The geomorphology of the Macleay River estuary

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1.0 EXECUTIVE SUMMARY

The Macleay estuary is a mature barrier-dominated system in a high-energy ocean wave setting. It is a filled (delta) system dominated by fluvial processes. It can be broken into three broad process zones that reflect differing degrees of fluvial and tidal interactions. The fluvial process zone is the spatially most extensive and extends from Belgrave Falls to Kinchela and can be broken into three reaches with different morphological attributes. Collectively, these three fluvial reaches represent a transition from the non-tidal gravel bed reaches of the middle Macleay catchment to the entirely estuarine-dominated reaches of the Lower Macleay River. A short transitional zone exists from Kinchela to Jerseyville Bridge and on Clybucca Creek. These segments of the estuary reflect a transition from entirely fluvial processes to both fluvial and tidal processes. In contrast, the remaining Lower Macleay River is dominated by tidal processes and the presence of marine-derived sediment.

Ninety per cent of the entire surveyed estuary is stable with 27 % of this being stabilised by rockwork. There are 25 km of eroding riverbanks with minor erosion being the most common erosion category. While there has been an increase in the incidence of minor bank erosion in the last 70 years there has been a marked reduction in moderate and severe bank erosion since (26 % and 68 % reduction respectively). The most active areas in the estuary are Kinchela Bench and Fattorini Island (fluvial reach 3). Kinchela Bench has eroded by up to 35 m since 1942 with the greatest rate of change occurring between 1942 – 1956 (reflecting the large floods of 1946, 1949 and 1950). Fattorini Island has also been reduced in length by 70 – 50 m since 1942. These locations are continuing to erode at high rates from wind and/or boat waves (relative contribution unknown).

The fluvial process zone has the most extensive occurrence of minor and moderate erosion and the only incidence of severe erosion, with 10 km of eroding riverbanks. Seventy eight per cent of the stable banks are naturally stable with the remaining 22 % stabilised with rockwork. The transitional process zone has 7.5 km of minor and moderate bank erosion with 43 % of the stable banks being rocked. The marine flood-tide process zone has the least erosion with 94 % of the surveyed area being stable (of which 43 % is naturally stable).

The dominant causes of bank erosion in the Macleay estuary are:

- Fluvial processes
- Wind and/or boat waves
- In-channel sedimentation
- Stock disturbance/reduced riparian vegetation
- Presence of rockwork on adjacent banks

The relative role of these controls varies considerably between process zones and is partly determined by local factors (deep or shallow water profiles). Furthermore, the history of catchment disturbance in the Macleay valley — including the 1.24 million tonnes of sediment that have been dredged from the estuary between 1929 and 1963 — continues to have important impacts on estuarine processes.
2.0 INTRODUCTION

2.1 Aims

To investigate the nature and extent of bank erosion and sedimentation at two spatial scales (i.e. process zone and site specific scales).

The Process-Zone Analysis will:

- Develop draft mapping from rectified orthophotos
- Differentiate areas of the estuary with similar characteristics (bank forms, sediment type, broad physical processes and tidal regimes) with a particular view to identify the occurrence and extent of four main depositional environments (i.e. coastal barrier sands, tidal delta sands, central mud basin and fluvial delta sands).
- For each process zone identify and map the major physical attributes associated (e.g. location of shoals, intertidal mud and sand flats)
- Provide a basis in which to assess the relative contribution of fluvial and tidal processes, while also providing a temporal context to the evolutionary pathway of the Macleay Estuary

The site-specific analysis will:

- Map and identify estuary related physical condition attributes focusing on the extent of bank erosion, areas of accelerated change, bank protection works and riparian vegetation.
- Provide basic statistical information that quantifies the relative extent of bank erosion classes, bank protection and riparian vegetation for each process zone.

The description of the Macleay floodplain and estuary at these two scales will encompass:

1. The spatial extent of each process zone
2. The extent of the bank erosion (mapped to a minimum resolution of 20 m)
3. The identification of the type and severity of bank erosion in each process zone
5. The identification of areas of accelerated change
6. The assessment of condition of each process zone
7. The identification of gaps in the data base relevant to riparian land management, bank erosion and sedimentation issues

3.0 \textbf{WAVE-DOMINATED COASTLINES IN SOUTH-EASTERN AUSTRALIA}

The coastline of south-eastern Australia is dominated by a high-energy ocean wave climate with a prevailing southerly swell pattern. The topography of the coastline is characterized by prominent headlands alternating with bay-beaches, barrier beaches and numerous micro-tidal estuaries partially filled with late Quaternary sediments (Roy et al., 1980, 1994; Roy, 1994; Sloss, et al., in press). Estuaries have been previously classified based on their biochemical properties, their physiographic attributes and their geomorphic/sedimentological characteristics (e.g Roy et al., 1980; Dalrymple et al., 1992). The latter of these classification schemes provides the most useful framework for assessing geomorphic processes, providing a sense of the depositional environments and an insight into the evolutionary pathway of any given estuary. Furthermore, the classification of estuaries based on their geomorphology and sedimentology incorporates an assessment of the spatial distribution of sedimentary units produced by fluvial, wave and tidal dominated sedimentary processes (Figure 1).

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{distribution_model.png}
\caption{Distribution model of energy and morphological tripartite facies distribution (after Dalrymple et al., 1992).}
\end{figure}
Roy et al., (1980) identified three primary types of estuaries in New South Wales based on the geomorphic attributes and entrance conditions of any given estuary. These include:

1. Wave-dominated barrier estuaries dominated by supra-tidal coastal barriers intersected by narrow entrance channels that connect low-energy back-barrier lagoons to the open ocean with attenuated tidal regimes.

2. Open ocean embayments with deep and relatively wide entrances with full tidal exchange.

3. Drowned river estuaries formed in steep and narrow incised valleys with large subaqueous tidal sand bodies and full tidal exchange.

The formation of such estuaries is a function of inherited topography, the extent of late Quaternary fill and catchment characteristics (i.e. sediment supply and river discharge). The evolutionary characteristics for the Macleay River (a wave-dominated estuary) are briefly discussed in the following section.

3.1 Estuary evolution for the Macleay River: a wave-dominated barrier estuary

Post-glacial marine transgression following the last glacial maximum (LGM) resulted in the deposition of much of the coastal alluvium in south-eastern Australia. While there are morphological examples of previous sea-level highstands in many parts of the eastern seaboard — including the Macleay — much of the alluvial morphology of the New South Wales coastline has formed as a function of rapid sea level rise since the LGM (20,000 years before present). Sea levels rose from 120 m below present in the LGM to one to two metres above present by 7500 – 6500 14C years. Sea levels have fallen since then to the present level ~ 3000 years ago and have remained essentially stable since. Very little chronological work has been undertaken on the Macleay estuary and the work by Walker (1963, 1970) really remains the only chrono-stratigraphic assessment. The closest analogue for which there is substantial data is the Clarence River to the north and the Shoalhaven River in the Illawarra (e.g. Umitsu, et al., 2001).

