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NSW Department of
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Hunter Estuary Processes Study

Report MHL1095
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HUNTER ESTUARY PROCESSES STUDY

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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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