Foreword

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

The Hunter Estuary Management Committee was formed in 1997 and amalgamated with the Hunter Coastal Management Committee.

Manly Hydraulics Laboratory, in conjunction with The Wetlands Centre, The Ecology Lab and the University of Newcastle, was commissioned by Newcastle City Council to undertake the second and third stages of the estuary management process for the Hunter estuary.
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1. Introduction

1.1 Aim
The aim of this report is to analyse whether the existing data for the Hunter estuary is sufficient to be able to define the ‘baseline’ conditions of the estuarine processes in a subsequent phase of the Estuary Management Process. For that purpose the current report summarises and synthesises a series of Technical Reports that together provide a comprehensive overview of the estuary characteristics. The Technical Reports have been included as a series of separate reports that address the I) geomorphology, II) terrestrial ecology, III) aquatic ecology, IV) water quality, and V) other characteristics (including hydrology/hydraulics) of the Hunter estuary. The compilation and review of existing data is a vital component of the project as work items may be refined following the review. In short, this synthesis aims to:

- provide an overview of data collected, analysed and interpreted in the context of the Hunter Estuary Processes Study and assess the existing data gaps
- address the implication of the data gaps for management issues
- advise on future data collection issues

1.2 Background
This report uses the Hunter Estuary Data Compilation Report (DLWC 1999) as a starting point. The data sources documented in the data compilation study are not necessarily repeated here. Based on the observations in the aforementioned report, additional data has been collated and analysed. The ‘assembly of existing data’ is the second step of the Estuary Management Process as formulated by the Estuary Management Manual (1992). It forms an essential prerequisite to a successful Estuary Processes Study (step 3).

1.3 Integrated Approach
The primary goal of the NSW Estuary Management Policy is to encourage the integrated, balanced, responsible and ecologically sustainable use of the State’s estuaries (1992). This requires an integrated approach to the estuary system in which the estuarine processes are analysed in their interaction. Yet, due to the complexity of estuary systems, it is difficult to accurately describe the integrated functioning of such a system and its response to changes. Numerous interactions and feedback mechanisms between the various subsystems can be identified. For instance, the economic activities, geomorphological processes and the ecological health of an estuary are tightly coupled and their interrelations need to be understood. The estuary is a dynamic system, which will change over time due to the various...
feedbacks. Apart from these internal dynamics, the estuary is also influenced by certain external influences. These external influences will affect the individual elements as well as the interactions between them. In the light of sustainable estuary management, a full understanding of the processes in the estuary and of external influences, is indispensable.

In general, a physical, ecological and human system can be distinguished in an estuary. These interact in various ways. The total estuary system is also under influence of, for instance, climatic change, political or institutional changes and changes in the world economy. This is schematised in Figure 11.

The physical system represents the natural a-biotic system and addresses physical and chemical processes that are relevant to the estuarine system. This includes issues regarding climate, soils, hydrology, morphology, nutrient and sediment flows in the estuary. The ecological system represents the natural biotic system. It concerns flora and fauna in the estuary and addresses issues of biodiversity, habitat loss, etc. The human system represents the total human activity in the estuary. This includes all socio-economic activity, such as residential, tourist and industrial use of land. It also includes less tangible aspects, such as heritage and the use of the estuary for amenity, cultural and spiritual purposes.

Estuaries around the globe, including the Hunter River estuary, are experiencing increasing pressure from human activity. Historically, man has been attracted to estuaries and other coastal zones for a variety of reasons including fertility of the land, food and other services offered by the environment, transportation facilities or the availability of strategic locations from the viewpoint of trade or defence. Other reasons are of a spiritual, cultural or amenity nature. The attractiveness of the coastal environment, both from an ecological and human point of view, has led to conflicts over scarce resources. Human activities have continuously modified the natural functioning of the estuary system to provide for their needs. These changes may have caused or aggravated problems such as erosion, subsidence and flooding. From a management perspective, the assessment of the long-term behaviour of the estuary in response to direct and indirect human interference and projected changes is an increasingly important issue. Equally important is to assess whether changes are occurring beyond the ‘natural variability’ of the system.

The data that have been collected and analysed will be presented in Section 2 under three broad headings of physical, ecological and human data. In Section 3 the actual linkages between the various parts of the system will be discussed in the context of current concerns in the Hunter estuary.

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2. Data Interpretation

2.1 Introduction

The Hunter region is a coastal region that is part of the interrelated Sydney-Newcastle-Wollongong urban area. It comprises the Hunter and Manning river catchments, the coastal waterways of the Myall and Wallis lakes, Port Stephens and Lake Macquarie (Dept of Planning 1989a). The total Hunter River catchment area is about 20,000 km² (see Figure 2.1). Its regional centre, Newcastle, is located about 180 km north of Sydney. This study concerns the Hunter estuary (see Figure 2.2), which is part of the larger Hunter catchment and the Hunter region. The Hunter estuary has played a significant role in the development of the region, after the first discovery of coal at the Hunter River mouth in the late 1700s.

In this section, an overview is given of the various types of physical, ecological and human data that are available or currently unavailable for the Hunter River estuary. The subdivision that has been made within each of the three major components is shown in Figure 2.3. A discussion is given of the 'importance' of each component, which is determined by the value of the specific data for developing a thorough understanding of the system. Some data can be essential for describing the estuarine system and the lack of this data may be unacceptable from a management point of view.

2.2 Physical Data

2.2.1 Introduction

The physical data that has been collated is represented under a number of general headings, namely climate, geology and soils, hydrology, hydraulics, geomorphology, water quality and sediment quality. Each of these issues is analysed in a more detailed manner in one of the Technical Reports. Here, only a summary of the main findings is presented.

2.2.2 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. The mean annual rainfall in the coastal range of the Hunter catchment is twice that of drier regions in the west of the catchment (Hydrotechnology 1995). Furthermore:

- 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 in the Hunter catchment ranges from approximately 700 mm p.a. inland to 1,600 mm p.a. on the coast and at Barrington Tops;
- summer wind speed and direction is predominantly from the east and north-east, with westerly winds dominating in winter;
- evaporation, with high values in summer and lower values in winter, ranges 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.
• global solar radiation is lowest in winter (mean 7 MJ/m²) and highest in summer (mean 22 MJ/m²) Mean values vary largely from day to day depending on weather conditions (clouds etc.)
• climatic changes may severely affect coastal areas and potential problems need to be accommodated in planning foreshore development, facilities and services

2.2.3 Geology and Soils

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 (Boyd 2001) Figure 24 shows the geology of the Hunter catchment. The types of rocks in the New England Fold Belt are mostly sediments (sandstone, shale, conglomerate and glacial deposits) and volcanics. In the Sydney Basin the same types of rocks can be found, in addition to coal measures. The rocks in the Eastern Australian Passive Margin consist mostly of subaerial lava field flows of alkali basalts. For a more detailed and comprehensive description of the composition, distribution and structure of rocks in the Hunter catchment we refer to Boyd (2001).

The soils of the Hunter Valley (see Figure 2.5), 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. 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). Most of the soil landscapes of the Hunter Valley catchment have a moderate to high erodibility factor based on soil properties.

2.2.4 Hydrology

• 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.
• 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.
• The aquifers in the study area are continually being recharged with fresh rainwater and the groundwater generally has a very low salinity.
• The present flood mitigation scheme comprises 160 km of levees, 3,800 m of spillways, 12 km of flood canals, 245 floodgates, 14 km of bank protection works and 40 km of control banks.
• Flood mitigation works limit tidal flows and can lead to loss of habitat.
2.2.5 *Hydraulics*

The Hunter estuary acts like a typical river 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 Bolwarra, approximately 60 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.
- Measurements of tidal flows at the entrance during spring and neap tides indicate a peak velocity during flood of 0.93 ms\(^{-1}\) and during ebb of 0.99 ms\(^{-1}\).
- Changes in water levels within the estuary are influenced by a range of phenomena that operate at different time scales, including astronomical tides, wind setup, freshwater inputs and floods, ocean storm surges, coastal trapped waves and sea level rise.
- There is a gradual reduction in the mean tidal range 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.
- The water quality in the Hunter, Paterson and Williams rivers is generally typical of an estuary influenced by tides and winds, with tidal forces having the greater impact. There is strong horizontal stratification in salinity, density, pH and backscatterance throughout the system and weak vertical stratification in temperature in the upper reaches.