Both represent mature infilled estuaries whose pattern and timing of infilling is likely to be similar to the Macleay River estuary.

While not dated the elevated terraces (Corangula and Madron) upstream of Kempsey described by Walker (1970) more than likely relate to lower sea levels prior to 7500 – 6500 years ago. As sea levels reached their maximum at this time the pre-Holocene Macleay valley would have been inundated with the deposition of a transgressive sand sheet between the rocky headlands of Crescent Head to South West Rocks (Figure 2). This transgressive sand sheet would have become the proto-barrier that bounded an open marine embayment — further bounded to the north by an inner Pleistocene barrier at Stuarts Point. Walker (1970) identified that this period also coincided with the formation of the Mungay terrace upstream of Kempsey. The presence of the transgressive sand sheet near the current coastline would have resulted in the deposition of river-dominated sediments on the Kempsey side (fluvial bay-head delta formation), deposition of terrigenous derived mud-dominated units in the central lagoon and additional marine influenced sediments associated with the barrier and tidal inlet processes (sensu Sloss et al., in press).
The formation of the proto-barrier further promotes barrier development with flood-tide delta and back-barrier deposition (Figure 2). This emergent barrier produces a low-energy environment in the central mud basin — conducive to the deposition of estuarine muds. On the Macleay River the deposition of these estuarine muds along with continued progradation of fluvial sediments at the landward side (i.e. immediately downstream of Kempsey) has essentially filled the lower valley producing a deltaic
plain. The timing of the final stages of infilling is unknown but may coincide with
terrace formation upstream of Kempsey ~ 3000 years ago. The Belmore and Clybucca
swamps represent the last areas of the central mud basin, which are continuing to slowly
infill. The birds foot deltas of Kinchella Creek and Belmore River indicate the
continued progradation of sediment from the Macleay River into these basins.

In partially filled estuaries the central mud basin facies are replaced by salt marshes,
mud flats and/or mangrove swamps. Such depositional environments are a reflection of
the increased dominance of riverine processes in the mature stage of estuary
development. During these latter infilling stages connectivity between the river channel
and tidal inlet increases resulting in a more efficient delivery of sediment to the ocean
(www.ozestuaries.org). This often results in the bypassing of the remaining central mud
basin and the formation of an ebb-tide delta. The preservation of such features on the
eastern seaboard of Australia however, is often restricted due to the naturally low
sediment supply rates, shoreline recession and sediment redistribution by high wave
energy (Heap et al., 2004). Indeed, Heap et al., (2004) further suggest that the final
filling stages of wave-dominated deltas in Australia — characterised by an increased
sediment delivery to the ocean and greater tidal penetration — may never actually result
in the development of the “classic” delta morphology.

4.0 GEOMORPHIC PROCESS ZONES OF THE MACLEAY ESTUARY

At the broadest scale the contemporary Macleay estuary can be classified as a wave-
dominated filled (delta) system — equivalent to the mature barrier-dominated estuary of
Roy et al., (1980). The system is river dominated by infilled mud basins (e.g. Belmore
and Clybucca Swamps) and extensive floodplains and levees that are inundated by
approximately the mean annual flood (LM&P, 1980). The mature state of the estuary is
also reflected in the relative abundance of intertidal flats, mangroves and saltmarsh
(Table 1).

| Morphological and tidal attributes of the Macleay Estuary (www.ozestuaries.org). |
|------------------------------|----------------------------|----------------|
| Barrier backbarrier (km²)    | 3.67                       | Tidal sand banks (km²) | 1.22 |
| Central basin (km²)         | 0.91                       | Rocky reef (km²)       | 0    |
| Fluvial bayhead delta (km²) | 0                          | Coral (km²)            | 0    |
| Flood/ebb delta (km²)       | 1.13                       | Channel (km²)          | 10.21|
| Intertidal flats (km²)      | 1.74                       | Bedrock (km²)          | 0    |
| Mangrove (km²)              | 5.94                       | Floodplain (km²)       | 4.76 |
| Saltmarsh/saltflat (km²)    | 4.22                       | Bedrock perimeter (km) | 3    |
| Water area (km²)            | 19.91                      | Entrance width (km)    | 0.18 |
| Perimeter (km)              | 157.73                     | Entrance length (km)   | 0    |
| Maximum length (km)         | 49.65                      |                           |      |
| Maximum width (km)          | 0.56                       |                           |      |
| Mean wave height (m)        | 1.55                       | Mean wave period (sec)  | 7.11 |
| Max wave height (m)         | 6.9                        | Max wave period (sec)   | 13.5 |
| Tidal range (m)             | 1.2 – 1.8                  | Tidal period (sec)      | Semi-diurnal |
The current morphology of the estuary can be broken into three broad process zones (Figure 3) that reflect differing degrees of fluvial and tidal interactions. These are:

- Fluvial process zone
- Fluvial-marine transitional zone
- Marine flood-tide process zone

4.1 Geomorphic attributes of the fluvial process zone

The fluvial process zone is the most extensive process zone within the estuary (reflecting the mature infilled character) and extends from the tidal limit at Belgrave Falls to Kinchela (including Belmore and Kinchela Creek and the upper Clybucca, Figure 3). While subject to varying degrees of tidal processes the overall morphology of this section of the estuary is dominated by fluvial processes and fluvial sediment and can be divided into three reaches each of which exhibit a similar morphology (reflecting the dominant fluvial process).

**Belgrave Falls to Kempsey Bridge – Fluvial Reach 1**

The upper most fluvial reach occurs from the tidal limit at Belgrave Falls to Kempsey and is characterised by bedrock outcropping on the concave banks with additional outcrops also occurring in the bed of the channel itself (Figure 3). This reach is characterised by a riffle-pool sequence with coarse bed material (cobble-gravels). Despite the coarse nature of the bedload, deep pools — up to 14 m depth — occur in this most upstream fluvial reach (e.g. at Kempsey Bridge, at Kempsey railway Bridge and at Mary’s Bay).

The Macleay River in this most upstream reach is set within Late Pleistocene and early Holocene terraces (e.g. Alda Villa, Huntingdon and Long Flat Soil Groups — Eddie, 2000) with a distinctly stepped channel margin. The older clay-rich terraces form an important lateral control on the channel location forming a resistant channel boundary. This lateral constraint provided by both the bedrock and the older terraces produce the highest degree of valley confinement throughout the Macleay estuary resulting in the formation of large vegetated chute-channels. This confinement along with slightly steeper gradients and the variable hydrological regime produce the stepped channel margin seen within this reach. This form of channel margin is a characteristic of southeastern Australian rivers which experience extremely variable hydrological conditions (sensu Erskine and Warner, 1988, 1998) and which have undergone various degrees of post-European channel expansion (sensu Cohen, 2003). These features set within the floodplain or terrace can be either erosional or depositional and are prone, when unvegetated, to fluvial erosion (most likely a function of the 2001 flood — Figure 4).

