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Temporal and spatial variations in erosion and sedimentation in alternating hydrological regimes in southeastern Australian rivers

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Abstract Alternating flood- (FDRs) and drought-dominated regimes (DDRs) impose great changes in water and sediment discharges in the coastal rivers of New South Wales. Changes in the former are detected in gauging records and in the latter by channel changes. This paper is concerned with examining the volumetric changes of sediments in these alternating regimes. In DDRs, material is added to the alluvial store by the deposition of in-channel incipient flood plains. In the last DDR (1901-1948) over 500 000 m^3 were added to the banks of a 4.5 km reach of the Nepean River. In FDRs channel widening removes much of this material, almost at the same rate. In the Hawkesbury River, 3.8 M m^3 were added to a 25 km length of channel in the first half of this century, while 1.9 M m^3 were removed in approximately half that time after 1948. It is suggested that knowledge of such systematic changes is important for engineers and planners.

INTRODUCTION

Alluvial channels are in a state of flux in response to changes in water and sediment discharges. Thus in periodic shifts in regime, where channel-forming discharges are greatly altered, there are systematic modifications to channel capacity. Such changes also affect sediments held in flood plain storage.

In New South Wales it has been shown that there are alternating flood- and drought-dominated regimes (Erskine & Warner, 1988; Warner, 1994). The former (FDRs) last for about 50 years; flood magnitudes are doubled and frequencies are higher than in the DDRs. FDRs have been found in the Hawkesbury from 1799 to 1820, 1857 to 1900 and 1949 to the present. DDRs have occupied the periods 1821 to 1856 and 1901 to 1948.

In flood regimes, channel capacities generally increase to accommodate the larger floods at the expense of alluvial banks of the flood plain (widths increase and depths decrease). In DDRs, the conveying capacity is reduced by in-channel alluviation and the build up of incipient flood plains, in agreement with Schumm's (1977) channel metamorphosis.

Hitherto, studies have concentrated on cross-section changes. These largely confirm these predictions, except where marked human influences are involved (Warner, 1987). Where cross sections are fairly close together, it is possible to compute areal changes to channel and flood plain. In this paper the main aim is to show in approximate terms what volume of sediment goes into flood plain lateral stores in DDRs, and what volume is removed in FDRs. This represents an initial view of DDR accretion and FDR erosion within channels. At present it is not possible to consider overbank accretion and stripping because accurate data do not exist. Such in-channel instability promotes concern for engineers and managers, and it needs to be understood if funds to rectify it are not to be wasted.

DATA USED IN THE PRESENT SURVEY

Some earlier surveys nearly coincide with breaks between regime types. Three reaches studied in previous work can be used to provide data for this initial investigation.

(a) In 1900, 46 Nepean cross sections were surveyed in a 4.5 km reach which ended about 0.5 km upstream of Penrith weir (Fig. 1(a)). Widths for the end of the nineteenth century FDR were compared with those measured from air photographs taken in 1947 (near the end of the last DDR) and then with widths obtained from resurveys carried out in 1982-83, some 26-27 years into the present FDR (Warner, 1984).

(b) Downstream in the tidal Hawkesbury, an engineer called Josephson carried out a detailed hydrographic survey from Richmond to Sackville in 1890 (Fig. 1(b)). This showed banktop positions and underwater data for a time 11 years before the end of a FDR. A photogrammetric survey using 1949 and 1955 air photographs (as the end of a DDR) and others taken in 1978 and 1980 was carried out between Richmond and Wisemans Ferry (71 km reach) to study bank changes in the present regime (PWD, 1987). Other resurveys in the 1990s have brought 12 km of this reach up to date (Warner, 1994).

(c) In the tidal Bellinger system (Fig. 1(c)) another photogrammetric survey was carried in eight arcs (half meanders) to predict bank erosion (Cameron McNamara, 1984). Near end of DDR photographs (1941-1942) were compared with those taken 41 years later (1981-1982), well into the present FDR (Warner & Paterson, 1987).

Figure 2(a) shows data for Penrith, with 1900 known widths and depths, known 1947 widths and known widths and depths for 1982-83. Five channel reaches were analysed: upper gorge, lower gorge, upper alluvium, shoal and lower alluvium. Figure 2(b) shows known, unknown and inferred data for the eight Hawkesbury reaches (named in Fig. 1) and Fig. 2(c) shows the locations of the 11 cross sections measured in each arc to derive concave and convex bank change data for the Bellinger.

