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NSW Department of Commerce

Hunter Estuary Processes Study

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HUNTER ESTUARY PROCESSES STUDY

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QA SYSTEM Manly Hydraulics Laboratory is Quality System Certified to AS/NZS ISO 9001:1994.

Foreword

This study has been prepared in response to an invitation from Newcastle City Council to the (then) NSW Department of Public Works and Services' Manly Hydraulics Laboratory (MHL). The report has been prepared by Helen Davies, Dr David van Senden, Michele Widdowson, Henriette Otter and Belinda Peterson of Manly Hydraulics Laboratory. MHL fieldwork was completed by Helen Davies, David Allsop, David van Senden and Michele Widdowson. Figures were produced by Mark Howden and Michele Widdowson. Report production was completed by Megan Jensen.

The investigations were undertaken in association with the University of Newcastle, The Wetlands Centre, The Ecology Lab Pty Ltd and ESE Pty Ltd for Newcastle City Council. Their overall investigations are reported separately, and form six technical reports completed as part of the Hunter Estuary Processes Study. The major findings of these specialist studies are included in this report.

Under the Public Sector Employment and Management (General) Order of 2 April 2003 the Department of Public Works and Services (DPWS) was abolished and its branches transferred to the Department of Commerce.

This report was substantially completed prior to the State Government departmental restructure in April 2003, and government department names prior to the restructure have been retained in the report.

Executive Summary

The Hunter River Estuary is typical of the larger NSW estuaries that have evolved over the millennia through various geological developments, climatic periods and sea level variations to the present day. The present-day estuary is a drowned river valley with an extensive floodplain delta where the river meanders to the sea.

The Hunter River catchment is one of the largest in NSW and reaches further inland than any other catchment, covering an area of approximately 22,000 km^2. Originating in the Mount Royal Range, the river is approximately 300 km long, and enters the sea at the port of Newcastle (Figure 1.1). Newcastle, which is a major coal exporting port, is NSW's second largest city, with a population of around 135,000.

In 1961 the population of Newcastle was approximately 142,500 and Maitland's population was 27,500 (ABS 1996). After a drop to 129,500 in 1986 the population of Newcastle recovered and is projected to continue to grow slowly in the coming years. Maitland's population has steadily increased since the 1960s and is approximately 50,000 today, with projections for continued growth in the coming years.

The natural processes that shaped the estuary morphology over the millennia have been altered by a range of human activities implemented over the past 200 years of European settlement. These activities include the clearing of the fertile river flats and catchment areas for agricultural use; grazing of the riparian zone; construction of the entrance groynes for navigation; construction of levees for flood mitigation; dredging of sand and gravel from the upper estuary and river for building materials; dredging of the lower estuary for port infrastructure; construction of floodgates and drainage channels to convert low-lying waterlogged lands to agricultural use; construction of bank stabilisation works to protect assets, reduce bank erosion and maintain a constant channel alignment; and urban development.

The objectives of the study were to:

1. Identify and document the physical, chemical and biological condition of the estuary and related processes and interactions through investigation and data collection.
2. Define a baseline condition of the estuarine processes and interactions on which management decisions can be made.
3. Identify and document the historical and contemporary natural attributes of the estuary through research, investigation and data collection.
4. Identify and document the roles, frameworks and relationships of relevant management authorities and identify any information data gaps and areas of overlap relevant to the estuary.
5. Review existing and strategic land use activities that have the potential to impact on the management needs of the estuary.

Study Area

The study area comprises the Hunter River and its tributaries to their tidal limits, wetlands, foreshores and adjacent lands, with a total waterway area of 26 km^2 (Figure 1.2). Tributaries of the estuary include the Paterson and Williams rivers, Wallis and Fishery creeks, Ironbark Creek, and Throsby, Styx and Cottage creeks. The tidal limit in the Hunter River occurs in the vicinity of Oakhampton, approximately 64 km from the ocean. The tidal limit for the Paterson River occurs between Paterson and Gostwyck, approximately 70-75 km from the ocean, and at Seaham Weir on the Williams River at approximately 46 km from the ocean. It is recognised that the processes in the estuary are closely linked or even driven by the processes operating in the catchment. and therefore broad-scale catchment processes were also taken into consideration in this study where relevant.

The relationships of geology and soil properties, and erosive forces of wind and water, have led to the evolution of landforms of the Hunter estuary. Major landforms of the Hunter estuary sub-catchment are the waterways, Lower Hunter and Tomago Coastal Plains, valleys (through which the Williams and Paterson rivers flow), low undulating hills, such as the East Maitland Hills, and hilly to steep slopes in the Paterson Mountains, Clarence Town Hills and Sugarloaf Range.

Climate

Weather and climate impact upon hydrodynamic processes, geological and geomorphological processes, and ecological processes, and are therefore important forcing factors driving many of the estuarine processes. The variability of weather and climate is also important for the interpretation of natural versus anthropogenic changes in ecosystem variables. The prevailing climate of the Hunter River estuary is warm and temperate, with a maritime influence. Summers are warm to hot and humid, winters are cold to mild.

Temperatures vary across the Hunter catchment depending on the local incidence of sea breezes and elevation above sea level. At Newcastle temperatures are generally mild to warm, with a mean summer maximum of 25°C (winter 17°C) and a mean summer minimum of 19°C (winter 9°C). Mean annual rainfall varies considerably across the catchment with the highest values near the coast (1,140 mm p.a.), and in elevated areas such as Barrington Tops (1,600 mm p.a.). Summer wind speed and direction is predominantly from the east and north-east, with westerly winds dominant in winter. Evaporation is an important factor in the water cycle of temperate climate regions, with high values in summer and lower values in winter. The catchment-wide evaporation average is approximately 1,092 mm p.a.. Solar radiation forms an important contribution to the estuary processes in two ways; as a source of heat influencing the thermal stratification in the river and as a source of sunlight for photosynthesising aquatic plants and algae (e.g. phytoplankton). The high sunlight intensity and long summer days of the Hunter region are ideal for plant growth, while in winter the shorter days and weaker intensity are less conducive to growth.

Climatic Change

The latest International Panel on Climate Change (IPCC) predictions suggest that in the Hunter Valley average temperatures are likely to rise across all seasons, while average rainfall is predicted to be higher in summer and lower in winter, relative to average 1990 conditions. An increase in extreme daily rainfall leading to more frequent heavy rainfall events with increased flooding is also likely (CSIRO 2001).

The most recent projected mean sea level rise is 0.09 to 0.88 m between 1990 and 2100 (Albritton et al. 2001). In general terms, sea level rise will directly affect tide (and storm surge) levels with a corresponding increase in inundation levels and the extent of wave runup at the shoreline. Estuarine features such as shoaling patterns, channel alignment, and water levels relative to artificial structures are likely to be altered. Wetland areas are also likely to be affected by longer periods of inundation and landward expansion where sufficient low-lying lands adjacent to wetlands exist.

Geology and Geomorphology

The geology of the Hunter Valley is complex because it lies at the boundary of three tectonic provinces; the New England fold belt, Sydney Basin and Eastern Australia Passive Margin. The New England fold belt is comprised of mainly sandstone, shale, conglomerate and glacial deposits and occurs in the north-eastern margin of the Hunter Valley down to Maitland. The Sydney Basin is comprised of similar rocks to the New England fold belt, in addition to coal measures. The Eastern Australian Passive Margin occurs in the northern margin of the Hunter Valley and the rocks consist mainly of sub-aerial lava flows of alkali basalts.

The soft rocks of the Sydney Basin coal measures represent more easily eroded rocks that provide the location of the modern Hunter River course in the middle and lower reaches of the valley. The local geology surrounding and underlying the Hunter estuary provides a control on sediment supply and evolution of the estuary.

Soils

The soils of the Hunter Valley, like the geology, are a complex grouping of multiple types, reflecting the diversity of geological parent material, variations in climate, geomorphology, organisms and time. In low rainfall parts of the Hunter Valley soils with alkaline horizons are common, but in higher rainfall parts the soils are characteristically more strongly leached, and are acid throughout the profile. Most of the soil landscapes of the Hunter Valley catchment have a moderate to high erodability factor based on soil properties.

An acid sulfate soil (ASS) risk assessment has been carried for the Hunter estuary and the bed of the Hunter River, and much of the associated foreshores and tributaries have been classed as having a high probability of ASS occurrence. Current land uses within these high probability areas include industrial and commercial, grazing/agriculture, and some SEPP 14 wetlands. The majority of areas found with high potential ASS in the Newcastle LGA are zoned industrial, while in Maitland and Port Stephens LGAs the majority of potentially affected land is zoned rural. While the effects of acid runoff in the rural areas and the immediate drainage channels have been documented there has been little work on the downstream impacts in the estuary and areas likely to be subject to acid runoff such as Fullerton Cove.

Catchment Hydrology

The large size and considerable inland extension of the Hunter Valley catchment influence river flows and flooding in the valley (NSW Public Works 1994). Sanderson and Redden (2001) determined the mean freshwater flow of the Hunter, Paterson and Williams rivers over the last 25 years as 3,120 ML/day. Similarly the median flow was 716 ML/day, the 90th percentile flow was 5,991 ML/day and the 95th percentile flow 11,918 ML/day. Flows of order 200 GL/day are considered a large flood and in weaker flood events peak flows of 20 GL/day are common. The Paterson, Allyn and Williams rivers, which drain from Barrington Tops where there is high annual rainfall, have a catchment area of 2,230 km^2, and 42% of the total flow comes from this 10% of the catchment.

Discharges of groundwater from underground aquifers form the baseflow of river systems in dry times. The natural balance between the groundwater and surface waters has been altered by the replacement of deep-rooted perennial native vegetation with shallow-rooted annual crops and pastures, causing water tables to rise and increasing the salinity of shallow groundwater and surface waters (Woolley 1995). Changes in the volume and/or quality of the groundwater flow to wetlands impacts on their sustainability. The annual input of groundwater to the middle estuary is estimated as about 183 GL/year.

The estimated total average annual water use of landholders extracting from the estuary is 10,650 ML (DLWC 1999). It is also estimated that 1,020 ha of land is under irrigation on the Paterson River up to Gostwyck and approximately 1,250 ha of land is irrigated on the Hunter River from Oakhampton to Duckenfield. However these calculations do not include all irrigated properties in the Hunter estuary.

There is a long history of flooding in the Hunter River and the largest flood experienced since European settlement in the valley occurred in February 1955, which resulted in the destruction of a large number of flood control structures and the loss of life. It appears that there have been distinct periods of major flooding over the years, with the most significant periods occurring between 1863 and 1880, during the 1890s, and between 1949 and 1956. Since the 1955 flood, significant flooding in the lower Hunter has occurred in 1971, 1972, 1977, 1978, 1985 and 1989. The massive 1955 flood prompted the State Government to establish the Hunter Valley Flood Mitigation Act in 1956, which led to a more controlled and planned implementation of flood mitigation in the valley.

History and Heritage

The general picture that exists of the Hunter River before the arrival of the Europeans is one of a mangrove-fringed river with a dense brush and huge trees lining the banks (Albrecht 2000). Due to the richness and variation in the landscape, there was an abundance of species, such as emus, kangaroos, dingos and a variety of birds and fish, living in the area. The region provided an ideal home range for the Awakabal, Worimi and Wanarua people, and these tribal groups maintained a sustainable lifestyle in the area for at least 30,000 years. About 2,000 Aboriginal sites have been recorded throughout the study area including sites along the valley floors of the major tributaries, rock shelter sites in the sandstone areas and shell middens around coastal lakes and estuaries (Department of Planning 1989a).

Early European settlement and industries of the Hunter River were based on exploitation of cedar trees and easily accessible coal deposits. By the mid 1800s the Hunter Valley, with high quality agricultural lands and short transportation times to Sydney, was one of the most populous parts of NSW. The earliest modifications to the wetlands of the Hunter Valley were initiated by the farming community in response to needs for arable land and to control surface water (Williams et al. 2000). Further transformations of the natural environment took place as transport requirements increased. Dredging programs were undertaken for shipping purposes and land was reclaimed for railways. In 1951 a 20-year dredging and land reclamation project resulted in the formation of a single land mass from the deltaic islands of the lower Hunter (Williams et al. 2000). Infrastructure and flood mitigation works since the 1950s have led to a substantial modification to the flow of the river and the shape of the riverbanks. In the 1970s concerns were raised by the public about the pollution and the extent of industrial development in the Hunter estuary. In the 1980s the region continued to develop and while the regional population increased, the population numbers in Newcastle began to decline. In the 1990s the rehabilitation of wetlands commenced.

The Hunter region is one of Australia's oldest European-settled regions and has produced a unique variety of structures, buildings, towns and landscapes. The Hunter Regional Environmental Plan 1989 has identified some 800 specific items that are deemed worthy of conservation for future generations.

Land Use

In the early 1800s, before European exploration and settlement, the lower Hunter floodplain was covered with thick rainforest. The riverbanks were covered with tall eucalypts and swamp oaks which often extended to the water's edge. Alternating strips of rainforest and naturally clear land across the floodplain, marked floodways and abandoned river channels (Patterson Britton & Partners 1993). Alluvial forest in the form of cedar brush covered most of the Wallis and Paterson Plains, but was removed by the late 1830s. By 1830 much of the floodplain up to Singleton had been claimed by settlers and upstream of Maitland the majority of rainforest had been removed. At this time riparian bank vegetation downstream of Oakhampton was left intact. Maitland and its surrounding rural area emerged as an important commercial and farming area in the late 1800s, when levee banks began to be constructed to protect and improve agricultural land. By 1900 the floodplain vegetation had mostly been removed and backwater lagoons or swamps had silted up to the point where they had become suitable for cultivation (Patterson Britton & Partners 1993).

Agricultural practices in the early years of settlement in the Hunter Valley were ruthless, with overgrazing, over-clearing and the soft, loose soil being compacted by sheep and cattle hooves resulting in dramatic alterations to the natural environment in a short time. These practices, combined with frequent flooding and occasional drought periods, resulted in the worst land and riverbank erosion in Australia, and in 1948 it was estimated that the total soil loss from erosion in the Hunter Valley was in excess of 765,000 cubic metres annually.

Flood Mitigation Works

Flood protection works were constructed around the Maitland area in a haphazard way from the late 1850s. A number of dams were built at this time that represent the first attempts to prevent inundation of the floodplain from the Hunter and Paterson rivers (Hawke 1960). Early works included a levee between Lorn and Bolwarra across the natural floodway through the Bolwarra flats (1889), floodgates in Wallis Creek (1870 and reconstructed in 1876 and 1941) and levees along the right bank below Maitland (Patterson Britton & Partners 1993).

The Hunter Valley Flood Mitigation Act of 1956 funded works designed for the purpose of preventing or mitigating the flooding or inundation of any lands within the lower Hunter Valley by waters from the river. The Lower Hunter Valley Flood Mitigation Scheme was begun in 1956, with the aim of reducing the frequency of flooding, reducing the time floodwaters lie on land after the flood has passed, and controlling the direction and velocity of floodwaters to reduce damage to farmlands and property. In total, the scheme consisted of

160 km of levees and spillways, 140 km of farm drains, 200 floodgates, 30 km of river bank protection works and 40 km of control and diversion banks (DLWC 2002). These works almost covered the entire length of the Hunter River between Morpeth and Hexham, as well as along the Williams River downstream of Seaham. Another levee bank extends from Tomago to the opposite side of Fullerton Cove.

Recreation

The Hunter estuary and its foreshores are used for a variety of activities including recreational and commercial fishing, boating, water-skiing, rowing, and foreshore reserves. Recreational and commercial fishing is allowed throughout the majority of the estuary. The primary fishery for the Hunter River is estuary prawn trawling. Commercial fin-fishing also occurs, although trawling for fin fish is not permitted (TEL 2001). Prawn trawling generally occurs in the estuary from October to May, and prawn trawling boats are found from Raymond Terrace downstream to the port area. Oyster leases occur in the north arm.

Boating facilities include major boat ramps at Carrington, Stockton, Raymond Terrace (Fitzgerald Bridge), Kooragang Island, Tomago and Morpeth, and a marina in Throsby Creek. Water-skiing generally occurs along the downstream reaches of the Williams River and, to a lesser extent, in the Hunter River between Raymond Terrace and Morpeth. Rowing occurs predominantly in the upper estuary along Swan Reach, and also in Throsby Creek. Foreshore reserves occur throughout the estuary, and are utilised for picnicking and leisure activities, including recreational shore fishing.

Impacts related to recreational uses of the Hunter estuary include possible effects on sustainability of fish populations, and effects on bank erosion from boat wakes. Anecdotal evidence suggests there has been a general increase in recreational activities in the Hunter estuary in recent years with the general view that the impacts need to be better managed.

Dredging

Dredging first commenced in the Hunter in 1845 and has been occurring almost continuously since 1859. The port has been dredged to develop new facilities as well as to maintain the channel due to the large amount of sand and silt that is carried down the Hunter River, especially in times of flooding. Annual maintenance dredging in the harbour removes around 300,000 m^3/year, with the majority of the material disposed offshore.

Sand and gravel is extracted from the banks and bed of the river at various locations. The Department of Land and Water Conservation administers the removal of sand and gravel within 40 m of a river under the *Rivers and Foreshores Improvements Act* to ensure that extraction operations do not destabilise the bed and banks of rivers (DLWC 1999). Maitland City Council has three quarry developments in the Maitland Local Government Area, with extraction rates of 462, 68,395 and 85,847 m^3/annum.

Floods

Two flood studies of the Hunter Valley have been conducted, the first in 1990 which considered the area from Oakhampton to Green Rocks (PWD 1990), and the second in 1994 covering the area from Green Rocks to Newcastle (NSW Public Works 1994). Estimated flood levels for the 1-in-100-year recurrence interval flood in the upper estuary reach 16 m AHD (Australian Height Datum) and the flood height gradually decreases downstream to a level of 8.6 m at the Paterson River junction, 3.7 m at Hexham Bridge and 1.3 m at Newcastle Port.

The extensive works constructed for the Lower Hunter Valley Flood Mitigation Scheme have changed the nature of flooding in the Hunter Valley significantly. In higher frequency, low discharge floods the flow is contained within the river's banks and levees. As flood severity increases, floodwaters overtop the natural and man-made levees and flow across the floodplain. During severe floods, above the 1-in-20-year flood, the majority of flow occurs as overland flow across the floodplain.

Periodic flooding of rivers and their floodplains is a natural phenomenon which serves to provide water to underground aquifers and replenish layers of silty topsoil on the floodplain. Constraining floodwaters to river channels inevitably alters natural river processes, such as sedimentation and erosion patterns, ecological processes and hydrodynamics. Major channel realignment of the Hunter River has occurred between Maitland and Morpeth, which can be partially attributed to the construction of levee banks in the area. The resulting constriction of the river to the confines of its channel has resulted in increases in flood energy, which over time has caused a number of cut-offs during floods, shortening the channel length and increasing the bed slope and thus further increasing the flood energy.

Hydraulics

The bathymetry of the Hunter estuary gradually shoals upstream. At the entrance and port area the maintenance dredging program maintains a depth of around 14 to 16 m AHD. Upstream of the port area, the south arm is relatively shallow (1 to 4 m deep) compared to the north arm, which takes most of the tidal and flood flows and maintains depths generally greater than 5 m. Between Hexham and Morpeth water depths vary between 3 and 9 m, with the deeper waters on the outside of the river bends. Further upstream the river gradually shoals and becomes a series of sand shoals and channels in the sandy river sediments, with large areas that dry at lower low water.

The largest contributions to the water budget are the tidal prism (±18,250 GL), catchment runoff (1,800 GL) and groundwater inflows (183 GL), while the rainfall (30 GL) and evaporation (-26 GL) contributions are negligible by comparison. The tidal contribution at the mouth is some ten times greater than the runoff. Further upstream the tidal prism diminishes and the relative importance of the catchment runoff becomes more significant.

The processes controlling exchange and mixing within the Hunter River estuary might be thought of in terms of three physical regimes. First, there is the concept of river flow displacing the volume of the estuary. This mechanism is dramatically evident, and solely important, during floods. Second, following floods there is an intrusion of salt into the estuary propagating upstream at depth, against the river flow. Third, during sustained low flow periods salt is dispersed upstream by the tidal dispersion. The first two mechanisms operate on short time scales, of the order of a day. The third process, on the other hand, modifies the salinity distribution over much longer time scales of the order of 100 days and hence is the major mechanism by which salt is transported upstream during prolonged dry periods. The flushing time varies on a similar range of time scales, and at low flow the relatively long flushing time suggests that inputs to the upper reaches, such as point source and diffuse pollution, will be retained within the system for extended periods.

Stratification is often important for enhancing exchange and limiting vertical mixing. The importance of stratification for water quality is often overlooked in these systems. The vertical salinity stratification in the main arm of the Hunter River is generally weak and occurs after flood events. In backwater areas such as in the wetlands and upper reaches where tidal currents are weaker and turbulent mixing is less energetic the likelihood of vertical stratification lasting for longer periods is much greater, however there are not sufficient data from these areas to quantify this effect. The vertical stratification has implications for water quality, including depletion of dissolved oxygen in deep water and algal blooms in surface waters.

Water Quality

Water quality data collected by the Hunter Water Corporation, EPA and Maitland City Council over the past 25 years were compiled into a database to facilitate holistic analysis of the data in conjunction with measurements of river flow. The analysis highlights interesting spatial patterns of nutrients and biota within the estuary and also provides a qualitative assessment of changes in the nutrient status during the last 25 years (Sanderson and Redden 2001a).

Spatial patterns of water quality variables under low flow conditions indicate a weak source of total phosphorus at around 40 km upstream (between Raymond Terrace and Morpeth) and a distributed source of dissolved inorganic nitrogen (DIN) along the lower reaches of the river. Chlorophyll-a data indicates high concentrations in the upstream reaches and decreases towards the mouth, which could be explained by a number of processes including a spatial shift from freshwater species upstream to saltwater species downstream, coupled with the effects of dilution in the lower reaches. The dissolved oxygen (DO) profile shows a slight increase downstream but generally shows that the estuary is well oxygenated throughout. Under high flows, the river becomes almost fresh, with brackish water near the mouth. Total phosphorus decreases downstream, most likely due to settling of particulate forms of phosphorus. DIN and DO are fairly constant along the length of the estuary, and essentially reflect the character of the inflow waters. From the available data it is not possible to draw any general trends in chlorophyll-a response in the lower estuary under high flows. The concentrations at times indicate a bloom of phytoplankton but lack of algal cell identification prevented assessment of particular bloom species.

A number of the water quality variables measured, including nutrients and chlorophyll-a, exceed the ANZECC (2000) guidelines for protection of aquatic ecosystems. The relatively high chlorophyll-a levels in the estuary suggest that algal blooms in the Hunter River are a common occurrence, although there have been few reports of harmful blue-green algal blooms. The high chlorophyll-a levels in most other estuaries would be highly visible but the high turbidity in the Hunter River probably masks the visual effects. Algal blooms are most likely limited by light availability in the turbid system rather than nutrients, except in locations where the algal uptake reduces the concentrations to limiting conditions. Mixing and flushing are also important factors influencing algal bloom dynamics.

A conceptual model of the nutrient cycling processes and factors controlling phytoplankton biomass has been derived from previous detailed studies in northern NSW rivers (Eyre 1998) and the interpretation of the data available for the Hunter estuary. The processes and factors controlling phytoplankton biomass in the Hunter River estuary may be summarised in terms of four broad stages, each driven by freshwater discharge and its effects on salinity concentrations, stratification and catchment inputs. Many processes affect the nutrient concentrations in estuarine environments. Nutrient sources, such as river inflows, stormwater drainage, industrial inputs, and sewerage inputs, have magnitudes that fluctuate greatly with changing seasons and weather conditions. Biological utilisation and recycling of nutrients is sometimes important, as may be various sedimentary processes. The derived nutrient budget indicates that about 5% of the total nitrogen and 23% of the total phosphorus loads are retained in the system and that there is a source of nutrient within the estuary, most likely sediment release.

Sedimentation and Erosion

Sedimentation and erosion processes operate at varying levels, from the catchment level through to the morphology of the river, and at varying time scales, from geological through to shorter-term time scales. Factors influencing sedimentation and erosion in the Hunter River catchment at geological time scales include geology, topography, slope classes and soils. These factors, together with rainfall, lead to the erodability of the catchment. Human influence can accelerate the rate of sedimentation and erosion through factors such as clearing, land use changes and river channel realignment.

In modern times there is an excess of sediment being supplied to the upper Hunter estuary due to deforestation and overgrazing (Boyd 2001). This sediment is transported primarily during major floods, such as the 1955 flood when a major area of deposition occurred from Oakhampton to Morpeth. In response to the major deposition during floods, local areas of erosion form, followed by subsequent attempts to re-establish equilibrium by eroding the channel bed and banks. Accretion of point bars on meander bends where the channel energy is lower result in the progressive removal of sediments along the outside bank of the meander and the storage of fluvial sand along the inside bank (MHL 2000). Some of the sand deposited in point bars will be eroded and transported further downstream by flood events, perhaps to be stored in another point bar.

A sediment budget has been derived from the available information. The mean annual sediment load and mean annual suspended sediment load for the Hunter River at Singleton are 2 million tonnes and 1.6 million tonnes respectively. The typical suspended sediment influx to the lower estuary (i.e. below Hexham) is of the order of 1 million tonnes per year.

Bank Stability

Bank erosion has been a significant issue since early settlement, affecting considerable reaches of the Hunter River and estuary. Changes to flood patterns, together with clearance of riparian vegetation lining the banks of the Hunter estuary following European settlement, led to river bank destabilisation and substantial bank erosion, such that a condition of greater instability now exists in the Hunter estuary (Patterson Britton & Partners 1995, Sinclair Knight & Partners 1990).

An assessment of the current condition of the banks of the Hunter estuary was carried out by MHL during field observations of the entire estuary (18–27 September 2002). This assessment involved mapping several factors including bank stability, riparian vegetation cover, together with an assessment of possible causes, including cattle access and boating activity. Much of the river was classified as unstable either due to a lack of vegetation, poor condition of rock revetment structures or the banks were obviously eroding. Cattle access was a major factor for much of the estuary and particularly upstream of Hexham. Bank protection works have largely come about because assets built at a fixed location are in the path of naturally migrating meanders. Protection of assets by construction of levees and bank stabilisation works has now become a major undertaking in the Hunter estuary, requiring significant capital investment.

Flora and Fauna

Estuarine floral habitat types in the Hunter estuary include mangroves, saltmarsh, fresh/fresh-brackish wetlands, *Phragmites australis* (common reed) swamps, *Casuarina glauca* (she oak) and *Melaleuca spp.* (paperbark) stands and remnant forests. *Phragmites australis* also occurs in the riparian zone in the upper Hunter estuary. Cleared land and cattle grazing to the water's edge in many areas in the upper estuary have greatly reduced the presence of estuarine floral habitats.

Aquatic and terrestrial fauna occur throughout the Hunter estuary. Major faunal groups include fish, crustaceans (such as prawns), benthic invertebrates, significant native amphibian, reptilian and mammalian populations and residential, seasonal and migratory avifaunal communities. The estuary provides significant resources for a large variety of migratory and resident bird species, but shows a low diversity of native amphibians, reptiles and mammals. Much of the native fauna has been destroyed as a result of habitat destruction and the introduction of new species. Faunal habitats closely follow the floral habitat types of the estuary, with additional faunal habitat types including tidal flats and saline open water bodies, fresh open water bodies, artificial structures and bare sandy sites.

Of the threatened species listed under State and Commonwealth legislation (*Threatened Species Conservation Act 1995*, *Environment Protection and Biodiversity Conservation Act 1999*), the Hunter estuary provides habitat for at least 23 bird species, one amphibian, seven mammals and two floral species..

Under the Threatened Species Conservation Act, endangered ecological communities include the Sydney Coastal Estuary Swamp Forest in the Sydney Basin Bioregion, and the Sydney Freshwater Wetlands. Of the former community, 11 of the 30 species that characterise that community are found on Ash Island. Of the Sydney Freshwater Wetlands community, at least seven species which characterise this community are found on Ash Island. Through the *Fisheries Management Act 1994*, mangrove communities are protected, and NSW Fisheries are also working towards protecting saltmarsh.

Key Threatening Processes to flora and fauna listed under State and Commonwealth legislation include degradation of native riparian vegetation along NSW watercourses; alteration to natural flow regimes of rivers, floodplains and wetlands; clearing of native vegetation; human-caused climate change; and predation, competition and habitat degradation from a number of introduced species, including the fish plague minnow, foxes, and feral cats, pigs and rabbits.

Fish and prawn resources in the Hunter estuary are affected by suitable nursery areas, which include saltmarsh, and obstacles to fish passage, which include the extensive flood mitigation network and other hydraulic structures. Rehabilitation of former fish habitat areas, and reinstatement of tidal inundation in areas such as Hexham Swamp, Ash Island and Tomago Wetlands should enhance the fish resources of the Hunter estuary.

Loss of Habitat and Diversity

The degradation of habitat and loss of biodiversity within the Hunter River estuary is intrinsically linked to the ongoing settlement, urbanisation and development of the Hunter estuary catchment (MacDonald 2001). In the upper estuary, forests have largely been cleared for timber, and converted to grazing land, with subsequent effects on biodiversity. Native riparian vegetation is in poor condition, resulting in impacts upon bank stability, but also reducing its potential use for faunal habitat corridors.

In the lower estuary, land clearing and reclamation for urban and industrial areas and port facilities have also reduced habitat cover and diversity. Restriction of tidal inundation has severely impacted upon estuarine habitats, resulting in the conversion of saltmarsh and mangrove areas to monospecific fresh/brackish wetlands. Reduction of habitat diversity has had subsequent effects on biodiversity in the area. Incursion of mangroves into saltmarsh and bare sandy habitats also has the potential to reduce habitat diversity. However the processes leading to the increase in mangrove extent are not well understood. Introduced species also affect the faunal diversity of the area, although lack of data regarding native and non-native species creates difficulties in assessing changes.

Conclusions

A number of issues of concern for the Hunter estuary were raised by the Hunter Coast and Estuary Management Committee and the community, and these issues were addressed as part of the Hunter Estuary Processes Study, including information gaps and future management considerations, and these are summarised in the table below.

Issue	Information Gaps	Solutions
Loss of Habitat	• lack of data about effects of habitat loss on aquatic and terrestrial flora and fauna species	• monitor remediation plans in place (e.g. Wallis Creek and Ironbark Creek floodgate openings) • incorporate detailed mapping already available. Central body required to co-ordinate regular updates once mapping has been revised. • remediation plans for loss of riparian vegetation and decreasing sediment input through integration with management plans such as Hunter Blueprint
Port operations	• lack of data about effects of dredging on marine biota and fish migration • impacts of proposed development unknown	• impacts on natural environment need to be thoroughly investigated through the EIS process
Erosion	• further information required on major sediment sources within the Hunter River catchment	• erosion control at catchment level to minimise the issue. Integrate remediation plans with Hunter Blueprint
Flooding	• effects of options for altering current flood mitigation structures	• utilise modelling to investigate options for altering current flood mitigation structures

Issue	Information Gaps	Solutions
Water Quality	• lack of data about the extent of impact of sediment flows from building sites into the estuary system • lack of information regarding extraction rates for irrigation, and impacts on the estuarine system • lack of information regarding groundwater quality and flow, and influence on wetlands.	• control of pollution at sources e.g. stormwater retention • adoption and enforcement of sedimentation and erosion controls in a planned manner between councils • undertake monitoring of water extraction in the Hunter catchment to improve understanding of impacts • undertake monitoring of groundwater quality and flow in the Hunter catchment to improve understanding of impacts on estuary.
Sand and Gravel Extraction	• lack of accurate data about quantities that are being extracted • lack of understanding about the effects of sand and gravel extraction on the natural environment	• monitor quantities of sand and gravel extraction • study the changes to the natural environment (e.g. habitats, diversity) in the vicinity of extraction activities • remediation works for riparian zone
Recreational	• lack of information about the effects of recreational activities on the natural environment • lack of information about the types of recreational activities and when and where they take place	• a recreational fishing survey is currently being undertaken. Review outcomes of study during management study
Heritage	• further information on areas of Aboriginal significance required from local Aboriginal groups..	• co-ordinate input from local Aboriginal groups
Fishing	• sustainability of fishery is uncertain • impacts of fishing on roosting sites unknown	• remediation of fish nursery habitats e.g. Hexham Swamp, Kooragang Island • investigate impacts of fishing on roosting sites in lower estuary in order to determine possible hotspots
Acid sulfate soils	• lack of research on occurrence of acid sulfate soils in the Hunter estuary catchment	• identification of priority areas for potential acid sulfate soils and implementation of development controls protect these areas
Climate change	• lack of knowledge regarding impacts of climate change on local conditions	• investigate local impacts of climate change and include as a consideration in planning, especially foreshore development

An important consideration for the future management study should be integration and incorporation with other management studies currently in place for the Hunter estuary and the broader Hunter River catchment, including the Integrated Catchment Management Plan for the Hunter Catchment (the Hunter ‘Blueprint’) and the Lower Hunter Valley Floodplain Management Study.

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List of Abbreviations

ABS	Australian Bureau of Statistics
AHD	Australian height datum
ANZECC	Australian and New Zealand Environment and Conservation Council
ANZSIC	Australian New Zealand Standard Industry Classification
ASS	acid sulfate soils
BHP	Broken Hill Proprietary
BOD	biological oxygen demand
BoM	Bureau of Meteorology
CBD	central business district
CMSS	catchment management support system
CSIRO	Commonwealth Scientific and Industrial Research Organisation
DIN	dissolved inorganic nitrogen
DLWC	Department of Land and Water Conservation (now Department of Infrastructure, Planning and Natural Resources (DIPNR))
DO	dissolved oxygen
DPWS	Department of Public Works and Services (formerly PWD) (now Department of Commerce)
EIS	Environmental Impact Statement
ENSO	El Niño Southern Oscillation
EPA	Environment Protection Authority
GIS	geographic information system
HCEMC	Hunter Coast and Estuary Management Committee
HCMT	Hunter Catchment Management Trust
HRC	Healthy Rivers Commission
HRSTS	Hunter River Salinity Trading Scheme
HSRP	Hexham Swamp Rehabilitation Project
HWC	Hunter Water Corporation
IPCC	International Panel on Climate Change
KWRP	Kooragang Wetland Rehabilitation Project
LEP	Local Environmental Plan
LGA	Local Government Area
LHCCREMS	Lower Hunter Central Coast Regional Environmental Strategy
MCC	Maitland City Council
MHL	Manly Hydraulics Laboratory
N	nitrogen
NCC	Newcastle City Council
NH_3	ammonia
NO_x	oxidised nitrogen
NPC	Newcastle Port Corporation
NPWS	National Parks and Wildlife Service (NSW)
P	phosphorus
PAR	photosynthetically active radiation

PASS	potential acid sulfate soils
PSC	Port Stephens Council
PWD	Public Works Department
SEPP	State Environmental Planning Policy
SHI	State Heritage Inventory
SHR	State Heritage Register
SMP	Stormwater Management Plan
SOI	Southern Oscillation Index
SRP	soluble reactive phosphorus
STP	sewage treatment plant
TEL	The Ecology Lab Pty Ltd
TN	total nitrogen
TP	total phosphorus
WWTP	wastewater treatment plant

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1. Introduction

1.1 Background

The Hunter River estuary is typical of the larger NSW estuaries that have evolved over the millennia through various climatic periods and sea level variations to the present day. The Hunter River forms a mature barrier estuary, with high sediment loads leading to the development of a sinuous river channel discharging directly into the ocean. The estuary lies at the confluence of the Hunter River, Paterson and Williams rivers, Wallis and Fishery creeks, Ironbark, Throsby, Styx and Cottage creeks. The total waterway area of the estuary is approximately 26 km^2.

The Hunter River catchment is one of the largest in NSW and reaches further inland than any other catchment, covering an area of approximately 22,000 km^2. The Hunter catchment is bound by the Liverpool Range, Mount Royal Range and Barrington Tops to the north, and the Hunter Range to the south (Figure 1.1). Major tributaries of the Hunter River catchment include the Goulburn River, Wollombi Brook, Merriwa River, Paterson and Allyn rivers, and Williams River. Originating in the Mount Royal Range, the Hunter River is approximately 300 km long, and enters the sea at the port of Newcastle (Figure 1.1). Newcastle, which is a major coal exporting port, is NSW's second largest city, with a population of around 135,000. The tidal limit in the Hunter River occurs in the vicinity of Oakhampton, approximately 65 km from the ocean.

The Paterson and Williams rivers together with the Allyn River drain an area of 2,230 km^2 to the north of the catchment, including the Barrington Tops which receive some of the heaviest rainfall for the Hunter River catchment (Figure 1.1). The tidal limit of the Paterson River extends to Gostwyck, approximately 75 km from the ocean. The Paterson River channel is typically narrow and shallow. Seaham Weir prematurely limits the tidal influence on the Williams River, approximately 47 km from the ocean.

Wallis and Fishery creeks drain an area of approximately 404 km^2 area in the upper estuary, and enter the Hunter River 3 km downstream of Maitland. The catchment incorporates rural, forested and urban areas. The channels are typically narrow and shallow, with steep levee banks, and tidal exchange in the creeks is affected by a floodgate at Wallis Creek. The tidal limit on Wallis Creek extends close to Cliftleigh approximately 68 km from the ocean. The tidal limit on Fishery Creek extends to Louth Park approximately 65 km from the ocean.

Ironbark Creek drains an area of 125 km^2 in the lower Hunter estuary, which includes urban, rural, forested land and wetland, in particular Hexham Swamp (Figure 1.2). Tidal exchange in Ironbark Creek is affected by the construction of a floodgate near the mouth of the creek. The channel is typically narrow, reaching its tidal limit near Wallsend where the creek has been converted to a concrete drain, approximately 20 km from the ocean.

Throsby, Styx and Cottage creeks drain the large urban and industrial areas of Newcastle (Figure 1.2), with a combined catchment area of approximately 48 km^2, entering into Throsby Basin and Newcastle port. Throsby Creek is a concrete canal upstream of Hannell Street bridge, and the tidal limit extends to approximately Mayfield, 8.5 km from the river entrance. Styx and Cottage creeks are both open concrete drains their entire length. The tidal limit on Styx Creek extends approximately to Hamilton in Newcastle 8 km from the ocean, and the tidal limit of Cottage Creek extends to The Junction (5.5 km from the ocean).

1.2 Scope of Study

The New South Wales Estuary Management Policy was developed to encourage the integrated, balanced, responsible and ecologically sustainable use of the State's estuaries. The policy is designed to reflect and promote co-operation between the State Government, local government, catchment management committees, landholders and estuary users in the development and implementation of estuary management plans for each estuary.

To assist in the development of estuary management plans, an Estuary Management Manual (NSW Government 1992) was published to outline the processes of implementation. Essentially, the process consists of eight steps. These steps are:

1) form an estuary management committee
2) assess existing data
3) carry out estuary processes study
4) carry out estuary management study
5) draft estuary management plan
6) review estuary management plan
7) adopt and implement estuary management plan, and
8) monitor and review management process.

In 1997 Newcastle City Council convened the Hunter Estuary Management Committee and amalgamated that committee with the established Hunter Coastal Management Committee, to form the Hunter Coast and Estuary Management Committee (HCEMC). The committee has broad representation from state government agencies, local government, management authorities, land owners, commercial and recreational interests and community representation. The charter of the committee is to identify the major issues affecting the estuary and then to proceed to preparation of a Management Plan to address any identified problems.

In 1999 the committee finalised the preparation of the data compilation study for the Hunter Estuary (DLWC 1999). This data compilation study was prepared in accordance with the NSW Government Estuary Management Manual (1992). The report presented an assessment of the existing literature pertaining to the Hunter estuary and a preliminary assessment of the issues which will need to be addressed in the Estuary Management Plan.

This estuary processes study represents the third step towards the implementation of an estuary management plan for the Hunter estuary.

As defined in the brief, the study area essentially comprises the Hunter River and its tributaries to their tidal limits, wetlands, foreshores and adjacent lands (Figure 1.2). Tributaries of the estuary include the Paterson and Williams rivers, Wallis and Fishery creeks, Ironbark Creek, and Throsby, Styx and Cottage creeks.

1.3 Study Objectives

Stated simply, the main objective of the estuary processes study is to identify and describe the cause and effect relationship that determines the ecological structure and function of the system. The study objectives as identified in the consultant's brief are to:

1. Identify and document the physical, chemical and biological condition of the estuary and related processes and interactions through investigation and data collection.
2. Define a baseline condition of the estuarine processes and interactions on which management decisions can be made.
3. Identify and document the historical and contemporary natural attributes of the estuary through research, investigation and data collection.
4. Identify and document the roles, frameworks and relationships of relevant management authorities and identify any information data gaps and areas of overlap relevant to the estuary.
5. Review existing and strategic land use activities that have the potential to impact on the management needs of the estuary.

1.4 Issues

The major issues concerning the community were derived from the Hunter Estuary Data Compilation Report (DLWC 1999), based on outcomes from a workshop attended by the community and local and state government agencies and special interest groups. The major issues detailed in the study brief are reproduced in Table 1.1.

Table 1.1 Hunter Estuary Issues Identified by the Community

Issue	Pressure
Loss of Habitat	• Restriction of tidal inundation to estuarine wetlands. • Loss of estuarine environment, loss of biodiversity. • Protection of foreshore aquatic vegetation such as mangroves by physical means and public education.
Environmental	• Introduction of exotic marine organisms into the marine environment through ballast water . • Impacts of dredging of the harbour for maintenance of waterways and port-related development.
Erosion	• Severe bank erosion due to floods along the river and its tributaries which probably contributes to sedimentation in the port of Newcastle.
Flooding	• Stormwater and floodplain management issues. • Lower levees to allow sediment access to floodplains.
Pollution	• Build-up of contaminated sediments along the south arm of the Hunter River.

Issue	Pressure
Water Quality	• Sedimentation at stormwater outlets due to non-compliance with sediment and water quality controls in existing and new developments.
Water Quality	• Poor water quality from pollutants including solid matter, sediments, nutrients, and possible leachate from garbage dump fill sites. Water quality vulnerable due to extent of industry, agriculture and urban development along the river. Stormwater contributing to deteriorated water quality of the estuary. • Wet weather flow from sewerage system overflows; extent and impact of unsewered properties. • High salinity in the Hunter River from discharges from coal mining and water demand from electricity generation. • Impact of flood mitigation structures on the shallowing of navigation areas and bays.
Sand and Gravel Extraction	• Overall plan of management required to optimise resource utilisation in a manner compatible with river stability requirements.
Recreational	• Conflicts between recreational boating and commercial activities and interaction with the natural environment. • Opportunities for improved and more efficient use of public reserves around the river foreshore. • Opportunities for recreational fishing in the estuary. • Safety of public using the river.
Heritage	• Identification of heritage structures and other visually significant features.
Fishing	• Conflicts between use of the estuary for commercial fishing and the natural environment. • Maintenance or improvement of fish and prawn production. • Introduction of obstacles to fish passage (including floodgates, low level road crossings and culverts).

A targeted stakeholders meeting held in July 2001 highlighted many of the issues included in Table 1.1. Additional issues not identified in Table 1.1 included:

- Acid discharge from old mines may have significant effect on water quality, particularly in Wallis and Fishery creeks.
- Concern over possible dredging of the north arm for a new development at Tomago.

The basic methodology employed for the estuary processes study was to address the identified problems within the context of the estuary processes, and as such, the processes study did not concentrate solely on the major issues.

Two significant factors in a number of the above issues are land use changes as a result of European settlement, and the impact of flooding on human assets, resulting in the construction of extensive flood mitigation structures throughout the estuary. Land use changes and flood mitigation structures affect flood behaviour, but also impact upon habitat and biodiversity, erosion and sedimentation, contaminated sediments, water quality and dredging.

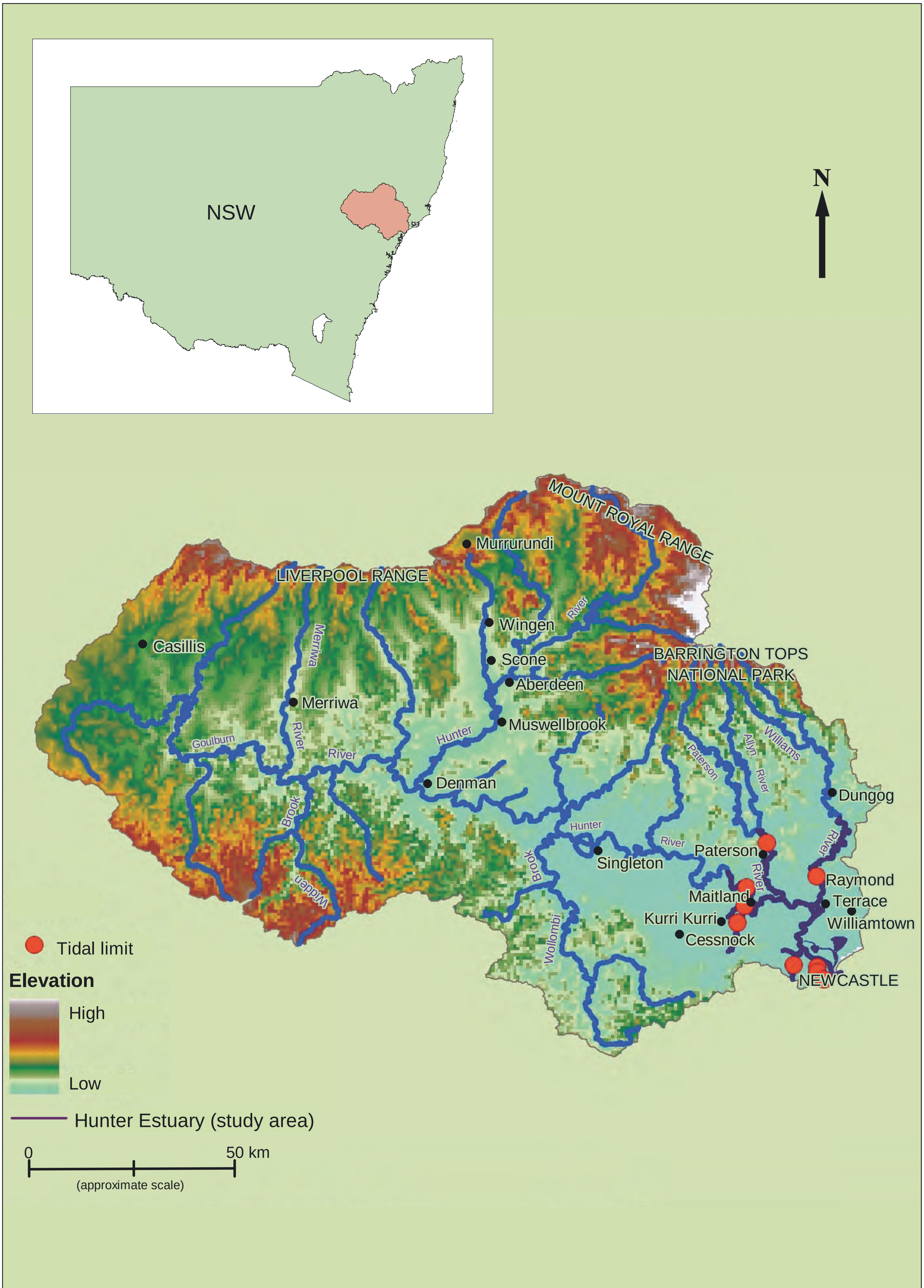
1.5 Study Approach and Methodology

The study methods adopted were consistent with the process outline in the NSW Estuary Management Manual (NSW Government 1992) and the study brief. Briefings were provided to the committee during the investigation which allowed review and exchange of ideas between the study team and the committee.

Given the size of the system, the emphasis within the estuary processes study has been to draw together all available information pertaining to the estuary rather than attempting detailed modelling of specific processes or comprehensive field data collection. The methodology employed relied on the interpretation of the extensive existing data with targeted field data collection to adequately address the specific issues identified. Specialist sub-consultants were employed to undertake specific aspects of the investigation, and some of these specialist investigations involved additional fieldwork. The major findings and conclusions are incorporated within this report, although the findings of their studies are reported separately and these reports also constitute part of the final documentation for the project. For more detail, the reader is referred to the following technical reports:

- *Geology and Soils of the Hunter Catchment, and Evolution and Sedimentation of the Hunter Estuary* (Boyd 2001).
- *The Terrestrial Ecology of the Hunter River* (MacDonald 2001).
- *Hunter Estuary Process Study – Aquatic Ecology* (TEL 2001).
- *Hunter River Estuary Water Quality Data Review and Analysis* (Sanderson & Redden 2001a).
- *Salinity Structure of the Hunter River Estuary* (Sanderson & Redden 2001b).
- *Characteristics of the Hunter Estuary and Catchment* (MHL2002).

Considerable effort was involved in the creation of a water quality database which included data collected by a number of agencies over the past 30 years for 25 different water quality variables. This database then enabled spatial and temporal interpretation of the water quality of the system. Fieldwork undertaken by Manly Hydraulics Laboratory and The Ecology Lab targeted issues relating to bank stability, riparian vegetation and recreational uses of the estuary and foreshore. An additional component of the study has been the collation of an extensive GIS data set that has been used to create the majority of the figures provided in this report.



NSW DEPARTMENT OF PUBLIC WORKS AND SERVICES
MANLY HYDRAULICS LABORATORY

HUNTER RIVER CATCHMENT

MHL Report 1095

Figure 1.1

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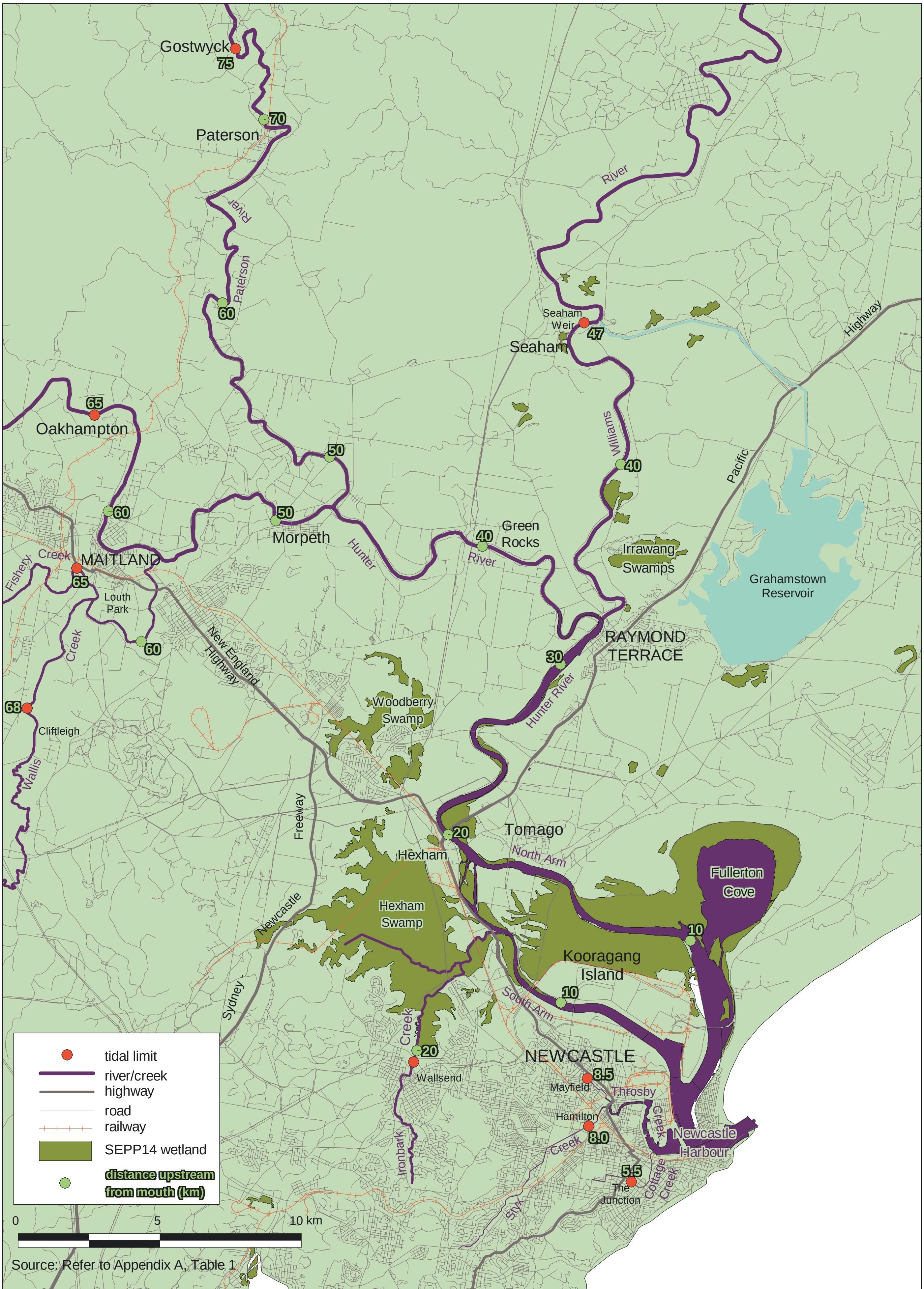

NSW DEPARTMENT OF PUBLIC WORKS AND SERVICES
MANLY HYDRAULICS LABORATORY

HUNTER ESTUARY STUDY AREA

MHL Report 1095

Figure 1.2

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2. Regional Setting

2.1 Climate

The prevailing climate of the Hunter River estuary is warm and temperate, with a maritime influence. Summers are warm to hot and humid, winters are cold to mild.

Climatic changes and weather-driven processes contribute greatly to the nature of the Hunter estuary ecosystem, and hence, weather and climate variability are important to the interpretation of natural versus anthropogenic changes in ecosystem variables.

Weather and climate impact upon hydrodynamic processes, geological and geomorphological processes, and ecological processes, and are therefore important forcing factors driving many of the estuarine processes.

2.1.1 Rainfall

Rainfall is recorded at a number of MHL and BoM sites across the Hunter River catchment. Rainfall varies considerably across the catchment with the highest values near the coast at Newcastle, in the north-east of the Hunter River catchment (Chichester Dam) and in elevated areas such as Barrington Tops (see Table 2.1 for rainfall data and Figures 1.1 and 2.1 for locations). Lower values are recorded inland at Cassilis and at Singleton (www.bom.gov.au). Overall, mean annual rainfall in the coastal range of the Hunter River catchment is almost twice that of the drier regions in the west (Hydrotechnology 1995).

Table 2.1 Mean Annual Rainfall in the Hunter Catchment

Station Location (lat., long.)	Maintained by	Years of Data	Mean Annual Rainfall (mm p.a.)
Belmore (32.43S, 151.33E)	MHL	5.5	735.2
Chichester Dam (32.24S, 151.68E)	BoM	58	1324.5
Gostwyck (32.34S, 151.36E)	MHL	1.5	881.5
Hexham (32.39S, 151.41E)	MHL	3	951.25
Murrurundi Post Office (31.77S, 150.84E)	BoM	130	828.8
Newcastle Nobbys Signal Station (32.92S, 151.80E)	BoM	138	1143.8
Paterson (Tocal) (32.63S, 151.59E)	BoM	33	913.5
Seaham (32.40S, 151.44E)	MHL	1.5	838.5
Singleton Army (32.61S, 151.17E)	BoM	21	723.7

The Southern Oscillation Index (SOI) gives an indication of whether a year was particularly wet or dry. The annual SOI is plotted for 1990 to 2001 in Figure 2.2. Negative values indicate drier than average years and positive indicate wetter years. Sustained values lower than –10 indicate an El Niño Southern Oscillation (ENSO) event which is usually associated with dry weather across northern and eastern Australia. It can be seen that major ENSO events have occurred in 1991-92, 1992-93, 1993-94, 1994-95 and 1997-98 and that on average 1998 to 2001 have been wetter than average years.

Rainfall across a catchment is a significant variable affecting the estuary as it determines the amount of freshwater runoff to the estuarine system, recharge of groundwater aquifers, and flood and drought events. These fluvial inputs, along with tidal variations, determine the water level in the estuary. Water levels impact on the availability of land for various uses, both natural and human-related, and also define the limits to estuarine habitats such as mangroves, saltmarshes and wetlands. The proportion of freshwater inflow relative to tidal inflow influences the salinity of the estuary and the hydrodynamics through the formation and breakdown of salt wedges. In combination with land use, vegetation, geology and topography, rainfall can also be a factor affecting erosion and the input of sediment to the estuarine system, as its direct impact can loosen and entrain soil.

2.1.2 Temperature

Temperatures vary across the catchment depending on the local incidence of sea breezes and elevation above sea level. At Newcastle temperatures are generally mild to warm, with a mean summer maximum of 25°C (winter 17°C) and a mean summer minimum of 19°C (winter 9°C).

Temperature is an important variable affecting estuarine processes due primarily to its role in ecological processes and functioning. Air and water temperatures are a significant factor in defining habitat for estuarine fauna and flora, as temperature affects metabolic processes as well as the seasonal trends of behaviour such as migration and spawning in fishes. Air temperature generally only heats the surface layers of the water, and thus has a role in the development of stratification in estuarine waters. Warmer waters have less capacity for dissolved oxygen and thus shallow, stagnant water can become deoxygenated and a stressful habitat for estuarine fauna. If air temperatures are sufficiently high and are combined with poor mixing of the water column, the surface layers of deeper water can also become low in oxygen.

2.1.3 Wind

Wind can play an important role in the circulation and mixing of estuarine waters, especially in systems where tidal flows are restricted. Summer wind speed and direction in the Hunter region is predominantly from the east and north-east, with westerly winds dominating in winter. Strong winds occur in the lower Hunter region occasionally as a result of strong easterly winds associated with deep depressions (ex-tropical cyclones) centred off the coast north of the catchment generating winds of over 95 km/h. Other causes may be strong gusts (up to 170 km/h, BoM) associated with local storms (Water Conservation and Irrigation Commission 1966).

2.1.4 Evaporation

Evaporation is an important component of temperate climate areas, with high values in summer and lower values in winter. Evaporation is higher inland as expected, ranging from 750 to 1,000 mm p.a. in the north-east of the catchment to 1,250 to 1,500 mm p.a. in the west (DLWC 2000). Values calculated in 1966 for the Hunter and Karuah catchments indicate a rate of 1,092 mm p.a. (Water Conservation and Irrigation Commission 1966).

Evaporation can affect estuarine water levels and salinity, especially in the upper reaches where tidal effects are reduced. If rainfall is low and temperatures high, then evaporation of fresh water can increase the salt content of the water quite significantly.

2.1.5 Solar Radiation

Solar radiation forms an important contribution to the estuary processes in two ways; as a source of heat influencing the thermal stratification in the river and as a source of sunlight for photosynthesising aquatic plants and algae (e.g. phytoplankton).

As sunlight enters the earth's atmosphere it is affected by the atmosphere in a number of ways. The Bureau of Meteorology provides daily estimates of the Global Solar Exposure at the earth's surface derived from satellite images. Data for 1998-2001 are shown in Figure 2.3 and indicate the seasonal cycle and also daily variations associated with cloudy and clear days.

2.1.6 Implications of Climate Change

Over the next 100 years the global mean temperature and sea level are expected to rise due to an increased 'greenhouse effect'. The greenhouse effect is a predicted global warming associated with the build-up of certain gases in the atmosphere. Greenhouse gases are essentially transparent to incoming short-wave solar radiation, but they absorb the longer wavelength infrared radiation (heat) emitted by the earth. Thus heat is trapped in the atmosphere and the global temperature is increased.

The most up-to-date estimates of temperature and sea level rise are those provided by the International Panel on Climate Change (IPCC). In the third assessment report of 2001 (Albritton et al. 2001), the IPCC predicts an increase of global averaged surface temperature of 1.4 to 5.8°C over the period 1990 to 2100. The range is due largely to uncertainty in the amounts of greenhouse gases which nations will emit and the use of a variety of different climate models. The projected temperature increases are higher and display a wider range than those in the IPCC second assessment report of 1995 (Houghton et al. 1996). Since then a greater understanding of climate change has developed due to improved data analysis and modelling techniques.

'Global warming' is associated with sea level rise as a result of thermal expansion of the oceans and melting of glaciers and ice sheets. Despite higher temperature change projections in the IPCC third assessment report, the sea level rise projections are slightly lower compared to earlier assessments. This is due to improved models that give a smaller contribution from glaciers and ice sheets. The latest projected global mean sea level rise is 0.09 to 0.88 m between 1990 and 2100 (Albritton et al. 2001).

The CSIRO Atmospheric Research Division has produced maps showing predicted changes to average climate conditions across Australia based on the IPCC predictions (CSIRO 2001). These show the ranges of change predicted for temperature and rainfall by around 2030 and 2070 relative to 1990. Table 2.2 summarises the predictions for the region that includes the Hunter Valley. This shows that average temperatures are likely to rise across all seasons, while average rainfall is predicted to be higher in summer and lower in winter, relative to average 1990 conditions.

The CSIRO report also states that there is likely to be an increase in extreme daily rainfall leading to more frequent heavy rainfall events (CSIRO 2001). These increases are likely to be associated with increased flooding, and can occur even where average rainfall is predicted to decrease. Evaporation is likely to increase, as is the deficit in annual net moisture balance that Australia generally experiences (CSIRO 2001).

Table 2.2 Predicted Average Seasonal and Annual Changes in Temperature and Rainfall Relative to 1990
(CSIRO 2001)

Variable	**Range of predicted change by**	
	2030	**2070**
Temperature (°C)		
Annual	0.3 - 2.0	1.0 - 6.0
Summer	0.3 - 2.0	1.0 - 6.0
Autumn	0.3 - 1.6	0.8 - 5.2
Winter	0.3 - 1.6	0.8 - 5.2
Spring	0.3 - 2.0	1.0 - 6.0
Rainfall		
Annual	-12% to +12%	-35% to +12%
Summer	-5% to +10%	-10% to +35%
Autumn	-15% to +15%	-35% to +35%
Winter	-12% to +12%	-35% to +12%
Spring	-12% to +12%	-35% to +12%

Sea level rise will directly affect tide (and storm surge) levels, with a corresponding increase in inundation levels and the extent of wave runup at the shoreline. Generally, it is believed that water depths and shoaling patterns will remain unaffected as the change in mean sea level will occur over an extended time period and shoals and channels will slowly adjust. Isolated problems relating to channel realignment and shoaling could be anticipated. The increase in water levels will, however, affect such things as clearance under bridges, the height and effectiveness of seawalls and levees and the operation of foreshore facilities such as wharves, jetties and stormwater outlets (MHL 1999). In addition wetland areas are also likely to be affected by longer periods of inundation and landward expansion where sufficient low-lying lands adjacent to wetlands exist.

2.2 Geology and Geomorphology

The geology of the Hunter Valley is complex and contrasting, because it lies at the boundary of three major tectonic provinces: the New England Fold Belt, Sydney Basin and Eastern Australian Passive Margin. The New England Fold Belt occurs in the north-eastern margin of the Hunter Valley, running from Murrurundi to Maitland. The rocks in this province are Devonian, Carboniferous and Permian (Figure 2.4) The types of rocks in the New England Fold Belt are mostly sediments (sandstone, shale, conglomerate and glacial deposits) and volcanics. The Sydney Basin makes up the central and southern portion of the Hunter Valley catchment, and the rocks are mostly Permian and Triassic in age. In the Sydney Basin the same types of rocks can be found as the New England Fold Belt, in addition to coal measures. The Eastern Australian Passive Margin occurs in the northern margin of the Hunter Valley. The rocks in this region consist mostly of sub-aerial lava field flows of alkali basalts (Boyd 2001).

The general positions of rivers that flow south through the New England Fold Belt from the Barrington Tops are controlled by a series of approximately north-south oriented folds and faults generated by early deformation in the New England Fold Belt of Carboniferous age. The rocks of the New England Fold Belt are largely resistant to erosion and make up the comparatively coarse topography between Dungog and Murrurundi. The soft rocks of the Sydney Basin coal measures represent more easily eroded rocks that provide the location of the modern Hunter River course in the middle and lower reaches of the valley. The sandstones which occur along the southern margin of the Hunter Valley are more resistant to erosion and form the sandstone plateaus and escarpments such as those of Wollombi Brook, Widden Brook and the Bylong River (Boyd 2001).

The local geology surrounding and underlying the Hunter estuary provides a control on sediment supply and evolution of the estuary. The Hunter estuary is primarily located on the less resistant Tomago Coal Measures, subcropping between Mayfield, Sandgate and Black Hill in the south, and Raymond Terrace and Port Stephens in the north. The boundaries of the estuary are made up of Carboniferous volcanics and sediments to the north around Port Stephens, Raymond Terrace and Seaham (Figure 2.5). To the south the boundary is made up of Permian sediments, particularly the Waratah Sandstone and conglomerates of the Newcastle Coal Measures, and Triassic sandstones in the Mount Sugarloaf and Cessnock areas. The folds and faults that cut across the Hunter River in a north-south direction are responsible for the termination of the estuary due to encountering the resistant rocks of the Lochinvar Anticline upstream from Maitland.

2.2.1 Stratigraphic Evolution and Depositional Environments

The stratigraphic evolution of the Hunter region is complex. The depositional histories and evolution across the entire study site area function of the same dominant processes, and therefore a consistent chronology can be identified. In the following discussion the generalised stratigraphy and evolution for the Hunter estuary is described.

Three major cycles of sediment fill in the Hunter Valley occurred during the Tertiary (> 1.8 million years Before Present), Pleistocene (>140,000 years Before Present) and Holocene (10,000 years Before Present to present). The Tertiary cycle resulted in a basal sediment fill in the estuary that is around 30 m thick at the coastline and extends landward as far as Tomago. This sediment consists mainly of floodplain mud and fluvial sand and gravel. The Holocene fill occupies the majority of the current estuary land surface, and can be seen in the Holocene swamps and floodplain (Figure 2.6). The Pleistocene was laid down in an earlier cycle of deposition at previous high sea level stands in much the same estuarine environments as the present Holocene estuary, and in much the same geographical distribution as the Holocene fill. However, the Pleistocene fill has since been partially eroded by the rivers incising at low sea levels and subsequently buried by the later Holocene fill. Hence the Pleistocene is present only as a remnant in the subsurface through much of the estuary. Pleistocene sediments are present at the surface at the inner barrier, and as terrace deposits around the margins of the former estuary near Largs, Morpeth and Hinton (Figure 2.6).

The Holocene sediment fill in the Hunter estuary can be divided into three main groups: marine fill, central basin fill and bay head delta/fluvial fill. The marine fill primarily consists of marine sand of quartz, shell and heavy mineral composition deposited in coastal barriers (beaches and dunes) and flood tidal delta complexes. These flood tidal deltas reach as far inland as Hexham in the subsurface (Figure 2.6). The coastal barriers consist of the beach, dunes and beach ridges between Stockton and Port Stephens. The central basin fill is primarily fine-grained mud supplied to the estuary by the river when the estuary was still open water. It currently is accumulating mostly in the lower estuary in areas such as Fullerton Cove, but previously occupied the majority of the estuary as far upstream as the tidal limit (e.g. at the Belmore Bridge - Paterson Britton Partners 1995). The bay head delta is the complex of sandy channels and bars formed as the river progrades into the open water body of the estuary. This is best shown at present by the upper Kooragang Island area and what was previously the Newcastle Steelworks site and down as far as Carrington. The fluvial fill consists of river channels, point bars and floodplains accumulated on top of the estuary after the estuary water body has been filled. This environment is best developed now in the upper estuary in the Morpeth-Maitland-Largs area but has extended over the former estuary as far seaward as the Hexham Swamp and Kooragang Island.

Boyd (2001) detailed eight stages in the Tertiary–Quaternary evolution of the region. The dominant processes resulting in the generalised stratigraphic sequences shown in Figure 2.6 are summarised below.

Stage 1 Tertiary (> 1.8 million years Before Present)
The early history of the Hunter estuary consists of the establishment of a drainage basin on the newly formed south-eastern Australian passive margin, and the erosion of a bedrock valley, delivering sediments to the bottom of the Tasman Sea, and later to the subsiding continental shelf.

Stage 2 Pleistocene (prior to 120,000 years Before Present)
Little record remains of the interval between the Tertiary and the Late Quaternary. In general, there were many sea level cycles that took place in this interval, but later cycles have removed most of their history. The lithology here consists of coarse fluvial gravels, and estuarine central basin clays, with dates indicating deposition in the interval 180-240,000 year BP. Most of this material lies in the base of the current valley, whose axis runs from Maitland through Tomago and crosses the coast at Williamtown (Figure 2.7).

Stage 3 Pleistocene (around 120,000 years Before Present)
Pleistocene high sea level stand up to approximately 4 m above the present sea level. The shoreline transgressed back into the estuary at this time, depositing a thick central basin estuarine mud deposit. The shoreline stabilised forming the Inner Barrier. In doing so it impounded a number of small valleys creating wetlands at Moffats Swamp and

Grahamstown. A fall in sea level saw the estuary change back to a river valley. The river course was forced south of its earlier course through Tomago and flowed around the inner barrier at Hexham prior to flowing east across the exposed continental shelf (Figure 2.7).

Stage 4 Pleistocene (around 85,000 years Before Present)
Melting ice sheets saw another rise in sea level around 85,000 years BP resulting in another shoreline transgression and the establishment of an outer barrier shoreline. Sediment availability saw progradation of this shoreline to form a beach ridge/shoreface system under falling sea level after 85,000 years BP (Figure 2.8).

Stage 5 Pleistocene (85,000 to 10, 000 years Before Present)
Sea level remained relatively low and the shoreline and estuarine environment was absent from the Hunter estuary, which existed as a river valley. The river eroded down over this 75,000 year period to generate a new valley inside the previous one, and to remove much of the earlier deposition. The river continued to be forced south around the Inner Barrier at Hexham (Figure 2.8).

Stage 6 Holocene (10,000 to 6,500 years Before Present)
Sea levels rose towards its present location during this time, and the shoreline migrated landward from 40 km further out on the shelf. The lower Hunter Valley changed from a river valley to an estuary around 10,000 years BP when the sea first penetrated back up the valley. The ocean filled the eroded river valley, and formed an extensive open water body estuary as far landward as Maitland, Paterson and Seaham. Rivers and bay head deltas migrated landward back up the valley during this transgression The majority of the estuary infilling occurred during this interval (Figure 2.8).

Stage 7 Holocene (6,500 to 3,000 years Before Present)
This phase recorded the transition from open water body to land over much of the estuary, primarily by progradation of the Hunter, Paterson and Williams rivers bay head deltas and associated fluvial deposits. These bay head deltas prograded from the tidal limits near Maitland, Paterson and Seaham, to a position near the upper part of Kooragang Island (Figure 2.8) (Boyd 2001).

Stage 8 Holocene (3000 years Before Present to present)
In this final stage the estuary moved to its present configuration. The bay head delta established itself into Newcastle harbour, the upper estuary was transformed into an alluvial plain with river channels meandering and migrating across the former estuary surface and aggrading a floodplain and levee system adjacent to the channels. Present day Fullerton Cove shoreline has migrated inward, water depths have diminished and the margins of the channels upstream from the Stockton Bridge have developed subtidal and intertidal flats. The steelworks channel has largely infilled upstream of the BHP site. Newcastle harbour requires continuous dredging to maintain a standard channel depth. Upstream, the river has occupied a variety of meandering courses between Maitland and Morpeth. Accumulation of levees adjacent to the major channel results in smaller catchments being dammed and turned into wetlands. Examples of this occur at Irrawang Swamp and Hexham Swamp (Figure 2.8) (Boyd 2001).

2.3 Topography

The topography of the estuary sub-catchment is highly variable, from the coastal plains and associated lowlands in the east, to the steep Paterson Mountains and Sugarloaf Range in the west (Figure 2.9). The Lower Hunter Plain and Tomago Coastal Plain cover much of the study area and consist of low-lying Quaternary deposits, with slopes of 0-2%. The level land increases to slopes of 2-10% in the lowland areas such as Medowie Lowlands and the foothills of the East Maitland Hills. The steepest slopes in the sub-catchment (slopes 20-50%) occur in the Paterson Mountains, Clarence Town Hills and Sugarloaf Range.

2.4 Soils

2.4.1 Soils of the Hunter Catchment and Estuary

The soils of the Hunter Valley (Figure 2.10), like the geology, are a complex grouping of multiple types, reflecting the diversity of geological parent material, variations in climate, geomorphology, organisms and time. In low rainfall parts of the Hunter Valley soils with alkaline horizons are common, but in higher rainfall parts the soils are characteristically more strongly leached, and are acid throughout the profile. Most of the soil landscapes of the Hunter Valley catchment have a moderate to high erodability factor based on soil properties.

The Hunter estuary makes up a distinctive subset of the catchment and is dominated by alluvial, estuarine and coastal soil types, surrounded by low topography of predominantly Permian bedrock (Boyd 2001). Soils of the southern margin of the Hunter estuary include yellow and brown podsolic soils and soloths, and moderately well drained yellow and red podsolic soils and soloths (Boyd 2001). In the upper part of the estuary common soils include deep prairie soils, brown clays, chernozerms, with alluvial soils and siliceous sands on river point bars and river banks. Soils of the coastal area including Tomago Coastal Plain consist of beach and aeolian soils. In the lower estuary in the vicinity of the river channel, deep poorly drained Prairie soils occur, with humic gleys in the low-lying swampy plains, while Solonchaks are present in mangrove and saltmarsh flats (Boyd 2001).

2.4.2 Soil Landscapes of the Estuary

A detailed description of the soil landscapes for the study area is provided in Matthei (1995) *Soil Landscapes of the Newcastle 1:100,000 Sheet*. A simplified map of the soil landscapes of the study area is provided in Figure 2.11. Soil landscape groupings are determined by interpretation of landform/topography, soil material and soil parent material features. This concept integrates soil and topographic constraints into one unit so that an area may be viewed in terms of limitations for urban and rural development (Matthei 1995).

Soil landscape groupings that occur in the estuary sub-catchment area are:

- Estuarine
- Alluvial
- Swamp
- Erosional
- Residual
- Aeolian
- Colluvial
- Transferral
- Vestigial
- Disturbed

An overview of the soil landscapes of the Hunter estuary sub-catchment including an assessment of the likelihood of erosion is provided below.

Estuarine landscapes occur where rivers and streams enter large bodies of water such as the sea, and therefore soil materials may be influenced by saline conditions (Matthei 1995). Estuarine landscapes are found in areas of low elevation, and occur throughout the lower Hunter estuary and the Williams River to Seaham (Figure 2.11). The estuarine landscapes in areas such as Fullerton Cove and Kooragang Island are prone to wave erosion from boats (Matthei 1995).

Alluvial soil landscapes are formed by deposition along rivers and streams. They are often found on meander plains, point bars, levees, terraces, prior and current stream channels (Matthei 1995). Alluvial soil landscapes occur in large areas of the upper Hunter estuary along the floodplain and stream channel of the Hunter River, Paterson River and Wallis/Fishery creeks (Figure 2.11). These soils are susceptible to water erosion.

Swamp soil landscapes are dominated by ground surfaces that are at least seasonally water-logged (Matthei 1995). In the Hunter estuary this landscape occurs in the low-lying swamp areas such as Hexham, Woodberry and Eskdale (Figure 2.11).

Erosional soil landscapes are primarily formed from the erosive action of running water, and occur on steep to undulating hillslopes (Matthei 1995). Erosional landscapes dominate the northern region of the sub-catchment, including the East Maitland Hills, and in the southern region of the Awaba Hills, and may be susceptible to further erosion from water flow.

Residual landscapes are dominated by sites where deep soils have formed from in situ weathering of parent materials. Residual soil landscapes typically have level to undulating topography (Matthei 1995), as occurs in the Hunter estuary, where they are found on the lowland slopes such as East Maitland Hills and Awaba Hills in the south. Residual landscapes are prone to water erosion, particularly in areas with steeper slopes (greater than 10%, Matthei 1995).

Aeolian landscapes accumulate by deposition of sand-sized particles from wind action and form the extensive Tomago sandbeds of the Tomago Coastal Plain, and Stockton Beach (Figure 2.11). These landscapes are susceptible to wind erosion (Matthei 1995).

Colluvial landscapes form from mass movements such as landslides (Matthei 1995), and are therefore found in steeper areas such as Paterson Mountains and Clarence Town Hills in the north, and Sugarloaf Range in the south (Figure 2.11). Colluvial landscapes are susceptible to water erosion (Matthei 1995).

Transferral landscapes are deep deposits of mostly eroded parent materials washed from areas upslope (Matthei 1995) and are therefore found in areas of low slope classes, such as footslopes and undulating hills. Due to the nature of the formation of these landscapes, they are highly prone to water erosion. In the Hunter estuary transferral landscapes occur in small areas such as the lowland hills of the Paterson Mountain region in the north (Matthei 1995).

Vestigial soil landscapes occur where shallow soils have formed from in situ weathering of typically resistant parent materials (Matthei 1995). In the Hunter estuary sub-catchment this landscape occurs in a small area in the Paterson Mountains and Clarence Town Hills in the north of the catchment (Figure 10.3) on resistant Carboniferous sediments. These vestigial landscapes are highly susceptible to water erosion (Matthei 1995).

Disturbed soil landscapes are dominated by ground surfaces arising from human activity where soil parent material has been moved, accumulated or replaced (Matthei 1995). In the Hunter estuary disturbed landscapes occur on the reclaimed Kooragang Island, the city of Newcastle along the south arm of the Hunter River, and smaller areas around Hexham Swamp, Tomago and south of Maitland. The erosion hazard of these landscapes is highly variable and dependent on the site.

2.4.3 Acid Sulfate Soils

In recent times, acid sulfate soil (ASS) risk assessments have been carried out along the NSW coast, including the Hunter estuary. Factors inherent in this assessment are elevation and marine influence, where low-lying areas in combination with a tidal influence provide a suitable climate for the creation of ASS. As a consequence of this risk mapping, the bed of the Hunter River and much of the associated foreshores and tributaries have been classed as having a high probability of ASS occurrence.

2.5 Landforms

The relationships of geology and soil properties, and erosive forces of wind and water, have led to the evolution of landforms of the Hunter estuary (Figure 2.12). Major landforms of the Hunter estuary sub-catchment are the waterways, Lower Hunter and Tomago Coastal Plains, valleys (through which the Williams and Paterson rivers flow), low undulating hills, such as the East Maitland Hills, and hilly to steep slopes in the Paterson Mountains, Clarence Town Hills and Sugarloaf Range. The watercourse of the estuary is influenced by the underlying geology, forming a path through the weaker strata of the Permian coal measures. The floodplain of the estuary correlates with Quaternary deposits, and Alluvial, Estuarine, Aeolian and Swamp soil landscapes. Hilly to steep slopes are found in the northern margin of the sub-catchment, correlating with Carboniferous sediments extremely resistant to erosion (Sinclair Knight & Partners 1990).

2.6 Catchment Hydrology

The Hunter River catchment is the second largest coastal basin in NSW with a catchment area of approximately 22,000 km^2 (DLWC 2000). The catchment extends further inland than any other coastal catchment in NSW, a factor influencing river flows and flooding in the valley (NSW Public Works 1994). The tidal limit at Oakhampton defines the upper boundary of the lower Hunter Valley and the Hunter estuary.

Streamflow is primarily a function of the precipitation in the catchment and the movement of that water through the process of runoff from the surface, infiltration into the groundwater, and seepage and spring flow from the groundwater. Human activities alter the natural streamflow, directly through the pumping of water from streams and connected aquifers and regulating flow by operating dams, and indirectly through land management in the catchment and possibly through climate change (DLWC 2000).

The average runoff from the Hunter catchment is 1,800,000 ML p.a., or about 12.5% of the total catchment rainfall. Of this total, 760,000 ML p.a. comes from the Paterson, Allyn and Williams rivers, which drain from Barrington Tops where there is high annual rainfall. These rivers have a catchment area of 2,230 km^2, and therefore 42% of the flow is derived from 10% of the Hunter River catchment area. The three regulating storages in the Hunter Valley - Glenbawn, Glennies Creek and Lostock dams - control 320,000 ML p.a., or 17.8% of the catchment yield (DLWC 2000).

The lower Hunter Valley floodplain contains several swamps that provide storage of floodwaters during overbank flow events. These are the Dagworth, Wentworth, Metford and McClements swamps to the east of Green Rocks, Mosman and Eskdale swamps on the eastern floodplain of the Williams River, and Woodberry and Hexham swamps on the southern floodplain of the Hunter River east of Green Rocks.

The volume of water entering the Hunter estuary is affected by extractive uses of water such as irrigation, stock, domestic or municipal water supply. An unpublished study conducted in 1997 estimated that the total average annual water use of landholders extracting from the estuary was 10,650 ML (DLWC 1999). This information was derived from a previous survey of Paterson River landholders in 1984, with an estimated average annual use of 4,400 ML from Gostwyck to the Hunter River junction, and a brief survey and local knowledge of the Hunter River, with average annual water use from Oakhampton to Duckenfield estimated at 6,250 ML. The same sources estimated that 1,020 ha of land is under irrigation on the Paterson River up to Gostwyck and approximately 1,250 ha of land is irrigated on the Hunter River from Oakhampton to Duckenfield. These estimates do not include properties irrigated from Wallis Creek, Howes Lagoon, Eskdale, McClements, Oakhampton and Wentworth swamps (DLWC 1999).

2.6.1 Catchment Runoff

As the waterway area is relatively small and the connection to the ocean is relatively large, freshwater inflows are able to drain to the ocean relatively quickly and hence the water levels in the north and south arms of the lower estuary do not increase markedly except during extreme events such as occurred in July 1998. By contrast, during widespread rainfall the large catchment conveys a large volume of water to a well-defined river channel incised in the floodplain and during these events the water levels in the upper estuary quickly rise and spill over the banks onto the floodplain.

Sanderson and Redden (2001a) determined the mean freshwater flow of the Hunter, Paterson and Williams rivers over the last 25 years as 3,120 ML/day. Similarly the median flow was 716 ML/day, the 90th percentile flow was 5,991 ML/day and the 95th percentile flow 11,918 ML/day. The geometric mean flow of the Hunter, Paterson and Williams rivers is 825 ML/day. The geometric mean flow can be considered a low flow. Given the tidal excursion is about 10-15 km in the lower estuary, a flow of around 6,000 ML/day (or 6 km/day in a channel 200 m wide by 5 m deep) is considered a high flow. Flows of order 200 GL/day are considered a large flood and in weaker flood events peak flows of 20 GL/day are common.

2.6.2 Contribution of Rainfall and Evaporation to the Estuary

Rainfall statistics derived from daily rainfall recorded at the Nobbys Head lighthouse over the 136-year period to 2001 were obtained from the Bureau of Meteorology. The volume of water entering the estuary due to direct rainfall on the water surface, Q_{Rain} (GL/year), may be estimated from:

$$Q_{Rain} = R\,A$$

where R is the annual rainfall in m/year, and A is the water surface area (26 km^2). Using the average annual rainfall, R = 1,142 mm at Nobbys Head as a reasonable representation of the rain falling on the whole estuarine surface area provides an estimate of the annual direct rainfall contribution of Q_{Rain} = 30 GL/year.

Similarly the loss of volume from the estuary surface due to evaporation, Q_{Evap} (MLd^{-1}), may be estimated using the annual evaporation rate of E = 1,000 mm and substituting into the equation

$$Q_{Evap} = E\,A$$

provides an evaporative loss of Q_{Evap} = 26 GL/year.

As can be seen from the above figures the evaporation and rainfall contribution almost balances the evaporative losses. In the wetland areas it is likely that the evapotranspiration exceeds rainfall contribution particularly during the drier periods.

2.7 Catchment Groundwater

Aquifers are storage areas of groundwater that are replenished or recharged by rainfall in the catchment that soaks into the ground, by floods and by leakage from other aquifers. Groundwater can discharge along the lowest points in the local landscape, often coinciding with rivers and creeks. In dry times it is these discharges of groundwater which form the baseflow of river systems. Groundwater discharging into surface waters has a direct impact on water quality. The natural balance between the two has been altered by the replacement of deep-rooted perennial native vegetation with shallow-rooted annual crops and pastures, causing water tables to rise, increasing the salinity of shallow groundwater and surface waters (Woolley et al. 1995). Considerable areas of pasture occur within the Hunter estuary study area, with potential impacts on groundwater.

The aquifers in the study area are continually being recharged with fresh rainwater. The potential for groundwater to move through the aquifer is measured by its hydraulic conductivity. The hydraulic conductivity of the aquifers composed of inner barrier sands has been measured to average between 10 m and 30 m/day. The transmissivity (hydraulic conductivity × saturated thickness) is approximately 400-500 m^2/day but can reach up to 4,000 m^2/day close to the coast (Woolley et al. 1995). The groundwater generally has a very low salinity, less than 150 mg/L of total dissolved solids (TDS) (Woolley et al. 1995). Being close to the estuary, it is expected that the fresh water will overlie deeper, denser saline groundwater.

Tomago Sand, Stockton Sand and Tomaree Sand are the most important parts of the Newcastle Formation (Woolley et al. 1995). There is limited data for Stockton Sand, however, its characteristics are thought to be similar to those for Tomago. The recharge coefficient (the proportion of mean annual rainfall that infiltrates to groundwater) is expected to be 25-30%. Based on the assumption that the outcrop area is 78 km^2, the mean annual recharge is about 21 GL p.a. (Woolley et al. 1995).

Wetlands in the study area occur where groundwater discharges close to a river or creek or where the groundwater is at or close to the surface (e.g. sand dunes). As such, the local groundwater system plays a crucial role in maintaining the viability of wetland areas. Changes in the volume and/or quality of the groundwater flow to these wetlands will impact on their sustainability. The Hunter Valley is the largest coastal catchment user of groundwater in the State, most of which is pumped from high yielding bores.

2.7.1 Groundwater Inflow to the Estuary

An estimate of the annual average groundwater flow to the Hunter estuary may be derived by assuming an average transmissivity, T, of the sandy aquifers in the lower floodplain of T = 400 m^2/day (Woolley et al. 1995), a hydraulic gradient of 0.1 m maximum change in groundwater level (or water table) over a minimum distance of 10 km, equating to the gradient value i = 0.01. The length, L, of shoreline of the estuary is about 100 km. Assuming the groundwater penetrates into the estuary over this distance then the average inflow, Q_{Gin}, may be calculated from the relationship, $Q_{Gin} = T\ i\ L$. Substituting the values above into this relationship gives the estimate of Q_{Gin} ~ 0.5 GL/day or an annual inflow of 183 GL.

As the rainfall is spread evenly throughout the year the watertable is regularly recharged and hence is unlikely to drop below the mean river level. The watertable in the low-lying areas near the mouth of the river may at times drop below the mean river water level and create a situation where river water may flow into the groundwater system. This groundwater outflow is likely to be negligible in comparison to the groundwater inflow.

2.8 Flooding

There is a long history of flooding in the Hunter River, with distinct periods of major flooding over the years, the most significant periods occurring between 1863 and 1880, during the 1890s, and between 1949 and 1956. The largest flood experienced since European settlement in the valley was in February 1955, which resulted in the destruction of a large number of flood control structures and the loss of life. It was the massive 1955 flood that prompted the State Government to establish the Hunter Valley Flood Mitigation Act in 1956, which led to a more controlled and planned implementation of flood mitigation in the valley. Since the 1955 flood, significant flooding in the Lower Hunter has occurred in 1971, 1972, 1977, 1978, 1985 and 1989 (Paterson Britton & Partners 1996a).

There are two likely flood-producing rainfall mechanisms in the Hunter Valley. The most common is a ‘coastal type’ in which a high proportion of the flood originates in the Allyn River, a large tributary of the Paterson River (see Figure 1.1), Williams and Wollombi (south-west of study area, see Figure 1.1) catchments from deep low pressure systems producing a moist south-easterly airstream resulting in heavy coastal rains. These systems are likely to cause the majority of smaller floods in the Hunter River.

The second mechanism is the more rare ‘inland type’ when a large tropical depression brings warm moist air into the centre of Australia from the north, causing heavy rainfall on the western portions of the Hunter River catchment. The 1955 flood was caused by such a mechanism, with large quantities of rainfall in the west of the Hunter catchment as well as in the Paterson and Williams catchments (NSW Public Works 1994). Local catchment runoff is of minor importance as far as large floods are concerned.

The Hunter River is more susceptible to flooding from these inland depressions than other NSW coastal rivers because of the inland penetration of the catchment. This inland penetration is attributed to the Great Dividing Range being the furthest from the coast at this point (Patterson Britton & Partners 1996a).