**Kempsey Bridge to Belmore River confluence – Fluvial Reach 2**

Fluvial Reach 2 extends from Kempsey Bridge to Belmore River confluence and represents a major shift in depositional processes. Downstream of Kempsey valley width increases dramatically, producing the wide deltaic plain of the Lower Macleay River (Figure 3). This increase in valley width results in a progressive reduction in bank and levee height in a downstream direction with bank heights decreasing from 6 – 5 m upstream of Kempsey to 5 – 4 m at Kempsey and 4 – 3 m at Belmore confluence.
Fluvial Reach 2 — between Kempsey and Seven Oaks — is characterised by alternate shoal, bar and bench development inset within an enlarged channel. Therefore, unlike the upstream reach, Fluvial Reach 2 represents the first major depositional zone within the estuary. The consistently shallower water depths seen in this reach further highlight this.

Figure 3 Distribution of process zones in the Macleay Estuary
Belmore River confluence to Kinchela – Fluvial Reach 3

Fluvial Reach 3 represents the most downstream reach dominated by fluvial processes and extends from Belmore confluence to Kinchela (including Belmore River and Kinchela Creek — Figure 3). Levee and bank heights on the Macleay River continue to decrease from 3 m to 2.5 m and the reach is characterised by the greatest extent of active erosion in the estuary. The major depositional units within the reach (i.e. Fattorini Island and Kinchela Bench) are actively eroding and the rate and extent of erosion is determined by both fluvial processes and wind and/or boat waves (expanded upon in Section 6). In contrast to the trunk stream, Belmore River and Kinchela Creek exhibit less in-channel sediment storage with sediment accumulation occurring through levee development. These low gradient tributaries — while predominantly stable — are extensively modified by drainage works. Thus, current channel processes most likely reflect the history of drainage operations while long-term depositional processes of the Macleay River (i.e. infilling of the Belmore and Kinchela swamps) have determined their overall morphology.

4.2 Geomorphic attributes of the fluvial-marine transitional zone

This process zone which extends from Kinchela to Jerseyville Bridge on the Macleay River and includes most of Clybucca Creek reflects a transition from entirely fluvial processes to both fluvial and tidal processes (Figure 3). This is apparent by the appearance of shoals that are deposited by fluvial processes but which are actively...
modified by diurnal tidal processes. Thus, shoals within this transitional zone contain fluvially and marine-derived sediment. This transition zone also denotes a further reduction in bank height from 2.5 m to 1.5 m with the formation of intertidal flats and the dominance of estuarine sediments in bank profiles.

The lower sections of this process zone (i.e. immediately upstream of Jerseyville Bridge and the lower end of Clybucca Creek) exhibit extensive shoal development. The deposition on the trunk stream is also accompanied by active erosion of Pelican Island (expanded upon in Section 6). Clybucca Creek — like Belmore River and Kinchela Creek — has also been extensively modified by drainage works in Clybucca Swamp and floodgates in Yarrahapinni Wetland. This has resulted in the formation of two active channels (one of which has been artificially created) with greatly modified depositional processes. Despite, the modifications most of Clybucca Creek has extensive areas of intertidal flat, salt marsh and mangrove development.

4.3 Geomorphic attributes of the marine flood-tide process zone

The Marine flood-tide zone is dominated by marine-derived sediment sourced from the inner continental shelf and from the coastal barrier systems. It extends from Jerseyville Bridge to the mouth of the Macleay River (including the abandoned Macleay arm — Figure 3). Extensive intertidal and supra-tidal flats occur within this process zone with extremely low bank heights (< 1.5 m) with little to no levee development. Thus, this process zone contains abundant marine sand and fine-grained (terrestrially sourced) estuarine sediment. Back swamp areas tend to firstly accumulate the fine-grained estuarine sediment. As such, many of the intertidal and supra-tidal flats are dominated by organic rich estuarine sediment. Individual floods influence the gross location of the sand shoals but tidal processes dominate the continued formation of the abundant sand flats, sand banks, mangroves and salt marshes (Table 1). The shoals within this process zone migrate upstream on the incoming tide and are partly reworked on the outgoing tide. This is particularly prevalent in areas such as the abandoned Macleay arm, which is progressively being infilled by marine-sourced sand.

5.0 An Assessment of Bank Erosion in the Macleay Estuary

Bank erosion was determined over a five day boat trip where lengths of bank erosion > 20 m were mapped with a GPS. Bank erosion severity, failure mechanism, along with inferred dominant processes were recorded for each location. In addition, bank erosion status (i.e. active or dormant) and the extent to which failed bank material was stored on the channel margin was also recorded. Absolute locations of bank erosion and the aerial extent of erosion are estimated to be accurate within ± 20 m. The entire study area represents 357 km of riverbank, 24% of which were inaccessible by boat. These unsurveyed areas only represent minor tributaries such as Fredrickton Creek, Spencers Creek and Upper Kinchela Creek.

The spatial extent of bank erosion is presented for the entire estuary as well as for individual process zones (presented as a percentage of area surveyed and as an absolute value). Table 2 presents a summary of the results and highlights that 90 % (245 km) of the area surveyed is stable with 10 % (25 km) experiencing erosion of some sort. Banks
Table 2 Severity of bank erosion in the Macleay estuary process zones

<table>
<thead>
<tr>
<th></th>
<th>Total length (km)</th>
<th>Total surv. (km)</th>
<th>Stable (km)</th>
<th>Min. (km)</th>
<th>Mod. (km)</th>
<th>Severe (km)</th>
<th>% Stable</th>
<th>% Min.</th>
<th>% Mod</th>
<th>% Severe</th>
<th>% stable=rocked</th>
</tr>
</thead>
<tbody>
<tr>
<td>ENTIRE ESTUARY</td>
<td>357</td>
<td>270</td>
<td>245</td>
<td>18</td>
<td>4</td>
<td>3</td>
<td>90</td>
<td>7</td>
<td>2</td>
<td>1</td>
<td>27</td>
</tr>
<tr>
<td>Fluvial</td>
<td>187</td>
<td>134</td>
<td>120.1</td>
<td>8</td>
<td>2.8</td>
<td>3</td>
<td>90</td>
<td>6</td>
<td>2</td>
<td>2</td>
<td>22</td>
</tr>
<tr>
<td>Transitional</td>
<td>80.5</td>
<td>69</td>
<td>61.2</td>
<td>6.3</td>
<td>1.2</td>
<td>-</td>
<td>89</td>
<td>9</td>
<td>2</td>
<td>-</td>
<td>43</td>
</tr>
<tr>
<td>Marine delta</td>
<td>95.9</td>
<td>70</td>
<td>66.1</td>
<td>3.8</td>
<td>-</td>
<td>-</td>
<td>94</td>
<td>6</td>
<td>-</td>
<td>-</td>
<td>23</td>
</tr>
</tbody>
</table>

Transitional (fluvial-marine transitional zone). Percentages are calculated as proportion of area surveyed.

that are mapped as stable however, may be naturally stable or stabilised by rock revetment. To determine the extent of naturally stable banks the bank erosion layer and the rockworks layer (see Telfer, 2005) were joined and analysed collectively. Twenty seven per cent of the 245 km that have been mapped as stable have been stabilised with rock or other type of bank revetment material (e.g. concrete, rubble, tyres). This suggests that approximately 75% (178 km) of the stable banks in the Macleay estuary are naturally stable.

