Episodic sediment pulses generated by forested flood plain stripping: Bruces Creek, Nadgee State Forest, southeastern Australia

ASHLEY A. WEBB[1] & D. DRAGOVICH[2]

1 *State Forests of New South Wales, Research & Development Division, PO Box J19, Coffs Harbour Jetty, NSW 2450, Australia*
ashleyw@sf.nsw.gov.au

2 *Division of Geography F09, University of Sydney, NSW 2006, Australia*

Abstract Sedimentological, stratigraphic and radiocarbon analyses of flood plain sediment indicate that flood plain pockets of Bruces Creek, a sand-bed forest stream, were completely removed by a catastrophic flood around 1000 years BP. The present flood plain redeveloped by lateral migration prior to 575 years BP and was colonised by an emergent *Eucalyptus* forest and *Tristaniopsis laurina* (Water Gum) trees. Since 300 years BP, channel stability has been controlled by riparian vegetation and large woody debris (LWD), as indicated by obliquely accreted fine-grained sediment deposits on the channel banks. This work indicates that sediment transfer through small sand-bed forest systems is minimal during extended periods of vegetation-controlled channel and flood plain stability. However, episodic high-energy catastrophic floods can exceed thresholds of channel stability, totally destroy alluvial landforms and the flood plain forest, and result in the delivery of massive pulses of sediment to the channel.

Key words catastrophic erosion; catastrophic floods; flood plain stripping; riparian vegetation; sediment transfer; southeastern Australia

INTRODUCTION

Sediment transfer through small, forested drainage basins in southeastern Australia depends largely upon the relative influences of erosion by rainfall and flood events, and stabilization by vegetation. Recent Australian research has investigated the relative roles of high magnitude floods and natural riparian vegetation in controlling sediment stability at the channel and flood plain scale. On Wheeny Creek, a high energy bedrock-confined stream, Webb *et al.* (2002) found that vegetation and large woody debris (LWD) played a minor short-term (10^0 years) role in small-scale island and in-channel bench formation. However, in the longer term (10^1–10^3 years) it was concluded that the formation and destruction of fluvial landforms, and therefore the transfer and deposition of sediment, was flood-driven and flood-dominated (Webb *et al.*, 2002). In contrast, research on less confined and lower energy forest streams in southeastern Australia, such as Tonghi Creek (Webb, 2002; Webb & Erskine, 2003) and Thurra River (Brooks *et al.*, 2003), has demonstrated that channel and flood plain sediment storage can be controlled in the longer term by riparian vegetation. Webb & Erskine (2003), however, acknowledge that extreme floods have been responsible for the creation of alluvial cut-offs on Tonghi Creek around 400 years BP and for forested flood plain stripping around 1000 years BP.

The aim of this paper is to investigate the relative roles of riparian vegetation (and LWD) and extreme floods in controlling the late Holocene channel and flood plain stability of Bruces Creek, a partially bedrock- and terrace-confined forest stream, and to determine the consequences for sediment dynamics in such environments.

Study site

Bruces Creek is a 79 km^2 left bank tributary of the Wallagaraugh River, located in the southeast of New South Wales, Australia (Fig. 1) where mean annual rainfall is 975 mm. Drainage basin geology is dominated by Devonian granitoids of the Bega Batholith, Ordovician Adaminaby Group metasediments and Tertiary fluvial sediments. The study reach is 310 m long and is located in a riparian reserve in Nadgee State Forest where the drainage basin area is 68 km^2. In the study reach, Bruces Creek is a sand-bed stream that is continuously flanked by large but discontinuous pockets of flood plain (Webb, 2002). It is a medium energy stream with a mean bankfull specific stream power of 20.7 ± 1.9 Wm^{-2} (mean ± 2 standard errors). Regional flood frequency analyses indicate that bankfull discharge (22.7 ± 4.7 m^3 s^{-1}) has a return period of between 1.5 and 1.8 years on the annual maximum flood series and is approximately equal to the mean annual flood (23.6 m^3 s^{-1}) (Webb, 2002).