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SELECTED RAINFALL STATION LOCATIONS IN THE HUNTER ESTUARY

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Figure 2.1

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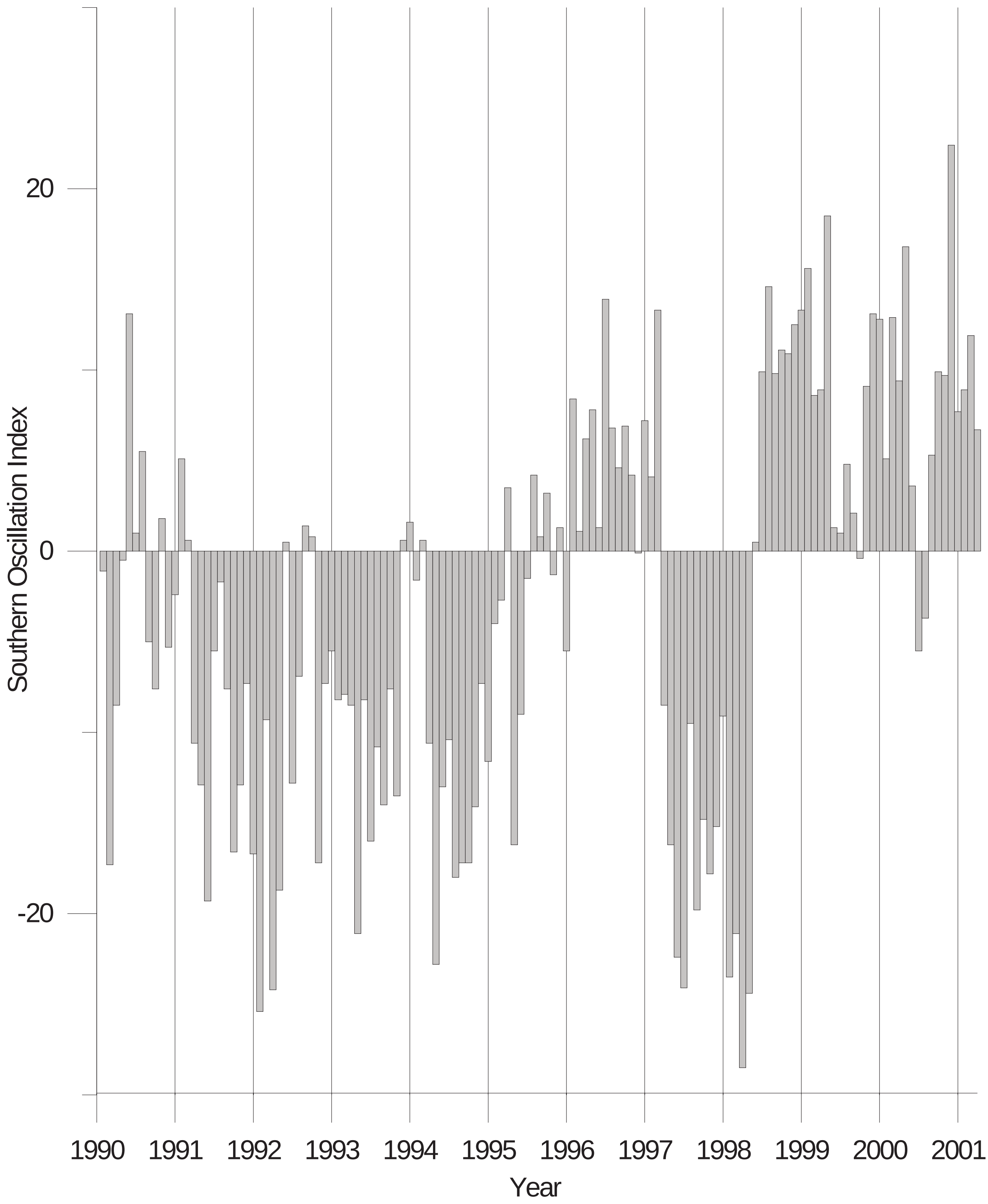

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SOUTHERN OSCILLATION INDEX
1990 - 2001

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Figure 2.2

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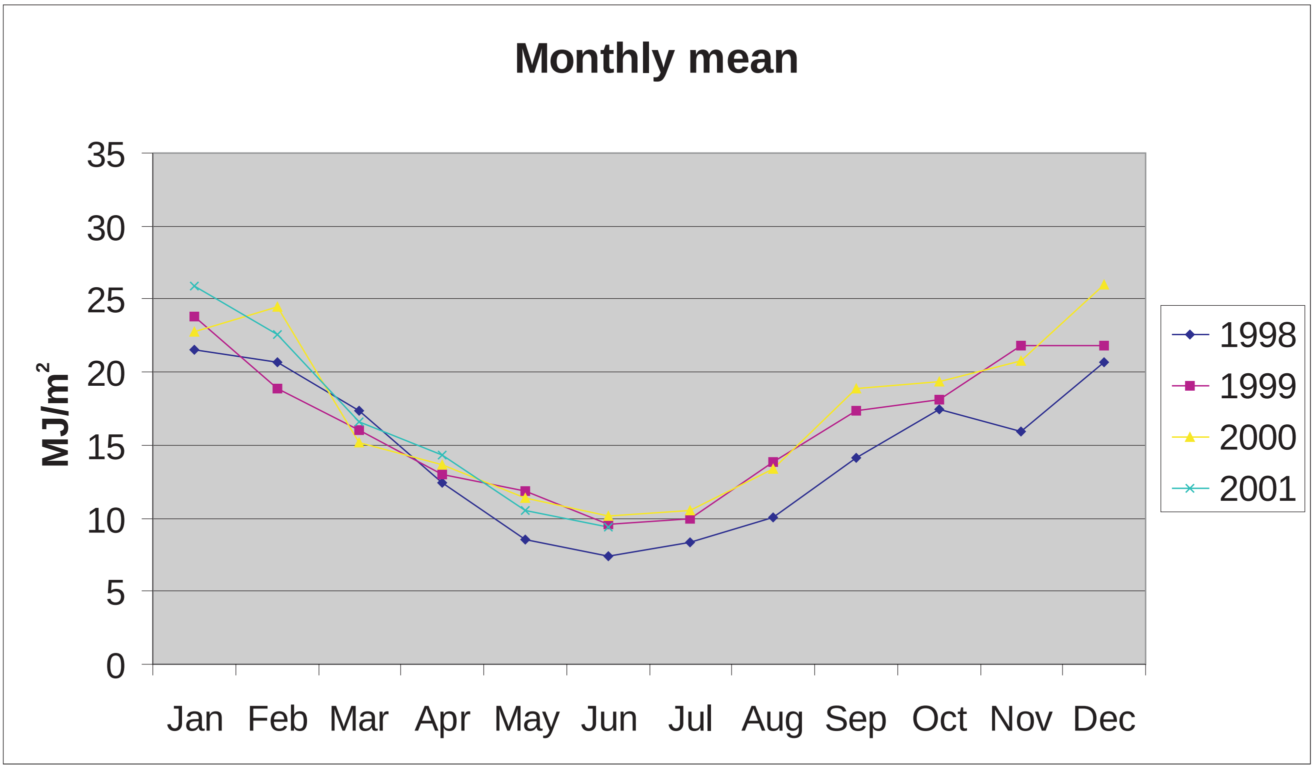

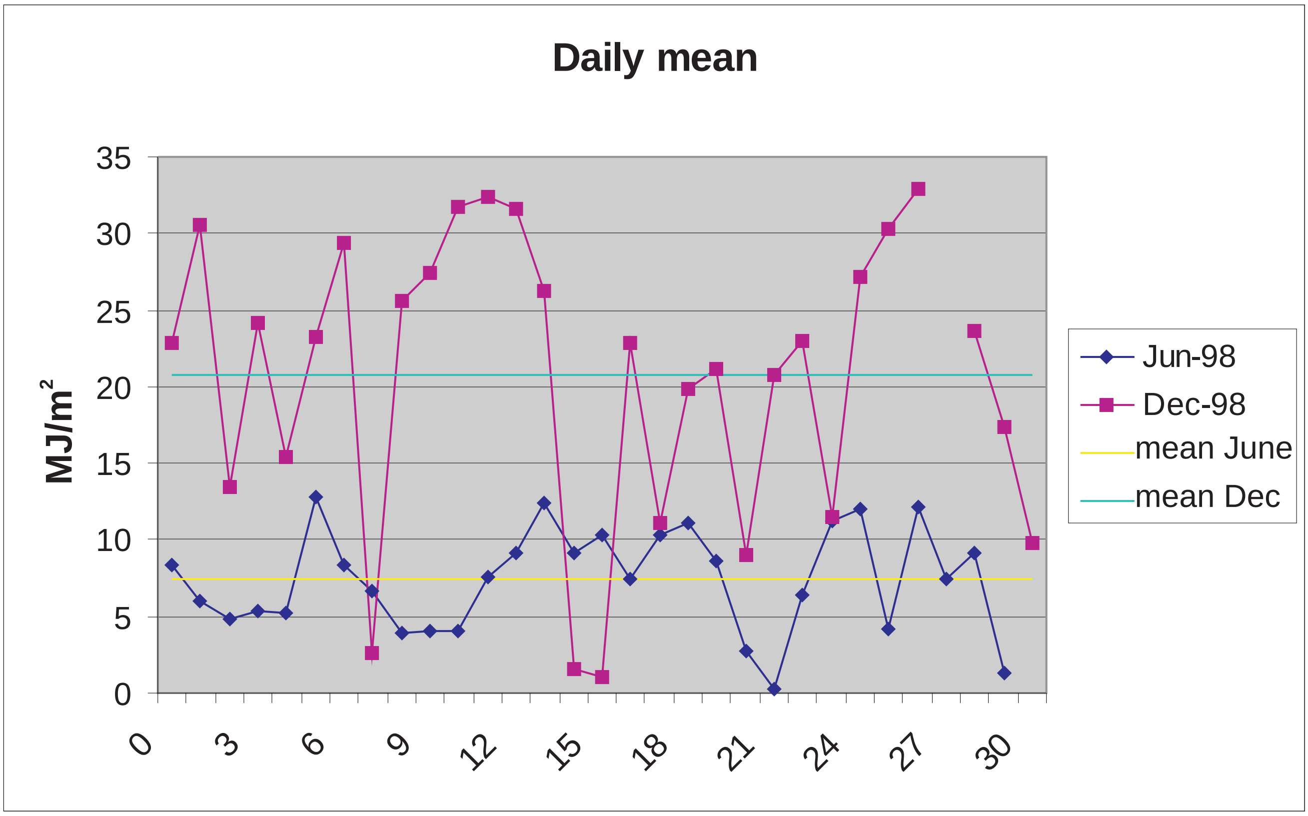

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GLOBAL SOLAR EXPOSURE IN HUNTER ESTUARY

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Figure 2.3

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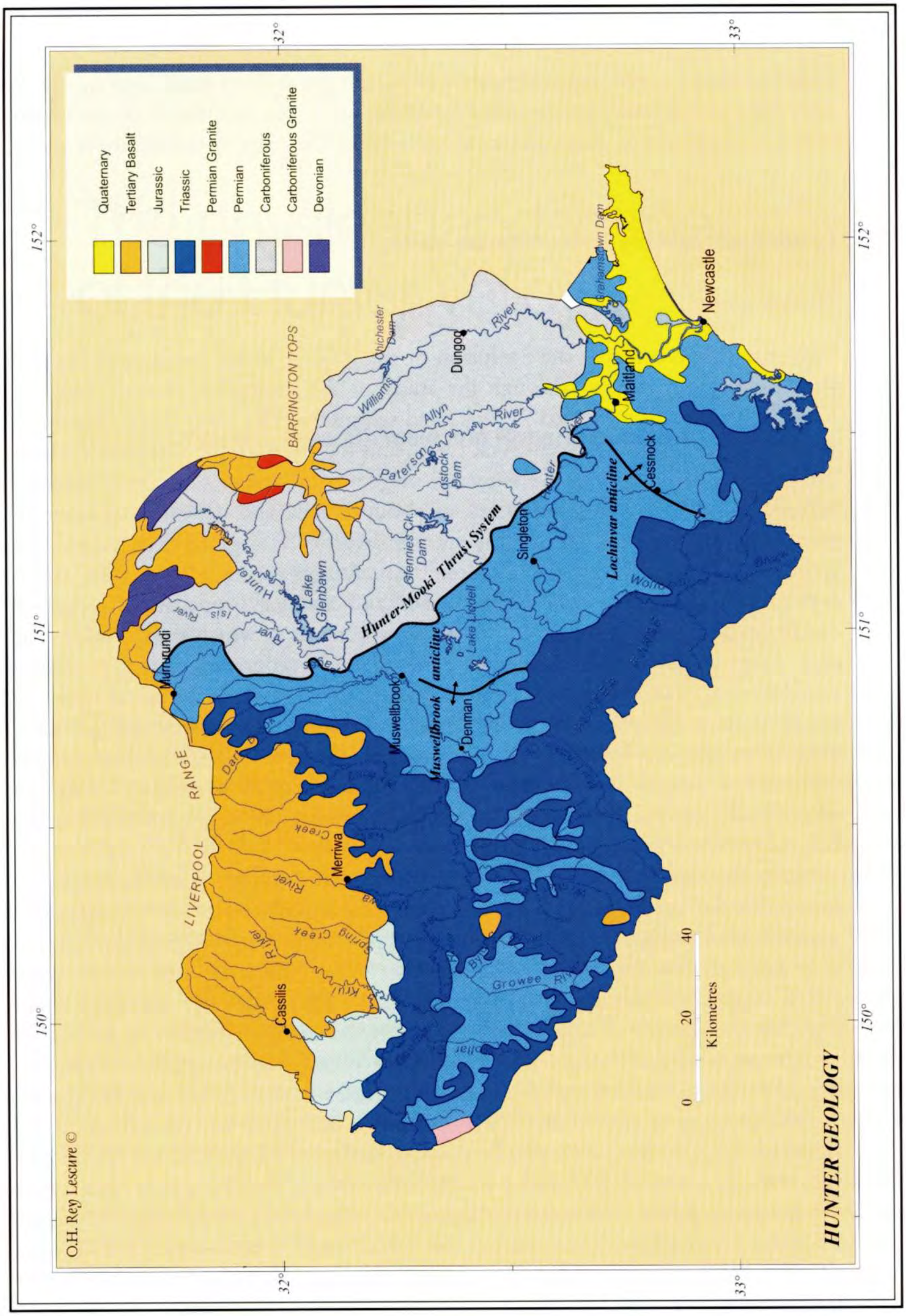

Source: McManus et al., 2000

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GEOLOGY OF THE HUNTER CATCHMENT

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Figure
2.4

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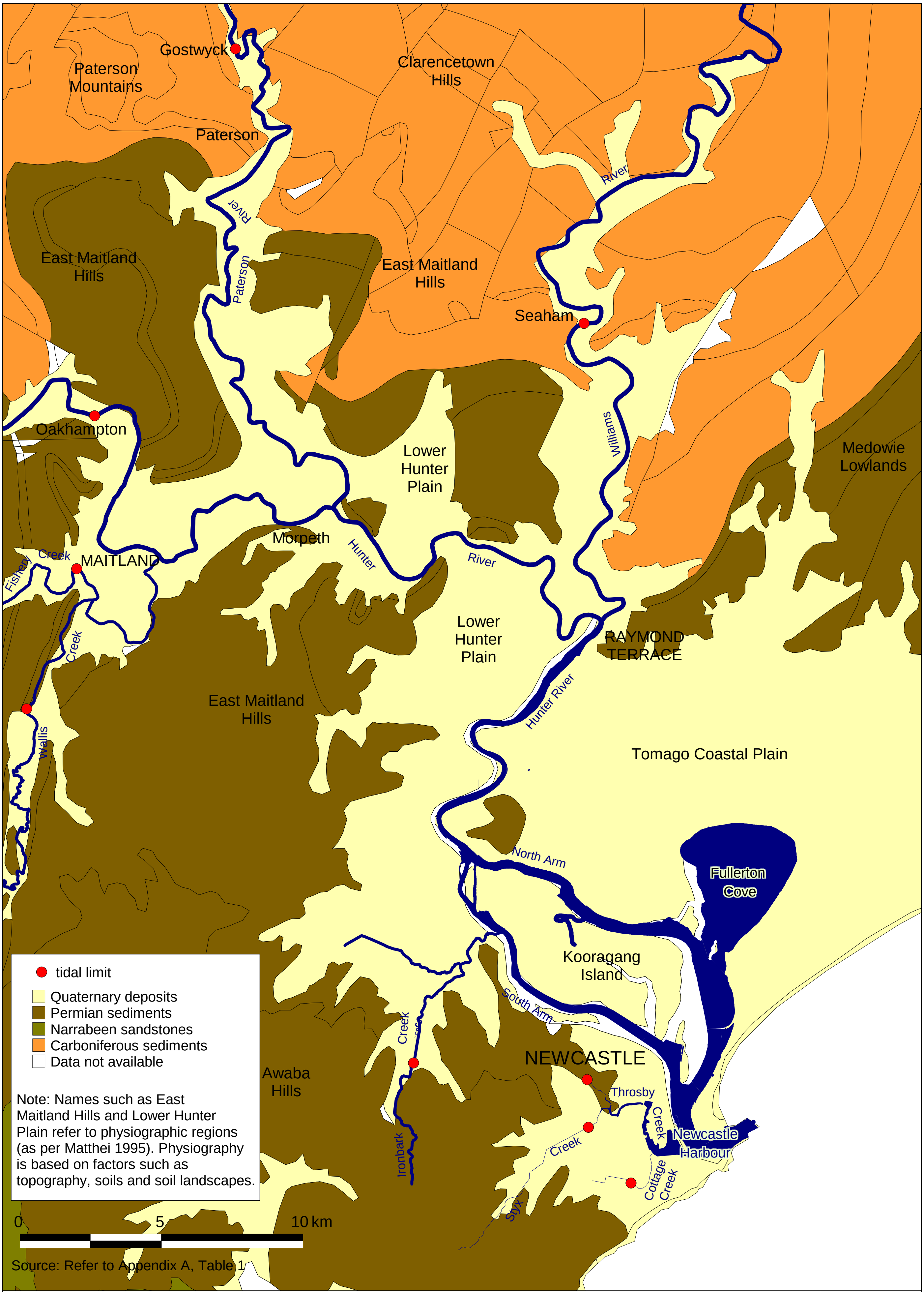

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HUNTER ESTUARY GEOLOGY

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Figure 2.5

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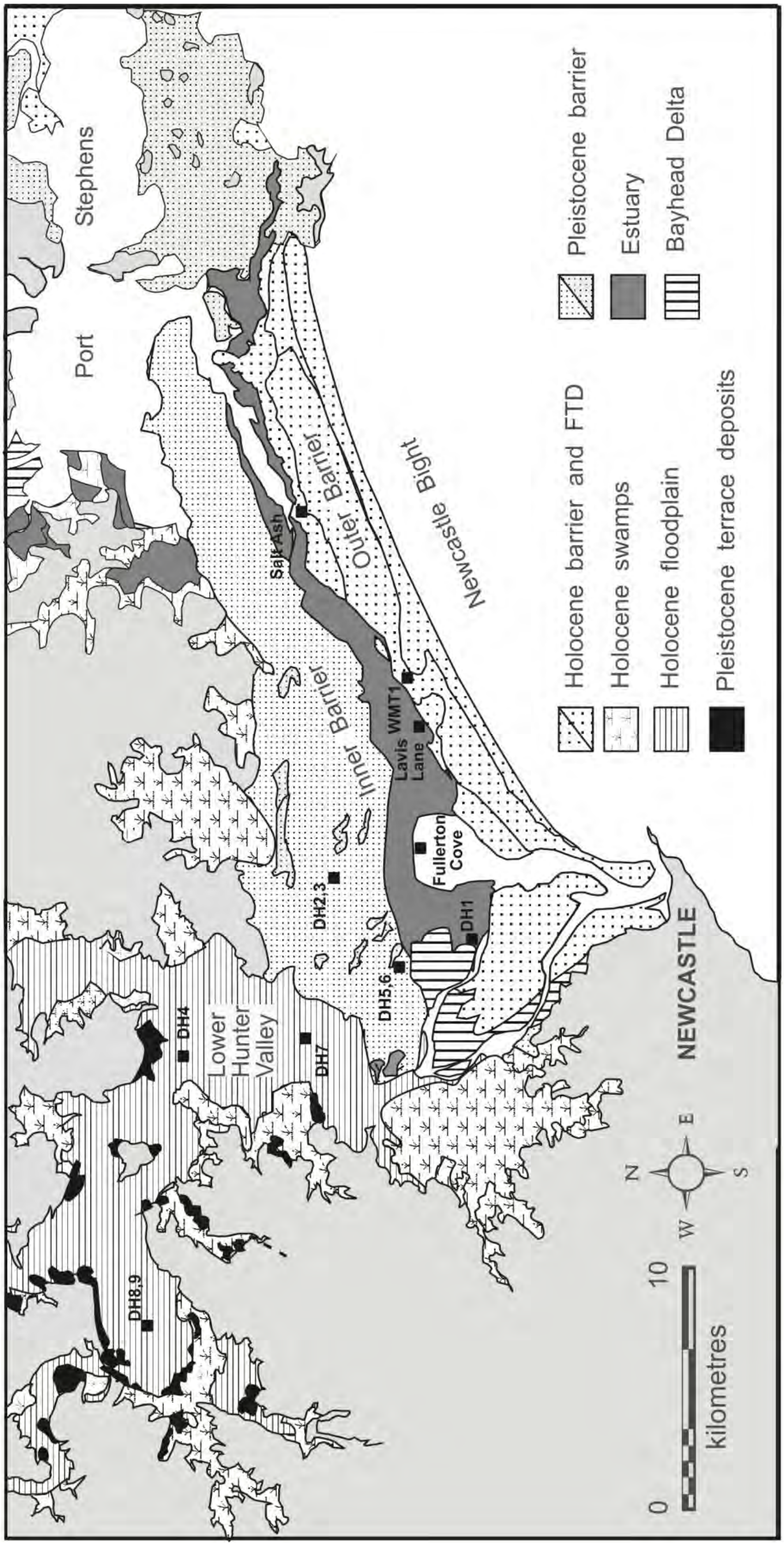

Source: Boyd 2001

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DEPOSITIONAL SEDIMENTARY ENVIRONMENTS OF THE LOWER HUNTER VALLEY

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Figure 2.6

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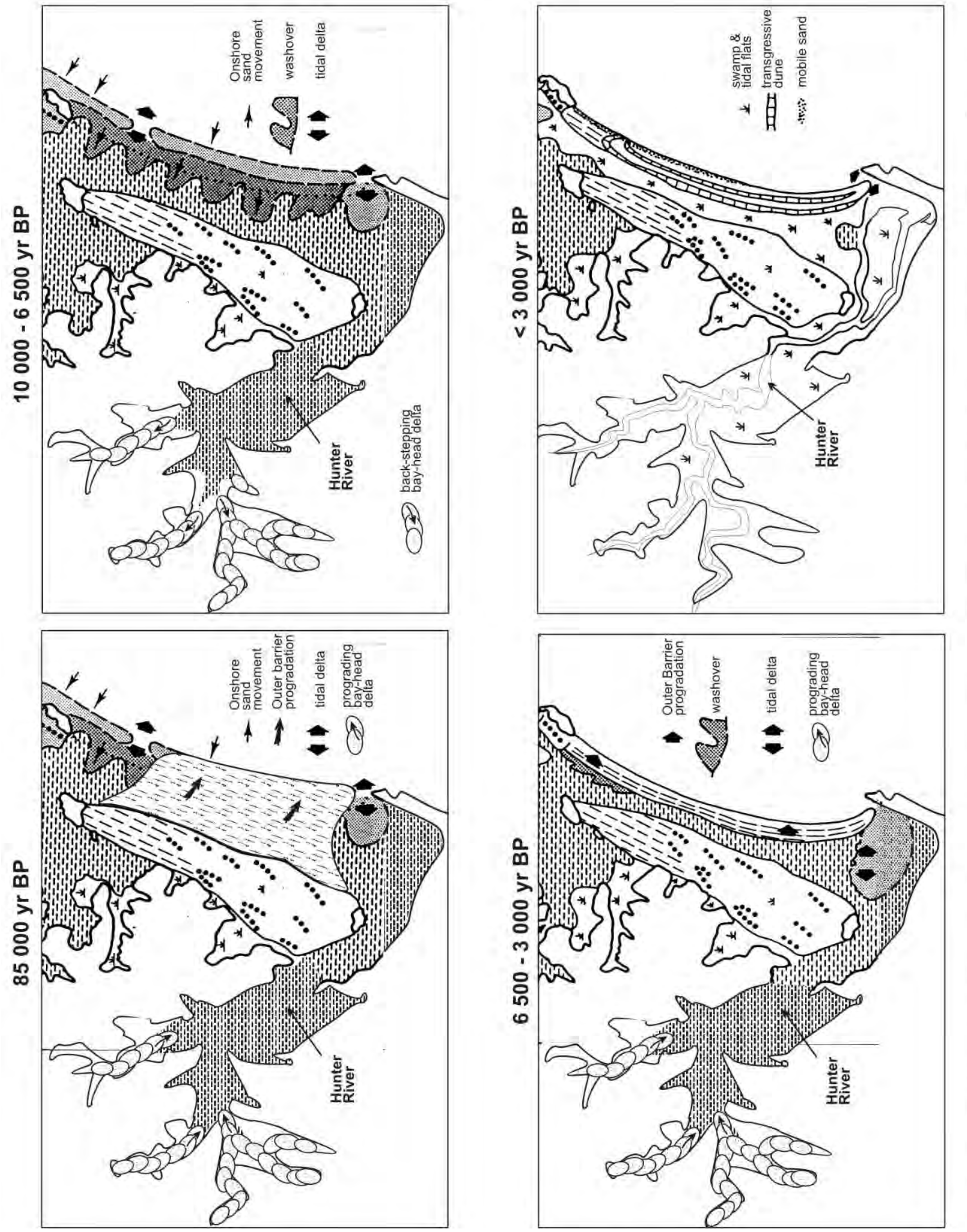

Source: Boyd 2001

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MODEL OF THE EVOLUTIONARY HISTORY OF THE LOWER HUNTER RIVER VALLEY (85,000 YEARS BP TO PRESENT)

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Figure 2.7

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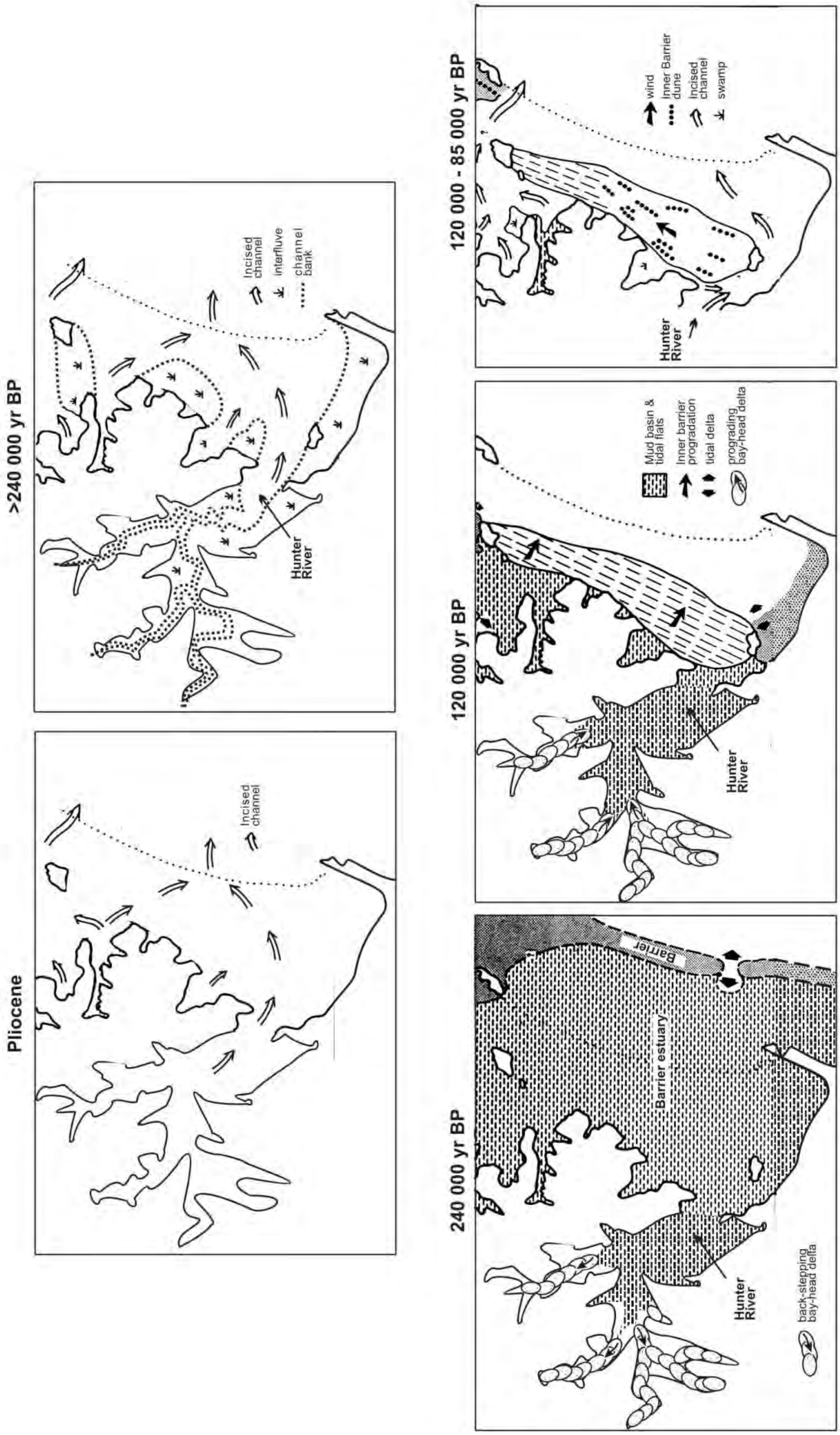

Source: Boyd 2001

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MODEL OF THE EVOLUTIONARY HISTORY OF THE LOWER HUNTER RIVER VALLEY (PLIOCENE-85,000 YEARS BP)

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Figure 2.8

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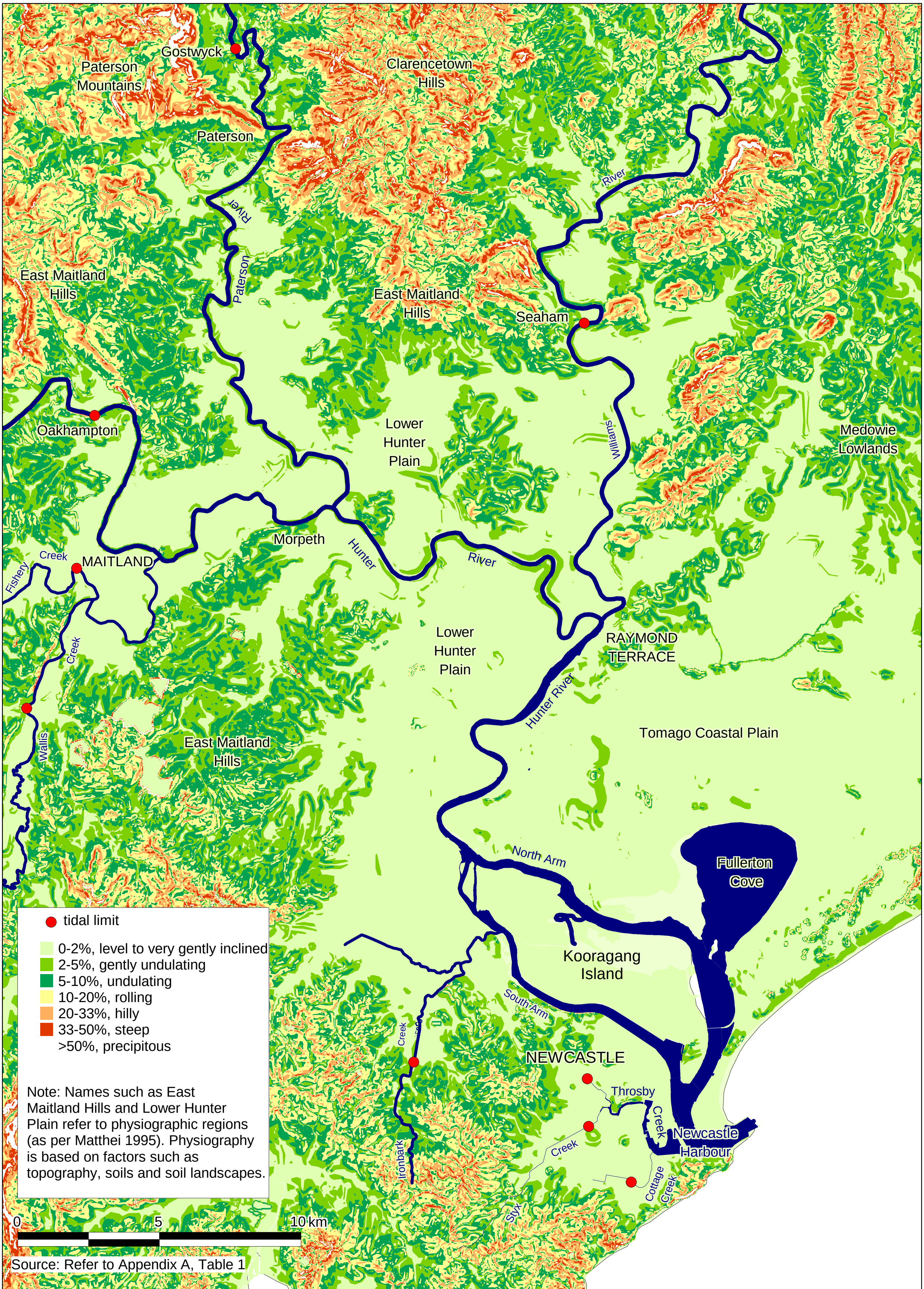

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SLOPE CLASSES OF THE HUNTER ESTUARY

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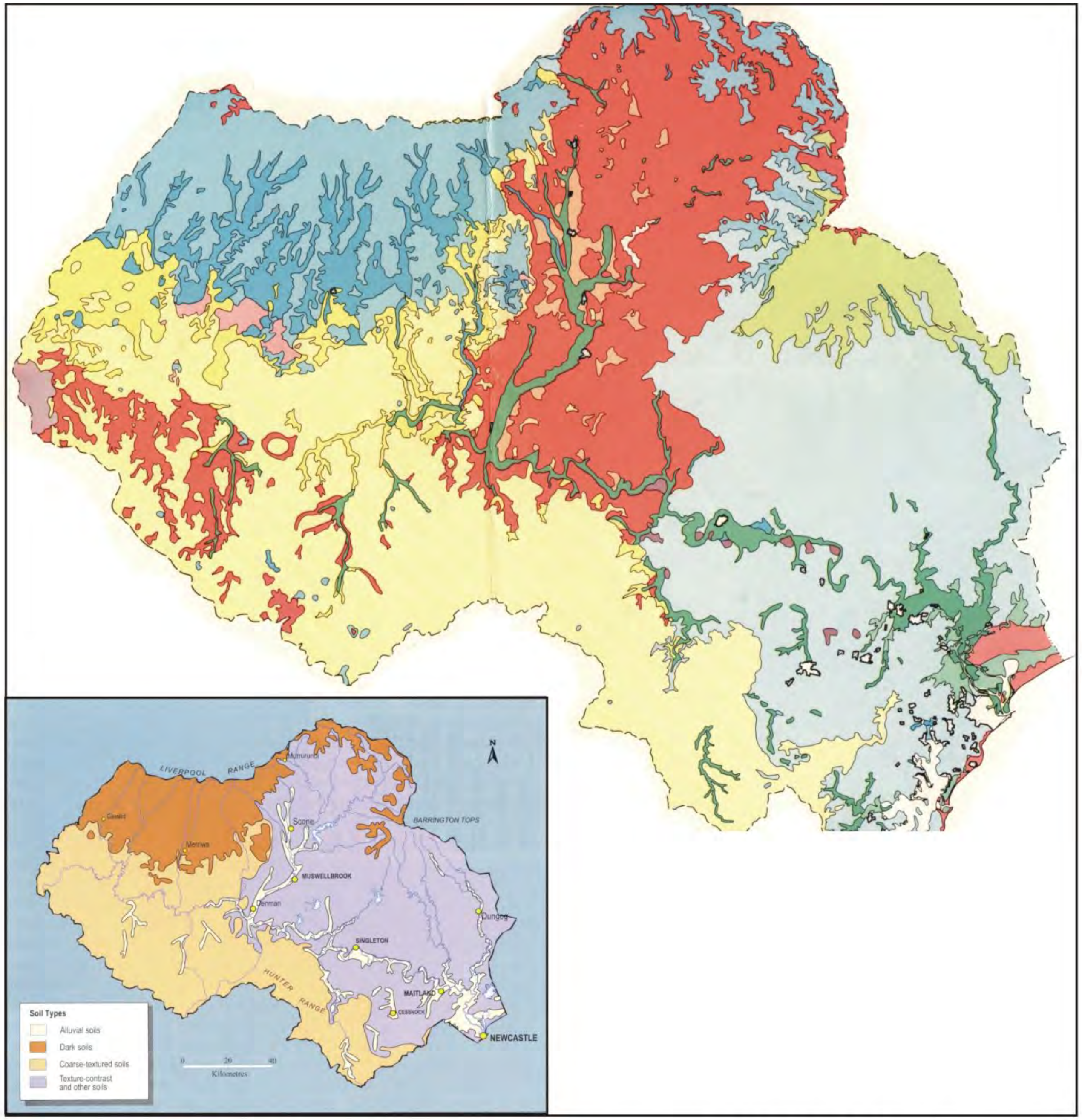
Figure 2.9

DRAWING 10_2.WOR



ASSOCIATIONS OF MOSTLY LEACHED SOILS

- Podzolic and skeletal soils, respectively on lower gentle slopes and on steeper slopes. Some earths. Occasional patches of cracking clays and solonetzic soils. Soils shallow in steep parts
- Leached, acid krasnozems on hill tops and slopes below basalt caps; sometimes stony. Red and brown podzolic soils and some brown earths on lower slopes. Some skeletal soils
- Strongly leached, acid krasnozems and transitional alpine humus soils. Krasnozems in lower parts, transitional alpine humus soils in highest parts, basalt floaters often present at high altitudes. Some fine-textured soils
- Humus-fron podzols and sandy aeolian regosols. Humus-iron podzols in inland dunes with some meadow and acid swamp soils in depressions, and yellowish white, single-grained, sandy aeolian regosols along the coast on sandy deposits. Podzolic soils on Permian shales and sandstones
- Deep, permeable, slightly acid krasnozems, some with secondary lime at depth, and areas with shallow stony krasnozems

ASSOCIATIONS OF SOILS OFTEN WITH SOME LIME IN THE PROFILE

- Solonetzic soils, skeletal soils, and earths. Solonetzic soils and patches of cracking clays and degraded black earths, with areas of earths on gentle slopes. Shallow or skeletal soils on steep slopes. Occasional podzolic soils
- Cracking clays, forming a nearly uniform soil cover. Soils deep, dark or black, linear gilgai common. Some stony patches. Narrow alluvial strips, with similar cracking clays, sometimes having thin eluvial A horizons
- Cracking clays, degraded black earths, and solonetzic soils. Complex pattern dominated by cracking clays and with degraded black earths and solonetzic soils co-dominant

ASSOCIATIONS OF MOSTLY SKELETAL AND SHALLOW SOILS

- Coarse-textured skeletal soils, with some fine-textured. Shallow miscellaneous soils in more stable parts. Deep earths on some plateaux
- Earths and skeletal soils, mostly sandy and shallow, except on colluvium. Solonetzic soils, especially on lower slopes of colluvial spreads
- Skeletal soils in steeper parts and gritty, often sandy earths on gentle slopes. Solonetzic soils in valley bottoms
- Shallow and immature cracking clays with fine-textured skeletal soils, the latter on the steeper slopes. Skeletal soils often humic at high altitudes. Some deeper cracking clays in less steep areas

ASSOCIATIONS ON ALLUVIUM OR RIVERINE DUNES

- Various soils depending on age of terrace, composition of parent material, and climate. Chernozems, solonetzic soils, cracking clays, earths, and alluvial regosols
- Badly drained soils. Acid swamp soils and meadow soils, with alluvial regosols which are mostly fine-textured and saline
- Sandy aeolian regosols, usually deep or very deep and single-grained

Source: van de Graaff (1963), McManus et al., (2000)

NSW DEPARTMENT OF PUBLIC WORKS AND SERVICES

MANLY HYDRAULICS LABORATORY

SOIL TYPES OF THE HUNTER CATCHMENT

MHL Report 1095

Figure 2.10

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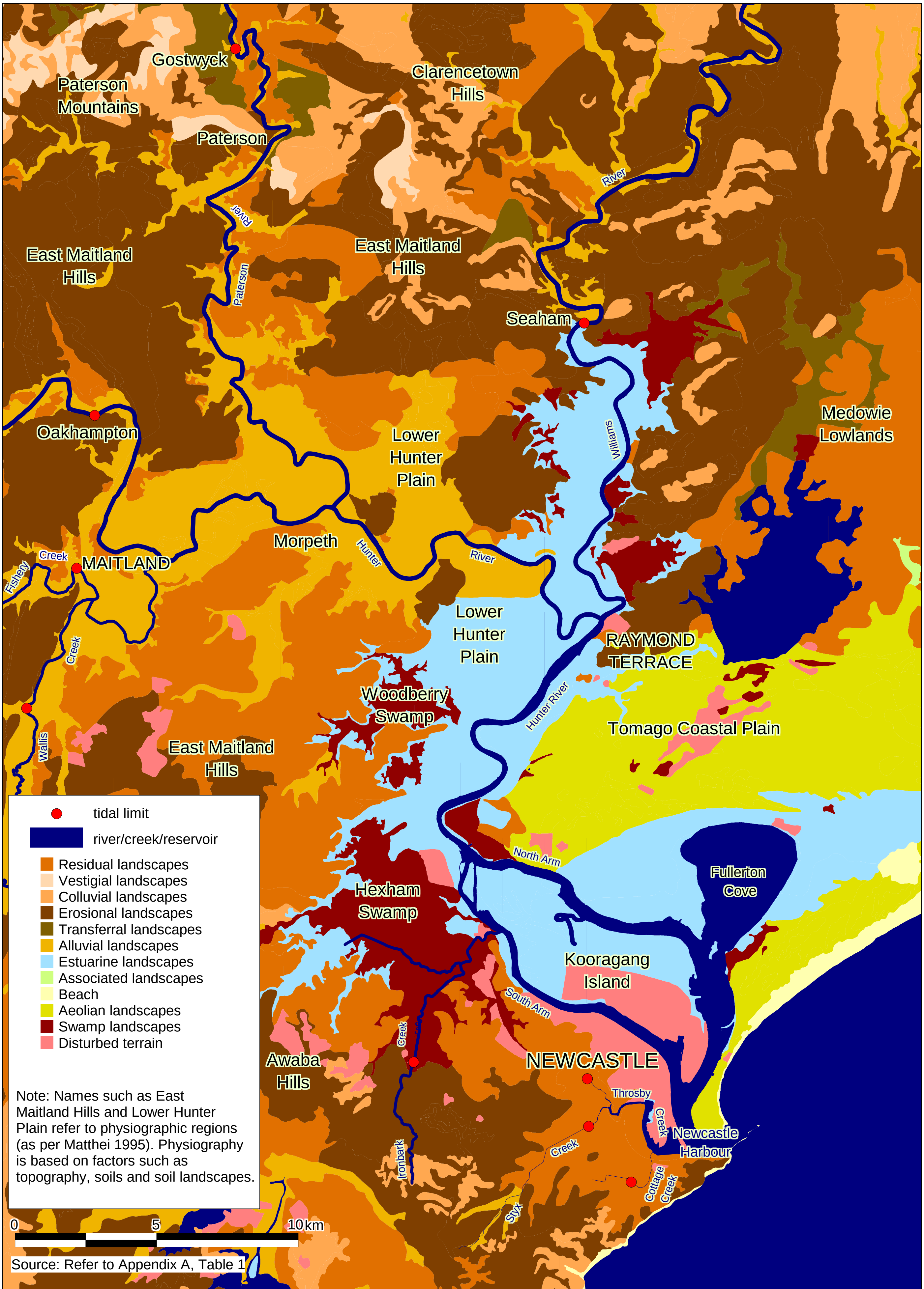

NSW DEPARTMENT OF PUBLIC WORKS AND SERVICES
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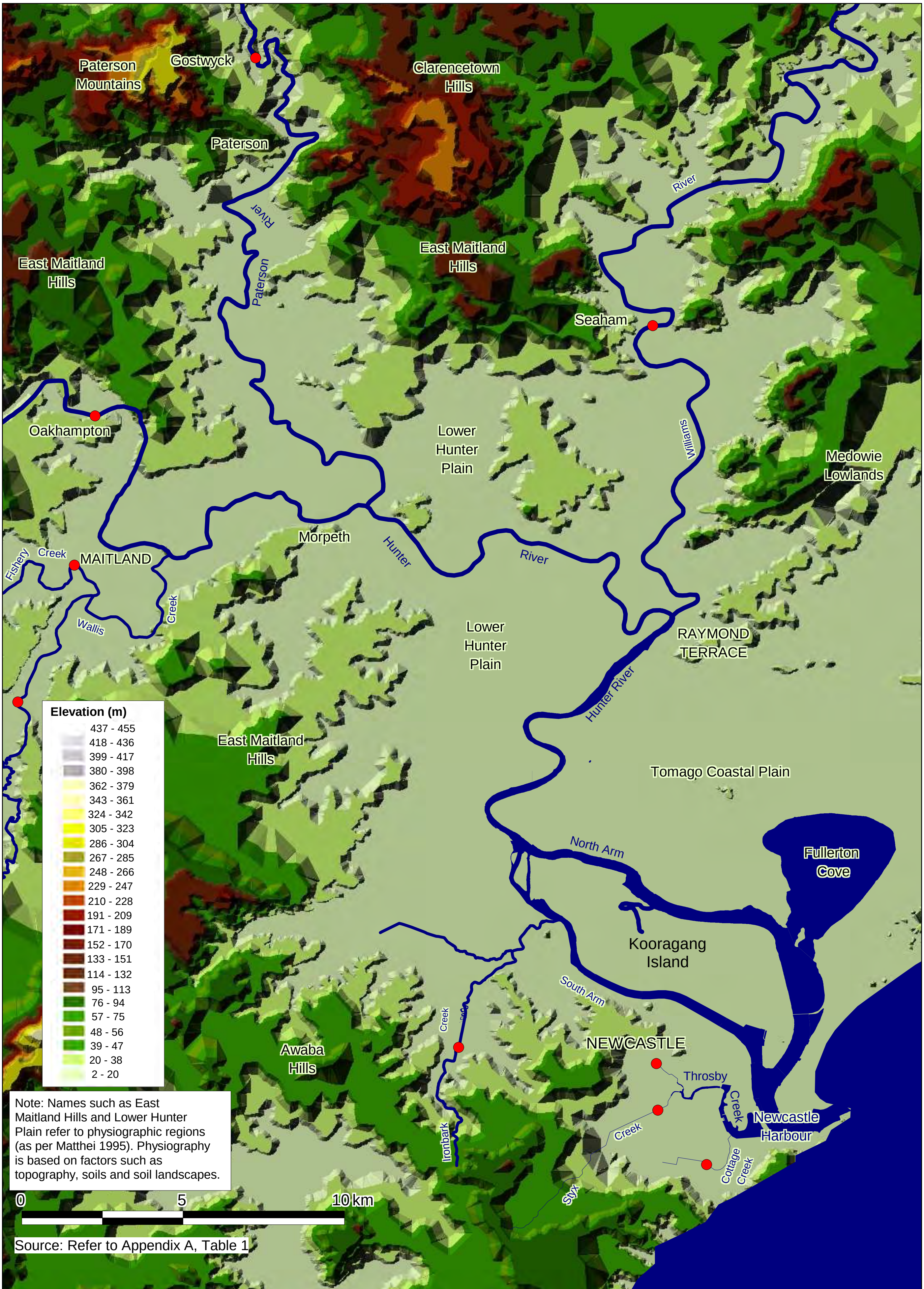
HUNTER ESTUARY SOIL LANDSCAPES

MHL Report 1095

Figure 2.11

DRAWING 10_3.WOR



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HUNTER ESTUARY LANDFORMS

MHL Report 1095

Figure 2.12

DRAWING 10_4.WOR

3. Catchment and Estuary Cultural Aspects

3.1 History and Heritage

3.1.1 Aboriginal History

The general picture that exists of the Hunter River before the arrival of the Europeans is one of a mangrove-fringed river with a dense brush and huge trees lining the banks (Albrecht 2000). Lofty forests of eucalypts and *Casuarina* with hills covered in light undergrowth and grass were present, together with wetlands around Hexham and between Singleton and Scone (Albrecht 2000). Due to the richness and variation in the landscape, there was an abundance of species, such as emus, kangaroos, dingos and a variety of birds and fish living in the area.

With a plentiful food supply from a wide variety of sources and a suitable climate, the region provided an ideal home range for the Awakabal, Worimi and Wanarua people. These tribal groups had maintained a sustainable lifestyle in the area for at least 30,000 years and their local knowledge upholds that their occupation of the Hunter region extends back even earlier, into the early reaches of the 'Dreaming'. Contemporary Aboriginal groupings now exist in the Hunter area, and include groups such as the Mindiribba.

3.1.2 European History

After the initial 'discovery' of the Hunter River by Europeans, their early settlements and industries were based on exploitation of cedar trees and easily accessible coal deposits. In 1797, on a search for escaped convicts, Lt. Shortland reported a coal seam at Nobbys Island and by 1799 private entrepreneurs were exporting coal overseas. After an initial convict mining operation failed through misconduct, a second convict penal settlement was established on the south shore of the river in 1804. This outpost was soon named Newcastle and was to supply coal, timber and lime for the service of the British Government. A small number of free settlers arrived, but it was not until the 1820s, when Newcastle passed from military to civilian status, that the actual colonisation took place. By the mid 1800s the Hunter Valley, with high quality agricultural lands and short transportation times to Sydney, was one of the most populous parts of NSW. Major changes were taking place at that time in the natural environment, primarily the transformation of swampy flood-prone areas into agricultural zones. Thus, the earliest modifications to the wetlands of the Hunter Valley were initiated by the farming community in response to needs for arable land and to control surface water (Williams et al. 2000). Further transformations of the natural environment took place as transport requirements increased. Dredging programs were undertaken for shipping purposes and land was reclaimed for railways.

After a large British Government land grant in 1827 the Australian Agricultural Company (AAC) was virtually given a monopoly on commercial coal mining and shipping. The monopoly position of AAC was revoked in 1847 following which the number of coal mines and output of coal industry grew rapidly. In the late 19th century Newcastle was one of the world's largest coal exporters (Doring and Doring 1996). The growth of the city was accompanied by major infrastructure works such as harbour dredging, foreshore reclamation, railway and wharf construction.

The proximity of coal has led to the development of energy-intensive industries such as steel production in Newcastle. The first industrial facilities in the Hunter estuary are generally considered to be the BHP smelters for which BHP acquired 10 ha of land at Port Waratah in 1896. Before that smaller saltworks and sulphuric acid plants were present on Mosquito Island (Williams et al. 2000). In the early 1900s the *Newcastle Iron and Steel Works Act* was passed which increased the amount of land available to BHP for heavy industry. In 1913 a major centre for engineering and ship building facilities was built at Walsh Island. After the Great Depression, during which the dockyards were closed, the military needs of World War II led to an increase in industrial output.

In the years after the war, the changes in the Hunter estuary continued as a result of industrial expansion. In 1951 the NSW Public Works Department began a new program of dredging and land filling in the Hunter River (Williams et al. 2000). In 1968 the complex of islands in the lower Hunter estuary were named Kooragang Island. The infrastructure and flood mitigation works over the subsequent years led to a substantial modification to the flow of the river and the shape of the river banks. In the 1970s concerns were raised by the public about the pollution and the extent of industrial development in the Hunter estuary. In the 1980s the region continued to develop and while the regional population increased, the population numbers in Newcastle began to decline. In the 1990s the rehabilitation of wetlands commenced.

A timeline of human activity in the Hunter estuary is summarised in Table 3.1.

Table 3.1 Timeline for Human Activity in the Hunter Region

(Williams et al. 2000, Doring and Doring 1999, Ruello 1976, HVRF 1999)

Year	Event
<1797	Awakabal, Worimi and the Wanarua people live in Hunter region
1797	Lt. Shortland discovers coal seam at Hunter River estuary mouth
1804	Establishment of convict penal settlement on the south shore of the river called 'Newcastle'
1808	Halting of salt production
1823	Penal settlement at Newcastle closed; new penal settlement started at Port Macquarie
1826	Newcastle passes from military to civilian status
1828	Great North Road completed
1827	Land grant to the Australian Agricultural Company boosts coal industry
1836	Saltworks constructed on Mosquito Island
1846	Completion of breakwater between mainland and Nobbys Island
1847	Number of coal mines and coal exports grow rapidly
1850	Construction of Pacific Highway
1859	Commencement of dredging in Newcastle harbour
1857	Opening of Great Northern Railway (from Honeysuckle Point to East Maitland)
1862	Construction of Bullock Island Dyke along alignment of South Channel

Year	Event
1878	Completion of wharf construction along south bank
1886	Opening of railway from Homebush to Newcastle
1896	BHP acquires 10 ha of land at Port Waratah for smelters
1900	Newcastle Iron and Steel Works Act
1913	State Engineering Workshops: development of major centre for engineering and ship building facilities at Walsh Island
1915	Commencement of steel production by BHP at Port Waratah
1917-1928	Continuation of reclamation works and wharf construction
1930s	Great Depression
1940-1945	WWII increases Hunter industrial output
1951	New program of dredging and land filling in the Hunter River
1955	Major flood in Hunter Valley (1:200 year flood)
1956	Hunter Valley Flood Mitigation Act passed
1968	Complex of islands in the lower Hunter estuary is named Kooragang Island
1970	Construction of floodgates at Ironbark Creek
1971	Completion of Stockton Bridge
1977	Commencement of harbour reclamation program
1980	Main site for coal exports moves from the dyke up the river to Port Waratah
1993	Launching of Kooragang Wetland Rehabilitation project
1999	Closing of BHP steel making facilities in Newcastle

3.1.3 Significant Aboriginal and European Historic Sites

Features of the landscape and rivers formed an integral part of their way of life and so were all identified by name (Albrecht 2000). A small number of Aboriginal names for different features within the estuary and the names of the tribes that frequented different areas are shown in Figure 3.1.and listed in Table 3.2.

Table 3.2 Aboriginal Names for Hunter Estuary Characteristics
(Albrecht 2000)

Aboriginal Name	European Name
Tahlbihn Point	Entrance to the river – south
Burrabihngarn	Entrance to the river – north (Pirate Point/Stockton)
Muloobinbah	Newcastle Harbour
Awakabal	Newcastle
Coquun/Myan/Coonanbarra	Hunter River (after Governor of British colony in NSW)
Dooribang	Williams River (after Colonel W. Paterson of the NSW Corps)
Yimmang	Paterson River (after Colonel W. Paterson of the NSW Corps)
Corrumbah	Chapman Island/Bullock Island/Carrington
Toorrnbing Creek	Ironbark Creek
Burraghihnbihng	Hexham Swamp

About 2,000 Aboriginal sites have been recorded throughout the study area including sites along the valley floors of the major tributaries, rock shelter sites in the sandstone areas and shell middens around coastal lakes and estuaries (Department of Planning 1989). However, due to large scale river works, land reclamation and urbanisation much of the remnants of Aboriginal occupation in the Hunter estuary have been destroyed.

An archaeological study completed in 1990 identified 70 sites of Aboriginal heritage to be contained in the Stockton Bight area. The Newcastle Bight committee was stated to have identified a further 116 sites, many of these being middens in the dunal barrier system (Port Stephens Council 2000a).

Within the Newcastle area there is a high incidence of places of Aboriginal cultural significance. Recently, the NSW Heritage Office provided funding for a City-wide Survey of Aboriginal Cultural Heritage Resources. This study aims to identify both physical and metaphysical places of Aboriginal cultural significance and propose strategies for their protection and conservation.

A request has been placed with the Aboriginal Lands Councils within the Hunter estuary for information relating to areas of Aboriginal significance (Susan Effenberger, Newcastle City Council, pers. comm. 2002). At the time of publication of this report information had not been received.

The Hunter region is one of Australia's longest European-settled regions. European settlement has produced a unique variety of structures, buildings, towns and landscapes. The Hunter Regional Environmental Plan 1989 (Heritage) (Department of Planning 1989) has identified some 800 specific items that are deemed worthy of conservation for future generations. They include urban and rural dwellings, public and commercial buildings, archaeological remains, bridges, collieries and cemeteries (Department of Planning 1989). All items are classified as being of State, regional or local significance.

The City of Newcastle is notable for its fine stock of buildings from the Victorian period and the original town layout of Henry Dangar (1823). Newcastle has acknowledged that heritage places are an integral part of the city's identity and adopted a City-Wide Heritage Policy in 1998. One of the sites with regional and national heritage significance is the Convict Lumber Yard, one of the oldest surviving convict industrial workplaces in Australia.

A National Trust site is also present on the eastern side of Fullerton Cove and is registered as a Hunter River Estuary Landscape Conservation Area.

3.1.4 Heritage Value of Historic Sites

The *Heritage Act 1977* has the following definitions of State and local heritage significance:

> 'State heritage/local heritage significance, in relation to a place, building, work, relic, moveable object or precinct, means significance to the State in relation to the historical, scientific, cultural, social, archaeological, architectural, natural or aesthetic value of the item.' (Heritage Act, s4A)

An item can be of both State and local heritage significance, however, an item that is of local heritage significance may or may not necessarily be of State heritage significance.

The State Heritage Inventory (SHI) contains heritage items on statutory lists in NSW, identified to be of State or local significance. Items considered to be of State significance are those that are listed on the State Heritage Register. If an item is listed on the SHR it means that the heritage item is:

- particularly important to the State
- legally protected under the NSW Heritage Act; and
- requires approval from the Heritage Council of NSW for certain kinds of work.

Within the Hunter estuary, there are 684 heritage items listed on the SHI, with 77 of these being of State significance. The total number of items of significance for each Local Government Area within the Hunter estuary are shown in Table 3.3. Items of State and local (and regional where designated) significance are shown in Figure 3.1. The Draft Newcastle LEP 2002 and the Port Stephens Council LEP 2000 both contain detailed lists of local and State significant heritage items within their particular LGAs. The Maitland LEP 1993 also contains a list of State and local significant heritage items, but has also grouped heritage items into a third category entitled ‘regional’ heritage items. The Port Stephens LEP also contains a list of potential heritage items. If work is being carried out within the vicinity of the heritage items both items of local and State significance as well as potential heritage items should be taken into consideration.

Table 3.3 State and Local Heritage Items for the Hunter Estuary

Local Government Area	Items of State Significance	Items of Local Significance	Total
Newcastle City	36	270	306
Port Stephens	7	98	105
Maitland City	34	239	273

3.2 Land Use

3.2.1 History of Land Use

The landscape of the Hunter Valley has changed drastically since European settlement. Over the last 200 years the natural environment has been transformed from forest and wetland areas into land for residential, agricultural and industrial purposes. This change in land use has had significant impacts on the river and estuarine environment, with major alterations to geomorphological processes and the linkage between the river and its floodplain, reduction in natural habitat area and diversity, and an increase in sediments and pollutants entering the river and estuary.

In the early 1800s, before European exploration and settlement, the lower Hunter floodplain was covered with thick rainforest. The river banks were covered with tall eucalypts and swamp oaks which often extended to the water’s edge. Alternating strips of rainforest and naturally clear land, across the floodplain, marked floodways and abandoned river channels (Patterson Britton & Partners 1993). In 1820 an early settler in the Maitland district gave detailed evidence on various timbers found in the known parts of the Hunter River district, notably red cedar, rosewood, pine, flooded gum, blue gum and ironbark. Cedar brush covered most of the Wallis and Paterson plains, consisting of giant red cedar trees, fig trees, myrtle and other softwood brush trees with interlinking climbers. The cedar brush was removed in the early 1800s and late 1830s because of its valuable trees and its location on the best alluvial soils (Department of Water Resources 1987). By 1830 much of the floodplain up to Singleton had been claimed by settlers and upstream of Maitland the majority of rainforest had been removed. At this time riparian bank vegetation downstream of Oakhampton was left intact. Maitland and its surrounding rural area emerged as an important commercial and farming area in the late 1800s, and this was the period when levee banks began to be constructed to protect and improve agricultural land. By the turn of the century floodplain vegetation had mostly been removed and backwater lagoons or swamps had silted up to the point where they had become suitable for cultivation (Patterson Britton & Partners 1993). The alluvial soils were rich, deep, soft and loose and easily brought into cultivation (Department of Water Resources 1987).

Agricultural practices in the early years of settlement in the Hunter Valley included overgrazing and over-clearing, and compaction of the soft, loose soil by sheep and cattle hooves resulted in dramatic alterations to the natural environment in a short time. These practices, combined with frequent flooding and occasional drought periods, resulted in the worst land and riverbank erosion in Australia (Department of Water Resources 1987). The Huddleston Report in 1948 estimated that the total soil loss from erosion in the Hunter Valley was in excess of 765,000 cubic metres annually (cited in Department of Water Resources 1987).

Basic settlement patterns in the Hunter were developed around colliery villages, early agricultural settlements on the rich alluvial flats and upland timber and coastal tourist/retirement centres. A more consolidated Newcastle urban area developed with the industrial growth of the 20th century (Department of Planning 1989).

From the first settlers, people have modified the natural environment to suit their needs. In the Hunter estuary a comprehensive scheme of flood mitigation works has been implemented over the years. Between the 1950s and the 1990s a large amount of natural area was lost, including 13% of the open waters and 67% of the saltmarsh (Williams et al. 2000). While there was also loss of mangroves in particular areas, the net area of mangroves in the Hunter estuary has increased in this period.

The direct loss of estuarine wetlands has been halted by the introduction of the State Environmental Planning Policy 14 (SEPP 14) in 1985 (DLWC 2000). If land clearing, draining, filling or construction of levees impact any SEPP 14 wetlands, these activities require government consent. Most estuarine wetlands in the Hunter catchment are covered by SEPP 14, the Fisheries Management Act and Policy and Guidelines for Aquatic Habitat Management and Fish Conservation 1998. Estuarine wetlands also receive protection by council local environmental plans. Concerning floodplain wetlands, many councils in the region have sought to protect them by appropriate development control zonings. A number of wetlands in the Hunter region have also been listed in the Directory of Important Wetlands in Australia (ANCA 1996). These are the Kooragang Nature Reserve (3,000 ha) and The Wetlands Centre (45 ha, formerly known as Shortland Wetland Centre). These areas are also listed Wetlands of International Significance under the Ramsar Convention.

3.2.2 Current Estuary Land Use, Zoning and Ownership

The land use map of the study area presented in Figure 3.2 was derived from DLWC land use information compiled in 2002 from aerial photography. In the upper part of the estuary, from Oakhampton to about Hexham and including the Paterson and Williams rivers as far as their tidal limits, the land use in the immediate river zone is agricultural. There is a distinct lack of bush or wetland areas along the river banks and a number of urban areas, including Maitland, Morpeth, Paterson, Seaham and Raymond Terrace, are located in the immediate vicinity of the rivers. This lack of natural areas and close proximity of economically and socially important agricultural and urban land to the rivers has played a large role in the hazard level posed by flood events and bank erosion over the years.

In the lower part of the estuary downstream of Hexham, the urban area of Newcastle dominates on the southern bank. The Newcastle port development, which encompasses roughly half of the south arm of the Hunter River, including Kooragang Island as well as Throsby Creek and Newcastle Harbour, comprises a large proportion of river-side land use in this area. The banks of the north arm of the Hunter River are, for a large part, dominated by the Kooragang Nature Reserve (managed by NPWS), and natural mangrove areas therefore dominate. The industrial area of Tomago and urban area of Stockton are located on either side of the Kooragang Nature Reserve on the northern bank and part of the port development on Kooragang Island is located on the north arm also.

The catchment beyond the immediate foreshore zone is a mixture of urban areas, bushland and industrial activities such as coal mining and quarrying, but in the upper estuary is predominantly agricultural land. A large area of land surrounding the Grahamstown Reservoir (which is itself outside of the study area) is reserved to protect the water quality of the reservoir. The city of Newcastle dominates the land area in the south-east of the catchment, with an area of approximately 9,000 hectares within the study area, and Hexham Swamp covers an area of approximately 2,500 hectares to the north-west of Newcastle. Much of Hexham Swamp is protected by the Hexham Swamp Nature Reserve (managed by NPWS). Beyond the extent of the study area, the catchments of the Paterson and Williams rivers contain significant areas of bushland in the Barrington Tops region to the north and the Wallis and Fishery creeks catchments to the south-west also contain bushland areas in their southern extremities.

Land zoning patterns have been provided by Newcastle City Council (mapping based on NCC LEP 2003), Maitland City Council (LEP 1993) and Port Stephens Council (LEP 2000) (Figure 3.3). The majority of the study area within these three local government areas is zoned for rural use. The larger areas zoned for residential use are Newcastle, East Maitland, Maitland and Raymond Terrace, with smaller areas at Morpeth, Seaham, Stockton, Beresfield, Woodberry, Hinton, Lorn, Bolwarra, Largs, Fern Bay and Wallalong. Areas zoned for industrial use include the Newcastle port area, Kooragang Island (excluding the Kooragang Nature Reserve area), Tomago, and areas in the vicinity of Beresfield. A Deferred Zone from the NCC LEP 1987 (industrial) has been imposed on part of Kooragang Island for an Infrastructure Corridor. Small patches zoned for business are located within each of the major urban areas of Newcastle, East Maitland, Maitland and Raymond Terrace. Land zoned for open space and recreation is typically located in association with residential areas and special use zoning relates to areas such as the Williamtown aerodrome and defence area at Stockton, various centres for further education, crematoriums and sewage treatment plants. Hexham Swamp Nature Reserve, Kooragang Nature Reserve (within Newcastle City Council boundaries only), and the Marine Park entailing the waterway of Fullerton Cove and part of the north arm are zoned National Park. Kooragang Nature Reserve in the vicinity of Fullerton Cove and Tomago is within the Port Stephens Council area, and this remains zoned as Rural (PSC pers. comm. 2003). Much of the area surrounding Hexham Swamp Nature Reserve is now zoned Environmental under the latest NCC LEP, as is the north-western end of Kooragang Island (Ash Island and Hexham Island). A large area surrounding Grahamstown Reservoir is zoned for environmental protection to maintain the water quality in the reservoir.

Ownership of land in the Hunter estuary was derived from Council cadastre layers, and relates primarily to Council-owned land, and National Park and Nature Reserve areas, owned by the State Government and administered by NSW National Parks and Wildlife Service.

Very little foreshore area along the Hunter estuary is owned by Council (Figure 3.4). Crown land does occur in some areas such as the foreshore on the left bank downstream of Raymond Terrace, the foreshore at Stockton and Walsh Point. Areas zoned Council operational land occur in small areas at Tomago, Raymond Terrace and Maitland. State Government ownership of National Park areas includes a large area of Hexham Swamp, Kooragang Nature Reserve, and north arm/Fullerton Cove, these areas forming part of the Kooragang Wetland Rehabilitation Project. The waterway of Fullerton Cove and part of the north arm is a Marine Park, and therefore comes under NPWS administration. In the estuary sub-catchment beyond the foreshore zone, land owned by Council is a combination of Crown, operational, lease and community lands.

3.2.3 Current Port-Side Land Use, Zoning and Ownership

Newcastle port-side land use (Figure 3.5, based on land information provided by DLWC) is dominated by industrial areas on both banks of the south arm, and Throsby Creek and Carrington Basin. Commercial areas occur along the Newcastle harbourfront and CBD, with the remainder of the Newcastle area and Stockton dominated by urban land use. Kooragang Nature Reserve (managed by NPWS) occurs along the northern side of Kooragang Island, and the eastern bank above Stockton Bridge, from Fern Bay to Sandy Island.

Extensive docking and wharf facilities occur throughout the port (Figure 3.5). Boating facilities within Throsby Creek include the marina utilised by the cruising yacht club, and Carrington boat ramp, also utilised by sea-faring vessels. Boat ramps are also located at Stockton and Kooragang Island.

Zoning of port land is largely a reflection of port-side land use (Figure 3.6). Significant areas of land on both banks of the south arm and Throsby Creek are zoned for industrial uses. Business zoning occurs along the foreshore of Throsby Creek, from Queens Wharf to Cowper Street bridge. The city of Newcastle is predominantly residential, with areas of open space, special uses, and business. Foreshore reserve along Stockton and in the vicinity of the northern breakwater is designated open space and special uses, and Stockton Hospital, Fort Wallace and sewage treatment works are zoned for special uses. Kooragang Nature Reserve is zoned National Park within the Newcastle City Council area, however within the Port Stephens Council area (northern bank of north arm), the Nature Reserve is zoned Rural (PSC pers. comm. 2003). The Marine Park in Fullerton Cove and the north arm is also zoned National Park by Newcastle City Council. Part of Kooragang Island is also zoned Environmental.

Ownership of port-side land is shared between a number of agencies (Figure 3.7). Newcastle Port Corporation owns port land in Carrington Basin, Throsby Basin and land along the breakwaters. BHP owns the old steelworks along the south arm which are currently being demolished, with future use of this land unclear at this point. Honeysuckle Development Corporation owns foreshore land along Throsby Creek and Throsby Basin, and this area is currently being developed by Honeysuckle Development Corporations. DPWS owns land along the south arm, Port Waratah, and around Walsh Point. State Rail Authority owns land along Steelworks Channel, and Grain Corp owns an area of land in Carrington Basin. Crown land extends around the Stockton Peninsula, and also at Walsh Point.

Newcastle Port Corporation has developed an Environmental Management Plan (EMP) for implementation in operations (NPC 1996). As part of the EMP, an Environmental Policy has been developed, and indicates NPC commitment to setting of rigorous environmental objectives and targets, conducting operations to minimise or eliminate environmental impacts, compliance with environmental legislation, and conducting business with other customers with a similar commitment. Under the EMP, tenants of NPC land are required to establish environmental management systems that comply with NPC policy and regulations. An Environmental Manual provides procedures for oil and cargo spills in the harbour.

3.2.4 Population Growth Effects

The entire Hunter region accounts for almost 10% of the State's total population. Population data and projections for the future for the Hunter region and the two main population centres in the Hunter estuary area, Newcastle and Maitland, are presented in Table 3.4. In 1961 the population of Newcastle was about 142,500 and Maitland's population was 27,500 (ABS 1996). Newcastle experienced a substantial steady decrease in its population in the 1970s and 1980s. This was mainly due to a migration from the older city areas. After a drop to 129,500 in 1986 the population of Newcastle recovered and is projected to continue to grow slowly in the coming years. The population of Maitland has steadily increased since the 1960s and is approximately 50,000 today, with projections for continued growth in the coming years.

Table 3.4 Populations and Projections

(ABS Census 1996)

	1961	**1981**	**1986**	**1991**	**1996**	**2006***	**2016***
Newcastle	142,574	135,193	129,490	131,309	133,686	141,400	144,000
Maitland	27,353	39,926	44,315	46,958	49,941	56,500	60,600
Hunter Region	355,840	458,704	482,774	513,765	540,499	615,800	663,800

* Medium level population projections

The increases in population that are predicted for the urban areas of the Hunter estuary sub-catchment have the potential to place increasing pressures on the state of the estuary. These could include a further decrease in natural habitat area and diversity with increasing development, conflicts of interest regarding the various uses of the river and estuary, increasing pollution problems through stormwater runoff and point source pollution such as discharges from sewage treatment plants, and reduction in biodiversity through increased levels of commercial and recreational fishing and habitat disturbance. There are, however, a range of policies and strategies that are in place or being prepared to control development and provide for human activities in the area without further degrading the environment. These include the Local Environment Plans and Development Control Plans developed by local councils and Lower Hunter and Central Coast Regional Environmental Management Strategy (LHCCREMS). A number of programs are also under way to rehabilitate the environment that has been degraded by past human activities in the area, including the Hexham Swamp Rehabilitation Program and the Kooragang Wetlands Rehabilitation Program. With appropriate management the Hunter estuary area should be able to provide for an increased population, while supporting important natural habitats and functioning as a healthy productive estuarine system.

3.3 Flood Mitigation

3.3.1 Early Flood Mitigation Works

Throughout the long history of flooding in the Hunter Valley there have been a large number of works carried out to prevent and mitigate against floods. Flood protection works were constructed around the Maitland area in a haphazard way from the late 1850s. A number of dams were built at this time that represent the first attempts to prevent inundation of the floodplain from the Hunter and Paterson rivers (Hawke 1960). Hawke (1960) states that the levee system, as it was known at the time of his report, was commenced at Maitland shortly after the 1864 floods and the levee system had begun to take shape by 1870. Cummins Dam was constructed in 1880 at Oakhampton across the natural floodway leading to Louth Park. A levee between Lorn and Bolwarra on the left bank of the Hunter River was first built in 1889 across the natural floodway through the Bolwarra flats. Floodgates were installed in Wallis Creek at the New England Highway crossing in 1870 and reconstructed in 1876 and 1941. Old levees along the right bank below Maitland were reconstructed and the river bank protected with stone in the 1930s (Patterson Britton & Partners 1993).

It is now known that the early levees constructed blocked natural flood relief channels and were often located too close to the river channel. The work was usually carried out by farmers without technical advice, with the objective of excluding all floodwaters. Without a coordinated valley-wide plan, the construction of levees often led to detrimental impacts on neighbouring properties and subsequent leveeing became necessary (Patterson Britton & Partners 1993). Further, many of these levees were destroyed in the record 1955 flood, with devastating consequences. Flood heights and velocities were increased by the high levee banks, with the result of increasing the damage to life and property across the floodplain.

3.3.2 The Lower Hunter Valley Flood Mitigation Scheme

Following the 1955 flood the State Government passed the Hunter Valley Flood Mitigation (HVFM) Act, which became law in December 1956 (this Act was later repealed, and its provisions taken up in the Water Management Act). The HVFM Act authorised the Department of Public Works with the concurrence of financial assistance of the Hunter Valley Conservation Trust (now known as the Hunter Catchment Management Trust), to carry out work designed for the purpose of preventing or mitigating the flooding or inundation of any lands within the lower Hunter Valley by waters from the river. Works to which the Act extended included:

- river bank protection and stabilisation
- river regulation
- river channel improvement
- river diversion
- dredging
- flood escapes and floodways
- floodgates
- levee banks (Hawke 1958).

The Public Works Department was responsible for works in the tidal region of the lower valley, while the Water Resources Commission had responsibility for the upper section of the valley (PWD 1980). In addition to the construction of flood mitigation works, the consequences of the 1955 flood provided impetus to the concept of managing development on the floodplain, which is now the preferred approach to reducing flood impacts in the lower Hunter Valley (HRC 2001).

The Lower Hunter Valley Mitigation Scheme was begun in 1956, with the aim of reducing the frequency of flooding, reducing the time floodwaters lie on land after the flood has passed, and controlling the direction and velocity of floodwaters to reduce damage to farmlands and property. The concept of the scheme was to confine the smaller floods to the river and when this was no longer possible in the case of larger floods, the aim was to gradually allow the floodwaters to spill into natural flood basins along the river (PWD 1980). As the rivers rise in the case of major floods, excess water is led through defined floodways and rejoins the river further downstream. Land is restored to normal production after floods by providing adequate drainage channels and floodgated outlets.

The flood mitigation scheme included a combination of methods and structures such as levees, drains, floodgates, spillways, floodways, control banks and bank protection works (see Figure 3.8). Levees are grassed earth embankments that are built along the river to confine the floodwaters of smaller floods. As they are designed to be overtopped in larger floods, levees are constructed with gentle backslopes to reduce the risk of scour and failure. After a large flood, floodwaters are trapped behind levees and in many places enlarged flood drains have been built to return the water to the river in a reasonable time. Where these large drains pass through a levee a floodgate is constructed, with a flap that opens only when the water level behind the levee is greater than that in the river, allowing trapped water to flow out. A spillway is the section of levee at the entrance to a floodway, which is the natural cross-country passage of overbank floodwaters. Spillways allow large volumes of flood water to leave the river in a controlled manner. Control banks are built perpendicular to the direction of flow at intervals along the length of some floodways. They form a series of basins which reduce the water velocity by dropping the floodwaters in steps safely across the land. Bank protection works are provided along the river in areas where serious erosion is occurring due to scouring action during floods (PWD 1980).

In total, the scheme consisted of 160 km of levees and spillways, 140 km of farm drains, 200 floodgates, 30 km of riverbank protection works and 40 km of control and diversion banks (DLWC 2002). These works almost covered the entire length of the Hunter River between Morpeth and Hexham, as well as along the Williams River downstream of Seaham. Another levee bank extends from Tomago to the opposite side of Fullerton Cove. In 1974, the majority of the levee banks were regraded and lowered (Mounser 1997).

The most significant parts of the scheme are in the Maitland area and comprise the Oakhampton and Bolwarra floodways, the Maitland levee and ring levees, and the Louth Park levees. The levee banks contain small and medium floods, while in larger floods the combination of spillways, control banks and levee banks allow floodwaters to leave the river near Oakhampton and flow around the towns of Maitland and Lorn.

3.4 Recreation

3.4.1 Recreational and Commercial Uses of the River and Foreshore

The Hunter estuary and its foreshores are used for a variety of activities including recreational and commercial fishing, boating, water-skiing, rowing, and picnicking at the foreshore reserves. The occurrence of each of these activities in the estuary may result in impacts on the estuary, and conflicts between the different users. These uses, impacts and conflicts are discussed below.

3.4.1.1 Recreational Fishing

The Hunter estuary is a popular place for fishing, although it is not generally renowned as one of the State's great fishing areas, except perhaps for mulloway (TEL 2001). Fishing methods are either shore-based or carried out using a range of boats, and methods include rods, hand lines, spears, prawn nets and crab pots (NSW Fisheries 2001). Preliminary results of an angling survey conducted by NSW Fisheries suggested that 30,000 recreational fishing events occur in the Hunter River, and 90% of these occur in estuarine or brackish areas. Most of these fishing trips occur from the shore (80%), and range from short bait collecting trips to a whole day of fishing (TEL 2001). The initial data suggest that the catch from the Hunter River is in the vicinity of 114,000 fish per annum, about 60% of which are likely to be retained and the remainder returned to the water. Ten of the most commonly caught species are flathead, mullet, luderick, bream, tailor, flounder, whiting, yellowtail, Australian bass and snapper (TEL 2001).

Recreational fishing occurs both from the shore and by boat in the Hunter estuary, and is allowed throughout the majority of the estuary. Areas with restricted activities (Figure 3.9) include:

- Throsby Creek upstream of Cowper Street bridge (no hoop nets or crab traps)
- south arm (no oysters or mussels)
- upstream of Hunter and Williams rivers from Raymond Terrace (only rods and handlines permitted) (TEL 2001).

Recreational fishing could potentially occur from a large number of shore areas in the Hunter River, however, certain reaches within the Hunter estuary may be more popular than others. Areas visited in the estuary for both shore and boat recreational fishing are summarised in Figure 3.9. Anecdotal evidence suggests that the northern breakwater of Newcastle Harbour is the most popular area for shore-based fishing in the estuary, with approximately 100 fishermen attending the site over a weekend (Warren Winter, NSW Fisheries, pers. comm. 2002). Shore-based fishing also occurs along the southern breakwater, Throsby Creek and Carrington Basin, however access is restricted due to public liability from the port-side landowners (Warren Winter, NSW Fisheries, pers. comm. 2002). Catches of dolphin fish (up to 3 kg) and striped tuna (up to 4 kg) have been reported around the port. Mulloway are also caught in this area and around the breakwalls at the entrance to the harbour. Other species commonly caught around the breakwalls include luderick, bream, tailor, mackerel and Australian salmon (TEL 2001).

Shore-based fishing also occurs at Stockton, the area being visited by approximately 12 fishermen on a weekend. Fishing also occurs at Tomago (approximately eight fishermen using the site over a weekend) and Kooragang Island (approximately six fishermen on a weekend) (Warren Winter, Fisheries Officer, pers. comm. 2002). Flathead are often caught around Stockton Bridge and there have been reports of 18 kg mulloway being caught from the deep water in this area (TEL 2001).

The south arm from Ironbark Creek to Hexham is used for shore fishing (approximately 10-20 people on a weekend), as public land next to the highway can be accessed in this reach. Upstream of Hexham to Raymond Terrace much of the land is privately owned, restricting access to the shore. Shore-based recreational prawning does occur in this reach, and fishing also occurs from the foreshore reserve at Raymond Terrace (Figure 3.9) (Warren Winter, NSW Fisheries, pers. comm. 2002).

In the upper estuary, a small amount of shore fishing occurs on the Paterson River, and was observed at several locations during fieldwork conducted by MHL (estimate of 10 people fishing from the shore in this reach on the weekend). A small amount of fishing occurs in the vicinity of Morpeth (MHL field observations), including the sewer outlet downstream of Morpeth. Recreational fishing on the Williams River is not common (Warren Winter, NSW Fisheries, pers. comm. 2002). A number of small private jetties occur in the upper reaches of the Hunter estuary including the Paterson River, and the Hunter River between Raymond Terrace and Morpeth (Figure 3.9, MHL field observations). Some of these jetties indicated use as fishing spots (e.g. chairs and rod holders present).

Anecdotal evidence suggests that fishing from boats is much more prevalent in the lower reaches of the estuary, particularly in the north arm at the mouth of Fullerton Cove, and upstream and downstream of the mouth of Fullerton Cove, shown in Figure 3.9 (MHL field observations, Warren Winter, NSW Fisheries, pers. comm. 2002, John Thompson, Waterways Authority, pers. comm. 2002). Some recreational fishing occurs in the north arm near Stockton Bridge, in the harbour (John Thompson, Waterways Authority, pers. comm. 2002) and was also observed in Mosquito Creek (MHL field observations). Fishing by boat is not common in the south arm, or upstream of Hexham to Raymond Terrace (Warren Winter, NSW Fisheries, pers. comm. 2002).

In the upper estuary, boat fishing occurs to some extent in the Paterson River (estimate of 12 boats over a weekend), with fishermen launching from the boat ramp near Tocal. Fishermen launching from the boat ramp at Morpeth (up to 10 on a weekend) may head downstream towards Raymond Terrace, or up the Paterson River (Warren Winter, NSW Fisheries, pers. comm. 2002).

3.4.1.2 Commercial Fishing

Commercial fishing is allowed in the majority of the estuary. The primary fishery for the Hunter River is the estuary prawn trawling, which involves approximately 33 trawlers (Warren Winter, Fisheries Officer, pers. comm. 2003). Commercial fin-fishing also occurs, although trawling for fin fish is not permitted (TEL 2001). Areas with limited commercial fishing activities are similar to those for recreational fishing (Figure 3.10). These include:

- Throsby Creek upstream of Cowper Street Bridge (closed to all methods).
- upstream of Hunter and Williams rivers from Raymond Terrace (only mesh netting permitted).
- main harbour area (closed to prawn trawling and meshing (TEL 2001).

The Hunter River has been divided into six sub-divisions for the purposes of regulating prawn trawling. NSW Fisheries determine where and when prawn trawling is permitted based on checks of the size and number of prawns caught in each sub-division, but most prawn trawling tends to occur in the north arm. There are no restrictions on the number of trawlers that work in a sub-division at any one time (TEL 2001).

Currently, the prawn trawling season is from October to May - the period when large maturing prawns are found in the lower reaches of the estuary (see Section 4.7.2.2). There are, however, no seasonal closures for mesh netting – this technique can be used every day of the year, 24 hours a day (TEL 2001). Further details of prawn trawling and commercial fishing are provided in the Aquatic Ecology Report (TEL 2001).

Approximately 20 oyster leases occur in the north arm near Fern Bay, occupying a relatively small area (Figure 3.10).

3.4.1.3 Boating

Boating activities occur throughout the estuary, as indicated by the presence of boating facilities. Common areas for recreational boating activity on the Hunter estuary are summarised in Figure 3.9. Boats in the Hunter estuary may be used for recreational and commercial fishing, and other activities such as water-skiing. Boating facilities include major boat ramps at Carrington, Stockton, Raymond Terrace (Fitzgerald Bridge), Kooragang Island, Tomago and Morpeth. Carrington and Stockton boat ramps are heavily used for offshore and harbour boating. Fitzgerald Bridge boat ramp is also regularly used (John Thompson, Waterways Authority, pers. comm. 2002). A marina is located in Throsby Creek as part of the yacht club. Mooring facilities are restricted in the estuary to a group of eight at Stockton (see Figure 3.9).

No sewage pumpout facilities for boats are present in the estuary.

3.4.1.4 Waterskiing

Waterskiing on the Hunter estuary generally occurs along the Williams River, with the most heavily used area being the first 1-2 km upstream of Fitzgerald Bridge. Some water-skiing also occurs in the Hunter River between Raymond Terrace and Morpeth (John Thompson, Waterways Authority, pers. comm. 2002). Waterskiing does not generally occur in the immediate vicinity of Raymond Terrace township due to speed restrictions (Figure 3.9) (Warren Winter, Fisheries Officer, pers. comm. 2002, Clive Carlstrom, Deputy President, Endeavour Rowing Club, pers. comm. 2002).

3.4.1.5 Rowing

Rowing in the upper Hunter estuary occurs predominantly along Swan Reach on the Hunter River (Clive Carlstrom, Deputy President, Endeavour Rowing Club, pers. comm.) (Figure 3.9). During the week, Swan Reach is utilised daily by approximately 10–15 rowers, increasing to 20-30 rowers on a Saturday or Sunday. Rowing also occurs in Throsby Creek, upstream of Cowper Street Bridge (John Thompson, Waterways Authority, pers. comm.. 2002).

3.4.1.6 Foreshore Reserves

Foreshore reserves and picnic areas occur throughout the estuary, and are associated with urban areas such as Newcastle, Raymond Terrace, Morpeth and Paterson (Figure 3.9). These areas are utilised for picnicking and leisure activities, including recreational shore fishing e.g. Raymond Terrace, Stockton. Picnicking areas are also provided on the Ash Island site of the Kooragang Wetlands (Figure 3.9).

3.4.1.7 Bird Watching

As part of the Kooragang Wetlands Rehabilitation Project, bird observation areas have been established at the Stockton Spit and on Ash Island (Figure 3.9). Bird watching is also conducted at The Wetlands Centre within Hexham Swamp.

3.4.1.8 Walking/Cycling Paths

As part of the Kooragang Wetlands Rehabilitation Project, walking/cycling paths have been established throughout the Ash Island site, providing an opportunity to observe wildlife (Figure 3.9).

3.4.2 Opportunity Areas for Tourism, Public Reserves and Facilities

Potential 'opportunity' areas for tourism were determined from observations during MHL's fieldwork. Areas considered to have potential to increase tourism include Throsby Creek and Newcastle harbourfront, and Morpeth may provide potential for an increase in water-based activities. The rehabilitation of Hexham Swamp and the re-opening of the floodgates may provide a tourism opportunity in the future, with the hopeful return of a rich and diverse wetland area, enabling greater observation opportunities (Reg Hyde, local resident, pers. comm. 2002).

Redevelopment plans for the Newcastle harbourfront and Throsby Creek have and will continue to improve the aesthetics of the area, and increase tourism opportunities (Honeysuckle Development Corporation 2002). The redevelopment forms part of the Throsby Creek Total Catchment Management Strategy to rehabilitate and develop its foreshores and includes consideration of waterway development (Public Works 1991, Patterson Britton 1988). Completed areas in the development plans include a foreshore reserve, cycle path and walkway at Throsby Creek (Figure 3.9). Construction of a Fishermen's Co-operative and second marina (Figure 3.9) at Throsby Creek will also enhance tourism opportunities for the area. Carrington boat ramp also enables waterway access. The redeveloped Cowper Street Bridge also allows for greater clearance of boats, although clearance is still relatively low (John Thompson, Waterways Authority, pers. comm. 2002).

As a historic town and popular destination for arts and crafts (Keith Hutchinson, resident, pers. comm. 2002), Morpeth has potential for an increase in water-based activities. While drawing a number of tourists for land-based activities, little advantage is taken of the possibility of alternative activities such as boating or fishing. The foreshore reserve is well located close to the town, with an amenities block and boat ramp, however, the boat ramp is relatively narrow, and consideration has been given to a potential upgrade in the past (John Thompson, Waterways Authority, pers. comm. 2002). The riparian vegetation near the town is degraded and sparse and therefore could be planted with native vegetation to enhance the stability of the bank and improve aesthetics. However, land tenure may restrict any works along the foreshore, as much of the land is privately owned.

A potential ‘opportunity’ area for a new foreshore reserve exists on the Paterson River, between Paterson and Tocal. This area would serve the dual purpose of removing riparian weeds, and replanting with native plants, and would also provide a foreshore reserve for the public. Removal of riparian weeds in some sections has already been carried out by C.B. Alexander Agricultural College. Available access points include the boat ramp at Tocal. Land tenure issues would need to be resolved to advance this potential opportunity, as this area forms part of Dungog Local Government Area.

The general condition of boat ramps in the Hunter estuary is considered reasonable (John Thompson, Waterways Authority, pers. comm. 2002). Stockton boat ramp has recently been upgraded as it is heavily used for boating within the harbour and offshore activities, and includes fish cleaning facilities (see Figure 3.9 for locations of boat ramps). Tomago and Raymond Terrace (Fitzgerald Bridge) boat ramps are in good condition, however carpark limitations are an issue at Raymond Terrace. Carrington boat ramp facilities have been an issue in the past, as the boat ramp is heavily utilised on weekends (John Thompson, Waterways Authority, pers. comm. 2002). This ramp, however, is in the process of being upgraded. Newcastle City Council and Waterways Authority are funding widening of the ramp and the construction of fish cleaning facilities. Morpeth boat ramp is restricted due to its narrowness. Previous plans for Morpeth included widening and relocation of the boat ramp, however these plans were affected by identification of a heritage site in the proposed development area (John Thompson, Waterways Authority, pers. comm. 2002). Kooragang Island boat ramp does require some maintenance, particularly in relation to rubbish disposal facilities. Rubbish disposal facilities do not currently exist at the site, consequently leading to rubbish dumping (John Thompson, Waterways Authority, pers. comm. 2002).

3.4.3 Impacts of Recreational Uses

Impacts related to recreational uses of the Hunter estuary include possible effects on sustainability of fish populations, and effects on bank erosion from boat wakes. Anecdotal evidence suggests there has been a general increase in recreational activities in the Hunter estuary in recent years (John Thompson, Waterways Authority, pers. comm. 2002), and increasing use may lead to an increase in conflicts and impacts.

The effect of commercial and recreational fishing on the sustainability of fisheries is uncertain (NSW Fisheries 2001). The use of indicators such as catch per year do not accurately reflect the health of a fishery, as factors such as life cycle and future recruitment are not taken into consideration. Large catches of targeted species may decrease their abundance, potentially to very small numbers, and could lead to over-fishing (TEL 2001).

Additional impacts of commercial fishing include by-catch issues, leading to non-target species being affected by the fishing. By-catch is a primary concern for large-scale fishing techniques such as trawling. Therefore the Hunter Estuary Prawn Trawling Fishery could potentially affect a variety of species of crustaceans and fish (TEL 2001).

Fishing gear such as prawn trawl nets can also affect habitat important for the long-term survival of many shellfish and finfish. This habitat includes seagrass, mangroves and saltmarsh (NSW Fisheries 2002).

Associated with boating activities such as fishing and water-skiing are potential impacts from boat wakes. Boat wakes may be an important factor in the lower estuary from Raymond Terrace to Hexham, and in narrow reaches near Campbell Island, Mosquito Creek and Smiths Creek (Figure 3.9, MHL field observations). In these reaches, the predominant wave energy is caused by boat wakes as they move along the river. Unvegetated banks are particularly susceptible to erosion, however some vegetated banks in these areas are also affected. Boat wakes from water-skiing in the Williams River may also affect bank stability, together with aeolian activity (Sinclair Knight & Partners 1990).

Recreational and commercial fishing also have an impact on shorebirds using roost sites such as the Kooragang Dykes and the Stockton Sandspit, as boating activities may lead to disturbance of the birds from their roosts.

3.4.4 Conflicts of Recreational Uses

Possible conflicts associated with recreational uses of the Hunter River include issues between recreational and commercial fishermen, and conflicts between boating activities, and other recreational activities such as rowing.

Conflicts can arise in regard to recreational fishers questioning possible impacts of commercial fishing on the sustainability of fisheries (John Thompson, Waterways Authority, pers. comm. 2002). Commercial fishers argue that environmental issue such as loss of habitat and impacts of pollution have a greater effect on decreasing fish stocks than commercial fishing (NSW Fisheries 2002a). Fishing closure zones help minimise any spatial issues between commercial and recreational fishermen, particularly in the harbour (Figures 3.9, 3.10). Prawn trawlers have agreed to trawl during daylight hours (6.00 am to 6.00 pm) on Mondays and Wednesdays only, to help prevent any conflict with recreational fishers.

Of growing concern is the issue of recreational boaters obstructing commercial shipping activities in the port, creating difficulties for commercial ships (John Thompson, Waterways Authority, pers. comm. 2002).

Conflicts between boat users for activities such as water-skiing and other recreational activities may potentially occur. The spatial separation of these activities minimises conflicts between these activities, with water-skiing occurring in the Williams River, and rowing occurring in Swan Reach in the Hunter River and in Throsby Creek (Figure 3.9). Occasional problems occur with water-skiers speeding past rowers in Swan Reach, but these are infrequent (Clive Carlstrom, Endeavour Rowing Club, pers. comm. 2002)

3.4.5 Sustainable Use of the Estuary as a Recreational Resource

Of primary concern for future ecologically sustainable use of the Hunter estuary as a recreational resource is the occurrence of fishing and boating activities. All fisheries can have impacts, and these impacts need to be managed. As a starting point, by-catch reduction devices to reduce incidental catches have been mandatory in the Estuary Prawn Trawling Fishery since December 2000 (NSW Fisheries 2002b).

Community consultation has recently been carried out by NSW Fisheries regarding sustainability of fishing in NSW, including the Hunter estuary, and possible management options (NSW Fisheries 2002a). One outcome of the consultation was a suggestion put forth by the Hunter Estuary Prawn Trawling Fishery involving the closure of an area of the north arm between Fern Bay and Sandy Island (see Figure 3.9) to prawn trawling. In addition to this, it was recommended that funding earmarked for the proposed recreational fishing strategies could be utilised to rehabilitate Mosquito Creek, and the swamp and saltmarsh areas in the north-west corner of Kooragang, for the purpose of improving these areas as potential fish nursery habitats (NSW Fisheries 2002a). This suggestion received support from the Hunter River Prawn Trawlers, Newcastle City Council, and the Hunter Coast and Estuary Management Committee(NSW Fisheries 2002a).

Decreasing the number of fishing licences in the Hunter estuary may also assist in improving the sustainability of the estuary as a recreational resource.

Management plans for the river channel would need to look closely at necessary controls on boating to preserve the fragile foreshore areas. Few restrictions on boat speeds currently occur in the Hunter estuary (Rob Colless, Waterways Authority, pers. comm.) Greater restriction on boat speeds in areas vulnerable to bank erosion, such as Williams River, Mosquito Creek, Smiths Creek and Campbell Island may assist in minimising further bank erosion.

3.5 Dredging

3.5.1 Dredging in Newcastle Harbour

Dredging first commenced in the Hunter in 1845 and has been occurring almost continuously since 1859. The port has been dredged to develop new facilities as well as to maintain the channel due to the large amount of sand and silt that is carried down the Hunter River, especially in times of flooding. In 1951 the Public Works Department of New South Wales commenced a 20-year dredging and land reclamation project (Patterson Britton & Partners 1996b). These activities were supported by the passage of the *Newcastle Harbour Improvements Act 1953* which also supported the formation of a single land mass from the nine islands of the lower Hunter (Williams et al. 2000). The formation of a single land mass of islands involved a resultant loss of an estimated 1,000 hectares of fisheries and other wildlife habitat (Henderson 1997). Much of the dredge spoil from the early dredging programs was put onto the shoals at the eastern end of Mosquito Island. Within a few years enough material had been deposited to form a new island, known as Walsh Island (Williams et al. 2000).

Dredging of the north arm of the Hunter River has been suggested as an option for reducing flood levels (Patterson Britton & Partners 1996b). A potential impact of this option is that the dredge channel would likely act as a sediment sink, leading to a requirement for ongoing maintenance dredging. Dredging has been largely concentrated in the area of the Kooragang coal loader on the west side of Walsh Island (Boyd 2001). Dredging in the Port of Newcastle began in 1858 and has been virtually continuous since. The entrance and harbour show high siltation rates, with annual maintenance dredging currently removing around 300,000 m^3/year (Newcastle Port Corporation, pers. comm. 2002). The amount of material dredged from Newcastle Harbour from 1851 to 1962 is shown in Table 3.5.

Table 3.5 Newcastle Harbour Dredging 1851-1962
(PWD 1963)

Date	Average millions of tons dredged
1851 – 1866	0.1
1866 – 1878	3.7
1878 – 1884	3.6
1884 – 1891	8.2
1891 – 1896	10.5
1896 – 1902	12.1
1902 – 1909	22.5
1909 – 1916	19.4
1916 – 1921	8.2
1921 – 1926	11.6
1926 – 1938	23.3
1938 – 1950	19.5
1950 – 1957	23.9
1957 – 1962	21.5

NB: Results obtained from sources other than map comparisons

Today, Newcastle Port Corporation's dredger the *David Allan* carries out dredging in the lower Hunter. The port is subdivided into four sub-sections – A, B, C and D, and maintenance dredging is carried out to a depth of 15.2–15.6 m (Figure 3.11). These areas take into account the history of sedimentation and physical layout of the port area (Patterson Britton & Partners 1996b). The majority of the material is disposed of offshore, with some being used for landfill. The current annual amount dredged from the port is approximately 300,000 m^3 (Newcastle Port Corporation, pers. comm. 2002). Table 3.6 presents the total dredging quantities for the period 1992–1994.

Table 3.6 Summary of Total Dredging Quantities 1992-1994
(Patterson Britton and Partners 1996)

Year	Dredging Quantity (tonnes)[1]
1992	196, 600
1993	300, 200
1994	255, 200

[1] As measured on board the dredger and noted in dredging logs

In 1995 a Technical Advisory Consultative Committee (TACC) was established in accordance with the special sea dumping permit obtained by the NPC for activities in the Port of Newcastle. The TAC drafted a set of goals and objectives as part of the development of a long-term strategy for the continued management of the dredged spoil. These included:

Goals

- Effective management of the marine environment
- demonstrated achievement of the above
- facilitate long-term port development and management, and
- develop and implement a long-term management strategy for dredge spoil in the Port of Newcastle.

Objectives

- Minimise the impact on marine habitats
- identify areas with potential elevated levels of heavy metals in the Port of Newcastle
- minimise the bio-accumulation of contaminants in marine organisms, and
- identify the source of contaminants existing within the Port of Newcastle.

NPC was granted a five-year sea dumping permit by Environment Australia that commenced in July 2000. For the purpose of permit applications, data is collected on dredged sediment. Sediment arriving in the port from upstream areas is not normally contaminated when it arrives in the port but may become so after a time due to the uptake of diffuse and point source pollution from the port environment. Because of this, areas that are regularly dredged, such as for maintenance dredging, tend to have lower levels of contamination (Patterson Britton & Partners 1996b). The build-up of contaminants in the sediments can potentially cause adverse impacts on the aquatic life in the harbour.

3.5.2 Other Dredging Areas

Dredging of Throsby Creek was conducted between Hannell Street and Cowper Street bridges during the early 1990s as part of the rehabilitation of Throsby Creek under the Throsby Creek Total Catchment Management Strategy (HCMT 2001). The dredged material was used to fill residential and open space land on either side of the creek, and was also disposed of on Kooragang Island.

Dredging was also observed on the Hunter River at Maitland during construction of the large rock revetment on the outside bend of the river (MHL field observations).

3.5.3 Impacts of Dredging

Dredging activities have the potential to impact upon habitats of both ecological and commercial significance within the Hunter estuary including:

- Extensive mangrove forests and salt marshes around Fullerton Cove and Kooragang Island.
- Wetlands of both national and international significance. There are some wetlands listed under SEPP 14 in the vicinity of Fullerton Cove, as well as wetlands listed under the Ramsar convention as they are utilised by migratory birds.
- Oyster leases in the northern arm of the Hunter River and Fullerton Cove.
- Species of fish and invertebrates that spend part of their lifecycle in the estuary.
- Recreational and commercial fishing within the estuary.
- Shore birds present within the estuary.

The potential impacts of the dredging include:

- Potential for the release of contaminants during dredging which can impact on oysters and other biota, however Patterson Britton & Partners (1996b) state that 'the likelihood of contaminants becoming bio-available during maintenance dredging to any significant degree is considered remote'.
- Dredging resuspends sediments, increasing turbidity, with potential impacts on filter-feeding animals such as oysters, foraging behaviour of fish, and increased risk of disease due to abrasion of protective mucus coats on fish (TEL 2001).
- Disturbance of benthic biota. During dredging, the top layer of sediments is removed. When this layer is removed, so too are the bottom dwelling biota on the harbour floor. Due to the disturbance, they are then required to re-colonise over a period of days to months.
- Removal of sand flats, therefore resulting in loss of wading habitat and overcrowding in those areas that remain for shore birds present in the estuary.
- Dredging may have the potential to disrupt the migration from the sea and the port of fish and invertebrates further into the estuary, as the turbid and possibly contaminated waters may deter fish and invertebrates from entering the estuary. On consideration of anecdotal evidence by Patterson Britton & Partners (1996b), the dredging activities were not considered to be a significant problem as species have been seen upstream of the port. It is recommended that more information be obtained regarding this issue.

Few studies have attempted to identify the effects of dredging on aquatic biota in the Hunter estuary. It is, however, almost certain that the organisms that would be affected most by dredging are the benthic invertebrates living in and on the sediments. Because no studies have sampled benthic invertebrates in the channels of the Hunter River, it is not known what species occur there. Studies of invertebrates in other dredged estuaries indicate that the assemblages may change greatly after being dredged, but there is little information available about the recovery of benthic invertebrates after dredging. Some results have suggested that recovery may start after just a couple of months, whilst others have detected no recovery after 11 months. It is important to understand, however, that dredged areas will be deeper than they were initially and consequently any assemblages of animals that colonise the dredged areas are likely to be different from those that existed in shallower areas prior to dredging (TEL 2001).

