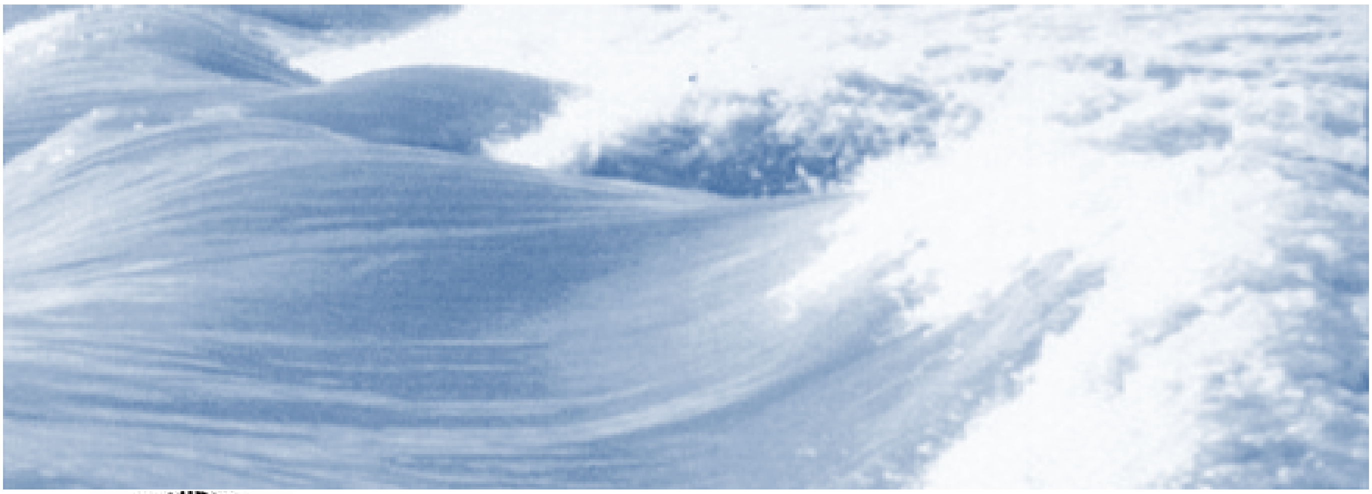
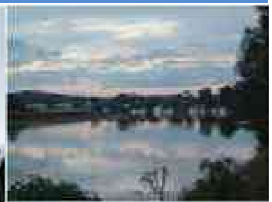


KEMPSEY SHIRE COUNCIL

MACLEAY RIVER ESTUARY PROCESSES STUDY



January 2009

Centre for Coastal Biogeochemistry
Southern Cross University

wma water

Level 2, 160 Clarence Street
Sydney, NSW, 2000

Tel: 9299 2855
Fax: 9262 6208
Email: wma@wmawater.com.au
Web: www.wmawater.com.au

MACLEAY RIVER ESTUARY PROCESSES STUDY

JANUARY, 2009

Project Macleay River Estuary Processes Study	**Project Number** 26017
Client Kempsey Shire Council	**Client's Representative** Ron Kemsley
Authors Graeme Hurrell Emily Barbour Anna Kauffeldt	**Prepared by**
Date 13 JANUARY 2009	**Verified by**

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FOREWORD

The Estuary Management Policy is one of a suite of natural resource management policies implemented by the NSW Government using the principles of total catchment management and ecologically sustainable development. The policy focuses on tidal rivers and coastal lakes which are affected by catchment development and uses.

The goal of the policy is to achieve an integrated, balanced, responsible and ecologically sustainable use of the State's estuaries. A specific objective of the policy is to encourage preparation of long term management plans for each estuary, in which all values and uses are considered.

The policy promotes cooperation between various authorities, catchment management, committees, landholders and estuary users in the development and implementation of management plans. The approach is strongly community focussed and is based on implementation by local Councils rather than private landholders.

The process by which the policy seeks to develop and implement estuary management plans can be summarised in the following stages:

- Formation of an Estuary Management Committee;
- Compilation of existing data;
- Estuary Processes Study,
- Estuary Management Study,
- Draft Estuary Management Plan;
- Draft Plan review; and
- Plan adopting and implementation.

The Macleay River Estuary Processes Study constitutes the third stage of the implementation process and was jointly funded by Kempsey Shire Council and the Department of Environment and Climate Change.

MACLEAY RIVER ESTUARY PROCESSES STUDY

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1. INTRODUCTION

1.1. Overview of the Study

The Macleay River estuary is located on the mid north coast of New South Wales, about 400 km north of Sydney. This Estuary Processes Study was prepared for Kempsey Shire Council under the NSW Estuary Management Program with assistance from the Department of Environment and Climate Change. The study was overseen for Council by the Macleay River Coast and Estuary Management Committee.

Webb, McKeown & Associates, now trading as WMAwater, were responsible for project management, review of the relevant catchment characteristics, detailed hydrodynamic analysis, sediment dynamics studies, water exchange modelling and human use assessment. Southern Cross University, School of Environmental Science assisted WMAwater with water and sediment quality analysis and ecological assessments.

The study area (shown in Figure 1) comprises the waterways, foreshores and adjacent lands of the Macleay River estuary from the ocean entrance to the tidal limit, a distance of approximately 54 km. It also includes the tidal reaches of the tributary streams of Kinchela, Belmore and Clybucca as well as the Macleay Arm. The impact of the wider catchment on the estuary was also considered.

The aim of the study was to define baseline conditions for the various estuarine processes and to examine the interactions between the processes and human use of the estuary. The study provides a basis for developing management strategies in the next stage of the Estuary Management Program, which is preparation of an Estuary Management Study and Plan.

The key areas covered by the study include:

1. **Catchment Characteristics**
   This chapter concentrates on those aspects of the catchment that influence estuarine processes. These include the topography, geomorphology, climate, land zoning and land use for the estuary and wider catchment.

2. **Hydrodynamics**
   The hydrodynamics chapter investigates the dynamics and distribution of fluvial and tidal flows throughout the estuary based on both recorded data and model results. It also describes the wave climate, and the flushing and mixing characteristics of the system. Changes in hydrodynamics and flow behaviour since pre-European settlement are estimated and the potential impacts of climate change in terms of sea level rise and changing rainfall patterns are discussed.

3. **Sediment Dynamics**
   This chapter provides a description of the sediment types and distribution throughout the estuary and how these can be used to assist in the definition of different estuary process

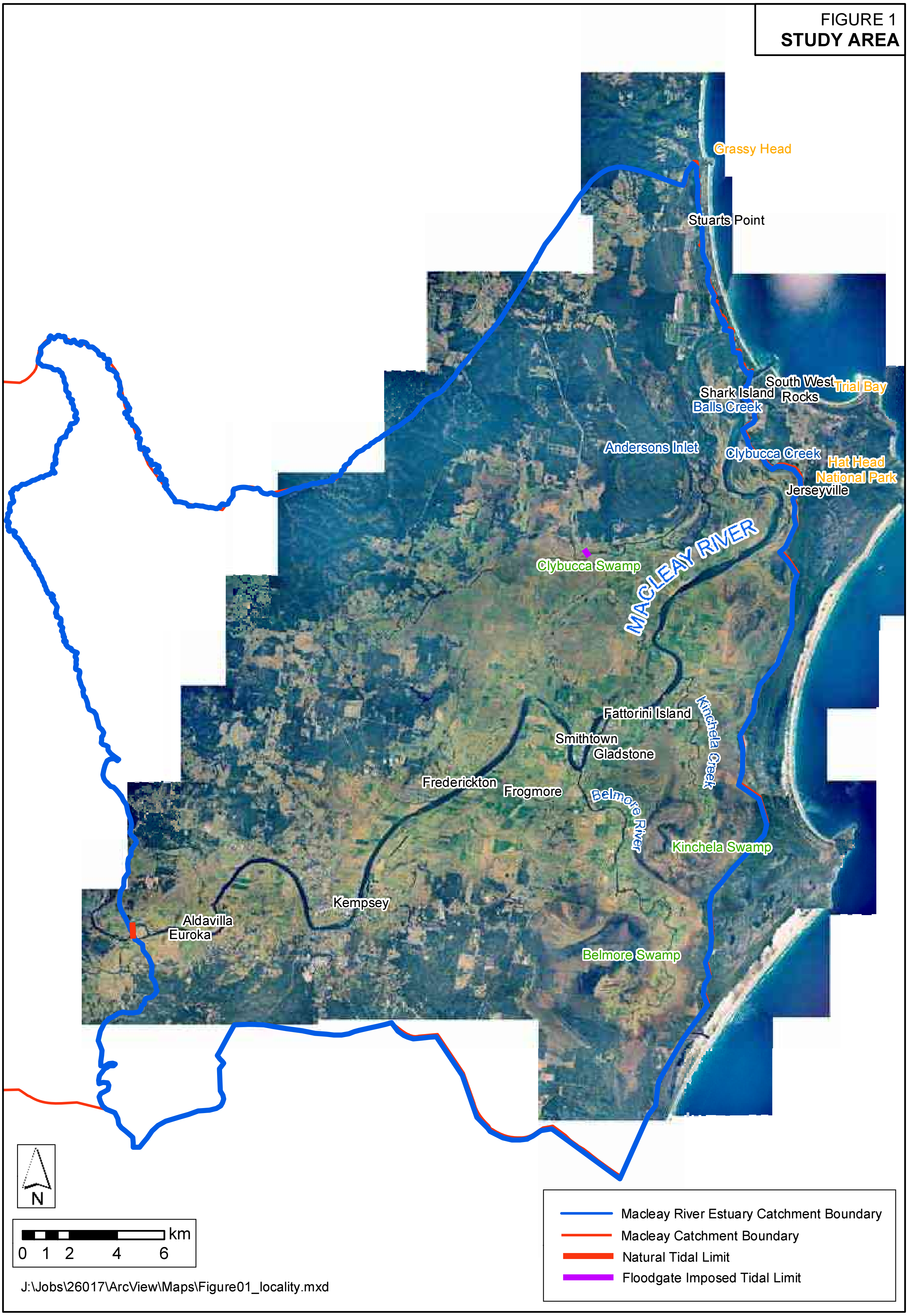

FIGURE 1
STUDY AREA
Grassy Head
Stuarts Point
South West Rocks
Trial Bay
Shark Island
Balls Creek
Andersons Inlet
Clybucca Creek
Hat Head National Park
Jerseyville
MACLEAY RIVER
Clybucca Swamp
Fattorini Island
Kinchela Creek
Smithtown
Gladstone
Frederickton
Frogmore
Belmore River
Kinchela Swamp
Kempsey
Aldavilla
Euroka
Belmore Swamp
N
0 1 2 4 6 km
Macleay River Estuary Catchment Boundary
Macleay Catchment Boundary
Natural Tidal Limit
Floodgate Imposed Tidal Limit
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zones. Both existing and historical morphology is examined and compared, to provide an indication of river change.

4. **Water and Sediment Quality**
   This chapter provides an overview of existing water quality in the Macleay estuary and summarises the primary processes that influence water quality and composition. The chapter also examines the potential sources and impacts of trace element contamination and acid sulfate runoff on sediment and water quality in the Macleay estuary.

5. **Ecological Characteristics**
   A summary of significant terrestrial and aquatic fauna within the Macleay estuary is provided, focusing on threatened species. The chapter also examines the key activities that influence fauna and habitat, such as flooding, eutrophication and overfishing.

6. **Waterway Usage**
   A description of human usage of the waterways and surrounding areas is provided. Uses include commercial aquaculture and fishing as well as recreational fishing, boating, swimming and other passive recreational activities. User facilities such as boat ramps, jetties and moorings are discussed. Potential conflicts between different uses of the estuary are also considered.

7. **Summary, Conclusions and Recommendations**
   The final chapter provides a summary of the main estuary processes and the issues associated with the interactions between these processes. Recommendations for the Estuary Management Study are also provided.

A glossary of terminology has been provided in Appendix A.

1.2. Key Issues

The purpose of the Estuary Processes Study was to provide a scientific and technical understanding of the estuary's physical, ecological and biogeochemical processes to facilitate the later preparation of an Estuary Management Plan. A number of key issues relating to the estuary were identified by the Kempsey Shire Council's Coast and Estuary Management Committee in consultation with stakeholders and the Mid North Coast Catchment Management Board. These issues have been considered as part of the current Processes Study, and are as follows:

- land use planning and development control,
- riparian land management and bank erosion,
- floodplain wetland management,
- acid sulfate soil management,
- floodgate and drain management,
- boating use,
- sedimentation,
- tourism management,
- habitat protection,
- fish/shellfish management,
- water quality,
- river health,
- climate change and sea level rise,
- information availability, and
- integration of projects.

Whilst this study considers these issues, it focuses on those which have been identified by Kempsey Shire Council and the Department of Environment and Climate Change as being of higher priority and have not already been adequately explored in previous studies.

2. CATCHMENT CHARACTERISTICS

2.1. General

The Macleay River Estuary forms part of the larger Macleay River catchment, which covers an area of approximately 11,500 km^2. The main tributaries of the Macleay include the Apsley, Muddy and Chandler Rivers, which form in the Great Dividing Range as shown in Figure 2. These flow across the New England Tablelands before descending through rugged gorge country. The Macleay River itself forms at the confluence of Salisbury Waters and the Gara River and emerges from the gorge country approximately 25km upstream of Belgrave Falls where the river becomes tidal. From here the river meanders for some 54km through low-lying coastal floodplains until it reaches the Pacific Ocean at South West Rocks.

The catchment for the Macleay River Estuary covers approximately 740km^2 of the total catchment area as shown on Figure 2. The main urban areas are sited on the river and include Kempsey, Frederickton, Smithtown, Gladstone, Kinchella, Jerseyville and South West Rocks. The following overview of the topography, geology, soils, vegetation and climatic conditions of the Macleay River catchment provide a background and context for the processes which occur within the estuary.

2.2. Topography

The topography of the Macleay River catchment can be divided into three broad zones: upper valley, mid valley and coastal plains, as shown in Figure 3 (Ashley et. al., 2007; Laurie, Montgomerie & Pettit, 1980).

The upper valley covers approximately 40% of the catchment area and forms part of the New England Tablelands. The area is mostly cleared grazing land with elevations mainly ranging between 900 m and 1200 m. It was described by Ashley and Graham (2001) as consisting of “rolling tablelands”, but also includes higher hills with elevations approaching 1600 m. A number of tributaries drain the area, many of which have been extensively modified as a result of historical clearing and farm management, as well as by urban development around Armidale and Walcha.

The mid valley covers approximately 35% of the catchment area and is characterised by rugged gorge and steep hill country. The land drops steeply from the tablelands over the escarpment and continues to fall until it levels out into lower hill country around 35km upstream of Kempsey. Most of the area is forested and the river system is largely unmodified with steep gradients in the upper regions, diminishing towards the coastal plains (Ashley et. al., 2007).

The remainder of the catchment encompasses the lower hill country to the east of the gorges, as well as the coastal floodplain and estuary. Much of this region is cleared, and used for grazing and agriculture. The major tributaries within the floodplain include Christmas and Clybucca Creeks to the north and the Belmore River and Kinchela Creek to the south. Natural levees have formed along the major waterways below Kempsey, some of which have been

FIGURE 2

MACLEAY RIVER CATCHMENT

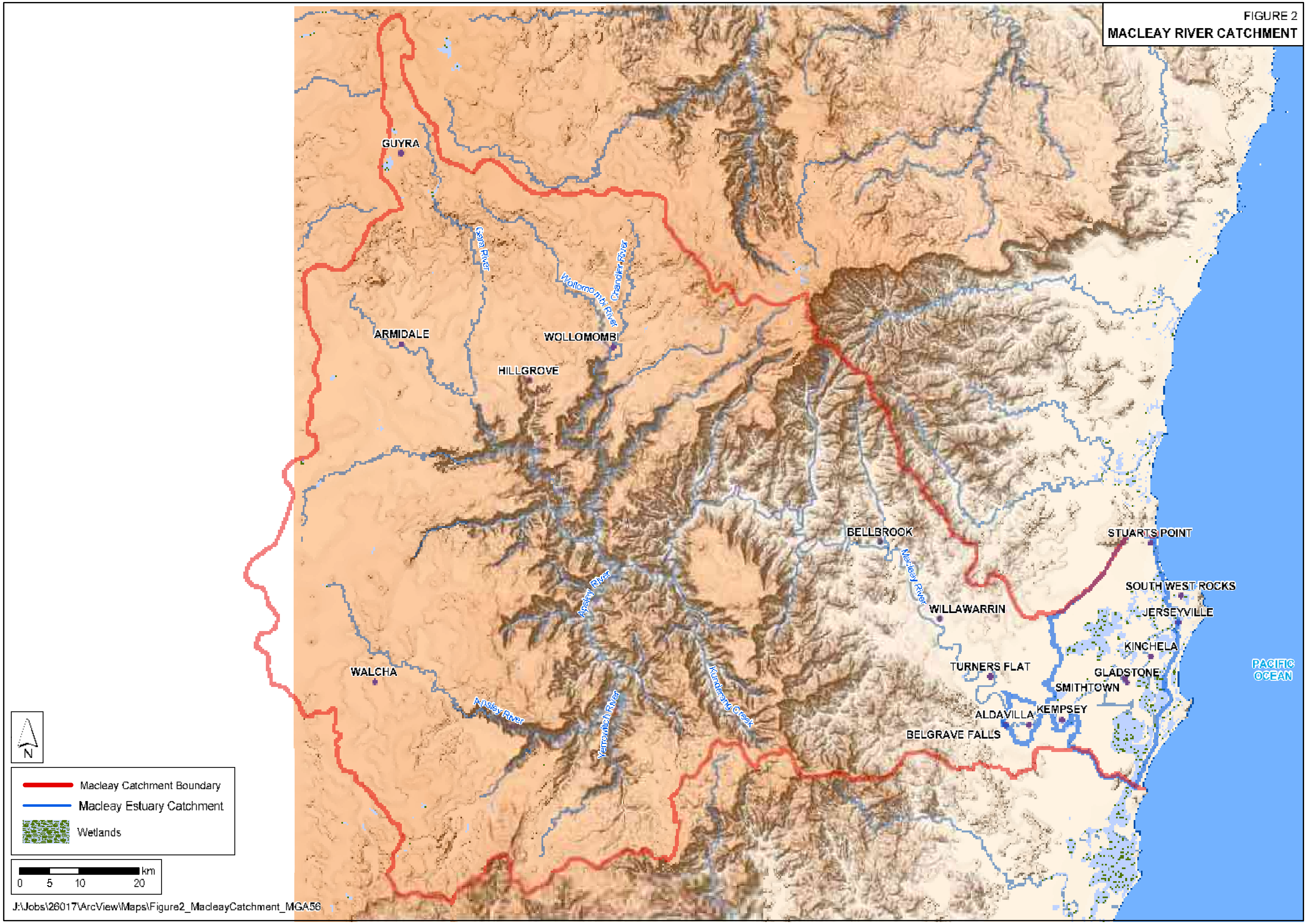

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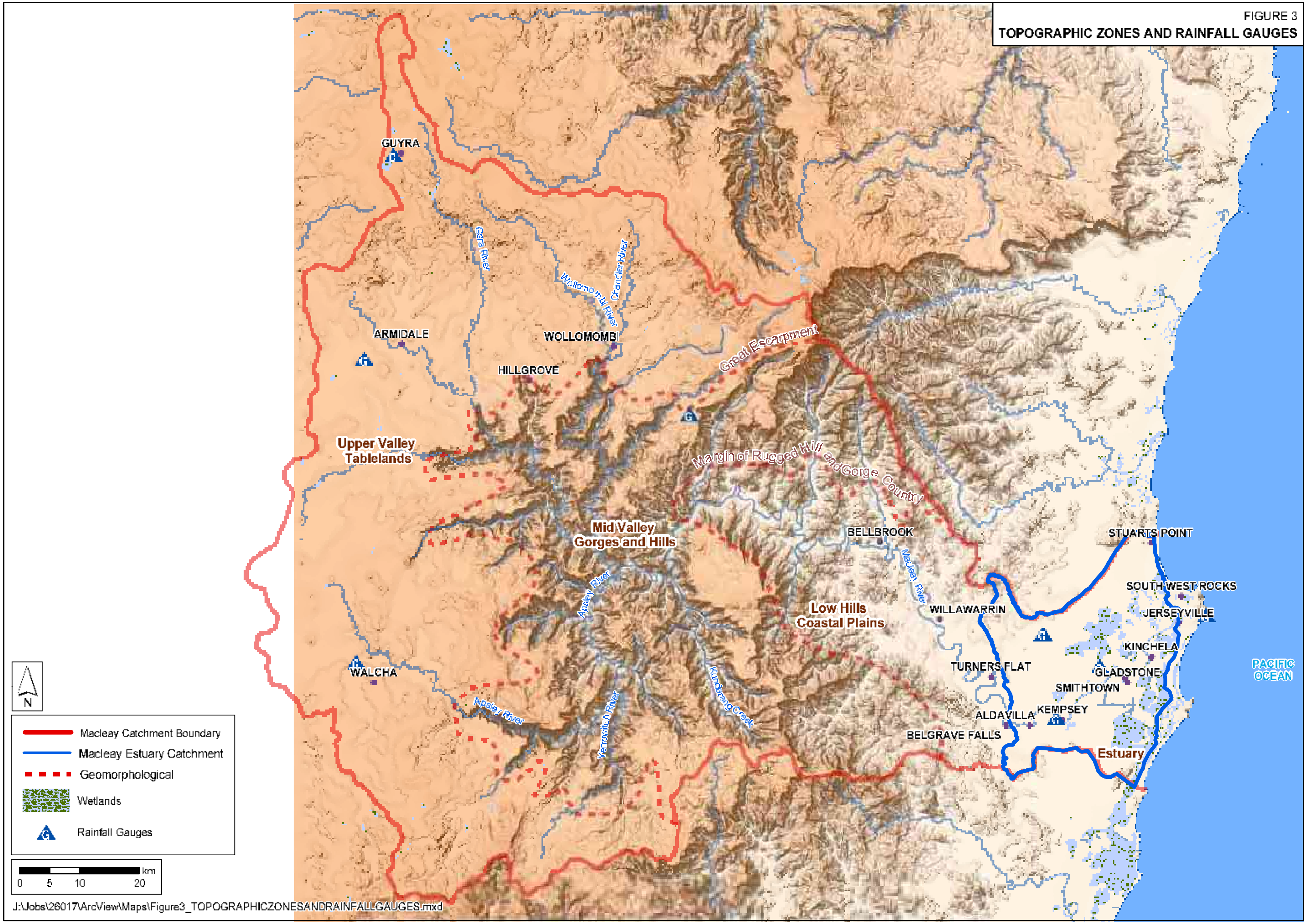
FIGURE 3

TOPOGRAPHIC ZONES AND RAINFALL GAUGES



J:\Jobs\26017\ArcView\Maps\Figure3_TOPOGRAPHICZONESANDRAINFALLGAUGES.mxd selectively raised as part of flood mitigation works. Behind the levees, extensive semi-permanent back swamps cover approximately 240 km^2 (60%) of the floodplain (Telfer, 2005).

The Macleay River estuary commences at the tidal limit at Bellgrave Falls. Fluvial processes dominate in the upper part of the estuary as far as Kinchela, after which there is a transition to tidal dominating process downstream of Jerseyville. A number of distributaries and islands have formed within the lower region of the estuary, including Fattorini Island downstream of Smithtown and Pelican Island near Jerseyville.

Throughout most of the 1800's, the river entered the Pacific Ocean at Grassy Head, 3 km north of Stuarts Point. However, a major flood in 1893 breached the sand barrier just north of South West Rocks. In 1896-97, extensive entrance training works were undertaken to stabilise the location of the entrance at South West Rocks (including major dredging and construction works such as breakwalls). Major dredging and bank protection/training works continued until the 1950's. The old entrance channel between South West Rocks and Grassy Head is now closed to the entrance, and has become an extensive backwater known as the Macleay Arm (WMA, 1997[1]).

Floodwaters mainly drain to the ocean through the main river entrance, but also drain to the ocean through Korogoro Creek, Ryans Cut, Killick Creek and South West Rocks Creek and either to or from Hastings catchment via Connection Creek, depending on relative flood and tide levels.

2.3. Geology

The geology of the catchment describes the types of rocks and sediment that make up the upper valley, mid valley and coastal plains. These were produced by past geological processes and indicate how the catchment and estuary were formed. Catchment geology influences estuary processes such as the formation and movement of sediment, water quality, fluvial processes and the ecology.

2.3.1. Evolution of Estuary Area

Much of the alluvial morphology of the New South Wales coastline formed as a result of the rapid sea level rise since the last glacial maximum (LGM), about 20 000 years ago. Whilst there has been minimal chronological work on the geologic evolution of the Macleay estuary, information has been derived from the Clarence and Shoalhaven catchments which are thought to have similar patterns of infilling (Cohen, 2005). Cohen (2005) provides an overview of the available information.

Sea levels rose from approximately 120m below present levels to a maximum of one to two meters above present by 6500 - 7500 years ago. Elevated sea levels inundated the pre-Holocene Macleay valley and resulted in the deposition of a transgressive sand sheet between the rocky headlands of Crescent Head and South West Rocks, as shown in Diagram 1. This transgressive sand sheet would have become the proto-barrier that bounded an open marine embayment, which was further bounded to the north by an inner Pleistocene barrier at Stuarts Point.

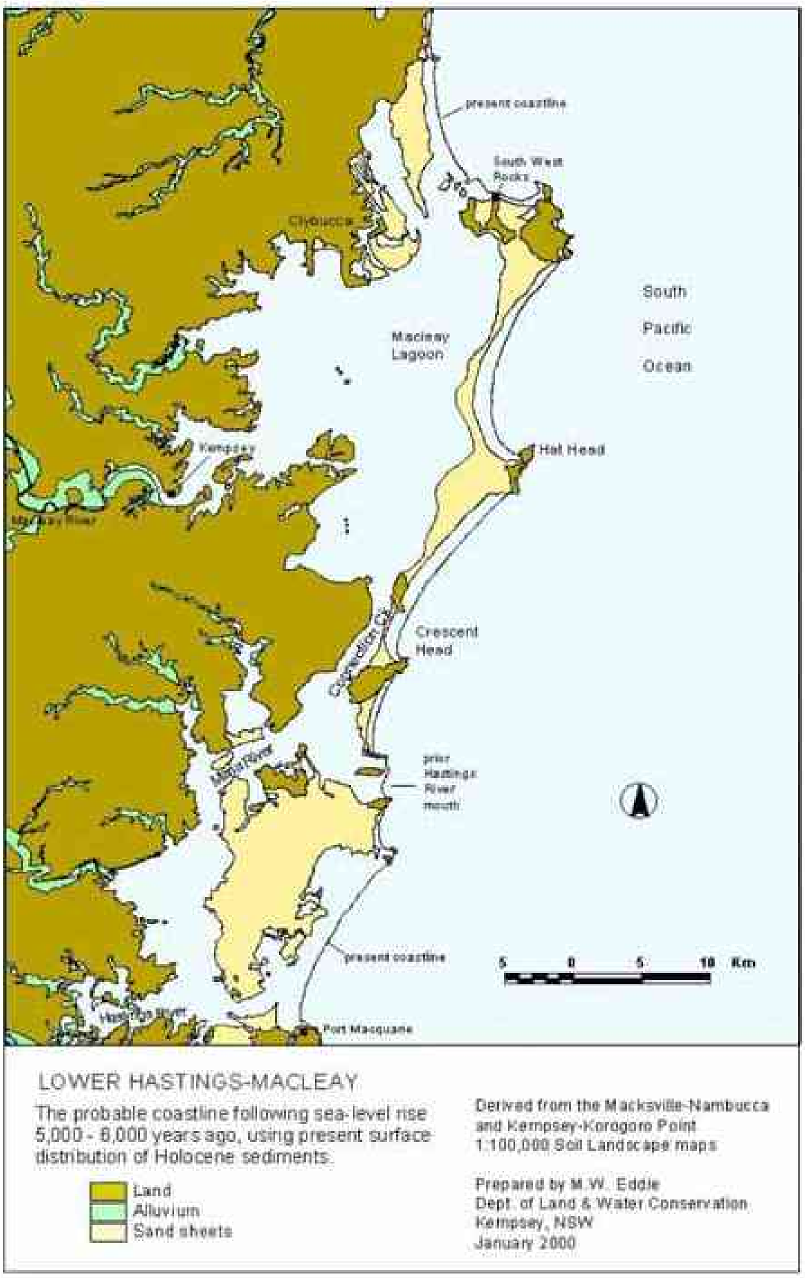


Diagram 1: The probable coastline of the Macleay Estuary during the mid Holocene (source: Eddie, 2000 cited in Cohen, 2005).

The formation of the proto-barrier promoted further barrier development with flood-tide delta and back-barrier deposition. This emergent barrier produced a low-energy environment in the central mud basin, which was conducive to the deposition of estuarine muds and marine influenced sediments associated with the barrier and tidal inlet processes. The deposition of estuarine muds along with continued deposition and progradation of fluvial sediments upstream of Kempsey essentially filled the valley producing a deltaic plain. The timing of the final stages of infilling is unknown but may have coincided with terrace formation upstream of Kempsey, approximately 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 Kinchela Creek and Belmore River indicate the continued progradation of sediment from the Macleay River into these basins.

2.3.2. Catchment Geology

Ashley and Graham (2001) provide a detailed description of the geology of the Macleay catchment. The following is an overview based on this information.

There are three major bedrock substrates in the Macleay River catchment (metasediments, granitoids, and basalt) that collectively occupy approximately 94% of the total area. Deposits of floodplain and estuary sediments cover the remaining 6%. The bedrock type usually determines the nature of stream sediments and can also influence water composition.

“Metasediments” is the term used to group the partially metamorphosed sedimentary rocks of Devonian and Permian periods which dominate the catchment (73% of the area). They are predominantly metamorphosed marine sediments such as mudstones and greywacke with a quartz and felspar composition. Intrusions of granitic rocks of Carboniferous to Triassic age occupy about 10% the catchment. These have high quartz and felspar content with small amounts of mica. They are also associated with mineral deposits of Au, Cu, Pb, Zn, Ag, Sb, Sa and Mo. Tertiary age basaltic volcanics and minor sedimentary rocks occupy a further 11% of the area.

The widespread metasediment substrate of the Macleay catchment typically gives rise to quatsofelspar lithic gravel deposits in the tableland streams and cobbles and boulders in the gorge country. Finer sediment fractions tend to dominate in the lower reaches of streams along the trunk Macleay valley. The sand to silty fraction of these sediments is dominated by quartz and felspar grains and lithic material.

Downstream of Kempsey, the materials constituting the floodplains are mostly unconsolidated sand-silt-muds, but gravels are more prevalent upstream. Silt-dominated levees occur along the Macleay and these may be bordered by muddy to organic-rich backswamp regions. However, these fluvial and swamp deposits overlie earlier estuarine deposits and display evidence for prograding of the floodplain-estuary system since the Pleistocene. The present estuary and coastal regions display interactions between Pleistocene to Recent barrier beach deposits, estuarine sand-silt-mud and saline to brackish wetland areas.

An estimated 534 known mineral deposits occur within the Macleay catchment. The most predominant of these are the mesothermal vein deposits, which mainly consist of a gold-antimony-arsenic (-tungsten) (Au-Sb-As (-W)) associations. These occur primarily within metasedimentary rocks as well as in some granitoid rocks. The highest concentration of mineral deposits occurs within the Hillgrove region. Additional minerals associated with granitic intrusions include copper (Cu), lead (Pb), zinc (Zn), silver (Ag), tin (Sn) and molybdenum (Mo).

Both the dominant substrate and the presence of mineral deposits can have an influence on the geochemical properties of local streams and stream sediment. Deposits containing sulphides such as the mesothermal vein deposits, Mn rich deposits and Ag-Au deposits can cause significant contamination and the effects can extend well beyond local streams.

2.3.3. Groundwater Potential

Ashley and Graham (2001) state that the estimated groundwater resources in the Macleay catchment total 12,000 ML/y on the tablelands and 36,000 ML/y in coastal areas. Fractured rock aquifers associated with granite, basalt and metasediments occur in the tableland areas. In coastal areas, unconsolidated estuarine and floodplain sediments generally provide groundwater of reasonable quality. Bores located on the Macleay floodplain can supply large quantities of water and are thought to be connected to the Macleay River via aquifers due to observed salinity variations coinciding with tidal cycles. In some coastal areas groundwater quality is affected by elevated salinity, organic and iron levels. Elevated arsenic levels have also been found to occur in town water supplies sourced from borefields at Stuarts Point and occasionally from South West Rocks (Geoff Smith, Kempsey Shire Council, pers.comm. January 2000, as cited in Ashley and Graham, 2001).

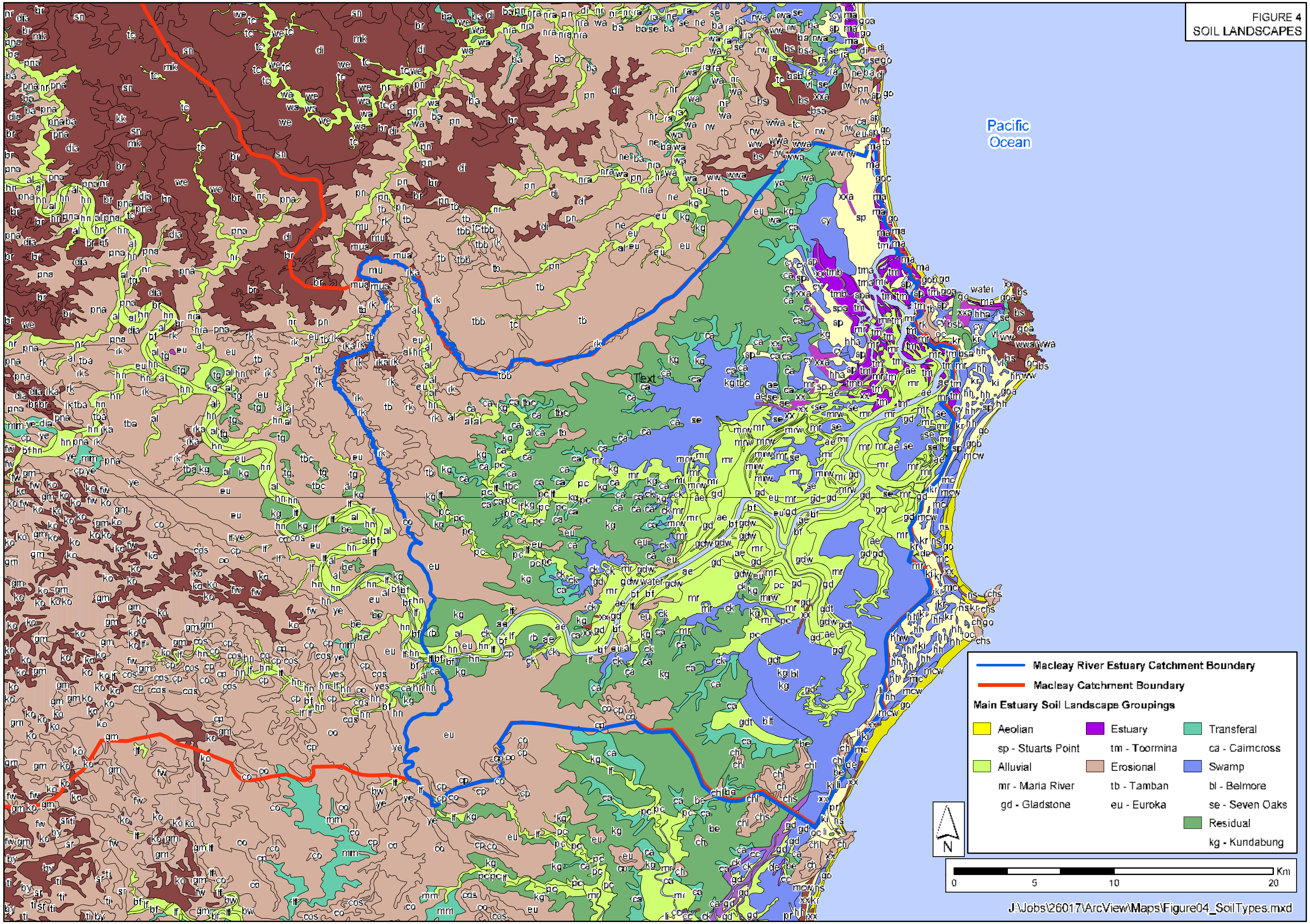
2.4. Soils

Soil landscapes describe the soils as well as the topography, land use and vegetation of an area. They provide information on characteristics such as erodibility, permeability, acid potential and fertility. These characteristics are important factors when examining catchment sediment loads, and when formulating and considering catchment management/estuary management strategies.

Soil landscape maps covering the Macleay River estuary catchment have been prepared and are shown on Land and Water Conservation Kempsey-Korogoro Point and Macksville-Nambucca sheets, as shown in Figure 4. These show that the estuary catchment is dominated by three soil landscape groupings, Alluvial - 28%, Residual – 24% and Swamp – 20%. A description of these and the other catchment groupings is included in the reports by Eddie (2000) and Atkinson (1999), *Soil Landscapes of the Macksville and Nambucca 1:100 000 Sheet* and *Soil Landscapes of the Kempsey 1:100 000 Sheet* respectively. A summary of the major groupings, soil and erosional characteristics is provided below (see also Figure 4).

Alluvial – 28% (eg. mr, gd, ae), were formed along the Macleay and Belmore Rivers and Kinchella and Clybucca Creeks as alluvial delta/levee formations by the deposition of sediment transported down the valley by rivers and streams. The soils are usually deep and contain stratified sediments ranging from gravels and clay. The alluvial soils tend to have high

FIGURE 4
SOIL LANDSCAPES



J:\Jobs\26017\ArcView\Maps\Figure04_SoilTypes.mxd erodibility, low wet bearing strength, low cohesion and high acid sulfate potential.

Residual – 24% (eg. kg), are sites where deep soils have formed from in-situ weathering of parent materials. Residual soil landscapes typically have level to undulating elevated topography. Stream channels are usually poorly defined and streams do not transport sediment out of the landscape. Residual soils tend to have high erodibility and acidity, low wet bearing strength and low fertility.

Swamp – 20% (eg. se, bl), are dominated by ground surfaces and soils which are at least seasonally waterlogged. Soil parent material includes large amounts of accumulated decayed organic matter. Watertables are frequently close to the surface. Landform elements include swamps, abandoned channels, and some lagoons. The swamp soils tend to have low wet bearing strength, low permeability, poor drainage, high aluminium toxicity potential and high to extreme acid sulfate potential. However, recent studies by Southern Cross University have indicated that some backswamp areas have high permeability due to the influence of macropores (DPI, pers. com., 2008).

Transferral – 10% (eg. ca), are deep deposits of eroded soil and parent materials washed down slopes from adjacent hill slopes. Stream channels are often discontinuous and slopes are generally concave. Down slope boundaries tend to merge with alluvial soil landscapes. Transferral soil landscapes tend to have low wet bearing strength, high erodibility, low permeability, strong acidity, aluminium toxicity potential and low fertility.

Aeolian – 4% (eg. sp), are beach ridge Holocene sands on Pleistocene sand barriers. Sandy soils with high erodibility, high permeability, very low water holding capacity and low fertility.

Erosional – 4% (eg. tb, eu), are shallow soils on rolling hills formed by the erosive action of running water on hill sides. Soils are stoney, have high erodibility, low permeability, strong acidity, aluminium toxicity potential and low fertility.

Estuary – 2% (eg. tm), occur where rivers and streams enter large bodies of tidal saline water. Channel flow is dissipated and modified by ebb and flow of tides and by wave action. Soil materials may be influenced by saline conditions. The estuarine soils in the Macleay catchment tend to have low wet bearing strength, moderate to high erodibility and acid sulfate potential.

Other 8%, includes highly disturbed urban areas and the actual estuary waterway area of the Macleay and its tributaries.

Note, in addition to the estuary catchment, the wider river catchment (particularly the mid valley gorge country) predominantly consists of Colluvial and Erosional soil landscapes. The soil and erosional characteristics of these groupings are summarised as follows:

Colluvial, sn, we, br, di and mk, are areas of mass movement although erosional processes may be dominant. Soil parent material includes landslide, mudflow and creep deposits. Soil depth is variable. Colluvial soil landscapes usually include cliffs, scarps, landslides and may include areas of rock outcrop. Colluvial landscapes in the Upper Valley tend to have very steep slopes, shallow soils, moderate to extreme erodibility, low fertility and low available water holding capacity.

Erosional, eu, co, fb, rk and pn, are formed by the erosive action of running water on hill slopes. Streams are well defined and transport their sediment load out of the landscape. Soil depth is usually shallow, and may be either absent, derived from water-washed parent materials or derived from in-situ weathered bedrock. Erosional soil landscapes in the Mid-Valley consist of steep to undulating slopes and rock outcrops. Erosional soils are stoney, have moderate to high erodibility, low fertility, low to moderate available water holding capacity and low to moderate permeability.

2.5. Climate

The Macleay River catchment has a warm temperate to subtropical climate. The climate is influenced by topography, latitude, local differences in altitude, proximity to the ocean, and temperature and precipitation patterns determined by the Tasman Sea. Hence there are climatic variations between the coastal areas and the rugged mountainous region and tablelands in the upper part of the catchment. In general, the coastal region experiences a warmer and wetter climate than the upper tablelands.

A brief summary of the Macleay River climatic conditions is provided below.

2.5.1. Rainfall

The Bureau of Meteorology (BOM) provides climatic summaries including rainfall data for the following locations within the Macleay catchment:

Table 1 Rainfall Gauges within the Macleay Catchment.

Station No.	Location	Operation Dates
059030	South West Rocks (SWR)	1939 - current
059065	Seven Oaks (S.Oaks) (Bellimbopinni)	1895 – 1920
059031	Tanban Forestry	1940 - 1960
059017	Kempsey	1882 - current
057017	Jeogla	1929 - 1971
056035	Walcha	1879 - 1996
056238	Armidale Airport	1993 - current
056016	Guyra Post Office	1886 - current

The location of these stations is shown in Figure 3 (page 4). South West Rocks, Seven Oaks, Tanban Forestry and Kempsey are all located within the estuary catchment. Jeogla is located in the northern part of the Macleay catchment near the top of the escarpment and so is more likely to be influenced by coastal rainfall patterns. Walcha, Armidale and Guyra all lie well west of the escarpment within the New England Tablelands and hence are less likely to be affected by coastal rainfall patterns.

A summary of the average monthly and annual rainfall for the BOM locations is shown in Table 1.

Table 2 Rainfall Data (mm)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Mean:													
SWR	149.8	163.4	185.7	163.9	135.6	131.1	79.9	82.0	55.7	92.6	111.5	120.1	1472.1
S. Oaks	90.7	113.5	120.0	105.3	116.6	92.8	85.4	67.8	65.7	66.0	95.6	100	1119.7
Tanban	149.4	191.3	145.7	96.2	64.2	109.9	70.1	101.2	45.0	77.6	95.6	120.1	1272.2
Kempsey	133.8	151.8	152.7	114.1	92.8	95.4	67.3	61.5	55.4	78.6	91.7	109.0	1205.2
Jeogla	205.9	209.8	209	106.3	79.9	119.8	76.1	81.7	64.7	98.1	111.6	151.5	1514.4
Walcha	103.9	86.3	63.1	44.8	46.0	58.6	54.4	53.4	56.1	70.7	80.8	90.0	808.2
Armidale	93.7	98.6	63.7	33.7	40.3	45.8	45.6	46	58.7	79.6	107.1	81.7	798.2
Guyra	113.4	93.2	71.5	48.1	51.4	61	59.8	54.9	57.4	81	87.3	99.8	877.6

Based on the data presented in Table 2, it can be seen that the wettest months are February and March for the coastal lowland areas and Jeogla, and November to January for the tableland region. The driest month occurs in September for coastal lowland areas and Jeogla, and April for the tablelands. The highest average annual rainfall occurs in Jeogla, followed by the more coastal areas and lastly the tableland region.

The rainfall data highlights the geographic impacts on rainfall distribution and the spatial variation in rainfall patterns. Other locations within the catchment could exhibit further variations. The data needs to be considered within this context. However, based on the available information the following catchment average rainfalls were adopted for the purpose of examining catchment hydrodynamics characteristics:

- 820 mm/yr – Upper Valley – Tablelands,
- 1510 mm/yr – Mid Valley – Gorges and Steep Hills,
- 1260 mm/hr – Lower Valley – Low Hills and Coastal Plains (including the Estuary).

2.5.2. Temperature

Monthly and annual temperatures were obtained from the Bureau of Meteorology for the same locations as listed above. Mean daily maximum and minimum temperatures for the period 1907 to 2000 are shown in the following table.

Table 3 Average Monthly and Annual Temperature Data

		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Mean Daily:														
South West Rocks	Maximum	26.8	26.9	26.1	24.0	21.3	18.7	19.7	19.7	21.7	23.1	24.4	25.9	23.1
	Minimum	19.5	19.7	18.8	16.6	14.2	11.2	11.2	11.7	13.4	15.1	16.7	18.4	15.6
Seven Oaks	Maximum	27.9	27.5	26.8	24.8	21.8	19.3	18.9	20.3	23	24.2	25.9	27.3	24
	Minimum	16.6	16.6	15.2	12.5	9	6.7	5.3	5.9	8.2	10.9	13.8	16	11.4
Tanban	Maximum	27.7	27.4	26.4	23.9	20.9	18.9	18.3	20.2	22.2	24.7	27.1	28.3	23.8
	Minimum	17.2	18.1	16.7	12.9	9.3	7.6	6.1	6.3	8.3	11.4	13.9	16.1	12
Kempsey	Maximum	29.2	28.8	27.8	25.5	22.6	20	19.7	21.3	24	25.6	27.1	28.6	25
	Minimum	17.6	17.9	16.5	13.2	9.7	7	5.7	6.2	8.9	11.7	14.3	16.5	12.1
Jeogla	Maximum	23.7	22.6	20.8	17.9	14.6	12.2	11.7	13	16.2	19.4	22.1	23.8	18.2
	Minimum	12.3	12.9	11.2	7.9	4.7	2.8	1.6	2.5	4.8	7.9	10.2	11.7	7.5
Walcha	Maximum	25.3	25.2	23.1	20.3	15.5	12.7	11.9	12.7	16.2	19.9	22.5	24.6	19.2
	Minimum	11.8	12.1	9.7	5.5	1.3	0	-2	-0.2	1.8	5.5	7.9	10.6	5.3
Armidale Airport	Maximum	26.1	25.3	23.1	19.9	15.8	12.8	12.2	13.9	17.7	20.3	22.2	24.9	19.5
	Minimum	12.9	12.9	11.3	7.3	4.5	2	1	1.6	4.7	7	9.5	11.7	7.2
Guyra	Maximum	24.5	23.5	21.7	18.3	14.1	11.1	10.2	11.9	15.4	18.8	21.5	23.8	17.9
	Minimum	10.8	10.8	9.2	5.6	2.4	0.3	-0.6	0.1	2.4	5.4	7.6	9.9	5.3

Based on the above data, the highest average monthly temperatures occur between December and February, and the lowest in June or July. In general, minimum temperatures are lower and there is a greater variation between winter and summer temperatures in the tablelands than near the coast. In the lower catchment, temperatures are influenced by the ocean, whereas in the upper catchment temperatures are influenced by elevation and the terrain (Laurie, Montgomerie & Pettit, 1980).

2.5.3. Prevailing Winds

Wind data has been recorded by the Bureau of Meteorology at a number of stations throughout the Macleay catchment since the late 1800's and early 1900's. Within the estuary, wind data is available for both South West Rocks and Kempsey. However, wind velocities at South West Rocks are recorded at Smoky Cape Lighthouse, at an elevation of 117 mAHD. Generally, wind velocities are measured and compared at a height of 10 m, as is the case at Kempsey. Higher wind velocities are therefore likely to occur at South West Rocks due to the greater elevation. Wind data from Port Macquarie, which is measured at 20 mAHD, was therefore used as an approximation of coastal wind conditions for the lower estuary. While not located within the estuary, the data from Port Macquarie provides a better indication of the wind velocities at 10 mAHD. Wind directions from Port Macquarie were compared with those of South West Rocks, and were considered to be sufficiently similar.

Diagrams 2 to 5 show the 9.00 am and 3.00 pm annual wind roses for Kempsey and Port Macquarie, whilst Table 4 and Table 5 show the combined annual 9.00 am and 3.00 pm records for Kempsey and Port Macquarie, based on the rose charts available for the sites.

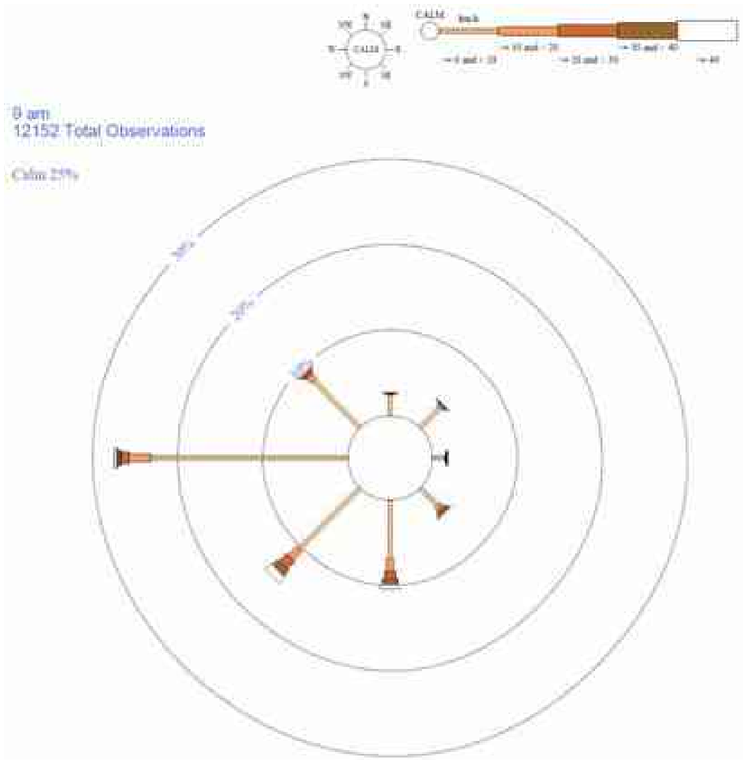


Diagram 2. Average annual 9am wind rose for Kempsey, based on data from January 1965 to December 2006 (source: Bureau of Meteorology website, accessed 21/11/07).

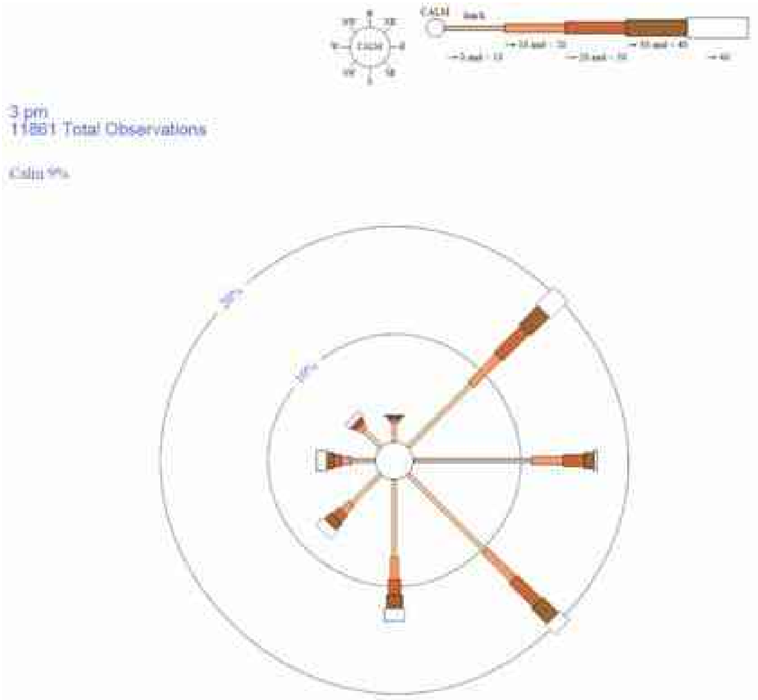


Diagram 3. Average annual 3pm wind rose for Kempsey, based on data from January 1965 to December 2006 (source: Bureau of Meteorology website, accessed 21/11/07).

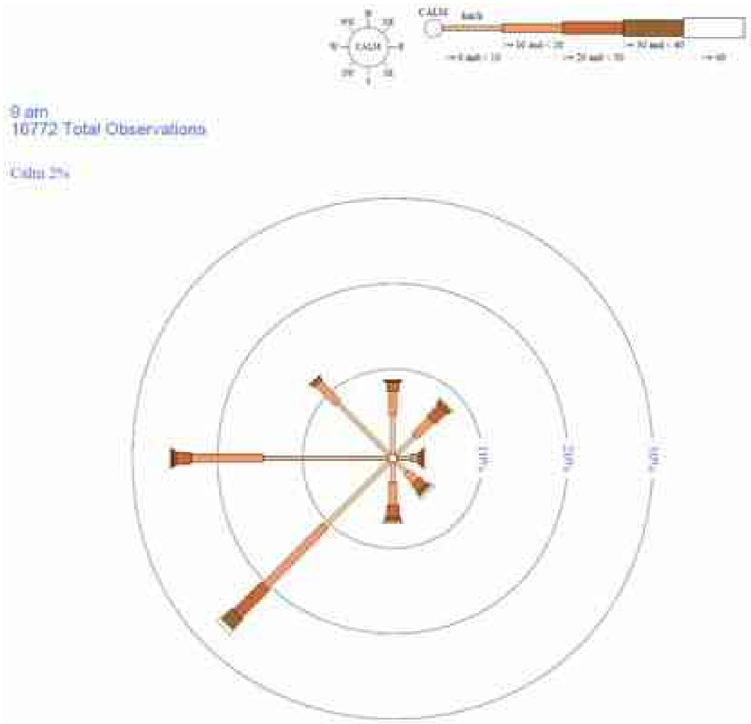


Diagram 4. Average annual 9am wind rose for Port Macquarie, based on data from January 1957 to October 2003 (source: Bureau of Meteorology website, accessed 20/3/08).

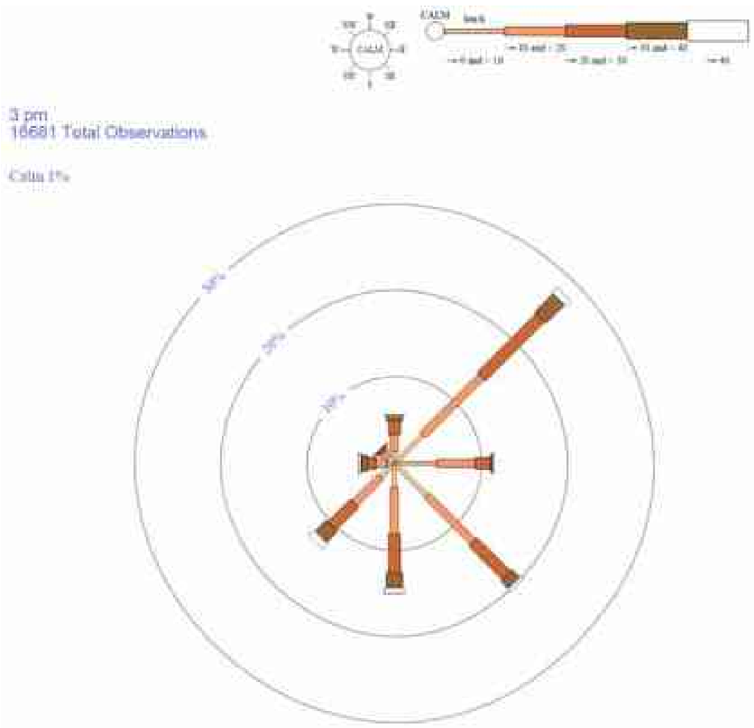


Diagram 5. Average annual 3pm wind rose for Port Macquarie, based on data from January 1957 to October 2003 (source: Bureau of Meteorology website, accessed 20/3/08).

Table 4 Average Wind Direction (%) and Velocity (m/s) for Kempsey (1965 to 2006)

	Velocity (m/s)						
Direction (%)	**Calm**	**0 - 10**	**10-20**	**20 - 30**	**30 - 40**	**>40**	**Total**
North		2.0	0.3	0.1	0.0	0.0	2.3
North-East		5.8	1.9	1.8	1.2	1.2	11.8
East		6.2	1.5	1.0	0.5	0.1	9.3
South-East		6.5	2.1	1.8	1.1	0.6	12.0
South		8.3	1.8	1.3	1.0	0.8	13.1
South-West		7.1	1.3	1.0	0.8	1.0	11.1
West		12.8	1.8	0.8	0.5	0.6	16.5
North-West	25	5.0	0.6	0.3	0.1	0.3	6.3

Table 5 Average Wind Direction (%) and Velocity (m/s) for Port Macquarie (1957 to 2003)

	Velocity (m/s)						
Direction (%)	**Calm**	**0 - 10**	**10-20**	**20 - 30**	**30 - 40**	**>40**	**Total**
North	1.5	3.1	2.4	1.4	0.5	0.1	7.6
North-East		3.7	6.3	5.9	1.9	0.5	18.3
East		3.2	2.5	1.1	0.2	0.2	7.3
South-East		3.4	4.8	3.4	1.0	0.4	12.9
South		2.3	4.1	2.9	1.2	0.4	10.9
South-West		6.4	7.2	4.3	1.7	0.8	20.4
West		7.8	4.9	1.4	0.5	0.2	14.9
North-West		4.7	2.0	0.5	0.1	0.0	7.4

At Kempsey the prevailing winds are variable during summer, with most winds from a north easterly through to southern direction, while in winter westerly winds dominate. During both summer and winter there is a significant proportion of time when conditions are calm. The annual prevailing winds at Port Macquarie are from the south west and north east. Calm conditions occur for only a small percentage of time.

Comparing the above tables shows that wind velocities at Kempsey are generally lower than at Port Macquarie. Approximately 78% of annual wind velocities are less than 10m/s at Kempsey, whereas at Port Macquarie only 36% are less than 10 m/s.

2.5.4. Evaporation

There are no gauges within the Macleay catchment which have evaporation data available from the Bureau of Meteorology. Consequently, evaporation data from four gauges in surrounding areas has been provided in Table 6. The data presented is average evaporation data from a standard Class A pan with bird guard.

Table 6 Mean Daily Evaporation (mm)

Location	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual	Period
Tamworth Airport (055054)	8.6	8.1	6.9	4.6	2.9	2	2.1	3	4.4	6	7.6	8.7	5.4	1973-1992
Yarras (060085)	3.7	3.2	2.7	2.2	1.6	1.5	1.6	2.4	3.3	3.8	3.6	4.1	2.8	1969-2007
Coffs Harbour (059040)	6.4	5.7	4.9	4.0	2.8	2.4	2.5	3.5	4.6	5.3	5.8	6.4	4.5	1968-2007
Taree (060030)	5.7	5.2	4.3	3.3	2.1	1.8	2	2.7	3.7	4.7	5.3	6.1	3.9	1970-1999

Of the sites examined the highest annual evaporation occurred at Tamworth Airport, followed by Coffs Harbour. However, it should be noted that the average daily rates were taken over different periods, which could potentially influence the results.

The evaporation rates for Tamworth, Yarras and Taree are applicable for exposed locations away from significant water bodies. The BOM advised that local meteorological effects (mainly humidity) near coastal waterways can cause reductions of 5 to 10 percent. These evaporation rates also do not include an allowance for heat loss due to water exchanged with the ocean and other localised effects such as sheltering, radiation from the bed and water depth. Based on the above, evaporation for the Macleay estuary was estimated to be approximately 1200 mm/yr, using adjusted data from the two closest gauges at Coffs Harbour and Yarras.

2.5.5. Climate Change

Research conducted by the United Nations Intergovernmental Panel on Climate Change (IPCC, 2007), has indicated that anthropogenic activities are likely to have contributed to observed increases in global temperatures and corresponding sea level rise. The 2007 IPCC Fourth Assessment Report provides a summary of observed climatic changes for the period 1850 to 2006, as well as future projections up to 2100 based on a range of different model scenarios. The Report indicates that global surface temperatures have increased 0.74 ^{o}C between 1906 and 2005, with the average rate being greatest in the last 50 years. Global sea level has risen by an average of 1.8 mm/yr (a total of 0.077m) between 1961 and 2003.

Across all scenarios provided in the IPCC (2007) report, the projected global average increase in temperature is between 1.8^{o} and 4^{o}C by 2090 to 2099. The scenarios provide for different levels of economic growth and greenhouse gas emissions. Temperature changes along the south east coast of Australia are predicted to be similar to the global average, with a projected rise of 2.6^{o}C by 2100 south of 30^{o} latitude (which covers the Macleay River Estuary and its catchment). In an associated report produced by CSIRO (2007), temperature projections for the east coast of Australia across the same IPCC scenarios for 2030, 2050 and 2070 are as follows:

- 2030: increase of 0.8 to 0.9 ^{o}C,
- 2050: increase of 1 to 2 ^{o}C, and
- 2070: increase of 1 to 4 ^{o}C.

Based on IPCC research, sea levels are predicted to rise between 0.18 and 0.59 m, from the 1980-1999 average to the 2090-2099 average level across all scenarios. Using a mid range scenario, the projected sea level rise for the east coast of Australia is 0.05 m to 0.1 m above the global average by 2090-2099. It should be noted that there are a number of uncertainties in these predictions, particularly including the influence of ice melt. The inclusion of potential increases due to ice melt is likely to further increase sea level rise projections by up to 0.2 m. Based on this information and modelling conducted by CSIRO, the Department of Environment and Climate Change (2007) have suggested that sea level rise is expected to be in the range of 0.18 to 0.91 by 2090/2100, with a mid range level of 0.55.

In addition to sea level rise, climate change is predicted to result in a change in rainfall patterns and extreme events. These changes have the potential to increase the occurrence of flooding, and impact upon estuarine processes. However, there is still much uncertainty about the specific nature of such changes on a regional basis. Along the south east coast of Australia, east coast lows are estimated to produce a significant proportion of heavy precipitation. However, CSIRO (2007) stated that the existing models do not provide sufficient indication of whether the occurrence of east coast lows will increase in frequency as a result of climate change.

Preliminary modelling undertaken by WMAwater (2008 [1]) has investigated the potential impact of climate change on flooding on rural residential properties in the lower Macleay and Kempsey CBD. It was found that a 0.18m to 0.91m increase in sea level resulted in a potential increase in the number of rural residential properties inundated during a 100 year flood by 3 to 14% and an increase in flood damages by 2 to 13%. Kempsey is located sufficiently far from the coast not to be directly affected by sea level rise during a flood. A 10 to 30% increase in rainfall was found to result in a potential increase in the number of rural residential properties by 26 to 74% and an increase in flood damages by 33 to 108%. An increase in rainfall was also found to cause a potential increase the flood levels in Kempsey CBD by 17 to 83%. This analysis indicates that an increase in sea level and rainfall has the potential to substantially increase the impact of flooding in the lower Macleay.

2.6. Zoning and Land Usage

Zoning and land use in the Macleay River catchment reflect the topography, soils, climate and history of the area. Knowledge of the zoning and land use within the catchment assists in the identification of possible pollutants and pollutant sources. These also influence the management of the catchment and the estuary.

2.6.1. Zoning

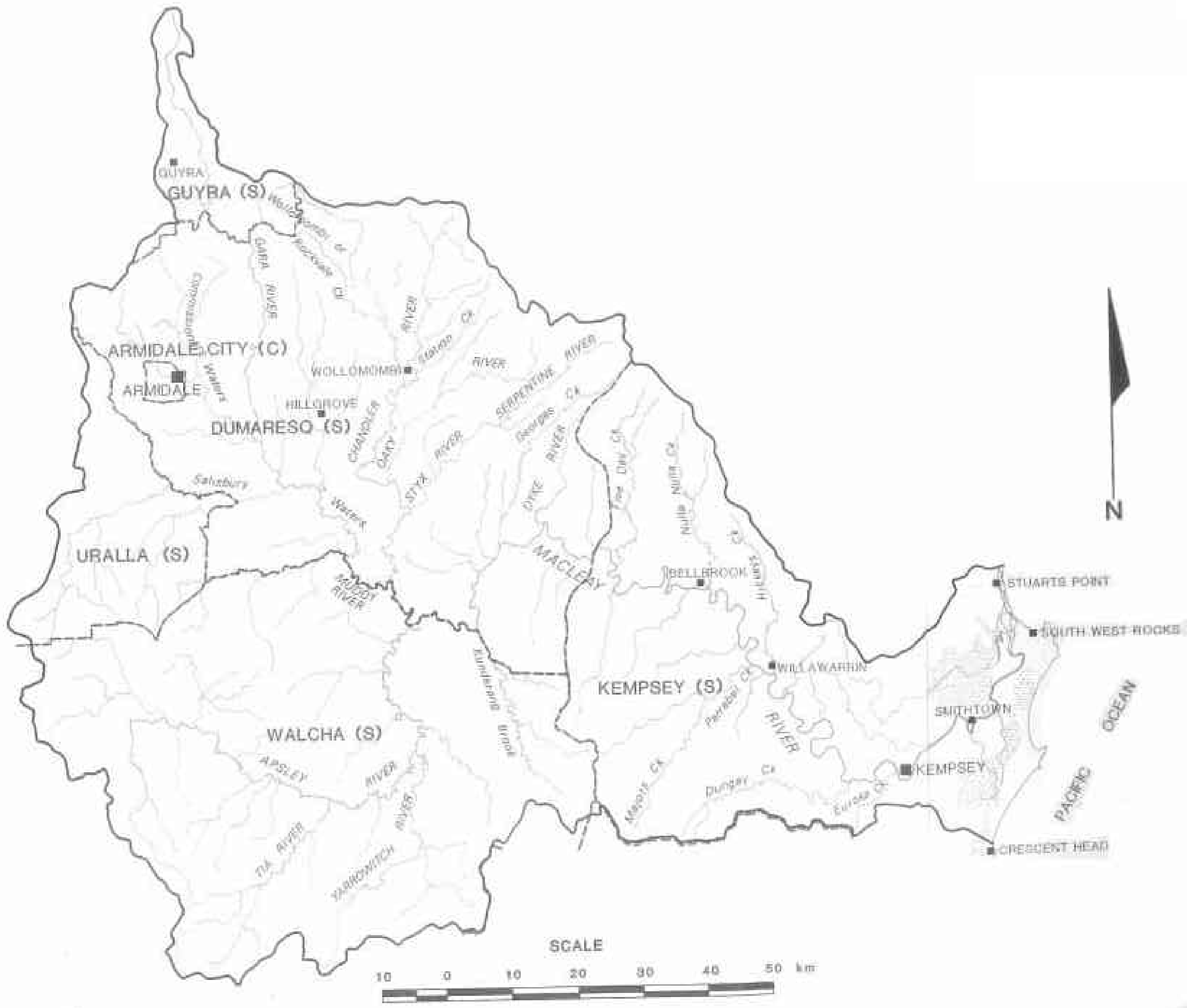
The entire Macleay River estuary and approximately 25% of the total Macleay catchment are within the Kempsey Shire Council Local Government Area. The upper Macleay catchment falls within four Local Government Areas – Walcha, Armidale Dumaresq, Uralla and Guyra, as shown in Figure 5.

Zoning categories for the estuary are specified within the Kempsey Local Environment Plan (1987). There are 8 major zoning categories within the estuary, as shown in Figure 6. The area covered by each of these is shown in the following table. The table also shows the length of river foreshore within each zone. Foreshore length has been measured along both banks, and covers the Macleay River from Bellgrave Falls to the entrance, as well as the main channel of the Macleay Arm.

Table 7 Estuary Catchment and River Foreshore Zoning

Major Zoning Category	Rural (1)	Residential (2)	Business (3)	Industrial (4)	Special Uses (5)	Open Space (6)	Protection (7)	National Parks (8)	Total
Area (km^2)	3051.2	12.3	1.1	2.2	1.3	6.6	123.4	210.8	**3408.9**
River Foreshore (km)	202	12	1	1	<1	4	46	6	**272**
Percentage of Total River Length	74%	4%	<1%	<1%	<1%	1%	17%	2%	**100%**

FIGURE 5
LOCAL GOVERNMENT AREAS



SOURCE: NSW COASTAL RIVERS FLOOD PLAIN MANAGEMENT STUDIES - MACLEAY VALLEY (LAURIE, MONTGOMERIE & PETTIT, 1980)
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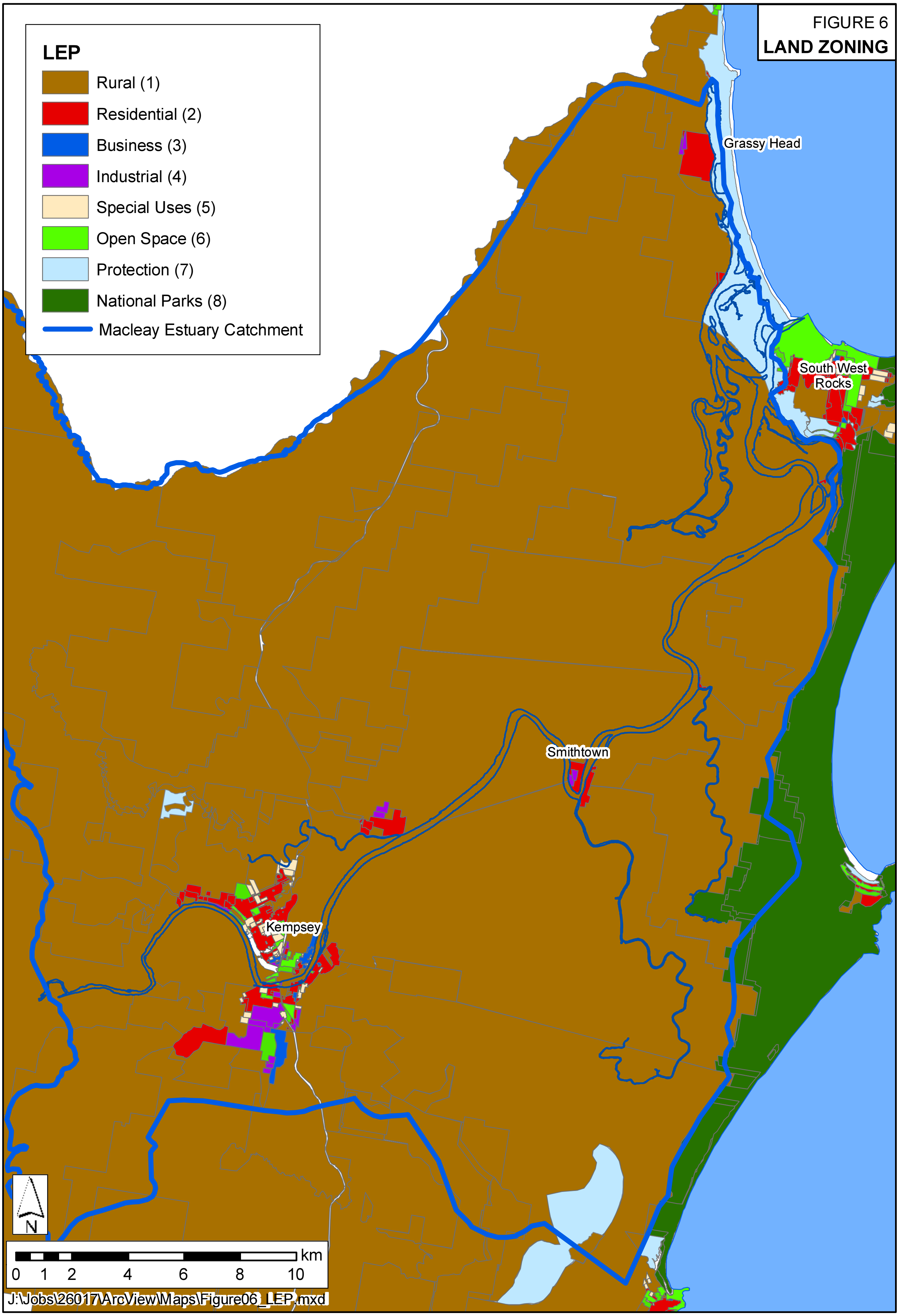
FIGURE 6
LAND ZONING
LEP
Rural (1)
Residential (2)
Business (3)
Industrial (4)
Special Uses (5)
Open Space (6)
Protection (7)
National Parks (8)
Macleay Estuary Catchment
Grassy Head
South West Rocks
Smithtown
Kempsey
N
km
0 1 2 4 6 8 10
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Nearly 90% of the catchment is zoned Rural, of which just over 60% is zoned rural 1(a1). The other major rural zonings are 1(f) Forestry and 1(a3) Agricultural Protection. Other major zonings include National Parks and Reserves 8(a) which covers approximately 7% of the catchment, and Protection (7) covering approximately 4%. Urban areas (including residential, business and industrial zones) and special use areas occupy less than 1% of the catchment.

Downstream of Kempsey, the majority of the Macleay River is within rural zoning. The last 2.5km of the Macleay River and the majority of the Macleay Arm are within areas zoned Protection (7) to the east, and a mix of rural, urban and open space zones to the west.

2.6.2. Land Usage

European settlement has resulted in significant changes to the land throughout the majority of the Macleay catchment. Alteration of the environment through early land uses has also impacted upon both current and future land management practices. The following section provides an overview of previous and current land use for the Macleay, and its impact on the environment.

Historical Land Use

Remnants from ancient middens in the Macleay valley provide evidence of habitation by Aborigines prior to European settlement. The Macleay entrance was first sited by Europeans in 1817, but the region was not settled until the 1830's. Land use was dominated by timber cutting and ship building until the early 1900's when alternative means of transport became accessible (Telfer, 2005).

Early settlement was concentrated in the lower Macleay, with the establishment of Kempsey in 1835. Settlement was also generally restricted to areas adjacent to the river until a series of floods in the late 1880's resulted in movement away from the riparian zone to the surrounding floodplain. This was accompanied by an increase in farming including cattle grazing and crops for fodder.

The upper tablelands were settled and cleared for agricultural use including beef and sheep grazing as well as crops such as maize, oats and lucerne in the far west. The escarpment, gorge country and hill area in the mid catchment remained largely unsuitable for cultivation, but some logging occurred (Laurie, Montgomerie & Pettit, 1980). From the early 1990's onwards, Kempsey Shire has grown with an influx of people wishing to live closer to the coast. This has corresponded with an increase in tourism and recreational activities (Telfer, 2005).

There are a number of small mines throughout the Macleay catchment, as well a few major mines. Major metal mining areas included Hillgrove, Rockvale and Enmore-Melrose in the tablelands; Halls Peak near Jeogla; and Mungay Creek near Willawarrin within the Macleay estuary catchment. Antimony – gold mining also occurs at Hillgrove (Ashley and Graham, 2001). Historical mining practices disposed large quantities of waste material adjacent to waterways that have been eroding over time and causing contamination of surrounding creek systems. Effluent runoff also occurs, and there is acid mine drainage from Halls Peak and Rockvale.

Elevated arsenic and antimony concentrations have been found to extend as far as the Pacific Ocean, originating from the Hillgrove area (Ashley and Graham, 2001).

Current Land Use

Current land use in the Macleay catchment is diverse and includes cattle and sheep grazing on the tablelands, dairying, horticulture and cropping, light industry, mining and quarrying, forestry, residential areas, tourism developments, fishing and oyster farming (Ashley and Graham, 2001; Telfer, 2005; Laurie, Montgomerie and Pettit, 1980).

The upper tablelands have been largely cleared for grazing and crops. The escarpment, gorge country and upper hill country are still predominantly vegetated, with the majority of the area being National Park, Crown Land or State Forest. Whilst some logging still continues, it has been substantially reduced. The floodplain and estuary has also been mainly cleared for agriculture including pasture for grazing and crop production. Additional land uses include fishing, oyster farming, residential development and tourism (Ashley and Graham, 2001).

Mining operations within the Macleay have largely ceased, with only one mine remaining at Hillgrove. Current mining practices have improved waste management practices, such as plastic lined tailings dams to prevent effluent runoff (Department of Primary Industries, pers. com., 2008).

The major towns in the Macleay catchment are Armidale, Kempsey, Walcha, Guyra and South West Rocks, as shown in Figure 2 (page 4). Land use in these areas is dominated by residential, commercial and light industrial development.

2.7. Tourism

The Macleay estuary is a popular tourist destination and attracts a number of visitors each year, particularly in coastal areas. Attractions include the scenic coastline and bushland, historical sites such as Trial Bay Gaol and Smoky Cape Lighthouse as well as a variety of waterways activities. Within the Kempsey Local Government Area (
Figure **5**, page 18) an approximate 415,000 people visit each year, spending on average a total of $90 million (Kempsey Shire Council, pers. com., 2006; ATS Group, 2005). Tourism is therefore a significant industry in the region. Figure 7 (A to C) shows the location of the different recreational areas and activities available within the Macleay estuary. Key uses include fishing, water skiing and the use of power boats. Multiple purpose high use areas are those which are generally most heavily used for a range of recreational activities, including both fishing and boating.

Kempsey Shire Council, Tourism New South Wales, National Parks & Wildlife Service and the Department of State and Regional Development jointly funded the preparation of a Tourism Strategic Plan for the Macleay Valley, for 2005 to the end of 2009 (ATS, 2005). The Plan has identified a shift in visitor trends from those who visit regularly and for whom the Macleay is a main destination to those who pass through on their way to somewhere else. This is particularly the case in non coastal areas such as Kempsey. As South West Rocks and the coast become

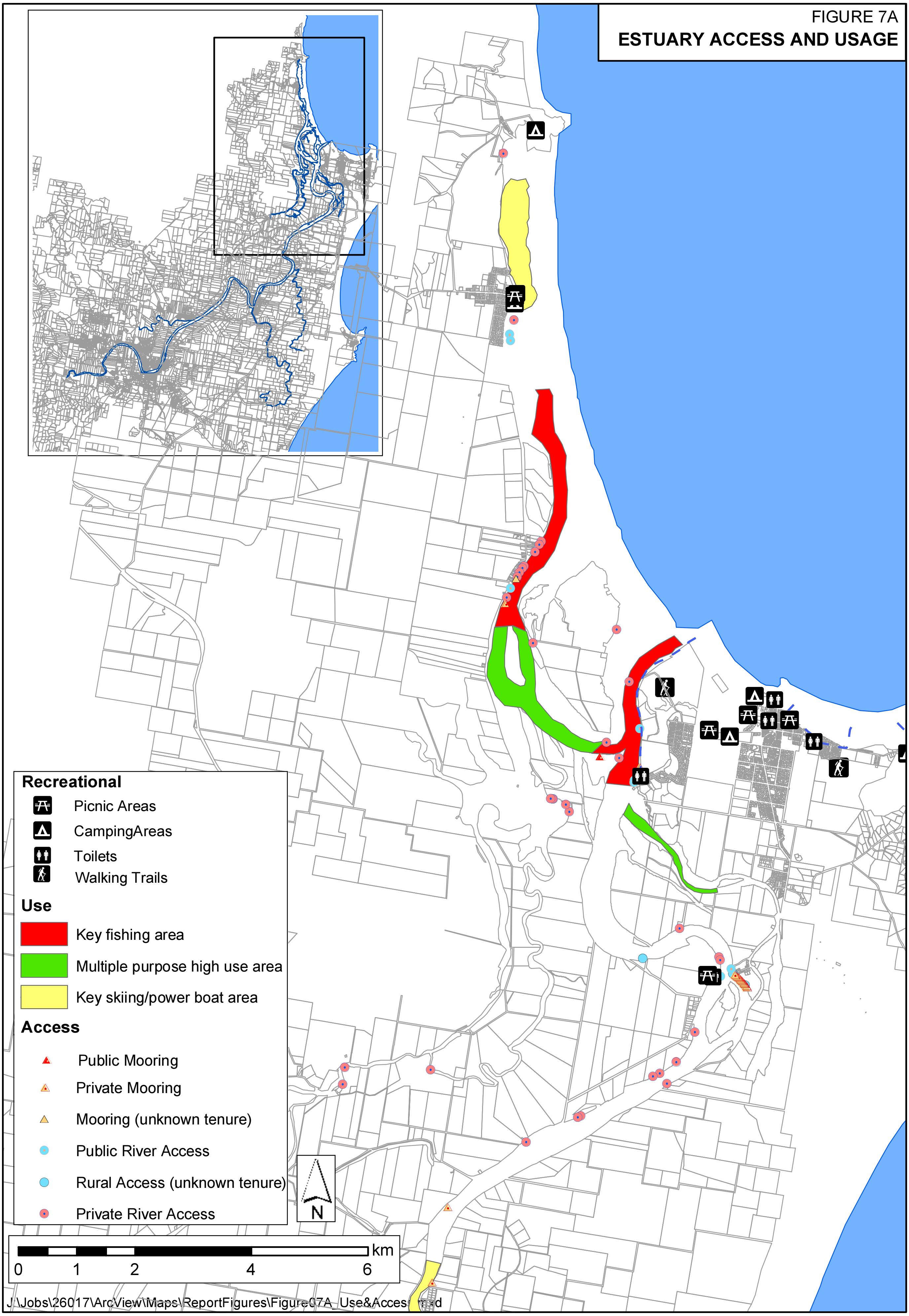
FIGURE 7A
ESTUARY ACCESS AND USAGE
Recreational
Picnic Areas
CampingAreas
Toilets
Walking Trails
Use
Key fishing area
Multiple purpose high use area
Key skiing/power boat area
Access
Public Mooring
Private Mooring
Mooring (unknown tenure)
Public River Access
Rural Access (unknown tenure)
Private River Access
N
0 1 2 4 6 km
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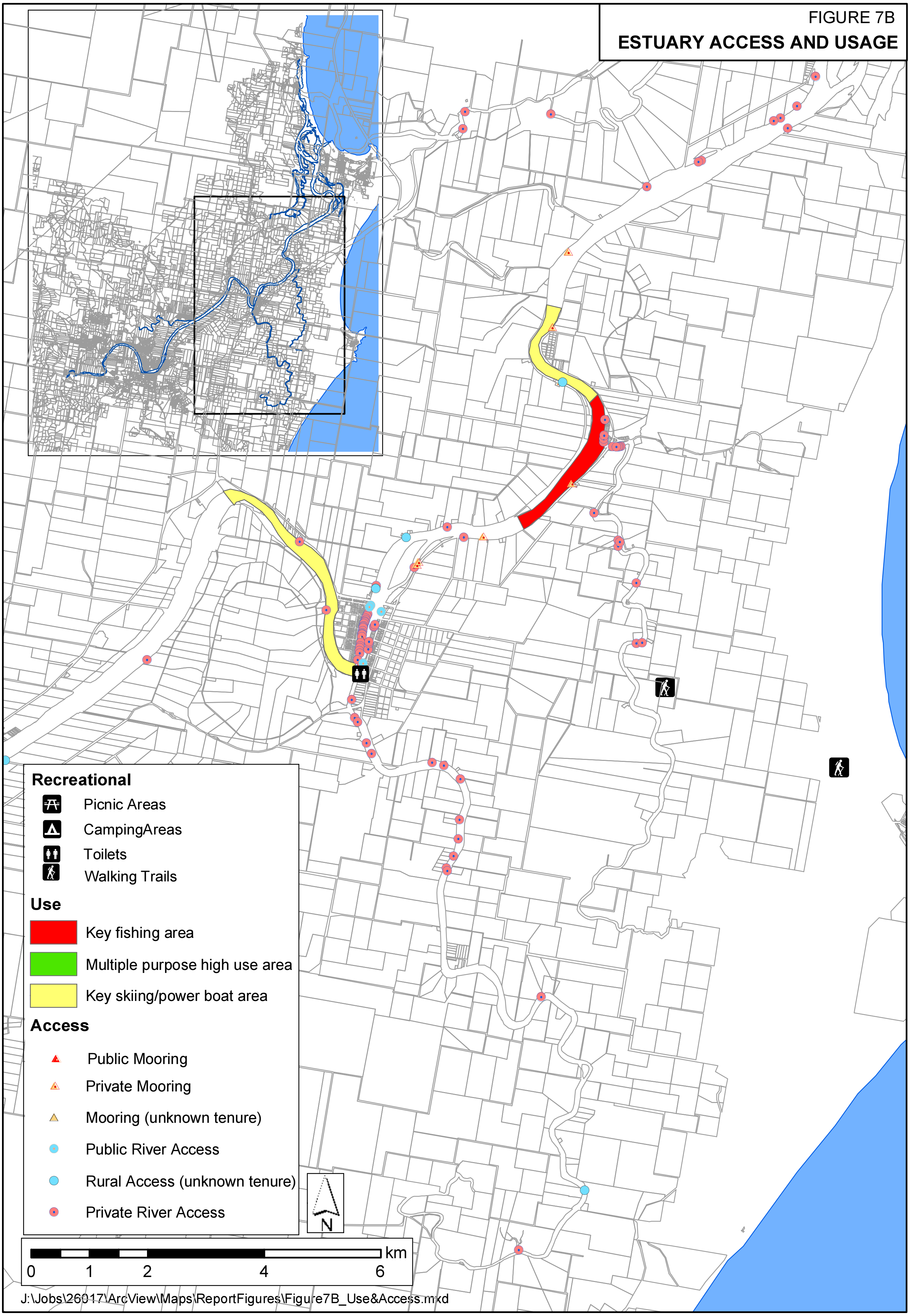
FIGURE 7B
ESTUARY ACCESS AND USAGE
Recreational
Picnic Areas
CampingAreas
Toilets
Walking Trails
Use
Key fishing area
Multiple purpose high use area
Key skiing/power boat area
Access
Public Mooring
Private Mooring
Mooring (unknown tenure)
Public River Access
Rural Access (unknown tenure)
Private River Access
N
0 1 2 4 6 km
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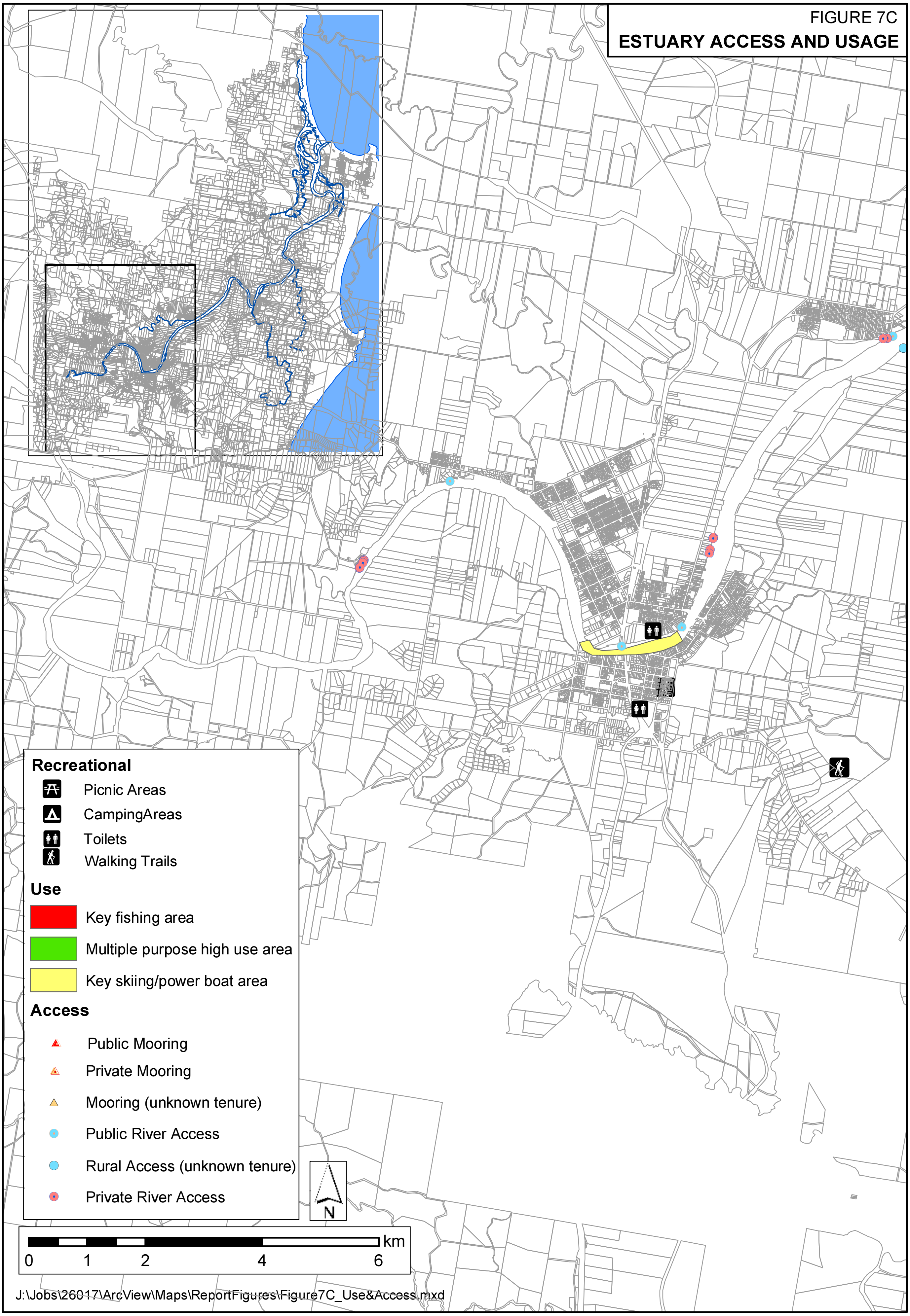
FIGURE 7C

ESTUARY ACCESS AND USAGE



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more developed and commercial some of the regular visitors are thought to have relocated their holiday destination to other coastal towns. Many of these towns have also become more accessible, which has also encouraged tourists to relocate.

