Second Australian Stream Management Conference
8-11 February 1999, Adelaide, South Australia

Landscape Stability, Quaternary Climate Change and European Degradation of Coastal Rivers in Southeastern Australia.

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SUMMARY: The rivers of southeastern Australia have undergone major but gradual hydrological and geomorphic change as a result of climate changes during the Quaternary (the last 2 Ma), but on a landscape that has been tectonically inactive for tens of millions of years. In this stable setting, European landuse practices have, in less than a century, wrought widespread channel degradation. The effective rehabilitation of these rivers and floodplains requires a sound understanding of their genesis, for river management practices will not be effective if imposed counter to natural environmental trends. Earlier in the last glacial cycle (125 ka to 25ka), the coastal rivers of southeastern Australia were relatively high energy, laterally active systems transporting coarse sediment. In low-gradient large valleys where these older coarser deposits remain as terraces, these rivers are not especially responsive to European impact. In contrast, during the late Holocene (the last 5 ka) and in smaller steeper-gradient valleys, low energy, fine grained, small channeled, systems have formed, becoming stabilised by riparian vegetation in the last 2 ka. These systems have been particularly responsive to European land clearance and, due to local stream power conditions, the middle reaches of these valleys are the most vulnerable. A detailed study of the Nambucca catchment has shown clearly that recent channel degradation has been caused by European land clearance. Changes can be separated into four phases, largely dictated by flood frequency, with the two dominant phases in the 1890s and the several decades following 1948. Today, many of the east-coast catchments require special management for they are something of an enigma; geomorphically active and unstable rivers in an otherwise highly stable landscape.

MAIN POINTS OF THIS PAPER:
- Climatic changes have caused major hydrological change in southeastern Australia over the last 2 million years despite a tectonically inactive landscape..
- In the 2000 years prior to European settlement streams in the Nambucca catchment were stable.
- The effects of European land clearance have been put into four phases, with destructive phases initiated by a clustering of large flood events.

1 INTRODUCTION

This paper briefly reviews the landscape evolution and Quaternary climate of river valleys in southeastern Australia using this evidence to interpret why the rivers and floodplains of this region have been so vulnerable to European landuse changes. For illustration, the study focuses on evidence of post-settlement stream degradation in the Nambucca River catchment in northern coastal New South Wales.

The characteristics of the rivers in the uplands and eastern slopes of southeastern Australia differ greatly from of those further to the west; the former are usually shorter, steeper and are confined to narrow valleys in relatively rugged terrain. Annual rainfall values are generally over 800 mm in eastern areas, and in places over 1800 mm, leading to catchments once forested with wet sclerophyll and rainforest. European forest clearance in an environment of frequent coastal storms, steep channel gradients, confined valleys and unconsolidated sediment have resulted in eastern rivers that have in many reaches become highly unstable.

2 LANDSCAPE EVOLUTION

The scientific understanding of the origin and evolution of the valleys of Australia's Eastern Highlands has changed greatly over a short time (Tooth and Nanson, 1995). Less than 160 years ago, Charles Darwin argued that the valleys of the Blue Mountains were carved by marine processes resulting from much higher sea levels than today. Only with the visit of the American James Dana in 1839 were these valleys recognised as having been formed by the rivers that flowed in them. However, over the next one hundred years it was assumed that the valleys must be geologically young, probably eroded by rivers with much larger discharges and sediment loads during what was presumed to have been a highly erosive period of enhanced rainfall in the Pleistocene epoch (the past ~2 Ma) when large parts of the world were experiencing severe glaciations.

A second major advance in understanding came with the work of Young (1977, 1978, 1983), Bishop et al. (1985) and Young and McDougall (1982, 1993) who were able to establish, using K/Ar dating, that the

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valleys of eastern Australia are, in fact, very old, resulting from landscape uplift and river incision at the very low denudation rates of about 0.7 to 1.7 m/Ma (Young, 1983) that started certainly more than 30 Ma and probably by about 100 Ma ago. They showed that, far from being the product of a short Pleistocene episode of extreme rainfall, these rivers eroded their valleys under an essentially continuous humid-fluvial regime, not greatly different from that, which prevails today. Quaternary fluctuations in climate have produced terraces, floodplains and changed channel styles, but they did not form the valleys themselves. In many places the eastern Australian landscape has remained essentially unaltered in form since the early Tertiary (some 50-60 Ma), in stark contrast to the more tectonically and fluvially active regions of Europe and North America where our understanding of fluvial processes, landscape erosion and rates of change have been very largely determined.

