Geomorphology and Sediment Dynamics

As discussed in Section 3.5, the three estuaries in the study area can be generally described as intermittent saline coastal lagoons (often referred to as intermittently open and closed lakes and lagoons: IOLLS). Under this classification Woolgoolga Creek is at an intermediate evolutionary phase with an as yet unfilled central mud basin (Woolgoolga Lake), while both Darkum and Willis creeks can be considered to be at a mature evolutionary phase and are essentially now saline coastal creeks.

The current morphology of the estuaries in the study area can be broken into four broad process zones that reflect differing degrees of fluvial, tidal and marine interaction. These include the:

- Marine Tidal Delta Process Zone which is common to all three estuaries;
- Estuarine Basin Process Zone which is confined to the Woolgoolga Lake estuary and which covers Woolgoolga Lake;
- Fluvial Transition Process Zone which occurs in the upper reaches of Woolgoolga and Poundyard Creeks, and
- Saline Coastal Creek Process Zone which occurs in Darkum and Willis Creek for the full length of the estuaries above the Marine Tidal Delta Process zone.

The distribution of the four identified process zones is shown in Illustration 5.1.

5.1 Geomorphic Process Zones

5.1.1 Marine Tidal Delta Process Zone

The Marine Tidal Delta Process Zone is dominated by marine-derived sediment sourced from the inner continental shelf and from the coastal barrier systems (refer to Plate 5.1-B). Tidal currents and wave action are the main forces that shape the estuary in this zone, however their relative effect depends on the entrance conditions. During periods of flooding all three creeks are capable of breaching the entrance berm and, while the entrance is open, scouring of the channel can occur resetting the patterns of shoaling in the creeks. While the entrance remains open, the sands forming subtidal dunes/shoals migrates upstream on the incoming tide and is partly reworked on the outgoing tide. By this process, sands ingress into the estuary at a rate generally determined by the degree of entrance opening, tidal velocities, and the supply of sand to the entrance through littoral and longshore transport.

In this zone bank heights are generally low (0.5 – 1.5m). Intertidal flats composed of a mix of marine sand and fine-grained (terrestrially sourced) estuarine sands and mud do occur but are not extensive in any of the three estuaries. The Darkum and Willis Creek channels run between the coastal barrier dune and back barrier dunes and flats, whilst the Woolgoolga Creek channel abuts bedrock on its northern margin (Troedson et al., 2004). Outside of bedrock areas, the sandy channel margin is easily eroded by floods, tidal scour or storm surges and it is in this zone that the majority of minor erosion was observed during the field survey (see below).

5.1.2 Estuarine Basin Process Zone

The Estuarine Basin Process Zone occurs only in Woolgoolga Lake estuary, essentially covering the reach of the creek that forms Woolgoolga Lake. This zone is a low-energy environment where tidal influences are generally balanced with fluvial influences although the long term trend is one of slow infilling with terrestrially sourced sediments. Sediments transported from the upstream Fluvial Transition Process Zone settle in the lake resulting in bed sediments dominated by fine sands, silt, estuarine shells, and organic material. These sediments are
periodically resuspended during floods or, where depths are less than 2 m, stirred up by wind waves. As a result, nutrient loadings and turbidity can be high. The channel bed forms are relatively planar although a depositional front can often be observed where the upstream confined sections of the Fluvial Transition Process Zone channel enters the embayment.

5.1.3 Fluvial Transition Process Zone

The Fluvial Transition Process Zone again occurs only in the Woolgoolga Lake estuary (including Woolgoolga Creek and Poundyard Creek). This process zone represents the transition from the upstream freshwater system to the estuary. Tidal influences are reduced in this zone, becoming almost negligible in the upper-most reaches. Consequently, channel form and sediment transport is mostly driven by floods although stream energy is low due to the negligible slope of the creek in this location. The channel generally cuts through Holocene floodplain deposits although occasionally abuts older Pleistocene terraces, coffee rock, or bedrock (Troedson et al., 2004). The channel bed is heterogeneous with deeper pools on outside bends and various subaqueous gravel shoals. Small areas of bank undercutting and subsequent tree fall and minor erosion were observed in this zone but mostly the channel was stable (refer to Section 5.2). Rock protection works were recorded in several locations.

