Macrochannel coastal plain transition in the Lake Illawarra Catchment, New South Wales

Kele Maher

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Macrochannel coastal plain transition in the Lake Illawarra Catchment, New South Wales

Abstract
Mullet creek, located on the south coast of New South Wales terminates in a shallow, wave dominated barrier estuary that developed during the Holocene. Sea level fluctuations have affected the current morphology of Mullet Creek not only in its delta, but also for a distance of approximately 8 km from the coast. During this investigation LiDAR data and subsurface sampling techniques have been used to investigate the alluvial terraces and macro-channel morphology, and transitional sedimentary sequences in the upstream floodplain and downstream channel reaches.

LiDAR revealed that an alluvial terrace is present in the mid to upper reaches in the Mullet Creek catchment, extending ~7 km from the foothills. This terrace provides evidence of higher sea level and examination of other terraces within the Lake Illawarra catchment indicates that terraces may provide evidence for sea level over two glacial cycles in this area. The results from subsurface sampling showed that the upstream study reach consists of an abandoned channel sequence and a buried Pleistocene floodplain sequence and sampling in the downstream channel reach has provided new evidence that the fluvio-deltaic sediments do not extent as far upstream of the delta as previously thought. Ground penetrating radar was also trialed in these setting but returned no useful results.

By conducting these investigations, the relationship between sea level, Mullet Creek and its current morphology can be better explain and used to predict how rising sea level will affect the system as a whole.

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Macro-channel coastal plain transition in the Lake Illawarra Catchment, New South Wales

By
Kele Maher

A thesis in part of the fulfillment of the requirements of the Honours degree of Bachelor of Science in the School of Earth and Environmental Sciences, University of Wollongong, 2011.
The information in this thesis is entirely the result of investigations conducted by
the author, unless otherwise acknowledged, and has not been submitted in part, or
otherwise, for any other degree or qualification.

Kele Maher
1st June 2011
Abstract

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By conducting these investigations, the relationship between sea level, Mullet Creek and its current morphology can be better explain and used to predict how rising sea level will affect the system as a whole.
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Macro-channel coastal plain transition in the Lake Illawarra Catchment, New South Wales
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1.1 Introduction

Fluvial systems that drain into oceans have an inherent relationship with sea level. To put it simply, as sea level rises, fluvial deposition decreases because of a decrease in channel gradient caused by the raising of base level. As sea level falls, incision, deposition and the development of deltaic environments increase and depositions cause them to extend further out into their receiving basin. The impacts of sea level fluctuations can be felt for kilometres upstream in a fluvial system (Twidale, 2004).

During the 20th century, it has been documented that surface air temperatures have increased by 0.6+/−0.2 °C (Houghton et al., 2001), enough to induce melting of small glaciers and grounded ice (Woodroffe, 2003), the result being an increase in sea level. Tidal gauge data has been collated over a number of centuries in some European cities (Pirazzoli, 1996), documenting the fact that sea level is indeed rising over the last few centuries. It has been predicted that globally, sea level will rise by 0.09-0.88 m by 2100 (Wigley and Raper, 1992; Douglas, 2001; Houghton et al., 2001). In light of the inevitable rise of sea level in the near future and the intricately related nature of sea level and fluvial systems it would be useful to know how a rise in sea level, subsequent raising and of base level and a decrease in stream gradient will affect the fluvial reaches upstream of its receiving basin.

This project will focus on a small coastal stream known as Mullet Creek that is located in the Lake Illawarra Catchment, flowing down from the escarpment and terminating in Lake Illawarra.

1.2 Aims & Objectives

The two aims of this project are to delineate the downstream extent of the alluvial terraces of Mullet Creek and to investigate the stratigraphy of the creek directly upstream of the Mullet Creek delta with the following objectives:
• Identify downstream characteristics of macro-channel morphology and link terrestrial macro-channel geomorphology with coastal deltaic plain development.

• Determine the extent of the marine influence and sediments upstream into the fluvially dominated regime.

• Trial the use of sub-surface geophysical techniques in the form of ground penetrating radar (GPR) in a fluvial floodplain setting.
Chapter 2 – Previous Research

2.1 Introduction

This chapter will focus on research previously undertaken in the Illawarra region with specific reference to Holocene sea level, the development to Lake Illawarra and the presence of macro-channels along Illawarra streams. It has been documented that sea level has not fluctuated in a uniform manner on a global scale throughout the Holocene (Fairbridge, 1961) and on a local scale Bryant (1992) suggested that Holocene sea levels in Australia ranged from +1.6 m in the north-west to +2.4 m in the south-east. Because of the variability in sea levels globally and locally, and the relationships between sea level and fluvial systems, previous research examined in this chapter will, for the most part, focus on local examples.

2.2 Sea Level history of Southeast Australia and landscape response

The rise and fall of sea level throughout earth’s history has played a vital role in landscape development on a variety of scales. Sea level not only has an effect on its immediate surroundings (i.e. coastal environments), but its effects are also felt by fluvial systems, sometimes hundreds of kilometres away (Twidale, 2004). For instance, a fall in sea level will create a new, lower base level and steeper stream gradient and will initiate downcutting of streams and erosive processes in fluvial systems. The effects of a fall in sea level will flow on to affect the amount of sediment received by the receiving basin (estuary, lagoon, lake, etc.) and the development of deltaic environments. During sea level lowstands coastal lakes and estuaries are infilled if the sediment being deposited is unable to be removed. This causes delta systems to build out towards the sea.

In contrast, during periods of rising or higher sea level, base level is raised resulting in a decrease in gradient for fluvial systems, erosive forces are greatly reduced, deposition is increased and aggradation may take place in some cases.
The receiving basin experiences a decrease in the deposition of sediments and delta systems retreats back towards the highstand coast (Summerfield, 1991).

This section will give an overview of the Holocene sea levels along the south east coast of Australia, specifically the Illawarra region, and coastal landforms that form as a consequence (e.g. estuaries, barrier systems and deltas) of changes in sea level. The influence of Holocene sea level will also be discussed in relation to its effects on fluvial systems in the region.