Several comparative studies of continental sediment yields broadly confirm that contemporary Australian yields are among the lowest in the world (Walling and Webb, 1983; Olive and Reiger, 1986; Reiger and Olive, 1988). The rivers of Australia's eastern highlands have abundant stream energy at certain times, however, in their *undisturbed* state, a pronounced lack of sediment supply means that natural sediment output must be exceptionally low (Hean and Nanson, 1987). Such long-term channel stability and limited sediment production has important implications for understanding recent fluvial behaviour in the valleys of this region where geological stability has been the norm for tens of millions of years. European landuse has converted what were exceptionally stable rivers into some of Australia's most degraded.

3 QUATERNARY ENVIRONMENTAL CHANGES

Nanson and Erskine (1988) stated that coastal New South Wales is an environment where most rivers have, since the early to mid Tertiary, operated uninterrupted by the direct effects of glaciation or by prolonged periods of aridity, and that as a consequence there no large stores of sediment derived from Quaternary glaciation or tectonism. However, they acknowledge that it remains to be established just what the contemporary patterns of fluvial erosion and deposition are in a landscape of such antiquity, natural stability and low rates of natural denudation.

Broadly speaking, the glacial climatic fluctuations presented southeastern Australia with conditions that fluctuated between drier and less fluvially active glacials (and lesser glacials termed stadials) and wetter and more fluvially active interglacials (and lesser interglacials termed interstadials). Coupled with these were changes in sea level between glacials (low) and interglacials (high) that must have greatly affected the lower reaches of the coastal rivers.

On the basis of research to date, the coastal valleys of southeastern Australia appear to have erosional and depositional records that roughly correspond to global glacial fluctuations. Fluvial changes on the Riverine Plain in the southeastern interior of New South Wales (Page et al., 1996; Page and Nanson, 1997) are seen to be very similar to those recorded across the divide on the Nepean River near Sydney by Nanson and Young (1988) (with a chronology revised by Nanson and Price; unpublished). Both the Nepean River and Riverine Plain show broad similarities with the Channel Country of western Queensland, much further to the north and inland (Nanson et al., 1992). Indeed, it appears that there is considerable congruency of flow regime changes in the middle to late Quaternary for rivers in Eastern Australia generally (Nanson et al., 1992). The following is a summary of these changes (Fig. 1):

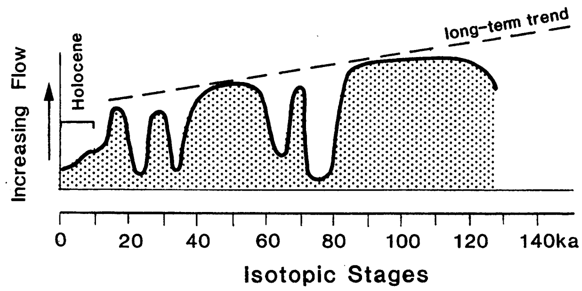

Figure 1: Declining cyclical trend of flow regime in southeastern Australia.

Stage 5 - Interglacial (130-75 ka): Details for the early part of this period are unknown, however, from about 110 ka to 75 ka the rivers of both the Riverine Plain and Sydney region appear to have been high-energy systems transporting significant sand and gravel. The depositional record indicates substantial run-off, extensive floodplains, coarse and more abundant sediment loads, and abundant woody debris. The Nepean River at this time transported very coarse gravels and reworked its entire floodplain of several kilometres in width; the river was probably braided at some locations (Nanson and Young, 1988).

Stage 4 Stadial (75-60 ka): There appears to have been a widespread period of relative fluvial inactivity between 80 and 70 ka probably asso-ciated with the Stage 4 stadial (a lesser glacial).

