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Late Holocene flood plain development following a cataclysmic flood

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Abstract Wollombi Brook in southeastern Australia is one of the most flood variable rivers in the world and was subjected to a catastrophic flood on 17–18 June 1949. At Paynes Crossing (1064 km^2), the flood peak discharge determined by the HEC-2 backwater model was ~22 times > mean annual flood. While this flood destroyed in-channel benches, it deposited up to 500 mm of slackwater deposits (SWDs) on a low flood plain inset into a high flood plain which was not inundated. Slackwater deposits preserved on the high flood plain record at least three late Holocene palaeofloods with peak discharges, estimated by the HEC-2 program calibrated against the 1949 flood data, up to ~32 times greater than the mean annual flood. Such events have been recorded in similar sized basins in New South Wales (NSW). However, at least one even larger flood occurred between 4280 and 3380 years BP which severely eroded most of the high flood plain. This cataclysmic late Holocene flood greatly exceeded the erosional effects of the catastrophic 1949 flood.

Key words catastrophic flood; cataclysmic flood; slackwater deposits; palaeoflood

INTRODUCTION

A catastrophic flood, with a peak discharge ~27 times greater than the mean annual flood at the most downstream gauging station at Warkworth, occurred between 17 and 18 June 1949 on Wollombi Brook in southeastern Australia following up to 508 mm of rainfall over the 2000 km^2 basin (Fig. 1). Erskine (1994; 1996) and Erskine & Saynor (1996) outlined in detail the hydrology of this flood and its geomorphic effects. Eighteen events greater than the mean annual flood were recorded between 1949 and 1956 on Wollombi Brook which has exceptionally high flood variability on a global scale. River response to this extraordinary flood sequence was spatially variable, being controlled by the degree of lateral channel confinement by materials of limited erodibility. In the middle reaches where the channel is closely confined by resistant quartz sandstone, Wollombi Brook widened by up to 100% due to erosion of in-channel benches and flood plain, the bed aggraded by up to 4 m and sand splays up to 2 m deep were deposited on a low flood plain. While the 1949 flood has been adopted as the designated flood for flood plain management purposes, a series of much larger events occurred during the late Holocene (see below for details).