Sea level curves are a graphical representation of changes in sea level throughout geological history. Many researchers (Thom and Chappell, 1975; Thom and Roy, 1985; Sloss, 2005; Sloss et al., 2006) have investigated Holocene sea level fluctuations and consequently a number of different curves have been published over recent decades. For instance, Thom and Chappell (1975) (Figure 1) calculated that the post-glacial marine transgression in Australia ended between 6-6.5 ka, however, their interpretation was based on data that had not been corrected for the marine reservoir effect or calibrated to sidereal years. Thom and Roy published a revised sea level curve, which addressed these imperfections, in 1985. Their revised sea level curve was based on radiocarbon dated samples which suggested that the post-glacial marine transgression occurred up to 500 years earlier (6.5-7 ka) than previously suggested by Thom and Chappell (1975).
Sloss et al. (2007), after reinterpreting previously published data, found that following the last glacial maximum, sea level was approximately 15-11m below present mean sea level (PMSL) at the start of the Holocene, reaching current levels between 7900-7000 years before present (Sloss, 2005; Sloss et al., 2007). The sea continued to rise until it reached a maximum height of 1.5-2m above PMSL and this highstand lasted for a period of approximately 2000 years (Sloss, 2005; Sloss et al., 2007). Since this stable period, sea level has slowly returned to current sea level (Sloss et al., 2004; Sloss et al., 2007) and this can be seen Figure 2.
2.3 Estuaries

Barrier estuaries are a common occurrence along the southeast coast of New South Wales and are of particular interest and relevance to this project as Mullet Creek terminates in Lake Illawarra (Figure 3) a shallow, wave dominated barrier estuary. Holocene sea level has been an important factor in barrier system development along the southeast coast of Australia.
There have been a number of attempts to describe and model the evolutionary history of estuaries (Roy, 1984; Roy et al., 2001; Sloss, 2005; Hopley and Jones, 2006; Sloss et al., 2006). Roy et al (2001) produced a four stage evolutionary model for barrier estuaries based on basin infill (Figure 4). Stage one is described as a youthful estuary where infilling is minimal. This was followed by what is described as an intermediate estuary, characterized by the initiation of basin infilling and delta progradation. The third stage is considered to represent a semi-mature estuary that contains extensively developed floodplains as a result of delta progradation. The final stage represents a mature estuary that has been infilled as a result of continuing delta progradation, leaving cut-off embayments.
The four stage model produced by Roy et al (2001) was modified by Sloss et al (2005; 2006) after investigating the stratigraphy of Lake Illawarra (Figure 5). This model includes two additional stages of evolution including the Pleistocene fluvial incision and flooding of the incised Pleistocene channels in response to rising sea level. The second stage also includes the deposition of a transgressive marine sand sheet ca. 7.6-5 ka.
Figure 5 Revised evolutionary model of barrier estuaries including two additional phases of development (from Hopley, ca. 2011, after Sloss et al., 2005; 2006)
2.3 Deltas

Deltas are accumulations of fluvially-derived sediment deposited into a receiving body of water (e.g. ocean, gulf, lagoon, estuary or lake) (Summerfield, 1991; Woodroffe, 2003). These sediment bodies are partially subaerial and extend out from the shore in a seaward direction (Summerfield, 1991; Hopley, in prep.) They exhibit variable morphological and depositional patterns, which are a reflection of the many different forces acting upon them. The interaction of river, wave and tidal regimes are the major influencing factors affecting delta morphology and are also the basis for the most widely used classification of deltas.

The morphology of deltas can be linked to the domination of fluvial, wave and tidal influences and they have been classified accordingly by the work of Wright and Coleman (1973), Coleman (1975) and Galloway (1975). The three major classifications are river dominated deltas, tide dominated deltas and wave dominated deltas (Figure 6).

![Ternary diagram based on Galloway (1975) depicting the most common classification scheme of deltas.](image)

Some Holocene delta morphologies are indicated within the diagram. (from Hopley, ca. 2001, after Galloway, 1975; Pigott, 1995)
The morphology of the Lake Illawarra barrier system provides shelter for the development of Mullet Creek delta from marine influences, particularly wave energy, and reduces but does not eliminate the effects of tidal fluctuations. Lake Illawarra has two deltas, Macquarie Rivulet delta located in Haywards Bay and Mullet Creek delta that is located in Koong Burry Bay. These deltas are considered to have morphologies consistent with river-tide dominated deltas, meaning that they are influenced by both river and tidal factors.

Work by Sloss et al. (2005) proposed that river-tide dominated deltaic facies found in Lake Illawarra (specifically Mullet Creek delta) were consistent with re-worked inter-tidal sand flats, tidal channel sands and flood tide deltas. He proposed that the delta lacked fluvial influences and that the sediments within the delta are marine in origin. New evidence (Hopley, in prep.) indicates that these facies are in fact the product of fluvio-deltaic processes interacting with a rising sea level, which is evidenced by the stratigraphy of the delta.

The stratigraphic record of sedimentary facies obtained by Hopley (in prep.) shows that as sea level rose along the south east coast of Australia during the Holocene, the delta was eroded back toward the escarpment. As sea level began to fall again, the delta built out into the lake. Sea level continued to fall and floodplain or levee sediments were deposited where the land surface had become subaerially exposed leading to the current morphology of Mullet Creek delta.

2.4 Fluvial tidal transitions

Fluvial tidal transitions occur where river waters interact with the waters of the receiving basin, ultimately controlling the location of sedimentary deposition within the receiving basin and delta system (Hopley, in prep.). Interactions of the two water bodies are categorized based on density differences, as the waters mix the different densities causes a layering effect. Minimal density differences between the two bodies of water are known as homopycnal (Figure 7a) and
typically occur in environments such as lagoons. The two water bodies are mixed intensely and sediment is deposited rapidly (Suter, 1994; Reading and Collinson, 1996; Haslett, 2000). When outflowing water is denser than the receiving body of water, it is described as a hyperpycnal conditions (Figure 7b). The latter are usually associated with flood events, where the outflowing river waters flow beneath the basin waters due to higher density and deposits sediment more distal to the river mouth (Suter 1994; Reading and Collinson 1996; Haslett 2000). When the outflowing water is less dense than the receiving basin, (i.e. freshwater entering saline waters) it flows over the denser water of the receiving basin and in the form of a buoyant plume and is known as hypopycnal (Figure 7c) conditions (Suter 1994; Reading and Collinson 1996; Haslett 2000). In this situation coarser material is usually deposited proximal to the shoreline while fine sediments are deposited offshore.

![Figure 7 Differences in flow types of outflowing water and receiving body of water (from Hopley, ca. 2011, after Haslett, 2000). The dark section represent the outflowing river waters and the light sections represent the waters of the receiving basin](image)

2.5 Downstream channel geometry relationships and macro-channels

The morphology of streams in the Illawarra is rather unusual in that they become smaller as they approach the coast (Nanson, 1981; Nanson and Young, 1981;
Young and Nanson, 1982) (Figure 8), a characteristic unique to this region. These unusual morphologies are attributed to a number of factors including an 80-90% reduction in specific stream power over a comparatively short distance, the nature of the alluvium downstream (very cohesive), vegetation and the extent of the floodplain (Nanson and Young, 1981).

The downstream channel geometry may have had an influence on the regions macro-channels which have been described as large river channels with prominent outer terrace banks that accommodate high magnitude flows and contain a smaller inset low flow channel (Reinfelds and Nanson, 2004; Roper, 2004; Christensen, 2005; Roper et al., 2005). Macro-channel morphologies exist throughout the world although they differ slightly from case to case and have generally been formed as a consequence of a variety of intrinsic and extrinsic mechanisms (Roper, 2004; Christensen, 2005). There are numerous examples of macro-channels around the globe and, although characteristically the same they have formed under a variety of differing and sometimes complex conditions. However, there are distinct similarities in the resultant morphologies such as the terrace alluvium banks. Tectonic activity may also play a key role in the development of these macro-
channel morphologies as does fluctuations in sea level (Posamentier et al., 1988; Posamentier and Vail, 1988; Summerfield, 1991; Williams et al., 1993; Lowe and Walker, 1997; Sloss et al., 2004; Sloss, 2005). A number of examples of macro channels will be discussed below to demonstrate the similarities in their morphologies and the different mechanisms acting upon these systems that yield such similar results.