Stage 3 - Interstadial (60-25 ka): On the Riverine Plain the early part (60 to about 40 ka) may have been as active as Stage 5, however, on the Nepean River, while there was enhanced flow between 70 and 40ka, only about half the Stage 5 (Cranebrook) terrace was reworked . On the Riverine Plain there was a further period of increased fluvial activity between about 32 and 25ka, prior to the Last Glacial Maximum, but this event has not yet been specifically identified on the coastal rivers.

Stage 2 - Glacial (26-12 ka): The Glacial Maximum (24 to 20 ka) was fluvially relatively inactive and sea levels were at their lowest point (declining to ÿ130 m). Immediately flowing this was a period of enhanced activity on the Riverine Plain (20-15 ka), although it was less significant than either of the fluvial episodes in Stage 5 or Stage 3. During this period, high magnitude flows reworked the more vulnerable overbank deposits along the Nepean River, but they did not extensively rework the basal floodplain units.

Stage 1 - Interglacial (Holocene (~12-0 ka): The Holocene has not been characterised by flow conditions comparable to the major events that have occurred in the past 100 ka, however, there is growing evidence that the early Holocene (~ 8-5 ka) was fluvially more active than the mid to late Holocene; terraces along many of the New South Wales coastal rivers date from this period (Walker, 1970; Hickin and Page, 1971; Warner, 1972; Blong and Gillespie, 1978; Melville and Erskine, 1986; Warner, 1992). Dodson (1986) obtained palynological evidence from Barrington Tops that suggests a wetter period between 8 and 5 ka, and Prosser et al. (1994) and Fryirs and Brierley (in press) found elsewhere in New South Wales that entire valley fills were excavated prior to about 6 ka and that alluviation has been predominant since then. With this decline in stream energy and an increase in fine-grained alluviation, riparian vegetation appears to have become a key factor in maintaining channel stability. In the absence of sufficient stream energy to rework valley fills, some floodplains became dominated by autocyclic episodes of alluvial accretion and erosion (Nanson, 1986).

Significance of Quaternary Climate Change for the rivers of southeastern Australia: On the basis of this summary, it would appear that these catchments have experienced episodes of considerable fluvial activity and sediment re-working several times in the last glacial cycle (the past ~130ka). Prior to 25ka, entire valley fills (fans, terraces and floodplains) would have probably been reworked such that there are almost no deposits remaining in the fluvially-active upper catchments that are older. Indeed, two of the oldest radiocarbon ages obtained from coastal river terraces are about 29-34ka (Walker) and Warner (1972, 1992) reports only a small area of Pleistocene terrace alluvium (dating at about 21ka) remaining in the Bellinger valley. Due to the confined nature and relatively steep gradients of most coastal valleys in southeastern Australia, even discharges during the early and mid Holocene, low energy period by comparison with earlier episodes during the glacial cycle, were able to rework most alluvial fills. The past 4ka would have been a period of relatively stable forested floodplains with little alluvial reworking except for progressive channel migration characteristic of many moderately active river systems. Since 2 ka these rivers have been exceptionally stable with erosion largely contained by riparian vegetation (Fig. 2).

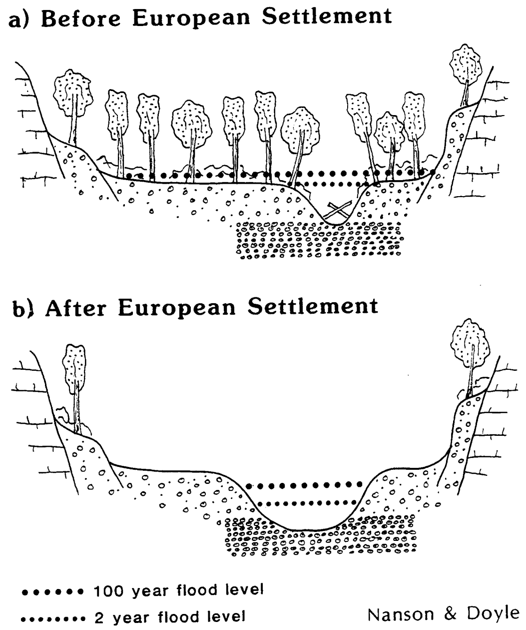

Figure 2: Channel enlargement due to European land clearance.