Riparian vegetation at Bruces Creek exhibits a distinct vertical zonation of species from the streambed to the flood plain. Shallow sections of the bed (riffles, runs and backwaters) are dominated by the macrophyte *Triglochin procerum* with occasional *Tristaniopsis laurina* (Water Gum), whereas pools are essentially free of vegetation, except for *T. laurina* attached

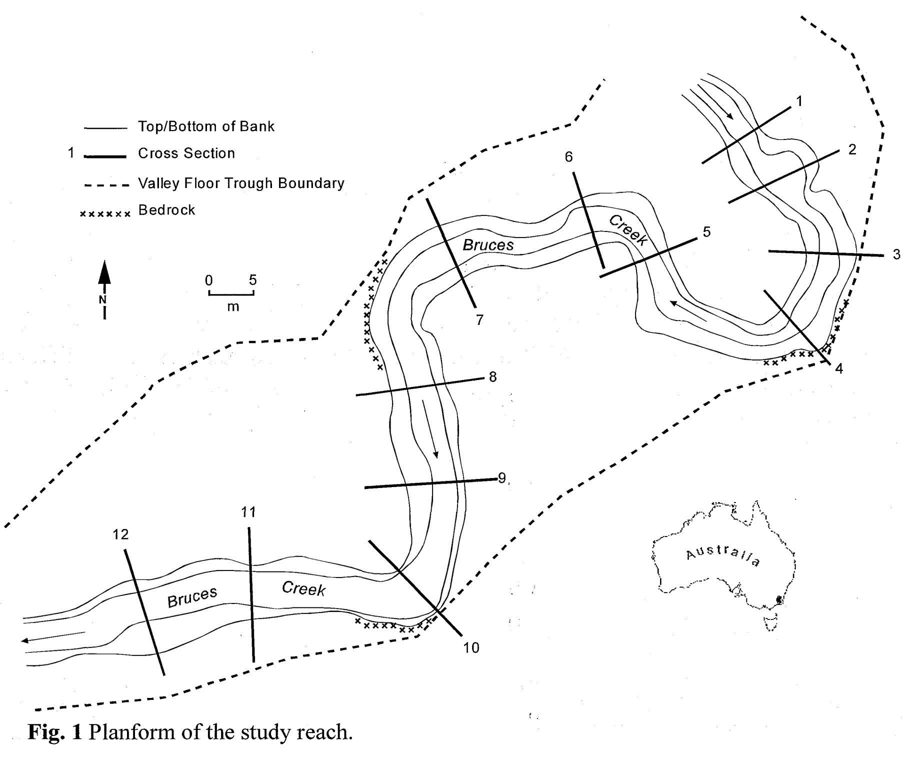

Fig. 1 Planform of the study reach.

to the lower stream bank. The bank vegetation is dominated by large *T. laurina* trees (up to 1.05 m diameter at breast height over bark—DBHOB) but also includes *Acacia mearnsii* and *Pittosporum undulatum* trees. Flood plain vegetation varies laterally away from the stream. *Tristaniopsis laurina* trees dominate next to the channel in association with species such as *A. mearnsii*, *P. undulatum* and *Babingtonia pluriflora*. Emergent trees occur on higher parts of the flood plain away from the immediate stream bank and include *Eucalyptus cypellocarpa* (maximum DBHOB 1.45 m), *E. elata*, *E. muelleriana* and *Angophora floribunda*. Further away from the channel banks on the slightly elevated remnant river terraces and footslopes, the density of riparian vegetation species declines while more sclerophyllous vegetation species become more dominant. The overstorey is dominated by eucalypts such as *E. muelleriana* and *E. cypellocarpa* along with hillslope species such as *Allocasuarina littoralis*.