2.2.6 *Geomorphology*

Over a geological time scale, the major sediment process within the Hunter estuary since sea level stillstand over the past 6,500 years has been deposition. However, once it has infilled, smaller scale deposition adjustments continue to influence the former estuary surface.

In the upper estuary above Hexham, there is both deposition and erosion taking place. Erosion is primarily occurring within the channel. The main processes causing stream bank erosion (Sinclair Knight and Partners 1990) in the Hunter are stream currents, rainfall, seepage, overbank drainage, obstacles in the stream, wave attack, wet-dry cycles, debris, and change in land use patterns. Sediment removal may also occur as stream bank failure, which is caused by swellings of clays due to absorption, pressure of groundwater from within the bank, minor soil movements of creep, change in channel shape due to bed scour or erosion of the bank face, increase of load on top of the bank, and rapid drawdown of water against the bank face. An additional cause of erosion (Sinclair, Knight and Partners 1990) is the removal of the bar at the Hunter entrance in Newcastle, hence causing an increase in tidal range and hence volume of exchanged water in each tidal cycle. The style of stream sedimentation in a low-moderate sandy system such as the lower Hunter is to take a meandering course with deposition on the inside of meander bends, and corresponding erosion on the outside of the bends. It is this style of sedimentation that is responsible for most of the erosion on the lower Hunter River.
The principal processes causing deposition are channel changes of decreased slope or current velocity, and floodplain deposition after flow expansion in floods when the river velocity decreases after leaving the main channel. In general, there is an excess of sediment being supplied to the Hunter estuary in modern times. This excess is derived from changes to the natural state of the river resulting from deforestation and overgrazing. However, the sediment is primarily transported by major floods, and in particular the 1955 flood, the major flood of record. Hence the detailed sedimentation pattern reflects a broad sediment deposition trend but also areas of local sediment erosion. These areas are formed in response to major deposition during the 1955 flood and subsequent attempts to re-establish equilibrium by eroding the channel bed and banks.

The major region of current bank erosion in the estuary is on the lower Hunter between Oakhampton and Morpeth. The remainder of the upper estuary between Morpeth and Hexham is undergoing net deposition.

In the upper estuary above Hexham there are a number of different styles and locations of sediment deposition. The contrast of upstream (5-10 m) to downstream (0-3 m) floodplain elevation possibly reflects the ratio of flood stage to normal stage discharge. Normal stage in the tidal reach is much larger than in the fluvial reach. In addition, there may be a net migration of sediment towards the Raymond Terrace-Hexham reach. This feature has been identified in other tidal estuarine reaches, and results from the confluence of sediment transport downstream from river processes, and upstream from tidal processes. The result is a zone of high sinuosity meanders such as that developed in the Maitland to Morpeth reach at the time of European settlement. Over time the location of this point of confluence migrates downstream and this may explain the recent increased development of meander bends towards Raymond Terrace.

The lower estuary is dominated more by tidal processes than the fluvially dominated upper estuary. Fluvial bedload is considered not to be reaching the lower estuary in significant quantities (Patterson, Britton and Partners 1989). 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 to accumulate on the middle of the continental shelf in water depths below 60 m. Hence the major sedimentation style in the lower estuary is deposition and the estuary is continuing to infill.

The major process of natural deposition in the lower estuary is to accumulate mud in low energy areas. The majority of the natural siltation has occurred in Fullerton Cove and along the northern and southern channels of the river above the Stockton Bridge and the Tourle Street Bridge.

The south channel of the Hunter River received a significant proportion of flow until 1930 when a weir was constructed between Hexham and Ash Island. Subsequently, flow in the north channel was increased at the expense of the south channel which has shoaled (most reaches are less than 2 m deep now) and experienced lateral accretion of the channel margin. The north channel was navigable for ocean-going ships until the 1960s, with ships loading coal at Hexham for transport to Sydney. The channel was maintained by dredging. Since the 1960s the channel has shoaled and the margins have prograded, particularly between Dunns Island and the Tomago Spillway.

A sediment budget (see Boyd 2001) is derived from the available information and conceptualised in Figure 2.6, based on the following considerations.
Based on estimates of mean annual sediment yield for the Hunter River discussed by Erskine (quoted in Patterson Britton 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, also referred to as 'the Port of Newcastle') is of the order of 1 million tonnes per year (Patterson Britton 1989). The actual average of the years 1974-83 was 1.9 million tonnes per year. Patterson Britton (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 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 (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 1995). Because this was a one-off event, it was not included in the sediment budget summary.

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2.2.7 Water Quality

Water quality monitoring measurements, made by the Hunter Water Corporation and the EPA, have been compiled into a database to facilitate holistic analysis of water quality data in conjunction with measurements of river flow. The analysis illuminates interesting spatial patterns of nutrients and biota within the estuary and also quantifies changes in the nutrient status during the last 25 years (Sanderson and Redden 2001).

The data set includes 25 water quality variables, measured at irregular locations and times between 1972 to early 2000. An overview of the water quality monitoring sites is presented in Figure 2.7. Details of the water quality analysis are presented in Sanderson and Redden (2001) and an overview is presented here.

2.2.7.1 Comparison with ANZECC (1992) Guidelines

The ANZECC (1992) water quality guidelines were designed to provide numerical and narrative criteria for the sustainable management of Australia’s national water resources. The criteria are based on research available at the time, and are specific for the intended use of the waterbody, such as protection of aquatic ecosystems, raw water for drinking water supply or recreational water quality. Guidelines for the protection of aquatic ecosystems are divided into the broad categories of fresh water or marine water, with additional indicative levels for estuaries for some water quality variables. The use of such broad categories highlights the recommendation of the guidelines that local water quality studies are desirable for determining appropriate and acceptable background levels for specific water bodies.

Water quality variables analysed for this study are discussed below in the context of the ANZECC (1992) guidelines. The ANZECC guideline levels are provided as an indication of the range of values typically found in ‘healthy’ systems. 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 a system.

Interestingly, inorganic nitrogen levels in the estuary are high, relative to the 1992 ANZECC indicative guidelines. Oxidised nitrogen, NO₃ (nitrate plus nitrite) 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. High inorganic nitrogen levels in the main channel near the entrance may be attributed to particularly high levels in Throsby Creek.

The ANZECC (1992) guidelines suggest that ammonia should not exceed 5 μg/L. Almost all measurements exceeded 5 μg/L, with 90% of the readings at least 25 μg/L. Ammonia (NH₃) has been stable through the 25-year period, with increasing concentrations towards the lower end of the estuary. NH₃ 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.
ANZECC indicative ranges for orthophosphate, PO₄, are 5-15 µg/L in estuaries. The upper limit is exceeded by the mean values of the closely related measure of bioavailable phosphorus, namely soluble reactive phosphorus (SRP). Indeed, the minimum concentration observed is 5 µg/L. Even in the more saline lower reaches of the estuary the average values of soluble reactive phosphorus are higher than 15 µg/L. Very high values of soluble reactive phosphorus are evident in side creeks adjacent to the upper estuary.

ANZECC guidelines for total phosphorus (TP) in rivers suggest an indicative range is 10-100 µg/L. 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.

The nutrient levels in the Hunter estuary 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.

ANZECC (1992) guidelines require that dissolved oxygen (DO) should not fall below 6 mg/L, as measured over a diurnal cycle. 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. The lowest DO level measured was 0.9 mg/L.