RESULTS

1. Nepean

In the period 1900-1947 (Table 1) accretion occurred in all five reaches of this part of the Nepean, varying from 1.5 m in the lower gorge to 53.6 m in the shoal (Warner, 1984). About 10.6 ha of land were added in the form of incipient flood plains and bars. The former reached up to 6 m above weir-crest stage. In that part of the present FDR which was surveyed (1947-1982/83), the upper three reaches continued to accrete by only 3.1 to 4.9 m although channel widening might have been expected (Table 1). Widening occurred on the shoal reach (30.4 m) and in the lower alluvium (12.8 m). Up to a decade ago, nearly 4 ha of land had been eroded but the channel was on average still 14 m narrower than in 1900.

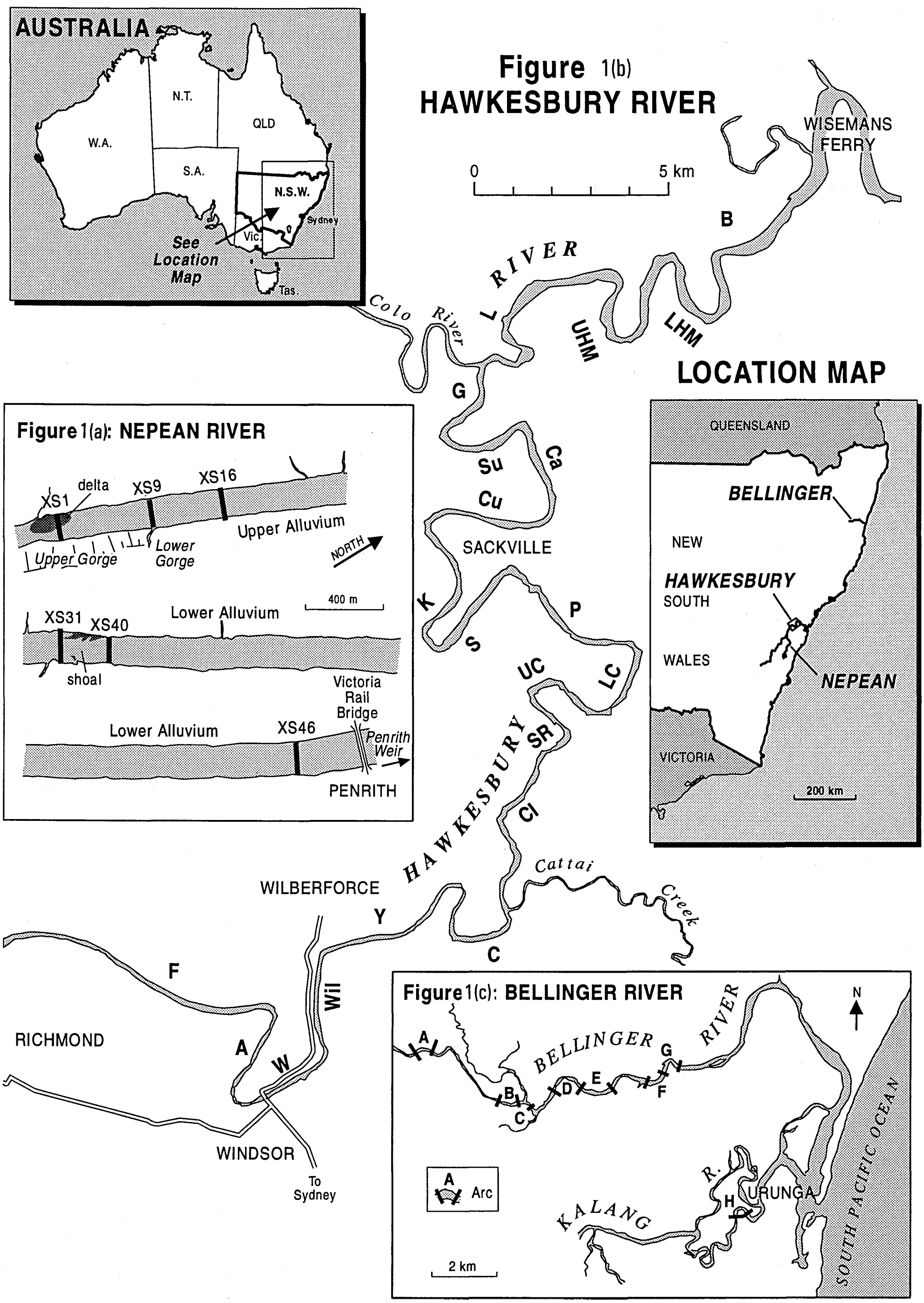

Fig. 1 Locality maps (Reaches on the Hawkesbury River: F Freemans; A Argyle; W Windsor; Wil Wilberforce; Y York; C Canning; Cl Clarence; SR Swallow Rock; UC Upper Crescent; L Lower Crescent; P Portland; S Sackville; K Kent; Cu Cumberland; Ca Cambridge; Su Sussex; G Gloucester; L Liverpool; UHM Upper Half Moon Bay; LHM Lower Half Moon Bay; B Bathurst).