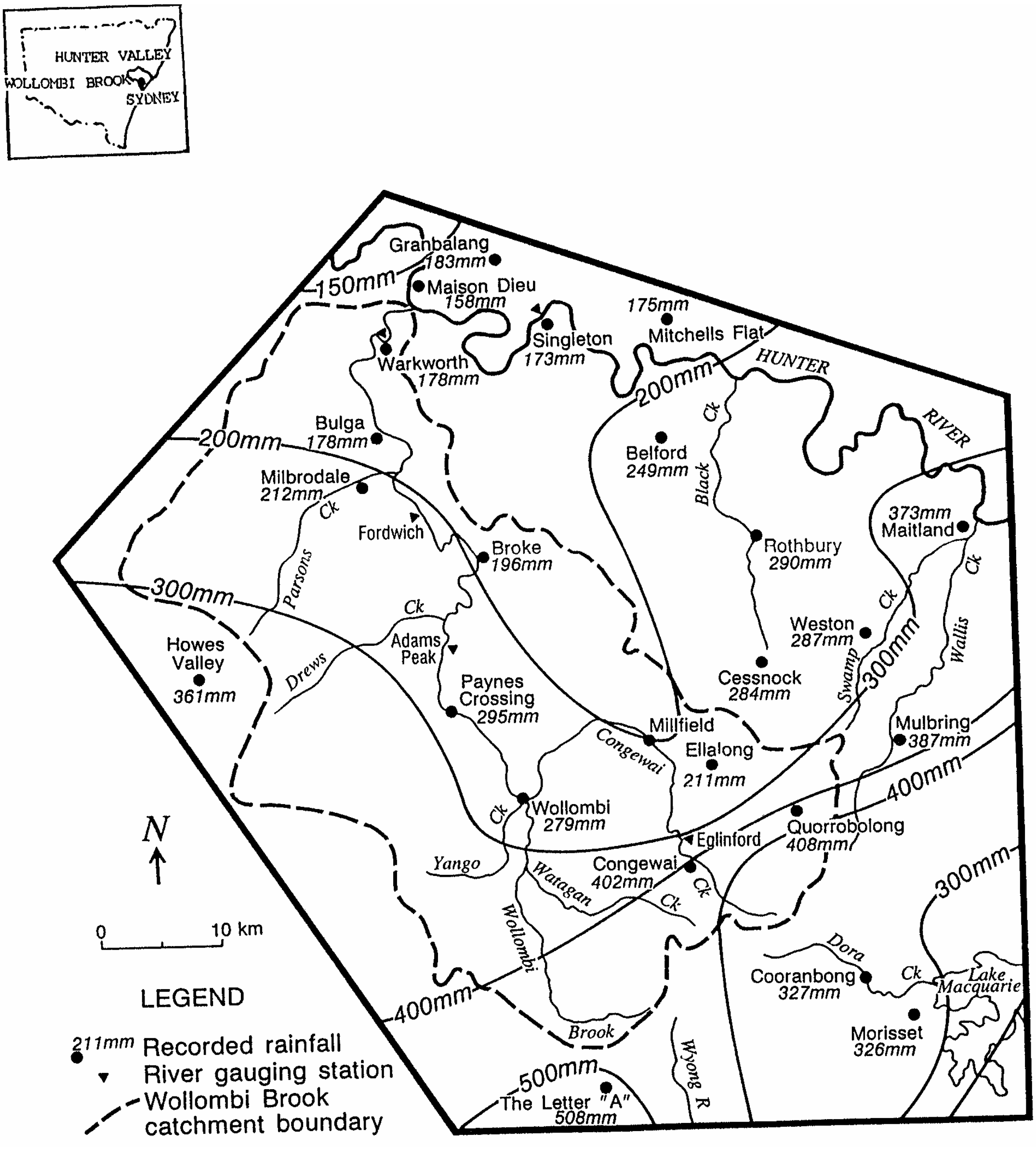

Fig. 1 Wollombi Brook drainage basin showing the isohyets for 17–18 June 1949.

Slackwater deposits are typically fine-grained sand and silt, which accumulate rapidly from suspension during major floods in protected areas where current velocities are locally reduced (Baker *et al.*, 1983; Baker, 1987). They are important indicators of the minimum height of large palaeofloods (Baker *et al.*, 1983) and can be used to estimate the peak discharge of the formative flood when there is no change in channel geometry over millennia (Baker, 1987). For this reason, bedrock-confined channels and gorges must be used for palaeoflood hydrology.

The aims of this paper are to present new data on the magnitude of the 1949 flood on Wollombi Brook at Paynes Crossing, to determine the mid to late Holocene palaeoflood history from the slackwater deposits (SWDs) record and to reconstruct the resultant palaeoflood impacts on flood plain erosion and deposition from the valley-fill lithostratigraphy and chronology.

1949 FLOOD AT PAYNES CROSSING

Reconnaissance investigations of SWD sites on Congewai Creek and Wollombi Brook in the bedrock (sandstone)-confined reach found that the highest, best preserved SWDs were located in a 6.75 km section of channel at Paynes Crossing (basin area of 1064 km^2). Only the lower 2.95 km were used for palaeoflood discharge calculations to avoid unnecessary complications due to inflows from large tributaries. The Paynes Crossing gauging stations 1a, 1b and 2 are located in the downstream study section. The Brickman family has owned the land since about 1829 and the oldest family member interviewed for this study lived there since 1897. Mr L. Brickman was the gauge reader during the June 1949 flood and provided detailed flood height information. Although the 1949 flood did not inundate the high flood plain, the high level SWDs exhibit minimal pedogenesis which indicates a young age, as corroborated by radiocarbon dating of transported charcoal (see below).

The June 1949 flood peak height at Paynes Crossing gauge 1b was surveyed by Bernard (1950) as 11.4 m. The slope–area method was then used to estimate the 1949 flood peak discharge as 3900 m^3 s^{-1}. Hydrodynamic modelling is used below to refine this estimate. At-a-station flood frequency analysis could not be used to estimate the return period of the 1949 flood because the Paynes Crossing discharge record is of very poor quality. Furthermore, regional flood frequency methods developed for the area only defined floods up to a return period of 1:100 years. The estimated 1949 flood peak discharge greatly exceeded this event and was nearly 20 times greater than the estimated mean annual flood.