The impact of dredging on tidal flushing depends on the amount and location of the dredging exercise and the existing tidal regime. Dredging will have its greatest effect in areas where the tidal gradients are greatest. The maintenance dredging in the entrance area is not likely to affect the tidal characteristics in the estuary because the dredged volume is not significant when compared to the volume of water in the lower port area. Dredging further upstream, say in the north arm, may impact the tidal regime and flushing within that region but this effect would diminish further upstream and would not impact the location of the tidal limits. The tidal flushing may be increased depending on the dredge volumes. For example a deepening from 5 to 14 m for shipping purposes is likely to lead to a minor increase in the tidal range further upstream.

The proposed dredging of the south arm may have significant impacts on river stability, which should be addressed in the EIS currently being undertaken for the South Arm Master Dredging Plan. The proposed dredging of the south arm will improve navigation for large vessels, and may also lead to an improvement in navigation of the south arm for smaller vessels. Current dredging of the port area and the proposed dredging of the south arm are unlikely to affect the location of the tidal limits in the estuary, due to the large distance between the port and the tidal limits.

3.5.4 Proposed Dredging

The current proposal for the dredging of the south arm involves dredging of the Hunter River to the Tourle Street bridge to enable shipping movements up the river to new wharf facilities which will service industry located at Tomago and on Kooragang Island (Wayne Green, Premiers Department, pers. comm. 2002, Douglas Partners 2001b, Newcastle Port Corporation, pers. comm. 2002). The current depth of the south arm is approximately 2-4 m, and it is proposed to increase this to a depth of 15.2 m, with the spoil to be dumped offshore or used for landfill (Newcastle Port Corporation, pers. comm. 2002). An Environmental Impact Statement for the South Arm Master Dredging Plan into the possible impacts of this dredging is currently being undertaken. It is recommended that when the EIS is finished, its results, conclusions and recommendations be taken into account regarding the management of the lower Hunter estuary.

3.6 Sand and Gravel Extraction

3.6.1 Sand and Gravel Extraction in the Hunter Estuary

Sand and gravel is extracted from the banks and bed of the river at various locations. The Department of Land and Water Conservation administers the removal of sand and gravel within 40 m of a river under the *Rivers and Foreshores Improvements Act 1948* to ensure that extraction operations do not destabilise the bed and banks of rivers (DLWC 1999).

Maitland City Council has provided details of quarry developments in the Maitland Local Government Area (LGA), including extraction rates (Table 3.7). The locations of these sand and gravel extraction operations within the study area are presented in Figure 3.13.

Table 3.7 Estimated Extraction Rates for Quarry Developments*

Quarry Name and Location	Estimated Extraction Rate (m^3/annum)
Maitland Sand and Soils Pitnacree Road, East Maitland	85,847
Rosebrook Sand and Gravel Campbells Road, Maitland Vale	68,395
Sarraf Goulburn Road, Largs	462

Source: Claire Hendley, Maitland City Council, pers. comm. 2002

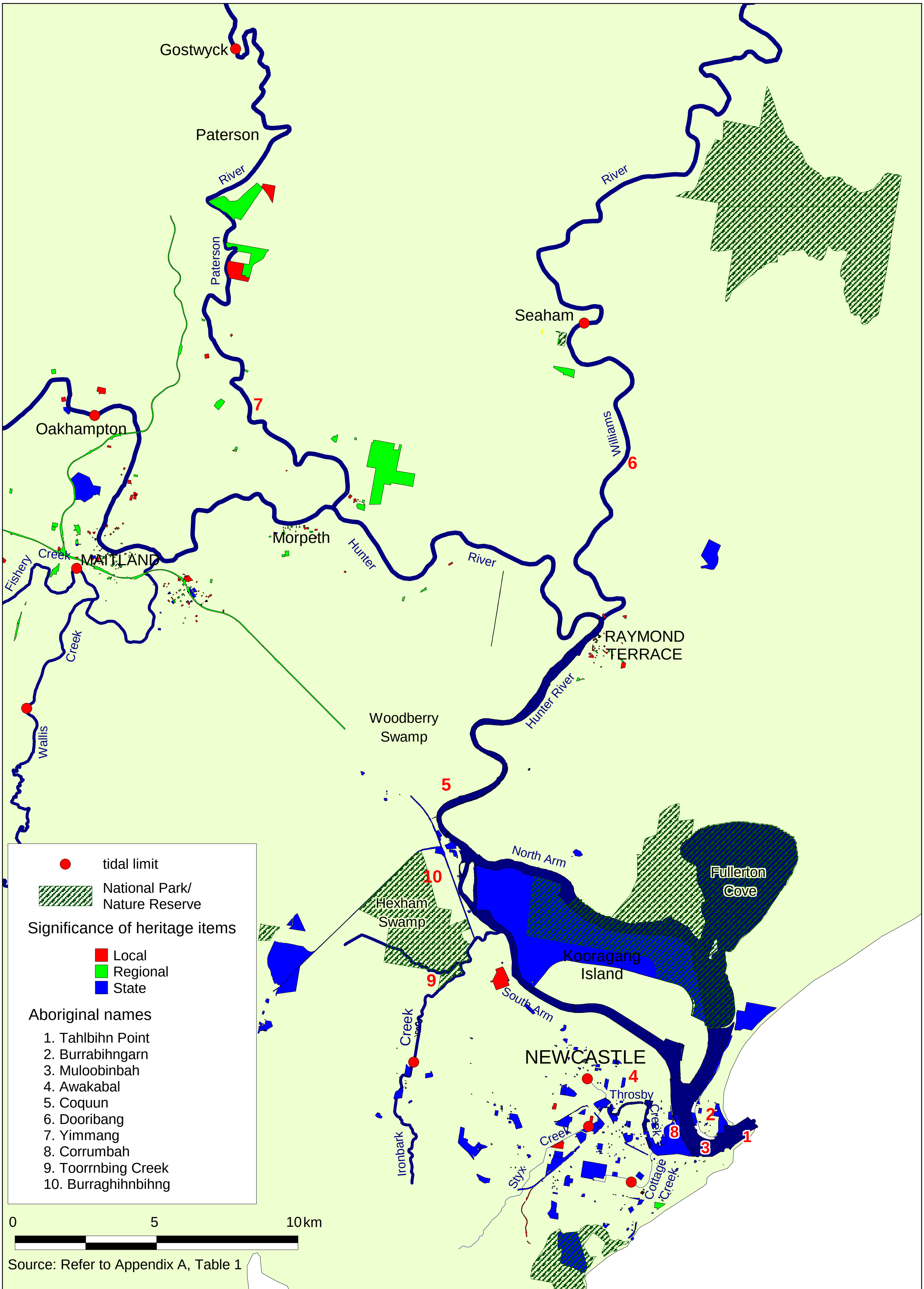
*Note: the extraction rates identified in the table are estimates based on the information supplied with the development applications for these sites and may not reflect the actual extraction from each site.

3.6.2 Impacts of Extraction

Sand and gravel extraction can initiate bed and bank erosion in two ways. Firstly, inappropriate extraction of the bed of a river can lead to upstream bed erosion and resultant channel widening. Secondly, removal of sediment bed loads can cause downstream sediment starvation, increasing the energy available to the river and resulting in bed and bank erosion (DLWC 2000).

3.6.3 Proposed Extraction

The nature of the current extraction licences is such that it is difficult to determine the length of time that current operations will continue. Maitland City Council does not currently have any applications lodged for new extraction areas in its LGA (Claire Hendley, Maitland City Council, pers. comm. 2002).



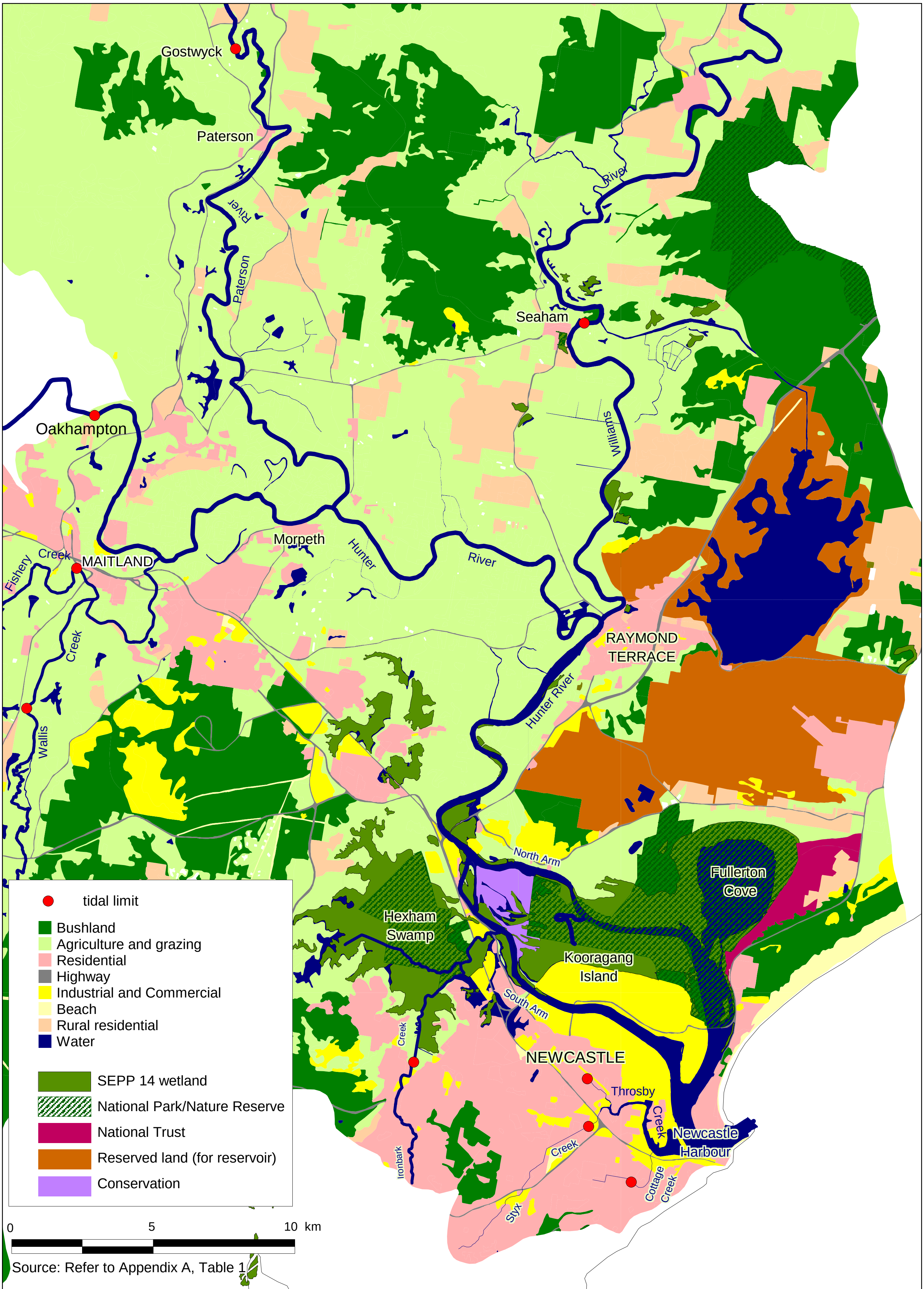
NSW DEPARTMENT OF PUBLIC WORKS AND SERVICES
MANLY HYDRAULICS LABORATORY

AREAS OF HERITAGE SIGNIFICANCE AND ABORIGINAL NAMES FOR HUNTER ESTUARY SITES

MHL Report 1095

Figure 3.1

DRAWING 7_1.WOR



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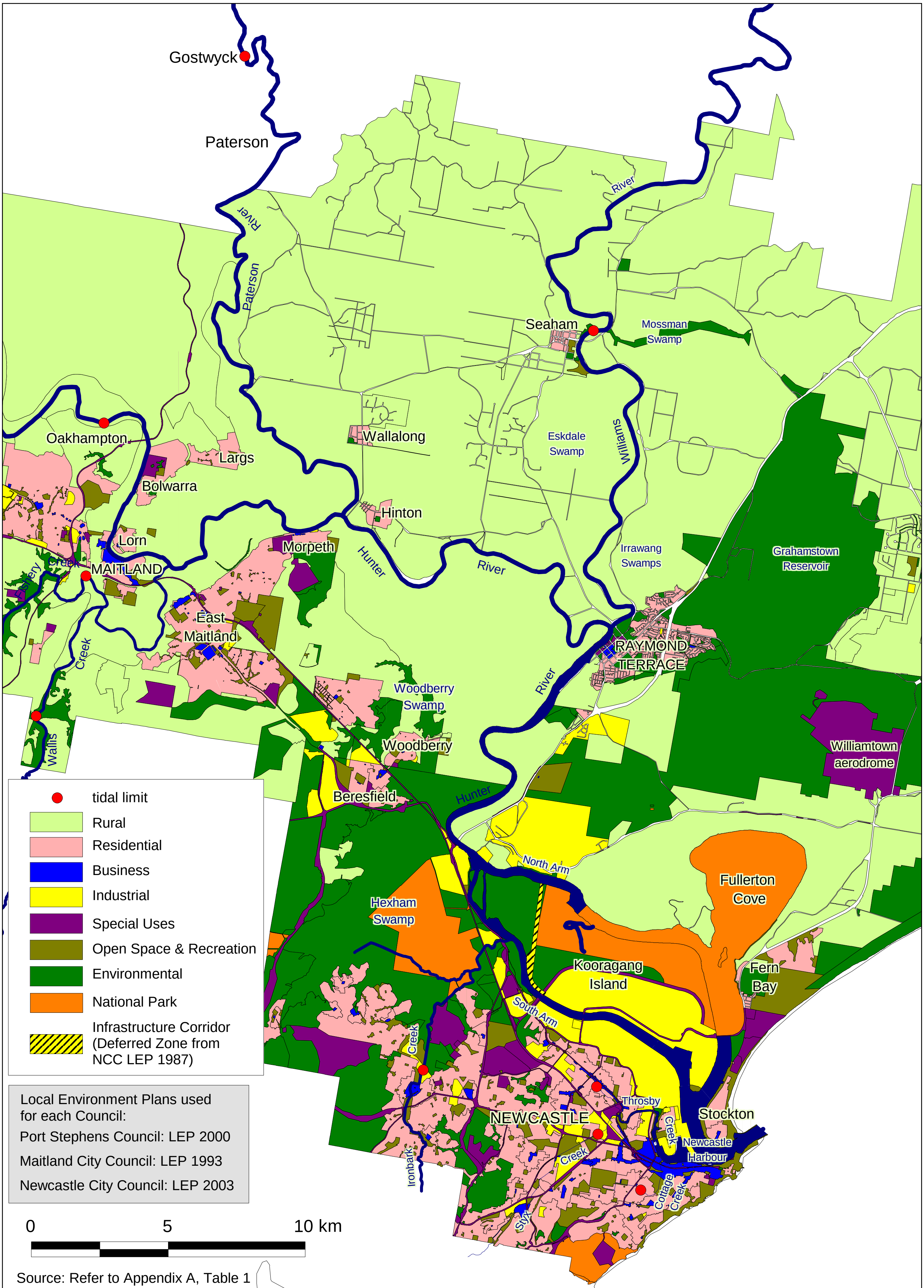
HUNTER ESTUARY LAND USE

MHL Report 1095

Figure 3.2

DRAWING 8_1.WOR



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HUNTER ESTUARY LAND ZONING

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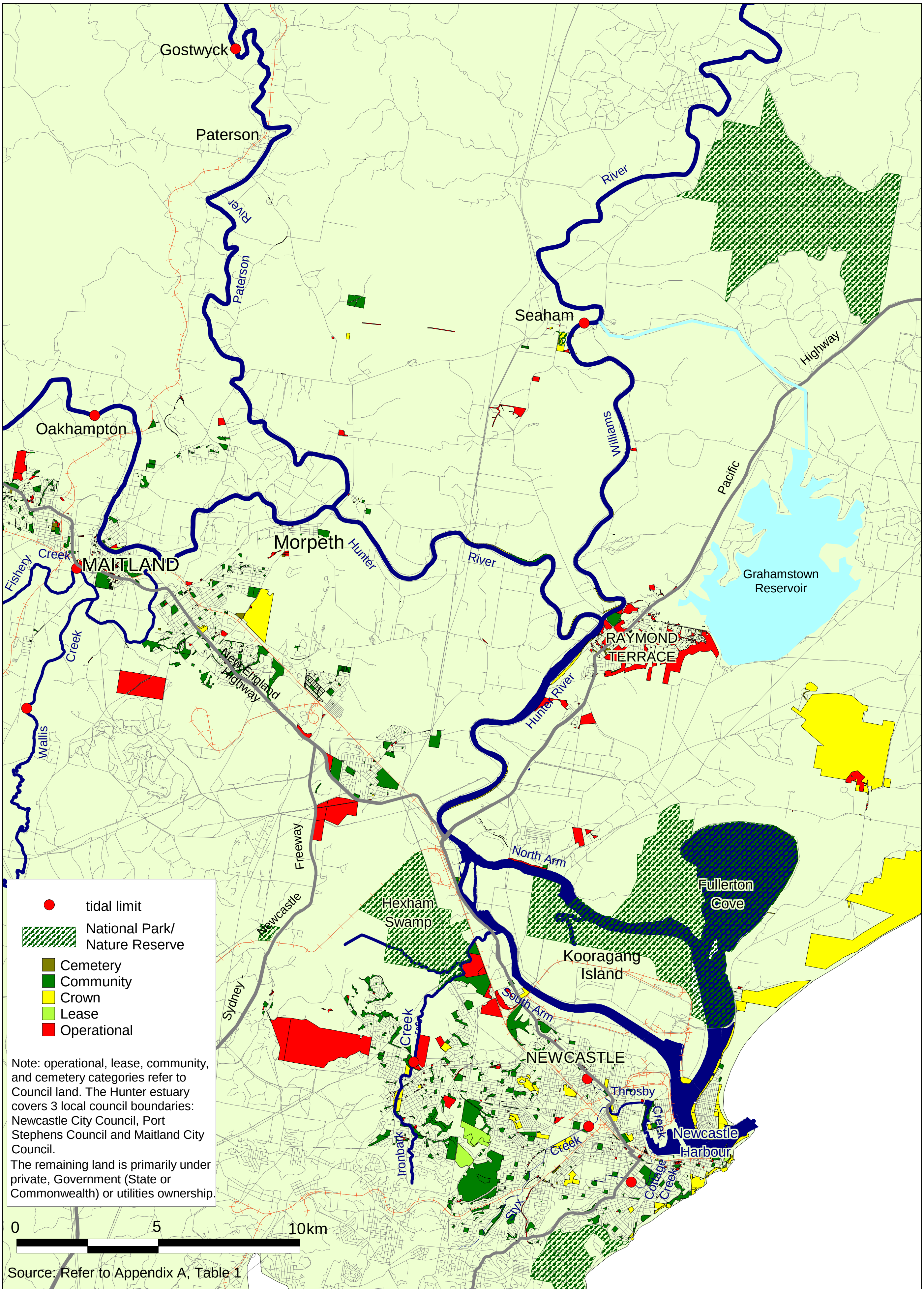
Figure 3.3

DRAWING 8_2.WOR



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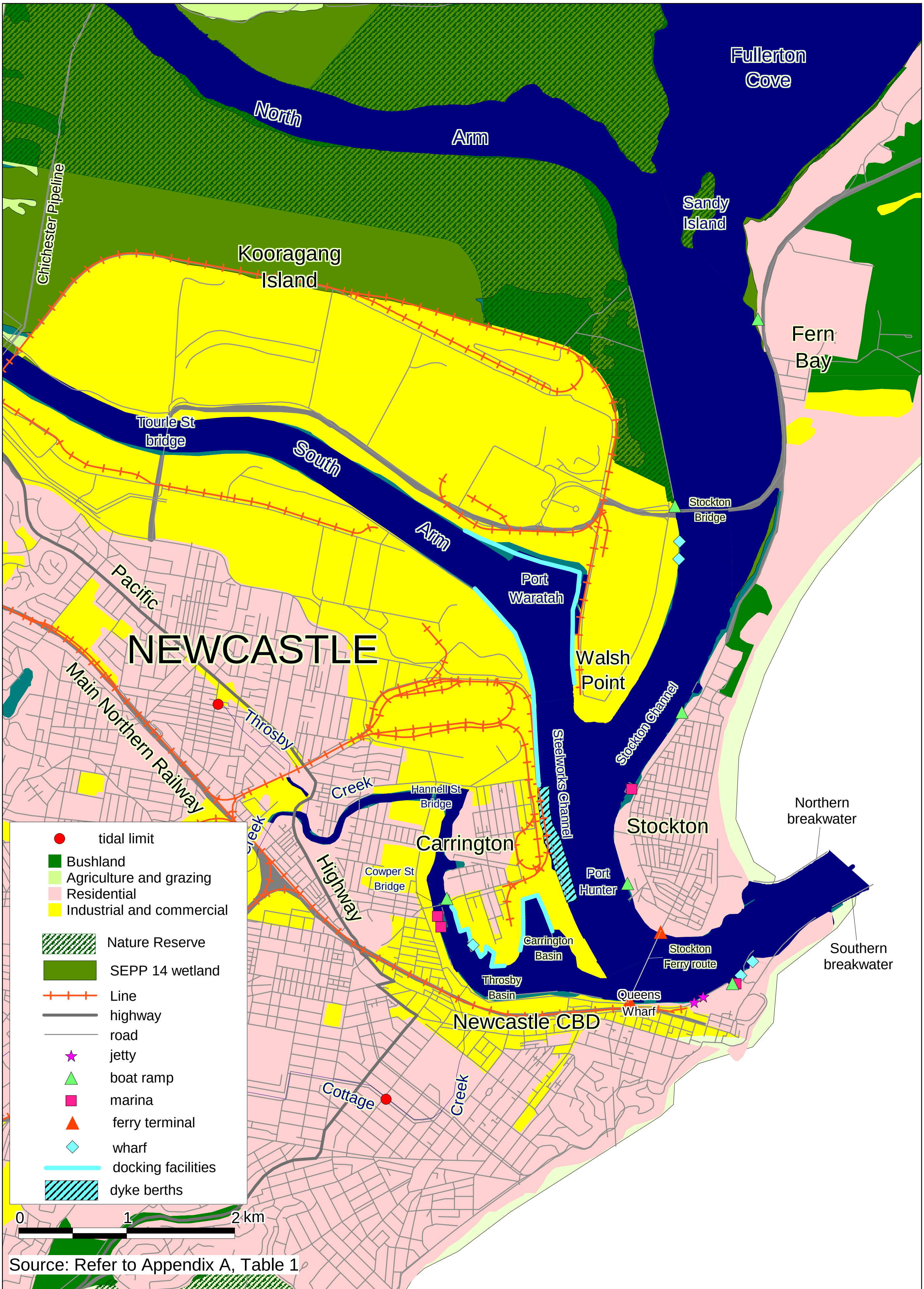
HUNTER ESTUARY LAND OWNERSHIP

MHL Report 1095

Figure 3.4

DRAWING 8_3.WOR



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NEWCASTLE PORT-SIDE LAND USE AND INFRASTRUCTURE

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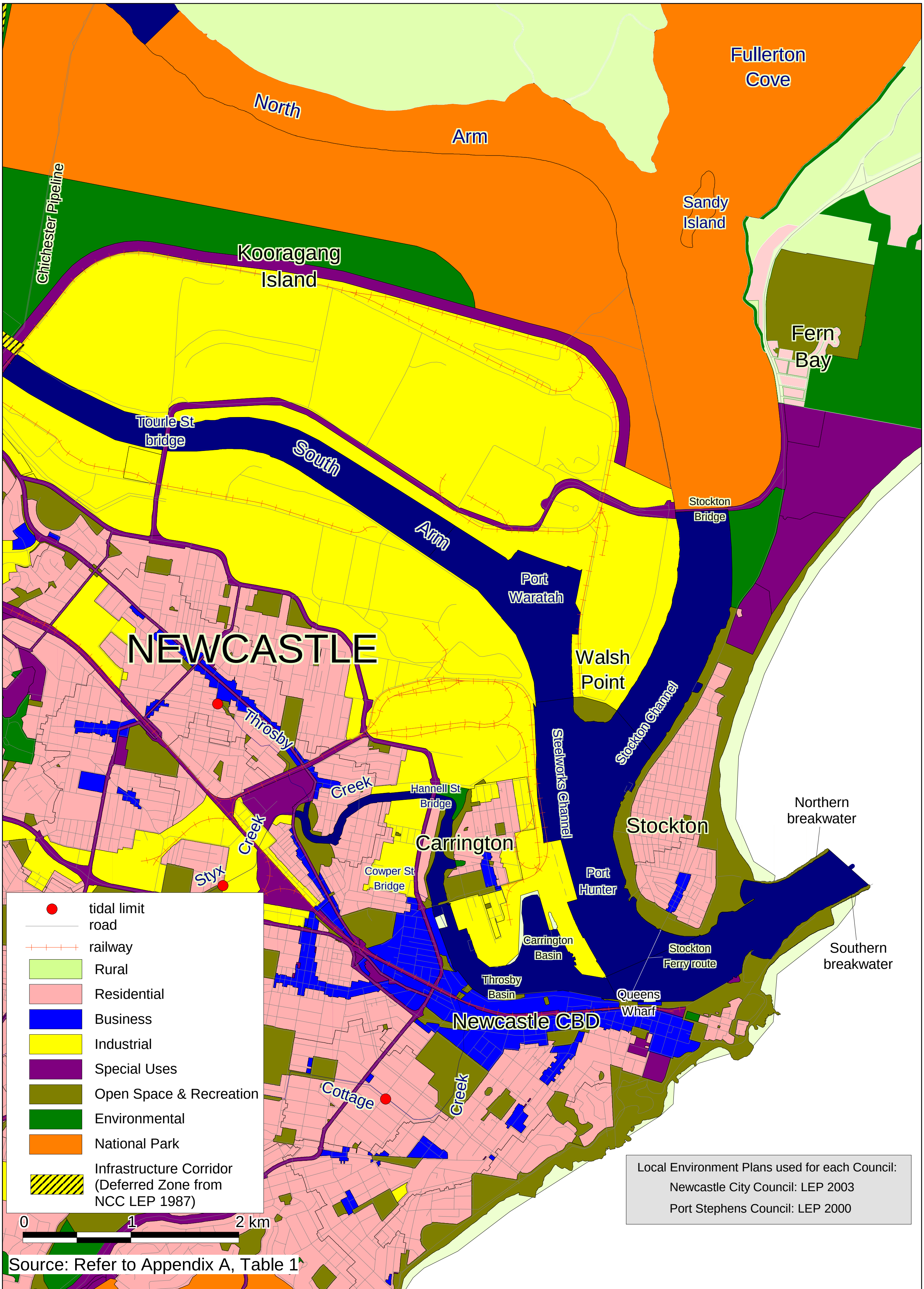
Figure 3.5

DRAWING 8_4.WOR



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NEWCASTLE PORT-SIDE ZONING

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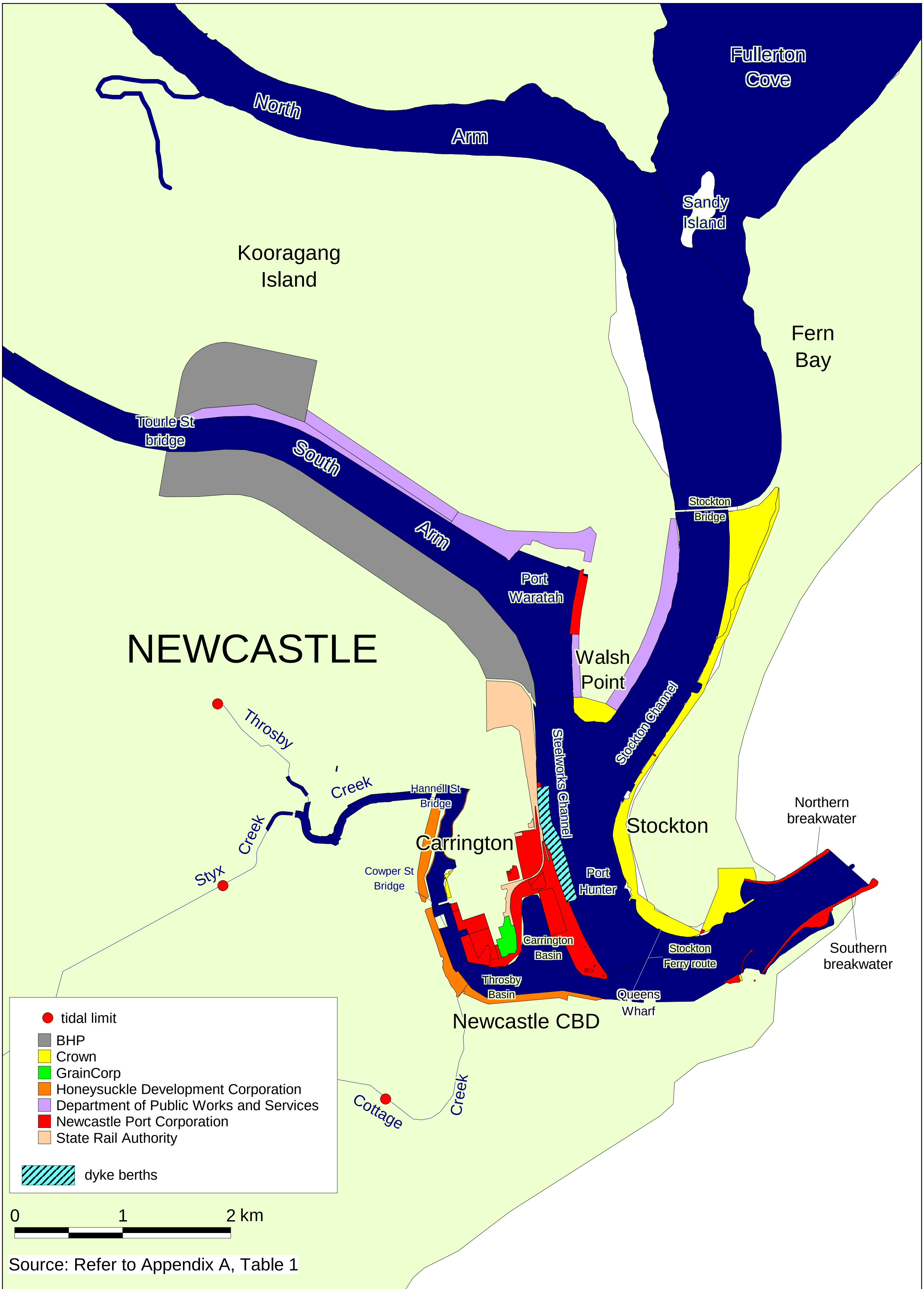
Figure 3.6

DRAWING 8_5.WOR



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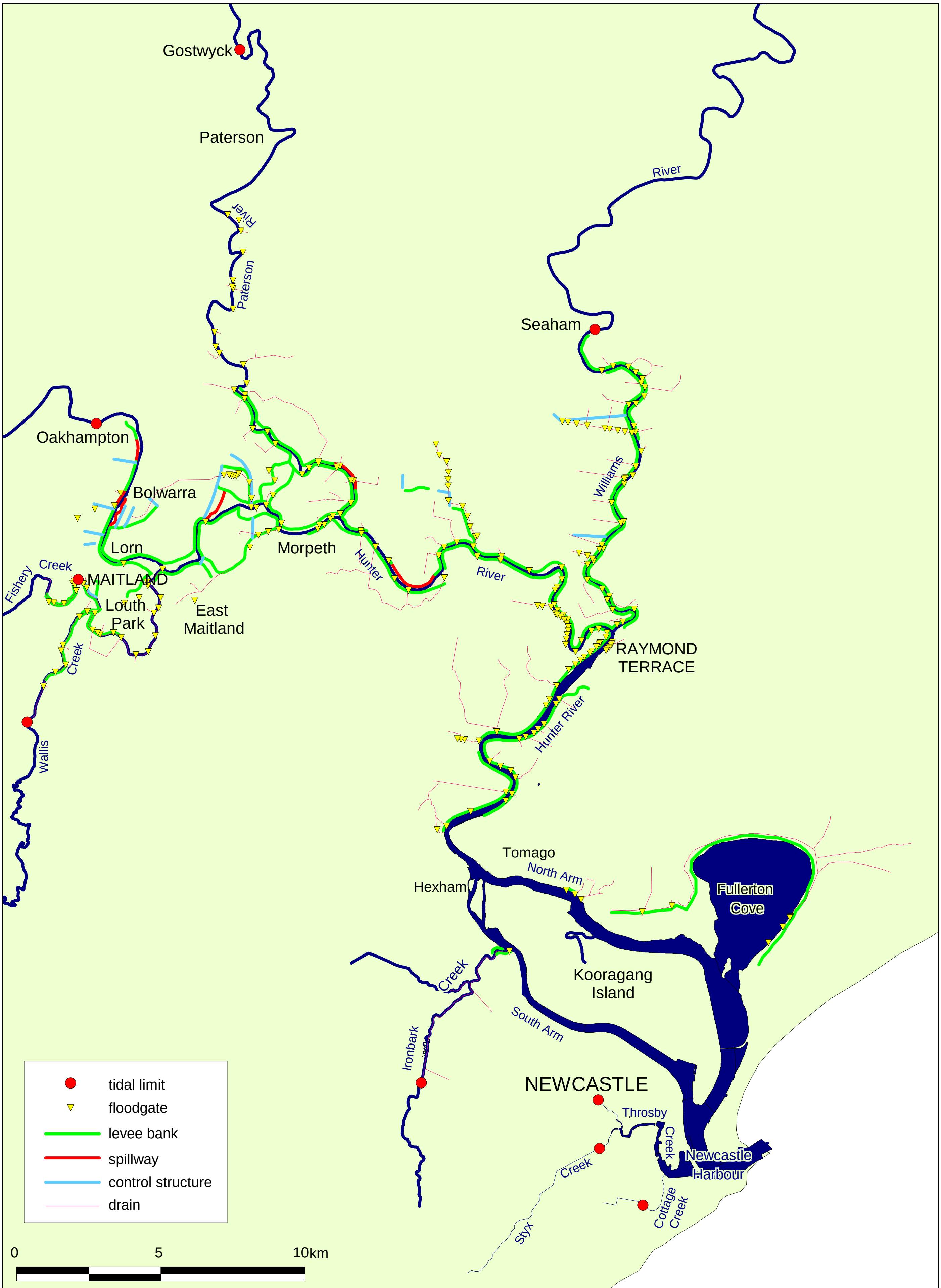
NEWCASTLE PORT-SIDE OWNERSHIP

MHL Report 1095

Figure 3.7

DRAWING 8_6.WOR



Source: Refer to Appendix A, Table 1

NSW DEPARTMENT OF PUBLIC WORKS AND SERVICES
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FLOOD MITIGATION STRUCTURES OF THE HUNTER ESTUARY

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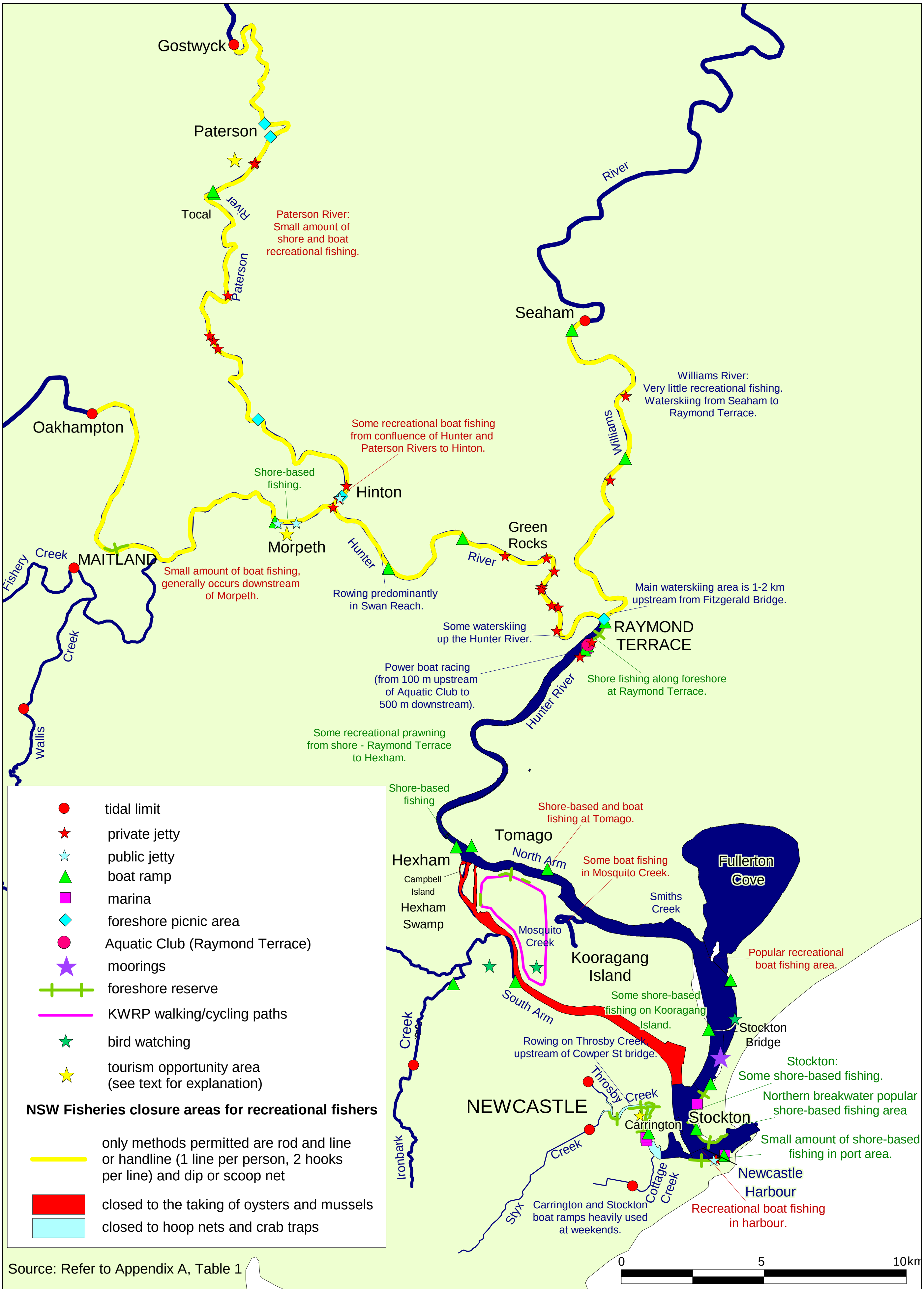
Figure 3.8

DRAWING 3_8.WOR



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RECREATIONAL ACTIVITIES ON THE HUNTER ESTUARY

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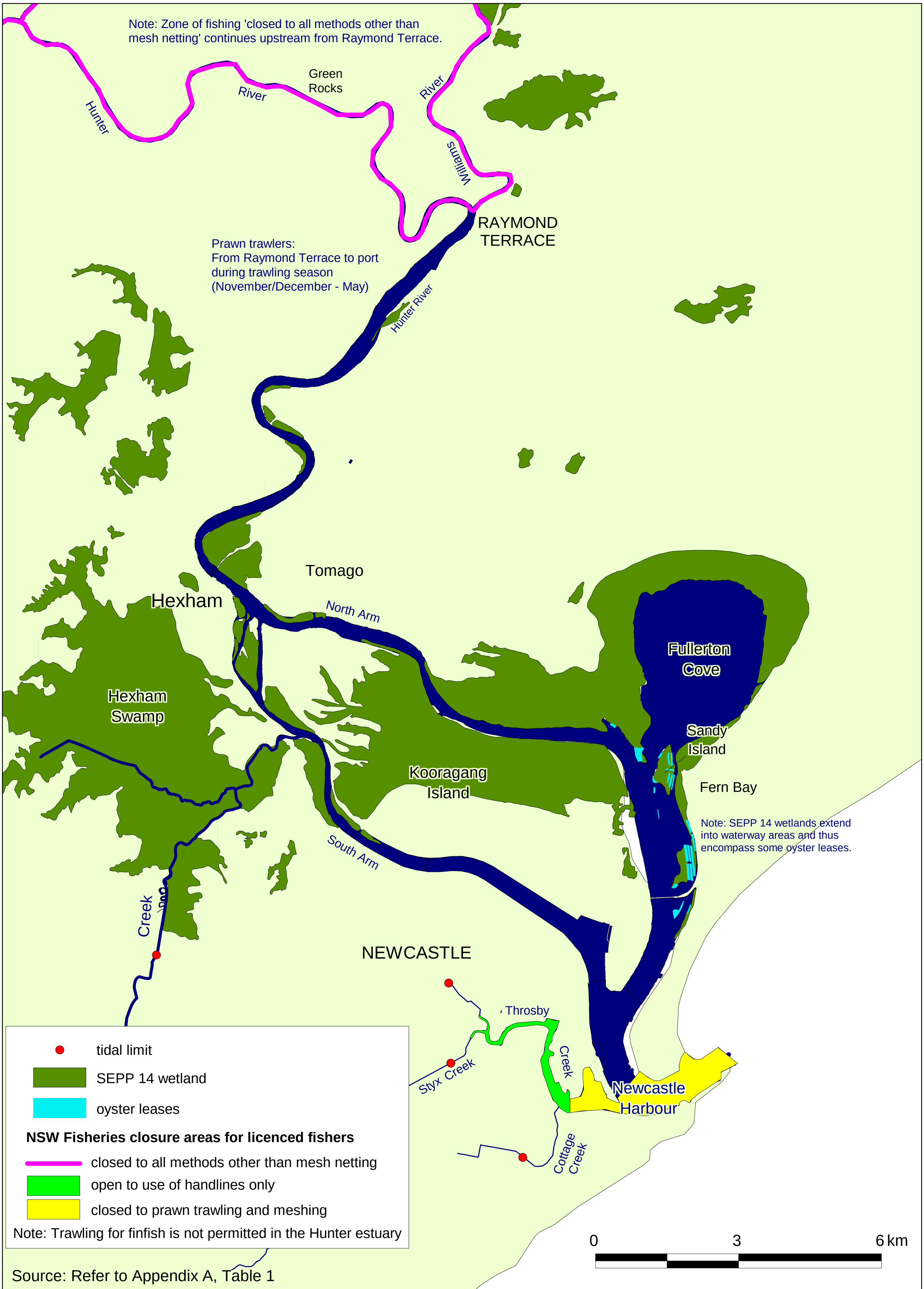
Figure 3.9

DRAWING 9_1.WOR



Source: Refer to Appendix A, Table 1

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COMMERCIAL WATERWAY USAGE IN THE LOWER ESTUARY

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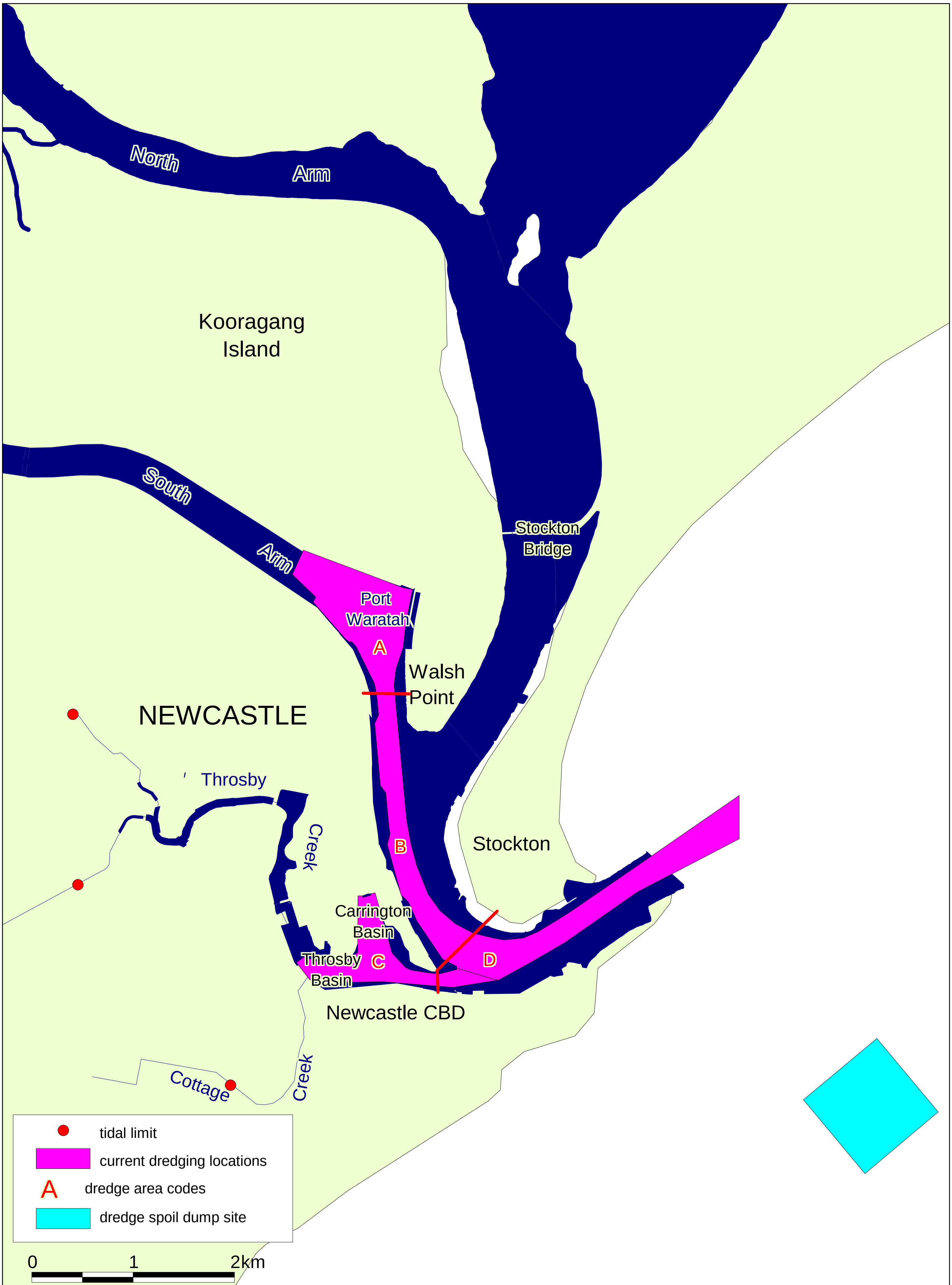
Figure 3.10

DRAWING 9_2.WOR



Source: Refer to Appendix A, Table 1

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CURRENT DREDGING AREAS WITHIN PORT OF NEWCASTLE

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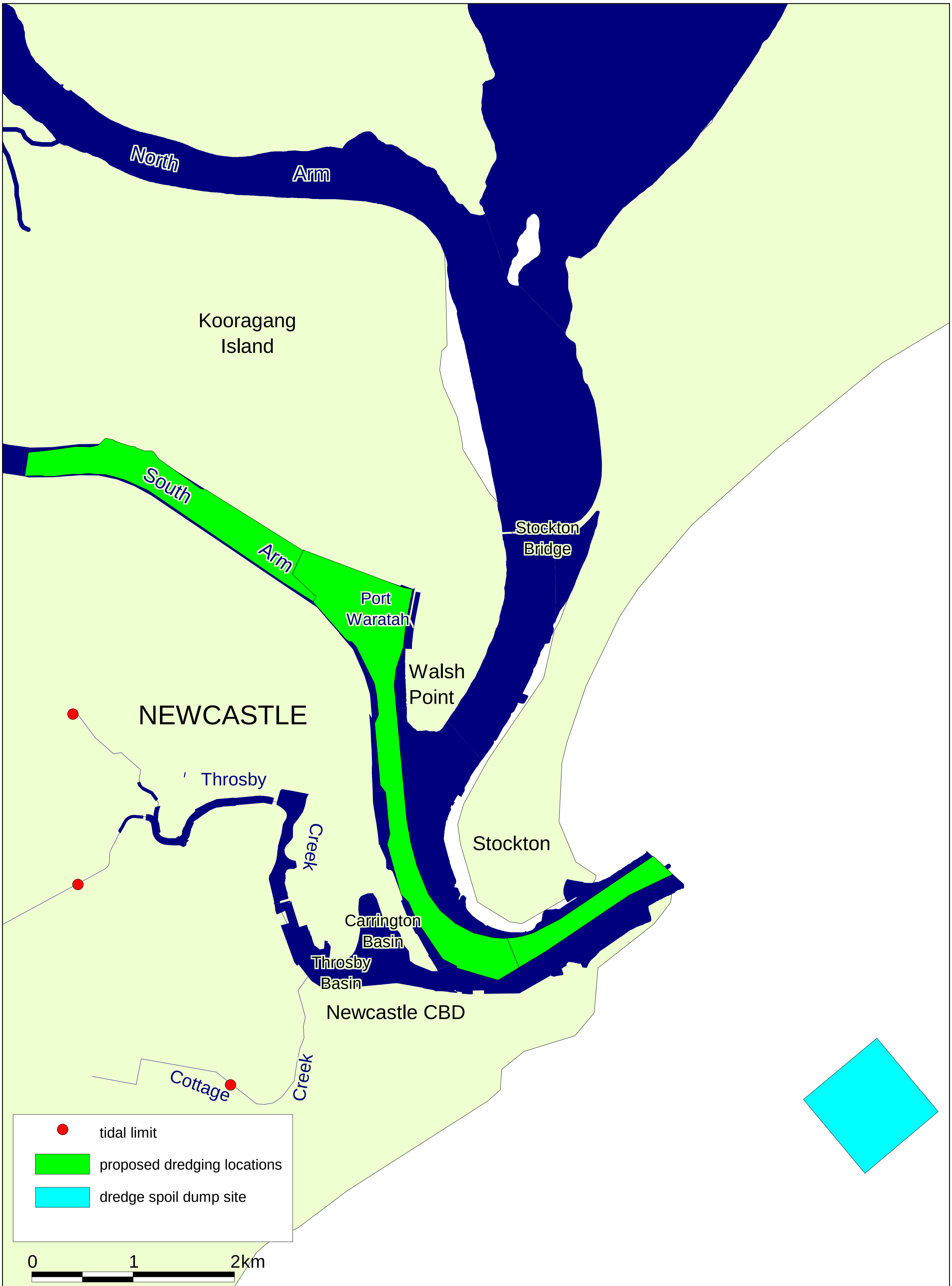
Figure 3.11

DRAWING 12_2.WOR



Source: Refer to Appendix A, Table 1

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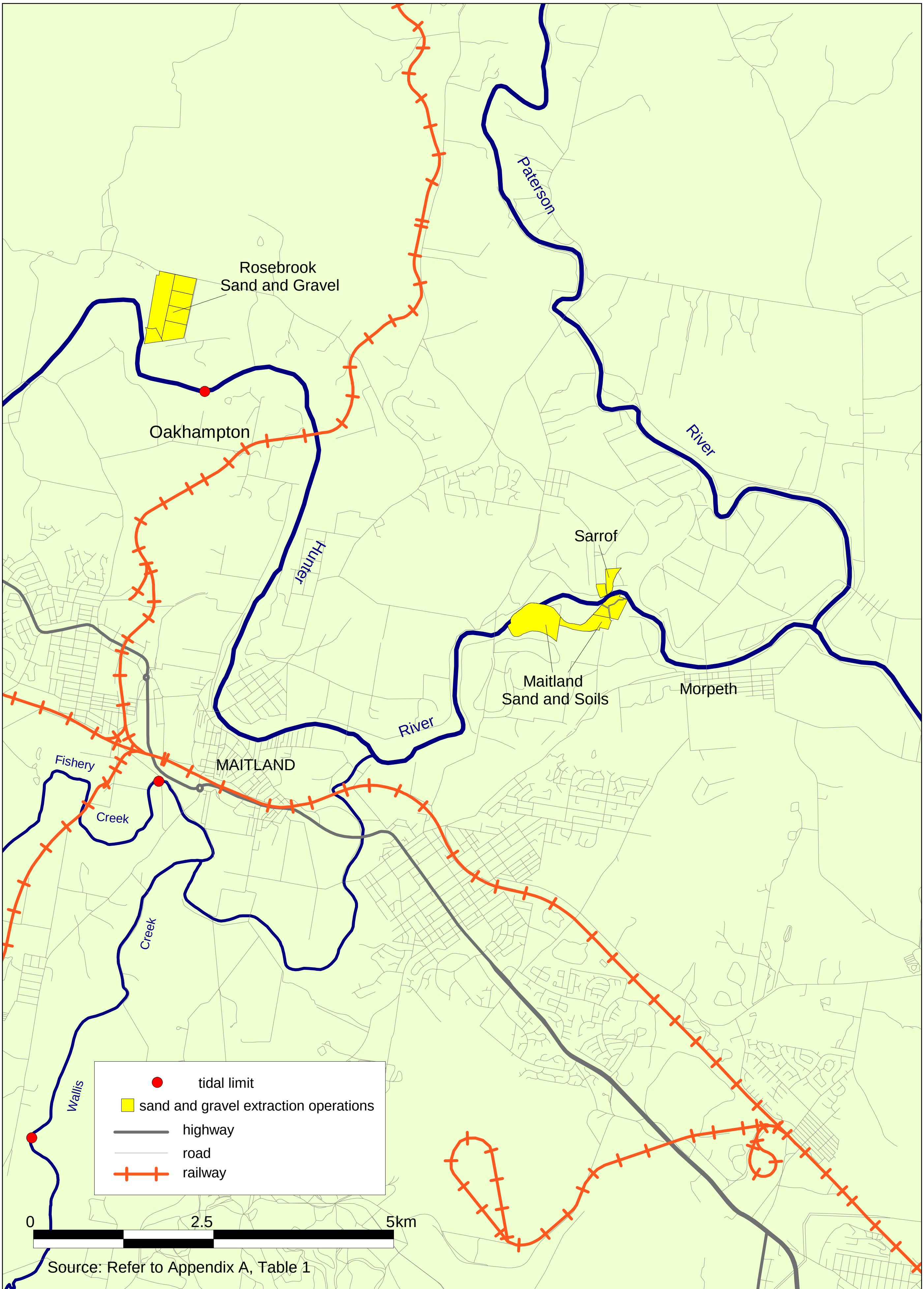
PROPOSED DREDGING AREAS WITHIN PORT OF NEWCASTLE

MHL Report 1095

Figure 3.12

DRAWING 12_3.WOR



NSW DEPARTMENT OF PUBLIC WORKS AND SERVICES
MANLY HYDRAULICS LABORATORY

AREAS OF SAND AND GRAVEL EXTRACTION IN THE UPPER ESTUARY

MHL Report 1095

Figure 3.13

DRAWING 12_1.WOR

4. Estuary Characteristics and Processes

4.1 Flooding

4.1.1 Flood Studies

Two flood studies of the Hunter Valley have been conducted, the first in 1990 which considered the area from Oakhampton to Green Rocks (PWD 1990) and the second in 1994 covering the area from Green Rocks to Newcastle (NSW Public Works 1994). The earlier study was aimed at modelling components of the flood mitigation scheme and assessing the behaviour of flood control structures in an event similar in magnitude to the 1955 flood, which is considered characteristic of a 1-in-100-year event (PWD 1990). Table 4.1 shows the peak water levels and peak discharges at a number of locations simulated for the design 1-in-100-year flood.

Table 4.1 Modelled Peak Water Levels and Discharges for a Design 1-in-100 year Flood
(PWD 1990)

Location	Peak Water Level (RL m AHD)	Peak Discharge (m^3/s)
Hunter River at Oakhampton	15.95	10,300
Hunter River at Belmore Bridge	11.66	4,200
Hunter River at Morpeth Bridge	8.61	2,200
Paterson River at Dunmore Bridge	8.67	1,300
Hunter River at Paterson River junction	8.59	5,500
Hunter River at Green Rocks	6.03	8,100

The reduction in levels and flow downstream is an indication of the behaviour of flood control structures, which divert extreme floodwaters away from the main Hunter River channel to flood channels and storage areas.

The 1994 flood study was aimed at providing information for the formation of a flood management strategy and used a numerical flood model to determine flood behaviour for various frequency floods (NSW Public Works 1994). Table 4.2 presents design flood levels and flood flows modelled for several locations downstream of Green Rocks.

Table 4.2 Peak Flood Levels and Discharges for Various Design Flood Events
(NSW Public Works 1994)

Location	Design Flood Event AEP #				
	20%	**10%**	**5%**	**2%**	**1%**
Peak Flood Levels (m AHD)					
Green Rocks	3.49	4.12	4.57	4.91	5.55*
Raymond Terrace	2.12	2.71	3.12	3.70	4.76
Hexham Bridge	1.44	1.99	2.45	2.81	3.73
Stockton Bridge	1.21	1.24	1.27	1.31	1.61
Port Newcastle	1.21	1.24	1.27	1.31	1.34
Peak Flood Discharges (m^3/s)					
Hunter River upstream of Green Rocks	1,100	2,000	3,300	4,600	6,200*
Williams River upstream of Raymond Terrace	400	1,000	1,200	1,200	1,100

AEP: Annual Exceedance Probability
* The discrepancy between Tables 4.1 and 4.2 regarding levels and discharges at Green Rocks is due to the NSW Public Works (1994) study considering the 1955 flood to be greater than a 1-in-100 year event.

Ocean water levels, influenced by tide and storm surges, have an effect on flood levels as far up the river as Green Rocks (Patterson Britton & Partners 1996a). Higher water levels in Newcastle Harbour will affect the passage of floodwaters by reducing the gradient toward the ocean. Due to the period of time it takes for floodwaters to reach the ocean, which is usually longer than one semi-diurnal tide cycle of 12 hours, it could be expected that the probability of a flood occurring with a high water level at Newcastle is quite high (Patterson Britton & Partners 1996a).

4.1.2 Flood Behaviour

The extensive works constructed for the Lower Hunter Valley Flood Mitigation Scheme have changed the nature of flooding in the Hunter Valley significantly. In higher frequency, low discharge floods, the flow is contained within the river's banks and levees. As flood severity increases, floodwaters overtop the natural and man-made levees and flow across the floodplain. During severe floods, above the 1-in-20-year flood, the majority of flow occurs as overland flow across the floodplain.

The flood studies described above have modelled the direction of flood flows for a range of flood levels. The following description, shown schematically in Figure 4.1, represents the predicted flow behaviour during a 1-in-100-year flood. It should be considered along with the locations of flood mitigation structures, presented in Figure 3.8.

During a high magnitude flood, over half of the total flow upstream of Maitland is directed into the Oakhampton and Bolwarra floodways, with the remainder contained within the river (PWD 1980). On the western river bank, water enters the Oakhampton floodway via two spillways and is ponded and slowed by a system of five control banks before entering temporary storage in Louth Park and the Wentworth and Dagworth swamps. On the eastern bank, water enters the Bolwarra floodway via the zig-zag Bolwarra spillway and flows via levees and controls across King Island and the Dunmore Flats to Phoenix Park. Downstream from Maitland on the southern bank water exits the banks at a control at Porters Hollow and over levees from Pitnacree to Raworth. Along with excess flood water from Louth Park it flows east via Howes Lagoon and returns to the river just upstream of Morpeth. On the eastern bank of the Paterson River, floodwaters flow over levee banks into the Wallalong-

Woodville area and into Scotts Dam. Water also flows over a spillway further downstream on the Paterson River and enters the Swan Reach area, joining water entering from the Hunter River near Hinton. These flows are directed to McClements Swamp. However, the whole area is inundated during large floods and forms part of the floodway extending from Bolwarra through Phoenix Park and flowing back into the Hunter River at Green Rocks. On the southern bank of the river downstream of Morpeth floodwaters overtop levee banks and enter the Metford Swamp flood storage area (PWD 1990).

At Green Rocks, the Hunter River has cut its channel into the floodplain exposing a rock intrusion that, along with the natural topography, causes a constriction to flow and a 'backing-up' of floodwaters. This causes floodwaters to spill across the Woodberry Swamp/Millers Forest area to the south, and towards Nelsons Plains to the north. Here they may combine with floodwaters spilling across the right bank of the Williams River. The eastern floodplain of the Williams River contains several large swamps that provide storage of floodwaters upstream of Raymond Terrace. The Millers Forest floodwaters travel southwards along the floodplain, until constrained by the New England Highway and north coast railway at Purgatory Creek. In large floods, almost 70% of the floodwaters are carried by the Woodberry and Millers Forest floodplains and 30% by the main Hunter channel upstream of Hexham. Some floodwaters are able to pass through culverts under the road and rail control, and when large enough, pass over the controls. Due to the constriction to flow caused by the combination of high ground at Tarro and the New England Highway, a proportion of the overbank flow is forced back into the main channel upstream of Hexham. This flow tends to be distributed across the north arm of the Hunter River due to the presence of the large area of fill on Kooragang Island. Hexham Swamp acts as a large flood storage for floodwaters that pass through the New England Highway control at Tarro. By the time the floodwaters reach Walsh Point, more than three quarters of the flow is carried in the north arm (NSW Public Works 1994). Some flow leaves the river at Hexham Bridge and travels overland through the Tomago Swamps to Fullerton Cove. During extreme floods there is insufficient capacity within the floodplain to contain all of the floodwaters within the catchment boundaries, in which case floodwaters spill into the adjacent Port Stephens catchment (Patterson Britton & Partners 1996a).

The Hunter River is continually experiencing geomorphological changes that have the potential to influence channel behaviour and flooding patterns in the lower Hunter River (Patterson Britton & Partners 1996a). The first of these is the presence of very large deposits of sandy sediments in the river between Singleton and Maitland. This 'slug' of sand is likely to continue moving down the river, increasing the potential for floodwaters to spill onto the floodplain earlier in flood events. The second factor is that the major channel realignments that have occurred in the last two centuries are not yet stabilised, meaning that further channel realignments may occur (Patterson Britton & Partners 1996a).

4.1.3 Impacts of Flooding

Throughout the history of settlement in the Hunter Valley, floods have been frequent and their impacts widespread and severe. The 1955 flood resulted in the loss of 14 lives, the destruction of many houses, especially in the Maitland area, and the inundation of thousands of acres of productive farmland. The 1955 flood was particularly severe due to the unique combination of meteorological and catchment events at the time, and also due to the ad hoc nature of a range of existing flood protection works. The levee banks were built too high, too close to the river and had closed off a number of natural flood routes, and many were overtopped and destroyed in the flood, causing extensive damage and hardship in the urban areas of Maitland and Lorn (PWD 1980).

The severity and impact of the 1955 flooding led to a change in flood mitigation methods, away from trying to confine all floods to the river channel and thus prevent floods, towards reducing the impact of floods by controlling their behaviour in a predictable way. The Lower Hunter Valley Flood Mitigation Scheme has changed the behaviour of floods and in most areas has reduced the impacts on the community.

Periodic flooding of rivers and their floodplains is, however, a natural phenomenon which serves to provide water to underground aquifers and replenish layers of silty topsoil on the floodplain. Constraining floodwaters to river channels inevitably alters natural river processes, such as sedimentation and erosion patterns, ecological processes and hydrodynamics.

4.1.4 Impacts of Flood Mitigation Works on Flood Behaviour

The flood mitigation works of the last two centuries have led to changes in the natural processes of the Hunter River and its tributaries. This has had consequences for many aspects of the system, including flood behaviour, sedimentation and erosion, channel alignment, water exchange, water quality and habitat diversity.

One of the main aims of the flood mitigation scheme was to reduce the frequency of flooding in the lower Hunter Valley. While some local farmers are not satisfied with the scheme due to continued occurrence of floods, studies have shown that increased rainfall has been responsible for periods of frequent flooding in recent years, particularly in the 1970s (Sinclair Knight & Partners 1981). Areas flooded prior to and after the flood mitigation works for a range of flood magnitudes are presented in Table 4.3 and 4.4. The scheme was designed to enable the natural flood sequence along the floodplain to be maintained. Raworth, Phoenix Park and Swan Reach are therefore the first to be inundated, but have been afforded greater protection and now have protection against floods with a return frequency of once in 2.5 to four years rather than the previous frequency of approximately 1.5 years.

Table 4.3 Areas Flooded Prior to Flood Mitigation Works

(Sinclair Knight & Partners 1981)

Minor Flood Sequence	Medium Flood	Major Flood
1 Raworth 2 Phoenix Park 3 Swan Reach 4 Berry Park 5 Millers Forest 6 Tarro Swamp 7 Hexham Swamp 8 Tomago-Fullerton Cove 9 Eskdale Swamp 10 Mosman Swamp 11 Irrawang Swamp	Areas flooded by Sequence 1 to 11 plus: 12 Webbers Creek 13 Bellevue 14 Greenwattle-Wallalong 15 Nelsons Plains	All areas flooded

Note: The terms minor, major and medium are indicative only and cannot be related to a particular frequency.

Table 4.4 Areas Flooded After the Flood Mitigation Works

(Sinclair Knight & Partners 1981)

Design Flood Frequency	Areas Flooded
2 to 4 years	Raworth Swan Reach Phoenix Park Berry Park-Brisbanefields Wallalong-Greenwattle Dunmore Dunns Creek Webbers Creek
4 to 8 years	Pitnacree Duckenfield-Millers Forest Tarro Swamp Eskdale Swamp Mosman Swamp Nelsons Plains Kennington Bellevue Irrawang Tomago-Fullerton Cove
18 to 25 years	Oakhampton Bolwarra Louth Park East Maitland Raymond Terrace Hexham
50 years	Lower part of Maitland with ring levee
100 to 120 years	Most of the City of Maitland flooded

4.1.5 Impacts of Flood Mitigation Works on Sedimentation and Deposition

The construction of levee banks has played a role in altering the geomorphology of the Hunter River system, which has consequently resulted in major channel realignment between Maitland and Morpeth. Along with factors such as vegetation clearance in the upper and middle catchment, resulting in greater sediment inputs to the river, increased frequency of floods due to changes in weather patterns, and direct human interference with the dredging of channels, the constriction of the river to the confines of its channel has resulted in increases in flood energy. Over time this has caused a number of cut-offs during floods, which has in turn shortened the channel length, increased the bed slope and thus further increased the flood energy. The following list details the history of channel morphology changes and Figure 4.2 presents these changes schematically.

- 1879 - First neck cut-off occurred at Pig Run near Raworth
- 1890 - Neck cut-off occurred at King Island
- 1893 - Diversion channel excavated through the neck of Horseshoe Bend
- 1950 - Pitnacree Loop cut along Macraes Hollow
- 1952 - Cut through the neck of Narrowgut Loop
- 1955/56 - Past cut-off bends at Pig Run and King Island abandoned by the 1955 and 1956 floods
- 1959 - Diversion channel constructed downstream of Goulburn Grove

Some of the events listed above were begun by floodwaters but continued by local landholders, who widened and deepened the cut-offs to reduce the meander path of the river (Patterson Britton & Partners 1993). These changes to channel morphology over a period of 90 years have resulted in a reduction of channel length between Maitland and Morpeth from 24 to 9.6 km (Figure 4.2).

The processes of sedimentation and erosion have been altered by the construction of levee banks. It is believed that the levees had the effect of raising maximum channel flood level and increasing the inbank velocity and discharge. As well, more sediment has to be transported in the channel and less distributed across the floodplain. The result is further heightening of the river banks by sediment deposition during floods, localised aggradation of the bed leading to channel steepening, and bank erosion to meet the increased sediment demand of the river (Patterson Britton & Partners 1993).

4.1.6 Flood Mitigation Management Options

One of the key recommendations of the Independent Inquiry into the Hunter River System (HRC 2001) was that a new plan should be developed for the Hunter Valley Flood Mitigation Scheme, including a review of the environmental impacts of the scheme. The Healthy Rivers Commission report (HRC 2001) states that since the scheme's inception, significant changes have occurred in community values, land uses, and the economic value of commercial activity within the floodplain. An example is the case of flood-protected agricultural lands where productivity is marginal and the economic benefits of environmental services provided by floodplain wetlands outweigh the agricultural returns, especially if maintenance costs are considered (HRC 2001).

Over recent years the emphasis when considering flood impact reduction has shifted from flood mitigation to floodplain management, with controls now placed on development and land use in flood-prone areas. This approach, when correctly implemented, allows areas of the river and floodplain to return to more natural flood regimes with flow-on effects in terms of enhanced natural habitats and biodiversity. In addition, changes to catchment practices, such as revegetation, have been suggested to reduce the rate of runoff to the river and lower the magnitude of flooding events. However, the flood mitigation structures that presently exist and have succeeded in reducing flood frequencies in the valley over time, still present a management dilemma.

Some management options suggested include the lowering of flood levee banks and a change in operation or complete removal of floodgates. Any permanent change to structures in the scheme will result in a reduction in flood protection to the local area, and the costs and benefits of any such action will need to be considered carefully. Any proposal to completely remove floodgates will require major consideration of flood behaviour in the area and the likely impacts of more frequent flooding on the land affected. The floodgates on Wallis Creek and Ironbark Creek are currently kept partially opened to allow tidal flows to return to the former estuarine areas of the creeks. It is intended that the floodgates will continue to be closed in times of flood to prevent the inflow of Hunter River floodwaters. A number of studies on the impacts of opening these floodgates are under way and while the results are not yet clear, it is predicted that increasing the tidal inflow to the creeks and adjacent wetlands will increase habitat diversity and improve the ecological health of the areas.

The Lower Hunter Valley Floodplain Management Study (Patterson Britton & Partners 1996a) presented an assessment of a range of strategic options for floodplain management, specifically for the area downstream of Green Rocks. The options considered that relate to flood damage reduction measures were:

- lower rural levees globally by 1 m
- construct flood bypass channel upstream of Hexham Bridge
- dredge the north arm of the Hunter River
- raise Raymond Terrace levee bank.

The options were assessed from a hydraulic perspective only (i.e. social and environmental consequences were not considered), using a hydrodynamic model of the lower Hunter River. It was determined that lowering levee heights to increase flood storage would result in only a minor impact on peak flood levels for major floods, such as the 1-in-100-year and 1-in-50-year, but would have no measurable effect on more severe events. The existing levee system is covered in floods greater than the 1-in-50-year event and therefore flood storage is maximised. In smaller floods, floodwaters would be distributed onto the floodplain at lower flood levels and as a result flood levels would be expected to be lower (Patterson Britton & Partners 1996a).

The construction of a flood bypass channel at Hexham Bridge, which was modelled to occur on the northern side of the river under the Pacific Highway, was found to lower peak levels upstream of Hexham Bridge for the full range of floods. The flood level reductions would be more significant for the smaller floods and would range from 100 to 150 mm depending on the severity of the flood. The flood level reductions would be largest over the 8 km reach immediately upstream of the bridge, while flood levels would increase by up to 100 mm in the reach downstream of the Tomago Aluminium Smelter for a distance of 3.5 km (Patterson Britton & Partners 1996a).

Dredging the north arm of the Hunter River down to RL –11.0 m AHD would lower peak flood levels downstream of Hexham Bridge by between 400 and 600 mm over the full range of floods. Upstream of the bridge flood levels would be lowered for all but the most severe events. Flood conveyance in the channel downstream of Hexham Bridge is a principal factor affecting flood behaviour in this area, and thus increased conveyance would reduce flood levels over the whole of the floodplain for this stretch of the river. As the bed slope would be modified by dredging, the channel would act as a sediment sink and maintenance dredging would be required to ensure that the flood mitigation benefit was available at times of flood (Patterson Britton & Partners 1996a).

Raising the levee system around Raymond Terrace to RL 7.5 m AHD in order to provide complete flood protection for the town was found to have no measurable effect on flood levels in the river or across the floodplain. The existing levee bank is at a crest level of RL 4.3 m AHD and provides flood protection in the town for up to the 1-in-50-year event. The exclusion of the Raymond Terrace town area from the floodplain would not noticeably affect the overall flood performance of the river system (Patterson Britton & Partners 1996a).

Under the guidance of the Hunter Catchment Management Trust there are a number of projects under way to restore habitats that have been degraded by the history of clearing, drainage, infilling and flood mitigation in the Hunter Valley. These include the Kooragang Wetland Rehabilitation Project (KWRP) and the Hexham Swamp Rehabilitation Project

(HSRP), which were begun in 1993 and 1997 respectively. The KWRP covers about 1,560 hectares over the three sites of Ash Island, Tomago and Stockton. Habitat rehabilitation forms the basis of the project, with the objectives including the enhancement of fish, prawn, crab and wading bird habitat, the regeneration and revegetation of dry littoral rainforest and the protection of river banks (HCMT 2002a). The HSRP involves returning the Hexham Swamp area, which has been drained and restricted from tidal flow for over 30 years, into a healthy productive estuarine wetland. This project involves acquisition of some private land, modification to the operation of Ironbark Creek floodgates, regeneration of native vegetation, reintroduction of native fish and crustacean species, continued management of the floodgates to exclude Hunter River floods, and wetland management to reduce mosquito habitat (HCMT 2002b). These projects are examples of significant work being undertaken to enhance the Hunter Valley environment following 200 years of human activities that have detrimentally altered estuarine and catchment processes.

4.2 Hydraulic Processes

4.2.1 Introduction

The natural hydraulic processes that shaped the estuary morphology over the millennia have been altered by a range of human activities implemented over the past 200 years of European settlement. These activities include the clearing of the fertile river flats and catchment areas for agricultural use, grazing of the riparian zone, construction of the entrance groynes for navigation, construction of levees for flood mitigation, dredging of sand and gravel from the upper estuary and river for building materials, dredging the lower estuary for the port infrastructure, construction of floodgates and drainage channels to convert low-lying waterlogged lands to agricultural use, and construction of bank stabilisation works to protect assets and reduce bank erosion. These activities have impacted on the regime of hydraulic processes operating within the estuary, and the purpose of this section is to describe the various processes and discuss the various changes that may have taken place since European settlement. An overview of locations mentioned in this chapter is provided in Figure 4.3.

4.2.2 Compilation Hydrosurvey

Depth surveys of various areas of the Hunter River estuary between the entrance and upstream of Maitland have been carried out at different times over the past 200 years (DPWS 1998). Most of these charts are available from the DPWS Survey Section archives but none have been digitised. The Newcastle Port Corporation (NPC) carry out regular surveys of the port area and the most recent results were provided for this study and are shown in Figure 4.4.

A hydrodynamic modelling exercise carried out by Hunter Water Corporation in the 1990s established model depths using the most recent surveys prior to 1992. These data were also provided and were added to the NPC data to extend the digital bathymetry further upstream. Note that the model representation of estuary bathymetry uses an averaging regime and tends to smooth the actual bathymetry.

At the entrance and port area NPC dredging maintains a depth of around 14 to 16 m AHD for shipping. Upstream of the port area in the south arm the depth quickly decreases to around 4 m and near the junction with the north arm at Hexham the depth is only around 1 m. In the north arm which takes most of the tidal flow depths vary between 7 and 9 m near the outside of bends and are generally greater than 5 m except near the tidal flats near Fullerton Cove. In the centre of Fullerton Cove maximum depths of 2 m occur but most of the system is very shallow.

4.2.3 Water Level Variability

Changes in water levels within the estuary are influenced by a range of phenomena that operate at different time scales, from a few minutes to millennia, including:

- astronomical tides
- wind setup
- freshwater inputs and floods
- ocean storm surges
- coastal trapped waves, and
- sea level rise.

While each of these phenomena contribute to the water levels at any given time or location the key factors will vary between times and locations. For example, within the wetland areas the tidal range is very low and the water levels vary in response to the longer time scale phenomena such as coastal-trapped waves and events such as floods. By contrast, in the harbour the major factor affecting water level is the astronomic tide.

4.2.4 Astronomic Tides

Astronomic tides are the ocean‘s response to the gravitational attraction of the planets. Each of the planetary and lunar orbits and the earth‘s rotation occur at set frequencies that force oscillations of the oceans - the tides – at similar frequencies. The major tidal components along the NSW coast occur in response to the lunar and solar attractions interacting with the rotating earth. The tides in the region are dominated by the semi-diurnal (twice per day) constituents with a strong spring-neap cycle as shown in the water levels recorded at a number of sites in the estuary (Figure 4.5). The figure highlights the attenuation of the tides towards the extremities of the system. For example, at Bolwarra near the tidal limit on the Hunter River the tidal range is considerably smaller than near the ocean entrance. This is also typical of backwater areas within the wetlands where water flow is inhibited by shoaling and other structures and the tidal range is very small.

The Hunter estuary acts like a typical riverine estuary system, with maximum tidal flows usually recorded during the two hours following mid-tide and minimum tidal flows (or slack water) usually recorded within one hour after high and low tide.

The tidal limit in the Hunter River occurs in the vicinity of Oakhampton, approximately 64 km from the ocean, in the Paterson River between Paterson and Gostwyck approximately 70-75 km from the ocean, and in the Williams River at Seaham Weir approximately 46 km from the ocean. There is a gradual reduction in the mean tidal range (see Table 4.5) along the Hunter River, with the range of approximately 1 m recorded at the entrance decreasing to 0.40 m at Belmore Bridge. Along the Paterson River there appears to be a slight amplification of the mean tidal range, being approximately 0.70 m at Dunmore. On the Williams River there is also slight amplification, with 0.91 m recorded at Raymond Terrace increasing to 0.96 m at Seaham Weir (MHL 1995).

Tidal lags also vary along the three rivers. At Bolwarra the low tides lag 8.8 and 6.3 hours after entrance tide and the high lags 3.8 hours. At Paterson Railway Bridge the low tides are 6.1 and 5.3 hours after the entrance tide and the high tide 4.3 hours. At Seaham Weir the low tides are 3.3 and 2.5 hours after entrance tide and the high tide 1.8 hours (MHL 1995).

The tidal excursion represents the distance a water parcel travels over a tidal cycle due to the water currents transporting it. In the lower estuary the tidal excursion is around 10 km at springs tide while at Morpeth the excursion decreases to around 3 km.

Tidal characteristics may also vary with changes to the river morphology, and between wet/dry years and with changes in the mean sea level.

4.2.5 Tidal Planes

Tidal planes are a series of water levels that characterise the standard tidal variability at a particular location. The tidal planes for the 12 sites in the estuary for which data have been collected are listed in Table 4.5. The tidal planes were derived from an harmonic analysis of hourly water level observations collected over at least a thirty-day period, used to predict the tides. The difference between the observed water levels and the tidal predictions is referred to as the tidal residual. In essence the residual signal provides a measure of the non-tidal water level oscillations such as floods and the other phenomena referred to above.

Table 4.5 Tidal Planes for the Hunter Estuary

River	Location	Distance from Ocean (km)	HHWSS	MHW	MSL	MLW	ISLW	MNR	MR	MSR	R	% MSR ocean
Hunter	Stockton Bridge	6	1029	543	18	-506	-889	795	1049	1302	1918	103
Hunter	Hexham Bridge	20	1063	611	110	-390	-744	790	1001	1213	1807	96
Hunter	Green Rocks	40	965	563	141	-280	-590	683	843	1003	1555	80
Hunter	Morpeth	48	900	542	194	-154	-426	580	696	812	1325	65
Hunter	McKimms Corner	52	891	553	242	-69	-325	516	621	727	1217	58
Hunter	Belmore Bridge	60	850	567	371	175	-39	309	392	476	889	38
Paterson	Hinton Bridge	48	874	518	173	-173	-443	576	691	807	1317	64
Paterson	Dunmore	54	957	598	245	-108	-382	586	706	825	1340	66
Paterson	Railway Bridge	63	950	610	291	-27	-287	518	637	757	1236	60
Williams	Raymond Terrace	29	1054	631	176	-280	-608	729	911	1092	1663	87
Williams	Seaham	45	1048	620	142	-337	-669	771	957	1143	1718	91
Wallis	Wallis Creek	55	767	520	313	106	-81	346	414	482	848	38

HHWSS	High High Water Solstices Springs
MHWS	Mean High Water Springs
MHW	Mean High Water
MHWN	Mean High Water Neaps
MSL	Mean Sea Level
MLWN	Mean Low Water Neaps
MLW	Mean Low Water
MLWS	Mean Low Water Springs
ISLW	Indian Spring Low Water
MSR	Mean Spring Range (MHWS - MLWS)
MNR	Mean Neap Range (MHWN - MLWN)
MR	Mean Range (MHW - MLW)
R	Range (HHWSS - ISLW)

Tidal ranges express the difference between successive high water and low water levels. Tidal range is maximum during spring tides and minimum during neap tides. The estuary tidal range at Green Rocks averages 88 % of the ocean tidal range, the percentage varying with the spring-neap cycle. This ratio depends on the conveyance characteristics of the channel that in turn are a function of the water level in the channel and the channel dimensions.

To investigate the possible change in tidal range in the Hunter estuary due to human impacts such as dredging of the harbour, levee bank construction and introduction of floodgates in low-lying areas over the past four decades, datasets from 1955 and 2000 were compared. The tidal planes for these two years were derived from at least 29 days of data collection, and hence form reliable estimates. It should be noted, however, that longer period tidal oscillations affect the spring tidal levels (e.g. king tides occur near the solstices) and hence exact agreement is unlikely even if the system characteristics had not changed. The 1955 and 2000 tidal ranges up the Hunter River from Stockton Bridge to the junction with the Paterson River (46 km from the entrance) are shown in Figure 4.6. The figure shows amplitude (in metres) as a function of distance from the ocean (in kilometres) for mean neap range (MNR), mean spring range (MSR) and range (R).

The results indicate that the spring tide range has increased upstream. Three possible mechanisms, or a combination of the three, may be invoked to explain this increase - construction of levees, construction of the floodgates that would subsequently confine the tidal prism volume to the main channel, or the dredging and deepening of the channels leading to a larger tidal conveyance. The *Shifting Sands at Stockton Beach* report (Umwelt 2002) suggests that the harbour dredging has had the major effect on the tides at Hexham Bridge between the 1950s and 1980s. The construction of the floodgates at Hexham Swamp was carried out in 1971 and the major harbour dredging was done in the early 1980s and hence it is not clear which mechanism affected the increased tidal range upstream. The impact on the high water components of the tidal planes is more consistent with a local influence such as the floodgates installation rather than the entrance dredging which is more likely to affect all the tidal planes. It must be stated, however, that both these mechanisms may have had an impact and a detailed numerical model covering the whole estuary and low-lying tidal areas would be required to assess the relative importance of each mechanism.

The rise in mean sea level of approximately 4.5 cm during this period (National Tidal Facility pers. comm. 2002) may also have contributed to the changing tidal characteristics, although this change is probably similar to the level of sedimentation and therefore difficult to distinguish its relative importance.

4.2.6 Low Frequency Sea Level Oscillations

Low frequency sea level oscillations include phenomena with periods greater than about four days such as the coastal trapped waves that propagate up the NSW coast causing ocean water level changes of 0.1 to 0.5 m. These changes are transferred to the estuary and result in significant changes in the water volume within the estuary. As these oscillations are smaller than the tidal range throughout much of the estuary they are masked by the tidal oscillations in the water level measurements. To separate these different signals the tidal residuals have been low pass filtered (or smoothed) to remove the oscillations with periods less than two days. The resultant longer period oscillations due to oceanic phenomena and freshwater inputs are shown in Figure 4.7. This figure shows the results of this process for the Sydney, Stockton and Hexham sites. Oscillations of about 3 to 10 days period occur with amplitudes of around 0.10 m associated with oceanic coastal trapped waves on top of the 15-day spring-neap cycle.

4.2.7 Wind Setup

Wind blowing across a water surface moves the surface waters in the direction of the wind. As this water approaches a shore it is forced to build up against the shore and this change in water level is known as the wind setup. In an estuary the wind setup essentially causes a water surface slope with lower water level at the upwind shoreline and higher levels near the downwind shoreline. After the wind ceases the surface slope will return to the level position and generally overshoots, resulting in oscillations at the scale of the basin. These motions, referred to as the surface seiche, are heavily damped and generally return to the still water position within a few cycles following cessation of strong winds.

4.2.8 Currents, Tidal Gaugings and Flow Characteristics

The sites of a tidal gauging exercise carried out in 1995 are shown in Figure 4.3 and Table 4.6 (MHL 1995). A summary of the results of the tidal gauging exercise is provided in Table 4.6. The tidal prism for the area downstream of Walsh Point (sites 1 and 2) was estimated as (1.7 m tidal range multiplied by the surface area downstream of Walsh Point) 5.6 x 10^6 m^3. The tidal prism for the Hunter River was then estimated as the sum of the tidal prism at sites 1 and 2 and the entrance area, and is approximately 38 x 10^6 m^3 and varies with the tidal range.

Table 4.6 Data Collection Sites

Site No.	Site Name
1	Hunter North Arm – Walsh Point
2	Hunter South Arm – Walsh Point
3	Williams River – Raymond Terrace
4	Hunter River – Raymond Terrace
5	Paterson River – Hinton Bridge
6	Hunter River – Morpeth
7	Paterson River – Paterson
8	Hunter River – Bolwarra

Table 4.7 Tidal Data

Site No.	1	2	3	4	5	6	7	8
Distance from Entrance (km)	5	5	30	30	45	48	55	60
Maximum Recorded Velocity (m/s)								
Flood	0.94	0.43	0.61	0.61	0.65	0.58	0.29	0.05
Ebb	0.99	0.26	0.51	0.56	0.56	0.54	0.26	0.29
Maximum Discharge (m^3/s)								
Flood	1,678	358	185	212	98	59	27	0.5
Ebb	1,552	493	178	197	73	48	23	2.7
Tidal Prism (m^3 x 10^6)								
Flood	23.7	5.4	2.4	2.9	1.4	0.7	0.3	0.0
Ebb	25.8	7.9	2.4	3.2	1.2	0.7	0.4	0.1
% of Entrance Flood	65.8	15.0	6.7	8.1	3.9	1.9	0.8	0.0
% of Entrance Ebb	67.9	20.8	6.3	8.4	3.2	1.8	1.1	0.3
Tidal Range (m)								
Flood range			1.33		0.93	0.95		0.22
Ebb range			1.33		0.92	0.94		0.22

Maximum velocities decrease upstream from around 0.99 ms^{-1} near the entrance during the ebb tide to around 0.54 ms^{-1} at Morpeth 48 km upstream in the Hunter River. During flood tide maximum velocity is around 0.94 ms^{-1}. While the velocity and tidal range have only increased by about 50% the tidal prism has decreased by 97%.

The tidal prisms for each flood and ebb tide sampled indicate the relative distribution of tidal flow from the entrance to the three arms, Williams River, Paterson River and Hunter River. The Williams River takes about 10% of the tidal prism while the Patterson River takes about 5% and 3% propagates upstream of Morpeth.

During floods the excess water due to the freshwater input causes an increase in the ebb flow that effectively decreases the flood flow. Tidal flows are more dominant through the north arm of the Hunter River. At times of larger floods the flows of the whole estuary are dominated by the freshwater inflow.

4.2.9 Water Budget

The water balance or change in volume (V) of water in the estuary may be described by the relationship:

$$\frac{dV}{dt} = Q_{Runoff} + Q_{Rain} + Q_{Gin} + Q_{TideIn} - Q_{Evap} - Q_{Gout} - Q_{TideOut}$$

where Q_{runoff} is the contribution flowing into the estuary from the catchment via the rivers, streams and overland flow and includes stormwater inputs and STP inputs, Q_{Rain} is the contribution due to direct rainfall over the water area, Q_{Gin} is the groundwater inflow contribution, Q_{TideIn} is the tidal inflow, Q_{Evap} is the evaporation from the estuary surface, Q_{Gout} is the groundwater outflow, and $Q_{TideOut}$ is the tidal outflow.

The contributions to the annual water budget due to each of the terms on the right side of the above equation have been estimated from available data. Calculations for estimates of direct rainfall, groundwater inflow and evaporative losses are provided in Sections 2.6. and 2.7. A summary of the results is provided in Table 4.8.

Table 4.8 Annual Water Budget Estimates

Contribution	**Annual Average (GL)**
Catchment runoff	1,800
Direct rainfall	30
Groundwater inflow	183
Tidal inflow and outflow	±18,250
Evaporation	-26

The largest contributions to the water budget are the tidal prism and catchment runoff, while the rainfall, groundwater inflows and evaporation contributions are negligible in comparison. The tidal contribution at the mouth is some ten times greater than the runoff. Further upstream the tidal prism diminishes and the relative importance of the catchment runoff becomes more significant.

4.2.10 Water Exchange and Flushing

The tidal prism is an important aspect of the flushing process. The tidal flushing volume is defined as the difference between the amount of 'new' waters that are input into the system over a tidal cycle or the volume of water exchanged between the estuary and ocean during the flood and ebb stages of the tide. The tidal prisms for a number of sites (Figure 4.1) within the estuary are shown in Table 4.3. Tidal prism calculations for flushing times can provide a lower bound but are subject to a high level of uncertainty. At entrances where the exchange efficiency is high the flushing volume is typically about one third of the tidal prism or 12 x 10^3 ML per tide.

The flushing time t_F (days) of an estuary can be defined as the time needed to replace its volume V_F (~ 102 x 10^3 ML) at the rate of the net flow through the estuary, which is given by the river discharge rate R (3,120 ML/day).

$$t_F = \frac{V_F}{R}$$

For typical values the average flushing time is approximately t_F = 32 days for the mean flow and decreases to about eight days for the 95th percentile flow. The flushing is dependent mainly on freshwater inflow transporting salt downstream versus tidal mixing transporting salt upstream by longitudinal dispersion. The greater the freshwater inflow and the greater the tidal velocities then the better the estuary is flushed.

In summary, the processes controlling exchange and mixing within the Hunter River estuary might be thought of in terms of three hydrodynamic regimes. First, there is the concept of river flow displacing the volume of the estuary. This mechanism is dramatically evident, and solely important, during floods when the freshwater inflow exceeds the tidal prism. Second, there is the intrusion of salt into the estuary, density driven flow and tidal pumping propagating against the river flow. This mechanism is fundamentally important immediately following floods when the stratification is strong. Third, salt is dispersed upstream by the tidal diffusion mechanism during sustained periods of relatively low flow. The first two mechanisms operate on short time scales, of the order of a day. The third low flow regime of shear-diffusion, on the other hand, modifies the salinity distribution over much longer time scales of the order of 100 days and hence is the major mechanism by which salt is transported upstream during prolonged dry periods. The flushing time varies on a similar range of time scales and at low flow the relatively long flushing time suggests that inputs to the upper estuary will be retained for relatively long periods (about 1-3 months) within the system.

4.2.11 Salinity Structure and Stratifcation

Sanderson and Redden (2001b) profiled the salinity structure along the length of the Hunter River estuary on 22 days over three months between 11 January 2001 and 3 April 2001. Their report provides an excellent overview of the dispersion processes and interactions that result in the observed salinity variability. The flow during the period increased from a low flow of 250 ML/day in mid-January to around 5,000 ML/day in mid-February with a number of small events during this time. A major runoff event occurred on 9 March 2001 when the inflow peaked at 200,000 ML/day and then gradually decreased to approximately 3,000 ML/day over the following twelve days before another smaller event on 23 March 2001.

During the flood event (flow of order 200 GL/day) on 9 March 2001 the freshwater inflow was observed to completely flush the estuary of salt water, except at depth in the dredged area of the harbour. A weaker flood event (peak flow of 20 GL/day) on 21 February 2001 was observed to flush the upper estuary and result in stronger horizontal and vertical salinity gradients in the lower estuary. Tidal mixing subsequently erodes the vertical salinity gradients generally within about five days.

These observations suggest that following catchment inflow events the salinity distribution relaxes at first in quasi-equilibrium as a balance between river inflow and the density (salinity) gradient. This implies there should be a direct relationship between the salt distribution and the total river flow on the previous day. As an example, the relationship between the river flow and the position along the river, x, of the 10 ppt value of vertically-averaged salinity was empirically determined to be:

$$x_{10} = 26.2444\, R^{-0.32442}$$

In the above equation x_{10} has units of km, and flow R is in units of GL/day. The above empirical relationship clearly does not apply when the river flow is weak (less than 1 GL/day) and they become inaccurate for river flows less than about 2 GL/day.

Similar formulae were derived for the 2 ppt and 30 ppt salinity values. Applying these to the daily river flows for the past 25 years provides the maximum and minimum positions of these isohalines, listed in Table 4.9.

Table 4.9 Maximum and Minimum Penetration Distances Upstream for the 2, 10 and 30 ppt Salinities for the 25 year period 1972 to 2000

(Distances derived from empirical relationships)
(Sanderson and Redden 2001b)

Salinity (ppt)	Maximum Distance Upstream (km)	Minimum Distance Upstream (km)
2	57	18
10	47	13
30	16	1

The maximum penetration distance is over-estimated by the model as it does not strictly apply to the very low flow conditions. These estimates indicate the large variability in the location of the salinity gradient. Salinity propagation in the Paterson River was assumed to be similar to conditions in the Hunter River. Salinity propagation in the Williams River is not as extensive due to the difference in tidal propagation within the Williams River arm of the estuary.

Stratification is often important for enhancing exchange and limiting vertical mixing. The importance of stratification for water quality is often overlooked in these systems. Sanderson and Redden (2001b) salinity observations suggest the vertical salinity stratification in the Hunter River estuary is generally weak and occurs for periods of a few days to a week after flood events. The vertical mixing by the tidal currents is strong and effectively homogenises the vertical salinity gradients. In backwater areas such as in the wetlands and upper reaches where tidal currents are weaker and turbulent mixing is less energetic the likelihood of vertical stratification lasting for longer periods is much greater. There are not sufficient data from these areas to quantify this effect. The vertical stratification has implications for water quality including depletion of dissolved oxygen in deep water, algal blooms in surface waters and sediment depositions at the fresh/saltwater interface.

4.2.12 Salt Balance Model

Salinity observations provide a tool with which water exchange can be estimated and modelled. Such water exchange has relevance for computing distributions of materials introduced into the estuary at either its head, entrance, or at locations within the estuary.

The measurements made in January 2001 were conducted during a dry period when the total river flow was low (less than 500 ML/day). At such times the estuary is vertically well mixed and the salt is diffused into the estuary by tidal mixing and transported out by freshwater flow. Assuming the system has reached a steady state, the upstream diffusive transport of salt into the estuary would be balanced by the transport of salt out of the estuary due to the river flow, according to the relationship

$$K\,S_x = u\,S$$

Up estuary salt flux by tidal mixing	Down estuary salt flux by freshwater inflow

Here, S_x is the along estuary salinity gradient, K is the eddy-diffusivity (or longitudinal dispersion co-efficient), and u is the flow speed associated with the river flow. In principle it is possible to obtain eddy-diffusivities from the measurements of salinity and knowledge of the flows in the Hunter, Williams, and Paterson rivers. To this end the averaged salinities and salinity gradients were calculated in different sections of the estuary. Applying this balance produced estimates of eddy-diffusivities, K, of about 100 m^2/s in the Hunter estuary, 60 m^2/s in the Hunter River upstream of Raymond Terrace, and 3 m^2/s in the Williams River upstream of Raymond Terrace. Such a balance assumes the system has reached a steady state condition.

It is interesting that the gradients are fairly uniform along the length of the estuary, except for the Williams River where gradients are markedly higher. Comparing the times at which Sanderson and Redden (2001b) sampled with river flows it is clear that river flows had been substantially higher within the 50 days prior to the observations than they were at the time of the observational program. This confirms that the salinity is not in equilibrium, and that the eddy-diffusivities calculated above should be regarded as approximate.

In summary, the salinity variability in the Hunter River estuary is determined by a balance between the freshwater inflows and tidal mixing transporting salt from the ocean into the estuary. At the ocean entrance salinity is usually around the ocean water value of 35 ppt. The location of particular isohalines (constant salinity) varies according to this balance and the variable inflow (Figure 4.8). The saline waters generally occur downstream of the Williams River confluence. During prolonged dry periods the salt water (say 1 ppt) will propagate upstream but it is unlikely to reach the Paterson River. Salinity between the Williams River and Maitland is typically about 0.2 to 0.5 ppt. It appears that there is a source of saline water to Fishery Creek with a mean value, derived from MCC data for the period 1995 to 2000, of 1.2 ppt immediately upstream of the STP inflow and 0.9 ppt immediately downstream, indicating dilution by the STP inflow. This conceptual salinity model is shown in Figure 4.9.