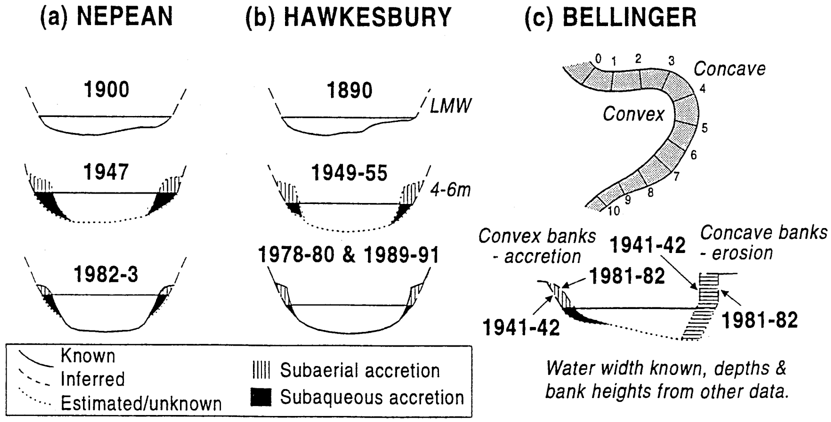

Fig. 2 Data availability in the three localities.

Using estimates of subaerial elevations and subaqueous profiles based on survey, it is possible to suggest that during the DDR (1900-1948) some 550 000 m^3 were added to the banks, whereas in the first 26-27 years of the following FDR, 160 000 m^3 were lost from the banks (Table 2). A previous survey (Warner, 1984) had revealed an increase in capacity of 600 000 m^3 in this reach from 1900-1982/3. If the banks have accreted by some 390 000 m^3 in this period, it follows that about 1 M m^3 of sediment has been removed from the bed.

2. Hawkesbury

The 1890 survey and the photogrammetric study (PWD, 1987) were used to reconstruct the loss of channel width in the DDR, for a 25 km section of river from Wilberforce to Sackville (Fig. 1(b)) for eight reaches varying between 2.3 and 4.1 km. From 1890 to 1949-1955, approximately 64 ha were added to the subaerial part of this channel (Warner, 1994). For the individual reaches average widths decreased by between 15 and 36 m, with a mean of 25.6 m.

Table 1 Nepean: changes in area – 1900 to 1947.

Reach	Distance	Area 1900-1947:			Area 1947-1982/83:		
	(m)	(000 m^2)		(m/m)	(000 m^2)		(m/m)
Upper Gorge	514	4.5	A	8.8	2.3	A	4.4
Lower Gorge	409	0.6	A	1.5	2.0	A	4.9
Upper Alluvium	783	8.2	A	10.4	2.4	A	3.1
Shoal	335	18.0	A	53.6	10.2	E	30.4
Lower Alluvium	2814	74.9	A	26.6	36.1	E	12.8
Total	4855	106.2	A	21.9	39.6	E	8.2

A = accretion; E = erosion; m/m = metres per metre of distance.

Table 2 Nepean: changes in volume – 1900-1947 and 1947-1982/3.

Reach	1900-1947 (000 m^3)		1947-1982/83: (000 m^3)		1900-1982/83: (000 m^3)		1900-1982/83: (000 m^3)*	
Upper Gorge	5	A	11	A	16	A	20	E
Lower Gorge	2.5	A	10	A	12.5	A	101.5	E
Upper Alluvium	40	A	13	A	53	A	207	E
Shoal	55	A	36	E	19	A	24	E
Lower Alluvium	450	A	160	E	290	A	307.9	E
Total	552.5	A	162	E	390.5	A	660.4	E

A = accretion; E = erosion; * channel capacity below cease to flow (from Warner, 1984).

Since accretion mainly involved incipient flood plains from about 4 to 6 m in elevation, it was relatively easy to assign conservative subaerial values for this feature. These estimates did not take into account alluvium draped up the face of the 8 to 10 m alluvial bluffs of the 1890 channel walls. Subaqueous values were more difficult to estimate but away from the steep bedrock cliffs which are an important feature of the gorge (Fig. 3), the channel margins were generally shallow at the end of the nineteenth century FDR.