Webb (2002) conducted a complete census of large woody debris (LWD) in the bed of the study reach. A total of 437 pieces of LWD was recorded at a mean density of 141 pieces per 100 m. The total loading of LWD was 751 m^3 ha^{-1}. Both the loading and density are very high and plot close to the envelope curve for world rivers of similar catchment area (Gippel, 1995). The majority of LWD pieces are small (diameters 0.1–0.3 m). Despite being less abundant, medium size pieces (diameters 0.3–0.7 m) contribute the majority of the total LWD volume in Bruces Creek (Webb, 2002). *Tristaniopsis laurina* trees that grow within the channel banks contribute 16.9% of the total LWD volume in the study reach. Webb (2002) also found a high density of log-steps and debris dams in the study reach. Free-fall over log-steps accounted for 56% of the total head loss, and as a result of high bed roughness up to 3300 m^3 of sand are stored in the bed of the study reach (Webb, 2002).

METHODS

To establish the late Holocene chronology of erosional and depositional events at Bruces Creek, a sub-reach of the study site was selected for detailed investigation. This sub-reach comprised three pockets of flood plain that occur in the most upstream 130 m of the study reach at cross-sections 1–5 (Fig. 2). A combination of pits, trenches and auger holes was excavated. The sediments were described in the field (after Northcote, 1979) and representative samples subjected to particle size analyses in the laboratory to determine the flood plain stratigraphy and sedimentology. A total of 15 charcoal samples was collected for radiocarbon dating using the AMS method in order to establish ages for different landforms and erosional and depositional events. These data were combined with the biogeomorphic evidence presented above (after Webb, 2002) to reconstruct a chronology of late Holocene channel and flood plain evolution in the study reach.

Flood plain and bench stratigraphy

Pockets of flood plain have developed between the bedrock valley sides and river terrace remnants. The Pleistocene river terraces are characterized by a well-developed duplex soil comprising a loamy sand to loam fine sandy A_1 horizon with a bleached A_2 horizon overlying a mottled sandy medium clay to heavy clay B horizon (Fig. 3). The flood plain at

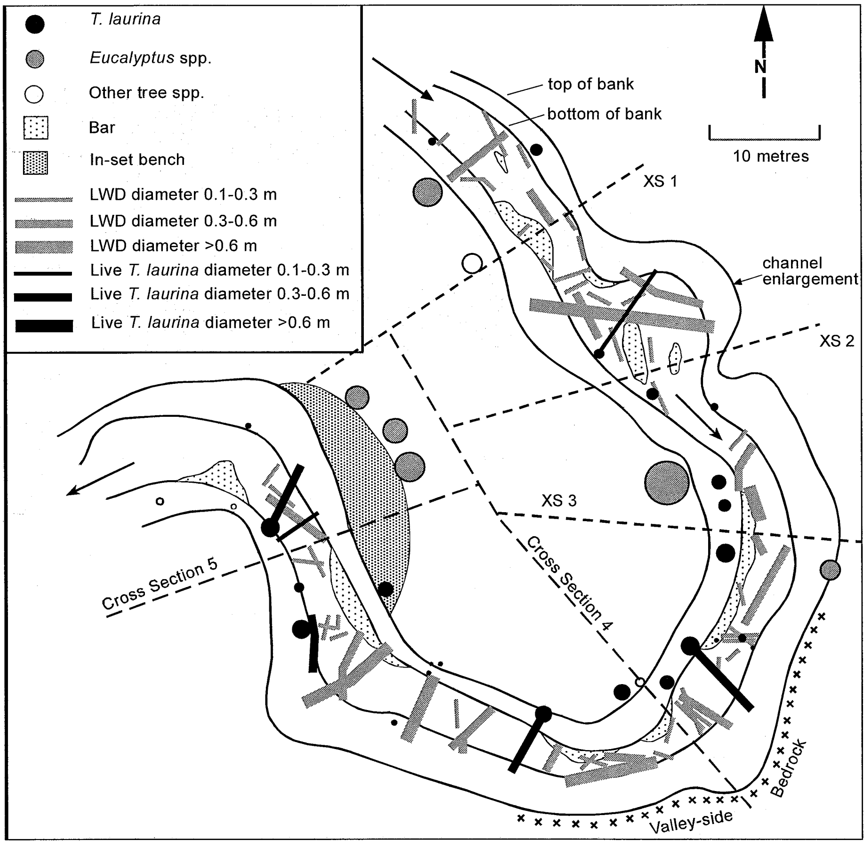

Fig. 2 Location of trees and large woody debris in a sub-reach of Bruces Creek. Circles represent tree diameters at breast height exaggerated by a factor of two.