4.3 Water Quality

Water quality monitoring measurements, made by the Hunter Water Corporation, EPA and Maitland City Council have been compiled into a database to facilitate holistic analysis of the data in conjunction with measurements of river flow. The analysis illuminates interesting spatial patterns of nutrients and biota within the estuary and also provides a qualitative assessment of changes in the nutrient status during the last 25 years (Sanderson and Redden 2001a). It should be noted that this water quality analysis has been conducted for surface waters only, due to the absence of groundwater quality monitoring in the Hunter estuary.

The data set includes 25 water quality variables, measured at irregular locations and times from 1972 to early 2000. An overview of the water quality monitoring sites is presented in Figure 4.10. Details of the water quality analysis are presented in Sanderson and Redden (2001a) and an overview is presented here. Estimates of diffuse source pollution loads have been derived using primarily CMSS (Marston 1993) nutrient generation rates (see Section 4.3.9.1) and point sources of pollution have been identified from information provided by Environment Australia's 'National Pollutant Inventory' (see Section 4.3.9.2).

4.3.1 Spatial and Temporal Trends in the Estuary

Sanderson and Redden (2001a) have analysed the dataset provided by the EPA and HWC and derived a range of statistics as well as empirical relationships between concentrations and river flow. Relationships were derived for dissolved inorganic nitrogen, chlorophyll-a, total phosphorus, turbidity and dissolved oxygen. Figure 4.11 shows the average wet and dry weather water quality variables and salinity as a function of distance up the estuary. The values for each of the water quality variables have been normalised for ease of comparison. It should be noted that the amount of data available for high flow conditions is less than that for low flow conditions, especially in the middle reaches of the estuary, and this influences interpretation of the data. A summary of the trends for each variable is provided below.

Under low flow conditions salinity propagates furthest upstream implying longer residence times for waters in the upstream reaches. Total phosphorus indicates a weak source at around 40 km upstream (between Raymond Terrace and Morpeth) that decreases toward the ocean. The decrease may be due to a combination of dilution by lower concentration sea water, biological uptake of phosphorus and settling in the lower reaches. Dissolved inorganic nitrogen (DIN) tends to increase towards the mouth, suggesting that a distributed source of DIN along the lower reaches contributes before the dilution with lower concentration sea water near the mouth (up to 10 km from the mouth). Chlorophyll-a indicates high concentrations in the upstream reaches and decreases towards the mouth, which could be explained by a number of processes including a spatial shift from freshwater species upstream to saltwater species downstream, coupled with the effects of dilution in the lower reaches. The dissolved oxygen profile shows a slight increase downstream but generally shows that the estuary is well oxygenated throughout.

Under high flows, the river becomes almost fresh with brackish water near the mouth. Total phosphorus decreases downstream, most likely due to settling of particulate forms of phosphorus. DIN and DO are fairly constant along the length of the estuary, and essentially reflect the character of the inflow waters. The available chlorophyll-a concentrations collected in the lower reaches show considerable scatter. This may be due to the influx from local areas of high chlorophyll water, seasonal effects or sampling regime. It is not possible to draw any general trends in chlorophyll-a response in the lower estuary under high flows. The concentrations at times indicate a bloom of phytoplankton but there were not sufficient algal cell identification data to assess the particular bloom species.

Sanderson and Redden (2001a) have identified temporal trends in some water quality variables that predominantly relate to predictable seasonal changes. Chlorophyll-a shows a clear peak in February-March in the lower estuary, while phytoplankton counts show a small peak at this time with a larger peak in September. Zooplankton counts are high from April to June and in October-November, showing a lag response to the peaks in chlorophyll-a and phytoplankton that is commonly observed in estuarine environments. Levels of turbidity and non-filterable residue are both highest in the winter months when the salinity is lowest, and this is attributed to the higher levels of turbidity found in rivers compared to the ocean (Sanderson and Redden 2001a). The decline in salinity during winter can be attributed to increases in river flows. Dissolved oxygen shows no strong seasonal cycle in the lower estuary, while in the upper estuary concentrations are low in the late summer and increase in the spring. This trend can be attributed to the seasonal temperature cycle as well as large river flows in late summer that act to depress the oxygen levels by increasing the load of organic and oxidisable material.

Oxidised nitrogen (NO_x), ammonia (NH_3) and total phosphorus were analysed for long-term changes by comparing the data collected prior to 1985 to that collected after 1985 (Sanderson and Redden 2001a). The year 1985 was chosen as a point for comparison as it represented a considerable break in the sampling effort, and was also approximately halfway through the database. To undertake this long-term analysis, and for other parts of the water quality analysis, the water quality monitoring sites were divided into 10 zones in order to compress the spatial information content of the data (see Figure 4.10). It appears that there has been a long-term increase in NO_x in all zones analysed (A, B and C) although part of that increase can be attributed to a wet weather bias of the measurement program after 1985. NH_3 concentrations have not statistically increased in these areas, which is of interest as oxidising environments result in NO_x while NH_3 is indicative of a reducing environment (Sanderson and Redden 2001a). Total phosphorus appears to have increased in zones E and G, beyond that which can be attributed to wet weather bias, while in zones A, B and C total phosphorus appears to have been steady.

4.3.2 Comparison of Water Quality Data to ANZECC Guidelines

The NSW EPA has produced water quality and river flow interim environmental objectives for the Hunter River catchment designed for use as guidelines for river, groundwater and water management committees (EPA 1999). These objectives were developed following extensive community consultation and provide priority objectives for the eight stream types found in the Hunter River catchment, which include, for example, town water supply sub-catchments, mainly forested areas, waterways affected by urban developments and the estuary. The water quality objectives for the estuary have been defined for the protection of aquatic ecosystems, visual amenity, primary and secondary contact recreation and aquatic foods (to be cooked before eating). The numerical criteria assigned to these objectives for a range of water quality variables were primarily taken from the ANZECC (1992) water quality guidelines, with acknowledgement that these should be adapted to local conditions over time. As the 1992 guidelines have since been reviewed and revised the more recent ANZECC (2000) water quality guidelines have been used in this study to assess the water quality in the estuary.

The ANZECC (2000) water quality guidelines were designed to provide numerical and narrative criteria for the sustainable management of Australia's national water resources. Guidelines for the protection of aquatic ecosystems are divided into six ecosystem types, one of which is estuaries. However, it is recommended that local water quality studies are undertaken to determine appropriate and acceptable background levels for specific water bodies (ANZECC 2000). Trigger values are presented which represent the best currently available estimates of ecologically low-risk levels of water quality indicators. If values exceed these or fall outside a specified range it is recommended that management action is taken. In addition, the Hunter River Management Committee has suggested local reference water quality levels in the catchment for total phosphorus, turbidity and salinity that are considered to be potentially achievable levels for aquatic ecosystem protection (EPA 1999). Recreational guidelines were not revised in ANZECC (2000) and it has been recommended that the ANZECC (1992) guidelines continue to be used until this revision is complete. Recreational guidelines accommodate two categories of sporting activity:

- primary contact – sports in which the user comes into frequent direct contact with water, either as part of the activity or accidentally, for example swimming or surfing
- secondary contact – sports that generally have less frequent body contact with the water, for example boating or fishing (ANZECC 2000).

The final water quality objective for safe consumption of aquatic foods (to be cooked before eating) will be assessed using the water quality guidelines for the protection of cultured fish, molluscs and crustaceans (ANZECC 2000). A summary of relevant ANZECC guidelines is shown in Table 4.10.

Table 4.10 ANZECC (2000) and EPA (1999) Guidelines for Water Quality Variables

Water quality variable	ANZECC aquatic ecosystem trigger values	ANZECC recreational guidelines	ANZECC saltwater aquaculture guidelines	EPA aquatic ecosystem guideline
Temperature		15-35 ºC	< 2.0 ºC change over 1 hr	
Dissolved oxygen		> 6.5 mg/L	> 5.0 mg/L	
pH	7-8.5	5.0-9.0	6.0-9.0	
Chlorophyll-a	4 µg/L			
NH_3		10 µg/L (as N)	< 100 µg/L (unionised)	
NO_x	15 µg/L			
NO_3		10 000 µg/L	< 100 000 µg/L	
NO_2		1000 µg/L	< 100 µg/L	
Total N	300 µg/L			
FRP (filterable reactive P)	5 µg/L			
Total P	30 µg/L			10-20 µg/L
Enterococci (organisms/100mL)		1º contact < 35 2º contact < 230		
Faecal coliforms (organisms/100mL)		1º contact < 150 2º contact < 1000		
Turbidity				< 5 NTU

Water quality variables analysed for this study are discussed below, in the context of the ANZECC (2000) and EPA (1999) guidelines where possible. The water quality variables analysed include physico-chemical and biological indicators. Physico-chemical variables include dissolved oxygen, turbidity and nutrients such as inorganic nitrogen, ammonia, phosphate and phosphorus. Biologically related indicators include biological oxygen demand, chlorophyll-a and phytoplankton. These variables are linked to the presence and concentrations of physico-chemical variables, and are indicators of the biological health of the estuarine system.

It should be noted that water quality monitoring measurements utilised in this study were not undertaken for the purpose of direct comparison to the ANZECC guidelines. Results may be temporally restricted, as sampling was generally conducted fortnightly or monthly, and some data may have a wet weather bias.

Water temperatures in the Hunter estuary range from about 10ºC in winter to 27ºC in summer. While the lower temperatures are below the ANZECC recreational guidelines (of 15-35ºC), only 10% of values fall below 15ºC and these are likely to have been measured in cooler months when recreational activities such as swimming are less popular. Temperature is only of ecological concern, from the perspective of aquaculture protection, if significant changes are experienced in a short period of time, for example a ~2ºC change over an hour. The seasonal cycle causes temperature changes of about 7ºC in the lower estuary and about 10ºC in the upper estuary. It is unclear to what extent the temperature of the estuary might have been modified by human activity. Factors affecting water temperature that have been subject to anthropogenic modification include turbidity, river flow, channel bathymetry and wetland area. Reduced wetlands, increased tidal range associated with dredging and increased wind stress associated with loss of trees/mangroves will act to reduce spatio-temporal variability of temperature. Reduced river flow might act to either increase or decrease temperature fluctuations depending upon circumstances particular to a variety of physical mechanisms (Sanderson and Redden 2001a).

ANZECC (2000) recreational guidelines require that ***dissolved oxygen*** (DO) should not fall below 6.5 mg/L, as measured over a diurnal cycle, while aquaculture protection guidelines for saltwater production require that DO should not fall below 5.0 mg/L. The present measurements are not made over a diurnal cycle but this is not expected to be a major issue when all the mechanisms that cause spatio-temporal variability in the Hunter River estuary are given due consideration. The mean value of DO is 6.4 mg/L, with increasing concentrations at the downstream end of the estuary. At times oxygen levels can be sufficiently low to stress fish, even in the main branches of the Hunter River estuary. Dissolved oxygen levels below 3 mg/L are likely to be fatal to most fish species. It is notable that DO levels are substantially lower in side creeks, with the mean values in Windeyers Creek, Four Mile Creek and Wallis Creek being 3.9 mg/L, 5.5 mg/L and 5.0 mg/L respectively. The extent to which these low oxygen levels may restrict nursery habitat of juvenile fishes (or restrict access to nursery habitat) is unclear, but is an issue of potential concern (Sanderson and Redden 2001a). The Wallis and Fishery Creeks Total Catchment Management Study (HCMT 1999) provides information from a limited range of water quality monitoring sites on Wallis and Fishery creeks. This report suggests that low DO concentrations are of concern in Wallis Creek, which may be attributed to high nutrient levels related to inputs from Fishery Creek, decaying organic materials (including aquatic plants such as the water hyacinth), and land use practices in the Wallis Creek catchment (HCMT 1999).

The ANZECC (2000) aquatic ecosystem trigger value for ***pH*** is a range from 7.0-8.5, while the recreational and aquaculture protection guidelines suggest a range from 5.0-9.0 and 6.0-9.0 respectively. Throughout the study area pH measurements vary from a minimum of 6.0 to a maximum of 9.0, which suggests that overall pH is not a water quality parameter of concern in the estuary. Interestingly, the pH in the lower estuary is not that much different from the upper estuary, while the pH in the upper estuary side creeks tends to be lower than in the main channels of the estuary (Sanderson and Redden 2001a). From information presented in HCMT (1999) it is apparent that the Kurri Kurri STP may be a potential source of low pH water in Fishery Creek. This only occurs on isolated occasions and generally between June and December. It also appears that pH values in Wallis Creek during dry weather conditions are influenced by tidal conditions in the Hunter River and that significant decreases in pH occur following major runoff events (HCMT 1999). The influence of acid sulfate soils on pH is difficult to assess because the complex transport mechanisms and chemical reactions affecting pH are not well documented. That pH declines after runoff events is consistent with the process of low pH near surface groundwater draining to the waterways.

The ANZECC (2000) aquatic ecosystem trigger value for ***chlorophyll-a*** is 4 µg/L, above which it is suggested that management action be taken. Chlorophyll-a concentrations increase progressing up the estuary. Mean values in the lower estuary of 2-7 µg/L suggest exceedances of the trigger value at times, with occasional peaks that may be indicative of algal blooms. In the upper estuary the mean values increase to 22 µg/L. Combined with this trend of increasing chlorophyll-a upstream in the estuary are seasonal trends in phytoplankton concentration. Seasonal cycles of phytoplankton counts and chlorophyll-a concentrations suggest peaks in late summer and early spring. Zooplankton counts peak about a month afterwards, suggesting grazing might influence the phytoplankton population. Clearly, the combined effect of high turbidity and strong vertical mixing (due to shear production of turbulent kinetic energy by tides) suggests that phytoplankton are probably also light limited. Exchange with the open ocean might also limit the phytoplankton concentrations observed in the lower estuary by vigorous mixing and flushing with low chlorophyll-a ocean water. The seasonal cycles indicate that phytoplankton uptake has no measurable effect on NO_x concentrations. From closer examination of two locations (the north arm compared to an adjacent unnamed creek and the main channel in zone A compared to Throsby Creek) it appears that higher chlorophyll-a concentrations are found in side creeks, which may be attributed to greater physical stability and lower flushing of the water column in the side creeks.

The ANZECC (2000) recreational guidelines suggest that ***ammonia*** should not exceed 10 µg/L. The majority of measurements exceeded this level, with 90% of the readings at least 25 µg/L and 10% at least 640 µg/L. Ammonia (NH_3) has been stable through the 25-year period, with increasing concentrations towards the lower end of the estuary. NH_3 concentrations are high in Four Mile Creek, but generally concentrations in side creeks are not anomalously high relative to the main branches of the Hunter River estuary. While it is not possible to easily isolate sources from water quality measurements in the estuary, potential sources of ammonia include anoxic sediments, industry (particularly nitrogen fertiliser industries), and wastewater treatment works (Sanderson and Redden 2001a). HCMT (1999) suggests that treated effluent from the Farley STP is introducing increased concentrations of ammonia into Fishery Creek. However, recent monitoring (July 2001–July 2002) of effluent from the Farley STP by Hunter Water indicates that ammonia levels are lower than those reported by HCMT (1999) (C. Turnbull, Hunter Water, pers. comm. 2003).

The ANZECC (2000) guidelines include recreational and aquaculture protection guidelines for ***nitrite*** (NO_2) and ***nitrate*** (NO_3) and an aquatic ecosystem trigger value for these compounds combined as ***oxidised nitrogen*** (NO_x). Nitrite and nitrate measurements, with mean values of 22 µg/L and 220 µg/L, generally do not exceed these guidelines (see Table 4.10). However, the aquatic ecosystem trigger value for NO_x of 15 µg/L is exceeded by over 90% of measurements, with the mean value being 225 µg/L. Oxidised nitrogen, NO_x, has increased slightly in the north arm and south arm over the last 25 years, and is indicative of a trend for increasing concentrations in the downstream end of the estuary. Throsby Creek in particular has shown a large increase in concentrations over time and thus appears to be a source of oxidised nitrogen to the lower estuary. The Wallis and Fishery Creeks Total Catchment Management Study (HCMT 1999) presents information suggesting that concentrations of oxidised nitrogen in Fishery Creek regularly exceed guideline levels. Data collected in Fishery Creek upstream and downstream of the Farley STP between 1995 and 2000 show considerable variability. Upstream of the STP NO_x ranges from 30 to 8,100 µg/L with a mean of 1,230 µg/L and standard deviation of 2,120 µg/L, while downstream values range from 70 to 3,400 µg/L with a mean of 1,180 µg/L and standard deviation of 820 µg/L. These values are extremely high and indicative of a source within the catchment. The STP loads were not available but the data suggest the STP input is low and contributes to diluting the upstream concentrations. All of these values exceed the ANZECC guidelines for aquatic ecosystem protection.

The available water quality data does not include measurements of organic nitrogen, so it is not possible to make a direct comparison of ***total nitrogen*** concentrations to the ANZECC (2000) guidelines. The aquatic ecosystem trigger value of 300 µg/L is often exceeded by the combination of NH_3 and NO_x, which forms the inorganic component of total nitrogen, and it is thus expected that measurements of total nitrogen would be in exceedance of the trigger value. Estimates of the total nitrogen loads to the estuary from catchment runoff and point sources are presented in Section 4.3.9. HCMT (1999) indicates that total nitrogen levels recorded in Fishery Creek are predominantly above guideline levels and that measurements increase significantly downstream of the Kurri Kurri and Farley STPs. A new STP is currently being constructed at Kurri Kurri and should provide reductions in total nitrogen loads (C. Turnbull, Hunter Water, pers. comm. 2003).

The ANZECC (2000) aquatic ecosystem trigger value for filterable reactive phosphorus (FRP) is 5 µg/L. Measurements of the similar measure of bioavailable phosphorus, namely ***soluble reactive phosphorus*** (SRP), indicate that this value is frequently exceeded, with a mean value being 45 µg/L. Indeed, the minimum concentration observed is 5 µg/L. Even in the more saline lower reaches of the estuary the average values of SRP are higher than 15 µg/L. Very high values of SRP are evident in side creeks adjacent to the upper estuary. In Fishery Creek the mean values were 4,260 and 3,680 µg/L up- and downstream of the STP while in Wallis Creek the mean was 700 µg/L. There has been a general decrease in concentrations over the last three years.

The ANZECC (2000) aquatic ecosystem trigger value for ***total phosphorus*** (TP) is 30 µg/L, while the EPA (1999) interim water quality objectives suggest a range of 10-20 µg/L for the protection of aquatic ecosystems. Hunter estuary waters typically exceed this range. Mean values are, respectively 290 µg/L, 157 µg/L and 176 µg/L for the Hunter, Paterson and Williams rivers. Estimates of the total phosphorus loads to the estuary from catchment runoff and point sources are presented in Section 4.3.9. The focus for sampling of total phosphorus in Wallis and Fishery creeks has been on monitoring the performance of the Kurri Kurri and

Farley STPs (HCMT 1999). This monitoring, undertaken by Hunter Water Corporation, suggests that there is a source of TP upstream of the Kurri Kurri STP and that improvements to effluent treatment in 1996 have reduced the concentrations of TP entering Fishery Creek from the Kurri Kurri STP (HCMT 1999). A new plant is currently being constructed at Kurri Kurri, and this should further reduce total phosphorus and nitrogen loads (C. Turnbull, Hunter Water, pers. comm. 2003).

Nutrient levels in the Hunter estuary, which include the various forms of nitrogen and phosphorus, exceed the ANZECC guidelines and are likely to be problematic. The increased levels of nutrients influence factors such as chlorophyll-a concentration and oxygen levels. An account of the history of algal blooms in the estuary, which may be attributable in part to nutrient enrichment, is provided in Section 4.3.3.

Biological oxygen demand (BOD) is a measure of the decrease in oxygen content, which is brought about by the bacterial breakdown of organic matter. A high BOD indicates increased activity (oxygen uptake) of organisms that decompose organic material and thus provides an indication of organic loads. BOD is notably high in Wallis Creek and Windeyers Creek. These high BOD values were due to the decay of plant material and poor flushing, although flushing has now been improved. There is also a significant increase in BOD during and following major rain events.

The ANZECC (2000) recreational guidelines for ***enterococci*** indicate that counts should be less than 35 organisms/100 mL for primary contact and less than 230 organisms/100 mL for secondary contact. When considering measurements at all sites a median count of 160 organisms/100 mL was obtained, with the 90th percentile at 2,600 organisms/100 mL and the 10th percentile at 20 organisms/100 mL. The values reported tend to have a wet weather bias and therefore might be expected to be higher than typical. Counts tend to be highest in the lower estuary.

The ANZECC (2000) recreational guidelines for ***faecal coliforms*** indicate that counts should be less than 150 organisms/100 mL for primary contact and less than 1000 organisms/100 mL for secondary contact. They also specify that values to be compared with these criteria should be determined from at least five samples collected at regular intervals not exceeding one month. The median count for all measurements is 100 organisms/100 mL and the 90th percentile is 1900 organisms/100 mL. The more recent measurements have a wet weather bias and as the conditions and activities on the days of sampling are unknown it is difficult to interpret these results. Faecal coliforms provide a measure of pathogens derived from warm blooded animals and without additional information it is not possible to speculate on the source (human or animal) of the measured values. HCMT (1999) suggests that faecal coliforms are periodically at elevated levels in Fishery Creek. The major source of faecal coliforms appears to be from diffuse catchment runoff, however the Kurri Kurri and Farley STPs do appear to increase these values. The new STP being constructed at Kurri Kurri will have UV disinfection and this should reduce the faecal coliform concentrations entering Fishery Creek from this plant (C. Turnbull, Hunter Water, pers. comm. 2003). The Maitland City Council data collected over the six years 1995 to 2000 have an average time between samples of 37, 36 and 45 days for the Fishery Creek upstream and downstream sites and the Wallis Creek site, respectively. Hence it is not possible to draw comparisons with the guideline levels. The observed values are generally high with median values over the six years of 150, 260 and 169 cells/100 ml at the three respective sites.

The mean ***turbidity*** is 15 NTU with a maximum value of 260 NTU. The EPA (1999) interim water quality objectives suggest that a concentration of less than 5 NTU is suitable for the protection of aquatic ecosystems in estuaries, coastal lakes and lagoons. Turbidity is higher in the upper estuary than in the lower estuary, mostly due to dilution with low turbidity seawater near the ocean. In Wallis and Fishery creeks mean values are 61 NTU and 26 NTU, respectively. In flood conditions the estuary behaves like a river and the flux of material seaward is rapid compared to fluxes associated with many biochemical processes. This obviously causes disturbances to the coastal environment during floods. Turbid waters are not visually appealing and high turbidity is symptomatic of land degradation and probably impacts many benthic processes. On the other hand, high turbidity limits phytoplankton blooms and growth of undesirable plants and algae. Given the high nutrient loads into the Hunter River estuary, high turbidity levels might be considered to have some desirable side effects, as far as phytoplankton control is concerned. This would need to be balanced against other potential adverse impacts.

Overall, the major water quality issues in the Hunter estuary appear to relate to excessive levels of nutrients, high turbidity levels and high concentrations of chlorophyll-a. At a general level, ANZECC (2000) and EPA (1999) aquatic ecosystem trigger levels are exceeded for total nitrogen (average DIN 110–400 µg/L during low flow conditions, 340–480 µg/L during high flow conditions), soluble reactive phosphorus, total phosphorus (average TP 51–243 µg/L during low flow, 210–276 µg/L during high flow), chlorophyll-a (average Chl-a 4-15 µg/L during low flow, 1-11 µg/L during high flow) and turbidity (average 6–13 NTU during low flow). ANZECC (2000) recreational guidelines are exceeded for ammonia and oxidised nitrogen, suggesting that some areas (particularly near point source discharges) may be unsuitable for swimming and other recreational activities. More detail and site specific information can be found in Sanderson and Redden (2001a). ANZECC (2000) aquaculture protection guidelines are exceeded for oxidised nitrogen. It therefore appears that greater control and management of the diffuse and point source production of nutrients is required to protect the aquatic ecosystem, recreational and aquaculture values of the estuary.

4.3.3 Algal blooms

In river and estuarine environments around Australia algal blooms have been increasing in frequency and intensity, indicating a general degradation of aquatic ecosystems. Factors that increase the risk of bloom development include high nutrient concentrations, high water temperatures, abundant sunlight, calm water conditions, and low turbidity (DLWC 2000). High pH favours the dominance of algal blooms by blue-green algae. Blue-green algal blooms are of particular concern as they sometimes produce toxins that are harmful to human health and to stock, and may be harmful to macroinvertebrates and fish. The excessive growth of algae reduces the sunlight available to aquatic plants and may lead to their death. When aquatic plants and algae die, large amounts of oxygen are required as decomposition occurs. This decrease in available oxygen can lead to the death of aquatic animals such as fish and can increase the release of nutrients and toxic chemicals from the sediments.

Algal blooms commonly occur in open waterbodies, including farm dams, water storages, weir pools and wetlands. DLWC (2000) lists the major blue-green algal blooms experienced in the Hunter catchment over the period 1993-97. It is apparent that all have occurred outside of the Hunter estuary study area, in the Lostock, Glenbawn and Glennies Creek storages, the Grahamstown Dam and the Seaham Weir pool on the Williams River. The DLWC ‘NSW

Algal Information' website states that the Hunter region experiences algal blooms nearly every year in its storages, with locations additional to the above including Anvil Creek, Black Creek, Ellalong Lagoon, Paterson River, the Hunter River at Aberdeen, Walka Waterworks, Richley Reserve ponds, Telarah Lagoon, Warrabrook Lagoon, and many farm dams.

Information provided by Maitland City Council indicates that there have been blue-green algal blooms in the Wallis Creek area in recent years (C. Hendley, MCC, pers. comm. 2002). A bloom occurred in Rathluba Lagoon, near Louth Park, in 2000 and 2001, with Wallis Creek downstream of the tidal limits also affected in 2001. Wallis Creek has also experienced occasional anoxic conditions over the past few years (C. Hendley pers. comm. 2002). Information provided by Newcastle City Council indicated that there is currently a blue-green algal bloom in Warabrook Lagoon near The Wetlands Centre at Shortland which has been present since the winter (C. Robson, NCC, pers. comm. 2002).

The relatively high chlorophyll-a levels in the estuary suggest that algal blooms in the Hunter River are a common occurrence, although there have been few reports of harmful blue-green algal blooms. The high chlorophyll-a levels in most other estuaries would be highly visible but the high turbidity in the Hunter River probably masks the visual effects. In addition, the strong tidal currents and mixing effectively smooth out sharp gradients such that high peak blooms do not occur.

4.3.4 Limiting Factors for Biological Productivity

In aquatic systems biological productivity is stimulated by a range of factors including the intensity of light (photosynthesis, available radiation, PAR), light penetration into the water column, nutrient concentrations, temperature, and the physical environment (turbulence and mixing).

At the latitude of the Hunter catchment the light intensity at the water surface is generally well above the intensity that plant photosynthesis mechanisms begin to function. The amount of light penetrating down into the water depends on the water clarity that is reasonably characterised by the turbidity. Highly turbid 'dirty' water blocks the downward light penetration thereby limiting the depth to which photosynthesis can occur and algal growth is confined to the near surface.

The nutrient levels in the estuary exceed the levels at which aquatic plants begin to consume nutrients and increase their biomass. Hence it is unlikely that nutrients are limiting growth except during periods of blooms when algal uptake may reduce the nutrient concentrations below the critical levels for uptake.

Mixing and flushing are also important factors influencing algal bloom dynamics. The relatively strong tidal currents and associated turbulence levels result in rapid horizontal mixing of particles of water such that localised blooms are quickly dispersed along the estuary. Blooms in the mid- to lower estuary are most likely to occur during post-flood recovery when the vertical salinity gradient may persist for several days. Under this situation the nutrient-rich inflow water flows downstream at the surface and the brackish oceanic water propagates upstream at depth. The surface layer, with its higher nutrients, is maintained and confines the vertical movement of algal cells to a shallow layer where ample sunlight leads to high algal growth. Turbulent mixing across the vertical gradient ultimately homogenises the water column over some days and the algal bloom will be diluted.

4.3.5 Impacts of High Turbidity on Aquatic Flora and Fauna

High turbidity, which is common in the Hunter estuary for a range of reasons, limits light penetration through the water, thereby limiting aquatic plant growth. There is very little seagrass present in the Hunter estuary. A small amount of *Ruppia* has been observed in Fullerton Cove, and very small beds of *Ruppia* were occasionally seen in the upper estuary during field inspections (TEL 2001, MHL field observations 2002).

Biota affected by increased turbidity include oysters, and it has been suggested that high turbidity is the reason for the small numbers of oysters present in the Hunter River (Ruello 1976). It is possible for sediment and other contaminant particles to be accumulated by oysters and other marine invertebrates. Increases in turbidity may also affect the foraging behaviour of fish and suspended sediments may abrade the protective mucus coats on fish, thereby increasing their susceptibility to disease, or clog gill filaments and suffocate the fish (TEL 2001).

4.3.6 Impacts of Recreational Uses on Water Quality

Recreational activities, particularly the use of diesel-powered boats, have the potential to affect water quality through fuel and oil entering the water as well as general litter discarded by waterway users. Boat wash is a potential factor causing bank erosion in some areas of the Hunter estuary, with sediment eroding from the banks contributing to high turbidity levels. Boat propellers may also stir up sediment from the bed of the river and its tributaries in shallow areas, further adding to water clarity issues. As the Hunter River is not a popular area for overnight boating activities such as houseboats, the potential for sewage discharges from boats is not large and the lack of sewage pumpout facilities is not a matter of immediate concern.

4.3.7 Impacts of Mines and Power Generation on Water Quality

4.3.7.1 Mines

While the Hunter region is the primary region in NSW where coal mining is undertaken, there are no active mines within the Hunter estuary study area. However, the environmental impacts of mining are of concern to the community and impacts on water quality, in particular increases in salinity, acidity and metal concentrations, can have consequences downstream and long after mining operations have ceased. The Department of Mineral Resources (DMR) and the EPA regulate the standards with which mines must comply (DMR 1997). A requirement is that mining companies continuously monitor their environmental performance. Environmental factors measured include dust, noise and water quality, through indicators such as pH, suspended solids/turbidity, electrical conductivity, metals, cyanide, oils and greases.

Acidity can be a particularly important hazard at mines where sulphides are mined (DMR 1997). Salinity is a major problem due to the high salt levels in areas of basalt geology in the Hunter Valley. A recent solution to rising levels of salinity in the Hunter River due to discharges from mining, among other factors, was the inception of the Hunter River salinity trading scheme, discussed further in Section 4.3.7.3.

A search of the DMR’s Abandoned Minesite Database (James Brisebois pers. comm. 2002) found two minesites of environmental concern that have been the subject of Derelict Mines Projects in recent years. These are the Glen Ayr Coal Mine at Testers Hollow, which is located 7 km south of Maitland in the Wallis Creek catchment, and the Dagworth Greta Colliery, situated 6 km south-east of East Maitland. Prior to rehabilitation works the Glen Ayr site was subject to acidic saline minewater seepage from old underground works, which had the potential to impact on Testers Hollow, a semi-permanent wetland immediately downstream which is a sanctuary for local and migratory birdlife. While rehabilitation of this site is not complete and monitoring continues, water management and pollution controls were undertaken from 1995 to 1997 at a cost of over $71,000. The Dagworth Greta Colliery site consists of a large catch dam and chitter stockpiles, with no surface mine entries, workings or infrastructure in existence. The water quality within the dam is mildly acidic, saline, and high in sulphate due to unsatisfactory rehabilitation of the stockpiles. Work has been undertaken to stabilise the stockpiles and monitoring suggests that there has been negligible impact on the existing creekline.

4.3.7.2 Power Generation

Thermal electricity-generating plants can impact on water quality due to their demand for water for cooling purposes, the release of saline water following its use for cooling, and the potential for thermal pollution. Power stations in the Hunter Valley are located upstream of the study area, at Liddell and Bayswater, but may impact on the water quality of the Hunter River downstream. The power stations abstract water from the main river, for cooling and generating steam, at the rate of approximately 60,000 ML per year (EPA 1994).

Discharges from power generating plants have played a role in increasing the salinity of the Hunter River in the past and are now part of the Hunter River salinity trading scheme, discussed in detail in Section 4.3.7.3. The water used by thermal power plants is used to absorb excess heat from the power generation process, and this water may be discharged at temperatures 5-10ºC warmer than the ambient water temperature. Storage ponds are often used, however, to reduce the water temperature before discharge and thus not affect the receiving water and biota.

4.3.7.3 Hunter River Salinity Trading Scheme

The Hunter River Salinity Trading Scheme (HRSTS) manages discharges of saline water from coal mines and electricity generators to the Hunter River so that river salinity does not exceed levels that are detrimental to agricultural productivity or environmental quality downstream. This is achieved by:

- extensive and continuous real time monitoring of environmental conditions and discharges
- scheduling saline discharges to complement high river flow rates and low background salinity levels so that salinity targets are not exceeded, and
- sharing the total allowable discharge according to dischargers' holdings of tradeable salinity credits.

The Hunter River valley contains over 20 of the world's largest coal mines and Australia's largest electricity generator comprising two coal-fired generating plants. During coal mining, salty water collects in mine pits and shafts and has to be pumped out to allow mining operations to continue. Although much of this water is recycled, in some cases the excess cannot be stored on site. Electricity generation uses large volumes of river water for cooling. As this water evaporates in use, natural salt is concentrated in what remains.

The inputs of water from coal mining and electricity generation, along with other human activities such as over-application of irrigation water and excessive clearing of deep-rooted vegetation, resulted in an increase in average conductivity in the Hunter River in the 1970s and 1980s. Salinity levels were particularly high during periods of dry weather and low river flows.

The Department of Land and Water Conservation now has an extensive network of real-time conductivity monitoring stations in the river, which have shown that spikes of high salinity occur in the initial stages of high flow periods. Following these spikes a period of hours or days of very low salinity is observed and it is at this time that discharges of saline water are allowed under the HRSTS (EPA 2002).

4.3.8 Impacts of Flood Mitigation Structures on Water Quality and Water Exchange

Flood mitigation works have placed considerable pressure on the river and floodplain environment, by isolating the floodplain from the river via levees and floodgates, and by decreasing floodplain, wetland and shore habitat via drainage, agriculture and development. Biodiversity and ecosystem functioning have suffered as a consequence (HRC 2001).

Floodgates are designed to prevent the inflow of floodwaters but also prevent saline water from entering wetlands and salt marshes, which are important ecological habitats. In general, flood mitigation works can limit tidal flows, affecting habitat structure and the movement of fish and crustaceans, and interfere with nutrient and energy transfer. Drainage works may lead to exposure of potential acid sulfate soils and the subsequent discharge of low pH waters into the estuary (DLWC 2000).

The Water Quality Task Group involved in the preparation of the Wallis and Fishery Creeks Total Catchment Management Study are concerned that the Wallis Creek floodgates are preventing the tidal flushing of the former estuarine sections of the two creeks. They believe that the gates are contributing to high pollutant levels and aquatic weed infestations that have been reported in the lower reaches of the creeks (Hunter Catchment Management Trust 1999). The operational guidelines for the floodgates were altered in 1996 so that two of the eight gates are opened approximately 150 mm above the high tide mark. The gates are only fully closed during Hunter River floods. It is as yet undetermined how much flushing the gate opening affords (Hunter Catchment Management Trust 1999).

The floodgates on Ironbark Creek were constructed in 1970-71 and were on the main drainage point for Hexham Swamp. An Environmental Impact Statement prepared in 1973 evaluating the effects of the floodgates on water quality in Ironbark Creek stated that the scheme reduces water exchange with the Hunter River and also reduces the mean volume of water within the drainage area. This increases the retention of pollutants, lowers salinity and reduces mean water level. The report concluded that the water quality existing at the time was satisfactory and appropriate for the maintenance of all ‘beneficial uses’, but the scheme would require a degree of additional care to ensure the maintenance of this condition. At the present time, one of the Ironbark Creek floodgates is kept open to allow limited tidal flow into the creek and surrounding Hexham Swamp area. The Hexham Swamp Rehabilitation Project aims to eventually open all of the eight floodgates on Ironbark Creek to return the creek and swamp to its estuarine condition, while still using the floodgates as a control to prevent Hunter River flood flows into the area.

The installation of floodgates at Tomago has also led to a reduction in water exchange. This reduction in water exchange is leading to the loss of a saltmarsh area that acts as a high tide roost for migratory wading birds and a fisheries nursery habitat.

4.3.9 Diffuse and Point Source Pollution

4.3.9.1 Catchment Nutrient Export Rates

Rainfall and the subsequent surface runoff across a catchment carries sediment and pollutants across the land and into the nearest waterway. Rainfall intensity, slope, soil characteristics and porosity, land use and vegetation cover are important factors influencing the amount of runoff and quantity of substances entering the waterway. Waterborne constituents picked up by the overland flow or leached into groundwater are given the term ‘diffuse source pollution’.

The pollutants that most commonly affect estuarine processes are nutrients, which are often represented by the measurement of total nitrogen (TN) and total phosphorus (TP). Land uses that typically produce large quantities of nutrients include intensive horticulture and agriculture, which often rely on the application of fertilisers to the soil, and low-scale urbanisation with ineffective means of sewage disposal. The levels of TN and TP entering a river from its catchment can be estimated using land use information and adopting representative nutrient generation rates that have been determined for each land use type.

The alternative approach used in the study involved the use of CMSS (Catchment Management Support System) nutrient generation rates that have been developed by CSIRO for use in the Hawkesbury-Nepean Basin (Marston 1993). These generation rates were derived by analysing a number of different source materials including published literature, expert knowledge and unpublished data. The derivation of the rates included consideration of local conditions by giving extra weight to data that came from studies close to the Hawkesbury-Nepean area. In the absence of nutrient generation rates developed specifically for the Hunter region, it is considered that the rainfall and soil conditions of the two areas are sufficiently similar such that the CSIRO rates from the Hawkesbury-Nepean are appropriate for use in the Hunter estuary study area.

The CMSS nutrient generation rates used in this study are presented in Table 4.11. The land use categories presented in the CSIRO report (Marston 1993) differ from the categories provided by the DLWC land use mapping of the study area, and as such the DLWC categories have been merged into the CSIRO categories for application to the study area catchment. The details of this process are presented in Appendix B. It was not possible to place all of the DLWC categories into the pre-defined CSIRO categories, and therefore two additional sources of nutrient generation rates were adopted – Smalls (1986) and USEPA (2001) – as discussed in Appendix B.

Table 4.11 Nutrient Generation Rates Used in this Study
(Marston 1993, *Smalls 1986, #USEPA 2001)

Land Use	Total Nitrogen (kg/ha/yr)	Total Phosphorus (kg/ha/yr)
Bushland	1.5	0.1
Established sewered urban	5.0	1.3
Unsewered peri-urban	4.0	0.6
General urban *	3.7	1.1
Open/non-urban #	2.1	0.1
Industrial and commercial	6.0	1.8
Unfertilised grazing	0.9	0.25
Fertilised grazing	8.0	1.25
Extensive agriculture – arable	12.5	2.5
Vegetable growing	8.0	8.0
Orchards	4.7	0.3
Highway	5.6	2.2
Water/wetland #	4.4	0.2

The entire catchment of the Hunter River will affect the amount and type of diffuse pollution entering the Hunter estuary, depending on the land uses. Due to the large size of the Hunter River catchment (22,000 km^2, Figure 1.1), categorisation of all land uses in the area would be a significant task. As the study area for the Hunter Estuary Processes Study extends to the tidal limits of the river, it was decided that calculations of diffuse pollution rates would be limited to those areas that discharge directly into the study area – the 'Hunter estuary catchment' (Figure 4.12). The area within the Hunter estuary catchment is primarily controlled by the three councils involved in the Hunter Estuary Processes Study - Newcastle City, Maitland City and Port Stephens.

Categorisation of land uses in the 'Hunter estuary catchment' is shown in Figure 4.12. The DLWC land use mapping does not currently extend across the entire extent of the Hunter estuary catchment area and as a result the land use in the western extremities of the Paterson River and Wallis and Fishery creeks catchments has been estimated from 1:25,000 topographical maps. The study area catchment has been divided into 14 sub-catchments using DLWC contour and drainage mapping, enabling estimates of nutrient loads for nitrogen and phosphorus from each sub-catchment to the estuary (see Figures 4.12, 4.13. 4.14).

Calculation of the nutrient load from each of the sub-catchments involved multiplying the nutrient generation rate by the land use area for each type of land use within the sub-catchment.

In order to provide an indication of the influence of rainfall on nutrient loads to the estuary, three estimates have been provided that represent an average year, a wet year and a dry year. The wet and dry estimates were calculated by applying scaling factors to the average year estimate. These factors were derived as the ratio of the median rainfall to the 90th percentile and 10th percentile of 79 years of rainfall data from the Bureau of Meteorology's East Maitland Bowling Club rain gauge. These factors were 1.3 for a wet year and 0.6 for a dry year.

The nutrient loads for each of the 14 sub-catchments are provided in Table 4.12, including the estimates for the average, wet and dry years and the sub-catchment areas. Figures 4.13 and 4.14 show the sub-catchments with a colour scaling applied to indicate the level of estimated diffuse source nutrient pollution contributed by each sub-catchment. The results indicate that the largest loads of TN and TP are derived from the largest sub-catchments, being sub-catchment 14 (upper Williams River) and sub-catchment 13 (Allyn River).

Table 4.12 Nutrient Loads to the Hunter Estuary from 14 Sub-catchments* for an Average, Wet and Dry Rainfall Year, and Estimated Nutrient Loads# from the Upper Hunter River Catchment

(see text for explanation of rainfall year derivation)

Hunter Estuary Catchment							
***Sub-catchment number**	***Sub-catchment area (ha)**	**Total Nitrogen (kg/year)**			**Total Phosphorus (kg/year)**		
		Average	**Wet**	**Dry**	**Average**	**Wet**	**Dry**
1	4,795	239	311	144	64	83	38
2	2,510	100	130	60	21	27	12
3	13,177	366	475	219	63	81	38
4	9,137	279	363	167	56	73	34
5	17,387	484	629	290	99	129	60
6	41,944	619	804	371	116	151	70
7	11,136	322	418	193	30	39	18
8	8,337	203	264	122	34	44	20
9	3,897	104	135	62	19	25	12
10	22,086	542	704	325	104	135	62
11	22,460	393	511	236	83	107	50
12	23,175	283	367	170	54	70	32
13	49,068	752	977	451	142	185	85
14	117,210	2,093	2,720	1,256	343	446	206
TOTAL	**349,319**	**6,776**	**8,809**	**4,066**	**1,226**	**1,594**	**736**
Upper Hunter River Catchment#							
	$Catchment area (ha)	**Total Nitrogen (kg/year)**			**Total Phosphorus (kg/year)**		
		Average		**Low flow**	**Average**		**Low flow**
TOTAL	**1,850,680**	**332,000**		**23,000**	**204,000**		**22,000**

*The sub-catchments refer only to the 'Hunter estuary catchment' depicted in Figure 4.12.
Estimates of nutrient loads from the remainder of the Hunter River catchment, the 'upper Hunter River catchment', derived from Sanderson and Redden (2001a) for inputs upstream of the tidal limit at Oakhampton.
$ Catchment area calculated by subtracting the total area of the Hunter estuary catchment (349,320 ha) from the total area of the Hunter River catchment of 22,000 km^2 (2,200,000 ha).

To provide an indication of nutrient export rate, i.e. nutrient load per hectare, the loads for each sub-catchment were divided by the sub-catchment area. The largest export rates occur in sub-catchment 1 (Throsby Creek), sub-catchment 2 (Kooragang Island) and sub-catchment 4 (Ironbark Creek), which indicates that the Newcastle urban area near the mouth of the Hunter estuary contributes significantly to nutrient loads in the estuary although they input to the rapidly flushed lower reaches.

Stormwater runoff from urbanised land can be a significant factor affecting water quality, with chemical contaminants and gross pollutants picked up by stormwater directly entering creeks and rivers. Stormwater management plans (SMPs) have been prepared by Port Stephens Council and Newcastle City Council, covering their local government areas. Maitland City Council is in the process of finalising its SMP (Claire Hendley, Maitland City Council, pers. comm. 2002) The Port Stephens SMP (PSC 2000b) includes Raymond Terrace, which has a population of 13,000 and discharges all its stormwater to either the Williams or lower Hunter rivers directly or to the lower Hunter River via Windeyers Creek. Management objectives for the area, with a range of associated options provided, include compliance with ANZECC water quality objectives and the reduction of gross pollutants entering the Hunter River (PSC 2000a). The Newcastle SMP covers the catchments of Ironbark, Throsby and Cottage creeks and directs inputs of stormwater from Newcastle City into the Hunter estuary. The plan states that there are 104 stormwater outlets discharging directly into Newcastle Harbour, all without treatment except for one major outlet that is screened to remove gross pollutants (NCC 2000).

As the Hunter River catchment beyond the study area is a significant source of nutrient loads into the estuary, load estimates derived from Sanderson and Redden (2001a) upstream of the tidal limit at Oakhampton were utilised to represent the input from the remainder of the catchment. These load estimates are provided in Table 4.12. From this table it can be seen that the contribution of the upper Hunter River to both nitrogen and phosphorus loads into the estuary is far greater than the total contribution of the Hunter estuary sub-catchments (e.g. 332,000 kg/yr nitrogen compared to 6,776 kg/yr during average flow conditions). This would be expected due to the large size of the Hunter River catchment. The significant input of the upper Hunter River catchment to nutrient loads in the estuary highlights the importance of integrated catchment strategies, such as the Hunter Catchment Blueprint, and the role that this plays in improving water quality within the Hunter estuary.

4.3.9.2 Point Source Pollution

The EPA is responsible for licensing point source pollution discharges under the *Protection of the Environment Operations Act 1997*. There are a number of industries within the catchment that have EPA licences to discharge TN and TP into local waterways, along with a number of other pollutants such as oil and grease, suspended solids and a range of metals. As these industries contribute pollutants from a specific location in the catchment they are generally referred to as ‘point source pollution’. A complete list of industries within the study area that have EPA licences to discharge is provided in Table 4.13, together with the pollutants/parameters for which they are required to undertake monitoring as part of their licence agreement. The locations of these industries are shown in Figures 4.13 and 4.14, using the Australian New Zealand Standard Industrial Classification (ANZSIC, as used by the Australian Bureau of Statistics) and the licensed activities of each premise. A number of poultry processing plants are also known to occur in the Lower Williams, Paterson and Hunter Valley that produce waste high in nitrogen and phosphorus (R. Cooke, DLWC, pers. comm. 2003), however these were not included in information provided by the EPA (2001).

Table 4.13 EPA-licensed Point Sources within the Hunter Estuary Study Area (EPA 2001)

Premises Name	Suburb and LGA	Pollutants/parameters monitored
The Shell Company of Australia Ltd	Hamilton, Newcastle	Oil and grease, TSS
RZM Tomago Separation Plant	Tomago, Port Stephens	pH, TSS
BP Australia Ltd	Carrington, Newcastle	Oil and grease, TSS
New Wallsend No. 2 Colliery	Wallsend, Newcastle	Oil and grease, pH, EC, TSS
PWCS Carrington Coal Terminal	Carrington, Newcastle	BOD, TSS
Dairy Farmers Hexham	Hexham, Newcastle	Oil and grease, BOD, TSS
Commonwealth Steel Company Limited	Waratah, Newcastle	Oil and grease, Chemical Oxygen Demand, TSS, total suspended particles, Mn, Hg, Cd, hazardous substances, SO_3, NO_x, filterable Fe
Incitec Ltd	Kooragang, Newcastle	Oil and grease, TSS, pH, temp., NH_4^+, particulate matter, fluoride, Cr (Hexavalent), Ar
Steggles Ltd	Beresfield, Newcastle	pH, TSS, BOD, temp.
PWCS - Kooragang Coal Terminal	Kooragang, Newcastle	Oil and grease, TSS, filterable Fe
Hexham Bowling Club Co-op Ltd	Hexham, Newcastle	Oil and grease, TSS, BOD, Cl (free residual)
Metcash Trading Limited	Hexham, Newcastle	Oil and grease, pH, TSS, BOD, Cl (free residual)
Hexham Engineering Pty Ltd	Hexham, Newcastle	Oil and grease, pH, TSS, BOD, Cl (free residual)
Newcastle Sewage System	Merewether, Newcastle	Oil and grease, pH, TSS, BOD
Shortland WWTW	Shortland, Newcastle	Oil and grease, pH, TSS, BOD
BHP Steel	Mayfield, Newcastle	pH, BOD, TSS, Cl (free residual), faecal coliforms
Weathertex Pty Ltd	Raymond Terrace, Port Stephens	pH
Tubemakers of Australia Ltd	Mayfield, Newcastle	pH, TSS, NH_4^+, filterable Fe, total Zn, filterable Mn
Bolwarra WWTW	Bolwarra, Maitland	pH, BOD, TSS,
Delta EMD Australia Pty Ltd	Mayfield, Newcastle	pH, temp., TSS, Mn
Minmi WWTW	Minmi, Newcastle	pH, BOD, TSS
PWCS Fines Disposal Facility	Kooragang, Newcastle	TSS
Minmet Operations Pty Ltd	Tomago, Port Stephens	pH, total Cr, Ar, total Pb
Forgacs Dockyard	Carrington, Newcastle	pH, TSS
Tomago Aluminium Company Pty Ltd	Tomago, Port Stephens	TSS, fluoride
(New) Morpeth WWTW	Morpeth, Maitland	pH, BOD, TSS
OneSteel Proprietary Limited	Mayfield, Newcastle	Oil and grease, pH, TSS, NH_4^+, filterable Fe, total Fe, filterable Fe, dissolved Fe, Mn (dissolved), total Zn
Farley WWTW	Farley, Maitland	pH, BOD, TSS
CSR Metford West Site including Fieldsend Pit	Metford, Maitland	pH, TSS

WWTW = Wastewater Treatment Works, TSS = total suspended solids, BOD = biological oxygen demand, EC = electrical conductivity, NH_4^+ = ammonium nitrogen, Ar = arsenic, Cr = chromium, Cl = chlorine, Hg = mercury, Fe = iron, Mn = manganese, Pb = lead, Zn = zinc

Note: a number of poultry processors are also known to occur in the Lower Williams, Paterson and Hunter Valley, which are not included in this list.

While information was provided by the EPA regarding the licence requirements for the point sources of pollution listed in Table 4.13, actual estimates of loads discharged annually into the estuary were obtained from the National Pollutant Inventory (NPI, managed by Environment Australia), which contains information relating only to a select number of point sources of pollution within the study area. The quantities of TN and TP that were reportedly discharged in the financial year from July 2000 to June 2001 are presented in Table 4.14.

Table 4.14 TN and TP Discharges to Water from Selected EPA-licensed Industries in the Study Area July 2000–June 2001#

(National Pollutant Inventory, Environment Australia, Alison McKenzie pers. comm. 2002)

Industry name	ANZSIC Industry Classification	TN (kg)	TP (kg)
Incitec Ltd Kooragang Island site	Fertiliser manufacturing	276,489	
Steggles Beresfield site	Poultry processing	98,915	20,145
Morpeth WWTW	Sewerage and drainage services	47,529	20,913
Raymond Terrace WWTW	Sewerage and drainage services	17,865	6,503
Shortland WWTW	Sewerage and drainage services		7,972
Stockton WWTW*	Sewerage and drainage services		4,784

# The National Pollutant Inventory provides discharges for a select number of EPA-licensed industries, and therefore this table does not provide discharges for all licensed point sources within the Hunter estuary study area.
WWTW = Wastewater Treatment Works
*Stockton WWTW now closed, and sewage previously treated by this plant is pumped to Shortland WWTW for treatment.

It should be noted that Stockton WWTW has recently been closed, and sewage from the Stockton catchment is now pumped to the upgraded Shortland WWTW. The load estimates provided by Hunter Water for July 2001–June 2002 for Morpeth WWTW and Raymond Terrace WWTW (C. Turnbull, Hunter Water, pers. comm. 2003) indicate reductions in TN and TP loads compared to July 2000–June 2001. TN and TP loads for 2001-2002 for Raymond Terrace WWTW were 13,154 kg and 3,917 kg respectively, and for Morpeth WWTW were 25,982 kg and 14,451 kg respectively.

In addition to those industries listed in Table 4.14 that are licensed to discharge TN and TP, there are an additional six industries that have EPA licences to discharge metals and halogens to the land or water within the study area, as contained in the National Pollutant Inventory. Values for metals and halogens that were reportedly discharged in the financial year from July 2000 to June 2001 are provided in Table 4.15. The locations of the industries are shown in Figures 4.13 and 4.14, using their ANZSIC industry classifications. Note that Incitec Ltd is presented in both Table 4.14 and 4.15 as it discharged arsenic, chromium (VI) and zinc in addition to total nitrogen.

A comparison between the nutrients entering the estuary via diffuse source pollution (Table 4.12) and from point sources (Table 4.14) indicates that the point sources form a highly significant contribution. The quantity of nutrients discharged from each of the point sources is in fact higher than the nutrient levels that have been estimated to be carried by runoff over the Hunter estuary catchment. Total nitrogen discharged by the fertilising manufacturer Incitec is of similar magnitude to the total nitrogen estimated to be derived from the upper Hunter River catchment (276,000 kg compared to 332,000 kg). The poultry processor Steggles is also a large source of total nitrogen (98,915 kg). A number of poultry sheds are also present within the Lower Williams River, Paterson River and Hunter Valley which produce significant waste high in nitrogen and phosphorus (R. Cooke, DLWC, pers. comm. 2003). As Table 4.14 contains loads pertaining only to the larger point sources within the estuary, it is expected that this is an underestimate of the point source contribution to total loads.

Overflows from the wastewater transport system can occur during heavy rainfall when the system is overloaded. Hunter Water operates the wastewater transport systems within the Hunter Valley, which is made up of 4,100 kilometres of sewer mains and 341 wastewater pumping stations. Hunter Water's Environmental Annual Report for 2000-01 states that in 2000, 538 overflows were attributed to heavy rain compared with 488 in the previous year (HWC 2001). Overflows can also result from failures in pumping stations, of which there were eight in 2000 compared with sixteen in the previous year. Hunter Water's operating licence sets a target of less than 1.4 sewer overflows per kilometre of sewer main, which was achieved in 2000-01 with a result of 1.04 overflows per kilometre (HWC 2001). Data is not available on the volumes of wastewater that these overflows represent, but the Environmental Annual Report states that due to the flow being so heavily diluted with rainfall, there is generally minimal environmental impact (HWC 2001). Hunter Water has provided a significant commitment to improving the health of the Hunter River in the last 10 years with a $90 million program of works including a number of WWTW upgrades, such as that completed at the Shortland WWTW in 1998 (Greg Bone, Hunter Water, pers. comm. 2001), and the recent closure of Stockton WWTW.

Table 4.15 Discharges from EPA-licensed Industries in the Study Area July 2000–June 2001
(National Pollutant Inventory, Environment Australia, Alison McKenzie pers. comm. 2002)

Industry	ANZSIC Industry Classification *	Discharge Destination	Substance emitted (kg) #										
			Ar	Be	Cd	Cr (III)	Cr (VI)	Cu	Cya	F	Pb	Mn	Zn
Tomago Aluminium Smelter	1	Water	4	3	3		16		208	1150	13		
OneSteel Newcastle Pipe and Tube Mill	2	Water									1	1	7
OneSteel Newcastle Pipe and Tube Mill	2	Land										2	2
OneSteel Newcastle Wire Mill	2	Water									3		14
Minmet Operations Pty Limited	3	Land											1
Incitec Ltd Kooragang Island Site	4	Water	7				12						404
Grahamstown Water Treatment Plant	5	Water								104			
Koppers Timber Preservation Beresfield	6	Land	26			22		13					

* ANZSIC Industry Classifications: 1 = Aluminium smelting; 2 = Basic iron and steel manufacturing; 3 = Chemical product manufacturing; 4 = Fertiliser manufacturing; 5 = Water supply; 6 = Wood product manufacturing.

Substances emitted: Ar = arsenic and compounds; Be = beryllium and compounds; Cd = cadmium and compounds; Cr (III) = chromium III compounds; Cr (VI) = chromium VI compounds; Cu = copper and compounds; Cya = cyanide (inorganic) compounds; F = fluoride compounds; Pb = lead and compounds; Mn = manganese and compounds; Zn = zinc and compounds.

4.3.10 Water Quality and Flushing Model

A conceptual model of the nutrient cycling processes and factors controlling phytoplankton biomass has been derived from previous detailed studies in northern NSW rivers (Eyre 1998) and the interpretation of the data presented in the preceding sections. Following Eyre (1998) the processes and factors controlling phytoplankton biomass in the Hunter River estuary may be summarised in terms of four broad stages, each driven by freshwater discharge (Figure 4.15).

Stage 1 – Flood events

During large floods the Hunter estuary, like other northern NSW estuaries (Eyre and Twigg 1997), flushes fresh to the mouth. Under these conditions floodwaters, sediment and nutrients discharge directly into the adjacent coastal waters and spill over the lower floodplain and backwater areas. During the flood, turbidity at the mouth of the estuary is very high (~180 NTU) when normally it is in the range 1-10 NTU. For sufficiently large floods the estuarine basin may remain fresh at the mouth for a number of days and significant scouring of the estuary channel can occur. In contrast, even if just a small part of the salinity gradient remains within the mouth of the estuarine basin there may be significant flocculation of fine particles, deposition and processing of material within the estuary. The scouring and export of particulate organic carbon (POC) during the larger floods may result in the estuary being net autotrophic.

Stage 2 – Estuarine recovery

As the Hunter estuary recovers from 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 homogenous system. Immediately following floods some of the sediment from the sediment-laden upper layer probably flocculates and settles through the halocline at slack water where it is caught in the lower layer, transported landward, and deposited near the salt/freshwater interface (Eyre and Twigg 1997, Eyre et al. 1997, Eyre 1999). 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. The amount of material trapped would depend on the flushing time of the estuary. Early in the recovery stage material passes through relatively conservatively due to short flushing times, but the processing of material increases with an increase in flushing time. The location of the salt/freshwater interface dictates where maximum deposition occurs in the estuary. For example, following a 1-in-20-year return period flood maximum sediment deposition in the Richmond River estuary occurred 10 to 15 km from the mouth, coinciding with the location of the salt/freshwater interface (Hossain 1997). During this stage nutrients are typically very high due to diffuse runoff from the catchment. However, phytoplankton growth is not stimulated due to either light limitation associated with the high turbidity and/or rapid flushing.

Stages 3 and 4 – Medium flow and extended dry periods

During dry periods the Hunter estuary returns to a vertically homogenous system due to low freshwater discharge and tidal mixing. The point source inputs in the upper estuary are retained within the system due to very long flushing times. The highest phytoplankton biomass probably occurs during the dry periods due to lower turbidity and slow flushing, however the resultant rapid uptake of nutrients may result in phytoplankton growth being nutrient-limited. Stage 3 represents a small runoff event during a dry period which provides additional diffuse sources of nutrients which in turn stimulate maximum phytoplankton growth. Because of the high turbidity phytoplankton growth is likely to be light-limited with short periods of nitrogen limitation. Small diffuse loading events during dry periods are likely to support primary productivity when the benthic supply of nitrogen is exhausted (Eyre and Twigg 1997). During Stage 4 diffuse runoff from the Hunter catchment makes up a smaller proportion of the total nutrient loadings and point sources make up a larger proportion compared to Stage 3. There may also be some nitrogen and phosphorus input from the ocean during these dry periods (McKee and Eyre 1997). Without the additional diffuse nitrogen loading during the dry months, the combination of a reduced loading, with a low nitrogen:phosphorus ratio, results in nutrient concentrations in the water column being even more limiting (particularly nitrogen) to phytoplankton growth. This results in a lower phytoplankton biomass during Stage 4 compared to Stage 3.

4.3.11 Nutrient Budget

Many processes affect the nutrient concentrations in estuarine environments. Nutrient sources, such as river inflows, stormwater drainage, industrial inputs, and sewage inputs, have magnitudes that fluctuate greatly with changing seasons and weather conditions. Biological utilisation and recycling of nutrients is sometimes important, as may be various sedimentary processes.

Some of the mechanisms that can affect nutrient levels are:

- Nutrient sources due to river inflow, localised rainfall, groundwater, stormwater inflow, sewage discharge/overflow, drainage from farms etc. River flows are continuously measured in the Hunter River, although nutrient levels of these flows are not. The nutrient fluxes from river inflow can be roughly estimated, given some knowledge of nutrient concentrations.
- Transport of nutrient-rich estuary water into the ocean represents a loss from the estuary. This term can be reasonably well determined given knowledge of the nutrient concentrations.
- Tidal mixing of estuary waters with the relatively nutrient-depleted waters of the adjacent ocean represents a sink for the estuary. To determine this term requires knowledge of gradients in nutrient concentrations, eddy diffusivities and estuary bathymetry.
- The major physical mixing and transport mechanisms that act to redistribute nutrients within the estuary are well understood. Mechanisms include horizontal transport and mixing, vertical mixing, vertical fluid motions associated with divergence/convergence zones, secondary circulations, wind-driven mixing/transport, wave action and wave-radiation stresses, and sinking/floating of particulate material.
- Within the estuary there may be many local sources, sinks and cycling mechanisms of a biogeochemical nature (Figure 4.15). Possible examples include:
    - Mineralisation in the estuary sediments. The sediment has near-surface layers in which oxidation occurs (producing NO_3^-, for example) and deeper layers where material is reduced (producing NH_4^+, for example). Denitrification is also an important loss of nitrogen from the estuary.
    - Uptake of nutrients by phytoplankton and subsequent transfer within the food chain can modify local nutrient levels within the water column.

- Water column bacteria provide sources of dissolved organic matter as well as nutrient sinks due to denitrification.
- Zooplankton grazing and leaky phytoplankton production are further sources of dissolved organic matter.
- Plants within salt marshes take up inorganic nutrients. Subsequent transport of dead and detached plant material provides a source of organic nutrients. Salt marshes can be regions of sediment deposition and are therefore a nutrient sink, the magnitude of which depends upon the rates of nutrient cycling and sediment accumulation within the salt marsh.

Sanderson and Redden (2001a) analysed the available nutrient data to derive empirical relationships between river flow and the concentrations of NH_3, NO_x, total phosphorus and non-filterable residue (NFR) in the Hunter, Paterson and Williams rivers. These empirical relationships have then been used to crudely estimate fluxes of nutrients and suspended sediment into the estuary from the three rivers upstream of the tidal limit and exiting the estuary at the mouth. The mean and geometric mean fluxes were estimated for each variable and by subtracting the total input (sum of individual fluxes from the Hunter, Paterson and Williams rivers) from the efflux at the entrance provides an estimate of the amount of material retained within the system. The geometric mean flow is a characteristic of lower flows while the mean is biased by the high flow events. Comparing mean flux estimates to geometric mean fluxes provides a qualitative measure of the estuary retention efficiency at high and low flows.

Total loads into and out of the Hunter River estuary derived using the above methods are shown in Table 4.16 (Sanderson and Redden 2001a) as well as the estimates derived using the CMSS model and the total point source loads as discussed in the previous section.

Loads from the groundwater may also be significant, particularly during dry periods, but there were not sufficient groundwater nutrient concentration data to admit an estimate.

Table 4.16 Mean and Geometric Mean Loads Into and Exiting the Hunter River Estuary, CMSS Load Estimates and Point Source Loads
(tonnes/year)

	NO_x		NH_3		TN[1]		TP	
	Mean	**Geom. Mean**	**Mean**	**Geom. Mean**	**Mean**	**Geom. Mean**	**Mean**	**Geom. Mean**
Hunter River	256	12	77	11	332	23	204	22
Paterson River	16	2	16	2	32	4	40	7
Williams River	35	2	24	2	59	4	62	7
Total	307	16	117	15	424	31	307	36
Exit Load	226	38	175	53	402	91	237	22
Retention	26%	-144%	-50%	-243%	5%	-193%	23%	40%
CMSS Lower Estuary load						7		1
Point Sources						441		60

[1] TN estimated as the sum of NH_3 and NO_X which is an underestimate as the organic nitrogen components of TN are not included.

The retention is calculated as the difference between the total input load (labelled Total in Table 4.16) and the exit load divided by the input load. Positive values indicate that material is retained in the system while negative values indicate a source within the estuary between the input points and the exit. Note the point sources are only provided in the total forms of the nutrients. The TN was estimated as the addition of NO_x and NH_3 loads which is an underestimate as the organic nitrogen components of the TN, generally measured as TKN, are not included. Unfortunately there were not sufficient data on TKN covering the whole period of the dataset to warrant its inclusion in the estimates of TN.

NO_x is an important dissolved inorganic nutrient that is bioavailable. The retention estimate indicates that about 26% of the mean input load is retained within the estuary while the geometric mean which represents conditions under lower flows suggests there is a source in the estuary producing NO_x. While a proportion of the source may be associated with the WWTW loads they cannot account for the overall retention, and the other most likely source is the sediments of the lower estuary, where organic inputs from upstream settle and decompose nitrogen in various forms.

The values for NH_3 indicate that the estuary always acts as a source as the retention for both the mean and geometric mean has negative values. This source may be associated with the WWTW inputs or the in situ reduction processes mentioned above.

The TN estimates are interesting in that only about 5% of the mean input is retained in the estuary while at low flows a large generation of TN that again may be in part attributed to the point source loads or sediment release. It must be remembered that this estimate of TN excludes the organic components and hence is likely to be an underestimate of the true value.

Total phosphorus retention indicates that the TP is retained within the estuary for both the higher mean flow and lower geometric mean flow. This is likely to be associated with binding of phosphorus to the finer particles and subsequent settling of these particulate forms during the lower flows when flushing is also reduced.

The nutrient budget is summarised in Figure 4.16.

4.4 Sedimentation and Erosion

4.4.1 Factors Affecting Sedimentation and Erosion

Sedimentation and erosion processes operate at varying levels from the catchment level through to the morphology of the river, and at varying time scales, from geological through to shorter-term time scales. Factors influencing sedimentation and erosion in the Hunter River catchment at geological time scales include geology, topography, slope classes and soils. These factors, together with rainfall, lead to the erodability of the catchment. Human influence can accelerate the rate of sedimentation and erosion through factors such as clearing and land use changes.

Most of the soil landscapes of the Hunter Valley catchment have a moderate to high erodability factor based on soil properties (Matthei 1995). These properties need to be considered in conjunction with slope and precipitation to assess erodability. The highest erodability of parent material is associated with the weaker strata of the Permian coal measures that currently crop out and subcrop in the centre of the valley. Other weaker strata are associated with structurally disturbed zones such as adjacent to the Hunter thrust fault or Williams River fault and associated faults. This is reflected by the removal of much of this material in the central sections of the valley, and its burial by Tertiary to Quaternary sediments (Figure 2.5). However, the highest rainfall in the Hunter catchment is currently found on the Barrington Tops and Liverpool Range, throughout the coastal zone and onto the Hunter Range in the Wollemi National Park on the southern escarpment. The highest slopes are also currently found approaching the Barrington Tops, the Liverpool Range and the Hunter Range (Figure 2.4). Hence these areas have the highest erodability in the current catchment, particularly where deep residual and colluvial soil landscapes are encountered by the retreating escarpments and steep slopes.

There is also a significant catchment erodability issue with respect to the contrasting parent material in the different sub-catchments of the Hunter. In particular, since the eroding basalt soils and parent material of the northern Hunter Valley are predominantly generating a muddy sediment source, sediment supplied by the Williams, Paterson and part of the Hunter source streams will be of mainly mud size. In contrast, on the southern side of the valley, the parent material is mainly sandstone, and when eroded, will predominantly generate sand-sized sediment, for example from the catchment of Wollombi Brook (see Figure 2.4). Grain size analysis indicates that the average sediment size in the Oakhampton to Hexham stretch is fine to medium sand with an average median diameter of 0.31 mm (Lawson and Treloar 1995). This is consistent with the sediment input identified from Wollombi Brook by Patterson Britton and Partners (1995), although the study area for this report did not extend into the upper Hunter River, and therefore other waterways such as the Goulburn River may also be contributing fine to medium sand into the Hunter estuary.

For the Hunter estuary sub-catchment, an indication of erodability is provided by actual erosion in the Hunter estuary catchment (Figure 4.17). Areas of the estuary sub-catchment undergoing erosion (namely sheet erosion) are found in the areas with the highest slope classes (Figure 2.9) in the northern and southern regions of the catchment such as the Paterson Mountains, Clarence Town Hills, and Sugarloaf Range.

Land use changes have modified and accelerated changes to the landform since European settlement. The floodplain of the Hunter River was once covered with dense forest, sediment yields were low and a pool riffle structure occurred upstream of Maitland (Patterson Britton & Partners 1995). Land clearing and flood mitigation works altered the sediment transport processes of the Hunter River catchment. Channel infilling was accelerated through increased erosion and mitigation works which impeded the transport of this mobilised sediment (Boyd 2001).

It is clear that the Hunter River catchment is a significant sediment source for the Hunter estuary, although its impact varies across the catchment. This highlights the importance of a catchment management approach when addressing sediment loading in the Hunter estuary.

4.4.2 Sediment Dynamics in the Estuary

The sediment composition and movements within the estuary and river play an important role in determining the morphology and also affect the exchange of compounds (e.g. nutrients) between the sediment and the water column. Coarse inorganic sediments (sand and mud) are generally transported as bed load under flood conditions and thus reworked by tidal flows particularly during spring tides.

Fine sediments delivered to the estuary during floods are generally comprised of inorganic clay material, and organic detrital material, often measured as particulate organic carbon (POC). These suspended particles and dissolved compounds determine turbidity in the water column.

This material has a range of properties that lead to flocculation of particles that settle in the estuary. The flocculation process involves complex ion interactions attracting individual particles, and is generally enhanced in more saline conditions. Hence it is generally thought that particles will flocculate and settle near the salt wedge , increasing POC concentrations in the sediments. The gradual decomposition of POC near the surface sediments releases nutrients into the water column and interstitial pore water of the sediment. Resuspension of the fine surficial sediments during stronger tidal flows exacerbates the releases and increases turbidity.

4.4.3 Erosion and Sedimentation Issues since European Settlement

Erosion and sedimentation in the Hunter River catchment have raised concerns since early European settlement (Department of Water Resources 1987). Fifty years after European settlement along the Hunter River, morphological changes led to altered sediment transport rates and tidal hydrodynamics, impaired navigability and increased bank erosion (Patterson Britton & Partners 1995). In 1832 concern was raised by the Harbour Master at Newcastle regarding silting up of the bar at the entrance of the harbour, and led to the commencement of work on the breakwater. In 1869 a Royal Commission was convened to report (now known as the Moriarty Report) on the best means of mitigating or preventing the ‘evils’ of floods. The Moriarty Report recommended that remedial works be carried out to alleviate erosion and the threat of flooding, however due to the size of the flooding and erosion problems, very little was done (Department of Water Resources 1987). In 1948 the ‘Huddleston’ report noted that erosion of the banks was continually taking place through the middle stretch of the Hunter River (Huddleston et al. 1950). An erosion survey carried out as part of the Huddleston report indicated that gullies and sheet erosion were occurring throughout the catchment, and much of this erosion was considered serious.

Historical dredging volumes for Newcastle Harbour may also be indicative of sedimentation and erosion issues, and related land use practices within the Hunter River catchment. Data compiled by Department of Water Resources (1987) indicate that dredging volumes rose from the 1860s until 1956, when river works were commenced to mitigate erosion problems in the Hunter River catchment. Following the commencement of the river works a gradual decrease in the average annual quantities removed by dredging was observed. However, it is difficult to ascertain a correlation between the river works and dredging volumes, as dredging effort is affected not only by sedimentation, but also by navigational channel depth requirements.

4.4.3.1 Long-term Changes in Bathymetry

Bathymetric records suggest modern sedimentation rates may be faster than those operating since sea level stillstand around 6,500 years BP (Boyd 2001). To quantify possible historical changes in sedimentation and erosion of the bottom morphology of the estuary since European settlement, a comparison of bathymetric surveys conducted in 1857 and 1990 was carried out, and is described below.

A detailed survey of the lower Hunter River was conducted by the Public Works Department in 1990. The survey consisted of 34 cross-sections covering the south arm from the entrance to the confluence with the north arm at Hexham Bridge. Some cross-sections were also taken along the lower part of the north arm.

Historic survey data is available from an 1857 survey conducted by S. Moriarty of the Public Works Department. A series of 40 cross-sections were undertaken on the Hunter River over the 64 km reach from Oakhampton to the ocean entrance.

To determine historic bathymetric changes for the Hunter River the 1990 data were compared to the 1857 data. To make comparison possible, the 1857 survey data were reduced to a common datum - AHD (Australian Height Datum) - which corresponds approximately to mean sea level. Since the 1990 data was only collected through the south arm any changes could only be determined for that area. The analysis provided a qualitative estimate of historic bathymetric changes from the entrance to approximately 20 km upstream for the river over the 133 years between the two surveys. The area close to the entrance has become substantially deeper between 1857 and 1990, which can be attributed to the dredging activities that have been undertaken in the harbour areas near the mouth. It appears that between 10 and 20 km upstream the river has become shallower over the years indicating some level of sedimentation. A factor seriously complicating valid comparison of the two datasets is the spatial distribution of data. Between the entrance and Hexham Bridge there are 34 measurements for 1990 but only five cross-sections for 1857, and hence it is not possible to quantify the amount of sedimentation.

4.4.4 Current Sedimentation and Erosion Patterns in the Estuary

On a geological timescale, the major sediment process within the Hunter estuary has been sedimentation. Within estuaries, the differences in the flood and ebb velocities of the flooding tide increase inland as the channel shallows and causes the tidal wave to become increasingly asymmetrical. This causes more sediment to be carried in than out. Thus, the upper parts of estuaries become net sediment traps and are predominantly depositional environments in which the trapped sediments are laid down and shaped by the tidal and freshwater flows. Fluvial processes dominate sediment transport within the upper estuary, whereas tidal processes and the episodic extreme events have the dominant effect in the lower estuary.

In modern times there is an excess of sediment being supplied to the upper Hunter estuary due to deforestation and overgrazing in the Hunter River catchment (Boyd 2001). This sediment is transported primarily during major floods, such as the 1955 flood (Boyd 2001). During the 1955 flood, a major area of deposition included Oakhampton to Morpeth. In response to the major deposition during floods, local areas of erosion form, followed by subsequent attempts to re-establish equilibrium by eroding the channel bed and banks.

Erosional processes are enhanced by flood mitigation works such as levee banks that constrain natural river shortenings. These shortenings increase the channel gradient and therefore the eroding capability (Boyd 2001). These factors can lead to erosion and channel widening upstream, and buildup of point bars and shoals downstream where the gradient is flatter (Patterson Britton & Partners 1995).

Accretion of point bars on meander bends where the channel energy is lower result in the progressive removal of sediments along the outside bank of the meander and the storage of fluvial sand along the inside bank (MHL 2000). Some of the sand deposited in point bars will be eroded and transported further downstream by flood events, perhaps to be stored in another point bar. Coarser material is deposited on point bar and mid-channel formations such as sand shoals.

Within the Hunter estuary, accretion of sand point bars has occurred primarily between Maitland and Morpeth (Figure 4.18). Substantial and widespread buildup of point bars in the last 30 years has occurred downstream of Morpeth to Raymond Terrace. Due to the large contemporary input of sandy sediment from the Hunter River catchment, creation of gravel point bars no longer occurs. One relict gravel point bar occurs at MacDougall's homestead, downstream of Maitland (Figure 4.18). Increased meandering of the north arm has also led to the creation of sand point bars within the channel. Additional areas of accretion within the channel are sand shoals. Visible sand shoals were observed during MHL fieldwork in the Maitland reach, in the upper reaches of the Paterson River, downstream of Raymond Terrace, and also in the lower estuary in the vicinity of Stockton Bridge and Fullerton Cove (Figure 4.18). Shoaling at Raymond Terrace is in response to the in-channel sand wave upstream in the Hunter River migrating and redistributing downstream (Patterson Britton & Partners 1995).

Sedimentation and erosion patterns within the estuary vary within different reaches and tributaries, and are shown schematically in Figure 4.19. Erosion is the primary process occurring in the upper estuary from Oakhampton to Morpeth, as sediments deposited during the 1955 flood are now being reworked and deposited further downstream (Patterson Britton & Partners 1995). This region of sedimentation/deposition occurs primarily from Morpeth to Raymond Terrace, leading to the formation of sand point bars in recent years. Deposition on inside point bars on bends, however, leads to meanders migrating laterally and downstream, resulting in bank failures on the outside of meander bends, and therefore erosion is also occurring in the Morpeth to Raymond Terrace reach (Patterson Britton & Partners 1995). Downstream of Raymond Terrace to Hexham is an area of net deposition, as sediments from upstream work through the system to the lower estuary (Patterson Britton & Partners 1995). Upper catchment sediment sources are also leading to minor sediment accretion in the Paterson River. A compilation hydrosurvey conducted by Sinclair Knight & Partners (1990) suggested that no morphological changes were occurring in the Williams River, although there was some channel widening at the surface level.

In the lower estuary, the south arm has shoaled (most reaches less than 2 m deep now) with lateral accretion of channel margins following the construction of a weir between Hexham and Ash Island in 1930. The majority of this accretion has been upstream of Tourle Street bridge and the former location of Spit Island (Figure 4.18). Since the 1960s the north arm has shoaled and margins have prograded, particularly between Dunns Island and Tomago Slipway. This pattern suggests sediment deposition has occurred on lateral or point bars, with channel narrowing and beginning to meander (Boyd 2001). Sedimentation also occurs in low energy areas such as Fullerton Cove, with an accumulation of mud, which is largely of fluvial origin (Boyd 2001, Williams et al 2000).

4.4.5 Sediment Contamination in South Arm of Hunter River

Extensive sampling of sediments has occurred in the south arm of the Hunter River, from the area of the Tourle Street bridge through to the entrance approach, due both to the ongoing dredging of the estuary and for the management of the large industrial sites, e.g. remediation of the BHP closure area and expansion of the Kooragang coal terminal. The data from these studies has recently been collated and statistically analysed (Patterson Britton & Partners 2001), with eight geographic zones being defined. Laboratory analysis has been predominantly for metals and polyaromatic hydrocarbons (PAHs), with some analysis of organochlorine pesticides (OCPs) and polychlorinated biphenyls (PCBs). More limited sampling has occurred throughout the rest of the Hunter estuary, with sampling from the river entrance, through the south arm, north arm, Fullerton Cove, Williams River to Seaham and in the Hunter River up to and including Wallis Creek (Birch et al. 1997). The majority of these samples were analysed for metals, although again limited analysis for OCPs and PCBs was conducted.

The results indicate that the south arm of the Hunter River is contaminated with metals (cadmium (Cd), lead (Pb), mercury (Hg), nickel (Ni) and zinc (Zn)) and PAHs. For metals, the mean values for Cd, Pb, Hg and Ni often exceed the ANZECC (1999) interim sediment quality guideline ISQG–low, and for Zn and, in one instance Hg, the ISQG–high. For PAHs, the values are often several orders of magnitude above the ISQG–high. The ANZECC guidelines suggest that above the ISQG-high there is a high probability that there will be toxic effects on benthic biota, although additional investigations may be required to determine such aspects as background concentrations, bioavailability, including carbon content, and toxicity testing. Based on the metal and PAH results for the south arm, it is likely that some level of adverse biological impact is occurring.

The other parts of the Hunter estuary have generally been shown to have low metal concentrations, being described as '… close to background for most elements' (Ingleton and Birch 1995). Additionally, areas in the south arm which are frequently dredged have been shown to be low in contaminants. It is thought that fine sediments from the upper estuary, with low contaminant concentrations, fill the dredge depressions. Over time, these fine sediments also become contaminated, but are dredged before their concentrations approach those of the undredged fine sediments.

From the limited analyses available, OCP and PCB concentrations appear low in the south arm and high in Throsby Creek (Ingleton and Birch 1995), which has inputs from urban and light industrial land uses. Without more sampling and analysis of sediments for pesticides throughout the estuary, it is not possible to confirm if agricultural inputs have resulted in elevated pesticide concentrations.

The contaminants found in the sediments of the south arm are likely to be transported into the lower estuary via the groundwater.

4.4.6 Sediment Sources and Sinks

Through a consideration of sedimentation and erosion processes in the Hunter estuary, an overview of sediment sources and sinks can be derived, and is shown schematically in Figure 4.19. A major source of fluvial sediment into the estuary is the Hunter River upstream of Oakhampton. The Paterson River upstream of Paterson is also a contributor. Bed and bank erosion creates a source of sediment from Oakhampton to Morpeth, and bank erosion from the Williams may also potentially be a source of sediment. The estuary entrance also forms a source of marine sediments. Urban areas such as Newcastle, Raymond Terrace and Maitland are also sources of sediment, through stormwater runoff and land developments. This leads to tributaries such as Throsby Creek, which drains the urban area of Newcastle, also becoming a sink for sediments (HCMT 2001).

As flood deposition is reworked and redeposited further downstream along the Hunter River, the Morpeth to Raymond Terrace reach becomes a sink for sediment, but also a source through erosional processes. Downstream of Raymond Terrace to Hexham is an area of net deposition, and therefore may be regarded as a sink. Kooragang Island is a major sink during floods, together with Fullerton Cove and Newcastle Harbour. Accretion also occurs in both the north and south arms, and these are therefore also considered to be sinks.

As the lower estuary is dominated more by tidal processes than the fluvially dominated upper estuary, fluvial bed load is not considered to be reaching the lower estuary in significant quantities. Nevertheless, fine river-derived sand has been found to dominate the channel sediments as far down the estuary as Tomago, just upstream of Fullerton Cove, and components of fluvial sand were present in Newcastle Harbour, especially after floods. The major volume of sediment supplied to the lower estuary is considered to be mud-sized and accumulates in the lower estuary and/or is flushed further seaward (Boyd 2001).

4.4.7 Sediment Budget

A **sediment budget** has been derived from the available information and conceptualised in Figure 4.20, based on the following considerations (Boyd 2001):

- Based on estimates of mean annual sediment yield for the Hunter River discussed by Erskine (quoted in Patterson Britton & Partners 1989) the mean annual sediment load and mean annual suspended sediment load for the Hunter River at Singleton are 2 million tonnes and 1.6 million tonnes respectively.
- Based on measurements of discharge and suspended sediment load (sediment rating function for Hexham Bridge) estimated for the period 1974-1983, the typical suspended sediment influx to the lower estuary (i.e. below Hexham) is of the order of 1 million tonnes per year (Patterson Britton & Partners 1989). The actual average of the years 1974-83 was 1.9 million tonnes per year. Patterson Britton & Partners (1995) also estimated an average minimum sediment flux (presumably of bedload) past Hexham of 25,000 tonnes per year. This was based on geomorphological and numerical modelling averaged over the period 1955-89.
- The average annual dredging in the Port of Newcastle between 1859 and 1988 was 1.8 million barge tons (or 1.03 million cubic metres), representing a removal from the lower estuary to the offshore dump site of 414,000 tonnes per year (Patterson Britton & Partners 1989).
- The average annual amount of sediment accumulating in the lower estuary between Hexham and the entrance to Newcastle Harbour can be estimated from calculating the water area of the estuary and assuming sediment accumulation throughout the estuary at the rate measured for Fullerton Cove of 2.3 mm per year (based on a long-term average) (Boyd 2001). This results in an average accumulation of 114,000 tonnes per year. A second estimate of sediment accumulating in the lower estuary can be derived from the results of Williams et al. (2000) who found that 750 hectares of siltation had occurred in

the lower estuary in the 193 years between 1801 and 1994. Assuming this siltation infilled an area originally averaging 1 m deep, the total sediment accumulating in the lower estuary would be an average of approximately 97,000 tonnes per year, a figure that is in general agreement with the Fullerton Cove estimate above. The lower figure was used, but a value of around 100,000 tonnes seems to be acceptable. Note that there is a disagreement between the amount of sediment accumulating in the lower Hunter estuary using the methods identified here, and the amount removed by long-term dredging. There are many possible reasons for this, including enhanced deposition in the dredge sites, intensive dredging in the middle of the 20th century removing more than was deposited, and poor estimates from inadequate sedimentation rates and bathymetric information.

- If 1 million tonnes are input to the lower estuary per year at Hexham, 414,000 tonnes are dredged out and 97,000 tonnes accumulate, then the remainder of 489,000 tonnes per year is discharged to the middle shelf where it accumulates in a large mud deposit.
- Major floods are the only time that sediment effectively escapes from the channel of the Hunter River in the floodplain below Oakhampton. Only the 1955 flood was capable of depositing major quantities of sediment (5.3 million tonnes) on the floodplain in the 20th century (Patterson Britton & Partners 1995). Because this was a one-off event, it was not included in the sediment budget summary.

4.4.8 Sediment and Water Quality Control Guidelines for Development

The effect of urban runoff on sedimentation and water quality in tributaries such as Throsby, Styx and Cottage creeks has led to the recognition of catchment plans to address the issue. Newcastle, Maitland and Port Stephens Councils participated in the development of, and are guided by, the *Erosion and Sediment Control – Regional Policy and Code of Practice* (PSC 2002) for the management of stormwater in existing and new developments. This policy incorporates the Hunter, Central Coast, Karuah, Great Lakes and Manning Regions of NSW. The objectives of the Policy and Code of Practice are:

- to prevent land from being degraded by soil erosion or unsatisfactory land and water management practices
- to protect stream and waterways from being degraded by erosion and sedimentation caused by unsatisfactory land and stormwater management practices
- to promote and protect biodiversity.

For any development with the potential to cause significant soil erosion and sedimentation an Erosion and Sediment Control Plan (ESCP) must be prepared. The major elements that should be contained in an ESCP include:

- site characteristics
- clearing and disturbance of site
- existing and proposed drainage patterns
- erosion control practices
- sediment control practices
- rehabilitation program.

In conjunction with the Erosion and Sediment Control Policy and Code of Practice the consultation of other documents including *Managing Urban Stormwater: Soil and Construction* (NSW Department of Housing 1998), and *Managing Urban Stormwater: Treatment Techniques* (EPA 1997) is recommended. While the *Regional Erosion and*

Sediment Control - Policy and Code of Practice is recommended as a minimum standard, stormwater management plans and development control plans for each council also provide guidelines for development. Control guidelines utilised by each council, including relative compliance and effectiveness, are discussed below.

4.4.8.1 Newcastle City Council

Newcastle City Council has implemented the *Erosion and Sediment Control Regional Policy and Code of Practice*, and also utilises *Managing Urban Stormwater: Soils and Construction* (Department of Housing 1998), and a Stormwater Management Plan (NCC 2000). The SMP has been developed to facilitate the coordinated catchment-based management of stormwater quality within Newcastle City and enhance the condition of degraded catchments and creek systems to improve water quality. This is designed to enable long-term protection for the important ecosystems of Hexham Swamp and the Hunter estuary. In the SMP, a priority stormwater management objective is for Newcastle to provide stormwater innovation and best practice for all new and proposed developments, to ensure no increase in pollutant load in the system occurs (NCC 2000).

Other methods used for the management of stormwater pollution in NCC include the *Newcastle Development Control Plan No. 50 – Stormwater Management for Development Sites* (NCC 1999). The DCP is an assessment tool for individual development sites and infill urban development proposals. This DCP '…seeks to promote the adoption of cost-effective on site stormwater management practices that achieve balanced environmental outcomes.' (NCC 2000) It provides guidance for stormwater management on development sites for matters such as site planning, offsite discharge, site drainage and onsite detention.

In order to increase awareness of the importance of stormwater management techniques on construction sites the Council provides industry awareness and training programs. NCC requires the implementation of erosion and sediment prevention plans at the outset of any new development or redevelopment.

Monitoring of performance will be achieved through water quality monitoring and observational monitoring. Water quality monitoring will be undertaken to provide information on the effectiveness of the SMP implementation strategies in reducing stormwater pollution within NCC as well as providing baseline data with which to compare future data collected. In conjunction with detailed water quality monitoring, staff and members of the community will participate in 'observational monitoring' or observing the effectiveness of activities on people's behaviours regarding stormwater (NCC 2000).

4.4.8.2 Port Stephens Council

In December 1999 PSC adopted the *Regional Erosion and Sediment Control - Policy and Code of Practice* (PSC 2002). A large proportion of funds is used to clean sediment from the stormwater drainage system due to poor sediment and erosion control methods on construction sites. Poor water quality due to stormwater pollution has the potential to affect the local Port Stephens economy due to effects it can have upon tourism, commercial fishing, oyster farming and aquaculture. In February 2000 PSC adopted an LGA-wide Stormwater Management Plan. The SMP was '…designed as a tool for identifying and mitigating existing stormwater issues and designing to prevent future problems.' (Port Stephens Council 2000b). Both long-term and short-term management objectives have been identified and the

SMP has been linked to the PSC Management Plan to ensure all management options identified in the SMP are undertaken. Monitoring will take place to ensure the objectives of the SMP are being met and results will be reported through the State of the Environment Report (Port Stephens Council 2000a).

Following the adoption of the *Regional Erosion and Sediment Control - Policy and Code of Practice* in 1999, PSC conducted an education and awareness campaign in the building and construction industry. An audit of business sites revealed that fewer than 50% of all building sites had implemented sediment and erosion control measures. This was followed by an education program for all builders that involved the option of a fine or attendance at a workshop on erosion and sediment control on building sites for non-compliance. Enforcement combined with education has proven effective in changing practices in the short term, however an ongoing commitment to enforcing compliance is required (Port Stephens Council 2000b).

4.4.8.3 Maitland City Council

The Maitland City Council *Sediment and Erosion Control Policy* is currently under review. In the interim *Managing Urban Stormwater: Soil and Construction* (NSW Department of Housing 1998) is referred to, combined with ANZECC (2000) water quality guidelines. Enforcement of sedimentation and erosion control measures is applied through the Protection of the Environment Operations Act, which includes random site checks by surveyors (Claire Hendley, MCC, pers. comm. 2002).

4.4.8.4 Summary

A regional policy and code of practice for erosion and sediment control has been developed for the Hunter region, and at present this has been adopted by two of the three councils in the Hunter estuary area – Port Stephens Council and Newcastle City Council. This regional code of practice is used in conjunction with stormwater management plans that vary between the councils. The level of enforcement carried out by each of the councils for sediment and erosion control at development sites also varies across the councils, with Port Stephens Council appearing to be the most active in conducting education and awareness campaigns.

4.5 Bank Stability

Bank erosion has been a significant issue since early settlement, affecting considerable reaches of the Hunter River and estuary. Changes to flood patterns, together with clearance of riparian vegetation lining the banks of the Hunter estuary following European settlement led to river bank destabilisation and substantial bank erosion, such that a condition of greater instability now exists in the Hunter estuary (Patterson Britton & Partners 1995, Sinclair Knight & Partners 1990). The episodic floods lead to natural channel changes with the redirection and realignment of the channel. This natural process includes deposition on the inside of point bars on bends, leading to meanders migrating laterally and downstream, and resulting in bank failures on the outside of meander bends (Boyd 2001). Development of urban areas and rural infrastructure in the floodplain led to the view of flooding as a hazard, thereby necessitating that the river channel be controlled in a fixed location requiring extensive flood mitigation and bank stabilisation structures along the estuary.

Since early settlement there have been numerous attempts to protect the bank with construction of both small and large scale bank revetment works. By 1994 more than $20 million had been spent on bank protection works to arrest mainstream erosion, generally on the outside of meander bends (Patterson Britton & Partners 1995). A summary of areas where bank protection works, both large and small scale (from major capital works through to ad hoc placement of small rocks), as observed during MHL's fieldwork, is provided in Figure 4.21.

In their assessment of bank erosion in the Hunter, Williams and Paterson rivers, Sinclair Knight & Partners (1990) suggested the causes of bank erosion are stream currents, rainfall, seepage, overbank drainage, obstacles and debris in the waterway, wave attack, wet-dry cycles, change in land use patterns, swellings of clays due to absorption of water, pressure of groundwater from within the bank, change in channel shape due to bed scour or erosion of bank face, increased load on top of bank, and rapid drawdown of water against the bank face. Sinclair Knight & Partners (1990) did not determine a direct relationship between bank stability and the presence of riparian vegetation, however it was noted that in appropriate locations native vegetation influences the ability of banks to resist erosion and thereby offset bank failure.

Methods of bank stabilisation in the Hunter estuary have included rock revetments using rocks of varying sizes, timber retaining walls, gabions, and wave berms. In some locations these protection works have been accompanied by native vegetation planting. These revetment structures have had varying degrees of success ranging from catastrophic failure during the first flood after placement due to under-engineered design (rock sizes too small and insufficient toe structures) to minor failure requiring minor maintenance, with more recent major works yet to be tested by a large flood. Generally, these structures have a design life of around 20 years (Sinclair Knight & Partners 1990) which in essence is about one large flood event.

Given the extent of the problem and number of stakeholders involved, in 1993-94 the State Government initiated the 'RiverCare' program that actively seeks to engage local landholders, who are the major group of stakeholders with ownership of considerable lengths of river frontage, in the rehabilitation process. Under the RiverCare program an assessment of riparian vegetation cover and type and bank stability was carried out by DLWC in 1995 and 1996, through assessment of 1994 aerial photography. MHL's field program used the RiverCare classification scheme and has now provided an update to their classification using actual observations rather than aerial photography.

The importance of riparian vegetation for bank stability was the basis for its inclusion in the field analysis of bank stability. Areas of unstable banks lacking in vegetation will be more vulnerable to erosion during a flood. Therefore bank stability and riparian vegetation were considered to be inter-linked. Land use changes are also significant for riparian vegetation cover. Grazing and agriculture may lead to removal of riparian vegetation that may be compounded by cattle access. Cattle access affects the bank stability directly through trampling, and also affects riparian vegetation, as germinating plants will be eaten, inhibiting re-growth of vegetation on cleared banks.

With this background and the developing RiverCare projects it was agreed that field observations of bank stability and riparian vegetation would provide a useful extension to the RiverCare program. In September 2002 MHL carried out field inspections throughout the Hunter estuary and the results of this assessment form the focus of this chapter.

4.5.1 Field Inspection Methodology

A qualitative assessment of the bank stability of the Hunter River was previously conducted by the Department of Land and Water Conservation (Paul Collins, DLWC, pers. comm. 2002). This assessment was completed through examination of aerial photography taken in 1994, and the presence and absence of native vegetation formed the basis of the categorisation of bank stability (Paul Collins, RiverCare Officer, DLWC, pers. comm. 2002). This method of assessment formed the basis of the bank stability assessment conducted by MHL, however other factors were also considered in MHL's assessment of bank stability, and included: bank slope and height, position in the channel (e.g. outside or inside of bends), and presence of structural works such as rock revetments.

An assessment of the current condition of the banks of the Hunter estuary was carried out by MHL during field observations of the entire estuary (18–27 September 2002). This assessment involved mapping several factors – bank stability (Figure 4.22), riparian vegetation cover (Figure 4.23), together with an assessment of possible causes, including cattle access (Figure 4.24) and boating activity.

In assessing the geomorphological status of the channels, the capacity of the channel to maintain dominant flow without accelerated bank erosion or deposition was examined. This geomorphological status was interpreted into three categories (DLWC 2000, devised by Raine and Gardner 1995):

Bank Stability Categories
Red - unstable areas which would require extensive structural river works following a flood event. Management is needed to reduce the impact of such events.
Yellow - areas showing signs of instability which would respond quickly to management strategies.
Green - essentially stable areas which would require only occasional isolated minor attention following flood events. Long-term management plans would assist in maintaining these areas in a stable state.