At the upstream extent of this zone fluvial features such as mid-channel and point bars composed of coarse angular gravels and coarse to fine sands are common (refer to Plate 5.1-A), and the banks are vegetated with structurally diverse riparian vegetation. Banks are generally steep with heights in the range of 2 – 3 m. In the lower reaches of this zone, small back channels and low swamp floodplains occur, often supporting saline or freshwater wetland communities or mangroves. Bank heights in the lower reaches reduce to 1 – 2 m. The deepest part of the channel is approximately 2 m and corresponds to a constriction in the channel close to the footbridge near Lakes Road where coffee rock forms the eastern bank of Woolgoolga Creek.

Plate 5.1 Examples of process zones within the Woolgoolga, Darkum, and Willis Creek estuaries. A) Fluvial Transition process zone, upper Poundyard Creek. B) Marine Tidal Delta process zone, lower Woolgoolga Creek. C) Saline Coastal Creek process zone, mid Darkum Creek. D) Saline Coastal Creek process zone, lower Willis Creek.
Broad Geomorphic Process Zones Occurring in the Darkum, Woolgoolga and Willis Creek Estuaries

LEGEND
- Estuary catchment boundaries
- Estuarine Basin
- Fluvial Transition
- Marine Tidal Delta
- Saline Coastal Creek

Information shown is for illustrative purposes only.

Source of base data: Coffs Harbour City Council
5.1.4 Saline Coastal Creek Process Zone

The Saline Coastal Creek Process Zone is very similar to the Fluvial Transition Process Zone described above for the Woolgoolga Lake estuary, but occurs in the Darkum and Willis creek estuaries. The main differentiating features are that the Saline Coastal Creek Process Zone is a lower energy environment having a mostly closed entrance (and therefore reduced tidal influence) and a smaller catchment (and therefore lower energy fluvial environment). This zone essentially represents the mature phase of an intermittent saline coastal lagoon estuary and the creek form is basically maintained through to the Marine Tidal Delta without flowing through a central mud basin. Depositional features are similar to the Fluvial Transition Process Zone with mid-channel bars and subaqueous deposits of coarse gravel and sands in the upper reaches grading to finer gravels, sands, and silts in the lower reaches.

Of the two estuaries, Willis Creek is the lowest energy system and is flanked by extensive low Holocene swamps and Pleistocene back barrier flats (refer to Plate 5.1-D). Darkum Creek is flanked by higher floodplains in its upper reaches (refer to Plate 5.1-C) with occasional bedrock outcropping on the northern channel margin, with more developed low floodplains and backswamps in the lower reaches, before flowing between the coastal barrier and back barrier dunes downstream of the walk bridge. The low energy environment means that the channel is stable with virtually no erosion observed during the field survey (refer to Section 5.2).

5.2 Bank Erosion

5.2.1 Analysis of Channel Change 1942–2009

Analyses of the extent of channel width change within the three estuaries over the available period of aerial photography (1942–2009) have not been possible within the timeframe of the current study. This analysis will be undertaken as a component of the Estuary Management Study phase. Gross changes in channel width and planform are not expected to be revealed in any of the three estuaries due to the relatively small catchment sizes, low energy environments, and stable bank conditions observed during the field assessments (detailed below).

5.2.2 Bank Erosion Mapping

Bank erosion was determined using a kayak and handheld GPS in January 2011. Bank erosion severity and probable failure mechanism were recorded for each location. In addition, bank erosion control works were recorded as were natural channel features contributing to stability such as the presence of bedrock or coffee rock. Absolute locations of bank erosion are estimated to be accurate within ±20 m. The entire study area represents 16.4 km of riverbank.