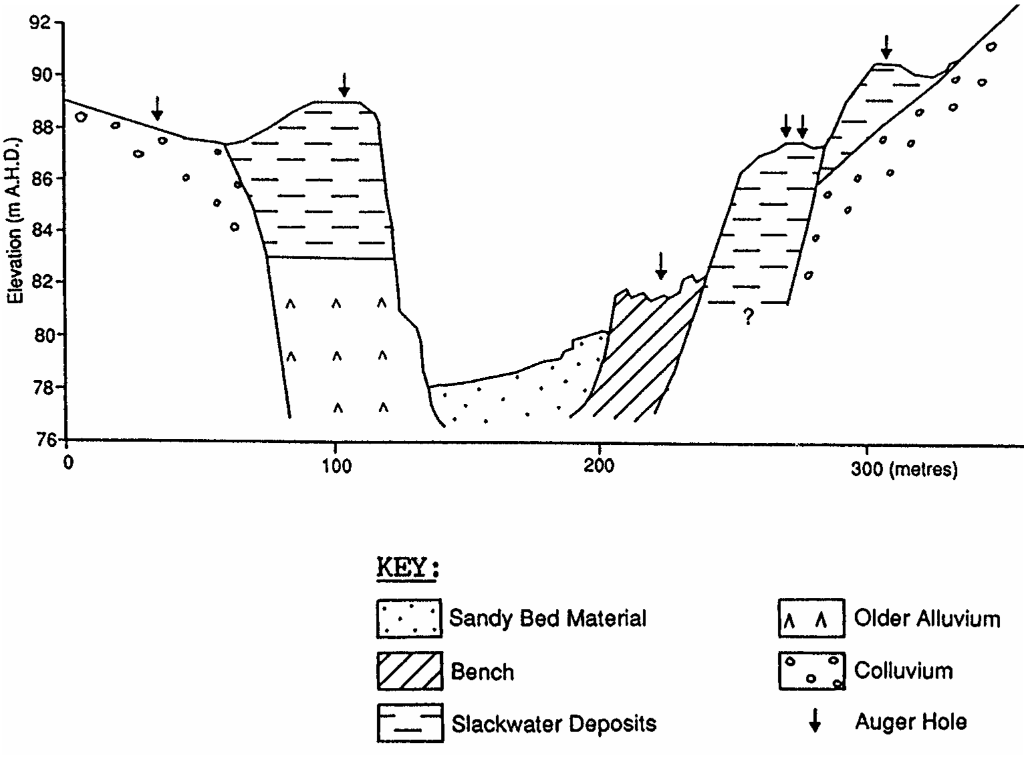

Fig. 2 Valley-fill sediments on Wollombi Brook at Paynes Crossing.

CHANNEL AND FLOOD PLAIN MORPHOLOGY

Wollombi Brook at Paynes Crossing is a 50-m-wide, sand-bed stream with ephemeral scour pools on abrupt-angle bedrock bends. It has a large bankfull channel capacity (>50 years on annual maximum series) but there are usually three, ephemeral, in-channel benches below the main valley flat (Erskine, 1994, 1996; Erskine & Livingstone, 1999). The channel flows down the centre of a sinuous bedrock valley whose alignment is strongly joint-controlled.

Two discontinuous, vertically accreted flood plains (low and high flood plain) are present in valley expansions or as valley margin deposits on the inside of valley bends where the channel alternates from one valley side to the other between bedrock valley meanders. The low flood plain is discontinuous, unpaired and inset into the high, discontinuous, often paired flood plain (Fig. 2). Both flood plains exhibit a natural levee–backslope–backswamp morphology (Fig. 2). Flood plain relief is modest with backswamps between 1.5 and 2.5 m below levee crests which are generally flat-topped and 10–40 m wide. Backswamps of the low flood plain abut against the high flood plain whereas backswamps of the high flood plain merge with colluvium (Fig. 2).