Meander belts on both the Grant River (Woltemade and Potter, 1994) and the Blue River (Lecce, 1997) in Wisconsin, USA, are two examples of fluvial systems that display macro-channel morphologies. The channels in both of these examples are bounded by alluvial terraces, which exhibit the presence of meander belts in the mid-upper catchments, the presence of a laterally migrating low-flow channel within the larger outer macro-channel is also evident (Woltemade and Potter, 1994; Lecce, 1997).

The Narmada River in India (Gupta et al., 1999) is another good example of a river with a macro-channel form, although they are referred to as a channel-in-channel form in the literature (Gupta et al., 1999). In this example large magnitude floods are also confined between alluvial terraces and an inset low-flow channel carries the normal capacity flow (Gupta et al., 1999) but it differs from the American examples in that this system contains both bedrock and alluvial meandering reaches (Gupta et al., 1999). The Narmada River acts on a large scale with the inset channel being up to 775 m wide, this is a reflection of the large drainage basin which covers an area of approximately 99,000 km² (Gupta et al., 1999).

The Sabie River in Southern Africa also displays macro-channel morphologies (Heritage et al., 1999). This river has an inset low-flow channel and is similar to parts of the Narmada River in that it is a bedrock dominated system. It is the nature of the bedrock in this system that is believed to be largely responsible for the macro-channel morphology that it exhibits. Sediment supply is also considered a factor in the form of the Sabie River (Heritage et al., 1999).
In the southeast of New South Wales, in the Hunter Valley, another example of macro-channel morphology has been described by Erskine and Livingstone (1999). In this example the term compound channel has been used to describe a channel morphology that is characterised by the presence of multiple in-channel benches (Erskine and Livingstone, 1999). Compound channels are very common throughout eastern Australia (Hickin, 1968; Woodyer, 1968; Woodyer, 1970; Riley, 1972; Warner, 1972; Warner et al., 1975; Abrahams and Cull, 1979; Woodyer et al., 1979; Erskine and Melville, 1983; Sherrard and Erskine, 1991; Warner, 1993; Erskine, 1994; Warner, 1994; Erskine, 1996; Erskine and Livingstone, 1999) and have also been recognised in a number of examples throughout the world (Petts, 1977; Erskine and Livingstone, 1999). The channel benches are described as bank attached sediment bodies (Erskine and Livingstone, 1999). The channels that display this morphology in the Hunter Valley are characterised by high flood variability and the ability to convey large flood discharges of varying magnitude within the confines of the alluvial terraces (Erskine and Livingstone, 1999), a characteristic shared with the macro-channels of the Illawarra region (Christensen, 2005; Roper et al., 2005).

The similar morphologies of the Illawarra and Hunter Valley macro-channels, as well as similarities in flood magnitude and frequency in the two regions supports suggestions that flood variability may play an important role in the development and morphology of the macro-channels (Erskine and Livingstone, 1999). Macro-channels in the Illawarra region are usually located in the mid-upper catchments of fluvial systems (Christensen, 2005; Roper et al., 2005) and have been the subject of recent research (Reinfelds and Nanson, 2004; Roper, 2004; Christensen, 2005; Roper et al., 2005). Of particular interest to this study are the macro-channels of Mullet Creek which Roper (2004) described as substantial channels of 50-300 m in width bounded by alluvial terraces carved into the resistant Pleistocene valley-fill sediment. Chronological investigations have found the terraces of the nearby Robins Creek are up to 250 +/- 40 ka in age (Nanson & Reinfelds, unpublished data). This date was calculated using optically stimulated luminescence (OSL) dating techniques, which built on those dates presented by Walker (1962) who used C14 dating and found the terraces to be no more than ~40 ka.
Petts and Foster (1985) recognised terraces as “key elements in understanding local and regional geomorphological setting”. The terraces represent a former floodplain that has been abandoned and which can be recognised by a planar surface which is set above the current floodplain and slopes down towards the channel (Morisawa, 1985; Petts and Foster, 1985; Summerfield, 1991). Terrace development is believed to be linked to a number of different factors and this has been the subject of much debate in the past (Young and Nanson, 1982; Walker, 1984; Posamentier et al., 1988; Posamentier and Vail, 1988; Summerfield, 1991; Williams et al., 1993; Lowe and Walker, 1997; Nanson and Doyle, 1999; Sloss et al., 2004; Christensen, 2005; Sloss, 2005). Advances in terrace research now indicates that terrace formation and abandonment on a global scale can be linked to tectonics, sea level fluctuations and climate change (Posamentier et al., 1988; Posamentier and Vail, 1988; Summerfield, 1991; Williams et al., 1993; Lowe and Walker, 1997; Sloss et al., 2004; Christensen, 2005; Sloss, 2005) however, in the Illawarra, it is believed that tectonics have played little to no role in the development of terraces in this area as there has been little tectonic activity during the late Quaternary (Young and Nanson, 1982; Walker, 1984).

In the Illawarra, investigations first carried out by Walker (1962) suggested that terrace development was exclusively the result of climatic changes. However, later investigation by Young and Nanson (1982) proposed that terrace development in this region is related to the reaching of a local intrinsic threshold. The relative tectonic stability of this region throughout the Quaternary suggests that tectonic instability had little effect on terrace development (Young and Nanson, 1982; Walker, 1984). It is believed however that terrace formation in the Illawarra is the result of a combination of the influences mentioned above, with extrinsic climatic changes mostly responsible for the development of terraces formed in the Pleistocene, while it is more likely that intrinsic, localised changes resulted in the formation of the Holocene terraces in the region (Young and Nanson, 1982; Walker, 1984; Hean and Nanson, 1985; Nanson and Hean, 1985; Nanson and Doyle, 1999).
The terraces play an important role in this region by conveying the high magnitude flows that are experienced on a much more frequent basis than would be expected in other parts of the world. Interestingly, Reinfelds and Nanson (2004) reported that the inset low flow channel plays little role in conveying the high magnitude flows and may in fact become in-filled or destroyed by erosion during one of these high magnitude events. A study by Reinfelds and Nanson (2004) found that catastrophic flood events in the Illawarra have an average recurrence interval (ARI) of approximately one in eight years. These events are typically high intensity, short duration events experiencing peak discharge intensities of up to 123 mm hr$^{-1}$ (Nanson and Hean, 1985). It is believed that the high frequency of these large bursts of intense rainfall enable the channels of the Illawarra to remain in a constant state of disequilibrium as they are in a state of constant recovery (Nanson, 1981; Nanson and Young, 1981; Nanson and Erskine, 1988; Grootemaat, 2000; Peterson, 2002; Reinfelds and Nanson, 2004). This differs from the common view that channels around the world, as well as those in the Illawarra exist is a state of equilibrium (Warner, 1992; Erskine and Warner, 1999).
3.1 Introduction

The area known as the Illawarra is located on the south coast of New South Wales (Figure 9), stretching from Helensburgh in the north to Shellharbour in the south. The region covers an area of approximately 8309km² (ABS, 2010) of narrow coastal plain, which is bound by the Pacific Ocean to the east and the prominent Illawarra Escarpment to the west.

