparison. Although the 1874 flood is not mentioned by S.C.R.C.C. (1957) it was a significant event in the upper catchment. Over 178 mm of rain in 24 hours was recorded at Bealey (The Press April 7, 1874) from which 317 mm in 24 hours can be calculated for Arthurs Pass from an equation given in N.C.C.B. (1986). Logan (1987) reported that the Otira River was dammed by a landslide during the 1874 flood, that the Taramakau River rose higher than ever recorded and that Christchurch was not flooded only because a new stopbank had been recently constructed. Flood depths during the 1874 event were 50 cm higher in Kaiapoi than during the 1868 flood (The Press, April 7 1879; The Times, April 8 1879).

The November 1926 flood was also of similar magnitude to the 1957 event. A flood stage of 4.72 m was recorded at the Gorge Bridge for this event (S.C.R.C.C., 1957), while the second highest flood reported in N.C.C.B. (1986), the February 1940 flood, had a stage of 3.35 m (Table 1). Rainfall at Arthurs Pass during the 1926 event was 467 mm over 30 hours, with 323 mm falling in 24 hours and 144 mm in 6 hours. The six-hour intensity of this rainfall event was similar to that recorded for the 1957 flood (Table 1). Chaneys and Coutts Islands were inundated by floodwaters up to 2.4 m deep (S.C.R.C.C., 1957). Speight (1928, p. 204) noted that "there is some evidence that the amount (of shingle) at the present time is on the increase. Patches of bush are at times buried by heavy deposits for several feet..." suggesting that the November 1926 event may have deposited some of the 'younger' gravel sheets.

The 'older' gravel sheets at Sites B and E and the 'older' erosion scarps on tributary fans downstream of Crow River may be the result of a flood of exceptional magnitude. The 'older' trim-lines on Crow River, Jordan Stream

TABLE 1 — Historical floods of the Waimakariri River between 1850 and 1957.

FLOOD	ARTHURS PASS RAINFALL	STAGE OTARAMA Q m^3s^{-1}	STAGE GORGE BRIDGE	STAGE WHITES BRIDGE	O.H.B. Q m^3s^{-1} (NCCB 1986)	COMMENTS
27 Dec 1957	324 mm/24 hr 157 mm / 6 hr	- -	-	-	3990	-
26 May 1950	457 mm/24 hr	-	3.81 m	-	2570	-
29 Feb 1940	204 mm / 24 hr 380 mm / 48 hr	- -	3.35 m	-	3740	-
10 Oct 1936	180 mm / 24 hr > 30 mm / hr for 5 hrs	- -	-	4.11 m	2680	-
5/7 Nov 1926	467 mm/30 hr 323 mm / 24 hr 144 mm / 6 hr	6.71 m 3540	4.72 m	3.65 m	-	Water 244 cm deep in Chaneys and Coutts Island
4 Dec 1925	-	- 3001	-	overtopped deck	3500	-
1906	-	- -	4.42 m	-	-	Date and other data unknown
1905	-	- -	4.11 m	-	-	Date unknown Waimak overflow to Styx River
1888	-	- -	-	-	-	Date unknown affected Chch
6 July 1887	-	- -	-	-	-	Water 239 cm deep in Kaiapoi
6 Apr 1874	178 mm/24 hr at Bealey approx 317 mm at Arthurs Pass	- -	-	overtopped bridge	-	Water 229 cm deep in Kaiapoi
4 Feb 1868	78 mm/24 hr at Bealey	- -	-	-	-	Easterly storm Water 168 cm deep in Kaiapoi

Rainfall, stage and discharge data for Arthurs Pass, Otarama, Gorge Bridge and Whites Bridge were obtained from newspaper reports of the day, S.C.R.C.C. (1957) and from unpublished data held at the Canterbury Regional Council. Discharge estimates for the Waimakariri River at the Old Highway Bridge (O.H.B.) were obtained from N.C.C.B. (1986).

and Bealey Rivers in particular cannot be explained by other means, such as elevated bed levels in conjunction with lateral migration, because floodplain levels adjacent to these scarps are consistent with present riverbed levels, or effects from glacial Lake Speight, because the scarps are at least 80 m above the highest discernible lake shoreline. In addition, the scarp on Jordan Fan is cut straight for several hundred metres, suggesting that a single event was responsible for its formation, while the coarse boulder bars at the downstream end of the Crow River scarp may also indicate a sizeable flood. The lack of matagouri on the 'older' scarps and size of the *Nothofagus* tree and stump in front of Crow River and opposite un-named tributary scarps, suggest that the flood responsible for the formation of these features occurred at least 250 years ago. Coincidental evidence for a recent high magnitude flood occurs in old overflow channels near Christchurch International Airport. Cox and Mead (1963) briefly described a gravel deposit 2 m thick which they suggested was deposited by a high magnitude flood. A kanuka log embedded in the gravel is dated at less than 200 years BP. Radiocarbon dates for the period 1850 to 1954, however, are prone to large errors because of increased fossil fuel burning and should be treated with caution (Williams et al., 1993). Hence there is a possible correlation between this gravel deposit and the flood causing the 'older' fan trims and the 'older' gravel sheets along the upper Waimakariri River.

Conclusion

Results from this preliminary investigation of geomorphic evidence for high magnitude floods along the upper Waimakariri River suggest that two floods of greater magnitude than the 100-year 1957 event have occurred over the last ca. 300 years. Further dendrochronological research would enable the ages of the gravel sheets and erosion scarps to be determined with more precision. Better age controls may clarify which of the ungauged historical floods was larger than the 1957 event, and provide more conclusive correlations between the evidence for an earlier and substantially larger flood. There is considerable scope for further investigation of the geomorphic, botanical and historical evidence for past floods along the Waimakariri River.

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