4 HUMAN INDUCED GEOMORPHIC CHANGE

Hughes and Sullivan (1981) proposed that prior to European settlement, aboriginal burning substantially increased fluvial sedimentation. More extreme views have suggested that the arrival of Aborigines could have completely altered the vegetation and climate over much of the continent (Flannery, 1994). If this is true then it would surely have lead to substantial geomorphological changes at the time of the appearance of humans in the southeast (~40-20 ka), however, there is no evidence to this effect.

While there is little support for the argument that aborigines greatly altered the geomorphic landscape, there is certainly a growing appreciation of the extent to which Europeans have caused dramatic changes (Young, 1976; Eyles,1977 a and b; Brooks and Brierley ,1997; Fryirs and Brierley, in press; Brierley and Fryirs, in press; Gale et al., in press). It is noteworthy that all but one of the above studies (Gale et al.) identified channel erosion rather than overall hillslope erosion as the primary mechanism for enhanced sediment yields (Wasson, 199?). There seems little doubt that in many New South Wales catchments, European deforestation, and in particular the clearance of vegetation from stream banks, has caused channel incision and bank erosion that has led to serious channel degradation. While controversy remains as to the relative impact of secular climate change compared to European settlement on the coastal rivers of southeastern Australia (Warner, 1987; Erskine and

Warner, 1998; Kirkup et al., 1998; Erskine and Warner, 1998), there is growing appreciation that land clearance and the development of agriculture must have been a major contributor.

4.1 Post-European Erosional Phases on the Nambucca River

At the time of European settlement, the river channels of the Nambucca catchment were narrow, sinuous, relatively deep channels with well forested banks and floodplains (Fig. 2a). The stratigraphy of the floodplains was dominated by fine gravel and silty sand laid down during the last laterally active phase, a low energy period from about 3-0 ka. The only coarse sediments were isolated terrace remnants. Following the arrival of Europeans there have been probably four recognisable phases of catchment destabilisation. The primary cause of degradation is entirely attributable to human impact, however, the timing of each phase is partly the product of the irregular nature of flooding, with large floods clustered into two distinct episodes (Phases 2 and 4).

Phase 1 (1830 to 1870): The first Europeans occupants of the Nambucca catchment above the tidal limit were 'cedar-getters' who arrived in the 1830s through to the 1850s (Townsend, 1993). They practiced a form of selective logging, and although they cut some of the largest trees from the floodplains and river banks, they did not greatly disturb the riparian forest, for they made no attempt to clear the land. Once they departed, the small gaps in the forests would have quickly recovered, aided by the extensive seed source close to hand. The same level of disturbance was probably true for the first pastoralists who's arrived in the 1840s but who attempts at farming failed. Most of the middle catchment was not settled until the 1870-1890s (Townsend, 1993). Phase 1 would have seen some increases in suspended load but probably little else.

Phase 2 (1870 to 1896): Serious land clearance for farming started in the catchment above the tidal limit in the 1870s and 1880s. Undoubtedly, land clearance on the floodplains would have been rapid, but it must have taken until the early 1890s before such activity would have had an appreciable impact on the rivers of the middle and upper Nambucca catchment upstream. As it happened, the early 1890s experienced a series of very large floods (there were 3 in 1890, including the largest on record, and a flood in each of 1893 and 1894) that were probably a major catalyst for channel change. It is not recorded as to what extent the stream banks were cleared, but there was probably no compelling reason seen at the time to leave them vegetated, despite Governor King's ordinance of 1803 which precluded clearance of vegetation within 10 yards of any stream, a law apparently largely ignored by settlers. A response to the removal of riparian vegetation would have been a substantial reduction in bank strength and a dramatic increase in channel width. The fine gravels released from the floodplain would have entered the stream as bed material, and the fine sands and silts would have either relocated to floodplains as overbank deposition, or have been flushed through the system to the tidal channels and the estuary. The addition of gravels to the bed would have exacerbated the problem of stream-bank erosion, as an increase in coarse bed-material itself causes additional channel widening. Velocities would have increased as the removal of trees along the channels must have terminated the supply of much of the large woody debris that enters streams in forested areas as a result of natural tree-fall, offering natural resistance to flow. Furthermore, widening of the channels would have meant that previously emplaced logs became outflanked and removed during floods. The last decade of the nineteenth century was probably a flood-induced period of severe channel erosion.