Coupled with MHL's bank stability mapping was an assessment of the riparian vegetation cover, with similar categories to the bank stability devised (DLWC 2000, devised by Raine and Gardner 1995) (Figure 4.23). Riparian vegetation cover was considered in terms of native vegetation only, due to the ecological importance of native vegetation. Native riparian vegetation in the Hunter estuary includes large beds of the reed *Phragmites australis*, particularly at the toe of the bank, species of *Casuarina*, and eucalyptus on the face and top of the bank, and *Lomandra* on the face of the bank. Extensive areas of mangroves and some areas of saltmarsh were also present in the lower estuary. Exotic species included giant reed (similar in feature to bamboo), bamboo, various species of willow, castor oil plants, lantana, and various vines such as balloon vine, morning glory and madeira vine. These vines produce nodules which are spread during floods (DLWC 2000).

Native trees such as *Casuarina* are instrumental in maintaining the integrity of the bank, due to their extensive root systems, which bind the bank (Sinclair Knight & Partners 1990). Exotic species, such as willows, which were common throughout the upper estuary, possess a shallow, but extensive mat-like root system that renders them unstable on riverbanks. Sediment tends to build around their root system such that after major flooding additional sediment and drawdown from oversaturation places excessive weight on the tree, causing it to collapse and expose a fresh bank scarp to floodwaters. Other exotic species such as giant reed and bamboo also possess a shallow root system that is easily undercut (Sinclair Knight & Partners 1990). This pattern of undercutting was also observed during MHL's fieldwork.

Accordingly, vegetation was classified as one of three categories: Red, Yellow, or Green:

Riparian Vegetation Cover Categories
Red – vegetation on the banks is either missing, the banks are bare, or are falling into the channel. Cover of native vegetation does not exceed 25%.
Yellow – vegetation on the banks is either sparse or exotic. Cover of native vegetation species is greater than 25%. These may also be areas that with some community effort, could change to green.
Green – Vegetation on the banks is in good condition with a good diversity of native species (DLWC 2000).

In combination with the presence of riparian vegetation, cattle access to the bank was considered an important influence on bank destabilisation and was therefore also mapped (Figure 4.24). Cattle access affects the bank stability directly through trampling, and also affects riparian vegetation, as germinating plants will quickly be eaten by cattle, inhibiting regrowth of vegetation on cleared banks. An assessment of cattle access was divided into the following categories:

Cattle Access Categories
Red – Cattle access
Yellow – Cattle access uncertain
Green – Cattle exclusion.

During the field assessment conducted by MHL, the type of bank protection work utilised was noted, and this detail is included in the GIS data, but is not presented in this report. Numerous digital photographs were also taken throughout the estuary, and the locations and descriptions of these photographs have been collated into a GIS layer for ease of reference.

4.5.2 Description and Assessment of Causes

DLWC's assessment of the stability of the banks of the estuary resulted in all banks surveyed being classified as in decline, and becoming unstable (yellow). Their assessment was carried out from the upper estuary downstream to Hexham. The field assessment conducted by MHL indicated greater variability in bank stability throughout the estuary (Figure 4.22). Some of this variability, particularly the MHL classification of some sections of the estuary as stable (green), may be attributed to recent bank protection works. The following discussion of MHL's field assessment, combined with the bank assessment conducted by Sinclair Knight & Partners (1990) has been divided into reaches.

4.5.2.1 Hunter River – Maitland to Raymond Terrace

The field assessment indicated that the banks within this reach were generally in decline and becoming unstable (yellow). The banks from Oakhampton to Morpeth were generally high (5–10 m) with steep bank faces. From Morpeth to Raymond Terrace bank height decreased, although bank faces were still often steep. The outside of meander bends where protection works had not been carried out were generally unstable (red). Areas of good stability correlated with areas where bank protection works had been constructed (see Figure 11.1).

The process of point bar formation and subsequent erosion of the outside bends in the Maitland to Raymond Terrace reach has led to bank instability, resulting in approximately 20 km of bank revetment being constructed, primarily on the outside bends (Patterson Britton & Partners 1995). Extensive bank protection works are currently under construction at Maitland, and major capital works have also been completed throughout the reach, particularly where buildings may have been under threat. However, areas of previous bank protection works did not necessarily correlate with stability, as signs of continuing erosion were evident in some areas.

Sinclair Knight & Partners (1990) identified the Oakhampton to Morpeth reach as an area of major erosion. Erosion in this reach has attacked both the bed and the banks, causing slip failures and slumping of high banks, and a subsequent widening of the river channel (Patterson Britton & Partners 1995, Boyd 2001). This erosion has been caused by aggradation with coarse sand from upstream. The erosion pattern is typical of a channel with a meandering thalweg, leading to deep water on the edge of the bank on the outside bend. Under high flow conditions the silty soil of the bank is undercut by fast currents, resulting in collapse and failure (Sinclair Knight & Partners 1990). Identified stress points in this reach include Porters Hollow, McKimms Corner, Narrow Gut, and Howes Lagoon re-entry (Patterson Britton & Partners 1995). It is suggested that the next major flood will redeposit more sand from upstream of Oakhampton in this reach, however this is also likely to be accompanied by further erosion (Boyd 2001).

From Morpeth to Raymond Terrace the pattern of meandering thalweg is also occurring, together with groundwater seepage and subsequent slumping of high banks of silt deposited from previous floods. In addition, wind wave action and probable tidal range and current increase are having significant effect on bank stability.

Riparian vegetation cover throughout this reach was minimal (Figure 4.22, majority classified as red), increasing the susceptibility of this reach to further bank erosion. As land use throughout this reach is dominated by grazing land (Figure 3.2), cattle access (Figure 4.24) to the bank may also increase susceptibility of the bank to further erosion by increasing instability. Cattle access in this reach was variable, with cattle often excluded from areas where bank stabilisation works had been carried out.

4.5.2.2 Paterson River

Bank stability within the Paterson River was generally in decline and becoming unstable (yellow, Figure 4.22). Bank height along the river was variable, ranging from 1-5 m. Areas of stability correlated with reaches of bank protection works, particularly on the lower reaches of the river. Significant bank protection works have been carried out at the confluence of the Paterson and Hunter rivers on the left bank, combined with some native tree planting on the face of the bank. This combination of bank protection works combined with native plantings has occurred at a number of reaches along the river, as indicated by areas of green stability and green vegetation, particularly in the reach from Narrowgut to Woodville. The planting of native vegetation will aid the stability of the banks. Natural rock outcrops also assisted stability in some reaches, particularly in the vicinity of Paterson.

Riparian vegetation along the remainder of the Paterson River was considered sparse or non-existent (yellow–red). The dominant land use along the Paterson River is grazing, leading to significant stretches of cattle access along the river, particularly the left bank where access was evident along the length of the bank. This combination of a lack of riparian vegetation and cattle access increases the susceptibility of banks within this reach to further erosion.

Areas of erosion in the Paterson are reported to be caused by slumping of previously deposited fine silt due to oversaturation and drawdown (Sinclair Knight & Partners 1990). Erosion in this reach may also be influenced by tidal action particularly at narrower sections and sharp bends where the tidal currents are accelerated.

4.5.2.3 Williams River

Bank stability along the Williams River varied from stable through to disintegrating and unstable (green through to red, Figure 4.22), with areas of bank undercutting present. Bank height in the river was generally low (1-2 m), with higher banks present around Seaham. Native riparian vegetation was often sparse. Riparian vegetation included significant stretches of *Phragmites australis*, but this was often the only vegetation present, and does not afford complete protection of the bank on its own. Berms and timber wave breaks to reduce the impact of wave action were evident in the Williams River. Speed limits in small stretches and signs informing boaters of erosion due to boat wake were also seen.

The dominant land use in this reach is grazing (Figure 3.2), leading to evidence of cattle access along the majority of the right bank. Riparian vegetation along this bank was minimal, with large reaches of this bank being classified as becoming unstable (yellow). One exception of good vegetation cover, but poor bank stability, was seen in the reach near Eskdale Swamp, and may be influenced by wave action. Banks in the vicinity of Seaham were generally classified as stable (green), and were combined with good native vegetation cover (Figure 4.23).

Erosion on the Williams River may be due to a combination of wind and boat wave action, and lack of riparian vegetation, resulting from cattle access (Sinclair Knight & Partners 1990). Water-skiing occurs throughout this reach, and therefore will be contributing to the boat wave action. Bank stability in the lower reach of the Williams River from the Fitzgerald Bridge upstream 1.5 km was particularly unstable, and correlates with the heavy use of this area for water-skiing. This reach is also an area of grazing, resulting in lack of riparian vegetation due to cattle access, which also acts to destabilise the bank.

4.5.2.4 Raymond Terrace to Hexham

Bank stability in this reach was generally stable, with some areas of instability on the outside of bends (Figure 4.22). Bank height in this reach was generally low (1–2 m). Large stretches of *Phragmites australis* in this region assisted stability, although cattle access on both banks reduced the effectiveness of the stabilising riparian vegetation. Large areas of mangroves upstream of Tomago also assisted bank stability on the left bank.

Areas of erosion in this reach may be attributed to boat wash and wind wave action. Combined with clearing of riparian vegetation for grazing and construction of levees, wave attack is directed right onto the bank. Trawling activities within 2 m of the bank may also be a contributor to wave attack (Sinclair Knight & Partners 1990).

4.5.2.5 North Arm and Fullerton Cove

Banks along the north arm upstream of Fullerton Cove were generally considered to be stable (Figure 4.22), with extensive stretches of mangroves providing protection from wave attack. Bank instability (yellow) was observed in the industrial area of Tomago, with little riparian vegetation present. An exception to the general stability of this reach was the north-west corner of Kooragang Island, with cleared vegetation and cattle access to the bank evident (Figure 4.24). Lack of vegetation increased the exposure of the bank to wave attack.

While close inspection of the banks of Fullerton Cove was not possible due to the shallow water level, the extensive stretches of mangroves play a significant role in bank stability. Inspection of Smiths Creek indicated that while the banks were well vegetated (Figure 4.23) with mangroves and saltmarsh, bank stability was generally considered to be disintegrating and becoming unstable. Observations of the effects of boat wake suggested that this may be causing some undercutting of the banks in Smiths Creek.

South of Sandy Island, bank stability in the north arm was generally stable to Stockton Bridge. Mangroves on the left bank near Sandy Island and Fern Bay are suffering from insect infestation that is reducing the health of the mangroves, with subsequent consequences on bank stability. On the right bank (Kooragang Island) a bund wall upstream of Stockton Bridge is now showing signs of decay.

The banks of Kooragang Island south of Stockton Bridge to Walsh Point were generally considered to be stable, due to the presence of rock walls, although the industrial area of Kooragang Island provides very little riparian vegetation. South of Stockton Bridge on the left bank, stability was generally unstable or becoming unstable. Ad hoc rock walls and dumpings were seen along this reach, and were showing signs of erosion, with bank undercutting possibly due to wave action, aeolian activity and tidal action. Lack of riparian vegetation in this reach did not assist stability.

4.5.2.6 South Arm – Campbell Island to Ironbark Creek

Bank stability in this reach was generally in decline and unstable (yellow–red, Figure 4.22). Riparian vegetation cover was variable, with thick mangroves on Kooragang Island and Hexham Island in parts, and saltmarsh in some areas of Hexham Island. Areas of cleared riparian vegetation were also present on these islands, together with the banks along Campbell Island, where numerous small docks were observed. Throughout these reaches, some bank undercutting was observed, and in some areas occurred even when thick mangroves were present.

The bank erosion in these waterways may be attributed to tidal action and wave action predominantly due to boat wakes. In the protected waterways, particularly around Campbell Island and Hexham Island, the limited fetch lengths mean wind waves are insignificant. The presence of the boat docks and observations during the field inspection indicated that wakes from boats created a significant wash against the banks, which may impact particularly upon areas with little riparian vegetation for stabilisation.

4.5.2.7 South Arm – Ironbark Creek to the Port

The banks of the south arm, particularly the right bank, have been significantly modified for industrial use. Banks along this reach of the south arm were generally stable (Figure 4.22). This may be attributed to a large rock wall on the right bank along the entire length of the south arm, varying in height from 5 to 15 m. Bank protection works were not as significant on the left bank. From Ironbark Creek to Tourle Street bridge, the presence of mangroves in some stretches enhanced bank stability. The bank was exposed in some areas in this section, with some signs of undercutting, and little riparian vegetation to provide protection. South of Tourle Street bridge bank protection works and port facilities increased bank stability. Erosion in this reach is likely to be caused by wave action and flood events.

4.5.2.8 Newcastle Port and Throsby Creek

The banks of Newcastle port have been significantly modified for use as commercial docking facilities, and therefore the assessment of bank stability within the port is different to the assessments of the upper estuary. Bank stability throughout the port was assumed as stable, due to the construction of large wharves in Port Hunter, Port Waratah, Carrington Basin and Throsby Creek which replace the underlying bank. In the remaining areas of the port, such as the Newcastle CBD foreshore and Stockton, large rock revetments have been constructed to withstand ocean swell waves as well as tidal currents and these walls were assumed to be stable. Vegetation throughout the port is minimal, even at the foreshore reserve around Stockton. New rock walls have also been constructed within Throsby Creek for bank stabilisation, from Cowper Street bridge to Hannell Street bridge, as part of the Honeysuckle Development in this area. Upstream of Hannell Street bridge, the creek becomes a concrete canal which was observed to be in a state of decay, particularly towards the junction of Throsby and Styx creeks.

4.5.2.9 Mosquito Creek

Bank condition in Mosquito Creek was stable to becoming unstable (green–yellow, Figure 4.22), with stretches of bank undercutting observed. Native riparian vegetation by way of saltmarsh and mangroves was present along the creek, however observations of boat wakes during the field inspection, and the presence of recreational fishing boats in the creek suggested that the banks were exposed to wave attack, which may be attributed to boat wakes.

4.5.2.10 Ironbark Creek

The stability of the banks of Ironbark Creek was variable (Figure 4.22). Bank height was generally low (1-2 m). The upper reaches of the creek were considered unstable, but improved to becoming unstable or stable, with the right bank displaying the greater stability.

While Hexham Swamp is a SEPP 14 wetland, grazing still occurs in parts of the swamp (Figure 3.2). This grazing affected the upper reaches of the creek in particular, as the banks have been cleared of vegetation and cattle access was evident (Figure 4.24). Further downstream, bank stability improved with greater native vegetation cover.

4.5.2.11 Wallis and Fishery Creeks

The banks of Wallis and Fishery creeks were generally considered to be unstable and in poor condition (Figure 4.22). Banks were generally high and steep (approximately 5 to 10 m), with very little vegetation of any kind present. Land use on both sides of the banks is predominantly agricultural and grazing, leading to cattle access along many parts of the creeks (Figure 4.22). The combination of these factors resulted in the banks being classified as unstable.

4.5.3 Assets Under Threat

Major floods will always cause some bank erosion (Sinclair Knight & Partners 1990), and therefore it is difficult to prevent threats to all assets. In the next major flood, possible outcomes that may place assets under threat include possible erosion issues at identified stress points in the Maitland to Morpeth reach – Porters Hollow, McKimms Corner, Narrow Gut, and Howes Lagoon re-entry. This would place pressure on bank revetments constructed on the outside bends of these reaches. Downstream of Morpeth due to substantial and widespread build-up of point bars in the last 30 years, considerable stress will be placed on river banks (Patterson Britton & Partners 1995).

Levee banks may be considered as assets under threat, and protection of these levee banks has occurred in the Morpeth to Raymond Terrace reach (Sinclair Knight & Partners 1990). By 1994 more than $20 million had been spent on bank protection works to arrest mainstream erosion, generally on the outside of meanders (Figure 4.21). These works are a short-term solution, are reactive rather than pre-emptive, and alter the environment of the riverine corridor (Patterson Britton & Partners 1995). Bank protection works should recognise that a design life of 20 years is all that can be expected (Sinclair Knight & Partners 1990).

The acknowledgement that bank protection works are a short-term solution leads to the requirement of an holistic approach that includes environmental enhancement and geomorphological process management. Patterson Britton & Partners (1995) recommended a Riverine Corridor Management Plan which included as its highest priorities, sand extraction, floodplain management, riparian vegetation strategy, a river monitoring system and a funding strategy.

4.6 Acid Sulfate Soils

Acid sulfate soils (ASS) are soils containing iron sulfides. In Australia the ASS of most concern are those formed within the Holocene period (last 10,000 years), after the last major sea level rise. Sediments that are core to the development of ASS are those deposited under estuarine conditions and which contain iron disulfide, otherwise known as iron pyrite. Iron sulfide layers are expected to be found where the surface elevation is less than 5 m above mean sea level (Sammut & Lines-Kelly 1996).

When sulfides are exposed to the air, iron sulfides oxidise and produce sulfuric acid. ASS are found in low-lying areas such as coastal floodplains and coastal wetlands, including areas within the Hunter estuary (Tulau 1999, Sammut & Lines-Kelly 1996). Iron sulfides are contained in a layer of waterlogged soil that is usually soft and dark grey in colour. The layer of water in the soil prevents oxygen reacting with the iron sulfides therefore stopping oxidisation and formation of sulfuric acid. This layer of soil is often termed potential acid sulfate soil (PASS) as it has the potential to oxidise to sulfuric acid. When iron sulfides are exposed to air they produce sulfuric acid, and are then known as actual ASS. Some of the acid produced is neutralised by the soil, however the remaining acid moves through the soil acidifying groundwater and eventually surface waters (Sammut & Lines-Kelly 1996).

4.6.1 Occurrence of Acid Sulfate Soils

Historically, drainage channels were established around the turn of the century in the Hunter estuary in areas of land susceptible to flooding (and therefore possibly PASS areas) to increase the agricultural productivity of these lands. PASS were almost certainly exposed during the excavation of drains located within the unions of Millers Forest, Hexham, Nelsons Plains and Alnwick (Avery & Main 1999).

In recent times, acid sulfate soil risk assessments have been carried out along the NSW coast, including the Hunter estuary. Factors inherent in this assessment are elevation and marine influence, where low-lying areas in combination with a tidal influence provide a suitable climate for the creation of ASS. As a consequence of this risk mapping, the bed of the Hunter River and much of the associated foreshores and tributaries have been classed as having a high probability of ASS occurrence (Figure 4.25). As part of an investigation into the viability of dredging the north arm for new wharf facilities, analysis of sediments from the river bed of the north arm was undertaken. Results from this investigation suggested the absence of ASS or PASS in the samples analysed (seven bore holes, Douglas Partners 2001a).

Current land uses within these high probability areas include industrial and commercial, grazing/agriculture, and some SEPP 14 wetlands (Figure 3.2). The majority of areas found with high potential ASS in the Newcastle LGA are zoned industrial, while in Maitland and Port Stephens LGAs the majority of potentially affected land is zoned rural (Figure 3.2).

A study of the nature and presence of acid sulfate soils has been carried out for the Port Stephens LGA (Environmental & Earth Sciences 2000a, 2000b). Within Port Stephens LGA, Fullerton Cove, wetlands, estuaries and flood-affected land have been identified as having very high probability of experiencing acid sulfate soils (Environmental & Earth Sciences 2000a, 2000b). Fullerton Cove has also been identified as an acid sulfate soil 'hot spot' (DLWC 2000).

4.6.2 Impacts of Acid Sulfate Soils

ASS can have wide-ranging impacts on soil and water quality, resulting in implications for agriculture, farming practices and the fishing industry within the Hunter estuary. During the transport of sulfuric acid through the soils, elements such as iron, aluminium and occasionally manganese are stripped from the soil, resulting in the soil becoming acidic and toxic and therefore an unsuitable environment for the growth of many plants. This in turn can lead to the encroachment of acid tolerant plants. These processes may be detrimental to the natural environment and will also decrease productivity in farming areas. Animal productivity may also decrease due to the ingestion of aluminium and iron (Sammut & Lines-Kelly 1996).

Impacts on water quality that may occur as a result of acid discharge entering waterways include:

- pH can drop locally from acceptable levels to a range of 2–4
- mixing of acid discharge with less acidic water leads to precipitation of iron, which can smother plants and streambed.

Reduction in water quality due to ASS can affect aquatic ecosystems, which in turn may affect industries dependent on the health of the ecosystem, such as commercial fishing. Approximately 70% of commercial fish species spend part of their life cycles in estuaries, and therefore acid discharge into an estuary raises major concerns (Sammut & Lines-Kelly 1996).

Potential short-term and long-term effects of ASS on waterways and ecology of the surrounding area are summarised in Table 4.17.

Table 4.17 Effects of Acid Discharge on Waterways and Ecology
(Sammut & Lines-Kelly 1996)

Short-term Effects	**Long-term Effects**
Fish kills	Loss of habitat
Fish disease	Persistent iron coatings
Mass mortalities of microscopic organisms	Alterations to water plant communities
Increased light penetration due to water clarity	Invasion by acid-tolerant water plants
Loss of acid-sensitive crustaceans	Reduced spawning success due to stress
Destruction of fish eggs	Chemical migration barriers
Oyster mortalities	Reduced food resources
	Dominance of acid-tolerant plankton species
	Growth abnormalities
	Reduced growth rates
	Increased predation
	Changes in food chain and food web
	Damaged and undeveloped eggs
	Reduced recruitment
	Higher water temperatures due to increased light penetration
	Increased availability of toxic elements
	Reduced availability of nutrients
	Poor growth in oysters and other bivalves

4.6.3 Acid Sulfate Soil Management Options

Recommendations arising from the study of ASS in Port Stephens LGA included that all land shown by risk and LEP planning maps as having a probability of ASS occurrence require management for ASS (Environmental & Earth Sciences 2000a, 2000b). This may include appropriate soil investigations for land use activities likely to disturb ASS, and a management plan should be developed to avoid environmental degradation (Naylor et al. 1998). Management strategies for Newcastle and Maitland City Councils do not currently include a consideration of ASS.

Possible management options for PASS and ASS areas include:

- prevention of ASS oxidation through zero to minimal disturbance
- treatment of actual acidity as a result of unavoidable oxidation of ASS
- prevention and control of any acid generated
- education of landholders of identifying features of ASS

- re-flooding
- introduction of acid-tolerant commercial plant species
- seawater neutralisation, which may be appropriate on regulated drains
- shallow drain design to prevent exposure of ASS.

(Environmental & Earth Sciences 2000a, 2000b, Sammut & Lines-Kelly 1996).

As the DLWC ASS maps are risk probability maps only, ground truthing with field inspections is recommended, as has been achieved by Port Stephens Council. While most of this work has focused on the drain areas the downstream effects of acid runoff in the estuary have not been well documented.

4.7 Flora and Fauna

4.7.1 Estuarine Floral Habitats and Communities

A number of estuarine floral habitat types have been described and mapped for the Hunter estuary. These include: mangroves, saltmarsh, fresh/fresh-brackish wetlands, *Phragmites australis* (common reed*)* swamps, *Casuarina glauca* (she oak) and *Melaleuca spp.* (paperbark) stands and remnant forests. The extent of each of these habitats/communities is shown in Figure 4.26, from modelling and mapping provided by LHCCREMS, and each habitat type is discussed further in the following sections.

These habitats types were included for the following reasons:

- they are influenced by tidal fluctuations and are therefore estuarine habitat
- they formed part of the study area as required by the brief (e.g. freshwater wetlands)
- based on the modelling conducted by LHCCREMS, they were likely to have been present along the estuary prior to European settlement (e.g. *Casuarinas*).

It should be noted that the mapping completed by LHCCREMS was utilised as it provided data for the entire study area. However, more accurate mapping has been completed in areas such as the Kooragang Nature Reserve. Such detailed mapping should be utilised for future management decisions.

Phragmites australis occurs in wetlands in the estuary and in the riparian zone in the upper Hunter estuary. Areas of *P.australis* along the banks of the estuary observed during MHL field inspections in September 2002 are shown in Figure 4.26. Cleared land and cattle grazing to the water's edge in many areas in the upper estuary prevented classification of many distinct estuarine habitats in these areas.

Potential estuarine aquatic floral habitat types in the Hunter estuary include clear, relatively shallow water for seagrasses, and rocky reefs/artificial structures for algae (seaweed). Seagrass beds have not been seen along the foreshores of the lower Hunter River for at least the past 30 years (TEL 2001). One type of seagrass, *Ruppia spp.*, which tolerates both salt and freshwater conditions, has been observed in some small channels on Kooragang Island, covering an area of approximately 0.15 km^2 (West et al. 1985, Williams et al. 2000). It has also been located in Hexham Swamp (Copeland 1993), and was observed in small, isolated patches in the upper estuary (MHL field observations 2002). Artificial structures in the form of breakwaters, rock revetments and bridge pylons occur throughout the estuary, however the occurrence of algae on these structures has not been studied.

4.7.1.1 Mangroves

Mangroves inhabit soft muddy sediments in sheltered areas. Large numbers of mangrove trees often occur together and are described as mangrove forests. In the Hunter River, the majority of mangrove trees belong to one species, *Avicennia marina* (the grey mangrove), but another species, *Aegiceras corniculatum* (the river mangrove) also occurs, primarily towards the landward edge of some of the mangrove forests (TEL 2001).

Mangrove habitats are thought to contribute significantly to estuarine productivity (for example, detrital material derived from mangroves may be an important food source for school prawns), and the trees also stabilise shorelines. Studies completed overseas have demonstrated that mangrove soils may also play a role as a sink for contaminants, particularly heavy metals (TEL 2001).

In the Hunter estuary, significant mangrove forests occur in the lower estuary at Tomago, around Fullerton Cove, and Kooragang Island (Figure 4.26), and are regarded as one of the largest mangrove forests in NSW (NPWS, pers. comm. 2003). These mangroves are protected by their inclusion within the NPWS Nature Reserve boundaries, and through SEPP 14.

4.7.1.2 Saltmarsh

Saltmarshes are estuarine habitats that occur high on the shore, typically just above the average high water mark. They are often found behind, or close to, mangrove forests and establish in soft, water-logged sediments. Saltmarsh habitats consist of small succulent plants, grasses, rushes, sedges and herbaceous plants. In general, the ecology of Australian saltmarshes is not well understood. Like mangroves, however, saltmarshes are believed to have important physical and biological functions in estuarine ecosystems (TEL 2001). Numerous saltmarsh plants are common throughout the Hunter River. Some of the most abundant are *Sueda australis*, *Sarcocornia quinqueflora*, *Sporobolus virginicus*, *Samolus repens*, *Triglochin striata*, *Juncus kraussii* and *Atriplex hastata*, although the types of species vary between locations. For example, in Shortland wetlands, species such as *Typha orientalis* have been reported as common around the saltmarsh areas. The distribution of plants within the saltmarshes is apparently related to the elevation of the land, with *Sarcocornia* seemingly most abundant in Kooragang Island in low-lying areas, but absent from ponds (TEL 2001). Saltmarsh occurs in the lower estuary in areas on Kooragang Island (in the nature reserve) and in small areas at Tomago and Fullerton Cove (Figure 4.26).

4.7.1.3 Freshwater and Fresh/Brackish Wetlands

Freshwater and fresh/brackish wetlands within the study area have increased over time at the expense of saline wetland ecosystems. These habitat types provide structural and floral diversity and, because of this, support a variety of faunal types. Within the Hunter River estuary fresh and fresh/brackish wetlands are located in Hexham Swamp, in Shortland wetlands, within the upland (but subsided) areas of Kooragang Island or in those areas excluded from tidal exchange, and around Tomago/Fullerton Cove (Figure 4.26). Smaller fresh and fresh/brackish wetlands within the Hunter River estuary tend to be largely ephemeral, appearing and disappearing, or shrinking and enlarging in response to rainfall. Larger, more permanent freshwater wetlands are also present within the study area, particularly Woodberry and Irrawang swamps (Figure 4.26). These habitat types, whether permanent or ephemeral, tend to be quite diverse, with species presence transient and dependent upon water level and salinity (MacDonald 2001).

4.7.1.4 Phragmites Australis Swamps

Phragmites australis swamps have become the dominant habitat type in Hexham Swamp and parts of the former Ironbark Creek saltmarshes. *P. australis* has also made large incursions into the Tomago/Fullerton cove area and exists in small, fresh/brackish areas on Kooragang Island (Figure 4.26). In all cases *P. australis* has formed dense, often completely monospecific stands excluding all other vegetation species (MacDonald 2001).

4.7.1.5 Phragmites Australis Riparian Zone

Significant beds of the common reed *Phragmites australis* occur between Hexham and Raymond Terrace, and along the Williams River. Smaller areas of *P. australis* also occur in the Hunter River upstream of the confluence with the Williams River, and along the Paterson River (Figure 4.26).

4.7.1.6 Casuarina Glauca and Melaleuca spp. Stands and Remnant Forests

Forested areas of *Casuarina glauca* and *Melaleuca spp* within the estuary have been drastically reduced over time. Patchy *C. glauca* and *Melaleuca spp.* stands and remnant trees exist throughout the western part of Kooragang Island (Ash Island), around the perimeter and upland areas of Tomago and Fullerton Cove and within Hexham Swamp, the Shortland wetlands and Ironbark Creek (Figure 4.7a). Dead trees, as patches or individuals, also exist throughout these areas. *C. glauca* continues to expand into degraded mangroves around Ironbark Creek and Tomago/Fullerton Cove, a process driven by tidal exclusion from these areas (MacDonald 2001). Areas of *Casuarina* forest also occur in small areas along the Hunter River between Hexham and Raymond Terrace, and fringing Woodberry Swamp (Figure 4.26).

4.7.2 Major Faunal Groups of the Hunter Estuary

Aquatic and terrestrial fauna occur throughout the Hunter estuary. Major faunal groups include fish, crustaceans (such as prawns), benthic invertebrates, significant native amphibian, reptilian and mammalian populations and residential, seasonal and migratory avifaunal communities. The estuary provides significant resources for a large variety of migratory and resident bird species, but shows a low diversity of native amphibians, reptiles and mammals. Biodiversity has been reduced through habitat destruction and the introduction of new species.

4.7.2.1 Fish

Over 100 species of fresh and saltwater fish have been recorded in the Hunter estuary during the past 25 years, and of these 32 species are economically important. Major groups of fish in the Hunter estuary include stingrays, eels, catfish, mullet, anglerfish, flathead, trevally, bream, gudgeons, gobies, pike, flounder, leatherjacket, sole and toadfish.

There have been five quantitative studies on fish in the Hunter estuary, and most of these have been carried out in the lower reaches of the estuary in the south arm and around Kooragang Island. Due to the temporal and spatial differences between the studies, and the variety of sampling techniques, it is difficult to make comparisons between the status of the fish over time (TEL 2001). In a study carried out in 1996-97 of the south arm, Ironbark Creek and the north arm near Walsh Point, 72 species of fish were caught and 23 of these were commercially important. The most abundant of these were sandy sprat, sea mullet, sand mullet, sand whiting, silver biddy and yellow-finned bream (TEL 2001).

4.7.2.2 Prawns

Prawns are an important commercial fishery in the Hunter River, and for this reason a brief discussion of their occurrence in the estuary is provided here. The habitat of prawns is influenced by their life cycle stages. Prawns migrate between fresh and salt water for breeding. Breeding of prawns such as the school prawn *(Metapenaeus macleayi*) occurs in oceanic waters. The post-larval stages of the species then migrate up estuaries into less saline waters for growth (known as nursery areas). In the Hunter River, *M.macleayi* enter the estuary during summer and early autumn (December –April). Many juveniles are found in salinity concentrations of approximately 20 ppt, but some of the youngest individuals move to areas upstream of Maitland where the salinity is less than 1 ppt. Juvenile prawns remain in the river during autumn-winter, then grow rapidly in spring (September). Increases in fresh water in the estuary due to flood events result in seasonal movements of larger maturing school prawns from the Hunter estuary to oceanic waters where they breed. This movement usually commences in October, and continues throughout spring-summer when there are large catches of prawns in the Hunter River and Stockton Bight. Investigations of eight waterways on Kooragang Island sampled 13 different species of decapods (prawns, shrimps), the most abundant species being grass shrimp (*Macrobrachium intermedium*) (TEL 2001).

4.7.2.3 Benthic Invertebrates

Benthic invertebrates include small crustaceans such as crabs, molluscs such as marine snails, marine worms, amphipods, isopods and copepods, and are common in mangroves, saltmarshes, intertidal and subtidal soft sediments and on rocky substrates. They are commonly classified according to their size: macrofauna (> 1 mm diameter), meiofauna (< 1 mm, but > 0.06 mm) and microfauna (< 0.06 mm). The majority of micro- and meiofauna lives in the top 1 cm of sediment, whereas macrofauna (such as marine snails and worms) may be found on the surface of the mud, or may burrow many centimetres down (TEL 2001). Abundance and distribution of benthic invertebrates in the Hunter estuary is difficult to determine, as there have been few studies on benthic fauna and unvegetated soft sediments in the Hunter estuary (TEL 2001).

Various studies of macro-invertebrates in the lower estuary resulted in the collection of 25 species of crabs, including the blue swimmer crab and mud crab, and two species of squid (TEL 2001). Sampling of the lower Hunter estuary to investigate the assemblages of meiofauna in mangroves found that nematode worms were the dominant animal, with copepods less abundant than expected. Marine worms, such as polychaetes and oligochaetes, were also collected though far less frequently than nematodes. It was suggested that the distributions of many species of nematodes were related to the presence of mature mangrove trees and algae covering the surface of mud and pneumatophores (TEL 2001).

4.7.2.4 Birds

Avifauna of the Hunter River estuary is the most widely studied and recorded faunal group. The estuary provides significant resources for migratory and resident bird species, and these occur in both the fresh/brackish and saline wetlands of the region. Many of the bird species resident during different seasons are covered by the JAMBA and CAMBA International Agreements for the Protection of Migratory Birds and Birds in Danger of Extinction and their Environment. Of the 66 bird species covered by these agreements, 38 visit the Hunter estuary.

The avifauna utilising the Hunter River estuary can be divided into three broad classes: waders; waterfowl; and wetland birds. Palearctic waders are a group of migratory birds that include plovers, dotterals, sandpipers, turnstones, whimbrels, curlews, knots, stints, godwits and ruffs, which spend the northern winter in Australia. The bird group described by the term 'waterfowl' generally includes ducks, geese and swans. Waterfowl commonly inhabit areas of open water and fresh/brackish swamp, with some species utilising the saltmarsh as foraging habitat. Waterfowl breeding habitat consists of vegetation fringing open water bodies (MacDonald 2001). The term 'wetland birds' refers to those species restricted to wetland habitats or those species that are typical residents of these ecosystems. This group includes herons, egrets, ibis, spoonbills and crakes, rails, moorhens and grebes. Birds classified within this group tend to utilise many different habitat types within the estuary, both freshwater, brackish and saline (MacDonald 2001).

Reports indicate the annual presence of between 8,000 and 10,000 migratory shorebirds and waders within the Hunter River estuary, comprising up to 38 different species. Kooragang Island has been found to support between 192 and 163 species of birds, 37 of which breed on the island. The Hunter River estuary is the only place in NSW providing habitat for significant populations of Black tailed godwits, Broadbilled sandpipers and Terek sandpipers. Several rare migratory waders, including Ringed plover, Large sand plover, Little Curlew, Pectoral sandpiper and Ruff have been recorded within the Kooragang Nature Reserve. The estuary also provides habitat for some of the largest populations of more common birds, including Eastern curlews, Curlew sandpipers, Bar tailed godwits, Greenshanks and Eastern Golden Plovers.

It should be noted that the presence and abundance of bird species within the Hunter River estuary varies with season, water level and with wetland habitat availability in other parts of NSW. In general, open saline water bodies, tidal mud flats, saltmarsh, open freshwater bodies and high diversity freshwater and fresh/brackish wetlands support the greatest number of individuals and species.

4.7.2.5 Mammals

Native mammalian diversity is low in the Hunter River estuary, and very few surveys have been conducted in the area. Small mammals such as water rats, native mice and bats have been recorded in the estuary area. Grey kangaroo, swamp wallaby and koalas have also been observed in the Tomago/Fullerton Cove area. Several mammal species have also been recorded in the Wallis and Fishery creeks catchments (HCMT 1999). A study of microchiropteran bats in the mangrove forests of Kooragang Island has recently been completed (Fly By Night Bat Surveys 2002). The Tomago Coastal Plain is recognised as supporting large populations of native mammals, notably koalas.

4.7.2.6 Amphibians

Surveys of amphibians in the Hunter estuary are limited. Freshwater and fresh/brackish wetlands provide habitat for native amphibians. A NSW NPWS survey of Hexham Swamp identified eleven frog species and 14 frog species are known to occur on Kooragang Island. The species identified, along with other unidentified species, may also occur in other freshwater and fresh/brackish wetlands within the Hunter River estuary, however a true determination of the diversity of the frog population will not be gained without extensive survey (MacDonald 2001). Four frog species have also been recorded in the Wallis and Fishery creeks catchment (HCMT 1999).

4.7.2.7 Reptiles

A lack of data relating to reptilian fauna of the estuary prevents a comprehensive assessment of these animals. The eastern long necked tortoise (*Chelodina longicollis*) is reported to exist in Hexham Swamp. Surveys of Tomago/Fullerton Cove recorded two species in the Tomago sand beds and three more species are expected to occur in the area. Analysis of Australian Museum records suggest that 20 additional reptilian species are likely to occur in the Hunter estuary. Seven reptile species have also been recorded in the Wallis and Fishery creeks catchment (HCMT 1999).

4.7.3 Faunal Habitats

Faunal habitat types closely follow the floral habitat types of the estuary, that is, mangroves, saltmarsh, fresh/fresh-brackish wetlands, *Phragmites australis* (reed) swamps, *Casuarina glauca* (she oak) and *Melaleuca spp.* (paperbarks) stands and remnant forests. Additional faunal habitat types include tidal flats and saline open water bodies, fresh open water bodies, and rocky reefs and artificial structures. Riparian vegetation such as native reeds also provide important refuge habitat for fish and prawns (HCMT 1999). Faunal habitat types and major animal groups within these habitats are shown in Figure 4.27 and discussed below. The potential of each of these habitats to support fauna is also discussed. A list of species that have been observed in various parts of the estuary, and groups of fauna that may be expected in certain habitat types (where studies are lacking), is provided in Table 4.18.

Table 4.18 Habitats and Areas in the Hunter Estuary, and Observed and Expected Fauna

Source: MacDonald (2001), TEL (2001), Straw (2000), HCMT (1999)

Habitat/Area	**Specific Area**	**Fauna Present**			
Mangrove		White Ibis	White faced heron	Little egret	Mangrove Warbler
		Mangrove Heron	Nankeen night heron		
	Mangrove Forest Adjacent to Fullerton Cove	Red Fruit Bat	Grey Headed Fruit Bat		
	Mangrove areas of the Kooragang Wetlands	Water rat	Red Fruit Bat	Grey headed fruit bat	
	Mangroves adjacent to the Stockton Bridge Site	Egret and Heron rookery of up to 430 breeding pairs			
Saltmarsh	Saltmarsh within Hexham Swamp	White faced heron	White Ibis	Grey teal	Chestnut teal
		Little egret	Japanese snipe		
	Saltmarsh zone	Sharp tailed sandpiper	Greenshank	Wood sandpiper	Marsh sandpiper
		Lesser golden plover			
		Benthic invertebrates e.g. polychaetes, crabs,	marine snails, isopods, amphipods		
Fresh open water	Fresh open water	Water fowl (Ducks, swans and geese)		Diving Birds (Cormorants, grebes and coots)	
	Open freshwater bodies within Hexham Swamp	Black duck	Coot	Grey teal	Black swan
	Open freshwater bodies within Shortland Wetlands	Little grebe	Black duck	Chestnut teal	Coot
		Little black cormorant			
	Open water bodies within *Phragmites australis* dominated Ironbark Creek area	Little grebe	Coot		
Fresh/Fresh-brackish wetlands	Seasonal and semi-permanent wetlands of Hexham Swamp	Black swan	Grey teal	Grass whistle duck	
		Black duck	Chestnut teal	Swamp hen	
		2 species of Egret	Japanese snipe	Straw Necked Ibis	
		2 species of Spoonbill			
	Fimbristylis ferruginea freshwater reed swamps	Brown Bittern	Grey teal	Ibis	Egrets
		Black duck	Chestnut teal	Herons	
Phragmites australis swamps	*Phragmites australis* reeds in Hexham Swamp	Little Bitterns	Australasian Bitterns		
		Brown Bittern	Reed Warbler	Little grass bird	Little Bitterns

Habitat/Area	**Specific Area**	**Fauna Present**			
Casuarina glauca and Melaleuca spp. Stands and remnant forests	*Casuarina glauca* and *Melalueca Spp.* stands within the Shortland Wetlands	Cattle Egret	Greater Egret	Cormorants use trees for nesting	
		Little Egret	Intermediate Egret		
	A *Melaleuca* stand in the Shortland Wetlands Lagoons	White Ibis	Straw Necked Ibis	Nankeen Night Herons	
	Drowned *Melaleuca* Trees in a dam in the Shortland Wetlands	Small Black Cormorants	Little Pied Cormorants		
	Melalueca Spp in a lagoon associated with the Shortland Wetlands	White Ibis	Nankeen Night Herons	Greater Egret	Intermediate Egret
		Straw Necked Ibis	Cattle Egret		
	Casuarina glauca and *Melalueca* Spp. stands in Hexham Swamp/Ironbark Ck	White Ibis	Cattle Egret - southernmost breeding colony		Intermediate Egret
		Greater Egret	Straw Necked Ibis		Little Egret
Tidal flats and saline open water bodies	Saline Open water areas within Hexham Swamp	Black swan	Chestnut teal	Grey teal	Black duck
	Tidal Flats and open water bodies of the Hunter River Estuary	Resident and migratory plovers	sandpipers	knots	
		dotterels	curlews	stints	
		Benthic invertebrates e.g. polychaetes, crabs,	marine snails, isopods, amphipods		
Rocky reefs and artificial structures		Invertebrates e.g. barnacles, oysters, crabs, ascidians			
Kooragang Island	Kooragang Nature Reserve and Kooragang Island	Little Tern THREATENED	Great Knot THREATENED	Black necked stork THREATENED	
		Broad billed sandpiper THREATENED			
		Pied oystercatcher THREATENED			
	The KWRP Ash Island Site	**Amphibians**			
		Green and Golden Bell Frog ENDANGERED (TSC act)	Striped marsh frog		
		Broad palmed frog	Spotted grass frog		
		Eastern dwarf tree frog	Ornate burrowing frog		
		Smooth toadlet	The common froglet		
		Birds			
		Common Sandpiper	Blue-billed Duck VUNERABLE (TSC Act)		
		Magpie Goose VUNERABLE (TSC Act)	Osprey VUNERABLE (TSC Act)		
		Fork-tailed Swift	Ruff		

Habitat/Area	Specific Area	Fauna Present			
		Great Egret	Pacific Golden Plover		
		Cattle Egret	Grey Plover		
		Little Egret	Rufous Fantail		
		Pectoral Sandpiper	Painted Snipe VUNERABLE (TSC Act)		
		Red-necked Stint	Little Tern ENDANGERED (TSC act)		
		Great Knot	Caspian Tern		
		Greater (Large) Sand Plover VUNERABLE (TSC Act)	Freckled Duck VUNERABLE (TSC Act)		
		Lesser Sand-plover, Mongolian Plover VUNERABLE (TSC Act)	Wood Sandpiper		
		White-winged Black Tern	Greenshank, Common Greenshank		
		Black-necked Stork ENDANGERED (TSC act)	Little Greenshank, Marsh Sandpiper		
		Latham's Snipe, Japanese Snipe	Buff-breasted Sandpiper		
		White-bellied Sea Eagle	Masked Owl VUNERABLE (TSC Act)		
		Grey-tailed Tattler	Regent Honeyeater		
		Wandering Tattler	Terek Sandpiper VUNERABLE (TSC Act)		
		White-throated Needletail	Eastern Curlew		
		Black Bittern VUNERABLE (TSC Act)	Whimbrel		
		Swift Parrot	Satin Flycatcher		
		Broad-billed Sandpiper VUNERABLE (TSC Act)			
		Asian Dowitcher			
		Bar-tailed Godwit			
		Black-tailed Godwit VUNERABLE (TSC Act)			
		Black-faced Monarch			
		Yellow Wagtail			
		Mammals			
		Large-eared Pied Bat, Large Pied Bat	Eastern Bentwing-bat VUNERABLE (TSC Act)	Large-footed Myotis VUNERABLE (TSC Act)	Yellow-bellied Sheathtail-bat VUNERABLE (TSC Act)
		Spotted-tail Quoll, Tiger Quoll	Eastern Freetail-bat VUNERABLE (TSC Act)	Long-nosed Potoroo (SE mainland)	Greater Broad-nosed Bat VUNERABLE (TSC Act)
		Little Bentwing-bat VUNERABLE (TSC Act)		Grey-headed Flying fox	
	Mosquito Creek	Greasyback Prawns	School Prawns	King Prawns	

Habitat/Area	**Specific Area**	**Fauna Present**			
Hexham Swamp/ Shortland Wetlands/ Ironbark Creek	Hexham Swamp	Black necked stork THREATENED	Blue billed duck THREATENED	Australasian Bitterns	The striped marsh frog
		Magpie goose THREATENED	Freckled duck THREATENED	The spotted grass frog	The common froglet
	Hexham Swamp/Shortland Wetlands Area	Eastern long-necked tortoise	Green and Gold Bell Frog (ENDANGERED)	Swamp snake	Striped skink
		Red-bellied black snake	Fence skink	Northern short nosed bandicoot	
	Typha oreintalis swamps in the greater Hexham Swamp area	Several species of duck	White necked heron	Royal spoonbill	Black duck
		Japanese snipe			
	Fresh meadows and grass swamps within Hexham Swamp	White Ibis	White egret	Yellow billed spoonbill	Grey teal
		Straw Necked Ibis	Plumed egret	Spur winged plover	Chestnut teal
		White faced heron	Little Egret	Black swan	Grass whistle duck
		Swamp hen	Comb crested jacana	Painted snipe	Lathams snipe
	Hexham Swamp Nature Reserve	Sharp tailed sandpiper	Greenshank	Wood sandpiper	Rails
	Brackish Swamps around the estuary and more open parts of Hexham Swamp	Lesser golden plover	Marsh sandpiper	Moorhen	Crakes
		Ringtail possum	Brushtail possum	Sugar glider	Little egrets
	Shortland Wetlands and Hexham Swamp	Pink eared duck	Blue winged shoveller	Freckled Duck - RARE	Blue billed duck - RARE
	Shortland Wetlands	White eyed duck	Musk duck		Little egrets
		Ringtail possum	Brushtail possum	Sugar glider	Burrowing skink
	Shortland Wetlands and Hexham Swamp	Swamp rat	Water rat		
	Ironbark Creek	Greasyback Prawns	School Prawns	King Prawns	
Tomago/Fullerton Cove	Tomago/Fullerton Cove particularly that area bounded by the Pacific Hwy and	Grey kangaroo	Red necked scrub wallaby	Swamp wallaby	Koala
	Tomago Rd.	Swamp rat	The dwarf tree frog	Ringtail possum	Common dunnart
	Tomago/Fullerton Cove	New holland mouse			
		Bearded dragon	Red-bellied black snake	Copper tailed skink	Eastern water skink
	Tomago Sand Beds	Garden skink	Lace monitor		
		Eastern long-necked tortoise	Red-bellied black snake	Fence lizard	Small eyed snake
	Proposed Shortland to Pacific Hwy Corridor of State Hwy No. 23	Striped skink	Burton's legless lizard	Copper tailed skink	Yellow faced whip snake
		She oak skink	Eastern scaly foot	Grass skink	Red napped snake
		Grass skink	Bearded dragon	Bar sided skink	Swamp snake
		Weasel skink	Tree dragon	Eastern blue tongued lizard	Eastern brown snake
		Three toed skink	Burrowing skink	Blind snake	Golden crowned snake
		Eastern water skink	Four fingered skink		
		Blacktailed godwits	Ringed plover	Pectoral sandpiper	Curlew sandpiper

Habitat/Area	**Specific Area**	**Fauna Present**			
Hunter Estuary	Hunter River Estuary	Broadbilled sandpipers	Large sand plover	Ruff	Bar tailed godwits
		Terek sandpipers	Little curlew	Eastern curlew	Greenshanks
		Eastern golden plover	Lesser golden plover		
		38 of the 66 bird *spp*. Covered by JAMBA and CAMBA visit the HRE			
		Opossum Shrimp	Stalked eye crab	Fantail mullet	Australian Bass
		Greasyback Prawns	Stripe-faced crab	Pipefish	Estuary perch
		Offshore greasyback prawn	Semaphore crab		
		School Prawns	Sentinel Crab	Anglerfish	Spotted Bigeye
		Giant Tiger prawn	Spanner Crab	Striped anglerfish	Sand whiting
		Brown tiger prawn	Dumpling squid	Ogilby's hardyhead	Trumpeter whiting
		Banana Prawn	Inshore squid	Southern Blue-eye	school whiting
		King Prawns	Estuary Stingray	River garfish	Tailor
		White Shrimp	Common Stingaree	Mosquitofish	White trevally
		Mantis Shrimp	Shortfin eel	Knight fish	Papuan trevally
		Snapping Shrimps	Longfinned eel	Flying gurnard	Skipjack trevally
		Pistol Shrimp	Pike eel	Fortescue	Yellowtail
		Grass Shrimp	Australian anchovy	Bullrout	Mangrove jack
		Spider Crab	Smelt	Red gurnard	Silver biddy
		Blue Swimmer Crab	Sprat	Flathead	Yellow-finned bream
		Beach crab	Sandy sprat	Flag-tailed flathead	Tarwhine
		Blood spotted crab	Freshwater herring	Dusky flathead	Mulloway
		Mud Crab	Castenlau's Herring	Sand flathead	Silver batfish
		Scarlet crab	Pilchard	Port Jackson glassfish	Luderick
		Domed shore crab	Estuary catfish	Ramsey's glassfish	Butterfish
		Red-fingered marsh crab	Longtailed catfish	Flat-tailed mullet	Tiger scat
		Mottled Shore Crab	Common jollytail	Sea Mullet	Toadfish
		Pebble crab	Juvenile goby	Sand mullet	Smooth toadfish
		Old wife	Oriental goby	Checkered mangrove goby	Common toadfish
		Eastern striped trumpeter	Bridled goby	Largemouth goby	Weeping toado
		Oyster Blenny	Half bridled goby	Eel goby	Brush-tailed toadfish
		Rough headed dragonet	Frayed-fin goby	Striped sea pike	Porcupine fish
		Gudgeon	Oyster giby	Short finned sea pike	Hairtail
		Empirefish	Exquisite sand goby	Lesser tassel fish	Yellowtail Kingfish
		Flathead gudgeon	Long finned goby	Large-tooth flounder	Blue Mackerel
		Dwarf flatheaded gudgeon	Tamar river goby	Small-tooth flounder	Carpet Shark
		Crimson-tipped gudgeon	Goby	Long-snout flounder	Fiddler Shark
		Striped gudgeon	Octopus	Black sole	School Shark
		Glass goby	Pipi	Narrow banded sole	Snapper

Habitat/Area	Specific Area	Fauna Present			
		Mangrove goby	Squid	Lemon-tongue sole	Southern Calamari
		Blue-spot goby	Juvenile toadfish	Yellow-finned leatherjacket	Cockle
		Crested goby	Fanbellied leatherjacket	Cuttlefish	
		Giant Herring RARE (NSW Fisheries)	Crescent perch RARE (NSW Fisheries)		
		Mud Goby RARE (NSW Fisheries)	Hairy Pipefish RARE (NSW Fisheries)		
Wallis Fishery Creek catchment		**Birds**			
		Wedge Tailed Eagle	Sooty Owl	Satin Bowerbird	Superb Fairy Wren
		Glossy Black Cockatoo	Southern Boobook Owl	Spotted Pardalote	Black winged stilt
		Red-kneed Dotterel			
		Mammals/Marsupials			
		Platypus	White-striped Mastiff-bat	Gould's Long-eared bat	Brown Antechinus
		Reptiles			
		Tree skink	Jacky Lizard	Land mullet	
		Amphibians			
		Red-backed Toadlet	Fletcher's frog		
		Rabbits/hares	Foxes	Cats	Wild/domestic dogs
Introduced Species	Kooragang Island	Rabbits/hares	Pigs	Black rat	Brown rat
	Hexham Swamp	house mouse	Cattle		

4.7.3.1 Mangroves

Mangroves are a productive habitat, supporting a wide variety of marine organisms, including fish, crabs, marine snails, seaweeds and tiny animals such as marine worms, amphipods and isopods.

Two species of birds, the Mangrove heron and the Mangrove Gerygone are dependent on mangrove habitat for survival. The Mangrove heron feeds, shelters and breeds in various parts of the mangrove system, and therefore requires structural diversity within the habitat. Mangrove forest adjacent to Fullerton Cove is known to provide one of only five diurnal roosting and breeding sites for the red fruit bat and the grey headed fruit bat in the lower Hunter area. Mangrove areas of Kooragang Island provide habitat for the water rat and the presence of three small mammals has been reported at Tomago/Fullerton Cove (MacDonald 2001).

4.7.3.2 Saltmarsh

Saltmarsh is a hugely productive habitat type, supporting a large number of species. It is utilised as feeding, roosting and breeding habitat by birds, and as feeding, breeding, shelter and nursery habitat for fish and invertebrates. Saltmarsh, however provides little habitat value for amphibians, reptiles and mammals (MacDonald 2001).

Saltmarsh provides high tide and nocturnal roosting sites for a variety of shore birds and waders. The number of roosts within the estuary has been greatly reduced in recent history, with the majority of migratory and residential waders now found at only three sites, two of which are saltmarsh habitats (NSW NPWS 1996).

4.7.3.3 Fresh and Fresh/Brackish Wetlands

Fresh and fresh/brackish marshes are noted for the diversity of faunal life that they support. Small mammals, amphibians, reptiles and birds all utilise these areas as feeding, foraging, refuge, breeding or resting habitat. These wetlands are important habitat for reptiles and amphibians, as these faunal groups are excluded from saline areas of the estuary. Freshwater and fresh/brackish wetlands are used as secondary and high tide feeding grounds for a variety of estuarine birds, including migratory waders. A range of microchiropteran bats use Hexham Swamp as a nocturnal foraging ground and it is also expected to provide habitat for two small mammals (MacDonald 2001).

Fresh and fresh/brackish wetlands support a variety of faunal types, and also provide important drought refuge habitat for inland bird species.

4.7.3.4 Phragmites australis Swamps

In all cases *P. australis* has formed dense, often completely monospecific, stands excluding all other vegetation species. These stands are often impenetrable to most faunal species, particularly waders, waterfowl and wetland birds (MacDonald 2001). It is acknowledged that *P. australis* stands in Hexham Swamp support the fewest avifaunal species of all habitat types within the area (MacDonald 2001). *P. australis* communities do provide refuge habitat for the Little and Australasian bitterns and these species are classified as vulnerable (MacDonald 2001).

4.7.3.5 Casuarina Glauca and Melaleuca spp. Stands and Remnant Forests

The value of this habitat type is as refuge, roosting and breeding habitat for a variety of bird species within the study area, and as refuge habitat for the few native small mammals remaining in the estuary (MacDonald 2001). Stands of *C. glauca* and *Melaleuca spp.* within the Shortland Wetlands and Hexham Swamp provide roosting and breeding habitat for many bird species (MacDonald 2001). The value of this habitat, in terms of avifaunal usage, is severely reduced by the patchy distribution and small extent of most remnant patches. This forest type does not provide the structural or floral diversity required to support a large number of mammals, and low density, widely spaced fragments provide little refuge value (MacDonald 2001).

A *Melaleuca* stand in one of the Shortland Wetlands lagoons (on private land) provided a permanent roosting site for hundreds of White ibis and Straw necked ibis, and for some Nankeen night herons in 1983 (Maddock 1983). Large black, Small black and Little pied Cormorants nest in drowned *Melaleuca* trees in a dam within the Shortland Wetlands. Ringtail possums have also been reported in the *Melaleuca spp.* areas of Tomago/Fullerton Cove (MacDonald 2001)

4.7.3.6 Tidal Flats and Saline Open Water Bodies

A very important habitat type, tidal flats are abundant within the estuary, although their historical extent has been greatly reduced by anthropogenic activity. The major extent of this habitat type is found in the Kooragang Nature Reserve, with Fullerton Cove providing the most extensive single expanse. Tidal flats are also located within the rehabilitation zones of Kooragang Island, however mangrove incursion into these areas is rapidly reducing the extent of this habitat type in this area (MacDonald 2001). Sand bars also occur in the north arm between Stockton Bridge and Fullerton Cove (Hunter Bird Observers Club, pers. comm. 2001). There are no tidal flats north of the flood mitigation works at Tomago/Fullerton Cove, nor are there any within the Hexham Swamp/Ironbark Creek area (MacDonald 2001).

Palearctic waders utilise the tidal mud flats extensively and are also known to forage within the saltmarsh zones. The saltmarsh and tidal flats of Fullerton Cove, the north-eastern end of Kooragang Island and the east bank of the north arm of the Hunter River (above Stockton Bridge) provide the majority of habitat for the migratory waders. In addition to migratory waders, residential species of plovers, dotterels and stilts also exist within the estuary, utilising the same habitats as the migratory species (MacDonald 2001).

Saline open water bodies are predominantly located on Kooragang Island, both within the Nature Reserve and the rehabilitation zone on Ash Island. This habitat type has been dramatically reduced within the estuary, and now no longer exists within the Hexham Swamp/ Ironbark Creek areas or Tomago/Fullerton Cove. Vitally important as high tide feeding habitat for a variety of bird species, saline open water bodies also provide fisheries feeding and nursery habitat (MacDonald 2001).

Areas of shallow, saline water surrounded by sparsely vegetated saltmarsh and salt scalds are often used as high tide diurnal and night time roosts by wading birds (MacDonald 2001).

4.7.3.7 Fresh Open Water Bodies

The extent of fresh open water bodies has increased within the study area over time. Many of these new water bodies occur in depression areas created by land subsidence in response to drainage and are largely ephemeral, expanding and retreating in response to rainfall. Permanent fresh open water bodies are mostly present within Hexham Swamp and the Shortland Wetlands, with the Shortland Wetlands providing the only deep open freshwater habitat in the estuary. Freshwater bodies found on Kooragang Island and within the Tomago/Fullerton Cove areas tend to be shallow and ephemeral (MacDonald 2001).

Fresh open water is utilised primarily by waterfowl (ducks, swans and geese) and diving birds such as cormorants, grebes and coots. Nine bird species have been reported in this type of habitat in the Hunter estuary. This habitat is also valuable as drought refuge, and is utilised by substantial flocks of ducks during drought (MacDonald 2001).

4.7.3.8 Rocky Reefs and Artificial Structures

There are very few natural rocky reefs in the Hunter estuary. Most of the rocky habitats occur intertidally (i.e. between the level of high and low water) and the vast majority of these are artificial rock walls (Figure 4.27). Much of the southern shoreline of the south arm is an artificial retaining wall which is colonised primarily by oysters. The breakwalls at the mouth of Newcastle Harbour consist of large concrete blocks which are home to a variety of marine organisms such as ascidians (sea squirts), barnacles, seaweeds and crabs. Pilings associated with bridges and wharves are other artificial structures that are often heavily encrusted with marine invertebrates (especially oysters) and algae. Such structures have the potential to influence the distribution and abundance of a variety of marine organisms, including fish. There are, however, no published studies on the flora and fauna associated with rocky reefs and artificial structures in the Hunter estuary (TEL 2001).

Oyster leases in the north arm of the Hunter River in Fern Bay provide an important foraging area for migratory waders. The rocky foreshore of Fern Bay and particularly the Kooragang dykes on Kooragang Island provide important roosting sites for migratory waders (Hunter Bird Observers Club, pers. comm. 2001).

4.7.3.9 Riparian Vegetation in the Upper Estuary

Riparian vegetation such as the beds of *Phragmites australis* along the banks of the estuary provide refuge habitat for fish and prawns, and potentially for amphibians (Figure 4.27) (HCMT 1999). In general, there is very little ecological information available about estuarine flora and fauna from these upper reaches. Given the importance of the upper reaches as ‘nursery areas’ for juvenile prawns, it would be advantageous to gain a better understanding of aquatic animals and habitats in this area and the effects of human impacts on them.

4.7.4 Rare and Endangered Species and Management Considerations

Under the Threatened Species Conservation Act, a vulnerable classification refers to fauna and flora species that are likely to become endangered unless the circumstances and factors threatening its survival or evolutionary development cease to operate. An endangered classification refers to flora and fauna species that are likely to become extinct in nature in NSW unless the circumstances and factors threatening its survival or evolutionary development cease to operate, or its numbers have been reduced to such a critical level, or its habitats have been so drastically reduced, that it is in immediate danger of extinction, or it might already be extinct, but is presumed not extinct (Schedule 1, part 1, Threatened Species Conservation Act 1995) (MacDonald 2001).

The Threatened Species Conservation Act (TSC Act) has recently been amended (Amendment 2002), to include provisions that update and increase the consistency of listing categories of the TSC Act with the Commonwealth's Environment Protection and Biodiversity Conservation Act (EPBC Act). The EPBC Act ensures that an assessment and approval process is required actions that are likely to have an impact on matters of National Environmental Significance (NES). Matters of NES include those affecting listed migratory species, Ramsar wetlands of international significance, and listed threatened species and ecological communities.

Of the 36 faunal species listed on the NSW NPWS threatened species lists as occurring within the Newcastle Local Government Area, the Hunter River estuary provides habitat for one amphibian, twenty-three birds and (minimally) seven mammals. These species are classified as either vulnerable or endangered. One floral species is listed as endangered in the Hunter estuary area (MacDonald 2001). Sightings of endangered species in the Hunter estuary area provided by NPWS are shown in Figure 4.28.

Of the 23 threatened birds listed as occurring within the study area, three are classified as endangered. These include *Ephippiorhynchus asiaticus* (the Black necked Stork), *Sterna albifrons* (the Little Tern) and *Xanthomyza phrygia* (Regent Honey Eater). *E. asiaticus* was sighted in Hexham Swamp, Kooragang Nature Reserves, Irrawang Swamps, Woodberry Swamp, Raymond Terrace, and wetlands in the vicinity of Seaham. *S. albifrons* was found in Kooragang Nature Reserve, and also in the catchment of Wallis Creek, although this is beyond the extent of the estuary study area. *X. phrygia* was sighted in the vicinity of Seaham, and also in the Fishery Creek catchment. All other species listed are classified as vulnerable (MacDonald 2001).

Information provided by the Kooragang Wetland Rehabilitation Project (P. Svoboda, pers. comm. 2003) indicates that at least twenty bird species occur on Ash Island which are protected through the migratory species listings of the Environment Protection and Biodiversity Conservation Act . These species include the Ruddy Turnstone, Curlew Sandpiper, Lesser Sand-plover, Mongolian Plover, Latham's Snipe, Japanese Snipe, White-bellied Sea Eagle, Grey-tailed Tattler, White-throated Needletail, Broad-billed Sandpiper, Bar-tailed Godwit, Black-tailed Godwit, Black-faced Monarch, Eastern Curlew, Whimbrel, Pacific Golden Plover, Rufous Fantail, Painted Snipe, Greenshank, Common Greenshank, Little Greenshank, Marsh Sandpiper, Regent Honeyeater, and Terek Sandpiper.

The majority of threatened bird sightings occur within either the Kooragang Nature Reserve or the Hexham Swamp Nature Reserve. Sightings of dabblers and waders [*Anseranas semipalmata* (Magpie Goose), *Oxyura australis* (Blue billed duck), and *Stictonetta naevosa* (Freckled duck)] occur more frequently in the fresher Hexham Swamp area, while shorebirds and estuarine waders [e.g. *Calidris tenuirostris* (Great Knot), *Limicola falcinellus* (Broad-billed sandpiper), *Limosa limosa* (Black tailed Godwit), *Haematopus longirostris* (Pied oystercatcher)] are found more frequently within Kooragang Nature Reserve and/on Kooragang Island (MacDonald 2001).

Of the seven threatened mammal species that are located within the Hunter River estuary study area, six are bats and one is a glider. All are listed as vulnerable. These species do not inhabit the estuary proper and have not been reported from either the Hexham Swamp or Kooragang Nature Reserves. Sightings have been reported from the west and north-west of Hexham Swamp, and in the upland forested areas. NSW NPWS reports the use of Hexham Swamp as nocturnal foraging habitat for several microchiropteran bat species, however it does not list which species have been observed (MacDonald 2001). The Grey-head Flying Fox is listed as vulnerable under the threatened species listings of the EPBC Act, and is noted to occur on Ash Island (P. Svoboda, KWRP, pers. comm. 2003).

The endangered Green and Golden Bell Frog (*Litorea aurea*) is known to occur on Kooragang Island. It has also been sighted in the Wallis and Fishery creeks catchment. The species is established in ephemeral and permanent fresh/brackish wetlands and appears to prefer rubble piles and *Juncus spp.* as refuge habitat. The fresh/brackish wetlands inhabited by the Green and Golden Bell Frog occur predominantly in areas that were previously occupied by saltmarsh, tidal flats and open saline water bodies. Tidal restriction, water table recession and land subsidence are primarily responsible for the conversion of saline wetlands to fresh/brackish systems (MacDonald 2001).

NSW NPWS reports the use of *P. australis* communities as refuge habitat by the Little and Australasian bitterns. These species are classified as vulnerable and are dependent on dense reed swamps for protection and shelter (MacDonald 2001).

Of the reptilian species present within the Hunter River estuary, two are significant for reasons of rarity. *Cyclodomorphus casuarinae* (She oak skink) has a very patchy distribution within NSW, restricted to tussock grassland and, in some cases, to wet sclerophyll forest. The record of this species within the Shortland Wetlands is the first for the Hunter Valley (MacDonald 2001).

Anomalopus sp. 3 (Burrowing skink) is threatened by loss of habitat to development and sand mining. *Anomalopus* sp. 3 has not been observed or collected from the Hunter River estuary, however suitable habitat is available at Sandgate Cemetery and other populations are known within the broader Hunter region. Based on this, it is reasonable to assume that the Burrowing skink does inhabit areas of the Shortland wetlands (MacDonald 2001).

Of those bats utilising the Hexham Swamp area as foraging habitat, several may be listed as vulnerable under the NSW Threatened Species Conservation Act. Six vulnerable bat species are listed as inhabiting areas to the west and north of Hexham Swamp (MacDonald 2001).

Sampling of fish in waters near Kooragang Island as part of the KWRP resulted in the collection of four species classified as rare. These included Giant herring, Hairy pipe fish, crescent perch, and mud goby. This classification was determined using data collected by NSW Fisheries (DLWC 2000).

Several faunal species listed on the Threatened Species Conservation Act have been recorded in the vicinity of the Wallis and Fishery creeks catchment. These include three marsupials, four birds and three bats (HCMT 1999).

Two threatened flora species occurs in the Hunter estuary – *Zannichellia palustris* and *Cynanchum elegans*. *Z. palustris* is an annual, submerged cosmopolitan species, with limited distribution within Australia. It occurs in brackish to fresh ponds close to estuaries. *Z. palustris* is listed as endangered and is reported at sites other than those provided by NSW NPWS. *Z. palustris* has been reported in ponds within the industrial area of Kooragang Island and also in an industrial pond at the limit of the previous Ironbark Creek wetlands (Greenwood 2001). None of the sites supporting *Z. palustris* are protected by Reserve status or by SEPP 14.

NSW NPWS states that the threatened rainforest vine, *Cynanchum elegans*, is located adjacent to the western boundary of the Kooragang Nature Reserve. *C. elegans* is listed as endangered under Schedule 1 of the Threatened Species Conservation Act. This vine is present in remnant fragments of littoral rainforest under the management of the Kooragang Wetland Rehabilitation Project (MacDonald 2001).

Under the Threatened Species Conservation Act, endangered ecological communities include the Sydney Coastal Estuary Swamp Forest in the Sydney Basin Bioregion, and the Sydney Freshwater Wetlands. Of the former community, 11 of the 30 species that characterise that community are found on Ash Island. Of the Sydney Freshwater Wetlands community, at least 7 species which characterise this community are found on Ash Island.

Through the Fisheries Management Act, mangrove communities are protected. NSW Fisheries are also working towards protecting saltmarsh through the agency's Aquatic Conservation Policy (P. Svoboda, KWRP, pers. comm. 2003).

Rare and endangered species are threatened by loss of habitat from development and urbanisation, and therefore development applications must take these species into consideration. Maintenance of viable habitat areas are also essential for the survival of rare and endangered species.

Habitat of species such as Z. *palustris* which is not presently protected through planning instruments are in particular danger from loss of habitat. Protection of the habitat of these species should therefore be taken into consideration in future planning.

4.7.5 Sensitivity to Pollution

Sources of pollution for estuarine biota include discharge of contaminants from industry, and issues associated with dredging. Biota at risk from these sources include benthic invertebrates, oysters, prawns and fish. The discharge of contaminants into the Hunter River has been occurring for many decades and has had serious effects on commercial fishing industries in the past. The oyster industry was devastated in the mid-1960s due to contamination of oysters from industrial pollutants, and the prawn industry has also been affected by apparent pollution from industry (TEL 2001).

In most cases, dredging will re-suspend sediments and increase the turbidity of the water. Although this may not persist for a long period of time, there may still be short-term effects of increased turbidity on aquatic biota. The Hunter River is typically very turbid and it has been suggested that the small number of oysters in the river is a consequence of this. Thus, increased turbidity during dredging may have adverse effects on oysters. There is also the potential for contaminants in the sediments to be accumulated by oysters and other marine invertebrates. However, a study conducted by The Ecology Lab investigating the potential bioaccumulation of contaminants by oysters during dredging in Newcastle Harbour found no evidence that dredging significantly increased the bioaccumulation of contaminants. Nevertheless, given that prawns and oysters from the Hunter River are sold for human consumption, potential accumulation of contaminants due to dredging cannot be dismissed (TEL 2001).

The high turbidity levels of the Hunter River have also been cited as a possible cause for the lack of seagrass in the Hunter estuary. High turbidity reduces light penetration through the water, in turn reducing the ability of plants to photosynthesise and therefore survive. High turbidity in the estuary is likely to be influenced by the relatively high erodability of soils in the Hunter catchment, combined with land use changes that have resulted in significant erosion of the catchment. The high turbidity may also be influenced by dredging of the harbour.

The abundance of fish and crustaceans may also be affected by dredging. In general, increases in turbidity may affect the foraging behaviour of fish and suspended sediments may abrade the protective mucus coats on fish, thereby increasing their susceptibility to disease, or clog gill filaments and suffocate the fish. It has also been suggested that the discoloured or contaminated water that results from dredging may drive fish and prawns away from the area and commonly imparts an unpleasant taste to cooked crustaceans and fishes. It may also stop the influx of young or adult fish to the estuary (TEL 2001).

General river health can be monitored through the use of biological indicators. The Hunter Valley Aquatic Macroinvertebrate Survey was designed to assess the impact of river conditions and land use on river health using macroinvertebrates as biological indicators. Of the sites monitored, one occurred within the study area, located on the Hunter River downstream of Maitland. The survey was conducted from 1995-1997, and the site was rated to be in poor health each year (DLWC 2000).

4.7.6 Status and Health of Fish Resource

Commercially important fisheries in the Hunter River are the estuarine finfish and estuarine prawn trawl. The oyster industry was an important resource in the early 1900s, but is now no longer as profitable as it once was (TEL 2001).

In the early 1900s, fishermen apparently earned a very good living in the Hunter River, but by the mid 1970s the industry was not as healthy. Today, the estuarine finfish fishery in NSW is worth $12 million per year and produces over 4,000 tonnes of fish. The Hunter River finfish fishery is the 10th largest in NSW, supplying just over 140,000 kg of fish per year. Sea mullet are by far the most important contributors (by weight) to the Hunter River fishery (85,690 kg), followed by river eels (14,784 kg), fantail mullet (8,577 kg), silver biddy (5,216 kg), sand mullet (4,584 kg), bream (4,494 kg), dusky flathead (3,339 kg), luderick (2,212 kg), sand whiting (1,525 kg) and silver trevally (99 kg) (TEL 2001).

A wide variety of methods are used by commercial fishers in the Hunter River, although fish trawling is not permitted anywhere in the estuary. In general, commercial fishing is permitted in most of the estuary, although there are closures to certain methods in some areas (Figure 3.9) (TEL 2001).

The major commercial fishery in the Hunter is the estuary prawn trawl fishery. Today, the total value of the prawn trawl fishery in the Hunter estuary is estimated at $322,261. The Hunter River is one of only five estuaries in the State where trawling for prawns is permitted, the others being the Clarence, Hawkesbury, Botany Bay and Port Jackson (TEL 2001).

School prawns *(Metapenaeus macleayi*) make up the vast majority of landings by trawlers in the Hunter River (57,781 kg in 1997-1998) and in the Clarence and Hawkesbury rivers, whereas the landings of eastern king prawns (*Peneaus plebejus*) are very small (2,447 kg in 1997-1998). The average landings of school prawns in the Hunter River have ranged between 40,000 and 70,000 kg per year over the last 15 years, but in comparison to some other estuaries, these landings are relatively constant (NSW Fisheries 1999). Landings of eastern king prawns have consistently been less than 4,000 kg per year. The trawling effort for prawns (i.e. total number of days fished by all trawlers) in the Hunter has fluctuated between 1,500 and 2,500 days per year over the last 15 years, although NSW Fisheries suggests that the level of effort has been relatively stable over this time. Catch rates (measured as weight of prawns caught per number of days fished) for school prawns and eastern king prawns in the Hunter and Hawkesbury rivers have varied over the years, but importantly there has been no pattern of decrease as has been evident in the Clarence River, Port Jackson and Botany Bay. In fact, data for the last 10 years indicate that catch rates for these prawns have been increasing steadily in the Hunter River (TEL 2001).

Although prawn trawling has always been important to the economy of the Newcastle region, there have been occasional setbacks to the industry. Prawns caught in the south arm in the past have been known to have a ‘gassy’ taste and this has resulted in the price of prawns from the entire region being reduced (TEL 2001).

4.7.7 Maintenance and Improvements of Fish and Prawn Production

Production of fish and prawns is highly dependent upon the viability of habitat and nursery areas. Habitat areas include saltmarsh and mangrove areas, and access to freshwater areas. Degradation of saltmarsh habitat due to clearance, drainage works, and mangrove incursion reduces the value of these areas as faunal habitat. Construction of floodgates and structures such as culverts and low-level road crossings may reduce prawn and fish access to the fresher reaches of the estuary such as Hexham Swamp, and the back of Fullerton Cove. These structures also affect access to reaches further up the river, such as beyond Seaham Weir. Reclamation of land such as areas of Kooragang Island also reduces access to fish habitat areas (S. Carter NSW Fisheries pers. comm. 2002).

A recommendation put forward by the Hunter River Prawn Trawling Fishery has been for the rehabilitation of Mosquito Creek, and the swamp and saltmarsh areas in the north-west corner of Kooragang Island (Ash Island), for the purpose of improving these areas as potential fish nursery habitats (NSW Fisheries 2002a).

4.7.8 Ballast Water

The primary survey of introduced species in the Hunter River was conducted by CSIRO in 1997. Surveys focused on areas where introduced species are most likely to occur, that is around wharves, slipways, deballasting areas, mariculture facilities, breakwaters and jetties, estuarine areas and dredge disposal areas in the north and south arms and in Throsby Creek.

Eight species have been identified in a schedule produced by the Australian Ballast Water Management Advisory Council (ABWMAC) and two of these were found in the survey of the Hunter River. These were the toxic dinoflagellates (single-celled organisms in a group called Protozoans) *Alexandrium catenella* and *Alexandrium minutum*. The report suggested that blooms of these species could potentially threaten mariculture industries (specifically the oyster industry), through bioaccumulation of neurotoxins, but also noted that there had been no evidence of such blooms in the region. It was recommended that monthly sampling be initiated for at least one year to try to ascertain how abundances of these species fluctuate. No evidence that any such sampling programme has been initiated has been found. Cysts of both species of dinoflagellates were found in dredge spoil grounds, highlighting the risks of spreading these organisms throughout the region (CRIMP 1999).

4.8 Loss of Habitat and Biodiversity

The degradation of habitat and loss of biodiversity within the Hunter River estuary is intrinsically linked to the ongoing settlement, urbanisation and development of the Hunter estuary catchment (MacDonald 2001). Important aspects of human impacts that influence biodiversity in the estuary include riparian vegetation damage, impacts of hydraulic structures and obstacles to fish migration and effects of mudflats. These factors and areas affected by them are discussed below, followed by an assessment of changes to habitat diversity since European settlement and an assessment of causes leading to the loss of habitat and biodiversity.

It should also be noted that key threatening processes have been identified through the following legislation: Fisheries Management Act (FM Act), Threatened Species Conservation Act (TSC Act) and the Environment Protection and Biodiversity Conservation Act (EPBC Act). These key threatening processes include:

- degradation of native riparian vegetation along New South Wales watercourses (FM Act)
- alteration to the natural flow regimes of rivers, streams, floodplains and wetlands (TSC Act, FM Act)
- clearing of native vegetation (TSC Act, EPBC Act)
- human-caused climate change (TSC Act, EPBC Act)
- removal of large woody debris (FM Act)
- predation by the plague minnow (*Gambusia holbrooki*) (TSC Act)
- predation by feral cats (TSC Act, EPBC Act)
- predation by the European Red Fox (*Vulpes vulpes*) (TSC Act, EPBC Act)
- predation, habitat degradation, competition and disease transmission by feral pigs (EPBC Act)
- competition and land degradation by feral rabbits (TSC Act, EPBC Act)
- invasion of native plant communities by bitou bush and boneseed (TSC Act) (Environment Australia 2003, NSW Fisheries 2003, NSW National Parks and Wildlife Service 2003).

4.8.1 Riparian Vegetation Damage

Native riparian vegetation cover in the Hunter estuary is highly variable. Field assessment of the banks of the Hunter estuary in September 2002 enabled classification of riparian vegetation throughout the estuary. Little riparian vegetation cover remains in the Newcastle port area due to land use changes such as land reclamation, urbanisation and the development of port facilities. Riparian vegetation in the lower estuary along the banks of the north arm, Fullerton Cove and the south arm north of the port area is generally in good condition. In the remaining areas of the estuary, including the banks of the Hunter River north of Hexham, the north-western section of Kooragang Island, upstream areas of Ironbark Creek, Williams River, Paterson River and Wallis and Fishery creeks, riparian vegetation cover is generally sparse and degraded (banks classed as yellow or red, see Figure 4.23 and Section 4.5 Bank Stability).

The dominant land use along the banks of the estuary in areas with poor riparian vegetation cover is agriculture and grazing (see Figure 3.2). These grazing areas have largely been cleared of native vegetation, including vegetation in the riparian zone. Cattle access to the banks severely affects regrowth of native riparian vegetation through consumption of seedlings that may occur and through trampling.

Cattle access to the riparian zone is a significant issue, particularly in the Hunter River north of Hexham, Williams River, Paterson River and Wallis and Fishery creeks (Figure 4.24). Areas of the Hunter River between Raymond Terrace and Morpeth where cattle were excluded often correlated with areas where bank protection works had been undertaken. Cattle access was evident along Ironbark Creek in areas adjacent to, and within, the SEPP 14 wetlands of Hexham Swamp (Figures 4.24 and 3.2). Riparian vegetation cover in these areas will continue to be affected as long as cattle access to the banks remains.

Another factor which may play a significant role in damage to riparian vegetation is the construction of flood mitigation works. For example, the thick *Phragmites australis* reed beds along the banks of the Hunter River at Millers Forest, upstream of Hexham, were badly damaged or destroyed in the drag-line construction of levee banks in 1969 (Ruello 1976). These reed beds are considered to be important sources of food and shelter for small fish and prawns, and therefore destruction of this riparian vegetation may have undesirable effects on the estuarine ecology (Ruello 1976).

4.8.2 Impacts of Hydraulic Structures

Flood mitigation and hydraulic structures occur extensively throughout the Hunter estuary. The evolution of structures and their occurrence are discussed in Section 3.3.2, and shown in Figures 3.8 and 4.29. Flood mitigation in the Hunter estuary has included construction of levees along river banks, the construction of drains through low-lying areas and floodplains, and the restriction of tidal inundation through the construction of culverts, floodgates and causeways.

Drains occur throughout the Hunter estuary catchment, particularly north of Hexham and around Fullerton Cove (Figure 3.8). Drains have been shown to eliminate floodplain wetlands, reduce the permanence of floodplain wetlands, result in the conversion of saline wetlands to fresh/brackish systems, reduce the capacity of floodplain wetlands to absorb floods, reduce water quality control, provide refuges for aquatic weeds, and to facilitate the development of acid sulfate soils (MacDonald 2001). The conversion of saline wetlands to fresh/brackish systems reduces the floral diversity of the area, with consequential impacts on faunal diversity.

There are approximately 200 floodgates in the Hunter estuary, and these occur extensively in the grazing areas north of Hexham, around Fullerton Cove, and also at Ironbark Creek. Floodgates have been found to isolate estuarine systems, reducing tidal exchange and altering water chemistry; increase the growth of aquatic weeds; impact estuarine vegetation resulting in eventual conversion to a fresh brackish system; and to alter the estuarine faunal structure by creating a barrier to movement, alteration of the physical and chemical environment and alteration of the biological environment (MacDonald 2001, TEL 2001). Reduced tidal inundation in Ironbark Creek has had devastating impacts on the floral and faunal diversity of Hexham Swamp.

There are approximately 59 culverts in the waterways of the Hunter estuary (TEL 2001), and these occur predominantly in the lower estuary on Kooragang Island, around Fullerton Cove, and around Newcastle (Figure 4.29, Williams et al 2000). Like floodgates, culverts also reduce tidal flushing, resulting in conversion of estuarine systems to freshwater systems that do not support the same level of biodiversity.

Levees occur extensively in the upper estuary north of Hexham, and also around Fullerton Cove. Levees have resulted in the elimination of floodplain wetlands; the reduction in permanence of floodplain wetlands, and an increase in the sedimentation of streams and rivers (MacDonald 2001). The construction of levees can also lead to the removal of riparian vegetation, as occurred on the Hunter River between Raymond Terrace and Hexham where extensive beds of *Phragmites australis* was removed (Ruello 1976).

4.8.3 Obstacles to Fish Migration

Fish migration involves movement resulting in alternation between two or more separate habitats. This migration is often for the purpose of breeding, and may be wholly within fresh water, or may be between fresh and salt water. For fish that have large scale migrations in their life-cycles, particularly between fresh and salt water, obstacles to fish migration cause local extinctions above barriers and can greatly reduce population numbers downstream of those barriers. Fish passage (or movement) at a local scale is also important (Thorncraft and Harris 2000).

Obstacles to fish migration may include a variety of structures across waterways, such as floodgates, culverts, low level road crossings, weirs, and land changes such as reclamation. There are no major barriers along the Hunter River within the estuary, however barriers into tributaries do exist, the majority of which are floodgates (Figure 4.30). These include gates at Purgatory Creek, Ironbark Creek, Greenways Creek, Wallis Creek. Seaham Weir also poses a major barrier to movement in the Williams River. A barrier also exists at Gostwyck, possibly in the form of a natural rock shelf (Scott Carter, NSW Fisheries, pers. comm. 2002). Several stormwater gross pollutant traps on Throsby and Styx creeks (NCC 2000) also limit fish passage. These waterways are largely concrete stormwater drains with low habitat potential, and therefore fish movements in these areas may be minimal in any case. Reclamation on Kooragang Island is also considered a significant barrier for fish passage in Mosquito Creek, as this closed off the creek at its confluence with the south arm (Scott Carter, NSW Fisheries, pers. comm. 2002, Williams et al 2000).

In the Hunter estuary, fish species whose life cycles may be significantly affected by barriers between fresh and salt water, due to migration being a requirement for breeding purposes, include Australian bass, common jollytail, short-finned eel and long-finned eel. Other species whose life cycles involve migration, but not for the purposes of breeding, include sea mullet, striped gudgeon, and southerm blue-eye (Thorncraft and Harris 2000). Commercially, the most significant species affected by obstacles to migration are prawns.

Historically, Hexham Swamp, Kooragang Island, Tomago and areas behind Fullerton Cove were important prawn nursery areas. In particular, Hexham Swamp was a significant king prawn nursery (Reg Hyde local resident pers. comm. 2002, and Roland Bow, NSW Fisheries, pers. comm. 2002). The construction of floodgates on Ironbark Creek, reclamation of Kooragang Island and flood mitigation works in the Tomago area have greatly reduced the potential of these habitats as prawn nursery areas.

Fish movement at smaller scales is also impeded by structures throughout the estuary that impede tidal flow, including culverts, low level road crossings, floodgates and levees (see Figures 3.8 and 4.29).

4.8.4 Loss of Mudflats

Large amounts of historic tidal mudflats have been lost from Tomago, Fullerton Cove, the original Hunter deltaic islands and Hexham Swamp/Ironbark Creek due to land reclamation (MacDonald 2001), however quantification of these losses has not been determined.

The estuary-wide phenomenon of mangrove expansion has resulted in the loss of tidal mudflats along the north bank of the north arm of the Hunter River, in the vicinity of Tomago. Increased sedimentation within the Hunter River system may result in increased sedimentation of Fullerton Cove. The subsequent increase in elevation within the cove could result in mangrove expansion into this mudflat, and the loss of a huge expanse of invaluable avifaunal and fisheries habitat (MacDonald 2001).

4.8.5 Condition of Wetlands, Saltmarsh and Macrophytes

The condition of mangroves, saltmarsh and other macrophytes (large plants) such as *Phragmites australis* (common reed) is variable along the Hunter estuary (Figure 4.31). Healthy mangrove communities are found along the banks of the Hunter River, along the banks of tidal creeks throughout Kooragang Island and around Fullerton Cove. Fullerton Cove has been described as one of the few remaining untouched mangrove forests in the Hunter River, and is considered to be well developed and healthy. Degraded mangrove stands are found along Ironbark Creek, within Hexham Swamp and along Creek Three, Ash Island, Kooragang Island (MacDonald 2001).

The extent of saltmarsh within the Hunter River estuary has been drastically reduced over time, and this reduction has accelerated over the last fifty years due to land reclamation and flood mitigation works. Functional saltmarsh communities are now largely restricted to the Kooragang Nature Reserve and to some small areas on Ash Island. Degraded saltmarsh is located within Hexham Swamp, on Kooragang Island and in the Tomago/Fullerton Cove areas, however tidal restriction has reduced the functionality of these fragments and has resulted in the conversion of the majority of these areas to fresh/brackish wetland or *Phragmites australis* swamp (MacDonald 2001).

Saltmarsh west of Fullerton Cove was used as a high tide roost for migratory wading birds before the floodgates were installed in the ring drain, which resulted in degradation of this habitat (P. Svoboda, KWRP, pers. comm. 2003).

The condition of the extensive *Phragmites australis* swamps such as Hexham swamp may be regarded as healthy, however due to the low diversity of biota that they support, a more productive habitat in these areas would be desirable. *P. australis* in the riparian zone does occur in large areas upstream of Hexham, and these beds are beneficial in terms of bank stability. The condition of *P.australis* along the banks of the estuary was variable, ranging from beds up to 5 m deep, to minimal cover affected by cattle grazing. However, any possible revegetation of the banks of the estuary should focus on providing a variety of native plant species to improve habitat potential, rather than solely on *P. australis*.

There is very little seagrass inhabiting the Hunter estuary and those populations of *Ruppia* spp. that were observed (MHL fieldwork 2002) were small and patchy. In addition the presence of epiphytes (organisms such as algae growing on the surface of the seagrass) suggest that the seagrass is in poor condition. Patches of *Ruppia* were observed in the upper estuary in the following locations (MHL fieldwork 2002):

- Hunter River, in the 3 km reach upstream of Morpeth
- Hunter River, approximately 1.2 km downstream of the confluence with the Paterson River
- Paterson River, in the vicinity of Hinton Bridge, Hinton
- Paterson River, approximately 11 km upstream of the confluence with the Hunter River, in the vicinity of Iona
- Paterson River, approximately 12.5–13 km upstream of the confluence with the Hunter River
- Paterson River, in the 1 km bend in the river at Paterson.

4.8.6 Habitat Linkages

The establishment of corridors is for the provision of habitat, and to link smaller and larger areas of vegetation (HCMT 1999). In disturbed areas, faunal habitat corridors occur along creeks and drainage lines and along road verges, as these are often the only place where native vegetation remains (HCMT 1999). The field assessment conducted by MHL for this study indicated that the majority of the riparian vegetation cover in the upper Hunter estuary is in relatively poor condition (Figure 4.23) and therefore its use as a faunal habitat corridor is limited. Rehabilitation of this riparian vegetation would serve the dual purpose of stabilising banks, and also potentially provide habitat corridors.

Regional habitat corridors for the Hunter estuary catchment identified by NSW NPWS are shown in Figure 4.32. At present corridors for the northern area only of the catchment are shown, as the southern region mapping has not yet been released by NPWS due to concerns regarding accuracy of the data. The habitat corridors have been classified as regional, subregional and State Forest. The corridors occur in the East Maitland Hills area, and a corridor through Irrawang Swamps links the wetland to the State Forest to the north. Focal species for these corridors include small mammals, birds, and marsupials such as koala. The Tomago Coastal Plain is also a regionally significant habitat link between the Hunter estuary and Port Stephens. To the south-west, significant undisturbed habitat in the Sugarloaf Range links to the Watagan Mountains.

Regional linkages have also been modelled and mapped by LHCCREMS. These data were acquired by MHL, but due to the broad scale at which they have been mapped, were deemed to be unsuitable for the Hunter Estuary Processes Study.

4.8.7 Assessment of Habitat Changes since European Settlement

Since European settlement the landscape has drastically changed. The natural environment has been transformed from forest and wetland areas into land for residential, agricultural and industrial purposes. Assessment of the change in vegetation distribution within the Hunter River estuary over time has indicated a massive loss of estuarine wetland habitat and an increase in low diversity grassland and fresh/brackish wetland habitat. Dramatic changes have occurred in the spatial location and extent of the vegetation communities of the Hunter River estuary since discovery in 1796 (MacDonald 2001).

Before the arrival of the Europeans, the Hunter River was a mangrove-fringed river with dense brush and huge trees lining the banks. There were lofty forests of eucalyptus, *Casuarina* and wetlands and the hills were covered with light underwood and grass. Due to the richness and variation in the landscape, there was an abundance of species, such as emus, kangaroos, dingoes and a variety of birds living in the area (MacDonald 2001). A vegetation map from 1850 shows that the low-lying coastal areas of the Hunter estuary were mainly saltmarsh with tidal ponds. These areas included the majority of Fullerton Cove and Tomago, and parts of Hexham Swamp, Ironbark Creek, Sandgate and the deltaic islands. The upland areas of the deltaic islands consisted of fresh/brackish swamps with temperate rainforests and palms. The low inland areas around Hexham, Shortland, Tomago and Fullerton Cove were classified as perennial fresh/brackish meadows with various fresh/brackish swamp forest species (MacDonald 2001).

GIS modelling conducted by LHCCREMS using environmental variables such as soil landscapes, climatic variables and topographic indices has produced a map detailing likely vegetation communities of the Lower Hunter before European settlement, shown in Figure 4.33. For the purposes of this study only selected floral communities in the Hunter estuary, including wetlands, are presented. The modelling results are supported by historical records (e.g. Williams et al 2000) that indicate that the Hunter River estuary and floodplain was previously covered with a rich diversity of vegetation communities. This included large areas of saltmarsh and mangroves in the lower estuary, and littoral rainforest in small areas of what is now Kooragang Island. *Casuarina* and swamp mahogany forests were found in the Hexham Swamp area, and along the Hunter River from Hexham Swamp to Irrawang Swamps. Swamp mahogany also occurred behind the saltmarsh areas of Fullerton Cove and Tomago and on the deltaic islands of the Hunter River. The banks of the upper estuary along the Hunter River and Paterson River were lined with dry rainforest. The floodplain in the upper reaches, including Wallis and Fishery creeks, was covered in wide expanses of alluvial forest. Freshwater wetlands occurred throughout the estuary, including Hexham Swamp, Woodberry Swamp, and Irrawang Swamps (Figure 4.33).

Since 1750 there has been a progressive loss of habitat in the study area (MacDonald 2001). Much of the original temperate rainforest, upland forest stands, saltmarsh, tidal flats and saline open water bodies have been lost. The reed *Phragmites australis* has become dominant in the Hexham Swamp area and mangroves have increased where the tidal hydrology has not been changed (e.g. Fullerton Cove coastline) and reduced where tidal restriction has been enforced (e.g. Hexham Swamp and Ironbark Creek) (MacDonald 2001).

Current vegetation was also modelled by LHCCREMS using environmental variables, site inspections, and interpretation of aerial photography. This mapping forms the basis of the floral communities and changes to habitat diversity since European settlement presented in Figure 4.34. Approximate changes in the cover of each community between 1750 and the present day based on the two maps are presented in Table 4.19. It should be noted that the modelling and mapping conducted by LHCCREMS was utilised for this study as it provided an overview of the entire estuary. However, the modelling conducted by LHCCREMS is currently being updated to improve its accuracy, and is being verified the Maitland City Council area. More accurate mapping has also been conducted in specific areas of the Hunter estuary, such as Kooragang Island. It is recommended that this more detailed mapping be utilised when forming the management study.

Table 4.19 Comparison of Floral Habitat Cover Between 1750 and 2000

Floral community/ habitat	Vegetation Cover pre-1750 (km^2)	Present Vegetation Cover (km^2)	Change in Vegetation Cover (km^2)	Change in Vegetation Cover (%)
Freshwater wetland	33	36	+3	+9%
Mangrove	28	22	-6	-21%
Saltmarsh	32	5	-27	-84%
Phragmites australis	0.1	9	+8.9	+8900%
Casuarina complex	56	13	-43	-77%
Swamp mahogany	89	14	-75	-84%
Alluvial forest	167	25	-142	-85%
Dry rainforest	26	12	-14	-54%
Littoral rainforest	1	0.05	- 0.95	-95%

Comparison of the two maps (Figures 4.33 and 4.34) indicates that a large proportion of Alluvial forest in the upper estuary has been cleared, with a loss in cover of approximately 85%. Areas of alluvial forest that remain in the catchment are no longer adjacent to the estuary (Figure 4.34). The vast majority of dry rainforest previously lining the banks of the Hunter and Paterson rivers has also been cleared, and this habitat is now found mainly in the East Maitland Hills physiographic regions, although very small remnant patches of this habitat are found along the Paterson River (Paul Collins DLWC, pers. comm., 2002). Swamp mahogany has also been cleared from the floodplain of the Hunter River from Woodberry Swamp to Seaham on the Williams River (Figure 4.33).

Casuarina forests previously extended from the confluence of the Hunter and Williams rivers, to Hexham Swamp (Figure 4.33), covering an area of 56 km^2. This forest cover has been reduced by approximately 77% to 13 km^2, now often occurring only on the outer boundaries of freshwater wetlands (e.g. Hexham Swamp and Woodberry Swamp).

Saltmarsh habitat has decreased markedly, from approximately 32 km^2in 1750 to 5 km^2, a loss of nearly 85% (Table 4.19). The loss of saltmarsh was most dramatic in the region around Tomago, Fullerton and Stockton and around Kooragang Island (MacDonald 2001). Saltmarsh has been replaced by pasture, dry grassland or cleared land (Fullerton Cove and deltaic islands) or by fresh/brackish wetlands (Hexham Swamp).

In contrast to the loss of saltmarsh is the large increase in *Phragmites australis* swamps, from approximately 0.1 km^2 in 1750 to 9 km^2 present day. This increase has occurred predominantly in Hexham Swamp, and in the former saltmarshes of Tomago/Fullerton Cove and Kooragang Island. These monospecific *Phragmites australis* stands have only been recorded as encroaching on the more diverse freshwater, fresh/brackish and saline wetlands within the Hunter River estuary since the 1950s (MacDonald 2001).