Three main types of bank erosion were identified, with many sites exhibiting evidence of two or all processes:

- Slab type block failure which results from either: inundation and subsequent slumping; or from fretting from constant wave action (wind or boat) and subsequent undercutting and failure. Material generally remains in-situ;
- Scour and undercutting which results from high velocity flows often acting on the bank toe. Material does not remain in-situ. Scour associated with major flooding can remove the evidence of slab type block failures. Undercutting may also cause tree falls; and
- Access impacts which may result in small areas of minor disturbance or erosion or loss of vegetation.

The categories of severity of erosion used were:

- Minor: where erosion had occurred but the processes which led to the erosion were now considered dormant and evidence of natural recovery (such as mangrove colonisation) was apparent;
- Moderate: where erosion had occurred but the processes which led to the erosion were now considered dormant but evidence of natural recovery (such as mangrove colonisation) was not apparent; and
- Severe: processes causing erosion were continuing and evidence of natural recovery mechanisms was not apparent.
The spatial extent of bank erosion in the three estuaries is presented in **Illustration 5.2**.

**Illustration 5.2** shows that the estuary bank erosion in the study area is limited to minor erosion with the majority occurring in the Marine Tidal Delta barrier process zone of all three estuaries (Plate 5.2- A and B). **Table 5.1** and **Table 5.2** present a summary of the results of the bank erosion field survey. The data highlights that 95% (15.5 km) of the area surveyed is stable with 5% (0.9 km) described as having minor erosion evident. No moderate or severe erosion was identified indicating that bank erosion is not a significant issue within the study area. Approximately 1.8% of stable banks were stabilised by erosion control works such as rock revetment (Plate 5.2-C), while 4.8% were naturally stable as a result of bedrock outcropping on the channel margin. This suggests that 93% of the creek banks are naturally stable (i.e. stable without the use of erosion protection works).

**Table 5.1**  Severity of bank erosion by estuary system in the Darkum/Woolgoolga/Willis Creek study area (mapped January 2011)

<table>
<thead>
<tr>
<th>Estuary</th>
<th>Total length (m)</th>
<th>Stable (m)</th>
<th>Min. (m)</th>
<th>Mod. (m)</th>
<th>Severe (m)</th>
<th>% Stable</th>
<th>% Min.</th>
<th>% Mod.</th>
<th>% Severe</th>
<th>% stable= works</th>
<th>% stable= bedrock</th>
</tr>
</thead>
<tbody>
<tr>
<td>Darkum Creek</td>
<td>5045</td>
<td>4608</td>
<td>437</td>
<td>-</td>
<td>-</td>
<td>89</td>
<td>9</td>
<td>-</td>
<td>-</td>
<td>2%</td>
<td></td>
</tr>
<tr>
<td>Woolgoolga Creek</td>
<td>7957</td>
<td>7875</td>
<td>82</td>
<td>-</td>
<td>-</td>
<td>91</td>
<td>1</td>
<td>-</td>
<td>-</td>
<td>3.5%</td>
<td>8%</td>
</tr>
<tr>
<td>Willis Creek</td>
<td>3379</td>
<td>2998</td>
<td>381</td>
<td>-</td>
<td>-</td>
<td>89</td>
<td>11</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>TOTAL</td>
<td>16381</td>
<td>15481</td>
<td>900</td>
<td>-</td>
<td>-</td>
<td>95</td>
<td>5</td>
<td>-</td>
<td>-</td>
<td>1.8%</td>
<td>4.6%</td>
</tr>
</tbody>
</table>

**Table 5.2**  Severity of bank erosion by estuary system in the Darkum/Woolgoolga/Willis Creek study area (mapped January 2011)