There has been an increase in tourists wishing to explore larger areas and those who want to experience different features of the area. The Tourism Plan indicates that this type of tourism is not currently well catered for within the Kempsey LGA. There is a lack of organised tours and a lack of adequate access to different parts of the region. The different experiences of the region have also not been sufficiently promoted.

Whilst the natural environment of the Macleay estuary has much to offer, the Tourism Plan also recognises the need to minimise environmental impacts. The Plan aims to promote sustainable development and tourism through identifying which areas can withstand increased tourist numbers, and which areas are highly sensitive and require protection. Revenue raising through initiatives such as day permit fees for those entering coastal protection zones, can also be used to protect the natural environment. The strategy behind the Plan is to develop a few central areas that are already resilient to human impacts and to provide links between them. For example, a walk between Trial Bay and Port Macquarie is proposed by the Plan. It is recommended that townships maintain a relaxed atmosphere, which is one of the attracting features of smaller coastal areas.

2.8. Heritage

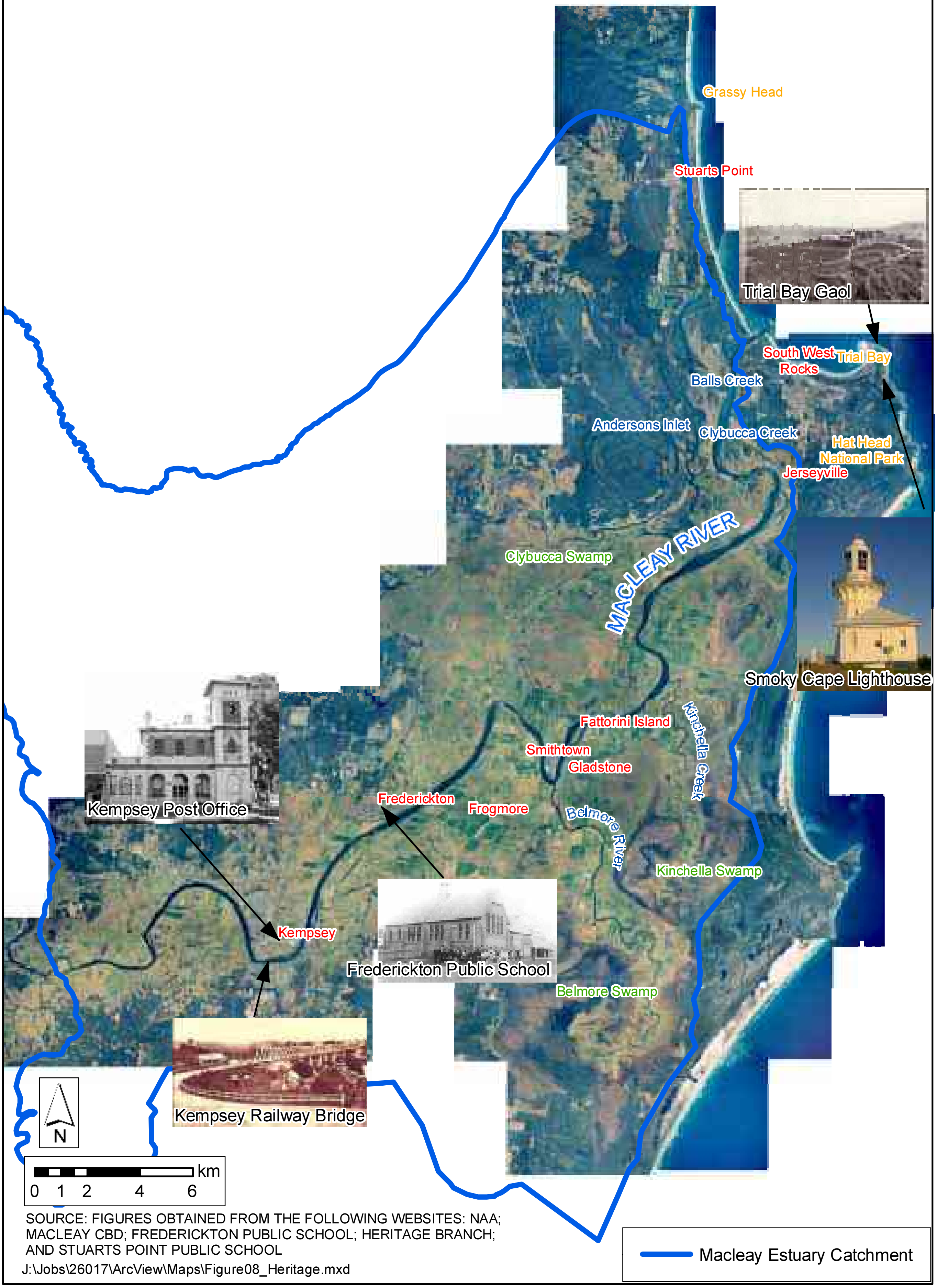
The Aboriginal people of the Macleay valley are the Dunghutti, who for generations before European settlement lived in community groups throughout the Macleay region. Their history may be traced by the remains of their ancient culture, as well as through the oral history of today's Aboriginal people. Local museums have preserved ancient artefacts and continue to educate the public. The Wigay Cultural Park run by the Kempsey TAFE's Djigay Centre also offers tours and insights into how life was like before the European colonisation (Kempsey Council web site, 2008). Heritage sites of Dunghutti people such as middens, a fish trap in the Limeburners Creek Nature Reserve and Bora Ring at Richardsons serve as important links with pre-colonial time.

The first European exploration in the area was in 1820 by John Oxley. However, Oxley did not realise the full potential of the area and it was not until 1926 that the region was revisited by the Commander of Port Macquarie Captain A.C. Innes, who constructed a cedar post north of Euroka Creek on the Macleay River (Kempsey Shire Council, 2005). Cedar logging served as the basis of the early economic revenue for the settlers. First land grants were surveyed and Enoch William Rudder bought 802 acres, becoming Kempsey's first white settler. Rudder surveyed the land and named it Kempsey remarking that it reminded him of the valley of Kempsey in Worcestershire, England (Kempsey Shire Council website, 2008). The majority of the early stations in the region ran sheep, but were later replaced with cattle and the growing of maize. Maize and beef farming became major industries in the region, and in the 1890's dairy farming also became significant with a number of butter and cheese factories becoming established.

There are currently 6 structures within Kempsey Shire Council listed under the NSW Heritage Act 1977, and an additional 10 listings by local and state government agencies. The North East Rainforest World Heritage Area along the Great Escarpment in the upper Macleay is also listed under the NSW Heritage Act and is on the World Heritage List (NSW Department of Planning, Heritage Branch website, 2008; Australian Government Department of the Environment, Water, Heritage and the Arts website, 2008). The *Draft Kempsey Shire Community-Based Heritage Study* (Kempsey Shire Council, 2005) recommends additional heritage listings. Figure 8 shows some of the sites with local historical significance.

Photograph 1 Aborigines in the Upper Macleay. (Source: Charles Kerry, 1890's, from State Library of Victoria website, 2008) **[This photograph contains images of deceased persons]**

FIGURE 8
HERITAGE SITES



SOURCE: FIGURES OBTAINED FROM THE FOLLOWING WEBSITES: NAA; MACLEAY CBD; FREDERICKTON PUBLIC SCHOOL; HERITAGE BRANCH; AND STUARTS POINT PUBLIC SCHOOL

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3. HYDRODYNAMICS

3.1. General

Hydrodynamics is the study of water movement, including the volume, velocity, surface level, variability and distribution of the flows. Within a river estuary like the Macleay, the two main forces driving water movement are fluvial inflows and ocean tides, although wind driven currents and waves can have localised impacts.

Fluvial inflows are generated by direct catchment runoff from rivers and creeks and intercepted groundwater. Tidal flows are generated by the differences in water levels between the estuary and the ocean. Wind generated currents and waves tend to develop towards the ends of longer more exposed reaches. All flows are influenced by the width and depth of the channels (particularly at the ocean entrance) and the length and shape of the various estuary arms.

Estuarine hydrodynamics are important because the inflow, mixing and exchange of fluvial and tidal waters impact on other estuarine processes such as bank erosion and sedimentation, water quality, ecosystem life cycles and human use. As a result three broad process zones are formed that reflect the differing degrees of fluvial and tidal interactions, as shown in Figure 9. These zones are:

- **Fluvial Process Zone**
  This zone extends from the tidal limit at Belgrave Falls to Kinchela (including Belmore, Kinchela and Upper Clybucca Creek). Cohen (2005) further divided this zone into three reaches with different morphological attributes which represent a transition from the non-tidal gravel bed of the upper estuary reaches to the estuarine sand bed reaches of the lower river.

- **Transitional Zone**
  The reach from Kinchela to the Jerseyville Bridge and most of Clybucca Creek is within the transitional zone. This zone reflects the transition between fluvial and tidal processes.

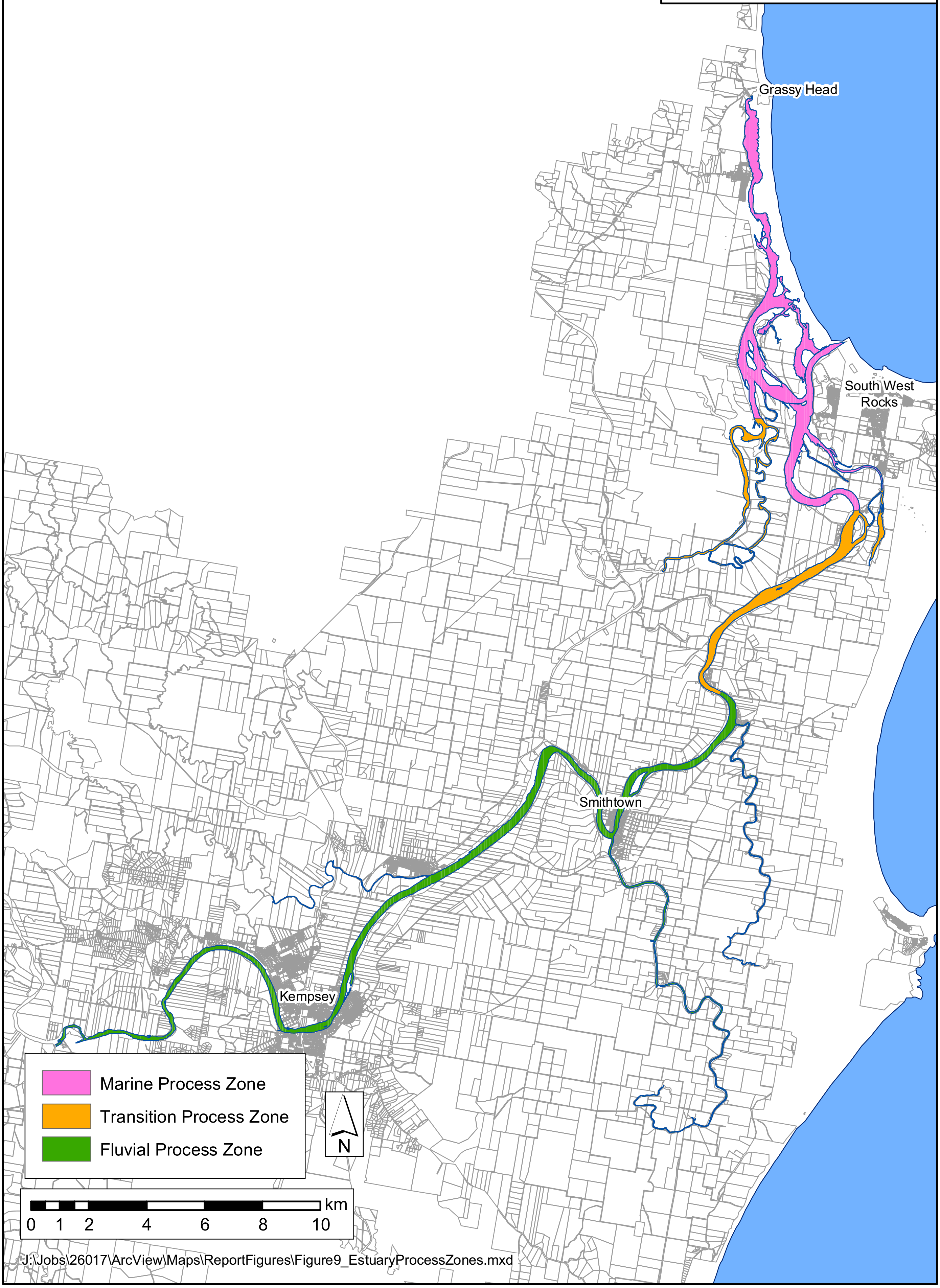
- **Marine Tidal Zone**
  The lower Macleay River (from Jerseyville to the mouth of the Macleay River, including the abandoned Macleay Arm) is dominated by tidal processes and the presence of marine derived sediments.

3.2. Numerical Modelling

A combination of hydrologic (rainfall-runoff) modelling and hydraulic open channel modelling calibrated to existing river flow and water level data was used to examine the hydrodynamics of the estuary for both fluvial and tidal conditions.

FIGURE 9

ESTUARY PROCESS ZONES



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A hydrologic model (WBNM) was set up and calibrated as part of the Kempsey Shire Flood Study (WMAwater, 2008 [2]) and was used in this study. The hydrologic model was used as input to the detailed quasi-two dimensional (quasi-2D) hydraulic model developed for the Lower Macleay Floodplain Management Study (WMA, 1997 [1]) and refined in the Kempsey Shire Flood Study.

The tidal assessment used a RMA-2 numerical model established for this study. This combined one and two dimensional model uses the 2003 hydrosurvey of the Macleay River Estuary from the ocean entrance up to near Belgrave Falls, as well as the tidal reaches of the Macleay Arm, Clybucca Creek, Kinchela Creek and Belmore River (see Figure 10 A-C). In addition, several sources of available overbank survey data including details of major drainage channels and the locations of floodgates were used. Historical aerial photographs, parish maps dating back to the 1860's and the 1956 hydro survey were also used.

The model was calibrated to tidal flow and height data from the April and May 2003 data collection exercise (MHL, 2004). This data included water levels at 29 sites, although not all of the recorders were set to a datum. Discharge and flow velocities were recorded at 9 sites on 16 April over a spring, ebb-flood semi-diurnal cycle.

Data from the permanent "ocean" water level recorders at Coffs Harbour and Crowdy Head and from periodic recorders throughout the estuary including in 1956 and 1991/92 was also available. It was used to establish tidal planes along the estuary and as tailwater boundary for the numerical model.

3.3. Fluvial Assessment

3.3.1. Gauged Streamflows

Fluvial inputs into the riverine system were measured at streamflow gauging stations. Most of them are located in the upper catchment and are not of direct relevance to this study. The data from the station at Turners Flat (AWRC 206011) just upstream of the tidal zone was analysed for the mean, median and peak flows, as shown in Table 8.

Table 8 Fluvial Flow Statistics

Gauging Station	Catchment Area (km^2)	Mean Flows (m^3/s)	Typical Daily Flows		
			Lower 10% (m^3/s)	Median (m^3/s)	Upper 10% (m^3/s)
Turners Flat	9980	47.3	2.2	11.3	80.8

Note: Peak flows shown in m^3/s are instantaneous flows based on rated number of ML/day.
Source: BOM, 2008

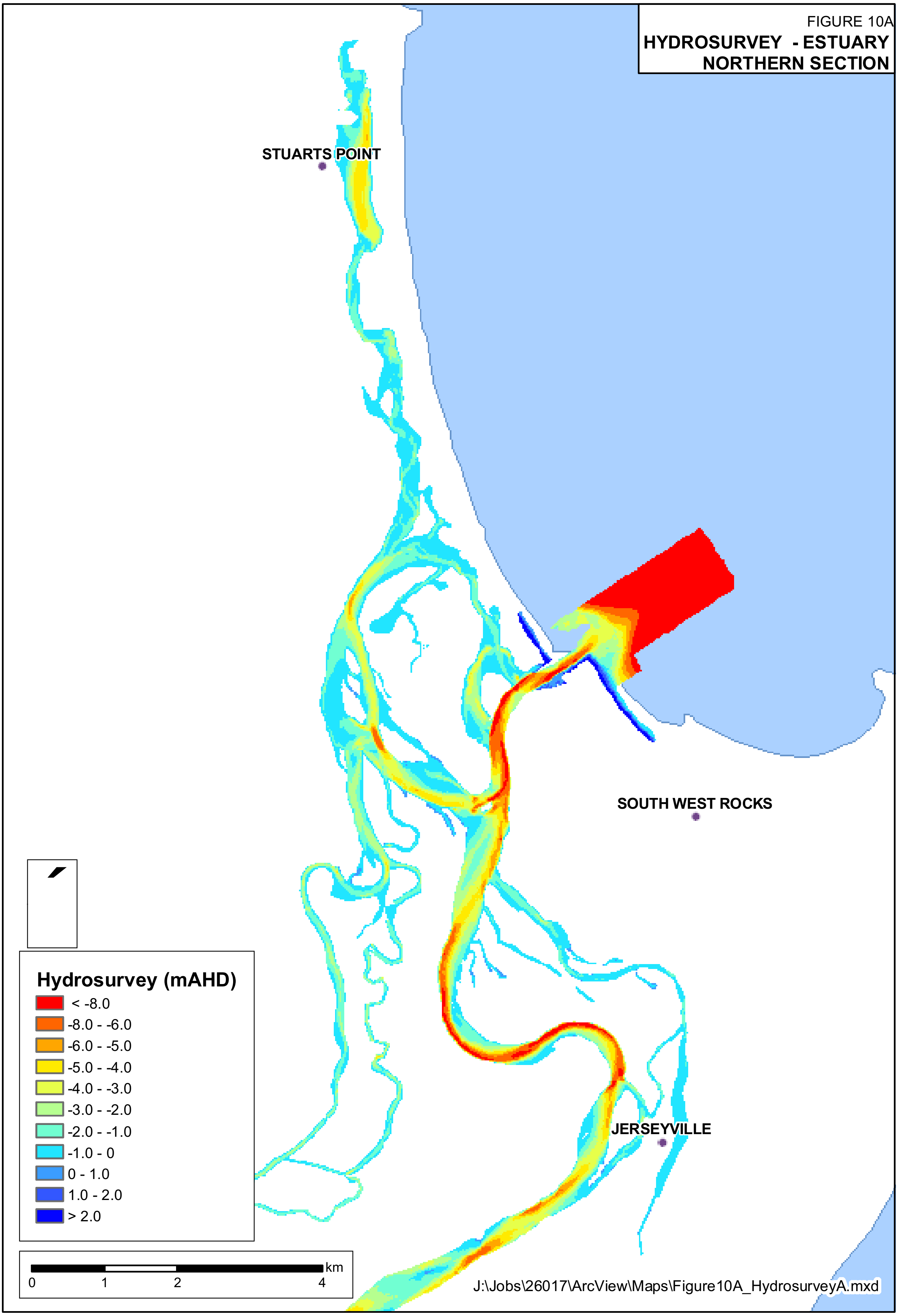
FIGURE 10A
HYDROSURVEY - ESTUARY
NORTHERN SECTION
STUARTS POINT
SOUTH WEST ROCKS
JERSEYVILLE
Hydrosurvey (mAHD)
< -8.0
-8.0 - -6.0
-6.0 - -5.0
-5.0 - -4.0
-4.0 - -3.0
-3.0 - -2.0
-2.0 - -1.0
-1.0 - 0
0 - 1.0
1.0 - 2.0
> 2.0
0 1 2 4 km
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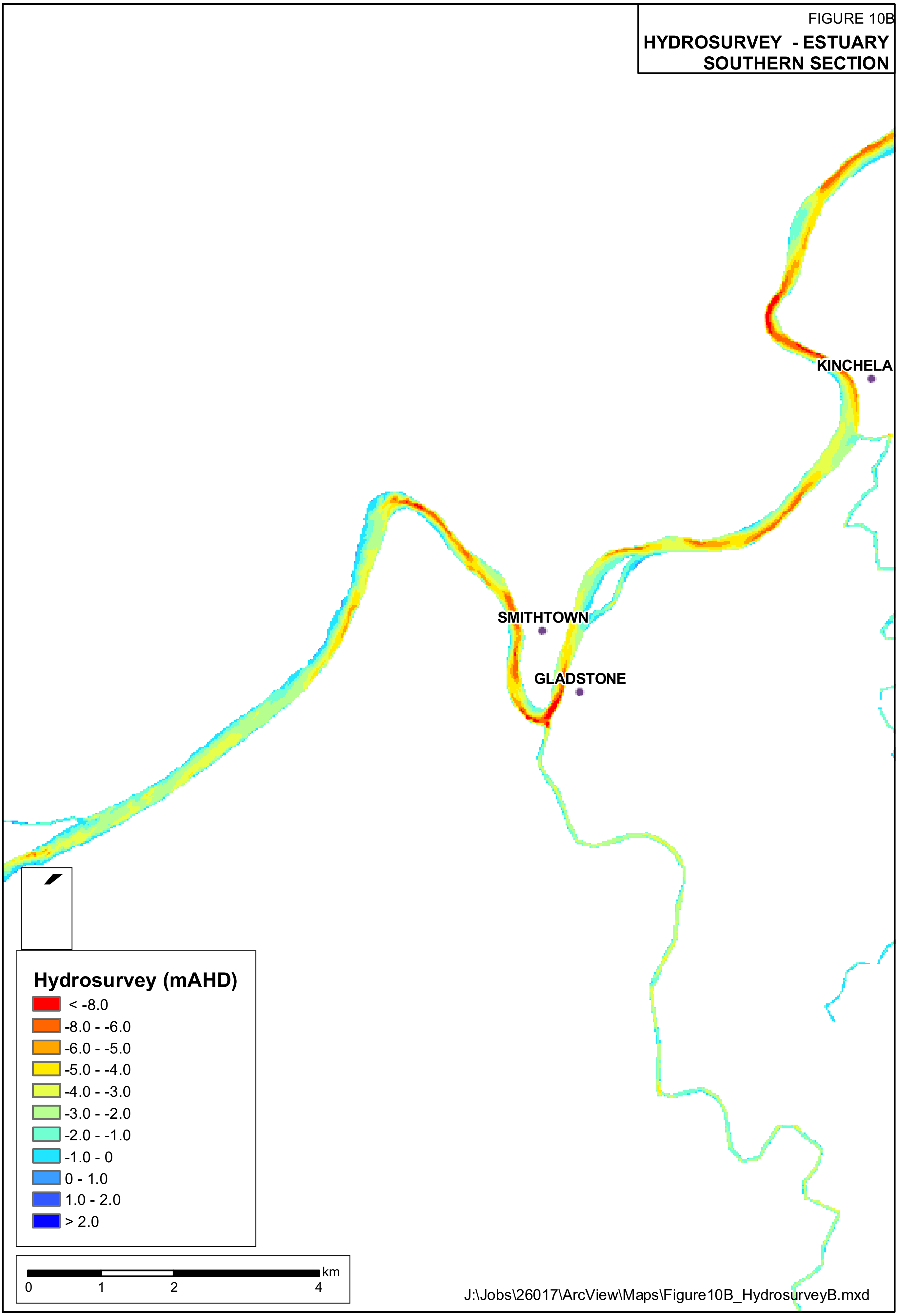
FIGURE 10B
HYDROSURVEY - ESTUARY
SOUTHERN SECTION
KINCHELA
SMITHTOWN
GLADSTONE
Hydrosurvey (mAHD)
< -8.0
-8.0 - -6.0
-6.0 - -5.0
-5.0 - -4.0
-4.0 - -3.0
-3.0 - -2.0
-2.0 - -1.0
-1.0 - 0
0 - 1.0
1.0 - 2.0
> 2.0
km
0
1
2
4
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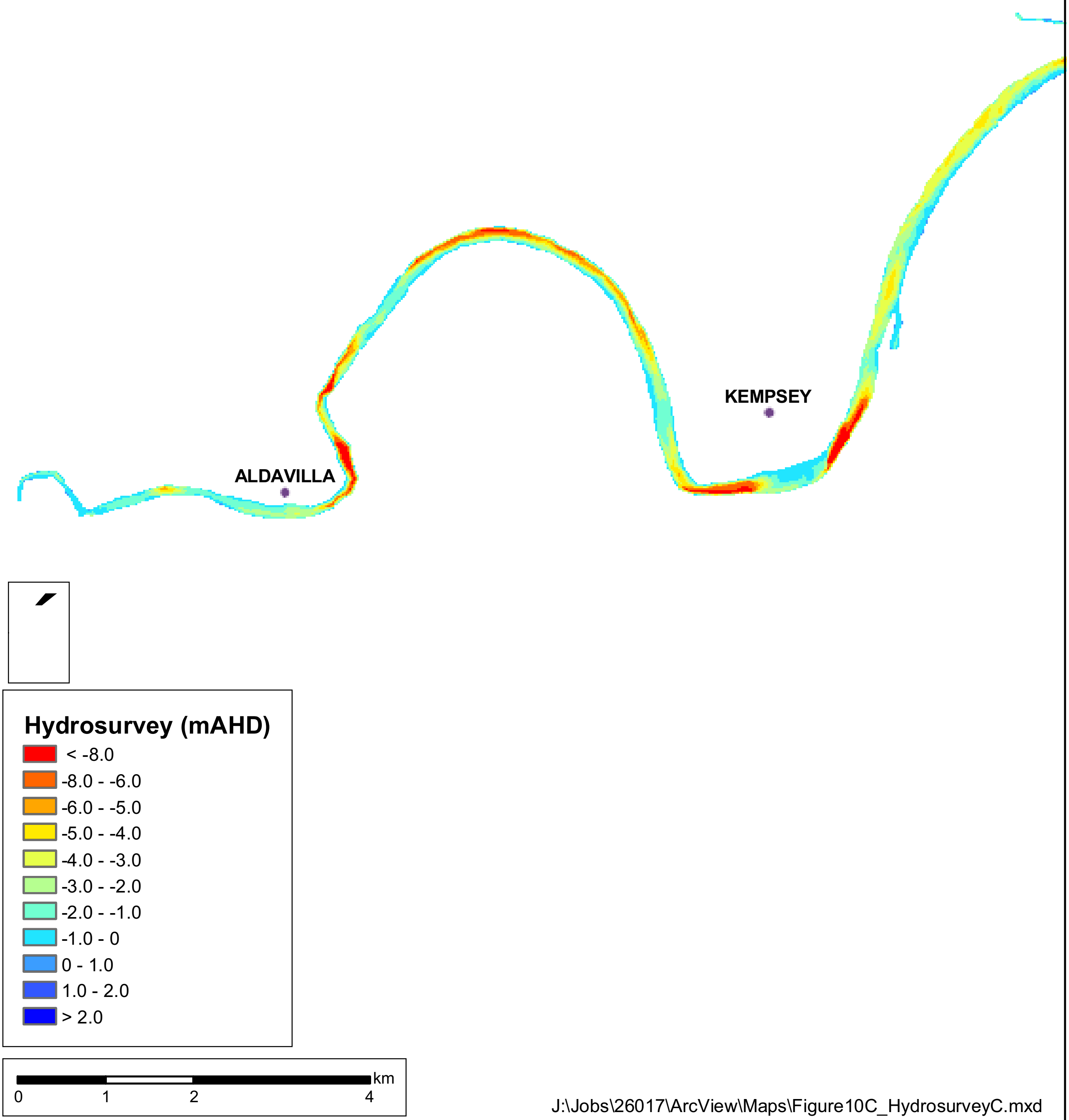
FIGURE 10C

HYDROSURVEY - ESTUARY WESTERN SECTION



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The table shows that the mean flow is some four times more than the median flow. This is typical of NSW catchment runoff because the mean flows include large average flows associated with flood events, whereas the median is more representative of flows when it is not raining. During drought periods the mean monthly flow can be less than 2 m^3/s for several months at a time. During the 1957 drought the river ceased to flow at Turners Flat for 16 consecutive days. Another period of no flow during the 1940-42 drought was reported by local residents (Laurie, Montgomerie & Pettit, 1980).

The lower 10% represents minor dry weather flows consisting mainly of groundwater outflows, while the upper 10% represents wet weather flow conditions occurring about once a month. The 10% low flow for Macleay is about five times less than the median and the 10% high flow more than seven times larger.

Although rainfall over the Macleay catchment is well distributed, on average there is more flow in summer and early autumn. However, flooding can occur any time of the year, although major floods are more likely in the December to April period. Heavy thunderstorm activity may cause local flooding, but it is general sustained rain related to tropical air masses that results in catchment-wide flooding. It is also during such events that major modifications to stream morphology may occur, with adjustments to channels and banks, and downstream movement of large sediment masses (Ashley & Graham, 2001).

The average annual discharge of the Macleay River is 2,150,000 megalitres, which is 19% of the annual rainfall volume and close to the average for coastal rivers. The lower Macleay River has the least variable rainfall, although even in the lower Macleay the average annual runoff ranges between 8 to 240% of the average flow.

3.3.2. Hydrologic Modelling

The Kempsey Flood Study (WMAwater, 2008 [2]) reviewed the standard daily rainfall records from all the BOM stations in the catchment as well as from the nine pluviometers. Turners Flat (AWRC 206011) gauges some 87% of the total catchment area and has been operational since 1945. Based on this information a hydrologic model (WBNM) was set up and calibrated against the March 2001 rainfall/flood event for flows at Turners Flat routed to the tidal limit at Belgrave Falls.

3.3.3. Hydraulic Modelling

To assess the hydrodynamics in the estuary during a rainfall/flood event, the model initially established and calibrated in 1997 as part of the Lower Macleay Floodplain Management Study (WMA, 1997[1]) was used. This quasi-two dimensional (quasi-2D) flow model was developed with the RUBICON software package. The model was progressively refined during the course of subsequent investigations (WMA,1999; WMA, 2004; and WMAwater, 2008 [2]). The Kempsey Flood Study updated the model with the latest survey data sets, recalibrated against the March 2001 event and validated using the May 1980, May 1963 and August 1949 events.

The performance of the model was reviewed for the Flood Study, leading to the conclusion that the RUBICON model provides a conservative yet reliable representation of the complex flow behaviour likely to be experienced for the overall Lower Macleay Floodplain and hence was considered suitable for this study. As with the hydrologic model, more information on the model can be found in the Flood Study (WMAwater, 2008 [2]).

3.3.4. Flood Flows and Levels

The Kempsey Flood Study estimated peak flood flows for a range of recurrence intervals at a number of locations throughout the lower catchment/estuary area relevant to this study. Peak flows and velocities for the 1 in 2 or 50% AEP flood, the 1 in 5 or 20% AEP flood, and the 1 in 100 or 1% AEP flood at key locations are shown in Table 9. The 50% AEP is also shown on Figure 11.

Table 9 Flood Flows

Location	Peak Flows (m^3/s)		
	50% AEP	20% AEP	1% AEP
Macleay River:			
Aldaville	3530	6100	15340
Kempsey	3510	6040	15040
Smithtown	2190	2290	2900
Kinchela	1930	1970	2110
Macleay Arm/South West Rocks	2620	2926	6950
Entrance	2690	2980	7260
Belmore River:			
Entrance	-370	-410	-610
Kinchela Creek:			
Entrance	-200	-210	-330
Macleay North Arm:			
Entrance/River Confluence	-750	-730	-750

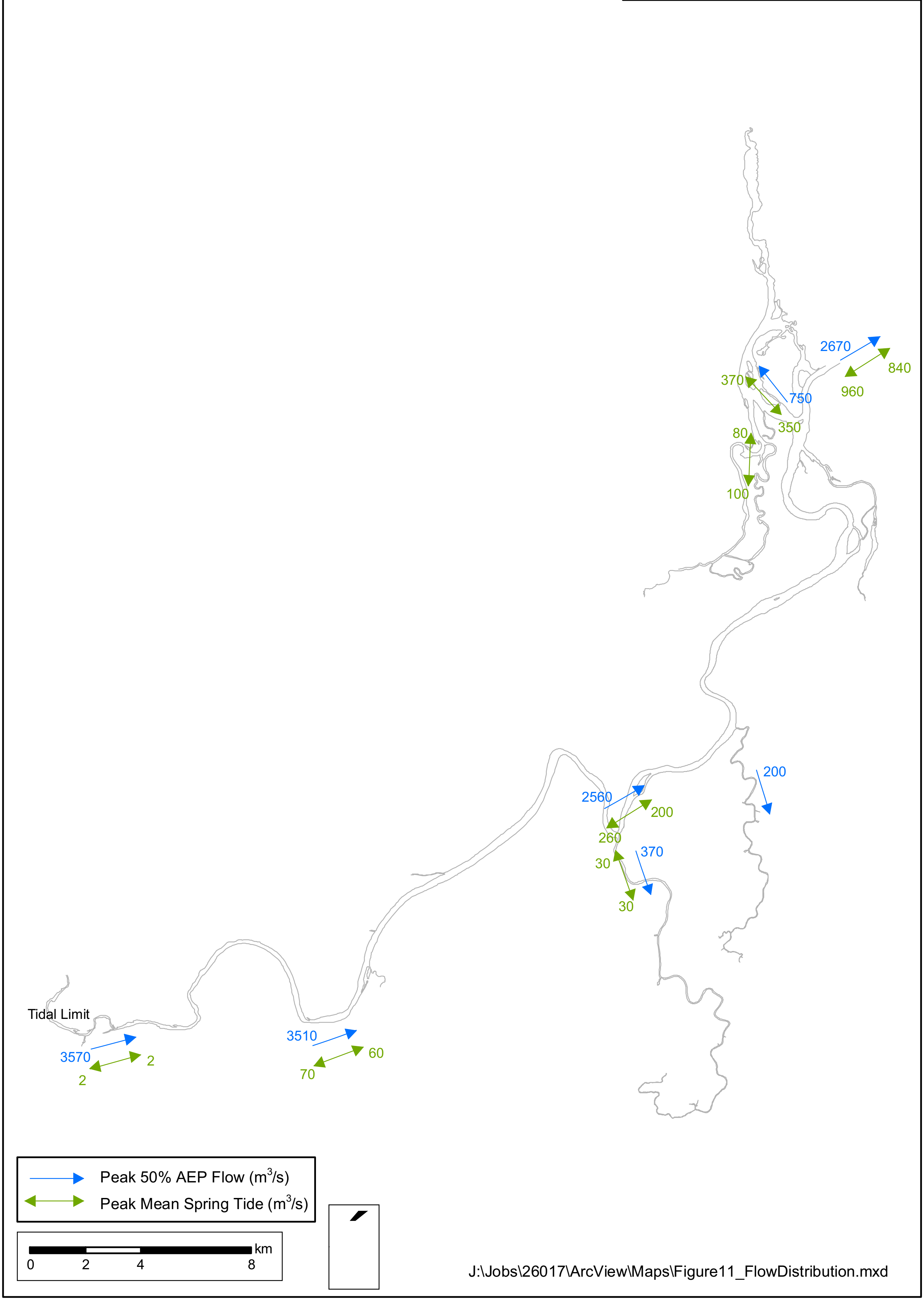
(Source: WMAwater, 2008[2])

Note: Positive flow direction is defined as from the estuary to the ocean, and negative from the ocean to the estuary.

The table shows that even for a comparatively small event like the 50% AEP, large flow volumes are diverted to storage on the floodplain and into the tributaries. The 1% AEP is some four times greater than the 50% AEP and around 2.5 times greater than the 20% AEP at Aldavilla. At the entrance, the 1% AEP peak flow is in the order of 2.5 times greater in magnitude than both the 50% AEP and 20% AEP peak flows. The peak flow for the 50% AEP event at Aldavilla is in the order of 300 times greater than the median flow at (Turners Flat some 16km upstream) and the 1% AEP peak flows 1400 times greater.

The critical storm duration for the catchment (i.e. the length of storm which produces the highest peak flows for a given AEP) was found to be around 2 days (WMAwater, 2008 [2]). Runoff from the Clybucca, Belmore and Kinchela Creek was likely to peak approximately 70 hours before the

FIGURE 11
ESTUARY FLOW DISTRIBUTION



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Macleay River (assuming a uniform rainfall distribution across the catchment) as smaller catchments have quicker response times.

The difference in peak flows, the effects of floodplain storage and the timing of the ocean tide all combine to complicate the timing of peak flood levels in the lower estuary. As a result, each flood has unique characteristics. This can be illustrated by considering past flooding of the estuary. The 1949 flood reached 8.34 mAHD at the Kempsey Road Bridge gauge and was considerably larger than the 1963 flood, which reached 7.14 mAHD. However, downstream of Jerseyville the 1963 flood reached higher levels than the 1949 flood mainly due to unusually high tide levels (WMA, 1989).

3.4. Tidal Assessment

Tidal levels throughout the estuary vary in response to the ocean water level and the bathymetric effect of the river channels, particularly at the entrance. The estuary tide level reflects how much water enters and leaves the entrance each tidal cycle and therefore provides a measure of the hydrodynamic efficiency of the entrance and the river channels. The estuary tide also brings marine waters into the estuary and after mixing, flushes catchment waters from the system. This has implications for estuarine water quality as well as influencing aquatic habitat and estuarine biological processes.

3.4.1. Tidal modelling

A RMA-2 numerical model was established to investigate the tidal dynamics of the estuary in order to gain a better understanding of the distribution of tidal flows, including flushing and exchange. RMA-2 is a finite element package for simulating two-dimensional (2D) flow conditions.

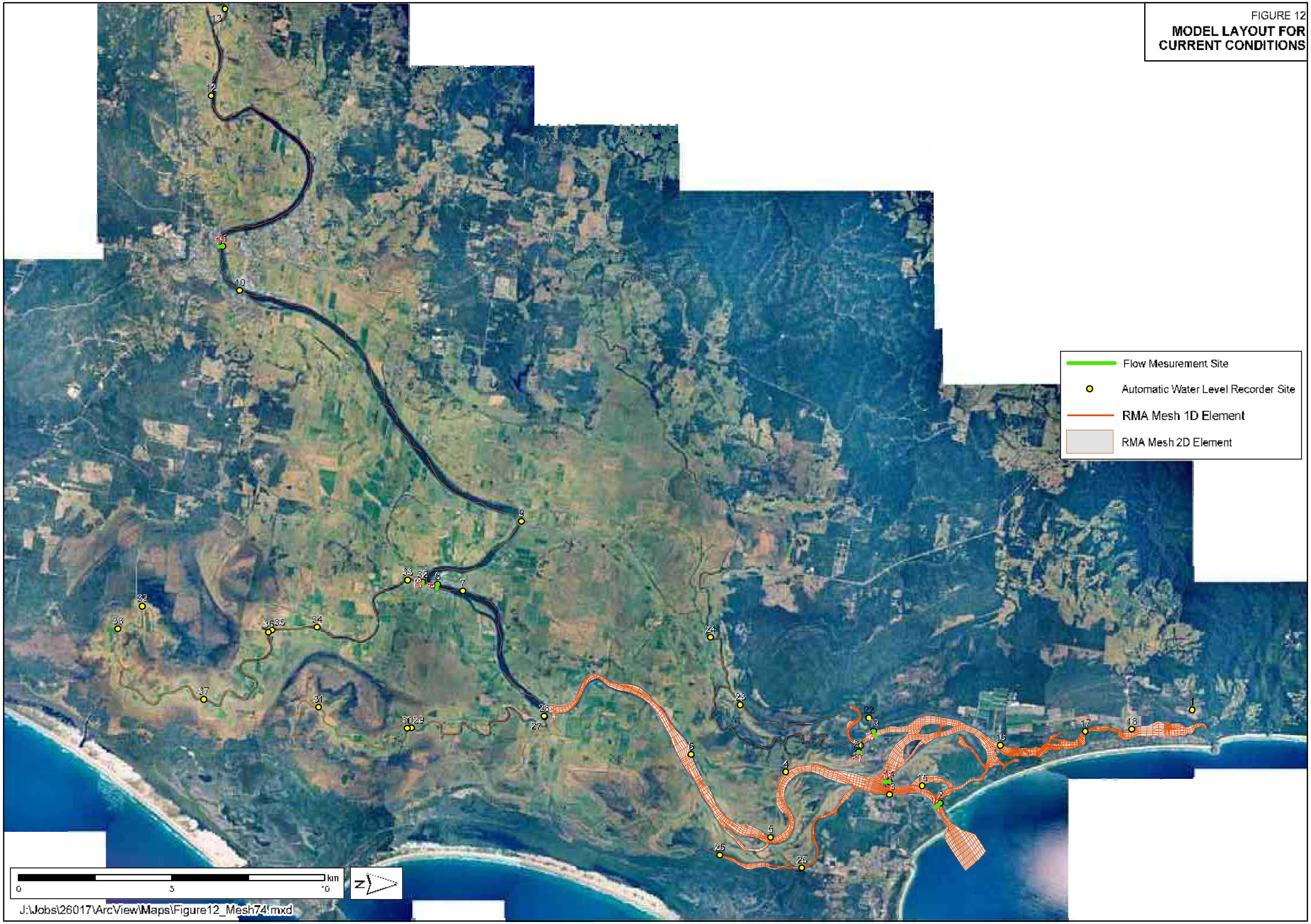
Key features of the hydrodynamics package (RMA-2) include:

- the ability to use time-varying boundary conditions (e.g. inflows, tides, floodgates) to yield fully dynamic solutions,
- the capacity to include one-dimensional (1D) and two-dimensional (2D depth-averaged) flow representations within a single mesh resulting in an efficient and complete representation of the tidal system,
- the ability to represent the wetting and drying of low-lying wetland areas in a robust and proven manner.

Being based on the finite element method, the definition of the model network can be readily adjusted to better represent regions of interest or areas where there are significant variations in flow/constituent behaviour. As a result, the RMA software can overcome many of the spatial discretisation limitations associated with other models based on finite difference schemes.

The model of Macleay Estuary was set up using the latest 2003 hydrosurvey to accurately represent the characteristics of the system. A mesh of 1D and 2D elements was created for the main waterways to best describe the dominant flow in each of the reaches (see Figure 12). In

FIGURE 12
MODEL LAYOUT FOR CURRENT CONDITIONS



addition, floodgates and drainage channels of significance to the model were determined by inspection, survey and aerial photographs.

The model was calibrated against flows at 7 different locations and water levels at a further 23 locations from the tidal data collection study (MHL, 2004). The relevant input data and the results of the calibration runs are shown in Appendix B.

The model was then run for a series of tide scenarios to quantify existing hydrodynamic conditions with zero fluvial inflows. These scenarios included:

- neap tidal range,
- mean tidal range,
- spring tidal range,
- maximum tidal range.

The mesh of the calibrated model was later modified to represent important per-development features of the estuary likely to have existed prior to European settlement in order to evaluate key changes in tidal dynamics and flow behaviour (see Figure 13). Due to the nature of the objective, the precision of the modifications is constrained owing to a lack of detailed information on the physical state of the estuary in the 19th Century. However, after reviewing a number of historical records, such as hydrosurvey from the 1890's and historical descriptions, key changes were made including:

- re-establishment of the untrained river entrance at Grassy Head that operated prior to the flood of 1893,
- re-definition of the river channel bathymetry in critical reaches based on available hydrosurvey records, particularly the wider and deeper river channel that existed along the Macleay Arm prior to 1893,
- removal of significant man-made components introduced throughout the estuary, such as Clybucca Creek drainage works.

3.4.2. Ocean Tide Levels

Ocean level tide recorders along the NSW coastline show that the level and timing of the tides does not vary significantly. Tidal ranges usually vary by less than ±0.1 m and the phase difference is ±15 minutes. NSW tidal waves are regular in slope (almost sinusoidal) and can have a pronounced diurnal inequality (subsequent tides can have significantly different ranges).

3.4.3. Estuary Tide Levels

Water level data for Coffs Harbour and the Macleay River estuary was analysed using the Foreman method to determine tidal planes and ranges from the ocean and up throughout the estuary (see Table 10-11 and Figure 14). The Foreman method eliminates the hydrological, oceanographic and metrological effects causing irregularities in the records to produce an astrological tide (MHL, 2004).

FIGURE 13
MODEL LAYOUT FOR HISTORICAL CONDITIONS

FIGURE 14
TIDAL PLANES

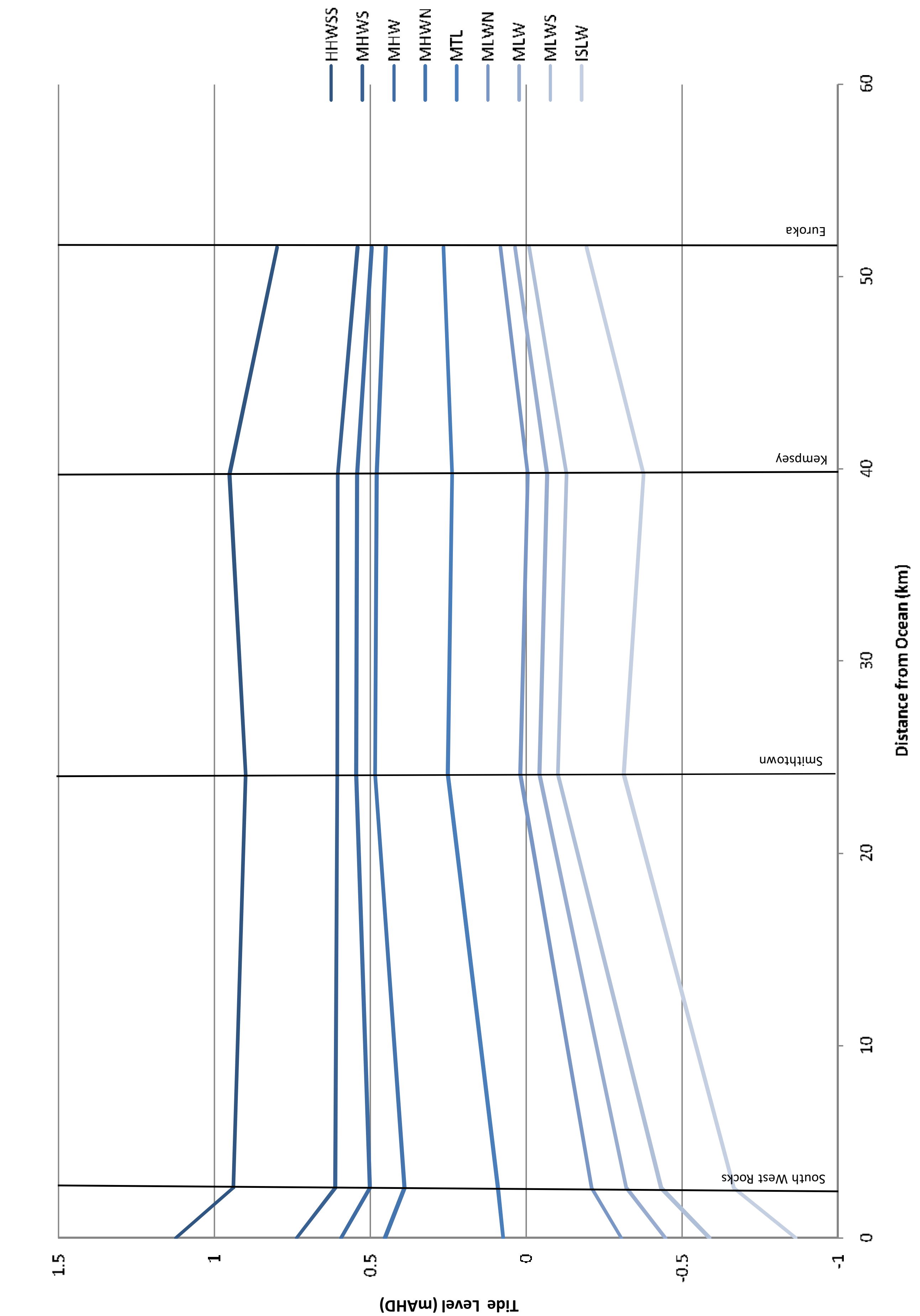


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Table 10 Tidal Planes for Macleay River (mAHD)

Tidal Planes	Coffs Harbour	South West Rocks	Smithtown	Kempsey	Euroka
HHWSS	1.124	0.940	0.900	0.952	0.799
MHWS	0.736	0.613	0.606	0.605	0.542
MHW	0.594	0.501	0.546	0.543	0.496
MHWN	0.453	0.390	0.485	0.480	0.450
MTL	0.074	0.090	0.252	0.238	0.266
MLWN	-0.304	-0.209	0.019	-0.005	0.082
MLW	-0.446	-0.321	-0.042	-0.067	0.036
MLWS	-0.587	-0.432	-0.102	-0.129	-0.010
ISLW	-0.864	-0.666	-0.313	-0.377	-0.194

Note: Negative values denote a level below the Australian Height Datum (approx mean sea level).

Table 11 Tidal Ranges and Mean Phase Lag for Macleay River

Tidal Ranges (m)	Coffs Harbour	South West Rocks	Smithtown	Kempsey	Euroka
HHWSS to ISLW	1.988	1.606	1.213	1.329	0.993
MHWS	1.328	1.045	0.708	0.724	0.553
MHW	1.040	0.822	0.587	0.610	0.460
MHWN	0.757	0.599	0.466	0.485	0.368
Mean Phase Lag (min)	0	40	155	203	284

The data shows a substantial decrease in tidal range through the entrance as a result of entrance losses associated with high velocities, turbulence and bed friction. The mean spring tidal range fell from 1.3 m at the ocean to 1.0 m at South West Rocks. The attenuation continued to at least Smithtown, after which the tidal range increased along the river reaching 0.7 at Kempsey. At Euroka the range had decreased to 0.5 m. The difference in time between the ocean tide and the estuary tide was some 40 minutes at South West Rocks, 155 minutes at Smithtown, 203 minutes at Kempsey and 284 minutes at Euroka. The mean tide level in the estuary was elevated above ocean level by around 250 mm.

The data shows that tidal flows are restricted by the channel shape and size at least until Smithtown, with the greatest restriction occurring at the entrance. Upstream of Smithtown (the tidal prism has decreased) tidal flows are lower and channel efficiency increases (narrows and straightens compensating for friction losses along the channel) resulting in an increase in tidal range. It should be noted that this increase is not due to internal reflection from the tidal limit as the tide time lag continues to increase upstream. Also, elevation of the mean tide level is typical for estuaries with relatively shallow entrances because the tidal wave distorts due to the greater efficiency of the entrance at higher tides (not because of catchment runoff).

3.4.4. Tidal Flows for Current Conditions

The April-May 2003 data collection exercise (MHL, 2004) provided tidal flow gauging at nine locations within the estuary over a complete ebb and flood cycle. These tides were used to calibrate the RMA model. The closest permanent ocean tide recorder at Coffs Harbour was used as the driving downstream ocean boundary condition in the model during calibration and to determine typical ocean tide neap, mean, spring and maximum ranges.

The model was then used to examine estuary conditions for typical ocean astronomic tides with a mean range of 1.05 m, a mean neap range of 0.80 m, a mean spring range of 1.35 m and a maximum range of 2.0 m. Neap, mean, spring and maximum tidal volumes and peak flows for dry weather conditions were then determined at strategic locations throughout the estuary as shown in Table 12.

Table 12 Estimated Tidal Prisms (Mm ^{3})

Location	Neap Tide	Mean Tide	Spring Tide	Maximum Tide
Macleay River:				
Entrance	9.38	11.40	13.63	18.11
Smithtown	2.91	3.37	3.85	4.79
Kempsey	0.81	0.93	1.04	1.27
Northern Arm:				
Entrance	3.67	4.50	5.41	7.28
Clybucca Creek D/S	1.03	1.24	1.47	1.93
Belmore Arm:				
Entrance	0.39	0.32	0.45	0.58

Table 13 Estimated Tidal Peak Flows (m ^{3}/s)

Location	Neap Tide		Mean Tide		Spring Tide		Maximum Tide	
	low	**High**	**Low**	**high**	**Low**	**high**	**low**	**high**
Macleay River:								
Entrance	-594	648	-711	795	-840	964	-1088	1317
Smithtown	-161	188	-181	223	-201	262	-238	344
Kempsey	-44	53	-49	62	-55	74	-67	97
Northern Arm:								
Entrance	-236	240	-291	299	-352	370	-476	520
Clybucca Creek D/S	-58	69	-69	86	-81	107	-106	150
Belmore Arm:								
Entrance	-21	21	-25	24	-30	29	-40	40

Note: Positive flow direction is defined as from the ocean to the estuary, and negative from the estuary to the ocean.

In general, the study shows higher peak flows for in flowing (flood) tides than for out flowing (ebb) tides. This is a characteristic feature for river estuaries, such as the Macleay River. The reasons for the discrepancies are shallow water and friction effects, which make the out flowing tide longer and more constant compared to the in flowing tide, which is shorter and hence has a higher peak to balance the volumes moving in and out (over time).

The mean tidal prism at the entrance is 11.4 Mm^3, slightly lower than the neighbouring Hastings River which has a mean tidal prism of around 14.2 Mm^3 (WMA, 1998) even though the two estuaries are relatively similar in size, 16 and 14 km^2 respectively. Both river entrances have twin breakwall fully trained entrances, but the difference in tidal prism indicates that the Macleay River entrance is marginally less efficient than the Hastings River. By comparison, the significantly larger but partially trained Manning River entrance has a mean tidal prism of around 10 Mm^3 (WMA, 1997[2]) and is significantly less efficient than both the Hastings and Macleay Rivers.

3.4.5. Tidal Flow Distribution

Figure 11 (page 26) shows the peak flows throughout the estuary during a typical spring tide with no fluvial inflows. Peak flows reflect the efficiency and waterway surface area of the upstream channels, and are much greater in the entrance area than in the upper parts of the estuary and the tributaries. Peak flows drop as the waterway area (and tidal range) upstream decreases. For example, peak flows at Smithtown are some 4 times larger than peak flows at Kempsey, about 17 km upstream. Also peak flows in the North Arm at the Macleay confluence are some 4 times larger than peak flows at the Clybucca confluence.

3.4.6. Tidal Flows for Pre-Development Conditions

In order to assess the changes in estuary tidal dynamics and flow behaviour as a result of catchment development, simulations were carried out for historical per-development pre and post flood conditions. Regular mean, neap, spring and maximum ocean tides were used as a downstream boundary condition. Simulations to assess the impact of the entrance conditions were run with no fluvial flows in order to evaluate entrance efficiency. Estimated tidal prisms and change compared to the current entrance are shown in Table 14.

Note, based on comparisons with existing untrained NSW coastal river, both pre and post flood entrance conditions were assessed because the untrained pre-flood entrance would have been much wider and shallower than the post flood entrance. Note also, pre-flood conditions would have been the predominant or more usual entrance condition.

Table 14 Estimated Tidal Prisms for Pre-Development Conditions and Change in Comparison to Current Conditions

Entrance Condition	Neap Tide		Mean Tide		Spring Tide		Maximum Tide	
	Prism (Mm^3)	% Change	Prism (Mm^3)	% Change	Prism (Mm^3)	% Change	Prism (Mm^3)	% Change
Pre-Development Pre- Flood	7.67	-18%	9.08	-20%	10.60	-22%	13.42	-26%
Pre-Development Post- Flood	7.67	-10%	9.08	-10%	10.60	-10%	13.42	-11%
Current Conditions	9.38		11.4		13.63		18.11	

The simulations showed that the pre-development historical entrance was less efficient, as it was shallower and wider than the current trained entrance. The change in tidal prism increased with tidal range, by 18% for neap tide to 26% for the maximum tide under normal pre-flood conditions (and around 10% for the less common post-flood conditions). The comparison shows the significant impact that the entrance conditions have on flow dynamics within the estuary.

3.5. Comparison of Fluvial and Tidal Flows

To provide a better understanding of the relative impacts of fluvial and tidal flows throughout the estuary a comparison has been made between the mean spring tide and the 50% AEP flood at strategic locations within the estuary. The flows are based on the findings in previous sections and have been summarised in Table 15 and Figure 11 (page 26).

Table 15 Fluvial Flow Statistics

Location	Peak Flows (m^3/s)			Difference in Magnitude
	50% AEP Flood	Mean Spring Tide		
Macleay River:				
Kempsey	3510	60	-70	54
Smithtown	2190	200	-260	10
Entrance	2690	840	-960	3
Northern Arm:				
Entrance	-750	350	-370	2
Belmore Arm:				
Entrance	-370	30	-30	12

Note: Positive flow direction is defined as from the estuary to the ocean, and negative from the ocean to the estuary.

Note, on average there are about 140 tidal ranges greater than the mean spring range each year but only one 50% AEP flood every two years (ie the tide occurrence is some 300 times more than the flood).

The table shows that floods with magnitudes around the 50% AEP have flows that are only two to three times greater than spring tidal flows in the lower estuary, but increase to around 10 times at Smithtown and 50 times at Kempsey. This indicates that tidal flows dominate the entrance area and North Arm but that floods play an important role, especially in the upper reaches of the estuary. Larger floods such as the 1% AEP with several times larger flows have a major effect throughout the estuary, but particularly in the upper estuary. Conversely, for median (or smaller) flows, tides are the main drivers, even in the upper reaches of the estuary.

3.6. Water Balance

An annual water balance is an estimation of the volume of water from various sources that passes a point within the estuary. By revealing the dominant sources of flow and the balance between them, it can be a useful tool for understanding the estuarine processes operating at a specific location. Examples of such processes include erosion and sedimentation processes and tidal flushing, which can affect other factors such as water quality.

The water balances for both current and historical conditions consist of tidal flows through the entrance, catchment runoff, and direct precipitation into and evaporation from the estuary. Table 16 summarises the data used for the water balance calculations. The next two sections cover the estimated average annual water balances for the existing and pre-development conditions.

Table 16 Water Balance Data

Variable	Details	Amount	
Annual Rainfall	BOM (Section 2.5.1)	Estuary Average	1260 mm/yr
Catchment Runoff	Section 3.3.1	Annual Average	2150 Mm^3
		Direct Rainfall Runoff	2114 Mm^3
	Ashley & Graham 2001 (Section 2.3.3)	Groundwater Interception	36 Mm^3
Annual Evaporation	BOM (Section 2.5.4)		1200 mm
Tidal Exchange	Current conditions (Section 3.4.4)	Average Mean Tide	11.40 Mm^3
	Pre-European Settlement (Section 3.10.1)	Average Mean Tide	9.1 Mm^3
Areas		Estuary Waterway Area	18km^2
		Catchment Area	9800km^2

3.6.1. Water Balance Current Conditions

Table 17 shows the average annual water balance at the ocean entrance for current conditions.

Table 17 Annual Water Balance for Current Conditions

Water Balance Component	Volume In (Mm^3)	Volume Out (Mm^3)
Entrance Flows	6960	9110
Catchment Runoff	2150	
Direct Precipitation	20	
Evaporation		20
Total	9130	9130

Tidal flows dominate the annual water balance at the entrance, representing about 76% of the average annual water balance. Catchment runoff amounts to approximately 24% of the water balance and direct precipitation made up less than 1% of the total.

3.6.2. Water Balance Pre-development Conditions

The annual water balance for the historical conditions with a pre-flood shoaled entrance, shown in Table 18. Note, in addition to reduced tidal flushing the assessment also includes a nominal allowance for increased catchment vegetation rainfall retention of 5% (see #3.9.3).

Table 18 Annual Water Balance for Pre-Development Conditions

Water Balance Component	Volume In (Mm^3)	Volume Out (Mm^3)
Entrance Flows	5840	7560
Catchment Runoff	1950	
Direct Precipitation	20	
Evaporation		20
Total	7810	7580

Again, tidal flows dominate the annual water balance at the entrance, representing about 75% of the average annual water balance. Catchment runoff amounts to approximately 25% of the water balance and direct precipitation made up less than 1% of the total.

3.7. Flushing and Salinity

Estuarine waterways are exposed to tidal forces that flush the system with ocean water and fluvial flows that flood the system with freshwater. This generates a constantly changing mix of water properties and constituents such as salinity and thereby the organisms within the estuary.

3.7.1. RMA-11 Model

Water quality modelling of the estuary was undertaken using the RMA-11 water quality modelling software. The RMA-11 model is capable of simulating physical, chemical and biological processes affecting a range of water quality parameters. A combined one-dimensional and two-dimensional depth-averaged transport model was set up with the mesh from the RMA-2 model for existing conditions. The underlying hydrodynamics were based on the calibrated RMA-2 model for the typical Dry Weather scenario established previously and a generated nominal spring/neap tide sequence. Longitudinal and transverse diffusion rates were set to 10 m^2/s, based on observations from extensive testing of the model performance for various conditions.

Once set up, the water quality model was started with zero salinity in the estuary and run for 240 days using a simulated 28 day tidal cycle. During this period there were no catchment fresh water inflows, only saline tidal flushing. Ocean water typically has a salinity of 35 psu (practical salinity units), approximately 35 ppt (parts per thousands), which was used as a boundary condition at the ocean. As a result, the fresh estuary waters were progressively exchanged for saline ocean waters.

The salinity distribution shown on Figure 15 (A) represents the results after 120 days. Comparison with the 12 month salinity profiling undertaken for this study (see Section 5.5) shows that the 120 day profile represents an approximate “average” condition for the sampled period. Further, comparison of the recorded times for salinity intrusion along the river after a fresh with the modelled times for a similar intrusion also shows very similar results. Based on the accuracy of the underlying RWA-2 hydrodynamic model and the similarities between the recorded and modelled salinity profiles, it was assumed that the RMA-11 model was adequately calibrated.

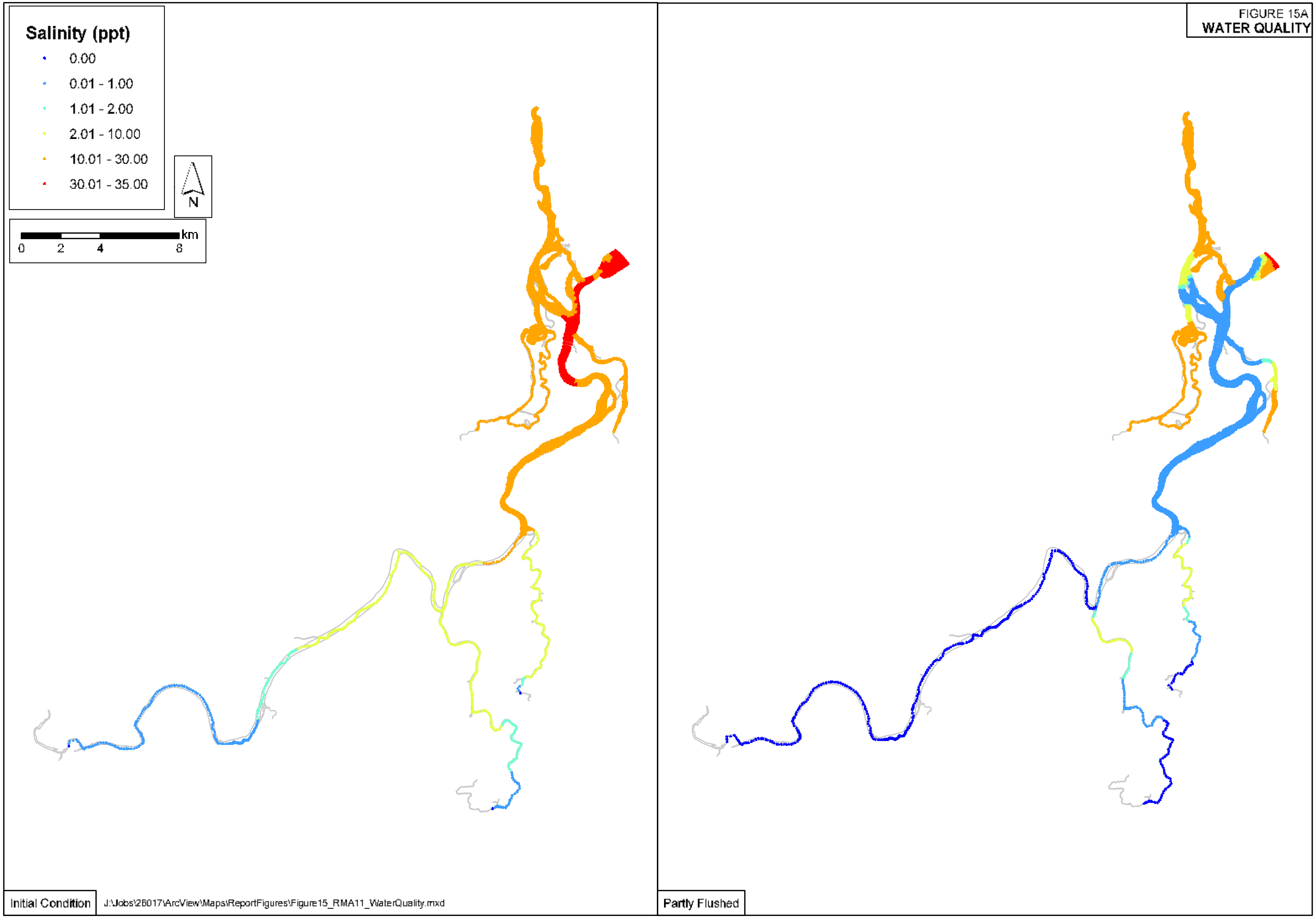
3.7.2. Tidal Flushing

Mixing in the estuary was investigated by monitoring the dilution of a globally distributed conservative pollutant. Flushing times for key locations in the estuary were determined by calculating the time required for the constituent to reduce from an initial concentration of 1 mg/l to 1/e mg/l (approximately 0.368 mg/l), commonly referred to as the e-folding time. The e-folding time provides an indication of the flushing within the estuary and can be used identify areas which may be susceptible to water quality issues. It should be noted that the e-folding time only considers tidal flushing, which will play a minor role in the upper reaches of the estuary as freshwater flows will be more important in those parts.

The RMA-11 model was again run for 240 days tide with an initial concentration of 1 mg/l throughout the estuary except for the ocean boundary where the concentration was set to 0 mg/l. The results of the modelling are shown in Table 19 (see also Figure 16A). The results show that as expected the e-folding times in the estuary increase as you move away from the entrance. The waters close to the mouth are well mixed and e-folding time is generally lower than 5 days up to some 7 km upstream the entrance. Further upstream the tidal mixing decreases gradually resulting in six times higher e-folding times a further 2.5 km upstream (a month compared to the 5 days).

The upper reaches of Clybucca and the Macleay Arm requires some 50-60 days until the threshold concentration is reached. Worth noting is also the higher flushing times for the Jerseyville anabranch, where waters get trapped and slow down the mixing process. Also, large parts of the estuary upper reaches do not meet the threshold concentration during the run, indicating slow mixing. However, as mentioned before e-folding times only considers tidal flushing and in reality fluvial input have a stronger effect in these upper reaches.

FIGURE 15A
WATER QUALITY



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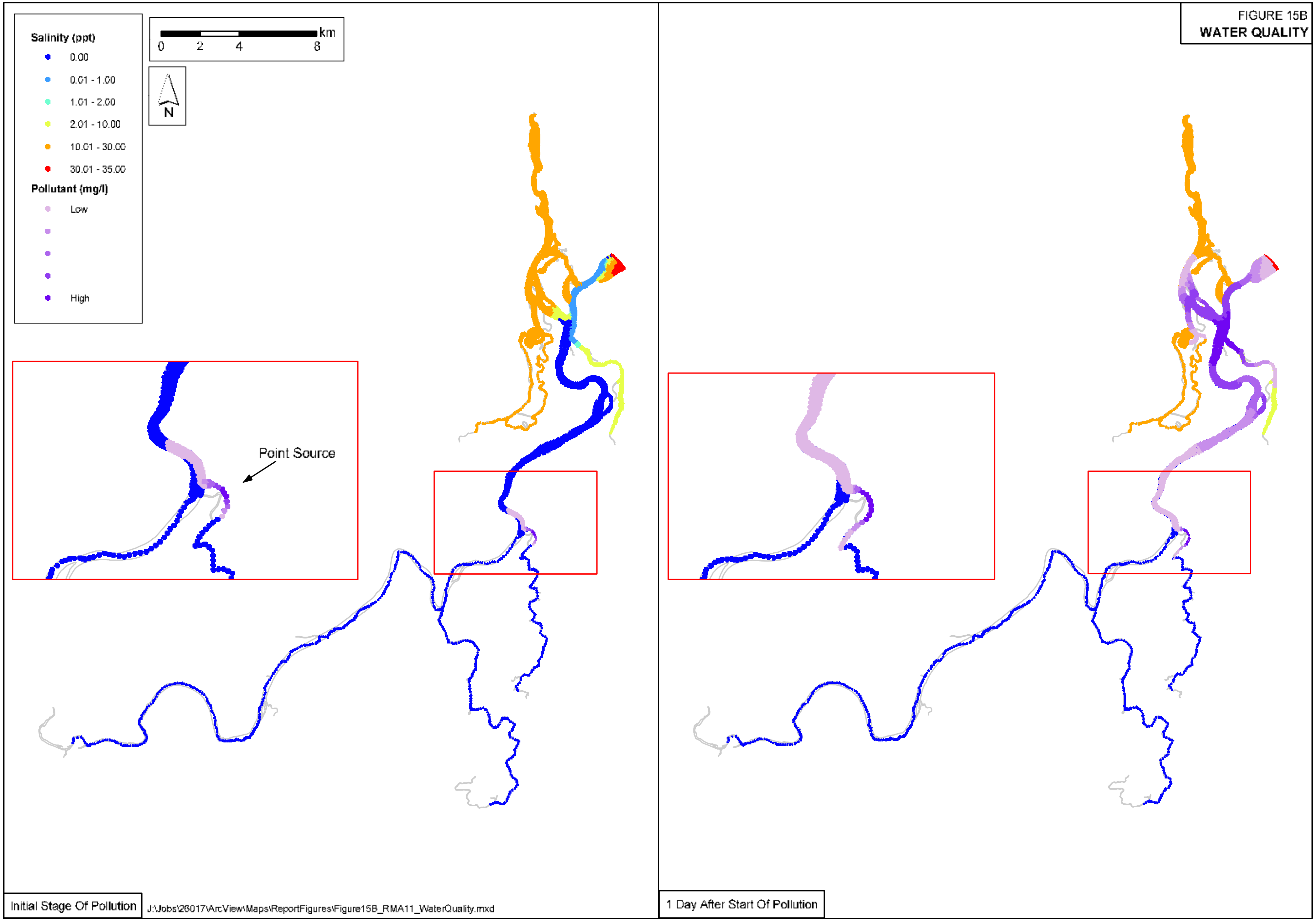
FIGURE 15B
WATER QUALITY
Salinity (ppt)
0.00
0.01 - 1.00
1.01 - 2.00
2.01 - 10.00
10.01 - 30.00
30.01 - 35.00
Pollutant (mg/l)
Low
High
0
2
4
8
km
N
Point Source
Initial Stage Of Pollution
1 Day After Start Of Pollution
J:\Jobs\26017\ArcView\Maps\ReportFigures\Figure15B_RMA11_WaterQuality.mxd

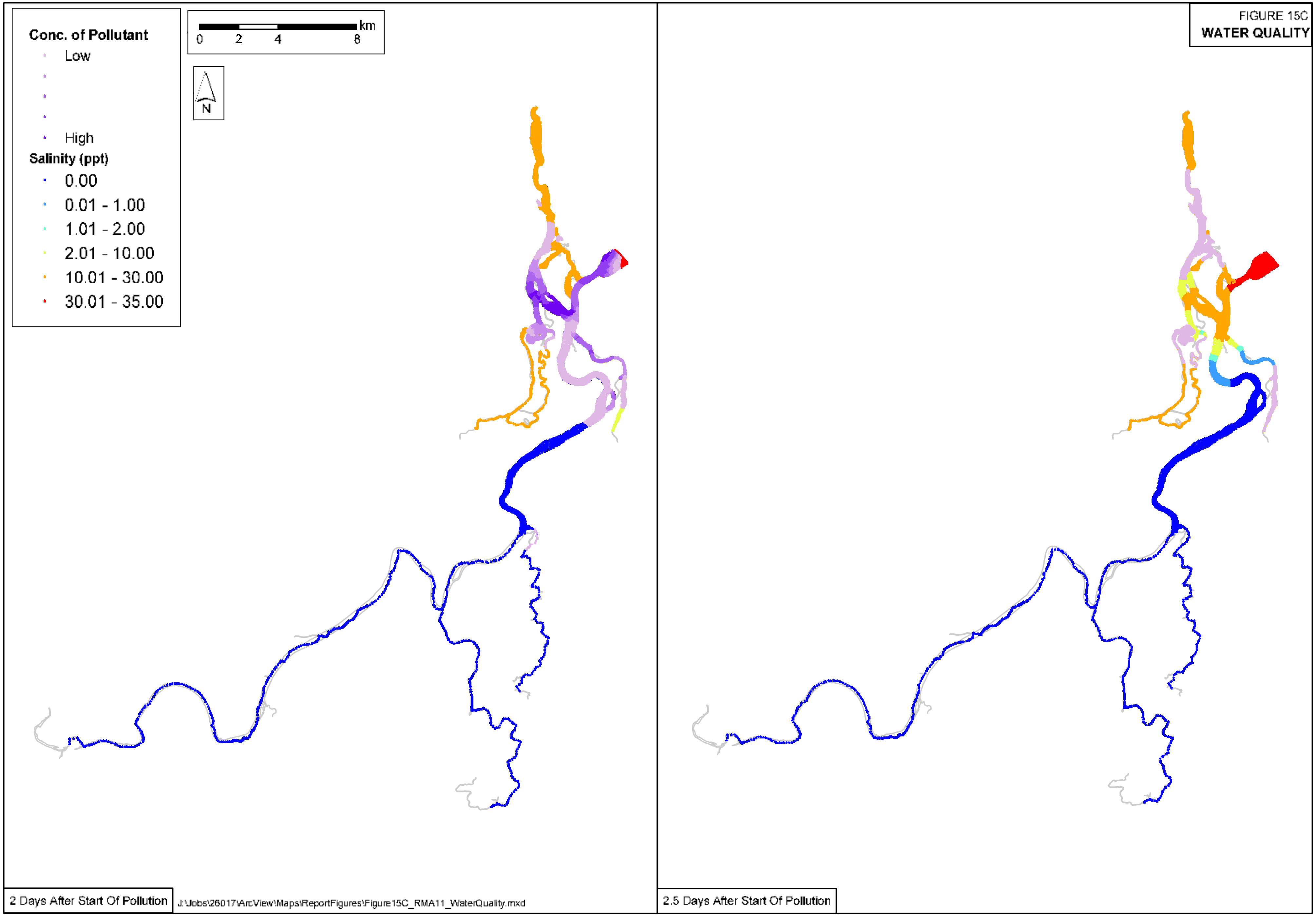
FIGURE 15C
WATER QUALITY
Conc. of Pollutant
Low
High
Salinity (ppt)
0.00
0.01 - 1.00
1.01 - 2.00
2.01 - 10.00
10.01 - 30.00
30.01 - 35.00
0
2
4
8
km
N
2 Days After Start Of Pollution
2.5 Days After Start Of Pollution
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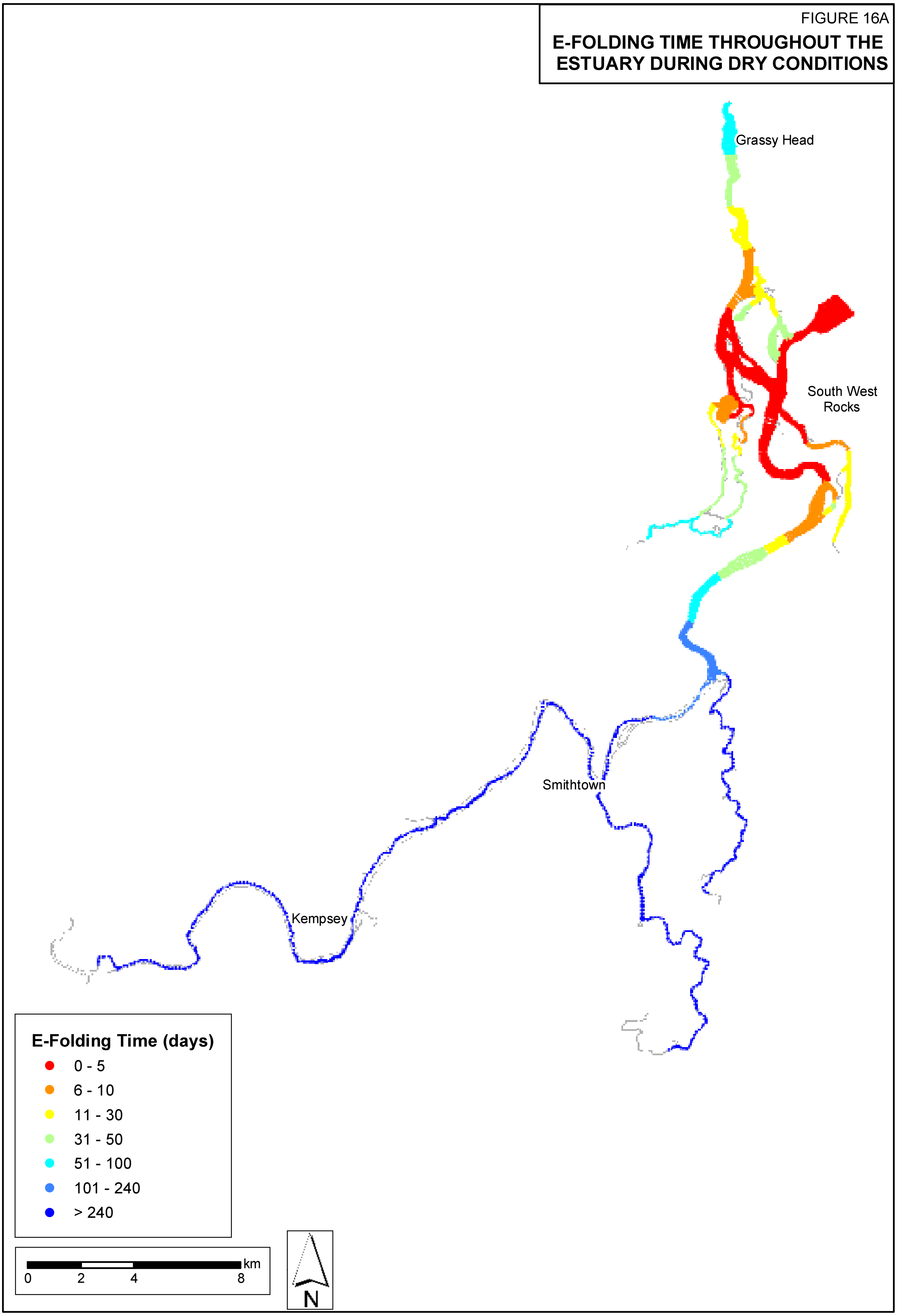

FIGURE 16A
E-FOLDING TIME THROUGHOUT THE ESTUARY DURING DRY CONDITIONS

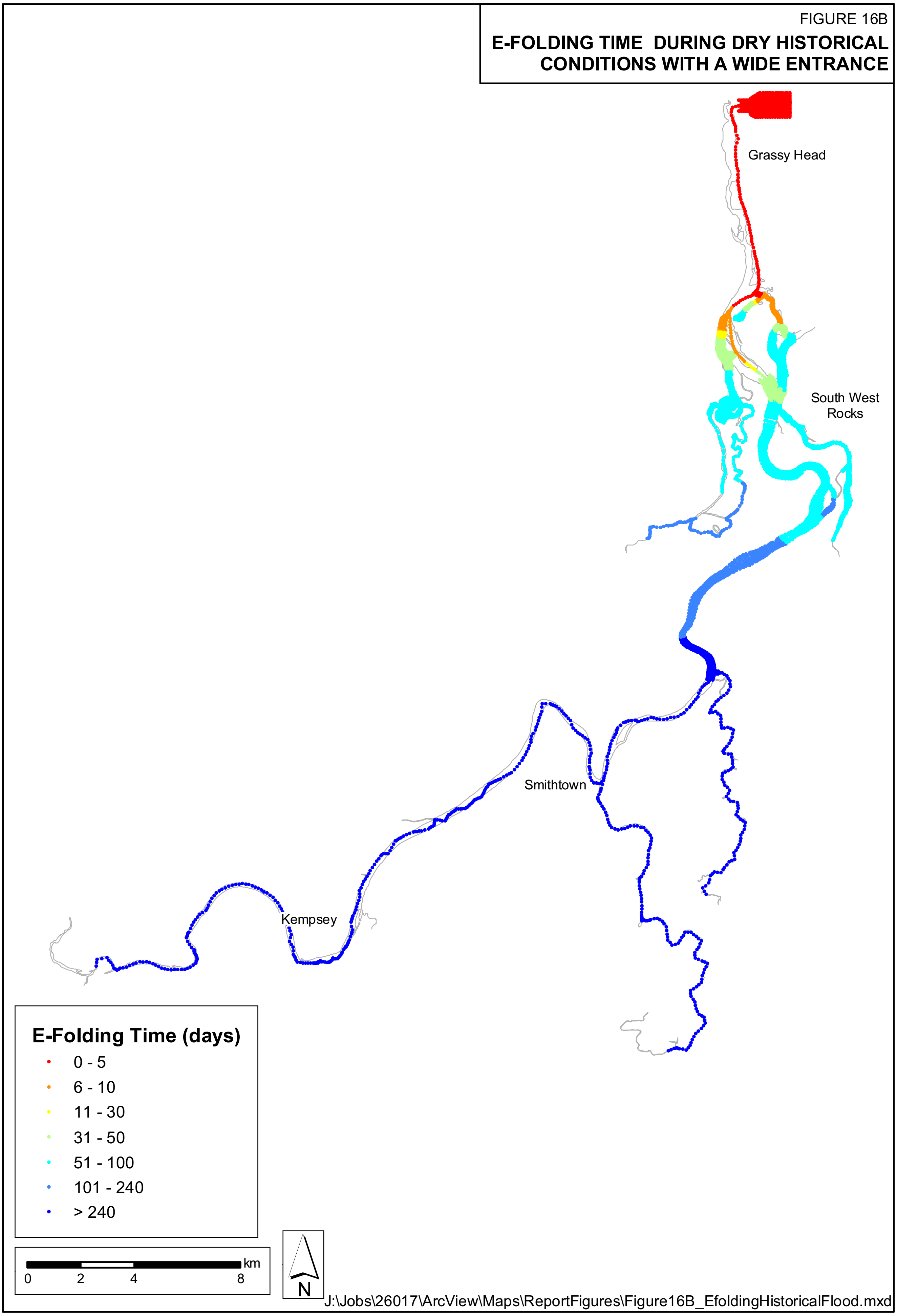
FIGURE 16B
E-FOLDING TIME DURING DRY HISTORICAL CONDITIONS WITH A WIDE ENTRANCE
Grassy Head
South West Rocks
Smithtown
Kempsey
E-Folding Time (days)
0 - 5
6 - 10
11 - 30
31 - 50
51 - 100
101 - 240
> 240
km
0
2
4
8
N
J:\Jobs\26017\ArcView\Maps\ReportFigures\Figure16B_EfoldingHistoricalFlood.mxd

FIGURE 16C

E-FOLDING TIME DURING DRY HISTORICAL CONDITIONS WITH A NARROW ENTRANCE

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Table 19 E-folding Time for Key Locations for Existing and Pre-development Conditions

Location	E-folding Time (days)		
	Existing Conditions	Pre-Development Conditions	
		Post - Flood	Pre-Flood
Macleay River:			
Kempsey	>240	>240	>240
Smithtown	>240	>240	>240
South West Rocks	<1	50	65
Northern Arm:			
Grassy Head	50	<1	<1
Clybucca Ck Floodgates	60	150	170
Shark Island	<1	35	50
Spencers Ck:			
near Jerseyville	10	90	110

The same tidal flushing scenario was then run for the pre-development estuary models. The results for these conditions are also shown in Table 19 and Figure 16 (B) and (C). Comparison of the existing and pre-development results shows that mixing in large parts of the estuary was slower before the entrance shifted and the walls were trained.