5.1 Bank erosion in the fluvial process zone

The fluvial process zone has the most severe bank erosion in the Macleay estuary (Table 2). Figure 5 presents the spatial distribution of bank erosion in the fluvial process zone and highlights that the areas of greatest erosion occur in Fluvial Reach 3 (around Kinchela Bend). Ninety percent (120 km) of the fluvial process zone is stable with 22% of this being stabilised with rock or any other type of bank revetment material. The bank erosion type and severity differs for each of the three fluvial reaches, reflecting the varying dominant processes and will be described below.

Figure 5 Spatial distribution of bank erosion severity in the Fluvial Process Zone.
Fluvial Reach 1

Bank erosion in Fluvial Reach 1 is dominated entirely by fluvial processes with most of the isolated occurrences being dormant. This reflects the four years since the last major flood (March 2001) which most likely caused most of the mapped erosion. Shallow slide of the bank or bench toe is the dominant failure mechanism for most of the smaller (< 100 m) cases of bank erosion within the reach. In contrast, mass failure is the dominant failure mechanism for the larger occurrences (> 100 m) of bank erosion seen in the reach (i.e. immediately downstream of Belgrave Falls on the left-bank and upstream of Kempsey Railway Bridge on the right-bank — Figure 5). The rotational slumps and slab-and-block type failure occur across the whole bank, rather than the shallow slides of the toe, indicating that critical bank height for the given bank strength has been exceeded (Figure 6).

In most instances of bank erosion bank strength has been markedly reduced due to the lack of structurally diverse riparian vegetation. Furthermore, continual stock access on the composite banks (i.e. gravel underlying silty or sandy loam) has rendered many of the alluvial banks more susceptible to both mass failure and shallow slides.

Figure 6 Mass failure (rotational slump) of banks downstream of Belgrave Falls. Bank strength of the Alda Villa and Huntingdon terrace material has been markedly reduced by the replacement of structurally diverse native vegetation with pasture species. Piping and gullying of the slumped zone, along with continued stock access, makes the banks susceptible to ongoing erosion.

Fluvial Reach 2

This depositional reach within the fluvial process zone is predominantly stable with extensive rockwork between Kempsey and Seven Oaks (Figure 5). Isolated toe scour (< 20 m) occurs on the depositional margin and there are small sections (< 100 m) of
fluvial erosion of inset features. Fluvial Reach 2 also exhibits the onset of wind and/or boat wave erosion. This is compounded, like the upstream reach, by stock access to the riparian zone making the small remaining alluvial banks susceptible to bank erosion (Figure 7).

![Figure 7](image)

**Figure 7** a) Notching of bank toe by wind and/or boat waves in Fluvial Reach 2. b) The impacts of stock on macrophyte growth and toe erosion with varying land use of the channel margin. Property on left has fenced off stock from the channel margin.

**Fluvial Reach 3**

Fluvial Reach 3 is the most actively eroding section throughout the fluvial process zone with the presence of 3 km of severely eroding bank at Kinchela bend and another 0.5 km of severe bank erosion at Fattorini Island (Figure 5). Both sections represent areas of active mass failure with slab-and-block type failure being the dominant process. Both sites represent sandy alluvium susceptible to flood-driven erosion and ongoing wind and/or boat wave erosion, albeit with differing tidal controls.

Fattorini Island has a steep sub-water surface profile resulting in deep water adjacent to the bank toe at both high and low tide (Figure 8). This morphology represents an ideal situation for ongoing erosion as a function of wind and/or boat waves. In contrast, Kinchela Bend has more subdued sub-water surface topography resulting in beach development at low tide. Thus, Kinchela bend only actively erodes at mid-high tide (Figure 9). The primary determinant in these two types of bank profiles is substrate type and local hydraulics (influenced by planform location). The right-hand channel of Fattorini Island represents an area of flow constriction combined with sandy and silty alluvium. Kinchela Bend however, is on the inside of a bend with sandy and silty alluvium overlying more erosion-resistant estuarine basal clay. Section 7 reviews the
nature of historical channel changes at Kinchela Bend and addresses current rates and causes of current bank erosion.

Belmore River is predominantly stable with isolated locations of minor active bank erosion and one location (~ 330 m) of moderate and active bank erosion. The impacts of stock access are common throughout Belmore River resulting in the increased susceptibility of the channel margin to tidal fretting by wind and/or boat waves (Figure 10). Shallow slides and block failure are the two most common forms of bank failure on Belmore River. In addition, there are many examples of dormant bank erosion — fluvial in origin — with evidence of failure scars on the channel margin. The pattern of bank erosion on Kinchela Creek is similar, with isolated locations of minor active bank erosion (Figure 5). Lower Kinchela Creek exhibits the greatest extent of bank erosion with evidence of stock impacts increasing the susceptibility of the banks to fretting by wind and/or boat waves at mid tide. This mid-tide notching of the bank toe by wind and/or boat waves appears to be the dominant erosion process.

Figure 8 Bank erosion of a ‘deep water’ profile at Fattorini Island. A steep sub-water surface profile results in active erosion at low and high tide.
Figure 9  

a) Bank erosion on the inside of Kinchela Bend at high tide.  
b) The local hydraulics and basal estuarine clay has resulted in the development of a more subdued sub-water topography with ongoing erosion occurring at mid-high tide only.
**Figure 10** Stock impacts on Belmore River resulting in reduced bank strength and increased susceptibility to wind and/or boat waves leading to slab-type block failure.
5.2 Bank erosion in the fluvial-marine transitional zone

The fluvial-marine transitional process zone represents the second most unstable process zone throughout the estuary with 6.3 km of minor bank erosion and 1.2 km of moderate bank erosion (9% and 2% of the process zone respectively) with no severe bank erosion (Table 2). Eighty-nine percent of the 69 km assessed in the fluvial-marine transitional zone are stable, of which 43% (30 km) are rocked (Table 2). This suggests that only half of the stable banks within this process zone are naturally stable. Indeed, the majority of the trunk stream within the transitional zone has been rocked with the unrocked areas around Pelican Island undergoing the most active minor and moderate erosion (Figure 11).