Expansion of *Phragmites australis* swamps has been coupled with a general increase in freshwater wetlands in Hexham Swamp, at the expense of much of the *Casuarina* forest. While freshwater wetlands in other areas of the upper estuary have been reduced, such as Woodberry Swamp and former wetlands near Fishery Creek, the overall freshwater wetland cover has shown a small increase from 33 km^2 in 1750 to approximately 36 km^2 today.

Mangrove cover in the Hunter estuary has decreased since 1750 from approximately 28 km^2 to 22 km^2, a loss of 21%. During the development of the industrial and port facilities in the lower Hunter, over 2 km^2 of mangroves was removed from Kooragang Island and 0.4 km^2 was lost along Throsby Creek (Williams et al. 2000) Mangrove cover in Hexham Swamp has also decreased. However the extent of mangroves in other areas has increased since the mid 1950s. Many of the increases in area occurred along the main channels of the river around Tomago, Fullerton and Stockton, but there were also increases in mangroves on Kooragang Island (Williams et al. 2000). The steady increase in mangroves is correlated with a decrease in saltmarsh habitat (TEL 2001).

Littoral rainforest previously occurred in small areas on the western corner of Kooragang Island, covering an area of approximately 1 km^2. Approximately 95% of this forest has been cleared, and now remains only as remnant patches (MacDonald 2001).

Monitoring of viable habitat in the Hunter estuary since the 1970s suggests that historical wader roosting and feeding sites have become seriously degraded. Preferred roost sites included bare, sandy spits, islands and beaches within the estuary, which are no longer available. Feeding areas such as mudflats upstream of Stockton Bridge, and into Fullerton Cove are also becoming degraded. Loss of roost sites has been attributed to encroachment of exotic weeds, and expansion of mangroves. Areas affected by these encroachments include Sandy Island, Stockton sandspit, and Kooragang Sandspit (Hunter Bird Observers Club, pers. comm. 2001).

A major habitat change in the lower Hunter estuary was the formation of Kooragang Island. The island known as Kooragang was a group of up to ten islands of various sizes that have since been amalgamated largely due to reclamation for industrial purposes (Williams et al 2000). Infilling of the islands commenced with dumping of dredge spoil in the late 1800s. In 1947 it was proposed to develop the deltaic islands into an industrial estate and in 1951 dredging and filling commenced. The passage of the Newcastle Harbour Improvements Act in 1953 led to the construction of a single land mass in the Hunter River estuary (MacDonald 2001). It is estimated that the creation of Kooragang Island led to the destruction of up to 10 km^2 of estuarine wetlands (DLWC 2000).

Open waters in the Hunter estuary have also decreased over time. Extensive research has shown that 37% of the open waters were lost between 1801 and 1994. This loss occurred in the lower estuary, and was due largely to reclamation of Kooragang Island, and also siltation of Fullerton Cove and the north arm. Dredging and erosion were responsible for a small increase in open water area, although the losses greatly outweighed the increases (Williams et al. 2000). Coupled with the reclamation of the deltaic islands was a decrease in shoreline, which would have provided valuable habitat for avifauna (Williams et al 2000).

4.8.8 Assessment of loss of biodiversity

Floral and faunal biodiversity has decreased as a result of changes in habitat availability within the estuary. Habitat availability within the Hunter estuary and this floodplain has been primarily affected by human land use changes, including clearing and conversion to grazing land of large areas of alluvial forest, rainforest, swamp mahogany and *Casuarina* forests. Factors identified as contributing to the loss of habitat and biodiversity in the Hunter estuary include:

- alteration to natural flow regimes of wetlands through flood mitigation works. This alteration is responsible for a number of the factors listed here.
- an increase in *Phragmites australis* distribution and abundance at the expense of more structurally diverse habitat types,
- a decrease in available saltmarsh, tidal mud flats and saline open water bodies and the replacement of these habitat types with low diversity grassland and fresh/brackish wetlands,
- the expansion of mangroves into saltmarsh, mud flats and saline open water bodies, particularly within rehabilitation zones and nature reserves,
- the decline of roosting, nesting and refuge habitat,
- reduction in forest structural diversity resulting from the removal of most of the littoral rainforest from the study area, and
- introduction of non-indigenous vegetation and faunal species to the estuary (MacDonald 2001).

Additionally, threats to aquatic biota include:

- shoreline industry and farming, particularly runoff from factories, farms, and seepage of contaminated groundwater,
- dredging for maintenance and further port facilities,
- the fishing industry (TEL 2001),
- sediment load from Hunter River increasing sedimentation of tidal flats.

Alteration to natural flow regimes through construction of floodgates, levee banks and drains, has influenced biodiversity within the Hunter estuary in a number of ways. Impacts have included the conversion of high diversity wetlands to lower diversity freshwater wetlands, degradation of saltmarsh and mangrove areas and incursion of mangroves into saltmarsh areas.

The replacement of saltmarsh areas with low-diversity grassland and weed species has reduced the floral diversity of the region. Saltmarsh areas are rapidly disappearing from the estuary, removed by tidal restriction or replaced by the expanding mangrove population. Whilst saltmarsh communities are not hugely diverse in terms of vegetative species numbers, the presence of this community type adds to the habitat diversity of a region. The major consequence of saltmarsh loss is the corresponding loss of fauna from the estuary. Saltmarsh provides feeding and foraging habitat for a wide variety of bird, fish and invertebrate fauna. Removal of large areas of this habitat reduces the capacity of the estuary to support faunal life, resulting in decreased biodiversity (MacDonald 2001).

The result of expansion of *Phragmites australis* within the Hunter River estuary has been a loss of both floral and faunal biodiversity. Floral biodiversity has been reduced due to the replacement of more diverse habitat types by monospecific *P. australis.* A follow-on effect of this process has been habitat loss for fauna within the estuary. The effect of habitat and biodiversity loss is increased by the large expanse of the estuary now covered by this habitat type. Continued expansion within Hexham Swamp and Tomago/Fullerton Cove will further reduce the faunal habitat potential of this area (MacDonald 2001).

For the same reason, the reduction in open water and tidal mud flats will have also reduced the faunal biodiversity of the estuary. Open water bodies and tidal backwaters provide foraging and feeding habitat for waders and shorebirds. Water bodies have been severely reduced within the Hunter River estuary, reducing the food and habitat sources available to fish and birds. Reduction of food sources reduces the number of species and individuals that the estuary can support. Tidal mudflats support the greatest number of bird species of all the habitat types within the estuary, with Fullerton Cove being the most important location. The recorded expansion of mangroves throughout the study area is a threat to the tidal mud flats.

While mangroves have only made a small incursion into the Fullerton Cove mudflat over time, increased sedimentation within the river and the shallowing of Fullerton Cove may lead to increased mangrove colonisation and the eventual loss of this vital mudflat area. The rehabilitation zones of Kooragang Island have become increasingly colonised by mangroves, resulting in a reduction in the area of salt marsh, tidal mudflats and open water available as habitat (MacDonald 2001). The cause of mangrove incursion in saltmarsh areas is not well understood, but may include climatic change, altered tidal regime, sedimentation and subsidence (MacDonald 2001).

Comparison of recent data collected by the Hunter Bird Observers Club and historical data indicate a severe decline in the total number of migratory waders using the Hunter estuary, particularly several small wader species. Several wader species are no longer seen at all in the estuary. As many as 16,000 migratory waders were recorded using the estuary during the 1970s, however today only 3,500 migratory waders can be counted (Hunter Bird Observers Club, pers. comm. 2001). Loss of former sandy roosting sites at Sandy Island and Stockton Spit due to weed and mangrove invasion have forced the remaining waders to use the rock retaining walls known as Kooragang Dykes (Hunter Bird Observers Club, pers. comm. 2001).

The loss of former roosting sites is currently being addressed by a collaboration of the Kooragang Wetland Rehabilitation Project, Hunter Bird Observer's Club and NPWS (NPWS, pers. comm. 2003). However, it ahs been reported by fishermen that artificial roost sites installed at Fullerton Cove are being utilized by pelicans and seagulls, and not the wading birds for which they were designed (Fisherman's Co-op, pers. comm. 2003).

The destruction of rainforest and swamp forest habitat within the estuary has decreased the refuge habitat available for small mammals. Lack of refuge habitat results in greater predator impact on the native animal population, particularly from introduced mammals such as foxes, cats and dogs (NSW NPWS 1996). Forests that have been destroyed through time have not been replaced within the estuary. Where forest still exists it is almost exclusively *Casuarina glauca*, occasionally in combination with *Melaleuca spp.*. This forest type does not provide the density or diversity of the littoral and temperate rainforest that previously occupied much of the estuary, and as such can provide habitat for fewer faunal species.

The destruction of roosting sites and breeding grounds used by various resident and migratory waders and shorebirds has also reduced the faunal biodiversity of the Hunter River estuary. The removal of a mangrove community in the early 1970s for the construction of Stockton Bridge is widely noted. Altered hydrology within the estuary has reduced the permanence of water bodies, reducing the protection of native fauna from predators such as foxes (MacDonald 2001).

Much of the native faunal diversity has been reduced as a result of habitat destruction and by the arrival of introduced faunal species to the region. Introduced species compete with native mammalian fauna for habitat or use the native species as prey. Where populations of native mammals continue to exist, their density and distribution has been much reduced (MacDonald 2001).

Numerous introduced species of marine invertebrates have been identified in the Newcastle port and include barnacles, bryozoans, marine worms, a sea squirt, and Japanese goby (*Acanthogobius flavimanus*). Most, if not all, of these species are found in other harbours along the coast of NSW. Furthermore, the majority of these species are not known to have any significant impact on native marine invertebrates, but a very limited number of studies have been done (TEL 2001). In one of the few other records of an introduced invertebrate species in the Hunter, the presence of the mysid (a shrimp-like animal) *Neomysis japonica* in Fullerton Cove was reported (TEL 2001).

Freshwater and fresh/brackish wetlands as well as shallow, freshwater bodies, are in danger of colonisation from the noxious waterweeds *Alternanthera philoxeroides* (Alligator weed) and *Eichornia crassipes* (Water hyacinth). These species have established populations in freshwater wetlands and water bodies within the Hexham Swamp/Ironbark Creek area, Tomago/Fullerton Cove and on Kooragang Island. These waterweeds are highly competitive, excluding native plant species, reducing the habitat value of open water bodies for fish and birds and creating eutrophic water by reducing flow rates (MacDonald 2001).

The NSW NPWS acknowledges that the introduction of weed species to native habitats results in direct competition with native species for light and nutrients. Weed species also have the potential to alter the composition and distribution of native vegetation communities, thereby affecting their habitat value for native fauna (MacDonald 2001).

Introduced fauna have been found to impact the biodiversity and health of native vegetation stands, however they are more likely to impact upon native fauna. These impacts on fauna result from predation, competition for habitat and competition for food. The study area is presently virtually devoid of native mammals however NSW NPWS suggests that the area would previously have harboured native rats, mice, bandicoots, possums, bats and macropods (wallabies, kangaroos). This inference is supported by the location of some of these animals in the remnant forest patches to the edge of the Fullerton Cove area (MacDonald 2001).

Cattle were introduced to the Hunter estuary early in its history. The grazing of cattle within freshwater wetlands is acknowledged to reduce biodiversity and vegetation coverage due to consumption and trampling of native vegetation. Trampling promotes erosion and soil compaction. Cattle also promote the spread of weed species, via faeces deposition. Conversely, cattle are also acknowledged to increase the biodiversity of wetland areas dominated by *Phragmites australis*. This effect arises from the reduction of *P. australis* coverage that results from consumption. This opens up areas of previously dense, monospecific vegetation for colonization by different species (MacDonald 2001).

Pigs occur in Hexham Swamp and have been implicated in the predation of waterfowl and eggs. Pigs cause soil and vegetation damage by uprooting large patches of wetland vegetation. Populations of the black rat, the brown rat and the house mouse are also well established throughout the region. The major impact of those species is likely to be as competitors against native species for habitat and food. Rats are also known to predate on hatchlings and eggs of water birds (MacDonald 2001).

The cane toad has been reported in the Newcastle area, however this species has not been recorded within the Kooragang or Hexham Swamp Nature Reserves. Introduction of this species to the freshwater wetlands of the area has implications for other amphibian species, due to the propensity of the cane toad to prey on tadpoles (MacDonald 2001).

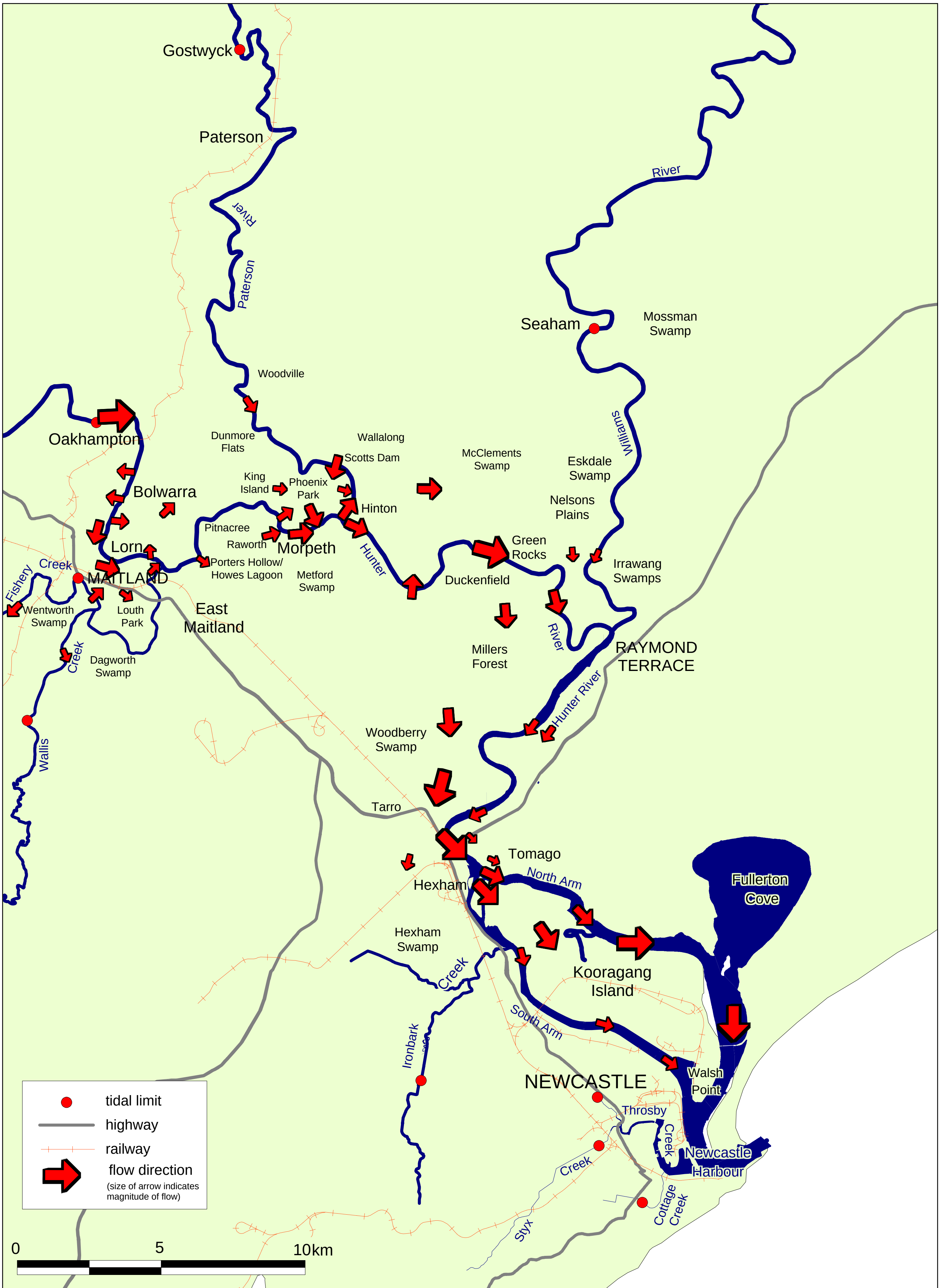
Poor water quality resulting from contaminated runoff and land uses may have wide-reaching effects on biodiversity within the estuary. Poor water quality is likely to reduce the diversity of aquatic floral habitat. Very few aquatic plants such as seagrasses exist in the Hunter estuary. Reduction of floral habitat may then affect faunal diversity. Poor water quality will also reduce the diversity of benthic invertebrates (DLWC 2000) towards species that are able to tolerate the poor conditions. Reduced diversity of benthic invertebrates will have adverse impacts upon other biota in the food web.

It is difficult to determine the sustainability of fisheries within the Hunter estuary, as estimates of catch per year do not take into consideration factors such as the lifecycle of fish and crustacean species. The inadvertent collection of unwanted species (by-catch) through large scale fishing results in impacts on both the targeted and non-targeted species.

Proposed development plans for industrial development and a transport corridor, as identified in the Newcastle Port Environs Concept Proposal may affect habitat in the lower estuary, and may also constrain rehabilitation currently in progress.

4.8.9 Summary of Ecological Processes in the Hunter Estuary

A conceptual model of the ecological processes occurring in the Hunter estuary is provided in Figure 4.35. This model has attempted to summarise and conceptualise the major steps in the food web that would be expected to occur in the Hunter estuary. However, due to the number of different habitats that occur in and around the estuary, interactions within the food web will vary between habitats. Key factors affecting each habitat have also been summarised, together with important human impacts on the ecology of the Hunter estuary.



Source: Refer to Appendix A, Table 1

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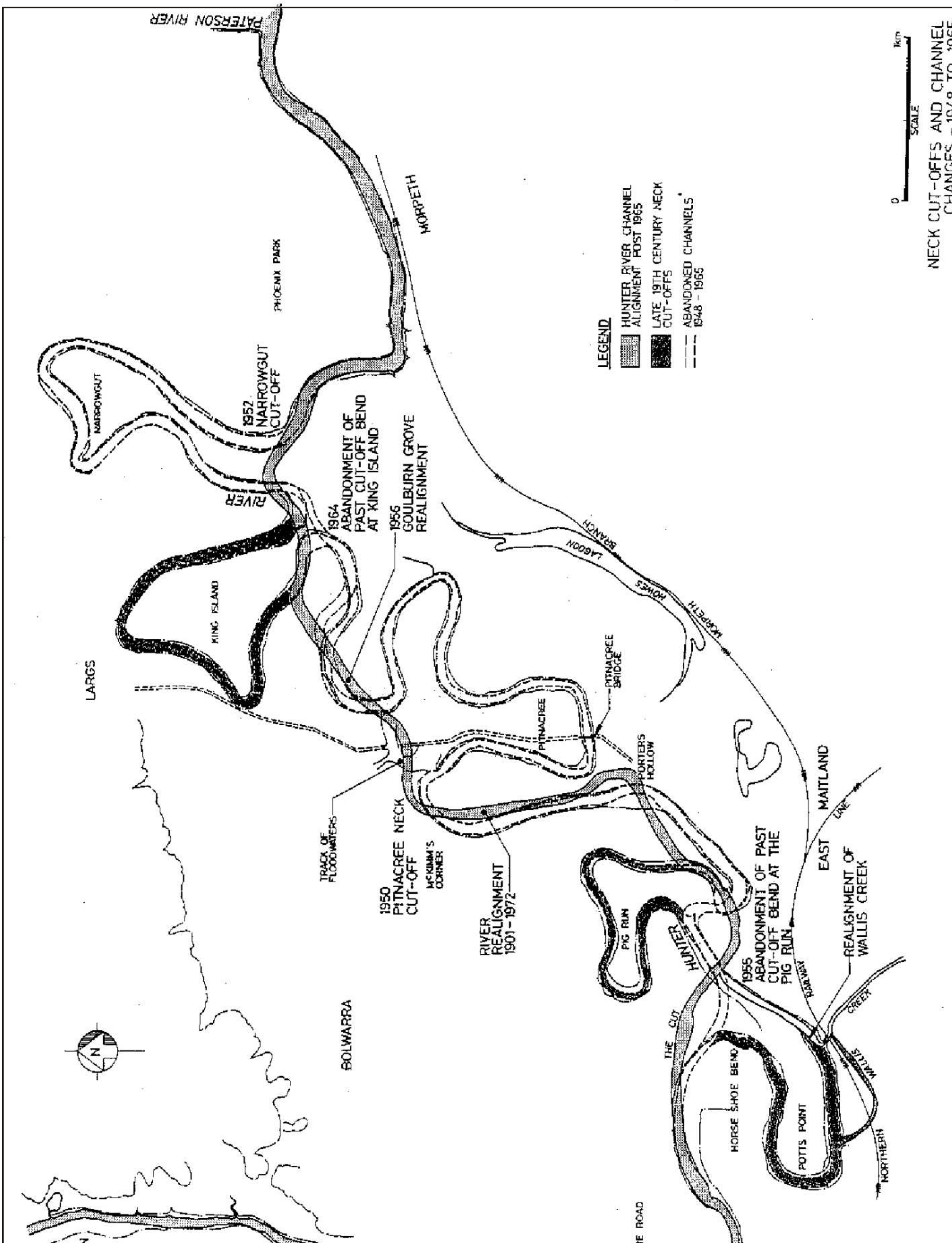
MANLY HYDRAULICS LABORATORY

FLOOD BEHAVIOUR AND LOCATIONS OF HYDROLOGICAL INTEREST

MHL Report 1095

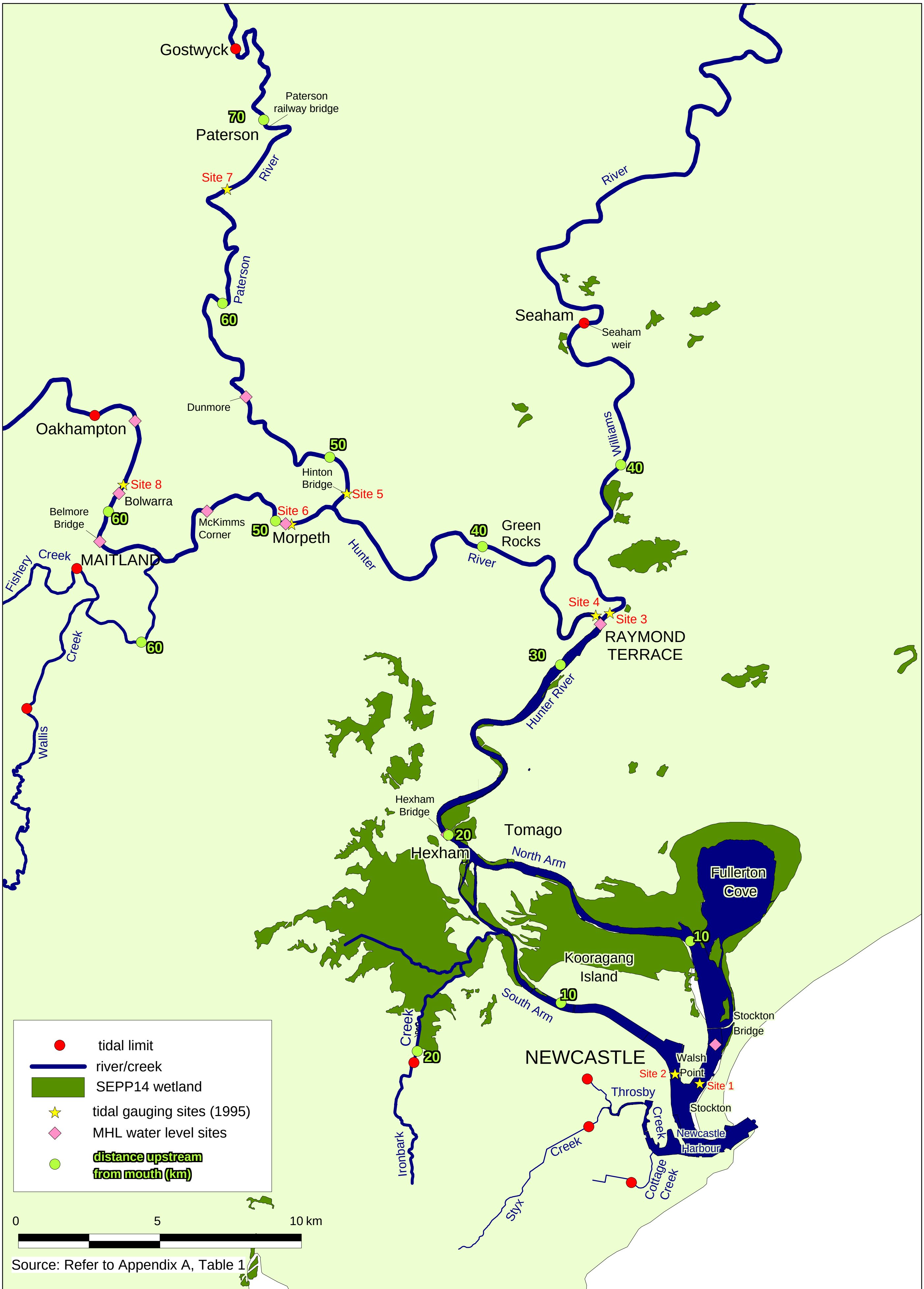
Figure 4.1

DRAWING 5_1.WOR



Source: Patterson Britton & Partners, August 1993

NSW DEPARTMENT OF PUBLIC WORKS AND SERVICES MANLY HYDRAULICS LABORATORY	CHANGE TO CHANNEL MORPHOLOGY BETWEEN MAITLAND AND MORPETH	MHL Report 1095 Figure 4.2 DRAWING 1095-04-02.CDR



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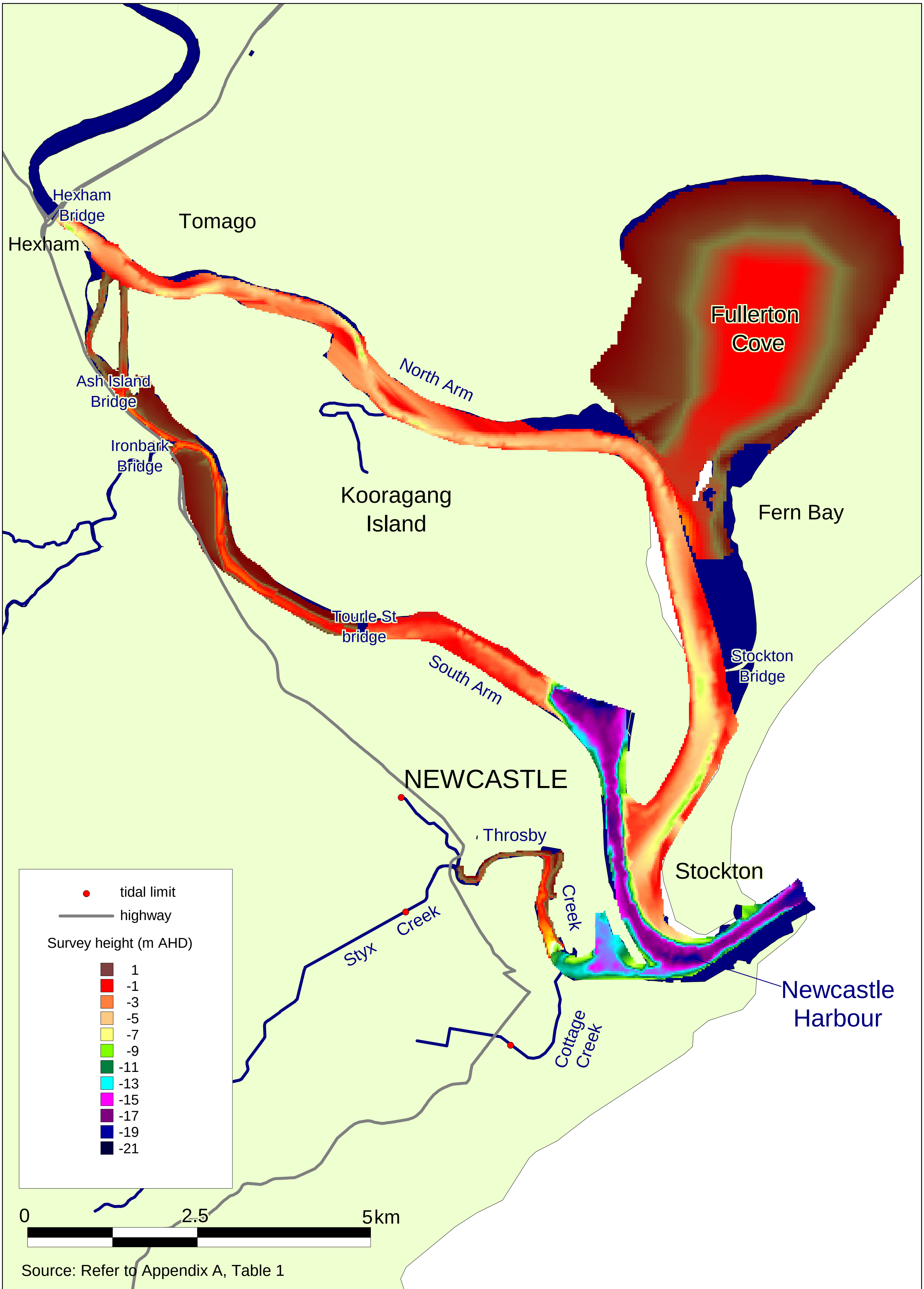
TIDAL GAUGING SITES AND LOCATIONS OF HYDRAULIC INTEREST

MHL Report 1095

Figure 4.3

DRAWING 4_1.WOR



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LOWER HUNTER RIVER BATHYMETRY

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Figure 4.4

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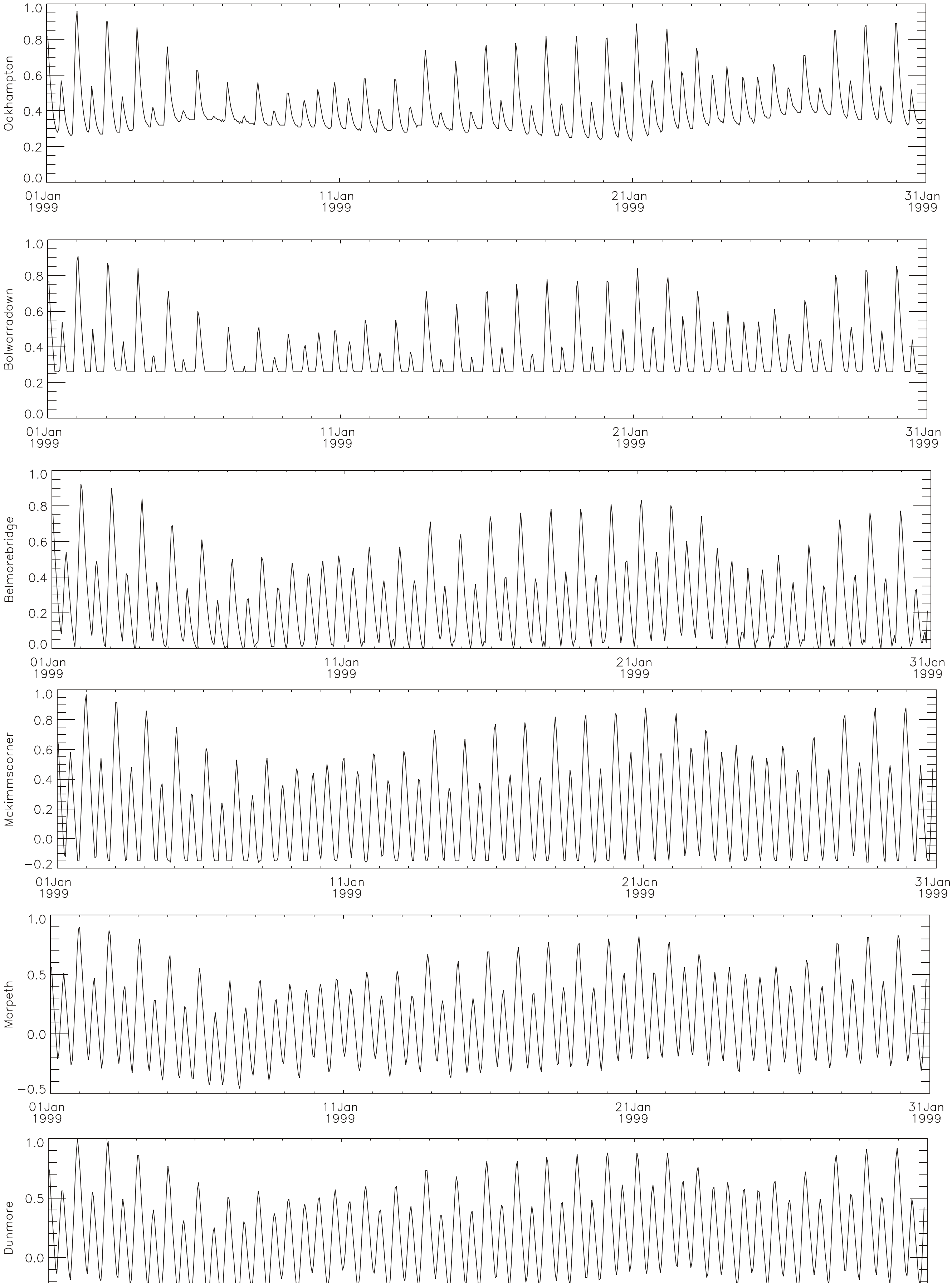

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TIDAL TRENDS IN THE HUNTER ESTUARY

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Figure
4.5

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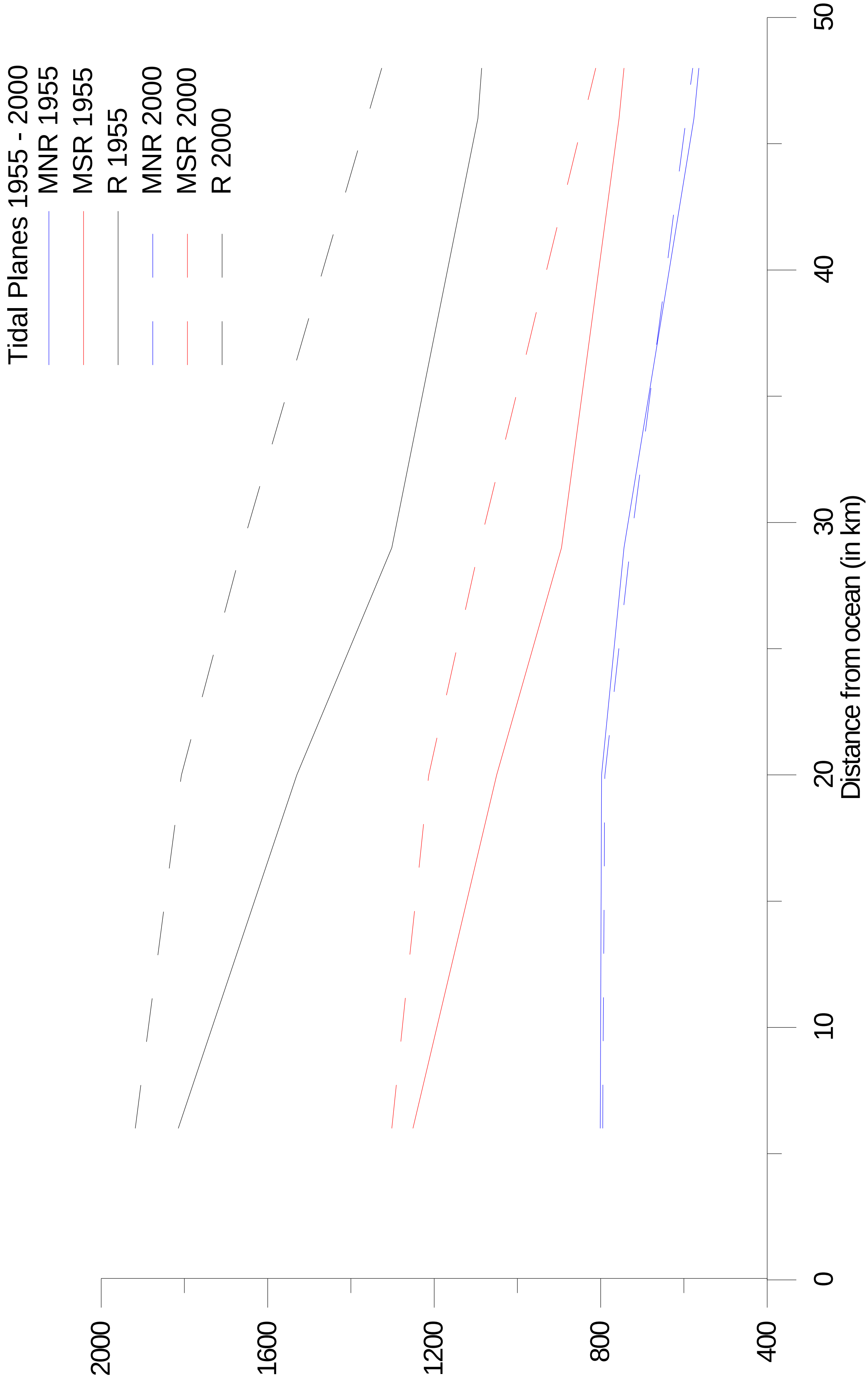

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TIDAL PLANES IN THE HUNTER RIVER
1955 - 2000

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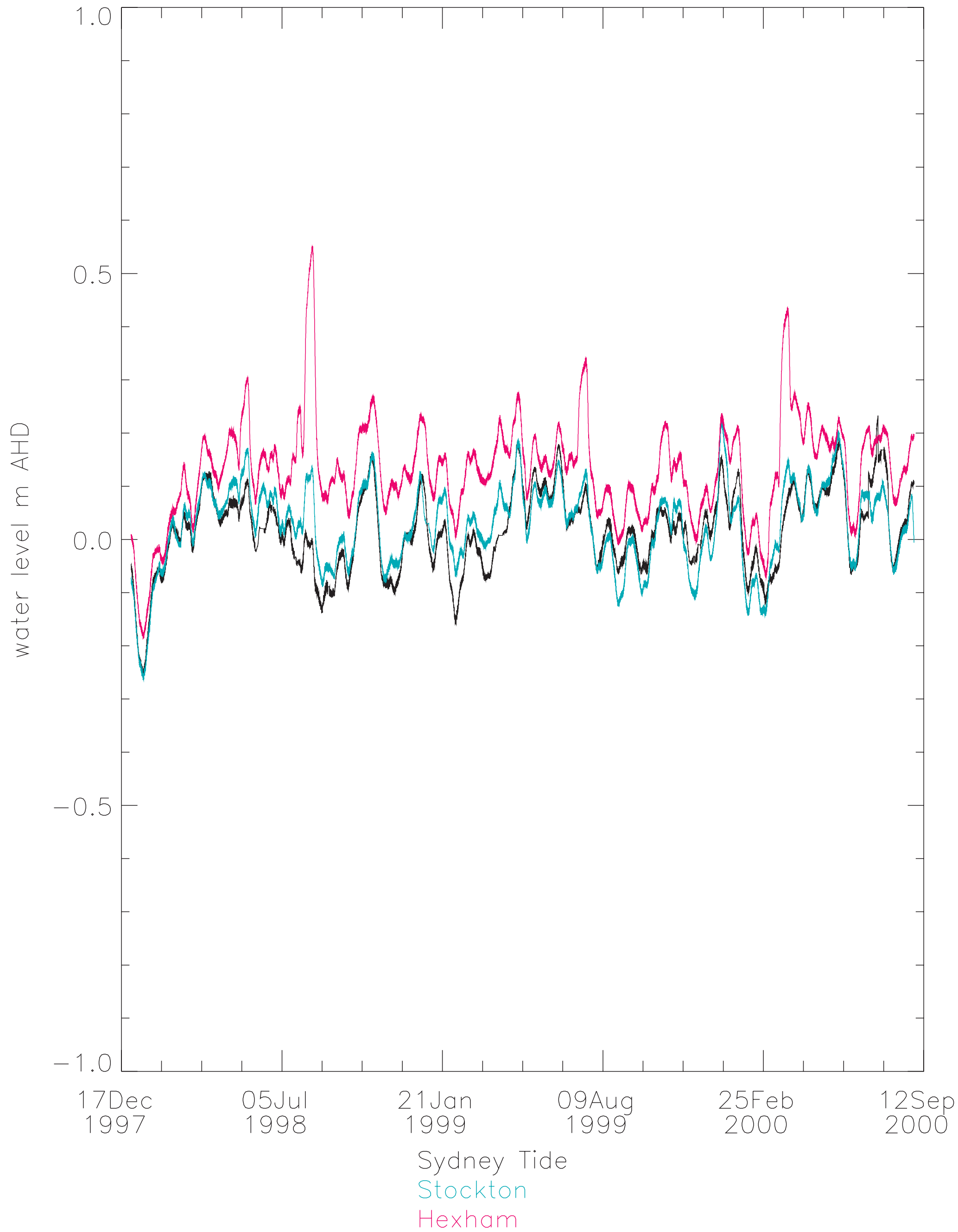
Figure 4.6

DRAWING 1095-04-06.CDR



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FILTERED WATER LEVELS THROUGH THE HUNTER ESTUARY

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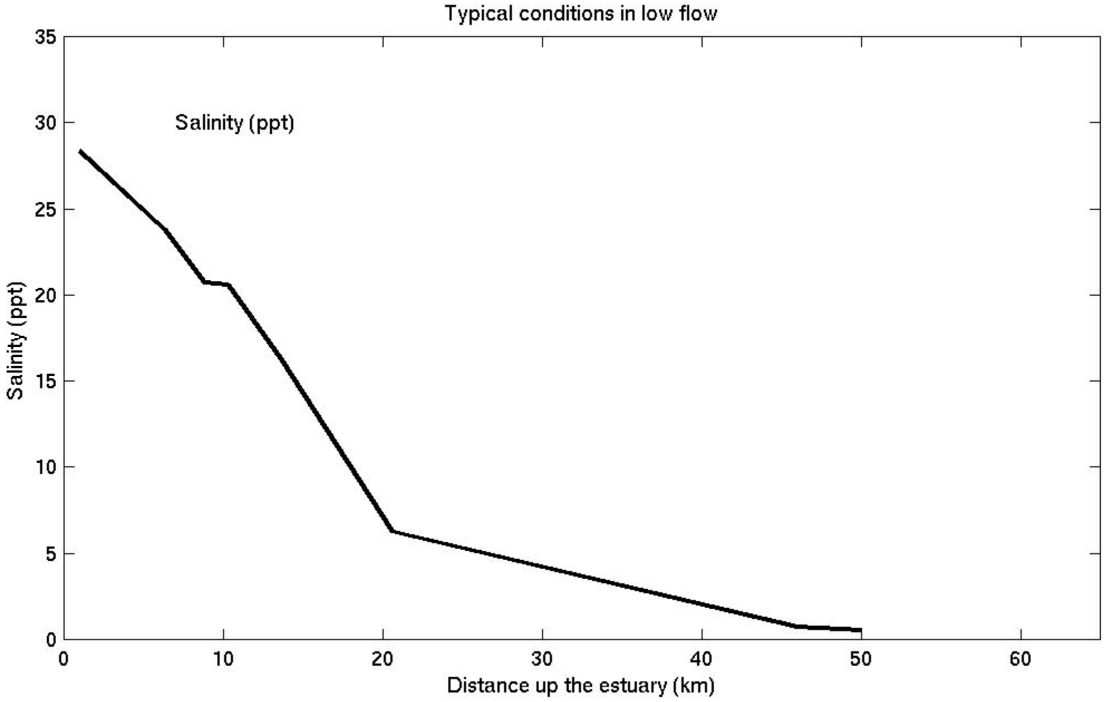
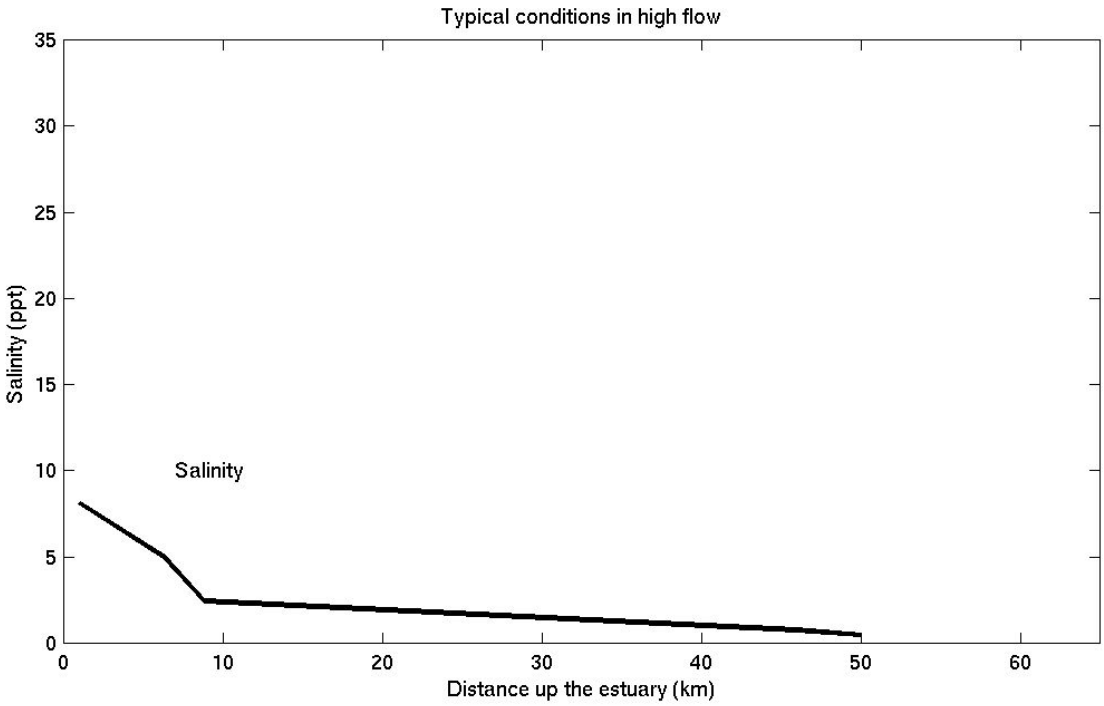
Figure 4.7

DRAWING 1095-04-07.CDR





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SALINITY STRUCTURES OF THE HUNTER RIVER

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Figure 4.8

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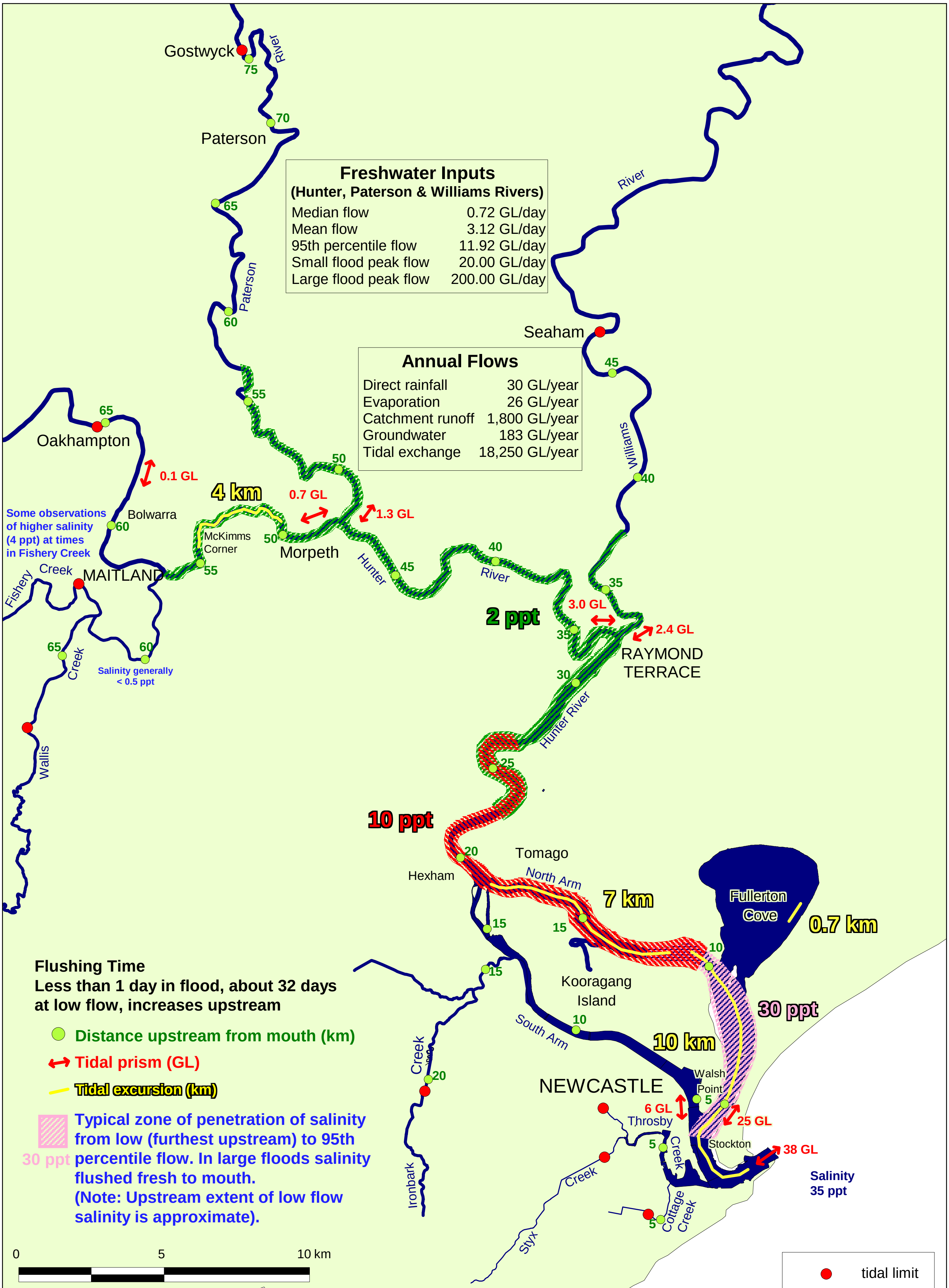

Source: Refer to Appendix A, Table 1

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WATER BALANCE AND SALINITY CONCEPTUAL MODEL

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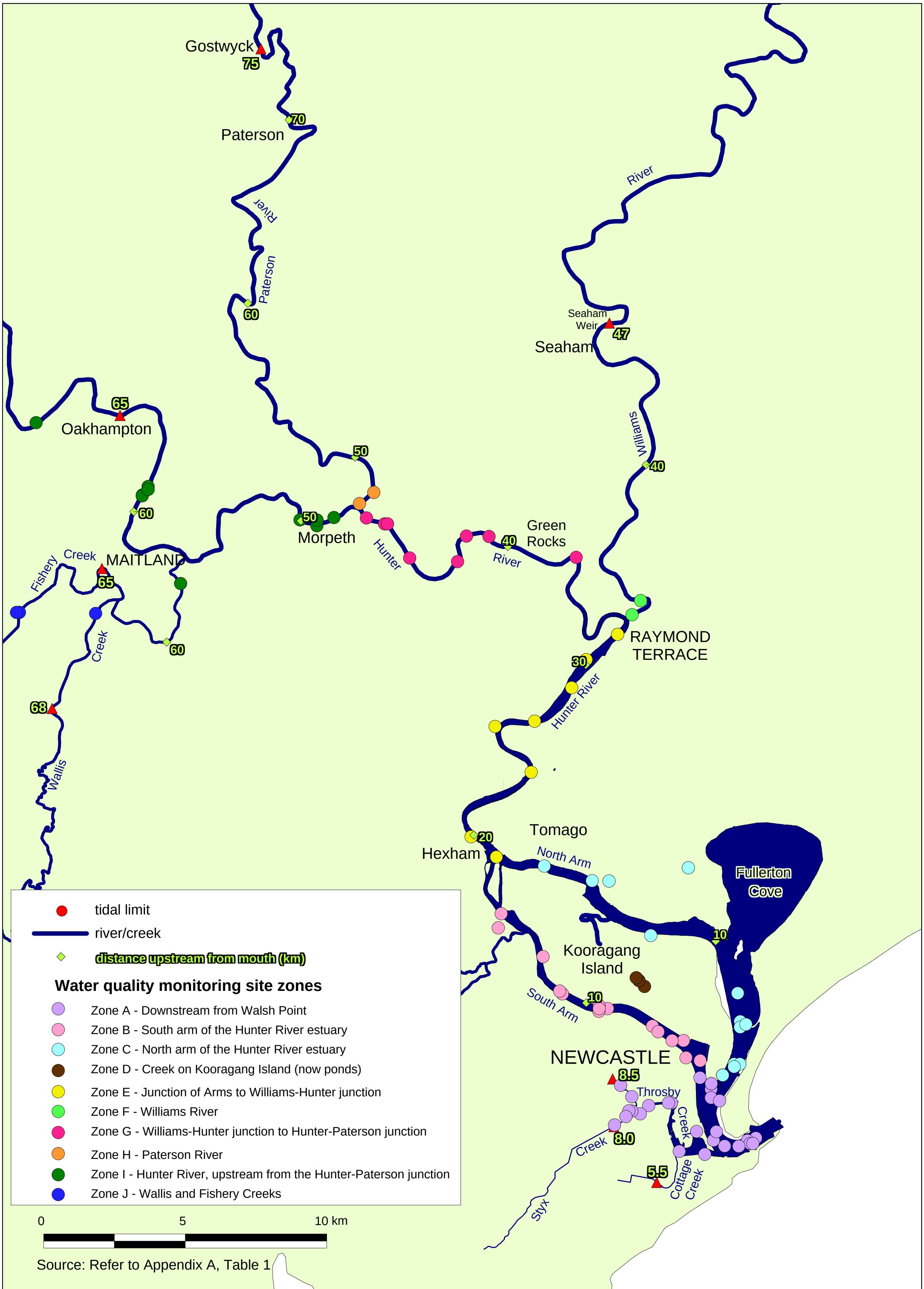
Figure 4.9

DRAWING 4_8.WOR



Source: Refer to Appendix A, Table 1

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WATER QUALITY MONITORING SITES

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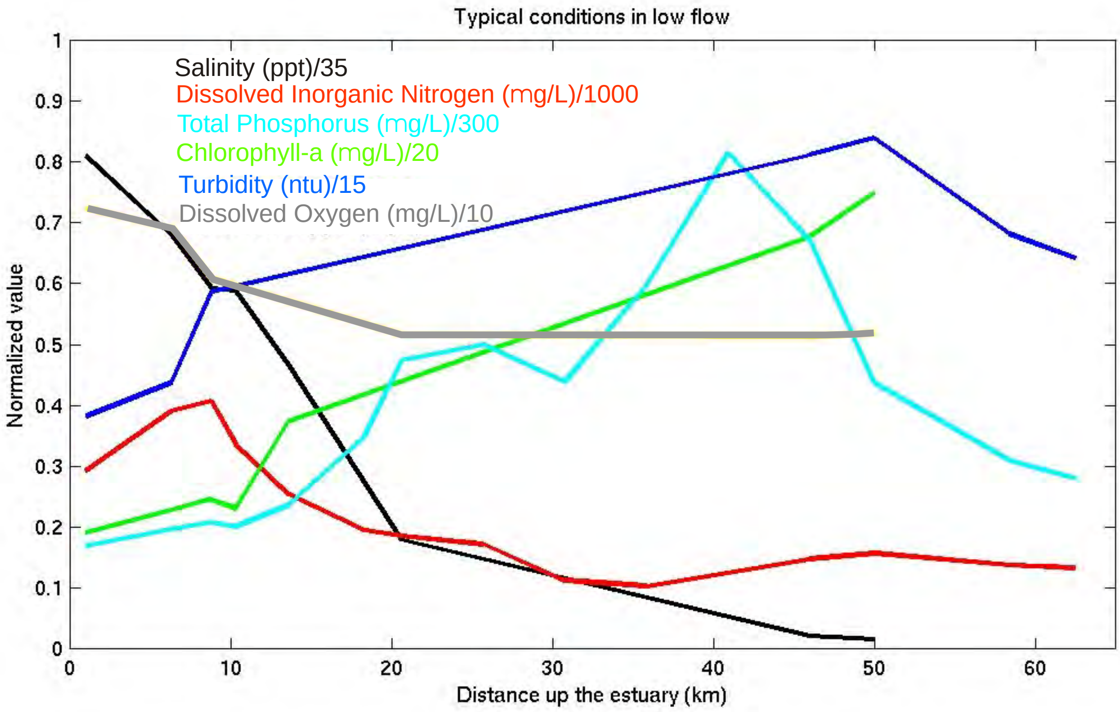
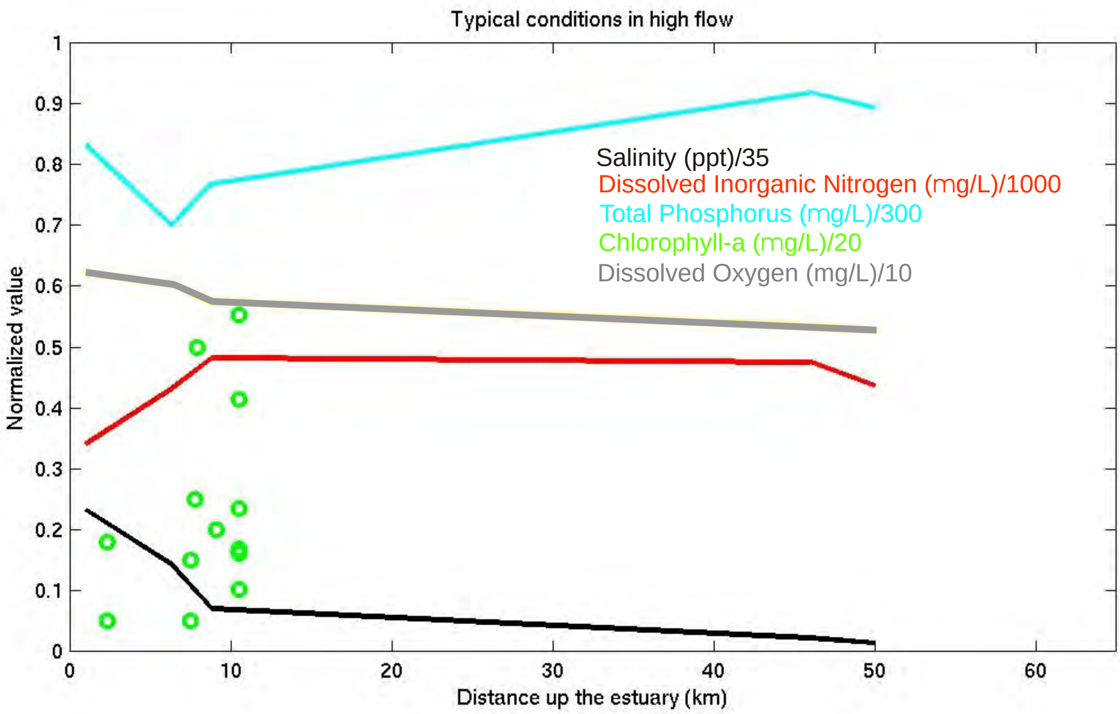
Figure 4.10

DRAWING 4_13.WOR





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NORMALISED VALUES OF WATER QUALITY VARIABLES IN HIGH AND LOW FLOW CONDITIONS

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Figure 4.11

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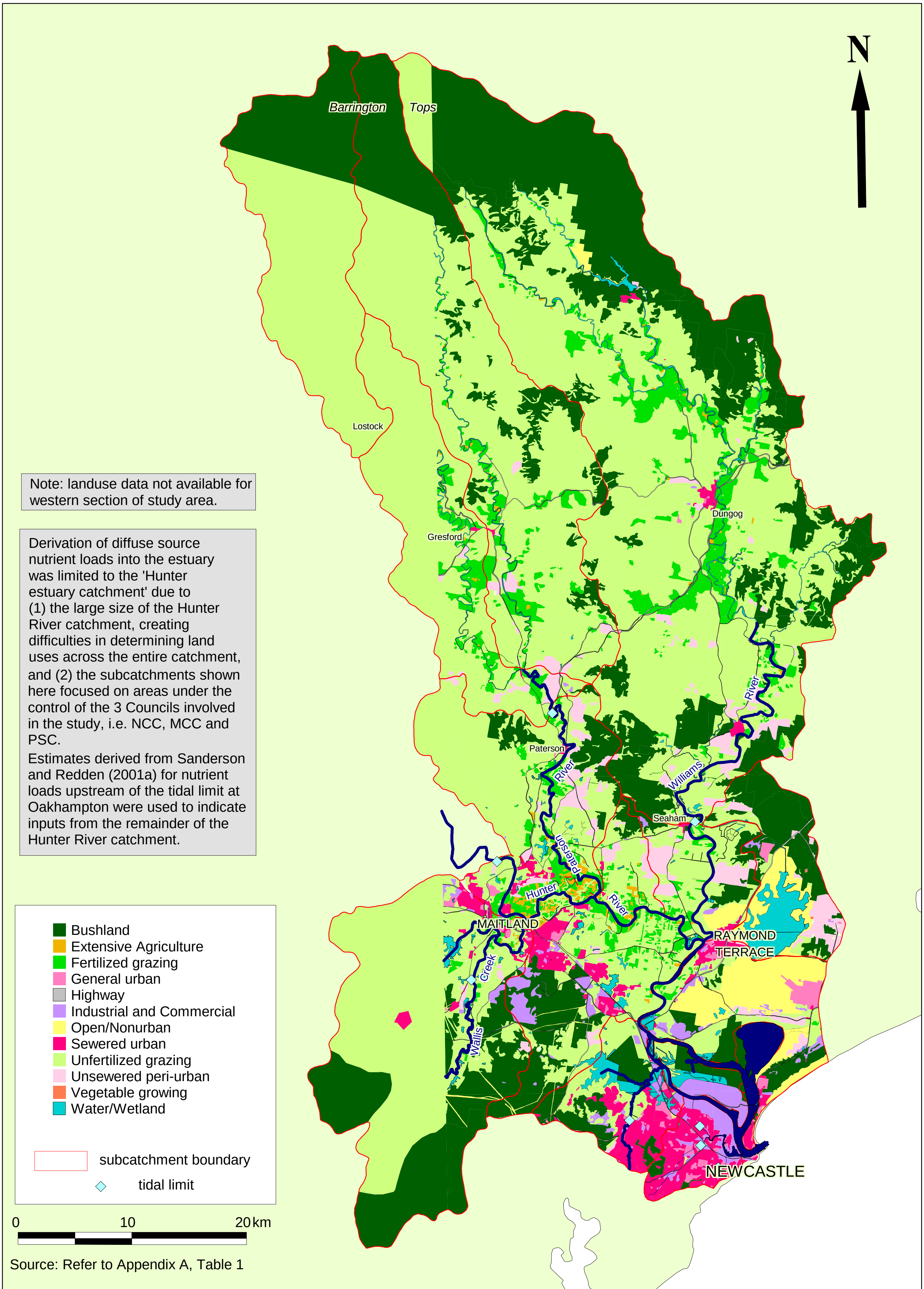

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CMSS LAND USE TYPES APPLIED TO THE HUNTER ESTUARY CATCHMENT

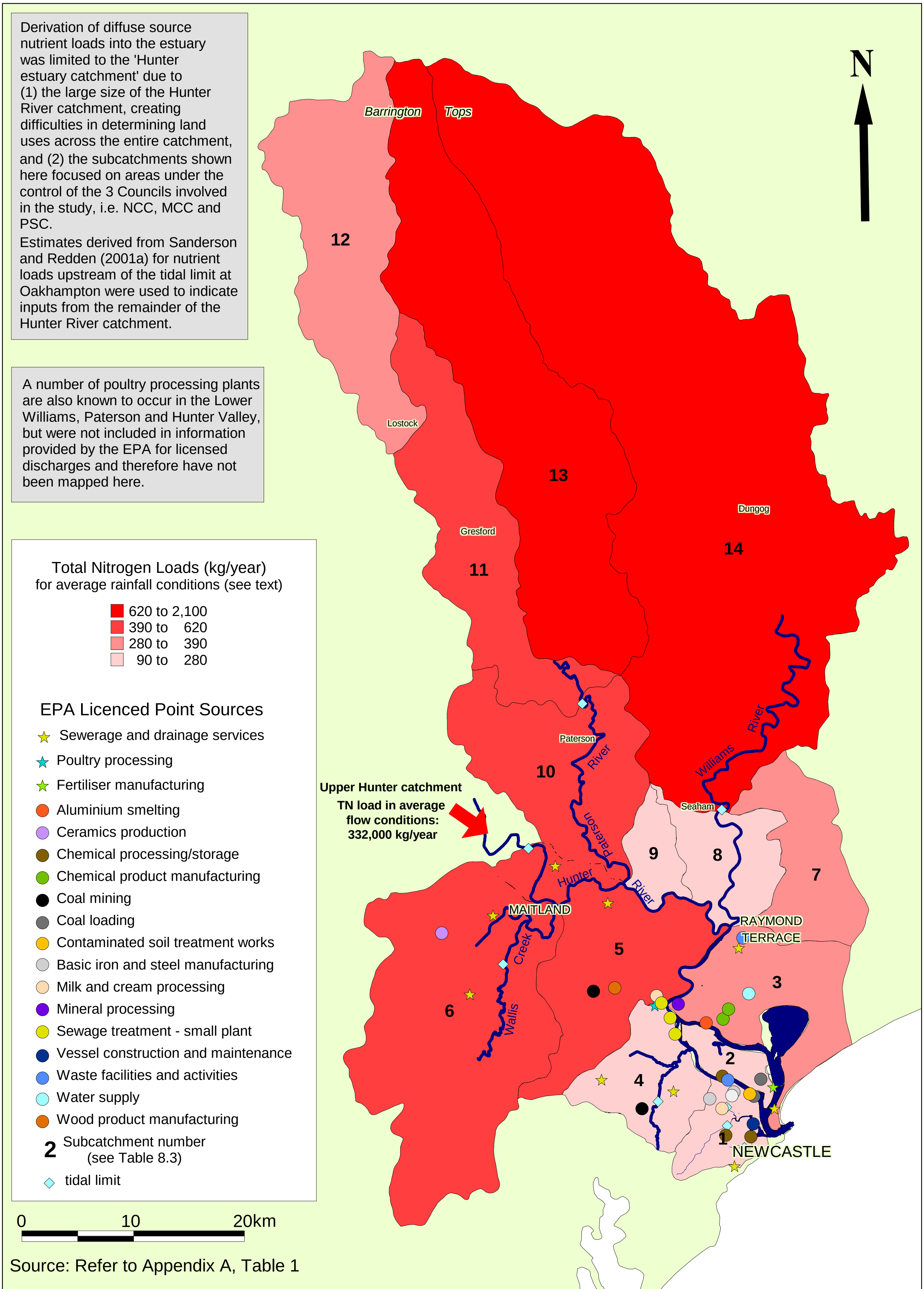
MHL Report 1095

Figure 4.12

DRAWING 8_7.WOR

Derivation of diffuse source nutrient loads into the estuary was limited to the 'Hunter estuary catchment' due to (1) the large size of the Hunter River catchment, creating difficulties in determining land uses across the entire catchment, and (2) the subcatchments shown here focused on areas under the control of the 3 Councils involved in the study, i.e. NCC, MCC and PSC.
Estimates derived from Sanderson and Redden (2001a) for nutrient loads upstream of the tidal limit at Oakhampton were used to indicate inputs from the remainder of the Hunter River catchment.

A number of poultry processing plants are also known to occur in the Lower Williams, Paterson and Hunter Valley, but were not included in information provided by the EPA for licensed discharges and therefore have not been mapped here.



Source: Refer to Appendix A, Table 1

NSW DEPARTMENT OF PUBLIC WORKS AND SERVICES
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SUB CATCHMENT TOTAL NITROGEN LOADS AND EPA LICENCED POINT SOURCES

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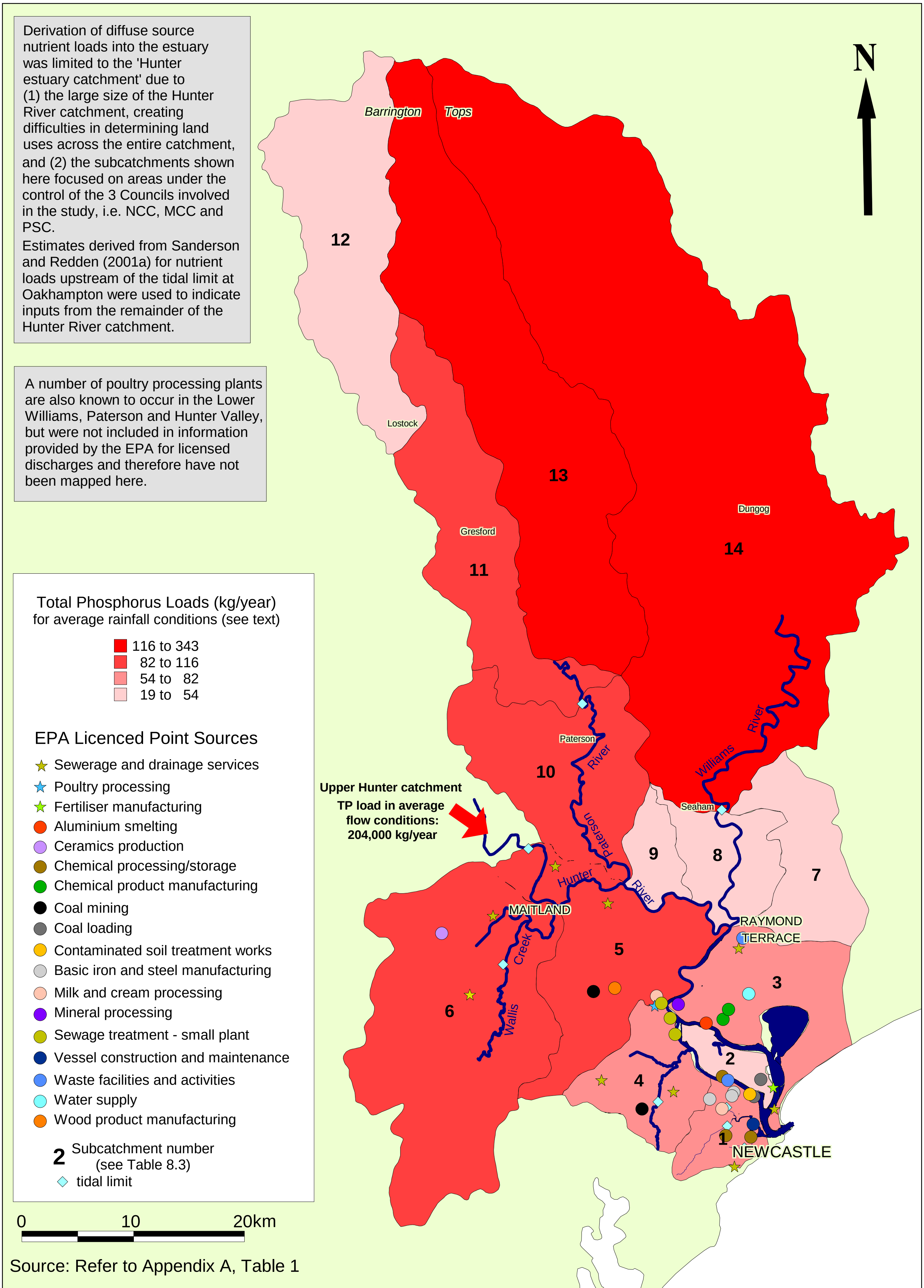
Figure 4.13

DRAWING 8_8.WOR



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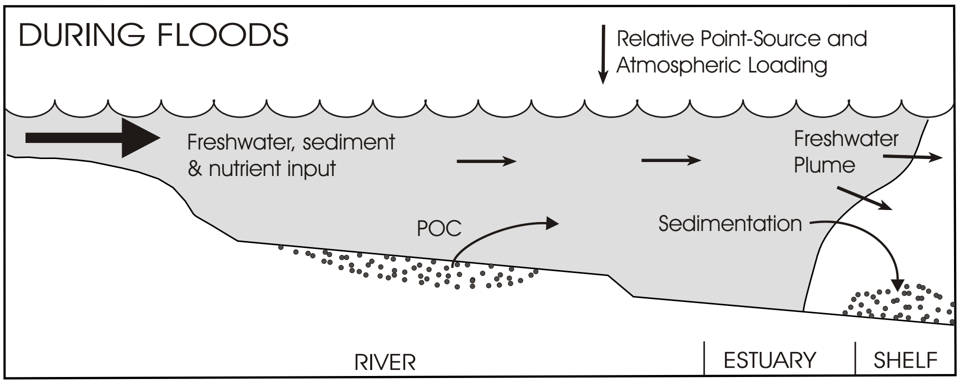
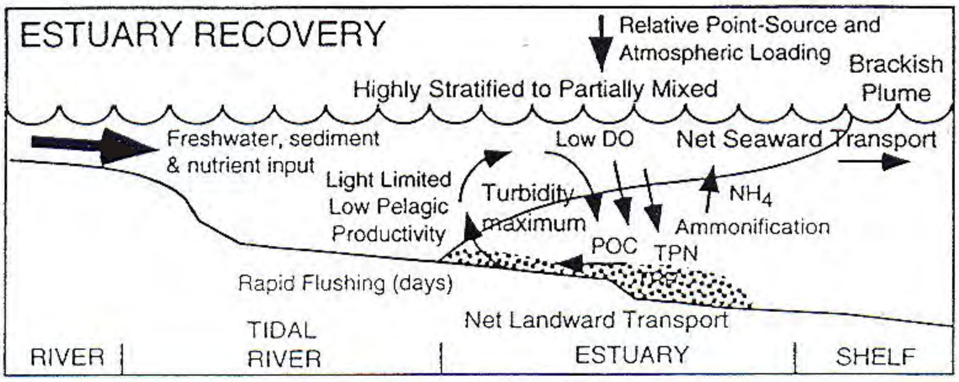
SUB CATCHMENT TOTAL PHOSPHORUS LOADS AND EPA LICENCED POINT SOURCES

MHL Report 1095
Figure 4.14
DRAWING 8_9.WOR

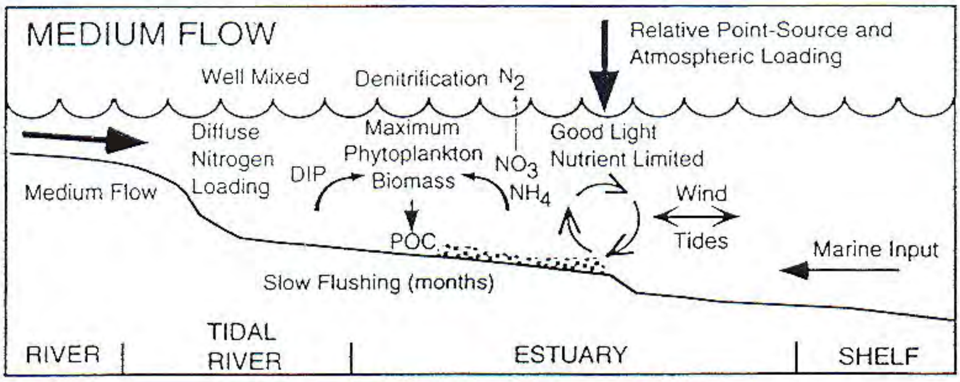
Stage 1



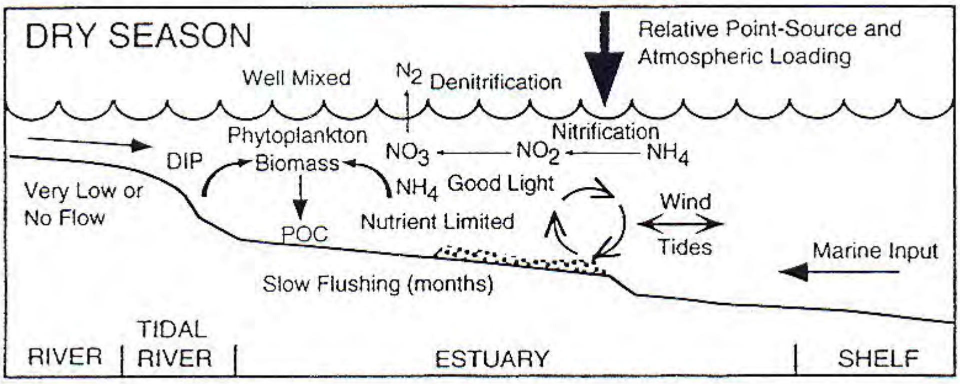
Stage 2



Stage 3



Stage 4



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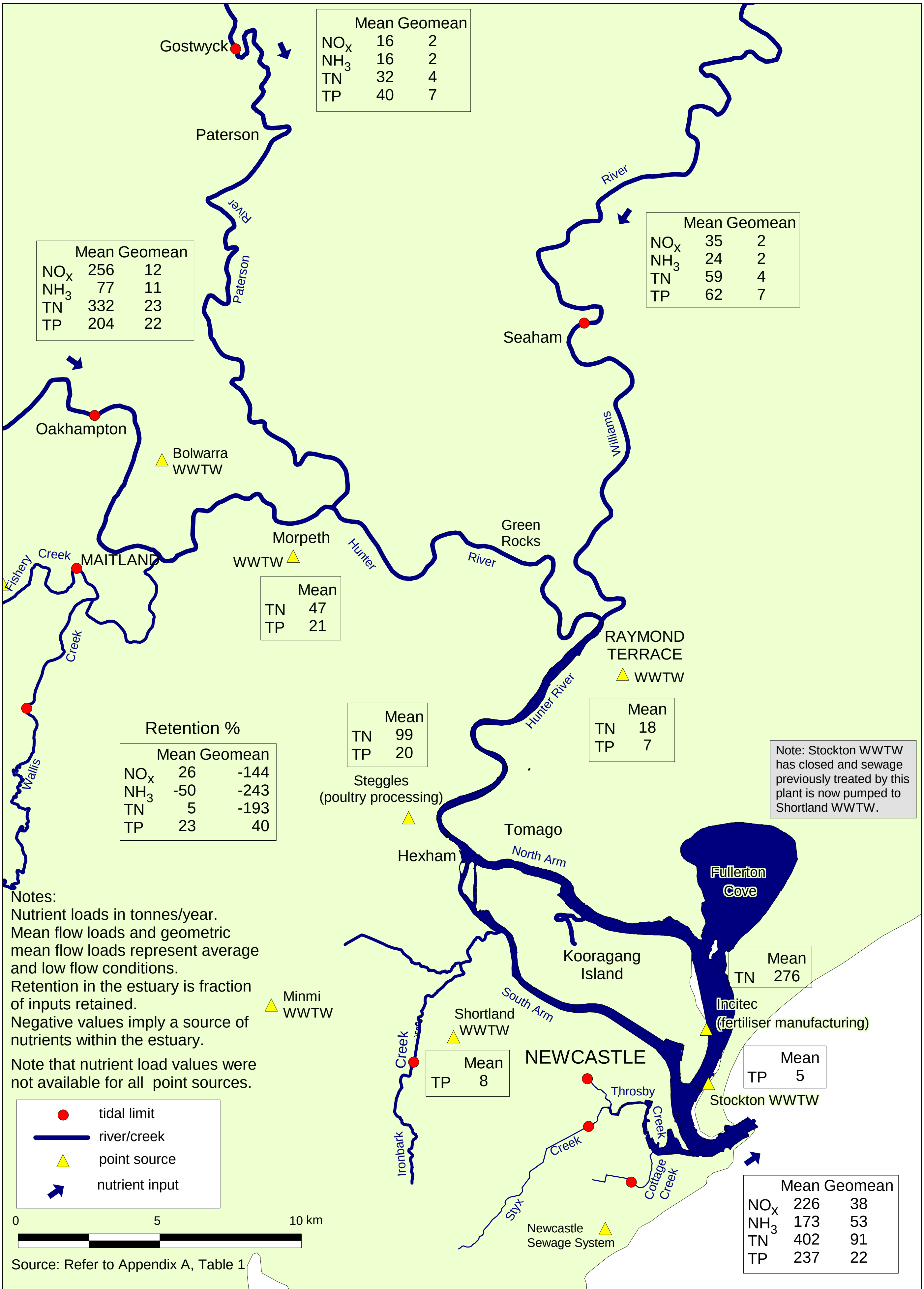
WATER QUALITY AND FLUSHING CONCEPTUAL MODEL

MHL Report 1095

Figure 4.15

DRAWING 1095-04-15.CDR



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ANNUAL NUTRIENT BUDGET FOR THE HUNTER ESTUARY

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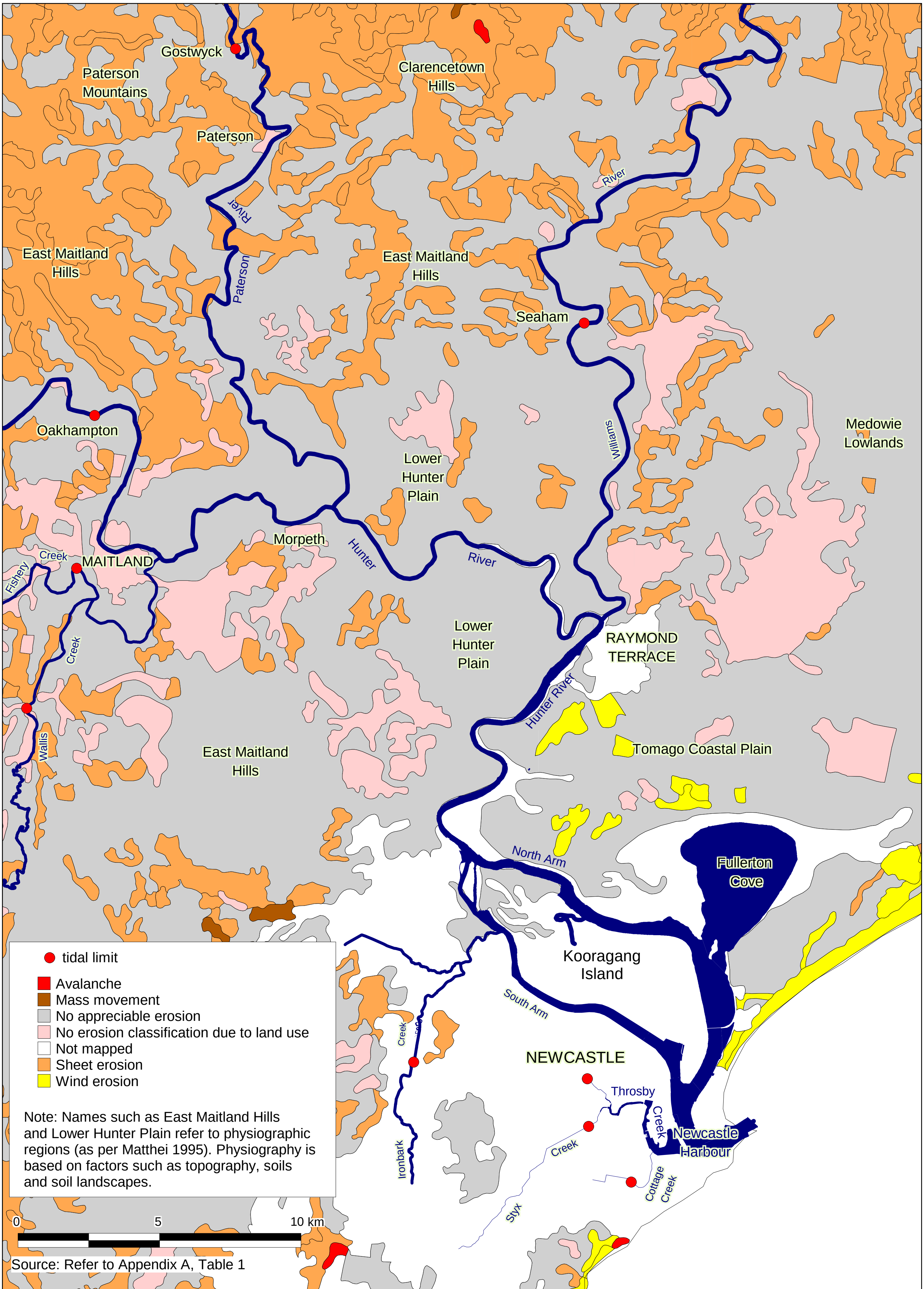
Figure 4.16

DRAWING 4_16.WOR



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HUNTER ESTUARY SOIL EROSION

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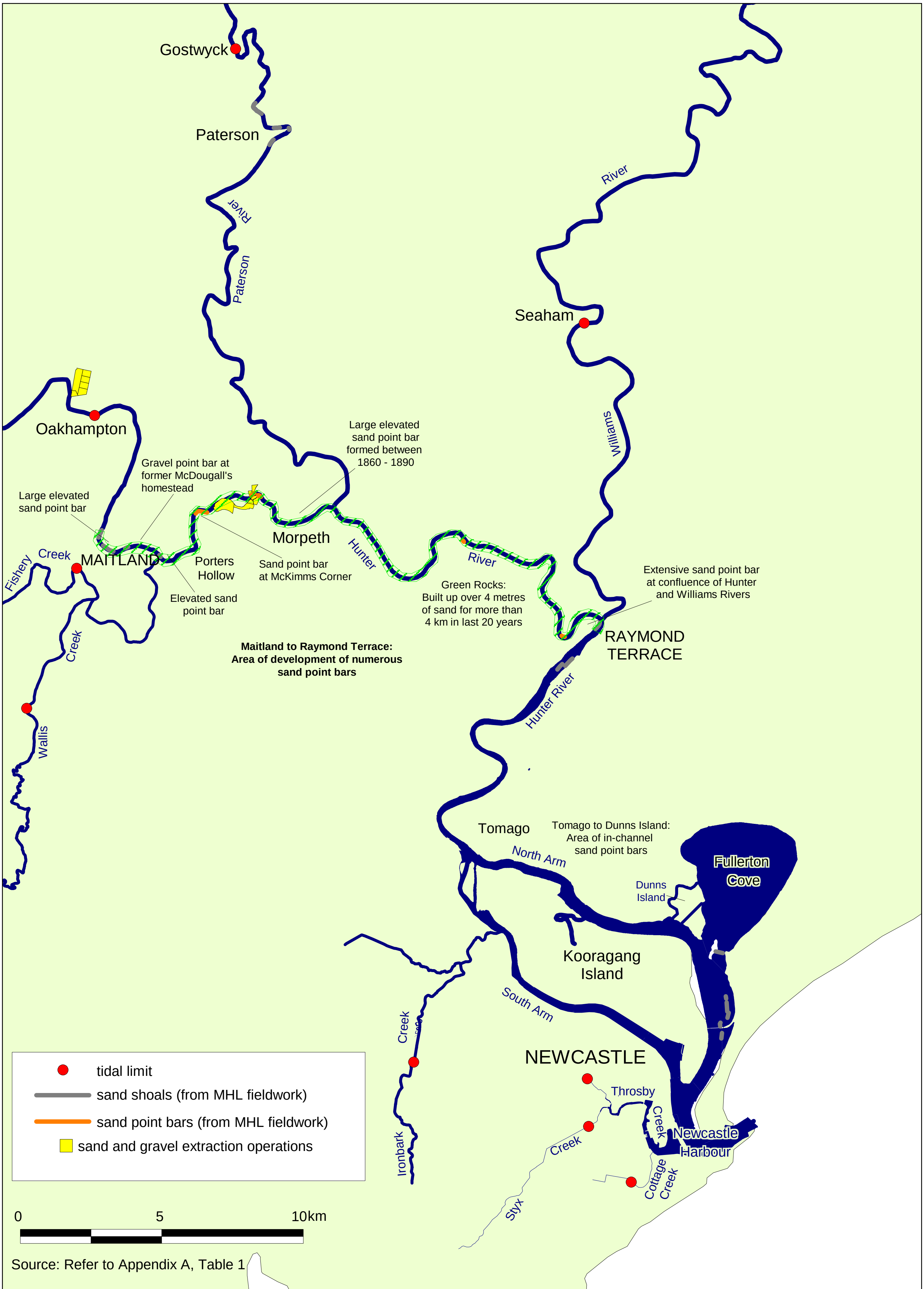
Figure 4.17

DRAWING 10_5.WOR



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SAND POINT BARS AND SAND SHOALS IN THE HUNTER ESTUARY

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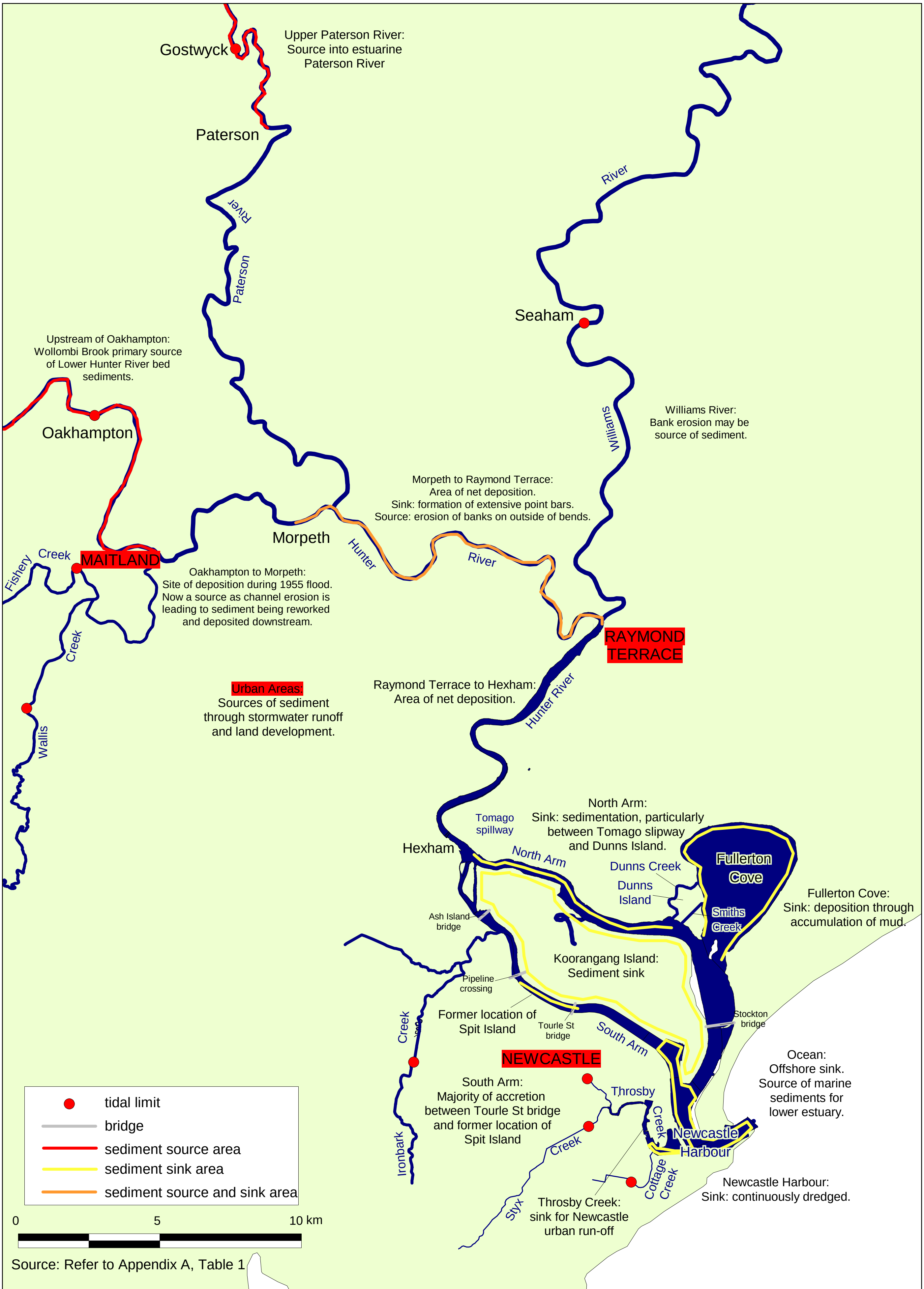
Figure 4.18

DRAWING 10_8.WOR



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SEDIMENT SOURCES AND SINKS

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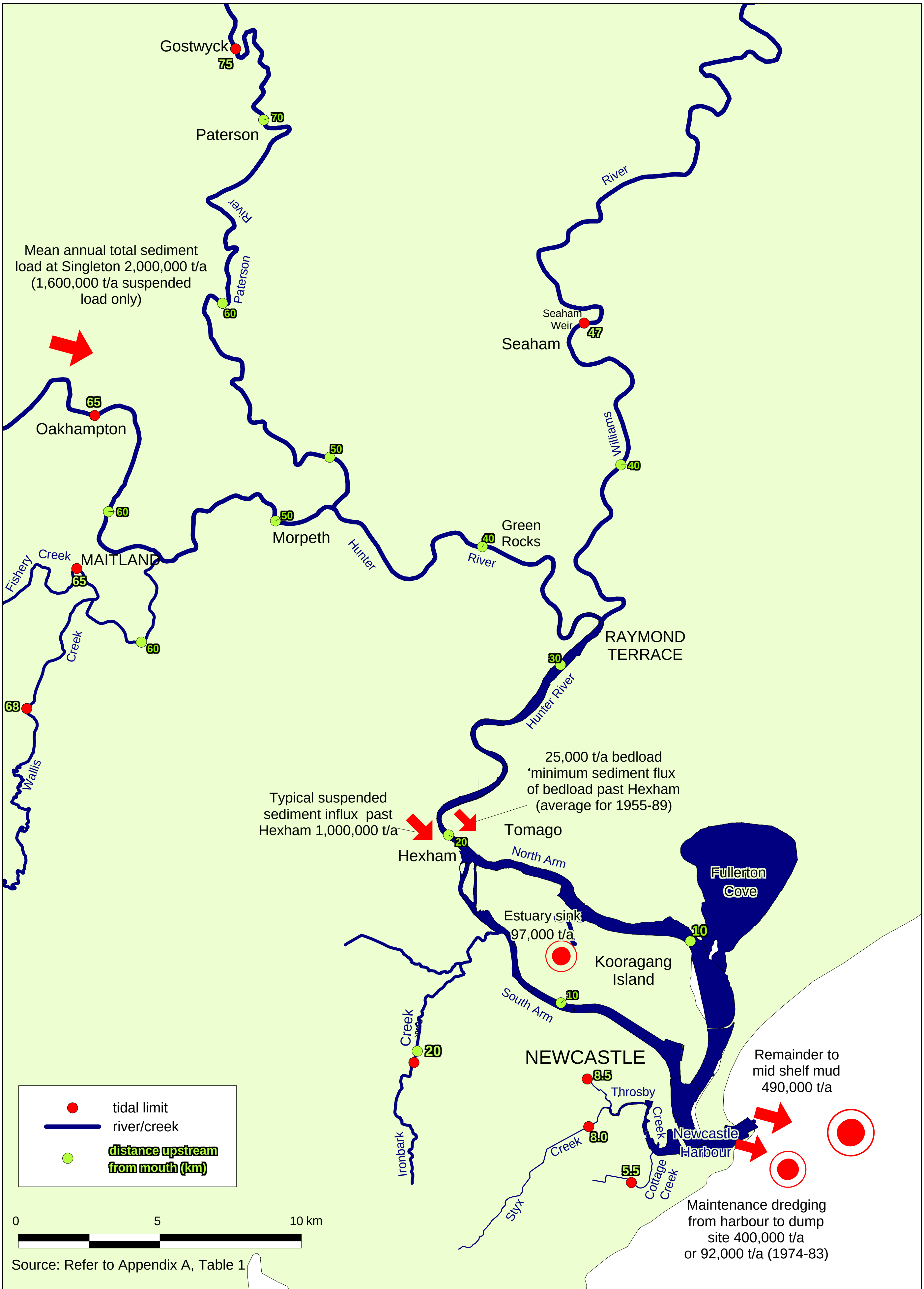
Figure 4.19