<table>
<thead>
<tr>
<th>Process Zone</th>
<th>Total length (m)</th>
<th>Stable (m)</th>
<th>Min. (m)</th>
<th>Mod. (m)</th>
<th>Severe (m)</th>
<th>% Stable</th>
<th>% Min.</th>
<th>% Mod.</th>
<th>% Severe</th>
<th>% stable= works</th>
<th>% stable= bedrock</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fluvial Transition</td>
<td>5122</td>
<td>5059</td>
<td>63</td>
<td>-</td>
<td>-</td>
<td>99%</td>
<td>1%</td>
<td>-</td>
<td>-</td>
<td>2.5%</td>
<td>8.1%</td>
</tr>
<tr>
<td>Estuarine Basin</td>
<td>1788</td>
<td>1788</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>100%</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Marine Tidal Delta</td>
<td>2072</td>
<td>1409</td>
<td>663</td>
<td>-</td>
<td>-</td>
<td>68%</td>
<td>32%</td>
<td>-</td>
<td>-</td>
<td>7.3%</td>
<td>10.6%</td>
</tr>
<tr>
<td>Saline Coastal Creek</td>
<td>7400</td>
<td>7225</td>
<td>175</td>
<td>-</td>
<td>-</td>
<td>98%</td>
<td>2%</td>
<td>-</td>
<td>-</td>
<td>1.5%</td>
<td></td>
</tr>
</tbody>
</table>
Bank Erosion Severity in the Darkum, Woolgoolga and Willis Creek Estuaries (Mapped January 2011)
Plate 5.2  Typical examples of minor bank erosion in the Marine Tidal Delta Process Zone.  
5.3 Estuary Sedimentation

Under natural conditions sediment supply to small coastal estuaries is relatively low and episodic (i.e. related to larger flood events) and as a result channel infilling processes are slow. Generally, fluvial sediment input is limited by catchment size and hydrological and land use factors. Marine inputs are also limited and dependent upon entrance conditions.

Plate 5.3 shows the longitudinal profiles of Darkum Creek and Woolgoolga Creek based on bathymetrically derived cross-sections collected in 2004 by the then Department of Commerce. No data is available for Willis Creek estuary. The longitudinal profiles show the nature of in-channel sediment storage in each system. The approximate slope of the creek channel is indicated on each figure. Areas of the channel bed closest to this line correspond to areas of net sediment storage while areas furthers from the line represent areas of channel scour.

Plate 5.3 2004 Longitudinal profile of the thalweg (deepest point in the channel) of Darkum Creek (top chart) and Woolgoolga and Poundyard Creeks (bottom chart).
Plate 5.3 provides a ‘snap shot’ of sediment storage patterns along the two estuaries in 2004 and as such does not indicate how these longitudinal patterns have changed through time. It is a commonly expressed community view that the estuary has “silted up” in recent years (e.g. the community forum held at the Woolgoolga Community Centre on 14 September 2010). Unfortunately there is no historic quantitative data with which to compare the 2004 bathymetry. Consequently it is not possible to confirm quantitatively the changes to sedimentation patterns or whether the rate of infilling is significantly above “natural” long-term trends. However, given that significant changes to catchment landuse and hydrology have occurred throughout coastal NSW and the Coffs Harbour region over the past century it is likely that rates of sedimentation are above what would have been observed in the absence of these changes.

5.4 Impacts of Climate Change

Climate change is expected to impact on marine and fluvial sediment processes and foreshore erosion. However the resultant changes to marine and fluvial features is uncertain.

Sea level rise will result in an increase in entrance channel depth which will allow marine sediment to be transported further upstream due to reduced frictional bed resistance. However, increased water depth will also increase waterway area, and therefore reduce velocities within the channel resulting in an upward shift of the marine delta profile. Sea level rise may also result in a landward shift of the beach profile / estuary mouth (Haines and Thom, 2007). Therefore it is anticipated that there will be a general upstream shift in the location of the marine tide delta.

The expected increases in annual and seasonal rainfall totals (except for decreases in autumn - refer to Section 3.4) will result in an increase in fluvial sediment loads delivered to the estuary and potentially an increase in marine sediment loads delivered to the estuary due to higher rainfall resulting in a more open entrance. However, the expected increases in frequency of high rainfall events in summer and autumn (refer to Section 3.4) will result in an increase in scouring events. The impact of these processes may result in greater variation in bed levels between scouring events and a more frequent cycle between sediment build up in the estuaries and scouring of the sediment build up during flood events.
This page has been left intentionally blank