cross-section 4 (Fig. 3(a)) comprises a series of coalescing point bar deposits that fine upwards from coarse sand to sandy loam. These sediments dip towards the channel and indicate that the dominant process of flood plain formation has been by lateral point bar accretion. They overlie a much coarser basal unit of slightly gravely coarse sand, and are capped by overbank deposits that fine laterally away from the channel (Fig. 3(a)). A unit of fine sandy loam has been plastered on the channel banks by the process of oblique accretion (Pickup & Warner, 1976) (Fig. 3(a)). These deposits have been induced by high roughness created by bank vegetation and LWD in the channel. Such deposition was observed in the field following a bankfull flood in April 2001. An inset bench has developed on the right bank of cross-section 5 and comprises a fining upwards sequence from coarse sand to fine sandy loam, overlying the basal unit of slightly gravely coarse sand (Fig. 3(b)).

Late Holocene chronology and formation of Bruces Creek

The five dates obtained from the stripped basal facies at cross-section 4 (Fig. 3(a)) do not become older with depth or with increasing distance from the present channel. The irregular

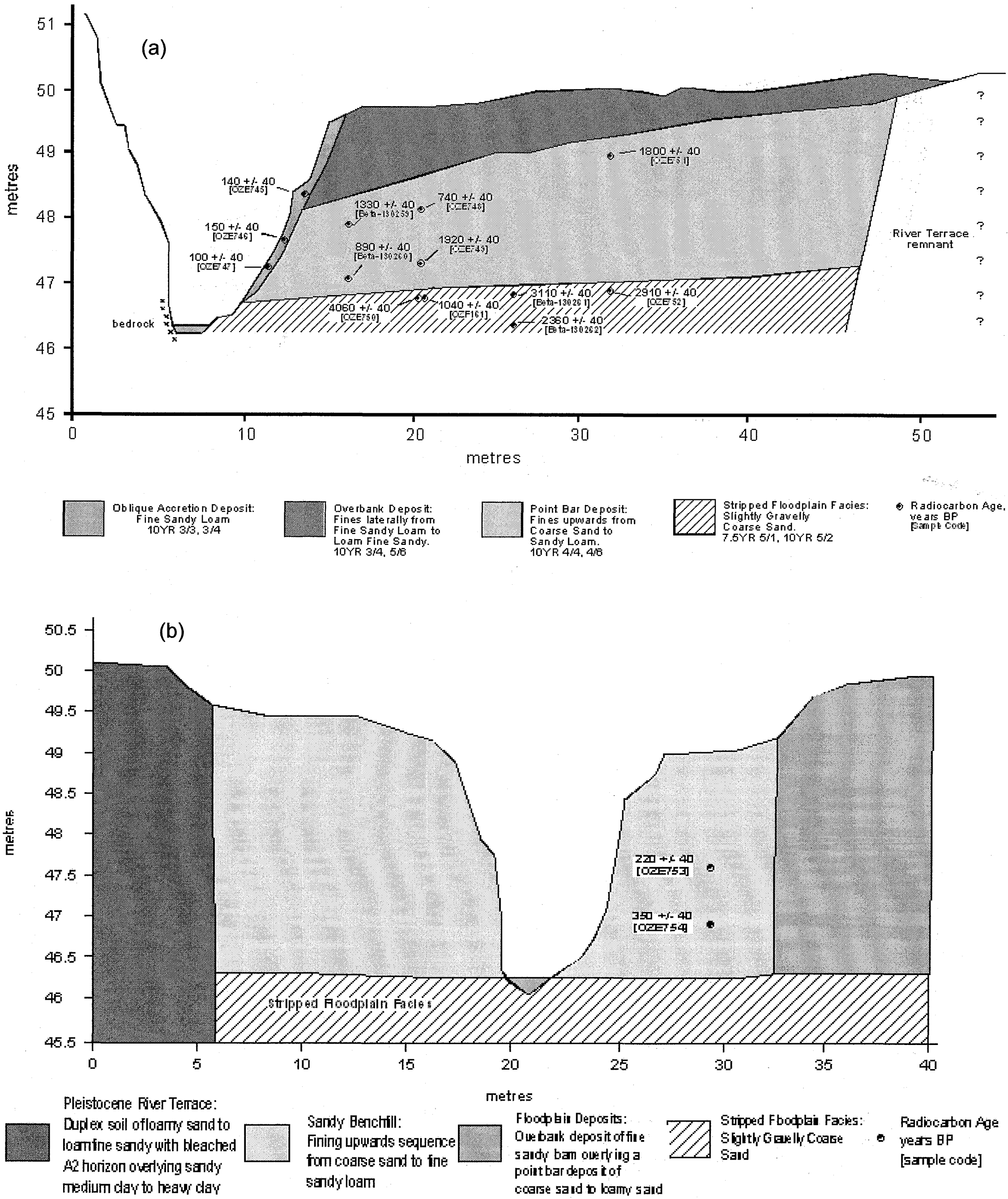

Fig. 3 (a) Flood plain stratigraphy at cross-section 4, and (b) flood plain and inset bench stratigraphy at cross-section 5.

age distribution of the dates, along with the coarse textured sediments, indicate reworking of the flood plain sediments and incorporation of older charcoal during substantial channel widening and flood plain stripping. It is plausible that a single catastrophic flood or a series of such events in rapid succession could effect large-scale flood plain erosion. The two adjacent charcoal samples from the stripped basal facies at cross-section 4 with an age difference of approximately 3000 radiocarbon years strongly supports substantial reworking of flood plain sediments. The age difference cannot simply be explained by sample size/mass (Blong & Gillespie, 1978), as the younger sample (OZF161) was in fact larger in diameter and mass than the other sample (OZE750) (Webb, 2002).