Figure 9 Location of Illawarra Region.

The Illawarra is considered to be the area that runs from Helensburgh in the north to Shellharbour in the south. It is bordered to the east by the Pacific Ocean and the Illawarra Escarpment to the west. (Source: Google Maps)

3.2 Geology

The Illawarra region is located in the southern part of the Permo-Triassic sedimentary Sydney Basin (Tye et al., 1996). The Sydney Basin covers an area of
approximately 64,000km² of marine and terrestrial terrain (GeoscienceAustralia, 2008) with its eastern margin extending to the edge of the continental shelf (Figure 10).

![Figure 10 Location of the Sydney Basin](image)

The Permian and Triassic sedimentary rocks are extensive throughout the Illawarra region while Permian volcanic sequences of considerable size are predominantly found in the Kiama area (Mills and Jakeman, 1995) and Tertiary basalts are scattered throughout the southern half of the basin, in areas including Moss Vale and Robertson (Mills and Jakeman, 1995).
Regional Setting

The major stratigraphic units in the Illawarra include the Shoalhaven Group which consists of marine sandstones and siltstones, the Illawarra Coal Measures which consists of fluvio-deltaic to shallow marine coal bearing sediments, the Narrabeen Groups which consists of fluvial sandstones and claystones and the Hawkesbury Sandstone (Figure 11).

![Geology of the Illawarra region and the relationship with Topography (Fuller and Badans, 1980)](image)

3.3 Climate

Australia's climate is divided into six major classification groups, based on a modification of the Köppen scheme, which was used to classify world climates based on the extent and type of native vegetation within distinct climatic zones.

The New South Wales coast is classified as having a temperate climate, which generally experiences mild to warm summers and cool winters, with no dry period (Cox, 1983; BOM, 2010). Rainfall in the Illawarra occurs throughout the year.
Macro-channel coastal plain transition in the Lake Illawarra Catchment, New South Wales

(Figure 12) with most high magnitude rainfall events typically occurring in summer and autumn (Nanson and Hean, 1985).

Figure 12. Climate data for the Illawarra Region (Source: BOM)

The variation in rainfall throughout the Illawarra region is attributed to the presence of the Illawarra Escarpment (Cox, 1983) and its close proximity to the ocean (Young, 1979; Bryant, 1982; Cox, 1983). Onshore winds force warm moist air masses to rise quickly over the plateau (orographic lifting), causing the warm air mass to cool quickly and condense (Christopherson, 2006). This results in, a higher concentration of precipitation at the escarpment edge than elsewhere on the plateau or coastal plain (Young, 1979; Bryant, 1982; Cox, 1983). Figure 13 shows the relationship between rainfall in the Illawarra and proximity to the escarpment.
Regional Setting

Figure 13 Rainfall data collected from various rainfall stations within the Illawarra depicting the general trend of rainfall totals increasing with proximity to the escarpment. Locations are listed in increasing distance from escarpment (i.e. Robertson is proximal to the escarpment and Albion Park is distal) (Source: BOM)

3.4 Geomorphology

The Illawarra region can be thought of in terms of 3 distinct areas, the escarpment, the foothills and the coastal plain. The escarpment has an average height of 350-450 m above sea level (asl) and a maximum height of 770 m asl near Robertson (Grootemaat, 2000). A gentle north-westerly dip is characteristic of the Escarpment and this plays an important role in the development of regional drainage patterns as it acts as a structural control. The Escarpment also has an influence on climatic conditions and rainfall distribution which are discussed in section 3.3, this in turn influences the fluvial and hydrological characteristics in this region. The sharp fall of the Illawarra Escarpment is met by the gently rolling and undulating foothills of the Illawarra. This is where macro-channels in the region most commonly occur (Roper, 2004). The floodplain eventually flattens out into the area known as the coastal plain which is a strip of coastal land that is narrow in the north and widens to the south in the vicinity Albion Park where it reaches its widest point. The widening of the coastal plain is directly linked to the presence of large streams draining from the Illawarra Escarpment and is discussed in further detail in section 3.5.
3.5 Regional Flooding

Drainage patterns in the Illawarra are controlled by the gentle north-west dip of the structurally resistant Hawkesbury Sandstone. The gentle dip of the plateau away from the coast is responsible for the presence of few large streams that drain in an easterly direction towards the ocean (Ollier, 1995). Over time the Escarpment has been eroded back towards the west, resulting in the widening of the coastal plain where stream such as Macquarie Rivulet, Minnamurra Rivulet and Mullet Creek are located (Young, 1979; Ollier, 1995). In the Illawarra, these streams are considered large when compared with streams in other parts of the region. On a global scale however, these streams are considered to be quite small.

Rainfall events in the Illawarra are typically high magnitude events that occur over short periods of time (24-48hrs) on a frequent basis (Nanson and Hean, 1985). The frequency and intensity of flooding events in the Illawarra region can be attributed to the movement of the storm cell in a down catchment direction, essentially following the flood wave, causing flash flooding downstream (Nanson and Hean, 1985). The channel and floodplain morphology of streams in the Illawarra have adjusted over time in response to these conditions and this is reflected in the floodplain extent which is unusually large for the comparatively small channels that are required to accommodate the significant volumes of water received during high magnitude events. Depending on the magnitude of the event, the typical recurrence interval of large flood events can be between two and eight years (Reinfelds and Nanson, 2001).

In February 1984, the Illawarra experienced an intense rainstorm that produced the highest 24 hr. rainfall ever experienced in temperate Australia, with recurrence intervals in excess of 100 years (Grootemaat, 2000). The rainstorm and subsequent flooding caused millions of dollars worth of damage to railway lines, road, bridges and housing (Grootemaat, 2000). In this instance the storm cell was
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centered over the Lake Illawarra catchment, however, rainstorm events of this magnitude occur throughout the Illawarra region and play a vital role in the development of the alluvial terraces in the upper reaches of the catchments. For example, in August 1998, the northern parts of the Illawarra experienced a rainstorm which left the affected areas in a state that can only be described as a natural disaster (Reinfelds and Nanson, 2001). This rainstorm was categorised as having a recurrence interval of 20 years of the Mullet Creek (West Dapto) area (Grootemaat, 2000). Without these high frequency high magnitude events, the streams of the Illawarra would not display the physical properties they currently exhibit.