Figure 11 Spatial distribution of bank erosion in the fluvial-marine transitional zone. Note the erosion of Pelican Island.
Like Fattorini Island, the active erosion of Pelican Island is an example of a ‘deep water’ profile. The sedimentology of this island is composed of estuarine basal clays underlyng stratified sands and silts. This results in a stepped profile with the estuarine clays forming a more erosion resistant ledge adjacent to deep water. The left-bank of the island is exposed to both northerly and southerly wind-generated waves and boat wake resulting in a 570 m length of moderate erosion occurring at both high and low tides (Figure 12). The basal estuarine clays are actively bioturbated by crabs at low tide resulting in the pre-conditioning of the bank profile to ongoing erosion while the loose overlying sandy alluvium erodes at high tide.

Figure 12 Bank erosion of a ‘deep-water’ profile at Pelican Island – low tide. Note the crab pellets of the basal clays resulting in the basal clay ledge being pre-conditioned to wind/boat wave erosion.

Clybucca Creek exhibits numerous examples of active minor erosion but no evidence of moderate or serious erosion. Clybucca Creek, like other areas in the transition zone, has low banks with many rocked channel margins. The history of drainage works in Clybucca Creek resulted in the formation of a new straight channel and the maintenance of the old sinuous channel. Almost the entire length of Upper Clybucca Creek (i.e. downstream of the barrage) has been rocked. Many areas however, have only been rocked for two thirds of the bank height resulting in the upper bank being susceptible to wind and/or boat wave erosion at mid-high tide. Slab-type block failures along with shallow slide are the dominant failure mechanisms — determined primarily by wind and/or boat wave erosion. This is also particularly apparent in areas where rockworks are discontinuous. Clybucca Creek also exhibits a riparian zone heavily impacted by stock increasing the susceptibility of banks to mid-high tide erosion. The planform location (i.e. outside of bend) of the active erosion in Lower Clybucca Creek suggests that erosion seen throughout this tributary may be indeed initiated in floods (i.e. fluvial in origin) but maintained by wind and/or boat waves.
5.3 Bank erosion in the marine flood-tide process zone

The marine-flood tide process zone is the most stable of the three process zones with 94% of the 70 km assessed being stable and 6% (3.8 km) experiencing minor bank erosion (Table 2). Of the stable banks 23% (16 km) are rocked highlighting that the majority of stable banks in the marine-flood tide process zone are naturally stable. The trunk stream within this process zone is predominantly stable with most of the channel margins being rocked. Minor bank erosion in this process zone occurs around Anderson’s Inlet, the old arm of the Macleay River and around Fisherman’s Beach (Figure 13). The first is dominated by slab-type block failure of the supra-tidal flat with active erosion occurring from wind and/or boat waves (Figure 14a). Most locations experiencing this type of minor erosion are ‘shallow water’ profiles, and as such erode at mid-high tide. The second type of bank erosion is the undercutting of mangrove and salt marsh by boat waves in the old arm between Fisherman’s Reach and Stuart’s Point (Figure 14b). In these areas buoy location — a function of shoal location — is resulting in boat waves impinging on the alluvial channel margin.

![Figure 13](image-url) Spatial distribution of bank erosion in the marine flood-tide process zone
Figure 14 Bank erosion in the marine flood-tide process zone. a) Slab-type block failure; b) Scour and undercutting of mangroves; c) Scour and undercutting of dune vegetation at Fisherman’s Beach.
The final type of erosion in the marine flood-tide process zone is that of the vegetated sand dunes where wind and/or boat waves are causing shallow slides and active undercutting of the remnant vegetation (Figure 14c). This is compounded in some locations — such as Fisherman’s Beach — by the impacts of access tracks which have reduced the vegetation density on dune margins.

6.0 A REVIEW OF HISTORICAL CHANNEL CHANGES AND CURRENT SEDIMENTATION ON THE LOWER MACLEY RIVER

This section reviews a number of documents that relate to historical channel changes and to issues of sedimentation in the Macleay Estuary. It then assesses historical trends of bank erosion to those previously described in Section 5 and investigates a number of sites that are currently the most active within the estuary.

6.1 Departmental Committee on Erosion – Macleay River Erosion, 1934

In 1934 a report by the Department of Lands was commissioned into erosion of the Macleay River (Departmental Committee on Erosion – Macleay River Erosion, 1934). This report presented a synopsis of a number of investigations identifying the various opinions as to the major causes of the erosion seen throughout the estuary. Based on these assessments it then provided an overall summary of the active erosion. The twelve major findings of the 1934 report include:

1. 700 acres had been lost by 1934 (but over the previous 40 years) (p.6).
2. Areas most severely impacted totalled ~ 6 miles.
3. Represents a loss of £20 per acre (total loss of £14,000).
4. Erosion of riverbanks changed inundation patterns.
5. Subsequent floods may result in a new waterway being cut in the vicinity of Jerseyville into Tidal or Cox’s Creek.
6. The principal causes of erosion are:
   - Floods
   - Wind-wave action
   - Tidal currents
   With minor contributions by:-
   - River traffic
   - Shoaling of the straighter reaches of the river
   - Removal of natural protective cover and cultivation of banks
   - Cattle grazing
7. Dredging has not caused the erosion but may have intensified erosion in some locations.
8. Remedial measures are called for if erosion is to be prevented
9. Cost is estimated to be £20,250 per annum with total costs of £225,000
10. Remedial measures in most cases are beyond the financial means of frontage landholders
11. The serious erosion seen on the Macleay is evident on other coastal streams
12. Due to regional scale of problem expenditure of public funds to determine effective means of protection is justified
These twelve major findings vary to other sources of information presented within the report and are therefore discussed in greater detail.

In 1934 it was estimated by Mr. Greg Brooks (Supervising Engineer, Department of Public Works) that 10.25 miles of riverbank (~ 16.5 km) were eroding in the Lower Macleay River. Of this, 9.5 km were rated as serious erosion (severe), 5.4 km of not so serious erosion (moderate) and 1.6 km of slightly eroded sections (minor). The 1934 report adopted and accepted the opinions of Mr. Greg Brooks with regards to the four primary causes of this erosion. Figure 15 highlights the approximate location of this erosion from maps presented within the 1934 report. This figure demonstrates that most of the areas of active erosion in 1934 are now predominantly stable — as a function of extensive rockwork (excluding Pelican Island, which is still actively eroding). A comparison of the 1934 figures with data presented in Section 5 demonstrates that there has been an increase in the spatial extent of bank erosion seen throughout the Lower Macleay River since 1934 (Table 3).

<table>
<thead>
<tr>
<th>BANK EROSION</th>
<th>Minor (km)</th>
<th>Moderate (km)</th>
<th>Severe (km)</th>
<th>TOTAL</th>
</tr>
</thead>
<tbody>
<tr>
<td>1934</td>
<td>1.6</td>
<td>5.4</td>
<td>9.5</td>
<td>16.5</td>
</tr>
<tr>
<td>2004</td>
<td>18</td>
<td>4</td>
<td>3</td>
<td>25</td>
</tr>
<tr>
<td>% change</td>
<td>+1025</td>
<td>-26</td>
<td>-68</td>
<td>+52</td>
</tr>
</tbody>
</table>

Caution must be exercised in this style of comparison, as the increase is primarily a function of the large increases in minor bank erosion. This in turn may simply reflect differing methodologies and definitions of ‘minor’ bank erosion and a reduced extent of the spatial survey. Importantly, these comparisons highlight that there has been a 26 % and 68 % reduction of moderate and severe bank erosion respectively since 1934.