During catastrophic events, large pockets of flood plain can be completely removed (Nanson, 1986; Webb *et al.*, 2002) and the eroded sediment is often deposited in the channel and reworked downstream as a sediment slug or bed load wave (Erskine, 1994). Therefore, it is expected that a number of the charcoal samples dated from the coarse stripped flood plain facies would have been reworked from flood plain pockets located upstream of the study site. In this case, the youngest date is important for interpreting the timing of flood plain stripping. Given that the youngest sample has a radiocarbon age of 1040 ± 40 years BP, it is likely that the catastrophic event, or series of events, occurred no earlier than this time. The date, when calibrated to calendar years using the curve of Stuiver *et al.* (1998) yields a 2-sigma (95% probability) range of between 805 and 1050 years BP.

Five samples were dated from the laterally accreted coalescing point bar deposits at cross-section 4 (Fig. 3(a)) and although the AMS dates generally become younger closer to the channel, at least one date (Beta-130259) is older than the date obtained for charcoal located beneath it in the profile. As much of the material eroded during the catastrophic event(s) would have been subsequently reworked downstream, the arrangement of dates in the point bar deposits is expected. The dates suggest that following the catastrophic erosion of flood plain pockets around 1000 years BP, a new flood plain developed by lateral migration in the remaining void between the river terrace remnant and the bedrock valley side. Given the 2-sigma calibration (Stuiver *et al.*, 1998) of the youngest dates in the lateral accretion deposit (Fig. 3(a)), it is suggested that the flood plain formed approximately 1000 to 575 years BP.