VALLEY-FILL LITHOSTRATIGRAPHY

The valley floor is often cut entirely through Triassic quartz sandstone and interbedded shale. In localized expansions, eroded remnants of Page's (1972) older alluvium (iron cemented, reddish brown, sands and clays) often underlie the low and high flood plains (Fig. 2). Older alluvium was deposited between at least 8980 and 4280 years BP (Table 1) but was then severely eroded before the high and low flood plains formed. The flood plains are largely composed of sandy SWDs which disconformably overlie the older alluvium and either onlap, or are disconformably inset into, gravelly sand colluvium (Fig. 2). The high flood plain was deposited between at least 3380 and 1300 years BP (Table 1). The low flood plain is disconformably inset into the high flood plain (Fig. 2) and was extensively reworked by the 1949 flood. In-channel benches exhibit the stratic and massive sediments of Erskine & Livingstone (1999) and are disconformably inset into the low flood plain or older alluvium (Fig. 2). They were extensively eroded by the 1949 flood but are rapidly constructed by subsequent smaller floods in the erosional void excavated by the catastrophic event (Erskine, 1994, 1996; Erskine & Livingstone, 1999).

Table 1 Radiocarbon dates for the Wollombi Brook valley-fill sediments near Paynes Crossing.

Lithostratigraphic unit	Age (years BP ± 1 σ)	Laboratory number	Source
Older alluvium	8980 ± 60	GaK-3264	Page (1972)
Older alluvium	5200 ± 90	GaK-3265	Page (1972)
Older alluvium	4280 ± 120	GaK-2722	Hickin & Page (1971)
High flood plain SWD: Palaeoflood 3	3380 ± 90: Maximum age	Beta-32134	This study
High flood plain SWD: Palaeoflood 3	1890 ± 60: Minimum age	Beta-39465	This study
High flood plain SWD: Palaeoflood 2	1300 ± 70: Maximum age	Beta-39464	This study

SLACKWATER DEPOSITS

A total of 11 sites on the low and high flood plains at Paynes Crossing were investigated in detail because the best palaeoflood record and most accurate palaeoflood stages are obtained when SWDs are correlated between multiple sites (Baker *et al.*, 1983; Baker, 1987). Detailed particle size analysis showed that the SWDs (*n* = 88) are poorly to very poorly sorted, strongly fine skewed, very leptokurtic, coarse silt to medium sand. In contrast, the channel bed-material in the same reach (*n* = 21) is moderately well sorted, coarse skewed, leptokurtic, fine to coarse sand. This indicates that SWDs consist of finer sand with greater mud content than the bed sediments. Slackwater deposits deposited by the 1949 flood on the low flood plain (*n* = 53) are more positively skewed, more poorly sorted and finer than the SWDs of the high flood plain (*n* = 35). This unusual result indicates that the palaeofloods that emplaced the SWDs on the high flood plain were much larger and more turbulent than the 1949 flood because suspended sediment usually becomes finer with increasing elevation above the river bed.

Slackwater deposits laid down by the 1949 flood on the low flood plain were between 50 and 500 mm thick, depending on elevation, and buried a dark, finer textured layer that contained an Aboriginal hearth and stone artefacts, and European artefacts. The flood peak profile of the 1949 flood in the study reach was surveyed on the basis of multiple points indicated by the gauge reader who actually pegged the points during the event for the gauging authority. Slackwater deposits were laid down and preserved to within 0.42 m of the 1949 flood peak height.

Slackwater deposits for individual palaeofloods that inundated the high flood plain varied in thickness from 200 to 600 mm, depending on site hydraulics and depth of inundation. Slackwater deposits on the low and high flood plain exhibited normally graded beds and fining-upwards sequences, which were better developed on the high flood plain. Four palaeoflood deposits are preserved in the upper 1 m of the high flood plain although all palaeoflood deposits are not present at each site (for example, see XS 10 in Fig. 3). Slackwater deposits on the natural levee crest are conformable and contiguous with those on the levee–backslope–backswamp (Fig. 3). Each bed fines laterally away from the channel with the jagged lines in Fig. 3 denoting the location of these lateral grain-size changes within a bed. Clearly the levee–backswamp morphology has formed by overbank deposition and not by flood scour. The highest preserved SWDs were for palaeoflood 1 (91.64 m AHD) (AHD = Australian Height Datum) followed by palaeoflood 3 (91.32 m AHD) and palaeoflood 2 (90.35 m AHD). These levels refer to the same cross-section (XS 5) that is not shown in Figs 2 and 3. The SWDs for palaeoflood 3 contained numerous Aboriginal hearths and stone artefacts.