As expected, the wider/deeper post-flood entrance is more efficient than shallower post flood entrance, resulting in a 20 days difference in e-folding time in the upper parts of Clybucca Creek and Spencer Creek for instance. However, both pre-development entrance configurations provide more efficient flushing in relation to distance from the ocean. Up to 8km upstream of the entrance along the (North Arm, then main river channel), waters would have decreased to the threshold concentration within 5 days. This is only slightly downstream of the current 5 day location, but reflects the confined/straight nature of the flows along the north arm as it operated as the main river channel rather than the efficiency of the entrances. This is confirmed by the location of the 240 day limit, which is some 5km further from the entrance than in current configuration.

3.7.3. Floodplain Discharges

Catchment waters stored behind floodgates can have high acid levels and/or low oxygen levels. In order to examine the effects of stored catchment water discharges into the estuary the model was set up to replicate inflows at known discharge locations. The model was then started with "average" salinity profile and median catchment inflows. A substantial volume of polluted water was then input to the estuary at a known discharge location over a nominal 24 hour period and the model run to track the distribution and dispersal of the pollutant.

For the purposes of this study two locations were adapted, the entrance of the Kinchela Creek and the head of Clybucca Creek. The results of modelling with the point source located in the lower part of Kinchela Creek are shown on Figure 15 (B and C) (page 35). As can be seen, the plume of polluted water spreads quickly through the main channel and reaches down to the up through the lower parts of Macleay Arm within a day. In this scenario, the fluvial flows promote plume spread downstream of the source, but also prevent the plume from moving very far upstream.

Two days after the start of the pollution event, freshwater flows have pushed the plume down to just upstream of Jerseyville in the main channel. At the Kinchela Creek entrance, close to the original location of the source, some polluted water is observed to have been trapped, but half a day later Kinchela Creek has been fully flushed. After 60 hours a low concentration of pollutant is still evident in parts of Macleay arm, Clybucca Creek and Spencer's Creek, but the main channel has been fully flushed.

The results from the plume simulation for Clybucca Creek floodgates are shown in Figure 17. Five hours after the opening of the floodgates (i.e. start of the release of polluted waters), the plume is still contained within Clybucca Creek and concentrations are fairly low. After a day of high discharge of polluted water, the plume is well developed throughout Clybucca Creek and low concentrations of the pollutant have reach Macleay Arm through to the ocean entrance.

At 24 hours after the floodgates have been closed (i.e. the release of contaminated waters have ceased) pollution in Macleay Arm and main channel is more extensive but the plume is largely unchanged. Two weeks after the floodgates were opened concentrations in Clybucca Creek have decreased significantly through the tidal flushing, but the plume formation is still apparent. The entire Macleay Arm now contains low concentrations of the pollutant and Spencers Creek is also fully contaminated. Further, trapping of water is apparent in the Jerseyville anabranch, which continues to exhibits low concentrations of the pollutant after the main channel has been flushed.

3.8. Waves

Waves are an important part of estuary hydrodynamics and within a river type estuary such as the Macleay, the three main wave generating sources are local wind waves, boat wash and ocean swells. Waves are important mechanisms for generating foreshore erosion and increasing water turbidity, and can contribute to mixing.

3.8.1. Ocean Swell

Ocean swells penetrate the entrance during periods when there are offshore waves from the east or northeast. Under these conditions waves break on the entrance bar and dissipate much of their energy, but then reform and continue up the entrance channel. Under extreme conditions waves up to 0.5 m high reach the South West Rocks mooring area, disrupting boating activities and causing significant sediment movement and bank erosion.

3.8.2. Wind Generated Waves

Local wind generated waves tend to be the dominant wave type across the estuary. The size of these waves at any time and location is related to the prevailing wind speed, wind direction and

FIGURE 17A

SCHEMATIC PLUME MIGRATION

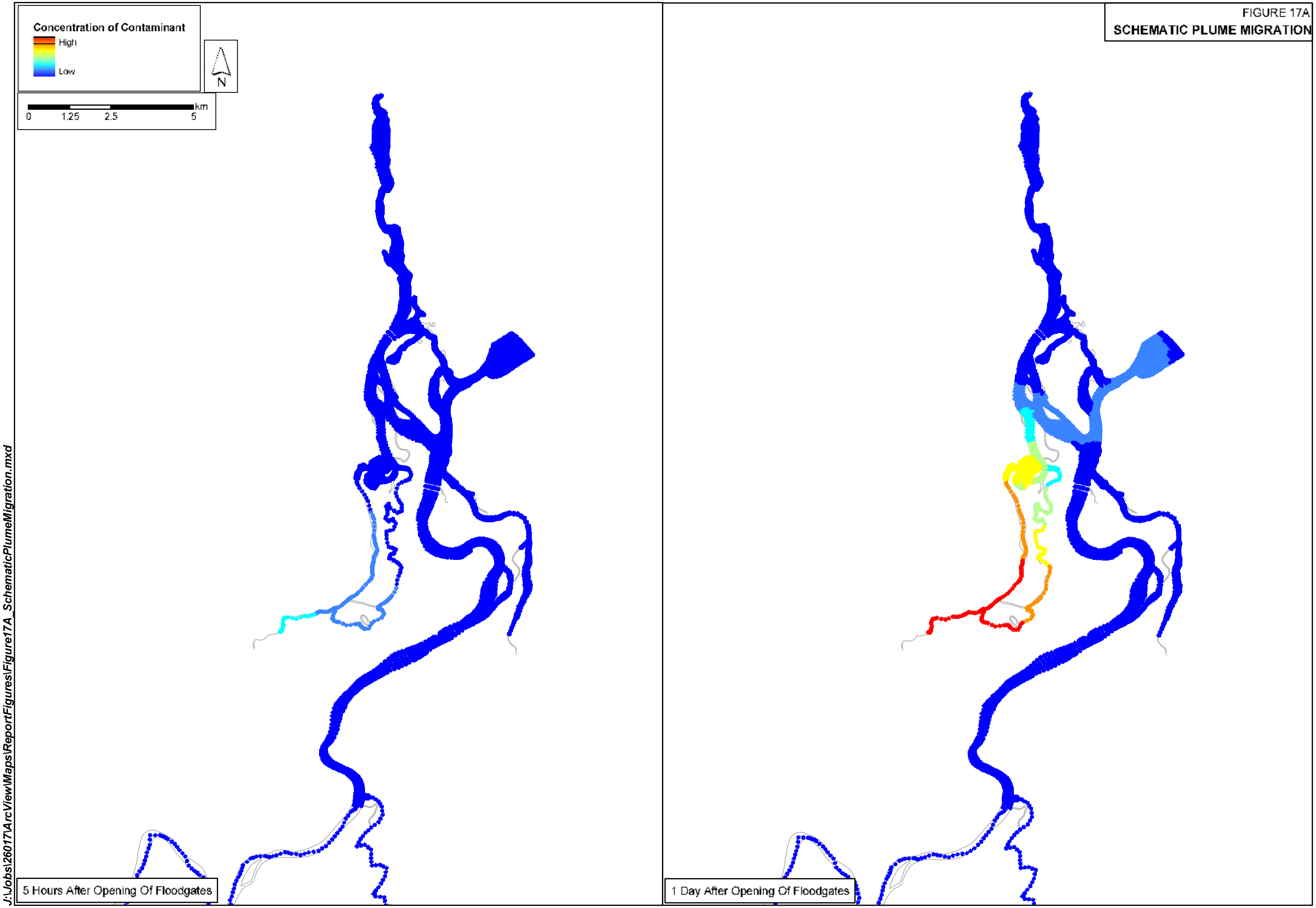

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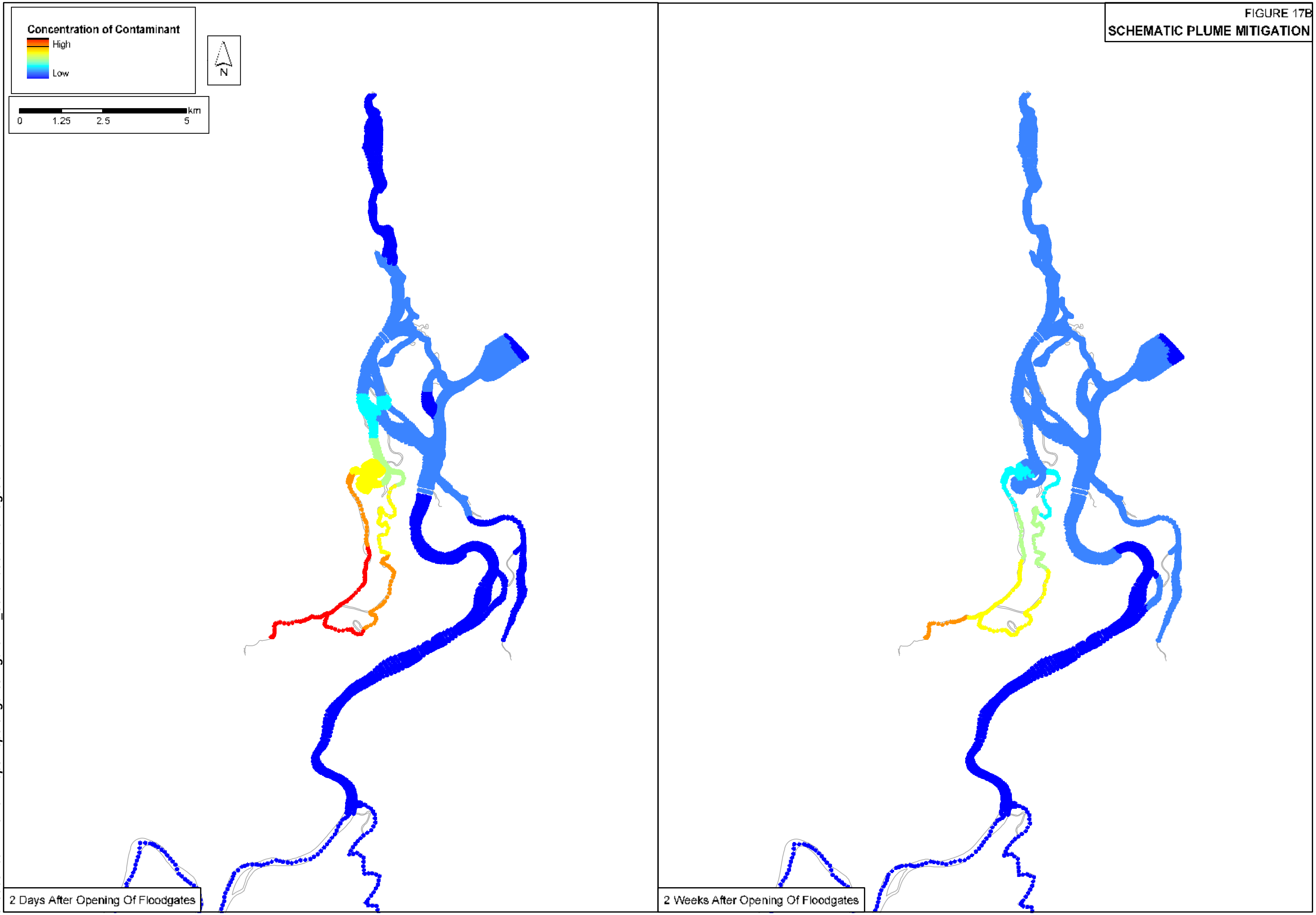
FIGURE 17B

SCHEMATIC PLUME MITIGATION



wind duration, as well as water depth and fetch length.

Wind data was obtained from the Bureau of Meteorology at Kempsey and Port Macquarie as discussed in Section 2.5.3. The record for Port Macquarie indicates that winds are on average in the range of 10 to 20 km/h, exceeding 10 km/h approximately 65% of the time and 20 km/h 30% of the time. The prevailing wind directions are from the North East (19% of the time) and the South East through to the South West (17% to 19% of the time).

At Kempsey, wind speeds are generally lower, being further from the coast. On average they are between 5 to 15 km/h and exceed 10 km/hr approximately 45% of the time and 20 km/hr less than 20% of the time. Calm conditions dominate for 25% of the time, with prevailing winds occurring from the West (16% of the time) and South to South East (12 to 13% of the time). The following table shows the approximate average wind speeds for Kempsey and Port Macquarie.

Table 20 Average Wind Speed for Kempsey and Port Macquarie

Wind Direction	Average Wind Speed (km/h)	
	Kempsey	Port Macquarie
N	7.0	14.6
NE	16.5	19.1
S	10.7	13.7
SE	14.4	17.3
S	13.0	18.9
SW	13.6	16.9
W	9.5	11.9
NW	9.5	9.7

An analysis of wind generated waves was undertaken for 23 sites along the estuary where erosion was shown to occur, as shown in Figure 18. Sites were limited to those where a fetch length of more than 700 m occurred, as any less than this would not generate wind-related waves of significance. Whilst there were additional locations where erosion had been identified (Figure 19 A to C), these were generally in more protected locations where the fetch over which waves could develop was much smaller. The current analysis is aimed at providing indicative values of wave height and energy within the estuary rather than a detailed analysis of every site.

For locations upstream of Smithtown wave calculations were based on wind data for Kempsey, whilst downstream areas utilised data from Port Macquarie. Wave heights were calculated using the wave prediction method outlined in *The Coastal Engineering Manual* (CEM) (Resio et. al., 2002) and the *Shore Protection Manual* (SPM) (U.S Army Corps of Engineers, 1984). This method estimates wave height based on fetch length (the distance over which waves can develop), wind speed and wind direction. Wind energy can then be calculated using wind height and length. In locations where there was a significant fetch in multiple directions the wave energy for each direction was calculated and the values summed.

As the wave calculations require wind data at an elevation of 10 mAHD, the Port Macquarie data

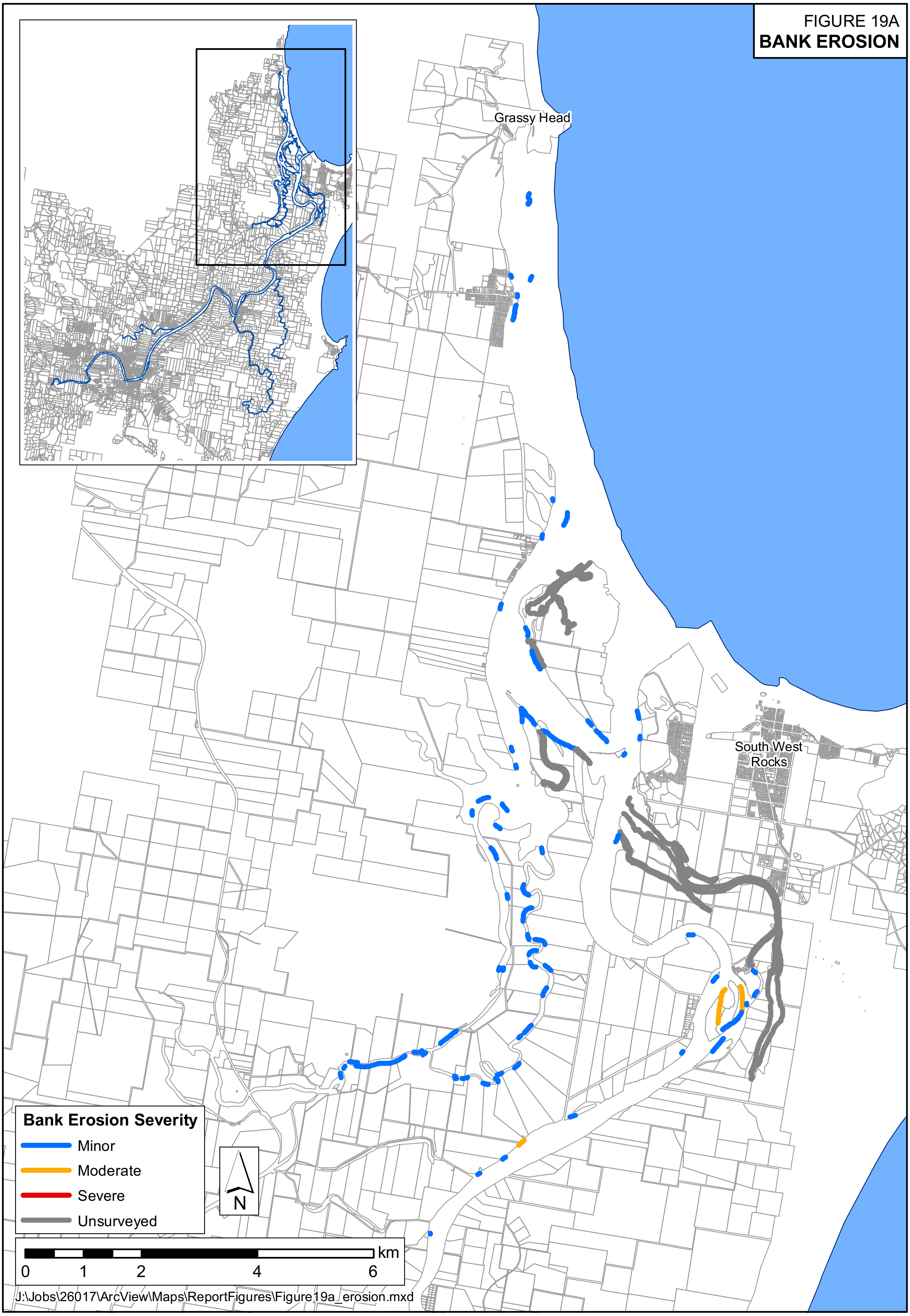


FIGURE 19A
BANK EROSION
Grassy Head
South West
Rocks
Bank Erosion Severity
Minor
Moderate
Severe
Unsurveyed
N
0
1
2
4
6
km
J:\Jobs\26017\ArcView\Maps\ReportFigures\Figure19a_erosion.mxd

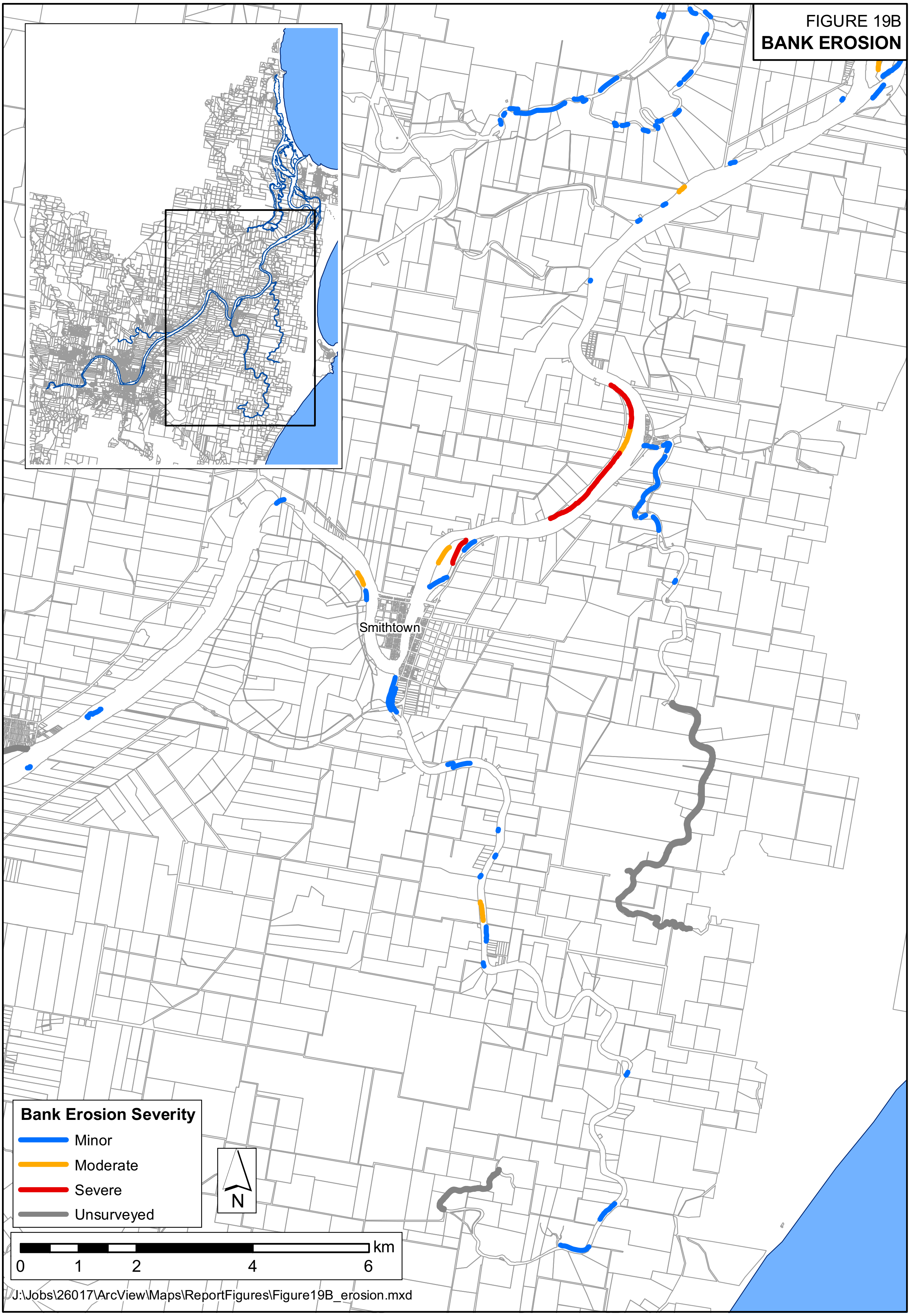


FIGURE 19B
BANK EROSION
Smithtown
Bank Erosion Severity
Minor
Moderate
Severe
Unsurveyed
N
0
1
2
4
6
km
J:\Jobs\26017\ArcView\Maps\ReportFigures\Figure19B_erosion.mxd

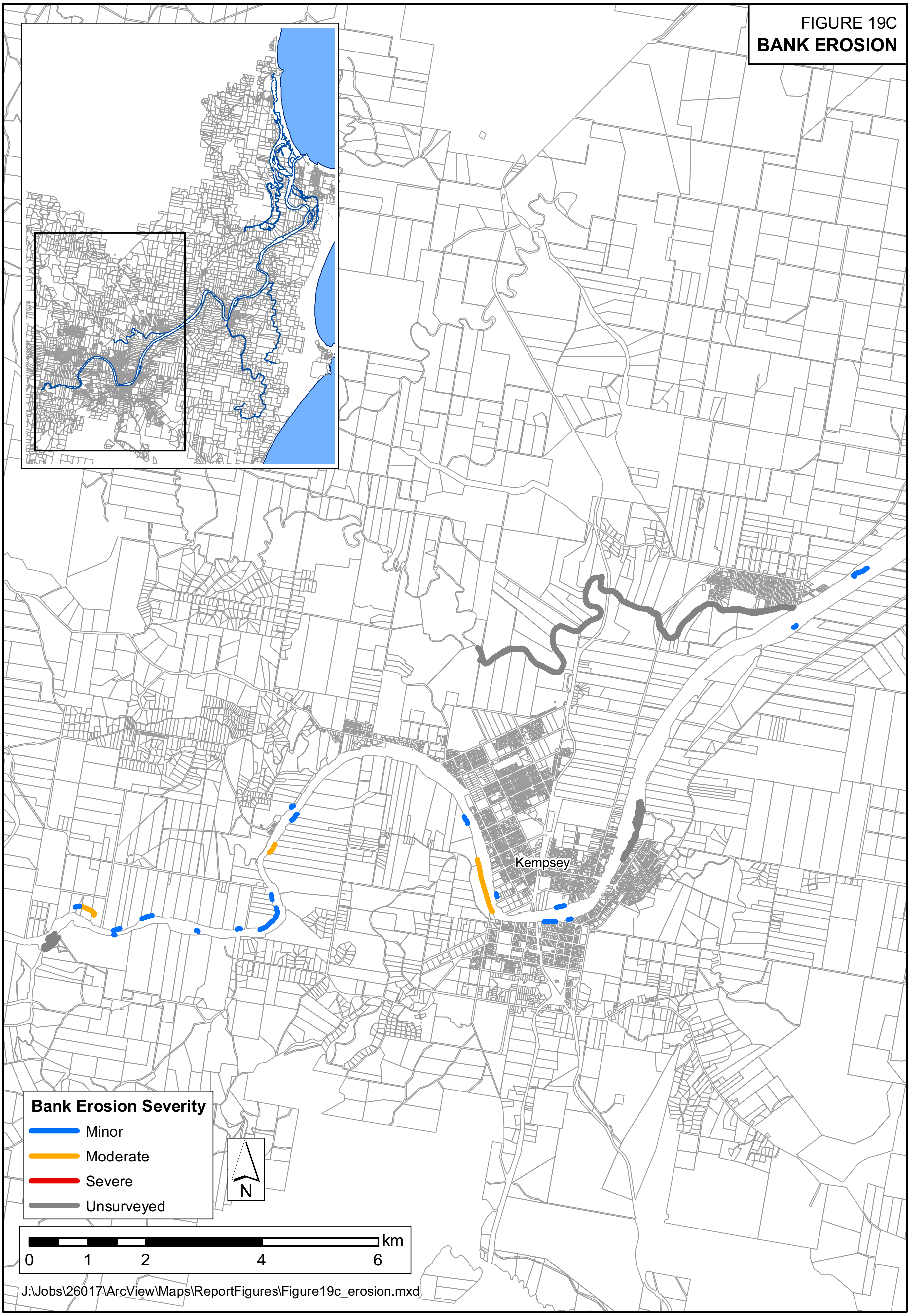
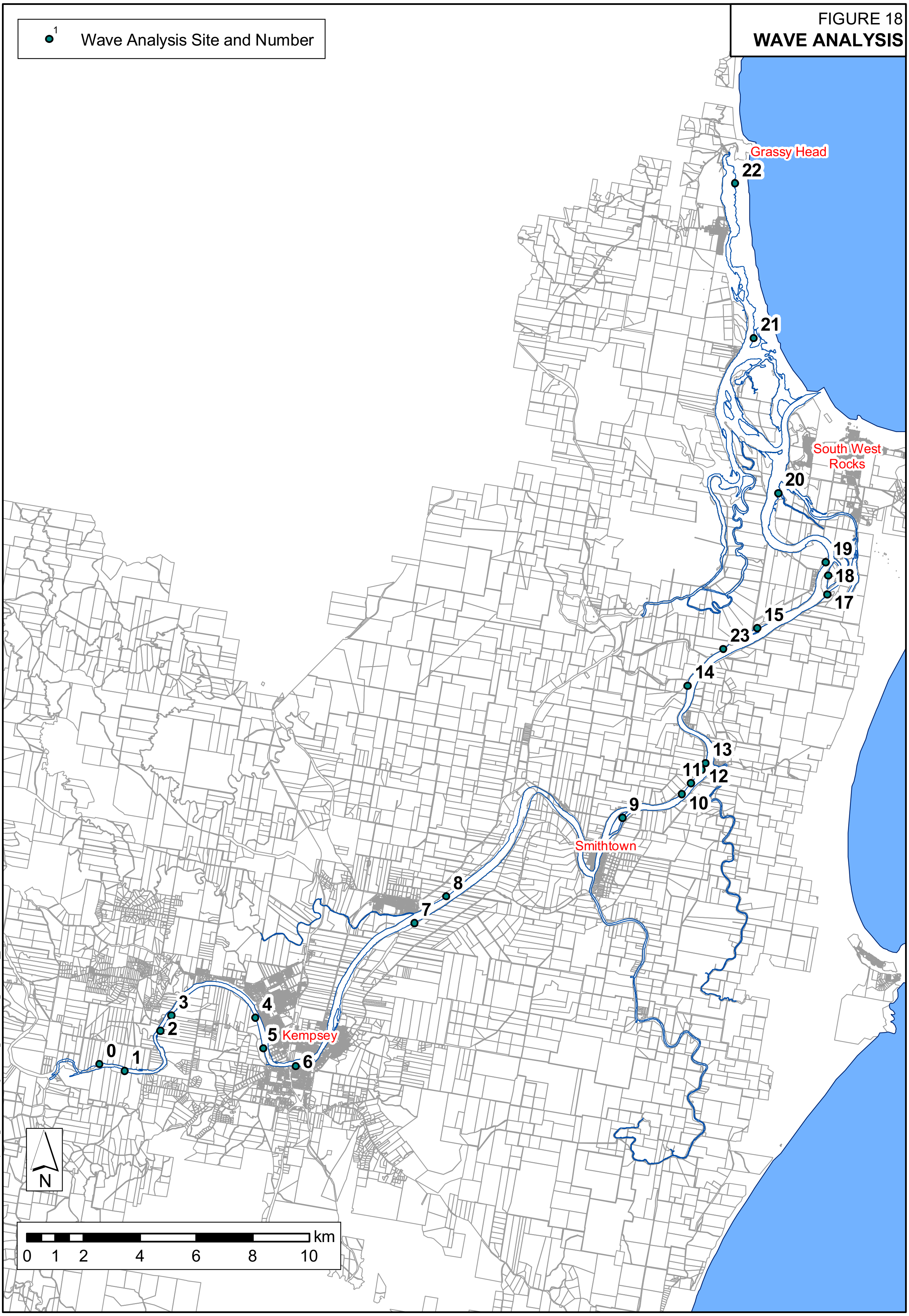


FIGURE 19C
BANK EROSION
Kempsey
Bank Erosion Severity
Minor
Moderate
Severe
Unsurveyed
N
km
0
1
2
4
6
J:\Jobs\26017\ArcView\Maps\ReportFigures\Figure19c_erosion.mxd

FIGURE 18

WAVE ANALYSIS



was adjusted to equivalent velocities at 10 mAHD using the adjustment formula in CEM (2002). Table 21 shows the maximum fetch, average wave height and approximate wave energy (per m of wave crest) for each site. The corresponding erosion category for each site, derived as part of the data compilation study (Telfer, 2005), has also been presented as a comparison.

Table 21 Wind Generated Wave Height and Energy

Site	Maximum Fetch (nearest 50m)	Average Wave Height (m)	Daily Wave Energy (nearest 100 J/m/day)	Erosion Category (Telfer, 2005)
0	900	0.14	200	Minor
1	1,000	0.15	300	Minor
2	700	0.21	800	Moderate
3	1,050	0.26	1,400	Minor
4	850	0.20	700	Minor
5	1,150	0.09	300	Moderate
6	1,050	0.20	1,800	Minor
7	1,350	0.25	5,000	Minor
8	1,050	0.23	4,000	Minor
9	800	0.24	1,400	Severe
10	1,550	0.33	2,400	Severe
11	1,100	0.25	4,500	Severe
12	1,100	0.24	3,800	Severe
13	800	0.24	1,900	Moderate
14	1,800	0.36	3,900	Minor
23	1,800	0.31	10,200	Minor
16	1,450	0.21	600	Moderate
15	2,800	0.38	14,300	Minor
17	1,200	0.32	8,400	Minor
18	1,400	0.27	6,200	Moderate
19	1,650	0.34	5,900	Minor
20	1,150	0.23	6,400	Minor
21	2,000	0.28	13,000	Minor
22	1,600	0.33	4,800	Minor

It can be seen from Table 21 that the highest wave energy occurs at locations 15 and 23 between Jerseyville and Kinchella and at location 21 along the Macleay Arm. These locations have a relatively long fetch length allowing for larger wave generation and being close to the coast are influenced by the stronger coastal winds. However, these locations only experience minor erosion, whilst locations classed as having severe erosion have lower wave energy values.

Observations from staff from the NSW Maritime Authority (pers.com., 2008) indicate that Long Reach (between Kinchela and Jerseyville) and between Frederickton and Seven Oaks typically experience larger waves compared with other parts of the estuary, due to the long fetch length. This is reflected in the higher wave energies reaching Sites 7, 8, 15, 16 and 23. However, the wave energy reaching some of these sites has been reduced by the sheltering action of surrounding banks in concave areas and as a result of shoaling and islands which can deflect waves and shorten fetch length.

3.8.3. Boat Generated Waves

Boat wake waves are a potential source of bank erosion in the Macleay River estuary. Boat wash is most significant in heavily used reaches.

There are several factors affecting the wave height from boat wash. These are:

- Boat speed, with the wave height rapidly increasing up to a critical boat speed (around 4m/s for small boats (Willoughby, 1991; Lesleighter, 1964)), after which any further increases in speed result in a slow decline in wave height;
- Boat size and stream lining, with larger boats displacing more water and so producing more wash;
- Boat weight, where heavier boats generally produce higher waves due to a greater displacement of water. Lesleighter (1964) found wave height to double for speedboats when the number of people on board was increased from 1 to 4;
- Water depth, with shallow depths resulting in larger wave heights unless the boat is travelling at a speed where the boat becomes lifted and planes across the water; and
- Distance from shore, with the wave height approaching the shore decreasing in height as the distance of the boat from the shore increases.

A number of regulations already exist within the estuary to restrict boat size and speed and hence to minimise the impact of boats on bank stability. For example, 4 knot speed limits occur in South West Rocks Creek (Back Creek) and the Macleay Arm near Stuarts Point. There are also a number of no wash zones within the Macleay River near the entrance to Spencer's Creek, as well as within Spencers Creek, Clybucca Creek and Kinchela Creek. A map of boating restrictions can be obtained from NSW Maritime.

An analysis of boat generated waves has been undertaken for the same 23 locations examined for wind generated waves in the previous section. Information obtained during a site visit in conjunction with discussions with NSW Maritime (pers. com., 2008), identified that the most used areas are between the South West Rocks boat ramp and the entrance; between Kemps Corner and Fishermans Reach and near the boat shed at Jerseyville. Other less used areas include Smithtown, between Stuarts Point and Fishermans Reach, and around Kempsey.

Throughout most of the estuary, small 3 to 4m long runabouts are the most popular boats, whilst larger boats utilise the South West Rocks boat ramp to access offshore. The number of boat passes during peak periods was estimated for each location based on anecdotal reports and is shown in Table 22. It should be noted that the number of boat passes at each location varies substantially throughout the year.

Table 22 Estimated Maximum Number of Boat Passes during Peak Periods

Site	Small Boat (< 7m)	Ski Boat	Fishing Boat (7-15m)
0-3 (near Belgrave Falls)	10	-	-
7-9 (Kempsey to Seven Oaks)	20	-	-
4-6 (near Kempsey), 14-18, 23 (Long Reach)	30	-	-
10-13 (Kinchela), 21 (Fishermans Reach)	40	-	-
19-20 (Jerseyville to Spencers Creek)	50	-	30
22 (Macleay Arm near Grassy Head)	40	20	-

In addition to the boats listed in Table 22, it has been estimated that up to 300-400 boat passes occur between the South West Rocks boat ramp and the entrance (NSW Maritime, pers. com., 2008). These are most likely to be larger fishing boats, as the entrance conditions are generally not suitable for smaller runabouts. The foreshores in this area are all rock armoured and so not significantly impacted by wave action.

Estimated waves per boat, wave height and period were based on typical values for recreational boating. Table 23 provides a summary of the wave conditions and calculated wave energy for three general categories of recreational boats. It should be noted that maximum wave energy was calculated as opposed to average energy. This was done for consistency as only maximum numbers of boat passes could be estimated.

Table 23 Boat Wave Energy Summary

	Small Boat	Ski Boat	Fishing Boat
Waves per Boat	3	3	3
Maximum Wave Height (m)	0.2	0.4	0.4
Maximum Wave Period (s)	1.7	2.0	2.5
Maximum Energy per Boat (J/m/boat)	0.7	3.8	5.9

The information in Table 23 was used to estimate the total wave energy generated at each site, as shown in Table 24.

Table 24 Boat Generated Wave Energy for Each Site

Site	Total Energy (nearest 10 J/m/day)
0 - 3 (near Belgrave Falls)	10
7-9 (Kempsey to Seven Oaks)	10
4-6 (near Kempsey), 14-18, 23 (Long Reach)	20
10-13 (Kinchela), 21 (Fishermans Reach)	30
19-20 (Jerseyville to Spencers Creek)	210
22 (Macleay Arm near Grassy Head)	100

It can be seen from Table 23 and Table 24 that larger boats produce significantly more wave energy than smaller boats. Whilst the largest boat generated energy of the sites examined occurred between Jerseyville and Spencers Creek (Sites 19 and 20) and along the Macleay Arm (Site 22), only minor erosion has been recorded at these locations.

3.8.4. Summary of Wave Generated Energy

It should be noted that the above analysis is approximate only, with values providing a general indication of wave energy rather than a detailed analysis. However, it can be seen that average wind generated wave energy is significantly greater than the maximum boat generated wave energy at all sites. Hence whilst boat wash is likely to contribute to bank erosion, it is currently unlikely to be the main contributing factor. This is consistent with previous studies, such as Lesleighter (1964), Meynink and Foster (1974), and Scholer (1974), that also found boat wave energy to be less than wind wave energy. However, possible increases in tourism and commercial fishing have the potential to increase the impact of boat use on bank stability. It is therefore recommended that the management of boating be considered as part of the Estuary Management Plan.

For both wind and boat generated waves, sites with the highest estimated wave energy did not correspond with locations exhibiting severe erosion. However, erosion is also largely dependent upon the soil constituents. As a result, more severe erosion can occur in areas with highly erodable foreshores even if wave energy is lower. Previous studies (Lesleighter, 1964; Willoughby, 1991) also suggest that wave energy is generally not the primary cause of bank erosion, with stream flow also being the major cause. Other possible causes of erosion include cattle access and local runoff causing slumping in areas devoid of vegetation.

3.9. Potential Impacts of Climate Change on Hydrodynamics

As discussed in (Section 2.5.5), climate change is predicted to result in an increase in ocean levels, and cause a change in rainfall patterns (IPCC, 2007; CSIRO, 2007). However, there is still uncertainty as to how rainfall patterns and storm activity are likely to change along the NSW coast.

Both sea level rise and a change in rainfall patterns have the potential to significantly impact upon the hydrodynamics of the Macleay estuary. Any increase in mean ocean tide levels would result in a corresponding increase in water levels inside the estuary and an increasing tidal range/extent.

Increasing ocean levels also have the potential to change the entrance conditions, which significantly influence the exchange of fluvial and tidal flows. Assuming shoaling at the entrance does not increase, tidal exchange and the average annual water balance would increase. The impact of tidal storms on the surrounding floodplain would also increase, as a more open entrance would allow elevated ocean levels due to storm surge and wave setup penetrate into the estuary.

Any increase in rainfall would increase the level of catchment runoff and the volume of fluvial flows in the estuary water balance. The result would be an increase in the water balance, but as mentioned above could also include some increase in tidal flows. Any decrease in rainfall would be associated in decreased catchment runoff and a smaller water balance.

To evaluate the impact of sea level rise on hydrodynamics and mixing/flushing processes, numerical modelling with different increases in ocean tide levels was performed. The sea level increase was based on the three scenarios stipulated by Department of Environment & Climate Change (DECC) as of 15/10/2007, as shown in Table 25 below. The scenarios are based on trends from IPCC 2007 and recent CSIRO modelling and give an indication of the sea level rise between 2090 and 2100.

Table 25 Sea Level Rise Scenarios (2090-2100)

	Sea Level Rise (m)
Low Level Ocean Impacts	0.18
Mid Range Ocean Impacts	0.55
High Level Ocean Impacts	0.91

Source: DECC, 2007

To accurately depict the influence a change in sea water level has on the estuary, the model was run with no fluvial flows and a spring tidal range. The change in tidal prisms and peak flows from the runs of the three scenarios compared to current conditions are shown in Table 26 and Table 27.

Table 26 Estimated Spring Tide Peak Flows for Current and Climate Change Scenarios

Location	Spring Tide Peak Flows (m^3/s)										
	Current State		Low Impact			Mid Impact			High Impact		
	Low	High	Low	High	Change	Low	High	Change	Low	High	Change
Macleay River:											
Kempsey	-55	74	-65	82	11-18%	-84	98	32-53 %	-101	113	53-84%
Smithtown	-201	262	-222	286	9-10%	-269	338	29-34%	-319	393	50-59%
Entrance	-840	964	-903	1044	8%	-1014	1193	21-24%	-1119	1313	33-36%
Macleay Arm:											
Clybucca	-81	107	-89	117	9-10%	-103	133	24-27%	-111	142	33-37%
Entrance	-352	370	-385	407	9-10%	-430	473	22-28%	-451	515	28-39%
Belmore River:											
Entrance	-30	29	-31	30	3%	-33	34	10-17%	-35	39	17-34%

Note: Positive flow direction is defined as from the ocean to the estuary, and negative from the estuary to the ocean.

Table 26 shows that peak flows at the ocean entrance will increase between 8% for the low impact scenario and 36% for the high impact scenario. The increase in peak flows is higher upstream in the Macleay River, reaching an increase of 80% for the outflowing tide at Kempsey with a high impact scenario. The Macleay Arm experiences increases slightly larger in magnitude compared to the ocean entrance, whereas peak flows at the entrance of Belmore River are less affected by the sea level rise and flows increase between 3 and 34% depending on the scenario.

Table 27 Estimated Change in Tidal Prisms for Climate Change Scenarios

Location	Increase in Tidal Prisms (%)		
	Low Impact	Mid Impact	High Impact
Macleay River:			
Kempsey	13	40	64
Smithtown	10	31	52
Entrance	9	24	36
Macleay Arm:			
Clybucca	11	28	39
Entrance	12	31	42
Belmore River:			
Entrance	5	17	30

The changes in tidal prisms follow the pattern of the increases in peak flows. For the low impact level scenario increases vary between 9 and 13%, with Kempsey being the most affected. In the mid range impact scenario, tidal prisms increase by 24 to 40% with further increases in the high impact scenario. Again, upper estuary reaches around Kempsey is the most affected with an increase of 64%, from 1.0 to 1.7 ML/tide, for the high impact scenario.

These simulations indicate that sea level rise will affect the hydrodynamics of the system and this is likely to affect sediment transport, water quality and ecology throughout the estuary. In addition, increased flooding could occur due to increases in rainfall and/or spatial/temporal variation.

3.10. Human Impacts on Hydrodynamics

Human impacts on the hydrodynamics of the estuary are mainly associated with the formation of a southern entrance with a substantially shorter channel and extensive trained breakwalls and channels along the lower estuary (Figure 20). However, the extensive system of levees and drains that form the flood mitigation works, ongoing catchment clearing and development, dredging and sand/gravel extraction operations and climate change have or potentially could have significant impacts. A summary of these is provided below, whilst the interaction of the hydrodynamic effects with other estuary processes such as sediment dynamics, water quality, and ecology are addressed in subsequent chapters.

3.10.1. Southern Entrance Formation and Bank Training

Formation of the shorter southern entrance and associated bank training works has fixed the location of the channel in the lower estuary/entrance area. The entrance training works have restricted littoral zone beach sands from entering the estuary and reduced bank movement in areas that have been protected. This has confined the passage of tidal and flood flows to a narrower, deeper entrance and increased the hydraulic efficiency of the entrance area.

Increased channel efficiency can promote additional bank and bed erosion in areas that have not been stabilised and also results in more tidal and flood flows passing through the entrance and main river channel than before the works were constructed. This means that tidal ranges

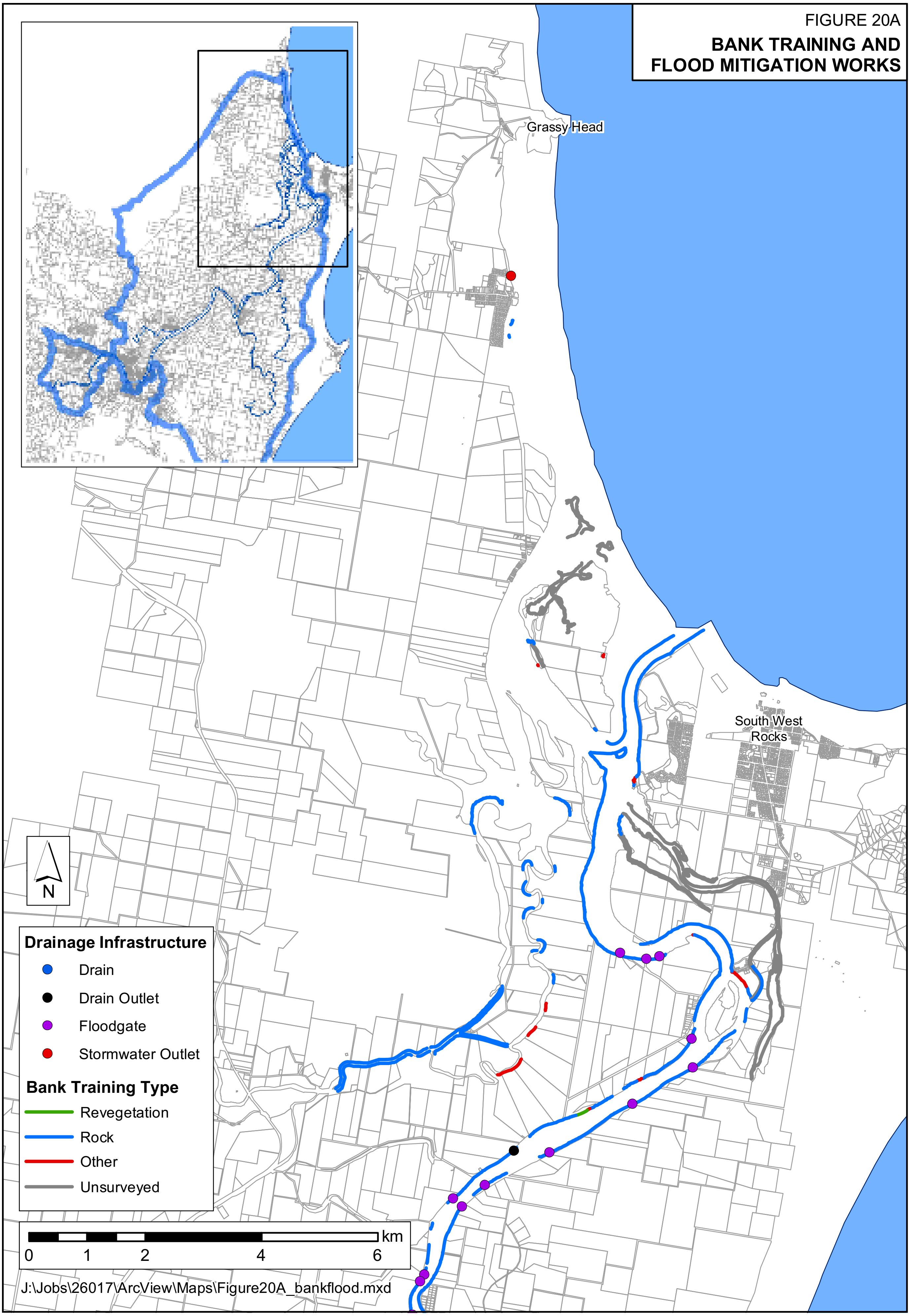


FIGURE 20A
BANK TRAINING AND
FLOOD MITIGATION WORKS
Grassy Head
South West
Rocks
N
Drainage Infrastructure
Drain
Drain Outlet
Floodgate
Stormwater Outlet
Bank Training Type
Revegetation
Rock
Other
Unsurveyed
km
0
1
2
4
6
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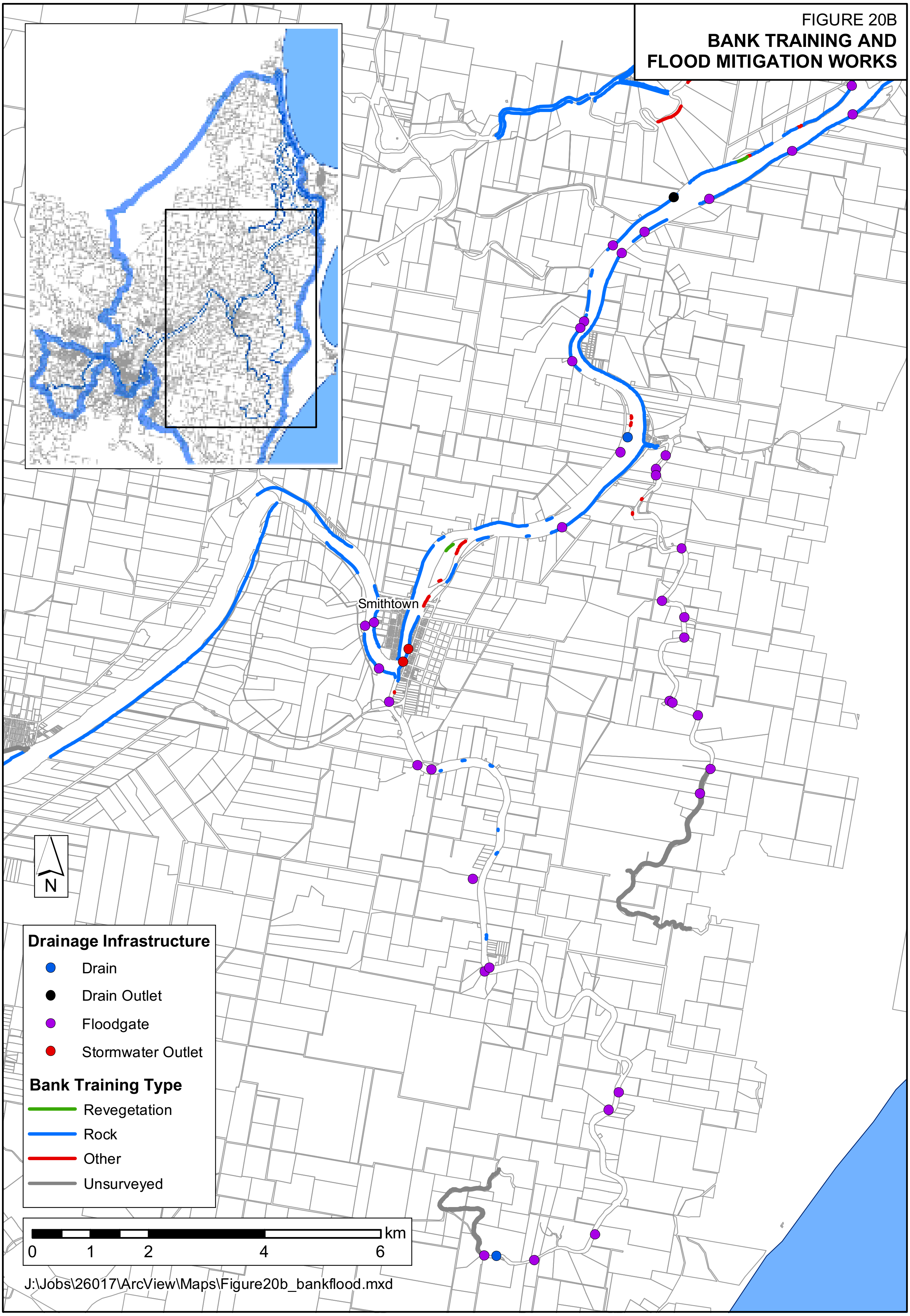
FIGURE 20B
BANK TRAINING AND FLOOD MITIGATION WORKS



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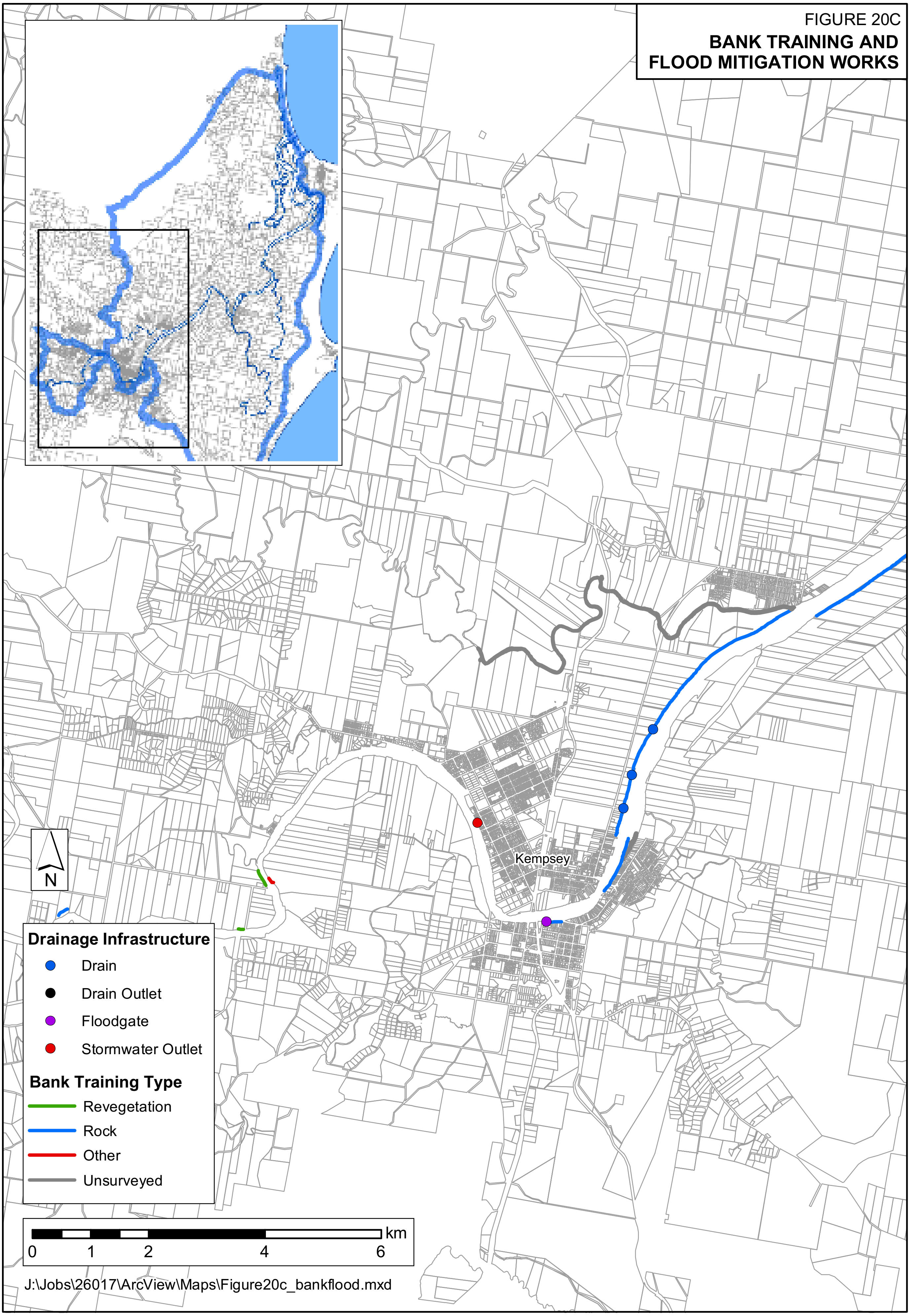
FIGURE 20C
BANK TRAINING AND
FLOOD MITIGATION WORKS
Kempsey
N
Drainage Infrastructure
Drain
Drain Outlet
Floodgate
Stormwater Outlet
Bank Training Type
Revegetation
Rock
Other
Unsurveyed
0
1
2
4
6
km
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throughout the estuary have increased and that the ranges are now less subject to entrance condition variation as a result of entrance shoaling and flood scour. This impact has had a significant effect on the sediment dynamics, water quality and ecology of the estuary (discussed in subsequent chapters).

The modelling also showed that the channel along Macleay Arm (which prior to development was a deep main river channel) conveyed more water for the historical configuration. The change in tidal prism varied between 0% for the maximum range tide to 21% for the neap tide.

3.10.2. Flood Mitigation Works

The hydrodynamic impacts of the levees and drains that form the extensive system of flood mitigation works within the Macleay, Belmore, Kinchela and Clybucca floodplains mainly relate to flood conditions, as these areas are not and were not significant tidal storages. The levees and drainage floodgates prevent inundation of low lying backswamp areas during small floods and freshes. This reduces damage to property and pastures but also creates ponds of local runoff that can have elevated organic and iron levels and/or high acidity.

The polluted ponded waters are often discharged into the main river system after flood levels have receded. These are not major hydrodynamic events, but are known to cause substantial ecological damage within the river such as fish kills and trigger red spot disease. As a result, the management and control of these waters is of major concern to estuary management. The RMA-11 model set up as part of this study should be a major tool for examining these discharges and their management in terms of movement and dispersion through the estuary as part of the Estuary Management Study and Plan.

3.10.3. Catchment Clearing and Development

Catchment clearing and urban development have affected the estuary by increasing the volume and peak flows of catchment runoff. Whilst no assessment of pre-development runoff has been conducted as part of this study, previous studies for similar areas (Mein, 1993) have indicated that clearing can increase runoff by approximately 15%. This can increase runoff for the whole catchment by approximately 5%. The greatest impact occurs during minor storms in the lower catchment area where clearing is greatest. The impact for extreme storm events and major catchment wide flooding would be minimal.

Catchment clearing and development have also increased sediment and pollutant transport into the estuary. Increased sediment transport can reduce channel capacity and hence result in increased bank erosion.

4. SEDIMENT DYNAMICS

Sediment dynamics describe the formation, distribution and movement of sediments within an estuary system. The distribution of different sediment types (facies) helps define the fluvial, transitional and marine process zones within the estuary. These zones also reflect different hydrodynamic, water quality and ecological conditions within the estuary. Further, the morphology (shape) of estuary channels, banks and floodplains form in response to sediment movement mechanisms, such as bank and bed erosion and shoaling/accretion. These mechanisms have a major impact on human use of the waterway and foreshores.

Sediment movement dynamics in the Macleay River estuary are primarily driven by tidal and fluvial (flood) flows, although wind and wave movements and human impacts (land management practices, boat wash, past channel dredging and bank training) also have localised effects.

The following sections review the type and distribution of sediments and the factors influencing sediment distribution, as well as estuary morphology and how that has developed.

4.1. Sedimentology

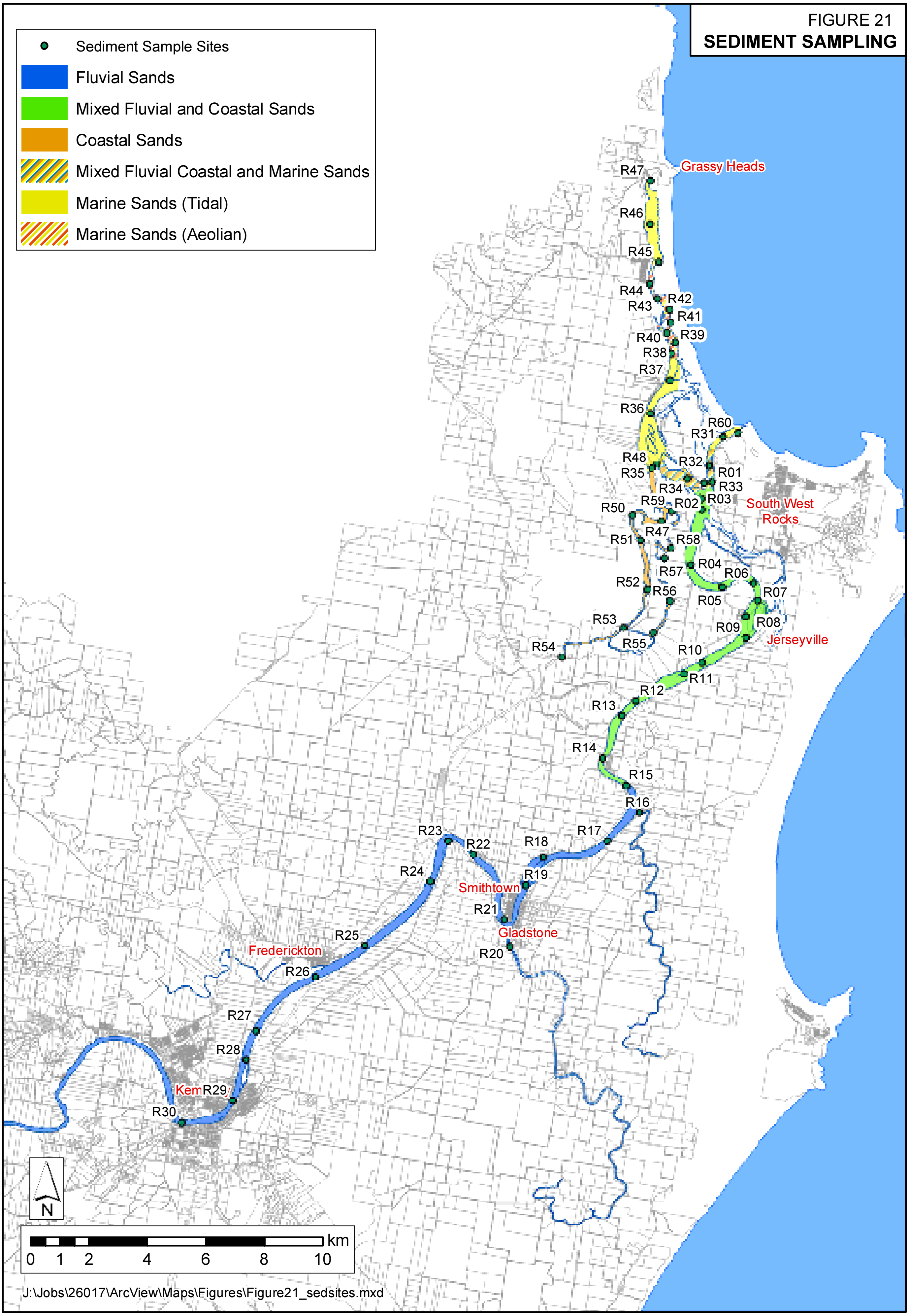
The mineral composition of the sediments in the Macleay River and tributary streams is generated by the bedrock types of the Macleay catchment, i.e., metasediments, granitoids and basalt, along with localised anomalous inputs (Ashley and Graham, 2001). As a result, the sediments show an abundance of quartz with minor amounts of felspars, clays, iron sulphides and oxides, jarosite and gypsum and traces of rutile and zircon. However, bed sediment distribution not only reflects the source of the sediments but also the dynamics of sediment movement, that is, the mobility of the sediments and the strength of the hydraulic (or aeolian) forces.

4.1.1. Sediment Sampling

To help determine and quantify the distribution of sediments through the Macleay estuary 59 bed sediment samples were collected from the river and tributaries as part of the present study. Samples were collected across the entire study area (shown in Figure 21) and analysed based on physical properties such as size, shape, degree of sorting, colour, mineral content, and staining. The sampling sites were chosen to provide a representative sample of bed sediments and the sediment movement processes. Sample locations included shoals, channel inverts, bends and straight reaches.

The sediments were washed over a 65µm sieve to remove the silt fraction, and the sand residue was examined at 12 times magnification. A summary description of each sample is shown in Table C1 in Appendix C. The examination showed that the samples could be grouped into three facies with fairly close associations in terms of grain size and shape, mineral composition and colour. A representative sample of each facie was then photographed.

FIGURE 21
SEDIMENT SAMPLING



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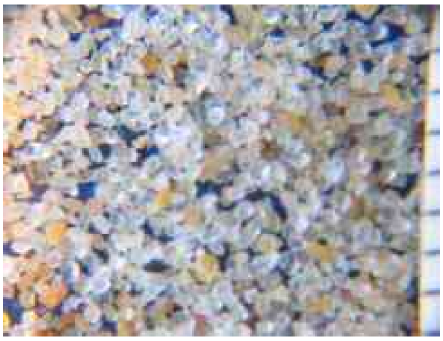
4.1.2. Sediment Facies

Surface bed sand sized sediments from the Macleay River estuary were divided into the following three facies related to their physical properties. The facies distribution is shown on Figure 21.

Beach and Nearshore Marine Sands

These sands constitute the existing beach and dune sands and were moved onto the coast during the last marine transgression. They are predominantly quartz, fine to medium sized with rounded grains and a small percentage of felspar, rutile and zircon grains and some larger sell fragments. They are mainly clear to fawn in colour with some minor iron staining. Tidal deposits tendered to be slightly larger and more well sorted than aeolian deposits which included a smaller grain fraction and were less well sorted.



Photograph 2 Typical Marine Sediment

Reworked Coastal Sands

These were deposited as earlier Pleistocene barriers but have been intersected and reworked by more recent estuary development. The sediments are predominantly quartz with a fine grain size, well sorted and rounded to sub-rounded. The percentage of felspar and other minerals was small around 10%. The grains were generally clear in colour but with significant traces of organic coating giving a light brown appearance. The proportion of fluvial deposited silts and clays was high in some samples.

Photograph 3 Typical Coastal Sediment

Fluvial Sands

Although these sands mainly consisted of quartz grains, the percentage of lithic particles and minerals was high, up to 60% in the upper river estuary to around 40% in the lower river estuary. The grains were sub-angular to angular and sourced from weathered bed rock and varied in colour from clear to black, resulting in an overall dark brown colour.

Photograph 4 Typical Fluvial Sediment

4.1.3. Sediment Distribution

Sediment distribution can be used to define different process zones reflecting fluvial and tidal interactions within an estuary. These zones are typically referred to as fluvial, transitional and marine. Fluvial zones are dominated by fluvial flows and sediments. Transitional zones are influenced by both fluvial and tidal flows, and are characterised by fluvial sediment deposits and shoals modified by tidal flows. Marine zones primarily consist of marine sediment and are dominated by tidal processes.

The distribution of the sediments through the estuary is shown in Figure 21 (page 46). The distribution is similar to other major NSW river estuaries (WMA, 1993; and WMA, 1998) with fluvial sand deposits along the upper estuary reaches and coastal/marine sands along the lower reaches. However, the Macleay differs from most other similar sized estuaries in that the fluvial sediments extend to within a couple of kilometres of the ocean entrance. Most other major river estuaries have a wide band of reworked coastal sands mixed with some fluvial sand along the lower coastal Marine Flood Tidal Zone and Transitional Zone respectively. However, in the Macleay the Transitional Zone is dominated by fluvial sediments, with a very short zone of mixed marine, coastal and fluvial sediments near the confluence between the river and the Macleay Arm.

The reasons for the differences between the Macleay River Estuary and other similar estuaries is not related to significantly different tidal or fluvial hydrodynamics or sedimentology, but rather to the relatively recent (geologically) change in the location of the river entrance and the effects of the entrance training works on beach littoral zone sand movements over the period since the entrance location changed.

The change in the location of the entrance effectively removed some 14 kilometres of the Marine

Flood Tide Zone and reworked coastal sands and marine sands from the river (they are now part of the Macleay Arm). Further, subsequent associated entrance breakwall training works have effectively prevented beach and nearshore marine sands from entering (in-feeding to) the estuary by trapping the sands on the beach between the entrance and South West Rocks (Section 4.6). Entrance dredging for the new entrance and natural deepening of the lower river channel associated with shortening of the river (and hence steepening the river grade) have further facilitated the movement of fluvial sediments into the entrance area.

4.2. Existing Morphology and Process Zones

The shape or morphology of the estuary basin (the channels, banks and floodplain areas) is formed by hydrodynamic and sediment movement forces that in turn affect both the ecology and human use of the area. Cohen (2005) examined the morphology and general sediment types within the estuary area and divided it into three "process" zones, as shown in Figure 9 (page 23):

- Fluvial Zone,
- Transitional Zone,
- Marine Flood Tide Zone (or Marine Tidal Zone).

Note, these zones are effectively the same as those derived from the hydrodynamic assessment (Section 3.1) but were formulated based on morphology not hydrodynamics.

4.2.1. Fluvial Zone

The fluvial process zone is the most extensive zone extending from the tidal limit at Belgrave Falls to Kinchela (including Belmore River and Kinchela Creek). Cohen (2005) divides this zone into a further three sections to reflect the dominant processes and morphology:

Fluvial Zone 1 (F1): Belgrave Falls to Kempsey

This section was characterised by bedrock outcropping on the concave banks with additional outcrops is occurring in the bed of the channel itself. The reach is dominated by riffle-pool sequences with coarse bed material (cobble gravels) as well as deep pools. The Macleay River in this most upstream reach was set within late Pleistocene and early Holocene terraces with distinctly stepped channel margins. The older clay-rich terraces form an important lateral control on the channel location, forming a resistant channel boundary.

Fluvial Zone 2 (F2): Kempsey to Belmore River

In this reach the valley width increases substantially, representing a major shift in depositional processes and producing the wide deltaic plain of the lower Macleay. There was a progressive reduction in bank and levee height moving downstream. The reach is characterised by alternate shoal, bar and bench developments, inset within an enlarged channel and shallower water depths.

Fluvial Zone 3 (F3): Belmore River to Kinchela Confluence

This reach showed the greatest extent of active erosion. In contrast to the main river, the

Belmore River and Kinchela Creek exhibited less in-channel sediment storage with sediment accumulation occurring through levee development. These low gradient tributaries, although predominantly stable, were extensively modified by drainage works.

4.2.2. Transitional Zone

Cohen (2005) described the transitional zone as extending from Kinchela to Jerseyville Bridge and including most of Clybucca Creek. This zone reflects a transition from entirely fluvial processes to a mix of both tidal and fluvial processes. This was apparent by the appearance of shoals that were deposited by fluvial processes but which were also modified by tidal processes. As a result, shoals within this transitional zone contained fluvial and coastal sediments. There was a further reduction in bank height moving downstream through this reach with the formation of intertidal flats and the dominance of estuary/coastal sediments in bank profiles.

The lower sections of the zone exhibit some shoal development, and deposition within the main river was accompanied by bank protection works and/or some erosion of the banks. Clybucca Creek was extensively modified by drainage works resulting in the formation of two active channels (artificially created) with locally modified deposition processes. However, most of Clybucca Creek had extensive areas of intertidal flats, salt marsh and mangroves.

4.2.3. Marine Tidal Zone

Cohen (2005) described this zone as extending from downstream of Jerseyville to the mouth of the Macleay River, including the Macleay Arm. The section was dominated by marine-derived sediment sourced from coastal barrier systems and the inner continental shelf. Extensive intertidal and supra-tidal flats occurred within this zone with extremely low bank heights with little to no levee development.

Individual floods influenced the gross location of the sand shoals but tidal and wind wave processes dominate the formation of abundant sand flats, sand banks, mangroves and salt marshes. Telfer (2005) found that the shoals within this zone migrated upstream on the incoming tide and were partly reworked on the outgoing tide, particularly in the Macleay Arm. This was identified as the process for progressive infilling. Note however, the sedimentology undertaken for the current study indicates that this filling is from aeolian marine sands from the current beach dune system and that there is no connection between marine-sourced sand in the current entrance and the Macleay Arm.

4.3. Existing Bed and Bank Conditions

Bank erosion not only causes a loss of valuable foreshore land, it also contributes to sedimentation and shoaling in the estuary and increases the concentration of suspended solids in the water column. High concentrations of suspended solids reduce water clarity and adversely affect seagrasses as well as other estuarine flora and fauna. Bank erosion can be caused by a number of different processes including fluvial scour, waves, the loss of riparian vegetation and cattle access. The following sections provide a description of the current extent of bank erosion and the mechanisms that contribute to that erosion.

An assessment of bank erosion in the Macleay River estuary was undertaken as part of a geomorphology study conducted by Cohen (2005). Bank erosion severity, failure mechanism and dominant processes were recorded for each location where erosion occurred for more than 20 m in length (Figure 19, page 38). 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. It should be noted that 24% of the 357 km of river bank is inaccessible by boat and was therefore not surveyed. Table 28 summarises the severity of erosion along the length of the surveyed riverbank.

Table 28 Severity of Bank Erosion in the Macleay Estuary Process Zones

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

Note: Percentages are calculated as proportion of area surveyed.

As shown in Table 28, the majority (90%) of the surveyed estuary has stable riverbanks, although a significant proportion of this has been rock stabilised. A description of erosion extent and cause for each process zone was provided by Cohen (2005), and is summarised below.

4.3.1. Fluvial Zone

The fluvial zone has the most severe bank erosion in the Macleay estuary, with the area of greatest erosion occurring near the Kinchela Bend. 90% of the fluvial zone is stable (22% of this being stabilised by bank revetment). The dominant cause of erosion was found to differ between the three fluvial zones, resulting in differing types and severity of bank erosion.

Fluvial Reach 1 was dominated by fluvial processes with significant erosion often resulting from major floods. The dominant erosion mechanisms were mass failure along extensive lengths (>100m) of river bank and bank or bench toe sliding on smaller sections. Rotational slumps and block failures occurred where there were very high banks. The typical bank soil structure of silty or sandy loam overlying gravel had increased risk of erosion where vegetation was cleared and cattle had river access.

Fluvial Reach 2 was predominantly stable with extensive rock protection between Kempsey and Seven Oaks. Isolated small sections of toe scour and fluvial erosion were observed.

Fluvial Reach 3 was the most active with significant bank erosion at Kinchela Bend (3 km) and Fattorini Island (0.5 km). The Kinchela Bend erosion is on the inside of a large bend and is largely wave driven. The Fattorini Island erosion is in a channel constriction and is impacted by both flood currents and ongoing wave erosion.

4.3.2. Transitional Zone

The transitional zone was the second most unstable area of bank erosion although there was no severe erosion and only 1.2 km of moderate erosion and 6.3 km of minor erosion. However, some 43% or 30 km of bank has been rock protected. The most significant erosion along the main river was at Pelican Island where there was basal clay layer and a “deep water” profile at low tide level and a wave eroded layer of sands and silts above that level. Erosion along Clybucca Creek mainly occurred along the outside of bends indicating a current induced process, although this appeared to be maintained by (wind and boat) waves.

4.3.3. Marine Tidal Zone

The marine tidal zone was the most stable, with only 6% (3.8 km) being assessed as having minor erosion. Of the stable banks 23% (16 km) had been rock protected. The bank heights in this zone were very low and the erosion appeared to be the result of wind and boat waves.

4.3.4. Erosion Sediment Yield

From the wave analysis in Chapter 3 it can be seen that average wind generated wave energy is significantly greater than the maximum boat generated wave energy at all the identified erosion sites. Hence, whilst boat wash is likely to contribute to bank erosion, it is currently unlikely to be the main contributing factor. This is consistent with previous studies, such as Lesleighter (1964), Meynink and Foster (1974), and Scholer (1974), that also found boat wave energy to be less than wind wave energy.

For both wind and boat generated waves, sites with the highest estimated wave energy did not correspond with locations exhibiting severe erosion. Previous studies (Lesleighter, 1964; Willoughby, 1991) also suggest that wave energy is generally not the primary cause of bank erosion, with the stream flow being the major cause. Other possible causes of erosion include soil type, cattle access and local runoff causing slumping in areas devoid of vegetation.

Cohen (2005) compared bank erosion data from 1934 and 2004 and found that there had been a substantial reduction in the length of severe (68%) and moderate (26%) erosion. Further, comparison with similar nearby estuaries such as the Hasting River (WMA, 1998) and Manning River (WMA, 1997[2]) estuaries (see table below) shows that the length and severity of the erosion in these estuaries was substantially worse than for the Macleay.

Table 29 Comparison of Estuary Bank Erosion (km)

	Major Erosion	Moderate Erosion	Minor Erosion
Macleay River Estuary (Cohen 2005)	3	4	18
Hastings River Estuary (WMA 1998)	7.5	3.5	> 6
Manning River Estuary (WMA 1997[2])	9.5	19.4	large

Based on the above and given that bank erosion along the Macleay River was not particularly active it is reasonable to assume that estuary bank erosion is not a major contributor to sediment loads in the estuary. However, possible increases in tourism and commercial fishing have the potential to increase the impact of boat use on bank stability. It is therefore recommended that the management of boating be considered as part of the Estuary Management Plan.

4.4. Historical Morphology

The geology and evolution of the Macleay River catchment and estuary are outlined in Chapter 2. This section looks at more recently recorded historical changes starting from around 1864 through to the present. An examination of morphological changes can assist in providing an indication of sediment movement patterns, and how these may influence present and future estuary processes. The most significant changes are associated with the shift in ocean entrance location from just south of Grassy Head to its present location approximately 1.6 km north of South West Rocks. This change was as a result of both natural and anthropogenic impacts. Early dredging, channel realignments and channel bed clearing, mainly from the 1880's to the 1940's but continuing up to the 1970's (Telfer, 2005) altered channel dimensions and consequently impacted on flows and sediment movement, particularly in the lower estuary.

Land clearing along the majority of the river length from the 1830's onwards reduced bank stability and enabled a higher rate of sediment transport to the river. Unprotected river frontage and cattle access increased the rate of bank erosion and collapse. Frequent flooding, such as occurred between 1863 and 1875, and 1949 to 1950, intensified the impacts caused by land clearing by initiating bank collapse and the formation of new flood paths (Telfer, 2005).

The extensive drainage works undertaken throughout the floodplain to reclaim land and minimise the impacts of floods also resulted in further changes to the morphology of the river, its tributaries and flood runners. From the 1930's onwards, bank stabilisation projects resulted in approximately 19% (66km) of the lower Macleay being protected using rock armouring (Cohen, 2005). This restricted channel adjustment in these areas, placing increased stress on surrounding unprotected banks.

Howard (1890), a hydrographical surveyor, provided a detailed description of the Macleay estuary and the changes that occurred up to 1888 in an appendix to Sir John Coode's report on improvement options for the Macleay entrance. A summary of Howard's description and subsequent available information is provided as follows (see also Figure 22 and Figure 23):

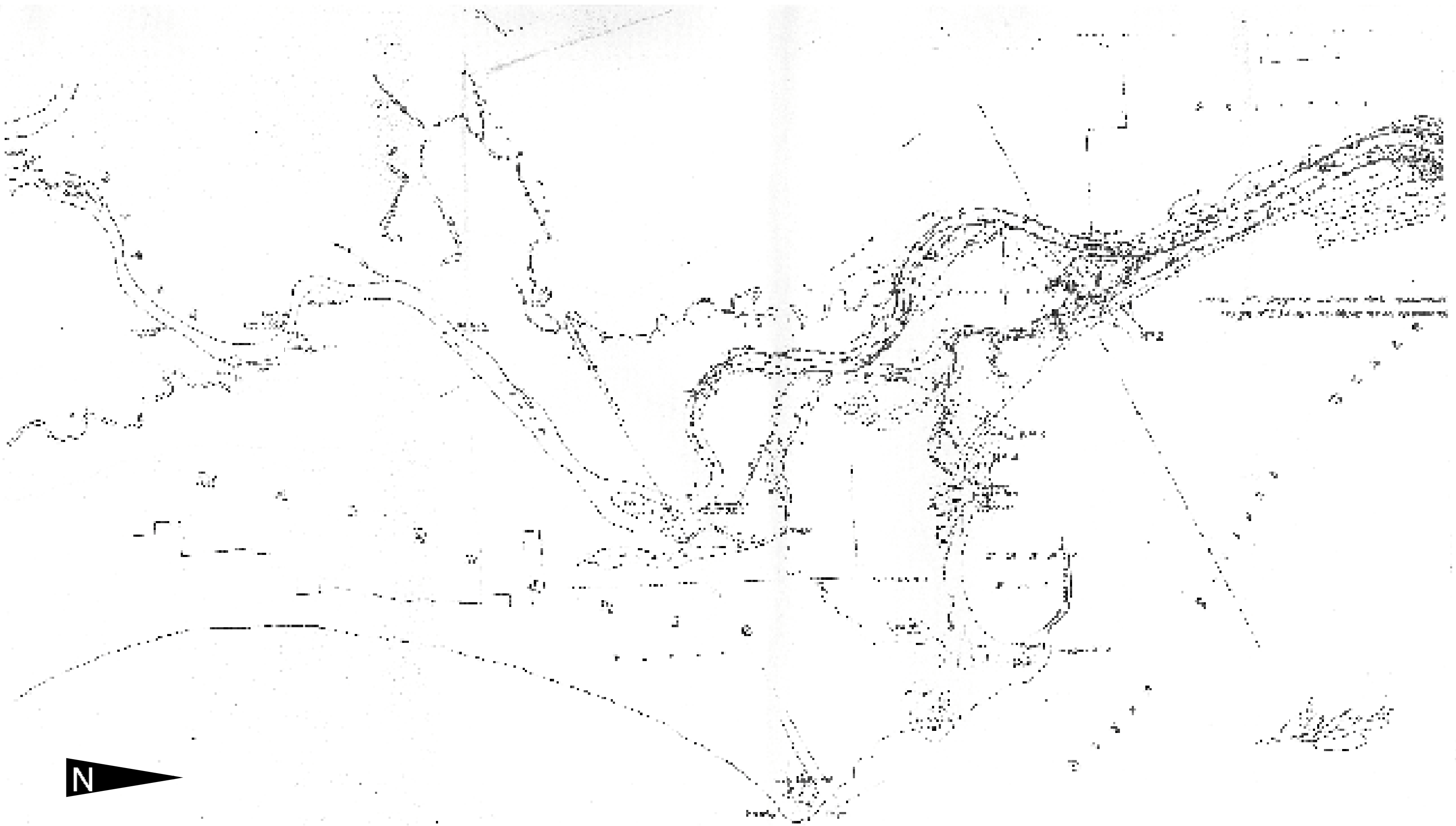
Prior to 1864

- The Macleay entrance was located immediately south of Grassy Head. The entrance was reported to be relatively stable, with minimal movement.

1864

- The entrance shifted further south during a heavy flood. It was reported that timber was washed into the river and blocked the original entrance, forcing the river to break through

FIGURE 22
1890 MACLEAY RIVER



SOURCE: SIR JOHN COODE'S REPORT (COODE, 1890)

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FIGURE 23
1890 OLD MACLEAY RIVER ENTRANCE

SOURCE: SIR JOHN COODE'S REPORT (COODE, 1890)

J://Jobs/26017/Admin/Reports/Figures/Other/Figs22_23.pdf in several locations further south. It was also observed that the new entrance, approximately 3km south, shifted over time but did not return to its original location.