Following the development of the present flood plain, *T. laurina* trees and associated riparian vegetation species colonized the channel banks. The presence of oblique accretion deposits suggests that the contemporary channel banks are relatively stable (Pickup & Warner, 1976). Calibration of the three dates obtained on charcoal excavated from the oblique accretion deposits (Fig. 3(a)) to calendar years (Stuiver *et al.*, 1998) suggests that the earliest time the banks became stable due to the influence of vegetation was 290 years BP. Thereafter, recruitment of LWD to the channel began after the trees reached maturity. The oldest radiocarbon date obtained from contemporary in-channel LWD was 160 ± 50 years BP (Webb, 2002). This date corresponds closely with the dates obtained for the oblique accretion deposits, supporting the hypothesis that channel and flood plain stability have only recently (10^2 years) been effected by riparian vegetation and associated LWD. Further evidence of recent vegetation colonization and LWD recruitment is provided by the fact that no LWD was found buried in the flood plain or bench sediments excavated at any of the cross-sections. Given that regional evidence indicates there have been no major changes in vegetation communities during the late Holocene (Kershaw *et al.*, 1991; Dodson, 1994), it is plausible that prior to catastrophic stripping, the former flood plain was forested. In this case, the lack of LWD buried in the flood plain supports the hypothesis that around 1000 years BP, the alluvial trough, including the flood plain, the flood plain forest and associated LWD, was cleaned out during a catastrophic flood or series of such events.

Since the channel was stabilized minor lateral channel adjustments have occurred. For example, channel widening has occurred at cross-section 2 (Fig. 2) where a very large debris dam has been outflanked and the channel locally enlarged by 100%. It is assumed that such localized channel expansions remain until the debris dam decays or is completely removed by a large flood. Inset benches then develop in the expansion. The inset bench at cross-section 5 (Fig. 3(b)) is likely to have been formed by this process. The radiocarbon dates obtained for charcoal incorporated in the sandy benchfill, when calibrated to calendar years (Stuiver *et al.*, 1998), suggest that the nucleus phase of bench formation began no earlier than 505 years BP. Given that Erskine & Livingstone (1999) demonstrated that in-channel benches are periodically reworked by floods, and that the two calibrated dates obtained in the bench are overlapping, it is likely that the bench formed around 300 years BP. Thus, channel adjustment at cross-section 5 occurred around the same time or just before vegetation-induced oblique accretion deposits were first deposited at cross-section 4.

CONCLUSIONS

In recent times (10^2 years) riparian vegetation and large woody debris have exerted a significant influence on channel and flood plain stability at Bruces Creek. Riparian trees, predominantly *T. laurina*, have been effective in binding the highly mobile sandy boundary sediments. The trees, along with a dense cover of shrubs and ground storey plants, have created high bank roughness that has induced the deposition of fine sandy sediments by oblique accretion. Recruitment of LWD to the channel has resulted in the formation of a large number of debris dams and log-steps, which dissipate considerable stream energy and therefore contribute to channel stability by reducing the competence of floods to erode the channel boundary. The high roughness in the channel created by LWD, furthermore, has induced the deposition and storage of large volumes of sand within the streambed. Apart from minor channel adjustments on a scale of hundreds of years (10^2 years), the majority of biogeomorphic evidence suggests that in partially confined, medium energy streams, such as Bruces Creek, short term channel and flood plain stability is controlled by riparian vegetation and associated LWD (Webb, 2002). However, the stratigraphic and radiocarbon evidence demonstrates that this is not the case in the long term. Catastrophic floods, like the one that occurred on Bruces Creek around 1000 years BP, are capable of exceeding thresholds of channel stability, totally destroying all alluvial landforms and completely removing the flood plain forest (Webb *et al.*, 2002; Erskine & Peacock, 2002). The results of this work indicate that sediment transfer through small sand-bed forest systems is minimal during the extended periods of channel and flood plain stability effected by riparian vegetation and LWD. However, episodic high-energy catastrophic floods can exceed thresholds of channel stability and result in the delivery of massive pulses of sediment to the channel.

Acknowledgements This research was funded by an Australian Postgraduate Award research scholarship, State Forests of NSW and two Australian Institute of Nuclear Science and Engineering grants. The authors are grateful for help provided by Wayne Erskine, Norm Webb, Natalie Marshall, Graham Lloyd and Chris Myers, with various aspects of this work.