Biological oxygen demand (BOD) is a measure of the decrease in oxygen content, which is brought about by the bacterial breakdown of organic matter. BOD is notably high in Wallis Creek and Windeyer's Creek. Although wastewater treatment plants (WWTP) are known to discharge effluent into these creeks, it is not reasonable to conclude, based on the present data, that WWTP are responsible for high BOD in Wallis Creek and Windeyer’s Creek.

Chlorophyll-a concentrations increase progressing up the estuary. Mean values in the lower estuary of 2-7 µg/L are within the ANZECC indicative range of 1-10 µg/L. In the upper estuary, the mean values increase to 22 µg/L. Combined with this trend of increasing chlorophyll-a upstream in the estuary, seasonal trends in 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 dilution with low chlorophyll-a ocean water. The seasonal cycles indicate that phytoplankton uptake has no measurable effect on NO₃ concentrations.

The mean turbidity is 15 NTU with a maximum value of 260 NTU. Turbidity is higher in the upper estuary than in the lower estuary, mostly due to dilution with low turbidity seawater near the ocean. 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

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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.

2.2.8 Salinity Structure

Sanderson and Redden (2001) have profiled the salinity structure along the length of the Hunter River estuary on 22 days during the first four months of 2001. A detailed description of this analysis is provided in MHL Report 1118 (2002).

In flood events (flows of order 200 GL/day) the freshwater inflow was observed to completely flush the estuary of salt water, except at depth in the dredged area of the harbour. Following floods the estuary is turbid and dissolved oxygen concentration can be low (20% saturated). A weaker flood event (peak flow of 20 GL/day) was observed to flush the upper estuary and result in stronger horizontal and vertical salinity gradients in the lower estuary. Tidal mixing subsequently eroded vertical salinity gradients.

Following flood events, saline water is observed to propagate up-estuary at depth as a salt wedge. A direct empirical relationship between the salt distribution and the total river flow on the previous day has been derived.

Figure 2.8 shows the vertically averaged salinity as a function of distance up the estuary. The empirical relationship admits estimates of the distance upstream that a particular isohaline (line of constant salinity) may be observed under a particular inflow. The distance to the 10 ppt and 30 ppt salinity values for three flow conditions (825 ML/day geometric mean flow, 5,991 ML/d the 90th percentile flow, and 11,918 ML/d the 95th percentile flow) are shown in Table 2.1.

Table 2.1 Distance Salt Propagates Upstream at Different Flows

<table>
<thead>
<tr>
<th>Flow Percentile</th>
<th>Flow ML/day</th>
<th>Distance to 10 ppt Isohaline (km)</th>
<th>Distance to 30 ppt Isohaline (km)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Geometric mean</td>
<td>825</td>
<td>27</td>
<td>13.5</td>
</tr>
<tr>
<td>90th percentile</td>
<td>5,991</td>
<td>14.7</td>
<td>4.3</td>
</tr>
<tr>
<td>95th percentile</td>
<td>11,918</td>
<td>11.7</td>
<td>2.9</td>
</tr>
</tbody>
</table>

Distance upstream is defined relative to the most downstream measurement site (as the crow flies). It must be emphasised that the actual distance a particular isohaline reaches also depends on the antecedent flow conditions over a period of months. High flows provide more reliable numbers from the empirical formulae. These results indicate that the lower estuary is rarely flushed fresh to the mouth although the surface water will become fresh as the vertical stratification will be strong during flood events.

Sanderson and Redden (2001) have been able to use river flow observations to estimate statistics for the salinity structure in the lower estuary over the last 25 years. A definitive model of the salinity structure and water exchange has not, however, been obtained for the Hunter River estuary. Extension of the fundamental knowledge to the upper estuary is quite feasible, but will require application of a more generalised model, along with a more sophisticated analysis of existing data, and perhaps some additional observations.
2.2.9 Summary of Water Quality Variability

Sanderson and Redden (2001) have also profiled the structure of a range of other water quality variables along the length of the Hunter River estuary. Empirical relationships were derived in a similar manner as for salinity. Figure 2.9 shows dissolved inorganic nitrogen, chlorophyll-a, total phosphorus, turbidity, dissolved oxygen, and salinity as a function of distance up the estuary. The values for each of the water quality variables have been normalised to ease comparison. A summary of the trends for each variable is given below.

Under low flow conditions, salinity propagates furthest upstream implying longer residence times for waters in the upstream reaches.

Total phosphorus indicates a source at around 25 km upstream 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 a distributed source of DIN along the lower reaches. The dissolved oxygen profile shows a slight increase downstream but is generally good.

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.

2.2.10 Sediment Quality

Extensive sampling of sediments has occurred in the south arm of the Hunter River, from the area of the Toule 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 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 guidelines 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.

2.3 Ecological Data

2.3.1 Introduction

The ecological data that has been collated is classified into terrestrial and aquatic flora and fauna.

2.3.2 Terrestrial Flora and Fauna

Seven major terrestrial habitat types were defined (MacDonald 2001) for the Hunter estuary, namely:

- tidal flats and saline open water bodies
- mangroves
- saltmarsh
- fresh open water bodies
- fresh/fresh-brackish wetlands
- *Phragmites australis* (common reed) swamps
- *Casuarina glauca* (she oak) and *Melaleuca spp.* (paperbarks) stands and remnant forests
Inhabiting these habitat types are 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. For a comprehensive overview of faunal communities occurring within the Hunter River estuary we refer to MacDonald (2001).

Concerning the loss of habitat, much of the original temperate rainforest, upland forest stands, saltmarsh, tidal flats and saline open water bodies have been lost. These areas have either been replaced by human activities or by fresh/fresh-brackish wetlands. At the same time there has been a massive increase in distribution of *Phragmites australis*. Extensive research has shown (Williams et al. 2000) that 13% of the open waters and 67% of the saltmarsh were lost between the 1950s and 1990s. Figure 2.10 shows current land cover of the lower Hunter estuary. The change in distribution of saltmarsh, open water and mangroves in the Hunter estuary is shown in Figures 2.11–2.13.

The changes in habitat have consequently lead to changes in floral and faunal biodiversity. The increase in *Phragmites australis*, at the expense of saltmarsh and freshwater wetlands, has decreased the floral diversity and the presence of waterfowl. The replacement of saltmarsh with grassland and weed has also reduced the floral diversity. The removal of this habitat also affects a wide variety of birds, fish and invertebrate fauna. The loss of water bodies and tidal mud flats also reduces food and habitat sources for fish and birds. The destruction of rainforest and swamp forest has decreased the refuge habitat of small mammals. The removal of mangroves has led to the loss of breeding grounds for various species of birds.

Data show a decline in the total number of migratory birds using the Hunter estuary. As an example, around 16,000 migratory waders were recorded during the 1970s, when today only 3,500 are counted (Hunter Bird Observers, pers. comm.). There are many factors that determine the number of migratory waders returning to the Hunter each year. One of those is the availability of habitat for roosting and feeding. Major day-time high tide roost sites, such as sandy spits, islands and beaches within the estuary have disappeared and many other roost and feeding sites have been degraded (Hunter Bird Observers, pers. comm.).

Four principal factors have been identified as contributing to the loss of habitat and biodiversity in the Hunter estuary. These are:

- restriction of tidal inundation to estuarine wetlands
- increased spatial extent of mangrove communities at the expense of saltmarsh
- conversion of saline vegetative systems to fresh/brackish systems
- introduction of non-indigenous vegetation and faunal species to the estuary
2.3.3 Aquatic Flora and Fauna

The uppermost reaches of the Hunter Estuary (upstream of Raymond Terrace) consist of sandy sediments and are lined with reeds, whereas the lower reaches are generally muddier and lined with mangroves and the seaward sections have a sandy bottom. Seagrasses have not been seen along the foreshores of the lower Hunter River for at least the past 30 years, but *Ruppia* sp (a native grass that occurs in fresh water and salt water) has been found in some small channels on Kooragang Island and in Hexham swamp (The Ecology Lab 2001). Estuarine aquatic fauna includes benthic invertebrates, fish, prawns and oysters.