3.6 Site-specific location

Mullet creek is located in to the east of Lake Illawarra. Its headwaters can be traced back up the Illawarra Escarpment where it flows down through the foothills and along the coastal plain terminating in the north west corner of Lake Illawarra in Koong Burry Bay.

The terrace investigations took place in the mid-upper reaches of Mullet Creek and the sedimentological investigations were carried out in the mid-lower reaches of the creek and were divided into two areas. These two areas will henceforth be referred to as the upstream floodplain reach and the downstream channel reach as displayed in Figure 14.
Figure 14 Location of upstream floodplain reach and downstream channel reach. White arrows indicate general direction of flow.
Chapter 4 – Methods

4.1 Introduction

The techniques used in this project included the use of geospatial datasets such as LiDAR and aerial photography, subsurface sampling, sediment analysis, particle size analysis and the use of subsurface geophysical techniques in the form of ground penetrating radar (GPR). Each of the techniques will be discussed in detail in the following sections.

4.2 LiDAR Analysis

LiDAR (light detection and ranging) is a technology that uses laser pulses to generate large amounts of data about the physical layout of the terrain and landscape features (CSIRO, 2008). LiDAR data can be collected using on-ground or airborne instruments. The data used in this project was collected using instruments mounted to the underside of an aircraft.

As the aircraft moves over the target the LiDAR instrument emits rapid pulses of light at the target (the land surface) and the time taken for the light pulse to be reflected is recorded (CSIRO, 2008). The recorded time is then used to calculate the distance between the aircraft and the target and from that a digital terrain map is created (CSIRO, 2008).

LiDAR has many applications and has been used in this project to observe and interpret physical features of the study area including abandoned channels, meander cut offs, the presence and extent of alluvial terraces and the bedrock margin.
4.2.1 Analysis for Drilling

The LiDAR data set was initially examined to determine the most suitable areas for drilling. LiDAR analysis was chosen as it allowed for a large scale investigation with large amounts of detail. Satellite imagery was also analysed but later discarded as it failed to show relief.

The analysis was undertaken at a scale of 1:4000 and the display resolution was set to zero, no point limits were applied to ensure that the highest level of detail was always visible. This scale and the display parameters were selected because they allowed the data to be interpreted easily in great detail. The areas selected for drilling included those where palaeochannels could be easily recognised. The upstream floodplain reach was chosen because of the presence of a number of meander cut offs which were of interest (Figure 15a). The downstream channel reach was selected because of the presence of a number of features including point bars, abandoned channels and also the channel morphology surrounding William Beach Park (Figure 15b). The accuracy of the LiDAR dataset was verified during field work when samples were taken. The observations made using the LiDAR dataset were also confirmed as accurate when site examination took place.
Methods

Following the creation of the terrain dataset the display parameters were adjusted to make the best use of the dataset. Default display parameter settings were set to equal interval classification with 9 classes, overview resolution and a point limit of 80,000 is automatically applied. This however, did not display the data adequately. Because of the remarkable decrease in channel gradient from the escarpment to the coastal plain the low lying, comparatively flat surface of the coastal plain is not displayed adequately, and little detail is visible. To combat this, the display parameters were altered in the following way: a quartile classification with 30

4.2.2 Analysis of Terraces

LiDAR data was supplied by the University of Wollongong from the AAMHatch 2006 dataset covering the Wollongong Local Government area. A terrain model was used to examine this dataset.

Following the creation of the terrain dataset the display parameters were adjusted to make the best use of the dataset. Default display parameter settings were set to equal interval classification with 9 classes, overview resolution and a point limit of 80,000 is automatically applied. This however, did not display the data adequately. Because of the remarkable decrease in channel gradient from the escarpment to the coastal plain the low lying, comparatively flat surface of the coastal plain is not displayed adequately, and little detail is visible. To combat this, the display parameters were altered in the following way: a quartile classification with 30
classes was applied to the dataset. The resolution was set to zero and no point limit was applied. Changing these settings allowed the maximum amount of detail to be viewed no matter what scale the data set was being view at.

Following the application of the appropriate display settings, the terrain dataset was used to create the river vector defining the location of Mullet Creek. This was completed at a scale of 1:2000 to ensure that the line of the creek was followed as closely as possible.

Topographic cross sectional profiles were created using the 3D Analyst profile graph tool on the terrain dataset. The data was exported to Excel in order to create graphical representations of the cross sections. The cross-sections were used to determine the presence and extent of the alluvial terraces along the length of the creek. Cross sections were taken in the mid to upper reaches of the catchment at a distance of approximately 100 m to determine their presence and delineate their extent.

Carrying out the cross sectional investigations allowed the extent of the terraces downstream to be recognised. In order to investigate the lateral extent of these terraces two vectors were created. The first vector was created using heads up digitizing of the terrain dataset to delineate the bedrock boundary of the confining valley. A polyline was created at a scale of 1:15,000, this was also based on visual interpretation, with reference made to Nanson and Hean’s (1985) map of terrace and floodplain locations of Mullet and Robin’s Creeks. The second vector created to investigate the lateral extent of the terraces was the terrace boundary vector. This was also created using heads up digitizing and visual interpretation of a slope class map. In order to create the slope class map the terrain dataset was converted to a 1 m by 1 m raster dataset and from this a slope class dataset was created using the Spatial Analyst Surface tools. The heads up digitizing of the terrace boundaries was completed at a scale of 1:5500. Figure 16 below shows a visual representation of
all datasets that were used and created during this project as well as showing the relationships between the datasets.

![Figure 16 Visual representation of the datasets used in GIS analysis and those created. Oval indicate datasets that were provided, rectangles represent those created prove the original datasets. Subsurface core samples were collected in the field.](image)

### 4.3 Subsurface Sampling

Subsurface sampling was conducted in both the upstream floodplain reach and the downstream channel reach. Subsurface stratigraphic data was also collected from previous research conducted by Hean and Nanson (1985) and the University of Wollongong's School of Earth and Environmental Science (unpublished data). The techniques used to collect subsurface stratigraphic data will be outlined in detail below.
4.3.1 Sample Locations

Samples were taken from the three sites in both the upstream and downstream fluvial reaches under investigation. Data from a previous study (Hean and Nanson, 1985) was also referred to. All AHD values were obtained from the LiDAR dataset.

4.3.2 Sampling Techniques

Two techniques were used to acquire subsurface samples in order to analyse the nature and deposition of the sediment immediately upstream on the Mullet Creek Delta. The techniques included auger drilling and petrol-powered vibracoring, each method is explained in more detail below. Samples were also collected by hand where the creek banks in areas similar to those depicted in Figure 17.

Figure 17. Creek bank where sediment samples were taken by hand

Auger drilling was conducted using a hand held auger with a hollow head to ensure samples had low contamination rates (as per Hopley, in prep). The auger drill bit was also used on a number of occasions with the aid of the mighty-mite, a petrol powered engine to speed up the drilling and extraction of the upper compact layer of sediment.
Methods

Petrol powered vibracoring was conducted in both subaerial (Figure 18a, b & c) and subaqueous (Figure 18e, f & g) conditions. The upper ~30 cm of sediment was removed using the auger to allow the barrel to more easily penetrate the sediment and reduce compaction in subaerial sites. The aluminum barrel is then inserted into the auger hole and a vibracore sample was collected. The sample was then retrieved and the amount of compaction recorded. All vibracore samples were stored in a cold room to reduce the amount of oxidation before they were split open using a circular saw.