REFERENCES

Brooks A. P., Brierley, G. J. & Millar, R. G. (2003) The long-term control of vegetation and woody debris on channel and floodplain evolution: insights from a paired catchment study in southeastern Australia. *Geomorphology* **51**, 7–29.

Blong, R. J. & Gillespie, R. (1978) Fluvially transported charcoal gives erroneous ^{14}C ages for recent deposits. *Nature* **271**, 739–741.

Dodson, J. R. (1994) Quaternary vegetation history. In: *Australian Vegetation* (ed. by R. H. Groves), 37–53. Cambridge University Press, London, UK.

Erskine, W. D. (1994) Sand slugs generated by catastrophic floods on the Goulburn River, New South Wales. In: *Variability in Stream Erosion and Sediment Transport* (ed. by L. J. Olive, R. J. Loughran & J. A. Kesby) (Proc. Symp., Canberra, December 1994), 143–151. IAHS Publ. 224. IAHS Press, Wallingford, UK.

Erskine, W. D. & Livingstone, E. A. (1999) In-channel benches: the role of floods in their formation and destruction on bedrock-confined rivers. In: *Varieties of Fluvial Forms* (ed. by A. Miller & A. Gupta), 445–475. John Wiley & Sons, Chichester, UK.

Erskine, W. D. & Peacock, C. T. (2002) Late Holocene floodplain development following a cataclysmic flood. In: *The Structure, Function and Management Implications of Fluvial Sedimentary Systems* (ed. by F. J. Dyer, M. C. Thoms & J. M. Olley) (Proc. Alice Springs Symp., September 2002), 177–184. IAHS Publ. 276. IAHS Press, Wallingford, UK.

Gippel, C. J. (1995) Environmental hydraulics of large woody debris in streams and rivers. *J. Environ. Engng* **121**, 388–395.

Kershaw, A. P., D'Costa, D. M., McEwen Mason, J. R. C. & Wagstaff, B. E. (1991) Palynological evidence for quaternary vegetation and environments of mainland southeastern Australia. *Quatern. Sci. Rev.* **10**, 391–404.

Nanson, G. C. (1986) Episodes of vertical accretion and catastrophic stripping: a model of disequilibrium flood-plain development. *Geol. Soc. Am. Bull.* **97**, 1467–1475.

Northcote, K. H. (1979) *A Factual Key for the Recognition of Australian Soils*. Rellim Technical Publications, Coffs Harbour, Australia.

Pickup, G. & Warner, R. F. (1976) Effects of hydrologic regime on magnitude and frequency of dominant discharge. *J. Hydrol.* **29**, 51–75.

Stuiver, M., Reimer, P. J., Bard, E., Beck, J. W., Burr, G. S., Hughen, K. A., Kromer, B., McCormac, J., Van der Plicht, J. & Spurk, M. (1998) Intcal 98 Radiocarbon age calibration, 24,000–0 cal BP. *Radiocarbon* **40**(3), 1041–1083.

Webb, A. A. (2002) Episodic erosion, riparian vegetation colonisation and the late Holocene stability of sand-bed, forest streams in southeastern Australia. PhD Thesis, University of Sydney, Australia.

Webb, A. A., Erskine, W. D. & Dragovich, D. (2002) Flood-driven formation and destruction of a forested floodplain and in-channel benches on a bedrock-confined stream: Wheeny Creek, southeast Australia. In: *The Structure, Function and Management Implications of Fluvial Sedimentary Systems* (ed. by F. J. Dyer, M. C. Thoms & J. M. Olley) (Proc. Alice Springs Symp., September 2002) 203–210. IAHS Publ. 276. IAHS Press, Wallingford, UK.

Webb, A. A. & Erskine, W. D. (2003) Distribution, recruitment, and geomorphic significance of large woody debris in an alluvial forest stream: Tonghi Creek, southeastern Australia. *Geomorphology* **51**, 109-126.