In addition to the four major causes of bank erosion, Mr. Greg Brooks (Departmental Committee on Erosion – Macleay River Erosion, 1934, p.4) also identified large overhanging trees, destruction of protective cover by cattle, cultivation of the banks below flood levels, crabs and the formation of shoals in the straight reaches of the river as additional causes of bank erosion. Dredging however, was not stated as a contributing factor due to the fact that it had not occurred within 45 ft of the bank. This opinion differed to those presented by landholders who in 1934 attributed the erosion to:

1. Floods
2. Dredging, too near high banks
3. Wind-wave action set up by prevailing winds
4. Tidal currents
5. Wash from river traffic
6. Diversion of channels consequent on accretions of flood debris
7. Removal of timber and the like cover from frontage lands
8. Cultivation of banks too close to river edge
9. Presence of hull of “Lady Beatrice” in river
10. Crabs

Dredging of the river channel was identified as the second most important mechanism for initiating erosion on the Lower Macleay River. At the time of the 1934 report
dredging was occurring to preserve navigation to a depth of 9 feet. This tended to occur at the crossings. Indeed, the specifications for dredging in the early 20th century indicate a technique similar to the removal of riffles in non-tidal reaches with an overall shortening of the thalweg (Figure 16). This form of localised channel shortening — in addition to the complete removal of shoals — certainly would have promoted localised gradient adjustments and/or re-orientation of the thalweg (see comments by Whalen, H in Departmental Committee on Erosion – Macleay River Erosion, 1934, Appendix A). Furthermore, the 1934 report identified that 440,650 tonnes of sediment were dredged between 1929 and 1934. It does not however, specify how much of this sediment was exported from the system totally or simply relocated to the channel margin as ‘spoil’. A further 812,000 tonnes were dredged over a twenty year period from 1943 – 1963 (Public Works Department Macleay River dredging file – R1029/7).

**Figure 15** Current distribution of bank erosion with approximate locations of 1934 bank erosion.
Figure 16 Specifications for the tidal dredging of shoals for the Lower Macleay River (sourced from Departmental Committee on Erosion – Macleay River Erosion, 1934).

It is safe to assume that the direct physical impacts of dredging in the early 20th century and the potential indirect impacts on sediment supply would have had profound implications for bank stability. Following the 1934 report instructions were given that no dredging should be carried out within 100 feet of riverbanks and that the ends of navigable channels at river crossings be “eased off”. It is unlikely however, that these modified dredging operations prevented further bank instability.

It is clear from the 1934 report that the Macleay River had already undergone a series of large channel changes in the early 19th century. These included an unquantified extent of bank erosion in the fluvial process zone following the 1864 flood and the formation of a new entrance south of Grassy Head in 1893 — essentially straightening the mouth of the estuary (Departmental Committee on Erosion – Macleay River Erosion, 1934, Appendix A). These channel changes, along with the onset of dredging, resulted in large areas of the channel margin becoming unstable by the early 20th century. The cause of these early changes was most likely related to changes to the overall boundary conditions of the Lower Macleay River (i.e. reduction in bank strength and floodplain roughness), but triggered by large flood events and maintained by wind wave action.

6.2 Sedimentation patterns of the Lower Macleay River

Little to no quantitative information exists on sediment loads for the Macleay River in either the tidal or non-tidal reaches. Furthermore, only rudimentary records exist for the volume of material extracted from the river. While the 1934 report provides an assessment of tidal dredging volumes for a short period in the early 20th century
Patterson Britton & Partners (2003) provide an indication of the volume of aggregate material being extracted from the non-tidal reaches (i.e. the source zone for the estuary).

Current extraction licenses for the non-tidal reaches between Toorooka and Belgrave Falls amounts to 86,000 m³/yr but with only 123,610 m³ actually extracted between 1997/98 and 2001/02 (in contrast to the 311,000 m³ that was permitted to be extracted). This equates to 24,722 m³/yr since 1997, which is approximately 7,000 m³ over the estimated annual transport rate of Laronne and Gurion (1994 – cited in Patterson Britton & Partners, 2003) or 4700 m³ over the annual rate estimated by Patterson Britton & Partners (2003). In either case, the estimated annual transport rate is extremely poorly quantified and should be considered unreliable. The net result is that there is little data that allows the quantification of sediment entering the estuary.

Ashley and Graham (2001) provide some context as to where the fine-grained sediment in the estuary is sourced. Their analysis of heavy metals and isotopic signatures identified a distinct downstream dispersal trend for Antimony (Sb) and Arsenic (As). Antimony values remain 3 – 90 times background from Bakers Creek in the upper catchment right down to the Pacific. In contrast, As values remain at 1.5 times background (primarily derived from Hillgrove mineral field). Importantly, their analyses highlighted the nature of floodplain sedimentation in the estuary with the preferential accumulation of sediment (and associated heavy metals) on the southern side of the Macleay River, downstream of Kempsey (e.g. in levees and backswamps such as Belmore swamp). Backswamps on the northern side of the river (e.g. Doughboy Swamp) appear to have been little affected by contaminated sediment from the Macleay River (Ashley and Graham, 2001). Their floodplain cores on the southern side showed a 15 times background Sb enrichment and 4 times background for As. Furthermore, they demonstrated that levees on the southern side had accumulated a greater volume of sediment (and associated heavy metals) than the backswamps.

Their preliminary findings indicate some important sedimentation patterns for the Lower Macleay River that ultimately reflect flooding patterns. The preferential accumulation of heavy metals on the southern floodplains and swamps suggest that either the drainage works in Clybucca Swamp are more effective in draining floodwaters than on the southern side, thus reducing rates of sedimentation. Or alternatively, the flood mitigation scheme diverts significant quantities of floodwaters to the southern floodplains and backswamps that previously were distributed over Clybucca swamp via Seven Oaks. Floodplain and estuary sediments exceed ISQG guidelines for Sb however their analyses did not detect metal uptake into edible tissue above food quality guidelines. As such, their investigation is continuing on the behaviour of Sb and As in floodplain and estuary sediments and the potential for uptake into plants and grazing animals. The study by Ashley and Graham demonstrates the importance of understanding sediment storage in both the tidal and non-tidal reaches. It is clear that there have been large-scale channel changes along with significant changes to the nature of floodplain sedimentation on the Lower Macleay River. The following section briefly assesses areas of accelerated channel change while relating these changes to in-channel sediment storage.
6.3 In-channel sediment storage on the Lower Macleay River

There has been no systematic compilation of historical channel changes of the Lower Macleay River, despite the extensive post-European modification. Indeed there is no synthesis of the changes to channel dimensions or planform of the Lower Macleay River. Isolated comparisons of hydrographic surveys from the 1950s show variable results with both increases and decreases in waterway area. Very few hydrographic surveys have demonstrated cross-sectional or longitudinal changes in bed elevation. Figure 17 presents a longitudinal profile of the Macleay River trunk stream from Belgrave Falls to the mouth (based on bathometrically derived cross-sections spaced at 1 km intervals).