Figure 18 Methods used to collect subaerial and subaqueous core samples. A, B, C and D show the set up of the quadrapod used to support the aluminium barrel, the attachment of the vibrating head, the application of downward force by standing on the vibrating head and the plug used to seal the core sample before retrieval respectively in subaerial conditions. E, F and G show the set up of the quadrapod retrieval of a subaqueous core sample from (Hopley, in prep.). E shows the collection of a subaqueous sample without the aid of the quadrapod.
4.4 Sediment analysis

After the samples were collected in the field they were returned to the University of Wollongong and stored under cold conditions in the Earth of Environmental Sciences cool room in order to reduce the rate of oxidation. Prior to sampling, they were split using a circular saw to allow for visual logging of the stratigraphic information contained within them before sampling for particle size analysis took place. The logging recorded details such as sediment size, color and any the presence of any organic or biological material was also (as per methods similar to; Sloss, 2004, Sloss et al, 2005; 2006; Hopley, in prep.).

Sediment samples were collected every 10 cm along the length of the barrel for particle size analysis using a Malvern Mastersizer. The Mastersizer uses laser diffraction to determine particle size, which will aid the interpretation of the environment of deposition. The percentage of sand, silt and clay were recorded and also the volume weighted mean. Once the samples had been analysed, the data was exported to Excel in order to examine and interpret the results.

4.5 Subsurface Geophysical Investigations

Initially the use of the GPR system was going to be conducted after the LiDAR data had been examined in order to determine the most suitable areas for investigation. Unfortunately, time restraints and limited experience using this technology meant that the use of GPR became a secondary investigation and was simply trialed in a fluvial floodplain setting to determine whether or not the results provided by the use of this technology would be useful for future research. It was hoped that the use of the GPR would limit the amount of subsurface drilling and also focus the areas where drilling would be needed.

Collection of data in the field was thought to be successful but on closer inspection during post processing it was found that the GPR system had failed to collect any useful data. It is thought that high salinity and saturated clay sediments and may
Methods

have affected the collection of data. The limited experience in the set up and use of this technology may have also affected data collection. The results of the GPR investigation will not be presented, as they do not yield any results that could be interpreted.
Macro-channel coastal plain transition in the Lake Illawarra Catchment, New South Wales
Chapter 5 – Results

5.1 Introduction

This chapter will present the findings of the investigations described in chapter 4. All data collected during the course of this investigation is available in the appropriate appendices.

5.2 Terrace Analysis

The objective of this investigation was to determine the extent of the terraces along the length of Mullet Creek extending from the base of the escarpment into the foothills and along the coastal plain. Previous studies (e.g. Reinfelds & Nanson, 2001; Roper, 2004) indicate that terraces typically exist in the mid to upper reaches of catchments in the Illawarra. A detailed examination of the Mullet Creek terraces was conducted using ArcGIS. In total 92 topographic cross-sections created in the mid to upper reaches of the creek. These cross-sections illustrate the presence and downstream extent of the alluvial terraces.

The terraces were examined in Excel using data exported from ArcGIS. Figure 19 below is an example of a typical cross-section in the mid to upper reaches of the Mullet Creek catchment that shows the active channel bound by a broad floodplain and terrace banks. Terraces are identified as a planar alluvial surface elevated above the Holocene floodplain, with an inset low-flow channel.
By analysing the topographic data (e.g. cross-section 85 in Figure 19), terraces were found to exist in the mid to upper reaches of Mullet Creek, extending approximately 7 km downstream from the foothills. The terrace investigation using a slope class map yielded very similar results, confirming that there is no surface exposure of terraces downstream of cross-section 5, which is denoted by the green star in figure 20. The slope class investigation involved creating a slope surface map to investigate both the lateral and downstream extents of the river terraces. The terraces were identified using the slope class map by the dark shading indicating a surface with a higher degree slope.
Results

Figure 20 Slope class map delineating the extent of the alluvial terraces (turquoise colouring) in mid-upper Mullet Creek. Star denotes location of cross-section 5 and the downstream extent of the macro-channel.

A map denoting the bedrock margin was also created using the LiDAR dataset in ArcGIS to aid the investigation of the terraces and to help determine why the terraces do not extend farther downstream than cross-section 5. It is thought that as well as a steep gradient and high stream power, it is possible that the extent of the terraces is closely linked to the confined river valley in which the catchment is situated. Figure 21 shows the location of Mullet Creek, the extent of the macro-channel and the bedrock margin. The widths of the macro-channel is highly variable but overall there is a general trend of decreasing channel width downstream as can be seen in figure 21. Examination of the bedrock margin (Figure 21) indicates that there is no obvious role of valley width in the middle to lower reaches of Mullet Creek below the downstream extent of the terrace surface exposure.
Figure 21 Terrace boundary and bedrock margin in the Mullet Creek Catchment. The green star denotes the location of cross-section 5 and the extent of the macro-channel.

5.3 Sub-surface Sampling and Particle Size Analysis

In total 16 sub-surface cores were collected from the upstream and downstream reaches. Nine of these were taken from the upstream floodplain reach (Figure 22) and the remaining 7 were taken from the downstream channel reach (Figure 23). All subsurface core samples are represented schematically in stratigraphic logs and can be found in Appendix B. Particle size analysis data is also available for those core and auger samples that were able to be processed using a Malvern Mastersizer in Appendix B. MC 10 was not able to be processed as the grain size exceeded the 2mm maximum for particle size analysis using a Malvern Mastersizer.
Figure 22 Core location in the upstream floodplain fluvial reach. Flow direction is from the bottom left corner to top right corner.

Figure 23 Core locations in the downstream channel fluvial reach. Flow direction is from left to right.
5.3.1 Upstream Floodplain Reach

The upstream floodplain reach was found to consist of predominantly overbank sequences underlain by fluvial channel sands and Pleistocene floodplain sediments typified by cross-sections A-B (Figure 24) and C-D (Figure 25). Cross-section A-B shows the spatial relationship of the overbank and fluvial channel sands with a small Pleistocene unit present at the northern end (right side) of the section. Cross-section C-D indicates that the Pleistocene sediment is more abundant distal to the abandoned channels present in this reach. Cross-sections E-F and G-H, which run almost perpendicular to cross sections A-B and C-D are illustrated in Appendix D.