Palaeoflood 3 occurred between 3380 ± 90 years BP (palaeoflood-deposited charcoal) and 1890 ± 60 years BP (charcoal from an Aboriginal hearth excavated into the SWDs) (Table 1). Saynor & Erskine (1993) used tandem accelerator mass spectrometry to date charcoal deposited by a very large palaeoflood on the nearby Nepean River at 3756 ± 72 years BP. This event may be synchronous with palaeoflood 3. Palaeoflood 2 occurred after 1300 ± 70 years BP (palaeoflood-deposited charcoal) (Table 1) while palaeoflood 1 occurred after palaeoflood 2 but before European settlement in the late 1820s.

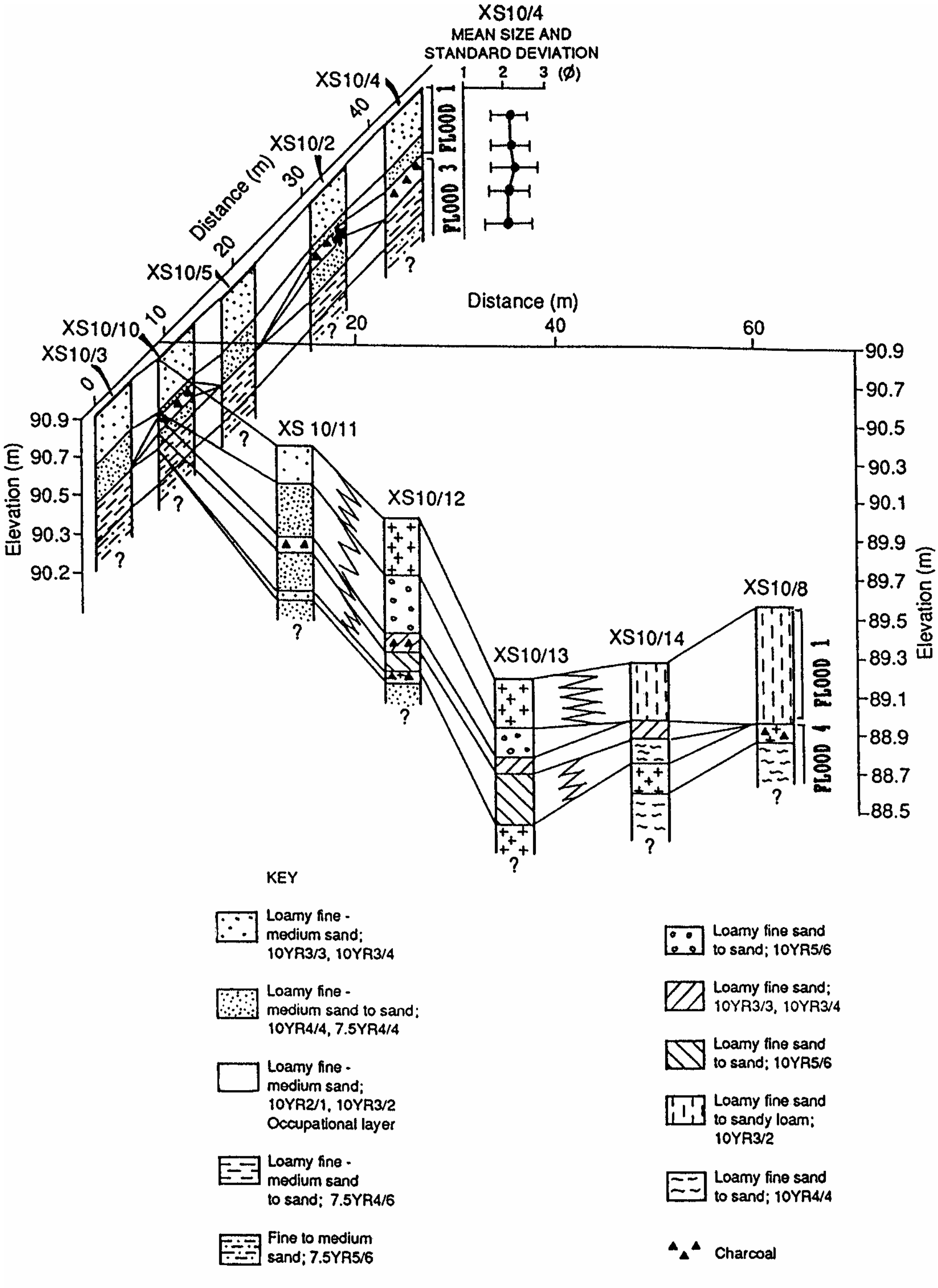

Fig. 3 Detailed three-dimensional SWD sedimentology of the high flood plain at the downstream cross-section (XS 10). Profiles 10/3, 10/10, 10/5, 10/2 and 10/4 are located along the levee crest and the other profiles extend across the backslope and backswamp on the cross-section. There are often multiple beds for each palaeoflood.

PALAEOFLOOD DISCHARGES

HEC-2, a one-dimensional, standard step, backwater model, calculates an energy balanced water surface profile for a range of discharges with subcritical, supercritical or mixed flow regimes using a number of surveyed cross-sections and a rating curve for the starting cross-section (Hydrologic Engineering Centre, 1982). It models channel sinuosity, variable roughness coefficients at and between cross-sections, and contractions and expansions. All sections in the 2.95-km study reach and SWDs were surveyed into Australian Height Datum from permanent benchmarks.

The surveyed water surface profile for the 1949 flood at Paynes Crossing was used to calibrate the HEC-2 model. Estimated peak discharge for the 1949 flood is 4400 $m^3 s^{-1}$ (~22 times greater than the mean annual flood) and the highest SWDs correspond to a peak discharge of 3950 $m^3 s^{-1}$. The HEC-2 peak discharge estimate is greater and more reliable than that obtained above by the slope–area method. Slackwater deposits underestimate the actual flood peak discharge by 9%. Estimated maximum mean flow velocities at the flood peak by HEC-2 range from 2.68 to 4.83 m s^{-1}. At gauging station 1b, the HEC-2 estimated maximum mean flow velocity is 4.4 m s^{-1} which agrees well with a maximum surface velocity of 5 m s^{-1} measured by the gauge reader during the flood (Erskine, 1996).