![Figure 17](image)

**Figure 17** 2003 Longitudinal profile of the thalweg of the Macleay River trunk stream from Belgrave Falls to the mouth — with linear regression (slope = 0.0006). Topography derived from bathometric data (source: DIPNR).

Even at this coarse resolution the longitudinal profile still highlights the nature of in-channel sediment storage along the Macleay trunk stream. A linear regression indicates areas of positive and negative residuals (i.e. areas of the channel bed above or below the line of best fit). These correspond to areas of net sediment storage and scour respectively with each of the three process zones having distinct sediment storage patterns. The three reaches within the Fluvial process zone are characterised by alternating locations of sediment accumulation and scour. Fluvial reach 1 (F1) is characterised by deep pools (10 – 12 m) while Fluvial reach 2 (F2) is predominantly characterised by sediment accumulation (Kempsey Bridge to Seven Oaks Bend – Figure 17). Sediment is preferentially scoured from the lower half of Fluvial reach 2 and deposited in Fluvial reach 3 (around Kinchela Bend). The transitional process zone is also characterised by zones of sediment accumulation (e.g. Pelican Island – Figure 17) whereas the marine flood-tide process zone is predominantly characterised by net scour. This is presumed to be a function of tidal scour of the marine sands and the increased flushing efficiency provided by the training walls.
Figure 17 provides a ‘snap shot’ of sediment storage patterns along the Lower Macleay River in 2003. It does not however, provide an indication of how these longitudinal patterns have changed through time. The sand and silt eroded from the banks and floodplains of the Middle and Upper Macleay River throughout the 20th century have been transported into the estuarine reaches and then re-distributed by later floods and tidal processes. Ultimately, it is these temporal and spatial patterns of sediment redistribution that determine current estuarine dynamics.

6.4 Sites of accelerated channel change on the Macleay River

This section reviews the nature and extent of planform changes (derived from ortho-rectified historical photographs) for the two most actively eroding sections identified in Section 5 (Kinchela Bench and Fattorini Island). These rectified images provide a data source in which to quantify rates of bank erosion within a ± 4 m error between individual photos. It draws upon the 1942, 1956, 1974, 1982, 1997 and 2003 aerial photographs. The 1942 photograph provides an indication of channel dimensions in a period of below-average flood activity prior to the large floods in 1946, 1949 and 1950. The 1956 and 1974 photographs represent a period of above-average flood activity while the 1982 – 2003 photographs represent another period of below-average flood activity.

6.4.1 Kinchela Bench

Kinchela Bench — as identified in Section 5 — is the most actively eroding section of the Lower Macleay River with the unusual occurrence of bench erosion on the inside of the bend. An analysis of the ortho-photographs indicates that the low bench at Kinchela Bend has eroded by up to 37 m since 1942. The greatest rate of bank erosion between individual time periods occurred between 1942 and 1956 at the apex of the bench — directly opposite Kinchela village (Figure 18). This rate of erosion has slowed at the apex since 1974 but increased at the upstream limb (immediately downstream of the Kinchela Creek confluence – Figure 18). It is most likely that the concave bank at Kinchela was rocked following the recommendations of the 1934 report. As such, the outer bank at Kinchela became resistant to erosion, halting rates of concave bank erosion and promoting the erosion of the inner bend. Net gains of fluvial sediment (i.e. bed aggradation) in this section of Fluvial Reach 3 will ultimately result in an adjustment of channel dimensions with the preferential erosion of the inner bend (the only deformable channel margin).

While large floods appear instrumental in shifting sediment into this reach and eroding the bench margin, it is clear that wind and/or boat waves also actively erode this site. A bank exposure experiment over a 72–hour period (with a prevailing southerly wind) clearly demonstrated the importance of wind and/or boat waves in eroding Kinchela Bench at mid-high tide (Figure 19a-b). This experiment further indicated the notching of a sand unit immediately overlying the basal estuarine clays resulted in active (~ 1 m) block failure (Figure19c-d). The basal estuarine clay unit eroded marginally (< 5 cm) over the 72–hour period but the notching of the overlying sand units produced the rapid rate of bank collapse. The Kinchela Bench therefore, is most susceptible to waves of any kind (southerly and northerly generated wind waves and boat waves) at mid-high tide.
Figure 18 Ortho-photograph of Kinchela Bench in 1942 with channel margin locations for 1956 – 2003 (derived from ortho-photographs). Flow is from bottom to top.
Figure 19  Bank exposure experiment at Kinchela Bench.  a) Clean vertical exposure on 19/11/04;  b) Notch development in 72 hours from a southerly wind;  c) – d) Erosion of sandy alluvium overlying the basal clays results in undercutting with subsequent block failure.
6.4.2  Fattorini Island

Fattorini Island has also undergone major changes since 1942 with an overall reduction in island size, but with the greatest changes occurring at the head and tail of the island (70 and 35 m respectively; Figure 20). As with Kinchela Bench, rates of erosion at Fattorini Island varied spatially with the greatest rate of erosion between an given time interval occurring in the period from 1942 – 1956. This period of enhanced flood activity occurred when there was little to no riparian vegetation, increasing the susceptibility of the riverbanks to ongoing erosion, resulting in the loss of 6000 m$^2$ (~1.5 acres) of land at the head of the island (Figure 20). In contrast, the tail of the island has experienced the greatest rates of erosion since 1982. The erosion of Fattorini Island has been further compounded by the prevalence of rock on the outer bend making Fattorini Island more likely to erode. It is most likely that Fattorini Island will continue to erode from fluvial processes and from wind and/or boat waves at both low and high tide given the rocked outer margin, the evidence of bed aggradation upstream of Fattorini Island (Figure 17) and the current ‘deep water’ bank profile.