![Figure 24 Mullet Creek cross-section A-B. See figure 22 for core locations](image1)

![Figure 25 Mullet Creek cross section C-D. Refer to figure 25 for stratigraphic key. See figure 22 for core locations.](image2)
Results

The overbank sequences are made up of a dark brown, organic rich soil, most likely a loamy clay, overlying fine sediments (silt and clay) with small to moderate amounts of sand present as typified by core samples MC 5 (Figure 26) and MC 6 (Appendix B). These sequences were present in all cores in this reach and encompass floodplain sequences, low flow deposits and organic rich mud. The organic rich mud was found in core sample MC 9 in this reach. It represents a low energy environment where organic matter is deposited and then subaerially exposed to allow decomposition to occur.

![Particle size analysis data from sample MC 5](image)

Figure 26 Particle size analysis data from sample MC 5

The fluvial channel sand deposits are recognized as sand units of fluvial origin based on the absence of marine evidence such as macrofossils that have been found in the fluvio-deltaic sequences (Hopley, in Prep). They are mostly likely quartz sand that has been eroded and transported from the Illawarra Escarpment, which is comprised of the quartz rich Hawkesbury Sandstone. The fluvial channel sands are typically upward fining sequences ranging from fine to medium grain size with relatively small amounts of fines present (Figure 27). This unit was found in core samples MC 1, MC 4 and MC 8 (Appendix B) in the upstream reach.
The Pleistocene sediments consist of very compact, mostly fine sediments with some fine to medium grained sand present and represent the Pleistocene floodplain in this reach. They have a similar particle size analysis signature to the overbank sequences but can be distinguished by the presence of abundant orange mottles scattered throughout the unit (Figure 28) caused by oxidation. Pleistocene sediment was found in core samples MC2, MC 3 and MC 6.

Figure 27 Particle size analysis from sample MC 1

Figure 28 Core MC6 sample displaying orange mottling of Pleistocene sediment. Red ovals denote presence of orange mottles within the core sample.
5.3.2 Downstream Channel Reach

The downstream channel reach consists of overbank sequences underlain by fluvial channel sands and flood couplets, typified by cross-section I-J (Figure 29).

Figure 29 Mullet Creek cross-section I-J. Refer to figure 25 for stratigraphic key. See figure 23 for core locations.

The overbank and fluvial channel sand sequences are similar to those in the upstream fluvial reach, yielding very similar particle size analysis results (Figure 29). The grain size of the fluvial channel sands found in the downstream channel reach however also included very coarse sand and small pebbles which is consistent with the base of a channel sequence (Figure 30 & 31). Overbank sequences consisting of organic rich topsoil overlying fine sediments were found in core samples MC 11, MC 12, MC 13 and MC 14 (Appendix B). All core samples collected in the downstream channel reach contained fluvial channel sands.
Flood couplets, which were found in core samples MC 11, MC 13 and MC 14 can be described as alternating layers of fine, medium and coarse sediment of varying thicknesses. Each layer within the flood couplet is typically a upward fining sequence which can be seen in Figure 32. These, most likely represent a historical record of fluctuations in flow and energy. The minor presence of these units indicates that these deposits would usually be destroyed by the high magnitude flood events frequently experienced by Mullet Creek and so are not readily preserved in the stratigraphic record.
Results

Figure 32 Particle size analysis data for sample MC 13
Chapter 6 – Discussion of Results

6.1 Introduction

The results of the investigations presented in chapter 5 will be discussed in this chapter. The discussion will focus on terrace distribution and analysis, downstream macro-channel morphology and transitional sedimentary sequences.

6.2 Terrace distribution and age relationships

The terrace investigation revealed that alluvial terraces along Mullet Creek extend approximately 7 km downstream from the foothills but below this, at cross section 6 surface exposure is no longer evident. During this investigation only one terrace surface was identified in the mid-upper reaches of the catchment (Figure 33). This result differed from the work of Walker (1962), who found that three river terraces were identifiable along the length of the nearby Macquarie Rivulet (Figure 34) which has been subject to the same influencing factors as Mullet Creek such as sea level and the development of the Holocene barrier of Lake Illawarra. The terraces examined by Walker (1962) were not all laterally extensive and he proposed that each of the terraces could be related to a particular sea level. The trend line in figure 33 indicates that the terraces were graded to a base level higher than the present base level. Hopley (in prep.) has recorded the presence of a Pleistocene high located within the delta which may be a downstream surface exposure of the terrace located in the upper reaches of Mullet Creek.
Walker also proposed that the alluvial terraces of the Illawarra were approximately 40,000 years in age based on C\textsuperscript{14} dating techniques. However, from dating conducted by Nanson and Reinfelds (unpublished data) we know that the nearby terraces of Robin’s and Duck Creek are in the order of 200,000 years of age.
Discussion

(Figure 35). Mullet Creek’s proximity to these channels makes it plausible to assume that its terraces are of similar age. This implies that Illawarra terraces may record sea levels not just within the last glacial cycle but potentially multiple glacial cycles. It is likely that the incision of the macro-channels relate to a time when sea level was lower than present and fluvial systems were highly active. The active phase was then followed by an inactive phase when sea level rose and the channel was effectively backfilled with younger sedimentary deposits. This is evidenced by the data in Figure 35 which shows two phases of deposition in the channel of Robins Creek.

![Figure 35 Chronological data for alluvial terraces located on Robins and Duck Creeks (from Nanson & Reinfelds, unpublished data). Dates indicate that there have been multiple phases of deposition.](image)

6.3 Downstream macro-channel morphology

The alluvial terraces are thought to disappear from the surface downstream of cross section 5 because their formation is driven by stream gradient and stream power, as well as the backwater effect brought on by a rise in sea level and infilling of the channel.

Stream gradient and stream power in the lower reaches of Mullet Creek are both linked to the tide and barrier conditions in Lake Illawarra. Work by Sloss et al
Macro-channel coastal plain transition in the Lake Illawarra Catchment, New South Wales

(2007) has noted that Mullet Creek was flowing into a more open system during the postglacial marine transgression (PMT), resulting in an increase in marine influences (such as tides, currents and waves) and the deposition of a transgressive sand sheet. As sea level rose during the Holocene, the development of the back barrier lagoon was initiated (ca. 5000-3200 years before present) and continued to fill as sea level rose in the lead up to the Holocene highstand (Sloss et al, 2007). The continued rise of sea level during the Holocene would have initiated the backwater effect causing stream velocity to decrease and deposition to increase causing the channels to backfill with Holocene alluvium.

By creating a new stream gradient and base level, the effects of the backwater effect may have been felt as far upstream as the tidal limit extended, possibly as far upstream as the upstream floodplain reach. The increase in base level and subsequent reduction in stream gradient would cause sediments to be deposited in the lower reaches and the channel to become more sinuous and migrate laterally through the landscape. As sea level steadily returned to its present level over the last 2000 years (Sloss et al., 2007), the increase in channel gradient would have resulted in the straightening of the channel (Twidale, 2004) and the abandonment of the meander loops resulting in the abandoned channel sequence seen in the upstream floodplain reach.