The calibrated HEC-2 model was then used to calculate water surface profiles for the SWDs for the three palaeofloods. The estimated palaeoflood peak discharges were increased by 9% to allow for the highest SWDs being lower than the maximum flood height. The corresponding discharges were 6200, 4800 and 5800 $m^3 s^{-1}$ for palaeofloods 1, 2 and 3, respectively and the largest palaeoflood discharge is 41% greater than the 1949 flood (>30 times greater than the mean annual flood). The largest palaeoflood peak discharge is less than the maximum peak discharge ever recorded for a similar sized basin in NSW (Erskine, 1994, 1996). Therefore, all palaeofloods are expectable events that are much greater than the largest historical flood. Furthermore, the palaeoflood that severely eroded the older alluvium must have been even larger than palaeoflood 1 because it eroded the sediments contained in the valley floor but did not leave a SWD record.

CONCLUSIONS: FLOOD PLAIN DYNAMICS AND LARGE FLOODS

Three sets of large floods are important for flood plain formation and destruction on the highly flood variable, bedrock-confined Wollombi Brook. Large floods (flood peak discharges between two and nine times greater than the mean annual flood) do not inundate the low flood plain but form a series of in-channel benches in the void eroded by much larger floods. Catastrophic floods have peak discharges at least 10 times greater than the mean annual flood and destroy in-channel benches and deposit thick SWDs on flood plains. A third category of very large floods that extensively erode flood plains to an irregular stump are called cataclysmic or super floods. Such events are likely to have flood peak discharges 40–50 times greater than the mean annual flood on Wollombi Brook. Rainfall generated cataclysmic floods may only occur on highly flood variable rivers although such events can be also generated by other mechanisms.

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