7.0  A Summary of Condition for the Macleay Process Zones

Table 4 presents a summary of the physical condition of each of the process zones, based on extent and types of erosion, the extent of ‘naturally’ stable banks and the spatial distribution of riparian vegetation. It provides a snap shot of the current physical condition and presents an indication of the future impacts and the likelihood of physical improvement. In general, the marine flood-tide process zone is in the best physical condition with the highest percentage of naturally stable banks and the least amount of erosion. In contrast, the fluvial process zone is in poor-moderate condition and has the greatest extent of erosion, extensive rockworks, major levee alteration and major tributary modification. The transitional process zone is also in poor condition with the greatest percentage of rocked stable banks, major levee alteration, little to no native riparian vegetation on the trunk stream and major tributary modification.
Figure 20 1942 ortho-photograph of Fattorini Island with channel margin locations for 1956 – 2003 (derived from ortho-photographs). Flow is from bottom to top.
Table 4 Summary of the physical condition of the process zones of the Macleay Estuary

<table>
<thead>
<tr>
<th>PROCESS ZONE</th>
<th>PRIMARY CHARACTERISTICS</th>
<th>NATURE OF IMPACTS</th>
<th>CONDITION</th>
<th>RECOVERY POTENTIAL</th>
</tr>
</thead>
</table>
| FLUVIAL      | • Three reaches dominated by fluvial processes.  
• Reach 1 – Gravel bed reach, confined with bedrock outer margins. Localised mass failure of entire alluvial channel margin, controlled by fluvial processes.  
• Reach 2 – Gravel-sand bed reach. First major depositional reach in the process zone. Onset of wind and/or boat wave erosion. Extensive rockwork.  
• Reach 3 – Sand bed reach with extensive rockwork, in-channel sedimentation. Slab-and-block failure of inset features (e.g. Kinchela Bench, Fattorini Island). | • Greatest extent of erosion and only occurrence of severe erosion.  
• 22% of stable banks are rocked.  
• Reach 1 – aggregate extraction, widespread stock impacts.  
• Reach 2 – dredging of main channel, levee construction, channel expansion. Belmore River and Kinchela Creek modified severely by drainage works. Loss of continuous native riparian zone.  
• Reach 3 – dredging of main channel, levee construction. Loss of continuous native riparian zone. | Poor-moderate | • Reach 1 – Moderate. This reach has bedrock outer channel margins which are well vegetated and naturally stable.  
• Reach 2 – Poor. This reach is greatly modified with large lengths of channel margin that are rocked and/or lacking riparian vegetation. Given its landscape position, this reach will always be a major depositional zone.  
• Reach 3 – Poor. This reach will also receive ongoing terrestrially-derived sediment | |
| TRANSITION   | • Dominated by fluvial and marine processes with the presence of marine-derived shoals reworked by tidal processes.  
• Formation of intertidal flats. | • High percentage of rockwork on the Macleay River with active minor and moderate erosion on remaining alluvial margins.  
• 43% of stable banks are rocked.  
• Loss or alteration of levees.  
• Tributary modification.  
• Widespread stock impact.  
• Erosion dominated by wind and/or boat waves. | Poor | • Macleay River – Poor. The high proportion of rock and the diminished riparian zone results in a greatly modified channel margin. Sediment supply from the fluvial process zone along with marine-derived sediment will also result in continued erosion of alluvial channel margins (e.g. Pelican Island). | |
| MARINE       | • Dominated by marine processes with the presence of marine-derived shoals reworked by tidal processes. Formation of sand and intertidal flats. | • Lowest percentage of erosion and highest percentage of naturally stable banks.  
• Localised stock impacts.  
• Wind and/or boat wave disturbance. | Moderate-good | • Macleay Arm – High. The large extent of native vegetation and naturally stable banks will increase the potential to improve the physical condition |
8.0 GAPS IN THE DATABASE RELEVANT TO RIPARIAN LAND MANAGEMENT, BANK EROSION AND SEDIMENTATION ISSUES

The data compilation and mapping stage has identified a number of important key gaps in the existing database for the Lower Macleay River. These gaps relate to critical questions regarding riparian land management, bank erosion and sedimentation. As these issues are inter-dependent they will be collectively outlined below.

The causes and preferred treatment options for a range of typical bank erosion scenarios cannot be answered at present as this study has only qualitatively assessed the primary causes of erosion in the Lower Macleay River, which are:

- Fluvial processes
- Wind and/or boat waves
- In-channel sedimentation
- Stock disturbance/reduced riparian vegetation
- Presence of rockwork on adjacent banks

It is important to note however, that very few alluvial channel margins (especially in Fluvial Reach 2 and 3 and the transitional process zone) have riparian vegetation with any structural or floristic integrity, greatly reducing bank strength in most locations. Furthermore, these primary causes have been shown to vary between process zones indicating that there is no one major cause of erosion for the entire Lower Macleay River.

The Lower Macleay River, as shown in Section 6.0, has undergone major direct modification throughout the 20th century. In addition, the middle to upper Macleay River has also been vastly transformed since European settlement, resulting in a greatly modified sediment supply regime. Both these factors partly determine where sedimentation and bank erosion currently occurs. To date however, there has been very little compilation of this information in which to make an informed assessment of the primary causes of erosion and sedimentation in the Lower Macleay River. It is this historical context that will provide an important insight into current channel processes. Hence, it is suggested that the following gaps be addressed in the context component of the process study.

1. Systematic collation of planform changes for the Lower Macleay River. This should focus on all styles of lateral adjustment (i.e. channel expansion, changes to meander wavelength, sinuosity within each of the three process zones) and should include the georeferencing of historical parish maps and/or portion plans. This will provide the context to current channel processes.

2. Systematic collation of historical hydrographic surveys demonstrating where bed elevations have changed.

3. Examination of changes to bankfull cross-sectional capacity at areas of accelerated change and representative sections of process zones. This should use photogrammetrically derived topographic data and should be compared with permanent bench-marked cross-sections (see following recommendations).
4. Systematic collation of the nature and timing of tidal dredging in the Lower Macleay River (*i.e.* how much, where and when?). This component should also aim to determine what proportion was entirely removed from the system.

In order to more confidently determine the causes of current bank erosion it is suggested that a number of process-based investigations be undertaken. These include:

1. Detailed topographic analysis from current bathometric data (*i.e.* cross section every channel widths distance) on trunk stream with an equivalent analysis on tributaries (*i.e.* Clybucca Creek, Belmore River and Kinchela Creek). This will provide a more thorough assessment of current sediment storage patterns.

2. Construct a sediment budget for the Lower Macleay River from the bathometric data, floodplain topographic data and the ortho-photographs. This should aim to assess sediment storage in each of the identified process zones while also incorporating current research undertaken by Ashley and Graham from UNE.

3. Determine the relative contribution of wind and boat waves for deep and shallow water profiles. A controlled experiment (*sensu* Nanson et al., 1994) in targeted areas that measures wave height, wave direction, wind speed and wind direction, bank erosion, sediment production and turbidity will quantitatively determine the relative contribution of wind and boat waves for the Lower Macleay River.

4. Establish permanent bench-marked cross-sections from floodplain to floodplain in areas of accelerated change and in representative sections of each process zone. These should be located using differential GPS and marked adequately for long-term monitoring.

A process study that investigates both the historical and current bank erosion processes will ultimately provide Kempsey Shire Council and DIPNR a more valuable database in which to make and develop management policies relevant to bank erosion and sedimentation.
9.0 REFERENCES:


Department of Lands (1934). Report by Departmental Committee on Erosion – Macleay River Erosion.


Walker, P.H. (1963) A reconnaissance of soils in the Kempsey District, N.S.W. CSIRO Soils and Land Use Series, 44.