Examination of the downstream channel width, and therefore capacity, of the macro-channels found that a slight linear relationship between distance from the creek mouth and channel width but is quite variable (Figure 36). By projecting the downstream width of the macro-channel it is expected that the width of the channel would decrease to a width of approximately 1.5 m. This however is not consistent with the current morphology of the creek mouth that is several metres wide, but may be explained by the unusual channel geometry that is characteristic of Illawarra streams. Hean and Nanson (1985) have demonstrated that stream in the Illawarra are constrained in their headwaters located on the escarpment and widen in the foothills and upper reaches. The channel then becomes narrower
again towards the coast with the width of the floodplain increasing with decreasing channel width. It is likely that the channel that is responsible for the incision of the macro-channel was constrained by the same factors as the current channel.

![Macro-channel width graph](image)

**Figure 36** Mullet Creek Macro-channel width showing a general decrease downstream from the foothills of the escarpment.

### 6.4 Transitional sedimentary sequences

The upstream floodplain reach has revealed overbank sequences, fluvial channel sands and Pleistocene sediments. There are a number of abandoned channels in this reach that may be a consequence of the backwater effect and a time when sea levels were higher and stream gradient would have been less than it is at present.

The upper reaches of Mullet Creek are clearly confined by its valley margin, but there seems to no obvious role of the valley margin in the lower reaches of the creek. The only constraint on the channel in its mid to lower reaches is the confining nature of the buried Pleistocene alluvium which is laterally extensive and more resistant to erosive processes than more recent depositional sequences. The Pleistocene alluvium in the mid to lower reaches is capped by Holocene alluvium that has been deposited during higher sea level and forms the inset low
flow channel, characteristic of macro-channel morphology and lines the active channel in the mid to lower reaches of the creek.

Previous work by Hean and Nanson (1985) suggested that the fluvio-deltaic sequences extended below the downstream channel reach (Figure 37). Research conducted by Sloss (2005), Sloss et al. (2007) and Hopley (in prep.) on Mullet Creek delta indicates that there is a transgressive sand sheet present that was initially interpreted as being comprised of marine derived sediments (Sloss, 2005). However, further investigation by Hopley (in prep.) suggests that the transgressive sand sheet is in fact comprised of fluvially derived sediments that have been reworked during Holocene sea level fluctuations. Figure 37 outlines the proposed changes to the original map produced by Hean and Nanson (1985) denoting the extent of the fluvio-deltaic sediments as well as Pleistocene and Holocene alluvium. The revised version of the Hean and Nanson (1985) map indicates that the marine influence does not extent far upstream from the delta itself. Sedimentary evidence from the downstream channel reach consisted of fluvially derived sediments only, no evidence of marine influences were found in this reach and the extent of the marine influence therefore lies somewhere downstream of the channel reach and upstream of the delta itself.
Discussion

The boundary of the fluvio-deltaic sediments and the Pleistocene alluvium with Holocene alluvium capping is still not yet clear, but this investigation has been able to refine the previous boundaries proposed by Hean and Nanson (1985). It is also important to note however, that although subsurface sampling was not undertaken in the floodplain surrounding the downstream channel reach, it is highly likely that the Holocene alluvium is laterally constrained by the buried Pleistocene alluvium in a similar manner to the upstream floodplain reach. Figure 38 is a schematic diagram depicting the spatial relationships of the transition from fluvio-deltaic sediments, Holocene channel sequences and Pleistocene terraces. The presence of a Pleistocene high noted by Hopley (in prep.) could be interpreted as downstream surface exposure of the terrace in the mid to upper reaches of the catchment that is graded to a higher sea level. The fluvio-deltaic sediments overly the Pleistocene alluvium and is overlain by Holocene alluvium capping. Figure 38 also depicts the relationship between stream gradient and deposition schematically. The Holocene alluvium is deposited in the lower reaches of the creek where the gradient is greatly reduced compared to the upper reaches where the Pleistocene terraces are present.

Figure 37 Revised version of Hean and Nanson (1985) (denoted in the legend by the symbol H&N) alluvium map. The red box denotes the location of the downstream channel reach.
Figure 38 Schematic long section of Mullet Creek depicting the relationship between the fluvio-deltaic sequences (olive green), the Holocene channel sequence (yellow) and the Pleistocene terrace sequence (grey).
Conclusions

Chapter 7 – Conclusions

The alluvial terraces that flank the boundaries of the Mullet Creek macro-channels extend approximately 7 km downstream from the foothills of the Illawarra Escarpment and have no surface exposure beyond topographic cross-section 5, equating to approximately 9.9 km from the coast. It is believed that the disappearance of the surface exposure of the terrace and macro-channel beyond this point is related to the backwater effect that was driven by the development of the Holocene barrier in Lake Illawarra, rising sea level and the backfilling of the macro-channels with more recent sedimentary deposits. During periods of higher sea level, broad deposition within the fluvial system occurred until sea level fell and induced incision and reworking.

The terraces in the Illawarra may provide a chronological record of not only the last glacial cycle as was expected, but possibly two glacial cycles and they represent land surfaces graded to a sea level higher than present. If sea level continues to rise as is predicted, stream gradient will decrease causing an increase in deposition in the lower reaches of Mullet Creek and the stream itself will once again become more sinuous and a meandering channel form will be exhibited. The degree to which these changes occur are, of course, dependent on the rate at which sea level rises and the height it will reach. The development of the delta, which is inherently linked to the fluvial system, will also be greatly affected by any rise in sea level, the result being the landward migration of the delta.

The fluvio-deltaic sequences initially identified by Hean and Nanson (1985) as extending beyond the downstream channel reaches has been revised and it is now thought that these sequences only extend to the area below the downstream limit of the downstream channel reach. Investigations into the stratigraphy in this area found no evidence of any marine influence, which is consistent with the work of Hopley (in prep.). Although the exact location of the upstream extent of the marine influence has not yet been specifically identified, further investigation into the sediments below the downstream channel reach may yield more precise results.
The use of GPR in the floodplain of the downstream channel reach was unsuccessful. Further investigation is needed to determine why the GPR investigation did not return any viable results. It has been suggested that salinity and saturated clay sediments may have been an issue but it is more likely that the limited experience in the use of this technology is the cause of its failure in this project.
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References


References


Appendix A

Appendix A – Terrace Topographic Profiles
Appendix B – Stratigraphic Logs
Stratigraphic key

- Overbank Deposit
- Flood Deposit
- Fluvial Channel
- Pleistocene
Appendix C – Particle Size Analysis Data
Particle size analysis was conducted on most of the auger and vibrcore samples collected during this investigation. However, it is important to note that not all data could be processed as the grain size of some of the sediment sampled exceeded the 2 mm size maximum and could not be analysed by a Malvern Mastersizer.
Appendix C

Percentage Sand, Silt & Clay
MC11

Volume Weighted Mean
MC11

Percentage Sand, Silt & Clay
MC12

Volume Weighted Mean
MC12

122
Appendix C

Percentage Sand, Silt & Clay
MC15

Volume Weighted Mean
MC15

Percentage Sand, Silt & Clay
MC16
Appendix C

Appendix D – Subsurface Cross-sections
Please refer to cross-section A-B for stratigraphic key.