The Ecology Lab (2001) distinguishes four broad categories of estuarine habitats for aquatic flora and fauna, namely mangroves, saltmarsh, unvegetated soft sediments and rocky reefs and artificial structures.

Mangrove forests create a habitat for a wide variety of marine organisms, including fish, crabs, marine snails, seaweeds and tiny animals such as marine worms, amphipods and isopods. 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. Mangrove soils may also play a role as sink for contaminants, particularly heavy metals.

Saltmarshes are often found behind, or close to mangrove forests and live 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.

Unvegetated mudflats and sandflats are productive marine habitats, supporting a variety of animals that live in or on the sediments. These areas are also important for more transitory visitors such as fish and birds. Unvegetated soft sediment habitats have, however, been studied far less than mangroves and saltmarshes.

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. 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.
Benthic invertebrates are common in mangroves, saltmarshes, intertidal and subtidal soft sediments and on rocky substrata. For an overview of the presence of macro-, meio- and microfauna in the Hunter estuary, we refer to The Ecology Lab (2001). There have been a number of quantitative fish studies in the Hunter estuary and a wide range of species has been recorded (The Ecology Lab 2001). The major commercial fishery in the Hunter estuary is the estuary prawn trawl fishery. Although prawn trawling has always been important to the economy of the Newcastle region, there have been occasional setbacks to the industry. The oyster industry in the Hunter estuary is no longer as profitable as it once was.

The most likely potential threats to aquatic biota in the Hunter Estuary are from:

- shoreline industry and farming, particularly runoff from factories, farms, seepage of contaminated groundwater
- dredging for maintenance and further port facilities
- tidal restrictions due to floodgates, culverts, etc
- fishing industry

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.

2.4 Human Data

2.4.1 Introduction

Before the arrival of the Europeans, the Hunter River was a mangrove-fringed river with a 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. 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. Human activity has altered the natural state of the estuary.

The human data that has been collated is represented under the headings of heritage, recreational, land use and flood mitigation works. For a historical overview of the events in the Hunter estuary, we refer to MHL Report 1118 (2001).

2.4.2 Heritage

The Koori people have inhabited the Hunter River for over 30,000 years. When the white settlers arrived, the landscape and the rivers in the region had all been identified by name by the Koori people (MHL 2001). About 2,000 Aboriginal sites have been recorded and these include sites along the valley floors of the major tributaries, rock shelter sites in the sandstone areas and shell middens around coastal lakes and estuaries. However, due to river works, land reclamation and urbanisation much of the remnants of Aboriginal occupation in the Hunter estuary has been destroyed.
From a European heritage point of view, the Hunter region is one of Australia’s longest settled regions. European settlement has produced a unique variety of structures, buildings, towns and landscapes. Some 800 specific items that are deemed worthy of conservation for future generations have been identified. They include urban and rural dwellings, public and commercial buildings, archaeological remains, bridges, collieries and cemeteries.

2.4.3 Population

The Hunter region accounts for almost 10% of the State’s total population. The Hunter estuary has two main population centres, namely Newcastle (Figure 2.14) and Maitland (Figure 2.15). In 1961 the population of Newcastle was about 142,500 and Maitland’s population was 27,500 (ABS 1996). Newcastle has experienced a substantial steady decrease in its population in the 1970s and 1980s. This is 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 growing slowly in the coming years. The population of Maitland has steadily increased over the years. Maitland’s population has continued to grow since the 1960s and is about 50,000 today. It is projected to keep growing in the coming years.

Table 2.2 Populations and Projections

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</thead>
<tbody>
<tr>
<td>Newcastle</td>
<td>142,574</td>
<td>135,193</td>
<td>129,490</td>
<td>131,099</td>
<td>133,686</td>
<td>141,400</td>
<td>144,000</td>
</tr>
<tr>
<td>Maitland</td>
<td>27,353</td>
<td>39,926</td>
<td>44,315</td>
<td>46,958</td>
<td>49,941</td>
<td>56,500</td>
<td>60,600</td>
</tr>
<tr>
<td>Hunter Region</td>
<td>355,840</td>
<td>458,704</td>
<td>482,774</td>
<td>513,765</td>
<td>540,499</td>
<td>615,800</td>
<td>663,800</td>
</tr>
</tbody>
</table>

Sources: ABS Census 1996, NSW DUAP 1994
* Medium level population projections

2.4.4 Recreational

The Hunter estuary is used by people for a variety of recreational activities, but detailed maps of foreshore recreation are not available. Boating and fishing are the most common activities. The Ecology Lab (2001) provides an overview of the most popular fishing areas, which are in the lower reaches of the estuary. Boats can be chartered from Newcastle Harbour, primarily for fishing trips along the open coast. Also, many people fish from their own boats and from the shore.

It has been estimated that there are approximately 30,000 recreational fishing events in the Hunter River per year (The Ecology Lab 2001). These events may range from short bait collecting trips to a whole day of fishing. There are some closures in place for recreational fishers. In particular, oysters and mussels cannot be collected from the south arm and hoop nets and crab traps are not permitted in Throsby Creek.

2.4.5 Land Use

As becomes clear from the introduction, the landscape has drastically changed since European settlement. Figures 2.16 and 2.17 show current land uses around Newcastle and Maitland respectively. The natural environment has been transformed from forest and wetland areas into land for residential, agricultural and industrial purposes. Agriculture is the largest sector in the Hunter region in terms of the area of land occupied for agricultural purposes. The approximate agricultural area in 1981 was 17,000 km² (Sinclair Knight 1981). At the end of the 1980s agricultural activities covered 20,000 km², which accounts for 55% of the total catchment area (Dept. of Planning 1989a).
Williams et al (2000) provide a comprehensive overview of changes to the natural habitat in the lower part of the Hunter estuary around Kooragang Island. Changes in flow patterns, morphology and land reclamation have led to an increase in land area of approximately 20% since 1801. A vegetation map from 1850 shows that the low-lying coastal areas of the Hunter estuary were mainly saltmarsh with tidal ponds (MacDonald 2001). Since 1850, there has been a progressive loss of habitat in the study area. Saltmarsh has been replaced by pasture, dry grassland or cleared land (Fullerton Cove and deltaic islands) or by fresh/brackish wetlands (Hexham Swamp). Phragmites australis has become dominant in the Hexham Swamp area and well established in the former saltmarshes of Tomago/Fullerton Cove. 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). Quantification of the losses is difficult because the various studies cover different study areas (MacDonald 2001).

The loss of natural areas is linked to the increase of human activity in the Hunter Estuary. 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 (see Section 2.4.7).

Concerning future changes, the Settlement Strategy for the Lower Hunter that is proposed in the Hunter Regional Environmental Plan 1989 (Dept of Planning 1989a) is one of growth based on existing urban settlements. The aim is to improve the overall accessibility to employment, shopping, health, and educational facilities. Growth is directed to those areas that have the capacity to expand economically and can accommodate an increasing range of facilities and services for the population.

2.4.6 Regional Economy

The economic base of the Hunter region is provided by coal mining, transport, power generation, and manufacturing (Dept of Planning 1989a). The output of coal is still increasing every year. In 1997, the coal production per capita was 184 tonnes in the Hunter as compared to 147 tonnes per capita in the whole of Australia. The narrow employment base of the Hunter economy implies that structural changes, such as the decline of particular industries, has led to a rise in unemployment figures. Over the years, there have been significant employment losses in manufacturing, specifically in the metal manufacturing and fabrication industries.

2.4.7 Flood Mitigation Works

As becomes clear from the introduction, the landscape has drastically changed since European settlement. Many of the changes to the natural environment occurred as a result of flood mitigation structures that were developed to safeguard human activities.