Phase 3 (1897-1947): Much of coastal NSW embarked on a quite remarkably dry and fluvially inactive period for the first half of this century (Pittock, 1975; Cornish, 1977; Erskine and Bell, 1982; Erskine, 1986, Nichols and Lavery, 1992). From 1896 to 1947, the Nambucca experienced only 4 floods over 8.9m at the Bowraville gauge. It is possible that the long-term impact of 1890s floods was partially mitigated as a result of a lack of subsequent major flood events. In other words, the river was probably prevented from making a complete transition to its fully modified enlarged rural form until the next flood-prone period in the latter half of the twentieth century. Although there would have been pressure on the catchment from the intensification of dairy farming, without a series of major flood events to greatly undermine the banks and to cause channels to shift laterally, gravels would not have been released into the system in large quantities. Long-term residents recall swimming and fishing in deep holes during this period, holes that disappeared in the 1950s to 1970s. In fact, this stability was a hiatus, simply the product of the flood-reduced flow regime of that period. Visible on the 1942 aerial photographs are channel beds that consisted of extensive gravel bars and in places there were scalloped banks indicating some bank collapse. However, because of a lack of frequent channel-modifying floods, it is clear that the active channels were considerably narrower than the present ones, they were more sinuous, there were trees in places growing on the beds, and pools remained in many locations where there are none today. In other words, they appeared as a severely degraded channels but still with some of the characteristics of the pre-disturbance channels. In none of the tributaries is there any sign that large volumes of gravel were released through to the lower reaches by the early 1940s. The greatest extent of change occurring during this phase was experienced in the middle reaches of the catchment where stream powers were large. During Phase 3, many of the channels were primed ready for greater disturbance with the next phase of flood-dominated conditions.

Phase 4 (1948-Present): This Phase proved a dramatic contrast to the previous half century. Remarkably, 11 floods over 8.9m were reported on the Nambucca River at Bowraville over an 18 year period between 1948 and 1965. Those in 1949 and the early 1950 were widely reported as channel-modifying events elsewhere in coastal New South Wales (Pickup, 1974, 1976; Erskine, 1986; Warner, 1987a; Erskine and Warner, 1988). These floods triggered nickpoints that migrated rapidly upstream causing bed degradation and subsequent channel expansion and straightening, grossly destabilising the system, particularly in the northern part of the catchment. More recent floods have continued these processes such that the Nambucca catchment has now made an almost complete transition to a expanded rural system modified by European land clearance (Fig. 3).

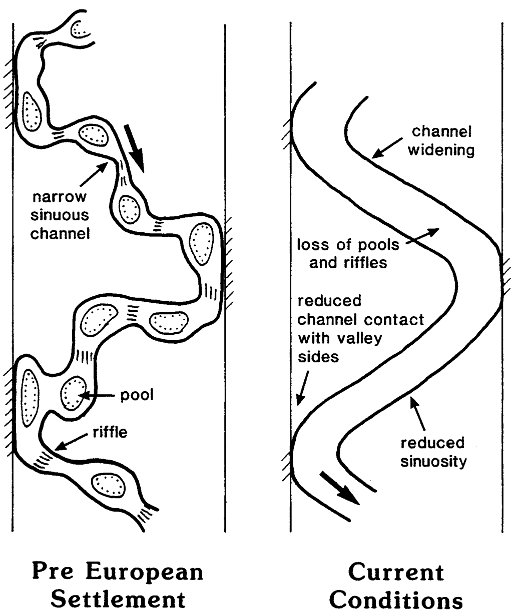

Figure 3. Planform of Pre-European and Post-European stream channels.

In addition to the dramatic hydrological change that occurred in the later half of this century, it is noteworthy that the availability of mechanised equipment greatly increased after World War II. This probably influenced the extent to which channel modification works were conducted and affected the rate at which gravel was officially and unofficially extracted from the channels. Certainly, the removal of channel and bank vegetation in the form of dead snags and large trees within the channel using mechanised equipment (eg. the form of a government approved 'Red Scheme' in the early 1970's) would have contributed to increased flow velocities and bank erosion on those reaches directly affected.