Prior to 1888 (time of reporting)

- Up to the time of reporting (1888) bars continued to form across the entrance, mainly due to windblown sand. The entrance would become deeper during floods and westerly winds.
- Dredging occurred to the west and north of Shark Island. The original shipping route was more easterly.
- Clybucca Creek opened into a lagoon.
- The channel ran between the two islands north of the entrance to Clybucca Creek and Shark Island.
- South of these islands there was a sand and mud bank with a channel dredged through to Shark Island.
- The section of river to the east of Shark Island used to be part of Spencers Creek, and Shark Island was a peninsula. In the early 1860's a small cutting was made between Spencers Creek and the main river. As the high and low tides occurred earlier in this part of Spencers Creek than in the Macleay (due to its closer proximity to the ocean), the small channel rapidly expanded to a 1,800 foot wide channel by 1888.
- The eastern Shark Island channel was reportedly later partially filled by material dredged from the main channel.
- There were four locations to the east of Shark Island where the river appears to have broken out to the sea. Note, these are still evident, the most southern one being South West Rocks Creek.
- South West Rocks Creek was connected to the Macleay River at the southern end of Shark Island.
- In approximately 1868 a 'cutting' was made inside the mouth of South West Rocks Creek to allow tidal inflows but the entrance silted up.
- In 1885 South West Rocks Creek was observed to not be connected to the ocean.
- In 1887 a gutter was dug through to the ocean to allow flood waters to drain from South West Rocks Creek. The entrance then remained open, although it nearly closed on two occasions during 1888.
- By 1888, two small islands had formed in South West Rocks Creek near its confluence with the Macleay. These nearly blocked the entrance into the Creek.
- Approximately 4km south of the northern entrance to Spencers Creek, tidal water flowed south into a lagoon. The lagoon filled during a flood tide from both the northern and southern reaches of Spencers Creek. This lagoon has now been extensively modified, and runs into a series of drains.
- The island south of Pelican Island (currently unnamed, but was originally called Pelican Island), had a similar shape during the 1888 survey as the early 1900's parish maps. It was slightly longer in length compared with the 2003 aerial, and had an inlet at the north western end.
- Half way along Long Reach (the straight stretch of the Macleay upstream of Jerseyville), is a shoaled area. Dredging between the right and left banks has occurred south of the

shoal. This shoal now appears to have formed an island (Long Reach Island).

- During floods, water flows over the western bank of Long Reach and enters the Clybucca.
- Kinchella Creek ends in extensive backswamps.
- Downstream of Smithtown are two Fattorini Islands, which now form only one island.
- At Seven Oaks (bend upstream of Smithtown), the left bank has been observed to be eroding, and the inside bend accumulating sediment. Significant change was already thought to have occurred. Floodwater was reported to overtop the low part of the bank and flow across the floodplain to Clybucca Creek.
- A shoaled area occurs upstream of Seven Oaks, through which dredging has occurred. This shoaling doesn't appear in current mapping of the area.
- Shoaling occurs along the right bank between Frederickton and Kempsey. Current mapping of shoals show one area on the left bank at Frederickton, another further upstream on the right bank, and in two more locations near Kempsey.
- Howard also reports a shoaled area at Kempsey, which may now be the small island near the entrance to Gills Bridge Creek.
- Approximately 800m upstream of Greenhill is a dredged crossing. From here upstream, the river banks are described as being highly likely to change during floods or large freshes.

1893

- A 1% AEP flood broke through to the ocean approximately 1.6km north of South West Rocks leaving the old channel and mouth south of Grassy Head to gradually become sediment filled (Telfer, 2005).

1897

- The new channel had been dredged and some training walls constructed by Public Works in the location of the new entrance (Telfer, 2005).

1898

- Some reports of an increase in bank erosion in the lower river since the new channel works, although one resident stated that the banks have always been eroding (Parliamentary Standing Committee on Public Works, 1898).

These historical records provide a valuable insight into the morphology of the estuary approximately 60 years after European settlement. They also assist in assessing the level of change that has occurred between 1888 and the present, and provide an indication as to factors which have influenced change. Howard's (1890) report and other historical documents indicate the potential for both natural processes such as flooding and human actions such as dredging, to significantly impact upon river shape and sediment dynamics.

4.5. River Planiform Changes

4.5.1. General Patterns of River Change

River planiform describes the shape and location of a river as viewed above. Rivers naturally change over time, adjusting to controlling factors such as different flows, sediment size and supply rates, bank characteristics, geology and catchment slope. For example, there is a natural tendency for rivers to increase in sinuosity as the outside bends become eroded due to higher velocities, and inside bends undergo deposition. Flooding can also result in bank collapse, avulsions (where new channels are formed by overbank flow), and sediment distribution from the river to the floodplain.

Planiform changes can provide an indication of how much a river has moved over time, and how stable it is. A river can be described as being in dynamic equilibrium when the rate of sediment supply is equal to sediment loss. Sediment supply can be from upstream reaches or bank erosion, and losses occur through transport to downstream reaches, through overbank flow or sand and gravel extraction. According to Blench (1962, cited in Richards, 1982), river equilibrium is the oscillation of morphological variables around a consistent mean, indicating that a river is constantly adjusting. Morphological variables describe channel form and include features such as channel width, mean depth, thalweg (maximum depth), channel slope and sinuosity.

Hydraulically efficient rivers are generally deep compared with their width as this minimises energy losses due to bed friction. However, if river slopes are steeper than the surrounding valley slope there is likely to be a net loss of sediment as velocities are too high. A river can adjust in a number of ways, such as by forming meanders that reduce slope and velocity. A river may also become wider and more shallow, which decreases velocities and encourages sediment deposition.

Human activities can have significant impacts on river morphology. For example, land clearance and cattle access can increase bank erosion and sediment transport into the river. This can decrease sinuosity and hence increase slope and velocity in an attempt to transport the excess sediment down the river. This has occurred in the Hunter River where an estimated 2.3 million m^3 or more of sand has caused the river to decrease from 27 to 9km between Maitland and Morpeth. Levee construction resulted in sediment being kept within the river rather than being transported onto the floodplain. To accommodate the reduced conveyance caused by the sediment, increased bank and river bed erosion occurred that further added to the downstream sediment load (Patterson Britton & Partners, 1995).

Bank erosion can also cause localised river widening and increased shoaling in depositional areas. While bank stabilisation works using rock armouring can protect sections of bank by restricting the river from adjusting in that area, increased adjustment can occur in surrounding unprotected reaches. Changes in river width are therefore likely to occur where adjacent banks are restricted by rock revetment.

4.5.2. Assessing River Change

A number of different methods exist for assessing the likelihood that a river has reached an equilibrium state, or whether it is still in a process of change. Planiform existence diagrams developed by Leopold and Wolman (1957), Ackers (1982) and Parker (1976) use information such as slope, discharge, channel dimensions and Froude number to estimate whether a river is in equilibrium. River characteristics are plotted on the planiform diagrams to determine the river's equilibrium state (straight, meandering or braided). If there is a discrepancy between the existing planiform and its predicted planiform the river is considered to be still adjusting. However, various studies have found these methods to be unreliable in predicting river change. This is partly due to the diagrams being based on specific river conditions, such as having erodible bed material.

Other studies such as the *Lower Hunter Geomorphology Study* (Patterson Britton & Partners, 1995) use the regime theory to predict river equilibrium. The regime theory states that a river is in equilibrium if the channel has a sediment transport capacity which equals the sediment supply rate (Richards, 1982). It utilises information on sediment size and concentration, channel cross section and slope. Whilst this theory has been developed specifically for artificial channels, it has been used to analyse natural rivers such as the Hunter River.

Whilst these equilibrium methods can provide some general indication of river change in highly unstable rivers, the uncertainties associated with them limit their application. They also do not take into consideration the impact of significant floods, climate change or human activities such as levee construction and rock revetment. An examination of previous planiform changes and the occurrence of controlling factors can often provide a more realistic indication of potential future changes. Given the lack of overall change along the majority of the Macleay River within the estuary, this method was considered to be the most appropriate.

4.5.3. Planiform Changes along the Macleay River

In order to examine the planiform changes for the Macleay River, aerial photographs from 2003 and 1956 were compared with historical parish maps from 1907 to 1913, as shown in Figure 24 (A to C). Compared with rivers such as the Hunter River, the Macleay has undergone minimal changes since the early 1900's along the majority of its length. Its overall location, channel width, length and sinuosity have not changed significantly, suggesting the river is in a relatively stable condition.

A summary of planiform changes for different sections of the Macleay River is provided below. It should be noted that the early 1900's river location is based on parish maps, for which survey data potentially has significant inaccuracies where there are no geographical landmarks. The 1956 aerial photographs are not orthorectified (have not been corrected for optical distortions), which limits the accuracy to which they can be geo-referenced. The 1956 aerials are also in black and white and are generally of poor resolution, making it difficult to clearly distinguish defining features. Areas of shoaling near the river edge also obscure the exact location of the

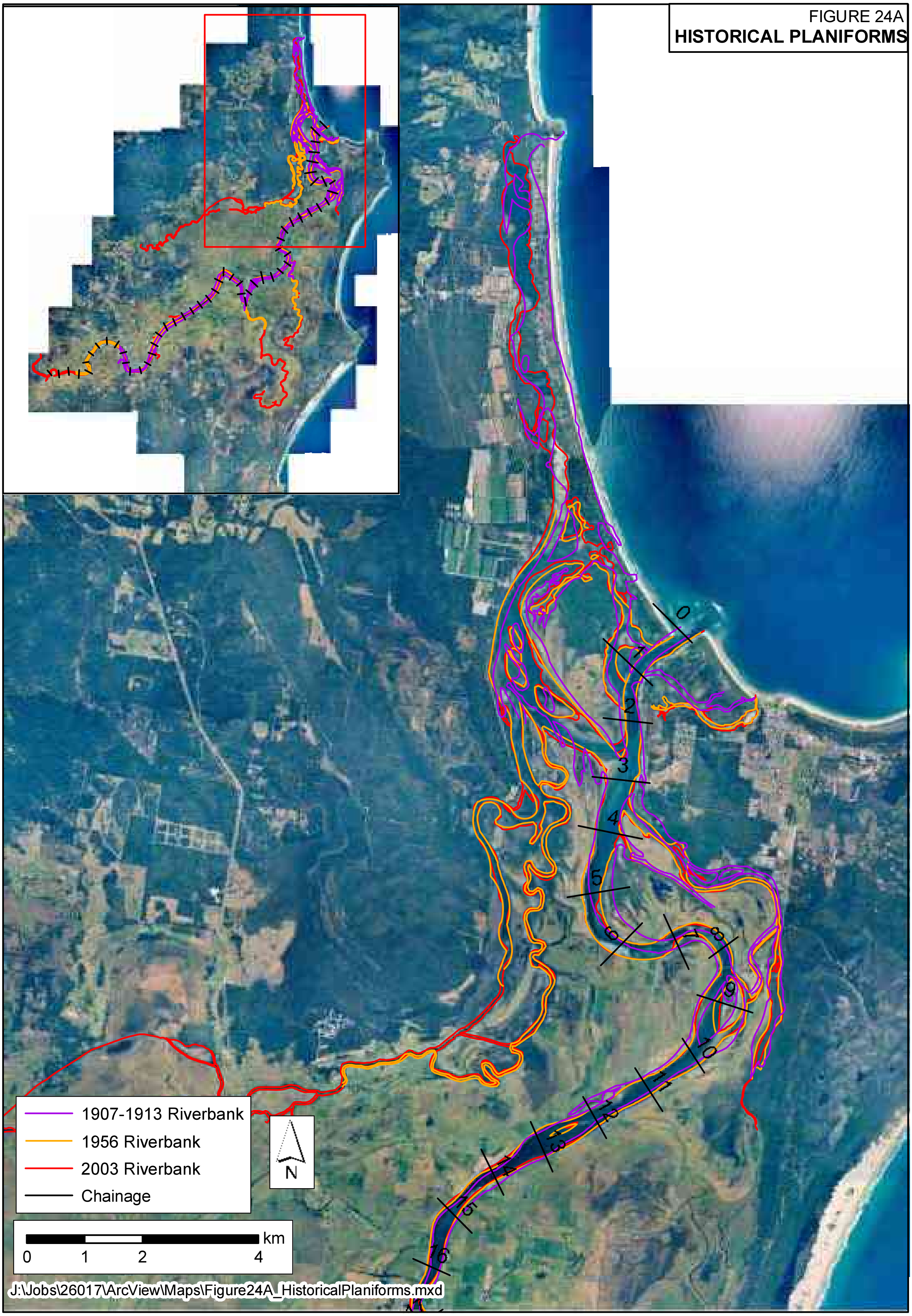

FIGURE 24A
HISTORICAL PLANIFORMS

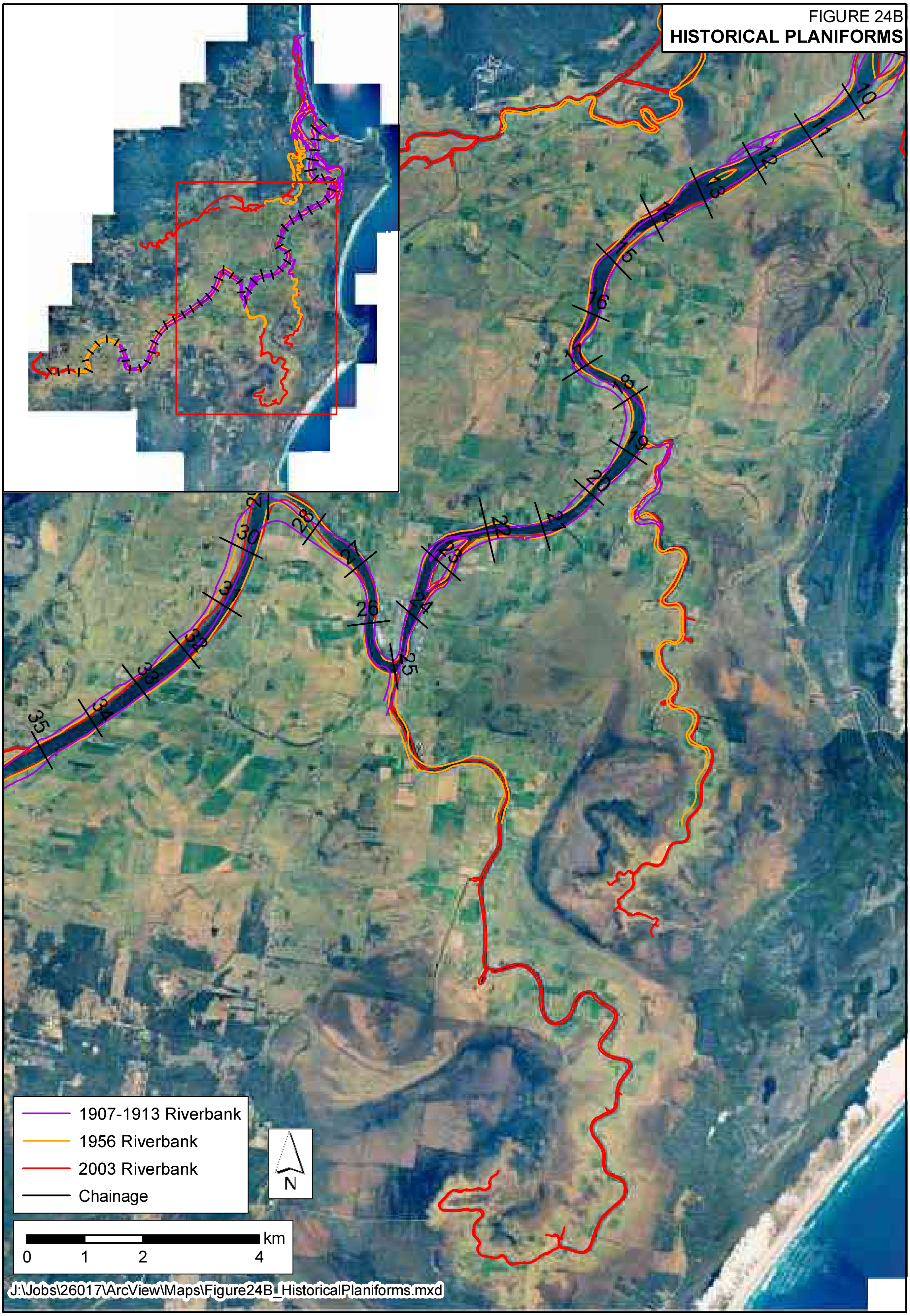
FIGURE 24B
HISTORICAL PLANIFORMS
1907-1913 Riverbank
1956 Riverbank
2003 Riverbank
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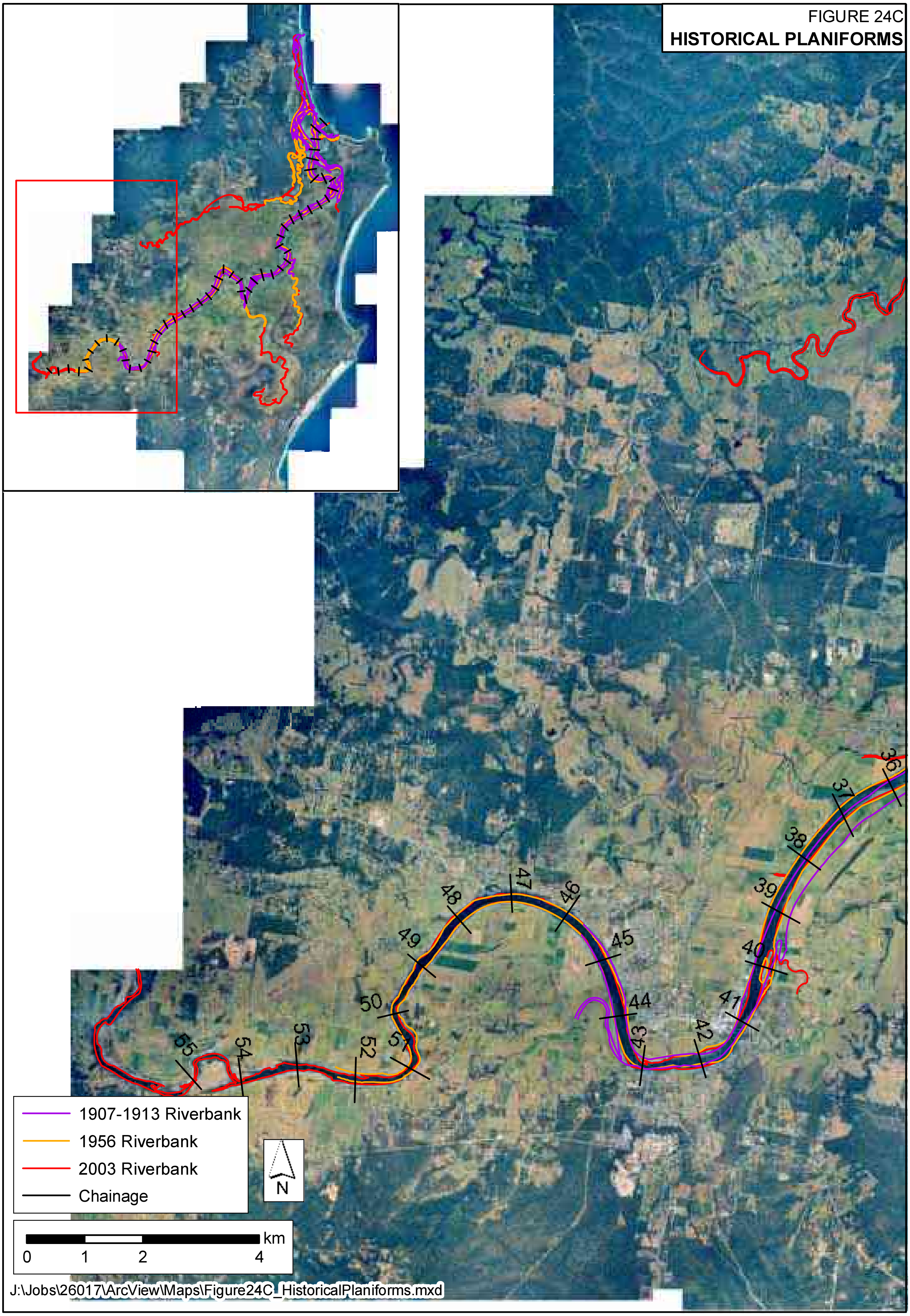

FIGURE 24C
HISTORICAL PLANIFORMS
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1907-1913 Riverbank
1956 Riverbank
2003 Riverbank
Chainage
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km
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1
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4
J:\Jobs\26017\ArcView\Maps\Figure24C_HistoricalPlaniforms.mxd

bank. Changes in riverbank location may therefore reflect these inaccuracies rather than actual changes in planiform. For this reason, only substantial changes have been focused on.

In order to understand some possible causes of changing morphology, general river processes as well as site specific data have been considered. For example, information on bank erosion, bank stabilisation works and the soil landscape can provide some indication of why certain changes may have occurred. However, this information is also limited in that:

- There is no quantitative historic information to indicate how bank erosion has changed and to determine whether it is increasing or decreasing; and
- The soil landscape mapping has been conducted on a 1:100,000 scale, limiting the accuracy at a river reach scale.

Existing bank erosion details has been taken from the 2005 survey by Cohen, bank stabilisation works information has been sourced from Telfer (2005) and the soil landscape details has been obtained from Eddie (2000) and Atkinson (1999).

Chainage 55 (Belgrave Falls) to 52

Only 2003 aerial photography is available for this section, preventing an analysis of planiform changes. Some minor and moderate erosion has been recorded along a small section of the outside left bank just downstream of Belgrave Falls at Ch 55. A section of rock revetment has been constructed immediately upstream of the existing bank erosion. Without having a previous record of bank erosion it is not known whether the rock work has increased erosion along the adjacent section of bank.

Chainage 52 to 46 (Greenhills and north western Kempsey)

Only 1956 and 2003 aerial photography is available for this section. There are no significant changes to channel shape or width. Between Ch 52 and 51, there has been some sediment accumulation on the northern (left) bank, and on the eastern (right) bank between Ch 51 and 50. The latter has occurred on the outside of the bend, which is atypical. Minor erosion has also been recorded at this location on the inside bend. There is some rock armouring at Ch 50 on the opposite (left) bank, which may have influenced erosion on the right bank. However, as the date of works is unknown, it is not possible to determine whether it occurred between 1956 and 2003. The soil landscape in this area suggests that the inside of the bank may have greater erosion potential than the outside, although there is not sufficient information to confirm this. The channel has reduced in width by an average of approximately 10 m, which is potentially due to mapping error rather than actual change.

Chainage 46 to 40 (North west to north east Kempsey)

The planiform changes suggest there is some accumulation of sediment on the inside of the bend, with some minor erosion on the outside of the bend, particularly between Ch 43 and 42 (near the Kempsey railway bridge). A shoal occurs on the inside of the bend. Much of the sediment accumulation appears to have occurred between 1956 and 2003. The majority of this section of river is bounded by soil landscapes of only moderate erosion potential, reducing the risk of bank instability. However, moderate erosion was recorded between Ch 44 and 43 during the 2005 survey by Cohen. Whilst this is not reflected in the planiform changes, it is possible that the river may begin to shift in this area. This could have significant consequences if the erosion extends further downstream as it could impact on adjacent properties in South Kempsey.

There has been some change in the vicinity of Ch 40, with the development of an island between the early 1900's and 1956 and the expansion of this island post 1956 to become rejoined to the bank. The existing bathymetry shows this area to be much shallower than upstream at Ch 41 and the parish maps show the river to be wider, encouraging sediment deposition. The soil landscape maps indicate that the right bank in this vicinity is likely to be highly erodible. It is therefore possible that a section of the bank collapsed, and began to form an island which then became rejoined to the bank. However, it is also possible that the island did exist in the early 1900's, but was omitted from the parish maps by the surveyor.

Chainage 40 to 27 (north eastern Kempsey to upstream of Gladstone)

This section shows significant change between the parish maps and the 1956 and 2003 planiforms, although there is minimal change between 1956 and 2003. Between Kempsey and Frederickton (ch 40 to 35), the parish map suggests there has been significant accumulation of sediment up to 250m in width, with erosion on the outside of the bend. There has been an overall reduction in channel width. However, at least some of this change may be attributed to inaccurate surveying or error in geo-referencing. Comparing two overlapping parish maps, the location of the river is significantly different, as is the channel width. There are fewer geographical landmarks such as roads in this location, hence it may have been more difficult to draw the river accurately.

Between Ch 35 and 30, sediment accumulation occurs on the western bank. From 31 to 30, the 1956 aerials suggest accumulation at a relatively constant rate between the early 1900's and 2003. This sediment is shown as a different soil landscape (Belgrave Falls) compared with the surrounding area (Austral Eden), which also indicates that deposition has occurred.

The meander between Ch 30 and 28 has shifted northward, increasing its radius of curvature and sinuosity. Whilst this section of river is within a soil landscape with a moderate erosion risk (Austral Eden), there is an increased risk of erosion on the outside of bends, particularly those devoid of vegetation. The soil landscape on the inside of the bend (Belgrave Falls) differs from the surrounding areas, suggesting deposition has occurred. There is currently only minor erosion occurring on the inside of the bend.

Extensive rock stabilisation works have been carried out along the majority of the river between ch40 and 27. The planiform changes coincide with the location of rock works, with stabilised areas showing minimal change between 1956 and 2003. However, the opposite banks have continued to accumulate sediment and progress into the river. This appears to have resulted in some narrowing of the river, although some of this change may be attributable to map error.

Chainage 27 to 24 (Gladstone and Smithtown)

Minimal change has occurred in this location between the early 1900's and 2003. The majority of this section has been stabilised with rock revetment. A small section of the right bank between areas of rock revetment has moderate bank erosion.

Chainage 24 to 17 (Smithtown to downstream of Kinchela)

There has been substantial change to Fattorini Island at Ch 23 since the early 1900's. The parish maps depict the Island as two smaller islands that appear to have joined to form a single larger island by 1956. The riverbed is shallow in this area and there is evidence of bed aggradation upstream of the island (Cohen, 2005). Since 1956 erosion has occurred at the southern and northern tips and on the north eastern and south eastern side. At the tips, shoaled areas are now present. Active erosion is still occurring along the eastern bank suggesting the island is still undergoing a period of change. Rock revetment along the outside (left) bank and a section of the inside (right) bank of the main river restricts erosion in these areas making erosion of Fattorini Island more likely (Cohen, 2005). The most severe erosion has been recorded along the north eastern bank of the Island. The planiform changes also suggest that the river extended further to the east, with deposition occurring between the early 1900's and 2003. The soil landscape maps show a different soil landscape in this area, which also suggests deposition has occurred.

Downstream of Fattorini Island the channel width in the vicinity of Ch 22 appears to have increased and shifted northward between the parish maps and 1956. The banks have remained relatively stable between 1956 and 2003, most likely due to the presence of rock revetment on the left bank and a short section on the right bank. Alluvial deposits shown in the soil landscape also suggest the river may have shifted.

Significant deposition is shown to have occurred between the early 1900's and 1956 on the inside (left) bank at ch20, and between Ch 19-17 (Kinchela Bench). However, minimal changes have occurred between 1956 and 2003, with some erosion in the vicinity of Ch 18. There are also minimal changes shown between the parish maps and 1956 aerial on the outside bank between Ch 21 and 18, but significant change between Ch 18 and 17. Rock revetment along the entire length of this reach on the outside (right) bank has limited the change between 1956 and 2003. However, severe and moderate erosion has been recorded along the inside bank despite this being an area of deposition prior to 1956.

An investigation into the erosion of Kinchela Bench was conducted by Cohen (2005). According to Cohen there is a net gain of sediment in this reach, resulting in a widening of the channel to compensate for the loss of depth. As the outside bend can no longer erode due to bank stabilisation works the inside of the bend erodes. The soil within the inside bank consists of estuarine clays overlayed by sands and silts that is easily eroded by flood waters as well as wind and boat waves. This highlights an area where the site specific soil constituents play a critical role in determining erodibility, as the soil landscape itself does not differ from surrounding sections of river. Cohen (2005) found the greatest rate of erosion to have occurred between 1942 and 1956, following on from the construction of rock revetment on the outside bend post 1934 (the date of a Department of Lands report and recommendations regarding bank erosion). This section of river was also dredged between 1949 and 1950, which may have increased sediment deposition on the inside bank as a response to the sediment lost.

Chainage 17 to 10 (Downstream of Kinchela to upstream of Jerseyville)

This section of river is within the transitional zone defined by Cohen (2005). There is extensive rock revetment along both sides of the river restricting channel movement between 1956 and 2003. There has been some change between the early 1900's and 1956 along the majority of the reach, as well as some adjustment between 1956 and 2003 in areas without any rock stabilisation works. There appears to have been some increase in channel width since the early 1900's. This is likely to be a compensation for sediment deposition and hence shallowing of the river. Extensive shoaling has also occurred. For example, the channel is wider in the vicinity of the island between Ch 13 and 12 to compensate for the lack of channel capacity caused by the island and shallow depths. Dredging between 1949 and 1950 has occurred along this area to remove some of the shoaling (Telfer, 2005).

Chainage 10 to 4 (Upstream of Jerseyville to northern end of Pelican Island)

There has been significant change to the island at Jerseyville. Much of the upstream (southern) end has eroded and become shoals. The width has also increased between the early 1900's and 2003. Currently, both moderate and minor erosion have been observed on both sides of the island (Cohen, 2005). The RMA model results show the majority of flows pass through the main channel, with only small velocities on the eastern side of the island. During low tide shoaled areas become exposed blocking the eastern passage at the upstream end. This suggests that deposition is occurring on the eastern side of the island with erosion on the western side where higher velocity flows occur.

There has been some deposition on the right bank of the river at the southern end of the island between the early 1900's and 1956. However, there has been minimal change to the river bank in this location between 1956 and 2003 due to rock revetment along the majority of the bank. This is likely to cause increased erosion of the island.

Between Ch 8 and 4, there has been characteristic deposition on the inside of bends and erosion on the outside between the early 1900's and 1956. This is particularly significant between Ch 6 and 5 where there has been over 300 m movement of the right bank. However, the majority of the left bank and a section of the right bank were rock armoured in the 1930's restricting movement between 1956 and 2003 (Telfer, 2005). Despite this restriction, shoaling is present along the inside bend, which effectively reduces the width of the river and causes deepening in adjacent sections.

The majority of this section of river lies within the Maria River (mr) alluvial/deltaic soil landscape with depositions of Austral Eden (ae) and Toormina (tm) including on the inside banks where the river has moved. Whilst these landscapes are generally classed as having low to moderate erosion risk it has also been noted that some of the subsoils may have higher erodibility and the influence of power boats, vegetation loss and stream flows can result in erosion. While there is currently no observed erosion or significant change between 1956 and 2003 along the inside of the bend between Ch 7 and 4 it is possible that some movement may have occurred given the rock revetment along the surrounding banks.

Estuary Mouth and Macleay Arm

The estuary mouth has undergone substantial changes since European settlement in 1835, primarily due to the effects of significant floods and human actions including excavation, dredging and other channel works. In addition to the immediate impacts caused by these activities, the river has undergone further changes to adjust to the new entrance conditions.

The Macleay entrance was near Grassy Head when observed by the explorer Clement Hodgkinson in the 1830's and 40's. The river was relatively straight with an average width of 400m and some shoaling near Shark and Pelican Islands (Hodgkinson, 1944, cited in Telfer, 2005). Similar conditions were depicted in the drawings of Sir John Coode's Report of 1890, as shown in Figure 22 and Figure 23. Howard (1890) indicates that the entrance at this location had been fairly stable, although there had been intermittent breakouts further south toward South West Rocks. One of these was South West Rocks Creek, which was connected to the main river and intermittently open to the ocean, although shoaling at the upstream end had already been observed. Howard also suggests that Spencers Creek had been directly connected to the eastern arm of the river adjacent to Shark Island, prior to the 1860's. However, there is no reference to this in Telfer's (2005) account of Hodgkinson's 1844 report.

The long sand spit to the east of the river is likely to have increased over time due to the process of longshore drift, with sand migrating northwards and hence also moving the river entrance further north. Erosion on the outside bend of the river next to the sand spit can narrow the width of the spit making it vulnerable to river breakouts during floods, as shown in Diagram 6. Once the river has formed a new entrance, the sand spit rejoins the northern beach, resulting in the formation of a river arm.

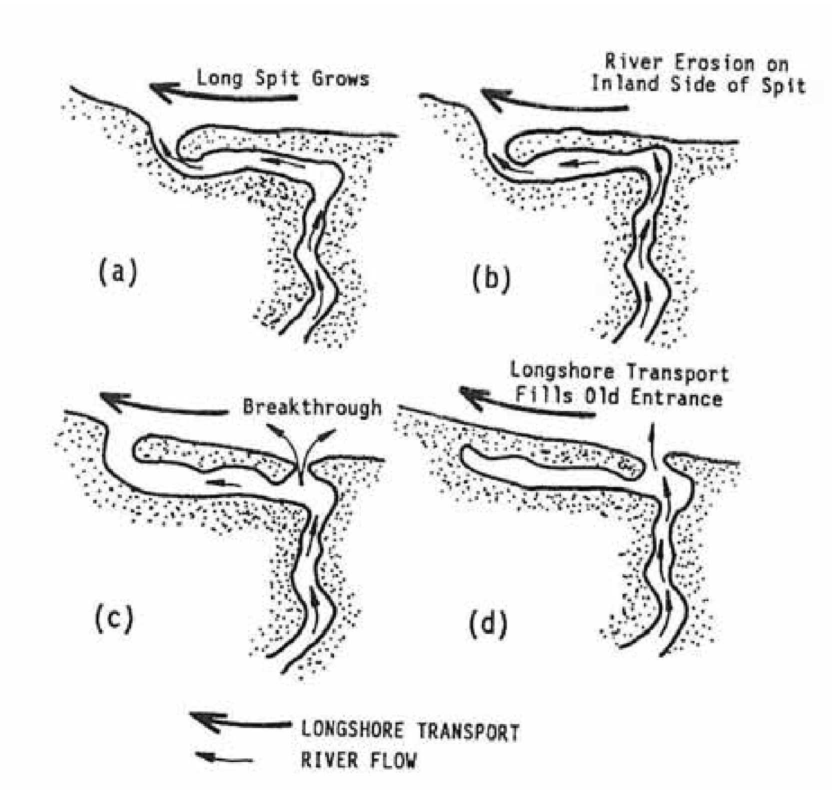

Diagram 6. Spit development and entrance breakthrough (source: NSW Government, 1990)

A major flood in 1893 broke through to the ocean north of South West Rocks. By 1901 this new entrance had been formalised by extensive channel excavations by Public Works and the closing of the original entrance, although it is not clear whether closing of the entrance referred to physical closing or closing for shipping movement. The parish maps of the early 1900's show the river to still enter the ocean south of Grassy Head, as well as at South West Rocks, yet there is no mention of the entrance remaining open in the historical description by Telfer (2005).

The parish maps show the Macleay Arm did not changed significantly between the Coode drawings of 1890 and the early 1900's, although the accuracy of both is unknown. The Arm was relatively straight and is shown further towards the east with a narrow strip of land separating it from the ocean. Near the entrance, the river curved toward the west, with a sand spit to the south of the entrance. A number of flood runners appear along the western side of the river, as well as a small island south of the entrance.

To the north of Fisherman's Island at the southern end of Shark Island the river appears to have moved westward since the early 1900's, with erosion of the outside bank and deposition along the inside bank. There has also been some additional deposition along the inside bank between 1956 and 2003. The parish maps show three islands near the entrance to Clybucca, whereas the 1956 and 2003 maps show four islands. North to south these are Muzzers Island, Snake Island, Whisky Island and Little Shark Island. The two southern islands shown in the parish maps are significantly different in size and shape from the current islands, whilst Muzzers Island shows less change in overall shape. Muzzers Island appears to have significantly decreased in size between the parish maps and 1956 and increased slightly on the western bank between 1956 and 2003.

What is now Snake Island and Whisky Island used to be a single island, long and narrow in shape except for at the southern end. Little Shark Island has significantly increased in size since the parish maps and has also extended further south between 1956 and 2003. The extensive shoaling in the area suggests that this was a depositional area for the major entrance channel dredging that continued until the 1940's. The deposition is likely to accompanied by erosion of the banks or bed to maintain the conveyance of the channel. The left bank to the south of Clybucca Creek has already eroded between 1956 and 2003.

The island to the north west of the entrance has also significantly increased in size between the early 1900's and 2003. To compensate for this increase, the outside banks of the channel have eroded in the vicinity of the island. However, further north, the channel has contracted, which is likely to be an adjustment in response to the reduced flow along the Macleay Arm after the movement of the entrance to South West Rocks.

The parish maps show South West Rocks Creek connected to the Macleay River near Ch 1. The creek is in a significantly different location compared to the location in 1956 and 2003, being further north and much wider. The parish maps do not show sufficient detail to determine the creek's shape near the ocean and it is unclear whether it was connected to the ocean at the time. Given the low topography of the surrounding swamps it is possible that the creek may form new paths during major floods, although some mapping error may also have occurred. By 1956 the creek had become separated from the Macleay River and appears to have been connected to the ocean. There does not appear to have been a significant change in planiform between 1956 and 2003, although the river location is difficult to determine from the 1956 aerial which is highly pixilated and very dark. The low relief also makes it difficult to determine the location of the top of bank in both the 1956 and 2003 aerials as the top of bank is highly dependent upon the water level in the creek at the time. Much of the creek is shoaled, with extensive shoaling just upstream of the entrance. This has been included within the river profile, however it is unknown at what water level it becomes covered.

The southern tip of Shark Island has been eroding since the early 1900's and between 1956 and 2003 a section has become separated from the main island to become a smaller island.

4.6. Coastal Change

Coastlines are continuously changing as a result of the sea, atmosphere, and coastal river processes. Waves can cause bank collapse and beach erosion, yet can also assist in beach formation through the deposition of offshore sediments. Along the NSW coastline, there is generally a net movement of sediment in a northerly direction due to dominant south-easterly wave conditions. Wind action can also play a significant role in the movement of sediment. Dominant south easterly winds in the Coffs Harbour area result in a general north westerly sand drift, although the magnitude of annual sand drift is predicted to be less than in other areas along the NSW coast (NSW Government, 1990).

Examination of the early 1900's parish maps and the 1956 and 2003 aerial photographs indicates that there has been a significant change to the Macleay coastline between the early 1900's and 2003. Figure 25 shows an outline of the approximate coastline over this period. Both the approximate location of the shoreline during low tide and the top of the beach have been shown. It should be noted that both of these are estimates as the tidal conditions at the time of the photos and drawings is unknown and the beach extent is dependent upon the amount of vegetation present.

Much of the observed change in shoreline can be attributed to construction of the training walls along the new entrance in 1897, which initially prevented the natural movement of sand northwards along the beach. This has resulted in an accumulation of sand down drift of the southern training wall and erosion of the beach to the north of the northern training wall.

In the early 1900's both Back Beach to the south of the entrance and the beach to the north were in line with one another. However, by 1956 approximately 220,000 m^3 of sand (assuming an approximate dune height of 3.5 m) had shifted from the southern end of Back Beach near Point Briner to the northern end of the beach south of the breakwall. Between the early 1900's and 1956, there was a significant loss of sand to the north of the breakwall, with the breakwall acting as a barrier to sand movement from further south. Within the accuracy of the Parish Map and the extent of the aerial photographs provided approximately 2,300,000 m^3 was lost over a distance of 3.2 km. On average, the shoreline retreated approximately 180 m.

Between 1956 and 2003 there was an additional accumulation of approximately 1,000,000 m^3 sand along Back Beach. However, the foredune became narrower due to the establishment of vegetation on the back dunes. To the north of the breakwall sand had accreted (by approximately 360,000 m^3), indicating that sand by-passing of the entrance was occurring. This sand movement across the entrance is also evident from the 2003 aerial photograph. Despite this more recent accumulation, there has been a net loss of approximately 4,500,000 m^3 to the north of the breakwall between the early 1900's and 2003.

4.7. Sediment Movement Summary

An examination of planiform changes between the early 1900's and 2003 indicate that the majority of Macleay River Estuary has not changed significantly over the last 100 years, suggesting it is relatively stable. The most significant changes have occurred in the lower estuary and along the coast, primarily the movement of the estuary mouth from Grassy Head to South West Rocks following a major flood in 1893. This has resulted in a westward shift and contraction in river width along the Macleay Arm as a result of infilling by aeolian sand from the beach dunes (and some dredged sand deposition). Along the NSW coastline, there is generally a net movement of sand in a northerly direction due to dominant south-easterly wave conditions. Localised wind conditions also suggest dominant south easterly winds, which contribute to the northerly movement of sand. The construction of breakwalls along the new entrance intercepted

FIGURE 25
COASTAL CHANGE

much of this northerly littoral zone sand movement, resulting in prograding of the coastline (seawards extension) to the south of the breakwalls and erosion/recession of the northern beach.

Extensive rock revetment along 66 km of river banks has restricted bank erosion and movement between 1956 and 2003. In areas that are free to adjust, the length and severity of the erosion is low when compared with similar nearby river estuaries. The erosion that is occurring appears mainly to be current initiated and then maintained by a combination of wind and boat waves. This is more likely to occur where the soils are highly erodible. The banks at Jerseyville, Kinchella, Fattorini Island and south west Kempsey are currently the most vulnerable to erosion.

Whilst rock revetment provides local bank stabilisation, it does not prevent the river from adjusting. By restricting river movement in an area of change, bed or bank erosion is likely to occur in surrounding unprotected areas. Whilst it is not possible to predict exactly where these changes will occur, or to what magnitude, it can be assumed that unprotected areas in close proximity to rocked areas will be affected. These changes are likely to be more pronounced in areas where there was significant movement prior to rock armouring.

It is not known how the river will continue to adjust to past changes. However, the most significant impacts are likely to be caused by major flooding, climate change, surrounding land practices and direct modifications to the river. Flooding can result in the formation of new channels and can cause major bank collapse. The majority of these changes are unpredictable, although exposed banks that are already vulnerable to erosion are more likely to be affected. Sea level rise combined with changed rainfall patterns have the potential to result in significant alterations to river processes, such as the tidal flux and the intensity and frequency of major flooding. Historical land practices have already resulted in extensive clearing of vegetation both on the floodplain and within the riparian corridor. This has the potential to increase the sediment load to the river as well as result in increased rates of bank erosion. Unless revegetation of the banks and the exclusion of cattle occurs, sedimentation and bank collapses are likely to continue.

5. WATER AND SEDIMENT QUALITY

Water and sediment quality has an impact on estuary health and can be affected by contaminants from both natural origins and human activities. When contaminants in the catchment are provided with a transport mechanism such as rainfall runoff, they can be washed into the estuary and become deposits on the river bed or become dissolved in the water column. Increased nutrients, faecal material and suspended solids from urban and rural runoff and sewerage system discharges are often the main contaminants in NSW estuaries. However, for the Macleay River Estuary, acid sulfate leachate resulting from the oxidation of pyrites (iron sulphide) in the soil is also an issue.

This chapter describes the existing water and sediment quality in the Macleay estuary and discusses the interactions between water and sediment quality and different estuarine processes. Due to the complexity and number of different interactions between estuarine processes, only those considered to be the most significant in terms of water and sediment quality were examined. These have been identified in consultation with Kempsey Shire Council and Southern Cross University and focus on issues which have not already been adequately addressed in previous studies.

The current study involved the collection and analysis of water and sediment samples and a review of previous studies. This chapter provides an overview of the following:

- existing water quality in the Macleay estuary and a comparison with historical data where available;
- an investigation into the impacts of septic tank effluent on water quality in the Macleay Arm;
- the derivation of a nutrient budget for the estuary;
- an investigation into the bioavailability of arsenic and antimony in sediments in the Estuary;
- a summary of acid sulfate soils; and
- a description of the process interactions.

5.1. Overview of Water Quality in the Macleay Estuary

Water quality in the Macleay Estuary is impacted by a number of different sources including diffuse runoff from the upper and lower catchment, urban runoff, and point-source discharges from wastewater treatment plants. Of particular concern are nutrients, metal and suspended sediment loads from the upper catchment, nutrient loads from urban runoff and wastewater treatment plants, and acidic and low dissolved oxygen runoff from the lower floodplain.

No spatially or temporally consistent water quality monitoring program has been undertaken in the Macleay Estuary. However, there are a number of individual water quality data sets:

- Nitrate, phosphate and dissolved oxygen data collected in 1950 (Rochford, 1952);
- Nutrient, chlorophyll-a and physicochemical data collected in 1996 (Eyre, 2000); and
- Physico-chemical data (tide level, conductivity, temperature, dissolved oxygen, pH) collected by Kempsey Shire Council from 1997 to 2005 under a number of different programs.

The Rochford (1952) and Eyre (2000) data provide a useful baseline against which change can be considered. However, the Eyre (2000) data is over 10 years old and did not include the tidal section of the Macleay River or the Macleay Arm, which are impacted by urban runoff and point source discharges. Kempsey Shire Council's water quality data mostly deals with runoff from acid sulfate soils, which is not a focus of this study as it has been dealt with under a number of other projects including the Hotspots program. A summary of the potential sources and impacts of acid sulfate runoff has been provided in Section 5.6.

Due to the lack of data in the tidal river and Macleay Arm it was decided to undertake an additional 12 months of water quality sampling from September 2006 to August 2007. This recent (2006/2007) water quality data along with the Rochford (1952) and Eyre (2000) data were compiled, synthesized and interpreted to:

(1) describe the salinity structure, hydrography and flushing characteristics of the Macleay Estuary,
(2) describe temporal and spatial variations in dissolved oxygen, pH and nutrient and chlorophyll concentrations, including the effect of flow events on water quality of the Macleay Estuary,
(3) compare water quality changes in the Macleay Estuary from 1950 to present, and
(4) compare water quality in the Macleay Estuary with ANZECC (2000) Guidelines.

5.1.1. Methodology

Water quality data from 1996 (Eyre, 2000) and 1950 (Rochford, 1952) were reviewed and an additional 12 months of water quality sampling was undertaken from September 2006 to August 2007. To allow a realistic comparison of water quality in the Macleay Estuary over time only samples collected under similar flows, collected during a similar time after a similar sized flow event, and at a similar time of year were compared (Eyre, 1997). Adopting these criteria allowed for comparison of one set of dry season and one set of wet season data. Identical methods were used for the Eyre (2000) and recent (2006/2007) data collection programs. The Eyre (2000) and Rochford (1952) methods have previously been compared and the data are comparable if small corrections are made (Eyre, 1997). Water quality data was compared with the ANZECC (2000) guidelines, which are summarised in the following table.

Table 30 Summary of ANZECC Water Quality Guidelines

Parameter	Estuary ($\mu g\ L^{-1}$)	Source
Total Nitrogen (TN)	100-750	ANZECC/ ARMCANZ, 2000
Ammonium (NH_4^+)	15	ANZECC/ ARMCANZ, 2000
Nitrate (NO_3^-)	15	ANZECC/ARMCANZ, 2000
Total Phosphorus (TP)	10-100	ANZECC/ ARMCANZ, 2000
Chlorophyll-a	2-10	ANZECC/ARMCANZ, 2000
Dissolved Oxygen	>80% saturation	ANZECC/ARMCANZ, 2000

The following provides a summary of the 2006/2007 sampling methodology and data analysis procedure adopted.

Estuarine Sampling Program

Twelve monthly sampling runs were undertaken from September 2006 to August 2007 along both the Macleay Arm and main arm of the Macleay Estuary. Sampling runs in the Macleay Arm were usually completed within about 1 hour and were timed to start at the seawater end member (saline end where the estuary joins the ocean) about 1 hour before high tide, and progress upstream. Sampling runs in the main river were usually completed within about 3 to 4 hours and were timed to start at the seawater end member at about high tide and progress upstream with the high tide crest to the freshwater end member (freshwater end). In the Macleay Arm, 5 samples were collected at geographical locations (Figure 26). In the Macleay River, samples were collected at different salinity concentrations, equivalent to intervals of approximately 2 to 3 on the Practical Salinity Scale, from seawater to freshwater along the axial salinity gradient of the estuary. Additional samples were also collected at geographical locations in the tidal river between Smithtown and the Kempsey railway bridge when saltwater did not intrude this far (Figure 26).

Surface samples (top 30 cm) were collected using an acid washed and sample rinsed bottle (being careful not to collect the surface scum) immediately filtered through 0.45 µm cellulose acetate membrane filters (Sartorius) into acid-washed and sample-rinsed polyethylene vials. At each sample location 500 to 2000 ml of water (depending of suspended sediment load) was filtered through glass fibre filters for chlorophyll analysis, and 500 ml of water was collected for suspended sediment analysis. Each filter was placed into an acid-washed 10 ml polyethylene vial. An unfiltered sample was collected in an acid-washed and sample-rinsed polyethylene vial for total nutrient analysis. All nutrient and chlorophyll samples were frozen immediately in the dark on dry ice. All analytical procedures and errors are given in Eyre (2000).


FIGURE 26
WATER AND SEDIMENT SAMPLE LOCATIONS
MA-5
MSG-2
MA-4
MSG-1
MA-3
MSG-3
MSG-4
MA-2
MSG-5
MSG-6
MA-1
SC-3
SC-4
SC-2
MR-1
SC-1
MR-2
MR-3
Legend
MA Macleay Arm Geographical Site
MSG Seagrass Site
MR Tidal River Geographical Site
SC Sediment Contaminant Site

Physico-chemical parameters (salinity/ conductivity, DO, Temperature, Turbidity) were measured in-situ at the point of sampling using a Hydrolab multiprobe. Salinity profiles were also undertaken at each sample location. Conductivity was calibrated against 0.005, 0.05, and 0.5 M standard potassium chloride solutions. pH was calibrated with standard buffer solutions at pH 4 and pH 7. Dissolved oxygen was calibrated against a zero oxygen solution (sodium sulfide) and an air saturated beaker of water checked with a Winkler Titration. The Hydrolab calibration was checked at the end of each sampling run and never exceeded ±2.5% of the correct standard value for any of the calibrated parameters. As such, no corrections for instrument drift have been made.

Mixing Plots

Nutrient concentrations were plotted as a function of salinity (mixing plot) to determine if there is net gain or loss during mixing. If there is a net gain (internal/ external nutrient source) within the estuary the mixing plot will show an upward curvature above the actual mixing line, as shown in Diagram 7(B). Conversely, if there is a net loss (nutrient sink) within the estuary the mixing plot will show a downward curvature below the actual mixing line (Diagram 7(C)). Nutrients passing through the estuary conservatively (i.e. no net source or sink) will plot along the actual mixing line (Diagram 7(A)). The mixing plots were used in combination to interpret the major processes occurring in the estuary.

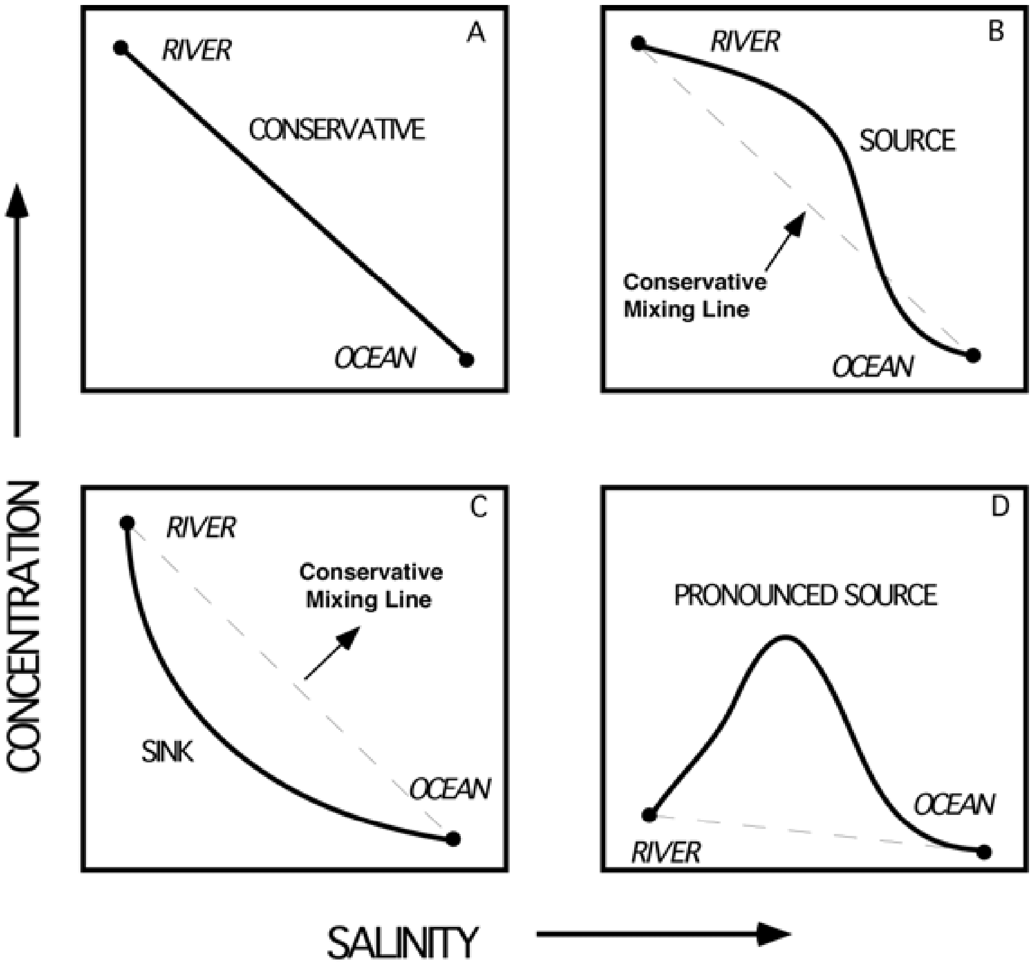

Diagram 7. Schematic representation of mixing plots showing the mixing of concentration-rich river water with concentration-poor seawater. (A) expected distribution of a substance that decreases in concentration as it moves through the estuary only due to dilution with concentration-poor seawater (i.e. it falls along the actual mixing line), (B) expected distribution of a substance if the estuary is acting as a source, (C) expected distribution of a substance if the estuary is acting as a sink, and (D) expected distribution of a substance if the estuary is acting as a pronounced source (i.e. where concentrations of the substance are higher in the estuary than the river and ocean).

Flushing Time Calculations

Flushing times were calculated using the fraction of freshwater method (Eyre 2000) using the formula:

$$T = V_f/Q$$

where T = Flushing time

V_f = Total volume of freshwater in a given section of the estuary

Q = Average river discharge over the period necessary to replace the freshwater in the estuary

$$V_f = fd$$

where f = Proportion of freshwater in a given section of the estuary

d = Volume of a given section of the estuary

$$f = (S_s - S) / S_s$$

where S_s = Seawater salinity

S = Salinity of a given section of the estuary

The estuary was divided into 23 boxes (section) by 24 echo sounding profiles (cross-section) at approximately 1000 to 2500 m intervals depending on the homogeneity of the estuarine section up to 40 km from the mouth (Eyre 2000). The average salinity (S) in each box (only along the salinity gradient that was inside the estuary mouth for each run) was calculated from vertical salinity profiles; lateral salinity variations were neglected. Box volumes (d) were calculated by multiplying the average of the two bounding cross-sections at high tide by the axial distance between them. The freshwater replacement time was calculated by summing daily discharges prior to the sampling date until V_f was filled. To determine the flushing time of the complete estuary, the flushing times of the individual sections were added.

5.1.2. Key Outcomes

The complete water quality data set is given in Appendix D. Only the data related to the key observations and discussion will be presented in the following sections.

Rainfall, River Discharge and Estuary Flushing Times

Yearly annual rainfall during the 2006/07 study period (1065 mm) was about 12% lower than the long-term yearly average between 1901 and 2007 (1205 mm). The lower annual rainfall during 2006/07 was due to six very dry months (Oct and Dec 2006 and Jan, April, May and July 2007), which received well below their average monthly rainfall, as shown in Diagram 8.

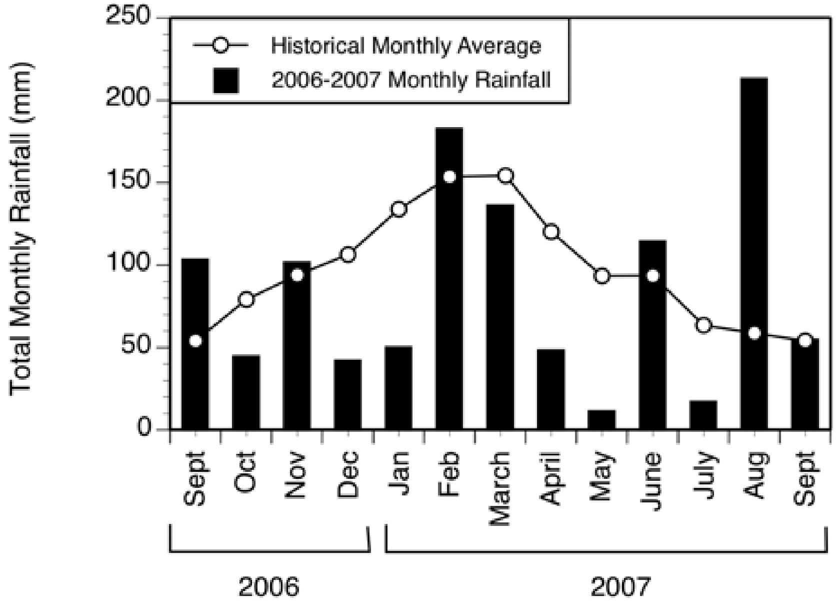

Diagram 8. Monthly rainfall during the 2006/2007 study period and the long term average monthly rainfall (1901 - 2007) for the study area.

With the exception of August 2007 (after the last sample run) which was very wet, rainfall during the remainder of the year was about average. The rain in late February, and early March 2007, resulted in a medium sized flow event in early March 2007 (28,000 ML d^{-1} at Turners Flat), as shown in Diagram 9. There were also smaller flow events in September and November 2006. The sampling program covered a range of river discharges including a sampling run just after the September 2006 and March 2007 flow events and sampling during a range of dry conditions (Diagram 9).

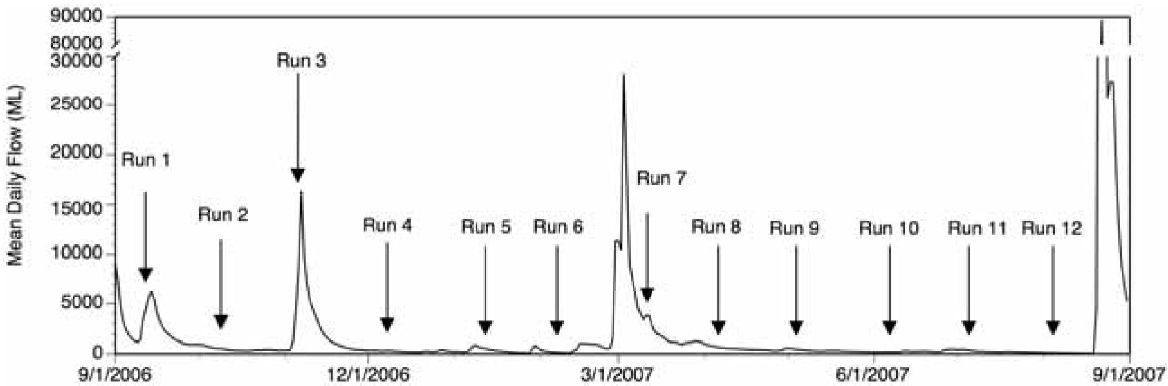

Diagram 9. Daily river discharge (Turners Flat) during the 2006/2007 study period and the timing of sampling runs.

Flushing times (

Figure 27) reflect the pattern of river discharges, ranging from about 3 days after the March 2007 flow event to about 57 days during run 11 to flush the complete estuary. A power curve was fitted to the 2006/07 data to develop an empirical relationship between the flushing time of the Macleay Estuary and the sum of the daily freshwater flow through the Turners Flat Gauging Station:

$$\text{Flushing Time (days)} = 1439 \times (\text{gauged flow (ML)} \times 1.07)^{-0.65}$$

Salinity Structure

Salinity profiles undertaken in the Macleay Estuary during 2006/07 show a full spectrum of mixing regimes from highly stratified to well mixed (Figure 28). During a number of sample runs during low flows saltwater (salinity >0.1) intruded upstream of the Kempsey railway bridge (our last sampling location) at about 40 km from the mouth. Following the March 2007 flow event the salt-freshwater interface was pushed down to 30 km from the mouth, but can be pushed out to sea during larger floods (Eyre, 2000). A power curve was fitted to the 2006/07 data to develop a empirical relationship between the distance the salt/freshwater interface intruded from the mouth of the Macleay Estuary and the sum of the daily freshwater flow through the Turners Flat Gauging Station:

$$\text{Intrusion Length (km)} = 60 \times (\text{gauged flow (ML)} \times 1.07)^{-0.08}$$

Physico-chemical

Oxygen concentrations were generally above the 80% saturation ANZECC (2000) guideline throughout most of the estuary for most runs, as shown in Figure 29. Run 7 (March 2007) immediately following the March 2007 flow event was an exception, when dissolved oxygen concentrations dropped below 70% saturation. The depressed dissolved oxygen concentrations were most likely associated with the breakdown of organic material (including NH_4 production by ammonification) mobilised by the flood waters and runoff from agricultural drains were oxygen is consumed via organic matter decomposition and oxidation of iron monosulphides (Eyre et al., 2006).

Oxygen concentrations were supersaturated in the upper estuary/tidal river during several of the runs, which reflected high rates of primary production by the dense macrophyte beds. These macrophyte beds consist of pond weeds (*Potamogeton spp*), water nymph (*Najas tenuifolia*), ribbon weed (*Vallisneria gigantea*), Clasped pondweed (*Potamogetonacea spp*), Pale Knotweed (*Polygonum lapathifolium*), Chara (*Chara spp*), dense waterweed (Egeria densa) and Elodea (Elodia canadensis) (MHL, 1997) *.* There were also supersaturated oxygen concentrations in the upper Macleay Arm during the summer runs reflecting high rates of seagrass production (runs 7 and 9) and phytoplankton production (run 6).

pH for all the sampling runs gave the expected distribution along the salinity gradient decreasing from seawater to freshwater (Figure 30). There was a slight depression of pH immediately following the March 2007 flow event. pH was elevated in the upper estuary/ tidal river during several of the runs reflecting high rates of primary production by the macrophyte beds which is

FIGURE 30

pH MIXING PLOTS SHOWING THE LOCATION OF THE GLADSTONE STP AND THE ANZECC (2000) GUIDELINES

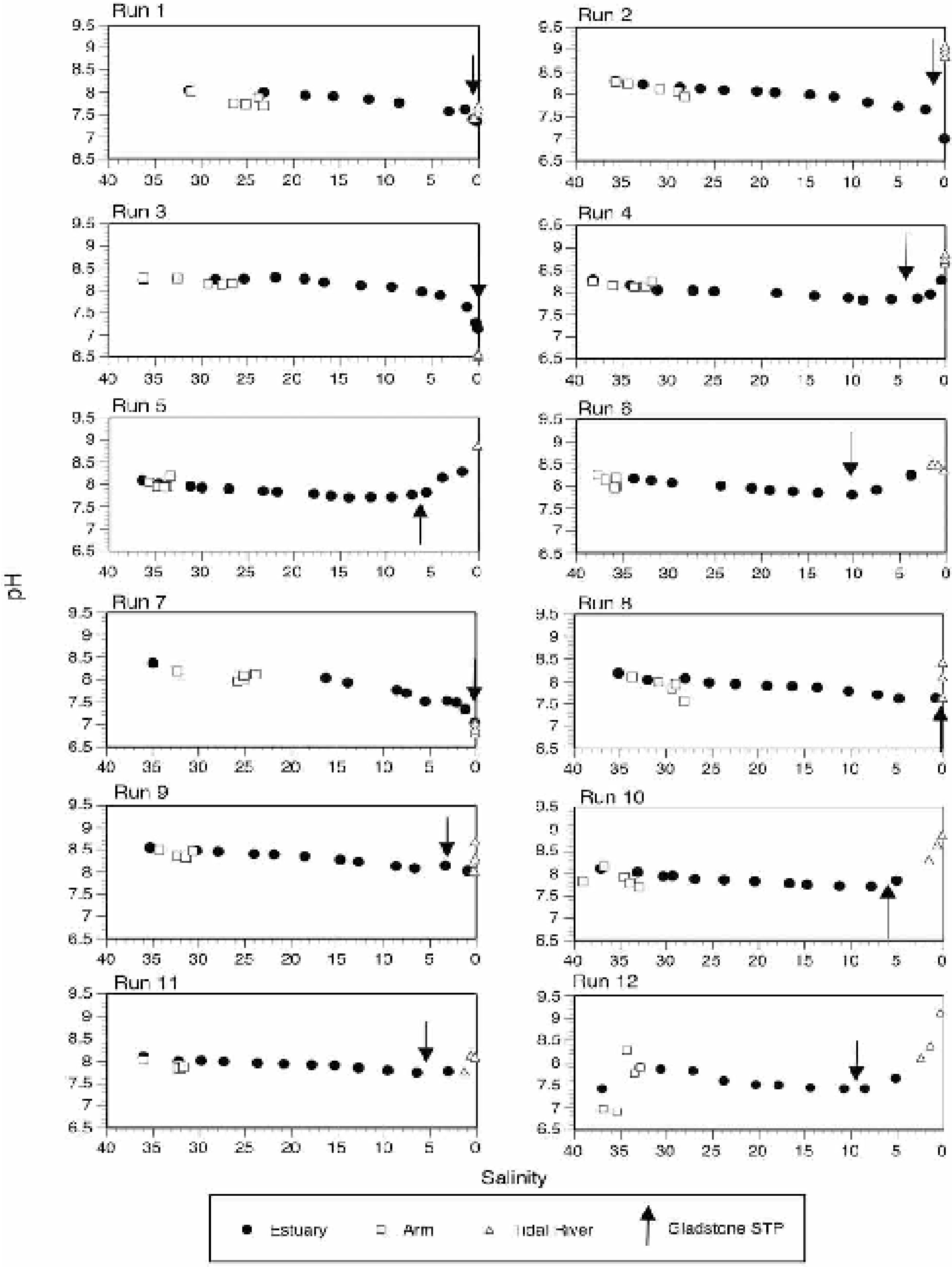

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FIGURE 28

HIGH TIDE LONGITUDINAL SALINITY DISTRIBUTION IN THE MACLEAY ESTUARY DURING EACH OF THE SAMPLING RUNS

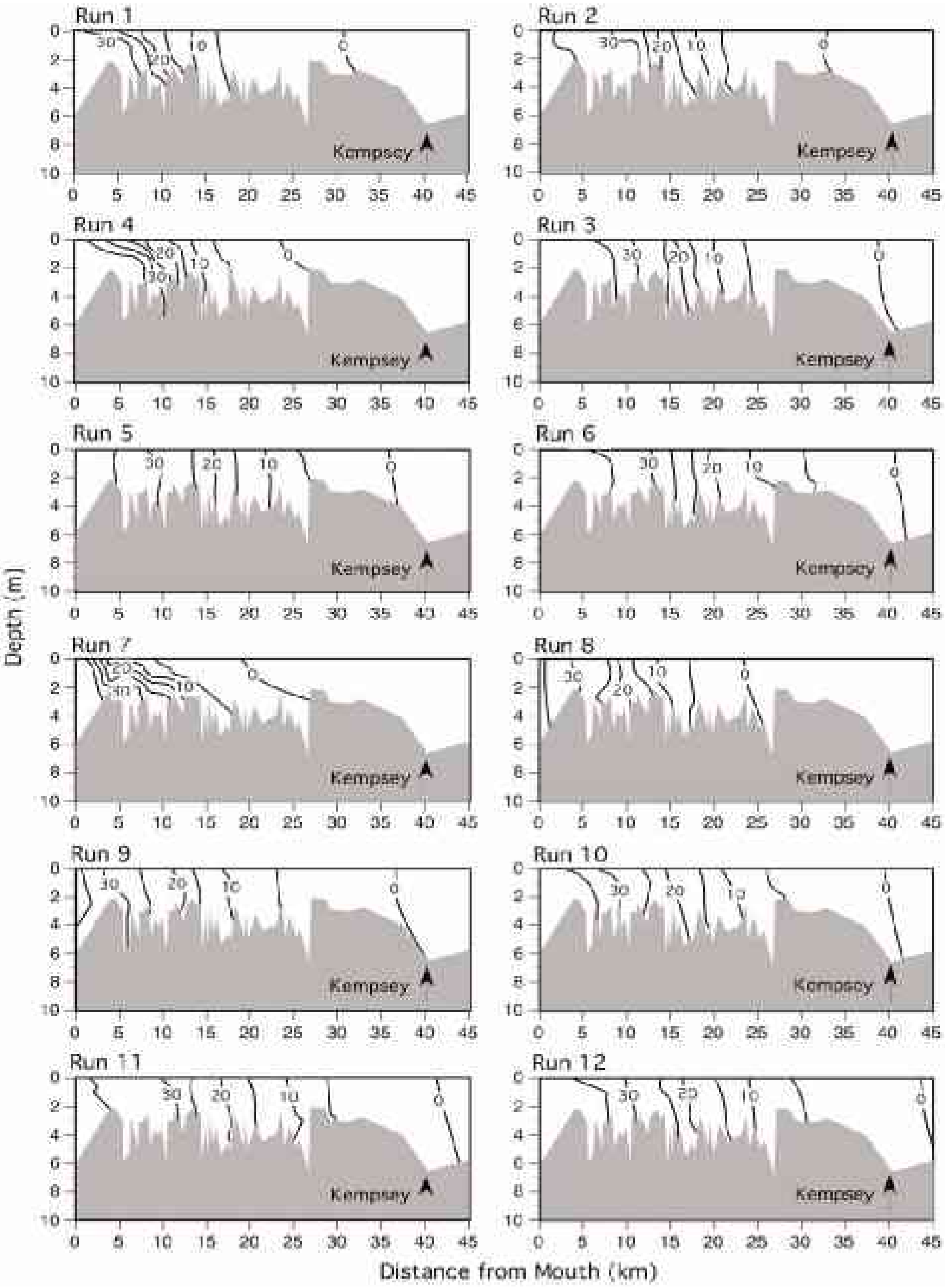

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FIGURE 29

DISSOLVED OXYGEN MIXING PLOTS SHOWING THE LOCATION OF THE GLADSTONE STP AND THE ANZECC (2000) GUIDELINES

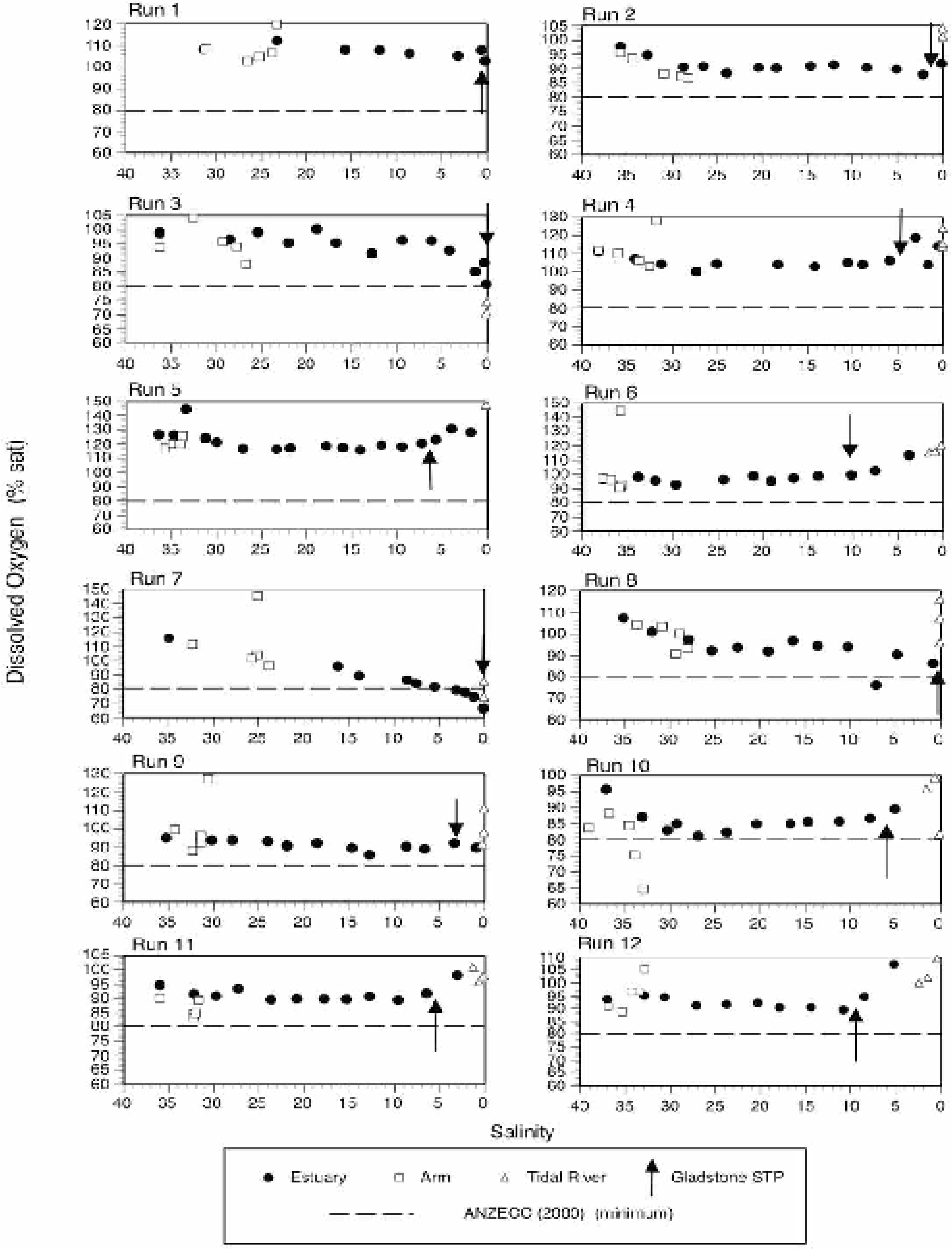

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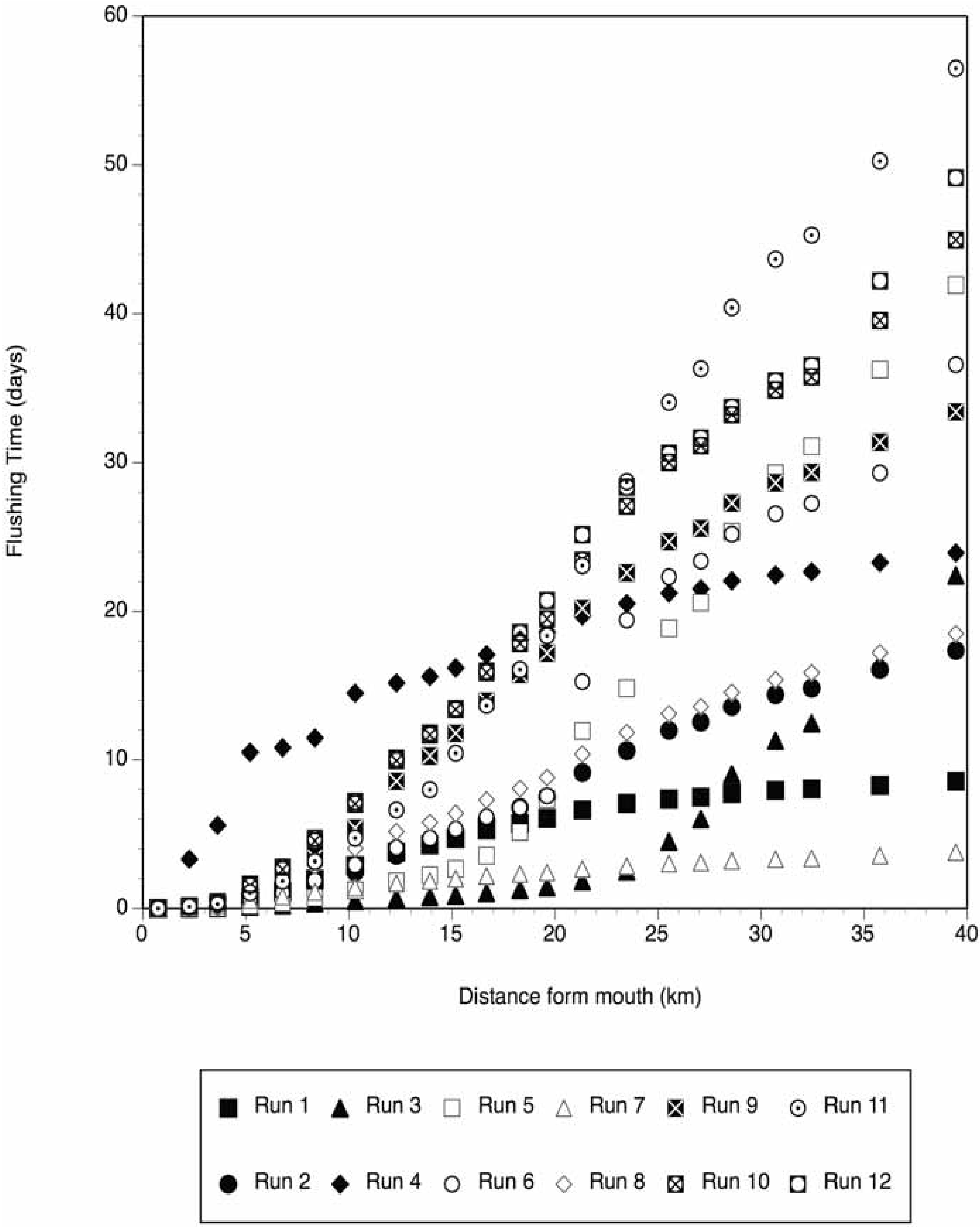
FIGURE 27

FLUSHING TIMES IN THE MACLEAY ESTUARY AS A FUNCTION OF DISTANCE FROM MOUTH DURING EACH OF THE SAMPLING RUNS



J:\Jobs\26017\PDFs\Figures\Figure27_FlushingTimes consistent with the supersaturated dissolved oxygen concentrations.

Total suspended sediment (TSS) concentrations were highest in the lower estuary and Macleay Arm due to wind resuspension, except during runs 7 and 8 following the March 2007 flow event (Figure 31). However, TSS concentrations following the flow event never exceeded TSS concentrations associated with wind resuspension. Secchi depths decreased from the seawater to the freshwater end member with the shallowest depths recorded during runs 7 and 8 following the March 2007 flow event (Figure 32).

Nutrients and Algal Biomass

Total nitrogen (TN) concentrations generally ranged between 250 and 350 µg L^{-1} throughout the estuary, which is well below the upper limit of the ANZECC (2000) guidelines (Figure 33). There was an increase in TN (mostly Dissolved Organic Nitrogen (DON)) in the lower Macleay Estuary and Macleay Arm during a number of runs. The exact source of the DON (shown in Figure 34) is unknown, but the highest concentrations were during summer (runs 4 and 5) suggesting release from seagrass beds, which can have high rates of benthic DON fluxes. There was a large increase in TN at the freshwater end member following the March 2007 flow event with concentrations up to 1200 µg L^{-1}; well above the ANZECC (2000) guidelines. Most of the TN in this diffuse runoff was delivered as dissolved organic nitrogen (DON) and nitrate (NO_3).

Nitrate (NO_3) and ammonium (NH_4) concentrations were below the ANZECC (2000) guidelines for many of the runs, except for NO_3 in the vicinity of the Gladstone wastewater discharge (Figure 35 and Figure 36). NO_3 and NH_4 concentrations also fell below the conservative mixing line for many of the runs reflecting phytoplankton uptake. During several of the runs NO_3 and NH_4 concentrations approached the detection limit suggesting phytoplankton growth in the Macleay Estuary can become nitrogen limited which is consistent with other northern NSW estuaries (Eyre, 2000).

Despite the largest wastewater nitrogen loads coming from the West and South Kempsey treatment plants that discharge into the upper estuary/tidal river, this load was not reflected in NO_3 or NH_4 concentrations suggesting these nutrients are rapidly assimilated by the macrophyte beds. The annual production by the macrophyte beds (822 t) would consume about 104 t of nitrogen (assuming a molar C:N of 10:1), which is more than the total wastewater load (18 t) from the West and South Kempsey and Frederickton sewage treatment plants. As such, wastewater nutrient loads may be helping maintain the growth of the macrophyte beds in the upper estuary/ tidal river, but these plants in turn are striping out the nutrients and making them unavailable to phytoplankton. It would be expected that algal biomass would be higher in the upper estuary/ tidal river without nutrient uptake by the macrophyte beds.

Total phosphorus (TP) concentrations generally ranged between 30 and 45 µg L^{-1} throughout the estuary, which is well below the upper limit of the ANZECC (2000) guidelines (Figure 37). During most of the dry runs phosphorus concentrations were higher at the seawater end member than the freshwater end member indicating an ocean source. Similar to TN, TP concentrations increased following the March 2007 flow event (run 7), but only just reached the upper limit of the ANZECC (2000) guidelines.