The Lower Hunter Flood Mitigation Scheme under the Public Works Department has completed 160 km of levees, 140 km of drains, 200 floodgates, 111 km of flood canals, 30 km of bank protection works, and 40 km of control and diversion banks. Figure 2.18 shows the development of infrastructure in the lower estuary area. Between the 1950s and 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 a number of environmental protection policies, such as the State Environmental Planning Policy 14 (SEPP 14) in 1985 (DLWC 2000) Estuarine wetlands also receive protection by council local environmental plans.
HUNTER RIVER ESTUARY

NSW DEPARTMENT OF PUBLIC WORKS AND SERVICES

MANLY HYDRAULICS LABORATORY

MHL
Report 1096
Figure 2.2
PHYSICAL SYSTEM
- climate
- geology and soils
- hydrology
- hydraulics
- geomorphology
- water quality
- sediment quality

ECOLOGICAL SYSTEM
- aquatic flora and fauna
- terrestrial flora and fauna

HUMAN SYSTEM
- heritage
- recreation
- land use
- flood mitigation works

COMPONENTS IN THE HUNTER ESTUARY SYSTEM
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 floofs often present at high altitudes. Some fine-textured soils.
- Humus-rich podzols and sandy soil日后 residuals. Humus-rich podzols in inland dunes with some meadow and acid swamp soils in depressions, and yellowish white, single-grained, sandy soil日后 residuals along the crest on sandy deposits. Podzolic soils on Permian shale 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
- Solonetnic soils, skeletal soils, and earths. Solonetnic 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 callovium. Solonetnic soils, especially on lower slopes of colluvial spreads.
- Skeletal soils in steeper parts and gritty, often sandy earths on gentle slopes. Solonetnic 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, solonetnic soils, cracking clays, earths, and alluvial regosols.
- Sandy drained soils. Acid swamp soils and meadow soils, with alluvial regosols which are mostly fine-textured and saline.
- Sandy alluvial regosols, usually deep or very deep and single-grained.

Source: van de Graaff (1963), McManus et al., (2000)
SUMMARY OF SEDIMENT BUDGET

Mean annual total sediment load at Singleton $2 \times 10^6$ t/a
(1.6 $\times 10^5$ t/a suspended load only)

Typical suspended sediment influx past Hexham $1 \times 10^5$ t/a

$25 \times 10^3$ t/a bedload minimum sediment flux of bedload past Hexham (av. for 1955-89)

$97 \times 10^3$ t/a estuary sink

$92 \times 10^3$ t/a (1974-83)

Remaining to mid shelf mud $0.49 \times 10^3$ t/a

Maintenance dredging from harbour to dump site $0.4 \times 10^3$ t/a or

NEWCASTLE

Ocean

Grahamstown Reservoir

Raymond Terrace

Oakhampton

Hunter River

Koonagang Island

Fullarton Cove
Zone A - Downstream from Walsh Point
Zone B - South Arm of the Hunter River Estuary
Zone C - North Arm of the Hunter River Estuary
Zone D - Creeks on Kooragang Island (now ponds)
Zone E - Junction of Arms to Williams-Hunter Junction
Zone F - Williams River
Zone G - Williams-Hunter Junction to Hunter-Paterson Junction
Zone H - Paterson River
Zone I - Hunter River, upstream from the Hunter-Paterson Junction
Typical conditions in low flow

Typical conditions in high flow

Salinity

Distance up the estuary (km)

PPT

0 5 10 15 20 25 30 35

0 5 10 15 20 25 30 35

SALINITY STRUCTURE OF THE HUNTER RIVER ESTUARY
Typical conditions in low flow

Salinity (ppt + 35)

Dissolved Inorganic Nitrogen (µg/L + 1000)
Chlorophyll-a (µg/L + 20)
Total Phosphorus (µg/L + 300)
Turbidity (ntu + 15)

Dissolved Oxygen (mg/L + 10)

Normalized value

Distance up the estuary (km)

Typical conditions in high flow

Salinity (ppt + 35)

Dissolved Inorganic Nitrogen (µg/L + 1000)
Chlorophyll-a (µg/L + 20)
Total Phosphorus (µg/L + 300)

Dissolved Oxygen (mg/L + 10)

Normalized value

Distance up the estuary (km)
CHANGE IN DISTRIBUTION OF SALTMARSH WITHIN
THE HUNTER RIVER ESTUARY 1954-1994

Source: Williams et al, 2000
Source: Williams et al, 2000
CHANGE IN MANGROVE DISTRIBUTION WITHIN THE HUNTER RIVER ESTUARY 1954-1994

Source: Williams et al, 2000
Source: Williams et al, 2000

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

MHL Report 1095
Figure 2.18
3. Data Gaps and Recommendations

3.1 Introduction

In the previous section a summary review of existing data for the Hunter Estuary Processes Study was presented. The next step is to decide upon what data is missing and consequently develop a strategy to collect this data. A crucial step in this phase is to determine the purpose of the data and information collection. Rather than collecting 'information for information's sake' the aim is to assess what data and information are required to successfully tackle the management issues in the Hunter estuary. Estuary management should be issue-led, not data-led.

The main management issues that were identified in the Hunter estuary by the Hunter Estuary Management Committee in close consultation with the community were

- loss of habitat
- environment
- erosion
- flooding
- pollution
- water quality
- sand and gravel extraction
- recreation
- heritage
- fishing

Some of these issues are of concern in the whole of the estuary while others are only local issues. An overview of the location issues in the Hunter River estuary is given in Figure 3.1. These issues will form the starting point for identification of data gaps and formulation of future data collection programs.

3.2 Data, Information and Understanding

3.2.1 Definitions

To avoid confusion about the issues that are presented, the following definitions will be used to guide the discussion.

- **Data** is the raw material from which information is produced.
- **Information** is a collection of data that has meaning, relevance and purpose to the recipient. Basically, information is data with a context.
- After being analysed, information can be transformed into an understanding of the issues that are being studied.

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1 March, 2002
• This understanding can subsequently be used to guide management actions

In a management process, decision makers and the general public are not so much interested in data as in information. The transformation of data into useful information, however, is hardly ever straightforward. It is a complex task which naturally requires expertise in the field that is studied, but also in data processing. There is a need for 'metadata', which is information about what data are available, where they are kept and who keeps them. In general, data should be

• available knowledge is required about what data exist
• accessible when relevant data are available it is essential to know how to gain access to them
• appropriate when data are available and accessible, the recipient must have a good understanding of the nature, quality and currency of the data, so that data can be used appropriately

A broad category of tools to collect raw data and transform them into useful information are 'assessments' and models. Assessments can include environmental impact assessments, risk assessments and cost-benefit exercises. Models can take a large variety of forms and shapes, e.g., stochastic or deterministic, descriptive or forecasting, etc.

3.2.2 Scale

The issue of 'scale' is an important one in this discussion. Estuary processes, whether human or natural processes, take place at a variety of temporal and spatial scales. An important issue is the choice for the scale or aggregation level at which the processes are observed and the effect of this choice on modelling. If a certain system is studied at an inappropriate scale level, this may lead to inadequate understanding of the processes involved. Many of the management issues in environmental systems are multiscaled in nature. Therefore, in order to understand the Hunter estuary system in all its complexity, it is necessary to identify the scales at which relevant processes work.

Choosing a scale level at which to describe the processes involves the choice of resolution and extent. Resolution is a measure for the amount of detail used in an analysis. It includes temporal and spatial steps, but can also include the degree of complication. Extent represents the domain and includes temporal extent, spatial extent and the number of components.

An example of temporal and spatial scales in an ecological process (carbon fixation through photosynthesis) is presented in Figure 3.2. The ecological processes being monitored and the variation observed within them depend on the scale over which they are measured, both in time and in space. A focus on small scale issues involves different processes and rates than a large scale focus.

Difficulties may occur if data, information and process knowledge are available at scales different from the ones required (e.g., for analysis or model development). In that case, the problem of 'scaling' (upscaling or downscaling) arises, which implies that one needs to aggregate (or disaggregate) available data to suit the needs.
3.3 Monitoring

3.3.1 Introduction

Successful estuary management requires the development of effective monitoring tools. A monitoring strategy should be developed for the detection of trends in the condition of the Hunter estuary system. Such a strategy can provide the scientific and technological basis for decision-making and simultaneously help to gain knowledge of the complex environmental system, including natural and human processes.