DRAWING 10_9.WOR



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SUMMARY OF SEDIMENT BUDGET

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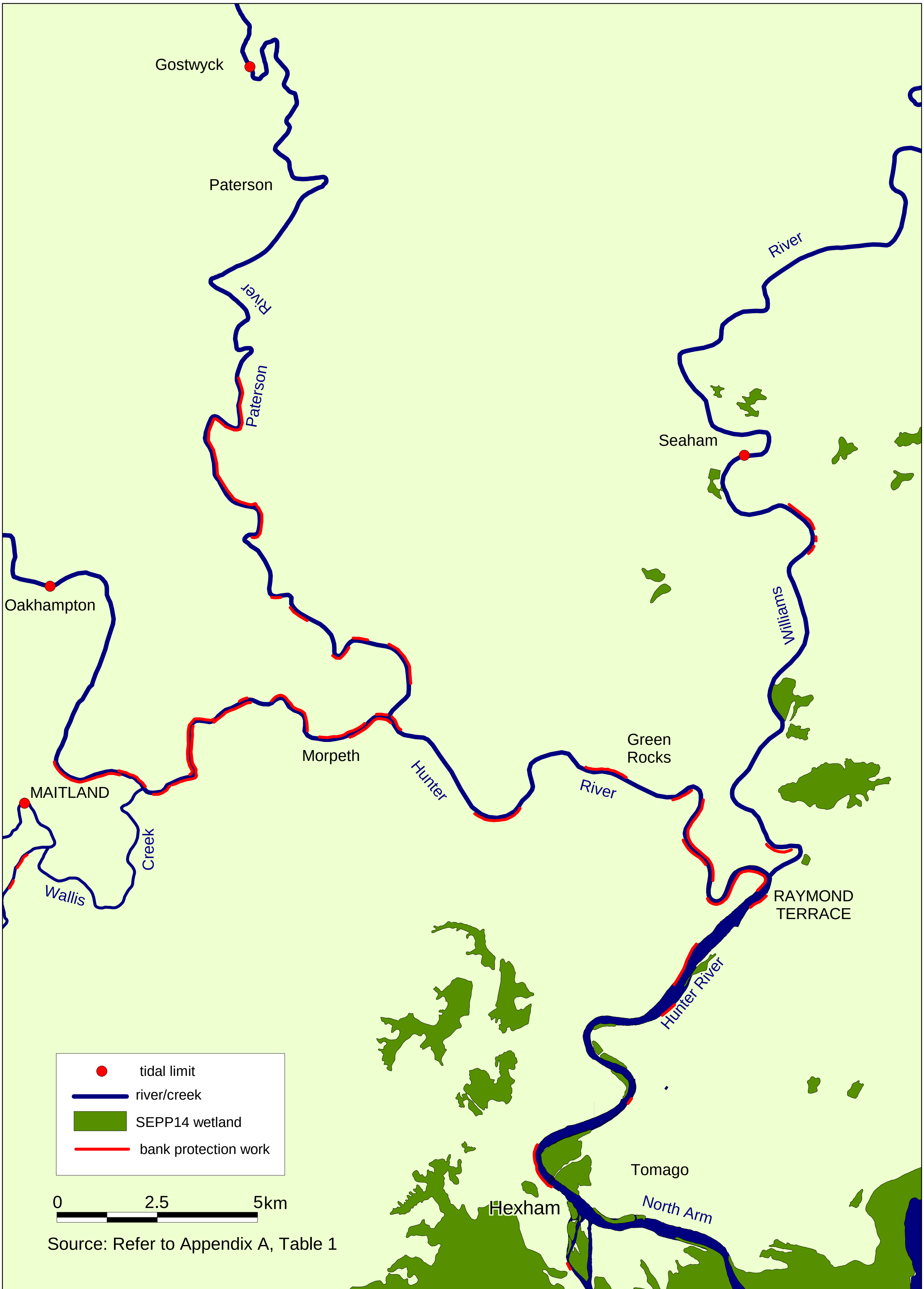
Figure 4.20

DRAWING 4_20.WOR



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BANK PROTECTION WORKS IN THE UPPER HUNTER ESTUARY

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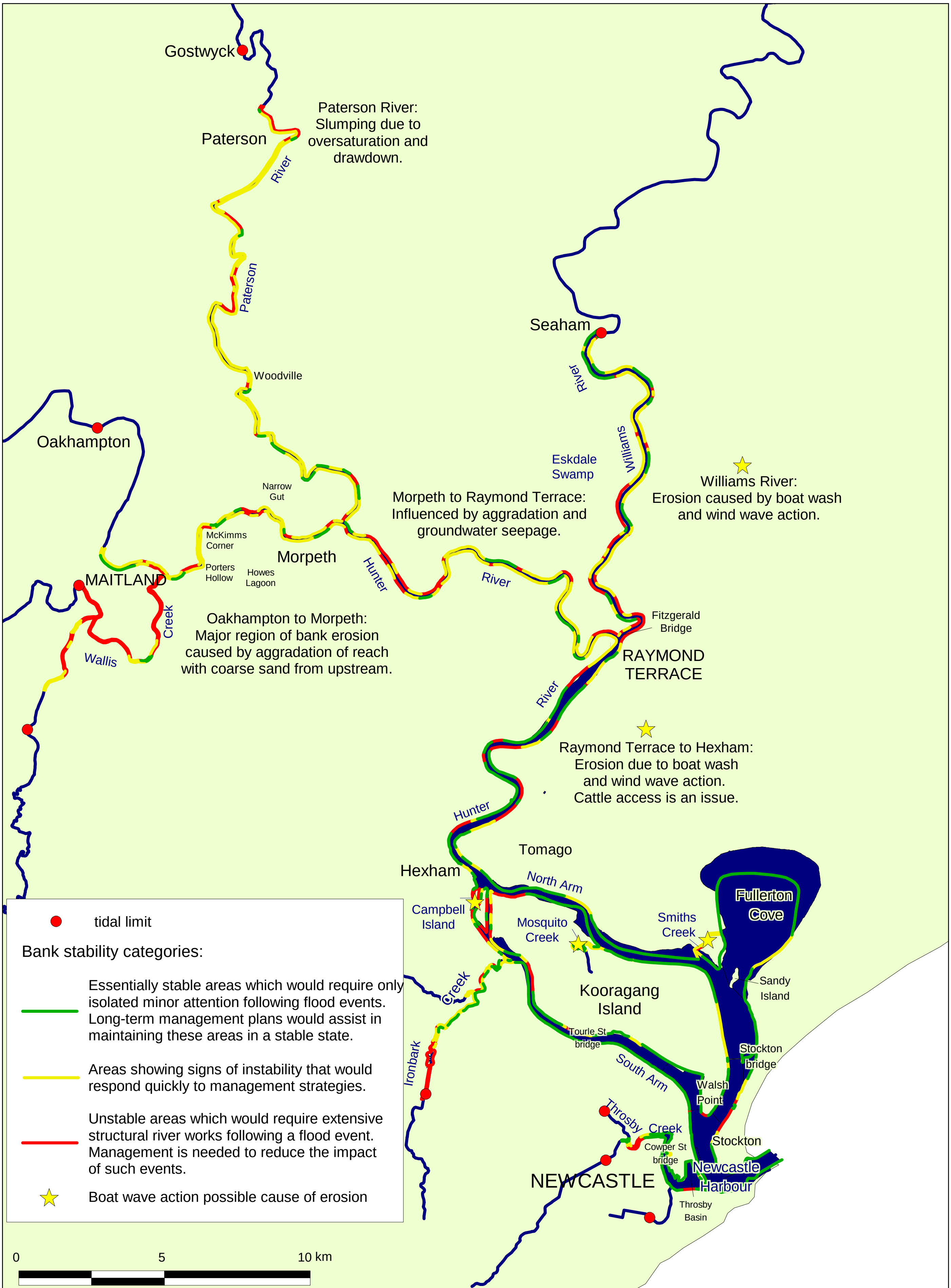
Figure 4.21

DRAWING 11_1B.WOR



Source: Refer to Appendix A, Table 1 (See text for explanation of stability categories)

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MHL BANK STABILITY ASSESSMENT

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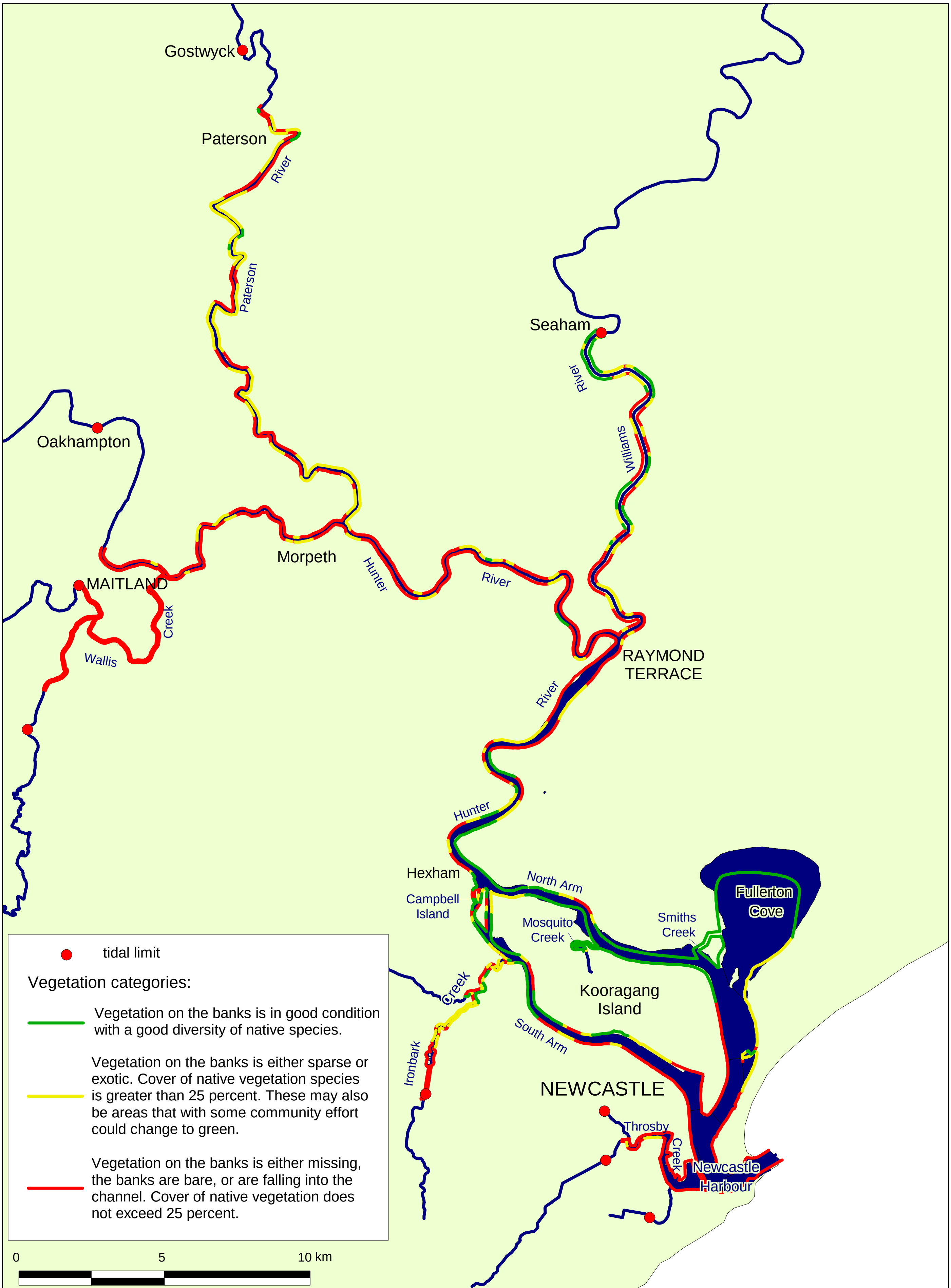
Figure 4.22

DRAWING 11_1.WOR



Source: Refer to Appendix A, Table 1 (See text for explanation of vegetation categories)

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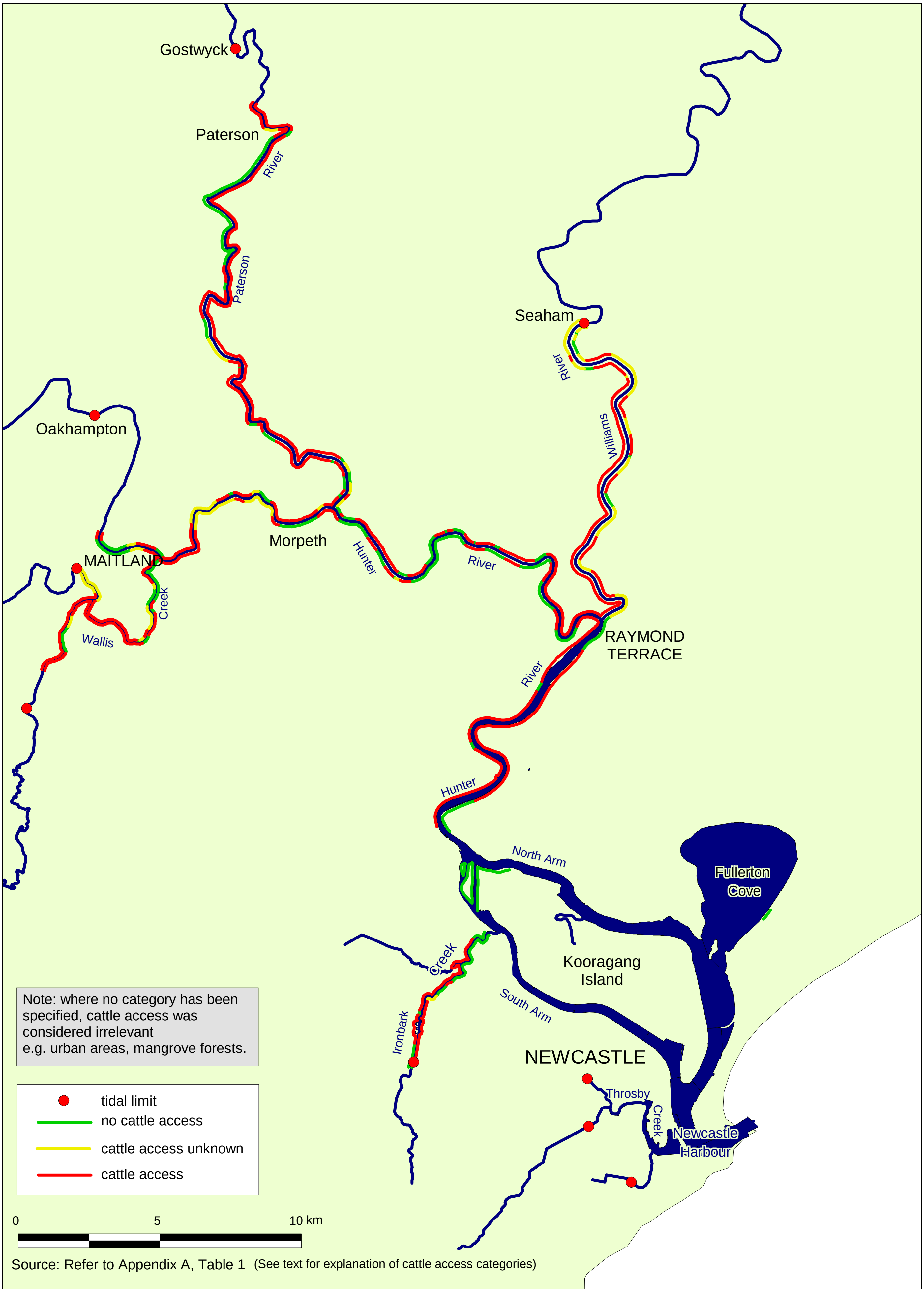
MHL RIPARIAN VEGETATION ASSESSMENT

MHL Report 1095

Figure 4.23

DRAWING 11_3.WOR



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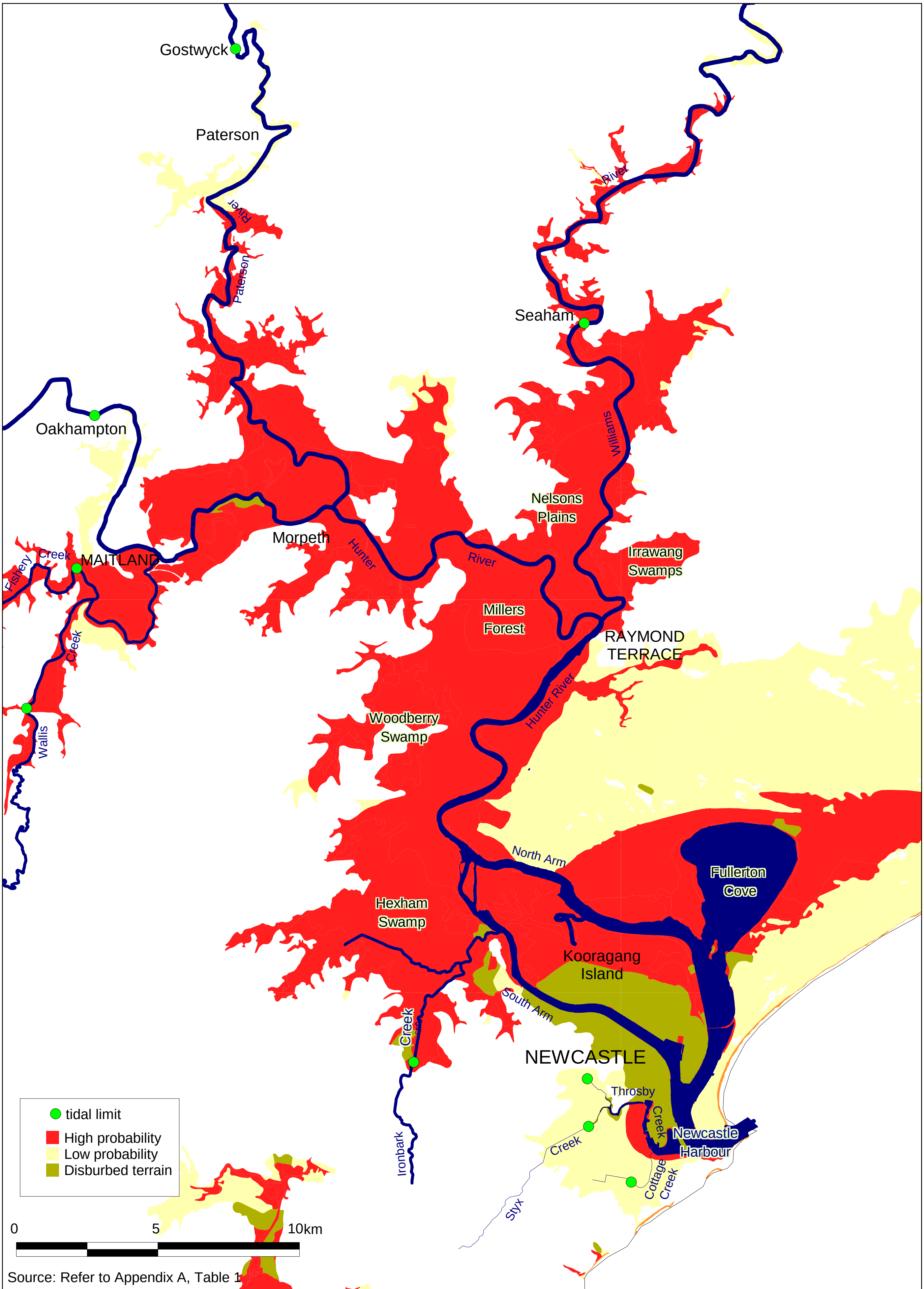
MHL CATTLE ACCESS ASSESSMENT

MHL Report 1095

Figure 4.24

DRAWING 11_4.WOR



Source: Refer to Appendix A, Table 1

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ACID SULFATE SOIL RISK

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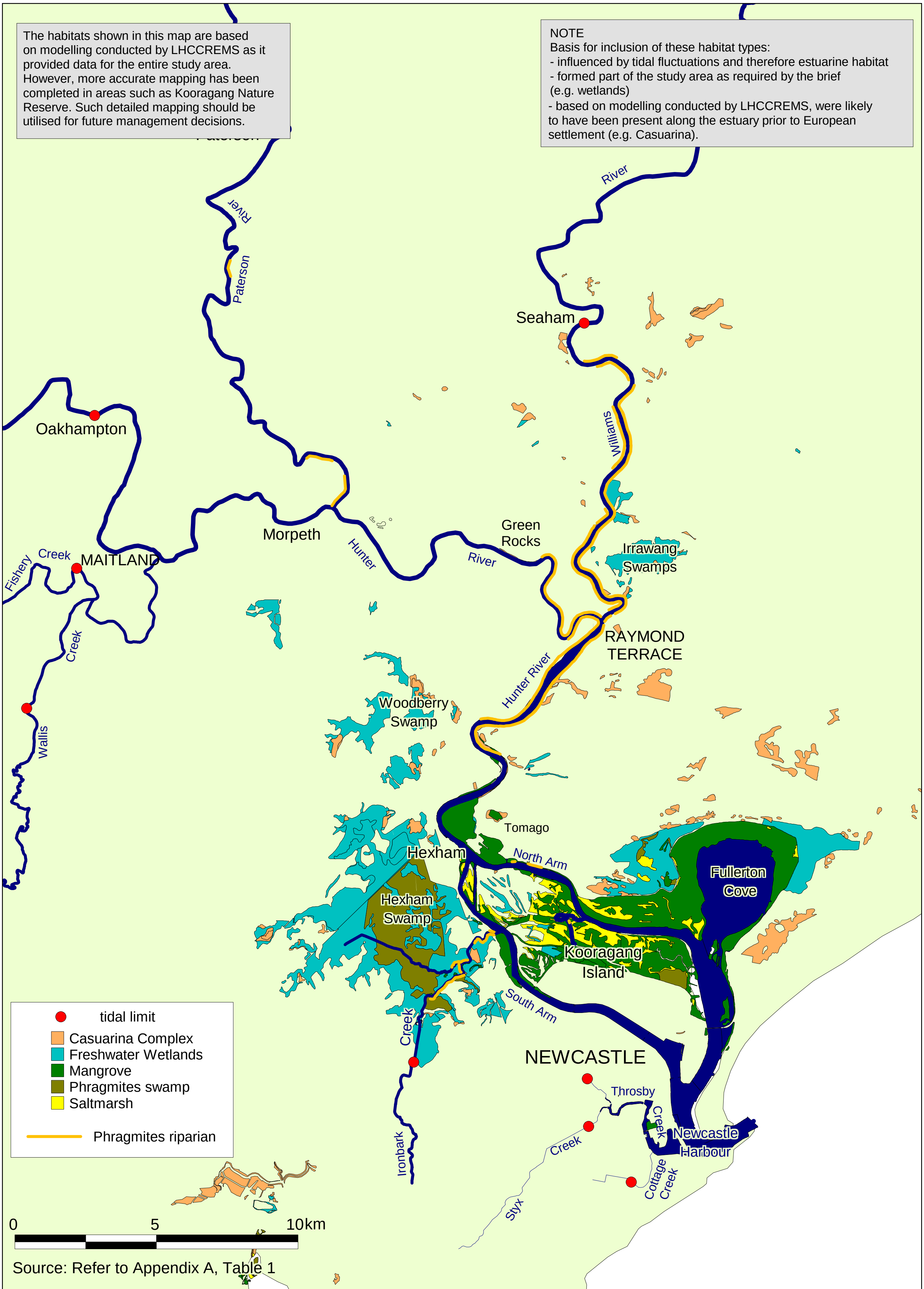
Figure 4.25

DRAWING 3_1.WOR



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SELECTED FLORAL HABITATS IN THE HUNTER ESTUARY AND CATCHMENT

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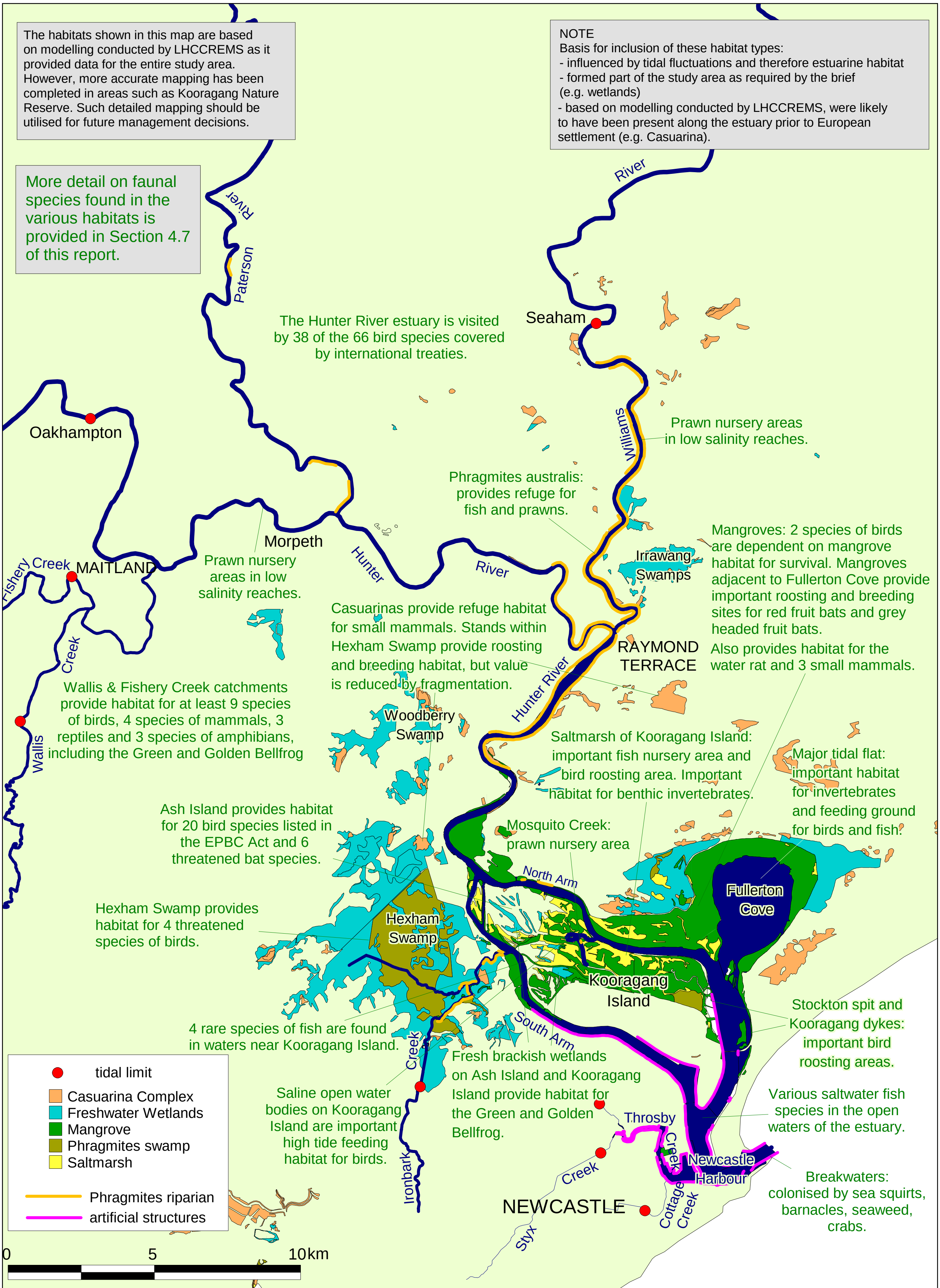
Figure 4.26

DRAWING 4_7a.WOR



Source: Refer to Appendix A, Table 1

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SELECTED NATIVE FAUNAL HABITATS AND COMMUNITIES OF THE HUNTER ESTUARY AND CATCHMENT

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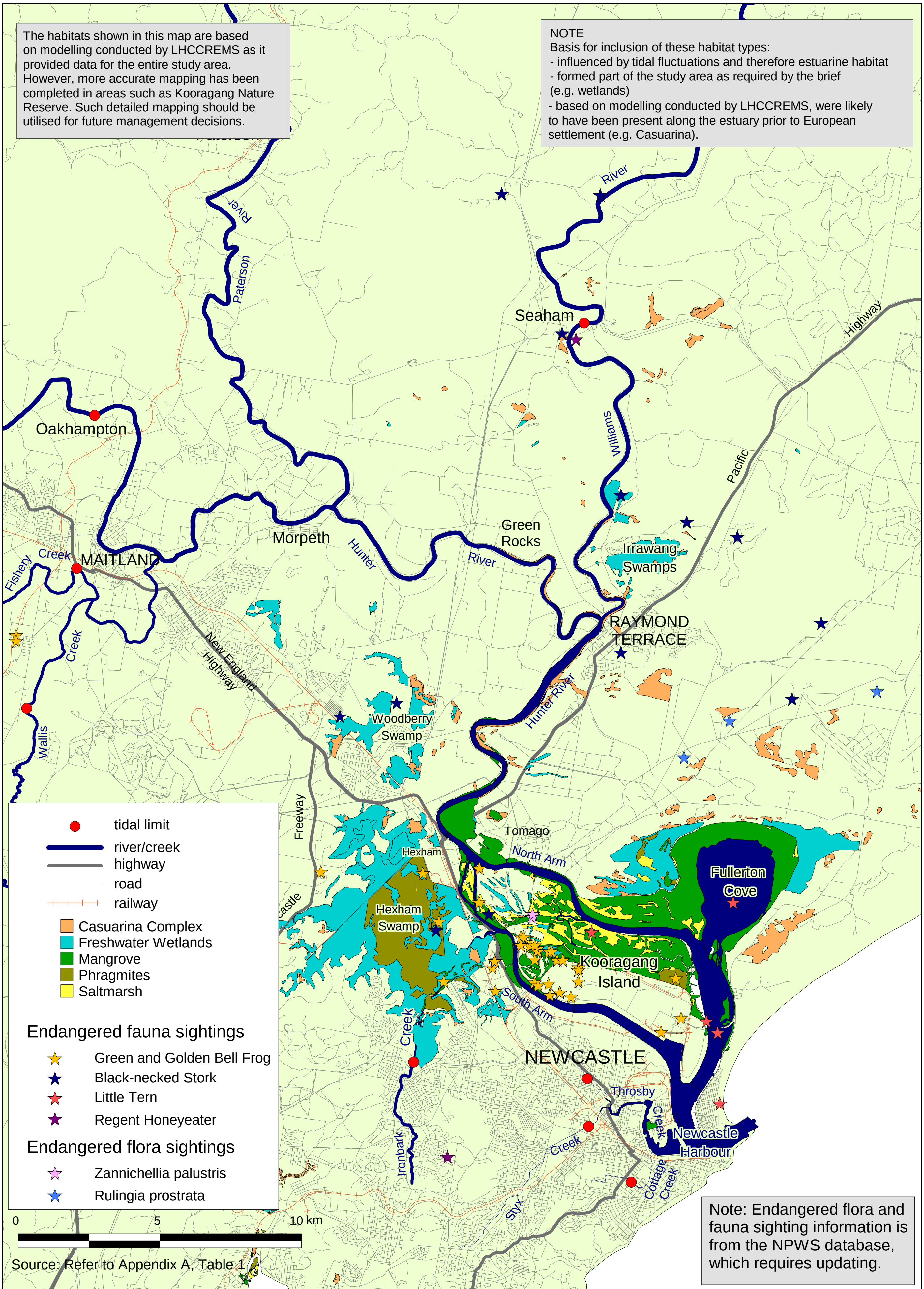
Figure 4.27

DRAWING 4_7b.WOR



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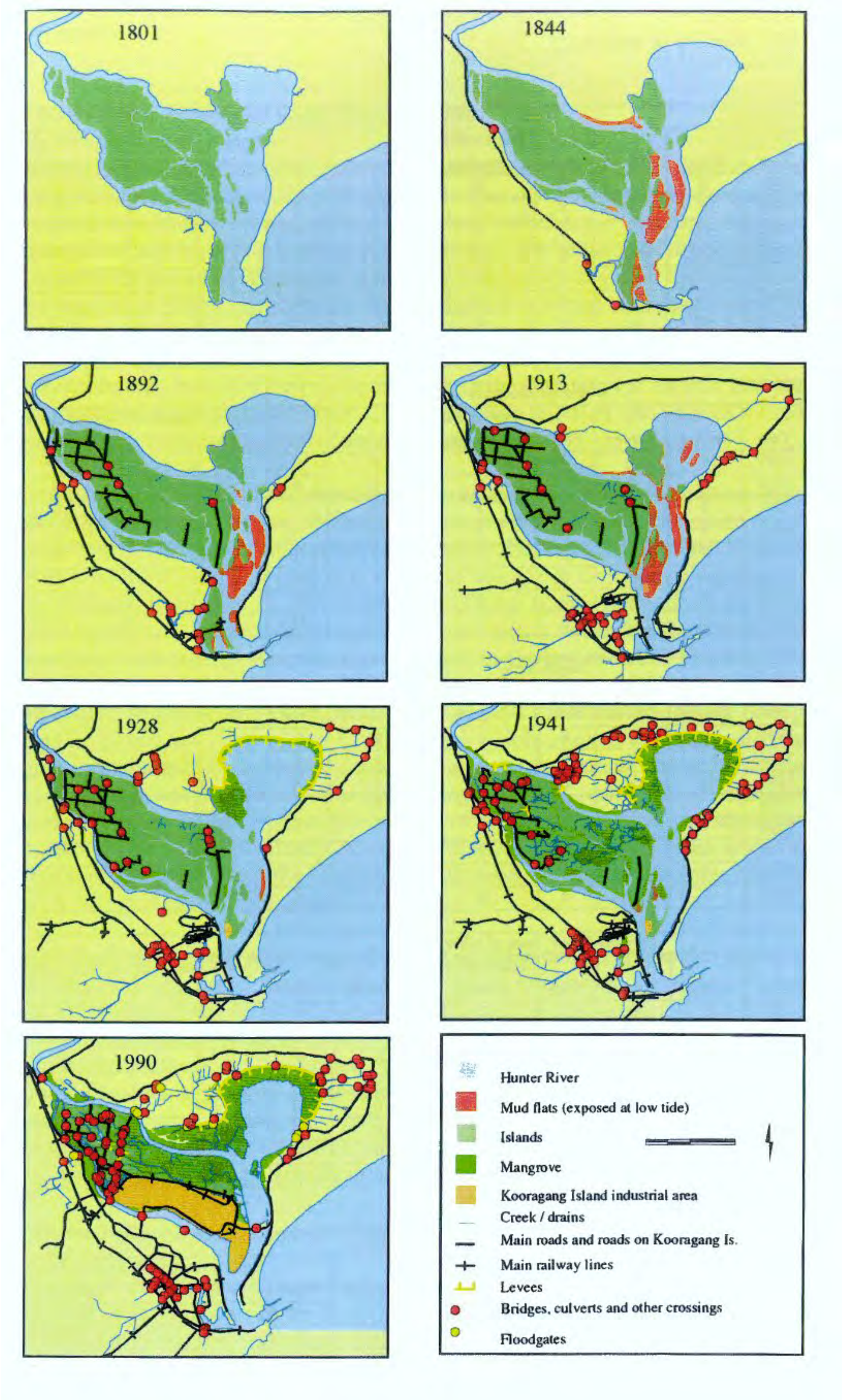
ENDANGERED FLORA AND FAUNA SIGHTINGS IN THE HUNTER ESTUARY AND CATCHMENT

MHL Report 1095

Figure 4.28

DRAWING 4_7c.WOR



Source: Williams et al, 2000

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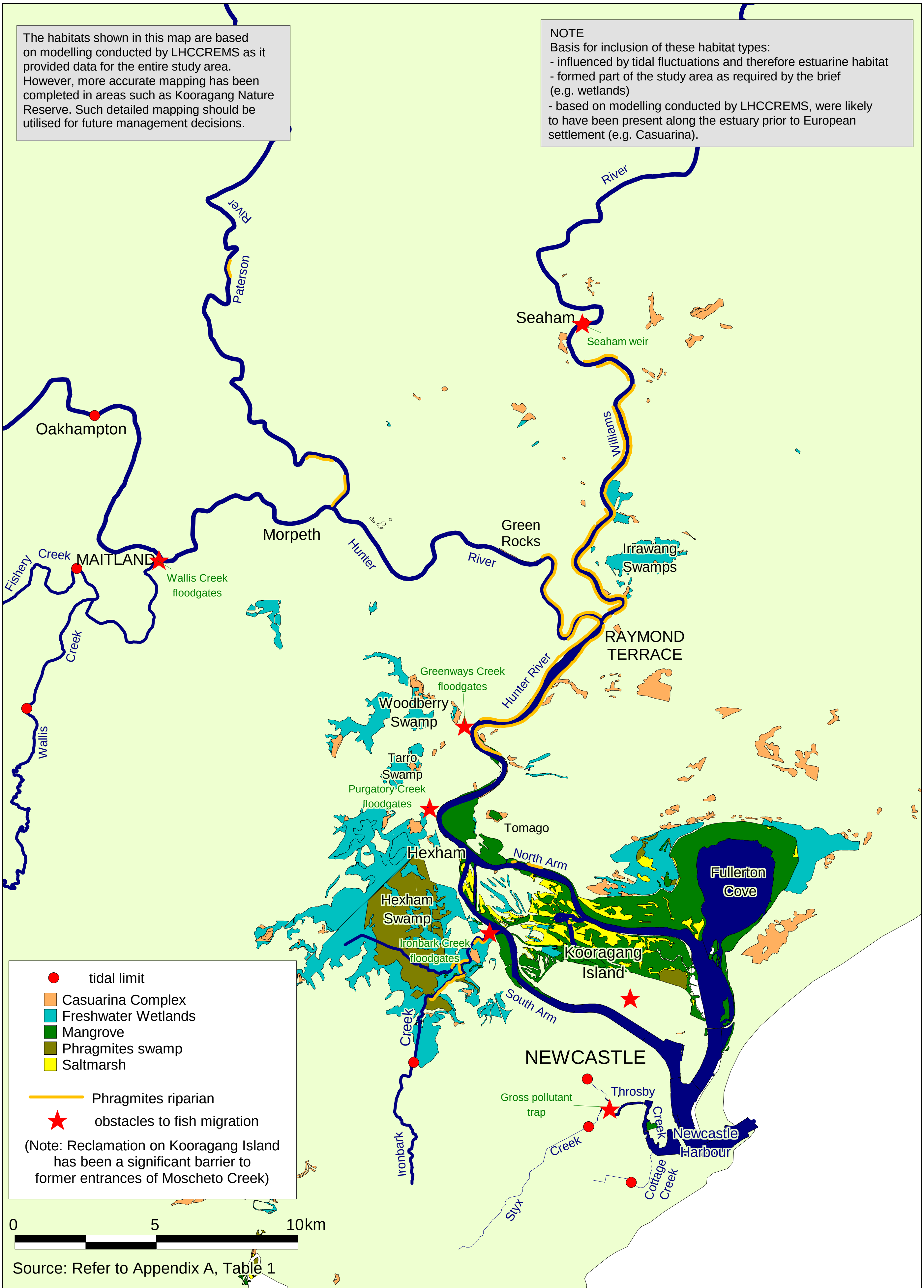
THE EVOLUTION OF STRUCTURES RESTRICTING TIDAL FLOW WITHIN THE HUNTER RIVER DELTAIC ISLANDS AND SUBSEQUENTLY, KOORAGANG ISLAND

MHL Report 1095

Figure 4.29

DRAWING 1095-04-29.CDR



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OBSTACLES TO FISH MIGRATION IN THE HUNTER ESTUARY

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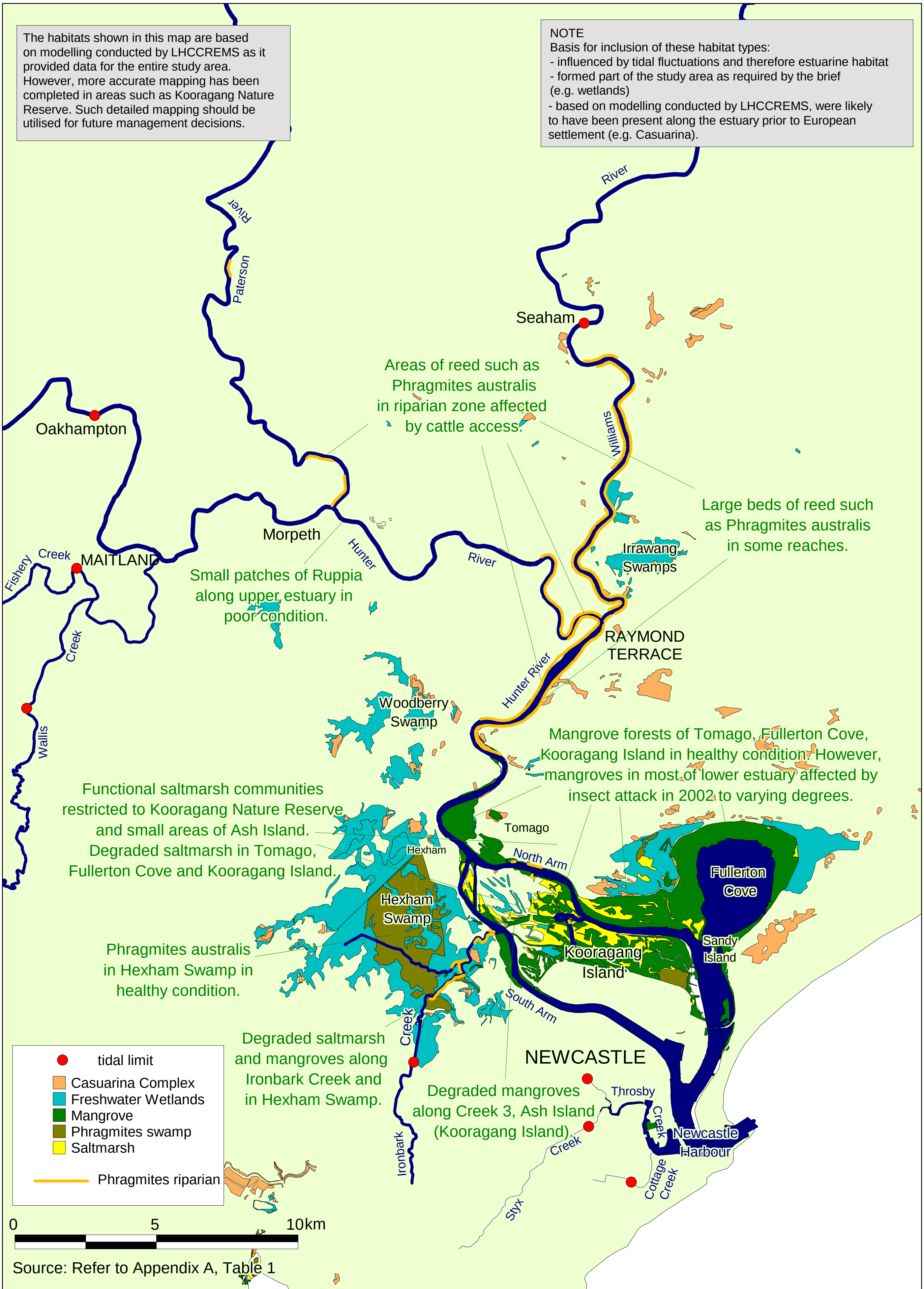
Figure 4.30

DRAWING 4_7f.WOR



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CONDITION OF SALTMARSH, MANGROVES AND MACROPHYTES

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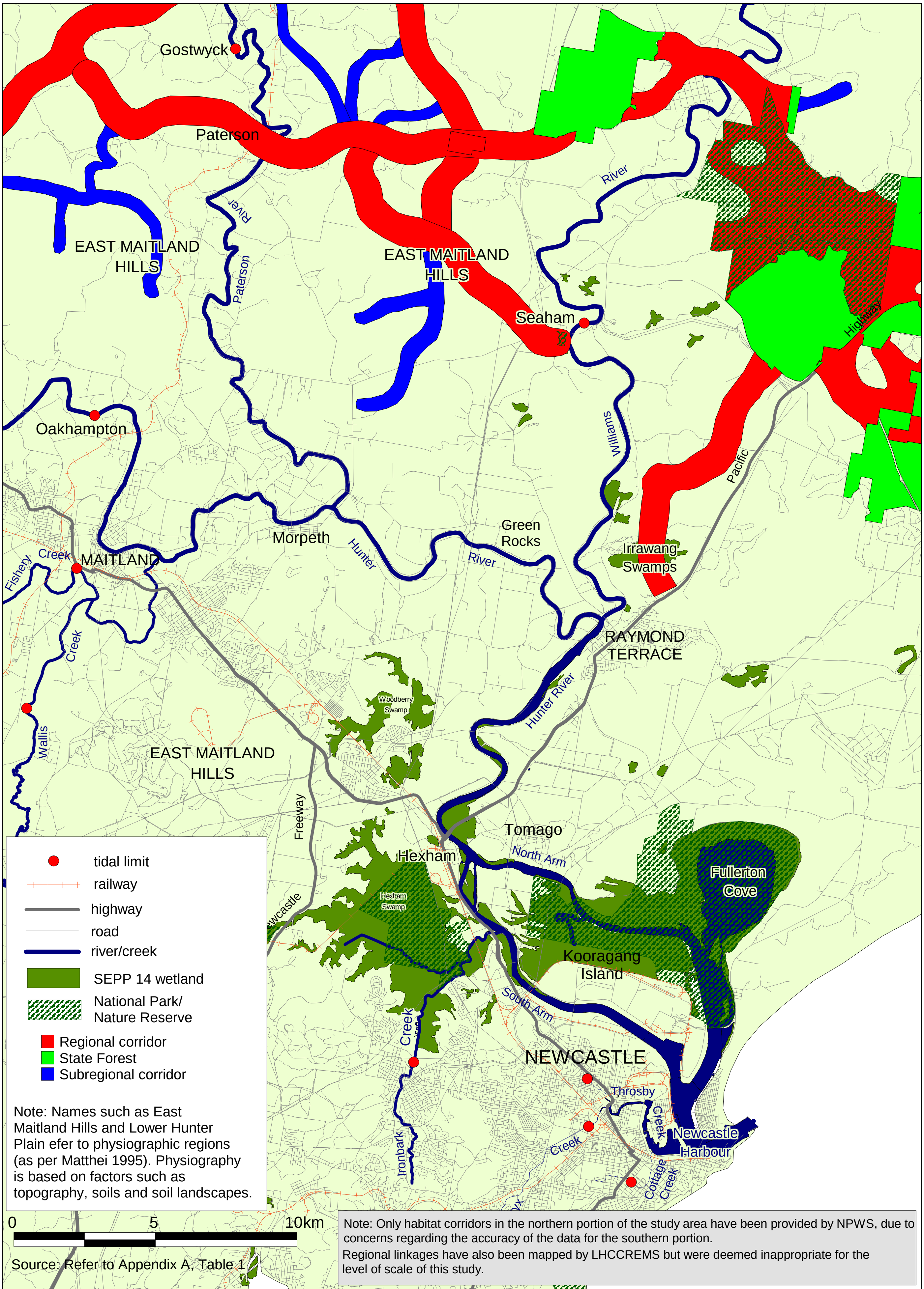
Figure 4.31

DRAWING 4_29.WOR



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PRELIMINARY REGIONAL HABITAT CORRIDORS IN THE HUNTER ESTUARY CATCHMENT

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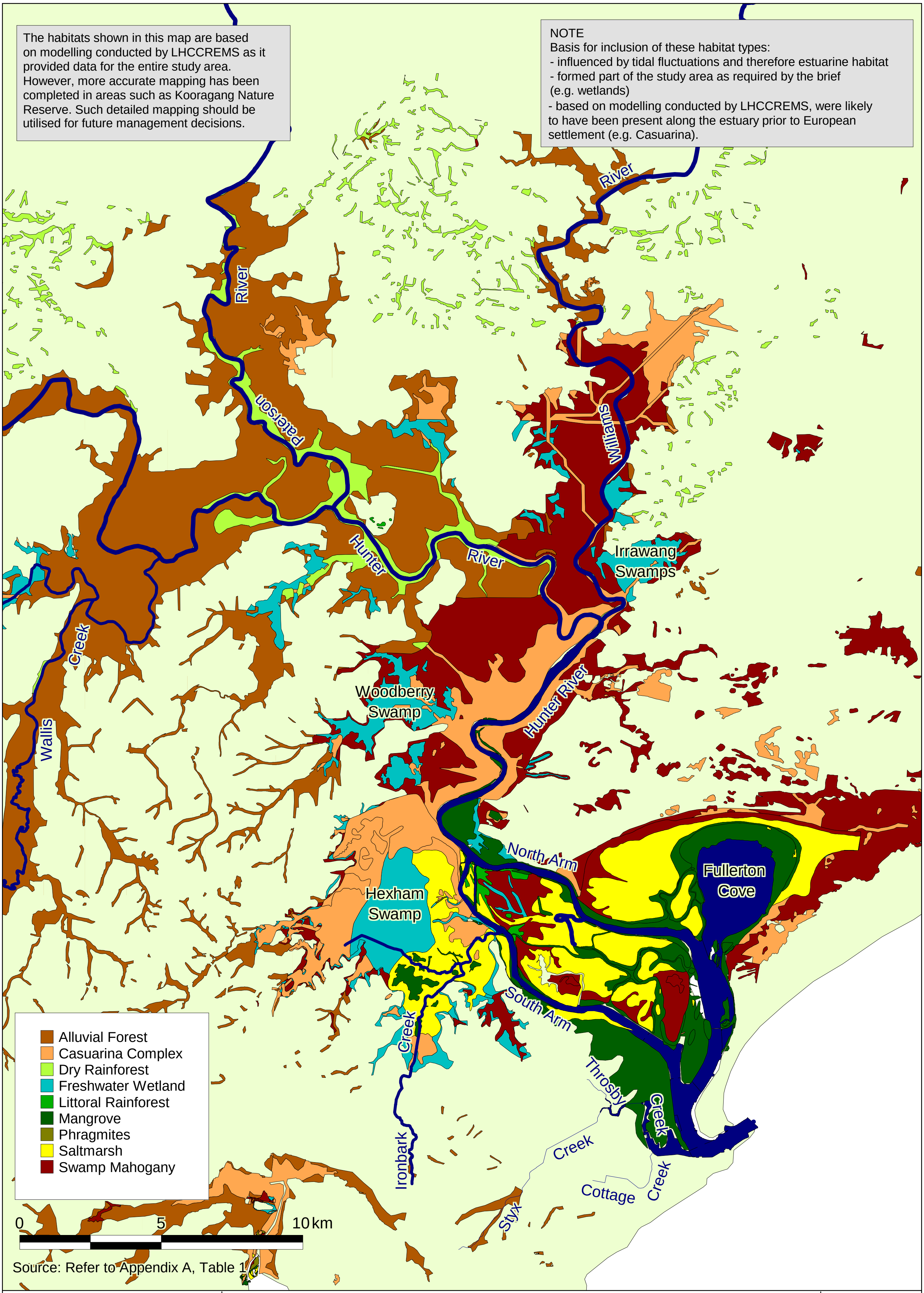
Figure 4.32

DRAWING 4_7d.WOR



Source: Refer to Appendix A, Table 1

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ESTUARINE HABITAT DIVERSITY PRE-1750

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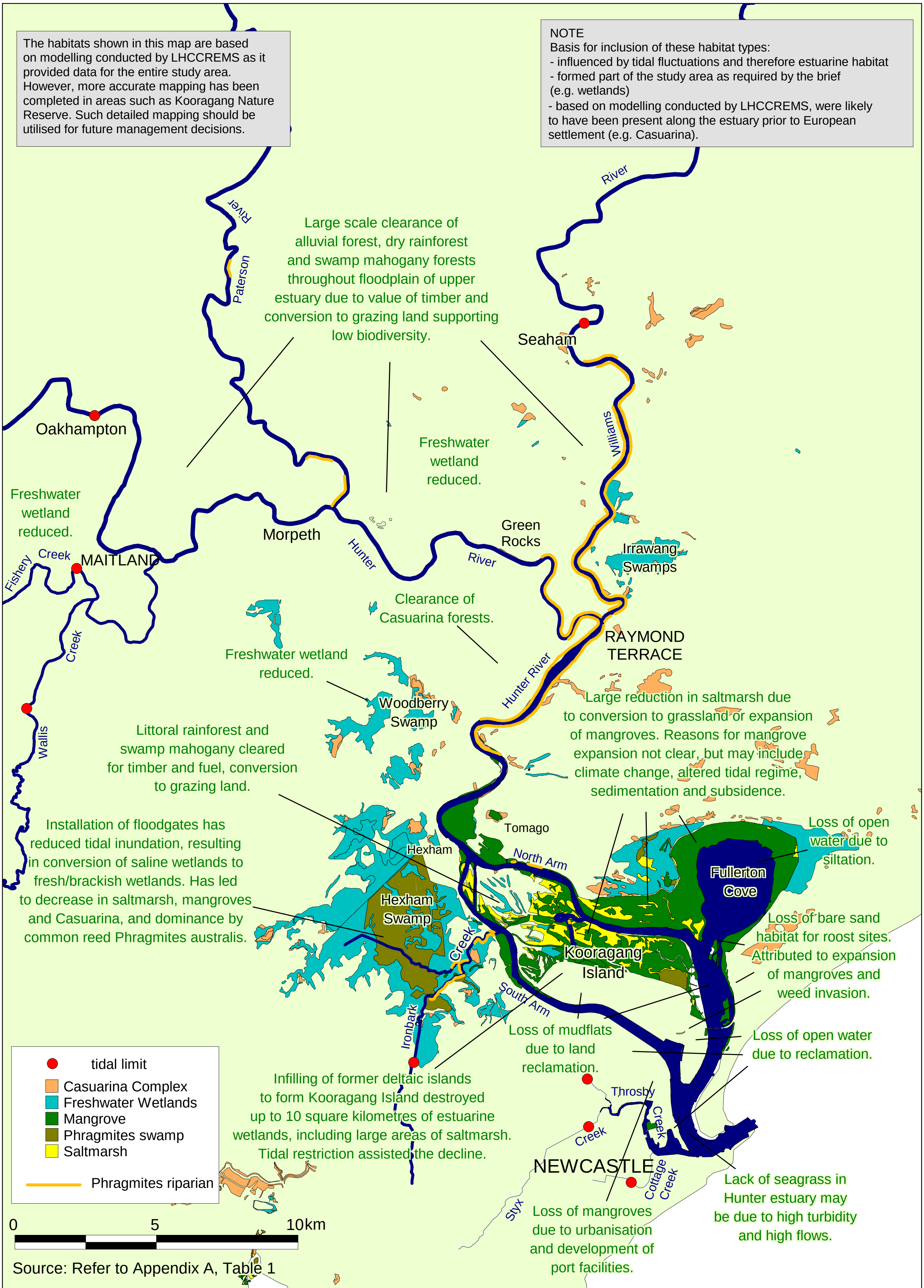
Figure 4.33

DRAWING 4_7e.WOR



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CHANGES TO HABITAT DIVERSITY SINCE EUROPEAN SETTLEMENT

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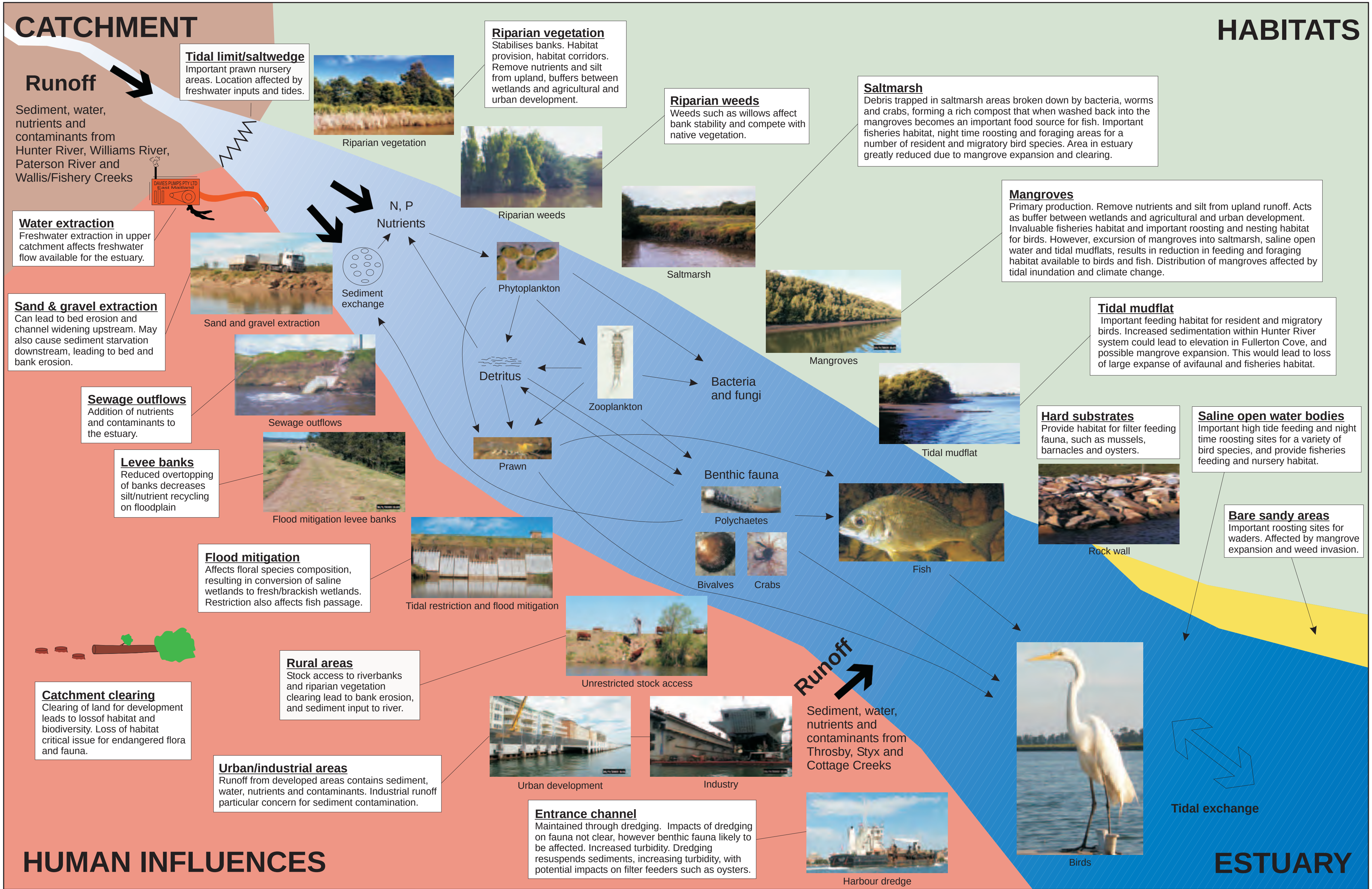
Figure 4.34

DRAWING 4_33.WOR



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CONCEPTUAL MODEL OF HUNTER ESTUARY ECOLOGICAL PROCESSES

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Figure 4.35

DRAWING 1095-04-35.CDR

5. Issues Analysis

5.1 Understanding Issues and Processes in the Hunter Estuary

To assist with the development of a Management Study and Management Plan, significant issues identified in the study brief and during the course of the investigation are tabulated in Table 5.1. The list of issues was initially developed by the Hunter Coast and Estuary Management Committee and was included in the investigation brief.

One of the main issues that has been well recognised is bank erosion and stability. Traditionally it was felt that the naturally meandering river could be redirected and controlled to maximise available farming area and protect fixed assets. The cost of maintaining this approach will escalate into the future if climate change predictions of increased rainfall intensity and flooding come to fruition. Reinstating the river banks, extending the riparian zone and perhaps relocating fixed assets could be considered in the management study.

As the Hunter Valley and port area change character from heavy industry to a broader mix of industry the population is likely to demand better protection of the environment and improved facilities for recreation. To this end the water quality issues need to be addressed and the initiatives already under way in terms of habitat remediation will require an ongoing commitment.

A well-balanced management plan should take into account all significant issues, acknowledging the complexity of interactions between the estuary processes and the effects on the values of the waterway.

5.2 Issues/Processes Matrix

The issues/processes matrix in Table 5.1 is an attempt to summarise the interactions between various aspects of the system. The matrix uses five categories to link the overall issue. The main process summarises the particular manifestation of the issue. The human influence describes impacts of human activities. The natural system identifies processes affected by the issue. Data gaps identify whether the issue requires additional information to better understand its implications, and the solutions category suggests possible activities that may resolve the issue.

Table 5.1 Understanding Issues and Processes in the Hunter Estuary

ISSUE	MAIN PROCESS	HUMAN INFLUENCE	NATURAL SYSTEM	INFORMATION GAPS	SOLUTIONS
Loss of Habitat	• restriction of tidal inundation to estuarine wetlands	• land use – clearing of habitat for rural activities and urban areas • land reclamation • flood mitigation works (including levees, drains, culverts, floodgates etc.)	• change in hydrology and hydraulic processes • change in tidal regime • conversion of saline vegetative systems to fresh/ brackish systems • changes in fish/invertebrate assemblages • threatened species, key habitats affected	• lack of data about effects of habitat loss on aquatic and terrestrial flora and fauna species • accurate mapping not completed for the whole estuary • Accuracy of LHCCREMS mapping requires improvement for management purposes	• identify key ecological relationships between habitats and the species they support (e.g. food, breeding grounds, shelter etc.) • monitor remediation plans in place (e.g. Wallis Creek and Ironbark Creek floodgate openings) • Incorporate detailed mapping already available. Central body required to co-ordinate regular updates once mapping has been revised. • remediation plans for loss of riparian vegetation
	• increased spatial extent of mangrove communities at the expense of saltmarsh • increased spatial extent of mangroves	• land use (e.g. agricultural development and urbanisation) • flood mitigation works	• change in tidal regime • climate change • increased sedimentation in tidal flat areas (e.g. Fullerton Cove)	• lack of understanding of processes leading to mangrove incursion into saltmarsh areas	• identify key ecological processes that alter the co-existence balance between saltmarsh and mangroves • catchment based approach to decrease sediment input
	• introduction of non-indigenous vegetation and faunal species to the estuary	• land use – clearing of habitat for rural activities and urban areas	• change in distribution of native vegetation • competition for habitat and food • reduction in biodiversity	• lack of data relating to the presence and abundance of native mammalian, reptilian and plant species in Hunter River estuary	• improve understanding of native and non-native species in areas where studies not undertaken • utilise community groups e.g. Landcare for onground works (already occurring)
Port operations	• introduction of exotic marine organisms into the marine environment through ballast water	• regional economy (e.g. port industry and shipping)	• competition for habitat and food • change in biodiversity	• there is little data about the effects of non-native species on native marine species in the Hunter estuary, but significant effects have been recorded elsewhere • lack of data on native marine species present in the Hunter River estuary	• Keep up to date with information provided by Australian Ballast Water Advisory Council

ISSUE	MAIN PROCESS	HUMAN INFLUENCE	NATURAL SYSTEM	INFORMATION GAPS	SOLUTIONS
Port operations (continued)	• dredging of the harbour for maintenance of waterways and port-related development	• regional economy (e.g. port industry and shipping)	• mobilisation of metals • change in hydrology and hydraulic processes	• lack of data about effects of dredging on marine biota and fish migration • lack of data on metal mobilisation processes and rates	• while the studies carried out so far do not indicate that metals are easily mobilised by dredging, the contamination in certain 'hot-spots' is so high that the process of mobilisation of contaminants through dredging (and its effects on biota) should be further studied
	• possible dredging of the North Arm for port facilities at Tomago • proposed development in the Newcastle Port Environs Proposal	• regional economy (e.g. shipping)	• change in hydrology and hydraulic processes • flora and fauna	• north arm dredging no longer proceeding, however South Arm dredging is being investigated	• impacts on natural environment need to be thoroughly investigated through the EIS process
Erosion	• bank erosion due to floods along the river and its tributaries	• change in land use patterns • flood mitigation structures • cattle grazing	• geomorphology • hydrology and hydraulic processes • climate/rainfall • riparian vegetation	• spatial resolution of rates of erosion	• determine hotspots to enable prioritisation of areas for remediation and revegetation • integrate remediation plans with Hunter Blueprint
	• long-term sedimentation and erosion processes and infilling of the estuary	• change in land use patterns • flood mitigation structures	• geomorphology • hydrology and hydraulic processes • tidal regime • flora and fauna	• further information required on major sediment sources within the Hunter River catchment • lack of understanding about contribution of marine sedimentation	• Investigate erosion rates by sub-catchment of the Hunter River • Erosion control at catchment level to minimise the issue • regular hydrosurveys of the estuary • monitoring of marine sediment transport into the estuary
Flooding	• inundation of urban, industrial and natural areas	• change in land use patterns • land reclamation and flood mitigation works	• geomorphology • climate/rainfall • hydrology and hydraulic processes • erosion and sedimentation • flora and fauna	• effects of options for altering current flood mitigation structures •	• utilise modelling to investigate options for altering current flood mitigation structures

ISSUE	MAIN PROCESS	HUMAN INFLUENCE	NATURAL SYSTEM	INFORMATION GAPS	SOLUTIONS
Pollution	• build up of contaminated sediments along the south arm of the Hunter River	• industrial activity (e.g. port industry)	• hydrology and hydraulic processes • dispersion • sediment contamination mechanisms • effects on flora/fauna	• lack of data about the effects of contaminants on aquatic and terrestrial flora and fauna and recreational amenity	• study chemical processes concerned with pollution in sediments and effects on living organisms
Water Quality	• industrial, agricultural and urban runoff into the river	• regional economy • sewage • public awareness of environmental problems	• hydrology and hydraulic processes • dispersion • water quality	• data has sparse coverage over broad spatio-temporal domain • lack of information on algal blooms and impacts of blooms on the system	• control of pollution at sources e.g. stormwater retention • better definition of appropriate local guideline values • adoption of sedimentation and erosion controls in a planned manner between councils • monitoring of algal species within the estuary, investigation of impacts on the system
	• leachate from garbage dump fill sites and sewerage overflow	• regional economy • zoning	• hydrology and hydraulic processes • dispersion • water quality	• data has sparse coverage over broad spatio-temporal domain, particularly leachate	• monitoring of leachate required to assess the issue
	• sedimentation at stormwater outlets due to non-compliance with sediment and water quality controls in existing and new developments	• commercial activity (e.g. building industry) • urban land use	• geomorphology • hydrology and hydraulic processes • dispersion • water quality	• lack of data about the extent of impact of sediment flows from building sites into the estuary system	• monitoring at stormwater outlets to quantify extent of sedimentation and erosion issues • enforce sedimentation and erosion control guidelines
	• saline discharges from coal mining and power generation	• coal mines and power-generating plants	• hydrology and hydraulic processes • water quality • flora and fauna	• impacts of discharges on water quality and aquatic biota	• localised monitoring of discharges to determine the extent of the issue
	• water extraction reducing freshwater inputs to the estuary	• regional economy • land use	• hydrology and hydraulic processes • water quality • flora and fauna	• lack of information regarding extraction rates for irrigation, and impacts on the estuarine system	• undertake monitoring of water extraction in the Hunter catchment to improve understanding of impacts

ISSUE	MAIN PROCESS	HUMAN INFLUENCE	NATURAL SYSTEM	INFORMATION GAPS	SOLUTIONS
	• Groundwater quality and flow	• land use • regional economy	• hydrology and hydraulic processes • recharge of wetlands • water quality • flora and fauna	• lack of information regarding groundwater quality and flow, and influence on wetlands	• undertake monitoring of groundwater quality and flow in the Hunter catchment to improve understanding of impacts on estuary.
Sand and Gravel Extraction	• balance between resource utilisation and effects on natural environment, including river stability	• regional economy (sand and gravel industry) • land use	• geomorphology • bank stability • hydrology and hydraulic processes	• lack of accurate data about quantities that are being extracted • lack of understanding about the effects of sand and gravel extraction on the natural environment	• monitor quantities of sand and gravel extraction • study the changes to the natural environment (e.g. habitats, diversity) in the vicinity of extraction activities • remediation works for riparian zone
Recreational	• conflicts between recreational boating and commercial activities	• recreational and commercial activities	• hydrology and hydraulic processes • water quality	• lack of published data about the types of recreational activities and when and where they take place	• monitor and report on recreational activities and changes to natural environment
Recreational (continued)	• impacts of recreational activities, including fishing, on natural environment	• recreation • public awareness	• geomorphology • hydrology and hydraulic processes • water quality • flora and fauna (e.g. roost sites) • bank stability	• lack of information about the effects of recreational activities on the natural environment	• a recreational fishing survey is currently being undertaken. Review outcomes of study during management study
	• improvement of public reserves around the river foreshore	• recreation • public participation	• hydrology and hydraulic processes • water quality • riparian vegetation • geomorphology	• lack of information about the types of recreational activities and when and where they take place	• More detailed surveys to prioritise operational programme
	• safety of public using the river	• recreation	• hydrology and hydraulic processes • water quality	• no data on the possible risks involved for the public	• educate the public by placing informative signs about the potential dangers of recreational activities in a natural environment

ISSUE	MAIN PROCESS	HUMAN INFLUENCE	NATURAL SYSTEM	INFORMATION GAPS	SOLUTIONS
Heritage	• heritage structures and other visually significant features	• cultural	• geomorphology • hydrology and hydraulic processes	• European heritage sites have been identified. • Further information on areas of Aboriginal significance required from local Aboriginal groups	• European heritage sites and a limited number of Aboriginal sites have been identified and their conservation is a basic consideration in development plans • Co-ordinate input from local Aboriginal groups
Fishing	• conflicts between use of the estuary for commercial fishing and the natural environment	• regional economy • public participation • recreational fishing	• hydrology and hydraulic processes • water quality • flora and fauna	• sustainability of fishery is uncertain • impacts of fishing on roosting sites unknown	• remediation of fish nursery habitats e.g. Hexham Swamp, Kooragang Island • investigate impacts of fishing on roosting sites in lower estuary in order to determine possible hotspots
	• introduction of obstacles to fish passage (including floodgates, low level road crossings and culverts)	• flood mitigation works • land use	• hydrology and hydraulic processes • water quality	• no data about effects on fish and prawn production	• remove obstacles as part of habitat rehabilitation
Acid sulfate soils	• drainage and disturbance of land containing potential acid sulfate soils	• land use • land reclamation and flood mitigation works	• water quality	• lack of research on occurrence of acid sulfate soils in the Hunter estuary catchment	• identification of priority areas for potential acid sulfate soils and implementation of development controls protect these areas
Climate change	• change in weather patterns and sea level rise		• hydrology and hydraulic processes • change in tidal inundation patterns • flooding • habitats	• lack of knowledge regarding impacts of climate change on local conditions	• investigate local impacts of climate change and include as a consideration in planning, especially foreshore development • mapping of potential increase of inundation zones associated with sea level rise

5.3 Loss of Habitat

Loss of habitat is an important issue throughout the Hunter estuary and adjacent lands, and is intrinsically linked to biodiversity. In the upper estuary, forests have largely been cleared for timber, and converted to grazing land, with subsequent effects on biodiversity. Native riparian vegetation is in poor condition, resulting in impacts upon bank stability, but also reducing its potential use for faunal habitat corridors.

In the lower estuary, land clearing and reclamation for urban and industrial areas and port facilities have also reduced habitat cover and diversity. Restriction of tidal inundation has severely impacted upon estuarine habitats, resulting in the conversion of saltmarsh and mangrove areas to monospecific fresh/brackish wetlands. Reduction of habitat diversity has had subsequent effects on biodiversity in the area. Incursion of mangroves into saltmarsh and bare sandy habitats also has the potential to reduce habitat diversity. However the processes leading to the increase in mangrove extent are not well understood. Introduced species also affect the faunal diversity of the area, although lack of data regarding native and non-native species creates difficulties in assessing changes.

It is recommended that an assessment of current rates of loss of habitat and biodiversity in the Hunter estuary is performed. This would include monitoring of remediation plans in wetlands such as Hexham Swamp, and greater collection of data for native and non-native faunal species. Identification of processes affecting the balance between mangroves and saltmarsh also requires further study. Central to this assessment is mapping of current habitats. Accurate mapping has been undertaken at a number of specific sites within the estuary, and these should be utilised for management studies through co-ordination of mapping by a central agency.

Sedimentation within the Hunter River catchment is a significant issue, with the potential to affect important habitats such as tidal mudflats in the lower estuary. This issue requires a catchment-based approach to decrease sediment inputs to the estuary, and should incorporate plans already developed as part of the Integrated Catchment Management Plan for the Hunter Catchment (the Hunter 'Blueprint'). This approach would utilise community groups already undertaken remediation works. Remediation of riparian vegetation for faunal habitat would also assist in greater bank stability in the upper estuary.

Current plans for development in the lower estuary also have the potential to significantly affect habitats. Potential impacts of proposed development on the natural environment require thorough investigation through the EIS process.

5.4 Dredging and Port Operations

Dredging of Newcastle harbour is important for commercial shipping within the port. The effects of dredging on aquatic flora and fauna and hydraulic processes such as tidal flushing are thought to be minimal but there has been no detailed and targeted monitoring to quantify these effects. Commercial shipping has resulted in the introduction of exotic species through ballast water, with potential impacts on native species.

While a previous dredging proposal for the north arm of the Hunter River is no longer being considered, an Environmental Impact Statement is currently being undertaken for proposed dredging of the south arm for new wharf facilities at Tomago. It is recommended that findings of this report are incorporated into future management strategies for the Hunter estuary.

5.5 Sedimentation and Bank Erosion

Sedimentation and erosion are important issues throughout the Hunter estuary. Sediment deposition in previous major floods from sources upstream of Oakhampton is currently being reworked in the upper estuary, resulting in significant bank erosion issues between Maitland and Morpeth. This is leading to deposition in reaches further downstream, particularly Morpeth to Raymond Terrace. Sedimentation is also occurring in the lower estuary, particularly in Fullerton Cove, which may have potential impacts for faunal habitats.

Bank instability is a significant factor in many reaches of the river, and has resulted in the construction of extensive bank protection works. Upstream sediment sources contribute to bank erosion in the upper estuary, however, lack of riparian vegetation and cattle access throughout the estuary are considered important factors in continuing bank instability. Erosion from boat wash may also be contributing to erosion in sections of the Williams River, and also in lower estuary areas.

It is recommended that management plans such as the Hunter Blueprint be utilised for addressing sedimentation within the catchment, which would include a riverine corridor management plan to assist in limiting further bank erosion. ‘Hotspot’ areas would need to be determined across the catchment to prioritise areas for remediation and revegetation.

5.6 Flooding and Flood Mitigation Management

Flooding is a major issue of concern for residents of the Hunter estuary floodplain, which resulted in the construction of significant flood mitigation structures. While these structures, which include levees, floodgates, spillways, controls and drains, have reduced the incidence of flooding in small events and improved the predictability of flows and drainage following large events, they have also had significant impacts on natural processes in the estuary. The construction of levees and bank protection works have altered processes of sedimentation and erosion in the river channel and reduced the incidence of sediment deposition on the floodplain. Hydrology and hydraulic processes have been altered by the installation of floodgates. This has resulted in a reduction in tidal inundation in some areas with subsequent impacts on estuarine habitats.

Floodgates on Ironbark Creek and Wallis Creek are partially opened during Hunter River low flow conditions, with the aim of reverting the areas previously inundated by the tide to functional estuarine habitats. The results of these actions are still being studied and will provide important information for the future management of floodgates throughout the estuary. Another potential management option for existing flood mitigation structures that has been suggested is the lowering of levees. Such action would improve the linkage between the river and its floodplain and could potentially increase areas of estuarine habitats such as wetlands. However, the impacts of lowering levees on flood behaviour would need to be comprehensively assessed to ensure that impacts on human activities are managed appropriately.

5.7 Sediment Contamination

Sediment contamination from industry is of particular concern in the port area. Results of previous sampling indicate that the south arm of the Hunter River is contaminated with metals, while other parts of the Hunter estuary have generally been shown to have low metal concentrations. The biogeochemical processes affecting heavy metal release, and effects of contaminants on flora and fauna are not well understood. Further studies to enhance this understanding is recommended.

5.8 Water Quality Management

While most of the water quality variables exceed the ANZECC (2000) water quality trigger levels, it is not clear that these trigger levels are appropriate to the Hunter River estuary. Nutrient loads have increased and a number of licensed point source discharges are located along the estuary. The nutrient loads and algal blooms should be monitored to assess whether there is a long-term trend towards deteriorating conditions, and to develop trigger levels specific to the Hunter estuary.

The stormwater management plans are attempting to address the water quality issue to some extent by recommending water quality improvement devices at stormwater outlets. Sedimentation and erosion control at building sites is an issue that requires addressing in a planned and integrated manner across the three councils to ensure standards are consistent, thereby reducing the risk that a particular council may be targeted for development due to less restrictive guidelines.

At present there is a lack of information available on water extraction rates within the Hunter estuary and catchment, and groundwater flows and quality. These are important issues as they influence freshwater flows into the estuary, and groundwater plays an important role in the recharge and viability of wetlands. These issues require monitoring to be undertaken to improve understanding of their impacts.

The high sediment loads into the estuary could be reduced with careful attention to the riparian zone management and reducing bank erosion, and such management should be undertaken through the Hunter Blueprint.

5.9 Sand and Gravel Extraction

Sand and gravel extraction is an important component of the Hunter regional economy, occurring primarily in the upper estuary. Rates of extraction are not well defined, and monitoring of extraction should therefore be considered as a management option. The impacts of extraction are not well understood, but potentially may lead to increases in bank instability, and also to sediment starvation of downstream reaches.

5.10 Fishing and Recreation Management

A number of recreational activities occur in the Hunter estuary, including fishing, boating, rowing, water-skiing and picnicking, and commercial activities such as estuary prawn trawling. Conflicts can arise between recreational and commercial fishing interests, and also between recreational boating and commercial shipping, although there is little evidence within the Hunter River. The impacts of fishing, both commercial and recreational on the sustainability of fish and other aquatic biota is not certain. Loss of fish nursery areas through habitat degradation and flood mitigation works have had considerable effects on fish stocks in the Hunter River. It is suggested that habitat remediation and removal of obstacles to fish movements, as is occurring as part of the rehabilitation of Hexham Swamp will enhance the sustainability of fishing in the Hunter estuary.

5.11 Aboriginal and European Heritage

European heritage sites in the Hunter estuary appear to be well understood. Many Aboriginal sites may have been disturbed or destroyed through river works, land reclamation and urbanisation, particularly before the introduction of the *National Parks and Wildlife Act 1974*. Further information is required on areas of Aboriginal significance, through negotiation with the local Aboriginal groups. Current and potential heritage items should be taken into consideration in development planning.

5.12 Acid Sulfate Soils

Acid Sulfate Soil (ASS) risk mapping indicates that the majority of the Hunter estuary and surrounding low lying areas are highly likely to contain acid sulfate, or potential acid sulfate soils. Mapping and ground truthing of these soils has currently only occurred in the Port Stephens Council area. The occurrence of acid sulfate soils is an important factor in relation to possible future disturbances of the soils. Disturbance of acid sulfate soils can result in degradation of lowland environments and estuarine water quality. It is recommended that further ground-truthing of acid sulfate soil mapping should be carried out, and the occurrence of these soils should be taken into consideration in future developments.

5.13 Climate Change

While studies have been carried out, the effects of climate change on the Hunter estuary are not well known. Possible climate changes include a likely increase in extreme daily rainfall leading to more frequent heavy rainfall events. These increases are likely to be associated with increased flooding, and can occur even where average rainfall is predicted to decrease. Any future development plans, particularly for foreshore areas, should ensure that possible climate changes are taken into consideration.

6. Conclusions

The physical, chemical and biological condition of the Hunter River estuary has been mapped and the related processes and interactions documented as far as practicable given the available information. The assessment utilised extensive data collation, analysis and interpretation to derive an understanding of the Hunter River estuary as a whole and hence the focus of works was directed to the broader estuary scale with reference to smaller scale sensitive areas such as the wetlands.

The results have been produced with an acknowledgement of the underlying issues identified by the committee and as such sufficient detail is provided to address management issues. During the next phase of the overall program it is highly likely that more detailed assessments will be required to address specific management options identified at the time.

The historical and contemporary natural attributes have also been documented through review of existing reports and the field mapping exercises. The impacts of human interventions over the past 200 years of European settlement on the natural processes and the resulting adjustments to the natural system have been discussed.

Land use activities have been described and the potential impacts of management needs of the estuary discussed.

The focus of this study has been on a thorough review and interpretation of existing available information, data sets and reports on various aspects of the system and to bring this together into an holistic overview of the system. While this approach has achieved a reasonable level of understanding for management of issues it must be recognised that the interpretation of disparate data sets collected for very different purposes is a subjective process relying on scientific intuition that the study team has to offer and hence some gaps in the knowledge base still require attention.

In addressing the issues identified by the committee, a number of considerations for future management have been developed. Loss of habitat is a significant issue within the estuary, and management considerations for this may include:

- monitor remediation plans in place (e.g. Wallis Creek and Ironbark Creek floodgate openings)
- incorporate detailed mapping already available. Central body required to co-ordinate regular updates once mapping has been revised.
- remediation plans for loss of riparian vegetation and decreasing sediment input through integration with management plans such as Hunter Blueprint

Port operations are an important component of the lower estuary, however there is concern regarding current development plans, the impacts of which are not certain. It is suggested that impacts on natural environment need to be thoroughly investigated through the EIS process.

Sediment input from the Hunter River catchment has a considerable effect on the Hunter estuary, and influences bank erosion in the upper estuary and habitats in the lower estuary. It is suggested that erosion control at a catchment level is required to minimize this issue, and requires integration with catchment remediation plans, such as the Hunter Blueprint.

Flood mitigation structures within the estuary affect a variety of processes, and their impacts are well recognised. Management options may include modelling to investigate options for altering current flood mitigation structures.

Water quality within the Hunter estuary is an area of concern, and is influenced by both diffuse and point sources of pollution. Possible management options for water quality within the estuary may include:

- control of pollution at sources e.g. stormwater retention
- adoption and enforcement of sedimentation and erosion controls in a planned manner between councils
- monitoring of water extraction in the Hunter catchment to improve understanding of impacts
- monitoring of groundwater quality and flow in the Hunter catchment to improve understanding of impacts on estuary.

Neither the impacts of sand and gravel extraction in the upper estuary, or actual extraction rates, are well understood. Management options for this issue may include:

- monitor quantities of sand and gravel extraction
- study the changes to the natural environment (e.g. habitats, diversity) in the vicinity of extraction activities
- remediation works for riparian zone

A considerable range of recreational activities occur within the Hunter estuary, although there is a lack of published information available. A recreational fishing survey is currently being undertaken, and is recommended that outcomes of the study be reviewed during the management study.

European heritage within the estuary is well-documented, and is considered as part of development plans. Less information is available regarding Aboriginal heritage in the estuary, and it is recommended that input from local Aboriginal groups is obtained.

Impacts of fishing on the local fauna, and the sustainability of the fisheries, is uncertain. Management options for the fishing issue may include:

- remediation of fish nursery habitats e.g. Hexham Swamp, Kooragang Island
- investigation of impacts of fishing on roosting sites in lower estuary in order to determine possible hotspots.

There is considerable risk of acid sulfate soils within the Hunter estuary, although there is a lack of research on their occurrence. Management options for this issue include:

- identification of priority areas for potential acid sulfate soils and implementation of development controls protect these areas

Climate change has the potential to influence a number of processes within the estuary, including flooding, inundation and habitats. Management options for this issue may include:

- investigation of local impacts of climate change, and include these as a consideration in planning, especially foreshore development

7. References

Albrecht, G., 2000, Rediscovering the Coquun: Towards an Environmental History of the Hunter River, Address given at the River Forum 2000.

Albritton, D.L. et al. 2001, A Report of Working Group of the Intergovernmental Panel on Climate Change; Summary for Policymakers, IPCC.

Australia New Zealand Environment Conservation Council (ANZECC) 1999, *Australian and New Zealand Guidelines for Fresh and Marine Water Quality*, (Draft).

Australia New Zealand Environment Conservation Council (ANZECC) 2000, *Australian and New Zealand Guidelines for Fresh and Marine Water Quality, Volume 1, The Guidelines (Chapters 1-7).* ANZECC and ARMCANZ Paper No. 4 – Volume 1, October 2000.

Australian Bureau of Statistics (ABS) Census 1996.

Australian Nature Conservation Agency (ANCA) 1996, A Directory of Important Wetlands of Australia.

Avery, E. and Main, R. 1999, *Hunter Estuary Data Compilation Report*, NSW Department of Land and Water Conservation, Hunter Region.

Birch G., Ingleton T. and Taylor S. 1997, Environmental implications of dredging in the worlds second largest coal exporting harbour, Port Hunter, Australia. *J .Marine Env. Engg.*, 4 (133:145).

Boyd, R., 2001, *Geology and Soils of the Hunter Catchment and Evolution and Sedimentation of the Hunter Estuary*, A report prepared for Manly Hydraulics Laboratory as part of the Hunter Estuary Processes Study.

Bureau of Meteorology (BoM) Monthly Averages Data, http://www.bom.gov.au

Carlstrom, C. 2002, Deputy President, Endeavour Rowing Club, Berry Park. Personal communication.

Colless, R. 2002, GIS Manager, Waterways Authority. Personal communication.

Collins, P. 2002, RiverCare Officer, Department of Land and Water Conservation, Muswellbrook. Personal communication.

Commercial Fisherman’s Co-operative 2003, Comments on draft Hunter Estuary Processes Study, personal communication.

Cooke, R. 2003, Department of Land and Water Conservation, Newcastle. Persona communication 29/01/2003.

Copeland, C.A. 1993, *The Ironbark Creek Ecosystem – Section 2: Ecosystems Task Group Report*. Prepared for Hunter Catchment Management Trust, Maitland, NSW.

CSIRO 2001, Climate Change Projections for Australia www.dar.csiro.au/publications/projections2001.pdf (accessed 10/9/02).

Department of Land and Water Conservation (DLWC) 2002, *Strengthening the silent sentinel* – Water Week Media Release. www.dlwc.nsw.gov.au/waterweek2002

Department of Land and Water Conservation (DLWC) 2000, *Hunter, Karuah and Manning Catchments, State of the Rivers and Estuaries Report*.

Department of Land and Water Conservation 1999, *Hunter Estuary Data Compilation Report*.

Department of Planning 1989, *Hunter Regional Environmental Plan 1989; Background Report*, Department of Planning, Sydney.

Department of Public Works and Services 998, Hydrographic Plan Catalogue for the Hunter River and its Tributaries, June 1998. Prepared by Geomatics Section, DPWS for Department of Land and Water Conservation.

Department of Water Resources 1987, *River Management in the Hunter Valley*, Department of Water Resources, River Management Muswellbrook, May 1987.

DLWC 2002. NSW Algal Information: Hunter Regional Algal Coordinating Committee.

Doring, C. and Doring, M.J. 1999, Coal, Railways and the Heritage of Newcastle etc., Transactions of Multi-disciplinary Engineering Australia, Vol.GE23.

Douglas Partners 2001b, Report on Geotechnical Investigation. Hunter River South Arm Newcastle. Prepared for NSW Premiers Department June 2001.

Douglas Partners, 2001a, Report on Contamination and Acid Sulphate Soil Assessment. Hunter River North Arm Newcastle. Prepared for NSW Premiers Department June 2001.

Dwyer, R., 2002, personal communication (email) 29 August 2002.

Environment Australia 2003, Environment Protection and Biodiversity Conservation Act 1999 – Listed Key threatening Processes. www.ea.gov.au

Environment Protection Authority (EPA) 1994, Environmental Economics Series: Using Economic Instruments to Control Salinity in the Hunter River. EPA 94/21, March 1994.

Environment Protection Authority 1997, *Managing Urban Stormwater: Treatment Techniques*

Environment Protection Authority (EPA) 1999, Water Quality and River Flow Interim Environmental Objectives: Hunter River Catchment. EPA 99/39, October 1999.

Environment Protection Authority (EPA) 2001, Hunter EPA licensed discharges. March 2001.

Environment Protection Authority (EPA) 2002, Hunter River salinity trading scheme. Website (accessed 17/7/02): www.epa.nsw.gov.au/licensing/hrsts/index.html

Environmental & Earth Sciences 2000a, Draft Port Stephens and Anna Bay Catchments Strategic Guidelines for Management of Acid Sulfate Soil. Unpublished

Environmental & Earth Sciences 2000b, Acid Sulfate Soil Occurrence in the Port Stephens and Anna Bay Catchments, Port Stephens Local Government Area, New South Wales. Unpublished.

Eyre, B.D. 1998, *Water Quality in the Clarence Estuary*, Centre for Coastal Management, Southern Cross University.

Eyre, B.D. and Twigg, C. 1997, Nutrient behaviour during post-flood recovery of the Richmond River estuary. *Estuarine, Coastal and Shelf Science* 44, 311-326.

Eyre, B.D., McKee, L., Hossain, S., Ferguson, A. and Gay, J. 1997, A preliminary conceptual model for Northern NSW estuaries: implication for management, in *Proceedings of the 7th Annual NSW Coastal Conference*, pp 160-171.

Fly By Night bat Surveys Pty Ltd 2002, Pilot survey for Microchiropteran bats of the mangrove forest of Kooragang Island, the Hunter Estuary, New South Wales. Report for Newcastle City Council.

Green, W. 2002, NSW Premiers Department, personal communication.

Greenwood, M. 2001, *Zannicheliaceae palustris* L. (Zannicheliaceae) in the Hunter Region. Honours thesis, University of Newcastle.

Hawke, W.C. 1958, A Report on the Flood of February, 1955, in the Hunter Valley of New South Wales. Maitland, July 1958.

Hawke, W.C. 1960, Levee Banks, Lower Hunter River. Maitland, January 1960.

Healthy Rivers Commission 2001, Independent Inquiry into the Hunter River System. Draft Report, December 2001.

Henderson, R. 1997, IPC – V1 Designing for a Sustainable Future: Conference Proceedings 'Wetland Rehabilitation And Sustainable Land Practices: An Harmonious Coexistence', Accessed on line: 01/09/02, http://www.rosneath.com.au/ipc6/ch02/henderson/.

Hendley, C. 2002, Maitland City Council, personal communication 29 August 2002.

Honeysuckle Development Corporation 2002, Honeysuckle Development Corporation Information Leaflet.

Hossain, S., Donnelley, R. and Eyre, B. 1997, *Increase in suspended sediment transport in the Richmond River Estuary since European Settlement*.

Houghton, J.T., L.G. Meira Filho, B.A. Callander, N. Harris, A. Kattenburg and K. Maskell (eds.) 1996, Climate Change 1995; The Science of Climate Change, Cambridge.

Huddleston, G., E. Green, L. Kaleski, R. Young 1950, Report of Hunter River Flood Mitigation Committee. Department of Conservation.

Hunter Catchment Management Trust (HCMT) 2001, Throsby Creek Total Catchment Management Strategy 2001.

Hunter Catchment Management Trust 1999, Wallis and Fishery Creeks Total Catchment Management Study: Water Quality Task Group Report. Issue No. 4, November 1999. Prepared by Patterson Britton & Partners Pty Ltd.

Hunter Catchment Management Trust 2002, Hexham Swamp Rehabilitation Project. Website: http://www.hcmt.org.au/hexham_swamp.php3 (accessed 6/11/02).

Hunter Catchment Management Trust 2002, Kooragang Wetland Rehabilitation Project. Website: http://www.newcastle.edu.au/discipline/biology/kooragang (accessed 6/11/02).

Hunter Valley Research Foundation (HVRF), Newcastle and the Hunter Region 1998-1999.

Hunter Water Corporation (HWC) 2001, Hunter Water Corporation Environmental Annual Report 2000-2001.

Ingleton T.C. and Birch G.F. 1995, The impact of urban and industrial development on the Hunter River, *Dept. Geology and Geophysics*, Sydney University, NSW.

Lawson and Treloar 1995, Lower Hunter River Geomorphology Study – Numerical Sediment Transport Modelling. Report prepared for Hunter Catchment Management Trust.

MacDonald, T. 2001, The Terrestrial Ecology of the Hunter River Estuary. A report prepared for Manly Hydraulics Laboratory as part of the Hunter Estuary Processes Study.

Maitland City Council 2001, Maitland State of the Environment Report 2000/2001, Maitland City Council

Maitland City Council 2002, Maitland Local Environmental Plan 1993, The Council of the City of Maitland. (Incorporates amendments gazetted up to January 2002).

Manly Hydraulics Laboratory 1995, Hunter River Data Collection 9 October 1995, MHL Report 750.

Manly Hydraulics Laboratory 1995-2000, Rainfall Annual Summaries, Contact MHL Publications Officer for more information.

Manly Hydraulics Laboratory 2000, *Clarence River Estuary Processes Study*, MHL Report 971, August 2000.

Manly Hydraulics Laboratory MHL 1999, Port Stephens/Myall Lakes Estuary Processes Study. Report MHL913, January 1999.

Marston, F.M. 1993, Nutrient Generation Rates for Land Uses in the Hawkesbury-Nepean Basin. CSIRO Division of Water Resources Technical Memorandum No. 93/3, January 1993.

Matthei, L.E., 1995, Soil Landscapes of the Newcastle 1:100000 Sheet. For Department of Land and Water Conservation.

Mounser, G. 1997, Review of the Hunter Valley Flood Mitigation Scheme. Volume 1: Report and Executive Summary. Hunter Catchment Management Trust.

MSB Hunter Ports Authority, year of publication unknown, Dredging – The Ongoing Task!

National Tide Facility 2002, Personal communication.

Naylor, S.D., Chapman, G.A., Atkinson, G., Murphy, C.L., Tulau, M.J., Flewin, T.C., Milford, H.B., Morand, D.T. 1998, Guidelines for the Use of Acid Sulfate Soil Risk Maps, 2nd ed., Department of Land and Water Conservation.

New South Wales Government 1992, *Estuary Management Manual*, New South Wales Government, NSW.

National Parks and Wildlife Service (NPWS) 2003, Comments on draft Hunter Estuary Processes Study, personal communication.

Newcastle City Council 1999, *Stormwater Management for Development Sites – Development Control Plan No. 50*, Draft August 1999.

Newcastle City Council 2000, Newcastle Stormwater Management Plan. Prepared by Newcastle City Council in conjunction with the Hunter Water Corporation, the Hunter Catchment Management Trust and the community.

Newcastle City Council 2001, Newcastle State of the Environment Report 2000/2001, Newcastle City Council.

Newcastle City Council 2002, Draft Newcastle Local Environmental Plan 2002, Newcastle City Council.

Newcastle Port Corporation 1996, Newcastle Port Corporation Environmental Management Plan.

Newcastle Port Corporation 2001, Newcastle Port Corporation Annual Report – 2001, Accessed Online: 01/09/02, http://www.newportcorp.com/annual_reports.html.

Newcastle Port Corporation 2002, personal communication - Minutes of MHL–NPC meeting held 17 September 2002, attended by Grant Beattie, Bass Randall, Trevor Heise (NPC), David van Senden and Helen Davies (MHL).

NSW Department of Housing 1998, Managing Urban Stormwater: Soils and Construction, NSW Government.

NSW Department of Mineral Resources (DMR) 1997, Environmental monitoring at mines in New South Wales. MinFact No. 85, November 1997. Accessed online at: http://www.minerals.nsw.gov.au/minfacts/85.htm

NSW Environment Protection Authority 2000, *NSW State of the Environment Report 2000*, Environment Protection Authority, Sydney, NSW.

NSW Fisheries 2001, Recreational Fishing. Region 5 – South of Seal Rocks to The Entrance. www.fisheries.nsw.gov.au

NSW Fisheries 2002a, Region 5 – Recreational Fishing Areas – Community Consultation Report. www.fisheries.nsw.gov.au

NSW Fisheries 2002b, Estuary Prawn Trawling EIS – Overview. www.fisheries.nsw.gov.au

NSW Fisheries 2003, Threatened Species Schedules of the Fisheries Management Act 1994 (updated 4/07/03) – Schedule 6 Key threatening processes. www.fisheries.nsw.gov.au

NSW Government 1992, Estuary Management Manual.