FIGURE31

TOTAL SUSPENDED SEDIMENT MIXING PLOTS SHOWING THE LOCATION OF THE GLADSTONE STP AND ANZECC (2000) GUIDELINES

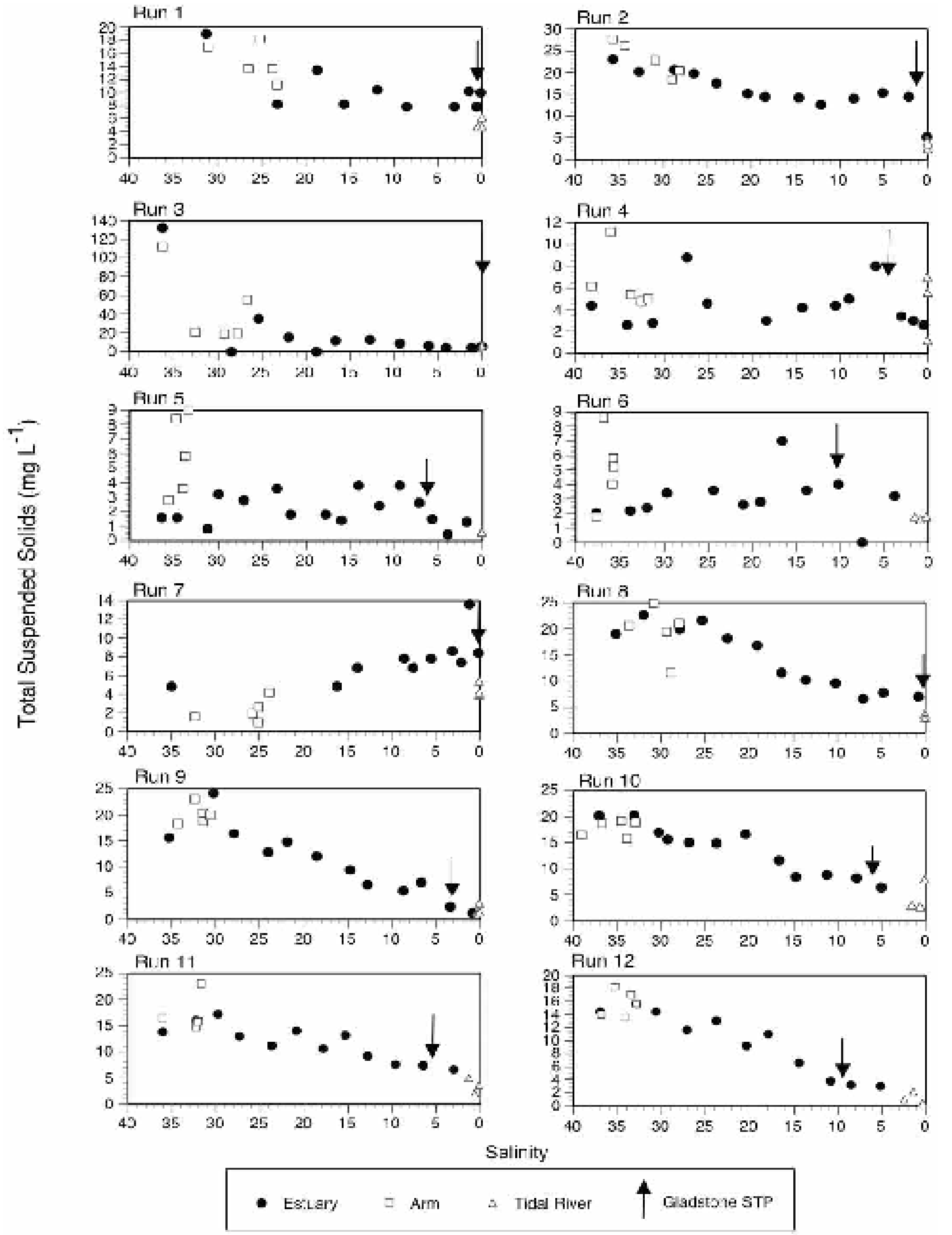


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FIGURE32

SECCHI DEPTH MIXING PLOTS SHOWING THE LOCATION OF THE GLADSTONE STP AND ANZECC (2000) GUIDELINES

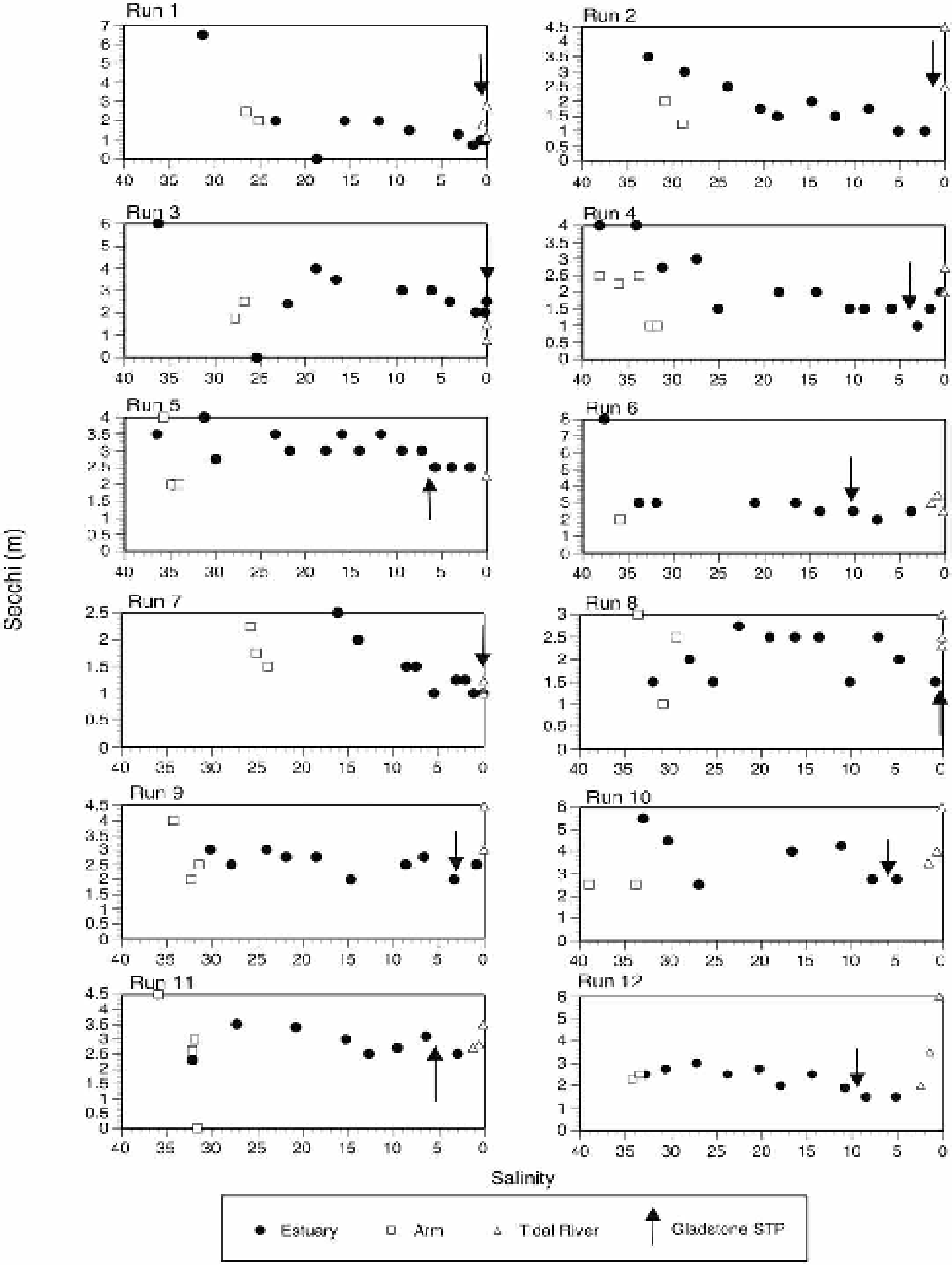

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FIGURE 33

TOTAL NITROGEN (NT) MIXING PLOTS SHOWING THE LOCATION OF THE GLADSTONE STP AND ANZECC (2000) GUIDELINES

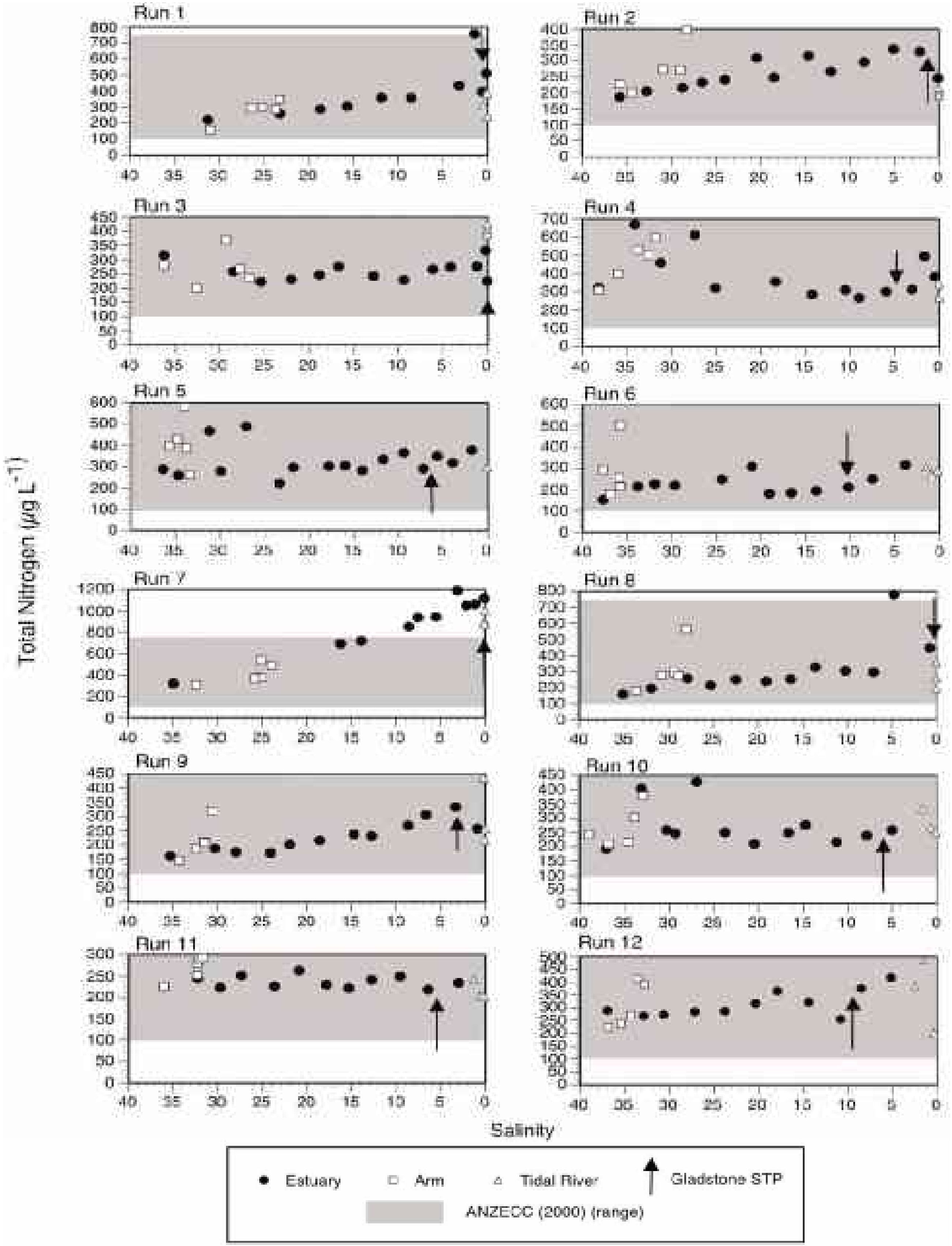

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FIGURE 34

DISSOLVED ORGANIC NITROGEN (DON) MIXING PLOTS SHOWING THE LOCATION OF THE GLADSTONE STP AND ANZECC (2000) GUIDELINES

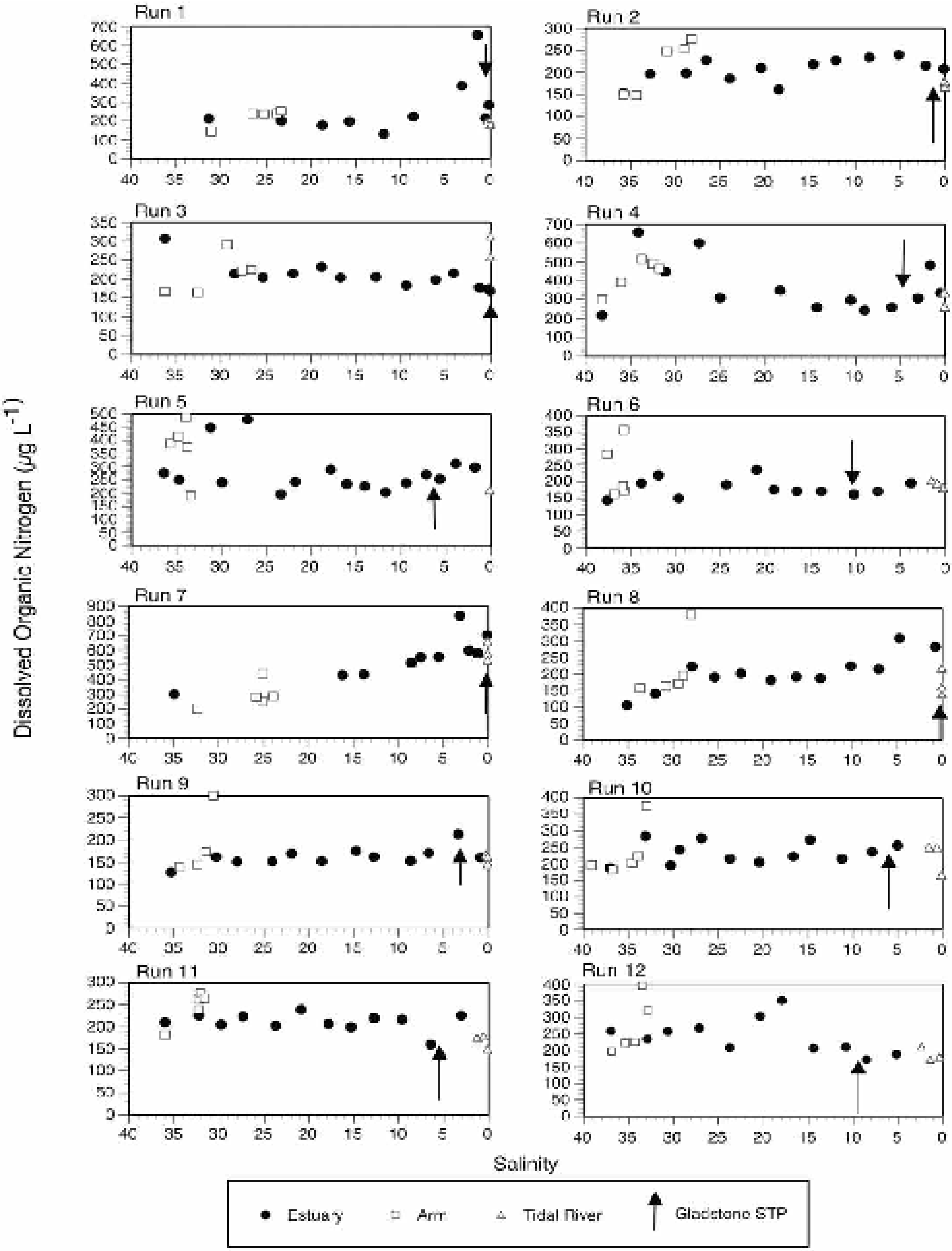

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FIGURE 35

NITRATE (NO_3)
MIXING PLOTS SHOWING THE LOCATION OF THE GLADSTONE STP AND ANZECC (2000) GUIDELINES

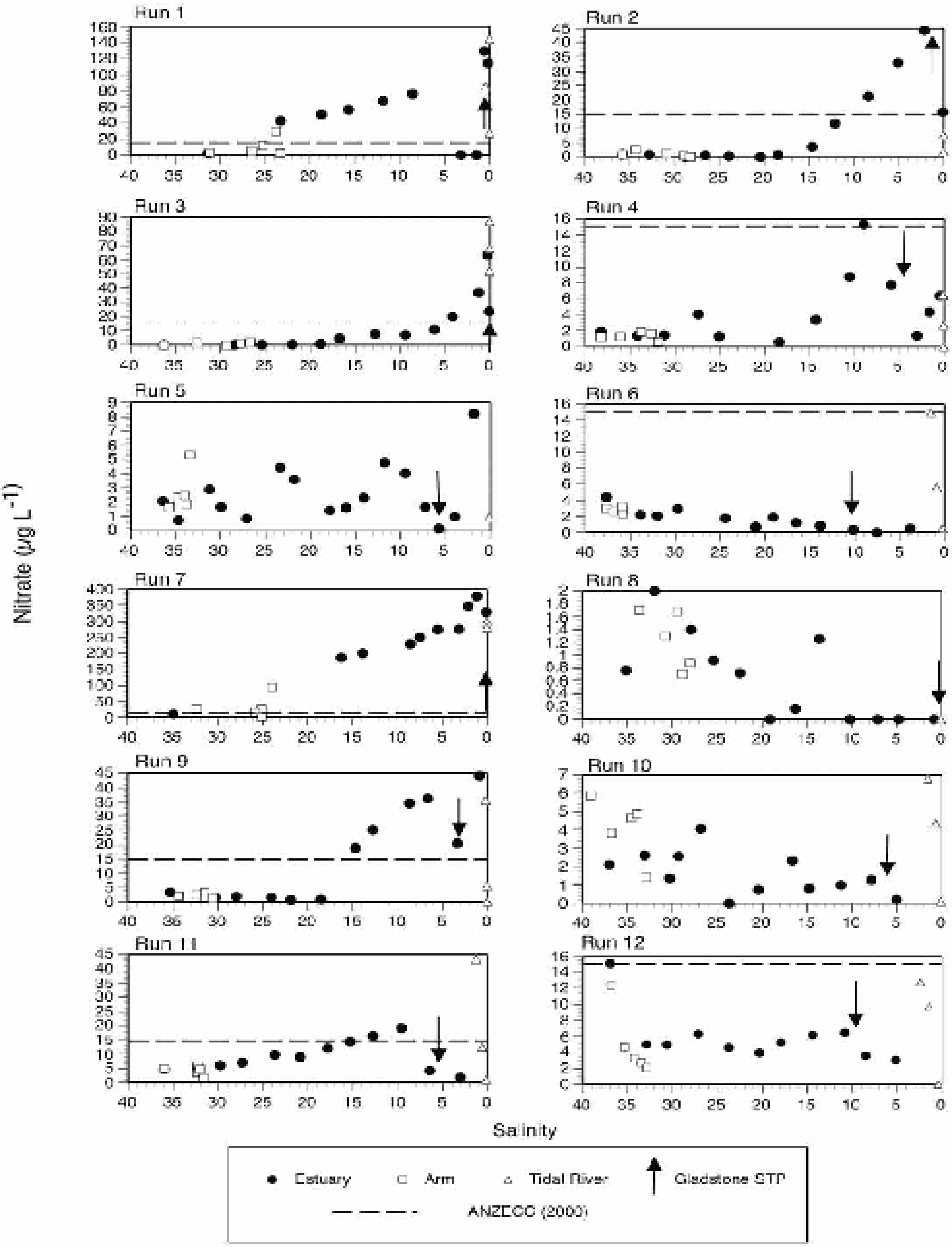

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FIGURE 36

AMMONIUM (NH_4)
MIXING PLOTS SHOWING THE LOCATION OF THE GLADSTONE STP AND ANZECC (2000) GUIDELINES

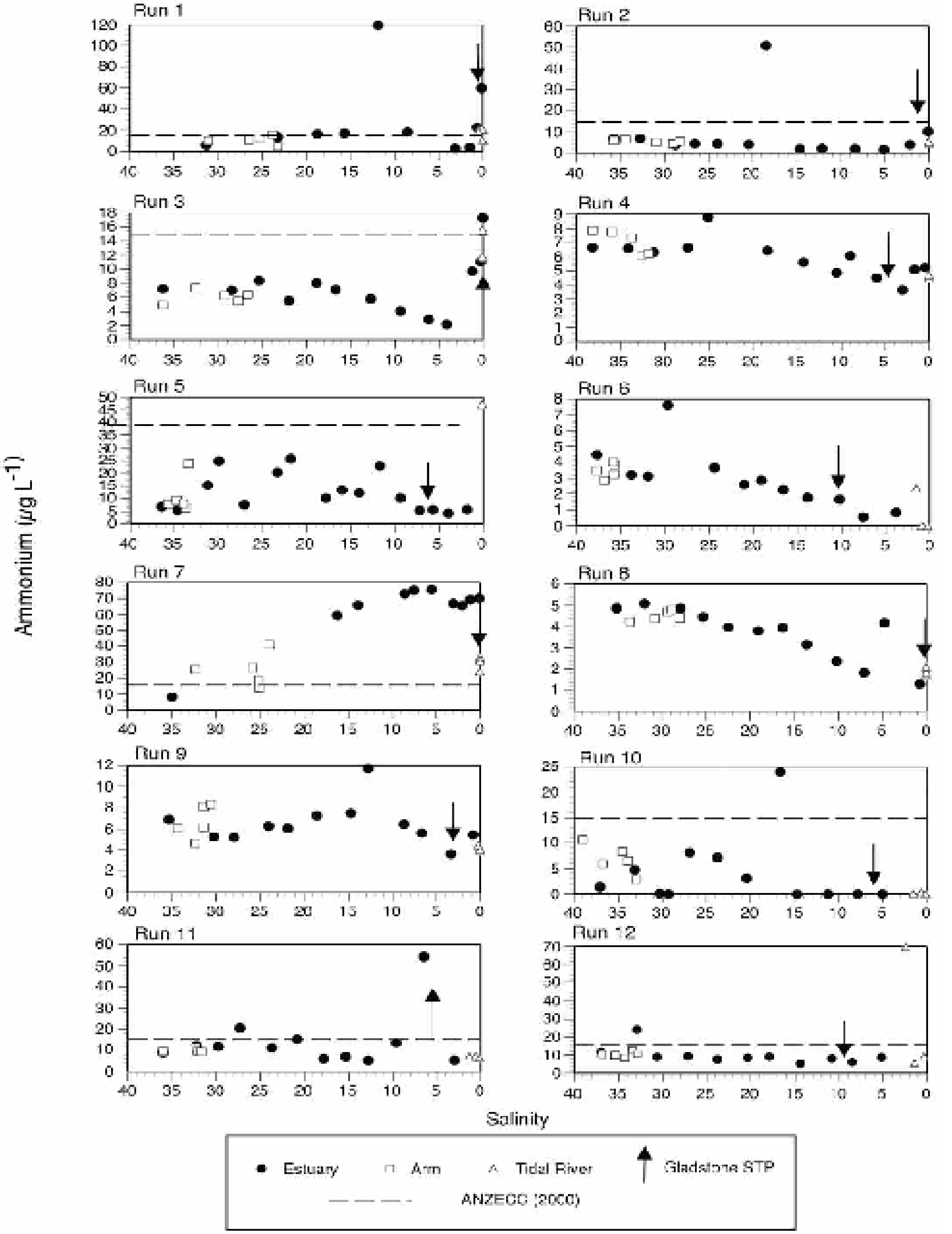

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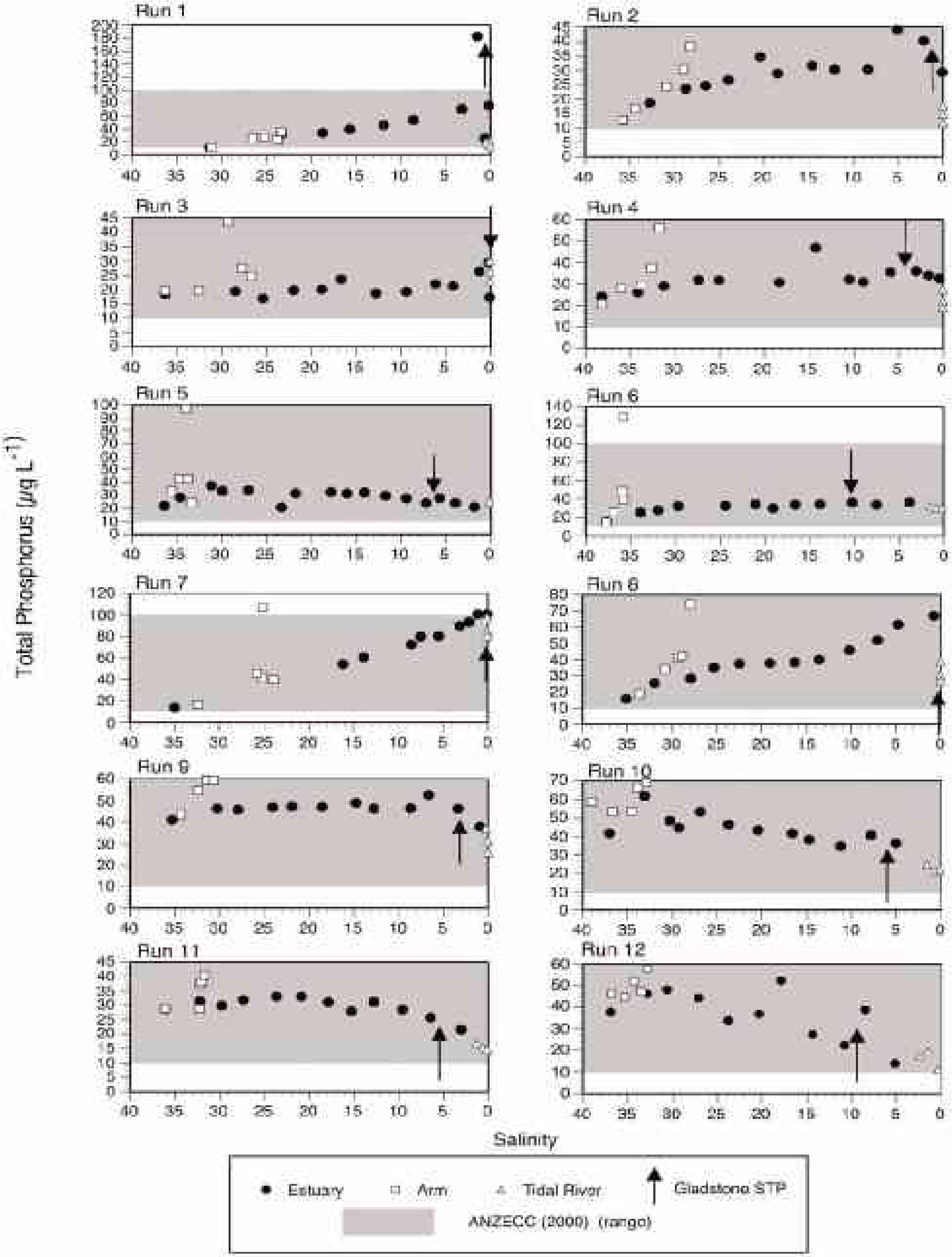
FIGURE 37

TOTAL PHOSPHORUS (TP)
MIXING PLOTS SHOWING THE LOCATION OF THE GLADSTONE STP AND ANZECC (2000) GUIDELINES



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There was some uptake of dissolved inorganic phosphorus (DIP) in the upper estuary associated with phytoplankton blooms downstream of the Gladstone wastewater discharge (Figure 38), but unlike NO_3 and NH_4, concentrations never approached the detection limit, reflecting the lack of phosphorus limitation. Phosphorus concentrations were also low in the upper estuary/tidal river, despite wastewater discharges from the West and South Kempsey treatment plants, again reflecting uptake by the macrophyte beds. Phosphorus concentrations were consistently higher in the Macleay Arm than the main estuary, particularly during the summer months adjacent to Grassy Head and Stuarts Point (runs 4, 5, 6). Possible sources of this phosphorus include discharge from septic tanks associated with peak holiday loadings and/or release from the sediments due to enhanced remineralisation during summer and resuspension. A similar increase in NO_3 and NH_4 was not seen probably due to rapid assimilation by phytoplankton, which is most likely nitrogen limited. Further investigation into the possible impact of septic tanks on water quality in the Macleay Arm is discussed in the following section (5.2).

Chlorophyll-a concentrations generally ranged between 1.0 and 2.5 µg L^{-1} throughout the estuary, which is around the lower limit of the ANZECC (2000) guidelines. A number of distinct patterns emerged in the algal biomass (chlorophyll-a) data (Figure 39). There was a consistent peak in chlorophyll-a concentrations downstream of the Gladstone wastewater discharge during the dry season reflecting a point-source input of nutrients. Chlorophyll-a concentrations were low immediately following the March 2007 flow event (i.e. runs 7 and 8), despite elevated nutrient concentrations, most likely due to rapid flushing (3 days) and some light limitation. The highest chlorophyll-a concentrations occurred during run 9 in the middle reaches of the estuary most likely due to a combination of elevated nutrient concentrations following the March 2007 flow event and increasing flushing times and improving light conditions (see Secchi) as the estuary recovered post-flood.

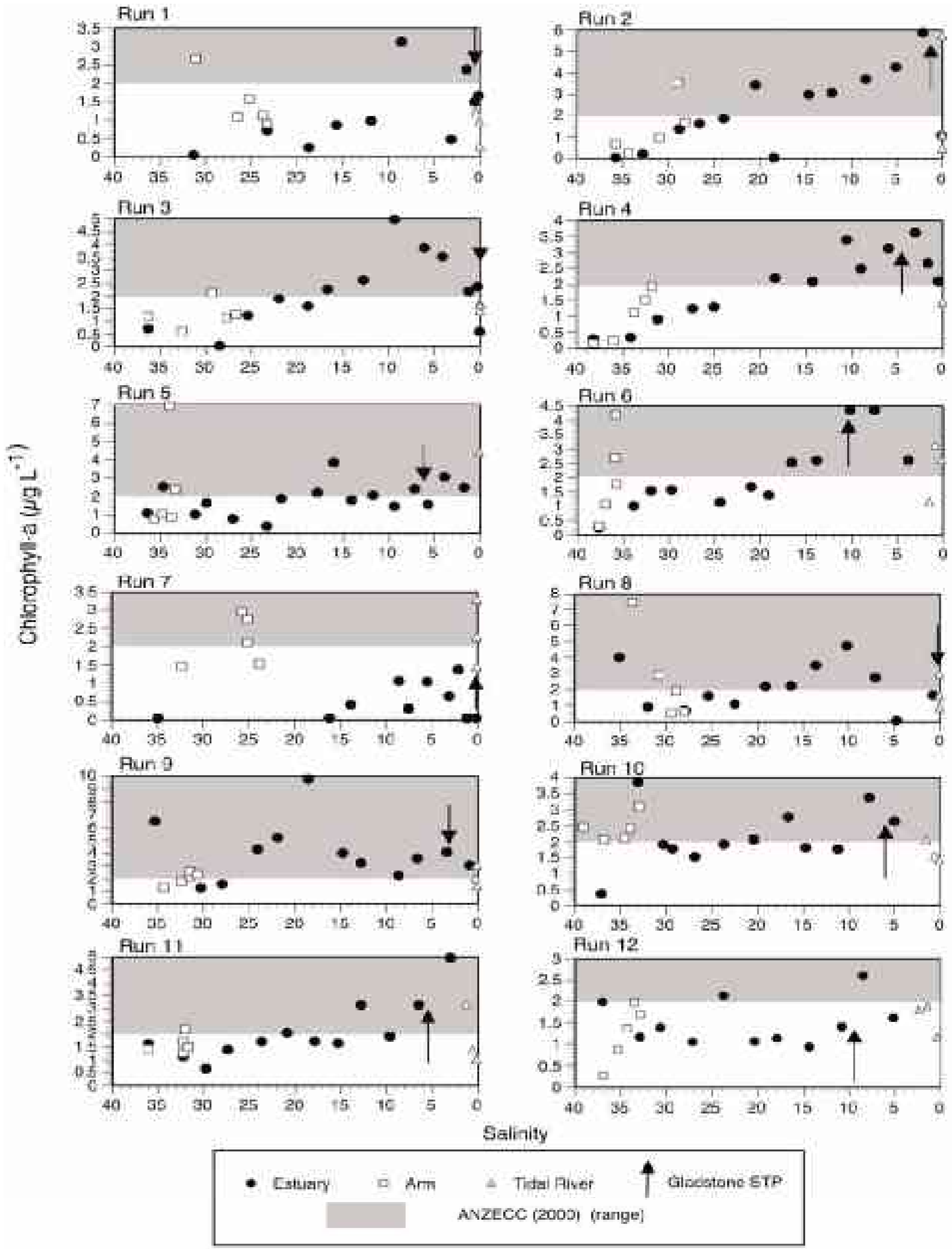
Chlorophyll-a concentrations were consistently low in the upper estuary/tidal river most likely due to nutrient uptake by the macophyte beds resulting in nutrient limitation of algal biomass. There was a phytoplankton bloom adjacent to Grassy Head in January and February 2007 (runs 5 and 6) probably driven by an increased load of nutrients and poor flushing in the upper Macleay Arm. Possible sources of nutrients includes discharge from septic tanks, which is also consistent with the slight enrichment of ^{15}N (a nitrogen isotope) in the seagrass adjacent to Grassy Head, and/or released from the sediments during summer due to enhanced remineralization. Further investigation of the factors controlling summer phytoplankton blooms (e.g. nutrient sources) in the Macleay Arm is recommended. This program should include water column measurements of nutrients, benthic fluxes measurements and stable isotope measurements.

Historical Comparison

Dry season dissolved oxygen concentrations throughout most of the estuary showed little difference between 1949, 1996 and 2007 (Figure 40). The only exception was the upper estuary/ tidal river where high rates of production by the macrophyte beds resulted in super-saturated dissolved oxygen concentrations in 2007. However, samples were only collected in

FIGURE 39

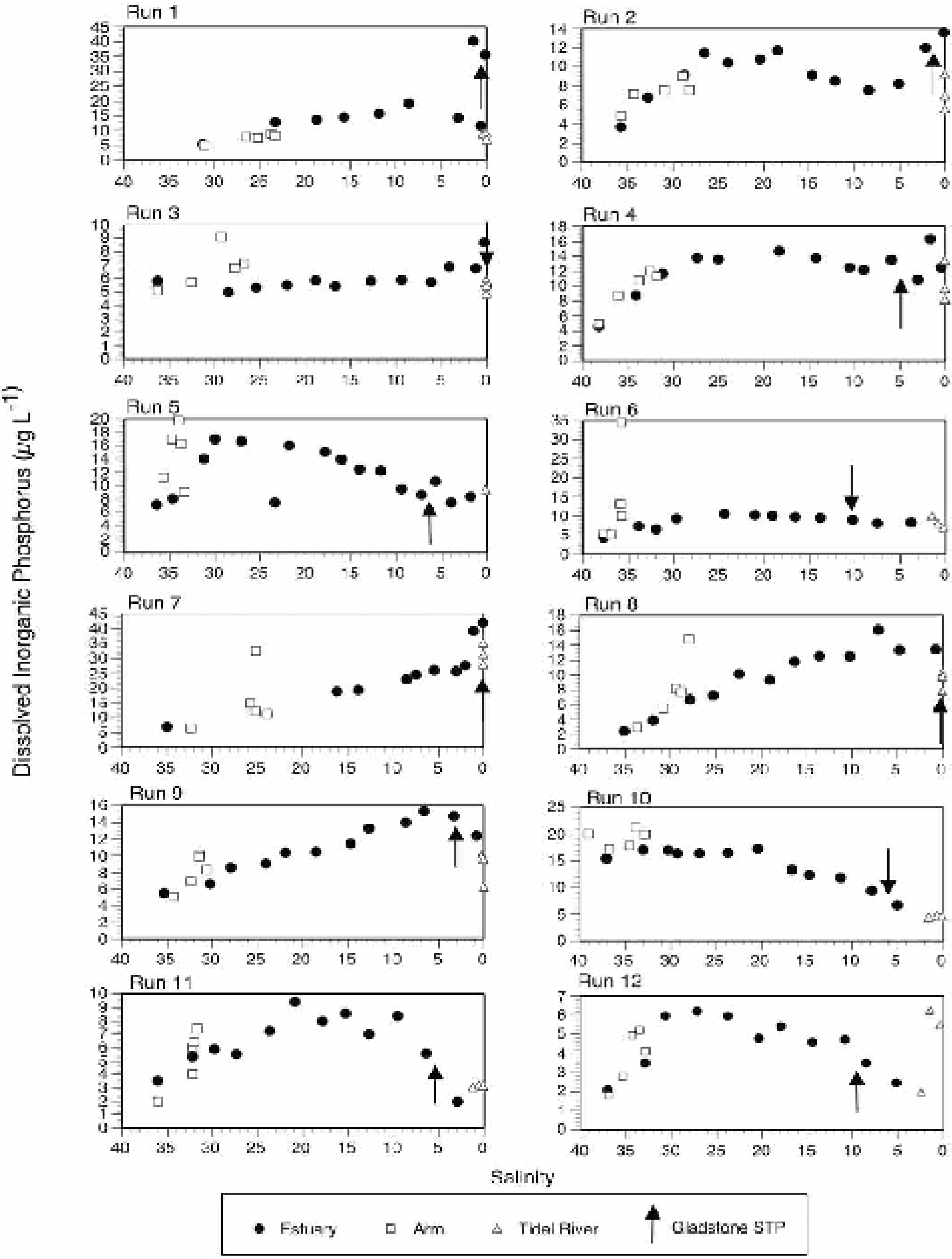
CHLOROPHYLL-A
MIXING PLOTS SHOWING THE LOCATION OF THE GLADSTONE STP AND ANZECC (2000) GUIDELINES



J:\Jobs\26017\PDFs\Figures\Figure39_Chlorophyll-a

FIGURE 38

DISSOLVED INORGANIC PHOSPHORUS (DIP) MIXING PLOTS SHOWING THE LOCATION OF THE GLADSTONE STP AND ANZECC (2000) GUIDELINES



J:\Jobs\26017\PDFs\Figures\Figure38_DissolvedInorganicPhosphorus the tidal river in 1949 for comparison. There was also little difference in dissolved oxygen concentrations in the wet season between 1949 and 2007 (Figure 41). Dissolved oxygen concentrations in the wet season in 1996 were much lower than in 1949 and 2007 suggesting a different source of floodwater that had been deoxygenated via organic matter decomposition and sulphide oxidation in agricultural areas (Eyre et al., 2006). A detailed flood analysis would be required to determine the source of this de-oxygenated water. Secchi depths in both the wet and dry seasons were also similar between 1996 and 2007. TSS concentrations in the wet season were similar between 1996 and 2007, but much higher in the dry season in 2007, probably due to wind resuspension.

TN concentrations in the dry season were slightly higher in 2007 than 1996, mostly due to higher DON concentrations (Figure 40). All the inorganic forms of nitrogen in the dry season showed similar concentrations between 1996 and 2007. TN, DON and NH_4 concentrations were also similar in the wet season between 1996 and 2007, but there were some differences in the other nitrogen fractions. NO_3 concentrations at the freshwater end member in the wet season were much higher in 2007 compared to 1996 and 1946, but particulate nitrogen (PN) concentrations were much lower. The higher NO_3 concentrations in 2007 most likely reflect an increase in diffuse nitrogen loading. NO_3 concentrations in the river at Turners Flat also increased over the last 10 years (Figure 42). It is unknown why the PN concentrations were so low in 2007 as TSS concentrations were similar.

TP concentrations in the dry season were much higher in 2007 compared to 1996 entirely due to higher dissolved organic phosphorus (DOP) concentrations (Figure 40). Dry season DIP concentrations, between 1949, 1996 and 2007, and particulate phosphorus (PP) concentrations between 1996 and 2007, were identical, reflecting the role internal geochemical water/ particle interactions play in controlling phosphate concentrations (Eyre, 1997). Wet season TP concentrations were slightly higher at the freshwater end member in 2007 compared to 1996 again due to high DOP concentrations. DIP and PP concentrations in the wet season in 1996 and 2007 were similar, but much higher than in 1949 at the freshwater end member. Similar to NO_3, the increased DIP concentrations at the freshwater end member most likely reflect an increase in diffuse phosphorus loading.

Despite a possible increase in the loading of NO_3 in the wet season, chlorophyll-a concentrations were similar between 1996 and 2007 (Figure 41). Dry season chlorophyll-a concentrations were higher in 2007 compared to 1996 in the mid reaches of the estuary, despite similar nitrogen and phosphorus concentrations and light conditions.

5.2. Impacts of Septic Tank Effluent on Water Quality in the Macleay Arm

Concern has been raised that septic tank effluent discharging into sandy soils from the townships of Stuart Point and Grassy Head may be impacting on water quality in the Macleay Arm. A preliminary survey of stable isotope signatures in seagrass was used to determine if septic tank effluent may be being biologically used along the Macleay Arm. The technique uses the ratio of ^{15}N to ^{14}N in dried plant material, compared to a worldwide standard, to determine the delta ^{15}N in the plant. As sewage effluent decomposes in the septic tank, bacteria have a

FIGURE 42

COMPARISON OF NITRATE (NO_3) CONCENTRATIONS VERSUS FLOW AT TURNERS FLAT BETWEEN 1996 AND 2007

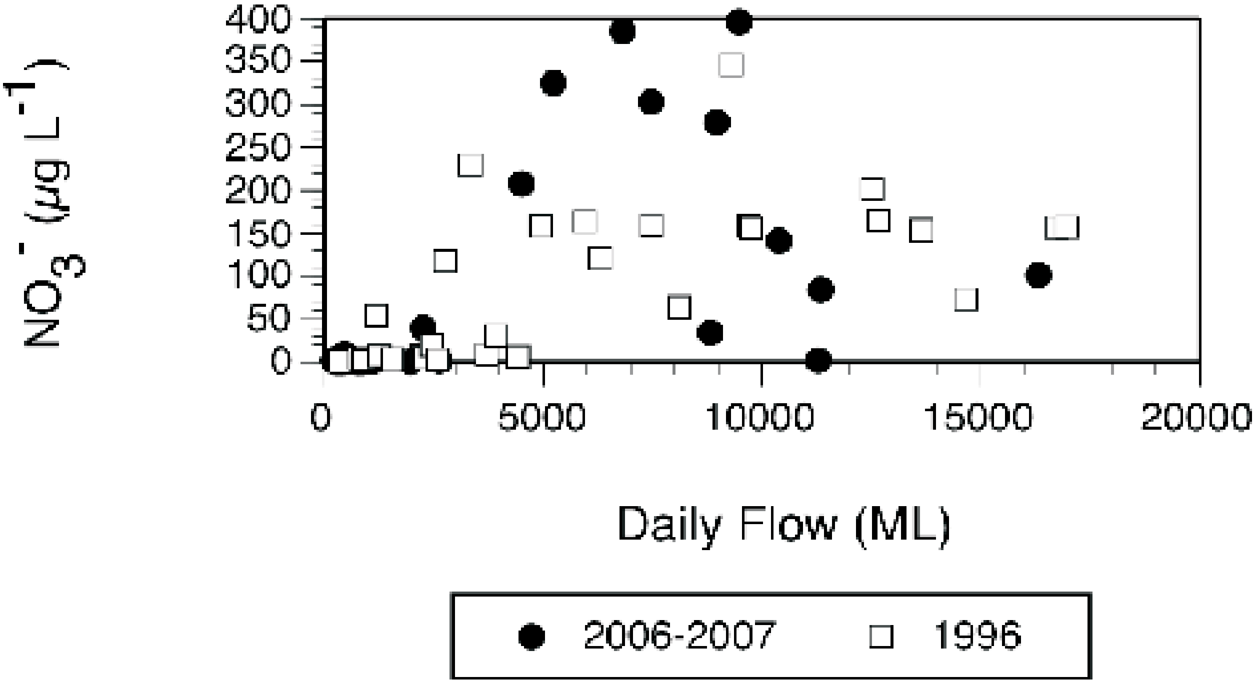


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FIGURE 41

COMPARISON OF WET SEASON WATER QUALITY IN THE MACLEAY RIVER BETWEEN 1949, 1996 AND 2007

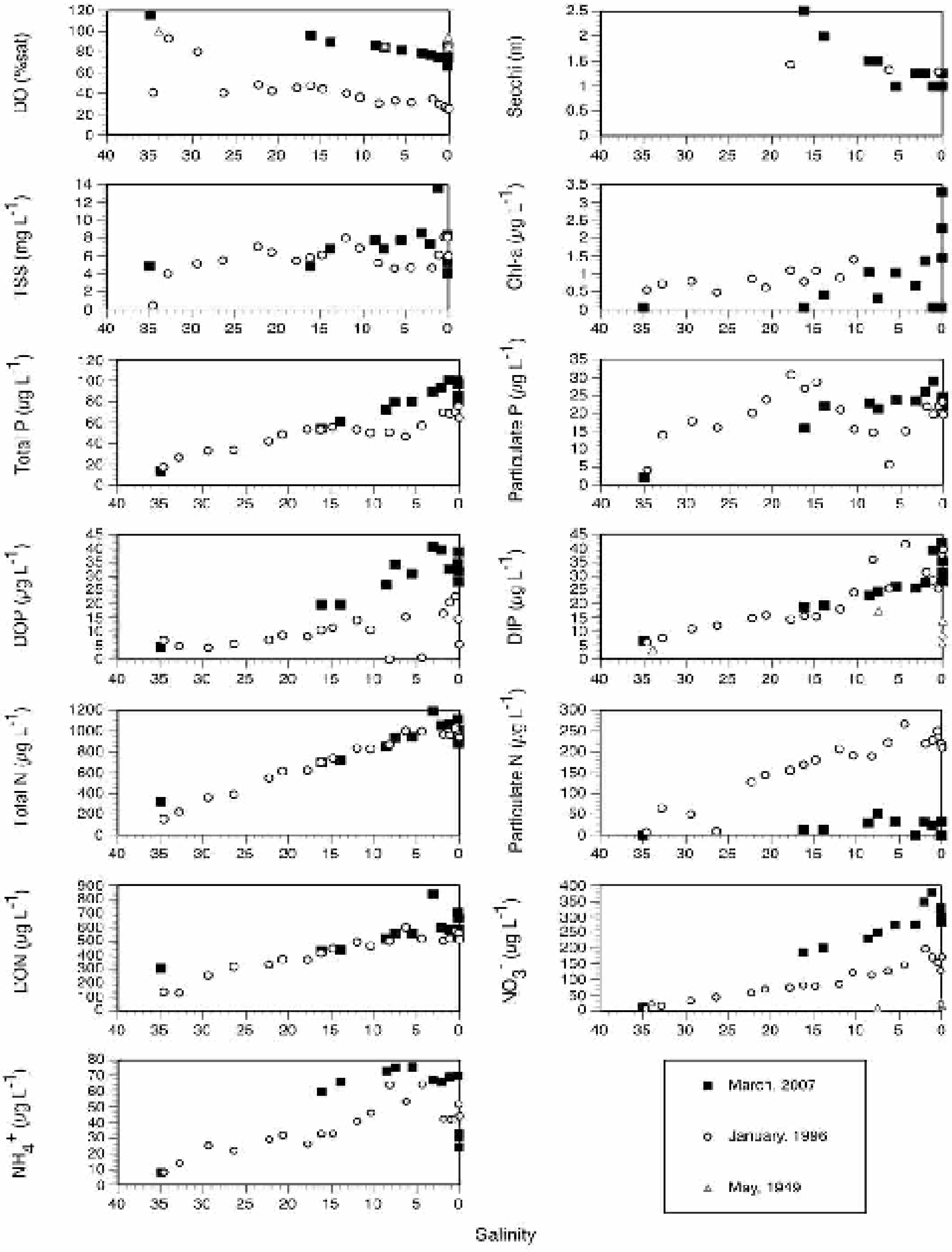

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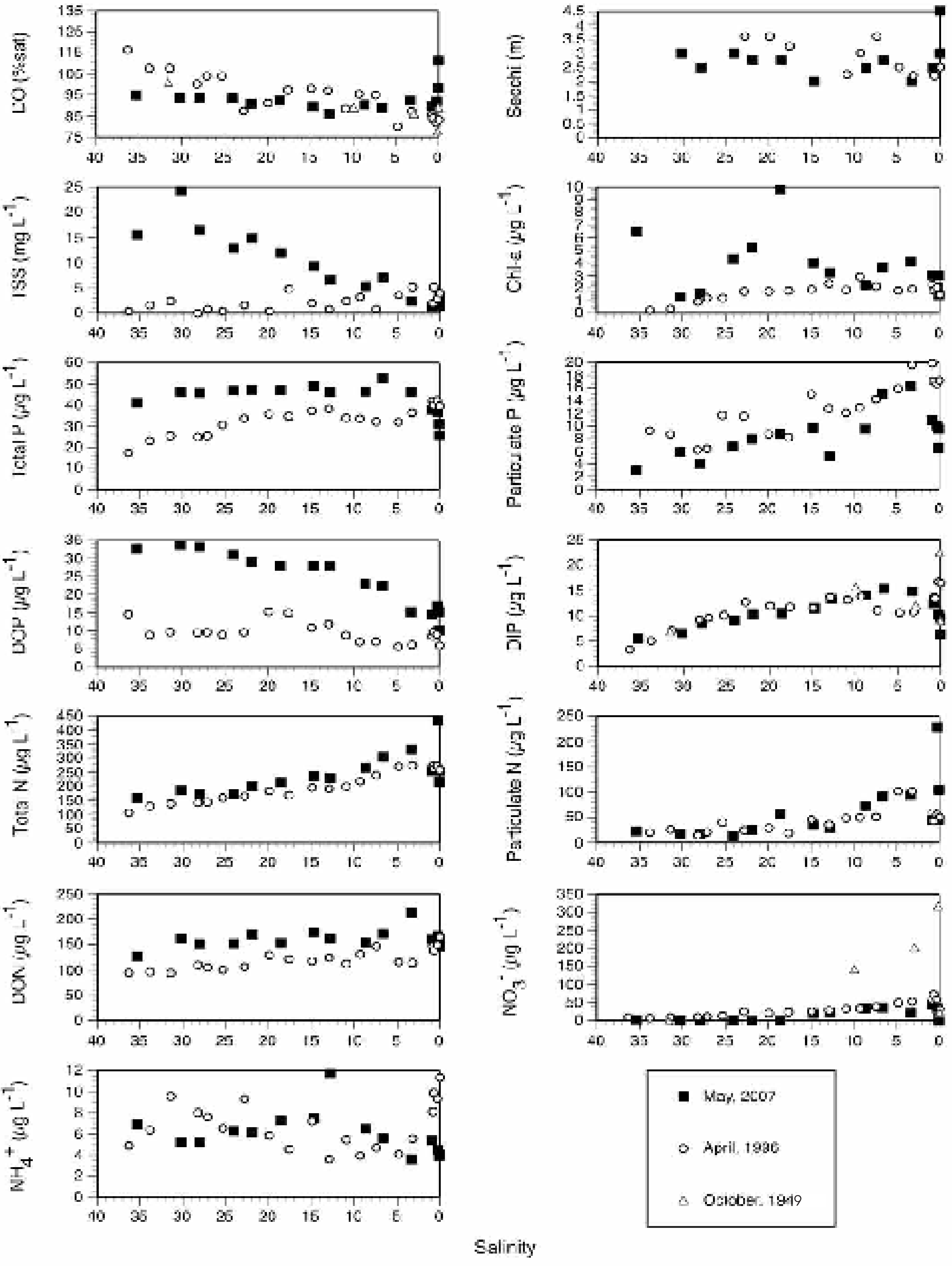
FIGURE 40

COMPARISON OF DRY SEASON WATER QUALITY IN THE MACLEAY RIVER BETWEEN 1949, 1996 AND 2007



J:\Jobs\26017\PDFs\Figures\Figure40_DrySeason preference towards ^{14}N over ^{15}N, making the effluent enriched in ^{15}N. When plants such as seagrass utilize this sewage nitrogen they become enriched in ^{15}N resulting in a distinct ^{15}N signature in these plants.

5.2.1. Methodology

Delta ^{15}N was measured in 6 seagrass samples collected along the Macleay Arm, as shown in Figure 26 (page 69). Sediment seagrass samples were wrapped in aluminium foil and placed in plastic bags and stored on ice until frozen at –20 ^{0}C in the laboratory. The seagrass samples were freeze-dried, ground to a powder and weighed to appropriate weights (i.e. approximately 0.20 mg for total carbon and 0.10 mg for nitrogen) and sealed in tin capsules. Capsulated samples were analysed by Continuous flow - Combustion - Isotope Ratio Mass Spectrometry (CF-C-IRMS). The CF-C-IRMS system is comprised of a Thermo FlashEA 1112 (combustion column at 1020°C, reduction column at 650°C, GC column at 45 °C, He carrier gas at a flow rate of approx. 100ml/min) interfaced through a Thermo Conflo-III to a Thermo Delta V Plus IRMS. Calibrated reference gas (CO_2 and N_2) was introduced via Conflo-III interface at the start of each run. Certified reference materials (NBS-19 and NIST 8457) were analysed at the start, middle, and end of each run as required by laboratory working standard AT-1 (Acetanilide, -1.58 +/- 0.2 delta^{15}N; -26.04 delta ^{13}C (n=20) calibrated against above certified reference materials).

5.2.2. Key Outcomes

The $\partial^{15}N$ (delta ^{15}N) signatures of seagrass in the Macleay Arm ranged from 5.7 to 7.7 (Diagram 10) which are 2 to 3 times higher than $\partial^{15}N$ signatures in seagrasses in Eastern Moreton Bay (Dennison and Abal, 1999), but similar to seagrass in the lower Richmond River Estuary away from the direct influence of sewage effluent (Eyre et al., 2007).

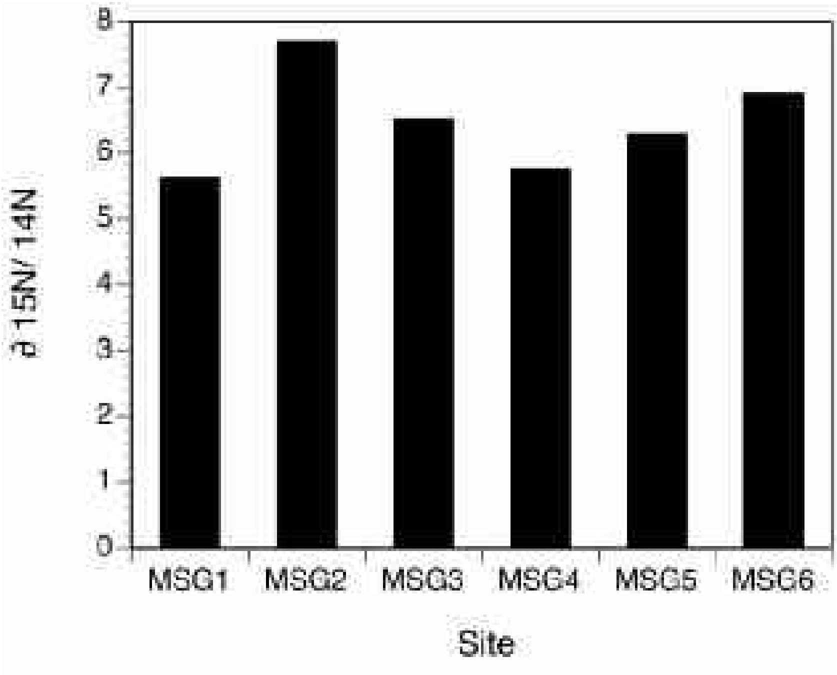


Diagram 10. ∂^{15}N values in seagrass along the Macleay Arm.

The low ∂^{15}N values in Eastern Moreton Bay away from the influence of sewage effluent compared to the Macleay Arm and the Richmond River Estuary reflects either a greater input of nitrogen via N-fixation in Moreton Bay, or the incorporation of some nitrogen from sewage effluent may be incorporated into vegetation at the sites in the Richmond and Macleay. The highest ∂^{15}N value in the seagrass was adjacent to Grassy Head, possibly indicating a greater use of sewage nitrogen at this location. The elevated ∂^{15}N value in the seagrass, combined with elevated nutrient concentrations and algal blooms (shown in Figure 39), indicates that further investigation of the input of septic tank effluent into the upper Macleay Arm is warranted.

5.3. Nutrient Budgets

Nutrient loads from a number of different sources are impacting on water quality in the Macleay Estuary (as discussed in Section 5.1). A nutrient budget is a way of quantifying the nutrient load contribution from each of the different sources. This then allows management actions to be directed towards the key problem areas. To illustrate the nutrient inputs to, and nutrient outputs from, the Macleay Estuary carbon, nitrogen and phosphorus budgets were calculated using the same framework as Eyre and McKee (2002).

5.3.1. Methodology

The budget modelling assumes steady state conditions; therefore the sum of inputs, outputs and storage of each element (C,N,P) within the defined system should equal zero± error. The model includes four major inputs for carbon, nitrogen and phosphorus:

- diffuse (Macleay River),
- urban runoff,
- sewage effluent, and
- atmospheric deposition.

A fifth input, primary production, was considered for carbon, and nitrogen fixation was also considered for nitrogen. Outputs of carbon, nitrogen and phosphorus include burial, fisheries harvest, and export to the ocean. A nitrogen loss through denitrification and a carbon loss through CO_2 exchange with the atmosphere were also considered.

Spatial and Temporal Boundaries

The nutrient budget included the main arm of the estuary between the mouth and Kempsey and the Macleay Arm. The nutrient budget was developed for the one year (September 2006 to August 2007). Some data were measured during a single season. Where possible these have been extrapolated for an entire year by considering seasonal patterns found by other similar studies in Australia (e.g. N-fixation). Where data have been collected or estimated for a number of hydrological regimes (i.e. flood, average, dry), average year fluxes were adopted for the budget construction.

Nutrient speciation, Units of Mass, Significant Figures and Errors

Due to the lack of information of the different nutrient species for some of the pathways only total nitrogen, total phosphorus and total carbon were considered. Mass (tonnes = 10^3kg) was used throughout all calculations. All terms were rounded to 0.1 tonne (100 kg), even though the accuracy this suggests is much greater than can be justified by the methods used. This was to avoid progressive accumulation of rounding errors and to avoid loss of some of the smaller fluxes, which were less than the rounding errors of the larger fluxes. Instead of a detailed quantitative error analysis, which is not particularly useful for this type of budgeting procedure, we applied a sensitivity analysis, to evaluate errors associated with the budget. The sensitivity analysis involved adjusting (e.g. halving, doubling) each of the terms in the budget (e.g. overall burial rates, denitrification rates in each individual benthic habitat) to determine if the overall conclusions derived from the budgets changed.

Diffuse Source Loading

Diffuse loadings to the estuary were calculated by integrating the product of flow-weighted concentrations and daily flows (Turners Flat Gauging Station). The sample collection station samples freshwater flows from about 93% of the total catchment and therefore should be representative of diffuse loads from the catchment as a whole. The hydrograph response of floods in such a large catchment typically spans several days, and as such, daily sampling during floods with samples collected on rising and falling stages is considered sufficient to characterise loads.

Sewage Effluent Loads

Monthly Sewage Treatment Plant (STP) loads for the West Kempsey Wastewater Treatment Plant were provided by Kempsey Shire Council. Monthly nutrient loadings for the Frederickton, Gladstone and South Kempsey wastewater treatment plants were calculated by correcting the West Kempsey loads for the respective size of the plant. For the purpose of this study nutrient loading to the Macleay Estuary from the South Kempsey STP was considered as a point-source, although by definition, it should be treated as a diffuse source having been transported to the estuary via Gills Creek. It is assumed that little assimilation occurs in the creek between the STP discharge point and the Macleay Estuary due to the short distance.

Urban Runoff Loads

The monthly nutrient loading from urban runoff was calculated using the formula (Eyre, 1997):

$$A_{ua}*R*X*C_{ur}$$

where:
- A_{ua} = the urban area (Kempsey, 10.3 km^2; Frederickton, 1.1 km^2; Gladstone 0.6 km^2; Smithtown 0.9 km^2);
- R = the 2006/2007 rainfall (Lawrence; 058033);
- X = an average runoff coefficient for urban areas of similar density, 0.4 (Singh, 1992);
- C_{ur} = an average nutrient concentration (TN: 1.4 mg l^{-1}; TP: 0.4 mg l^{-1}; $N0_3$: 0.5 mg l^{-1}; NH_4: 0.6 mg l^{-1}) adapted from urban runoff studies in Lismore, Mullumbimby and the lower Tweed Estuary (PWD, 1991; Kerr and Eyre, 1995; Malcolmson, 1998).

The use of urban runoff concentrations for Lismore, Mullumbimby and the lower Tweed Estuary was considered appropriate, because Lismore, Mullumbimby and the lower Tweed Estuary are regional urban centres with similar rainfall patterns, total impervious surfaces, and traffic and populations densities to Kempsey, Frederickton and Gladstone.

Atmospheric Loads

Atmospheric deposition loads were estimated using rainfall concentration data for coastal northern NSW 300 km north of the study area (McKee and Eyre, 2001), mean annual rainfall for the study area and the total surface area of the study area. The northern NSW rainfall concentration data were from coastal sites and therefore represent similar conditions to the study area (i.e. clean air sourced from the Pacific Ocean). No dry fall data was available. As such, the wet fall loads were multiplied by 1.2 which is the ratio of total nitrogen deposition (wet + dry) to wet nitrogen deposition for the South Pacific Ocean (Paerl, 1995); the same ratio was assumed to apply for phosphorus.

Carbon Production

Pelagic productivity was estimated using average chlorophyll-a concentrations collected monthly over the 12 month period and a chlorophyll-a biomass / productivity relationship developed in the sub-tropical Brunswick Estuary (Gay, 2002). Benthic habitats were mapped from aerial photographs and previous NSW Fisheries seagrass mapping (Figure 43). Benthic productivity for each habitat in the study area was estimated by multiplying the average measured productivities for each similar habitat in the Hastings Estuary (Maher et al., 2007) by its surface area. Mangrove productivity was estimated by multiplying the mangrove biomass in the study area by mangrove biomass/ productivity ratios measured in Moreton Bay (Dennison and Abal, 1999). Benthic productivity of the macrophyte beds in the upper estuary was estimated from the excess oxygen measured in the water column.

Nutrient Burial

Carbon burial was estimated for the whole study using average burial rates for mangrove and seagrass communities, and non-vegetated estuarine sediments (Duarte et al. 2005) and their aerial extent. Nitrogen and phosphorus burial was estimated by applying the measured sediment C:N and C:P ratios to the carbon burial.

Pelagic and Benthic Respiration (Carbon Loss)

Pelagic respiration was estimated by assuming a 2:1 ratio of diatoms to dinoflagellates and applying respirations rates for diatoms (16%) and dinoflagellates (35%) in Moreton Bay (Eyre and McKee, 2002) to the phytoplankton productivity. Benthic respiration was estimated for each habitat in the study by multiplying the average of measured benthic respiration rates (i.e CO_2 flux) in each similar habitat in southern Moreton Bay (Eyre et al., in prep) by its area. It was assumed that 78% of the mangrove production was lost through plant and heterotrophic respiration (Alongi, 1998).

Denitrification, N-fixation and net N_2 loss

Nitrogen inputs via N-fixation, and nitrogen losses via denitrification, were estimated by multiplying the average of the measured N-fixation and denitrification rates in southern Moreton Bay (Eyre et al., in prep) by the area of each habitat.

Fisheries Harvest

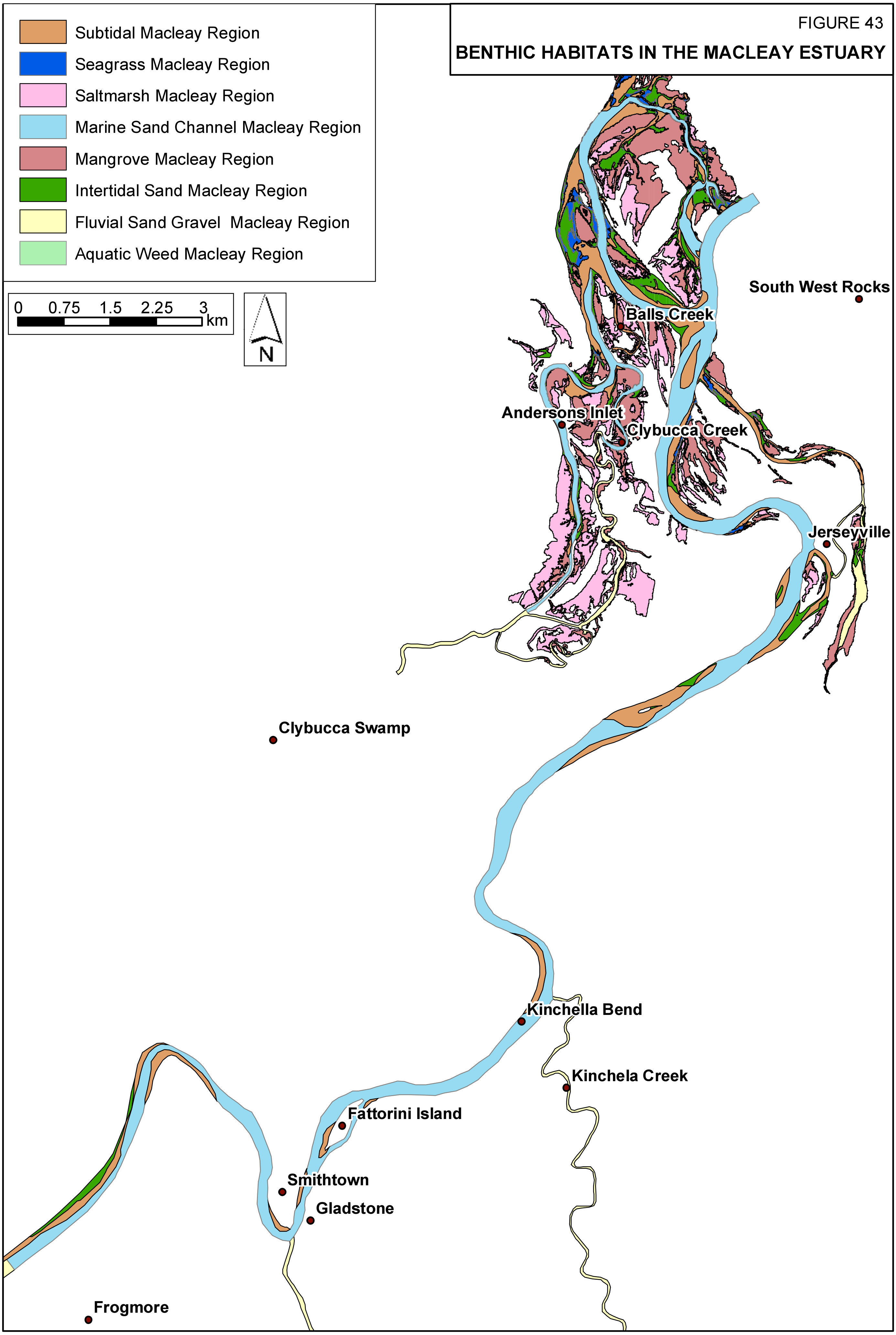
The commercial catch of fish was obtained from NSW Fisheries records. The harvest of fish by recreational fishers was estimated to equal the commercial catch. Dry weight was assumed to be 20% of the wet catch and the carbon, nitrogen and phosphorus content of the dry catch to be 50%, 15% and 0.62% respectively (Eyre and McKee, 2002).

Ocean Exchange

When all the nutrient inputs and outputs were added the ocean exchange of phosphorus and nitrogen was calculated by difference; +ve = an export an -ve = an input. This term also includes the sum of the errors associated with the other components of the budget.

FIGURE 43

BENTHIC HABITATS IN THE MACLEAY ESTUARY



J://Jobs/26017/dmin/Report/Figures/Other/Figure43_BenthicHabitatsintheMacleayEstuary.mxd

5.3.2. Key Outcomes

Annual physical inputs of nitrogen and phosphorus to the Macleay Estuary were dominated by diffuse runoff (Table 31 and Table 32). However, during the dry months wastewater nitrogen loads can equal diffuse nitrogen loads. Urban loads were the smallest inputs of nitrogen to the Macleay Estuary and atmospheric loads were the smallest input of phosphorus (Table 33). Ocean inputs of phosphorus to the Macleay Estuary were larger than the urban load, atmospheric load and wastewater load. An input of phosphorus from the ocean is consistent with the mixing plots that show increasing concentrations towards the ocean. N-fixation was the largest input of nitrogen to the Macleay Estuary (426 t) with most of the N-fixation occurring in the subtidal shoals (shown in Figure 43) reflecting the large surface area. However, some caution needs to be applied to these values as they are extrapolated from Moreton Bay and N-fixation rates may not be as high in the Macleay Estuary (discussed in Section 5.2).

Primary production by the macrophyte beds, mangroves, seagrasses, phytoplankton and benthic microalgae contributed 20,787 tonnes of carbon to the Macleay Estuary. Benthic micro algae (BMA) were the largest source of carbon to the study area (7,792 t) and seagrass was the second largest source (4,888 t). Part of the seagrass productivity measurements include production by BMA and epiphytes that were contained within the field chambers, further highlighting the importance of BMA as a carbon source in the Macleay Estuary. Studies that have measured seagrass, BMA and epiphyte production within a seagrass community have found that the seagrasses alone have only contributed about 10% of the total community production (Moncreiff and Sullivan, 2001).

Nitrogen outputs were dominated by denitrification and burial, whereas phosphorus outputs were predominantly by burial. Most of the denitrification occurred in the subtidal shoals (461 t) and seagrass beds (85 t). Carbon loss from the Macleay Estuary was dominanted by atmospheric exchange of dissolved inorganic carbon (CO_2) associated with benthic and pelagic respiration, and by ocean exchange. Benthic respiration was about 19 times higher than pelagic respiration, reflecting the shallow water column in the Macleay Estuary. Burial was the next largest loss of carbon, and fisheries harvest only accounted for a small amount of carbon loss. The budgets were most sensitive to burial rates. However, if the rates were halved or doubled the same conclusions would be reached.

5.3.3. Management Implications of the Budgets

Importance of Benthic Production

The C, N and P budgets highlighted the importance of benthic production as a carbon source for the Macleay Estuary. It is this carbon supply that supports higher order consumers such as fish. As such, it is critical that management actions are directed towards maintaining benthic production. The most important factor is to minimise light attenuation in the water column as this allows light to reach the bottom and maintain benthic production. To minimise light attenuation both TSS and chlorophyll-a concentrations must not be allowed to increase. Chlorophyll-a concentrations can be reduced by decreasing nutrient loads to the estuary.

Importance of Denitrification

Denitrification was the largest output of nitrogen from the Macleay Estuary. As such, it is critical that management actions are directed towards maintaining benthic denitrification. The most important factor to maintain is low pelagic carbon loading rates (algal production). Increased organic loading from phyto-detritus leads to an increase in benthic carbon decomposition and oxygen consumption with more nitrogen recycled to the water column as ammonium and less nitrogen lost to the atmosphere via coupled nitrification-denitrification (Eyre and Ferguson, in press).

Table 31 Monthly Physical Total Nitrogen Loads (t) delivered to the Macleay Estuary for the period September 2006 to August 2007.

	Urban					Wastewater					Diffuse	Total Load
	Kempsey	Fredrickton	Gladstone	Smithtown	Total Urban	West Kempsey	South Kempsey	Fredrickton	Gladstone	Total Wastewater		
Jan	0.88	0.09	0.05	0.08	1.11	0.43	0.14	0.04	0.07	0.69	2.74	15.17
Feb	0.89	0.09	0.05	0.08	1.11	0.30	0.10	0.02	0.05	0.47	7.64	5.10
Mar	0.69	0.07	0.04	0.06	0.87	1.23	0.41	0.10	0.21	1.96	93.48	2.039
Apr	0.54	0.06	0.03	0.05	0.67	0.53	0.18	0.04	0.09	0.84	4.21	14.76
May	0.54	0.06	0.03	0.05	0.67	0.89	0.30	0.07	0.15	1.41	4.58	21.13
Jun	0.37	0.04	0.02	0.03	0.46	1.44	0.48	0.12	0.24	2.28	3.05	39.46
Jul	0.34	0.04	0.02	0.03	0.42	1.52	0.51	0.13	0.25	2.40	2.55	44.68
Aug	0.31	0.03	0.02	0.03	0.39	2.15	0.72	0.18	0.36	3.41	107.93	3.05
Sep	0.46	0.05	0.03	0.04	0.57	2.24	0.75	0.19	0.37	3.55	15.82	17.81
Oct	0.54	0.06	0.03	0.05	0.68	0.90	0.30	0.08	0.15	1.43	4.49	21.66
Nov	0.61	0.07	0.04	0.05	0.77	1.10	0.37	0.09	0.18	1.73	49.75	3.32
Dec	0.77	0.08	0.04	0.07	0.97	0.28	0.09	0.02	0.05	0.44	2.61	10.98
Annual	**6.93**	**0.74**	**0.40**	**0.61**	**8.68**	**13.02**	**4.34**	**1.09**	**2.17**	**20.62**	**298.85**	**199.15**

Table 32 Monthly Physical Total Phosphorus Loads (t) delivered to the Macleay Estuary for the period September 2006 to August 2007

	Urban					Wastewater					Diffuse	Total Load
	Kempsey	Fredrickton	Gladstone	Smithtown	Total Urban	West Kempsey	South Kempsey	Fredrickton	Gladstone	Total Wastewater		
Jan	0.25	0.03	0.01	0.02	0.32	0.01	0.00	0.00	0.00	0.02	0.18	3.50
Feb	0.25	0.03	0.01	0.02	0.32	0.01	0.00	0.00	0.00	0.02	0.61	1.96
Mar	0.20	0.02	0.01	0.02	0.25	0.02	0.01	0.00	0.00	0.03	8.38	0.32
Apr	0.15	0.02	0.01	0.01	0.19	0.00	0.00	0.00	0.00	0.01	0.33	1.39
May	0.15	0.02	0.01	0.01	0.19	0.01	0.00	0.00	0.00	0.02	0.18	3.97
Jun	0.10	0.01	0.01	0.01	0.13	0.01	0.00	0.00	0.00	0.02	0.13	7.61
Jul	0.10	0.01	0.01	0.01	0.12	0.01	0.00	0.00	0.00	0.01	0.15	3.44
Aug	0.09	0.01	0.01	0.01	0.11	0.01	0.00	0.00	0.00	0.01	6.23	0.14
Sep	0.13	0.01	0.01	0.01	0.16	0.02	0.01	0.00	0.00	0.02	1.71	1.28
Oct	0.15	0.02	0.01	0.01	0.19	0.00	0.00	0.00	0.00	0.01	0.22	1.63
Nov	0.17	0.02	0.01	0.02	0.22	0.01	0.00	0.00	0.00	0.01	2.78	0.26
Dec	0.22	0.02	0.01	0.02	0.28	0.01	0.00	0.00	0.00	0.02	0.13	4.56
Annual	**1.98**	**0.21**	**0.12**	**0.17**	**2.48**	**0.12**	**0.04**	**0.01**	**0.02**	**0.19**	**21.03**	**30.06**

Table 33 Carbon, Nitrogen and Phosphorus Budgets for the Macleay Estuary for the period September 2006 to August 2007

	Carbon (t)	Nitrogen (t)	Phosphorus (t)
INPUTS			
Wastewater	82.5	20.6	0.2
Diffuse	3347.1	298.8	21.0
Urban	97.3	8.7	2.5
Amosphere	28.6	9.3	0.5
N-fixation		426.2	
Pelagic Production	4033.2		
BMA Production	7792.3		
Mangrove Production	3250.7		
Seagrass	4887.9		
Macrophytes	822.4		
Net Ocean Exchange			2.6
OUTPUTS			
Pelagic Respiration	891.7		
Benthic Respiration	16690.6		
Mangrove Respiration	2535.6		
Denitrification		605.5	
Burial	903.1	106.2	26.6
Fisheries	3.9	1.2	0.0
Net Ocean Exchange	2412.2	30.1	

5.4. Heavy Metal Contamination

Trace metal contamination of river systems can occur from a range of sources, as a result of both natural and anthropogenic processes. For example, natural erosion from mineralized rocks that occurs over geologic time can result in elevated concentrations of metals in floodplain sediments. Mining activities can enhance the exposure of naturally mineralised areas and processing operations can contribute to increased metal loads. In addition, land use activities that enhance erosion can contribute to sediment associated contaminant loading on the floodplain. Urban and industrial effluent can also be a contributing source of metals. The following section provides a summary of the impacts of historic mining practices on water and sediment quality and the bioavailability of two trace elements, antimony and arsenic that have been found in elevated concentrations within the Macleay estuary.

5.4.1. Impacts of Historic Mining Practices on Water and Sediment Quality

The Macleay catchment has naturally mineralised areas that have resulted in approximately 534 recorded mineral deposits, some of which have been actively mined. Mineral deposits in the Macleay catchment have been reported to contain metals including abundant gold, copper, lead, zinc, silver, arsenic, antimony, tin and molybdenum. However, prolific mineral deposits mainly consist of gold, antimony and arsenic (Gilligan et al., 1992).

As detailed in Ashley et al. (2007) and Ashley and Graham (2001), historic mining practices in the upper Macleay catchment have resulted in significant arsenic (As) and antimony (Sb) contamination of soil and in-stream sediments extending considerable distances downstream. The major mineralised areas include Hillgrove, Halls Peak, Rockvale, Enmore-Melrose and Mungay Creek. The Hillgrove mineral field is the largest of these, and historic waste disposal practices have caused a dispersion train of contaminated material for over 300km in length.

Major production in the Hillgrove region has come from 14 mines, with all but one being underground. Large volumes (estimated at approximately 7Mt) of mine waste and mill tailings have been produced over the long mining history. Due to historic (pre 1970) waste-disposal practices, the majority of this material has been transported from mine dumps and mining derived scree down the Bakers Creek-trunk Macleay River system by fluvial transportation. Modern (post 1980) mill tailings (~1Mt) are stored in a dam, but much of the area surrounding the mill and tailing dam has strong contamination of soil with Sb and As. Whilst only low levels of seepage occurs from several mine openings and the tailing dam, it contains high concentrations of Sb, As and sulfate. No acid mine drainage occurs at Hillgrove due to the presence of hydrothermal carbonate in the ore and host-rock that buffers acid production from the oxidative breakdown of sulfides. However, acid mine drainage does occur at Halls Peak and Rockvale.

Sediments with high Sb and anomalous As values are widely spread across the floodplain and estuary and extend to depths of up to 400 mm on levees. At depths of 1 - 2 m values of Sb and As are similar to the regional catchment background values.

The system is contaminated by Sb and As from Hillgrove to the Pacific Ocean, a distance of over 300 km. This is evident in levels of Sb and As in stream sediments, stream water, riparian vegetation and aquatic algae. There is an uptake of metalloids into pasture species on the Macleay floodplain. Stream sediment quality has been compromised throughout.

The typical annual discharge of the Macleay River is approximately 2,000 Mm^3 (Hydrodynamic Section – 3.8), therefore, based on average dissolved Sb and As contents in water of the lower Macleay River ~1t of Sb and 2t of As could be delivered in solution each year to the Pacific Ocean. Although a proportion of the dissolved and suspended load of Sb and As would be derived from weathering and erosion of background rocks in the Macleay catchment, it is likely that at least 80 - 90% of Sb and ~50% of As are from contaminant point sources based on stream sediment and water compositions.

Since the dominant sources of Sb and As remain in the Bakers Creek-trunk Macleay River system, flux of metalloids will continue for the foreseeable future, with time frames of at least hundreds to thousands of years, judging by the amounts of Sb and As bound in stream sediments and the residence time of sediments in stream systems. It is predicted that the fluvial, deltaic and estuarine sediments of the Macleay will preserve a stratigraphic horizon with anomalous Sb and As contents into the geologic future.

5.5. Bioavailability of Arsenic and Antimony in Sediments

Trace metals do not degrade in the environment over time and can be stored, remobilised and cycle through various compartments of the environment. Arsenic is toxic to both animals and plants and the level of toxicity depends on the species and solubility (Ng, 2005). The inorganic forms of arsenic are proven carcinogens in humans and chronic exposure can lead to cancer of the skin, lung, and bladder as well as vascular diseases and an increased risk of diabetes mellitus (IPCS, 2001). Depending on the source, arsenic can be taken into the body from drinking water, air and food.

Sediments of the Macleay floodplain are elevated in some metals including both arsenic and antimony, and the risk to human health depends on the land use associated with the contaminated floodplain area and subsequent exposure pathways. The presence of acid sulfate soils can influence the mobility and toxicity of trace elements.

5.5.1. Introduction

Trace element contamination was not historically recognized as an environmental stressor in the Macleay River and receives only very limited acknowledgement in reports from the 1960s, 1970s and 1980s. Stream health indicators included riparian vegetation, bank condition, terrestrial vegetation cover, the presence of structures, extent of Acid Sulfate Soil (ASS) risk, and water quality, but did not consider the potential impacts of trace elements (e.g. SPCC, 1987; NSW DLWC, 1999).

Historical development and management of flood prone land in some cases is likely to have increased the distribution and mobilisation of trace elements. For example, some reports recommended the use of pasture fields to provide storage for flood waters (Lee, 1968), which potentially enhanced the deposition rates of upstream sediment (and hence trace elements) onto the floodplain during flood events. Others recommended the drainage of farm land (anon, 1968) and a general lack of understanding of ASS resulted in exposure of ASS in floodplain areas (NSW Agriculture & Fisheries, 1989).

Although the working party report “Review of Land and Water Management Impacts on Fisheries and Agriculture Resources in the Lower Macleay” (NSW Agriculture & Fisheries, 1989) identified ASS as a serious concern for the lower Macleay River, only aluminium and iron were considered contaminants of potential concern. The possible impact of the mobilization and toxicity of other trace elements during acid water events was not considered. More recent floodplain studies have focused on the active management of floodgates to alleviate the impact of ASS (e.g. NSW Fisheries 2002).

5.5.2. Arsenic and Antimony Contamination in the Catchment

Previous environmental geochemical work in the Macleay River catchment has included stream sediment surveys, such as Muller (1994), Lottermoser et al. (1997), Lottermoser (1998), Weir (1998), Ashley and Lottermoser (1999), Doherty (1999) and Hogan (1999). However, these surveys are generally unpublished, only cover a small area of the Macleay River catchment and exhibit highly irregular data coverage (Ashley and Graham, 2001). Other studies have been conducted since the 1960s as part of mineral exploration work although quality control was limited and metal suites were variable (Ashley and Graham, 2001).

Relatively recent studies have identified that some elements (metals and metalloids) are elevated in concentration in sediments of a few sub catchments of the Macleay River (Ashley and Graham, 2001; Ashley et al., 2007). In the study by Ashley and Graham (2001) over 500 stream sediments and 70 water samples were collected. Sediment samples were sieved (<180µm) and analysed for copper, lead, zinc, cadmium, arsenic, antimony, iron and manganese, while water samples were filtered to determine dissolved forms of the above metals.

Ashley and Graham (2001) showed that urban areas and major traffic routes had only limited or local effects on the metal loading (lead, zinc, antimony and to a lesser extent copper and arsenic) in the catchment. Many mineral deposits within the catchment are small and metal dispersal was not detectable within the scale of sampling. However, there are some mineral fields that have caused contamination in long stretches of stream sediments, as discussed in Section 5.4 (Ashley and Graham, 2001). Background values of antimony and arsenic in stream sediments in the Macleay catchment are ~50% higher than the median values in the adjacent Clarence River (Cohen et al., 1995 in Ashley et al., 2007) because large volumes of mine waste and mill tailings have been produced in the catchment.

5.5.3. Floodplain loading of arsenic and antimony

Ashley's et al. (2007) study on the loadings of antimony and arsenic in the Macleay River catchment focused on the sources, mobilization, deposition and consequences of fluvial dispersion. In the study some areas within 50km of the Macleay River mouth were found to be elevated in both arsenic and antimony. Ashley and Graham (2001) also completed a detailed study of metal loading in the Macleay River catchment and found that there has been extensive dispersion of antimony and to a lesser extent arsenic. The dispersion spreads across the floodplain and estuary region, more specifically on the southern side of the river downstream from Kempsey (Ashley and Graham, 2001).

Floodplain alluvial (levee) sediments contained between 0.1mg/kg and 35.1mg/kg antimony (ISQG –LOW 2mg/kg –HIGH 25mg/kg) and 1.8mg/kg to 26.8mg/kg arsenic (ISQG –LOW 20mg/kg –HIGH 70mg/kg) and backswamp sediments generally had higher concentrations of both arsenic and antimony (Ashley et al., 2007). Actual floodplain sediment cores indicated only surface contamination of antimony and below about 60cm antimony was around background concentrations. Arsenic concentrations at depth were similar to surface sediments (e.g. 6-12 mg/Kg) (Tighe et al., 2005a; Ashley and Graham, 2001; Ashley et al., 2007) and even sediments deposited on the floodplain 2 weeks after a flood event had a comparable average of 9.3 mg/Kg antimony and 8.7 mg/Kg arsenic (Ashley et al., 2007). At depths of 1-2 m values of antimony and arsenic were similar to regional catchment values (Ashley and Graham, 2001).

In Ashley and Graham's (2001) study 20 cores of depths up to 3.5 meters were collected from the Macleay floodplain. Trace metal concentrations as well as acid sulfate soil profiles and sedimentology were determined in these cores. These sediment cores do not provide strong evidence of metal mobility mediated by ASS processes. This can probably be accounted for by the behaviour of some metals such as antimony under various pH conditions. Recent studies based on Macleay River floodplain soils investigated the sorption behaviour of antimony (V) and it was found that antimony has a bonding affinity to humic acid and iron hydroxides that corresponds to pH change (Tighe et al. 2005b). Generally there is a decreased sorption with increased pH, and pH values of around 3.5 (point of zero charge -PZC) have the greatest sorption capacity for antimony (v) (Tighe et al., 2005b). Desorption of antimony (V) from humic acid occurred at pH values of around 6.0-6.5.

The concentration of antimony (V), other co-occurring elements such as iron and aluminium, and clays will influence the sorption capacity due to competition between these ions. Tighe et al., (2005b) concluded that the retention of antimony (V) in floodplain soils would be maximized at pH values around 3.0-4.6 depending on the specific soil. Ashley and Graham (2001) noted that only under strongly acidic conditions (expected pH <3.0) would the anomalous antimony and arsenic in floodplain sediments potentially be liberated and become bioavailable.

5.5.4. Bioavailability Studies on Arsenic and Antimony

Bioavailability data on arsenic and antimony are limited, and a realistic health risk assessment of arsenic from mine tailings in Australia cannot currently be made (e.g. Ng, 2005). Several studies have investigated the uptake of antimony and/or arsenic in vegetation and animals under controlled experimental conditions or in natural conditions (Ng, 2005; Tighe et al., 2005a; Ashley and Graham, 2001; Ashley et al., 2007).

An investigation of arsenic uptake in cattle that were fed an arsenic enriched diet and cattle that grazed on arsenic contaminated rehabilitated tailing for 6.5-8 months has been made in Ng (2005). Analyses of the blood, muscle, liver, kidney and other saleable tissue were made and showed relatively low bioaccumulation of arsenic, suggesting that rehabilitated mine tailing sites may be suitable for stock grazing. The low bioaccumulation of arsenic recorded by Ng (2005) may be due to a variety of factors including the solubility and binding capacity of arsenic associated with the environmental conditions at the study location and these were not defined in the study. Ng (2005) suggests that further studies are required to assist regulatory agencies to develop guideline values and policy in relation to mine closure.

In the Macleay area over 30, 000ha or 90% of the floodplain is enriched in arsenic and antimony (Tighe et al., 2005b). Tighe et al., (2005b) showed that there has been uptake of arsenic and antimony in pasture species (*Cynodon* and *Paspalum*) growing on the Macleay River floodplain (see also Tighe 2005). Grasses growing on floodplain soils with arsenic and antimony concentrations of 21mg/Kg and 18mg/Kg respectively were up to one to two orders of magnitude higher than background values in plants. In some cases antimony in pasture species were similar in both moderately contaminated soils on the floodplain and highly contaminated soil in the catchment inferring higher relative availability of antimony under floodplain conditions (Tighe et al., 2005b).

Water, sediment, riparian vegetation and aquatic algae were assessed for antimony and arsenic loading in Ashley et al., (2007) in order to gain an understanding of environmental cycling of these elements. Plant species (*Persicaria* and *Lomandra*) rooted in contaminated sediments in the Hillgrove area (contaminated area) showed a notable uptake of antimony but a modest uptake of arsenic (Ashley et al., 2007). Plants (*Lomandra* and *Cynodon*) were enriched in arsenic only in the immediate area around Hillgrove. Uptake by algae mimicked the relative amounts of arsenic and antimony in stream water and enrichment continued at least 20km downstream of the Hillgrove site (Ashley et al., 2007).

Oysters from the Macleay River have also been tested for a range of trace elements including arsenic (Ashley and Graham, 2001). Although the sample size was limited to four samples (Wild oyster -Jerseyville, South West Rocks Creek, the Macleay River entrance; Commercial oyster–Andersons Inlet lower Clybucca Creek) some interesting results were found. Arsenic as well as copper and zinc were very strongly partitioned into the tissues compared to the shell. The commercial oyster contained lower concentrations of these elements than the wild oyster and there was no evidence of antimony uptake by any oysters sampled. Arsenic concentrations in oysters collected from the Macleay River entrance (1.15 mg/kg) and South West Rocks Creek (1.0 mg/kg) were slightly higher than the Australian and New Zealand Food Authority Standard of 1.0mg/kg (Ashley and Graham, 2001)

Ashley et al., (2007) noted that research is required on:

- residence time and the physical and chemical behaviour of contaminated sediments
- leaching and bioavailability of metalloids from sediments and biomagnifications of cycling of metalloids through aquatic organisms
- mobility of metalloids in the floodplain environment and their transfer into crop pastures and grazing animals

5.5.5. Arsenic and Antimony Toxicity

The toxicity of inorganic compounds is often dependant on their speciation. Both antimony and arsenic are in the same group of the periodic table and hence have similar chemical properties. As with arsenic, antimony can be in the trivalent (3+) or pentavalent (5+) oxidation state and both these states can form complex negatively charged ions with oxygen (oxyanions) in the environment. The 5+ oxidation state of both elements is most commonly found in the environment. Although there is a general lack of knowledge of the environmental behaviour of antimony and it has only recently been recognized as a potential inorganic toxicant, (Tighe et al., 2005b) some inferences could be made using available information on arsenic.