Table 3 shows accretion volumes by reach for this period, with a total of 3.8 M m^3 going into in-channel storage. These data are for a period of 60-66 years, but the first 11 years were still part of the late nineteenth century FDR and erosion may still have been a feature. For the years of the DDR something like 80 000 m^3 a year went into storage.

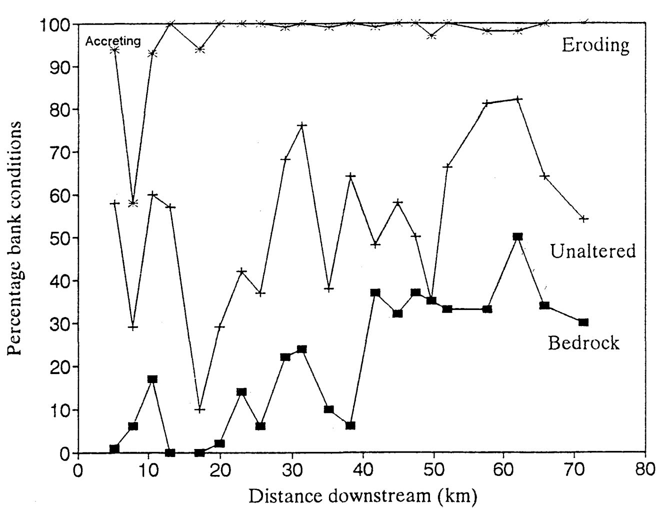

Fig. 3 Hawkesbury: percentages of bedrock, unaffected, eroding and accreting banks by reach. (Over the distance shown in Fig. 1, from Freemans Reach downstream.)

Table 3 Hawkesbury: subaerial and subaqueous accretion – 1890-1949/55.

Reach	Subaerial (000 m³)	Subaqueous (000 m³)	Total accretion (000 m³)	Accretion m³/m² of channel
York	606	63	669	162
Canning	480	54	534	193
Clarence	583	72	655	224
Swallow Reach	397	40	437	163
Upper Crescent	323	57	380	95
Lower Crescent	224	43	267	117
Portland	461	158	619	160
Sackville	184	63	247	85
Total	3258	550	3908	151

Table 4 Hawkesbury: subaerial and subaqueous erosion – 1949/55-1978/80.

Reach	Subaerial (000 m³)	Subaqueous (000 m³)	Total erosion (000 m³)	Erosion in m³/m² of channel
York	366	75	441	107
Canning	244	50	294	106
Clarence	270	59	349	120
Swallow Rock	228	55	283	106
Upper Crescent	124	36	160	47
Lower Crescent	44	18	62	27
Portland	185	59	244	63
Sackville	86	32	118	39
Total	1547	374	1921	76

Table 5 Hawkesbury: subaerial and subaqueous erosion – 1978/80-1989/91.

Reach	Subaerial (000 m³)	Subaqueous (000 m³)	Total erosion (000 m³)	Erosion in m³/m² of channel
York	143	15	158	38
Canning	85	9	94	32
Clarence	64	8	72	28
Swallow Reach	94	16	110	45
Total	386	48	436	36

In the present FDR erosion has been marked, with mean bank erosion of 4.3 to 17 m per reach in less than 32 years. Consequently about 30 ha of the accreted land had been removed by the early 1980s. Table 4 shows the changes for that period. Approximately half the material (1.9 M m^3) added in the DDR had been eroded.

Further resurvey of the four upper reaches reveals continued erosion up to 1989-1991 (over 400 000 m^3) (Table 5). Thus in the upper half of the section, some 1.8 M m^3 have been eroded from the 2.3 M m^3 added in the DDR, and at almost at the same rate (45 000 m^3 $year^{-1}$).

3. Bellinger

The photogrammetric study in the lower part of this valley was part of an engineering investigation to predict bank erosion (Cameron McNamara, 1984). In the eight arcs, erosion and accretion for each bank were measured at 11 cross sections for the 41 year period (1941-1942 to 1981-1982) (Warner & Paterson, 1987).

Bank elevations and subaqueous profiles were determined from earlier surveys (Warner, 1993) and estimated where data were not available. Table 6 shows the mean volumes for each arc for both concave and convex banks. Approximately 600 000 m^3 were removed in that period from concave banks, whilst 175 000 m^3 were added to the convex banks, giving a net erosion of more than 400 000 m^3. Rates for each arc are variable; they are highest in the upper parts of the tidal reach where sandy non-cohesive banks are still found, and lowest in the deltaic parts of the channel. In the latter, finer sediments are more cohesive and slow the rate of bank erosion. The seven North Arm arcs represent some 5.7 km of 23.5 km distance to the channel entering the sea. However, these arcs were the main bends and probably represent most of the active erosion.