Prior to implementing any monitoring, it is important that clear objectives for the monitoring be established and agreed to by the various stakeholders. Broad objectives for monitoring include:

- to obtain information to satisfy public health requirements
- to ensure there is proper maintenance of assets and that these are not having deleterious effects on the estuary, and
- to understand various physical, chemical and biological processes including obtaining information for calibration and verification of models of processes.

To satisfy these different objectives, different sampling strategies are required and the different forms of monitoring can be undertaken by different groups. Monitoring to assess compliance with public health regulations is best undertaken by Council. Monitoring to assess the performance and condition of assets could be done by a combination of Hunter Water, Council and local groups. In order to obtain improved understanding through scientific research, process-oriented monitoring could be undertaken by local educational institutions or consultants with the assistance of Council.

Detailed recommendations for compliance, maintenance and process monitoring in the Hunter estuary will be discussed in Section 3.5.

3.3.2 Considerations for Monitoring in the Hunter Estuary

It was proposed (MHL 2000) that the results of the water and sediment quality data review that has now been undertaken, will be used to design targeted water and sediment quality sampling programs that address the key issues as identified through the review and discussion with the committee. From the water quality perspective, the analysis of the ACCESS water quality database (established for the Hunter Estuary Processes Study) in many regards provides suggestive rather than conclusive information about processes. Unfortunately, many of the additional measurements required to fill in holes cannot be made in retrospect. For example, to determine the extent to which changing fluxes from the rivers are responsible for the observed change in the nutrient status of the estuary within the last 25 years, it would have been essential to have more nutrient measurements in the rivers before 1985.

The present water quality database has a sparse coverage over a broad spatio-temporal domain and highlights the scale issue. In general, the knowledge obtained from this database cannot be significantly augmented by a short duration (six-month) low cost ($40,000) water quality monitoring program that was proposed. Similar considerations are made for the proposed sediment sampling program.
The existing data gives measures of 'what is' or 'what was'. There seems to be little data to quantify mechanisms. Water quality (even according to the limitations of ANZECC 1992) is most properly defined in terms of how the aquatic environmental system functions. There is a need to obtain more measurements that are targeted to quantify key environmental processes. Examples would include measuring the growth rate response of key primary producers to turbidity (light), measuring grazing rates, measuring nutrient cycling rates in the water column, wetlands, mangrove forests, and benthos. Unfortunately, most of these measurements seem to be impossible to make given the constraints placed on funding available for the measurement program.

Given the finite resources available to the study it is not possible to develop a scientifically rigorous understanding of all the processes affecting the issues in the Hunter estuary. MHL is aware of these limitations and has proposed a study that optimises the outcomes to an appropriate level of process understanding commensurate with the needs of the management planning program. To achieve this, MHL has retained a degree of flexibility in its approach so that the study priorities could be redirected during the course of the investigations as new information comes to light and in discussion with the committee. This adaptive approach is particularly relevant to the Hunter system where a large body of information exists but has yet to be fully integrated into an holistic review of processes and their interactions.

3.3.3 Complexity of the Hunter Estuary

Quantification of key estuary processes is indispensable, but will require a huge scientific effort. Due to the complexity of the Hunter estuary system, it is difficult to quickly obtain an integrated understanding of the underlying processes. The processes affecting the various issues identified by the estuary management committee and outlined in the study brief need to be documented to a degree that supports effective management decision-making. MHL has undertaken a preliminary assessment of the identified issues and the processes most likely to affect (or to be affected by) each issue (MHL 2000). The management issues that were identified in the Hunter estuary cover a large part of the estuary system. After reviewing and analysing available data and information for the Hunter estuary, it is now possible to more accurately link specific processes to the issues that were identified by the community, industry, and government in the Hunter estuary. Yet, the linkages and possible feedback mechanisms between the processes still make it difficult to obtain a comprehensive overview. Furthermore, issues raised by the community are seldom 'independent' and more often linked to each other. To illustrate the complexity of the system a conceptual representation of the interactions involved for the management issue 'loss of habitat' is presented in Figure 3.3.

Figure 3.3 does not claim to provide a comprehensive overview of all the processes involved in the issue 'loss of habitat'. It mainly introduces the interaction of human, physical and ecological processes (as introduced in Section 1) leading up to a loss of habitat. The conceptual diagram could be extended by including feedbacks in the system i.e. the effects of habitat loss on biodiversity, recreational activities, etc. The aim of Figure 3.3 is to provide an idea of the complexity involved in studying the processes that influence just one aspect of the Hunter estuary system.

Although data may be available, if the processes are poorly understood this data may not lead to a better understanding of the overall system that we are studying. Once we start to understand the processes, data can be used to increase our knowledge of the system (e.g. through modelling).
In Table 3.1 we introduce ISSUES, MAIN PROCESS, HUMAN SYSTEM, NATURAL SYSTEM, DATA GAPS and SOLUTIONS for the Hunter estuary. The ISSUES are those that have been identified by the committee and the community as major management issues. The MAIN PROCESSES are directly linked to the ISSUES and can affect or be affected by the issues involved. The HUMAN AND NATURAL SYSTEMS present the involvement of human and natural processes in the MAIN PROCESS. These related human and natural processes are linked to the main process either as causes or effects. The DATA GAPS column lists the possible lack of data or understanding that is involved with the particular process. In the SOLUTIONS column a short description is given of the possible strategy to overcome the lack of data or information.