Arsenic is toxic to both animals and plants. The ANZECC and ARMCANZ (2000) guideline trigger value for arsenic in livestock drinking water is 0.5 mg/L, while there is no trigger value for antimony. The inorganic forms of arsenic are proven carcinogens in humans and chronic exposure can lead to cancer of the skin, lung, and bladder as well as vascular diseases and an increased risk of diabetes mellitus (IPCS, 2001). Depending on the source, arsenic can be taken into the body from drinking water, air and food.

Arsenic toxicity is dependant on the solubility and 'species' of arsenic formed. Generally the trivalent arsenic (arsenite) is more acutely toxic than the pentavalent (arsentate) form. In most reducing conditions that are acid to mildly alkaline, the trivalent arsenite species (H_3AsO_3) predominate (Ng, 2005). At moderate or high redox potential (Eh) arsenic is generally stabilised as a series of pentavalent oxyanions. When humans ingest inorganic arsenic it is usually rapidly converted to methylated metabolites (Adair et al. 2005). Although the methylation process is generally understood, the metabolism of some arsenicals is not clear and research continues in this field (Adair et al. 2005). There is some evidence that the pentavalent forms of arsenic can be toxic over long time scales (Ng, 2005).

Further research is required to understand the toxicity of both arsenic and antimony in the Australian estuarine environment.

5.5.6. Assessment of Bioavailability

Four sites sampled in duplicate were selected in the Macleay River Estuary to provide a snapshot assessment of bioavailability of arsenic and antimony in sediments, as shown in Figure 26 (page 69). Site descriptions are as follows:

- SC1 - downstream from Kempsey near Frederickton,
- SC2 - 100m upstream Belmore River near Gladstone,
- SC3 – depositional island Jerseyville near Pelican Island, and
- SC4 - Clybucca Creek and Andersons Inlet confluence (associated with large backswamp wetland known to have elevated metalloid concentrations and abundant sulphidic and organic material (Ashley and Graham, 2001)).

Methods

A portion of the top few centimetres of each core from each site was collected and frozen for storage until analysis. Prior to analysis, samples were dried and ground. Total metal analyses were completed for iron, aluminium, arsenic and antimony using aqua regia digestion and subsequent analyses by ICP –MS at the EAL. As well, a bioavailable trace metal leach was completed using a 1 hour 0.1M hydrochloric acid digest and samples were subsequently analysed for arsenic and antimony by ICP –MS at the EAL. The leachable fraction (a measure of bioavailability) is the portion of most environmental concern because it is available for accumulation by benthic organisms, mobilization into the pore water and the water column, and subsequent uptake by aquatic organisms. Total organic carbon and total sulphur were determined by Elementar Analyser at the EAL. Grain size was determined according to Lewis and McConchie (1994).

Key Findings and Discussion

Total arsenic in all sediment samples collected were below the Australian Interim Sediment Quality Guidelines ISQG –LOW guidelines of 20mg/Kg (Table 34). In contrast, antimony concentrations in all sediment samples apart from SC4a and SC4b were higher than the ISQG - LOW value of 2mg/Kg, however they were below the ISQG –HIGH value of 20mg/Kg (Table 34). Grain size analyses showed that most sites were predominantly (>80%) fine to medium sand (Table 35). The exceptions are site SC2a and SC2b, and site SC4b which have a greater contribution of very fine sand and mud in the sediment. Site SC2b has 23.57% mud and this was the highest amount of fine particles (<75µm) found. Both total arsenic and total antimony concentrations are more elevated at site SC2a and SC2b than at other sites. Site SC1a has a higher loading of antimony, which does not seem to be linked to the relative quantity of finer particles.

Table 34 Results of the Analyses of Four Duplicate Sediment Samples, from the Macleay River Estuary, to Determine the Bioavailability of Arsenic and Antimony

	SC1a	SC1b	SC2a	SC2b	SC3a	SC3b	SC4a	SC4b
	Downstream from Kempsey near Fredrickson		100m upstream Belmore River near Gladstone		Depositional island Jerseyville near Pelican Island		Cybucca Creek and Andersons Inlet confluence	
Total Phosphorus (mg/Kg)	540	356	664	390	368	349	77	84
Total Sulphur (%S)	0.096	0.052	0.496	0.374	0.046	0.051	0.136	0.092
Total Carbon (%C)	1.51	0.492	2.24	2.81	0.0991	0.0814	0.665	0.516
Total Arsenic (mg/Kg)	6.9	5.3	15.6	9.6	7.1	6.8	3.0	3.1
Bioavailable Arsenic (mg/Kg)	2.0	1.3	1.8	2.8	1.4	1.9	0.7	0.8
Total Antimony (mg/Kg)	9.2	5.2	7.4	8.2	2.8	2.1	0.7	0.6
Bioavailable Antimony (mg/Kg)	0.5	0.5	0.7	0.9	0.3	0.3	0.0	0.1
Iron (%)	2.9	3.0	3.6	2.6	2.4	2.2	7.1	1.2
Aluminium (%)	1.5	1.4	3.0	1.5	1.0	0.9	0.4	0.9

Table 35 Grain Size Analyses of Four Duplicate Sediment Samples from the Macleay River Estuary

SAMPLE ID	>2mm Gravel/Organic Matter	1 - 2mm Very Coarse Sand	600µm - 1mm Coarse Sand	212 - 600µm Medium Sand	106 - 212µm Fine Sand	75 - 106µm Very Fine Sand	<75µm Mud (Silt/Clay)
SC1a	0.64%	0.43%	0.69%	53.89%	30.80%	5.21%	8.34%
SC1b	0.03%	0.09%	0.21%	71.97%	23.96%	1.82%	1.93%
SC2a	2.14%	6.49%	4.19%	22.53%	37.64%	13.14%	13.86%
SC2b	0.30%	1.02%	0.49%	21.48%	34.11%	19.03%	23.57%
SC3a	0.01%	0.39%	1.22%	89.58%	7.00%	1.11%	0.69%
SC3b	0.05%	0.15%	0.79%	91.86%	5.89%	0.72%	0.53%
SC4a	1.27%	0.94%	0.92%	36.45%	48.39%	4.85%	7.18%
SC4b	1.08%	3.74%	6.46%	27.49%	30.20%	12.31%	18.72%

A greater proportion of the total arsenic was leachable in the four sediments (11.5 - 29.2%), compared with the proportion of leachable antimony (0-16.7%) in the sediment, as shown in Diagram 11 and Diagram 12.

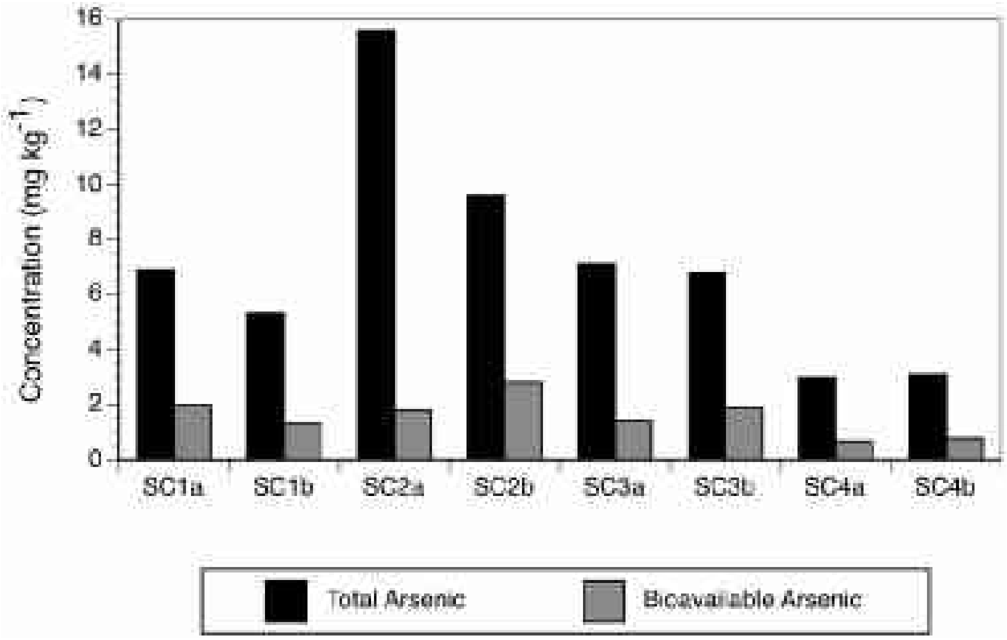


Diagram 11. Total and bioavailable arsenic concentrations in Macleay Estuary sediments.

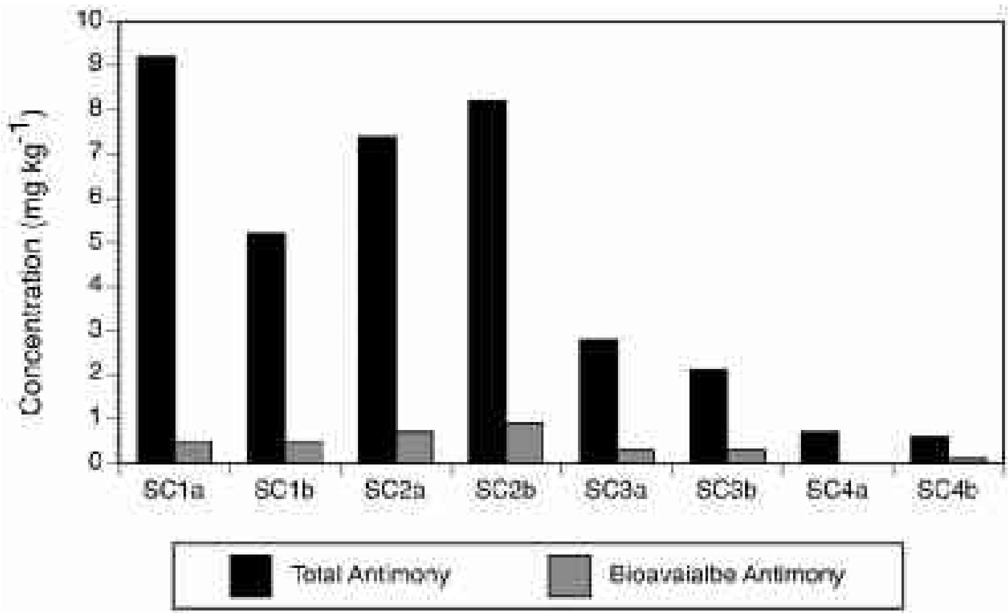


Diagram 12. Total and bioavailable antimony concentrations in Macleay Estuary sediments.

It is interesting to note that site SC4a and SC4b were lower in both arsenic and antimony than the other sites. Previous studies have shown that the Clybucca area is known to have elevated concentrations of both arsenic and antimony. Site SC2a and SC2b were elevated in both arsenic and antimony compared to other sites. The relationship between total arsenic and antimony in all samples was not strong (R^2=0.425) (Diagram 13) although the relationship between the leachable components of these toxicants is stronger (R^2=0.765) (Diagram 14).

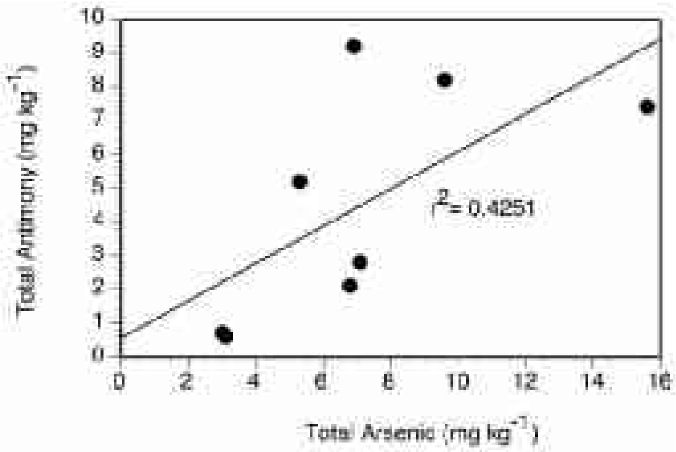


Diagram 13. The relationship between total arsenic and total antimony using analyses from all sediments testing in this study.

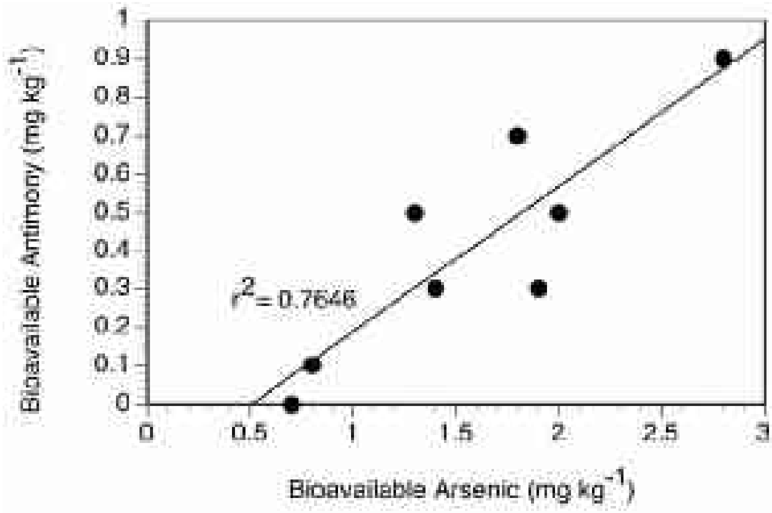


Diagram 14. The relationship between bioavailable arsenic and total antimony using analyses from all sediments testing in this study.

5.5.7. Bioavailability issues

The results of this assessment provide some understanding of bioavailability and it is clear that both arsenic and antimony concentrations are elevated in estuarine sediments. Up to 29.2% of the total arsenic is leachable (potentially bioavailable). Total arsenic concentrations, although elevated, do not exceed the ISQG –LOW guidelines. Antimony concentrations in sediments consistently exceed the ISQG –LOW guidelines throughout the lower estuary (see also Ashley and Graham, 2001), however less than 16% of the total is leachable. It should be noted that the dilute hydrochloric acid leach provides an indication of bioavailability and more detailed studies could provide more definitive information.

Oysters are recognized as very efficient bioaccumulators of trace metals (e.g. McConchie and Lawrence 1991). Some preliminary investigations of arsenic and antimony accumulation in oysters from the Macleay Estuary suggest that arsenic levels slightly exceed the Australian New Zealand Food Authority (ANZFA) guidelines. The oyster industry is the most profitable aquaculture industry in NSW and although there have been some severe impacts on the industry from QX disease the Macleay River is an important and growing production area. It will be important to ensure a viable oyster industry that is not threatened by trace element contamination in the Macleay in the future.

Arsenic and antimony uptake by pasture plants growing on contaminated alluvial soils has been measured (Ashley et al., 2007) and should be considered in future floodplain development and remediation.

Studies on bioaccumulation and potential toxicity of arsenic and antimony are lacking for estuarine environments in Australia. At pH values above 6.0-6.5 and below 3.0 arsenic and antimony may be mobilized and taken up by organisms. Low pH water (e.g. <3.0), which may be a result of heavy rainfall events after long periods of dry in areas of acid sulfate soils, can influence metal speciation and result in higher concentrations of dissolved forms of metals which are more toxic to organisms (see also Tighe et al, 2005b).

Previous studies have shown that flood events result in the deposition of additional contaminated sediments from upstream onto the floodplain (Ashley et al., 2007) therefore the issue of antimony and arsenic contamination on the floodplain will continue to manifest.

5.6. Acid Sulfate Soils

Acid sulfate soils are the result of the deposition of organic rich sediments in coastal embayments during and after the last ice age, some 10 000 years ago. Bacteria in the presence of sea water reduced the available plant sulfates to form iron sulphide or iron pyrite. When these soils are drained due to either natural or artificial lowering of the water table, pyrite is oxidised to sulphuric acid and an acid leachate is formed. This acid leachate can then take iron and aluminium from the soil and when washed into the estuary can be very harmful to aquatic life and vegetation. During dry periods, high concentrations of acidic leachate can accumulate in streams and backswamps, which can become mobilised during flood events.

The Macleay River Estuary floodplain contains large areas considered likely to contain high risk Acid Sulfate Soils (ASS), as shown Figure 44. Inspection of the floodplain reveals many coastal drainage schemes, creek diversions and flood mitigation structures (floodgates), all of which may be associated with the draw-down of groundwater levels, the subsequent exposure of potential ASS, and the formation of actual ASS which have oxidised to form sulphuric acid.

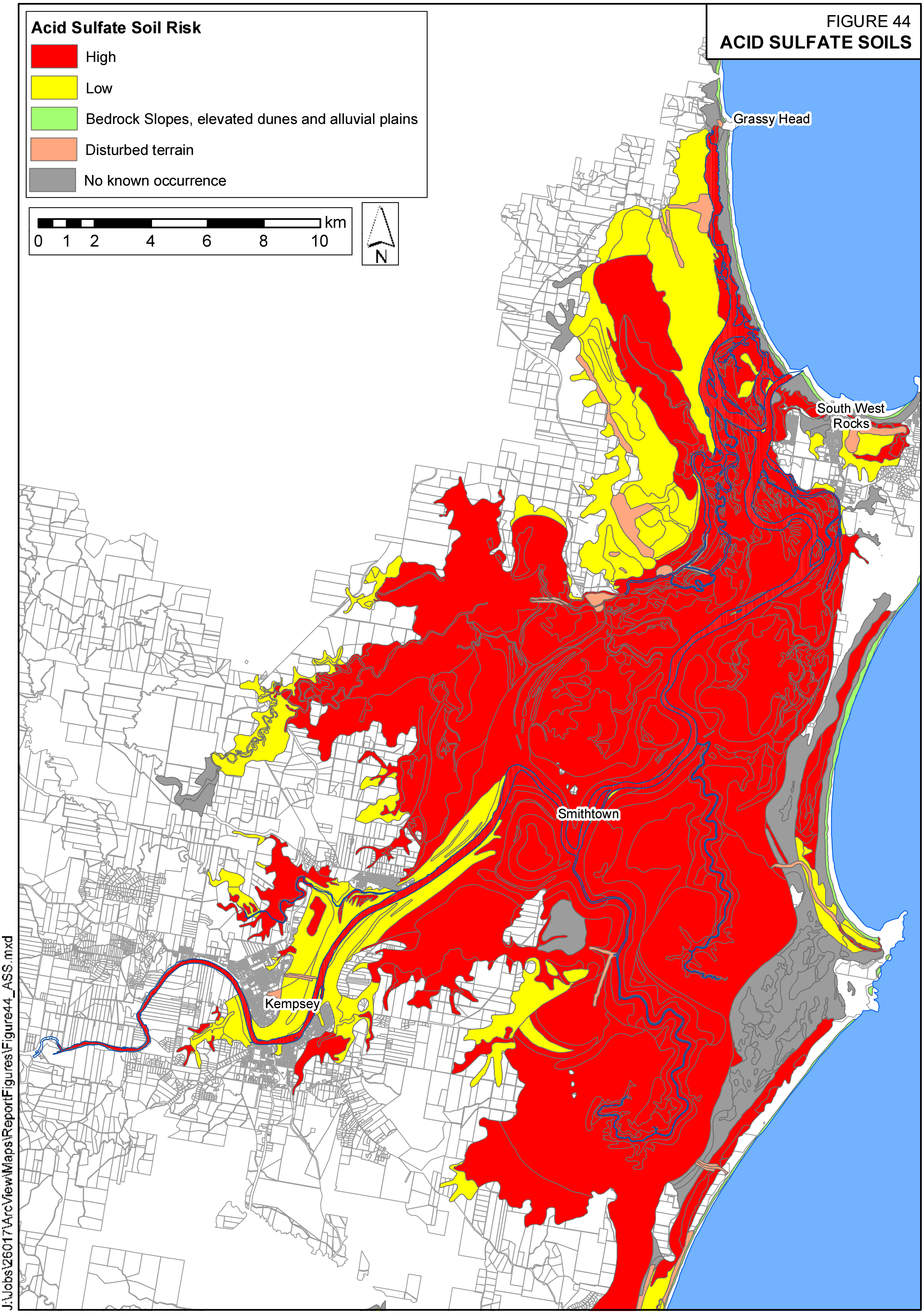


FIGURE 44
ACIDE SULFATE SOILS
Acid Sulfate Soil Risk
High
Low
Bedrock Slopes, elevated dunes and alluvial plains
Disturbed terrain
No known occurrence
0 1 2 4 6 8 10 km
N
Grassy Head
South West Rocks
Smithtown
Kempsey
J:\Jobs\26017\ArcView\Maps\ReportFigures\Figure44_ASS.mxd

Local recordings of pH below 3.0 are not uncommon in some drains (it is considered that pH below 4.0 is toxic, while pH below 6.5 will cause problems for aquatic species over long periods). There are numerous signs of the presence of ASS in the Lower Macleay. These include the presence of shunted vegetation and a total lack of pasture in some areas, deposits of yellow jarosite near the surface, red or brown discolourisation of the water and corrosion of concrete and steel structures. In many areas, acid affects have reduced the viability of the local dairying, grazing and cropping activity.

The following sections provide details of some of the key risk areas in the Macleay estuary. These areas have been highlighted in the Department of Environment and Climate Change's *Acid Sulfate Soil Management Priority Areas in the Lower Macleay Floodplain* and rehabilitation programs in some of the areas have commenced.

5.6.1. Yarrahapinni

Yarrahapinni Broadwater is situated off Andersons Inlet, an arm of the Macleay estuary. Prior to drainage, the area was a large estuarine wetland and a major contributor to the Macleay commercial and recreational fishery.

Works undertaken by Kempsey Shire Council in the area include the construction of floodgates, levees and the Yarrahapinni Drain itself (which refers to the engineered lower section of Borirgalla Creek). These works converted the wetland from a strong tidal estuarine environment to a freshwater wetland near the headworks, grading to a large area of low elevation grazing land.

The soils of the wetland were sampled as part of the ASS Risk Monitoring Program. Oxidised sediments were found to often be within 10 - 40 cm of the soil surface and the water table occurring 50 - 90 cm below the surface, depending on the seasonal conditions. Soil pH was found to be commonly below 3.5. The store of acidity is therefore close to the soil surface and readily available for transport from the groundwater to the estuary. Many areas are scalded and devoid of vegetation.

Soil and water acidification in the wetland can largely be attributed to artificial drainage which has excluded saline water, lowered watertable levels and exposed pyrite to oxidation. The installation of floodgates and deepening and straightening of Borirgalla Creek has increased the drainage and discharge of acidified waters to Anderson Inlet.

The Yarrahapinni Wetland Rehabilitation Program has commenced, which aims to assist in reducing the impacts of past drainage schemes and modifications. As part of the Program, the Yarrahapinni floodgates have been retrofitted to allow controlled volumes of saline water to intrude into the wetland.

5.6.2. Collombatti - Clybucca

The Collombatti - Clybucca wetlands consist of extensive backswamps in the northern part of the Macleay floodplain, centred on Collombatti Creek upstream of Clybucca. The land is privately owned and the drainage system is managed by the Seven Oaks Drainage Union. The wetlands have a long history of drainage, and are currently bisected by the Seven Oaks Drain, a large main drain that links the wetlands to Clybucca Creek and the Macleay River. Tidal ingress into the Seven Oaks Drain is prevented by the Clybucca floodgates. The control structure is a series of 21 floodgates that control tidal flow and prevent saltwater intrusion, which would otherwise extend 10 - 15 km upstream of the gates.

ASS in the wetlands are known to be extensive. It is generally accepted that artificial drainage and flood mitigation have lowered average watertable levels, accelerating oxidation of pyrite and resulting in soil and groundwater acidification. Oxidation in the large scalded area of Mayes swamp occurs to a depth of 1 m beneath the surface, representing a huge store of acid, and the wetlands include some of the worst affected areas in Australia. Soil pH is usually below 3.5 near the surface, to 6.5 - 8.0 in the deeper soil.

Runoff from these soils causes acidification of the Seven Oaks Drain and Clybucca Creek, with fish kills being reported in Clybucca Creek for many years.

A number of ASS/backswamp remediation projects have been undertaken in this area to address ASS and water quality land productivity issues.

5.6.3. Belmore Swamp

Belmore Swamp is a large expanse of backplain and backswamp centred on an area of approximately 13 km east of Kempsey, in the south-eastern part of the Macleay floodplain. Prior to flood mitigation and drainage, Belmore Swamp included approximately 1300 ha of seasonal freshwater wetlands for about six months of the year. The Belmore Swamp is privately owned, apart from a number of portions of Crown land, including leasehold land, in the central section of the swamp. The area was previously managed in part by the former Gladstone Drainage Union.

The Belmore system has been part of a large-scale flood mitigation scheme consisting of extensive structural works such as floodgates, artificial drainage channels and levees. The Belmore River Control Gate is opened to allow floodwaters into the natural flood basin of Belmore Swamp. The floodwaters released into the natural basin are then drained back into Belmore River and Kinchela Creek via the system of artificial drainage channels and floodgates, and through ocean outlets (ie. Killick Creek and Ryan’s Cut).

The engineered system of water management in Belmore has drastically altered the ecological balance of the wetlands. Drainage of the wetlands has led to major changes in vegetation species - water tolerant species have been replaced with couch, smartweed and pinrush. These less water tolerant species die and decay very quickly during inundation and flooding. Decomposition of the pastures causes deoxygenation of the water which then drains back into the river, contributing to fish kills. Alteration of the water balance in the wetlands has also caused the accelerated oxidation of pyritic sediments to ASS.

Topsoil pH ranges from 4.5 - 6.0, whilst subsoils range from 4.5 - 7.0. Oxidation of the estuarine sediments is widespread throughout the wetlands. Extremely acid grey clays with distinctive jarositic mottling occur within 50 cm of the soil surface in many of the lowest areas. The water table occurs at 50 - 80 cm.

Drainage of the wetlands of Belmore has played a large role in the accelerated oxidation of the ASS, and the transport of acid and other oxidation products such as aluminium to the river. Water quality monitoring to date indicates that acidity levels are often toxic to aquatic life.

A number of remediation projects are also being undertaken in this area to address the impacts of ASS.

5.6.4. Frogmore

Frogmore is an area of backswamps centred on Frogmore Drain, 6 km north-east of Kempsey, on the south-eastern side of the Macleay River. Frogmore is privately owned and managed. Floodwaters are drained from the wetlands via Frogmore Drain, a relatively large and straight drain which joins the Belmore River. Other major drains include Lancasters and Darkwater Branch Drains. These deep main drains have cut into sulfidic layers. Numerous other smaller drains remove surface waters to Frogmore drain. Drainage and tidal water intrusion is controlled by a large set of floodgates at the river.

ASS materials occur generally within 60 cm of the soil surface. pH levels of the soil have been measured at around 3.7. Artificial drainage of these soils appears to be having a significant impact on the water quality in the drains and ultimately the river. The acidity within the Frogmore drain is often toxic to aquatic life.

Floodgates have been actively managed by landholders since 2002, to improve water quality and aquatic habitat within the drainage network.

5.6.5. Kinchela Swamps

Kinchela is a large backswamp area centred on Kinchela Creek and Swan Pool, to the east of the Belmore River, approximately 16 km east-north-east of Kempsey, adjacent to the coastal sand masses of Hat Head National Park. Kinchela Swamp is mostly privately owned, although small sections in the Upper Kinchela Creek area are part of the Hat Head National Park.

Kinchella Creek is part of the Macleay flood mitigation system consisting of extensive structural works such as floodgates, artificial drainage channels and levees. The Kinchela Creek Right Bank and Left Bank Control Gates are opened to allow floodwaters into the natural flood storage basins of Kinchela Swamp. The floodwaters released into the natural basin are then drained back into Kinchela Creek and Korogoro Creek via the system of artificial drainage channels and floodgates. As with Belmore, the engineering drainage and flood mitigation works have drastically altered vegetation species in the Kinchela wetlands.

pH ranges have been recorded from 5.5 - 6.0 in both topsoil and subsoil, although it is likely that materials with lower pH also occur. Oxidation of the estuarine sediments is widespread throughout the wetlands. Extremely acid grey clays with distinctive jarositic mottling occur within 50 cm of the soil surface in many of the lowest areas.

Drainage of the wetlands of Kinchela has played a large role in the accelerated oxidation of the ASS and the transport of acid and other oxidation products, such as aluminium, to the river. Kinchela Creek regularly experiences fish kills. Water entering the creek from the drains has often been toxic to aquatic life with very high levels of acidity, iron and aluminium. Drainage water is periodically deoxygenated because of the inundation of pastures by floodwater.

5.6.6. Raffertys

Raffertys is a wetland approximately 20 km north-east of Kempsey. The wetland is located in a depression separating the Macleay River levee and the coastal sand dunes between Hat Head and South West Rocks. The wetland is privately owned and managed. Drainage of the Raffertys area consists of Raffertys Drain, the main drain bisecting the area, smaller feeder drains and a larger set of floodgates near the river.

Oxidation of estuarine sediments has occurred in the area, although the lateral and vertical extent of oxidation is not known. In some of the lowest areas the acid sulfate soil layer is extremely close to the ground surface and during dry periods, small acid scalds have been observed. It may be that drainage of the area has caused irreversible soil shrinkage, lowering the ground surface. The acidic water and milky green flocs (normally associated with aluminium rich water) from Raffertys drain have been observed to discharge into the river on many occasions.

This particular area has not been the focus of attention for ASS in the lower Macleay. No long term water quality monitoring has been carried out of discharges from the Raffertys area. However, 3km of the original 3.8km of deep drainage system has been decommissioned and replaced with a wide and shallow dish drain.

5.7. Summary and Synthesis – Key Biogeochemical Processes that Control and Maintain the Ecological Health of the Macleay Estuary

Physical, biogeochemical and ecological processes in the Macleay Estuary can be conceptualised in terms of three broad stages (Eyre and Twigg, 1997; Eyre 2000; Eyre and Ferguson, 2006), each driven by freshwater discharge. These are discussed below.

Stage 1 (flood)

During large floods (e.g. May 1996) the Macleay Estuary, like other east Australian subtropical estuaries (Eyre, 2000), flushes fresh to the mouth. When floodwater pushes the salt intrusion through the mouth, estuarine processes are by-passed and freshwater, sediment and nutrients are discharged directly onto the continental shelf. If the flood is sufficiently large the estuarine basin may remain fresh at the mouth for a number of days and significant scouring of the estuary channel can occur. For example, during a 1 in 5 year return period flood the Richmond River estuary flushed fresh to the mouth for about 10 days and more sediment was delivered to the shelf than was imported from the catchment (i.e. scouring of the estuarine basin). In contrast, even if just a small part of the salinity gradient remains within the mouth of the estuarine basin there may be significant deposition and processing of material within the estuary. This was illustrated in the sub-tropical Brisbane River estuary during a 1 in 20 year return period flood in May 1996, where the flushing time decreased to only 0.3 days, but the flood failed to push the salt intrusion through the mouth and 22% of the flood-borne sediment was deposited within the estuarine basin (Eyre *et al.*, 1998).

Large floods will also inundate the floodplain where floodwaters will be de-oxygenated via the decomposition of organic matter and disturbance of sulphides in agricultural drains (Eyre et al., 2006), and sediments contaminated with antimony and arsenic will be deposited (Ashley et al., 2007). Floods also impact on the higher order ecology of the estuarine system. Positive impacts include an increase in nutrient supply, restoration of water levels in floodplains and the creation of habitat diversity. Negative impacts include nest disturbance, temporary loss of habitat, and loss of food supply (i.e. fish kills) due to poor water quality (i.e. low pH, low dissolved oxygen).

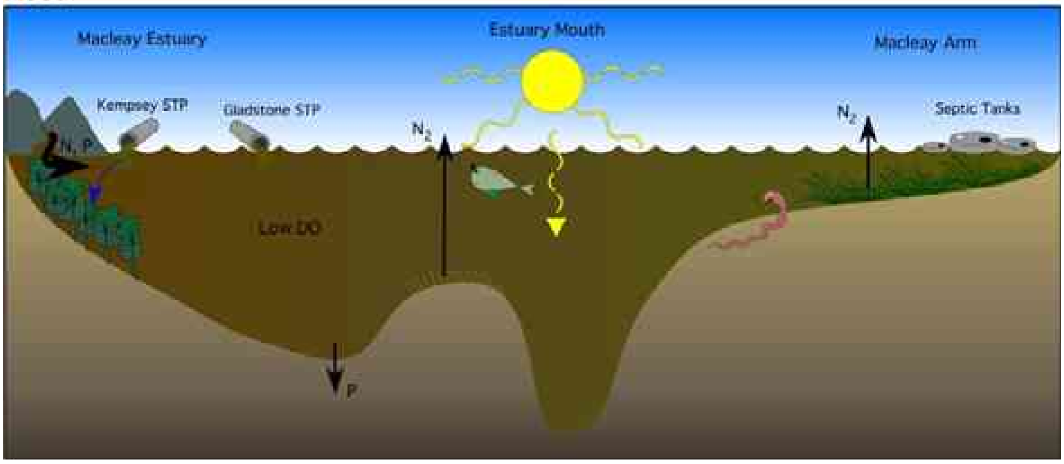


Diagram 15. Conceptual model of key physical, biogeochemical and ecological processes in the Macleay Estuary during flood.

Stage 2 (post-flood recovery)

As the Macleay Estuary recovers following floods it progresses from a highly stratified salt wedge estuary, through a partially mixed system with a well developed two layered circulation, to a vertically homogeneous system. Immediately following floods some of the sediment from the sediment-laden upper layer probably settles through the halocline at slack water where it would be caught in the lower layer, transported landward, and deposited near the salt / freshwater interface (Eyre 2000). Dissolved oxygen concentrations in the water column are reduced due to the breakdown of organic material (including NH_4 production by ammonification) mobilised by the floodwaters, and the discharge of de-oxygenated floodwaters from agricultural areas were oxygen is consumed via organic matter decomposition and oxidation of iron monosulphides (Eyre et al., 2006). Maximum algal biomass can occur during this stage due to elevated nutrients associated with diffuse runoff, increasing flushing times and improving light conditions. Post-flood, nitrate freshwater endmember concentrations in the estuary, and river nitrate concentrations at Turners Flat have both increased slightly over the last 10 years.

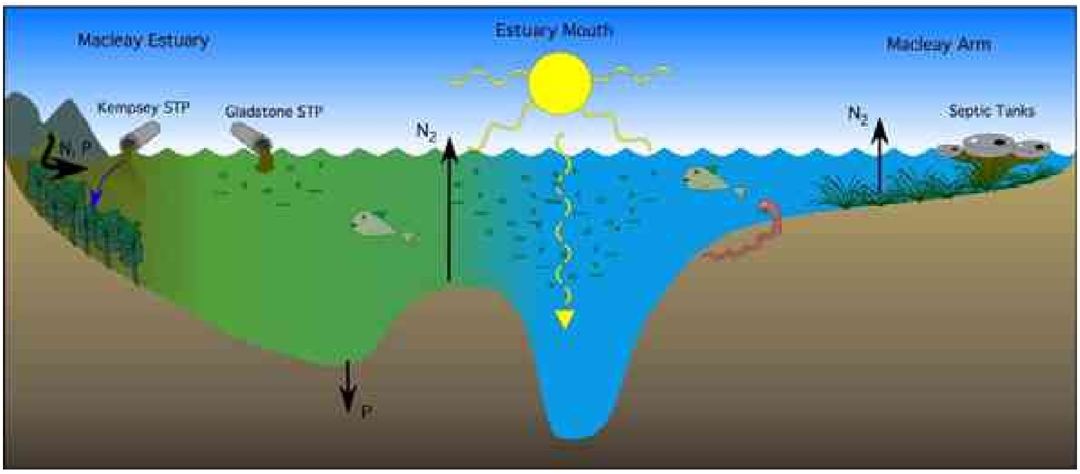


Diagram 16. Conceptual model of key physical, biogeochemical and ecological processes in the Macleay Estuary during post flood periods.

Stage 3 (dry season)

During the dry season the Macleay Estuary is a vertically homogenous system due to low freshwater discharge. Wastewater can contribute up to 44% of the monthly total nitrogen input, but only up to 8% of the monthly phosphorus input. Despite the largest wastewater loads being discharged in the upper estuary/ tidal river (i.e. South and West Kempsey STPs) nutrient and algal biomass concentrations are low due to uptake by the macrophyte beds in the reach between Frederickton and Kempsey. Wastewater nutrient loads are most likely helping maintain the growth of the macrophyte beds in the upper estuary/ tidal river, but these plants are in-turn striping out the wastewater nutrients and making them unavailable to phytoplankton. It would be expected that algal biomass would be higher in the upper estuary/ tidal river without nutrient uptake by the macrophyte beds.

Maximum dry season algal biomass occurs adjacent to, and downstream from, the Gladstone wastewater discharge suggesting the input of nutrients are stimulating phytoplankton growth. The estuary can become nutrient limited as shown by nutrient concentrations that approach the detection limit due to biological removal. As such, any additional nutrient inputs are likely to result in an increase in algal biomass. However, there does not appear to have been any significant changes in dry season nutrient or algal biomass concentrations in the main arm of the Macleay Estuary over the last 10 years. Summer phytoplankton blooms adjacent to Grassy Head and Stuarts Point were probably driven by an increased load of nutrients and poor flushing in the upper Macleay Arm. Possible sources of nutrients includes discharge from septic tanks, which is also consistent with the slight enrichment of ^{15}N in the seagrass adjacent to Grassy Head, and/or released from the sediments during summer due to enhanced remineralization and resuspension. Further investigation of the factors controlling summer phytoplankton blooms (e.g. nutrient sources) in the Macleay Arm is recommended.

The carbon, nitrogen and phosphorus budgets highlighted the importance of benthic production as a carbon source for the Macleay Estuary. It is this carbon supply that supports higher order consumers such as fish. As such, it is critical that management actions are directed towards maintaining benthic production. The most important factor to maintain is low light attenuation in the water column as this allows light to reach the bottom and maintain benthic production. To maintain low light attenuation both TSS and chlorophyll-a concentrations must not be allowed to increase.

Denitrification was the largest output of nitrogen from the Macleay Estuary. As such, it is critical that management actions are also directed towards maintaining benthic denitrification. The most important factor to maintain is low pelagic carbon loading rates (algal production). Increased organic loading from phyto-detritus leads to an increase in benthic carbon decomposition and oxygen consumption with more nitrogen recycled to the water column as ammonium and less nitrogen lost to the atmosphere via coupled nitrification-denitrification.

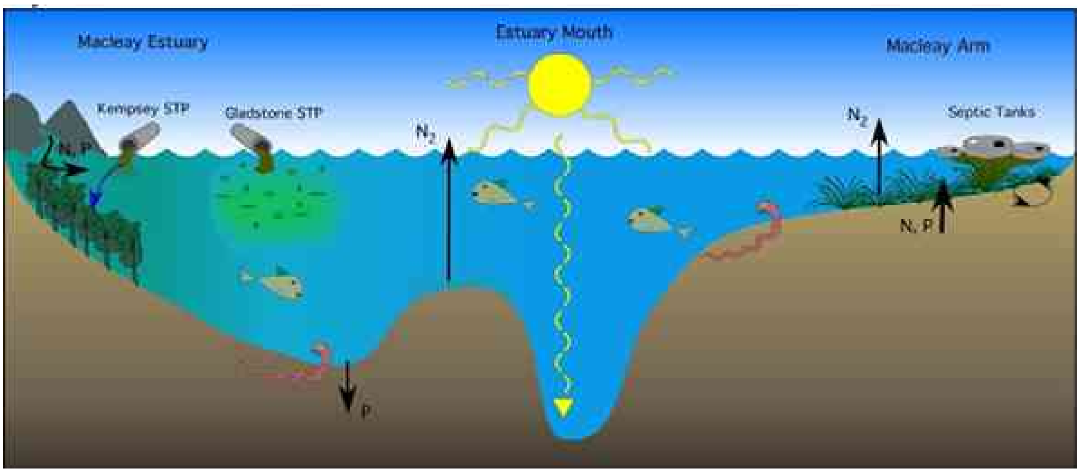


Diagram 17. Conceptual model of key physical, biogeochemical and ecological processes in the Macleay Estuary during post dry seasons.

5.8. Water Quality Interaction

5.8.1. Catchment Drainage Characteristics

In order to understand water quality processes in the estuarine environment, it is necessary to understand the path by which water is mobilised throughout the estuary and identify catchment sources of water contaminants. A general description of the estuary and catchment characteristics is presented in Chapter 2, with a review of the system hydrodynamics in Chapter 3, so only a number of salient points for consideration of estuarine water quality are presented here.

By far the greatest movement of water occurs as a result of tidal flows into and out of the ocean entrance (see Section 3.4.4). It is the interaction of these saline marine waters with fresh (and possibly partially contaminated) catchment runoff waters which determines estuarine water quality. The catchment waters are sourced from three main topographical drainage systems, each of which has different pollution source characteristics:

1. a coastal plains/swamp drainage system,
2. a coastal floodplain/mid valley drainage system,
3. an upper valley/catchment drainage system.

5.8.2. Process Interactions

Contaminants which enter the Macleay River estuary via the various drainage systems can decay, be washed out to sea, deposited on the floodplain, incorporated into bed sediments, or be taken up by plants or animals and enter the biological system. Contaminants which are not incorporated into bed sediments can be remobilised under certain conditions and can be taken into the biological system, lost to the estuary or again returned to the sediments.

Natural Decay

Marine waters are naturally slightly alkaline, a feature associated with the dissolved carbonate. This low alkalinity helps to neutralise or buffer acid runoff. The mixing of acid waters with marine waters is therefore an important control on leachate impacts. However, the mixing can also cause the deposition of dissolved minerals, such as iron and aluminium, and takes carbonate (used for making shells) from the water.

Oxygen levels are an important indication of the capacity of the waterway to sustain aquatic animal life. Excessive amounts of organic material with a high biochemical oxygen demand (BOD), such as can occur in sewage effluent, can reduce dissolved oxygen levels as a result of bacteria oxidising the organic matter.

Nutrients, particularly nitrogen compounds (complex organic nitrogen proteins, acids and urea which are found in sewage effluent), are oxidised to form ammonia nitrogen, which in turn can then be oxidised to form nitrites and finally nitrates. The oxidation products are more readily available for uptake by plants. Under anaerobic (non oxygen) conditions nitrogen compounds can be broken down to form free nitrogen.

Most human pathogenic organisms (again associated with sewage) die off when exposed to estuarine conditions. Under most conditions bacteria such as faecal coliforms die off more quickly in receiving waters than do enteric viruses and most parasites.

Tidal Exchange

The movement and exchange of water through the ocean entrance is a major component of the estuarine water quality process. Pollutants which enter the waterway do not necessarily reman in the estuary but can be exchanged for ocean waters by tides or flushed from the system during floods.

Tidal exchange is highly dependent on both the level of tidal flows and on the mixing rates between polluted catchment inflows and ocean waters. As discussed in Section 3.4.4, tidal flows are largely determined by the relative ocean tide levels. The mixing of estuary waters with ocean tide waters inside the estuary is a more complex problem which depends upon a range of factors such as flow velocities, channel shape, bed conditions and wind generated currents.

Fluvial flushing is mainly dependent on the volume of water entering the estuary from the catchment during a particular flood/flushing event.

Sediment Transfers

Fine sediments are an important part of water quality processes because not only do they act as pollutants themselves in the form of suspended solids, but they also act as a carrier for other pollutants, particularly nutrients, heavy metals and chemicals such as pesticides. The movement and deposition of fine sediments throughout the estuary is therefore of interest when determining pollution export rates.

Biological Cycling

Nutrients in the estuary are often recycled. Nutrients taken up by plants can be returned to the water as animal waste after being eaten and expelled by aquatic animals. Alternatively the plants will eventually die and the nutrients released as the plant matter breaks down.

Nutrients attached to fine bed sediments can be released when conditions at the bed become anoxic. These conditions usually develop in deep holes under stratified water layers where the BOD is sufficient to lower the levels of dissolved oxygen. Nutrients released from bed sediments become available for plant growth.

5.8.3. Impact of Climate Change on Water Quality

Changes in ocean levels as a result of climate change may reduce acid leachate levels by reducing the exposure of acid sulfate soils to oxygen, but are unlikely to have a major impact on estuary water quality. Possible impacts include:

- Increasing temperature will change the solubility of different compounds in water eg will decrease the solubility of oxygen, hence reduce dissolved oxygen concentrations which will negatively impact upon aquatic fauna and may lead to more algal blooms, eutrophication etc.
- Increasing ocean levels could change entrance characteristics, salinity profile and flushing characteristics.
- Changing rainfall patterns could change flushing characteristics and hence nutrient transport. More intense rainfall could lead to more runoff producing events and more transport of sediment and contaminants into the estuary.

6. ECOLOGICAL CHARACTERISTICS

This chapter provides a summary of significant terrestrial and aquatic fauna and their habitat in the Macleay estuary. It also discusses how the ecology of the Macleay estuary is affected by significant processes such as flooding, eutrophication and overfishing. Additional information relating to the habitat of terrestrial species can be found in *The Macleay Estuary Data Compilation Study – Flora and Fauna Habitat Study* (ID Landscape Management, 2005).

6.1. Threatened Terrestrial Fauna and their Habitat on the Macleay River Floodplain

The specific objectives of this section are to:

- Identify any rare or endangered species or communities and areas of conservation significance that may require special management attention, using the mapped fauna of the river and its floodplain wetlands.

- Describe the role of flood events on the ecology of the river and its floodplain, identifying critical times of year for different biota life cycle functions, such as nesting and breeding.

Information on the threatened fauna and their habitats of the Macleay River floodplain was obtained from existing data sources, specifically ID Landscape Management (2005) and GECO Environmental (2005).

This section firstly summarises the threatened and significant terrestrial fauna known to the study area. The section then focuses on those species that use the river (including its estuary) and/or the associated floodplain wetlands. Species that do not use wetlands as their primary habitat will not be subject to detailed consideration. In the context of this chapter, “wetland” is used broadly to refer to brackish estuarine habitats (including open water) and to permanent and ephemeral freshwater wetlands of the floodplain.

6.1.1. Threatened Fauna and Other Significant Species

A total of 46 threatened fauna species listed under the NSW *Threatened Species Conservation Act* 1995 (TSC Act) have been recorded in the study area, comprising 7 endangered and 39 vulnerable species (Table 36). Six of these species are also listed under the Commonwealth *Environment Protection and Biodiversity Conservation Act* 1999 (EPBC Act). Based on their known distribution and habitat requirements, a further 21 threatened fauna listed under the TSC Act have the potential to occur in the study area, including 3 species listed under the EPBC Act. This report focuses on those species that have actually been recorded in the study area. Moreover, detailed consideration is only given to those species that occupy estuarine or floodplain wetlands (Table 37).

Table 36 Summary of Threatened Fauna Species known or with the Potential to occur in the Study Area

	No. Species	
Status	**TSC Act**	**EPBC Act**
Known		
Endangered	7	4
Vulnerable	39	2
Amphibians	2	1
Reptiles	4	0
Birds	24	3
Mammals	16	2
Total Known	**46**	**6**
Potential		
Endangered	8	2
Vulnerable	13	1
Total Potential	**21**	**3**
Total Species	**67**	**9**

A total of 82 migratory species (73 birds, 6 mammals, 3 reptiles) listed under the EPBC Act have been recorded or potentially occur in the study area, but only 39 of these are dependent on wetland habitats (Table 38). Of these, 32 are migratory waders principally in the Family Charadrii. These species spend the non-breeding season in Australia where intertidal flats are the primary foraging habitat. The remaining seven migratory species are either raptors (birds of prey) or terns, which feed over open water.

Bird and mammal taxa represent most of the threatened species known to the study area (Table 36). Bird species are more likely to be dependent upon estuarine and floodplain wetlands than mammals (Table 37), suggesting that bird taxa are most likely to be affected by hydrological conditions. Bird species also constitute most of the migratory species potentially occurring in the study area. Thus, bird species are mostly likely to require management attention within wetland habitats in the study area.

Table 37 Threatened Fauna Species known to occur in the Study Area, the Vegetation Communities they have been recorded in and the likely use of each community

Status: E = endangered, V = vulnerable; use categories: F = foraging, R = roosting, N = nesting, E = entire life cycle

Ecological information derived from (Schodde and Tidemann 1988; Clancy 1991; Strahan 1995; Cogger 1996; Churchill 1998; Pizzey and Knight 2001; Fitzgerald *et al.* 2002[1,2]; Morcombe 2003).

* Note: these are high-flying bats, while they would forage above the indicated habitats they would not actually use it in a direct way.

Species		Status		Vegetation Community							
Common Name	Scientific Name	TSC	EPBC	Rainforest	Riparian Forest	Open Forest	Mangrove	Open Water	Intertidal Flats	Saltmarsh	Freshwater Wetlands
Reptiles											
Stephen's Banded Snake	*Hoplocephalus stephensi*	V		E	E	E					
Birds											
Magpie Goose	*Anseranas semipalmata*	V									F
Black Bittern	*Ixobrychus flavicollis*	V					E			F	E
Black-necked Stork	*Ephippiorhynchus asiaticus*	E					F			F	F
Osprey	*Pandion haliaetus*	V		R, N	R, N		F, R	F			F
Square-tailed Kite	*Lophoictinia isura*	V			F	F					
Comb-crested Jacana	*Irediparra gallinacean*	V									F, N
Sooty Oystercatcher	*Haematopus fuliginosus*	V					F		F, R		
Pied Oystercatcher	*Haematopus longirostris*	V					F		F, R		
Painted Snipe	*Rostratula benghalensis australis*	E	V				R		F	F	F, R
Little Tern	*Sterna albifrons*	E	E					F			
Rose-crowned Fruit-dove	*Ptilinopus regina*	V		F, N	F, N?						
Wompoo Fruit-dove	*Ptilinopus magnificus*	V		F, N?	F, N?						
Glossy Black-cockatoo	*Calyptorhynchus lathami*	V			F, R, N	F					

Species		Status		Vegetation Community								
Common Name	Scientific Name	TSC	EPBC	Rainforest	Riparian Forest	Open Forest	Mangrove	Open Water	Intertidal Flats	Saltmarsh	Freshwater Wetlands
Swift Parrot	*Lathamus discolor*	E	E		F	F					
Powerful Owl	*Ninox strenua*	V		F, R, N	F, R, N						
Sooty Owl	*Tyto tenebricosa*	V		F, R, N	F, R, N						
Marbled Frogmouth	*Podargus ocellatus*	V		E	E						
Barred Cuckoo-shrike	*Coracina lineata*	V		F, R, N	F, R, N	F					
Regent Honeyeater	*Xanthomyza phrygia*	E	E			F					
Mammals											
Eastern Blossom-bat	*Syconycteris australis*	V		R	F						
Grey-headed Flying-fox	*Pteropus poliocephalus*	V	V	F, R	F, R	F	R				
Yellow-bellied Sheath-tail Bat	*Saccolaimus flaviventris*	V		F, R	F, R	F, R	F*		F*	F*	
Eastern Freetail Bat	*Mormopterus norfolkensis*	V		F, R	F, R		F*		F*	F*	
Hoary Wattled Bat	*Chalinolobus nigrogriseus*	V		F, R	F, R						
Little Bent-wing Bat	*Miniopterus australis*	V		F	F						
Greater Broad-nosed Bat	*Scoteanax rueppellii*	V		F, R	F, R	F, R					

Table 38 Migratory Species Listed under the EPBC Act known or potentially occurring within the Study Area. Only species requiring wetland (freshwater and brackish) and open water habitats are shown.

Common Name	Scientific Name	Known
Ruddy Turnstone	*Arenaria interpres*	✓
Cattle Egret	*Budulcus ibis*	✓
Sharp-tailed Sandpiper	*Calidris acuminata*	
Red Knot	*Calidris canutus*	
Curlew Sandpiper	*Calidris ferruginea*	
Long-toed Stint	*Calidris minutilla*	
Red-necked Stint	*Calidris ruficollis*	✓
Great Knot	*Calidris tenuirostris*	
Large Sand-dotterel	*Charadrius leschenaultia*	
Mongolian Sand-dotterel	*Charadrius mongolus*	
White-winged Black Tern	*Chlidonias leucoptera*	
Sanderling	*Crocethia alba*	
Great Egret	*Egretta alba*	✓
Latham's Snipe	*Gallinago hardwickiii*	✓
White-bellied Sea-eagle	*Haliaeetus leucogaster*	✓
Caspian Tern	*Hydropopgne tschegrava*	✓
Broad-billed Sandpiper	*Limicola falcinellus*	
Bar-tailed Godwit	*Limosa lapponica*	✓
Black-tailed Godwit	*Limosa limosa*	✓
Eastern Curlew	*Numenius madagascariensis*	✓
Little Curlew	*Numenius minutus*	
Whimbrel	*Numenius phaeopus*	✓
Osprey	*Pandion haliaetus*	✓
Ruff	*Philomachus pugnax*	
Glossy Ibis	*Plegadis falcinellus*	✓
Pacific Golden Plover	*Pluvialis dominica*	
Grey Plover	*Pluvialis squatarola*	
Painted Snipe	*Rostratula benghalensis*	✓
Little Tern	*Sterna albifrons*	✓
Crested Tern	*Sterna bergii*	✓
Common Tern	*Sterna hirundo*	✓
Grey-tailed Tattler	*Tringa brevipes*	
Wood Sandpiper	*Tringa glareola*	✓
Common Sandpiper	*Tringa hypoleucos*	
Wandering Tattler	*Tringa incana*	
Common Greenshank	*Tringa nebularia*	✓
Marsh Sandpiper	*Tringa stagnatilis*	✓
Buff-breasted Sandpiper	*Tryngites subruficollis*	
Terek Sandpiper	*Xenus cinereus*	

6.1.2. Habitat Areas of Conservation Significance

Threatened fauna often require specific habitats or a combination of specific habitat types. Any habitat essential to the life cycle of a threatened species may, therefore, be of conservation significance. Specific habitat types may also have legislative protection. The TSC Act lists a number of floodplain vegetation communities as Endangered Ecological Communities (EEC). State Environmental Planning Policy (SEPP) 14 Coastal Wetlands and SEPP 26 Littoral Rainforests are also mapped for conservation purposes. Many habitat areas of the Macleay floodplain have legislative protection of some form. The EECs and SEPP 14 wetlands are considered further in this report. Many floodplain fauna are dependent upon specific wetland habitats to complete major components of their life cycle, such as breeding.

Seven different wetland types have been mapped under SEPP 14 – Coastal Wetlands: mangroves, saltmarshes, Melaleuca forests, Casuarina forests, sedgelands, brackish and freshwater swamp, and wet meadows. However, a number of other groundwater-dependent ecosystems were omitted from SEPP 14. Recently, a number of these communities were listed as EECs under the TSC Act (the most relevant being Coastal Saltmarsh and Freshwater Wetlands on Coastal Floodplains, Subtropical Coastal Floodplain Forest, Swamp Sclerophyll Forest on Coastal Floodplains, Swamp Oak Floodplain Forest and River-flat Eucalypt Forest). The wetland types considered important to threatened and migratory species are mangroves, saltmarshes, sedgelands, brackish and freshwater swamp and wet meadows.

In estuaries and on floodplains, the frequency and duration of inundation, substrate type, and salinity are the major determinants of wetland type (Goodrick 1970; Davis *et al.* 2001; Peirson *et al.* 2002). Wetland boundaries can change in response to variation in the amount of rainfall, which affects water levels. In estuarine habitats, the frequency and extent of tidal inundation are also important determinants of habitat type. In coastal catchments, floods represent extreme but short-lived increases in water levels.

Thirteen major areas of habitat were identified on the Macleay floodplain, as shown in Table 39. Only three significant wetland areas were identified on the upper floodplain (corresponding to Zone C of ID Landscape Management 2005). Two of these were the only substantial billabongs in the study area. The freshwater wetland/fresh meadow on upper Christmas Creek is smaller than similar habitats in the mid section of the floodplain.

Table 39 Significant Areas for Significant Fauna on the Macleay Floodplain

"Zone" refers to the division of the Macleay floodplain as defined by ID Landscape Management (2005, Plan 1).

Area	Zone	Significance
Christmas Creek (north of Kempsey)	C	Freshwater wetland on upper floodplain
Barnetts Lagoon	C	Billabong on upper floodplain
Old Pola Creek	C	Billabong on upper floodplain
Cooroobongatti Swamp	B	Freshwater wetland on mid floodplain
Swamp W & SW Clybucca	B	Freshwater wetland on mid floodplain
Swamp NE Kinchela	B	Freshwater wetland on mid floodplain
Swamp SE Kinchela	B	Freshwater wetland on mid floodplain
Swamp S Jerseyville	B	Freshwater wetland on lower floodplain
Clybucca Creek	A	Tidal Channel, saltmarsh / wetland
Andersons Inlet	A	Tidal Channel,
Pelican Island	A	Saltmarsh / wetland
N of Rainbow Beach (b't river & Clybucca Ck)	A	Saltmarsh / wetland
Shark Island & adjacent channels	A	Tidal Channel, saltmarsh, extensive mudflats

Five freshwater wetlands/fresh meadows were identified on the mid floodplain (corresponding to Zone B of ID Landscape Management 2005). Four of these are large freshwater wetlands/fresh meadows. The swamp south of Jerseyville is relatively small, but it occurs in close proximity to other wetlands (i.e. the wetland north-east of Kinchela). While these wetlands are predominantly fresh, there is likely to be some brackish influence resulting in areas of saltmarsh. In the middle section of the study area the Macleay River channel is beginning to broaden and small intertidal flats have developed.

The lower floodplain (corresponding to Zone A of ID Landscape Management 2005) has substantial areas of wetland and it is only possible to document the most significant of these. Infilling of the estuary has resulted in the formation of a delta, with the resulting formation of islands (e.g. Pelican Island, Shark Island), which have extensive areas of intertidal flats around their margins. The landward communities of the estuary are comprised mainly of mangroves and saltmarsh.

6.1.3. Flooding and the Ecology of Significant Floodplain Fauna

Rainfall in Australia is highly variable. Many Australian catchments experience intense rainfall events that result in flooding. Floods may have both positive and negative effects on wetland fauna. However, the precise impact of flooding is determined by a number of factors. These include the extent, duration, frequency and season of flooding (Davis et al. 2001; Peirson et al. 2002).

Positive Effects of Flooding

The positive effects of flood events include the transport of nutrients. The regular input of nutrients maintains the productivity of floodplains and estuaries. These habitats can therefore support a high biomass, commencing at low levels of the food chain, which ultimately translates into larger populations of vertebrate species (Peirson et al. 2002). The increased productivity associated with flooding is regarded to benefit the breeding of many wetland birds (Davis et al. 2001), although specific species may be adversely affected (see below). Flooding also provides variability to flow regimes (Davis et al. 2001; Peirson et al. 2002). Flood events fill freshwater wetlands and form ephemeral (temporary) wetlands. Such recharge events restore water levels in floodplain wetlands, maintaining their quality. As wetlands subsequently dry out, prey species such as fish and eels become concentrated and easier to harvest. This benefits species such as the Black-necked Stork (*Ephippiorhynchus asiaticus*) (Dorfman *et al.* 2001).

New channels and billabongs can be formed during flood events. This creates habitat diversity, which facilitates use of an area by a greater number of species. The creation of billabongs enables new floodplain wetlands to become available as older ones progressively infill. Flood events build, shape and maintain habitats and habitat features (Peirson et al. 2002). Sediment deposited during flood events creates the mudflats required for foraging by migratory waders. As mudflats build they eventually become colonised by mangroves. Mangroves are used as roosting habitats by species such as migratory waders. Floods also transport large logs, which then deposit in wetlands and estuaries. Logs are used as perches by estuarine birds. Floods maintain wetland health by removing organic matter that accumulates during low flow periods, replenishing dissolved oxygen levels (Peirson et al. 2002).

Negative Impacts of Flooding

One of the negative effects of flooding is nest disturbance (Smith 1990). Some threatened birds, such as the Little Tern (*Sterna albifrons*) and the Pied Oystercatcher (*Haematopus longirostris*), nest on beaches and on sand spits in estuaries. Nesting may be disrupted by flood events during the nesting period, which is given in Table 40.

Flood events increase the water levels in estuaries and on floodplains, which may have the effect of temporarily lowering habitat availability (e.g. water may be too deep for foraging). This effect would only last as long as the flood event, but prolonged flooding may result in the mortality and/or redistribution of prey species (e.g. fish, crustaceans) (Peirson et al. 2002). Flood waters trapped behind flood gates not only destroy foraging habitat but can become anoxic and/or can mix with ASS waters. When released these low pH water enter the estuary and can cause fish kills and deplete the food supply for species such as the Little Tern, Osprey (*Pandion haliaetus*) and Black-necked Stork.

Estuarine and Floodplain Fauna

Many fauna species use, but are not dependent on, wetland habitats. These species may still benefit from flooding in general ways, such as nutrient inputs and deposition of logs. For example, logs provide habitat for fish species, which are predated upon by many bird species (e.g. Osprey, Little Tern). However, species dependent on wetland habitat, such as those found in estuaries and on floodplains, are more likely to require management of specific wetland habitats (Table 38).

The fauna described in Table 40 use a variety of habitat types. The life cycle stage most likely to be adversely affected by flooding is breeding. The species that are particularly vulnerable are those that breed on sand spits or beaches, such as the Little Tern and the Pied Oystercatcher. Both species commence nesting in spring, with their young fledging in summer. The protection of potential breeding habitat (e.g. specific sand spits) is a possible management option.

Intertidal mudflats and sandbanks are important foraging habitats. These habitats are used by a wide range of birds, including migratory waders (spring to autumn), the Black-necked Stork and Oystercatchers. The adjacent Mangrove habitat provides roosting habitat for many species. Saltmarshes are secondary foraging habitat for many bird species that forage in intertidal habitats. Floods are likely to alter food availability in intertidal habitats (e.g. freshwater input) in the short-term, but in the longer-term they maintain productivity.

Floodplain swamps are also important foraging habitat for the Black-necked Stork, Magpie Goose (*Anseranas semipalmata*) and the Comb-crested Jacana (*Irediparra gallinacea*) (Table 40). These species also breed in floodplain swamps, although not currently in the study area. Floods would affect nesting attempts by the Comb-crested Jacana, which nests on floating vegetation in the swamp. The Black-necked Stork and Magpie Goose would be less affected because they nest in trees. Floodplain wetlands may also provide temporary foraging habitat for species such as the migratory waders, the Little Tern and Osprey. Floods restore water levels in floodplain wetlands, which is important in maintaining wetland diversity.

The protection of trees adjacent to the estuary, floodplain swamps and the river channels is important in protecting the foraging habitat of the Black Bittern (*Ixobrychus flavicollis*) and the nesting habitat of species including the Black Bittern, Black-necked Stork and Osprey (Table 40).

While the wetland habitats in the study area potentially provide nesting habitat for a number of species, most of these do not currently breed on the Macleay floodplain (Keating and Jarman 2004; Clancy 2005). Management attention is likely to be required to change this situation by improving habitat quality. The most important current function of the wetlands in the study area is to provide foraging habitat for a significant number of threatened and migratory species listed under the TSC Act and the EPBC Act.

Table 40 Seasonal Summary of Key Events in the Life Cycle of Threatened and Migratory Wetland Fauna. Significant fauna are those dependent on estuarine and/or floodplain habitats

Season / Species	Activity	Habitat
Spring		
Magpie Goose [1]	Fledge young, which commence foraging	Swamps
	Foraging	Swamps and floodplains
Black Bittern	Commences nesting	Tree overhanging water; mangroves, Casuarinas (She-oaks)
Osprey	Fledge young, which commence foraging	Open waters: estuary and nearby ocean
Comb-crested Jacana	Commences nesting	Permanent wetlands, nest built of floating vegetation
Pied Oystercatcher	Nesting	Sandy beaches
	Foraging	Beaches, sand bars, mud flats
Migratory waders (incl. threatened species)	Return from northern hemisphere (September onwards)	Mud flats, sand bars, freshwater wetlands
Little Tern [3]	Migrates to S.E. Aust., commences nesting	Sand spits
Summer		
Black Bittern	Nesting	Tree overhanging water
	Roosting	Mangroves
Black-necked Stork [2]	Commences nesting	Large tree near water; estuary or floodplain
Comb-crested Jacana	Fledge young, which commence foraging	Permanent wetlands
	Foraging	Floating vegetation in swamps (e.g. waterlilies)
Pied Oystercatcher	Fledge young, which commence foraging	Beaches, sand bars, mud flats
Migratory waders (including threatened species)	Foraging, need to build energy reserves	Mud flats, sand bars, freshwater wetlands
Little Tern	Fledge young, which commence foraging	Sand spits
	Foraging	Open estuarine waters, flooded coastal wetlands, adjacent ocean
Autumn		
Black Bittern	Fledge young, which commence foraging	Tree overhanging water
	Foraging	Fresh and estuarine wetlands with permanent water
Black-necked Stork	Fledge young, which commence foraging	Productive fresh and saline wetlands
	Foraging	Productive fresh and saline wetlands
Migratory waders (incl. threatened species)	Return to northern hemisphere breeding grounds (March)	
Winter		
Magpie Goose	Commence nesting	Swamps
Osprey	Commence nesting	Large (often dead) tree near water
	Foraging	Open waters: estuary and nearby ocean
Pied Oystercatcher	Commence nesting	Sandy beaches

1 The Magpie Goose is not currently known to nest in the Macleay Valley.

2 The Black-necked Stork is not currently known to nest to the Macleay Valley. However, the study area is near the current southern breeding limit of this species (Clancy 2005).

3 The Little Tern migrates to South East Australia and a small component of the total population breeds there. The Macleay estuary is a former breeding area, but there have been no recent records (Keating and Jarman 2004).

6.2. Aquatic Fauna and their Habitat in the Macleay River Estuary

The Macleay River Estuary has a diverse range of habitats utilised by a suite of aquatic organisms for feeding, reproduction, nursery or shelter. There is limited data on the diversity of aquatic organisms found within the Macleay River Estuary; however some generalised statements relating to the specific importance of each of the habitats can be made based on data from similar estuaries.

Maher et al (2007) found the highest abundance and diversity of benthic macrofauna to be associated with seagrass beds in the Hastings River Estuary and Camden Haven Estuary and this is also likely to be true for the Macleay River Estuary. The increased structural complexity, coupled with high primary productivity rates are the main causal factors for the high abundance and diversity of benthic macrofauna found in seagrass habitats. Intertidal sand shoals are also extremely productive and are commonly associated with high abundances of crustaceans, molluscs and polychaetes which feed on the benthic microalgae, and which in turn are an important food source for commercially and recreationally important fish species. The importance of mangrove and saltmarsh habitats as nursery areas for many important fish and crustacean species is well documented, and this is also likely to be true for these habitats within the Macleay River Estuary.

The structure and function of the estuarine habitats within the Macleay River Estuary needs to be maintained to ensure the continuing health of the aquatic organisms that reside within the estuary. This chapter provides an overview of the significant aquatic fauna of the Macleay River Estuary, and describes some of the key threatening processes.

6.2.1. Status of Threatened Species

Only one threatened aquatic species is likely to currently utilise the Macleay River Estuary. A number of additional threatened species which have been found to occur in the Macleay region either rarely enter estuaries or are thought to no longer occur in the area. A summary of threatened species in or around the area is as follows.

The Green Sawfish (*Pristis zijsron)* is listed as endangered under the Threatened Species Conservation Act 1995 and the Fisheries Management Act 1994. It is also listed as vulnerable under the Environmental Protection and Biodiversity Act 1999. The last sighting of this species in NSW was in 1972, 36 years ago. This species is particularly susceptible to gill and prawn nets due to its studded rostrum (saw), and consequently would be seen in the fish catch statistics (as bycatch) if it was still found in NSW estuaries. It is likely that this species no longer occurs in NSW estuaries.

The Black Cod (*Epinephelus damelii*) is listed as vulnerable under both the Threatened Species Conservation Act 1995 and the Fisheries Management Act 1994 and its reported distribution ranges from the southern coast of Queensland to eastern Victoria. This species does inhabit estuaries on the North Coast of NSW (and this is likely to include the Macleay Estuary). Black Cod inhabit rocky reef areas (Kuiter, 2000) and as such it is likely that their distribution in the

Macleay Estuary would be limited to the rocky areas along the breakwall and the other smaller patches of rocky substrate generally restricted to the lower estuary.

Marine turtles including the Loggerhead (*Caretta caretta*), Green (*Chelonia mydas*) and Leathery (*Dermochelys coriacea*) turtle are known to occur in the Macleay geographical area (DECC 2008). The Loggerhead Turtle is listed as endangered under both the federal Environmental Protection and Biodiversity Act 1999 and the NSW Threatened Species Conservation Act 1995. The Green and Leathery Turtles are listed as vulnerable under both the Environmental Protection and Biodiversity Act 1999 and the Threatened Species Conservation Act 1995. Loggerhead turtles are known to nest on beaches situated on the NSW North Coast which is the southernmost distribution of their nesting range (Limpus *et al*. 1992). Green and Leathery turtles are generally confined to the reefs off the coast and as such do not utilise the Macleay Estuary. These three marine turtle species are oceanodromous, meaning they spend the majority of their life in the ocean and as such are rarely found in estuaries.

Incidental sightings of Dugongs (*Dugong dugon*) are also reported to occur in the Northern Rivers Catchment Management Area, however sightings are extremely rare and are likely to be of individuals that have strayed from their home range (DECC, 2008). The southern limit of viable dugong populations is Moreton Bay on the southern Queensland coast.

There are two shark species protected under the Environment Protection and Biodiversity Conservation Act 1999 that are found in the coastal waters of NSW. They are the Great White Shark (*Carcharodon carcharias*) which is listed as protected under the EPBC Act 1999 as it is migratory and is also listed as vulnerable, and the East Coast population of the Grey Nurse Shark (*Carcharias taurus*) which is listed as critically endangered. These species are oceanadromous (i.e. spend their life in the ocean) and are rarely found in estuaries.

6.2.2. Common Fish Species

Fish species of commercial and recreational importance are listed in Table 41 along with their status, their estuarine residency, spawning season (if known) and the estuarine habitats they utilise. This list is not a comprehensive list of fish species present in the Macleay Estuary, a complete inventory of fish species would require significant field work. However the fish species listed are those targeted by commercial and recreational fishers and as such are subject to the most significant amount of anthropogenic pressure.

Table 41 Fish Species of Commercial and Recreational Importance in the Macleay Estuary

Common Name	*Scientific Name*	Status[1]	Residency	Spawning Season[2]	Estuarine Habitats[3]
Australian Bass	*Macquaria novemaculeata*	C	Spawns in estuary only	Winter	P
Bonito	*Sarda australis*	C	oceanodromous	X	P
Bream, Black and Yellowfin	*Acanthopagrus australis Acanthopagrus bucheri*	C	resident/transient	Winter	P, B, M, S, I
Catfish, Estuary	*Cnidoglanis macrocephala*	C	resident	ND	B
Cobia	*Rachycentron canadum*	C	oceanodromous	X	P
Crab, Blue Swimmer	*Portunus pelagicus*	C	resident typically spawn offshore	Spring-Summer	S, I, B
Crab, Mud	*Scylla serrata*	C	resident typically spawn offshore	Spring-Summer	M, B, I
Dart	*Trachinotus sp.*	C	transient	X	P
Eel, Longfin River	*Anguilla reinhardtii*	C	Catadromous	X	B
Eel, Shortfin River	*Anguilla australis*	C	Catadromous	X	B
Flathead, Dusky	*Platycephalus fuscus*	C	resident/transient	Summer	B, I
Flathead, Sand	*Platycephalus arenarius, Platycephalus bassenis*	C	resident/transient	Summer	B, I
Garfish, River	*Hyporhamphus regularis*	C	resident	Winter/Spring	S, P
Garfish, Sea	*Hyporhamphus australis*	C	resident/transient	Winter/Spring	S, P
Garfish, shortbill	*Hyporhamphus quoyi*	C	resident	Winter/Spring	S, P
Leatherjacket, Unspecified	*family Monacanthidae*	C	oceanodromous	X	S, B
Longtom	*Ablennes hians*	C	resident/transient	ND	S, P
Luderick	*Girella tricuspidata*	C	resident	Winter	S, R, B
Mullet, Fantail	*Paramugil georgii*	C	resident/transient	Winter	S, P
Mullet, Pink-eye	*Trachystoma petardi*	C	resident/transient	Winter	S, P
Mullet, Sand	*Myxus elongatus*	C	resident/transient	Winter	S, P, I
Mullet, Sea	*Mugil cephalus*	C	resident/transient	Winter	S, P
Mulloway	*Argyrosomus japonicus or hololepidotus*	C	resident/transient	Summer	B, P
Octopus	*Octopus australis, Octopus tetricus*	C	resident	ND	B, R
Pilchard	*Sardinops sagax*	C	transient	X	P
Prawn, Greasyback	*Metapenaeus benettae*	C	resident/transient	Summer	B, S
Prawn, School	*Metapenaeus macleayi*	C	resident/transient	Summer-Autumn	B, S
Sandy sprat (whitebait)	*Hyperlophus vittatus*	C	transient		S, P
Shark, Black Tip	*Carcharhinus melanopterus*	C	transient	X	P

[1] C =Common, R = Rare, T = Threatened, E = Endangered

[2] X = species that spawn in open ocean, ND = No data

[3] P = Pelagic Zone, B = Benthic Zone, M = Mangrove Habitat, S = Seagrass Habitat, I = Intertidal Habitat

Common Name	*Scientific Name*	Status[1]	Residency	Spawning Season[2]	Estuarine Habitats[3]
Shark, Fiddler	*Trygonorrhina fasciata*	C	resident/transient	ND	B
Shark, Hammerhead	*Sphyrna sp.*	C	transient	X	P
Shark, School	*Galeorhinus galeus*	C	transient		P, B
Shark, Shovelnose	*Aptychotrema rostrata*	C	resident/transient		B
Silver biddy	*Gerres subfasciatus*	C	resident/transient		S, P
Sweetlip, Unspecified	*Plectorhinchus sp*	C	resident/transient		B, P
Tailor	*Pomatomus saltatrix*	C	transient	X	P
Tarwhine	*Rhabdosargus sarba*	C	resident/transient		P
Trevally, Black	*Caranx lugubris*	C	resident/transient		P
Trevally, Silver	*Pseudocaranx dentex*	C	resident/transient		P
Whiting, Sand	*Sillago ciliata*	C	resident		S, B, I
Yellowtail	*Trachurus novaezelandiae*	C	transient	X	P
Yellowtail kingfish	*Seriola lalandi*	C	transient	X	P

6.2.3. Key Threatening Processes

Estuarine ecosystems are subject to significant anthropogenic influences including eutrophication (due to increased nutrient supply), hydrological stress (through water extraction, water course deviations and drainage of the floodplain), overfishing, acid runoff, water deoxygenation (associated with flood events), habitat destruction/modification (including riparian vegetation) and gross pollutant inputs (eg plastic bags, rubbish etc). These impacts can have chronic or acute impacts upon the ecosystem depending upon the timing and magnitude of the events.

The Macleay Estuary is subjected to all of the mentioned threatening processes to some degree although there is insufficient data to determine the magnitude of these threatening processes on specific species.

Eutrophication

Eutrophication can be defined as the increase in the supply of organic matter to an estuary (Nixon, 1995), and typically is related to an increased supply of nutrients which stimulates phytoplankton and macroalgae growth. When this “excess” organic matter dies and decomposes it consumes oxygen which can lead to anoxic conditions at the benthic surface, causing stress and even mortality to benthic organisms. Coupled with this anoxia is the release of nutrients back to the water column, which can stimulate more plant growth which continues the cycle.

Within the Macleay Estuary there are signs of eutrophication in the Upper Estuary around Kempsey with dense beds of aquatic macrophytes becoming well established. These beds however act as a net sink for nutrients and most likely act as an efficient filter, efficiently stripping the water column of nutrients preventing algal blooms, as discussed in Section 5.1.2. The macrophyte beds most likely act as an important habitat area both structurally and in terms of supply of organic matter to higher trophic levels (including fish). There is no data on the functional importance of these beds, and further investigation is required.

In the mid and lower estuary phytoplankton blooms occur adjacent to the Gladstone wastewater discharge, Grassy Head and Stuarts Point, (discussed in Section 5.1.2). These blooms are associated with nutrient inputs and are an indication of some degree of eutrophication in these areas. If these blooms increase in magnitude and frequency, shifts in the trophic structure and the aquatic organism community composition will occur. Planktivorous fish will start to dominate the icthyfauna, the benthic community will become dominanted by species tolerant of low dissolved oxygen, and aquatic organism diversity will decrease. This can have flow on financial effects for the communities situated along the Macleay Estuary. A decrease in fisheries production has an economic impact on commercial fishers and is likely to reduce recreational fishing which may in turn also impact on tourism. This should be a key area of focus in sustaining the health of the estuary, and should be incorporated into future monitoring programs.

Hydrological Stress

Hydrological stress within the Macleay Estuary is primarily associated with the historical drainage of floodplain wetlands, and current water extraction from the upper catchments. The *Stressed Rivers Assessment Report* (DLWC, 1999) found that 18% of the subcatchments (based on 33 subcatchments) of the Macleay River suffered from medium to high water extraction stress at the 1999 water extraction levels. Based on full development of water licences this percentage would increase to over 24%. Water extraction reduces the inflow of freshwater to an estuary and shifts the saline/freshwater interface landward. This has implications for freshwater aquatic life as habitat area shrinks as the saltwedge intrudes further upstream (see Bishop, 2006).

Many estuarine organisms use changes in flow as a trigger mechanism for critical life-history events such as spawning (Harris, 1986), migration and recruitment (Strydom et al. 2002). Small freshes also deliver nutrients to the estuary which may be an important element in sustaining primary production (Alber, 2002). The salinity gradient profiles undertaken throughout 2006/2007 displayed saltwater intrusion beyond Kempsey during low rainfall periods suggesting some degree of hydrological stress during these periods.

Overfishing

As with most NSW estuaries, the Macleay Estuary is subject to considerable fishing pressure. Both recreational and commercial fishers harvest fish from the Macleay Estuary, with the main species caught by commercial fishers being mullet, luderick, eels and mud crabs (Table 42). With the exception of eels these species are also important to recreational fishers.

Table 42 Value of Commercial and Recreational Fishing for 1998/1999

Species	Weight (kg)	% of Weight	Value (Dollars)	% of Dollars	Recreational Fishery Value
Bonito	10	0.0%	$39	0.0%	Low
Bream, Black and Yellowfin	2,023	2.2%	$15,616	5.5%	High
Catfish, Estuary	4	0.0%	$5	0.0%	Low
Catfish, Unspecified	2	0.0%	$6	0.0%	Low
Crab, Blue Swimmer	74	0.1%	$462	0.2%	High
Crab, Mud	8,696	9.5%	$115,000	40.7%	High
Dart	16	0.0%	$46	0.0%	Medium
Diamond Fish	65	0.1%	$237	0.1%	Low
Eel, Conger	3	0.0%	$9	0.0%	Low
Eel, Longfin River	9,239	10.1%	$14,869	5.3%	Low
Eel, Shortfin River	2,029	2.2%			Low
Eel, Unspecified	99	0.1%	$384	0.1%	Low
Fish, Unspecified Estuary	195	0.2%	$566	0.2%	
Flathead, Dusky	1,193	1.3%	$3,965	1.4%	High
Flathead, Sand	11	0.0%	$25	0.0%	High
Garfish, River	135	0.1%	$357	0.1%	Medium
Garfish, Sea	1	0.0%	$5	0.0%	Medium
Garfish, shortbill	63	0.1%	$297	0.1%	Medium
Leatherjacket, Unspecified	4	0.0%	$10	0.0%	Medium
Longtom	8	0.0%	$19	0.0%	Low
Luderick	12,401	13.6%	$14,647	5.2%	High
Mullet, Fantail	416	0.5%	$381	0.1%	Medium
Mullet, Pink-eye	2,746	3.0%	$2,999	1.1%	Medium
Mullet, Sand	1,075	1.2%	$1,042	0.4%	Medium
Mullet, Sea	43,841	47.9%	$64,853	23.0%	Medium
Mullet, Unspecified	58	0.1%	$90	0.0%	
Mulloway	2,052	2.2%	$14,183	5.0%	High
Nipper	127	0.1%			High
Octopus	11	0.0%	$45	0.0%	Low
Old Maid	12	0.0%	$19	0.0%	Low
Pike	7	0.0%	$10	0.0%	Medium
Pilchard	243	0.3%	$400	0.1%	Low
Pipi	25	0.0%	$53	0.0%	High
Prawn, Greasyback	481	0.5%	$3,420	1.2%	Low
Prawn, School	1,842	2.0%	$14,888	5.3%	Low/Medium
Sandy sprat (whitebait)	4	0.0%			Low
Shark, Black Tip	486	0.5%	$2,291	0.8%	Low
Shark, School	146	0.2%	$666	0.2%	Low
Shark, Unspecified	66	0.1%	$195	0.1%	
Silver biddy	7	0.0%	$17	0.0%	High
Sweetlip, Unspecified	8	0.0%	$42	0.0%	High
Tailor	42	0.0%	$190	0.1%	High
Tarwhine	3	0.0%	$14	0.0%	High
Trevally, Silver	521	0.6%	$1,533	0.5%	High
Whiting, Sand	1,009	1.1%	$8,478	3.0%	High
Totals	**91,498**		**$282,371**		

Whilst there is minimal data on the recreational catch of fish in the Macleay Estuary, commercial fish catch is readily available from NSW DPI. By comparing the total fish catch of the Macleay Estuary to the fish catch in similar estuaries throughout NSW (i.e. mature barrier estuaries, Type IIID as defined by Roy et al. 2001) an indication of the commercial fishing pressure within the Macleay Estuary can be interpreted. Diagram 18 and Diagram 19 display commercial fish catch for the Macleay Estuary compared to other geomorphically similar estuaries throughout NSW. Data is based on total fish landings (kg) normalised for estuary area.

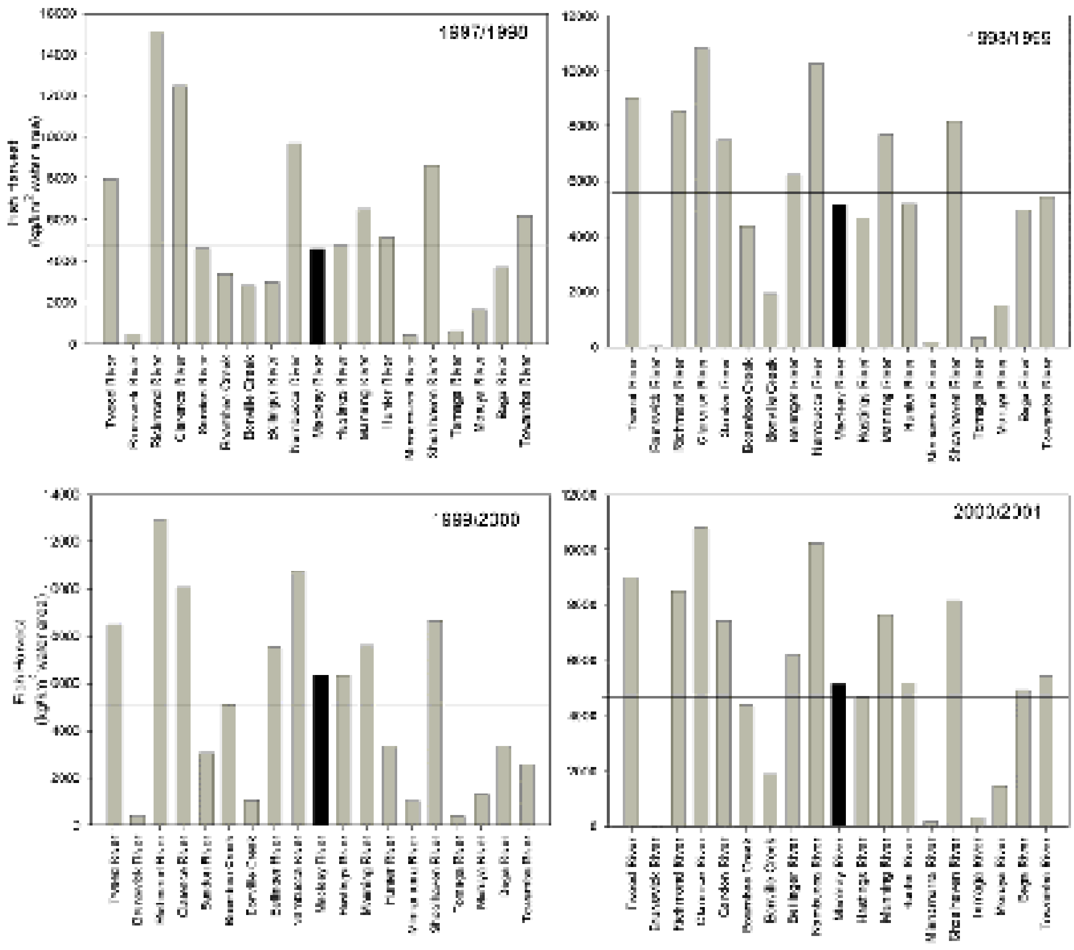


Diagram 18. Comparison of commercial fish catch in the Macleay Estuary (dark bar) to other similar estuaries in NSW for the financial years 1997/98 to 2000/01 (data normalised for estuary area). Line represents mean value for all estuaries.