Table 6 Bellinger: concave bank erosion, convex bank accretion and net erosion of arcs.

Arc	Concave erosion (000 m^3)	Convex erosion/accretion (000 m^3)	Net erosion (000 m^3)	Erosion in m^3/m^2 of arc
A	51	19 E	70	113
B	155	65 A	90	163
C	83	11 A	72	141
D	125	60 A	65	51
E	138	36 A	102	94
F	5	1.2 A	3.8	4
G	21	3.3 A	17.7	29
H	35	17.5 A	17.5	28
Total	613	175 A	438	76

A = accretion; E = erosion.

DISCUSSION

It has been known for some time that the large, frequent floods of FDRs effect bank erosion in mobile reaches by enlarging channels in the wetter regime. It is assumed that conditions are reversed in DDRs. This study has produced initial estimates of the volumes going into storage in DDRs and being eroded in FDRs. Individual cross-section data are shown to be highly variable along a reach, as are the grouped data.

1. Nepean

Sediment volume changes in this reach have been affected not only by regime shifts but three other factors. The Penrith weir has ponded water in this section for about 100 years and a build up of boulders behind the wall is a feature of the lower weir pond. Elsewhere the bed has been subject to degradation. Accretion during the twentieth century DDR was essentially normal until 1944. In that year a large flood in Glenbrook Creek evacuated a large volume of sandstone blocks into the Nepean, just above the uppermost of the cross sections surveyed in 1900 (Fig. 1(a)). It reduced the channel width by two-thirds at maximum width and has survived essentially in the same state. This delta has acted as a partial weir, with its own hydraulic jump (Warner, 1987) and has promoted bed erosion immediately downstream. Additional bed erosion has been effected by the third factor, the Warragamba Dam which withholds water and sediment from 8000 km^2 of the 11 000 km^2 drainage area above this reach. However, large overdam floods have removed much coarse sediment from the bed of the gorge, as well as from this reach (660 000 m^3). In fact, the nature of bank accretion evident from this study means that more than 1 M m^3 has been removed from the bed. An average increase in depth of 1.5 m is indicated.

2. Hawkesbury

This tidal reach had significant, but spatially variable accretion in the last DDR. Since then there has been progressive erosion. For the 25 km section, measured erosion up to 1978-1980, was about half of that which had been deposited earlier in the DDR. In the upper half of this section, an additional hydrographic survey revealed that the erosion had been continued up to 1989-1991 and that the rate of erosion per year was very similar. Although this section is farther from the dam, the effects of sediment starvation are still apparent in the bed (Warner, 1994). These effects have been compounded by the extraction of aggregate from the bed between Penrith and Wilberforce. The erosion has increased the sub-tidal capacity of the FDR channel, when depths would be expected to decrease. (The channel was very shallow in the 1890 survey towards the end of the late nineteenth century FDR). If the present FDR lasts much longer, it seems likely that most of the incipient DDR flood plain will be eroded. The more cohesive banks of 1890 will then be systematically eroded. At present erosion of these banks is limited to areas where the incipient DDR flood plain has already been removed.

3. Bellinger

In this smaller tidal channel, bed accretion in the present FDR has been evident for some time (Warner, 1993). From eight concave banks some 613 000 m^3 has been removed in 41 years, compared with only 175 000 m^3 added to the convex banks in the same period. This gives a net loss in the present regime of over 400 000 m^3. Unfortunately there are no data for the earlier DDR but it seems probable that concave bank erosion would have been at a slower rate than at present and that convex bank accretion would have been faster than in the current regime to allow the development of the channel seen in the 1941-1942 air photographs.

Spatial variations at individual cross sections and for groups in the arcs reflect local conditions of geology, alluvial sedimentology and bend curvature. These can all modify stream-power effectiveness, as well as present very different perimeter conditions. Therefore, notions of downstream channel size increase do not always follow. These, as well as the changes described here, need to be noted for effective management of banks and channels.

CONCLUSIONS

Flood-dominated regimes are characterized by erosion of the flood plain store. While channel widths increase, depths would normally decrease but in contemporary conditions of sediment starvation (by dams, weirs and extractions), they may increase. In drought-dominated regimes, low fluvial activity in the presence of a sediment supply will promote channel shrinkage and the growth of incipient flood plains. While depths may increase, widths certainly decrease. In this study the volume of materials lost and gained during these periods has been estimated from cross-section and photogrammatic data. This information is useful for those seeking to control bank erosion in the current FDR.

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