NSW Heritage Office, Heritage Register accessed on line: 17/07/02. http://www.interimtechnology.com.au/heritage/inventory/search/search_shr.cfm

NSW National Parks and Wildlife Service 2003, Threatened Species Conservation Act – Key threatening process listing. www.nationalparks.nsw.gov.au

NSW Public Works 1994, Lower Hunter Flood Study (Green Rocks to Newcastle), Newcastle City Council, Port Stephens City Council, Report No. PWD 91077.

Patterson Britton & Partners 1988, Newcastle Harbour Recreational Boating and Fishing Industry Facilities Study. Summary of Findings of Stage 1. For Public Works Department.

Patterson Britton & Partners 1993, Lower Hunter Geomorphological Study, Literature Review Report. Report to Department of Public Works and Hunter Catchment Management Trust.

Patterson Britton & Partners 1993, Lower Hunter Geomorphology Study: Literature Review Report. Prepared for the Hunter Catchment Management Trust, August 1993.

Patterson Britton & Partners 1995, Lower Hunter Geomorphology Study. Draft Final Report. Report to Department of Public Works and Hunter Catchment Management Trust.

Patterson Britton & Partners 1996a, Lower Hunter River Floodplain Management Study Volume A; Assessment of Strategic Options for Newcastle City Council and Port Stephens Council.

Patterson Britton & Partners 1996b, A study to assist in preparation of a long term sea dumping strategy Port of Newcastle, Prepared for Newcastle Port Corporation.

Patterson Britton & Partners 2001, Hunter River sediment data summary report, prepared for BHP, Newcastle by Patterson Britton & Partners Pty Ltd, North Sydney, NSW.

Port of Newcastle MSB Hunter Ports Authority, (undated) Mobility Study, Dumped Dredge Spoil: Outline of Stage 1 and Stage 2 Study Findings.

Port Stephens Council 2000a, *Port Stephens State of the Environment Report 2000*, Port Stephens Council.

Port Stephens Council 2000b, *Urban Stormwater Management Plan 2000*.

Port Stephens Council 2001, *Local Environmental Plan 2000*, Port Stephens Council.

Port Stephens Council 2002, Port Stephens Council website, Accessed online: 11/09/02 http://portstephens.local-e.nsw.gov.au/environment/02/

Public Works Department 1963, Newcastle Harbour – Hydrographic History. Department of Public Works, N.S.W, Harbours and Rivers Branch, Hydraulic and Soils Laboratory, Manly.

Public Works Department 1980, The Lower Hunter Valley Flood Mitigation Scheme, Public Works Department, New South Wales.

Public Works Department 1990, Lower Hunter Valley Flood Study (Oakhampton to Green Rocks), Report No. PWD 89014.

Public Works Department 1991, Throsby Creek Dredging and Rehabilitation. Preliminary Design Report.

Raine, A.W. and Gardiner, J.N. 1995, Rivercare: guidelines for ecologically sustainable management of rivers and riparian vegetation. Occasional Paper 03/95. Land and Water Resources Research and Development Corporation, Canberra.

Ruello, N.V. 1976, Environmental and Biological Studies of the Hunter River, Operculum, pp.76-84.

Sammut, J. and Lines-Kelly, R 1996, An Introduction to Acid Sulfate Soils, National Library of Australia

Sanderson and Redden 2001b, Salinity Structure of the Hunter River Estuary, a report prepared for Newcastle Council.

Sanderson, B and Redden, A 2001a, Hunter River Estuary Water Quality Data Review and Analysis. Submitted to Manly Hydraulics Laboratory.

Sinclair Knight & Partners 1981, New South Wales Coastal Rivers Flood Plain Management Studies: Hunter Valley. March 1981.

Sinclair Knight and Partners 1990, LHVFMS Monitoring & Assessment of Bank Erosion in the Hunter, Paterson and Williams River.

Smalls, I. 1986, Stormwater runoff and some environmental implications in the Sydney region. Water Research Foundation of Australia. 12th Symposium: Stormwater quality in urban areas, pp. 6.1-6.13. WRFA, Illawarra Regional Committee, Wollongong, NSW.

Straw, P 2000, *Hunter Estuary Wader Habitat Investigation - Stage 2*. Report to NSW National Parks and Wildlife Service.

Svoboda, P. 2003, Kooragang Wetland Rehabilitation Project. Summary of Threatened Species and Communities on Ash Island spreadsheet. Personal communication.

The Ecology Lab (TEL) 2001, Hunter Estuary Process Study: Aquatic Ecology. Report to Manly Hydraulics Laboratory, Final Draft June 2001.

Thompson, J. 2002, Boating Services Officer, Waterways Authority, personal communication.

Thorncraft, G and Harris, J, 2000, Fish Passage and Fishways in New South Wales: A Status Report. Cooperative Research Centre for Freshwater Ecology Technical Report 1/2000.

Tulau, M. 1999, "Management of Acid Sulfate Soils in New South Wales – Policy Organisation and Regulation", The Australasian Journal of Natural Resources Law and Policy, Vol 6, No.1 1999.

Turnbull, C., 2003, Regional Manager, Hunter Water, personal communication 20/02/2003.

Umwelt, 2002, Shifting Sands at Stockton Beach, report prepared by Umwelt Australia Pty Ltd for Newcastle City Council, June, 2002.

United States Environmental Protection Agency (USEPA) 2001, PLOAD version 3.0: An ArcView GIS Tool to Calculate Nonpoint Sources of Pollution in Watershed and Stormwater Projects. User's Manual. Appendix IV Event Mean Concentrations and Export Coefficients. United States Environmental Protection Agency, January 2001.

Water Conservation and Irrigation Commission 1966, Water Resources of the Lower Hunter Valley Including the Karuah Valley.

Website (accessed 28/11/02): http://www.dlwc.nsw.gov.au/care/water/bga/management/racc/hunter/index.html

West, R.J., Thorogood, C.A., Walford, T.R., and Williams, R.J. 1983, An Estuarine Inventory for New South Wales, Australia. Division of Fisheries, NSW Department of Agriculture, Sydney, Australia.

Williams, R.J., F.A. Watford and V. Balashov 2000, Kooragang Wetland Rehabilitation Project: History of Changes to Estuarine Wetlands of the Lower Hunter River, NSW Fisheries Office of Conservation, NSW Final Report Series No. 22.

Winter, W. 2002, NSW Fisheries, Hunter Office.

Woolley, D., T. Mount and J. Gill 1995, Tomago, Tomaree, Stockton Groundwater-Technical Review, Department of Water Resources Parramatta.

Appendix A

GIS Sources

Appendix A GIS Sources

Figure Number	GIS Layers used	Source of Layer
1.1	Catchment boundary Elevation Drainage Tidal limits	Auslig Auslig DLWC, modified by MHL MHL
1.2	Drainage Cultural (highways, roads, rail) SEPP 14 wetlands Tidal limits Distances upstream	DLWC, modified by MHL DLWC Dept of Planning MHL MHL
2.5	Geology Drainage Tidal limits	DLWC DLWC, modified by MHL MHL
2.9	Slope Classes Drainage Tidal limits	DLWC DLWC, modified by MHL MHL
2.11	Soil Landscapes Drainage Tidal limits	DLWC DLWC, modified by MHL MHL
2.12	Contours Drainage Tidal limits	DLWC, modified by MHL to 3D DLWC, modified by MHL MHL
3.1	Heritage items Heritage Heritage (derived from cadastre) Drainage SEPP 14 wetlands Cultural (highways, roads, rail) Tidal limits Aboriginal location names	Newcastle Council Port Stephens Council Maitland City Council DLWC, modified by MHL Dept of Planning DLWC MHL Derived from Albrecht 2000
3.2	Land use Drainage SEPP 14 wetlands Tidal limits	DLWC, modified by MHL DLWC, modified by MHL Dept of Planning MHL
3.3	Zones 1-7 (LEP 2003) LEP 2000 zones Land zoning (LEP 1993) Drainage Tidal limits	Newcastle Council Port Stephens Council Maitland City Council DLWC, modified by MHL MHL
3.4	Land regions Owner categories Cadastre regions National Parks Drainage Cultural (highways, roads, rail) Tidal limits	Newcastle Council Port Stephens Council Maitland City Council NPWS DLWC, modified by MHL DLWC MHL

Figure Number	GIS Layers used	Source of Layer
3.5	Land use Boat and dock facilities SEPP 14 wetlands Drainage Cultural (highways, roads, rail)	DLWC, modified by MHL MHL, derived from fieldwork Dept of Planning DLWC, modified by MHL DLWC
3.6	Zones 1-7 (LEP 2003) LEP 2000 zones Drainage Cultural (highways, roads, rail) Tidal limits	Newcastle City Council Port Stephens Council DLWC, modified by MHL DLWC MHL
3.7	Port ownership Drainage Cultural (highways, roads, rail) Tidal limits	Newcastle Port Corporation AutoCad drawing, modified by MHL DLWC, modified by MHL DLWC Dept of Planning
3.8	Levee banks Spillways Control structures Floodgates Drains Drainage Tidal limits	MHL derived from Sinclair Knight & Partners 1981 MHL derived from Sinclair Knight & Partners 1981 MHL derived from Sinclair Knight & Partners 1981 Newcastle City Council Newcastle City Council DLWC, modified by MHL MHL
3.9	Boating facilities, foreshore reserves, picnic areas, tourism opportunity areas Fishing and boating areas Moorings Fishing Closure areas Drainage Tidal limits	MHL, derived from fieldwork MHL, derived from fieldwork MHL, derived from fieldwork Derived from discussions with Waterways Authority, NSW Fisheries and Endeavour Rowing Club Derived from discussions with Waterways Authority Derived from TEL 2001 DLWC, modified by MHL MHL
3.10	Fishing Closure areas Oyster leases Prawn trawling area Drainage SEPP 14 wetlands Tidal limits	Derived from TEL 2001 NSW Fisheries Derived from discussions with Waterways Authority DLWC, modified by MHL Dept of Planning MHL
3.11	Dredging areas and spoil site Drainage Tidal limits	Newcastle Port Corporation AutoCad drawing, modified by MHL DLWC, modified by MHL MHL
3.12	Dredging areas and spoil site Drainage Tidal limits	Newcastle Port Corporation AutoCad drawing, modified by MHL DLWC, modified by MHL MHL

Figure Number	GIS Layers used	Source of Layer
3.13	Extraction sites Drainage Cultural (highways, roads, rail) Tidal limits	Maitland City Council DLWC, modified by MHL DLWC MHL
4.1	Flood behaviour Drainage Cultural (highways, rail) Tidal limits	MHL, adapted from PWD 1990, Patterson Britton & Partners 1996a DLWC, modified by MHL DLWC MHL
4.3	Tidal gauging sites Water level sites Drainage SEPP 14 wetlands Tidal limits	MHL MHL DLWC Dept of Planning MHL
4.4	Compilation hydrosurvey NPC Compilation hydrosurvey HWC Drainage Cultural (highways) Tidal limits	MHL, derived from Newcastle Port Corp data MHL derived from Hunter Water Corp data DLWC, modified by MHL DLWC MHL
4.9	Freshwater inputs Annual flows Tidal prisms Tidal excursions Salinity zones Distances upstream Drainage Tidal limits	MHL, derived from Sanderson and Redden (2001b) MHL, derived from DLWC data MHL MHL MHL, derived from Sanderson and Redden (2001b) MHL DLWC, modified by MHL MHL
4.10	Water quality monitoring sites Distances upstream Drainage Tidal limits	MHL, derived from Sanderson and Redden (2001a) MHL DLWC, modified by MHL MHL
4.12	Land use Sub-catchment boundaries Drainage	DLWC, modified by MHL DLWC, modified by MHL DLWC, modified by MHL
4.13	Sub-catchment boundaries EPA Licensed Point Sources Drainage Tidal limits	DLWC, modified by MHL NSW EPA – Hunter EPA licensed discharges 2001 DLWC, modified by MHL MHL
4.14	Sub-catchment boundaries EPA Licensed Point Sources Drainage Tidal limits	DLWC, modified by MHL NSW EPA – Hunter EPA licensed discharges 2001 DLWC, modified by MHL MHL
4.16	Nutrient inputs EPA Licensed Point Sources Drainage Tidal limits	MHL, derived from Sanderson and Redden (2001a) Environment Australia DLWC, modified by MHL MHL

Figure Number	GIS Layers used	Source of Layer
4.17	Soil Erosion Drainage Tidal limits	DLWC DLWC, modified by MHL MHL
4.18	Sand shoals, sand point bars Sand and gravel point bars Extraction sites Drainage Tidal limits	MHL, derived from fieldwork, Patterson Britton & Partners 1995. Maitland City Council DLWC, modified by MHL MHL
4.19	Sources and sinks Drainage Tidal limits	MHL, derived from Boyd 2001, Patterson Britton & Partners 1995 DLWC, modified by MHL MHL
4.20	Sediment loads Distances upstream Drainage Tidal limits	MHL, derived from Boyd 2001 MHL DLWC, modified by MHL MHL
4.21	Bank protection works Drainage SEPP 14 wetlands Tidal limits	MHL, derived from fieldwork DLWC, modified by MHL Dept of Planning MHL
4.22	Bank stability Drainage Tidal limits	MHL, derived from fieldwork DLWC, modified by MHL MHL
4.23	Riparian vegetation cover Drainage SEPP 14 wetlands Tidal limits	MHL, derived from fieldwork DLWC, modified by MHL Dept of Planning MHL
4.24	Cattle Access Drainage SEPP 14 wetlands Tidal limits	MHL, derived from fieldwork DLWC, modified by MHL Dept of Planning MHL
4.25	Acid Sulfate Soil Risk Drainage Tidal limits	DLWC DLWC, modified by MHL MHL
4.26	Current estuarine habitats Occurrence of riparian Phragmites Drainage Tidal limits	LHCCREMS MHL, derived from fieldwork DLWC, modified by MHL MHL
4.27	Native faunal habitats Current estuarine habitats Occurrence of riparian Phragmites Drainage Tidal limits	MHL, derived from McDonald 2001,TEL 2001, Straw 2000, HCMT 1999, Svoboda 2003. LHCCREMS MHL, derived from fieldwork DLWC, modified by MHL MHL

Figure Number	GIS Layers used	Source of Layer
4.28	Endangered flora and fauna sightings Current estuarine habitats Drainage Cultural (highways, roads, rail) Tidal limits	NPWS, Svoboda 2003 LHCCREMS DLWC, modified by MHL DLWC MHL
4.30	Obstacles to fish migration Current estuarine habitats Occurrence of riparian Phragmites Drainage Tidal limits	MHL, derived from discussions with NSW Fisheries LHCCREMS MHL, derived from fieldwork DLWC, modified by MHL MHL
4.31	Condition of saltmarsh, mangroves and macrophytes Current estuarine habitats Occurrence of riparian Phragmites Drainage Tidal limits	MHL, derived from McDonald 2001 and TEL 2001 LHCCREMS MHL, derived from fieldwork DLWC, modified by MHL MHL
4.32	Habitat corridors Drainage Cultural (highways, roads, rail) SEPP 14 wetlands Tidal limits	NPWS DLWC, modified by MHL DLWC Dept of Planning MHL
4.33	Estuarine habitats pre-1750 Drainage	LHCCREMS DLWC, modified by MHL
4.34	Changes to habitat diversity Current estuarine habitats Occurrence of riparian Phragmites Drainage Tidal limits	MHL, derived from McDonald 2001, TEL 2001 and Williams (2000) LHCCREMS MHL, derived from fieldwork DLWC, modified by MHL MHL

Appendix B

Conversion of DLWC Land Use Types to CMSS Land Use Types

Appendix B Conversion of DLWC Land Use Types to CMSS Land Use Types

The DLWC land use GIS layer contains a large number of land use types which have been converted into categories relating to nutrient generation rates. The majority of these categories are from the CMSS system used in the development of nutrient generation rates for the Hawkesbury-Nepean Basin (Marston 1993), while two other sources have been used to account for those DLWC land use classes that could not be appropriately assigned to CMSS categories. These two sources are Smalls (1986), whose generation rates were derived from research in the Sydney region, and the USEPA (2001) user manual for the PLOAD modelling tool, whose generation rates were derived from a range of sources in the United States.

Table B1 presents the DLWC mapping codes and land use classes that are accounted for by each of the 'CMSS land use types' and the source of the land use categories. The nutrient generation rates for each of these land use types are presented in Table 4.12. It should be noted that not all of the DLWC land use classes listed are found within the Hunter Estuary study area.

Table B1 CMSS Land Use Types and Their Equivalent DLWC Mapping Codes and Land Use Classes

CMSS Land Use Type	DLWC Mapping Code	DLWC Land Use Class
Bushland (Marston 1993)	9	native forest
	10	native forest – logged
	11	native forest – regeneration
	13	native forest – filter strips in softwood plantation
	14	softwood plantation
	15	softwood plantation – nursery
	24	windbreak/tree corridor (usually residual stands of native species found along Crown roads or road reserves)
	25	treelot (planted stands or corridors of native or exotic species)
	27	private conservation agreement
	30	riparian vegetation – exotic species (principally willows)
	41	hardwood plantation
	52	poplar plantation
	66	recently burnt areas (of woody vegetation)
	67	native woody shrub
	68	recently cleared land (cleared of forest vegetation, as yet not covered by crop or pasture)
	69	native shrub plantation (e.g. tea tree)
	70	woodland
	99	foreshore protection – vegetated foredune
	110	forest dominated by camphor laurel

CMSS Land Use Type	DLWC Mapping Code	DLWC Land Use Class
Sewered urban (Marston 1993)	17	urban – residential
	29	sewage disposal ponds
	77	university & other tertiary institutions
	92	government facility – gaol, training centre, school
	94	caravan park, mobile home village
Industrial and commercial (Marston 1993)	7	quarry
	16	urban – industrial/commercial
	33	landfill
	44	mining site
	49	restored mining lands, both open cut and pit operations
	60	abattoir
	62	irrigation from abattoir & other industries
	78	fly ash dam/spoil dump
	95	restored sand mining area
Vegetable growing (Marston 1993)	39	horticulture - vegetables
	40	horticulture - rice
Orchards (Marston 1993)	2	horticulture – orchard
	3	horticulture – vineyard
	35	horticulture – eucalypts for cut flower arrangements
	37	horticulture – seed production, including clover seed
	38	horticulture – olives
	42	nursery
	53	building associated with horticultural industry (winery, packing shed)
	81	shade house
	87	abandoned orchard and vine land; trees/vines not maintained and may be dying; regrowth of native shrubs and trees may be occurring
	102	horticulture – bananas
	104	horticulture – pecan, macadamia and other nuts
Fertilised grazing (Marston 1993)	5	grazing – improved perennial pasture
	6	grazing – irrigated pasture
	26	intensive animal production
Unfertilised grazing (Marston 1993)	4	grazing – volunteer, naturalised or improved pasture
	48	lantana infestations; total surface area of ground cover by lantana
	90	horse stud
Extensive agriculture (Marston 1993)	1	cropping – continuous or rotation
	84	fodder cropping

CMSS Land Use Type	DLWC Mapping Code	DLWC Land Use Class
General urban (Smalls 1986)	31	urban – recreation
	32	defence facility
	36	aerodrome/airport
	50	cemetery
	61	research facility
	93	electricity substation
	100	marina
	103	communications facility
Open/non-urban (USEPA 2001)	45	airstrip (local/farmer, not sealed)
	47	energy corridor
	58	foreshore land to DLWC dam
	59	foreshore or reserved land to water supply dam (Sydney Water, Hunter Water or Public Works Dam)
	64	beach
	72	trig station or beacon
	82	grassland within mining lease
	83	degraded land (salt site, eroded area)
	96	sand spit/estuarine sand island
	109	cliff/rock outcrop
Highway (USEPA 2001)	19	road/road reserve
	20	railway
Water/wetland (USEPA 2001)	8	farm dam
	12	river and riparian zone: includes the bed and bank of a river system and adjoining riparian vegetation
	21	floodplain swamp – backswamp
	22	floodplain swamp – billabong
	23	swamp
	28	river
	34	fish, prawn farm
	46	reservoir
	51	river training work
	54	mangrove
	55	mudflat
	56	coastal marsh
	57	drainage channel
	63	river navigation structure
	65	river gravel deposit
	71	flood or irrigation structure
	73	wetland – dunal swamp
	74	floodplain – swamp
	76	lagoon
	79	drain
	80	water supply pressure reservoir
	85	temporary storage area (e.g. rice farming, opportunistic storage of water)

CMSS Land Use Type	DLWC Mapping Code	DLWC Land Use Class
Water/wetland (cont'd)	86	inland salt lake
	91	evaporation basin
	98	aquaculture – oyster spoil & sheds, but not actual submerged leases
	105	coastal lake
	106	estuarine waters
	107	canal (e.g. canal estate, navigation canal)
	108	river and riparian zone, where the river channel is filled by more than 50% of cumbungi or phragmites vegetation

Appendix C

Glossary of Technical Terms

Appendix C Glossary of Technical Terms

accretion	Deposition of sediment in the channel and on the banks of the estuary resulting in the growth of bars and other depositional features.
acid runoff	The runoff of sulfuric acid from acid sulfate soils.
acid sulfate soil	Estuarine sediments in which metal sulfides (mainly pyrite) accumulate, and the subsequent dehydration of these sediments by evapotranspiration and/or disturbance which enables the oxidation of pyrite/sulfides to produce sulfuric acid.
advection	The transport of water or substances in the water, independent of dispersion processes.
advective transport	The transport of dissolved material by water movement.
algae	Non-rooted aquatic plants, specifically non-vascular photosynthetic organisms with unicellular reproductive organs, including phytoplankton and seaweeds.
algal bloom	The excessive growth of phytoplankton, generally caused by high nutrient levels. Can result in deoxygenation of the water mass, leading to the death of aquatic flora and fauna.
amenity	Those features of an estuary that foster its use for various purposes, e.g. clear waters and sandy beaches make beach-side recreation attractive.
amphibian (In the context of the National Parks and Wildlife Act, 1974)	"Any frog or other member of the class amphibia that is native to Australia, including the eggs and the young thereof".
amphipods	Laterally compressed crustacea, e.g. sand hoppers.
anaerobic conditions	The absence of free oxygen required for certain biological processes.
annual exceedance probability	The chance or likelihood that an event of a nominated size or greater (e.g. flood discharge) will occur in any year.
anoxic	A lack of oxygen in the water.
aquifer	A rock or sediment formation which stores water and allows water to travel through it.
Australian Height Datum (AHD)	A common national plane of level corresponding approximately to mean sea level.
baseline monitoring	A monitoring program aimed at determining long-term and possibly pre-disturbance levels and variation in some parameter of interest, e.g. dissolved oxygen.
bathymetry	The measurement of depths of water; also information derived from such measurements.

bed load	That portion of the total sediment load that flowing water moves along the bed by the rolling or saltating of sediment particles .
benthic fauna	Animals living in or on the bed of a water body.
benthos, benthic organisms	Organisms living in or on the bed of a waterbody.
biodiversity	The range of all species, including the genes they contain and the ecosystems of which they are part.
biological oxygen demand	Oxygen required by aerobic bacteria in metabolising detritus.
biological uptake	The process by which organisms absorb substances, including nutrients.
biomass	The mass of living material contained in a system of interest (includes both plant and animal matter).
biota	Living organisms.
breakwater	Structure protecting a shoreline, harbour, anchorage or basin from ocean waves.
buffer zone	An appropriately managed and unalienated zone of unconsolidated land between beach and development, within which coastline fluctuations and hazards can be accommodated in order to minimise damage to the development.
catchment	The area draining to a site. It always relates to a particular location and may include the catchments of tributary streams as well as the main stream.
colluvial storage	The deposition of sediment (often in depressions) at the base of slopes in a catchment.
consent authority	In relation to a development or building application: • the council having the function to determine the application; or • where an environmental planning instrument specifies a Minister or public authority (other than a council) or the Director (of the Department of Environment and Planning) as having the function to determine a development application, that Minister or public authority or the Director as the case may be.
Crown land	Crown lands are those lands, including the beds of creeks, rivers, estuaries and the ocean, that remain by title under the administration of the New South Wales Department of Conservation and Land Management. Such lands may be vacant, occupied under licence or reserved. Occupied or reserved Crown land can be managed by the Department of Conservation and Land Management, Councils or Trusts.
degradation	A reduction in the area of estuarine habitat; or in the well-being, health and viability of estuarine ecosystems; or in estuarine amenity.

detritus All non-living organic material, including animal waste products and the remains of animals, plants and micro-organisms, together with the associated microbial community (bacteria and fungi) .

development The erection of a building or the carrying out of work; or
the use of land or of a building or work; or
the subdivision of land.

infill development: refers to the development of vacant blocks of land that are generally surrounded by developed properties.
new development: refers to development of a completely different nature to that associated with the former land-use. For example, the urban subdivision of an area previously used for rural purposes. New developments typically require major extensions of existing urban services, such as roads, water supply, sewerage and electric power.
redevelopment: refers to the rebuilding of an area. For example, as urban areas age, it may become necessary to demolish and reconstruct buildings on a relatively large scale. Redevelopment generally does not require major extensions to urban services.

diffuse source pollution Pollution originating from a widespread area, e.g. urban stormwater runoff, agricultural runoff.

discharge The rate of flow of water measured in terms of volume over time. It is to be distinguished from the speed or velocity of flow which is a measure of how fast the water is moving rather than how much is moving.

discharge Volumetric flow rate of water, typically measured in terms of cubic metres per second (m^3/s).

dispersive transport The transport of dissolved matter through the estuary by vertical, lateral and longitudinal mixing associated with velocity shear.

dissolved oxygen Atmospheric oxygen that dissolves in water. The solubility of oxygen in water depends upon temperature and salinity.

diurnal A daily variation, as in day or night.

ebb tide The outflow of coastal waters from bays and estuaries caused by the falling tide.

ecologically sustainable development Development that does not interfere with the short and long term well-being, health and viability of estuarine ecosystems.

ecosystem A community of living organisms, together with the environment in which they live and with which they interact.

eddies Large, circular, swirling movements of water, often metres or tens of metres across.

effluent The outflow from a sewage treatment plant.

endangered fauna (In the context of the National Parks and Wildlife Act, 1974)	"Protected Fauna of a species named in Schedule 12".
entrance bar	A deposit of sand or silt across the entrance to an estuary. The material may be either fluvial or marine in origin.
environmental impact (In the context of the Environmental Planning & Assessment Act, 1 979)	"An assessment of the impact of a proposed development".
epifauna	An animal attached to another organism, usually for support.
estuarine processes	Those processes that affect the physical, chemical and biological behaviour of an estuary, e.g. predation, water movement, sediment movement, water quality, etc.
estuary	An enclosed or semi-enclosed body of water having an open or intermittently open connection to coastal waters in which water levels vary in a periodic fashion in response to ocean tides.
estuary management process	A sequence of activities starting with the formation of an Estuary Management Committee and culminating in the implementation of an Estuary Management Plan that will foster the balanced and sustainable use of estuaries.
eutrophication	The build-up of nutrient levels in a water body leading to the excessive growth of aquatic plants, which in turn depletes dissolved oxygen levels in the waterbody.
event monitoring	The monitoring of some parameter during a particular physical, chemical or biological event of interest, e.g. the variation of turbidity levels in an estuary during the passage of a flood, the effect of dredging on the distribution of a certain species of fish.
fauna (In the context of the National Parks and Wildlife Act, 1974)	"Any mammal, bird, reptile or protected amphibian".
fetch (fetch length)	The horizontal distance over which a wind blows in generating waves.
flood	Relatively high stream flow which overtops the natural or artificial banks in any part of a stream or river.
flood hazard	Potential for damage to property or persons due to flooding.

flooding	The State Emergency Service uses the following definitions in flood warnings: **minor flooding:** causes inconvenience such as closing of minor roads and the submergence of low level bridges. The lower limit of this class of flooding, on the reference gauge, is the initial flood level and the upper limit is determined by local conditions. **moderate flooding:** low-lying areas are inundated requiring removal of stock and/or evacuation of some houses. Main traffic bridges may be covered. The range on the reference gauge is determined by local conditions. **major flooding:** extensive rural areas are flooded with properties, villages and towns isolated and/or appreciable urban areas are flooded. The threshold for this class of flooding is the upper limit of moderate flooding .
flood liable land	Land which would be inundated as a result of the standard flood.
flood mitigation works	Structures that are designed to manage floodwaters (e.g. levees, retarding basins).
floodplain	The portion of a river valley, adjacent to the river channel, which is covered with water when the river overflows during floods.
floodplain management measures	The full range of techniques available to floodplain management.
floodplain management options	The measures which might be feasible for the management of a particular area.
flood standard (or designated flood)	The flood selected for planning purposes. The selection should be based on an understanding of flood behaviour and the associated flood risk. It should also take into account social, economic and ecological considerations.
flood storages	Those parts of the floodplain that are important for the temporary storage of floodwaters during the passage of a flood.
flood tide	The inflow of coastal waters into bays and estuaries caused by the rising tide.
floodways	Those areas where a significant volume of water flows during floods. They are often aligned with obvious naturally defined channels. Floodways are areas which, even if only partially blocked, would cause a significant redistribution of flood flow, which may in turn adversely affect other areas. They are often, but not necessarily, areas of deeper flow or the areas where higher velocities occur
fluvial	Pertaining to non-tidal flows.
fluvial delta	Area of sediment deposition at the downstream end of a non-tidal stream.
fluvial processes	The erosive and transport processes that deliver terrestrial sediment to creeks, rivers, estuaries and coastal waters.

fluvial sediments	Land-based sediments carried to estuarine waters by rivers.
foreshore	The area of shore between low and high tide marks and land adjacent thereto.
frictional resistance	The resistance to the flow of water as it travels against the bed and banks of the river or estuary.
geomorphology	The study of the origin, characteristics and development of land forms.
gravitational circulation	A residual circulation in the lower reaches of an estuary characterised by landward flowing bottom currents and ocean flowing surface currents, driven by the gravitational forces associated with differences in salinity levels along the estuary.
greenhouse effect	A term used to describe the likely global warming predicted to accompany the increasing levels of carbon dioxide and other "greenhouse" gases in the atmosphere.
ground truthing	Checking by site inspection of information derived remotely.
groundwater	Water beneath the surface of the ground.
habitat	The places in which an organism lives and grows. Many estuarine organisms require different habitats at different stages of their life cycles.
halocline	A gradient in salinity.
heavy metals	Generally, those metals that occur in Groups IB to VIIIB of the Periodic Table with atomic numbers between 21 and 84, but excluding Rare Earth elements. Heavy metals generally have specific gravity of 5.0 or more and include chromium, iron, nickel, copper, zinc, silver, cadmium, platinum, gold, mercury and lead. Although essential in trace concentrations, some heavy metals are toxic to aquatic organisms at higher concentrations, e.g. mercury, lead, copper and zinc. Even when present in sub-lethal concentrations, heavy metals may adversely affect the health of aquatic organisms.
hydraulic	The term given to the study of water flow in a river, in particular the evaluation of flow parameters such as stage and velocity.
hydraulic regime	The variation of estuarine discharges in response to seasonal freshwater inflows and diurnal tides.
hydrogeology	The study of the geological aspects of water, usually associated with the study of groundwater.
hydrograph	A graph which shows how the discharge changes with time at any particular location.
hydrology	The term given to the study of the rainfall and runoff process as it relates to the derivation of hydrographs for given floods.
intertidal	Pertaining to those areas of land covered by water at high tide, but exposed at low tide, e.g. intertidal habitat.

invertebrate	Animal without a backbone, e.g. jellyfish.
isohaline	A line connecting parts of the water mass having the same salinity, i.e. a contour of equal salinity levels.
levee	A man-made embankment or wall built to exclude floodwaters, or a natural embankment adjacent to a waterway built by the deposition of silt from floodwaters.
lithology	The character of rock - its mineral composition, structure, grain size and arrangement of its component parts. Most commonly applied to sedimentary rocks.
lowland	Area at the downstream end of a catchment area.
macrophytes (aquatic)	Rooted aquatic plants, e.g. eelgrass.
macroinvertebrate	Invertebrates large enough to be seen with the human eye, usually very small, less than 2 cm.
main stream	Inundation of normally dry land occurring when water conveyed to the
flooding	locality from further upstream overflows the natural or artificial banks of the principal watercourse in the catchment. It generally excludes any watercourses constructed with pipes or artificial channels or considered as stormwater channels.
management plan	A document including, as appropriate, both written and diagrammatic information describing how a particular area of land is to be used and managed to achieve defined objectives. It may also include description and discussion of various issues, problems, special features and values of the area, the specific management measures which are to apply and the means and timing by which the plan will be implemented.
mangroves	An intertidal plant community dominated by trees.
marine sediments	Sediments in coastal waters moved along the coast by littoral processes .
morphology	Form or structure. Can apply to plants and animals, or the physical form of lands, regions or towns.
native plant (In the context of the National Parks and Wildlife Act, 1974)	"Any tree, shrub, fern, creeper, vine, palm or plant that is native to New South Wales, and includes the flower and any other part thereof".
neap tides	Tides with the smallest range in a monthly cycle. Neap tides occur when the sun and moon lie at right angles relative to the earth (the gravitational effects of the moon and sun act in opposition on the ocean).
nutrients	Substances containing or conveying nourishment. Common nutrients are phosphorus and nitrogen.

peak discharge	The maximum discharge occurring during a flood event.
photosynthesis	The synthesis of complex organic materials by plants from carbon dioxide, water and inorganic salts using sunlight as the source of energy and with the aid of a catalyst such as chlorophyll.
physical model	The representation of physical processes of interest, e.g. water movement or sediment movement, by a scale model of the estuary and the process.
physico-chemical	Physical and chemical parameters or processes.
phytoplankton	Microscopic free-floating aquatic plants (algae).
pneumatophores	Specialised root branches produced in large numbers by plants growing in tidal waters - the root branches of mangroves.
point bar	A deposition feature attached to the bank of the estuary usually forming on the inside of a bend.
point-source pollution	Specific localised source of pollution, e.g. sewage effluent discharge, industrial discharge.
pollute (In the context of the Clean Waters Act, 1970)	(a) To place in or on, or otherwise introduce into or on to, the waters (whether through an act or omission) any matter, whether solid, liquid or gaseous, so that the physical, chemical or biological condition of the waters is changed; or (b)To place in or on, or otherwise introduce into or on to, the waters (whether through an act or omission) any refuse, litter, debris or other matter, whether solid or liquid or gaseous, so that the change in the condition of the waters or the refuse, litter, debris or other matter, either alone or together with any other refuse, litter, debris or matter present in the waters makes, or is likely to make, the waters unclean, noxious, poisonous or impure, detrimental to the health, safety, welfare or property of persons, undrinkable for farm animals, poisonous or harmful to aquatic life, animals, birds or fish in or around the waters or unsuitable for use in irrigation, or obstructs or interferes with, or is likely to obstruct or interfere with persons in the exercise of enjoyment of any right in relation to the waters; or (c)To place in or on, or otherwise introduce into or on to, the waters (whether through an act or omission) any matter, whether solid, liquid or gaseous, that is of a prescribed nature, description or class or that does not comply with any standard prescribed in respect of that matter".
poorly-mixed estuary	An estuary characterised by poor vertical mixing, pronounced vertical salinity gradients and a discrete body of saltwater (a salt wedge) underlying freshwater.
primary production	The synthesis of the total organic material in a given time by autotrophs of an ecosystem.
probable maximum flood	The flood calculated to be the maximum which is likely to occur.

public lands	Public lands in New South Wales are those lands which by title (and usually day to day administration and management) are under control of any Commonwealth, State or Local Government agency. Examples of Public lands include national parks, state forests, railway corridors, public roads and Crown land.
receiving waters	Waters into which effluent or waste streams are discharged or discharge.
relic	Surviving from a past period. Can apply to human activities and structures or to the natural environment.
residual sediment flux	The net upstream or downstream movement of sediment over a tidal cycle, often determined by tidal distortion and gravitational circulation.
revetments	Walls built parallel to the shoreline to limit shoreline recession.
riparian vegetation	Vegetation growing along banks of rivers, including the brackish upstream reaches of an estuary.
runoff	The amount of rainfall which actually ends up as streamflow, also known as rainfall excess.
salinity	The total mass of dissolved salts per unit mass of water. Seawater has a salinity of about 35 g/kg or 35 parts per thousand .
salinity limit	The landward limit of salinity intrusion along an estuary. The location of the salinity limit changes with freshwater discharge, high freshwater inflows moving the limit downstream, whilst low flows allow salt and the salinity limit to migrate upstream.
saltmarsh	A coastal wetland subject to tidal flooding and vegetated by grasses, herbs and low shrubs that are tolerant of high salinity.
salt wedge	The wedge-shaped body of saltwater that underlies freshwater in poorly-mixed estuaries.
sand bypassing	A procedure whereby sand deposited on the updrift side of a training wall or similar structure is mechanically delivered to the downdrift side. This facilitates the natural longshore movement of the sediment.
sand dunes	Mounds or hills of sand lying to landward of the beach berm. Sand dunes are usually classified as an incipient dune, a foredune or hinddunes. During storm conditions, incipient and foredunes may be severely eroded by waves. During the intervals between storms, dunes are rebuilt by wave and wind effects. Dune vegetation is essential to prevent sand drift and associated problems.
scour	Erosion, normally by the action of flowing water or wave action.
sediment budget	An accounting of the rate of sediment supply from all sources (credits) and the rate of sediment loss to all sinks (debits) from an area of coastline to obtain the net sediment supply/loss.

sediment load	The quantity of sediment moved past a particular cross-section in a specified time.
semi-diurnal tides	Tides with a period, or time interval between two successive high or low waters, of about 12.5 hours. Tides along the New South Wales coast are semi-diurnal.
shoals	Shallow areas in an estuary created by the deposition and build-up of sediments.
slack water	The period of still water before the flood tide begins to ebb (high water slack) or the ebb tide begins to flood (low water slack) .
spring tides	Tides with the greatest range in a monthly cycle, which occur when the sun, moon and earth are in alignment (the gravitational effects of the moon and sun act in concert on the ocean) .
stratified	Having a vertical structure or layering within a terrestrial or aquatic environment.
stratigraphy	That branch of geology dealing with the ordering of rocks into their relative ages.
suspended sediment load	That portion of the total sediment load held in suspension by turbulent velocity fluctuations and transported by flowing water.
surging waves	The wave does not "break" but maintains its basic shape as it moves towards the shore, where it surges up the beach. Very little white water is evident before surging waves reach the shore.
survey plan	A plan prepared by a registered surveyor.
tailings	The residue of mined ores after the target mineral has been extracted.
thalweg	The longitudinal profile of a river or estuary, usually taken to be the line joining the deepest points.
tidal amplification	The increase in the tidal range at upstream locations caused by the tidal resonance of the estuarine waterbody, or by a narrowing of the estuary channel.
tidal delta	The build-up of shoals in the lower reaches of an estuary due to the gradual accumulation of marine sands transported into the estuary through its entrance.
tidal exchange	The proportion of the tidal prism that is flushed away and replaced with 'fresh' coastal water each tide cycle.
tidal excursion	The distance travelled by a water particle from low water slack to high water slack and vice versa.
tidal lag	The delay between the state of the tide at the estuary mouth (e.g. high water slack) and the same state of tide at an upstream location.
tidal limit	The most upstream location where a tidal rise and fall of water levels is discernible. The location of the tidal limit changes with freshwater inflows and tidal range.

tidal planes	A series of water levels that define standard tides, e.g. 'Mean High Water Spring' (MHWS) refers to the average high water level of spring tides.
tidal prism	The total volume of water moving past a fixed point on an estuary during each flood tide or ebb tide.
tidal propagation	The movement of the tidal wave into and out of an estuary.
tidal range	The difference between successive high water and low water levels. Tidal range is maximum during spring tides and minimum during neap tides.
tides	The regular rise and fall of sea level in response to the gravitational attraction of the sun, moon and planets. Tides along the New South Wales coastline are semi-diurnal in nature, i.e. they have a period of about 12.5 hours.
total catchment management (in the context of the Catchment Management Act, 1989)	"The coordinated and sustainable use of land, water, vegetation and other natural resources on a water catchment basis so as to balance resource utilisation and conservation".
topography	The relief features or surface configuration of an area.
training walls	Walls constructed at the entrances of estuaries and rivers to improve navigability.
turbidity	A measure of the ability of water to absorb light.
vegetation degradation	The process by which coastal vegetation is "degraded" or damaged; this reduces the effectiveness of vegetation in protecting coastal landforms and increases the potential for erosion of underlying soil materials by wind (resulting in sand drift), water or waves.
velocity shear	The differential movement of neighbouring parcels of water brought about by velocity gradients. Velocity shear causes dispersive mixing, the greater the shear (velocity gradient), the greater the mixing.
water quality	The suitability of the water for various purposes, as measured by the concentration or level of a wide variety of contaminants.
well-mixed estuary	Estuary characterised by strong vertical mixing and weak or non-existent vertical salinity gradients.
wind fetch	The horizontal distance in the direction of wind over which waves are generated by wind.

Appendix D

References from Technical Report

Geology and Soils of the Hunter Catchment, and Evolution and Sedimentation of the Hunter Estuary

Dr Ron Boyd, University of Newcastle

Appendix D References

Hodgins, B. 1995. Cainozoic seismic stratigraphy of the continental shelf off Newcastle. BSc honours thesis, Department of Geology, University of Newcastle, (unpublished).

Kovac, M., and Lawrie, J.W. 1991. Soil Landscapes of the Singleton 1:250,000 Sheet. Report, Soil Conservation Service of NSW, Sydney.

McManus, P., O'Neill, P., Loughran, R. and Lescure, O.R., 2000. Journeys: The making of the Hunter Region. Allen and Unwin, Sydney, 276p.

Manley, F.S., 1963. Newcastle Harbour – Hydrographic History. NSW Department of Public Works, Harbours and Rivers Branch, Hydraulic and Soils Laboratory, Manly, Report 102, 35 p. plus appendices.

Matthei, L.E., 1995. Soil Landscapes of the Newcastle 1:100, 000 Sheet, Report, DLWC, Sydney.

Patterson, Britton and Partners, 1989. Mobility Study, Dumped Dredge Spoil, Port of Newcastle. Prepared for MSB Hunter Ports Authority.

Patterson, Britton and Partners, 1995. Lower Hunter Geomorphological Study, Draft Final Report to Department of Public Works and Hunter Catchment Management Trust.

Port Stephens Council, 2003. GIS Unit, personal communication 6/8/2003.

Public Works, 1993. Lower Hunter Flood Mitigation Scheme levee bank restoration project - Geotechnical Investigation, Report No. 93-HK26, Vol. 1-4, July, State Projects, Division of NSW Public Works.

Ramage, R., 1994. Bedrock topography of the Lower Hunter Valley and the internal structure of the inner barrier. BSc Honours thesis, Geology Department, University of Newcastle (unpublished).

Roy, P.S., 1977. Does the Hunter River supply sand to the New South Wales coast today? Royal Society of NSW, Journal and Proceedings, 110, 117-124.

Roy, P.S., 1980. Quaternary deposition environments and stratigraphy of the Fullerton Cove region, central NSW. Department of Mineral Resources and Development: Records of the Geological Survey of NSW, 19 (2), 189-219.

Roy, P.S., and B.G. Thom, 1991. Cainozoic shelf model for the Tasman Sea margin of southeastern Australia. Geological Society of Australia, Special Publication 18, 119-136.

Roy, P.S., and R. Boyd, 1996. Quaternary Geology of Southeast Australia: A Tectonically stable, wave-dominated, sediment deficient margin. NSW Department of Mineral Resources, 174p.

Roy, P.S, Hudson, J.P. and R. Boyd, 1995. Quaternary geology of the Hunter delta - an estuarine valley fill case study. In Sloan, S., ed. Engineering Geology of the Newcastle-Gosford Region, Conference Proceedings, Australian Geomechanics Society, Newcastle, 64-84.

Scheibner, E., and Basden, H., 1998. Geology of NSW, - Synthesis, Vol. 2, Geological Evolution. Geological Survey of NSW, Memoir Geology, 13, 2.

Sinclair Knight and Partners, 1990. Lower Hunter Valley Flood Mitigation Scheme: Monitoring and Assessment of Bank Erosion in the Hunter, Paterson and Williams Rivers. Public Works Department Report No. 0730559599.

Thom, B.G., Shepherd, M., Ly, C.S., Roy, P.S., Bowman, G.M., and P.A. Hesp, 1992. Coastal Geomorphology and Quaternary Geology of the Port Stephens - Myall Lakes Area. Australian National University, Department of Biogeography and Geomorphology, Monograph 6, 407 p.

Van de Graaff, R.H.M., 1963. Soils of the Hunter Valley. General Report on the Lands of the Hunter Valley, Land Research Series 8, CSIRO, Melbourne, 465-514.

Walker, A., 1999. Quaternary sequence stratigraphy of the lower Hunter River valley. Department of Geology, University of Newcastle, MSc thesis, unpublished, 213 p.

Williams, R.J., Watford, F.A., and V. Balashov, 2000. Kooragang Wetland Rehabilitation Project: History of Changes to the Estuarine Wetlands of the Lower Hunter River. NSW Fisheries Final Report Series No. 22, 82 p.

Appendix E

References from Technical Report:
The *Terrestrial Ecology of the Hunter River Estuary*
Dr Tracey MacDonald, The Wetlands Centre

Appendix E References

Anisfeld, S.C. and G. Benoit. 1997. Impacts of flow restrictions on saltmarshes: an instance of acidification. Environmental Science and Technology 31(6):1650-1657

Anisfeld, S.C., M.J. Tobin, and G. Benoit. 1999. Sedimentation rates in flow-restricted and restored saltmarshes in Long Island Sound. Estuaries 22(2A):231-244

Barden, W. 1976. Report on public meeting held by Newcastle Flora and Fauna Protection Society in conjunction with the National Trust to discuss action required on Kooragang Island, Fullerton Cove and Hexham Swamp, held at Council chambers, City Hall, on Friday, 28th May,1976. Hunter Natural History 8(2):117-120

Briggs, S. 1977. Flood mitigation. The National Parks Journal 21(2):5-8

Briggs, S.V. 1978. Hexham Swamp - vegetation and waterbird habitats. 1-7

Buckney, R.T. 1987. Three decades of habitat change: Kooragang Island, New South Wales. Nature Conservation: The role of remnants of native vegetation. 1(19):227-232

Browne, R. 2001. School of Biological and Chemical Sciences, The University of Newcastle, NSW, Australia

C.D. Field and Associates. 1983. An investigation of natural areas: Kooragang Island, Hunter River.

Coleman, P.S.J. 1998. Changes in a mangrove/samphire community, North Arm Creek, South Australia. Transactions of the Royal Society of South Australia 122(4):173-178

Committee of advice of flood control and mitigation. 1957. Committee of Advice on Flood Control and Mitigation - interim report number 5. 5:1-36

Conroy, B.A. and P.M. Lake. 1992. A vegetation analysis of Hexham Swamp. 1-7

Dale, P.E.R., K. Burmeister, and G. Mulder. 1998. Impacts of habitat modification on saltmarshes in southeast Queensland. 10(1):174-186

Dames and Moore. 1978. An assessment of the effect on the environment of the proposed Stage II landfill scheme at Kooragang Island, Newcastle, New South Wales.

Douglass, P., J. Johnston, D. Lewis, I. Munro, and T. Yates. 1989. Ironbark Creek: An holistic management approach for a sustainable ecosystem. Volume One: The Report. 1-51

Dunstan, D.J. 1968. Fisheries destroyed by unchecked estuarine development. The Fisherman 2(12):1-8

Dunstan, D.J. 1990. Some early environmental problems and guidelines in New South Wales estuaries. Wetlands (Australia) 9(1):1-6

Ericsson, L.J. 1990. Dieback in the Grey Mangrove: a case study in Ironbark Creek, Hunter Estuary. 1-102

Hamer, A. 2001. School of Biological and Chemical Sciences, The University of Newcastle, NSW, Australia

Hunter Bird Observers Club, Monthly Wader Count, Hunter River Estuary, September – October, 2000

Hunter Valley Conservation Trust. 1958. Hunter Valley Conservation Trust Annual Report, 1958 - 1969.

Hutchings, P. 1983. The wetlands of Fullerton Cove, Hunter River, New South Wales. Wetlands (Australia) 3(1):12-19

http://www.environment.gov.au/water/wetlands/ramsar/site/site24.htm. 17.01.2001

Ironbark Creek TCM Committee. 1995. Ironbark Creek Draft TCM Strategy. 1-54

James B. Croft and Associates. 1980. Environmental impact statement for an aluminium smelter at Tomago, NSW.

Landsystems EBC Pty Ltd. 1994. Kooragang Wetland Rehabilitation Project Strategic Landscape Plan. 1-50

Loneragan, N.R. and S.E. Bunn. 1999. River flows and estuarine ecosystems: implications for coastal fisheries from a review and a case study of the Logan River, southeast Queensland. Australian Journal of Ecology 24:431-440

MacDonald, T.A. 2001. Investigating the estuarine wetlands of the lower Hunter River: rehabilitation potential of tidal reinstatement following degradation caused by tidal restriction. The University of Newcastle, NSW, Australia. Unpublished PhD thesis.

MacDonald Wagner Engineers Managers. 1984. Ecological study of State Highway No. 23 (Shortland to Pacific Highway Corridor). 1-118

Maddock, M. 1983. Hunter Valley wetlands birds raise conservation issues. Wetlands (Australia) 3(2):71-80

Mahony, M. 2001. School of Biological and Chemical Sciences, The University of Newcastle, NSW, Australia

McDonald, K. 1972. Notes on the vegetation of Kooragang Island. Hunter Natural History 4(3):216-219

McGregor, W.N. 1980. The environmental effects of flood mitigation with particular reference to floodgate structures on estuarine tidal creeks. 1-130

McLoughlin, L. 1987. Mangroves and grass swamps: changes in the shoreline vegetation of the middle Lane Cove River, Sydney, 1780's - 1880's. Wetlands (Australia) 7(1):13-24

Middleton, M.J., M.A. Rimmer, and R.J. Williams. 1985. Structural flood mitigation works and estuarine management in New South Wales - case study of the Macleay River. Coastal Zone Management Journal 13:1-23

Moss, J. 1977. Hunter Regional Plan - working paper No. 18 - Wetlands. 10-18

New South Wales Department of Conservation. 1948. Report of Hunter River Flood Mitigation Committee.

New South Wales Department of Public Works. 1965. Lower Hunter Valley Flood Mitigation Scheme. 1

New South Wales Department of Public Works. 1972. Hunter Valley Flood Mitigation. Hexham Swamp Environmental Impact Report. 1-30

New South Wales Department of Public Works. 1980. The Lower Hunter Valley Flood Mitigation Scheme.

New South Wales National Parks and Wildlife Service. 1996. Kooragang Nature Reserve and Hexham Swamp Nature Reserve: Draft Plan of Management. 1-47

New South Wales National Parks and Wildlife Service. 2001. Atlas of New South Wales Wildlife Data

New South Wales State Pollution Control Commission. 1972. Inquiry into pollution from Kooragang Island, reports and findings of the commissioner.

Newcastle City Council and Port Stephens City Council. 1994. Lower Hunter River Flood Study (Green Rocks to Newcastle). PWD91077:1-48

Outhred, R.K. and R.T. Buckney. 1983. The vegetation of Kooragang Island, New South Wales. Wetlands 3(2):58-70

Pressey, R.L. 1981. A survey of the lower Hunter floodplain, New South Wales. 1-92

Pressey, R.L. and M.J. Middleton. 1982. Impacts of flood mitigation works on coastal wetlands in New South Wales. Wetlands (Australia) 2:27-44

Ruello, N.V. 1976. Environmental and biological studies of the Hunter River. Operculum :76-84

Saintilan, N. and T.R. Hashimoto. 1999. Mangrove-saltmarsh dynamics on a bay-head delta in the Hawkesbury River estuary, New South Wales, Australia. Hydrobiologia 413:95-102

Saintilan, N. and R.J. Williams. 1999. Mangrove transgression into saltmarsh environments in south-east Australia. Global Ecology and Biogeography Letters 8(2):117-124

Shortland Wetlands Centre and TUNRA. 1992. Kooragang Island Wetland Compensation Project Feasibility Study. 1-52

Sinclair and Knight, C.E. 1971. Tomago-Williamtown-Longbight Flood Mitigation. 1-28

Sinclair Knight and Partners Pty Ltd. 1981. New South Wales Coastal Rivers Floodplain Management Studies. Summary Report - Hunter Valley. 1-29

Streever, W.J., L. Wiseman, P. Turner, and P. Nelson. 1996. Short term changes in flushing of tidal creeks following culvert removal. Wetlands (Australia) 15(1):21-29

Svoboda, P.L. and C. Copeland. 1998. Kooragang wetland rehabilitation project: evolution of an Australian rehabilitation project in an urban setting. 1(1):749-759

van Gessel, F. and T. Kendall. 1974. Report on the proposed "natural area" on Kooragang Island. Hunter Natural History 6(2):81-86

West, R.J., C.A. Thorogood, T.R. Walford, and R.J. Williams. 1985. An estuarine inventory for New South Wales. 2

Williams, R.J., J. Hannan, and V. Balashov. 1995. Kooragang Wetland Rehabilitation Project: Fish, decapod crustaceans and their habitats. 1-106

Williams, R.J. and F.A. Watford. 1997. Change in the distribution of mangrove and saltmarsh in Berowra and Marramarra Creeks, 1941 - 1992. 1-21

Williams, R.J. and F.A. Watford. 1999. Distribution of seagrass, mangrove and saltmarsh in the Cowan Creek catchment management area - a report to the SHURE and the Cowan Creek Catchment Management Committee. 1-27

Williams, R.J., F.A. Watford, and V. Balashov. 2000. Kooragang Wetland Rehabilitation Project: History of changes to estuarine wetlands of the Lower Hunter River. 22:1-82

Winning, G. 1992. Western Kooragang Island Vegetation Study. 1-17

Winning, G. 1996. Vegetation of Kooragang Nature Reserve and Hexham Swamp Nature Reserve and adjoining land. 1-15

Appendix F

References from Technical Report:
Hunter Estuary Process Study: Aquatic Ecology
The Ecology Lab

Appendix F References

Batley, G.E. and Brockbank, C.I. (1994). *Investigation Report CET/IR263B - Monitoring Studies of Sediments from the Port of Newcastle*, Investigation Report - Monitoring Studies of Sediments from the Port of Newcastle, CET/IR263B. Prepared for: MSB Hunter Ports Authority. CSIRO,

Battaglene, S.C. (1985). *Preliminary Study of the Fish Resources of the Hunter Valley*, Prepared for: Water Resources Commission of NSW. NSW Fisheries, Cronulla, NSW.

Birch, G., Ingleton, T., and Taylor, S. (1997). Environmental Implications of Dredging in the World's Second Largest Coal Exporting Harbour, Port Hunter, Australia. *J Mar Env Eng* **4**, pp. 133-145.

Bray, G. (1994). *Regional Statistics New South Wales*, Catalogue No. 1304.1. Australian Bureau of Statistics, Canberra, ACT.

Broadhurst, M.K., Kennelly, S.J., Watson, J.W., and Workman, I.K. (1997). Evaluations of the Nordmore Grid and Secondary Bycatch-Reducing Devices (BRD's) in the Hunter River Prawn-Trawl Fishery, Australia. *Fishery Bulletin* **95**, pp. 209-218.

Centre for Research on Introduced Marine Pests (1999). *Introduced Species Survey, Newcastle, New South Wales*, CSIRO Marine Research, Hobart, Tasmania.

Chapman, M.G. and Underwood, A.J. (1995). Mangrove Forests. In: *Coastal Marine Ecology of Temperate Australia*, Underwood, A. J. and Chapman, M. G., (eds). University of New South Wales Press Ltd, Sydney. pp. 187-204.

Commission of Inquiry Environment and Planning (1991). *Aluminium Fluoride Plant Complex Australia Limited Kooragang Island, Newcastle*, Prepared for: Minister for Planning and Minister for Energy. Commissioners of Inquiry Environment and Planning, NSW.

Copeland, C.A. (1993). *The Ironbark Creek Ecosystem - Section 2: Ecosystems Task Group Report* , Prepared for: Hunter Catchment Management Trust, Maitland, NSW.

DeGrave, S. and Whitaker, A. (1999). Benthic Community Re-adjustment Following Dredging of a Muddy-Maerl Matrix. *Marine Pollution Bulletin* **38**, pp. 102-108.

EPA (1995). *Hunter Environmental Monitoring Program 1992-1994*. Environment Protection Authority, Sydney, NSW.

EPA (1996). *Hunter Environment Monitoring Program 1992-1996*, Environment Protection Authority, Sydney, NSW.

EPA, Department of Land & Water Conservation (DLWC), NSW Agriculture, NSW Fisheries, and NSW National Parks & Wildlife Service (NPWS) (1997). *Proposed Interim Environmental Objectives for NSW Waters: Hunter Catchment*, Prepared for: NSW Government. Environment Protection Authority of NSW (EPA), Sydney, NSW.

Erskine, W. D. (1985). Downstream geomorphic impacts of large dams: the case of Glenbawn Dam, NSW. *Applied Geography* **5,** pp. 195-210.

Field and Associates (1983). *An Investigation of Natural Areas, Kooragang Island, Hunter River*, Prepared for: Insearch Ltd. (commissioned by the Dept. of Env. & Plng.). C.D. Field and Associates, Sydney.

Gibbs, P., McVea, T., and Louden, B. (1999). *Utilisation of Restored Wetlands by Fish and Invertebrates*, NSW Final Report Series No.16, FRDC Project No. 95/150. NSW Fisheries, Pyrmont.

Glasby, T. M. and Connell, S. D. (1999). Urban structures as marine habitats. *Ambio* **28**, pp. 595-598.

Godrick, G. N. (1973). A survey of wetlands of coastal N.S.W. Technical memorandum No. 5. CSIRO Wildlife Research, 36 pp.

Hodda, M. and Nicholas, W.L. (1985). Meiofauna Associated with Mangroves in the Hunter River Estuary and Fullerton Cove, South-eastern Australia. *Australian Journal of Marine and Freshwater Research* **9**, pp. 41-48.

Hodda, M. and Nicholas, W.K. (1986). Nematode Diversity and Industrial Pollution in the Hunter River Estuary, NSW, Australia. *Marine Pollution Bulletin* **17**, pp. 251-255.

Hodda, M. and Nicholas, W.L. (1990). Production of Meiofauna in an Australian Estuary. *Wetlands* **9**, pp. 41-48.

Hutchings, P. (1983). The Wetlands of Fullerton Cove, Hunter River, New South Wales. *Wetlands* **3**, pp. 12-21.

Ingleton, T.C. and Birch, G.F. (1995). *The Impact of Urban and Industrial Development on the Hunter River*. In: Proceedings of the Twenty Ninth Newcastle Symposium on "Advances in the Sydney Basin", University of Newcastle, 6-9, 1995, Boyd, R. L. and MacKenzie, G. A. (eds). Department of Geology, University of Newcastle, Newcastle.

Inglis, G. (1995). Intertidal Muddy Shores. In: *Coastal Marine Ecology of Temperate Australia*, Underwood, A. J. and Chapman, M. G., (eds). University of New South Wales Press Ltd, Sydney. pp. 171-186.

Johnston, S. A. (1981). Estuarine dredge and fill activities: a review of impacts. *Environmental Management* pp. 427-440.

Jones, A. R. (1986). The effects of dredging and spoil disposal on macrobenthos, Hawkesbury Estuary, N.S.W. *Marine Pollution Bulletin* **17 No.1**, pp. 17-20.

Kaplan, E.H., Welker, J.R., Kraus, M.G., and McCourt, S. (1975). Some Factors Affecting the Colonization of a Dredged Channel. *Marine Biology* **32**, pp. 193-204.

Maddock, M. (1983). Hunter Valley Wetland Birds Raise Conservation Issues. *Wetlands* **3**, pp. 71-80.

McGregor, W.N. (1980). *The Environmental Effects of Flood Mitigation With Particular Reference to Floodgate Structures on Estuarine Tidal Creeks*, Prepared for: State Pollution Control Commission of New South Wales. State Pollution Control Commission of New South Wales, Australia.

McGuinness, K.A. (1988). *The Ecology of Botany Bay and the Effects of Man's Activities: a Critical Synthesis*, The Institute of Marine Ecology, University of Sydney, Sydney, NSW.

Morrisey, D. (1995). Saltmarshes. In: *Coastal Marine Ecology of Temperate Australia*, Underwood, A. J. and Chapman, M. G., (eds). University of New South Wales Press Ltd, Sydney. pp. 152-170.

New South Wales Government (1992). *Estuary Management Manual*, NSW Government Printing Office, NSW.

NSW Fisheries (1999). *Status of Fisheries Resources 1998/99*, Prepared for: NSW Fisheries Research Institute. NSW Fisheries Research Institute, Cronulla, NSW.

Outhred, R.K. and Buckney, R.T. (1983). The Vegetation of Kooragang Island, NSW. *Wetlands* **3**, pp. 58-70.

Patterson Britton & Partners Pty Ltd (1996). *A Study to Assist in Preparation of a Long Term Sea Dumping Strategy Port of Newcastle*, Prepared for: Newcastle Port Corporation. Patterson & Britton & Partners Pty Ltd, North Sydney NSW.

Ruello, N.V. (1973a). Burrowing, Feeding, and Spatial Distribution of the School Prawn *Metapenaeus Macleayi* (Haswell) in the Hunter River Region (Australia). *Journal of Experimental Marine Biology and Ecology* **13**, pp. 189-206.

Ruello, N.V. (1973b). The Influence of Rainfall on the Distribution and Abundance of the School Prawn *Metapenaeus Macleayi* in the Hunter River Region (Australia). *Marine Biology* **23**, pp. 221-228.

Ruello, N.V. (1976). Environmental and Biological Studies of the Hunter River. *Operculum* pp. 76-83.

Shepherd, M. (1994). *A Report to the Ecosystem Group of Ironbark Creek Catchment Management Committee on the Effects of Flood Mitigation Structures of Ironbark Creek on the Fish and Prawn Populations of the Mangrove Swamp Community*, Prepared for: Ironbark Creek Catchment Management Committee. Macquarie University, Macquarie University, NSW.

Sinclair Knight Merz (1994). *Proposed Augmentation of Shortland WWTW - Environmental Impact Statement Final Draft No.2*, Prepared for: Hunter Water Corporation. Sinclair Knight Merz, Sydney, NSW.

SPCC (1989). *Coastal Resource Atlas for Oil Spills in and Around the Port of Newcastle*, State Pollution Control Commission (now NSW EPA), Sydney NSW.

Streever, W.J. and Genders, A.J. (1997). Effect of Improved Tidal Flushing and Competitive Interactions at the Boundary Between Salt Marsh and Pasture. *Estuaries* **20**, pp. 807-818.

Streever, W.J., Wiseman, L., Turner, P., and Nelson, P. (1996). Short Term Changes in Flushing of Tidal Creeks Following Cluvert Removal. *Wetlands* **15**, pp. 22-30.

Tam, N. F. Y. and Wong, Y. S. (1995). Mangrove soils as sinks for wastewater-borne pollutants. *Hydrobiologia* **295**, pp. 231-241.

The Ecology Lab Pty Ltd (1993). *Kooragang Island Saltmarshes and Mangroves – a Site Inspection*. Prepared for: GHD Pty Ltd. The Ecology Lab Pty Ltd, Sydney, NSW.

The Ecology Lab Pty Ltd (1997). *Investigation of Bioaccumulation in Estuarine Fauna, South Arm of the Hunter River*, Prepared for: CMPS & F. The Ecology Lab Pty Ltd, Sydney, NSW.

The Ecology Lab Pty Ltd (1998). *Bioaccumulation in Aquatic Fauna From the Hunter River - Final Report*, Prepared for: CMPS & F. The Ecology Lab Pty Ltd, Sydney, NSW.

The Ecology Lab Pty Ltd (1999). *Bioaccumulation of Heavy Metals in Oysters Deployed Near a Dredging Operation, Newcastle Harbour*, Prepared for: Patterson Britton & Partners. The Ecology Lab Pty Ltd, Balgowlah, NSW.

Timperley, M. and Kuschel, G. (1999). Swat's Up, Doc? - The Effects of Stormwater and Transport on Urban Streams and Estuaries. *Water & Atmosphere* **7**, pp. 22-25.

Walsh, C.J. (2000). Urban Impacts on the Ecology of Receiving Waters: a Framework for Assessment, Conservation and Restoration. *Hydrobiologia* **431**, pp. 107-114.

West, R.J., Thorogood, C.A., Walford, T.R., and Williams, R.J. (1985). *An Estuarine Inventory for New South Wales, Australia*, Division of Fisheries, NSW Department of Agriculture, Sydney, Australia.

Williams, R.J. and Watford, F.A. (1996). An Inventory of Impediments to Tidal Flow in NSW Estuarine Fisheries Habitat. *Wetlands* **15**, pp. 44-54.

Williams, R.J., Hannan, J., and Balashov, V. (1995). *Kooragang Wetland Rehabilitation Project: Fish, Decapod Crustaceans and Their Habitats*, Prepared for: Kooragang Wetland Rehabilitation Project. NSW Fisheries, Cronulla, NSW.

Williams, R.J., Watford, F.A., and Balashov, V. (2000). *Kooragang Wetland Rehabilitation Project: History of Changes to Estuarine Wetlands of the Lower Hunter River*, NSW Fisheries Final Report Series, 22. NSW Fisheries, Cronulla, NSW.

Williamson, R.B. and Morrisey, D.J. (2000). Stormwater Contamination of Urban Estuaries. 1. Predicting the Build-Up of Heavy Metals in Sediments. *Estuaries* **23**, pp. 56-66.

Appendix G

References from Technical Report:
Hunter Estuary Water Quality; Data Review and Analysis
Dr Brian G. Sanderson and Dr Anna M. Redden, University of Newcastle

Appendix G References

AEC 1987. *Nutrients in Australian Waters*. Report #19, AGPS, Canberra.

ANZECC 1992. *Australian Water Quality Guidelines for Fresh and Marine Waters,* Australian and New Zealand Environment and Conservation Council.

Avery E. and R. Main. 1999. *Hunter Estuary Data Compilation Report.* NSW Department of Land and Water Conservation, Hunter Region.

Bartram, J. and R. Ballance. 1996. Water Quality Monitoring, E & FN Spon, London, 383 pp.

Center for Coastal Management. 2000. *Brunswick River Estuary Study, Water Quality Assessment Report*, Southern Cross University.

Laxton, J. H. 1997. *Water Quality of Gosford Lagoons and Brisbane Water (1996)*, Gosford City Council.

Neumann G. and W. J. Pierson. 1966. *Principles of Physical Oceanography*, Prentice-Hall Inc., Englewood Cliffs, NJ.

Parsons T. R., M. Takahashi and B. Hargrave. 1977. *Biological Oceanographic Processes*, second edition, Pergamon Press Ltd, 332 pp.

Sanderson B. G. and B. K. Pal. 1990. *Patch diffusion computed from Lagrangian data, with application to the Atlantic Equatorial Under Current*. Atmosphere Ocean 28(4), 444-465.

Sanderson B. G., I. T. Webster, S. Kioroglou, A. Okubo and R. Appeldoorn. 1995. *Chaotic drifter trajectories on the southwestern Puerto Rican insular shelf*. Mathematical and Computer Modelling, 21(6), 39-63.

Sanderson B. G. and A. M. Redden (in prep.) *Salinity Structure of the Hunter River Estuary.*

Walker J. W., J. Lawler and R. Kadluczka. 1999. *Shortland Wastewater Treatment Works Diffuser Performance Study,* Hunter Water Corporation.

Appendix H

Draft Scope of Works for Hunter Estuary Management Study and Management Plan

HUNTER ESTUARY
MANAGEMENT STUDY
AND MANAGEMENT PLAN

DRAFT SCOPE OF WORKS

NSW Department of Commerce
Manly Hydraulics Laboratory

Foreword

A requirement of the brief for the Hunter Estuary Processes Study was for the NSW Department of Public Works and Services' Manly Hydraulics Laboratory (MHL) to prepare a draft Scope of Works for the Estuary Management Study and Management Plan.

This draft scope of works is provided to the Hunter Coast and Estuary Management Committee (HCEMC) for their consideration and possible incorporation into a brief for the ensuing studies.

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1. The Study Area

The study area, as defined in the NSW Government Estuary Management Manual, essentially comprises:

- the waterway of the Hunter estuary
- the foreshore and adjacent lands, including wetlands whether saline, brackish or fresh, and
- any tributary rivers or creeks up to the limit of tidal influence.

When considering the appropriateness of data, consideration is also given to the wider catchment, insofar as it may impact on the estuarine environment. In the case of the Hunter estuary, this includes the catchments of the Hunter River, Paterson and Williams rivers, Wallis and Fishery creeks, Ironbark Creek, and Throsby, Styx and Cottage creeks.

The Hunter River estuary is typical of the larger NSW estuaries that have evolved over the millennia through various climatic periods and sea level variations to the present day. The estuary is a drowned river valley with an extensive floodplain delta where the river meanders to the sea. The estuary lies at the confluence of the Hunter River, Paterson and Williams rivers, Wallis and Fishery creeks, Ironbark, Throsby, Styx and Cottage creeks. The total waterway area of the estuary is approximately 26 km^2.

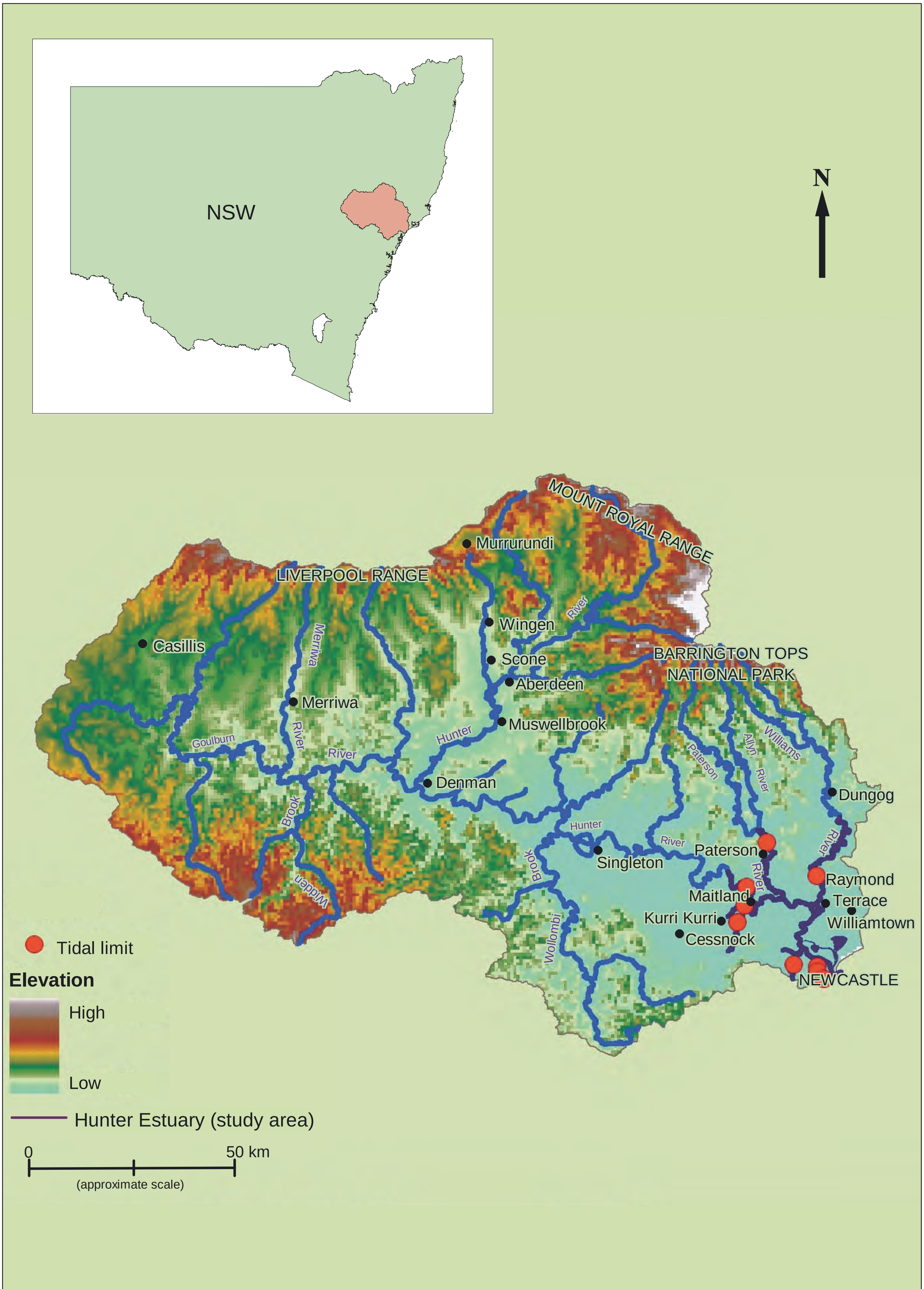
The Hunter River catchment is one of the largest in NSW and reaches further inland than any other catchment, covering an area of approximately 22,000 km^2. The Hunter catchment is bound by the Liverpool Range, Mount Royal Range and Barrington Tops to the north, and the Hunter Range to the south (Figure 1.1). Major tributaries of the Hunter River catchment include the Goulburn River, Wollombi Brook, Merriwa River, Paterson and Allyn rivers, and Williams River. Originating in the Mount Royal Range, the Hunter River is approximately 300 km long, and enters the sea at the port of Newcastle (Figure 1.1). Newcastle, which is a major coal exporting port, is NSW's second largest city with a population of around 135,000. The tidal limit in the Hunter River occurs in the vicinity of Oakhampton, approximately 65 km from the ocean.

The Paterson and Williams rivers together with the Allyn River drain an area of 2,230 km^2 to the north of the catchment, including the Barrington Tops which receive some of the heaviest rainfall for the Hunter River catchment (Figure 1.1). The tidal limit of the Paterson River extends to Gostwyck approximately 75 km from the ocean. . The Paterson River channel is typically narrow and shallow. Seaham Weir prematurely limits the tidal influence on the Williams River, approximately 47 km from the ocean.

Wallis and Fishery creeks drain an area of approximately 404 km^2 area in the upper estuary, and enter the Hunter River 3 km downstream of Maitland. The catchment incorporates rural, forested and urban areas. The channels are typically narrow and shallow, with steep levee banks, and tidal exchange in the creeks is affected by a floodgate at Wallis Creek. The tidal limit on Wallis Creek extends close to Cliftleigh approximately 68 km from the ocean. The tidal limit on Fishery Creek extends to Louth Park approximately 65 km from the ocean.

Ironbark Creek drains an area of 125 km^2 in the lower Hunter estuary, which includes urban, rural, forested land and wetland, in particular Hexham Swamp (Figure 1.2). Tidal exchange in Ironbark Creek is affected by the construction of a floodgate near the mouth of the creek. The channel is typically narrow, reaching its tidal limit near Wallsend where the creek has been converted to a concrete drain, approximately 20 km from the ocean.

Throsby, Styx and Cottage creeks drain the large urban and industrial areas of Newcastle (Figure 1.2), with a combined catchment area of approximately 48 km^2 entering into Throsby Basin and Newcastle port. Throsby Creek is a concrete canal upstream of Hannell Street bridge, and the tidal limit extends to approximately to Mayfield, 8.5 km from the river entrance. Styx and Cottage creeks are both open concrete drains their entire length. The tidal limit on Styx Creek extends approximately to Hamilton in Newcastle 8 km from the ocean, and the tidal limit of Cottage Creek extends to The Junction (5.5 km from the ocean).



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HUNTER RIVER CATCHMENT

MHL Report 1095

Figure 1.1

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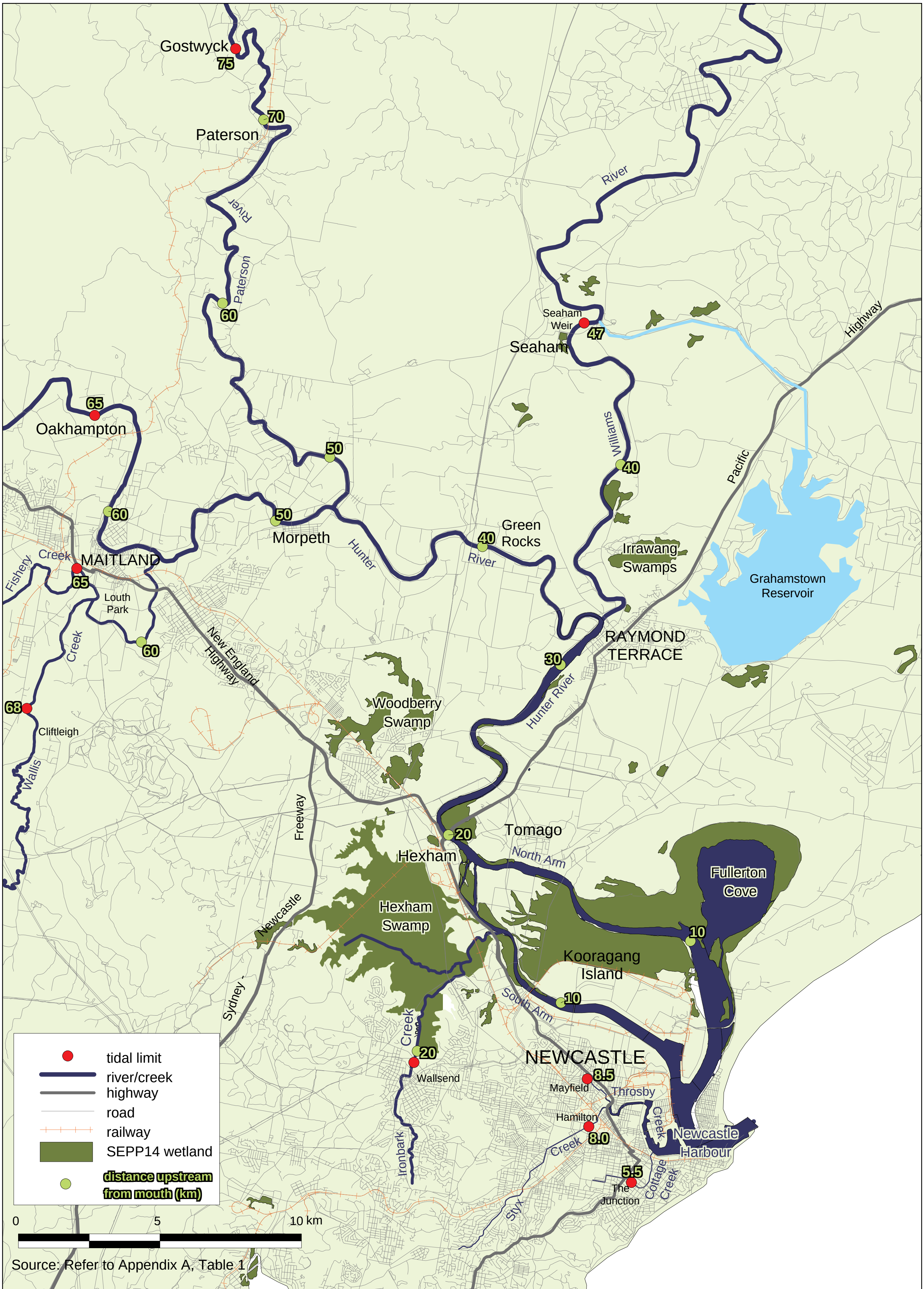

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MANLY HYDRAULICS LABORATORY

HUNTER ESTUARY STUDY AREA

MHL Report 1095

Figure 1.2

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2. Objectives

2.1 Objective

The primary objective of the investigations proposed is the preparation of an Estuary Management Study and Estuary Management Plan for the Hunter River estuary in accordance with the requirements of the NSW Government Estuary Management Manual (draft). This management plan will provide the strategy and framework for the management of the estuary in the foreseeable future.

2.2 Estuary Management Study

The Management Study will:

- identify and describe the likely future development pressures confronting the Hunter estuary and catchment with particular reference to existing and perceived problems
- identify management objectives which address these existing or perceived adverse impacts and which seek to balance competing community demands for the use of the estuary and the catchment at present and for the future
- evaluate options for achieving these objectives
- reconcile these options with the competing stakeholder expectations through a program of community consultation, and
- recommend an overall strategy based on these options.

An important outcome of the Management Study will be the development of a decision-making process for evaluating likely future changes to the catchment and the estuary resulting from any proposed usage, activity or development and for determining the likely impact of these changes on the performance and condition of the estuary.

2.3 Estuary Management Plan

The Estuary Management Plan will be prepared concurrently with the Management Study and finalised once the Management Study has been accepted by the Committee. The objective is to prepare an Estuary Management Plan which best achieves and implements the recommended management objectives developed in the Management Study.

The primary focus of the plan will be the implementation of management strategies and planning controls to achieve the objectives of the Committee for the conservation, restoration and use of the estuary and catchment. As appropriate a program of achievable remedial measures and works may be included in the management plan.

An important outcome from the Management Plan will be the implementation of an ongoing monitoring program aimed at:

- monitoring the condition of the various physical and chemical aspects of the estuary and the environment so that potential problems may be readily identified, and
- overall assessment of the condition of the estuary for future reference through monitoring of identified parameters which are repeatable and measurable.

3. Scope of Works

3.1 Estuary Management Study

The Estuary Management Study will use the information gathered and collated during the Data Compilation Study and the Estuary Processes Study to evaluate a range of management options for the estuary and then recommend an overall strategy, encompassing the appropriate aspects of these options.

The consultant will be able to access via the Committee any information gathered during the estuary processes study, which includes the water quality database.

The management study should be cognisant of the need to ensure the long-term conservation of the important values of the estuary and catchment which include the waterway integrity, water quality, ecosystem productivity, habitat and species diversity, recreational and commercial activity. The management study and plan should also consider the objectives of other planning strategies and policies such as the Lower Hunter Valley Floodplain Management Study and Plan to ensure an integrated approach with compatible and achievable objectives.

Based on the broad requirements of the Estuary Management Manual, the Management Study will, amongst other things, seek to:

- identify the significance of the Hunter estuary in terms of broader catchment and coastal zone planning issues;
- identify 'essential features' of the estuary, be they physical, chemical, biological, aesthetic; social or economic;
- document the current uses and conflicts of use in the estuary and identify strategies to resolve these conflicts;
- identify possible future land use activities and assess their impact on the objectives adopted for the future management of the estuary;
- assess any requirements for conservation of important environments and habitats and any remedial measures necessary to restore the value of degraded environments or habitats;
- identify and assess management objectives for the estuary;
- assess planning controls, works and strategies to achieve these objectives; and
- recommend an overall management strategy for consideration and development into a Management Plan for the estuary.

The Management Study will define the management objectives for the estuary. It will then outline a range of options for management of the estuary to achieve these objectives and evaluate the likely impacts of these options on the use and values of the estuary. The investigation should address the available funding sources for the various options and provide a preliminary cost benefit analysis for each option to assist in the selection process.

In considering the appropriate objectives, a matrix of issues has been identified by the Hunter Coast and Estuary Management Committee and these were addressed through the Estuary Processes Study. The tabulation of these issues and the comments relevant to these issues arising from the Estuary Processes Study are provided in Table 1. The consideration of issues/ objectives should not be limited to these identified concerns but must explain how (if at all) each of these concerns will be addressed by the proposed strategies.

Fundamental to the future health of the estuary will be a plan for improving water quality, rehabilitating estuarine habitat, restoring riparian vegetation and managing waterway activities.

An important outcome of the Management Study will be the development of a decision-making/evaluation process which will allow the assessment of the significance or otherwise of management strategies, development proposals and activities in terms of the key values of the estuary. It is proposed that this process will provide a valuable tool for the ongoing management of the estuary.

3.2 Draft Estuary Management Plan

The draft estuary management plan will comprise a scheduled sequence of recommended activities that need to be undertaken to achieve the estuary management objectives. The management plan will clearly identify those aspects which are considered once-off works or measures and those aspects which contain an ongoing commitment to works or measures. The funding implications of each will be summarised and they must be achievable.

The plan will take into account the considered views of all parties on the Estuary Management Committee. The plan may incorporate compensatory balances to accommodate differing viewpoints.

The management plan will incorporate:

- a clearly stated objective for the management of the estuary
- a prioritised program of works and strategies to implement the plan which clearly identifies capital and recurrent elements
- a costed program including consideration of funding sources for implementation of the programmed works and strategies
- relevant statutory requirements to be considered during implementation of the plan, and
- a detailed and costed monitoring program to
  - assess the health and condition of the estuary, and
  - to measure the effectiveness of elements of the management strategy once they have been implemented.

3.3 Community Consultation

Fundamental to the success of the management study and the management plan is a sense of ownership by the local community. This will be achieved through a process of community consultation to be implemented by the consultant.

The consultant will detail the methods to be employed to facilitate community participation in the estuary management process including strategies for public exhibition of the preliminary and final report on the management study.

It is expected that, in addition to formal public meetings/workshops and attendance at Estuary Management Committee meetings, the consultant will demonstrate capacity for widespread liaison with the community through contact with broad sections of the community at large and including recreational groups, commercial groups and user groups and organisations with an interest in the estuary and catchment.

It is suggested that a minimum of two public meetings/workshops be held to gain feedback on the management options and to canvass public support for the management strategy during the management study. Given the size of the catchment, these public meetings would need to be repeated at a minimum of three locations throughout the catchment on consecutive nights.

The consultant will allow for attendance at a minimum of four meetings of the Estuary Management Committee including one at commencement of the study, concurrently with the public meetings and a final meeting to present the draft management plan.

Table 1 Understanding Issues and Processes in the Hunter Estuary

ISSUE	MAIN PROCESS	HUMAN INFLUENCE	NATURAL SYSTEM	INFORMATION GAPS	SOLUTIONS
Loss of Habitat	• restriction of tidal inundation to estuarine wetlands	• land use – clearing of habitat for rural activities and urban areas • land reclamation • flood mitigation works (including levees, drains, culverts, floodgates etc.)	• change in hydrology and hydraulic processes • change in tidal regime • conversion of saline vegetative systems to fresh/ brackish systems • changes in fish/invertebrate assemblages • threatened species, key habitats affected	• lack of data about effects of habitat loss on aquatic and terrestrial flora and fauna species • accurate mapping not completed for the whole estuary • Accuracy of LHCCREMS mapping requires improvement for management purposes	• identify key ecological relationships between habitats and the species they support (e.g. food, breeding grounds, shelter etc.) • monitor remediation plans in place (e.g. Wallis Creek and Ironbark Creek floodgate openings) • Incorporate detailed mapping already available. Central body required to co-oridnate regular updates once mapping has been revised. • remediation plans for loss of riparian vegetation
	• increased spatial extent of mangrove communities at the expense of saltmarsh • increased spatial extent of mangroves	• land use (e.g. agricultural development and urbanisation) • flood mitigation works	• change in tidal regime • climate change • increased sedimentation in tidal flat areas (e.g. Fullerton Cove)	• lack of understanding of processes leading to mangrove incursion into saltmarsh areas	• identify key ecological processes that alter the co-existence balance between saltmarsh and mangroves • catchment based approach to decrease sediment input
	• introduction of non-indigenous vegetation and faunal species to the estuary	• land use – clearing of habitat for rural activities and urban areas	• change in distribution of native vegetation • competition for habitat and food • reduction in biodiversity	• lack of data relating to the presence and abundance of native mammalian, reptilian and plant species in Hunter River estuary	• improve understanding of native and non-native species in areas where studies not undertaken • utilise community groups e.g. Landcare for onground works (already occurring)

ISSUE	MAIN PROCESS	HUMAN INFLUENCE	NATURAL SYSTEM	INFORMATION GAPS	SOLUTIONS
Port operations	• introduction of exotic marine organisms into the marine environment through ballast water	• regional economy (e.g. port industry and shipping)	• competition for habitat and food • change in biodiversity	• there is little data about the effects of non-native species on native marine species in the Hunter estuary, but significant effects have been recorded elsewhere • lack of data on native marine species present in the Hunter River estuary	• Keep up to date with information provided by Australian Ballast Water Adivsory Council
Port operations (continued)	• dredging of the harbour for maintenance of waterways and port-related development	• regional economy (e.g. port industry and shipping)	• mobilisation of metals • change in hydrology and hydraulic processes	• lack of data about effects of dredging on marine biota and fish migration • lack of data on metal mobilisation processes and rates	• while the studies carried out so far do not indicate that metals are easily mobilised by dredging, the contamination in certain 'hot-spots' is so high that the process of mobilisation of contaminants through dredging (and its effects on biota) should be further studied
	• possible dredging of the North Arm for port facilities at Tomago • proposed development in the Newastle Port Environs Proposal	• regional economy (e.g. shipping)	• change in hydrology and hydraulic processes • flora and fauna	• north arm dredging no longer proceeding, however South Arm dredging is being investigated	• impacts on natural environment need to be thoroughly investigated through the EIS process
Erosion	• bank erosion due to floods along the river and its tributaries	• change in land use patterns • flood mitigation structures • cattle grazing	• geomorphology • hydrology and hydraulic processes • climate/rainfall • riparian vegetation	• spatial resolution of rates of erosion	• determine hotspots to enable prioritisation of areas for remediation and revegetation • integrate remediation plans with Hunter Blueprint

Issue	Main Process	Human Influence	Natural System	Information Gaps	Solutions
	• long-term sedimentation and erosion processes and infilling of the estuary	• change in land use patterns • flood mitigation structures	• geomorphology • hydrology and hydraulic processes • tidal regime • flora and fauna	• further information required on major sediment sources within the Hunter River catchment • lack of understanding about contribution of marine sedimentation	• Investigate erosion rates by sub-catchment of the Hunter River • Erosion control at catchment level to minimise the issue • regular hydrosurveys of the estuary • monitoring of marine sediment transport into the estuary
Flooding	• inundation of urban, industrial and natural areas	• change in land use patterns • land reclamation and flood mitigation works	• geomorphology • climate/rainfall • hydrology and hydraulic processes • erosion and sedimentation • flora and fauna	• effects of options for altering current flood mitigation structures •	• utilise modelling to investigate options for altering current flood mitigation structures
Pollution	• build up of contaminated sediments along the south arm of the Hunter River	• industrial activity (e.g. port industry)	• hydrology and hydraulic processes • dispersion • sediment contamination mechanisms • effects on flora/fauna	• lack of data about the effects of contaminants on aquatic and terrestrial flora and fauna and recreational amenity	• study chemical processes concerned with pollution in sediments and effects on living organisms
Water Quality	• industrial, agricultural and urban runoff into the river	• regional economy • sewage • public awareness of environmental problems	• hydrology and hydraulic processes • dispersion • water quality	• data has sparse coverage over broad spatio-temporal domain • lack of information on algal blooms and impacts of blooms on the system	• control of pollution at sources e.g. stormwater retention • better definition of appropriate local guideline values • adoption of sedimentation and erosion controls in a planned manner between councils • monitoring of algal species within the estuary, investigation of impacts on the system
	• leachate from garbage dump fill sites and sewerage overflow	• regional economy • zoning	• hydrology and hydraulic processes • dispersion • water quality	• data has sparse coverage over broad spatio-temporal domain, particularly leachate	• monitoring of leachate required to assess the issue

Issue	Main Process	Human Influence	Natural System	Information Gaps	Solutions
	• sedimentation at stormwater outlets due to non-compliance with sediment and water quality controls in existing and new developments	• commercial activity (e.g. building industry) • urban land use	• geomorphology • hydrology and hydraulic processes • dispersion • water quality	• lack of data about the extent of impact of sediment flows from building sites into the estuary system	• monitoring at stormwater outlets to quantify extent of sedimentation and erosion issues • enforce sedimentation and erosion control guidelines
	• saline discharges from coal mining and power generation	• coal mines and power-generating plants	• hydrology and hydraulic processes • water quality • flora and fauna	• impacts of discharges on water quality and aquatic biota	• localised monitoring of discharges to determine the extent of the issue
	• water extraction reducing freshwater inputs to the estuary	• regional economy • land use	• hydrology and hydraulic processes • water quality • flora and fauna	• lack of information regarding extraction rates for irrigation, and impacts on the estuarine system	• undertake monitoring of water extraction in the Hunter catchment to improve understanding of impacts
	• Groundwater quality and flow	• land use • regional economy	• hydrology and hydraulic processes • recharge of wetlands • water quality • flora and fauna	• lack of information regarding groundwater quality and flow, and influence on wetlands	• undertake monitoring of groundwater quality and flow in the Hunter catchment to improve understanding of impacts on estuary.
Sand and Gravel Extraction	• balance between resource utilisation and effects on natural environment, including river stability	• regional economy (sand and gravel industry) • land use	• geomorphology • bank stability • hydrology and hydraulic processes	• lack of accurate data about quantities that are being extracted • lack of understanding about the effects of sand and gravel extraction on the natural environment	• monitor quantities of sand and gravel extraction • study the changes to the natural environment (e.g. habitats, diversity) in the vicinity of extraction activities • remediation works for riparian zone
Recreational	• conflicts between recreational boating and commercial activities	• recreational and commercial activities	• hydrology and hydraulic processes • water quality	• lack of published data about the types of recreational activities and when and where they take place	• monitor and report on recreational activities and changes to natural environment

ISSUE	MAIN PROCESS	HUMAN INFLUENCE	NATURAL SYSTEM	INFORMATION GAPS	SOLUTIONS
Recreational (continued)	• impacts of recreational activities, including fishing, on natural environment	• recreation • public awareness	• geomorphology • hydrology and hydraulic processes • water quality • flora and fauna (e.g. roost sites) • bank stability	• lack of information about the effects of recreational activities on the natural environment	• a recreational fishing survey is currently being undertaken. Review outcomes of study during management study
	• improvement of public reserves around the river foreshore	• recreation • public participation	• hydrology and hydraulic processes • water quality • riparian vegetation • geomorphology	• lack of information about the types of recreational activities and when and where they take place	• More detailed surveys to prioritise operational programme
	• safety of public using the river	• recreation	• hydrology and hydraulic processes • water quality	• no data on the possible risks involved for the public	• educate the public by placing informative signs about the potential dangers of recreational activities in a natural environment
Heritage	• heritage structures and other visually significant features	• cultural	• geomorphology • hydrology and hydraulic processes	• European heritage sites have been identified. • Further information on areas of Aboriginal significance required from local Aboriginal groups..	• European heritage sites and a limited number of Aboriginal sites have been identified and their conservation is a basic consideration in development plans studies • Co-ordinate input from local Aboriginal groups
Fishing	• conflicts between use of the estuary for commercial fishing and the natural environment	• regional economy • public participation • recreational fishing	• hydrology and hydraulic processes • water quality • flora and fauna	• sustainability of fishery is uncertain • impacts of fishing on roosting sites unknown	• remediation of fish nursery habitats e.g. Hexham Swamp, Koorangang Island • investigate impacts of fishing on roosting sites in lower estuary in order to determine possible hotspots
	• introduction of obstacles to fish passage (including floodgates, low level road crossings and culverts)	• flood mitigation works • land use	• hydrology and hydraulic processes • water quality	• no data about effects on fish and prawn production	• remove obstacles as part of habitat rehabilitation

ISSUE	MAIN PROCESS	HUMAN INFLUENCE	NATURAL SYSTEM	INFORMATION GAPS	SOLUTIONS
Acid sulfate soils	• drainage and disturbance of land containing potential acid sulfate soils	• land use • land reclamation and flood mitigation works	• water quality	• lack of research on occurrence of acid sulfate soils in the Hunter estuary catchment	• identification of priority areas for potential acid sulfate soils and implementation of development controls protect these areas
Climate change	• change in weather patterns and sea level rise		• hydrology and hydraulic processes • change in tidal inundation patterns • flooding • habitats	• lack of knowledge regarding impacts of climate change on local conditions	• investigate local impacts of climate change and include as a consideration in planning, especially foreshore development • mapping of potential increase of inundation zones associated with sea level rise