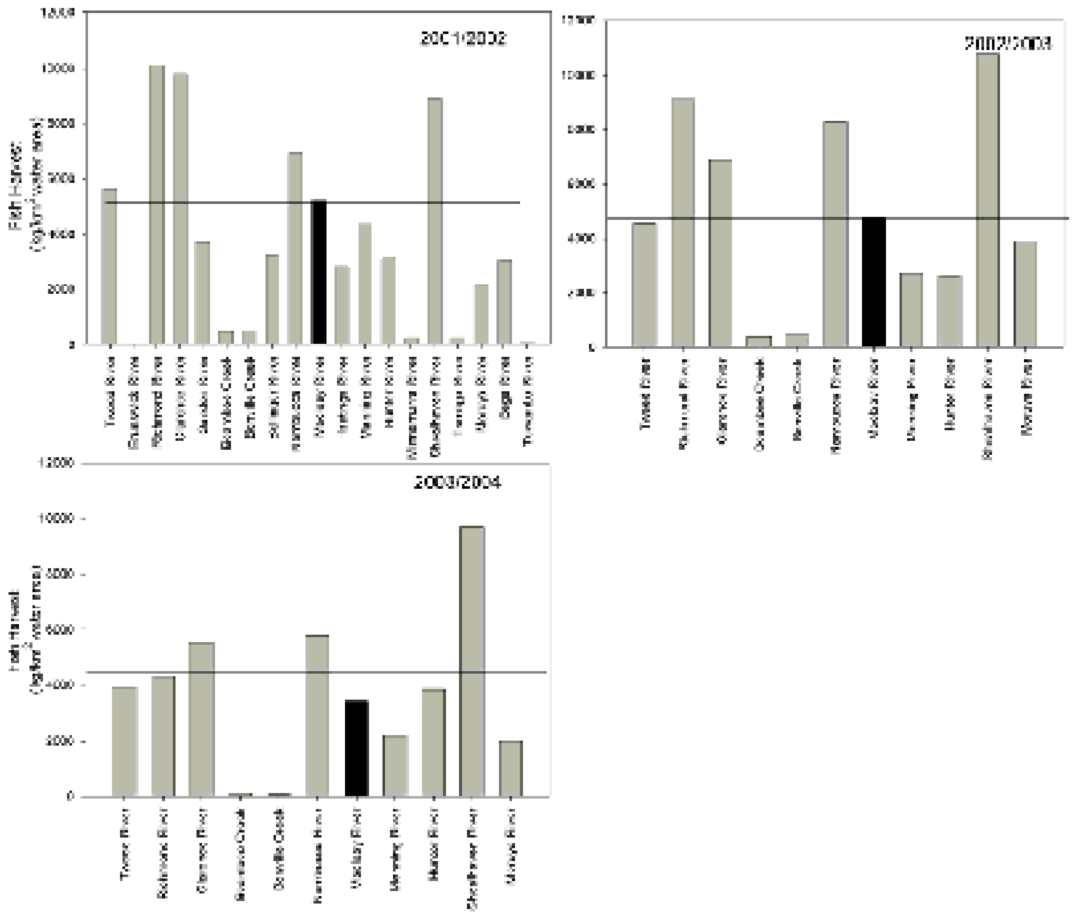


Diagram 19. Comparison of commercial fish catch in the Macleay Estuary (dark bar) to other similar estuaries in NSW for the financial years 2001/02 to 2003/04 (data normalised for estuary area). Line represents mean value for all estuaries.

Diagram 18 and Diagram 19 show that the commercial fish catch within the Macleay Estuary has remained relatively stable around ~ 4000 kg/km ^{2}/year and is generally similar to the average fish catch for NSW Type IIID estuaries. This suggests that stocks of commercial fish are above the threshold for maintaining adequate recruitment to sustain the population. This data also suggests that recreational fishing pressure on those same species is not excessive as a decline in the commercial fish catch would be evident if this was the case.

Overall the data available suggests that generally the stocks of fish targeted by commercial fishers (which incorporates most species targeted by recreational fishers) are stable and that overfishing does not appear to be occurring. However data on by-catch is not as readily available and it is possible that stocks of some non-target species may in fact be in decline. More data is required for a complete assessment of the fish stocks within the Macleay in particular, those species that are not recorded in commercial catch returns that may be of integral importance to the estuarine ecosystem.

More detail on commercial and recreational fishing is contained in the following chapter on Waterway Usage.

Acid Runoff/Water Deoxygenation Events

As discussed in Section 5.6, acid sulfate soils are formed in estuaries and oceans by the deposition of marine derived reduced sulphur minerals (mainly pyrite and iron monosulphides). During the Holocene period ~ 10 000 years ago, sea levels were approximately 35 m higher than present day and as a result coastal floodplains along the NSW coast (including the Macleay) were inundated. Under the right conditions (typically high organic carbon loads, high dissolved iron concentrations and reducing conditions) acid sulfate soils were formed. Sea level has regressed and these soils are now found within the floodplains of most NSW estuaries.

Whilst these soils remain permanently inundated such as in wetlands and areas of high groundwater levels, they remain in a reduced state and have a minimal impact on the surrounding environment. These are often referred to as potential acid sulfate soils. However, exposure of the soils causes oxidation to sulfuric acid. The exposure of acid sulfate soils in the Macleay floodplain has been exacerbated by the drainage of backswamp areas, and construction of an extensive flood mitigation system which is comprised of 138 km of drains, 180 flood control structures and 352 floodgates (Henderson 2001). Runoff and floodwaters subsequently passing over the acidified soils can transport and distribute them throughout the floodplain and into waterways. Acidified floodwaters can also cause the release of bound metals which become soluble under lower pH conditions some of which are toxic to aquatic organisms (eg aluminium). When the water drains from the floodplain to the estuary, or floodgates are opened, this acidic, metal rich, low dissolved oxygen (DO) water can have a significant impact upon aquatic organisms, leading to mass mortality in some extreme cases. The effects of acid runoff are normally coupled with the stripping of dissolved oxygen from the water column due to the break down of organic matter on the floodplain and organic matter washed into the estuary from large rainfall events (see Eyre et al, 2006 for example in the Richmond River).

Fish kills have occurred periodically in the Macleay Estuary following flood events. Fish mortality has been linked to a lack of DO in the water column (e.g. Kemsley, 2001). This is likely to be due to a combination of the breakdown of organic matter on the floodplain and in the water column, and the chemical oxygen demand associated with the oxidation of acid sulfate soils. Inherent difficulties exist in trying to prevent the deoxygenation of water due to the break down of organic matter on the floodplain due to the number of stakeholders, and the large-scale nature of the issue. Simple measures such as the restoration of riparian vegetation communities may assist in reducing the rate at which deoxygenated water re-enters the estuary. Management of floodgates and acid sulfate soil areas should focus on minimising the disturbance of acid sulfate soils (and hence preventing oxidation of pyrites) and leaving floodgates open wherever possible (Pollard and Hannan, 1994).

Habitat Destruction/Modification

Estuarine habitats have been mapped and are shown in Figure 43. The importance of seagrass habitats to estuarine functioning is well documented (e.g. Pease, 1981: Bell and Pollard, 1989 Pease, 1999; Saintilan, 2004). Seagrass provides structural habitat and is a key area for carbon fixation (food supply) within many subtropical estuaries. Within the Macleay Estuary seagrass is generally restricted to the Macleay Arm which has extensive meadows of *Zostera capricorni*. These seagrass beds are important nursery habitat areas for many commercially important fisheries species, and due to the restricted distribution of seagrass within the Macleay Estuary it is essential to maintain optimal water quality conditions in the Macleay Arm for seagrass survival. The key water quality parameters for seagrass health are minimal turbidity/suspended solids (to ensure sufficient light penetration) and minimal inorganic nutrient inputs (to prevent algal dominance).

Mangrove and saltmarsh areas are also critical habitats to estuarine ecosystems as they provide nursery habitat and nutrient cycling, and supplement food supply to the estuarine food chain. Mangrove and saltmarsh habitats are restricted to the lower estuary, in areas where clearing for agriculture has not been feasible. Mangroves, saltmarshes and seagrasses are protected under the Fisheries Management Act 1994, preventing future destruction. These habitats can be significantly affected by changes in hydrology. Increased flow can cause erosional stress and dieback in even well established mangrove stands (Jiminez et al, 1985), as can significant deposition of fine particulate materials during flood inundation (Ellison 1998). Management of the lower estuary needs to ensure minimal changes in hydrology to maintain the health of the saltmarsh and mangrove habitats.

Exotic species

Without extensive surveys of the aquatic flora and fauna (including zooplankton and phytoplankton) within the Macleay Estuary it is difficult to ascertain the impact of exotic species. One notable and obvious exception is the dense macrophyte beds in the upper estuary (shown in Figure 43), which have overtaken the native aquatic flora in this area. It is likely that these beds are composed predominantly of dense waterweed (*Egeria densa*) and Elodea (*Elodia canadensis*). These are likely to have altered the way in which the upper estuary functions, in particular the habitat structure and productivity. There may also be feedback mechanisms associated with dietary shifts from the native primary producers to the introduced Elodea. These beds however seem to be effectively removing excess nutrients from the water column, which otherwise would be available to promote nuisance algal blooms. More study into the importance of these beds in terms of habitat structure and biogeochemical cycling is recommended.

6.2.4. Health of Aquatic Ecology in the Macleay Estuary

Without extensive data on species diversity and abundance it is very difficult to give a definitive overview of the health of the aquatic ecology within the Macleay Estuary. Based on the commercial fish catch data it appears that fish stocks are in good condition, as the catches have remained relatively stable over the last decade. Reports on the recovery of the Macleay Estuary following the large fish kill in 2001 indicate that the estuarine fish stocks showed considerable recovery within 5 months (Kennelly and McVea, 2002). This suggests that the aquatic ecology is quite robust within the Macleay Estuary and recruitment from other nearby estuaries and coastal waters supplements in situ recruitment.

The most critical habitats for maintaining estuarine ecological health occur within the Macleay Arm, where most of the seagrass meadows, mangrove stands, and saltmarsh are situated. These habitats are essential nursery areas for many aquatic organisms (including important commercial and recreational fish species) and consequently management should focus on maintaining optimal conditions for sustaining these habitats. Minimising changes in hydrology, turbidity and nutrient concentrations will ensure the protection of these habitats, as described in the preceding water quality chapter (Chapter 5).

Studies in the nearby Hastings River and Camden Haven Estuaries (Maher et al 2007) have found that intertidal and shallow subtidal shoals are the significant areas of estuarine primary productivity and this is likely to be the case in the Macleay Estuary as well. As with seagrass meadows, to maintain the productivity in these habitat areas it is crucial to minimise turbidity and the nutrients available to phytoplankton and macroalgae. Primary productivity (by terrestrial plants, mangroves, algae and seagrasses) is the base of the food web, without which higher order aquatic organisms can not survive. The nutrient budget discussion in Section 5.3 and the summary and synthesis of key biogeochemical processes in Section 5.7, emphasise the importance of carbon production in the intertidal shoals and seagrass areas, with estuary wide production being dominated by benthic microalgae. Management should focus on maintaining the balance of primary producers and the productivity rates within the Macleay Estuary. This will ensure that the trophic structure and hence the abundance and diversity of aquatic organisms within the Macleay River Estuary are maintained.

7. WATERWAY USAGE

The Macleay estuary and surrounding areas offer a wide variety of activities, including water sports, commercial and recreational fishing, bushwalking, and cultural activities. The natural environment is highly productive, and supports a number of commercial uses including fishing, oyster farming, agriculture and tourism. However, these uses along with increasing urban development have had significant impacts on the environment and areas of cultural significance. It is therefore of increasing importance that a balance is met between environmental management, cultural heritage and human activities. Both the Kempsey Shire Council 20 year *Community Strategic Plan* and the *Macleay Valley Coast Tourism Strategic Plan 2005-2009* (ATS Group, 2005) emphasize the need for greater promotion and protection of the area's environmental and social values and assets.

The following sections provide a summary of the main waterway uses within the Macleay Estuary, whilst 18
Figure 7 (page 20) shows the locations of the current estuary access and usage.

7.1. User Groups and Stakeholders

The number of user groups reflects the wide range of activities which occur within the Macleay estuary. These are summarised below:

- Local residents in urban centres and towns,
- Developers,
- Aquaculture industry,
- Commercial and recreational fishers,
- Agriculture industry,
- Indigenous groups,
- Environmentalist groups, and
- Tourists and the tourism industry.

These groups rely on the Macleay estuary for resources, whilst also impacting on each other and the environment. It is therefore necessary that a balance is met between the needs of each group and how these needs impact upon the surrounding estuary.

7.2. Fishing and Aquaculture

The Macleay estuary offers a full range of fishing opportunities, both within the river and along the coastline. Warm currents and the proximity to the continental shelf provide ideal conditions for a number of different species (Kempsey Council website, 2008). Species such as freshwater bass and catfish can be found in the upper reaches, with estuarine species such as bream, flathead and luderick can be found near the entrance. The area offers significant opportunities for both commercial and recreational fishing as well as aquaculture.

7.2.1. Aquaculture

The oyster industry is the only aquaculture industry which currently operates within the Macleay estuary. In 2000, the North Coast Sustainable Aquaculture Strategy (NSW DPI, 2000) identified 1890 ha of land within the Macleay estuary which would be suitable for land based aquaculture, however, this is not currently developed for such purpose.

Oyster farming is currently the most valuable fishery in NSW, valued at $34.6 million for the year 2006/2007. It has consequently been the focus of a state wide strategy to manage the industry at a sustainable level under the *NSW Oyster Industry Sustainable Aquaculture Strategy* (OISAS) (NSW DPI, 2006[1]). OISAS is given effect through the State Environmental Planning Policy (SEPP) 62 – Sustainable Aquaculture. This policy requires that all development which has the potential to have an adverse impact on oyster production is referred to the NSW Department of Primary Industries (DPI) for comment. In determining a development application, the consent authority must take any NSW DPI comments into consideration.

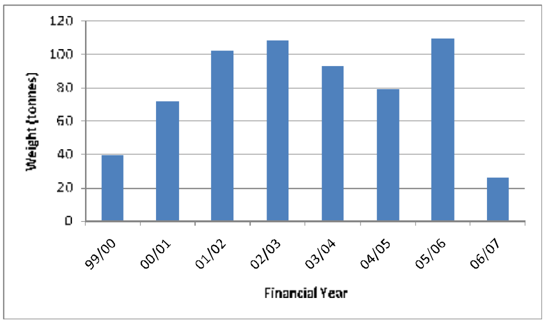
OISAS involved identifying areas that were considered to be suitable as Priority Oyster Aquaculture Areas (POAA) for oyster farming and establishing water quality and flow objectives to improve the viability of the industry. POAAs are areas where commercial oyster aquaculture is a priority intended outcome. The water quality objectives outlined in OISAS are shown below in Table 43.

Table 43 OISAS Water Quality Objectives (source: NSW DPI, 2006 [1])

Parameter	Guideline	Source
Faecal (thermotolerant) coliforms	90th percentile of randomly collected Faecal coliform samples do not exceed 43MPN or 21 MF/100mL	ASQAP Operations Manual 2002 and the NSW Shellfish Program Operations Manual 2001.
pH	6.75 – 8.75	Schumway (1996).
Salinity	20.0 – 35.0 g/L	Australian and New Zealand Guidelines for Fresh and Marine Water Quality (2000).
Suspended solids	<75 mg/l	
Aluminium	<10µg/L	
Iron	<10µg/L	
Other parameters	For other parameters please refer to Section 4.4 and Section 9.4 of the Australian and New Zealand Guidelines for Fresh and Marine Water Quality (2000)	

The oyster industry is reliant on good water quality to grow healthy oysters which are fit for human consumption. Oyster aquaculture in NSW is threatened by declining estuarine water quality, increased use of waterways and development adjacent to estuaries. These affect both oyster productivity and the suitability of oysters for human consumption (NSW DPI, pers. com., 2008). As oysters feed by filtering water and extracting nutrients and other suspended material, they also play an important role in maintaining adequate water quality and are seen as indicators of estuary health (NSW DPI, 2006 [1]; NSW DPI, pers. com., 2008).

The Sydney rock oyster (*Saccostrea glomerata*) is the primary species which is harvested both within the estuary and throughout the state. The Macleay Oyster Industry produces on average approximately 2% of the total NSW production, valued at approximately $530,000 (NSW DPI, 2001 to 2008[1]). Diagram 20 shows the quantity and value of the Macleay Oyster industry from 1999/2000 to 2006/2007.



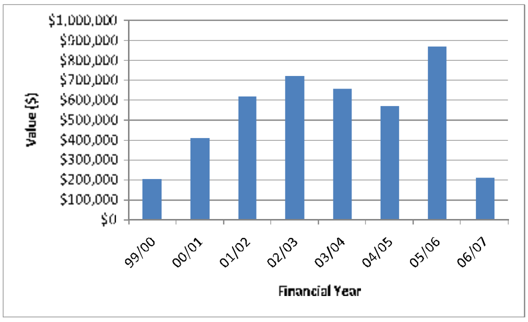


Diagram 20. The Macleay Estuary oyster industry showing (a) total production and (b) total value for the years 1999/2000 to 2006/2007 (source: derived from NSW DPI 2001 to 2008 [1]).

The Macleay oyster leases are currently contained within three harvest areas, all of which are close to the estuary mouth, as shown in Figure 45. These harvest areas are Clybucca Creek, Fishermans Reach and New Entrance (NSW Food Authority, 2008 [1]). All current leases and some former leases were identified as POAAs in OISAS, as shown in Figure 46. The operation of each area is regulated by a separate harvest area management plan. Clybucca Creek and Fishermans Reach harvest areas are classed as conditionally restricted, which requires oysters to be depurated before consumption. Water quality data suggests that faecal coliform concentrations are slightly higher in these areas (NSW Food Authority, 2005). New Entrance is conditionally approved, which means that oysters can be harvested directly except for under predicted adverse conditions such as rainfall exceeding a trigger level. The water quality objectives in OISAS aim to improve all oyster harvest areas to direct harvest standard, enabling oysters to be sold directly for human consumption.

A number of depuration plants are located in oyster sheds adjacent to the entrance to Spencers Creek. These draw estuarine water from the area. Depuration is a purification process where oysters are held in land based plants containing purified estuarine water for a minimum period of 36 hours. This allows the purging of their gastrointestinal contents, including any potentially harmful bacteria. The estuarine water used in the depuration plant is exposed to high intensity, germicidal ultra-violet light twice every hour to ensure its quality (NSW DPI, pers.com., 2008; SafeFood NSW, 2001).

The Department of Environment and Climate Change (DECC) has established the *NSW Water Quality and River Flow Objectives* for each catchment area including the Macleay (DECC website, accessed 2008). As part of the consultation process for Macleay, oyster growers

FIGURE 45

NSW FOOD AUTHORITY

OYSTER HARVEST AREAS

SOURCE: NSW FOOD AUTHORITY, 2008

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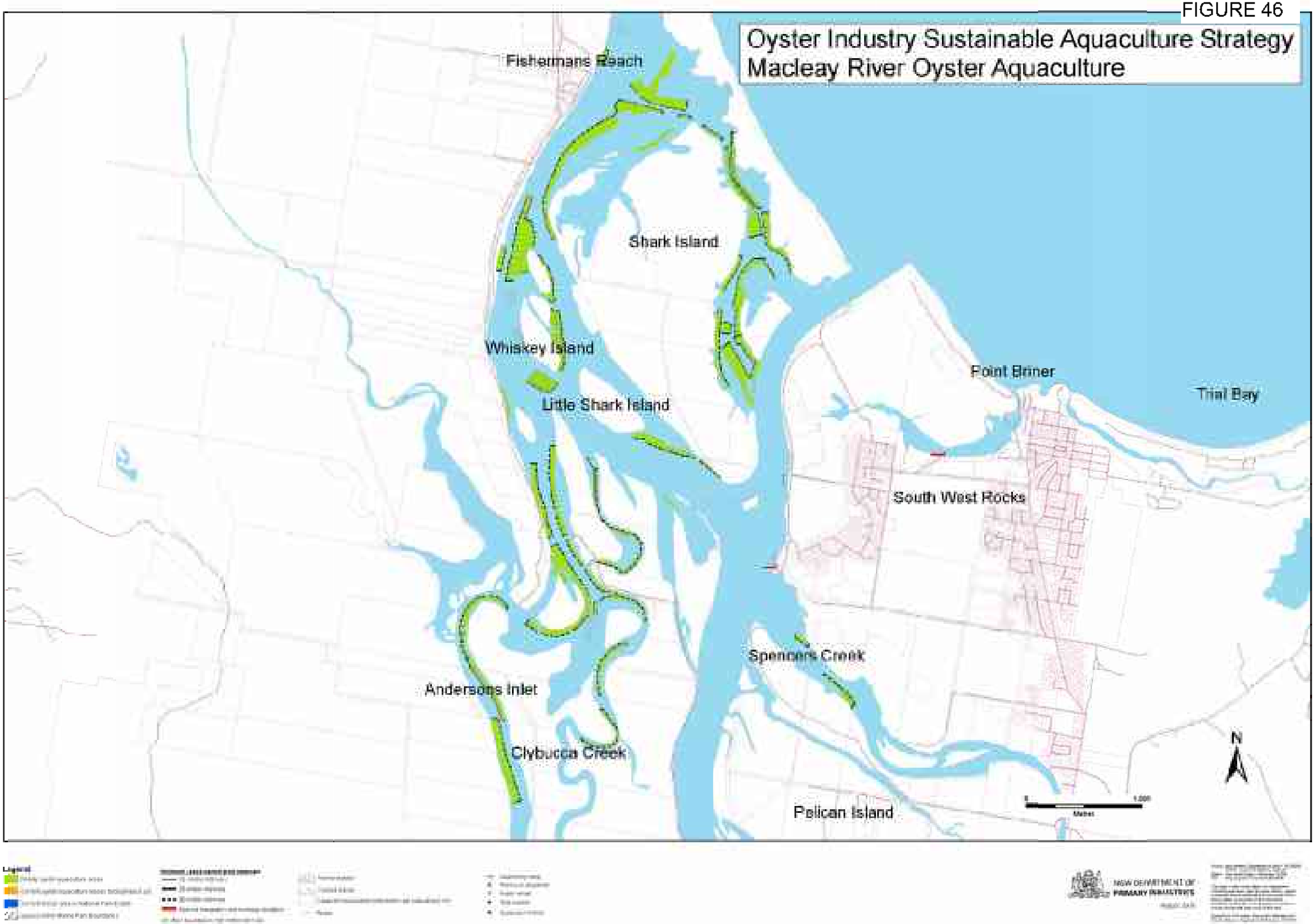
FIGURE 46



J://Jobs/Admin/ReportFigures/Other/Figure46_OysterStrategy.pdf expressed concern over discharges such as inadequately treated sewage, which have the potential to impact upon the water quality in the estuary. Whilst pathogens originating from faecal matter (both human and animal) generally present the highest risk of contamination, food poisoning from oyster consumption is extremely rare (NSW DPI, pers. com., 2008). There have been no recorded food poison outbreaks in the Macleay due to the oyster industry.

During the period March 2000 to March 2008, approximately 20 routine closures occurred. The New Entrance harvest area had the most with 24 closures, followed by Clybucca Creek (20) and Fishermans Reach (17). The higher number of closures at New Entrance were primarily due to the stricter conditions stipulated by the harvest area management plan compared with the other two areas. The majority of closures for all areas were due to rainfall events. Water quality can be reduced by runoff from the surrounding catchment carrying contaminants into the estuary. Both rainfall and water quality data are therefore collected to determine whether closures are necessary. Low salinity levels can also trigger a closure, as they are often an indication of significant rainfall in upstream areas (NSW Food Authority, 2008 [2]; NSW Food Authority, pers. com., 2008). Minimum salinity levels must be maintained for oyster health (Dove, 2003). The remaining closures were primarily due to microbiological levels exceeding trigger values (NSW Food Authority, 2008 [2]).

Water quality sampling undertaken as part of this study over the period September 2006 to August 2007 included measurement of salinity as well as pH and total suspended solids. Over this period, salinity did not drop below the lower OISAS limit of 20mg/L in the Macleay Arm. The sample locations in other parts of the lower estuary could not be directly compared with the location of the oyster leases, as they were based on salinity rather than geographic locations. In terms of pH, no samples exceeded the OISAS guidelines during the sample period, although during August 2007 they were close to 6.75 in the Macleay Arm. Total suspended solids only exceeded 75mg/L once during November 2006. This may be related to there being increased flow during that month, which is likely to increase sediment transport.

The impact of rainfall on water quality is also reflected in data collected as part of the *Water Bacteriology and Phytoplankton Survey* (NSW Food Authority, 2005). The survey measured faecal coliforms and potentially toxic phytoplankton species present between January 2003 and July 2005 at a number of sites within commercial shellfish harvest areas in NSW, including the Macleay estuary. Faecal coliform levels were found to be elevated within the Macleay estuary after rainfall events.

Water quality is routinely measured at a number of different pollution sources throughout the catchment. These include sewage treatment plant discharge sites, septic tank discharge areas and cattle access locations. Generally, water quality is only observed to deteriorate during rainfall events, although there are some instances of reduced water quality at other occasions. This is reported to occur most frequently in the Fishermans Reach area (NSW Food Authority, pers. com., 2008).

Compared with other NSW estuaries, the Macleay estuary appears to have relatively good water quality in the New Entrance area. New Entrance is one of only 3 approved harvest areas in the NSW North Coast, whilst Clybucca and Fishermans Reach are two of 21 restricted areas (NSW Food Authority, pers.com., 2008). The NSW Food Authority 2003-2005 survey found that the highest mean faecal levels occurred within Clybucca Creek, whilst the highest faecal coliform counts during the sample period occurred in Fishermans Reach and Spencers Creek after rainfall. Only one sample taken near Kemps Corner exceeded the trigger value for potentially toxic phytoplankton species.

The Macleay oyster industry has also been affected by the oyster disease QX since 2006, a disease caused by the protozoan *Marteilia sydneyi*. Whilst QX has not been found to transfer to humans, it has had a significant impact on the oyster industry. QX is thought to only affect the Sydney rock oyster and has been found throughout the majority of estuaries along the southeast Queensland and northern NSW coast (NSW DPI website QX Oyster Disease, accessed 2008; NSW Food Authority, pers. com., 2008).

QX initially resulted in a death rate of approximately 70% of oysters in the Macleay in 2006, which has improved to approximately 30%. This improvement has not been seen in the majority of other affected locations. Whilst the cause of QX is not currently known, it is thought to be linked to poor water quality, which can compromise the immune system of oysters. However, areas in Macleay (such as Clybucca Creek) which have low pH levels due to acid sulfate soil runoff, have been found to have lower incidences of QX deaths. It is thought that the acidic water kills the QX disease (NSW Food Authority, pers. com., 2008).

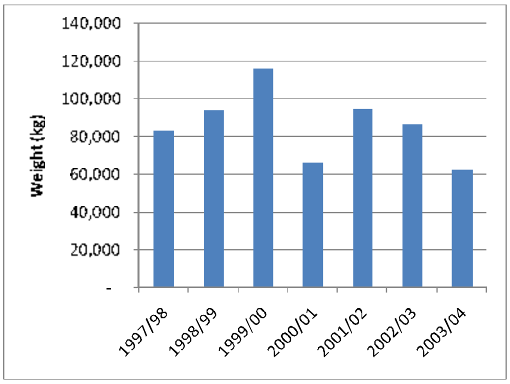
Ashley and Graham (2001) investigated the bioaccumulation of heavy metals in oysters as part of a wider study of heavy metal loadings in the Macleay. Of the four samples taken, some bioaccumulation of copper, zinc and arsenic was found, although levels were less than or close to the Australian and New Zealand Food Authority (2000) permitted concentrations. It was also found that concentrations in wild oysters were higher than the single commercial oyster sample. No bioaccumulation of lead, selenium and antimony was observed. Heavy metal contamination testing for cadmium, copper, lead, mercury, selenium, zinc and arsenic, is also undertaken by the oyster industry every three years. Previous results (1999, 2002 and 2005) indicated levels have been below trigger values (NSW Food Authority, pers.com., 2008).

7.2.2. Commercial Fishing

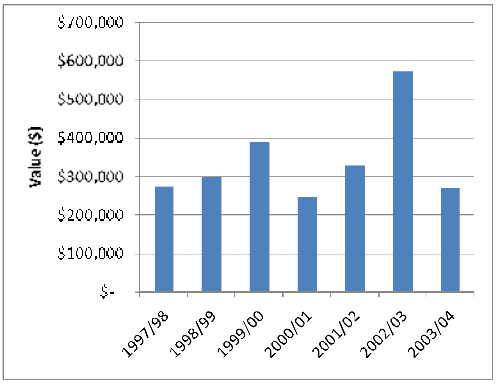
The Macleay River is part of the Region 3 – North Coast fishing region, which extends from Wooli Wooli River in the north to Camden Haven River in the south (NSW DPI, 2008 [2]). Commercial fishing within the Macleay estuary is part of the Estuary General Fishery, which is one of 9 fisheries within NSW. The commercial fleet also accesses a number of oceanic fisheries. An Environmental Impact Statement (EIS) and Fishery Management Strategy have been developed for each fishery, to assess the impacts of the fishing industry and define specific management rules.

Commercial fishing in the Macleay estuary and surrounds is a locally significant industry, generating on average 86,000 kg of fish, which is worth approximately $340,000 per annum (based on 7 years of data from the 1997/98 season onwards). This constitutes on average approximately 1.7-1.8% of the total NSW estuary catch per year (NSW DPI, 2004 [1]). For the 1997/98 and 1998/99 seasons, the Macleay was listed within the top 20 estuaries in NSW based on the total weight of fish sold (NSW Fisheries, 2001). Over 50 different species are caught within the estuary or close to the estuary mouth. Sea mullet accounts for the most significant species by total weight (approximately 45%), whilst mud crabs are the most significant species caught in terms of total value (approximately 38%), based on 1997/98 and 1998/99 catch data (NSW DPI, 2004[1]). Other predominant species include luderick, eels, black and yellowfin bream, sand whiting, mulloway and school prawns. The majority of species utilise both the estuary and the ocean, generally within inshore areas.

Fishing effort throughout the year is generally consistent, although there is some increased activity during particular seasons such as the mullet run over autumn (NSW DPI, pers. com., 2008). Despite some yearly variations in catch size and catch value, the industry has remained relatively stable between 1997/98 and 2003/04, as shown in Diagram 21.



(a)



(b)

Diagram 21. Variation in Macleay Estuary commercial catch between 1997/98 and 2003/04 showing (a) total gross catch weight and (b) total catch value.

The primary fishing methods used are mesh and haul netting, crab and fish trapping, hand lining and hand gathering from ocean beaches. A number of netting restrictions are in force throughout the Macleay, its tributaries and South West Rocks Creek, as specified under a Section 8 Notification of the *Fisheries Management Act 1994* (NSW DPI website – Fishing Closure, accessed 2008).

Historically, the commercial fleet was distributed between Jerseyville, New Entrance at South West Rocks and at South West Rocks Creek. However, between 1978 and 1991, the number of vessels at South West Rocks Creek reduced from 17 to 6, primarily due to the entrance bar across the creek and sedimentation within the creek (GHD, 1992). The fleet currently consists of 14 vessels operating out of Jerseyville (NSW Maritime, pers.com., 2008). The majority of commercial fishing is offshore, with major activities including prawn trawling, fish and lobster trapping, hand lining and haul netting from ocean beaches. Offshore fishing is part of four different fisheries: Ocean Trap and Line, Ocean Trawl, Ocean Haul and Lobster Fisheries. The average ocean catch between 1997/98 and 2003/04 was approximately 152,000 kg, worth approximately $1 million (NSW DPI, 2004 [1]). The majority of the combined estuary and ocean catch is sold to external markets, with a proportion also sold locally through the Fisherman's Co-operative at Jerseyville.

The fishing industry is vulnerable to poor water quality within the Macleay and its tributaries. Poor water quality can arise after a flood event, due to the mobilisation of pollutants and the deoxygenation of floodwaters caused by the decay of vegetation on the surrounding floodplains. The most recent occurrence of significantly reduced water quality was following a flood in March 2001, which resulted in a major fish kill and 3.5 months of closures. The fish kill was most severe downstream of Jerseyville, and affected a number of commercially significant species such as luderick, yellowfin bream, dusky flathead and sand whiting (Macbeth et al., 2002). As discussed in Chapter 3 and as indicated by NSW Fisheries water quality testing, the primary cause of the fish kill was likely to be the release of deoxygenated water within the Macleay River (Macbeth et. al., 2002). The closures were partially lifted in July 2001, although some closures remained in place until March 2002. These closures are likely to account for the reduced catch during the 2000/01 season shown in Diagram 21.

7.2.3. Recreational Fishing

Recreational fishing is a popular activity in the Macleay River Estuary. Activity is highest during holiday periods, particularly over the Christmas/New Year period. There are a number of fishing clubs (including two based from South West Rocks, two from Kempsey, one at Smithtown and one at West Kempsey).

Recreational fishing occurs in all areas of the Macleay River, from its upper reaches to the ocean entrance and includes crabbing, prawning and hand-line fishing. In 2001, a survey of recreational fishing in the lower Macleay was conducted over four months (July to October) for NSW Fisheries (Steffe and Macbeth, 2002). The survey covered the area from south of Kinchela to the entrance. It was found that approximately 48% of recreational fishers were locals and approximately 40% of total fishing was boat based with 60% shore based. The most popular fishing area was near the Entrance (38% of total hours), followed by the Kemps Corner/Clybucca area (28%), Stuarts Point (21%) and the main river (13%). During the period sampled, the fishers surveyed reported approximately 36% of boat based trips to be unsuccessful and 61% of shore based trips.

Over the four month period, approximately 45,300 fish and crabs were caught (25.2 tonnes), across 16 different taxa. The primary species caught were luderick, yellowfin bream, dusky flathead, striped seapike, tailor and sand mullet. Both boat and shore based fishers surveyed primarily targeted luderick, flathead, bream and mulloway, with a high percentage having no specific fishing target. Steffe and Macbeth (2002) found that species caught were similar to those recorded during a recreational fishing survey conducted in 1990. Australian bass are also a significant recreational species, with a "Bass Catch" event held each year during September, which can attract more than 100 competitors. The *NSW Freshwater Fish Stocking Fishery Management Strategy 2005* permits the stocking of additional bass in the Macleay River (NSW DPI, 2005[1]).

7.3. Boating

The Macleay estuary is well suited to small to medium sized boats, which can access most parts of the estuary and its major tributaries up to the tidal limit. Shallow depths in a number of sections throughout the river limit the passage of larger boats to the lower estuary and out into the ocean. 18

Figure 7 (page 20) shows the key access areas. The following section provides a summary of the boating uses and facilities available within the estuary.

7.3.1. Boating Use

The predominant boating use within the estuary is commercial and recreational fishing. Small, recreational runabout boats of approximately 3 to 4 m in length are the most common vessel on the Macleay River and along the Macleay Arm between Fishermans Reach and Stuarts Point. A significant number of larger boats of up to 8 m utilise the South West Rocks boat ramp and the Macleay Entrance to access the ocean. The commercial fishing fleet, which consists of 14 vessels of up to 15 m in length, operates daily out of Jerseyville to offshore (NSW Maritime, pers. com., 2008).

The number of boats utilising the Macleay estuary varies greatly depending on location, season and other factors such as weather conditions. During peak periods, up to 300 - 400 boat passes through the Macleay Entrance are possible. These are likely to primarily consist of medium to large boats, as the conditions near the entrance can be unsuitable for smaller boats. Other popular areas are generally confined to locations near access points, and include the Macleay Arm and areas near Jerseyville, Smithtown and Kempsey. The more exposed reaches between Kempsey and Seven Oaks, and between Kinchela and Jerseyville can have significant wind waves and hence are less favourable for boating. The peak period is generally between December and March, although there is relatively consistent usage throughout the year.

Whilst the estuary provides opportunities for a range of other boating activities, there are currently low levels of waterway usage compared with other estuaries (DECC, pers. com., 2008). Reasons for this include a lack of adequate area wide tourist facilities, a lack of waterway specific facilities (see Section 7.3.3), a lack of adequate promotion of waterway opportunities and low numbers of tourists spending significant periods of time in the area.

Other than fishing, current waterway activities include the use of power boats such as ski boats and jet skis, water skiing, canoeing, kayaking, rowing, sailing and house boats. A cruise boat also offers site seeing along the lower Macleay estuary. Water skiing is generally not a major activity along the Macleay, although some does occur. The most used areas are upstream of the South West Rocks boat ramp, near Jerseyville, Smithtown and Kempsey, as well as north of the Stuarts Point footbridge along the Macleay Arm. Between 7 and 10 ski boats are estimated to utilise the Macleay Arm during peak periods. Jet skis also utilise the area near Smithtown. The reach upstream of Smithtown and the area near Greenhill upstream of Kempsey have been identified as suitable areas for waterskiing (DECC, pers. com., 2008). The area north of Stuarts Point is also suitable for a variety of water craft and is used by jet skis, ski and wake board vessels, runabouts and canoes.

The reach downstream of Kempsey and around Frederickton was a popular water skiing area but the waterway in this area has largely been blocked by the prolific growth of exotic macrophytes as mentioned in Section 6.2.3, Eutrophication. These weed, mainly Egeria densa and Elodea Canadensis, are Class 5 noxious weeds in NSW but have been identified as providing a beneficial effect in the Macleay by taking up nutrients and hence preventing algal blooms (Section 6.2.3). However, the macrophytes are so dense and widespread that they effectively restrict boating between Kempsey and Frederickton and have a significant impact in the immediate areas both upstream of Kempsey and downstream of Frederickton.

Whilst there are currently no known canoe or kayak hire facilities within the estuary, a number of people who own their own boats use the river (Macleay Valley Coast Tourism, pers. com., 2008). River conditions in the Macleay generally provide relatively safe opportunities for canoeing and kayaking (Kempsey Shire Council website, 2008). In previous years, rowing regattas were held along the Macleay River. However, this no longer occurs. Consultation with the local tourism office has suggested that the river is being used by the Crescent Head surf club for surf boat training and one resident has made a proposal to introduce dragon boat racing (Macleay Valley Coast Tourism, pers. com., 2008).

Similarly, sailing is not a popular activity in the area and there are no sailing clubs. However, those who own their own boats are able to access the river. The northern part of the Macleay Arm near Stuarts Point provides appropriate conditions for sailing, with adequate water depth and width and winds.

Macleay River Houseboats at Kempsey provide houseboat hire for visitors to explore the river between Kempsey and South West Rocks. One or two house boats are usually present on the estuary for various periods of time. However, there is a lack of adequate pumping facilities and moorings.

There are a number of boating restrictions within the estuary, to warn boaters of hazards as well as to minimise environmental impacts such as bank erosion. No wash zones are located near the South West Rocks boat ramp, along a section of the Macleay Arm near the Stuarts Point caravan park, along Spencers Creek, Clybucca Creek and Kinchela Creek, as well as along the south bank of the Macleay between Kemps Corner and Clybucca Creek. 4 knot speed zones occur in South West Rocks Creek and in the Macleay Arm near Stuarts Point. Areas such as the northern part of the Macleay Arm are also protected seagrass areas under the *Fisheries Management Act 1994*, which restricts any activity which could negatively impact upon the seagrass. Toward the upper reaches of the estuary, boating is restricted by shallow water and gravel bars which cross the river. The river is navigable up to Belgrave Falls at the tidal limit for smaller boats.

Whilst boating does not currently appear to have a significant impact on bank stability or instream ecology, there are some areas which are potentially more sensitive to boat use. For example, mangroves along the shoaled area within the Macleay Arm have been uprooted, which is thought to be a result of boat wash (DECC, pers. com., 2008). As a result of extensive shoaling in this area, boats are required to pass close to the banks, which increases the impact of boat wash on bank stability. Should boating use within the Macleay increase, it is possible that additional management of boating is necessary to balance both the environmental needs and needs of waterway users.

7.3.2. Boating Facilities

The majority of river frontage along the Macleay and its tributaries is connected to private land, which restricts river access and is a significant limitation to boating. Whilst there are many private boat ramps and jetties, there are only 9 formal public access points located throughout the estuary, at the following areas:

- Stuart's Point;
- South West Rocks along South West Rocks Creek;
- South West Rocks at The Boat Shed Marina along the Macleay River;
- Jerseyville;
- Kinchela;
- Smithtown;
- Frederickton;
- Kempsey; and
- Greenhill.

An informal public access point is also located along Clybucca Creek at the end of Suez Road (NSW Maritime, pers. com., 2008).

The majority of these access points have limited facilities and are not always located in areas suitable for boat launching. Many do not have toilet facilities, adequate car parking space or picnic areas. Only a few locations have jetties as well as boat ramps, and some jetties such as that at the main Kempsey boat ramp are not necessarily at an appropriate height for the range of boats using the area. Use of the Kempsey boat ramp is also severely impacted by the dense growth of macrophytes that extend from downstream where they effectively restrict navigation to upstream.

A new boat ramp and jetty has been suggested by Council for the Green Hill area upstream of Kempsey. The identified location is at an old quarry site, approximately 4 km upstream of the railway bridge. The river in this location is suitable for water skiing, wide and sheltered, the banks are bedrock or grassed slopes and the land base is close to but isolated from other urban developments. The area is also upstream of the impacts of the macrophyte bloom. Although further investigations are required, development of this area should be of major benefit to boating in the Kempsey area.

The boat ramps at Frederickton and Smithtown are old vehicular ferry ramps with no facilities that are not easy to use for launching. At Frederickton the boat ramp is located in a shallow area with extensive macrophytes and some seagrasses. The land base for the existing ramp will also be affected by the proposed Kempsey By-Pass. As a result there has been a proposal to provide a new boat ramp facility in the Frederickton area. The new ramp and jetty would need to extend far enough into the river such that the water depth was sufficient to enable boats to use the facility without impacting on the seagrasses.

Council has developed a new boat ramp facility at Jerseyville with a landing jetty, parking, picnic facilities and toilets. This facility provides good access to the middle/lower Macleay River but is not preferred to the South West Rocks (Macleay River) ramp, which is closer to the ocean and the Macleay Arm.

The jetty at South West Rocks (Macleay River) is the most popular public access points, with approximately 150 boats being launched each day during the peak season (summer). However, these predominantly consist of offshore vessels. The lack of parking spaces limits the number of vessels using the jetty. Council is currently proposing to increase the size of the parking area, as well as to provide a separate access pontoon. A beaching area is available along the shoaled area immediately upstream of the boat ramp and there are toilet facilities.

The boat ramp in South West Rocks Creek is another popular area for boats wishing to go offshore because of its proximity to the urban area and direct access to the ocean. However, the entrance conditions are difficult during even moderate swells, which limits ramp use. The area is also a popular swimming location. Historically, a significant proportion of the commercial fishing fleet was based at South West Rocks Creek (GHD, 1992). However, much of the Creek is shoaled, restricting navigation particularly at low tide. Consequently, only two boats are still moored in this area (Letcher et. al., 2007).

The Australian National University in consultation with Kempsey Shire Council, GECO Consulting and BAE Services examined a number of different management options for South West Rocks Creek using a decision making tool “CLAM” (Coastal Lake Assessment and Management). Options considered included increased dredging of the entrance. The study found that the options had both positive and negative impacts and in some cases were very costly. A more detailed summary of results is contained in *Back Creek South West Rocks Sustainability Assessment Report* (Letcher et. al., 2007). The facilities at the boat ramp are also limited, having no public toilets, fish bins or picnic areas.

7.4. Passive Recreation

The Macleay Estuary catchment provides opportunities for a number of activities in addition to fishing and boating. Activities include swimming, bushwalking, golf, bowls, tennis, squash, ten pin bowling, horse and greyhound racing, horse riding and bird watching. A number of historical sites also attract both locals and visitors (Kempsey Shire Council website, 2008).

The water quality in the Macleay River and South West Rocks Creek is generally considered adequate for primary contact and there are a few popular swimming areas include near the boat ramp at Kempsey and at South West Rocks Creek (DECC, pers. com., 2008; Kempsey Council, pers. com., 2008). Swimming areas generally require easy access, a relatively gradual decline in base topography, sufficient water quality, protection from high velocity flows, and protection from boating. Within the Macleay, swimming locations are restricted by the lack of public access in safe swimming areas.

There are a number of formal walking trails throughout the estuary, although most of these are concentrated near the coast and in Hat Head National Park. The 2005 tourism plan for the Macleay Valley (ATS, 2005, as described in Section 2.7) suggests that there is scope for additional walking trails which link different parts of the estuary. Picnic areas are also generally located in urban areas and in the National Park. A number of picnic areas do not have sufficient amenities such as toilets.

Facilities for sporting activities and horse and greyhound racing are primarily located in Kempsey, with some facilities also located in South West Rocks.

7.5. Conflicting Usage

The relatively low waterway usage within the Macleay has limited the conflict between different user groups, with some groups actually complementing each other, such as recreational fishing and tourism. Whilst active conflict is not especially apparent, different uses throughout the estuary do impact on each other and also impact upon the environment. Activities such as historical and current farming practices, mining operations and the disposal of untreated sewage have the potential to significantly impact upon waterway activities which rely on good water quality such as the oyster industry and fishing. The following provides a summary of the main conflicting uses within the estuary.

7.5.1. Commercial and Recreational Fishing

Conflict between commercial and recreational fishers appears to be generally limited to the common perception of recreational fishers that commercial fishers are overfishing. Anecdotal evidence has indicated that there is also the perception that the number of commercial fishers have increased due to restrictions in commercial fishing in surrounding coastal areas (Department of Fisheries, pers. com., 2008). However, there is no evidence to suggest that the numbers of commercial fishers have increased, or that they are overfishing (Department of Fisheries, pers. com., 2008). Given that the majority of commercial fishing occurs offshore and the majority of recreational fishing is within the estuary, the conflicts are generally minor.

Historical trends suggest that the commercial fishing catch has remained fairly stable and boat numbers and sizes are limited due to the shallow entrance conditions and lack of mooring facilities (GHD, 1992). There is likely to have been an increase in the number of recreational fishers corresponding with the population increase in South West Rocks and increase in tourism. Should conditions allow a significant increase in either commercial or recreational fishing in the future, it is possible that there will be more conflict between these groups.

7.5.2. Floodplain Use, Fishing and Aquaculture

The major floodplain activities that have the potential to impact on estuary users are farming, human habitation and mining. In many cases the most significant impacts caused by these activities are due to historical practices, such as habitat clearing, extensive drainage works and previous mining practices. However, current activities have the potential to either continue to operate in the environment shaped by this history or to assist in remediation and minimising impacts.

Extensive floodplain drainage works aimed at reclaiming arable land and minimising flood damage has resulted in many adverse environmental impacts such as the exposure of acid sulfate soils and the destruction of wetlands. Wetland species have been replaced by pasture which cannot withstand periods of inundation, causing pasture damage but also creating large bodies of water with low dissolved oxygen levels. Following flood events, runoff re-entering the river and tributaries is therefore of poor water quality and has been associated with fish kills and oyster closures (Macbeth et al., 2002; NSW Food Authority, 2008 [2]).

Poor water quality has been identified by stakeholders as having a significant impact on the oyster and fishing industry (NSW Department of Primary Industries, pers. com., 2008; NSW DPI, 2006; Macbeth et. al., 2002). Human habitation has the potential to impact upon water quality through the discharge of inadequately treated sewage and inadequate development controls. Elevated nutrient levels were observed near wastewater discharges in the River at Gladstone and in the Macleay Arm at Stuarts Point and Grassy Head (Section 5.1.2 and 5.2.2). Nutrient discharges from the Kempsey Sewerage Treatment Plant have been identified as fuelling the major macrophytes growth in the Kempsey to Frederickton area that has effectively prevented boating in that area. There are also concerns about unsewered areas such as at Stuarts Point and from illegal camping such as near the Macleay Entrance (DECC, pers. com., 2008) and the potential for these to cause similar problems in the poorly flushed Macleay Arm.

Historical mining operations in the areas of Hillgrove, Halls Peak, Rockvale, Enmore-Melrose and Mungay Creek have produced significant quantities of mine waste containing heavy metals such as antimony (Sb) and arsenic (As). Much of this waste material has been washed into surrounding waterways, and transported downstream. Whilst most contamination has been observed in localised areas surrounding the mines, in some cases significant transport of heavy metals has been recorded. Elevated Sb and As levels thought to be sourced from the Hillgrove mineral field have been found to occur at the mouth of the Macleay. During periods of flood, contaminated sediment can become mobilised and deposited throughout the floodplain (Ashley and Graham, 2001). Ashley and Graham (2001) found elevated Sb and As levels in the top layer of floodplain sediments which are above background concentrations.

In light of these issues, oyster growers have expressed a desire for improved water quality monitoring, particularly for microorganisms (DECC website – *NSW Water Quality and River Flow Objectives*, accessed 2008). There was also concern that increasing population and tourism has the potential to result in further deterioration of water quality.

7.6. Potential Impacts of Climate Change on Waterway Usage

Increasing temperatures, sea level, and changing rainfall patterns have the potential to substantially change the existing waterway and floodplain land use. It is necessary to plan for these changes to minimise future impacts on the community. Increasing temperatures may affect the viability of the aquaculture and fishing industry, as many aquatic species are vulnerable to increases in water temperatures. Sea level rise will change the location of the saltwater/freshwater boundary, which will affect aquatic habitats and hence may also influence commercially and recreationally important aquatic species. Sea level rise will also affect existing development in flood prone areas, with an increase in the frequency, extent and impact of flooding, as discussed in Section 2.5.5. There is likely to be a loss of beach area along Horseshoe Cove, which is backed by a rocky headland. Boating will be affected as access areas such as jetties, boat ramps and mooring locations would need to be modified to account for elevated ocean levels.

A change in rainfall patterns also has the potential to increase the frequency and intensity of flooding, and hence will impact on existing development. An increase in runoff is likely to increase the transportation of sediment, contaminants and acidic surface soils into waterways. Greater periods of inundation will also increase the frequency of low dissolved oxygen runoff impacting on downstream areas. A reduction in water quality is likely to have a significant impact on the viability of the aquaculture and fishing industry, as well as on recreational use.

8. SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

8.1. General

The aim of the Estuary Processes Study was to define baseline conditions for the various estuarine processes operating in the Macleay River Estuary and to examine the interactions between these processes and human use of the estuary and catchment. The purpose of the study was to provide a basis for developing management strategies as part of the next stage, preparation of an Estuary Management Study and Plan.

8.1.1. Summary

Study Area

The study area (shown in Figure 11, page 26) comprises the waterways, foreshores and adjacent lands of the Macleay River estuary from the ocean entrance to the tidal limit, a distance of approximately 54 km. It also includes the tidal reaches of the tributary streams of Kinchela, Belmore and Clybucca as well as the Macleay Arm. The impact of the wider catchment on the estuary was also considered.

Topography

The topography of the Macleay River catchment can be divided into three broad zones: upper valley, mid valley and coastal plains, as shown in Figure 3 (page 4). The upper valley covers approximately 40% of the catchment area and forms part of the New England Tablelands. The area is mostly cleared grazing land with elevations mainly ranging between 900 m and 1200 m. The mid valley covers approximately 35% of the catchment area and is characterised by rugged gorge and steep hill country covered in native forests. The remainder of the catchment encompasses lower hill country and the coastal floodplains (including the estuary). Most of this area is cleared and used for grazing and agriculture.

The Macleay River estuary commences at the tidal limit at Bellgrave Falls, some 8 km upstream of the Kempsey rail bridge. Prior to 1893 the ocean entrance was at Grassy Head, at the northern end of the Macleay Arm. However, a major flood in 1893 breached the sand barrier north of South West Rocks and subsequent entrance training works (including major dredging and breakwall construction) stabilised the entrance at that location. Major stabilisation works, including dredging and bank protection continued until the 1950's.

Geology

Partially metamorphosed mainly marine sedimentary rocks with a quartz and felspar composition dominate the catchment (73% of the area). Intrusions of granitic rocks with high quartz and felspar content with small amounts of mica occupy about 10% the catchment. These are associated with mineral deposits of Au, Cu, Pb, Zn, Ag, Sb, Sa and Mo. Tertiary age basaltic volcanics and minor sedimentary rocks occupy a further 11% of the area. Deposits of floodplain and estuary sediments cover the remaining 6%.

The materials constituting the floodplains are mostly unconsolidated sand-silt-muds, with gravels prevalent upstream. Silt-dominated levees occur along the river often bordered by muddy to organic-rich backswamps overlying earlier Pleistocene estuarine deposits. The estuary and coastal regions display interactions between Pleistocene to recent barrier beach deposits, estuarine sand-silt-mud and saline to brackish wetland areas.

Climate

The Macleay catchment has a warm temperate to subtropical climate. The climate is influenced by topography, latitude, local differences in altitude, proximity to the ocean, and temperature and precipitation patterns. Hence there are climatic variations between the coastal areas and the rugged mountainous region and tablelands in the upper part of the catchment. In general, the coastal region experiences a warmer and wetter climate than the upper tablelands.

Based on BOM rainfall data the wettest months are February and March for the coastal and mid valley areas and November to January for the tableland region. The driest month occurs in September for coastal and mid valley areas and April for the tablelands. The highest average annual rainfall occurs in the mid valley, followed by the coastal areas. The rainfall has significant spatial variations and needs to be considered within this context but based on the available information the following catchment average rainfalls were adopted:

- 820 mm/yr – Upper Valley – Tablelands,
- 1510 mm/yr – Mid Valley – Gorges and Steep Hills,
- 1260 mm/hr – Lower Valley – Low Hills and Coastal Plains (including the Estuary).

Temperature

Based on BOM data, the highest average monthly temperatures (around 26 ^{o} C) occur between December and February and the lowest (around 12 ^{o} C) in June or July. In general, minimum temperatures are lower and there is a greater variation between winter and summer temperatures in the tablelands than near the coast. In the lower catchment, temperatures are influenced by the ocean, whereas in the upper catchment temperatures are influenced by elevation and the terrain.

Winds

Again based on BOM data, comparing wind velocities at Kempsey with the nearest low coastal location (at Port Macquarie), approximately 78% of annual wind velocities are less than 10m/s at Kempsey, whereas at Port Macquarie only 36% are less than 10 m/s. The prevailing winds at Kempsey are variable during summer, with most winds from a north easterly through to southern direction, while in winter westerly winds dominate. During both summer and winter there is a significant proportion of time when conditions are calm. The annual prevailing winds nearer the coast (at Port Macquarie) are from the south west and north east. Calm conditions occur for only a small percentage of time.

Evaporation

Using adjusted BOM data from the two closest gauges at Coffs Harbour and Yarras, evaporation for the Macleay estuary was estimated to be approximately 1200 mm/yr.

Climate Change

Based on IPCC research, sea levels are predicted to rise between 0.18 and 0.59 m, from the 1980-1999 average to the 2090-2099 average level across all scenarios. Using a mid range scenario, the projected sea level rise for the east coast of Australia is 0.05 m to 0.1 m above the global average by 2090-2099. The inclusion of potential increases due to ice melt is likely to further increase sea level rise projections by up to 0.2 m. Based on this information and modelling conducted by CSIRO, the Department of Environment and Climate Change (2007) have suggested that sea level rise is expected to be in the range of 0.18 to 0.91 by 2090/2100, with a mid range level of 0.55.

In addition to sea level rise, climate change is predicted to result in a change in rainfall patterns and extreme events. These changes have the potential to increase the occurrence of flooding, and impact upon estuarine processes. However, there is still much uncertainty about the specific nature of such changes on a regional basis. Along the south east coast of Australia, east coast lows are expected to produce a significant proportion of heavy precipitation. However, CSIRO stated that the existing models do not provide sufficient indication of whether the occurrence of east coast lows will increase in frequency as a result of climate change.

Zoning

The entire Macleay River estuary and approximately 25% of the total Macleay catchment are within the Kempsey Shire Council Local Government Area. Zoning categories for the estuary are specified within the Kempsey Local Environment Plan (1987). There are 8 major zoning categories within the estuary. Nearly 90% of the catchment is zoned Rural. Other major zonings include National Parks and Reserves 8(a) which covers approximately 7% of the catchment, and Protection (7) covering approximately 4%. Urban areas (including residential, business and industrial zones) and special use areas occupy less than 1% of the catchment.

Downstream of Kempsey, the majority of the Macleay River is within the Rural zoning. The last 2.5km of the Macleay River and the majority of the Macleay Arm are within areas zoned Protection (7) to the east, with a mix of rural, urban and open space zones to the west.

Land Use

Current land use in the Macleay catchment is diverse. The upper tablelands have been largely cleared for grazing and crops. The escarpment, gorge country and upper hill country are still predominantly vegetated, with the majority of the area being National Park, Crown Land or State Forest although some logging still continues. The floodplain and estuary have mainly been cleared for agriculture including pasture for grazing and crop production. The major towns are Armidale, Kempsey, Walcha, Guyra and South West Rocks. Land use in these areas is dominated by residential, commercial and light industrial development. Other important catchment land uses include fishing, oyster farming, residential development and tourism, and in the past numerous mining operations.

Mining operations within the Macleay have largely ceased, with only one antimony and gold mine remaining at Hillgrove. However, major metal mining was undertaken at Hillgrove, Rockvale and Enmore-Melrose on the tablelands and Halls Peak near Jeogla and Mungay Creek near Willawarrin within the Macleay estuary catchment. Historical mining practices disposed of large quantities of waste material adjacent to waterways that have resulted in elevated arsenic and antimony concentrations extending as far as the ocean.

Tourism

The Macleay estuary is a popular tourist destination and Kempsey Shire attracts some 415,000 visitors each year, particularly in coastal areas. Attractions include the scenic coastline and bushland, historical sites such as Trial Bay Gaol and Smoky Cape Lighthouse as well as a variety of waterways activities. Tourism is a significant industry brining some $90 million into the area each year.

There has been an increase in tourists wishing to explore larger areas and those who want to experience different features of the area. However, Council's Tourism Plan (ATS, 2005) indicates that this type of tourism is not currently well catered for within the Kempsey LGA and that there is a lack of organised tours and a lack of adequate access to different parts of the region. The Plan aims to promote sustainable development and tourism through identifying which areas can withstand increased tourist numbers, and which areas are highly sensitive and require protection.

8.1.2. Conclusions and Recommendations

There are a number of conclusions that can be drawn from the General Catchment assessment:

- In terms of most catchment characteristics such as topography, geology and climate, the Macleay River catchment is similar to other NSW North Coast Rivers, particularly the Hastings and Manning Rivers.
- The Macleay Catchment differs from many other North Coast Rivers in relation to the large number of metal mines that have operated in the catchment in the recent past. This has affected water and sediment quality.
- The Macleay Estuary differs from other North Coast Rivers in that the location of the entrance and hence the length of the estuary has recently (geologically) shortened substantially. This affects the estuary hydrodynamics and sediment movement.
- Rural and protection zonings over most of the estuary catchment and alone the foreshores helps to control development.
- The Macleay Catchment has limited opportunities for tourists to explore larger areas. This could affect tourist numbers and hence waterway use.
- Climate Change will impact on the hydrodynamics of the system as a result of sea level rise and increased storminess, particularly in the lower estuary.

8.2. Hydrodynamics

The hydrodynamics of the Macleay estuary has two main driving forces, fluvial inflows and ocean tides. Wind driven currents and waves can also have localised impacts. Hydrodynamics are important because the inflow, mixing and exchange of fluvial and tidal waters impacts on other estuarine processes such as bank erosion and sedimentation, salinity levels and water quality, nutrient and contaminant distribution, ecosystem life cycles and human use.

As a result of the hydrodynamic interactions, three process zones are formed that reflect the differing degrees of fluvial and tidal influence. Fluvial processes dominate in the upper part of the estuary from Belgrave Falls as far downstream as Kinchela, after which there is a transition to tide dominated processes, which dominate downstream of Jerseyville to the ocean entrance.

8.2.1. Summary

Numerical Modelling
A combination of hydrologic (rainfall-runoff) modelling and hydraulic open channel modelling calibrated to existing river flow and water level data was used to examine the hydrodynamics of the estuary for both fluvial and tidal conditions. The hydrologic WBNM model was used to model catchment inflows. A RUBICON quasi-two dimensional hydraulic model was used to examine food flows and a combined one and two dimensional RMA-2/11 numerical model was used to model tidal flows and water quality. All the models were calibrated to existing data as far as possible.

Fluvial Flows
Fluvial inflow data for the Macleay shows that the average annual discharge is around 2,150 Mm^3, although this can vary by between 8% and 240% anually. The flood data shows that the 50% AEP peak flow at Belgrave Falls was in the order of 300 times greater than the median flow and the 1% AEP peak flow was 1400 times greater. However, the modelling showed that even for a comparatively small event like the 50% AEP, large flow volumes were diverted to storage on the floodplain and into the tributaries. The modelling showed that the 1% AEP was some four times greater than the 50% AEP at the top of the estuary, at Belgrave Falls, but in the order of 2.5 times greater at the ocean entrance.

Tidal Flows
The data showed that for existing conditions there was a substantial decrease in tidal range through the entrance as a result of entrance losses associated with high velocities, turbulence and bed friction. The mean spring tidal range fell from 1.35 m at the ocean to 1.0 m just inside the entrance (at South West Rocks). Tidal flows then remain constricted by the channels until around Smithtown (where the fluvial dominated channels are quite wide but the tidal flows are beginning to get quite small).

In general, the study showed higher peak flows for in flowing (flood) tides than for out flowing (ebb) tides, with the out flowing tides longer and more constant. The mean tidal prism at the entrance was 11.4 Mm^3, slightly lower than the neighbouring Hastings River, which is relatively similar in size. By comparison, the significantly larger but partially trained Manning River entrance has a mean tidal prism of around 10 Mm^3 and is significantly less efficient than both the Hastings and Macleay Rivers.

Comparison of Fluvial and Tidal Flows
To provide a better understanding of the relative impacts of fluvial and tidal flows throughout the

estuary a comparison has been made between the mean spring tide and the 50% AEP flood. Note, on average there are about 140 tidal ranges greater than the mean spring range each year but only one 50% AEP flood every two years (ie the tide occurrence is some 300 times more than the flood).

The data showed that floods with magnitudes around the 50% AEP have flows that are only two to three times greater than spring tidal flows in the lower estuary, but increase to around 10 times at Smithtown and 50 times at Kempsey. This indicates that tidal flows dominate the entrance area and Macleay Arm but that floods play an important role, especially in the upper reaches of the estuary. Larger floods such as the 1% AEP with several times larger flows have a major effect throughout the estuary, but particularly in the upper estuary.

Water Balance

An annual water balance is an estimation of the volume of water from different sources that passes a point in the estuary. By identifying the dominant source and the balance between the sources it can provide useful information on the processes operating at that location. Comparison was also made between current conditions and the conditions that would have existed prior to major development.

The analysis showed that flows at the entrance are dominated by tidal flows 75%, with catchment inflows representing 24% and direct precipitation on the estuary <1%. The predevelopment analysis was similar, with 77% tidal and 22% fluvial.

Tidal Flushing and Salinity

Flushing times for key locations in the estuary were determined by calculating the e-folding times. The e-folding time provides an indication of flushing within an estuary and can be used to identify areas which may be susceptible to water quality issues. It should be noted that the e-folding time only considers tidal flushing, which only plays a minor role in the upper reaches.

The results show as expected that e-folding times increase as you move up the estuary. Within 7 km upstream the entrance the waters are well mixed and the e-folding time is lower than 5 days. Further upstream the tidal mixing decreases, resulting in 30 days or six times higher e-folding times a further 2.5 km upstream. The upper reaches of Clybucca and the Macleay Arm requires some 50-60 days until the threshold concentration is reached. Much higher flushing times occur for the Jerseyville anabranch, where waters get trapped and also for the estuary upper reaches that are a long way from the ocean.

Floodplain Discharge Flushing

Catchment waters stored behind floodgates can have low oxygen levels and/or high acid levels. The RMA model was set up to replicate stored catchment water discharges at known locations so that different floodplain release scenarios could be examined as part of subsequent Management Study considerations. For the purposes of this study, two locations were modelled, the entrance of the Kinchela Creek and the head of Clybucca Creek. The results of the model runs compared well with anecdotal reports but far more scenarios need to be examined as part of the Estuary Management Study so as to develop management strategies.

Waves

Waves are important mechanisms for generating foreshore erosion and increasing water turbidity, and can contribute to mixing. Within an estuary the main generating sources are local wind waves and boat wash.

Local wind generated waves tend to be the dominant wave type across the estuary. As part of the study an analysis of wind generated waves was undertaken for 23 sites along the estuary where erosion was known to occur. The analysis showed that the highest wave energy occurs at two locations between Jerseyville and Kinchella and along the Macleay Arm. These locations have a relatively long fetch length allowing for larger wave generation and being close to the coast are influenced by the stronger coastal winds. However, these locations only experience minor erosion.

An analysis of boat generated waves was also undertaken for the same 23 locations examined for wind generated waves. The highest energy was calculated for the area between Jerseyville and Spencers Creek and along the Macleay Arm, although again only minor erosion was recorded at these locations.

For both wind and boat generated waves, sites with the highest estimated wave energy did not correspond with locations exhibiting major erosion. However, erosion is also dependent upon the soil constituents. As a result, more severe erosion can occur in areas with highly erodable foreshores even if wave energy is lower. Previous studies in other rivers suggest that wave energy is not always the primary cause of bank erosion, with stream flow also being the major cause. Other possible causes of erosion include cattle access and local runoff causing slumping in areas devoid of vegetation.

Climate Change

As discussed in the Catchment summary, climate change is likely to have a significant impact on the hydrodynamics of the Macleay Estuary. Any increase in mean ocean tide levels would result in a corresponding increase in water levels inside the estuary and an increasing tidal range/extent. Increasing ocean levels would also have the potential to change the entrance conditions, which significantly influence the exchange of fluvial and tidal flows. Assuming shoaling at the entrance does not increase, tidal exchange and the average annual water balance would increase. The impact of tidal storms on the surrounding floodplain would also increase, as a more open entrance would allow elevated ocean levels due to storm surge and wave setup penetrate into the estuary.

Any increase in rainfall would increase the level of catchment runoff and the volume of fluvial flows in the estuary water balance. The result would be an increase in the water balance, but as mentioned above could also include some increase in tidal flows. Any decrease in rainfall would be associated in decreased catchment runoff and a smaller water balance.

8.2.2. Conclusions and Recommendations

There are a number of conclusions that can be drawn from the Hydrodynamics assessment in relation to human impacts:

- The estuary can be divided up into three zones based on the hydrodynamics, a Fluvial Zone from Belgrade Falls to Kinchela, a Transitional Zone from Kinchela to Jerseyville and a Marine Tidal Zone from Jerseyville to the ocean.
- Substantial energy losses occur at the ocean entrance due to the high velocities, turbulence and friction effects, but these are less for the fully trained entrance than when compared to predevelopment conditions or partially trained entrances like the Manning River.
- The peak inflowing tide is higher than the out flowing tide, which is longer and flatter.
- Tidal exchange is the main flow mechanism in the lower river and the Macleay Arm but has very little impact in the upper river above Kinchela or in the Clybucca Anabranch.
- Fluvial flushing is the main flow mechanism in the upper river and creeks.
- The release of low DO or pH ponded waters from behind floodgates can cause substantial ecological damage. The RMA model as established allows for different discharge scenarios to be examined as part of the Management Study.
- Sea level rise will affect the hydrodynamics of the system and this is likely to affect sediment transport, water quality and ecology throughout the estuary,
- Increased flooding due to Climate Change could occur due to increases in rainfall and/or spatial/temporal variation.

8.3. Sediment Dynamics

8.3.1. General

Sediment dynamics describe the formation, distribution and movement of sediments within an estuary system. The distribution of different sediment types (facies) helps define the fluvial, transitional and marine process zones within the estuary. Further, the morphology (shape) of estuary channels, banks and floodplains form in response to sediment movement mechanisms, and have a major impact on human use of the waterway and foreshores.

Sediment movement dynamics in the Macleay River estuary are primarily driven by tidal and fluvial (flood) flows, although wind and wave movements and human impacts (land management practices, boat wash, past channel dredging and bank training) also have localised effects.

8.3.2. Summary

Sedimentology

The widespread substrate of the Macleay catchment typically gives rise to quartsofelspar lithic gravel deposits in the tableland streams and cobbles and boulders in the gorge country but finer sediment fractions dominate in the lower reaches dominated by quartz and felspar grains and lithic material. To help determine and quantify the distribution of sediments through the Macleay

Estuary 59 bed sediment samples were collected and analysed. Based on this analysis the sediments were divided into three broad facies:

- Beach and Nearshore Marine Sands,
- Reworked Coastal Sands,
- Fluvial Sands.

The analysis showed that the distribution was similar to other major NSW river estuaries with fluvial sand deposits along the upper estuary reaches and coastal/marine sands along the lower reaches. However, the Macleay differed from most other similar sized estuaries in that the fluvial sediments extended to within a couple of kilometres of the ocean entrance. Most other major river estuaries have a wide band of reworked coastal sands mixed with some fluvial sand along the lower coastal zone. However, in the Macleay the Transitional Zone is dominated by fluvial sediments, with a very short zone of mixed marine, coastal and fluvial sediments near the confluence between the river and the Macleay Arm.

The reasons for the differences is not related to significantly different tidal or fluvial hydrodynamics or sedimentology, but rather to the relatively recent (geologically) change in the location of the river entrance and the effects of the entrance training works on beach littoral zone sand movements over the period since the entrance location changed.

Existing Bed and Bank Conditions

Bank erosion not only causes a loss of valuable foreshore land, it also contributes to sedimentation and shoaling in the estuary and increases the concentration of suspended solids in the water column. Bank erosion can be caused by a number of different processes including fluvial scour, waves, the loss of riparian vegetation and cattle access. An assessment of bank erosion was undertaken as part of the Data Compilation Study. Bank erosion severity, failure mechanism and dominant processes were recorded for each location where erosion occurred for more than 20 m in length.

The Fluvial Zone has the most severe bank erosion although 90% is stable (22% of this being stabilised by bank revetment). The dominant causes of erosion were found to differ. The upper reaches were dominated by fluvial processes with significant erosion often resulting from major floods with an increased risk where vegetation was cleared and cattle had river access. The middle reaches between Kempsey and Seven Oaks were predominantly stable with extensive rock protection. Isolated small sections of toe scour and fluvial erosion were observed. The lower fluvial reaches were the most active with significant (mainly wind) bank erosion at Kinchela Bend (3 km) and Fattorini Island (0.5 km) where the erosion was in a channel constriction and is impacted by both flood currents and ongoing wave erosion.

The Transitional Zone was the second most unstable area of bank erosion although there was no severe erosion and only 1.2 km of moderate erosion and 6.3 km of minor erosion. However, some 43% or 30 km of bank has been rock protected. The most significant erosion along the main river was at Pelican Island where waves were eroding a layer of sands and silts. Erosion along Clybucca Creek was mainly along the outside of bends indicating a current induced process, although this appeared to be maintained by (wind and boat) waves.

The marine tidal zone was the most stable, with only 6% (3.8 km) being assessed as having minor erosion. Of the stable banks 23% (16 km) had been rock protected. The bank heights in this zone were very low and the erosion appeared to be the result of wind and boat waves.

River Planiform Changes

River planiform describes the shape and location of a river as viewed above. Rivers naturally change over time, adjusting to controlling factors such as different flows, sediment size and supply rates, bank characteristics, geology and catchment slope. For example, there is a natural tendency for rivers to increase in sinuosity as the outside bends become eroded due to higher velocities, and inside bends undergo deposition. Planiform changes can provide an indication of how much a river has moved over time, and how stable it is. Morphological variables describe channel form and include features such as channel width, mean depth, thalweg (maximum depth), channel slope and sinuosity.

Human activities can have significant impacts on river morphology. For example, land clearance and cattle access can increase bank erosion and sediment transport into the river. This can decrease sinuosity and hence increase slope and velocity in an attempt to transport the excess sediment down the river.

In order to examine the planiform changes for the Macleay River, aerial photographs from 2003 and 1956 were compared with historical parish maps from 1907 to 1913. This examination showed that although there had been significant localised bank movements, the majority of Macleay River Estuary had not changed significantly over the last 100 years, suggesting it is relatively stable. The most significant changes had occurred in the lower estuary and along the coast, primarily the movement of the estuary mouth from Grassy Head to South West Rocks following a major flood in 1893. This resulted in a westward shift and contraction in river width along the Macleay Arm as a result of infilling by aeolian sand from the beach dunes (and some dredged sand deposition). The construction of breakwalls along the new entrance intercepted much of the northerly littoral zone sand movement, resulting in prograding of the coastline (seawards extension) to the south of the breakwalls and erosion/recession of the northern beach.

Extensive rock revetment along 66 km of river banks has restricted bank erosion and movement between 1956 and 2003. In areas that were free to adjust, the length and severity of the erosion is low when compared with similar nearby river estuaries. The erosion that is occurring appears mainly to be current initiated and then maintained by a combination of wind and boat waves. This is more likely to occur where the soils are highly erodible.

Whilst rock revetment provides local bank stabilisation, it does not prevent the river from adjusting. It is not known how the river will continue to adjust to past changes. However, the most significant impacts are likely to be caused by major flooding, climate change, surrounding land practices and direct modifications to the river. Historical land practices have already resulted in extensive clearing of vegetation along the banks. This has the potential to increase rates of bank erosion. Unless revegetation of the banks and the exclusion of cattle occurs, sedimentation and bank collapses are likely to continue.

8.3.3. Conclusions and Recommendations

There are a number of conclusions that can be drawn from the Sediment Dynamics assessment in relation to human influences:

- The estuary can be divided into the same three zones as for the hydrodynamics, a Fluvial Zone from Belgrade Falls to Kinchela, a Transitional Zone from Kinchela to Jerseyville and a Marine Tidal Zone from Jerseyville to the ocean.
- Bank erosion along the Macleay is not severe when compared to many NSW coastal rivers, mainly due to the extensive bank protection works undertaken in the past.
- Ongoing bank erosion is continuing but the causes are very variable.
- Planiform changes in the last 100 plus years indicate that although there have been significant localised bank movements these changes have not altered the overall sediment dynamics except in the lower estuary/entrance area where there were major changes associated with the movement and stabilisation of the entrance from Grassy Head to near South West Rocks.

8.4. Water and Sediment Quality

8.4.1. General

Water quality can be affected by a number of different processes. The hydrodynamics of the estuary can influence flushing characteristics and hence mixing of the estuary, the salinity structure, and how quickly nutrients and contaminants are distributed as well as removed. Rainfall patterns and the surrounding land use can influence the volume and quality of runoff

8.4.2. Water Quality Summary

Maintaining adequate water quality is essential for the health and functioning of aquatic species as well as for human use. Guidelines such as ANZECC and the OISAS Water Quality Objectives provide recommendations on the amount of different constituents that are unlikely to result in adverse biological and ecological impacts. Typical parameters used to measure water quality include salinity, dissolved oxygen, temperature, total suspended solids, nutrients, pH, toxicants, chlorophyll-a, faecal coliforms, and the presence of any pathogens.

Water quality can be affected by a number of different processes. The hydrodynamics of the estuary can influence flushing characteristics and hence mixing of the estuary, the salinity structure, and how quickly nutrients and contaminants are distributed as well as removed. Rainfall patterns and the surrounding land use can influence the volume and quality of runoff during storm events. The drainage of acid sulfate soils for farming and other land uses can reduce pH in the estuary, and the planting of flood-intolerant pasture species can cause deoxygenation through the decomposition of organic material. Wastewater discharge can increase nutrient concentrations and algal blooms, and bank instability can increase total suspended solids. Mining operations have also resulted in elevated concentrations of arsenic and antimony within the Macleay River, its tributaries, and sediments in the surrounding floodplain.

Poor water quality can adversely impact on aquatic habitats and aquatic species. Many aquatic species play an important role in cycling nutrients and maintaining adequate water quality. Other species such as riparian vegetation and birds which prey on estuarine fish may be affected by poor water quality. Commercial activities reliant on aquatic species such as aquaculture and fishing would be affected, as would primary and secondary contact use of the estuary such as swimming and boating.

Sampling Program

As part of the study 12 monthly sampling runs were undertaken from September 2006 to August 2007 along both the Macleay Arm and main arm of the Macleay Estuary. Sampling runs in the Macleay Arm were usually completed within about 1 hour and were timed to start at the ocean entrance about 1 hour before high tide. Sampling runs in the main river were usually completed within about 3 to 4 hours and were timed to start at the ocean at about high tide and progress upstream with the high tide crest to Kempsey. In the Macleay Arm, 5 samples were collected at set locations. In the Macleay River, samples were collected at different salinity concentrations, from seawater to freshwater along the estuary and set locations between Smithtown and the Kempsey when saltwater did not intrude that far.

Salinity, Dissolved Oxygen, pH and Suspended Solids

Flushing times were dependent upon the flow of freshwater from upstream and tidal patterns. Over the study period flushing times ranged from 3 days to 57 days depending on flow. Salinity profiles varied from highly stratified to well mixed and the salt/freshwater interface was upstream of Kempsey or pushed out to sea. Dissolved oxygen concentrations were generally within ANZECC guidelines, except after flood events when they dropped due to the decomposition of organic material. Near the macrophyte beds in the upper estuary, oxygen was supersaturated, probably a result of the high rates of primary production. pH decreased along the salinity gradient from the saltwater to fresh and decreased after high flows. An increase in pH occurred near the macrophyte beds, consistent with supersaturated dissolved oxygen concentrations. pH values were generally within the recommended values for oyster growth. Total suspended solids were higher in the lower estuary due to wind resuspension, and also increased after a flow event.

Nutrient Levels and Sources

Total nitrogen concentrations were generally below ANZECC guidelines. They were higher in the lower estuary and Macleay Arm, especially during summer. This was probably due to the presence of seagrass beds. Concentrations exceeded ANZECC levels in the upper estuary after high flow events due to increased runoff. Nitrate and ammonium concentrations exceeded ANZECC levels near the Gladstone wastewater plant, although were well assimilated by the macrophyte beds. Low nitrogen levels throughout the estuary suggest that the estuary was nitrogen limited.

Total phosphorus concentrations were also below the ANZECC guidelines, and were higher at the ocean end, suggesting an ocean source. Concentrations were also higher after increased flow from runoff. There was some uptake of phosphorus by the macrophyte beds, although the estuary is unlikely to be phosphorus limited. The Macleay Arm, especially near Grassy Head and Stuarts Point were found to experience higher phosphorus concentrations during summer, possibly due to effluent from septic tanks or release from sediments.

Chlorophyll-a levels were found to be generally around the lower limit, with a peak downstream of Gladstone Wastewater Treatment Plant. Concentrations are generally lower immediately after high flows, followed by an increase due to increased nutrients transported from the floodplain. Phytoplankton blooms were more frequent during summer, and it is recommended that additional research is conducted into the cause of summer phytoplankton blooms.

Comparison of nutrient concentrations with those measured during previous studies indicated that generally there were minimal differences, although there appears to have been an increase in nitrate and dissolved inorganic phosphorus concentrations from runoff during high flow events.

Preliminary research into the potential impact of septic tanks on water quality has indicated that there is the potential that there are increased nitrogen levels due to septic tank effluent in the Macleay Arm. However, the results are inconclusive, and it is recommended that further research is conducted.

Carbon, nitrogen and phosphorus nutrient budgets were developed for the estuary to determine the major nutrient sources and sinks. The budgets highlighted the importance of benthic production as a carbon source, which supplies higher trophic levels such as fish. Benthic production requires adequate light penetration (low Total Suspended Solids and low chlorophyll-a), and low nutrient concentrations. The main nitrogen and phosphorus inputs are from runoff and in the dry season the largest nitrogen input is from wastewater. Benthic denitrification was the largest output of nitrogen, which relies on low algal production. The main phosphorus output is through burial.

Biogeochemical and Physical Processes

The main biogeochemical and physical processes within the estuary are largely depended upon flooding. These processes in turn influence the ecological health of the estuary. During a flood, freshwater can extend into the ocean and there can be substantial transport of sediment that may be deposited either within the estuarine basin or delivered to the continental shelf. Floodwaters from the surrounding floodplain may be deoxygenated and contain higher concentrations of sulphides, nutrients, and sediment containing antimony and arsenic. Additionally, acid sulfate runoff can result in a reduction in pH. Floods can create habitat diversity, but can also cause disturbance, a temporary loss in habitat and loss of food supply due to poor water quality.

Immediately following a flood, a highly stratified salt wedge develops, which becomes partially mixed and then vertically homogeneous. Deposition of sediment at the salt/freshwater interface is likely to occur and oxygen levels remain low due to the decomposition of nutrients. The estuary is vulnerable to algal blooms during this stage.

During dry seasons, the estuary remains vertically homogeneous due to low freshwater flows.

Nutrient levels are generally low in the upper estuary due to uptake by macrophyte beds, although elevated algal biomass concentrations can occur adjacent to and downstream of the Gladstone wastewater discharge and adjacent to Grassy Head and Stuarts Point.

8.4.3. Sediment Quality Summary

Significant areas within the Macleay estuary catchment and floodplain contain sediments with elevated antimony and arsenic concentrations. The majority of the estuary is also classed as being of high acid sulfate soil (ASS) risk. Acidic and contaminated sediments have an impact on the ecology of the floodplain, and can also reduce water quality and impact upon in-stream ecology. Arsenic is toxic to both animals and plants. The environmental behaviour of antimony is less well known, although it is expected to behave similarly to arsenic as it has similar chemical properties. Further research is recommended to investigate the metabolism of different forms of arsenic and antimony.

Metal Contamination

The Macleay catchment has naturally elevated concentrations of heavy metals and has a number of major mineralised regions, the most significant being the Hillsgrove region. Contamination of sediments and waterways can result from natural processes such as erosion of mineralised rock or from mining processes such as waste disposal practices. Land uses which remove vegetation and increase erosion can increase the transport of sediment from the floodplain to the Macleay River and its tributaries. Mining of arsenic and antimony has resulted in a dispersion train as long as 300km from Hillgrove to the ocean.

There has been some preliminary research into the bioavailability of arsenic and antimony in the Macleay catchment. Elevated arsenic and antimony concentrations have been found in pastures but investigations into the impact of arsenic on cattle found that there was no detectable impact on cattle grazing on arsenic contaminated tailings. The studies also showed some uptake of arsenic by algae and some uptake in oysters. Studies have also found that there was a greater uptake of antimony compared with arsenic in riparian vegetation but no measurable uptake of antimony in oysters.

As part of the current study, analysis of four sediment samples indicated that all arsenic concentrations were below the ISQG – low guidelines. In three samples antimony concentrations were above the ISQG – low value but below the ISQG - high value. A higher percentage of arsenic (29%) was found to be leachable and hence potentially bioavailable compared with antimony (<16%). Both arsenic and antimony are more likely to be mobilised at pH above 6-6.5 and below 3.

Acid Sulfate Soils

ASS cover a significant area of the Macleay estuary catchment. Key affected areas include Yarrahapinni, Collombatti – Clybucca wetlands, Belmore Swamp, Frogmore area, Kinchela Swamps and Raffertys wetland. ASS can reduce the pH of soil and waterways, which can make them toxic to plants and animals.

8.4.4. Conclusions and Recommendations

The following conclusions and recommendations can be drawn from the Water and Sediment Quality assessment:

- Water quality parameters were generally within ANZECC guidelines, with exceptions being low dissolved oxygen after flood events, and elevated nitrogen concentrations in the upper estuary after high flows. Elevated nitrogen and ammonium concentrations were also observed near the Gladstone wastewater discharge, although nutrients are generally assimilated by the macrophyte beds.
- It is recommended that the incorporation of additional nutrient removal as part of the wastewater treatment process is investigated, to reduce nutrient concentrations and reduce the expanse of macrophytes in areas designated for boating use.
- Phytoplankton blooms were found to occur more frequently over summer. It is recommended that further investigation is undertaken to determine the causes of these blooms, and possible ways to minimise them.
- Preliminary investigations indicate that septic tank effluent may be impacting upon water quality in the Macleay Arm. Further research into the possible impact of the effluent is recommended.
- Nutrient budgets have highlighted the importance of benthic production, which requires low total suspended solids and nutrient concentrations to minimise algal blooms.
- Acid sulphate soils and arsenic and antimony contamination affect significant areas of the Macleay estuary as well as the wider Macleay catchment. These may negatively impact upon water and sediment quality, as well as the ecology of the estuary.
- More research is recommended into the bioavailability of different forms of arsenic and antimony, as well as the potential impacts upon the ecology and the commercial fishing industry.