5 SUMMARY:

The valleys of southeastern Australia are geologically ancient bedrock flumes in which Tertiary and Quaternary alluvium has been temporarily stored. Long-term denudation rates are extremely low so marked increases in sediment mobility must be supplied from colluvium or alluvium stored on valley side-slopes or in terraces and floodplains. Fluvial activity during the mid to late Quaternary resulted in the deposition of coarse sediment still present in some wide low-gradient valleys, where it remains relatively resistant to European-induced channel changes.

In the early Holocene, the confined valleys of the Nambucca catchment were largely flushed clear of Pleistocene fills by a flow regime less energetic than those of Stages 5 or 3, but more erosive than those that followed. Detailed stratigraphic evidence indicates that between the mid and late Holocene (~4000 to 2000 years BP), less active channel migration and infrequent floodplain stripping probably reworked large sections of Nambucca catchment's floodplains and formed relatively wide shallow channels that reworked fine gravels as a floodplain base over which silty sands were built by vertical accretion. At about 2000 years BP there was a change to even more stable conditions. The channels ceased to shift laterally and they aggraded *in situ*, forming narrow stable conduits with well-defined banks and levees built of overbank fines, particularly in the upper and middle reaches (Fig. 2).

Periodic avulsion would have occurred due to the gradual constriction of the primary channels and to blockages from large woody debris, causing a new main channel to form and the cycle to repeat itself. The result would be relatively stable channels with a mosaic of different-aged palaeochannel infills occurring across the floodplain, but with no large part of the system being reworked at any one time. Channels would have been, for the most part, narrow, cluttered with large woody debris, characterised by deep pools and infrequent riffles formed of boulders, gravel or logs, and shaded by riparian forest. This would have been the channel and floodplain system that Europeans confronted in the mid to late Nineteenth Century.

European settlement and land clearance has caused such systems to adjust in an extreme fashion. The effect of clearing forest from floodplains and lower hillslopes would have been to reduce flow transmission times by increasing channel and floodplain velocities, and thereby increasing peak flood-discharges. Forest removal would have also temporarily increased valley-side erosion and slope wash, however, by far the most important source of silt, sand and gravel for the channels was widespread enlargement of the channels themselves. Vegetation was cleared from the stream banks allowing them to erode and large woody debris within the channels was systematically cleared, with no source of replacement in streams that had mostly become too wide to reform substantial debris dams. As a result, the channels eroded by widening, deepening and straightening, and by infilling pools and consuming adjacent floodplain as they did so (Fig. 3). Nickpoint erosion was a primary mechanism. Gravel extraction and artificial channel realignment have also contributed to increased flow velocities, channel expansion and excessive sediment transport. With channels now straighter and many times larger and less cluttered by debris, a far greater proportion of a flood discharge is transported in the channel than occurred prior to clearing.

Clusters of large floods are the triggering mechanism for channel erosion in disturbed catchments such as the Nambucca. A series of large floods in the 1890's would have almost certainly initiated channel expansion, following immediately on the heels as they did of extensive floodplain clearing. The second major wave of channel change was initiated by the 1948-1965 floods, particularly those early in that period. In the intervening period between the 1890s and the late 1940s, there were no significant clusters of flood events and hence after each individual large flood there was time for vegetative recovery before the next flood.

6 CONCLUSION

Today, many of the smaller coastal catchments in southeastern Australia are something of a geomorphological enigma. Their streams are laterally unstable and with relatively mobile gravel or sand beds, superficially identifiable with rivers in tectonically active regions like New Zealand. Yet these coastal rivers occur in a landscape of great long-term stability. Their river beds, floodplains and terraces are effectively a non-renewable resource, for even over many tens of thousands of years they will not be replaced at present rates of landscape uplift and denudation. Unlike in the rehabilitation measures adopted for geologically active regions with an abundance of sediment supply, river restoration measures here need to acknowledge that sediment can be supply limited, and bed material must often be conserved for use in the rehabilitation process.

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