Based on Table 3.1 we will provide a detailed set of recommendations for the next phase of the Hunter Estuary Processes Study.
<table>
<thead>
<tr>
<th>Issue</th>
<th>Main Process</th>
<th>Human System</th>
<th>Natural System</th>
<th>Data Gaps</th>
<th>Solutions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Loss of Habitat</td>
<td>• restriction of tidal inundation to estuarine wetlands</td>
<td>• land reclamation and flood mitigation works (including levees, drains, culverts, floodgates etc)</td>
<td>• change in hydrology and hydrodynamics</td>
<td>• lack of data about effects of habitat loss on aquatic and terrestrial flora and fauna species</td>
<td>• identify effects of structures</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>• change in tidal regime</td>
<td></td>
<td>• identify key ecological relationships between habitats and the species they support (e.g. food, breeding grounds, shelter etc)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>• conversion of saline vegetative systems to fresh/brackish systems</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>• changes in fish/invertebrate assemblages</td>
<td></td>
<td></td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>• increased sedimentation</td>
<td></td>
<td>• identify key ecological processes that alter the co-existence balance between saltmarsh and mangroves</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>• change in tidal regime</td>
<td></td>
<td></td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>• sea level rise</td>
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<tr>
<td></td>
<td>• increased spatial extent of mangrove communities at the expense of saltmarsh</td>
<td>• land use (e.g. agricultural development and urbanisation)</td>
<td></td>
<td>• lack of understanding of processes leading to loss of saltmarsh</td>
<td>• collect data about native and non-native species, although lack of 'base' data makes it difficult to assess changes in composition and diversity</td>
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<tr>
<td></td>
<td>• introduction of non-indigenous vegetation and faunal species to the estuary</td>
<td>• land use</td>
<td>• change in distribution of native vegetation</td>
<td>• lack of data relating to the presence and abundance of native mammalian, reptilian and plant species in Hunter River estuary</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>• competition for habitat and food</td>
<td></td>
<td></td>
</tr>
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<td></td>
<td></td>
<td></td>
<td>• change in biodiversity</td>
<td></td>
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</tr>
<tr>
<td>Environmental</td>
<td>• introduction of exotic marine organisms into the marine environment through ballast water</td>
<td>• regional economy (e.g. port industry and shipping)</td>
<td>• competition for habitat and food</td>
<td>• 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</td>
<td>• the few studies that have been undertaken in the Hunter estuary are unable to show significant effect of ballast water on native marine species</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>• change in biodiversity</td>
<td></td>
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<tr>
<td></td>
<td>• dredging of the harbour for maintenance of waterways and port-related development</td>
<td>• regional economy (e.g. port industry and shipping)</td>
<td>• mobilisation of metals</td>
<td>• lack of data about effects of dredging on marine biota also in relation to commercial fishing</td>
<td>• 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</td>
</tr>
<tr>
<td>ISSUE</td>
<td>MAIN PROCESS</td>
<td>HUMAN SYSTEM</td>
<td>NATURAL SYSTEM</td>
<td>DATA GAPS</td>
<td>SOLUTIONS</td>
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</tr>
<tr>
<td>Erosion</td>
<td>• bank erosion due to floods along the river and its tributaries</td>
<td>• change in land use patterns</td>
<td>• geomorphology</td>
<td>• lack of data to compose an accurate sediment budget</td>
<td>• monitoring program to measure suspended sediment</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• cattle grazing</td>
<td>• hydrology and hydrodynamics</td>
<td></td>
<td>• compose short-term and long-term sediment budgets (including contributions of tributaries and losses to Hexham Swamp)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>• climate/rainfall</td>
<td></td>
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<tr>
<td></td>
<td>• long-term sedimentation and erosion processes and infilling of the estuary</td>
<td></td>
<td>• geomorphology</td>
<td>• lack of understanding about contribution of tidal sedimentation</td>
<td>• monitor changes in depth of the river</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>• hydrology and hydrodynamics</td>
<td></td>
<td>• as tidal discharge is usually larger than river discharge the magnitude of upstream sediment transport, and the effects on infilling, should be assessed</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>• tidal regime</td>
<td></td>
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<tr>
<td>Flooding</td>
<td>• inundation of urban, industrial and natural areas</td>
<td>• change in land use patterns</td>
<td>• geomorphology</td>
<td>• effects of flood-induced sediment transport (and delivery to floodplains) on terrestrial and aquatic flora and fauna</td>
<td>• study changes in vegetation composition and distribution over time and link these changes to flood events</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>• land reclamation and flood mitigation works</td>
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<td></td>
<td></td>
<td></td>
<td>• climate/rainfall</td>
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<td></td>
<td></td>
<td></td>
<td>• hydrology and hydrodynamics</td>
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<td></td>
<td></td>
<td></td>
<td>• erosion and sedimentation</td>
<td></td>
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</tr>
<tr>
<td>Pollution</td>
<td>• build up of contaminated sediments along the south arm of the Hunter River</td>
<td>• industrial activity (e.g. port industry)</td>
<td>• hydrology and hydrodynamics</td>
<td>• lack of data about the effects of contaminants on aquatic and terrestrial flora and fauna</td>
<td>• study chemical processes concerned with pollution in sediments and effects on living organisms</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• land reclamation and flood mitigation works</td>
<td>• dispersion</td>
<td></td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>• sediment contamination mechanisms</td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td>• effects on flora/fauna</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Water Quality</td>
<td>• industrial, agricultural and urban runoff into the river</td>
<td>• regional economy</td>
<td>• hydrology and hydrodynamics</td>
<td>• data has sparse coverage over broad spatio-temporal domain</td>
<td>• aim to define water quality in terms of quantification of key environmental processes</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• sewage</td>
<td>• dispersion</td>
<td></td>
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<tr>
<td></td>
<td></td>
<td>• public awareness of environmental problems</td>
<td>• sedimentation at stormwater outlets due to non-compliance with sediment and water quality controls in existing and new developments</td>
<td></td>
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</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>• hydrology and hydrodynamics</td>
<td>• lack of data about the effects of sediment flows from building sites into the estuary system</td>
<td>• monitoring at stormwater outlets</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>• dispersion</td>
<td></td>
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<tr>
<td></td>
<td>• leachate from garbage dump fill sites and sewerage overflow</td>
<td>• regional economy</td>
<td>• hydrology and hydrodynamics</td>
<td>• data has sparse coverage over broad spatio-temporal domain</td>
<td></td>
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<tr>
<td></td>
<td></td>
<td>• zoning</td>
<td>• dispersion</td>
<td></td>
<td></td>
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<tr>
<td></td>
<td>• sedimentation at stormwater outlets due to non-compliance with sediment</td>
<td>• commercial activity (e.g. building industry)</td>
<td>• geomorphology</td>
<td>• data has sparse coverage over broad spatio-temporal domain</td>
<td></td>
</tr>
<tr>
<td></td>
<td>and water quality controls in existing and new developments</td>
<td></td>
<td>• hydrology and hydrodynamics</td>
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<td></td>
<td></td>
<td>• dispersion</td>
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</tbody>
</table>


<table>
<thead>
<tr>
<th>ISSUE</th>
<th>MAIN PROCESS</th>
<th>HUMAN SYSTEM</th>
<th>NATURAL SYSTEM</th>
<th>DATA GAPS</th>
<th>SOLUTIONS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sand and Gravel Extraction</td>
<td>• balance between resource utilisation and effects on natural environment</td>
<td>• regional economics</td>
<td>• geomorphology</td>
<td>• lack of data about quantities that are being extracted</td>
<td>• monitor quantities of sand and gravel extraction</td>
</tr>
<tr>
<td></td>
<td>• effects on river stability</td>
<td>• land use</td>
<td>• hydrology and hydrodynamics</td>
<td>• lack of understanding about the effects of sand and gravel extraction on the natural environment</td>
<td>• study the changes to the natural environment (e.g. habitats, diversity) in the vicinity to extraction activities</td>
</tr>
<tr>
<td>Recreational</td>
<td>• conflicts between recreational boating and commercial activities</td>
<td>• public participation</td>
<td>• hydrology and hydrodynamics</td>
<td>• lack of data about the types of recreational activities and when and where they take place</td>
<td>• monitor recreational activities and changes to natural environment</td>
</tr>
<tr>
<td></td>
<td>• effects on natural environment of recreational activities, including fishing</td>
<td>• recreation</td>
<td>• geomorphology</td>
<td>• there is a lack of data about the effects of recreational activities on the natural environment Yet, fishing activities are strongly regulated and there are no signals of major disturbances</td>
<td>• a recreational fishing survey is currently being undertaken and there seems no need for further investigations at this stage</td>
</tr>
<tr>
<td></td>
<td>• improvement of public reserves around the river foreshore</td>
<td>• recreation</td>
<td>• hydrology and hydrodynamics</td>
<td>• no data about the types of recreational activities and when and where they take place</td>
<td>• establish facilities in public reserves (toilets, picnic tables)</td>
</tr>
<tr>
<td></td>
<td>• safety of public using the river</td>
<td>• cultural</td>
<td>• hydrology and hydrodynamics</td>
<td>• no data about the types of recreational activities and the possible risks involved for the public</td>
<td>• educate the public by placing informative signs about the natural environment and how to preserve it</td>
</tr>
<tr>
<td>Heritage</td>
<td>• heritage structures and other visually significant features</td>
<td>• cultural</td>
<td>• geomorphology</td>
<td>• Aboriginal and European heritage sites have been identified and their conservation is a basic consideration in development plans</td>
<td>• no need for further data collection studies</td>
</tr>
<tr>
<td>ISSUE</td>
<td>MAIN PROCESS</td>
<td>HUMAN SYSTEM</td>
<td>NATURAL SYSTEM</td>
<td>DATA GAPS</td>
<td>SOLUTIONS</td>
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<tr>
<td>Fishing</td>
<td>• conflicts between use of the estuary for commercial fishing and the natural environment</td>
<td>• regional economy</td>
<td>• geomorphology</td>
<td>• catches have been consistent over the years possibly indicating that there are no major negative effects on the natural environment (?)</td>
<td>• the current situation does not indicate a need for major investigations, if catches drop drastically the sustainability of fisheries should be investigated</td>
</tr>
<tr>
<td></td>
<td>• introduction of obstacles to fish passage (including floodgates, low level road crossings and culverts)</td>
<td>• public participation</td>
<td>• hydrology and hydrodynamics</td>
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<td></td>
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<td>• conflict resolution</td>
<td>• pollution</td>
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<td></td>
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<td></td>
<td>• ecosystem resilience</td>
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<td></td>
<td>• flood mitigation works</td>
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<td>• land use</td>
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<tr>
<td></td>
<td>• hydrology and hydrodynamics</td>
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<td></td>
<td>• pollution</td>
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<tr>
<td></td>
<td>• no data about effects on fish and prawn production</td>
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</table>
3.4 Considerations for Recommendations

From Table 3.1, a general overview concerning data gaps in the Hunter Estuary Processes Study can be derived. The previous discussions make clear that data collection and the development of models should involve more than just providing information on the state of the estuary environment. Information should help to identify trends, help the decision-maker to ask the right questions and guide the choice for management tools.