8.5. Ecological Characteristics

8.5.1. Summary

In total 46 threatened fauna have been found to occur within the Macleay estuary, of which 7 are endangered and 39 are vulnerable under the NSW Threatened Species Conservation Act 1999. The majority of threatened species are mammals and birds. Birds are considered to be the most likely to use the estuary for roosting, nesting, foraging or their entire life cycle. A number of migratory birds also utilise the estuary during the non-breeding season.

Endangered ecological communities and protected habitat areas have been identified within the estuary. Endangered ecological communities within the estuary induce the following:

- Coastal Saltmarsh;
- Freshwater Wetlands on Coastal Floodplains;
- Subtropical Coastal Floodplain Forest;
- Swamp Schlerophyll Forest on Coastal Floodplains;
- Swamp Oak Floodplain Forest; and

- River-flat Eucalypt Forest.

Protected habitat areas include those listed under State Environmental Planning Policy 14 Coastal Wetlands, and State Environmental Planning Policy 26 Littoral Rainforests. Fourteen habitat areas of particular significance were identified as part of the study (listed below), the majority of which are freshwater wetlands.

- Christmas Creek (north of Kempsey);
- Barnetts Lagoon;
- Old Pola Creek;
- Cooroobongatti Swamp;
- Swamp W and SW Clybucca;
- Swamp NE Kinchela;
- Swamp SE Kinchela;
- Swamp S Jerseyville;
- Clybucca Creek;
- Andersons Inlet;
- Pelican Island;
- N of Rainbow Reach (between the Macleay River and Clybucca Creek); and
- Shark Island and adjacent channels.

Only one vulnerable aquatic species (Black Cod) is known or considered likely to utilise the Macleay estuary. The Black Cod inhabits estuaries along the north coast of NSW, and it is generally found in rocky reef areas. It is therefore likely that its occurrence within the Macleay estuary would be limited to rocky areas in the lower estuary. A number of commercially and recreationally significant species are also found in the estuary, which rely on adequate aquatic habitat and water quality.

The ecological health of the estuary is influenced by other estuarine processes, including hydrodynamics, the location of the saline/freshwater interface, water quality, sediment dynamics and quality, and human usage. Hydrodynamics can influence water quality as well as habitat health and availability, whilst the location of the saline/freshwater interface can influence the extent of saline habitat. Flooding can have both a positive and negative impact by creating new aquatic habitat in wetland areas, whilst removing habitat for terrestrial species.

Water and sediment quality have a direct impact on the health of aquatic species, and can also impact upon habitat used by terrestrial species. Sediment dynamics such as bank erosion can reduce light penetration in the water column, which can impact negatively upon aquatic species. Water and sediment transport from the floodplain can also affect aquatic health by increasing nutrient concentrations, lowering dissolved oxygen concentrations, and reducing pH.

Human usage of the estuary has had the most significant impact on the ecological health of the estuary. Development has resulted in a loss of habitat, and increased transport of sediment, nutrients and pollutants. Mining activities have increased arsenic and antimony contamination of waterways and their surrounding floodplains. Bank stabilisation works and dredging have also influenced sediment dynamics, and can increase bank erosion and hence loss of riparian habitat in unprotected areas.

8.5.2. Conclusions and Recommendations

The following conclusions and recommendations can be made from the Ecological Characteristics assessment:

- The ecology of the Macleay estuary has been substantially altered as a result of land clearing, development, the construction of floodplain mitigation structures and drainage systems, and other human uses. However, the existing ecology appears to be relatively stable, and adequate water quality has helped maintain in-stream ecology.
- Of the 46 threatened terrestrial species likely to occur in the Macleay estuary, the majority are birds and mammals. Birds are considered the most likely to rely upon estuarine habitat.
- Only one vulnerable aquatic species is considered likely to occur within or near the Macleay estuary (the Black Cod). This species is more likely to be found near the rocky areas in the lower estuary.
- The estuary supports a number of commercially and recreationally significant aquatic species. Commercial catch has remained relatively stable compared with other NSW estuaries, indicating that stocks are likely to be above the threshold required to sustain the population.

8.6. Waterway Usage and Facilities

The lower Macleay River and surrounding floodplain support a wide variety of commercial and recreational uses, including fishing, aquaculture, agriculture, boating, swimming, walking, and tourism. Both the oyster and commercial fishing industry are locally significant, producing approximately 2% of the total NSW production. Existing recreational usage of the Macleay estuary waterways appears to be limited by a lack of adequate river access and facilities. There is also scope for improved access, facilities and promotion of the surrounding catchment, to encourage both the local community and tourists to utilise and appreciate the natural and cultural attractions. Future development and increases in usage should be planned for, to ensure that it occurs in a sustainable manner. This requires consideration of appropriate locations for different uses, any necessary restrictions on usage, and the ongoing monitoring of impacts. Historical and current land uses have already significantly impacted upon the health and functioning of the estuary. It is necessary to engage the community to address existing issues such as riparian habitat loss, the loss of wetland and flood tolerant vegetation, and acid sulfate soils. The potential impacts of climate change should also be considered.

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Figures

Appendix A

APPENDIX A: GLOSSARY OF TERMS

acid sulfate soils	Are sediments which contain sulfidic mineral pyrite which may become extremely acid following disturbance or drainage as sulfur compounds react when exposed to oxygen to form sulfuric acid. More detailed explanation and definition can be found in the NSW Government Acid Sulfate Soil Manual published by Acid Sulfate Soil Management Advisory Committee.
Annual Exceedance Probability (AEP)	The chance of a flood of a given or larger size occurring in any one year, usually expressed as a percentage. For example, if a peak flood discharge of 500 m^3/s has an AEP of 5%, it means that there is a 5% chance (that is one-in-20 chance) of a 500 m^3/s or larger event occurring in any one year (see ARI).
Australian Height Datum (AHD)	A common national surface level datum approximately corresponding to mean sea level.
Average Recurrence Interval (ARI)	The long term average number of years between the occurrence of a flood as big as, or larger than, the selected event. For example, floods with a discharge as great as, or greater than, the 20 year ARI flood event will occur on average once every 20 years. ARI is another way of expressing the likelihood of occurrence of a flood event.
catchment	The land area draining through the main stream, as well as tributary streams, to a particular site. It always relates to an area above a specific location.
development	Is defined in Part 4 of the Environmental Planning and Assessment Act (EP&A Act).
discharge	The rate of flow of water measured in terms of volume per unit time, for example, cubic metres per second (m^3/s). Discharge is different from the speed or velocity of flow, which is a measure of how fast the water is moving for example, metres per second (m/s).
ecologically sustainable development (ESD)	Using, conserving and enhancing natural resources so that ecological processes, on which life depends, are maintained, and the total quality of life, now and in the future, can be maintained or increased. A more detailed definition is included in the Local Government Act 1993. The use of sustainability and sustainable in this manual relate to ESD.
flood	Relatively high stream flow which overtops the natural or artificial banks in any part of a stream, river, estuary, lake or dam, and/or local overland flooding associated with major drainage before entering a watercourse, and/or coastal inundation resulting from super-elevated sea levels and/or waves overtopping coastline defences excluding tsunami.
flood liable land	Is synonymous with flood prone land (i.e. land susceptible to flooding by the probable maximum flood (PMF) event). Note that the term flood liable land covers the whole of the floodplain, not just that part below the flood planning level (see flood planning area).
floodplain	Area of land which is subject to inundation by floods up to and including the probable maximum flood event, that is, flood prone land.
flood prone land	Is land susceptible to flooding by the Probable Maximum Flood (PMF) event. Flood prone land is synonymous with flood liable land.
hydraulics	Term given to the study of water flow in waterways; in particular, the evaluation of flow parameters such as water level and velocity.

hydrograph	A graph which shows how the discharge or stage/flood level at any particular location varies with time during a flood.
hydrology	Term given to the study of the rainfall and runoff process; in particular, the evaluation of peak flows, flow volumes and the derivation of hydrographs for a range of floods.
local overland flooding	Inundation by local runoff rather than overbank discharge from a stream, river, estuary, lake or dam.
mainstream flooding	Inundation of normally dry land occurring when water overflows the natural or artificial banks of a stream, river, estuary, lake or dam.
mathematical/ computer models	The mathematical representation of the physical processes involved in runoff generation and stream flow. These models are often run on computers due to the complexity of the mathematical relationships between runoff, stream flow and the distribution of flows across the floodplain.
peak discharge	The maximum discharge occurring during a flood event.
Probable Maximum Flood (PMF)	The PMF is the largest flood that could conceivably occur at a particular location, usually estimated from probable maximum precipitation, and where applicable, snow melt, coupled with the worst flood producing catchment conditions. Generally, it is not physically or economically possible to provide complete protection against this event. The PMF defines the extent of flood prone land, that is, the floodplain. The extent, nature and potential consequences of flooding associated with a range of events rarer than the flood used for designing mitigation works and controlling development, up to and including the PMF event should be addressed in a floodplain risk management study.
Probable Maximum Precipitation (PMP)	The PMP is the greatest depth of precipitation for a given duration meteorologically possible over a given size storm area at a particular location at a particular time of the year, with no allowance made for long-term climatic trends (World Meteorological Organisation, 1986). It is the primary input to PMF estimation.
probability	A statistical measure of the expected chance of flooding (see AEP).
risk	Chance of something happening that will have an impact. It is measured in terms of consequences and likelihood. In the context of the manual it is the likelihood of consequences arising from the interaction of floods, communities and the environment.
runoff	The amount of rainfall which actually ends up as streamflow, also known as rainfall excess.
stage	Equivalent to “water level”. Both are measured with reference to a specified datum.
stage hydrograph	A graph that shows how the water level at a particular location changes with time during a flood. It must be referenced to a particular datum.
water surface profile	A graph showing the flood stage at any given location along a watercourse at a particular time.
wind fetch	The horizontal distance in the direction of wind over which wind waves are generated.

GLOSSARY OF BIOGEOCHEMICAL TERMS

Ambient Nutrient Concentrations	The surrounding or background concentrations in the estuarine water column.
Ammonium (ammonia)	Compound consisting of a single nitrogen atom and four (or three) hydrogen atoms.
Benthic	Belonging to the bottom of the estuary.
Bloom	When the biomass and species composition of phytoplankton populations change rapidly.
Biomass	The living weight of plant and animal material.
Chlorophyll	The green pigments of plants which capture and use the energy from the sun to drive the photosynthesis processes.
Conservative	Concentrations of a given material decrease (or increase) due only to dilution (i.e. they are not subjected to biogeochemical processes).
Denitrification	Bacterial reduction of nitrate to nitrous oxide (gas, N_2).
Dissolved Inorganic Phosphorus (DIP)	The most reactive or bio-available form of phosphorus. Sometimes referred to phosphate, ortho-phosphate (PO_4), reactive phosphorus, or dissolved reactive phosphorus (DRP).
End-member	Concentraction at the ocean or freshwater end of the salinity gradient.
Flushing Time	The time it takes to replace the freshwater in an estuary at a rate equal to the river discharge.
Isotope	Element with the same atom number (number of protons), but a different number of neutrons ^{14}N: 7 protons + 7 neutrons; ^{15}N: 7 protons + 8 neutrons.
Mixing plot	A plot of a given parameter as a function of salinity.
^{15}N	Stable isotope of nitrogen (see Isotope). 99.64% of the nitrogen on the earth is ^{14}N and 0.36630% is ^{15}N.
Nitrate	The NO_3 anion.
Nitrite	The NO_2 anion.
Nutrients	Substances required for plant growth. Phosphorus and nitrogen are considered the most important nutrients because they commonly provide the limiting controls on primary production.
Nutrient Limitation	The restriction of phytoplankton growth rates and biomass accumulation by the low availability of a nutrient.
Oxygen Saturation	The maximum amount of oxygen that can be held in a body of water at a given temperature and salinity.
Phosphate	See Dissolved Inorganic Phosphorus.

Photic Depth	The depth of 1% surface irradiance.
Phytoplankton	Microalgae which live in the water column.
Practical Salinity Scale	The practical salinity scale is used for measuring and reporting the salinity of water. It has been the official scale recognised by all international authorities since the early 1980's. The practical salinity scale is defined as a conductivity ratio and hence has no units.
Redfield Ratio	The ration of nitrogen to phosphorus that phytoplankton typically require (i.e. 16:1 molar).
Stratified	Where there is a distinct difference in salinity between the surface and bottom of the water column.
Well Mixed	Where there is little difference in salinity between the surface and bottom of the water column.

Appendix B

Table B 1: Sediment Sampling Results

Sample No	Sample Overall				Quartz				Lithic				Silt & Clay Content	Shell Content	Fe Stain	Organic Coating
	Size	Shape	Sorting	Colour	%	Size	Shape	Sorting	%	Mica	Feldspar	Other				
RIVER ENTRANCE																
R60	Fine-Medium	Rounded	Well	Fawn	96	Fine-Medium	Rounded	Well	4	None	Traces	Traces	None	Traces	Some	None
R31	Medium	Rounded	Well	Fawn	95	Medium	Sub-rounded	Well	5	None	Traces	Traces	None	Some	Some	None
R32	Fine-Medium	Sub-rounded	Well	Fawn	82	Fine-Medium	Sub-rounded	Well	18	Traces	Traces	Some	None	Some	Some	None
R33	Fine-Medium	Sub-rounded	Well	Fawn	83	Fine-Medium	sub-rounded	Well	17	None	Traces	Some	None	Some	Some	None
RIVER LOWER																
R1	Fine-Medium	Sub-rounded	Well	Faun-Grey	63	Fine-Medium	Sub-rounded	Well	37	None	Major	Major	None	Some	Some	None
R2	Fine-Medium	Sub-rounded	Well	Fawn-Grey	63	Fine-Medium	Sub-rounded	Well	37	Traces	Minor	Minor	None	None	Some	None
R3	Fine-Medium	Sub-rounded	Well	Fawn-Grey	62	Fine-Medium	Sub-rounded	Well	38	Traces	Minor	Minor	None	Few	Some	None
R4	Fine-Medium	Sub-rounded	Well	Fawn-Grey	61	Fine-Medium	Sub-rounded	Well	39	Traces	Minor	Minor	None	Few	Some	None
R5	Fine	Sub-rounded	Well	Fawn-Black	60	Fine	Sub-rounded	Well	40	Some	Major	Minor	High	None	None	None
R6	Medium	Sub-rounded	Moderate	Fawn-Black	66	Medium	Sub-rounded	Well	34	Traces	Minor	Minor	High	None	None	None
R7	Fine	Sub-rounded	Well	Fawn-Black	59	Fine	Sub-rounded	Well	41	Some	Major	Minor	Little	None	None	None
RIVER - LOWER MIDDLE																
R8	Fine-Medium	Sub-angular	Well	Fawn-Black	57	Fine-Medium	Sub-rounded	Well	43	Traces	Minor	Minor	None	None	None	None
R9	Fine-Medium	Sub-angular	Moderate	Black-Fawn	58	Fine-Medium	Sub-rounded	Moderate	42	Some	Major	Minor	Little	None	None	None
R10	Fine-Medium	Sub-angular	Moderate	Black-Fawn	61	Fine-Medium	Sub-rounded	Moderate	39	Some	Major	Minor	Medium	None	None	None
R11	Fine-Medium	Sub-angular	Moderate	Black-Fawn	53	Medium	Sub-rounded	Moderate	47	Some	Major	Minor	Medium	None	None	None
R12	Fine-Medium	Sub-angular	Moderate	Black-Fawn	58	Medium	Sub-rounded	Moderate	42	Traces	Major	Minor	Med-High	None	None	Traces
R13	Fine-Medium	Sub-angular	Moderate	Black-Fawn	56	Medium	Sub-rounded	Moderate	44	Some	Major	Minor	None	Few	None	None
R14	Fine-Medium	Sub-angular	Moderate	Black-Fawn	53	Medium	Sub-rounded	Moderate	47	Some	Major	Minor	Med-High	None	None	Traces
RIVER - UPPER MIDDLE																
R15	Medium	Sub-angular	Well	Dark Brown	49	Medium	Sub-angular	Well	51	Traces	Major	Minor	High	None	None	Traces
R16	Med-Coarse	Sub-angular	Poor	Dark Brown	47	Medium	Sub-angular	Well	53	Traces	Major	Minor	High	None	None	Traces
R17	Medium	Sub-angular	Well	Dark Brown	50	Medium	Sub-angular	Well	50	Traces	Major	Major	Medium	None	None	Traces
R18	Medium	Sub-angular	Well	Dark Brown	46	Medium	Sub-angular	Well	54	Some	Major	Major	High	None	None	Traces
R19	Medium	Sub-angular	Well	Dark Brown	44	Medium	Sub-angular	Well	56	Traces	Major	Major	Little	None	None	Traces
R20	Fine	Sub-angular	Well	Brown	44	Medium	Sub-angular	Well	56	Some	Major	Minor	High	None	None	Traces
R21	Medium	Sub-angular	Well	Dark Brown	42	Medium	Sub-angular	Well	58	Traces	Minor	Major	High	Few	None	Traces
R22	Fine	Sub-angular	Well	Brown	55	Fine	Sub-angular	Well	45	Traces	Major	Minor	Medium	None	None	Traces
R23	Medium	Sub-angular	Poor	Dark Brown	40	Med-Coarse	Sub-angular	Moderate	60	Traces	Major	Major	High	Few	None	Traces
R24	Fine	Sub-angular	Well	Brown	42	Fine	Sub-angular	Well	58	Traces	Minor	Minor	Medium	Trace	None	Traces
RIVER – UPPER																
R25	Med-Coarse	Angular	Well	Dark Brown	40	Med-Coarse	Angular	Well	60	Traces	Major	Major	High	None	None	Traces
R26	Med-Coarse	Angular	Well	Dark Brown	48	Med-Coarse	Angular	Well	52	Traces	Major	Major	Medium	None	None	Traces
R27	Med-Coarse	Angular	Well	Dark Brown	39	Med-Coarse	Angular	Well	61	Traces	Major	Major	Little	None	None	Traces
R28	Med-VCoarse	Angular	Poor	Dark Brown	41	Med-Coarse	Angular	Poor	59	None	Major	Major	High	None	None	Traces
R29	Med-Coarse	Angular	Well	Dark Brown	31	Med-Coarse	Angular	Well	69	Traces	Major	Major	High	None	None	Traces
R30	Med-Coarse	Angular	Well	Dark Brown	43	Med-Coarse	Angular	Well	57	Traces	Major	Major	Little	None	None	Traces
ARM – LOWER																
R34	Fine	Sub-rounded	Well	Light Grey	83	Fine	Sub-rounded	Well	17	None	Minor	Minor	None	Traces	Traces	None
R35	Fine-Medium	Sub-rounded	Well	Fawn	87	Fine-Medium	Sub-rounded	Well	13	None	Minor	Minor	Medium	Some	Traces	Traces
R48	Medium	Rounded	Well	Clear	91	Medium	Rounded	Well	9	None	Minor	Minor	None	Traces	None	None
R36	Fine	Rounded	Moderate	Clear	92	Fine	Rounded	Moderate	8	None	Minor	Traces	High	Traces	None	None
ARM – MIDDLE																
R37	Fine-Medium	Rounded	Moderate	Fawn	92	Medium	Rounded	Well	8	None	Traces	Traces	None	Traces	Traces	None
R38	Fine-Medium	Rounded	Moderate	Fawn	91	Medium	Rounded	Well	9	None	Traces	Traces	None	Traces	Some	None
R39	Fine-Medium	Rounded	Moderate	Fawn	92	Medium	Rounded	Well	8	None	Traces	Traces	None	Traces	Some	None
R40	Fine-Medium	Rounded	Moderate	Fawn	91	Medium	Rounded	Well	9	None	Traces	Traces	None	Traces	Some	None
R41	Fine-Medium	Rounded	Moderate	Fawn	92	Medium	Rounded	Well	8	None	Traces	Traces	None	Traces	Traces	None
R42	Fine-Medium	Rounded	Moderate	Fawn	92	Medium	Rounded	Well	8	None	Traces	Traces	Little	Some	Traces	None
R43	Fine-Medium	Rounded	Moderate	Fawn	92	Medium	Rounded	Moderate	8	None	Traces	Traces	None	Traces	Some	None

R44	Fine-Medium	Rounded	Moderate	Fawn	95	Medium	Rounded	Moderate	5	None	Traces	Traces	None	Traces	Some	None
R45	Fine-Medium	Rounded	Moderate	Fawn	92	Medium	Rounded	Moderate	8	None	Traces	Traces	None	Traces	Some	None
ARM – UPPER																
R46	Fine-Medium	Rounded	Well	Fawn	91	Fine-Medium	Rounded	Well	9	None	Minor	Traces	None	Traces	Some	None
R47	Fine-Medium	Rounded	Well	Fawn	95	Medium	Rounded	Well	5	None	Some	Traces	None	Traces	Some	None
CLYBUCCA – WEST																
R49	Fine-Medium	Rounded	Well	Fawn	87	Fine-Medium	Rounded	Well	13	None	Minor	Minor	Medium	Some	None	None
R50	Fine	Sub-rounded	Well	Light Brown	89	Fine-Medium	Sub-rounded	Well	11	None	Minor	Minor	High	Traces	None	Traces
R51	Fine	Sub-rounded	Well	Light Brown	88	Fine	Sub-rounded	Well	12	None	Minor	Minor	High	None	None	Traces
R52	Fine	Sub-rounded	Well	Light Brown	88	Fine	Sub-rounded	Well	12	None	Minor	Minor	High	None	None	Traces
R53	Fine	Sub-rounded	Well	Light Brown	93	Fine	Sub-rounded	Well	7	None	Minor	Minor	High	None	None	Traces
R54	Fine	na	Well	na	0	na	na	na	0	na	na	na	Very High	None	na	Traces
R59	Fine-Medium	Sub-rounded	Well	Fawn	89	Fine	Sub-rounded	Well	11	None	Minor	Minor	Medium	Traces	None	Traces
R58	Fine	Sub-rounded	Well	Light Brown	88	Fine	Sub-rounded	Well	12	None	Minor	Minor	High	None	None	Traces
R57	Fine	Sub-rounded	Well	Light Brown	83	Fine	Sub-rounded	Well	17	None	Minor	Minor	High	None	None	Traces
R56	Fine	Sub-rounded	Well	Light Brown	87	Fine	Sub-rounded	Well	13	None	Minor	Minor	Very High	None	None	Traces
R55	Fine	Sub-rounded	Well	Light Brown	91	Fine	Sub-rounded	Well	9	None	Minor	Minor	High	None	None	Traces

Appendix C

Table C 1: Water Quality Data – Physicochemical Parameters and Algal Biomass

Sample ID	Salinity	Cond	DO	Temp	pH	Turb	Sechi Depth	Total Suspended Solids	Chlorophyll a	Phaeophytin
units		mS/Cm	mg/L	oC		NTU	m	mg/L	ug/L	ug/L
MWQ1- 1	31.34	53.7	8.19	20.00	8.05	2.4	6.5	19.0	0.1	1.1
MWQ1- 2	31.11	53.3	8.22	19.93	8.03	0.0	B	17.0	2.7	0.1
MWQ1- 3	23.77	39.6	8.87	17.38	7.89	22.7	B	13.6	1.1	0.1
MWQ1- 4	25.21	41.1	8.78	16.65	7.74	21.1	2	18.2	1.6	0.1
MWQ1- 5	26.51	43.3	8.47	17.03	7.75	7.7	2.5	13.6	1.1	0.7
MWQ1- 6	23.28	38.0	10.19	16.41	7.71	22.4	bottom	11.2	0.9	1.1
MWQ1- 7	23.25	39.6	9.21	18.29	8.00	29.9	2	8.2	0.7	0.4
MWQ1- 8	15.69	27.2	9.40	17.50	7.91	34.5	2	8.2	0.9	0.7
MWQ1- 9	11.89	20.9	9.68	17.15	7.85	9.4	2	10.4	1.0	0.8
MWQ1- 10	8.57	15.4	9.81	16.80	7.77	1.7	1.5	7.8	3.1	1.3
MWQ1- 11	3.16	6.1	10.04	16.78	7.58	4.0	1.3	7.8	0.5	0.9
MWQ1- 12	1.47	2.9		16.16	7.62	11.2	0.75	10.2	2.4	0.1
MWQ1- 13	0.17	0.4	9.96	16.90	7.35	26.3	1	10.0	1.7	2.1
MWQ1- 14	0.61	1.3	10.46	16.69	7.40	3.3	1	7.8	1.5	1.2
MWQ1- 15	0.04	0.1		17.45	7.56	4.8	1.2	6.2	1.0	1.5
MWQ1- 16	0.48	1.0		17.48	7.44	10.2	1.8	4.8	1.2	1.6
MWQ1- 17	0.02	0.0		18.37	7.70	6.8	2.8	4.8	0.3	0.6
MWQ1- 18	18.73	32.1	11.19	17.65	7.93	0.0		13.4	0.2	0.9
MWQ2- 1	35.77	54.5	7.18	20.24	8.29	0.0	bottom	23.0	0.1	0.4
MWQ2- 2	35.77	54.5	7.02	20.21	8.28	0.0	bottom	27.6	0.7	0.1
MWQ2- 3	34.39	52.6	6.89	20.51	8.23	0.0	bottom	26.2	0.2	1.3

Sample ID	Salinity	Cond	DO	Temp	pH	Turb	Sechi Depth	Total Suspended Solids	Chlorophyll a	Phaeophytin
units		mS/Cm	mg/L	oC		NTU	m	mg/L	ug/L	ug/L
MWQ2- 4	30.93	4.8	6.54	21.22	8.12	1.2	2	22.8	1.0	0.5
MWQ2- 5	29.00	4.5	6.53	21.35	8.07	8.1	1.25	18.4	3.5	0.5
MWQ2- 6	28.24	44.1	6.63	20.29	7.94	0.3	bottom	20.4	1.7	0.8
MWQ2- 7	32.79	50.3	7.00	20.89	8.22	0.0	3.5	20.2	0.2	0.5
MWQ2- 8	28.77	45.1	6.82	21.09	8.16	0.0	3	20.6	1.4	0.6
MWQ2- 9	26.57	41.7	6.92	21.14	8.13	12.0	bottom	19.8	1.6	0.6
MWQ2- 10	23.98	38.0	6.82	21.29	8.10	4.2	2.5	17.6	1.9	1.2
MWQ2- 11	20.45	32.8	7.10	21.40	8.07	1.9	1.75	15.2	3.4	0.1
MWQ2- 12	18.48	29.8	7.17	21.38	8.04	25.0	1.5	14.4	0.1	7.1
MWQ2- 13	14.67	24.3	7.39	21.40	7.99	5.2	2	14.2	3.0	0.8
MWQ2- 14	12.12	20.3	7.53	21.45	7.94	6.8	1.5	12.6	3.1	1.1
MWQ2- 15	8.43	14.6	7.59	21.58	7.82	4.9	1.75	14.0	3.7	1.3
MWQ2- 16	5.15	9.2	7.66	21.75	7.72	1.2	1	15.4	4.3	1.3
MWQ2- 17	2.19	4.1	7.64	21.71	7.66	9.5	1	14.4	5.9	1.2
MWQ2- 18	0.14	0.3	8.05	21.85	7.00	10.3	bottom	5.2	1.1	2.4
MWQ2- 19	0.07	0.1	8.88	21.75	8.85	14.3	bottom	2.5	5.7	3.1
MWQ2- 20	0.06	0.1	8.90	21.89	8.99	13.7	2.5	3.6	1.1	0.9
MWQ2- 21	0.06	0.1	9.07	22.30	9.09	6.9	4.5	4.2	0.5	0.9
MWQ3- 1	36.30	55.2	7.20	20.42	8.23	0.0	6	132.5	0.7	0.3
MWQ3- 2	36.30	55.1	6.83	20.46	8.28	3.1	bottom	112.2	1.2	0.1
MWQ3- 3	32.62	5.0	7.60	21.48	8.27	0.0	bottom	21.2	0.6	0.3
MWQ3- 4	26.69	41.8	6.53	22.36	8.15	12.0	2.5	55.6	1.3	0.1
MWQ3- 5	27.76	43.2	6.97	22.20	8.13	0.0	1.75	20.0	1.1	0.3
MWQ3- 6	29.33	45.5	6.83	23.90	8.14	0.0	bottom	19.3	2.1	0.7
MWQ3- 7	28.50	44.6	7.10	22.42	8.25	0.0	bottom		0.1	5.2

Sample ID	Salinity	Cond	DO	Temp	pH	Turb	Sechi Depth	Total Suspended Solids	Chlorophyll a	Phaeophytin
units		mS/Cm	mg/L	oC		NTU	m	mg/L	ug/L	ug/L
MWQ3- 8	25.41	34.5	7.32	23.12	8.26	14.5		35.0	1.2	0.5
MWQ3- 9	22.01	34.9	7.23	22.81	8.29	27.8	2.4	15.2	1.9	0.1
MWQ3- 10	18.85	30.5	7.73	22.83	8.26	24.7	4		1.6	0.5
MWQ3- 11	16.70	27.3	7.43	22.99	8.18	27.5	3.5	11.8	2.3	0.4
MWQ3- 12	12.77	21.1	7.32	22.83	8.11	35.6	B	12.8	2.6	0.1
MWQ3- 13	9.39	16.1	7.84	22.91	8.08	15.2	3	8.8	5.0	0.5
MWQ3- 14	6.14	11.1	8.00	22.76	7.97	11.8	3	6.0	3.9	2.9
MWQ3- 15	4.15	7.6	7.78	22.90	7.89	36.3	2.5	4.0	3.5	0.4
MWQ3- 16	1.24	2.4	7.30	22.67	7.63	12.2	2	4.2	2.2	0.4
MWQ3- 17	0.28	0.6	7.58	22.90	7.28	3.8	2	4.2	2.4	0.5
MWQ3- 18	0.07	0.1	6.94	22.84	7.14	0.0	2.5	5.2	0.6	0.4
MWQ3- 19	0.06	0.1	6.11	22.24	6.60	3.1	1.5	5.0	1.4	1.3
MWQ3- 20	0.06	0.1	6.22	21.86	6.52	5.4	0.75	5.4	1.7	1.1
MWQ3- 21	0.06	0.1	6.55	21.82	6.56	2.1	0.75	5.8	1.6	1.2
MWQ4- 1	38.20	57.6	7.76	22.24	8.28	17.3	4	4.4	0.3	0.1
MWQ4- 2	38.20	57.6	7.80	22.25	8.24	15.8	2.5	6.2	0.2	0.1
MWQ4- 3	36.04	54.0	7.60	23.51	8.15	16.3	2.25	11.2	0.2	0.3
MWQ4- 4	33.78	57.5	7.36	24.16	8.12	24.4	2.5	5.4	1.1	0.1
MWQ4- 5	32.59	49.9	7.22	23.84	8.13	31.1	1	4.8	1.5	0.1
MWQ4- 6	31.81	49.4	8.95	24.16	8.23	35.0	1	5.0	1.9	0.9
MWQ4- 7	34.14	52.4	7.46	23.75	8.16	13.9	4	2.6	0.3	0.1
MWQ4- 8	31.22	48.0	7.31	24.23	8.05	21.6	2.75	2.8	0.9	0.1
MWQ4- 9	27.40	42.8	7.16	24.27	8.04	27.1	3	8.8	1.3	0.1
MWQ4- 10	25.07	39.4	7.55	24.45	8.02	16.3	1.5	4.6	1.3	0.2
MWQ4- 11	18.35	29.7	7.83	24.36	7.98	8.6	2	3.0	2.2	0.2

Sample ID	Salinity	Cond	DO	Temp	pH	Turb	Sechi Depth	Total Suspended Solids	Chlorophyll a	Phaeophytin
units		mS/Cm	mg/L	oC		NTU	m	mg/L	ug/L	ug/L
MWQ4- 12	14.26	23.5	7.94	24.29	7.92	8.3	2	4.2	2.1	0.3
MWQ4- 13	10.55	17.9	8.21	24.77	7.88	6.5	1.5	4.4	3.4	0.3
MWQ4- 14	8.97	15.4	8.16	25.04	7.83	5.4	1.5	5.0	2.5	0.8
MWQ4- 15	5.94	10.9	8.44	25.35	7.85	4.7	1.5	8.0	3.1	0.4
MWQ4- 16	3.08	5.6	9.57	25.40	7.87	5.1	1	3.4	3.6	0.2
MWQ4- 17	1.66	3.2	8.48	25.13	7.95	3.7	1.5	3.0	2.7	0.5
MWQ4- 18	0.48	1.0	9.30	25.56	8.27	1.7	2	2.6	2.1	0.4
MWQ4- 19	0.13	0.3	9.37	25.08	8.67	0.4	2	7.0	1.4	0.5
MWQ4- 20	0.09	0.2	10.20	25.18	8.73	0.0	2.75	5.6	1.4	0.4
MWQ4- 21	0.08	0.2	9.44	25.71	8.86	0.4	2.75	1.2	1.5	0.5
MWQ5- 1	36.44	55.1	8.64	24.02	8.09		3.5	1.6	1.1	0.1
MWQ5- 2	35.70	54.2	8.44	21.14	8.06		4	2.8	0.8	1.9
MWQ5- 3	34.81	52.8	8.10	25.43	7.95		2	8.4	1.0	1.2
MWQ5- 4	33.79	51.5	8.27	26.97	7.95		bottom	5.8	0.9	0.5
MWQ5- 5	34.01	51.6	7.88	27.10	7.94		2	3.6	6.9	3.7
MWQ5- 6	33.41	50.9	9.52	27.04	8.19		bottom	9.0	2.4	0.1
MWQ5- 7	34.69	52.6	8.63	24.56	8.03		2	1.6	2.5	0.1
MWQ5- 8	31.23	48.0	8.46	25.85	7.96		4	0.8	1.0	0.1
MWQ5- 9	29.97	46.2	8.40	25.34	7.93		2.75	3.2	1.6	0.1
MWQ5- 10	27.09	42.1	8.21	25.28	7.90		bottom	2.8	0.8	0.1
MWQ5- 11	23.36	36.8	8.42	24.94	7.85		3.5	3.6	0.4	0.4
MWQ5- 12	21.82	34.7	8.40	25.97	7.83		3	1.8	1.9	0.1
MWQ5- 13	17.84	28.8	8.69	26.13	7.79		3	1.8	2.2	0.1
MWQ5- 14	16.03	26.2	8.63	26.44	7.75		3.5	1.4	3.8	0.1

Sample ID	Salinity	Cond	DO	Temp	pH	Turb	Sechi Depth	Total Suspended Solids	Chlorophyll a	Phaeophytin
units		mS/Cm	mg/L	oC		NTU	m	mg/L	ug/L	ug/L
MWQ5- 15	14.09	23.3	8.64	26.16	7.71		3	3.8	1.8	0.4
MWQ5- 16	11.74	19.7	8.96	26.62	7.72		3.5	2.4	2.1	0.8
MWQ5- 17	9.43	16.0	8.96	26.81	7.72		3	3.8	1.5	1.3
MWQ5- 18	7.23	13.3	9.27	26.72	7.77		3	2.6	2.4	1.1
MWQ5- 19	5.72	10.2	9.54	26.74	7.82		2.5	1.5	1.6	2.4
MWQ5- 20	3.96	7.3	10.18	26.89	8.15		2.5	0.4	3.1	0.8
MWQ5- 21	1.82	3.5	10.13	26.81	8.29		2.5	1.3	2.5	0.9
MWQ5- 22	0.15	0.3	11.70	27.17	8.87		2.25	0.6	4.5	1.5
MWQ6- 1	37.69	56.7	6.45	24.85	8.27		8	2.0	0.3	0.1
MWQ6- 2	37.69	56.7	6.46	24.93	8.26		bottom	1.8	0.3	0.1
MWQ6- 3	36.90	54.7	6.29	26.22	8.15	3.7	bottom	8.6	1.1	0.1
MWQ6- 4	35.76	53.9	5.95	27.89	8.00	6.2	2	5.2	1.8	0.2
MWQ6- 5	35.91	54.1	5.81	27.83	7.97	4.8	2	4.0	2.7	0.2
MWQ6- 6	35.81	53.8	8.92	30.30	8.19	9.7	bottom	5.8	4.2	0.6
MWQ6- 7	33.85	51.5	6.47	26.83	8.17	0.0	3	2.2	1.0	0.1
MWQ6- 8	31.94	48.6	6.35	27.07	8.13	0.0	3	2.4	1.5	0.1
MWQ6- 9	29.70	45.7	6.22	27.44	8.08	0.0	bottom	3.4	1.6	0.1
MWQ6- 10	24.41	38.9	6.59	27.76	8.01	0.0	bottom	3.6	1.1	0.4
MWQ6- 11	21.04	33.5	6.91	27.64	7.96	0.0	3	2.6	1.7	0.1
MWQ6- 12	19.10	30.7	6.75	27.54	7.91	0.0	bottom	2.8	1.4	0.1
MWQ6- 13	16.59	27.0	6.97	27.65	7.88	0.0	3	7.0	2.5	0.3
MWQ6- 14	13.85	22.9	7.17	27.77	7.85	0.0	2.5	3.6	2.6	0.2
MWQ6- 15	10.21	17.3	7.32	28.28	7.81	1.7	2.5	4.0	4.4	0.3
MWQ6- 16	7.54	13.1	7.65	28.21	7.92	0.0	2		4.4	0.3

Sample ID	Salinity	Cond	DO	Temp	pH	Turb	Sechi Depth	Total Suspended Solids	Chlorophyll a	Phaeophytin
units		mS/Cm	mg/L	oC		NTU	m	mg/L	ug/L	ug/L
MWQ6- 17	3.82	7.0	8.63	28.38	8.25	0.0	2.5	3.2	2.6	0.1
MWQ6- 18	1.53	3.0	8.93	28.15	8.50	0.9	3	1.8	1.2	0.4
MWQ6- 19	0.89	1.8	8.98	28.15	8.48	0.8	3.5	1.6	3.1	0.1
MWQ6- 20	0.26	0.5	9.34	28.54	8.37	2.1	2.5	1.8	2.6	0.3
MWQ7- 1	34.95	53.0	7.82	25.17	8.37	0.0	bottom	4.8	0.1	0.4
MWQ7- 2	32.36	49.5	7.59	25.45	8.20	0.0	bottom	1.6	1.5	0.1
MWQ7- 3	23.89	37.7	6.94	25.05	8.12	14.4	1.5	4.2	1.5	0.3
MWQ7- 4	25.15	39.5	7.45	24.91	7.99	13.5	1.75	1.0	2.1	0.4
MWQ7- 5	25.80	40.3	7.25	25.05	7.97	15.2	2.25	2.0	2.9	0.3
MWQ7- 6	25.12	39.3	10.25	25.80	8.09	6.8	bottom	2.6	2.7	1.7
MWQ7- 7	16.21	27.4	7.14	25.69	8.04	0.0	2.5	4.8	0.1	2.1
MWQ7- 8	13.87	22.9	6.73	25.77	7.94	7.9	2	6.8	0.4	0.4
MWQ7- 9	8.57	14.8	6.74	25.54	7.77	0.0	1.5	7.8	1.1	0.3
MWQ7- 10	7.54	12.0	6.56	25.59	7.71	0.0	1.5	6.8	0.3	0.5
MWQ7- 11	5.51	9.8	6.47	25.51	7.51	9.1	1	7.8	1.0	0.4
MWQ7- 12	3.10	5.2	6.35	25.51	7.53	1.4	1.25	8.6	0.7	0.6
MWQ7- 13	2.09	3.9	6.27	25.49	7.49	0.0	1.25	7.4	1.4	0.9
MWQ7- 14	1.16	2.3	6.08	25.44	7.34	3.5	1	13.6	0.1	3.4
MWQ7- 15	0.13	2.6	5.49	25.15	7.03	4.9	1	8.4	0.1	1.2
MWQ7- 16	0.07	0.2	6.07	25.35	7.02	0.0	1.25	5.4	2.3	0.7
MWQ7- 17	0.07	0.1	6.15	25.03	6.81		1.25	4.0	1.4	0.5
MWQ7- 18	0.07	0.1	6.88	26.30	6.89	1.6	1	4.2	3.3	0.1
MWQ8- 1	35.13	53.3	7.33	24.52	8.19	3.0	bottom	19.0	4.0	0.1
MWQ8- 2	33.66	51.4	7.16	24.57	8.10	0.0	3	20.6	7.4	0.1

Sample ID	Salinity	Cond	DO	Temp	pH	Turb	Sechi Depth	Total Suspended Solids	Chlorophyll a	Phaeophytin
units		mS/Cm	mg/L	oC		NTU	m	mg/L	ug/L	ug/L
MWQ8- 3	30.81	47.4	7.22	24.62	7.99	2.5	1	24.8	2.9	0.1
MWQ8- 4	29.40	45.5	6.45	23.92	7.84	2.9	2.5	19.4	0.5	3.2
MWQ8- 5	28.90	44.8	7.12	24.10	7.95	0.0	bottom	11.6	1.9	0.1
MWQ8- 6	28.01	43.4	6.76	23.41	7.56	7.6	bottom	21.0	0.6	0.4
MWQ8- 7	31.97	49.0	7.00	24.59	8.04	3.3	1.5	22.6	0.9	1.2
MWQ8- 8	27.91	43.4	6.93	24.40	8.07	0.0	2	20.0	0.7	0.4
MWQ8- 9	25.35	40.0	6.67	24.39	7.98	1.4	1.5	21.6	1.6	0.5
MWQ8- 10	22.47	35.7	6.88	24.40	7.95	0.0	2.75	18.2	1.1	0.1
MWQ8- 11	19.09	31.6	6.89	24.37	7.91	0.0	2.5	16.8	2.2	1.3
MWQ8- 12	16.32	26.8	7.37	24.34	7.90	1.6	2.5	11.6	2.2	0.5
MWQ8- 13	13.60	22.5	7.34	24.04	7.87	0.2	2.5	10.2	3.5	0.1
MWQ8- 14	10.23	17.4	7.46	23.97	7.79		1.5	9.6	4.7	7.5
MWQ8- 15	7.10	12.5	7.74	12.47	7.71	0.0	2.5	6.6	2.8	0.2
MWQ8- 16	4.80	8.6	7.38	24.13	7.62	1.1	2	7.8	0.1	15.4
MWQ8- 17	0.80	1.6	7.21	24.03	7.63	2.7	1.5	7.0	1.7	0.6
MWQ8- 18	0.07	0.1	8.05	24.09	7.65	2.3	2.3	3.8	0.9	0.6
MWQ8- 19	0.07	0.1	8.97	24.31	8.11	7.3	3	3.2	3.0	0.1
MWQ8- 20	0.06	0.1	9.62	24.85	8.44	9.9	2.5	3.0	1.6	0.7
MWQ9- 1	35.31	53.7	6.71	22.46	8.54	0.0	bottom	15.6	6.5	0.1
MWQ9- 2	34.33	52.4	7.12	22.04	8.49	0.1	4	18.4	1.3	0.1
MWQ9- 3	32.39	49.8	6.47	21.39	8.37	0.7	2	23.0	1.8	0.1
MWQ9- 4	31.44	48.6	6.85	21.19	8.31	3.7	2.5	20.4	2.2	0.1
MWQ9- 5	31.43	48.5	7.11	21.03	8.32	6.2	bottom	18.8	2.5	0.1
MWQ9- 6	30.62	47.3	9.26	22.24	8.46	4.0	bottom	20.0	2.3	0.9
MWQ9- 7	30.26	46.8	6.86	22.16	8.47	0.2	3	24.2	1.3	0.1

Sample ID	Salinity	Cond	DO	Temp	pH	Turb	Sechi Depth	Total Suspended Solids	Chlorophyll a	Phaeophytin
units		mS/Cm	mg/L	oC		NTU	m	mg/L	ug/L	ug/L
MWQ9- 8	27.95	43.4	6.99	21.91	8.45	0.0	2.5	16.4	1.6	0.1
MWQ9- 9	24.05	37.6	7.15	21.55	8.40	0.0	3	12.8	4.3	0.1
MWQ9- 10	21.89	31.4	7.08	21.36	8.39	0.0	2.75	14.8	5.2	0.1
MWQ9- 11	18.54	30.1	7.36	21.17	8.35	0.0	2.75	12.0	9.8	0.1
MWQ9- 12	14.73	24.7	7.30	21.22	8.27	0.0	2	9.4	4.0	0.1
MWQ9- 13	12.76	21.2	7.13	20.90	8.22	0.0	bottom	6.6	3.2	0.1
MWQ9- 14	8.68	15.0	7.60	21.44	8.13	0.0	2.5	5.4	2.3	0.1
MWQ9- 15	6.66	11.8	7.63	21.09	8.08	0.0	2.75	7.0	3.6	0.5
MWQ9- 16	3.36	6.2	8.05	21.11	8.14	0.0	2	2.4	4.1	0.6
MWQ9- 17	0.88	1.7	8.00	20.77	8.02	0.0	2.5	1.2	3.1	0.4
MWQ9- 18	0.25	0.5	8.28	20.45	8.03	0.0	bottom	1.4	2.0	1.4
MWQ9- 19	0.09	0.2	8.80	20.72	8.30	0.0	3	3.0	3.0	0.1
MWQ9- 20	0.06	0.1	9.87	21.21	8.68	0.0	4.5	1.4	1.4	0.3
MWQ10- 1	37.06	56.1	6.75	21.95	8.11	0.0	bottom	20.2	0.4	0.1
MWQ10- 2	36.76	55.7	6.32	21.21	8.16	0.0	bottom	18.8	2.1	0.1
MWQ10- 3	34.56	53.0	6.43	18.51	7.92	15.7	bottom	19.2	2.1	0.1
MWQ10- 4	39.04	52.3	6.24	18.20	7.83	13.1	2.5	16.4	2.5	0.1
MWQ10- 5	33.90	52.2	5.79	18.31	7.79	8.6	2.5	15.8	2.4	0.2
MWQ10- 6	32.93	50.8	5.03	18.01	7.69	8.4	bottom	19.0	3.1	0.1
MWQ10- 7	33.10	51.8	6.50	20.08	8.03	0.0	5.5	20.2	3.9	0.1
MWQ10- 8	30.32	47.1	6.43	18.92	7.94	4.8	4.5	17.0	1.9	0.1
MWQ10- 9	29.31	45.8	6.63	18.92	7.95	1.7	bottom	15.6	1.8	0.1
MWQ10- 10	26.89	42.7	6.46	18.58	7.88	1.1	2.5	15.0	1.5	0.1
MWQ10- 11	23.73	38.8	6.70	18.44	7.86	0.0	bottom	14.8	1.9	0.1
MWQ10- 12	20.43	32.8	7.07	18.29	7.83	0.0	bottom	16.6	2.1	0.1

Sample ID	Salinity	Cond	DO	Temp	pH	Turb	Sechi Depth	Total Suspended Solids	Chlorophyll a	Phaeophytin
units		mS/Cm	mg/L	oC		NTU	m	mg/L	ug/L	ug/L
MWQ10- 13	16.66	27.4	7.26	18.14	7.78	0.0	4	11.6	2.8	0.1
MWQ10- 14	14.74	24.6	7.40	18.10	7.75		bottom	8.4	1.8	0.1
MWQ10- 15	11.24	18.3	7.58	18.01	7.72	0.0	4.25	8.8	1.8	0.1
MWQ10- 16	7.83	13.7	7.84	17.89	7.71	4.2	2.75	8.2	3.4	0.3
MWQ10- 17	5.06	9.1	8.24	17.89	7.85	0.0	2.75	6.4	2.6	0.1
MWQ10- 18	1.58	3.0	9.07	17.52	8.30	0.0	3.5	3.0	2.1	0.1
MWQ10- 19	0.65	1.3	9.42	17.76	8.64	0.1	4	2.8	1.6	0.3
MWQ10- 20	0.13	0.3	7.78	17.70	8.87	0.0	6	8.0	1.4	0.2
MWQ11- 1	36.04	55.0	7.13	18.68	8.09		4.5	13.8	1.6	0.2
MWQ11- 2	36.04	55.0	6.79	18.70	8.02		4.5	16.6	1.4	0.1
MWQ11- 3	32.27	50.0	6.80	16.49	7.92	3.1	bottom	14.8	1.3	0.1
MWQ11- 4	32.27	50.1	6.86	15.28	7.84	7.5	2.6	15.8	1.7	0.1
MWQ11- 5	32.06	49.8	6.99	15.26	7.84	12.2	3	15.8	2.2	0.1
MWQ11- 6	31.68	49.2	7.43	15.01	7.87	3.1		23.0	1.5	0.1
MWQ11- 7	32.25	49.5	7.24	17.32	8.00	124.0	2.3	16.0	1.1	0.1
MWQ11- 8	29.77	46.5	7.38	16.71	8.01	124.0	bottom	17.2	0.7	0.1
MWQ11- 9	27.34	43.0	7.80	16.09	7.99		3.5	13.0	1.4	0.1
MWQ11- 10	23.68	37.9	7.74	15.50	7.96		bottom	11.2	1.7	0.1
MWQ11- 11	20.87	33.6	7.96	15.12	7.94		3.4	14.0	2.0	0.1
MWQ11- 12	17.84	29.2	8.17	14.73	7.92		bottom	10.6	1.7	0.1
MWQ11- 13	15.32	25.6	8.32	14.55	7.91		3	13.2	1.7	0.1
MWQ11- 14	12.78	21.6	8.59	14.27	7.85	4.8	2.5	9.2	3.1	0.1
MWQ11- 15	9.61	16.6	8.66	14.16	7.79	9.0	2.7	7.6	1.9	0.1
MWQ11- 16	6.47	11.5	9.09	13.98	7.74	5.0	3.1	7.4	3.1	0.1
MWQ11- 17	3.02	5.7	9.95	13.82	7.77		2.5	6.6	5.0	0.2

Sample ID	Salinity	Cond	DO	Temp	pH	Turb	Sechi Depth	Total Suspended Solids	Chlorophyll a	Phaeophytin
units		mS/Cm	mg/L	oC		NTU	m	mg/L	ug/L	ug/L
MWQ11- 18	1.31	2.6	10.31	13.96	7.76		2.7	5.0	3.2	0.1
MWQ11- 19	0.62	1.3	9.83	14.09	8.14	20.2	2.8	2.0	1.4	0.6
MWQ11- 20	0.18	0.4	10.10	13.84	8.09		3.5	3.6	1.0	0.2
MWQ12- 1	36.97	56.2	6.93	19.39	7.42	52.7	bottom	14.4	2.0	0.1
MWQ12- 2	36.88	56.1	6.76	19.16	6.97	30.9	bottom	14.0	0.3	0.2
MWQ12- 3	35.37	54.2	6.89	17.37	6.91	47.2	bottom	18.2	0.9	0.1
MWQ12- 4	34.31	52.8	7.63	16.74	8.28	45.4	2.3	13.6	1.4	0.1
MWQ12- 5	33.50	51.7	7.71	16.50	7.76	56.2	2.5	17.0	2.0	0.2
MWQ12- 6	32.85	50.8	8.43	16.55	7.90	55.0	bottom	15.6	1.7	0.5
MWQ12- 7	32.89	50.7	7.51	17.19	7.90	24.3	2.5	15.6	1.2	0.1
MWQ12- 8	30.64	47.7	7.62	16.80	7.86	20.5	2.75	14.4	1.4	0.1
MWQ12- 9	27.16	43.1	7.50	16.91	7.82	16.1	3	11.6	1.1	0.1
MWQ12- 10	23.78	38.0	7.83	16.01	7.60	20.7	2.5	13.0	2.1	0.1
MWQ12- 11	20.35	33.1	8.12	15.58	7.51	24.0	2.75	9.2	1.1	0.1
MWQ12- 12	17.92	29.3	8.12	15.36	7.50	23.9	2	11.0	1.1	0.2
MWQ12- 13	14.42	24.7	8.34	15.15	7.45	25.7	2.5	6.6	0.9	0.3
MWQ12- 14	10.81	18.5	8.47	14.95	7.42	24.9	1.9	3.8	1.4	0.9
MWQ12- 15	8.51	14.8	9.15	14.55	7.42	27.7	1.5	3.2	2.6	0.9
MWQ12- 16	5.19	9.3	10.56	14.58	7.65	21.6	1.5	3.0	1.6	0.4
MWQ12- 17	2.45	4.5	10.06	14.50	8.11		2	1.0	1.8	0.6
MWQ12- 18	1.45	2.8	10.33	14.38	8.39	17.8	3.5	2.2	1.9	0.7
MWQ12- 19	0.40	0.8	10.85	15.62	9.12	10.8	6	0.4	1.2	0.4

Table C 2: Water Quality Data - Nutrients

Sample ID	TN	PN	TDN	DON	DIN	NO3	NO2	NH4	TP	PP	TDP	DOP	DIP
	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L
MWQ1- 1	221	<10	221	213	8	2	<2	6	12	<10	12	<10	5
MWQ1- 2	158	<10	158	146	13	3	<2	10	12	<10	11	<10	5
MWQ1- 3	285	<10	285	238	47	30	<2	16	23	<10	16	<10	9
MWQ1- 4	297	33	264	236	28	11	4	12	27	<10	18	10	8
MWQ1- 5	293	40	253	237	16	5	<2	11	25	<10	17	<10	8
MWQ1- 6	348	85	263	255	8	<2	<2	5	36	16	20	<10	8
MWQ1- 7	260	<10	260	202	58	43	<2	14	32	<10	23	10	13
MWQ1- 8	304	30	274	198	76	57	<2	17	40	15	25	10	15
MWQ1- 9	357	37	320	131	189	68	<2	119	46	16	31	15	16
MWQ1- 10	356	36	320	223	96	77	<2	18	54	15	38	19	19
MWQ1- 11	435	46	389	385	4	<2	<2	3	71	22	48	34	14
MWQ1- 12	758	96	662	657	6	<2	2	4	183	64	119	79	40
MWQ1- 13	512	48	464	286	178	115	4	60	77	23	53	18	36
MWQ1- 14	397	27	371	216	155	129	3	23	25	10	15	<10	12
MWQ1- 15	386	16	370	201	170	145	3	21	21	<10	13	<10	9
MWQ1- 16	310	15	295	188	107	86	2	19	19	<10	12	<10	9
MWQ1- 17	239	18	221	181	40	28	<2	10	14	<10	10	<10	7
MWQ1- 18	286	40	246	177	69	51	<2	17	34	11	23	<10	14
MWQ2- 1	186	25	160	152	8	<2	<2	7	13	<10	11	<10	4
MWQ2- 2	228	72	156	149	7	<2	<2	6	13	<10	10	<10	5
MWQ2- 3	201	44	157	148	9	3	<2	7	17	<10	12	<10	7
MWQ2- 4	273	19	254	248	6	<2	<2	5	24	<10	17	10	8
MWQ2- 5	272	13	258	253	5	<2	<2	4	30	11	20	11	9
MWQ2- 6	397	116	281	276	6	<2	<2	6	38	17	22	14	8

Sample ID	TN	PN	TDN	DON	DIN	NO3	NO2	NH4	TP	PP	TDP	DOP	DIP
	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L
MWQ2- 7	205	<10	205	197	8	<2	<2	7	19	<10	14	<10	7
MWQ2- 8	215	11	204	199	5	<2	<2	4	24	<10	18	<10	9
MWQ2- 9	232	<10	232	228	5	<2	<2	4	25	<10	19	<10	11
MWQ2- 10	240	49	191	186	5	<2	<2	4	27	<10	20	<10	10
MWQ2- 11	308	94	214	210	4	<2	<2	4	35	14	20	<10	11
MWQ2- 12	247	34	213	161	52	<2	<2	51	29	<10	23	11	12
MWQ2- 13	316	92	224	219	5	4	<2	<2	32	12	19	10	9
MWQ2- 14	266	25	242	227	14	12	<2	2	30	11	20	11	9
MWQ2- 15	296	38	258	234	24	21	<2	<2	30	11	19	12	8
MWQ2- 16	335	59	276	240	36	33	<2	<2	44	25	19	11	8
MWQ2- 17	328	62	266	216	51	44	2	4	40	19	21	<10	12
MWQ2- 18	245	<10	235	208	27	16	<2	10	29	<10	20	<10	14
MWQ2- 19	201	15	187	173	14	8	<2	6	18	<10	12	<10	9
MWQ2- 20	211	18	193	180	13	8	<2	5	15	<10	10	<10	7
MWQ2- 21	193	19	173	166	7	<2	<2	5	12	<10	<10	<10	6
MWQ3- 1	316	<10	316	308	8	<2	<2	7	18	<10	12	<10	6
MWQ3- 2	281	110	172	166	5	<2	<2	5	19	<10	11	<10	5
MWQ3- 3	199	27	172	163	9	<2	<2	7	19	<10	11	<10	6
MWQ3- 4	235	<10	235	226	9	<2	<2	6	25	<10	15	<10	7
MWQ3- 5	267	37	230	222	8	<2	<2	5	28	14	14	<10	7
MWQ3- 6	369	70	299	292	7	<2	<2	6	44	18	25	16	9
MWQ3- 7	258	36	222	215	7	<2	<2	7	19	<10	12	<10	5
MWQ3- 8	222	<10	214	205	9	<2	<2	8	17	<10	12	<10	5
MWQ3- 9	231	<10	221	215	6	<2	<2	5	20	<10	11	<10	5
MWQ3- 10	247	<10	242	233	9	<2	<2	8	20	<10	12	<10	6
MWQ3- 11	276	60	216	204	12	4	<2	7	24	11	12	<10	5
MWQ3- 12	243	23	220	206	14	8	<2	6	19	<10	12	<10	6

Sample ID	TN	PN	TDN	DON	DIN	NO3	NO2	NH4	TP	PP	TDP	DOP	DIP
	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L
MWQ3- 13	228	33	195	183	12	7	<2	4	19	<10	12	<10	6
MWQ3- 14	266	53	213	198	15	11	<2	3	22	10	12	<10	6
MWQ3- 15	274	35	240	216	24	20	<2	2	21	<10	13	<10	7
MWQ3- 16	276	51	225	177	47	36	<2	10	26	12	15	<10	7
MWQ3- 17	332	82	250	174	76	63	<2	11	29	15	14	<10	9
MWQ3- 18	224	15	210	167	43	23	<2	17	17	<10	11	<10	5
MWQ3- 19	406	20	386	314	72	52	5	15	30	14	16	<10	6
MWQ3- 20	426	21	404	316	89	68	5	16	26	11	15	<10	5
MWQ3- 21	390	27	363	260	103	87	4	12	23	<10	14	<10	5
MWQ4- 1	322	96	226	217	9	<2	<2	7	24	<10	18	13	5
MWQ4- 2	309	<10	309	299	10	<2	<2	8	21	<10	17	12	5
MWQ4- 3	401	<10	401	391	10	<2	<2	8	28	<10	20	12	9
MWQ4- 4	529	<10	529	519	10	<2	<2	7	29	<10	26	16	11
MWQ4- 5	501	<10	501	493	8	<2	<2	6	38	<10	30	18	12
MWQ4- 6	598	123	475	467	8	<2	<2	6	56	24	32	21	11
MWQ4- 7	669	<10	669	660	9	<2	<2	7	26	<10	23	14	9
MWQ4- 8	460	<10	460	451	8	<2	<2	6	29	<10	26	14	12
MWQ4- 9	612	<10	612	601	11	4	<2	7	32	<10	28	14	14
MWQ4- 10	320	<10	320	309	11	<2	<2	9	32	<10	24	10	14
MWQ4- 11	356	<10	356	348	8	<2	<2	6	31	<10	31	16	15
MWQ4- 12	286	19	267	258	9	3	<2	6	47	26	21	<10	14
MWQ4- 13	310	<10	310	296	15	9	<2	5	32	<10	30	18	13
MWQ4- 14	266	<10	265	242	23	15	<2	6	31	10	21	<10	12
MWQ4- 15	301	30	271	258	14	8	<2	5	36	15	21	<10	14
MWQ4- 16	313	<10	313	307	6	<2	<2	4	36	15	21	10	11
MWQ4- 17	495	<10	495	484	11	4	<2	5	34	10	24	<10	16
MWQ4- 18	382	34	348	335	13	6	<2	5	33	11	22	<10	13

Sample ID	TN	PN	TDN	DON	DIN	NO3	NO2	NH4	TP	PP	TDP	DOP	DIP
	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L
MWQ4- 19	277	<10	277	264	12	6	<2	4	27	<10	21	<10	14
MWQ4- 20	345	<10	345	337	8	3	<2	5	22	<10	17	<10	10
MWQ4- 21	267	<10	267	261	5	<2	<2	5	19	<10	13	<10	8
MWQ5- 1	286	<10	286	276	10	2	<2	7	22	<10	16	<10	7
MWQ5- 2	397	<10	397	387	10	<2	<2	8	33	<10	26	15	11
MWQ5- 3	427	<10	427	415	12	2	<2	9	43	10	33	16	17
MWQ5- 4	384	<10	384	376	9	<2	<2	6	43	10	33	16	16
MWQ5- 5	580	80	500	488	12	2	<2	8	97	55	42	22	20
MWQ5- 6	262	43	218	189	29	5	<2	24	24	<10	18	<10	9
MWQ5- 7	257	<10	257	250	7	<2	<2	5	28	<10	21	12	8
MWQ5- 8	466	<10	466	447	19	3	<2	15	37	12	25	11	14
MWQ5- 9	278	<10	269	241	27	<2	<2	25	33	<10	26	<10	17
MWQ5- 10	488	<10	488	479	9	<2	<2	8	34	<10	27	<10	17
MWQ5- 11	221	<10	221	196	25	4	<2	20	21	<10	21	13	7
MWQ5- 12	294	21	273	243	30	4	<2	26	31	<10	25	<10	16
MWQ5- 13	300	<10	300	289	12	<2	<2	10	32	<10	26	11	15
MWQ5- 14	302	51	251	236	16	<2	<2	13	31	<10	22	<10	14
MWQ5- 15	281	41	240	225	15	2	<2	12	32	11	21	<10	12
MWQ5- 16	333	101	232	203	28	5	<2	23	30	<10	21	<10	12
MWQ5- 17	365	111	253	239	14	4	<2	10	28	<10	18	<10	9
MWQ5- 18	289	10	278	271	8	<2	<2	5	24	<10	17	<10	9
MWQ5- 19	347	88	259	253	6	<2	<2	5	28	12	16	<10	11
MWQ5- 20	317	<10	317	312	6	<2	<2	4	24	11	13	<10	7
MWQ5- 21	376	63	313	298	15	8	<2	6	21	<10	12	<10	8
MWQ5- 22	293	32	261	212	49	<2	<2	47	25	12	14	<10	9

Sample ID	TN	PN	TDN	DON	DIN	NO3	NO2	NH4	TP	PP	TDP	DOP	DIP
	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L
MWQ6- 1	153	<10	153	144	9	4	<2	4	15	<10	15	11	4
MWQ6- 2	291	<10	291	284	7	3	<2	3	15	<10	15	<10	5
MWQ6- 3	178	<10	169	163	6	3	<2	3	26	<10	17	12	5
MWQ6- 4	213	32	180	173	7	3	<2	4	39	11	29	19	10
MWQ6- 5	255	60	194	186	8	3	<2	4	48	17	31	18	13
MWQ6- 6	502	140	361	355	7	2	<2	3	129	47	81	47	34
MWQ6- 7	213	12	202	196	6	2	<2	3	25	<10	24	16	7
MWQ6- 8	226	<10	226	220	6	2	<2	3	28	<10	21	14	7
MWQ6- 9	219	58	161	149	11	3	<2	8	32	<10	26	17	9
MWQ6- 10	247	50	197	191	6	<2	<2	4	33	<10	23	12	11
MWQ6- 11	306	67	239	236	4	<2	<2	3	34	<10	26	15	10
MWQ6- 12	181	<10	181	176	5	<2	<2	3	30	<10	24	14	10
MWQ6- 13	185	<10	176	171	4	<2	<2	2	34	<10	24	14	10
MWQ6- 14	194	20	174	171	3	<2	<2	<2	34	11	23	14	10
MWQ6- 15	210	45	165	162	3	<2	<2	<2	36	14	22	13	9
MWQ6- 16	250	78	172	171	<2	<2	<2	<2	34	13	21	13	8
MWQ6- 17	315	117	198	196	2	<2	<2	<2	36	13	23	15	8
MWQ6- 18	304	80	224	205	19	15	<2	2	32	<10	24	15	10
MWQ6- 19	267	66	201	194	7	6	<2	<2	31	12	19	11	8
MWQ6- 20	289	107	182	181	<2	<2	<2	<2	30	14	16	<10	7
MWQ7- 1	320	<10	320	300	19	11	<2	8	14	<10	12	<10	7
MWQ7- 2	307	50	257	205	52	26	<2	25	17	<10	15	<10	7
MWQ7- 3	488	62	426	287	139	94	4	41	40	13	27	16	11
MWQ7- 4	378	84	294	246	48	27	2	19	42	13	28	16	12
MWQ7- 5	370	45	325	282	43	15	<2	26	46	16	30	15	15
MWQ7- 6	538	80	457	440	17	3	<2	14	107	33	74	42	33
MWQ7- 7	694	14	680	429	251	187	5	60	54	16	38	20	19

Sample ID	TN	PN	TDN	DON	DIN	NO3	NO2	NH4	TP	PP	TDP	DOP	DIP
	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L
MWQ7- 8	720	14	706	434	273	200	6	66	61	22	39	20	19
MWQ7- 9	851	29	822	514	308	229	6	73	73	23	50	27	23
MWQ7- 10	937	52	886	553	332	250	7	75	80	21	59	34	24
MWQ7- 11	943	32	911	554	357	275	7	75	80	24	57	31	26
MWQ7- 12	1186	<10	1186	836	350	276	7	67	90	24	66	40	26
MWQ7- 13	1053	30	1022	599	423	348	9	66	93	26	67	40	28
MWQ7- 14	1062	23	1039	578	461	379	13	69	101	29	72	32	39
MWQ7- 15	1115	<10	1115	705	409	328	11	70	101	24	76	34	42
MWQ7- 16	1003	<10	1003	659	344	300	10	33	97	23	74	39	35
MWQ7- 17	899	<10	899	578	321	281	9	31	85	22	63	32	31
MWQ7- 18	878	31	848	532	315	282	9	24	81	24	56	28	28
MWQ8- 1	157	46	111	105	6	<2	<2	5	16	<10	12	<10	2
MWQ8- 2	182	18	164	158	6	<2	<2	4	19	<10	16	13	3
MWQ8- 3	274	104	170	164	6	<2	<2	4	34	12	22	17	6
MWQ8- 4	293	116	177	170	6	<2	<2	5	41	11	31	23	8
MWQ8- 5	272	71	201	196	6	<2	<2	5	42	12	30	22	8
MWQ8- 6	562	175	386	380	6	<2	<2	4	74	26	48	34	15
MWQ8- 7	194	46	148	140	7	<2	<2	5	26	<10	20	16	4
MWQ8- 8	257	29	228	222	6	<2	<2	5	28	<10	21	15	7
MWQ8- 9	212	16	196	191	6	<2	<2	4	35	<10	26	19	7
MWQ8- 10	250	44	206	201	5	<2	<2	4	38	<10	29	18	10
MWQ8- 11	239	53	187	182	4	<2	<2	4	38	<10	31	21	9
MWQ8- 12	253	57	196	192	5	<2	<2	4	38	<10	31	19	12
MWQ8- 13	326	134	192	188	5	<2	<2	3	40	<10	33	21	13
MWQ8- 14	304	78	227	224	3	<2	<2	2	46	<10	38	26	13
MWQ8- 15	296	79	218	215	2	<2	<2	<2	52	11	40	24	16
MWQ8- 16	778	466	313	308	4	<2	<2	4	62	17	45	32	13

Sample ID	TN	PN	TDN	DON	DIN	NO3	NO2	NH4	TP	PP	TDP	DOP	DIP
	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L
MWQ8- 17	446	162	284	282	<2	<2	<2	<2	67	11	56	42	13
MWQ8- 18	358	138	220	217	3	<2	<2	<2	39	<10	31	21	10
MWQ8- 19	262	95	166	163	4	<2	<2	2	30	<10	24	14	10
MWQ8- 20	196	53	142	140	2	<2	<2	<2	27	<10	19	11	8
MWQ9- 1	160	23	138	127	11	3	<2	7	41	<10	38	33	5
MWQ9- 2	147	<10	147	138	9	2	<2	6	44	<10	39	34	5
MWQ9- 3	186	34	152	145	8	2	<2	5	55	11	44	37	7
MWQ9- 4	211	24	187	175	12	3	<2	8	60	12	48	38	10
MWQ9- 5	208	26	182	173	9	<2	<2	6	59	10	49	39	10
MWQ9- 6	319	<10	310	300	10	<2	<2	8	59	12	48	39	8
MWQ9- 7	187	18	169	162	7	<2	<2	5	46	<10	40	34	7
MWQ9- 8	175	17	158	151	7	<2	<2	5	46	<10	42	33	9
MWQ9- 9	172	13	159	151	8	<2	<2	6	47	<10	40	31	9
MWQ9- 10	201	25	176	169	7	<2	<2	6	47	<10	39	29	10
MWQ9- 11	216	56	160	152	8	<2	<2	7	47	<10	38	28	10
MWQ9- 12	237	35	203	175	28	19	<2	7	49	<10	39	28	11
MWQ9- 13	230	29	201	162	39	25	<2	12	46	<10	41	28	13
MWQ9- 14	267	73	195	152	42	35	<2	6	47	<10	37	23	14
MWQ9- 15	305	91	214	171	44	36	<2	6	53	15	38	22	15
MWQ9- 16	332	93	239	213	26	20	<2	4	46	16	30	15	15
MWQ9- 17	256	44	212	161	51	44	<2	5	38	11	27	15	12
MWQ9- 18	436	227	209	167	41	35	<2	4	37	10	27	17	10
MWQ9- 19	217	45	172	162	10	6	<2	4	31	<10	25	15	10
MWQ9- 20	255	104	151	146	5	<2	<2	4	26	<10	16	10	6
MWQ10- 1	191	<10	191	187	3	2	<2	<2	42	<10	38	23	15
MWQ10- 2	210	18	191	182	10	4	<2	6	53	<10	53	36	17

Sample ID	TN	PN	TDN	DON	DIN	NO3	NO2	NH4	TP	PP	TDP	DOP	DIP
	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L
MWQ10- 3	217	<10	217	203	14	5	<2	8	54	<10	45	27	18
MWQ10- 4	242	29	213	196	17	6	<2	11	59	<10	51	31	20
MWQ10- 5	302	67	235	224	11	5	<2	6	66	15	51	30	21
MWQ10- 6	380	<10	380	375	5	<2	<2	3	69	16	53	33	20
MWQ10- 7	404	113	291	284	7	3	<2	5	62	18	44	27	17
MWQ10- 8	258	59	199	196	3	<2	<2	<2	48	<10	40	23	17
MWQ10- 9	247	<10	247	243	3	3	<2	<2	45	<10	42	26	16
MWQ10- 10	427	136	292	278	13	4	<2	8	53	<10	44	28	16
MWQ10- 11	250	27	223	216	7	<2	<2	7	46	<10	44	27	17
MWQ10- 12	210	<10	210	205	5	<2	<2	3	43	<10	43	26	17
MWQ10- 13	249	<10	249	223	26	2	<2	24	42	<10	37	24	13
MWQ10- 14	275	<10	275	274	<2	<2	<2	<2	38	<10	37	24	12
MWQ10- 15	216	<10	216	215	<2	<2	<2	<2	35	<10	32	20	12
MWQ10- 16	238	<10	238	236	2	<2	<2	<2	41	11	29	20	9
MWQ10- 17	258	<10	258	256	<2	<2	<2	<2	36	12	24	18	7
MWQ10- 18	333	72	261	251	9	7	2	<2	24	<10	19	15	4
MWQ10- 19	266	12	254	249	5	4	<2	<2	21	<10	20	15	5
MWQ10- 20	251	82	169	167	<2	<2	<2	<2	22	<10	15	11	5
MWQ11- 1	224	<10	224	210	14	5	<2	9	29	<10	28	24	4
MWQ11- 2	225	28	198	182	15	5	<2	9	29	<10	24	22	2
MWQ11- 3	280	<10	280	263	17	6	<2	10	29	21	<10	<10	4
MWQ11- 4	253	<10	253	238	15	4	<2	11	37	<10	28	22	6
MWQ11- 5	290	<10	290	275	15	5	<2	9	38	<10	29	22	6
MWQ11- 6	293	17	276	265	11	<2	<2	9	40	<10	32	24	7
MWQ11- 7	244	<10	244	226	19	6	<2	12	31	<10	22	17	5
MWQ11- 8	223	<10	223	205	18	6	<2	12	30	<10	25	19	6
MWQ11- 9	252	<10	252	224	28	7	<2	21	32	<10	27	22	6

Sample ID	TN	PN	TDN	DON	DIN	NO3	NO2	NH4	TP	PP	TDP	DOP	DIP
	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L
MWQ11- 10	226	<10	224	203	21	10	<2	11	33	<10	25	17	7
MWQ11- 11	263	<10	263	239	25	9	<2	15	33	<10	28	18	9
MWQ11- 12	230	<10	225	207	18	12	<2	6	31	<10	22	14	8
MWQ11- 13	222	<10	222	200	22	14	<2	7	28	<10	23	15	9
MWQ11- 14	241	<10	241	219	22	17	<2	5	31	<10	24	17	7
MWQ11- 15	250	<10	250	216	34	19	<2	14	29	<10	20	11	8
MWQ11- 16	219	<10	219	160	59	4	<2	54	26	13	13	<10	6
MWQ11- 17	234	<10	233	225	8	<2	<2	5	22	<10	12	10	2
MWQ11- 18	242	15	226	174	52	43	<2	7	17	<10	<10	<10	3
MWQ11- 19	203	<10	200	180	20	13	<2	7	16	<10	<10	<10	3
MWQ11- 20	202	46	156	148	8	<2	<2	7	15	<10	<10	<10	3
MWQ12- 1	289	<10	289	260	30	15	3	12	38	<10	36	34	2
MWQ12- 2	223	<10	222	197	25	12	2	10	46	<10	38	37	<2
MWQ12- 3	239	<10	239	223	16	5	<2	10	45	11	34	31	3
MWQ12- 4	271	33	238	226	12	3	<2	8	52	13	39	34	5
MWQ12- 5	412	<10	412	396	15	3	<2	13	47	<10	42	37	5
MWQ12- 6	392	58	334	321	13	2	<2	11	58	<10	58	54	4
MWQ12- 7	268	<10	264	235	29	5	<2	24	46	<10	38	34	3
MWQ12- 8	272	<10	272	259	14	5	<2	9	48	10	38	32	6
MWQ12- 9	284	<10	284	269	16	6	<2	9	44	<10	37	30	6
MWQ12- 10	286	66	220	208	13	5	<2	8	34	<10	34	28	6
MWQ12- 11	316	<10	316	304	13	4	<2	8	37	<10	32	27	5
MWQ12- 12	366	<10	366	351	14	5	<2	9	52	24	29	23	5
MWQ12- 13	322	104	218	206	12	6	<2	5	27	<10	24	20	5
MWQ12- 14	255	30	225	210	15	6	<2	8	22	<10	22	18	5
MWQ12- 15	375	192	183	173	10	4	<2	6	39	14	25	21	3
MWQ12- 16	418	217	201	189	12	3	<2	9	14	<10	<10	<10	2

Sample ID	TN	PN	TDN	DON	DIN	NO3	NO2	NH4	TP	PP	TDP	DOP	DIP
	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L
MWQ12- 17	385	91	294	211	84	13	<2	70	17	<10	<10	<10	2
MWQ12- 18	483	294	190	174	16	10	<2	6	19	14	<10	<10	6
MWQ12- 19	201	11	190	180	10	<2	<2	9	11	<10	<10	<10	5

Table C 3: ????

Sample	Date	Time	NO3	NO2	NH4	DIN	DON	TDN	PN	TN	PO4	DOP	TDP	PP	TP
			ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L
1	18/9/06	12:23	<2	<2	3	6	181	186	<10	186	4	<10	11	<10	14
2	4/10/06	11:00	<2	<2	<2	<2	214	216	<10	216	3	<10	10	<10	13
3	18/10/06	1:40	<2	<2	5	7	331	338	<10	338	3	<10	<10	<10	11
4	6/11/06	11:05	34	3	40	77	422	499	18	517	5	14	19	16	35
5	7/11/06	9:10	101	3	45	149	357	507	<10	507	8	14	23	14	37
6	8/11/06	12:42 PM	396	5	19	420	491	912	8	920	9	38	47	<10	52
7	9/11/06	11:10 AM	385	6	18	409	598	1008	<10	1008	8	17	25	11	36
8	10/11/06	11:20	325	5	7	337	390	727	<10	727	8	15	23	<10	29
9	15/11/06	12:40 PM	<2	<2	9	9	488	497	<10	497	8	11	19	<10	28
10	22/11/06	11:45	<2	<2	41	43	205	248	<10	251	4	15	20	<10	26
11	29/11/06	11:35	<2	<2	10	12	369	381	<10	381	3	<10	11	<10	17
12	12/12/06	3:15pm	<2	<2	6	6	203	209	52	260	3	<10	<10	<10	14
13	20/12/06	10:25	<2	<2	8	11	347	358	<10	358	3	<10	<10	11	20
14	28/12/06	11:30	<2	<2	3	3	210	213	<10	219	2	<10	<10	<10	12
15	8/1/07	9:45	<2	<2	5	6	179	184	46	230	2	<10	<10	<10	12
16	14/2/07	9:25	9	2	63	74	223	297	16	313	6	11	17	18	35
17	20/2/07	2:20	<2	<2	11	12	158	170	38	208	3	11	14	<10	14
18	28/2/07	11:15	<2	<2	28	31	291	323	<10	323	9	<10	19	<10	23
19	1/3/07	10:10	84	8	24	116	409	525	228	753	9	29	38	25	63
20	2/3/07	9:15	141	8	75	225	362	587	102	689	14	10	25	40	65
21	5/3/07	9:15	279	10	90	379	547	926	15	940	29	27	56	20	76
22	6/3/07	9:20	303	9	49	361	381	742	98	840	25	31	56	22	78
23	8/3/07	3:00pm	208	8	91	306	351	658	<10	658	30	22	51	15	67
24	14/3/07	9:10 AM	40	<2	21	64	344	409	<10	409	20	15	35	<10	35
25	20/3/07	2:45 PM	<2	<2	11	15	338	353	<10	353	19	13	33	<10	37

Sample	Date	Time	NO3	NO2	NH4	DIN	DON	TDN	PN	TN	PO4	DOP	TDP	PP	TP
			ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L
26	27/3/07	1:50 PM	<2	<2	17	20	296	315	<10	315	10	12	21	<10	28
27	12/4/07	2:00 PM	<2	<2	11	13	210	223	<10	223	5	<10	14	<10	18
28	18/4/07	2:30 PM	<2	<2	14	16	262	277	<10	277	4	11	15	<10	18
29	26/4/07	2:38 PM	5	<2	20	26	189	215	47	262	4	12	16	<10	18
30	2/5/07	9:50	<2	<2	8	9	119	128	<10	129	3	10	13	<10	17
31	15/5/07	12:15	5	<2	76	82	108	190	122	312	3	<10	12	<10	18
32	23/5/07	2:30 PM	2	<2	13	16	288	304	725	1029	3	<10	11	<10	17
33	7/6/07	2:20 PM	3	<2	13	17	307	323	<10	323	3	14	17	<10	17
34	27/6/07	11:40	5	<2	18	24	361	385	<10	385	3	11	14	<10	14
35	4/7/07	10:29	<2	<2	12	13	303	316	<10	316	2	<10	<10	15	18

Sample	Silver	Aluminum	Arsenic	Cadmium	Chromium	Copper	Iron	Manganese	Nickel	Lead	Selenium	Zinc	Mercury
	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
1	0	0.0088	0.0011	0	0	0.0006	0.1086	0.0044	0	0	0.0006	0.0021	0
2	0	0	0.0015	0	0	0.0013	0.1098	0.0043	0	0	0.0005	0.0076	0
3	0	0	0.0015	0	0.0015	0.0021	0.1412	0.0059	0	0	0.0005	0.0024	0
4	0	0.225	0.0012	0	0.0007	0.0018	0.4702	0.0101	0.0006	0	0.0006	0.002	0
5	0	0.1656	0.0015	0	0.0007	0.0017	0.321	0.0178	0	0	0.0006	0.0038	0
6	0	0.2156	0.0014	0	0.0005	0.0017	0.3626	0.0138	0	0	0.0007	0.0021	0
7	0	0.139	0.0014	0	0.0012	0.0026	0.2801	0.0101	0.0005	0	0.0006	0.0022	0
8	0	0.0833	0.0015	0	0.0009	0.0014	0.2369	0.0093	0	0	0.0005	0	0
9	0	0.0313	0.0025	0	0	0.0015	0.2516	0.0187	0	0	0.0006	0.0025	0
10	0	0.0035	0.0022	0	0	0.0009	0.184	0.0124	0	0	0.0005	0.0021	0
11	0	0.0053	0.0023	0	0	0.0005	0.1749	0.0105	0	0	0.0006	0.0034	0
12	0	0.0052	0.0024	0	0.0005	0.0009	0.1724	0.0138	0	0	0.0006	0.0114	0

Sample	Silver	Aluminum	Arsenic	Cadmium	Chromium	Copper	Iron	Manganese	Nickel	Lead	Selenium	Zinc	Mercury
	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
13	0	0.0145	0.0018	0	0.0007	0.0008	0.1719	0.0169	0	0	0.0005	0.0122	0
14	0	0	0.0019	0	0.0006	0.0009	0.1312	0.0064	0	0	0.0007	0.0094	0
15	0	0	0.0019	0	0.0007	0	0.1598	0.0117	0	0	0.0008	0.0041	0
16	0	0.132	0.003	0	0.001	0.003	0.309	0.032	0.002	0	0	0.056	0
17	0	0.023	0.003	0	0.001	0.002	0.121	0.009	0.001	0	0	0.031	0
18	0	0.023	0.003	0	0.001	0.002	0.147	0.013	0.001	0	0	0.018	0
19	0	0.492	0.003	0	0.001	0.003	0.515	0.026	0.001	0.00 1	0	0.018	0
20	0	0.58	0.004	0.001	0.002	0.004	0.608	0.027	0.002	0.00 2	0	0.012	0
21	0	0.356	0.005	0	0.001	0.005	0.543	0.047	0.002	0.00 1	0	0.025	0
22	0	0.277	0.006	0	0.001	0.003	0.487	0.038	0.002	0.00 1	0	0.023	0
23	0	0.152	0.007	0	0.001	0.003	0.426	0.04	0.002	0	0.001	0.019	0
24	0	0.064	0.006	0	0.001	0.003	0.289	0.03	0.001	0	0.001	0.011	0
25	0	0.04	0.006	0	0.001	0.003	0.268	0.019	0.001	0	0.001	0.011	0
26	0	0.04	0.005	0	0.001	0.004	0.195	0.011	0.002	0	0.001	0.012	0
27	0	0.028	0.003	0	0.001	0.003	0.119	0.008	0.001	0	0	0.01	0
28	0	0.027	0.003	0	0.001	0.003	0.107	0.01	0.001	0	0	0.013	0
29	0	0.02	0.003	0	0.001	0.009	0.112	0.009	0.001	0	0	0.021	0
30	0	0.025	0.002	0	0.001	0.002	0.087	0.005	0.001	0	0	0.016	0
31	0	0.034	0.002	0	0.001	0.008	0.079	0.007	0.002	0	0	0.041	0
32	0	0.022	0.002	0	0.001	0.007	0.073	0.005	0.002	0.00 1	0	0.018	0
33	0	0.018	0.001	0	0.001	0.002	0.065	0.006	0.001	0	0	0.006	0
34	0	0.035	0.001	0	0.001	0.003	0.047	0.004	0.001	0	0	0.007	0
35	0	0.03	0.001	0.001	0.001	0.002	0.058	0.007	0.001	0.00	0.001	0.005	0

Sample	Silver	Aluminum	Arsenic	Cadmium	Chromium	Copper	Iron	Manganese	Nickel	Lead	Selenium	Zinc	Mercury
	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
										1			

Sample	type(R, U, D)	Comments
1	r	1 wk after heavy rainfall
2	r	fine weather, minor coastal showers
3	r	showers on previous two days
4	u	Heavy Rain over weekend. Slight rise in river and slightly brown
5	r	river light brown and fast moving
6	d	river light brown some flood weed debris
7	d	water level dropping, light brown
8	d	fish jumping clarity improving
9	r	clear
10	r	clear
11	r	level dropping slightly, clear
12	r	river low- base flow
13	r	level dropping- base flow
14	r	slightly above base flow, clear
15	r	light coastal showers, base flow, clear
16	r	slight rise in water level after 3 days of rain
17	r	slow flow (base), clear
18	r	slight rise in level, swift flowing
19	u	river rising, brwon water
20	u	swift flowing, rising slowly, brwon
21	d	falling, swift and brown
22	u	discoloured brown
23	d	colour clearing

24	r	clear, slow flowing
25	r	clear
26	r	after heavy rainfall
27	r	clear
28	r	clear
29	r	showers
30	r	clear- base flow
31	r	clear water
32	r	clear, level dropping
33	r	raining
34	r	after rain event
35	r	