The general recommendation for the next phase of the Hunter Estuary Processes Study is to gain further knowledge about the effects of human activity on the natural functioning of the Hunter estuary. This necessitates a large scale view. As was undertaken in Table 3.1, it is necessary to first identify the key processes involved and their role in management issues. An example study could focus on the poorly understood chain of reactions that leads to loss of habitat and biodiversity in the Hunter estuary. Available information tells us that the installation of flood mitigation works has led to changes in hydrology and sediment fluxes. This has led to loss of habitat and consequently loss of biodiversity. While the general mechanism is known, there is no solid understanding of the rates of change, their temporal and spatial variability, etc.

In order to develop more detailed recommendations for monitoring in the Hunter estuary, it is necessary to link them to the available management tools in the estuary management framework on a local level.

3.4.1 Estuary Management Framework

In general, the key to successful environmental management is to adopt a mix of instruments to achieve the objectives that have been set. A wide variety of coastal zone management instruments is available, such as (adapted from OECD 1997):

- collection and updating of relevant information and development of coastal environment indicators to guide planning and monitoring of activities and processes
- establishment of environmental objectives for land use planning and zoning, conservation requirements, ecosystem protection and restoration, water quality for receiving waters and waters flowing into the coastal zone, and control and reduction of inputs from polluting and hazardous substances
- establishment and maintenance of monitoring and enforcement procedures for environmental objectives and targets
- environmental assessment incorporating economic and social criteria
- public education and participation in decision-making at an early stage of policy formulation and project assessment, and adoption of wider public participation procedures
- application of regulations and economic instruments within the framework of the ‘Polluter Pays Principle’, and pricing coastal zone resources to reflect social costs of use and depletion
- where appropriate, enactment of national legislation to enforce coastal zone management objectives

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Council is responsible for estuary and catchment management and planning. Major legislative acts that are associated with Council’s responsibility are the *Environmental Planning and Assessment Act 1979* and the *Local Government Act 1919*. The functions and control that flow out of these acts are shown in Table 3.2.

### Table 3.2 Legislation Associated with Council Estuarine Management

<table>
<thead>
<tr>
<th>Environmental Planning and Assessment Act 1979</th>
<th>Local Government Act 1919</th>
</tr>
</thead>
<tbody>
<tr>
<td>• environmental protection and tree preservation</td>
<td>• building controls</td>
</tr>
<tr>
<td>• zoning of land use</td>
<td>• management of public reserves, public wharves and bathing areas</td>
</tr>
<tr>
<td>• protection of heritage items</td>
<td>• dredging</td>
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<tr>
<td>• development standards</td>
<td></td>
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<tr>
<td>• conditions of development consent</td>
<td></td>
</tr>
<tr>
<td>• environmental impact assessment</td>
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</tbody>
</table>

According to the Estuary Management Manual (1992) Council should implement Estuary Management Plans through local environmental plans (LEPs), development control plans (DCPs), building policies and public works.

LEPs are the basis for most land use control and establish zonings with permissible land uses, prohibited uses and development controls for each zone (Estuary Management Manual 1992). DCPs aim to provide more detailed guidelines for applying controls contained in an LEP.

### 3.5 Recommendations for Monitoring in the Hunter Estuary

The aim of a monitoring strategy (see Section 3.3) is the detection of trends in the condition of the Hunter estuary system. Following the discussion in the previous sections, the main data collection needs to be focused on gaining process understanding. Therefore, MHL recommends to undertake a process monitoring program.

Process monitoring for trends necessitates adopting a long-term view and the development of long-running programs. Within these programs, both high frequency and lower frequency measurements should be undertaken. Most of the data that is currently available for the Hunter estuary is of a short-term, small scale nature (e.g., seasonal variability is well understood). The major gaps that were encountered in the data involves processes taking place on longer time scales and (mostly) larger spatial scales. This is clearly a situation in which data, information, and process knowledge are available at scales different from those relevant from a management perspective (see Section 2.2). If issues are studied at a small scale level, this involves different processes and rates than a large scale focus. Naturally, this leads to an incomplete or inadequate understanding of the processes involved. To overcome the current 'data gaps' for understanding changes in the estuary, monitoring programs need to be designed with a focus on long-term process understanding.

One-off monitoring exercises can be undertaken to gain specific process understanding at the local scale. Ongoing monitoring programs to detect trends may encompass:

- Identification of effects of installation of flood mitigation works on hydrology and sediment fluxes.

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- identification of key environmental processes leading to loss of habitat and the species they support
- measurement of suspended sediment in an effort to compose short-term and long-term sediment budgets
- identification of the effects of flood events in terms of changes in vegetation composition and distribution
- identification and quantification of pollution sources and their zone of impact
- targeted chemical and ecological processes studies aimed at testing hypotheses concerned with water and sediment quality effects on natural environment

A more detailed monitoring program can be established in close consultation with Council. An iterative prioritisation is required in which the opportunities that Council has in managing a complex estuary system are taken into account. Furthermore, the spatial and temporal scales of monitoring programs as well as available funding are important considerations.
Land Use Change with development of urban areas such as Newcastle, Maitland, Raymond Terrace, Morpeth, Seaham, Paterson

Water Quality issues such as algal blooms in upper estuary in response to nutrient inputs. General increase in turbidity due to catchment practices

Flooding in lower estuary in extreme events

Bank erosion from Oakhampton to Morpeth due to cattle grazing and land use changes

Deposition between Morpeth and Hexham

Change of habitat due to construction of floodgates and flood mitigation work. Changes to hydrology and tidal regime has led to saltmarsh and mangroves being replaced by fresh/brackish wetland

Loss of biodiversity

Fish nurseries and fish passage affected by flood mitigation works

Loss of habitat such as saltmarsh and open water bodies, expansion of mangroves due to construction levees and drains to restrict tidal inundation

Deposition of Sediment in south arm contaminated with metals and PAHs from industry. Contamination levels suggest adverse biological impacts

Oyster and prawn industries affected by industrial pollutants

Aboriginal and European heritage considered in development plans. Newcastle adopted City Wide Heritage Policy in 1998 to acknowledge heritage places

Pollution of Throsby Creek with high levels of organochlorine pesticides and heavy metals. Inputs from urban and industrial land uses

Loss of habitat such as mudflats due to land reclamation and industrialisation. Loss of important habitat for fish and birds

Conflicts between recreational boating and commercial activities

Dredging for maintenance of waterways. Changed hydrology and hydrodynamics, possibly mobilisation of contaminants in sediment. Consequential effects on aquatic biota

LOCATION OF ISSUES
TEMPORAL AND SPATIAL SCALES IN AN ECOLOGICAL PROCESS

Source: Beeby and Brennan, 1997
LOSS OF HABITAT

- land reclamation and flood mitigation
- clearing of native vegetation
- introduction of non-native species

structures to decrease tidal (salt) inundation of wetlands
- drainage of floodplains
- lower water table
  - subsidence
  - loss of salinity
  - conversion of saline wetlands to fresh/brackish swamps
  - loss of estuarine wetlands
  - loss of saltmarsh
  - loss of mangrove

 greater (fresh water) inundation of wetlands
  - increased mangrove distribution

external influence
human influence
effects on habitats

climatic change
impact on native vegetation
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